



# Pro C# 8 with .NET Core 3

Foundational Principles and Practices  
in Programming

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*Ninth Edition*

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Andrew Troelsen  
Phil Japikse

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## ***Pro C# 8 with .NET Core 3: Foundational Principles and Practices in Programming***

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*To my family, Amy (wife), Conner (son), Logan (son), and Skylar (daughter),  
thank you for all of the support and patience you have given me. Also, to my father (Cor);  
father, husband, inventor, and my center of excellence.*

*—Phil*



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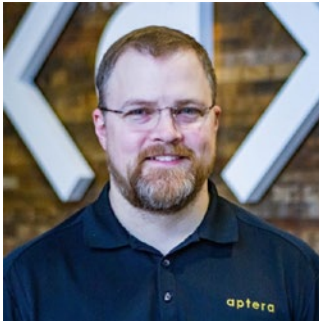
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—Phil Japikse

# Introduction

## We're a Team That Includes You

Technology authors write for a demanding group of people (for the best of possible reasons). You know that building software solutions using any platform or language is extremely complicated and is specific to your department, company, client base, and subject matter. Perhaps you work in the electronic publishing industry, develop systems for the state or local government, or work at NASA or a branch of the military. Collectively, we have worked in a variety of industries, including developing children's educational software (Oregon Trail/Amazon Trail), various enterprise systems, and projects within the medical and financial industries. The chances are almost 100 percent that the code you write at your place of employment has little to do with the code we have authored over the years.

Therefore, in this book, we have deliberately chosen to avoid creating demonstrations that tie the example code to a specific industry or vein of programming. Given this, we explain C#, OOP, the CoreCLR, and the .NET Core base class libraries using industry-agnostic examples. Rather than having every blessed example fill a grid with data, calculate payroll, or whatnot, we stick to subject matter we can all relate to: automobiles (with some geometric structures and employee payroll systems thrown in for good measure). And that's where you come in.

*Our job* is to explain the C# programming language and the core aspects of the .NET Core platform the best we possibly can. As well, we will do everything we can to equip you with the tools and strategies you need to continue your studies at this book's conclusion.

*Your job* is to take this information and apply it to your specific programming assignments. We obviously understand that your projects most likely don't revolve around automobiles with friendly pet names (Zippy the BMW or a Yugo named Clunker, among others), but that's what applied knowledge is all about!

Rest assured, once you understand the topics and concepts presented within this text, you will be in a perfect position to build .NET Core solutions that map to your own unique programming environment.

## An Overview of This Book

*Pro C# 8 with .NET Core* is logically divided into eight distinct parts, each of which contains a number of related chapters. Here is a part-by-part and chapter-by-chapter breakdown of the text.

### Part I: Introducing C# and .NET Core

The purpose of Part I is to acclimate you to the nature of the .NET Core platform and various development tools used during the construction of .NET Core applications.

## Chapter 1: Introducing .NET Core

This first chapter functions as the backbone for the remainder of the text. The primary goal of this chapter is to acquaint you with a number of .NET Core-centric building blocks, such as the Common Language Runtime, Common Type System, Common Language Specification, and base class libraries. Here, you will take an initial look at the C# programming language and the .NET Core assembly format.

## Chapter 2: Building C# Applications

The goal of this chapter is to introduce you to the process of compiling C# source code files. After installing the .NET Core SDK and runtimes, you will learn about the completely free (and fully functional) Visual Studio Community edition as well as Visual Studio Code. You will also learn how to configure your development machine using the new workload-based Visual Studio installation.

## Part II: Core C# Programming

The topics presented in this part of the book are quite important because you will use them regardless of which type of .NET Core software you intend to develop (e.g., web applications, desktop GUI applications, code libraries, or services). Here, you will learn about the fundamental data types of .NET Core, work with text manipulation, and learn the role of various C# parameter modifiers (including optional and named arguments).

## Chapter 3: Core C# Programming Constructs, Part 1

This chapter begins your formal investigation of the C# programming language. Here, you will learn about the role of the `Main()` method and numerous details regarding the intrinsic data types of the .NET Core platform and variable declaration, and you will work with and manipulate textual data using `System.String` and `System.Text.StringBuilder`. You will also examine iteration and decision constructs, narrowing and widening operations, and the `unchecked` keyword.

## Chapter 4: Core C# Programming Constructs, Part 2

This chapter completes your examination of the core aspects of C#, beginning with creating and manipulating arrays of data. Next, you examine how to construct overloaded type methods and define parameters using the `out`, `ref`, and `params` keywords. You will also learn about the `enum` type, structures, and nullable data types, and you will understand the distinction between value types and reference types. Finally, you will learn about tuples, a new feature in C# 7.

## Part III: Object-Oriented Programming with C#

In this part, you will come to understand the core constructs of the C# language, including the details of object-oriented programming. This part will also examine how to process runtime exceptions and will dive into the details of working with strongly typed interfaces. Finally, you will learn about object lifetime and garbage collection.

## Chapter 5: Understanding Encapsulation

This chapter begins your examination of object-oriented programming (OOP) using the C# programming language. After you are introduced to the pillars of OOP (encapsulation, inheritance, and polymorphism), the remainder of this chapter will show you how to build robust class types using constructors, properties, static members, constants, and read-only fields. You will wrap up with an examination of partial type definitions, object initialization syntax, and automatic properties.

## Chapter 6: Understanding Inheritance and Polymorphism

Here, you will examine the remaining pillars of OOP (inheritance and polymorphism), which allow you to build families of related class types. As you do this, you will examine the role of virtual methods, abstract methods (and abstract base classes), and the nature of the polymorphic interface. Then you will explore pattern matching, and finally, this chapter will explain the role of the supreme base class of the .NET Core platform, `System.Object`.

## Chapter 7: Understanding Structured Exception Handling

The point of this chapter is to discuss how to handle runtime anomalies in your codebase through the use of structured exception handling. Not only will you learn about the C# keywords that allow you to handle such problems (`try`, `catch`, `throw`, `when`, and `finally`), but you will also come to understand the distinction between application-level and system-level exceptions. In addition, this chapter will examine various tools within Visual Studio that allow you to debug the exceptions that escape your notice.

## Chapter 8: Working with Interfaces

The material in this chapter builds upon your understanding of object-based development by covering the topic of interface-based programming. Here, you will learn how to define classes and structures that support multiple behaviors, how to discover these behaviors at runtime, and how to selectively hide particular behaviors using explicit interface implementation. In addition to creating a number of custom interfaces, you will also learn how to implement standard interfaces found within the .NET Core platform. You will use these to build objects that can be sorted, copied, enumerated, and compared.

## Chapter 9: Understanding Object Lifetime

The final chapter of this part examines how the CLR manages memory using the .NET Core garbage collector. Here, you will come to understand the role of application roots, object generations, and the `System.GC` type. Once you understand the basics, you will examine the topics of disposable objects (using the `IDisposable` interface) and the finalization process (using the `System.Object.Finalize()` method). This chapter will also investigate the `Lazy<T>` class, which allows you to define data that will not be allocated until requested by a caller. As you will see, this feature can be helpful when you want to ensure you do not clutter the heap with objects that are not actually required by your programs.

## Part IV: Advanced C# Programming

This part of the book will deepen your understanding of the C# language by walking you through a number of more advanced (but important) concepts. Here, you will complete your examination of the .NET Core type system by investigating collections and generics. You will also examine a number of more advanced

features of C# (e.g., extension methods, operator overloading, anonymous types, and pointer manipulation). You will then examine delegates and lambda expressions, take a first look at Language Integrated Query, and finish the section with two chapters that focus on processes and multithreaded/async programming.

## Chapter 10: Collections and Generics

This chapter explores the topic of *generics*. As you will see, generic programming gives you a way to create types and type members, which contain various *placeholders* that can be specified by the caller. In a nutshell, generics greatly enhance application performance and type safety. Not only will you explore various generic types within the `System.Collections.Generic` namespace, but you will also learn how to build your own generic methods and types (with and without constraints).

## Chapter 11: Advanced C# Language Features

This chapter deepens your understanding of the C# programming language by introducing you to a number of advanced programming techniques. Here, you will learn how to overload operators and create custom conversion routines (both implicit and explicit) for your types. You will also learn how to build and interact with type indexers, as well as work with extension methods, anonymous types, partial methods, and C# pointers using an unsafe code context.

## Chapter 12: Delegates, Events, and Lambda Expressions

The purpose of this chapter is to demystify the delegate type. Simply put, a .NET Core delegate is an object that points to other methods in your application. Using this type, you can build systems that allow multiple objects to engage in a two-way conversation. After you have examined the use of .NET Core delegates, you will then be introduced to the C# event keyword, which you can use to simplify the manipulation of raw delegate programming. You will wrap up this chapter by investigating the role of the C# lambda operator (`=>`) and exploring the connection between delegates, anonymous methods, and lambda expressions.

## Chapter 13: LINQ to Objects

This chapter begins your examination of Language Integrated Query (LINQ). LINQ allows you to build strongly typed query expressions that can be applied to a number of LINQ targets to manipulate data in the broadest sense of the word. Here, you will learn about LINQ to Objects, which allows you to apply LINQ expressions to containers of data (e.g., arrays, collections, and custom types). This information will serve you well as you encounter a number of additional LINQ APIs throughout the remainder of this book.

## Chapter 14: Processes, AppDomains, and Load Contexts

Now that you have a solid understanding of assemblies, this chapter dives deeper into the composition of a loaded .NET Core executable. The goal of this chapter is to illustrate the relationship between processes, application domains, and contextual boundaries. These topics provide the proper foundation for Chapter 15, where you will examine the construction of multithreaded applications.

## Chapter 15: Multithreaded, Parallel, and Async Programming

This chapter examines how to build multithreaded applications and illustrates a number of techniques you can use to author thread-safe code. The chapter opens by revisiting the .NET delegate type to ensure explaining a delegate's intrinsic support for asynchronous method invocations. Next, you will investigate the types within the `System.Threading` namespace. The next section covers the Task Parallel Library (TPL). Using the TPL, .NET developers can build applications that distribute their workload across all available CPUs in a wickedly simple manner. At this point, you will also learn about the role of Parallel LINQ, which provides a way to create LINQ queries that scale across multiple machine cores. The remainder of the chapter covers creating nonblocking calls using the `async/await` keywords, introduced in C# 5, and local functions and generalized async return types, both new in C# 7.

## Part V: Programming with .NET Core Assemblies

Part V dives into the details of the .NET Core assembly format. Not only will you learn how to deploy and configure .NET Core code libraries, but you will also come to understand the internal composition of a .NET Core binary image. This part also explains the role of .NET Core attributes and the role of resolving type information at runtime. This section will also explain the role of the Dynamic Language Runtime (DLR) and the C# `dynamic` keyword. The final chapter covers the syntax of Common Intermediate Language (CIL) and the role of dynamic assemblies.

## Chapter 16: Building and Configuring Class Libraries

At a high level, *assembly* is the term used to describe a binary file created with a .NET Core compiler. However, the true story of .NET Core assemblies is far richer than that. Here, you will learn how to build and deploy assemblies and learn the difference between class libraries and console applications and the difference between .NET Core and .NET Standard class libraries.

## Chapter 17: Type Reflection, Late Binding, and Attribute-Based Programming

This chapter continues your examination of .NET Core assemblies by checking out the process of runtime type discovery using the `System.Reflection` namespace. Using the types of this namespace, you can build applications that can read an assembly's metadata on the fly. You will also learn how to load and create types at runtime dynamically using late binding. The final topic of this chapter will explore the role of .NET Core attributes (both standard and custom). To illustrate the usefulness of each of these topics, the chapter shows you how to construct an extendable application complete with snap-ins.

## Chapter 18: Dynamic Types and the Dynamic Language Runtime

.NET 4.0 introduced a new aspect of the .NET runtime environment called the *Dynamic Language Runtime*. Using the DLR and the C# `dynamic` keyword, you can define data that is not truly resolved until runtime. Using these features simplifies some complex .NET Core programming tasks dramatically. In this chapter, you will learn some practical uses of dynamic data, including how to leverage the .NET Core reflection APIs in a streamlined manner, as well as how to communicate with legacy COM libraries with a minimum of fuss and bother.



## Chapter 19: Understanding CIL and the Role of Dynamic Assemblies

The goal of the final chapter in this section is twofold. In the first half (more or less), you will examine the syntax and semantics of CIL in much greater detail than in previous chapters. The remainder of this chapter will cover the role of the `System.Reflection.Emit` namespace. You can use these types to build software that can generate .NET Core assemblies in memory at runtime. Formally speaking, assemblies defined and executed in memory are termed *dynamic assemblies*.

## Part VI: Introducing the .NET Base Class Libraries

By this point in the text, you have a solid handle on the C# language and the details of the .NET Core assembly format. Part VI leverages your newfound knowledge by exploring a number of commonly used services found within the base class libraries, including file I/O, database access using ADO.NET, and database access using Entity Framework Core.

## Chapter 20: File I/O and Object Serialization

The `System.IO` namespace allows you to interact with a machine's file and directory structure. Over the course of this chapter, you will learn how to create (and destroy) a directory system programmatically. You will also learn how to move data into and out of various streams (e.g., file based, string based, and memory based). The latter part of this chapter will examine the object serialization services of the .NET Core platform. Simply put, serialization allows you to persist the state of an object (or a set of related objects) into a stream for later use. Deserialization (as you might expect) is the process of plucking an object from the stream into memory for consumption by your application. After you understand the basics, you will learn how to customize the serialization process using the `ISerializable` interface and a set of .NET Core attributes.

## Chapter 21: Data Access with ADO.NET

This chapter covers database access using ADO.NET, the database API for .NET Core applications. Specifically, this chapter will introduce you to the role of .NET data providers and how to communicate with a relational database using ADO.NET, which is represented by connection objects, command objects, transaction objects, and data reader objects.

## Chapter 22: Introducing Entity Framework Core

This chapter introduces Entity Framework (EF) Core. EF Core is an object-relational mapping (ORM) framework built on top of ADO.NET. EF Core provides a way to author data access code using strongly typed classes that directly map to your business model. Here, you will come to understand the building blocks of EF Core, including the `DbContext`, Entities, the specialized collection class `DbSet<T>`, and the `DbChangeTracker`. Next, you will learn about query execution, tracking vs. non-tracking queries, and some of the more notable features of EF Core. The final piece of theory in this chapter is the EF Core global tool for the .NET Core Command Line Interface (CLI). Next, you will build the entities for the CarLog database using data annotations and the Fluent API to shape the tables and update the database using EF Core migrations. Finally, you will build the initialization code to populate the database with test data.

## Chapter 23: Finishing the Data Access Layer

This chapter completes the AutoLot data access layer. It begins with building a platform for executing integration tests (using xUnit) of the data access layer. Then it completes the code to Create, Read, Update, and Delete (CRUD) data. Finally, the chapter covers an implementation of a repository pattern for encapsulating common code. Through this chapter, you will learn to interact with the database using LINQ to Entities.

## Part VII: Windows Presentation Foundation

The initial desktop GUI API supported by the .NET platform was termed Windows Forms. While this API is still fully supported, .NET 3.0 introduced programmers to an API called Windows Presentation Foundation (WPF). Unlike Windows Forms, this framework integrates a number of key services, including data binding, 2D and 3D graphics, animations, and rich documents, into a single, unified object model. This is all accomplished using a declarative markup grammar called Extensible Application Markup Language (XAML). Furthermore, the WPF control architecture provides a trivial way to restyle the look and feel of a typical control radically using little more than some well-formed XAML.

## Chapter 24: Introducing Windows Presentation Foundation and XAML

In this chapter, you will begin by examining the motivation behind the creation of WPF (when there was already a desktop development framework in .NET). Then, you will learn about the syntax of XAML and, finally, take a look at the Visual Studio support for building WPF applications.

## Chapter 25: WPF Controls, Layouts, Events, and Data Binding

This chapter will expose you to the process of using intrinsic WPF controls and layout managers. For example, you will learn to build menu systems, splitter windows, toolbars, and status bars. This chapter will also introduce you to a number of WPF APIs (and their related controls), including the Ink API, commands, routed events, the data-binding model, and dependency properties.

## Chapter 26: WPF Graphics Rendering Services

WPF is a graphically intensive API; given this fact, WPF provides three ways to render graphics: shapes, drawings and geometrics, and visuals. In this chapter, you will evaluate each option and learn about a number of important graphics primitives (e.g., brushes, pens, and transformations) along the way. This chapter will also examine ways to incorporate vector images into your WPF graphics, as well as how to perform hit-testing operations against graphical data.

## Chapter 27: WPF Resources, Animations, Styles, and Templates

This chapter will introduce you to three important (and interrelated) topics that will deepen your understanding of the Windows Presentation Foundation API. The first order of business is to learn the role of logical resources. As you will see, the logical resource (also termed an *object resource*) system provides a way for you to name and refer to commonly used objects within a WPF application. Next, you will learn how to define, execute, and control an animation sequence. Despite what you might be thinking, however, WPF animations are not limited to the confines of video games or multimedia applications. You will wrap up the chapter by learning about the role of WPF styles. Similar to a web page that uses CSS or the ASP.NET theme engine, a WPF application can define a common look and feel for a set of controls.

## Chapter 28: WPF Notifications, Validations, Commands, and MVVM

This chapter begins by examining three core WPF framework capabilities: notifications, validations, and commands. In the notifications section, you will learn about observable models and collections and how they keep your application data and UI in sync. Next, you will dig deeper into commands, building custom commands to encapsulate your code. In the validations section, you will learn how to use the several validation mechanisms available in WPF applications. The chapter closes with an examination of the Model-View-ViewModel (MVVM) pattern and ends by creating an application that demonstrates the MVVM pattern in action.

## Part VIII: ASP.NET Core

Part VIII is devoted to an examination of constructing web applications using ASP.NET Core. ASP.NET Core can be used to build web applications and RESTful services.

## Chapter 29: Introducing ASP.NET Core

This chapter introduces ASP.NET Core and the Model-View-Controller (MVC) pattern. The next section lists (and explains) features brought forward into ASP.NET Core from classic ASP.NET MVC/WebAPI. These include controllers and actions, model binding, routing, and filters. The next section covers new features introduced in ASP.NET Core, including built-in dependency injection, cloud-ready, environmentally aware configuration system, deployment patterns, and the HTTP request pipeline. The rest of the chapter creates the two ASP.NET Core projects that will be finished in the next two chapters, shows the options to run ASP.NET Core applications, and begins the configuration process of the two ASP.NET Core projects.

## Chapter 30: RESTful Services with ASP.NET Core

This chapter finishes the ASP.NET Core RESTful service application. The chapter begins with a demonstration of the different mechanisms for returning JSON results to a client and the built-in support for service applications provided by the ApiController attribute. Swagger/OpenAPI is added next to provide a platform for testing and documenting your service. The rest of the chapter builds the controllers for the application, as well as creating the exception filter.

## Chapter 31: MVC Applications with ASP.NET Core

This is the final chapter covering ASP.NET Core, and finishes the MVC-based web application. The chapter starts with a deep look in views and the Razor View Engine, including layouts and partials. Next, Tag Helpers (another new feature in ASP.NET Core) are explored, followed by managing client-side libraries and bundling/minification of those libraries. An HTTP Client service wrapper is then created and added into the DI container, and the view component is built for the data-driven menu. Next, the CarsController and its views are built, along with the custom tag helpers, completing the application.

**PART I**



# **Introducing C# and .NET Core**

## CHAPTER 1



# Introducing .NET Core

Microsoft's .NET platform and the C# programming language were formally introduced circa 2002 and have quickly become a mainstay of modern-day software development. The .NET platform enables a large number of programming languages (including C#, VB.NET, and F#) to interact with each other. A program written in C# can be referenced by another program written in VB.NET. More on this interoperability in this chapter.

On June 27, 2016, Microsoft officially launched .NET Core. Like .NET, .NET Core allows languages to interop with each other (although a limited number of languages are supported). More importantly, this new framework is no longer limited to running on the Windows operating system, but can also run (and be developed) on iOS and Linux. On September 23, 2019, Microsoft launched .NET Core 3.0 and C# 8. While the prior versions of C# all run on the original .NET framework (version dependent of course), C# 8 will only run on .NET Core 3.0 and above. This version of C# introduces a lot of new features that would create breaking changes in prior versions of the .NET Framework (as well as .NET Core). Coupled with the fact that many of the prior versions of the .NET Framework are embedded in various Windows operating systems, there wasn't any way for the .NET framework to be updated to support C# 8. For that reason, the entirety of the code samples in this edition depends on .NET Core 3.1 or above (since 3.0 is already out of support).

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**Note** Some of the C# 8 features *can* be used with the .NET Framework through a combination of NuGet packages (for some features) and setting the current version used in the project file. For completeness and to reduce confusion, I made the decision to move this entire book to .NET Core.

---

As mentioned in the book's introduction, the goal of this text is twofold. The first order of business is to provide you with a deep and detailed examination of the syntax and semantics of C#. The second (equally important) order of business is to illustrate the use of numerous .NET APIs. These include database access with ADO.NET and Entity Framework (EF) Core, user interfaces with Windows Presentation Foundation (WPF) and WinForms, and finally RESTful services and web applications with ASP.NET Core. As it is said, the journey of a thousand miles begins with a single step; and with this, I welcome you to Chapter 1.

This first chapter lays the conceptual groundwork for the remainder of the book. Here, you will find a high-level discussion of a number of .NET-related topics such as assemblies, the Common Intermediate Language (CIL), and just-in-time (JIT) compilation. In addition to previewing some keywords of the C# programming language, you will also come to understand the relationship between various aspects of the .NET Core Framework, such as the .NET Core Common Language Runtime (CoreCLR), the .NET Core Libraries (CoreFX), the Common Type System (CTS), the Common Language Specification (CLS), and .NET Standard.

This chapter also provides you with a survey of the functionality supplied by the .NET Core base class libraries, sometimes abbreviated as BCLs. Here, you will get an overview of the language-agnostic and platform-independent nature of the .NET Core platform. As you would expect, these topics are explored in further detail throughout the remainder of this text.

■ **Note** Many of the features highlighted in this chapter (and throughout the book) also apply to the original .NET Framework. In this book, I always use the terms .NET Core framework and .NET Core runtime over the general term .NET to be explicitly clear that the features are supported in .NET Core.

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## Some Key Benefits of the .NET Core Platform

The .NET Core framework is a software platform for building web applications and services systems on the Windows, iOS, and Linux operating systems, as well as WinForms and WPF applications on Windows operating systems. To set the stage, here is a quick rundown of some core features provided courtesy of .NET Core:

- *Interoperability with existing code:* This is (of course) a good thing. Existing .NET framework software can interop with newer .NET Core software and vice versa through .NET Standard.
- *Support for numerous programming languages:* .NET Core applications can be created using C#, F#, and VB.NET programming languages (with C# being the primary focus for ASP.NET Core).
- *A common runtime engine shared by all .NET Core languages:* One aspect of this engine is a well-defined set of types that each .NET Core language understands.
- *Language integration:* .NET Core supports cross-language inheritance, cross-language exception handling, and cross-language debugging of code. For example, you can define a base class in C# and extend this type in Visual Basic.
- *A comprehensive base class library:* This library provides thousands of predefined types that allow you to build code libraries, simple terminal applications, graphical desktop applications, and enterprise-level websites.
- *A simplified deployment model:* .NET Core libraries are not registered into the system registry. Furthermore, the .NET Core platform allows multiple versions of the framework as well as applications to exist in harmony on a single machine.
- *Extensive command-line support:* .NET Core Command Line Interface (CLI) is a cross-platform tool chain for developing and packaging .NET Core applications. Additional tools can be installed (globally or locally) beyond the standard tools that ship with the .NET Core SDK.

You will see each of these topics (and many more) examined in the chapters to come. But first, I need to explain the new support lifecycle for .NET Core.

## The .NET Core Support Lifecycle

.NET Core versions are released much more frequently than the .NET Framework. With all of these releases available, it can be difficult to keep up, especially in an enterprise development environment. To better define the support lifecycle for the releases, Microsoft has adopted a variation of the Long-Term Support Model,<sup>1</sup> commonly used by modern open source frameworks.

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<sup>1</sup>[https://en.wikipedia.org/wiki/Long-term\\_support](https://en.wikipedia.org/wiki/Long-term_support)

Long-Term Support (LTS) releases are major releases that will be supported for an extended period of time. They will only receive critical and/or nonbreaking fixes throughout their lifespan. Prior to being end-of-lifed, LTS versions will be changed to the designation of maintenance. LTS releases with .NET Core will be supported for the following time frames, whichever is longer:

- Three years after initial release
- One year of maintenance support after subsequent LTS release

Microsoft has decided to name Short-Term Support releases as Current, which are interval releases between the major LTS releases. They are supported for three (3) months after a subsequent Current or LTS release.

.NET Core 3.0, the first version to support C# 8, was released in September 2019 and was released as a “current” release. .NET Core 3.1, released December 2019, was released as an LTS version. Support for .NET Core 3.0 ends March 2020, and .NET Core 3.1 is supported until at least December 2022. It’s important to check the support policy for each new version of .NET Core that is released. Just having a higher number doesn’t necessarily mean it’s going to be supported long term. The full policy is located online here:

<https://dotnet.microsoft.com/platform/support-policy/dotnet-core>

## Introducing the Building Blocks of the .NET Core Platform (CoreCLR, CoreFX, CTS, and CLS)

Now that you know some of the major benefits provided by .NET Core, let’s preview four key (and interrelated) topics that make it all possible: the Core Runtime (formally the CoreCLR and CoreFX), CTS, and the CLS. From a programmer’s point of view, .NET Core can be understood as a runtime environment and a comprehensive base class library. The runtime layer is composed of the .NET Core Common Language Runtime, or CoreCLR, and the .NET Core Libraries, or the CoreFX. The CoreCLR is a set of minimal implementations that are tied specifically to a platform (Windows, iOS, Linux) and architecture (x86, x64, ARM). Only the types that have to be tied to the deployment target are included in the CoreCLR, but are defined as private and should not be accessed through the CoreCLR. The CoreFX is *mostly* platform-agnostic and includes all of the base types for .NET Core. These also include the public implementations of the private types in the CoreCLR. Together, the CoreCLR and CoreFX comprise the .NET Core framework, and must be used together in order to run .NET Core applications.

Another building block of the .NET Core platform is the *Common Type System*, or CTS. The CTS specification fully describes all possible data types and all programming constructs supported by the runtime, specifies how these entities can interact with each other, and details how they are represented in the .NET Core metadata format (more information on metadata later in this chapter; see Chapter 17 for complete details).

Understand that a given .NET Core language might not support every feature defined by the CTS. The *Common Language Specification*, or CLS, is a related specification that defines a subset of common types and programming constructs that all .NET Core programming languages can agree on. Thus, if you build .NET Core types that expose only CLS-compliant features, you can rest assured that all .NET Core languages can consume them. Conversely, if you make use of a data type or programming construct that is outside of the bounds of the CLS, you cannot guarantee that every .NET Core programming language can interact with your .NET Core code library. Thankfully, as you will see later in this chapter, it is simple to tell your C# compiler to check all of your code for CLS compliance.

## The Role of the Base Class Libraries

The .NET Core platform also provides a set of base class libraries (BCLs) that are available to all .NET Core programming languages. Not only does this base class library encapsulate various primitives such as threads, file input/output (I/O), graphical rendering systems, and interaction with various external hardware devices, but it also provides support for a number of services required by most real-world applications.

The base class libraries define types that can be used to build any type of software application and for components of the application to interact with each other.

## The Role of .NET Standard

The number of base class libraries in the .NET framework far outnumbers those in .NET Core, even with the release of .NET Core 3.0. This is understandable, as .NET had a 14-year head start on .NET Core. This disparity created issues when attempting to use .NET code with .NET Core code. The solution (and requirement) for .NET/.NET Core interop is .NET Standard.

.NET Standard is a specification that defines the availability of .NET APIs and base class libraries that must be available in each implementation. The standard enables the following scenarios:

- Defines uniform set of BCL APIs for all .NET implementations to implement, independent of workload
- Enables developers to produce portable libraries that are usable across .NET implementations, using this same set of APIs
- Reduces or even eliminates conditional compilation of shared source due to .NET APIs, only for OS APIs

The chart located in the Microsoft documentation (<https://docs.microsoft.com/en-us/dotnet/standard/net-standard>) shows the various compatibility between .NET and .NET Core. This is very useful for prior versions of C#. However, C# 8 will only run on .NET Core 3.0 (or above) or .NET Standard 2.1 (or above), and .NET Standard 2.1 is not available to the .NET framework.

## What C# Brings to the Table

C# is a programming language whose core syntax looks *very* similar to the syntax of Java. However, calling C# a Java clone is inaccurate. In reality, both C# and Java are members of the C family of programming languages (e.g., C, Objective-C, C++) and, therefore, share a similar syntax.

The truth of the matter is that many of C#'s syntactic constructs are modeled after various aspects of Visual Basic (VB) and C++. For example, like VB, C# supports the notion of class properties (as opposed to traditional getter and setter methods) and optional parameters. Like C++, C# allows you to overload operators, as well as create structures, enumerations, and callback functions (via delegates).

Moreover, as you work through this text, you will quickly see that C# supports a number of features traditionally found in various functional languages (e.g., LISP or Haskell), such as lambda expressions and anonymous types. Furthermore, with the advent of *Language Integrated Query* (LINQ), C# supports a number of constructs that make it quite unique in the programming landscape. Nevertheless, the bulk of C# is indeed influenced by C-based languages.

Because C# is a hybrid of numerous languages, the result is a product that is as syntactically clean as (if not cleaner than) Java, is about as simple as VB, and provides just about as much power and flexibility as C++. Here is a partial list of core C# features that are found in all versions of the language:



- No pointers required! C# programs typically have no need for direct pointer manipulation (although you are free to drop down to that level if absolutely necessary, as shown in Chapter 11).
- Automatic memory management through garbage collection. Given this, C# does not support a `delete` keyword.
- Formal syntactic constructs for classes, interfaces, structures, enumerations, and delegates.
- The C++-like ability to overload operators for a custom type, without the complexity.
- Support for attribute-based programming. This brand of development allows you to annotate types and their members to further qualify their behavior. For example, if you mark a method with the `[Obsolete]` attribute, programmers will see your custom warning message print out if they attempt to make use of the decorated member.

C# 7 is an already powerful language and, combined with the .NET Framework, enables building a wide range of application types.

## Major Features in Prior Releases

With the release of .NET 2.0 (circa 2005), the C# programming language was updated to support numerous new bells and whistles, most notably the following:

- The ability to build generic types and generic members. Using generics, you are able to build efficient and type-safe code that defines numerous *placeholders* specified at the time you interact with the generic item.
- Support for anonymous methods, which allow you to supply an inline function anywhere a delegate type is required.
- The ability to define a single type across multiple code files (or, if necessary, as an in-memory representation) using the `partial` keyword.

.NET 3.5 (released circa 2008) added even more functionality to the C# programming language, including the following features:

- Support for strongly typed queries (e.g., LINQ) used to interact with various forms of data. You will first encounter LINQ in Chapter 13.
- Support for anonymous types that allow you to model the *structure* of a type (rather than its behavior) on the fly in code.
- The ability to extend the functionality of an existing type (without subclassing) using extension methods.
- Inclusion of a lambda operator (`=>`), which even further simplifies working with .NET delegate types.
- A new object initialization syntax, which allows you to set property values at the time of object creation.

.NET 4.0 (released in 2010) updated C# yet again with a handful of features:

- Support for optional method parameters, as well as named method arguments.
- Support for dynamic lookup of members at runtime via the `dynamic` keyword. As you will see in Chapter 19, this provides a unified approach to invoking members on the fly, regardless of which framework the member implemented.
- Working with generic types is much more intuitive, given that you can easily map generic data to and from general `System.Object` collections via covariance and contravariance.

With the release of .NET 4.5, C# received a pair of new keywords (`async` and `await`), which greatly simplify multithreaded and asynchronous programming. If you have worked with previous versions of C#, you might recall that calling methods via secondary threads required a fair amount of cryptic code and the use of various .NET namespaces. Given that C# now supports language keywords that handle this complexity for you, the process of calling methods asynchronously is almost as easy as calling a method in a synchronous manner. Chapter 15 will cover these topics in detail.

C# 6 was released with .NET 4.6 and introduced a number of minor features that help streamline your codebase. Here is a quick rundown of some of the new features in C# 6:

- Inline initialization for automatic properties as well as support for read-only automatic properties
- Single-line method implementations using the C# lambda operator
- Support of static imports to provide direct access to static members within a namespace
- A null conditional operator, which helps check for null parameters in a method implementation
- A new string formatting syntax termed *string interpolation*
- The ability to filter exceptions using the new `when` keyword
- Using `await` in `catch` and `finally` blocks
- `nameof` expressions to return a string representation of symbols
- Index initializers
- Improved overload resolution

C# 7, released with .NET 4.7 in March 2017, introduces additional features for streamlining your codebase, and it adds some more significant features (such as tuples and `ref` locals and returns) that developers have been asking to have included in the language specification for quite some time. Here is a quick rundown of the new features in C# 7:

- Declaring out variables as inline arguments
- Local functions
- Additional expression-bodied members
- Generalized `async` return types
- New tokens to improve readability for numeric constants
- Lightweight unnamed types (called *tuples*) that contain multiple fields

- Updates to logic flow using type matching in addition to value checking (pattern matching)
- Returning a reference to a value, instead of just the value itself (ref locals and returns)
- The introduction of lightweight throwaway variables (called *discards*)
- Throw expressions, allowing the throw to be executed in more places, such as conditional expressions, lambdas, and others

C# 7 has had two minor releases, adding the following features:

- The ability to have a program's main method be `async`.
- A new literal, `default`, that allows for initialization of any type.
- Correction of an issue with pattern matching that prevented using generics with the new pattern matching feature.
- Like anonymous methods, tuple names can be inferred from the projection that creates them.
- Techniques for writing safe efficient code, a combination of syntax improvements that enable working with value types using reference semantics.
- Named arguments can be followed by positional arguments.
- Numeric literals can now have leading underscores before any printed digits.
- The “`private protected`” access modifier enables access for derived classes in the same assembly.
- The result of a conditional expression (`?:`) can now be a reference.

The previous edition of this book covered up to (and including) C# 7.1. That is also the edition where I added (New) and (Updated) to section titles to make it easier to find the changes in the language from the previous version.

I am leaving those descriptors in the titles, but updating them with the relevant version. The new features added in C# 7 are notated in the section header with “(New 7.x)” and updated features will be shown with “(Updated 7.x)”, where “x” is the specific version of C# 7.

## New Features in C# 8

C# 8, released September 23, 2019, added the following features:

- Readonly members for structs
- Default interface members
- Pattern matching enhancements
- Using declarations
- Static local functions
- Disposable ref structs
- Nullable reference types
- Asynchronous streams

- Indices and ranges
- Null-coalescing assignment
- Unmanaged constructed types
- `stackalloc` in nested expressions
- Enhancement of interpolated verbatim strings

New features in C# 8 are indicated as “(New 8)” in their section headings, and updated features are indicated as “(Updated 8)”.

## Managed vs. Unmanaged Code

It is important to note that the C# language can be used only to build software that is hosted under the .NET Core runtime (you could never use C# to build a native COM server or an unmanaged C/C++-style application). Officially speaking, the term used to describe the code targeting the .NET Core runtime is *managed code*. The binary unit that contains the managed code is termed an *assembly* (more details on assemblies in just a bit). Conversely, code that cannot be directly hosted by the .NET Core runtime is termed *unmanaged code*.

As mentioned previously, the .NET Core platform can run on a variety of operating systems. Thus, it is quite possible to build a C# application on a Windows machine and run the program on an iOS machine using the .NET Core runtime. As well, you could build a C# application on Linux using Visual Studio Code and run the program on Windows. With Visual Studio for Mac, you can also build .NET Core applications on a Mac to be run on Windows, macOS, or Linux.

Unmanaged code can still be accessed from a C# program, but it then locks you into a specific development and deployment target.

## Additional .NET Core Aware Programming Languages

Understand that C# is not the only language that can be used to build .NET Core applications. .NET Core applications can generally be built with C#, Visual Basic, and F#. ASP.NET Core applications are limited to C#.

The .NET framework had a very large list of language implementations. .NET Core, being relatively new, has the three provided by the .NET Core team at Microsoft and (at the time of this writing) one other language, PeachPie, an implementation of PHP for .NET Core.

## An Overview of .NET Assemblies

Regardless of which .NET Core language you choose to program with, understand that despite .NET Core binaries taking the same file extension as unmanaged Windows binaries (\*.dll), they have absolutely no internal similarities. Specifically, .NET Core binaries do not contain platform-specific instructions but rather platform-agnostic *Intermediate Language (IL)* and type metadata.

---

■ **Note** IL is also known as Microsoft Intermediate Language (MSIL) or alternatively as the Common Intermediate Language (CIL). Thus, as you read the .NET/.NET Core literature, understand that IL, MSIL, and CIL are all describing essentially the same concept. In this book, I will use the abbreviation CIL to refer to this low-level instruction set.

---

When a \*.dll has been created using a .NET Core compiler, the binary blob is termed an *assembly*. You will examine numerous details of .NET Core assemblies in Chapter 16. However, to facilitate the current discussion, you do need to understand four basic properties of this new file format.

First and foremost, unlike .NET Framework assemblies that can be either a \*.dll or \*.exe, .NET Core projects are *always* compiled to a file with a .dll extension, even if the project is an executable. Executable .NET Core assemblies are executed with the command “dotnet <assembly name>.dll”. New in .NET Core 3.0, the dotnet.exe command is copied to the build directory and renamed to <assembly name>.exe. Running this command automatically calls the dotnet <assembly name>.dll file, executing the equivalent of “dotnet <assembly name>.dll”. The \*.exe with your project name isn’t actually your project’s code; it is a convenient shortcut to running your application.

Second, an assembly contains CIL code, which is conceptually similar to Java bytecode, in that it is not compiled to platform-specific instructions until absolutely necessary. Typically, “absolutely necessary” is the point at which a block of CIL instructions (such as a method implementation) is referenced for use by the .NET Core runtime.

Third, assemblies also contain *metadata* that describes in vivid detail the characteristics of every “type” within the binary. For example, if you have a class named SportsCar, the type metadata describes details such as SportsCar’s base class, specifies which interfaces are implemented by SportsCar (if any), and gives full descriptions of each member supported by the SportsCar type. .NET Core metadata is always present within an assembly and is automatically generated by the language compiler.

Finally, in addition to CIL and type metadata, assemblies themselves are also described using metadata, which is officially termed a *manifest*. The manifest contains information about the current version of the assembly, culture information (used for localizing string and image resources), and a list of all externally referenced assemblies that are required for proper execution. You’ll examine various tools that can be used to examine an assembly’s types, metadata, and manifest information over the course of the next few chapters.

## The Role of the Common Intermediate Language

Let’s examine CIL code, type metadata, and the assembly manifest in a bit more detail. CIL is a language that sits above any particular platform-specific instruction set. For example, the following C# code models a trivial calculator. Don’t concern yourself with the exact syntax for now, but do notice the format of the Add() method in the Calc class.

```
//Calc.cs
using System;

namespace CalculatorExamples
{
    //This class contains the app's entry point.
    class Program
    {
        static void Main(string[] args)
        {
            Calc c = new Calc();
            int ans = c.Add(10, 84);
            Console.WriteLine("10 + 84 is {0}.", ans);
            //Wait for user to press the Enter key
            Console.ReadLine();
        }
    }
}
```

```
// The C# calculator.
class Calc
{
    public int Add(int x, int y)
    { return x + y; }
}
}
```

After this code is compiled, there is a single-file \*.dll assembly that contains a manifest, CIL instructions, and metadata describing each aspect of the Calc and Program classes.

---

■ **Note** Chapter 2 examines how to use graphical integrated development environments (IDEs), such as Visual Studio Community, to compile your code files.

---

For example, if you were to output the IL from this assembly using `ildasm.exe` (examined a little later in this chapter), you would find that the `Add()` method is represented using CIL such as the following:

```
.method public hidebysig instance int32
    Add(int32 x,
        int32 y) cil managed
{
    // Code size          9 (0x9)
    .maxstack 2
    .locals init (int32 V_0)
    IL_0000: nop
    IL_0001: ldarg.1
    IL_0002: ldarg.2
    IL_0003: add
    IL_0004: stloc.0
    IL_0005: br.s        IL_0007
    IL_0007: ldloc.0
    IL_0008: ret
} // end of method Calc::Add
```

Don't worry if you are unable to make heads or tails of the resulting CIL for this method – Chapter 19 will describe the basics of the CIL programming language. The point to concentrate on is that the C# compiler emits CIL, not platform-specific instructions.

Now, recall that this is true of all .NET Core compilers. To illustrate, assume you created this same application using Visual Basic, rather than C#.

```
' Calc.vb
Namespace CalculatorExample
    Module Program
        ' This class contains the app's entry point.
        Sub Main(args As String())
            Dim c As New Calc
            Dim ans As Integer = c.Add(10, 84)
            Console.WriteLine("10 + 84 is {0}", ans)
        End Sub
    End Module
End Namespace
```

```

        'Wait for user to press the Enter key before shutting down
        Console.ReadLine()
    End Sub
End Module
' The VB.NET calculator.
Class Calc
    Public Function Add(ByVal addend1 As Integer, ByVal addend2 As Integer) As Integer
        Return addend1 + addend2
    End Function
End Class
End Namespace

```

If you examine the CIL for the `Add()` method, you find similar instructions (slightly tweaked by the Visual Basic compiler, `vbc.exe`).

```

.method public instance int32 Add(int32 addend1,
                                   int32 addend2) cil managed
{
    // Code size          9 (0x9)
    .maxstack 2
    .locals init (int32 V_0)
    IL_0000: nop
    IL_0001: ldarg.1
    IL_0002: ldarg.2
    IL_0003: add.ovf
    IL_0004: stloc.0
    IL_0005: br.s      IL_0007
    IL_0007: ldloc.0
    IL_0008: ret
} // end of method Calc::Add

```

As a final example, the same simple `Calc` program developed in F# (another .NET Core language) is shown here:

```

// Calc.fs
open System

module Calc =
    let add x y =
        x + y

[<EntryPoint>]
let main argv =
    let ans = Calc.add 10 84
    printfn "10 + 84 is %d" ans
    Console.ReadLine()
    0

```

If you examine the CIL for the `Add()` method, once again you find similar instructions (slightly tweaked by the F# compiler).

```
.method public static int32 'add'(int32 x,
                                int32 y) cil managed
{
    .custom instance void [FSharp.Core]Microsoft.FSharp.Core.CompilationArgumentCounts
    Attribute::.ctor(int32[]) = ( 01 00 02 00 00 00 01 00 00 00 01 00 00 00 00 00 )
    // Code size          4 (0x4)
    .maxstack 8
    IL_0000: ldarg.0
    IL_0001: ldarg.1
    IL_0002: add
    IL_0003: ret
} // end of method Calc::'add'
```

## Benefits of CIL

At this point, you might be wondering exactly what is gained by compiling source code into CIL rather than directly to a specific instruction set. One benefit is language integration. As you have already seen, each .NET Core compiler produces nearly identical CIL instructions. Therefore, all languages are able to interact within a well-defined binary arena.

Furthermore, given that CIL is platform-agnostic, the .NET Core Framework itself is platform-agnostic, providing the same benefits Java developers have grown accustomed to (e.g., a single codebase running on numerous operating systems). In fact, there is an international standard for the C# language. Prior to .NET Core, there were numerous implementations of .NET for non-Windows platforms, such as Mono. These still exist, although the need for them is greatly reduced with the cross-platform capability of .NET Core.

## Compiling CIL to Platform-Specific Instructions

Because assemblies contain CIL instructions rather than platform-specific instructions, CIL code must be compiled on the fly before use. The entity that compiles CIL code into meaningful CPU instructions is a JIT compiler, which sometimes goes by the friendly name of *jitter*. The .NET Core runtime environment leverages a JIT compiler for each CPU targeting the runtime, each optimized for the underlying platform.

For example, if you are building a .NET Core application to be deployed to a handheld device (such as an iOS or Android), the corresponding jitter is well equipped to run within a low-memory environment. On the other hand, if you are deploying your assembly to a back-end company server (where memory is seldom an issue), the jitter will be optimized to function in a high-memory environment. In this way, developers can write a single body of code that can be efficiently JIT compiled and executed on machines with different architectures.

Furthermore, as a given jitter compiles CIL instructions into corresponding machine code, it will cache the results in memory in a manner suited to the target operating system. In this way, if a call is made to a method named `PrintDocument()`, the CIL instructions are compiled into platform-specific instructions on the first invocation and retained in memory for later use. Therefore, the next time `PrintDocument()` is called, there is no need to recompile the CIL.



## Precompiling CIL to Platform-Specific Instructions

The .NET Framework supports “pre-JIT” of an assembly with a utility called `ngen.exe`, which ships with the .NET Framework SDK. There is a similar utility in .NET Core called `crossgen.exe` which can be used to pre-JIT your code. Fortunately, in .NET Core 3.0, the ability to produce “Ready To Run” assemblies is built into the framework. More on this later in this book.

## The Role of .NET Core Type Metadata

In addition to CIL instructions, a .NET Core assembly contains full, complete, and accurate metadata, which describes every type (e.g., class, structure, enumeration) defined in the binary, as well as the members of each type (e.g., properties, methods, events). Thankfully, it is always the job of the compiler (not the programmer) to emit the latest and greatest type metadata. Because .NET Core metadata is so wickedly meticulous, assemblies are completely self-describing entities.

To illustrate the format of .NET Core type metadata, let’s take a look at the metadata that has been generated for the `Add()` method of the C# `Calc` class you examined previously (the metadata generated for the Visual Basic version of the `Add()` method is similar; again, more on the use of `ildasm.exe` in just a bit).

TypeDef #2 (02000003)

```
-----
TypeDefName: CalculatorExamples.Calc (02000003)
Flags       : [NotPublic] [AutoLayout] [Class] [AnsiClass] [BeforeFieldInit] (00100000)
Extends     : 0100000C [TypeRef] System.Object
              Method #1 (06000003)
-----
```

```

MethodName: Add (06000003)
Flags      : [Public] [HideBySig] [ReuseSlot] (00000086)
RVA       : 0x00002090
ImplFlags : [IL] [Managed] (00000000)
CallConvtn: [DEFAULT]
hasThis
ReturnType: I4
2 Arguments
  Argument #1: I4
  Argument #2: I4
2 Parameters
  (1) ParamToken : (08000002) Name : x flags: [none] (00000000)
  (2) ParamToken : (08000003) Name : y flags: [none] (00000000)
```

Metadata is used by numerous aspects of the .NET Core runtime environment, as well as by various development tools. For example, the IntelliSense feature provided by tools such as Visual Studio is made possible by reading an assembly’s metadata at design time. Metadata is also used by various object-browsing utilities, debugging tools, and the C# compiler itself. To be sure, metadata is the backbone of numerous .NET technologies including reflection, late binding, and object serialization. Chapter 17 will formalize the role of .NET Core metadata.

## The Role of the Assembly Manifest

Last but not least, remember that a .NET Core assembly also contains metadata that describes the assembly itself (technically termed a *manifest*). Among other details, the manifest documents all external assemblies required by the current assembly to function correctly, the assembly’s version number, copyright

information, and so forth. Like type metadata, it is always the job of the compiler to generate the assembly's manifest. Here are some relevant details of the manifest generated when compiling the `Calc.cs` code file shown earlier in this chapter (some lines omitted for brevity):

```
.assembly extern /*23000001*/ System.Runtime
{
    .publickeytoken = (B0 3F 5F 7F 11 D5 0A 3A ) // .?_....:
    .ver 4:2:1:0
}
.assembly extern /*23000002*/ System.Console
{
    .publickeytoken = (B0 3F 5F 7F 11 D5 0A 3A ) // .?_....:
    .ver 4:1:1:0
}
.assembly /*20000001*/ Calc.Cs
{
    .hash algorithm 0x00008004
    .ver 1:0:0:0
}
.module Calc.Cs.dll
.imagebase 0x00400000
.file alignment 0x00000200
.stackreserve 0x00100000
.subsystem 0x0003 // WINDOWS_CUI
.corflags 0x00000001 // ILONLY
```

In a nutshell, this manifest documents the set of external assemblies required by `Calc.dll` (via the `.assembly extern` directive) as well as various characteristics of the assembly itself (e.g., version number, module name). Chapter 16 will examine the usefulness of manifest data in much more detail.

## Understanding the Common Type System

A given assembly may contain any number of distinct types. In the world of .NET Core, *type* is simply a general term used to refer to a member from the set {class, interface, structure, enumeration, delegate}. When you build solutions using a .NET Core language, you will most likely interact with many of these types. For example, your assembly might define a single class that implements some number of interfaces. Perhaps one of the interface methods takes an enumeration type as an input parameter and returns a structure to the caller.

Recall that the CTS is a formal specification that documents how types must be defined in order to be hosted by the CoreCLR and CoreFX. Typically, the only individuals who are deeply concerned with the inner workings of the CTS are those building tools and/or compilers that target the .NET Core platform. It is important, however, for all .NET programmers to learn about how to work with the five types defined by the CTS in their language of choice. The following is a brief overview.

### CTS Class Types

Every .NET Core language supports, at the least, the notion of a *class type*, which is the cornerstone of object-oriented programming (OOP). A class may be composed of any number of members (such as constructors, properties, methods, and events) and data points (fields). In C#, classes are declared using the `class` keyword, like so:

**// A C# class type with 1 method.**

```
class Calc
{
    public int Add(int x, int y)
    {
        return x + y;
    }
}
```

Chapter 5 will begin your formal examination of building class types with C#; however, Table 1-1 documents a number of characteristics pertaining to class types.

**Table 1-1.** CTS Class Characteristics

Class Characteristic	Meaning in Life
Is the class sealed?	Sealed classes cannot function as a base class to other classes.
Does the class implement any interfaces?	An interface is a collection of abstract members that provides a contract between the object and object user. The CTS allows a class to implement any number of interfaces.
Is the class abstract or concrete?	Abstract classes cannot be directly instantiated but are intended to define common behaviors for derived types. Concrete classes can be instantiated directly.
What is the visibility of this class?	Each class must be configured with a visibility keyword such as <code>public</code> or <code>internal</code> . Basically, this controls whether the class may be used by external assemblies or only from within the defining assembly.

## CTS Interface Types

*Interfaces* are nothing more than a named collection of abstract member definitions and/or (new in C# 8) default implementations, which are implemented (optionally in the case of default implementations) by a given class or structure. In C#, interface types are defined using the `interface` keyword. By convention, all .NET interfaces begin with a capital letter *I*, as in the following example:

**// A C# interface type is usually  
// declared as public, to allow types in other  
// assemblies to implement their behavior.**

```
public interface IDraw
{
    void Draw();
}
```

On their own, interfaces are of little use. However, when a class or structure implements a given interface in its unique way, you are able to request access to the supplied functionality using an interface reference in a polymorphic manner. Interface-based programming will be fully explored in Chapter 8.

## CTS Structure Types

The concept of a structure is also formalized under the CTS. If you have a C background, you should be pleased to know that these user-defined types (UDTs) have survived in the world of .NET Core (although they behave a bit differently under the hood). Simply put, a *structure* can be thought of as a lightweight class type having value-based semantics. For more details on the subtleties of structures, see Chapter 4. Typically, structures are best suited for modeling geometric and mathematical data and are created in C# using the `struct` keyword, as follows:

**// A C# structure type.**

```
struct Point
{
    // Structures can contain fields.
    public int xPos, yPos;

    // Structures can contain parameterized constructors.
    public Point(int x, int y)
    { xPos = x; yPos = y; }

    // Structures may define methods.
    public void PrintPosition()
    {
        Console.WriteLine("{0}, {1}", xPos, yPos);
    }
}
```

## CTS Enumeration Types

*Enumerations* are a handy programming construct that allow you to group name-value pairs. For example, assume you are creating a video game application that allows the player to select one of three character categories (Wizard, Fighter, or Thief). Rather than keeping track of simple numerical values to represent each possibility, you could build a strongly typed enumeration using the `enum` keyword.

**// A C# enumeration type.**

```
enum CharacterTypeEnum
{
    Wizard = 100,
    Fighter = 200,
    Thief = 300
}
```

By default, the storage used to hold each item is a 32-bit integer; however, it is possible to alter this storage slot if need be (e.g., when programming for a low-memory device such as a mobile device). Also, the CTS demands that enumerated types derive from a common base class, `System.Enum`. As you will see in Chapter 4, this base class defines a number of interesting members that allow you to extract, manipulate, and transform the underlying name-value pairs programmatically.

## CTS Delegate Types

*Delegates* are the .NET Core equivalent of a type-safe, C-style function pointer. The key difference is that a .NET Core delegate is a *class* that derives from `System.MulticastDelegate`, rather than a simple pointer to a raw memory address. In C#, delegates are declared using the `delegate` keyword.

```
// This C# delegate type can "point to" any method  
// returning an int and taking two ints as input.  
delegate int BinaryOp(int x, int y);
```

Delegates are critical when you want to provide a way for one object to forward a call to another object and provide the foundation for the .NET Core event architecture. As you will see in Chapters 12 and 14, delegates have intrinsic support for multicasting (i.e., forwarding a request to multiple recipients) and asynchronous method invocations (i.e., invoking the method on a secondary thread).

## CTS Type Members

Now that you have previewed each of the types formalized by the CTS, realize that most types take any number of *members*. Formally speaking, a type member is constrained by the set {constructor, finalizer, static constructor, nested type, operator, method, property, indexer, field, read-only field, constant, event}.

The CTS defines various *adornments* that may be associated with a given member. For example, each member has a given visibility trait (e.g., `public`, `private`, `protected`). Some members may be declared as `abstract` (to enforce a polymorphic behavior on derived types) as well as `virtual` (to define a canned, but overridable, implementation). Also, most members may be configured as `static` (bound at the class level) or `instance` (bound at the object level). The creation of type members is examined over the course of the next several chapters.

---

■ **Note** As described in Chapter 10, the C# language also supports the creation of generic types and generic members.

---

## Intrinsic CTS Data Types

The final aspect of the CTS to be aware of for the time being is that it establishes a well-defined set of fundamental data types. Although a given language typically has a unique keyword used to declare a fundamental data type, all .NET language keywords ultimately resolve to the same CTS type defined in an assembly named `mscorlib.dll`. Consider Table 1-2, which documents how key CTS data types are expressed in VB.NET and C#.

**Table 1-2.** *The Intrinsic CTS Data Types*

CTS Data Type	VB Keyword	C# Keyword
System.Byte	Byte	byte
System.SByte	SByte	sbyte
System.Int16	Short	Short
System.Int32	Integer	Int
System.Int64	Long	Long
System.UInt16	UShort	Ushort
System.UInt32	UInteger	UInt
System.UInt64	ULong	Ulong
System.Single	Single	Float
System.Double	Double	double
System.Object	Object	object
System.Char	Char	char
System.String	String	string
System.Decimal	Decimal	decimal
System.Boolean	Boolean	bool

Given that the unique keywords of a managed language are simply shorthand notations for a real type in the System namespace, you no longer have to worry about overflow/underflow conditions for numerical data or how strings and Booleans are internally represented across different languages. Consider the following code snippets, which define 32-bit numerical variables in C# and Visual Basic, using language keywords as well as the formal CTS data type:

```
// Define some "ints" in C#.
int i = 0;
System.Int32 j = 0;

' Define some "ints" in VB.
Dim i As Integer = 0
Dim j As System.Int32 = 0
```

# Understanding the Common Language Specification

As you are aware, different languages express the same programming constructs in unique, language-specific terms. For example, in C# you denote string concatenation using the plus operator (+), while in VB you typically make use of the ampersand (&). Even when two distinct languages express the same programmatic idiom (e.g., a function with no return value), the chances are good that the syntax will appear quite different on the surface.

```

// C# method returning nothing.
public void MyMethod()
{
    // Some interesting code...
}

' VB method returning nothing.
Public Sub MyMethod()
    ' Some interesting code...
End Sub

```

As you have already seen, these minor syntactic variations are inconsequential in the eyes of the .NET Core runtime, given that the respective compilers (`csc.exe` or `vbc.exe`, in this case) emit a similar set of CIL instructions. However, languages can also differ with regard to their overall level of functionality. For example, a .NET Core language might or might not have a keyword to represent unsigned data and might or might not support pointer types. Given these possible variations, it would be ideal to have a baseline to which all .NET Core languages are expected to conform.

The CLS is a set of rules that describe in vivid detail the minimal and complete set of features a given .NET Core compiler must support to produce code that can be hosted by the CoreCLR and CoreFX while at the same time be accessed in a uniform manner by all languages that target the .NET Core platform. In many ways, the CLS can be viewed as a *subset* of the full functionality defined by the CTS.

The CLS is ultimately a set of rules that compiler builders must conform to if they intend their products to function seamlessly within the .NET Core universe. Each rule is assigned a simple name (e.g., CLS Rule 6) and describes how this rule affects those who build the compilers as well as those who (in some way) interact with them. The *crème de la crème* of the CLS is Rule 1.

*Rule 1:* CLS rules apply only to those parts of a type that are exposed outside the defining assembly.

Given this rule, you can (correctly) infer that the remaining rules of the CLS do not apply to the logic used to build the inner workings of a .NET Core type. The only aspects of a type that must conform to the CLS are the member definitions themselves (i.e., naming conventions, parameters, and return types). The implementation logic for a member may use any number of non-CLS techniques, as the outside world won't know the difference.

To illustrate, the following C# `Add()` method is not CLS compliant, as the parameters and return values make use of unsigned data (which is not a requirement of the CLS):

```

class Calc
{
    // Exposed unsigned data is not CLS compliant!
    public ulong Add(ulong addend1, ulong addend2)
    {
        return addend1 + addend2;
    }
}

```

However, consider the following code that makes use of unsigned data internally in a method:

```
class Calc
{
    public int Add(int x, int y)
    {
        // As this ulong variable is only used internally,
        // we are still CLS compliant.
        ulong temp = 0;
        ...
        return x + y;
    }
}
```

The class still conforms to the rules of the CLS and can rest assured that all .NET Core languages are able to invoke the `Add()` method.

Of course, in addition to Rule 1, the CLS defines numerous other rules. For example, the CLS describes how a given language must represent text strings, how enumerations should be represented internally (the base type used for storage), how to define static members, and so forth. Luckily, you don't have to commit these rules to memory to be a proficient .NET developer. Again, by and large, an intimate understanding of the CTS and CLS specifications is typically of interest only to tool/compiler builders.

## Ensuring CLS Compliance

As you will see over the course of this book, C# does define a number of programming constructs that are not CLS compliant. The good news, however, is that you can instruct the C# compiler to check your code for CLS compliance using a single .NET attribute.

```
// Tell the C# compiler to check for CLS compliance.
[assembly: CLSCompliant(true)]
```

Chapter 17 dives into the details of attribute-based programming. Until then, simply understand that the `[CLSCompliant]` attribute will instruct the C# compiler to check every line of code against the rules of the CLS. If any CLS violations are discovered, you receive a compiler warning and a description of the offending code.

## Understanding the CoreCLR and CoreFX

In addition to the CTS and CLS specifications, the final acronyms to contend with at the moment are the CoreCLR and CoreFX, collectively known as the .NET Core Runtime. Programmatically speaking, the term *runtime* can be understood as a collection of services that are required to execute a given compiled unit of code. For example, when Java developers deploy software to a new computer, they need to ensure the Java virtual machine (JVM) has been installed on the machine in order to run their software.

The .NET Core platform offers yet another runtime system. The key difference between the .NET Core runtime and the various other runtimes I just mentioned is that the .NET Core runtime provides a single, well-defined runtime layer that is shared by *all* languages and platforms that are .NET Core.



## The Assembly/Namespace/Type Distinction

Each of us understands the importance of code libraries. The point of framework libraries is to give developers a well-defined set of existing code to leverage in their applications. However, the C# language does not come with a language-specific code library. Rather, C# developers leverage the language-neutral .NET Core libraries. To keep all the types within the base class libraries well organized, the .NET Core platform makes extensive use of the *namespace* concept.

A namespace is a grouping of semantically related types contained in an assembly or possibly spread across multiple related assemblies. For example, the `System.IO` namespace contains file I/O-related types, the `System.Data` namespace defines basic database types, and so on. It is important to point out that a single assembly can contain any number of namespaces, each of which can contain any number of types.

The key difference between this approach and a language-specific library is that any language targeting the .NET Core runtime uses the *same* namespaces and *same* types. For example, the following two programs all illustrate the ubiquitous Hello World application, written in C# and VB:

### // Hello World in C#.

```
using System;

public class MyApp
{
    static void Main()
    {
        Console.WriteLine("Hi from C#");
    }
}
```

### ' Hello World in VB.

```
Imports System
Public Module MyApp
    Sub Main()
        Console.WriteLine("Hi from VB")
    End Sub
End Module
```

Notice that each language is using the `Console` class defined in the `System` namespace. Beyond some obvious syntactic variations, these applications look and feel very much alike, both physically and logically.

Clearly, once you are comfortable with your .NET Core programming language of choice, your next goal as a .NET Core developer is to get to know the wealth of types defined in the (numerous) .NET Core namespaces. The most fundamental namespace to get your head around initially is named `System`. This namespace provides a core body of types that you will need to leverage time and again as a .NET Core developer. In fact, you cannot build any sort of functional C# application without at least making a reference to the `System` namespace, as the core data types (e.g., `System.Int32`, `System.String`) are defined here. Table 1-3 offers a rundown of some (but certainly not all) of the .NET Core namespaces grouped by related functionality.

**Table 1-3.** *A Sampling of .NET Namespaces*

.NET Namespace	Meaning in Life
System	Within System, you find numerous useful types dealing with intrinsic data, mathematical computations, random number generation, environment variables, and garbage collection, as well as a number of commonly used exceptions and attributes.
System.Collections System.Collections.Generic	These namespaces define a number of stock container types, as well as base types and interfaces that allow you to build customized collections.
System.Data System.Data.Common System.Data.SqlClient	These namespaces are used for interacting with relational databases using ADO.NET.
System.IO System.IO.Compression System.IO.Ports	These namespaces define numerous types used to work with file I/O, compression of data, and port manipulation.
System.Reflection System.Reflection.Emit	These namespaces define types that support runtime type discovery as well as dynamic creation of types.
System.Runtime.InteropServices	This namespace provides facilities to allow .NET types to interact with unmanaged code (e.g., C-based DLLs and COM servers) and vice versa.
System.Drawing System.Windows.Forms	These namespaces define types used to build desktop applications using .NET's original UI toolkit (Windows Forms).
System.Windows System.Windows.Controls System.Windows.Shapes	The System.Windows namespace is the root for several namespaces that are used in Windows Presentation Foundation (WPF) applications.
System.Windows.Forms System.Drawing	The System.Windows.Forms namespace is the root for several namespaces used in Windows Forms applications.
System.Linq System.Linq.Expressions	These namespaces define types used when programming against the LINQ API.
System.AspNetCore	This is one of many namespaces that allows you to build ASP.NET Core web applications and RESTful services.
System.Threading System.Threading.Tasks	These namespaces define numerous types to build multithreaded applications that can distribute workloads across multiple CPUs.
System.Security	Security is an integrated aspect of the .NET universe. In the security-centric namespaces, you find numerous types dealing with permissions, cryptography, etc.
System.Xml	The XML-centric namespaces contain numerous types used to interact with XML data.

## Accessing a Namespace Programmatically

It is worth reiterating that a namespace is nothing more than a convenient way for us mere humans to logically understand and organize related types. Consider again the `System` namespace. From your perspective, you can assume that `System.Console` represents a class named `Console` that is contained within a namespace called `System`. However, in the eyes of the .NET Core runtime, this is not so. The runtime engine sees only a single class named `System.Console`.

In C#, the `using` keyword simplifies the process of referencing types defined in a particular namespace. Here is how it works. Returning to the Calc example program earlier in this chapter, there is a single `using` statement at the top of the file:

```
using System;
```

That statement is a shortcut to enable this line of code:

```
Console.WriteLine("10 + 84 is {0}.", ans);
```

Without the `using` statement, the code would need to be written like this:

```
System.Console.WriteLine("10 + 84 is {0}.", ans);
```

While defining a type using the fully qualified name provides greater readability, I think you'd agree that the C# `using` keyword reduces keystrokes. In this text, we will avoid the use of fully qualified names (unless there is a definite ambiguity to be resolved) and opt for the simplified approach of the C# `using` keyword.

However, always remember that the `using` keyword is simply a shorthand notation for specifying a type's fully qualified name, and either approach results in the same underlying CIL (given that CIL code always uses fully qualified names) and has no effect on performance or the size of the assembly.

## Referencing External Assemblies

Prior version of the .NET Framework used a common installation location for framework libraries known as the Global Assembly Cache (GAC). Instead of having a single installation location, .NET Core does not use the GAC. Instead, each version (including minor releases) is installed in its own location (by version) on the computer. When using Windows, each version of the runtime and SDK gets installed into `c:\Program Files\dotnet`.

Adding in additional assemblies into *most* .NET Core projects is done by adding NuGet packages (covered later in this text). However, .NET Core applications targeting (and being developed on) Windows still have access to COM libraries. This will also be covered later in this text.

In order for an assembly to have access to another assembly that you are building (or someone built for you), you need to add a reference from your assembly to the other assembly and have physical access to the other assembly. Depending on the development tool you are using to build your .NET applications, you will have various ways to inform the compiler which assemblies you want to include during the compilation cycle.

## Exploring an Assembly Using `ildasm.exe`

If you are beginning to feel a tad overwhelmed at the thought of gaining mastery over every namespace in the .NET platform, just remember that what makes a namespace unique is that it contains types that are somehow *semantically related*. Therefore, if you have no need for a user interface beyond a simple console application, you can forget all about the desktop and web namespaces (among others). If you are building a painting application, the database namespaces are most likely of little concern. Like any new set of prefabricated code, you learn as you go.

The Intermediate Language Disassembler utility (`ildasm.exe`) allows you to create a text document. .NET Core assembly and investigate its contents, including the associated manifest, CIL code, and type metadata. This tool allows you to dive deeply into how their C# code maps to CIL and ultimately helps you understand the inner workings of the .NET Core platform. While you never *need* to use `ildasm.exe` to become a proficient .NET Core programmer, I highly recommend you fire up this tool from time to time to better understand how your C# code maps to runtime concepts.

■ **Note** The `ildasm.exe` program no longer ships with the .NET Core runtime, but must be compiled from the CoreCLR source, which can be located at <https://github.com/dotnet/coreclr> (.NET Core 3.1) or <https://github.com/dotnet/runtime> (.NET 5). The home page for the repo has platform-specific instructions to build and locate the `ildasm` tool. I have included `ildasm.exe` in the Chapter 1 folder of this book's Git repo. The good news is that the previous versions of `ildasm.exe` will typically work for .NET Core assemblies developed on Windows.

---

After you build `ildasm.exe`, you can run the program from the command line to get help. At a minimum, you have to specify the assembly to extract the CIL.

An example command line is as follows:

```
ildasm /all /METADATA /out=csharp.il calc.cs.dll
```

This will create a file named `csharp.il` exporting all available data into the file.

## Summary

The point of this chapter was to lay out the conceptual framework necessary for the remainder of this book. I began by examining a number of limitations and complexities found within the technologies prior to .NET Core and followed up with an overview of how .NET Core and C# attempt to simplify the current state of affairs.

.NET Core basically boils down to a runtime execution engine (the CoreCLR and CoreFX) and base class library. The Common Language Runtime is able to host any .NET Core binary (aka assembly) that abides by the rules of managed code. As you saw, assemblies contain CIL instructions (in addition to type metadata and the assembly manifest) that are compiled to platform-specific instructions using a just-in-time compiler. In addition, you explored the role of the Common Language Specification and Common Type System.

In the next chapter, you will take a tour of the common integrated development environments you can use when you build your C# programming projects. You will be happy to know that in this book you will use completely free (and feature-rich) IDEs, so you can start exploring the .NET Core universe with no money down.

## CHAPTER 2



# Building C# Applications

As a C# programmer, you can choose from among numerous tools to build .NET Core applications. The tool (or tools) you select will be based primarily on three factors: any associated costs, the OS you are using to develop the software, and the computing platforms you are targeting. The point of this chapter is to provide a survey of the most common integrated development environments (IDEs) that support the C# language. Do understand that this chapter will *not* go over every single detail of each IDE; it will give you enough information to select your programming environment as you work through this text and give you a foundation to build on.

The first part of this chapter will examine a set of IDEs from Microsoft that enable development of applications that target Windows operating systems as well as ASP.NET Core applications that target Windows, macOS, or Linux.

---

**Note** This chapter will give you an overview of a good number of IDEs. However, this book will assume you are using the (completely free) Visual Studio 2019 Community Edition. If you want to build your applications on a different OS (macOS or Linux), this chapter will guide you in the right direction; however, your IDE will differ from the various screenshots in this text.

---

## Installing .NET Core

To get started developing applications with C# 8 and .NET Core (on Windows, macOS, or Linux), the .NET Core SDK needs to be installed (which also installs the .NET Core runtimes). All of the installs for .NET and .NET Core are located at the convenient URL: [www.dot.net](https://www.dot.net). From the download page, you can select either the .NET Framework or .NET Core. After selecting .NET Core, the most recent version can be downloaded directly from this page, or you can download previous versions from the “All .NET Core downloads...” link.

For this book, you will need to install the SDK for .NET Core version 3.0 or higher. I recommend using the latest LTS release, which at the time of this writing is .NET Core 3.1.

---

**Note** Installing Visual Studio 2019 also installs the .NET Core SDK and runtimes.

---

## Confirm the .NET Core Install

To confirm the installation, open a command window and use the .NET Core Command Line Interface (CLI) `dotnet .exe`. To check the current version of the .NET Core SDK installed on your machine, enter

```
dotnet --version
```

The result needs to be 3.0.100 (or higher).

To show all of the .NET Core Runtimes installed, enter

```
dotnet --list-runtimes
```

There are three different runtimes:

- Microsoft.AspNetCore.App
- Microsoft.NETCore.App
- Microsoft.WindowsDesktop.App

Each of these must be version 3.0.0 or higher.

Finally, to show all of the SDKs installed, enter

```
dotnet --list-sdks
```

Again, the version must be 3.0.100 or higher.

## Building .NET Core Applications with Visual Studio

As you will see over the course of this chapter, you can choose from a variety of IDEs to build C# applications; some come from Microsoft, and others come from third-party (many of which are open source) vendors. Now, despite what you might be thinking, many Microsoft IDEs are completely free. Thus, if your primary interest is to build .NET Core software on the Windows operating system, you will find the following major options:

- Visual Studio 2019 Community
- Visual Studio 2019 Professional
- Visual Studio 2019 Enterprise

The Community and Professional editions are *essentially* the same. The most significant difference is in the licensing model. Community is licensed for open source, academic, and small-business uses. Professional and Enterprise are commercial products that are licensed for any development, including enterprise development. As one would expect, the Enterprise edition has many additional features above the Professional edition.

---

■ **Note** For specific licensing details, please go to [www.visualstudio.com](http://www.visualstudio.com). Licensing Microsoft products can be complex, and this book does not cover the details. For the purposes of writing (and following along with) this book, Community is legal to use.

---

In addition to the Visual Studio family of IDEs, there is also Visual Studio Code, a free and open source IDE from Microsoft. It is much lighter weight than Visual Studio and is used mainly to build ASP.NET Core and/or cross-platform service applications. Visual Studio Code also runs on macOS and Linux, but note that you cannot build Windows applications (WinForms or WPF) using Visual Studio Code.

Each IDE ships with sophisticated code editors, key database designers, integrated visual debuggers, GUI designers for desktop and web applications, and so forth. Since they all share a common core set of features, the good news is that it is easy to move between them and feel quite comfortable with their basic operation.

## Installing Visual Studio 2019

Before using Visual Studio 2019 to develop, execute, and debug C# applications, you need to get it installed. The installation experience changed dramatically with the 2017 version, and is worth discussing in more detail.

---

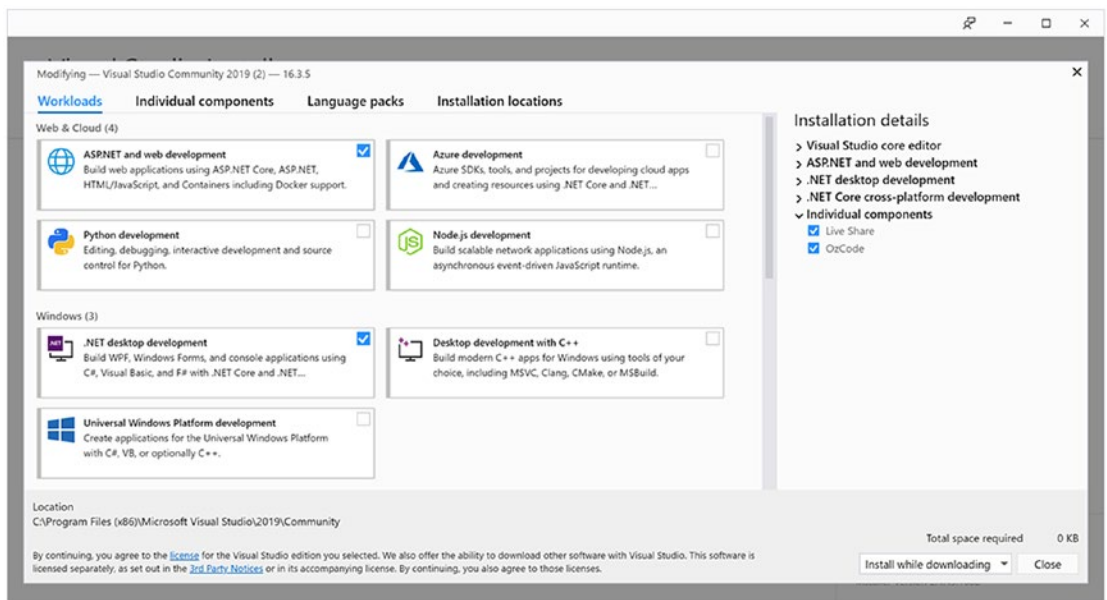
■ **Note** You can download Visual Studio 2019 Community from [www.visualstudio.com/downloads](http://www.visualstudio.com/downloads). Ensure that the version you download and install is at least 16.4 or later.

---

The Visual Studio 2019 installation process is now broken down into application-type workloads. This allows you to install just the components you need for the work you plan on doing. For example, if you are going to build web applications, you would install the “ASP.NET and web development” workload.

Another (extremely) significant change is that Visual Studio 2019 supports true side-by-side installation. Note that I am not referring to just previous versions of Visual Studio but to Visual Studio 2019 itself! For example, on my main work computer, I have Visual Studio 2019 Enterprise installed for my professional consulting work and also Visual Studio 2019 Community for use in my books, course, and conference lectures. If you have Professional or Enterprise supplied by your employer, you can still install the Community edition to work on the open source projects (or the code in this book).

When you launch the installer for Visual Studio 2019 Community, you are presented with the screen shown in Figure 2-1. This screen has all of the workloads available, the option to select individual components, and a summary on the right side showing what has been selected.



**Figure 2-1.** The new Visual Studio installer

For this book, you will want to install the following workloads:

- .NET desktop development
- ASP.NET and web development
- Data storage and processing
- .NET Core cross-platform development

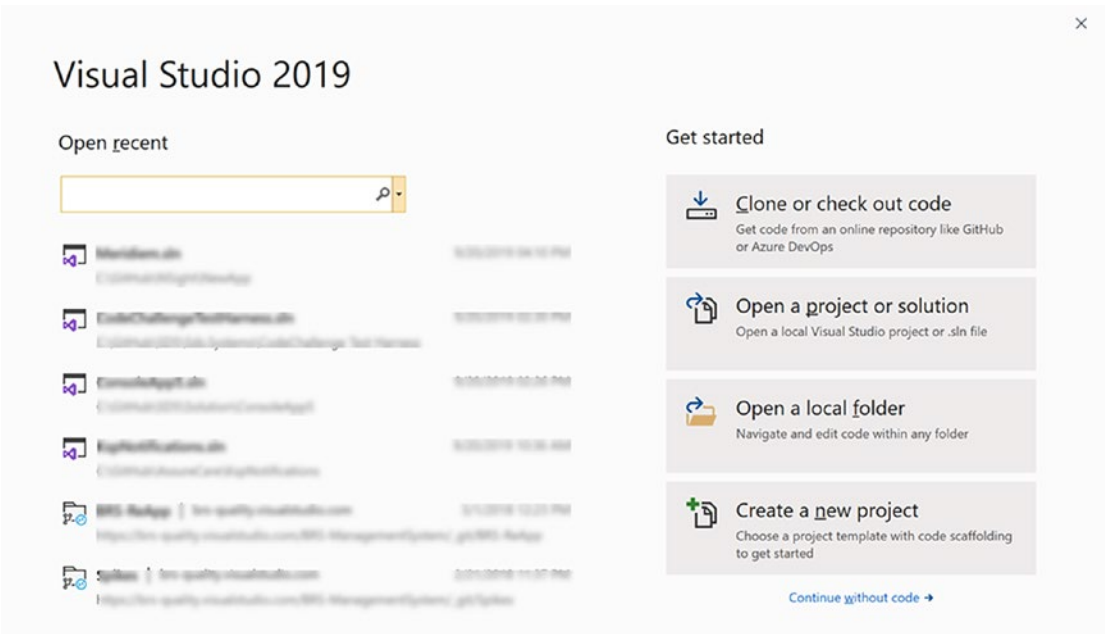
Once you have all of them selected, click Install. This will provide you with everything you need to work through the examples in this book.

## Taking Visual Studio 2019 for a Test-Drive

Visual Studio 2019 is a one-stop shop for software development with the .NET platform and C#. Let’s take a quick look at Visual Studio by building a simple .NET Core Console application.

## The New Project Dialog Box and C# Code Editor

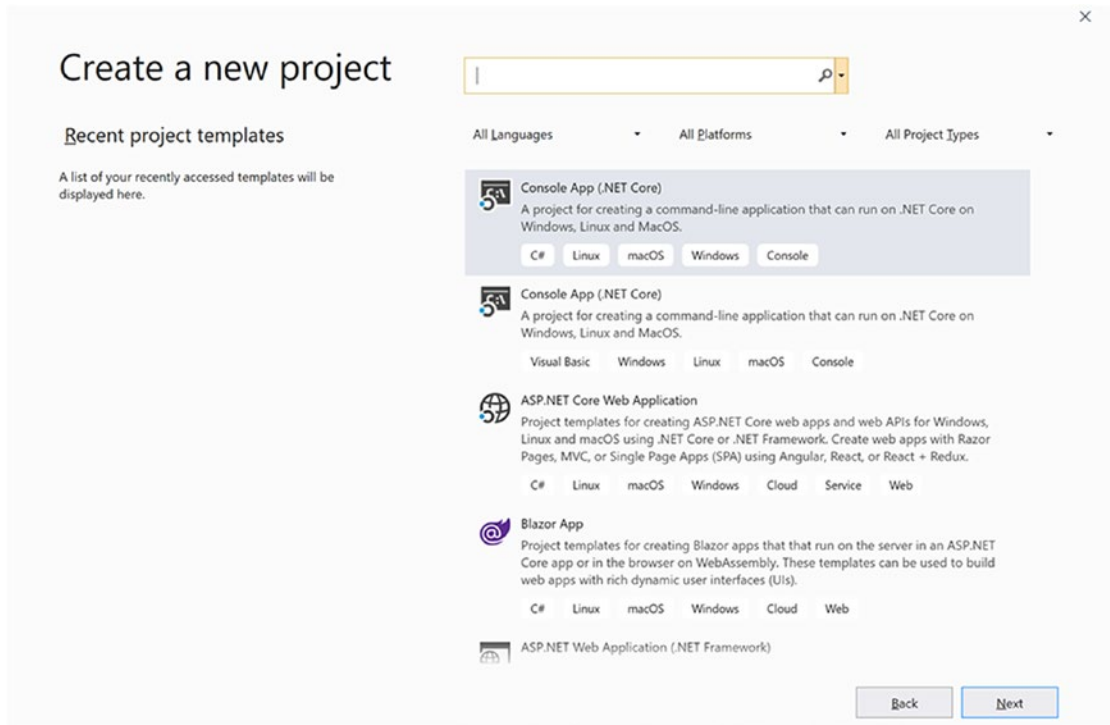
When you start Visual Studio, you will see the updated Launch dialog, as shown in Figure 2-2. The left side of the dialog has the most recently used solutions, and the right side has options of launching Visual Studio by launching code from a repository, open an existing project/solution, open a local folder, or create a new project. There is also an option to continue without any code, which just launches the Visual Studio IDE.



**Figure 2-2.** The new Visual Studio Launch dialog



Select the “Create a new project” option and you will be prompted with the “Create a new project” dialog. As shown in Figure 2-3, recently used templates (if any) are on the left and all available templates are shown on the right, including a set of filters and a search box.



**Figure 2-3.** The Create a new project dialog

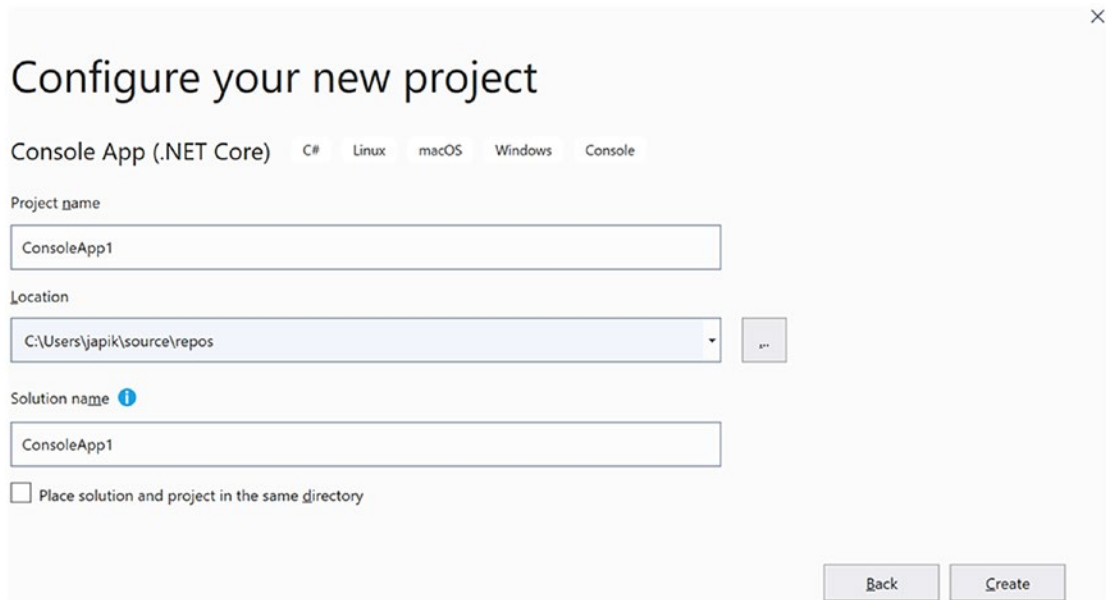
To start, create a new “Console App (.NET Core)” C# project, making sure to select the C# version and not the Visual Basic version.

The next screen is the “Configure your new project” dialog as shown in Figure 2-4. Enter SimpleCSharpConsoleApp for the project name and select a location for the project. The wizard will also create a Visual Studio solution, by default named after the project name.

---

■ **Note** Creating solutions and projects can also be accomplished using the .NET Core CLI. For example, to create a new solution, enter `dotnet new sln -n SimpleCSharpConsoleApp`. To create a new .NET Core C# Console application, enter `dotnet new console -lang C# -n test`. To add the new console app to the solution, enter `dotnet sln add SimpleCSharpConsoleApp`. This is just a small sample of what the CLI is capable of. To discover everything the CLI can do, enter `dotnet -h`.

---



**Figure 2-4.** The *Configure your new project* dialog

Once the project has been created, you will see that the initial C# code file (named `Program.cs`) has been opened in the code editor. Replace the single line of code in the `Main` method with the following C#. You'll notice as you type that IntelliSense will kick in as you apply the dot operator.

```
static void Main(string[] args)
{
    // Set up Console UI (CUI)
    Console.Title = "My Rocking App";
    Console.ForegroundColor = ConsoleColor.Yellow;
    Console.BackgroundColor = ConsoleColor.Blue;
    Console.WriteLine("*****");
    Console.WriteLine("***** Welcome to My Rocking App *****");
    Console.WriteLine("*****");
    Console.BackgroundColor = ConsoleColor.Black;

    // Wait for Enter key to be pressed.
    Console.ReadLine();
}
```

Here, you are using the `Console` class defined in the `System` namespace. Because the `System` namespace has been automatically included at the top of your file via a `using` statement, you have no need to qualify the namespace before the class name (e.g., `System.Console.WriteLine()`). This program does not do anything too interesting; however, note the final call to `Console.ReadLine()`. This is in place simply to ensure the user must press a key to terminate the application. If you did not do this, the program would disappear almost instantly when debugging the program!

## Changing the Target .NET Core Framework

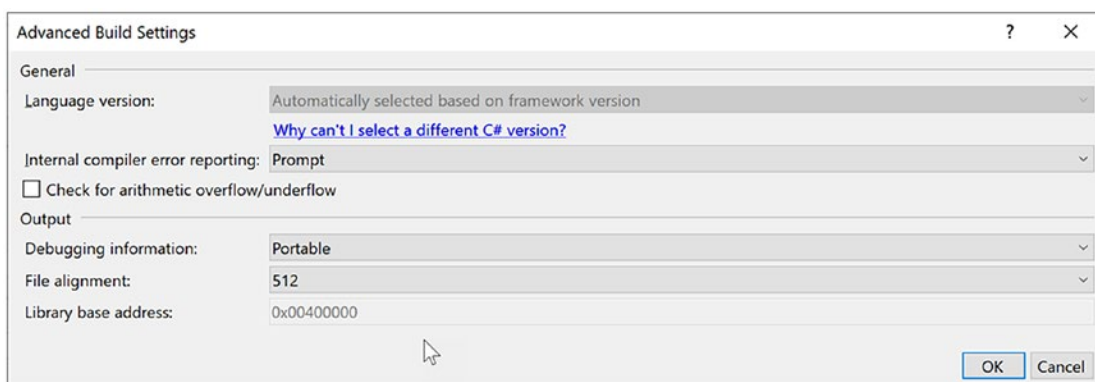
At the time of this writing, the default .NET Core version for .NET Core applications is 3.0. To use .NET Core 3.1 (or to just check the version of .NET Core your app is targeting), double-click the project in Solution Explorer. This opens up the project file in the editor (this is a new feature for Visual Studio 2019 and .NET Core). You can also edit the project file by right-clicking the project name in solution explorer and selecting “Edit Project file”. You will see the following:

```
<Project Sdk="Microsoft.NET.Sdk">
  <PropertyGroup>
    <OutputType>Exe</OutputType>
    <TargetFramework>netcoreapp3.1</TargetFramework>
  </PropertyGroup>
</Project>
```

To change to a different .NET Core version (such as .NET Core 2.1), simply change the `TargetFramework` value. You can also change the target framework by right-clicking the project name in solution explorer and selecting Properties.

## Using C# 8 Features

In prior versions of .NET, the version of C# supported by a project could be changed. With .NET Core 3.0+, the version of C# used is tied into the framework version. To confirm this, right-click the project name in solution explorer, and select Properties. On the Properties dialog, click Build in the left rail and then Advanced in the lower right corner. That will bring up the dialog shown in Figure 2-5.



**Figure 2-5.** The Advanced Build Settings

For .NET Core 3.x project, the language version is locked into C# 8. Table 2-1 lists the target frameworks (.NET Core, .NET Standard, and .NET Framework) and the default C# version utilized.

**Table 2-1.** C# 8 Version and Target Framework

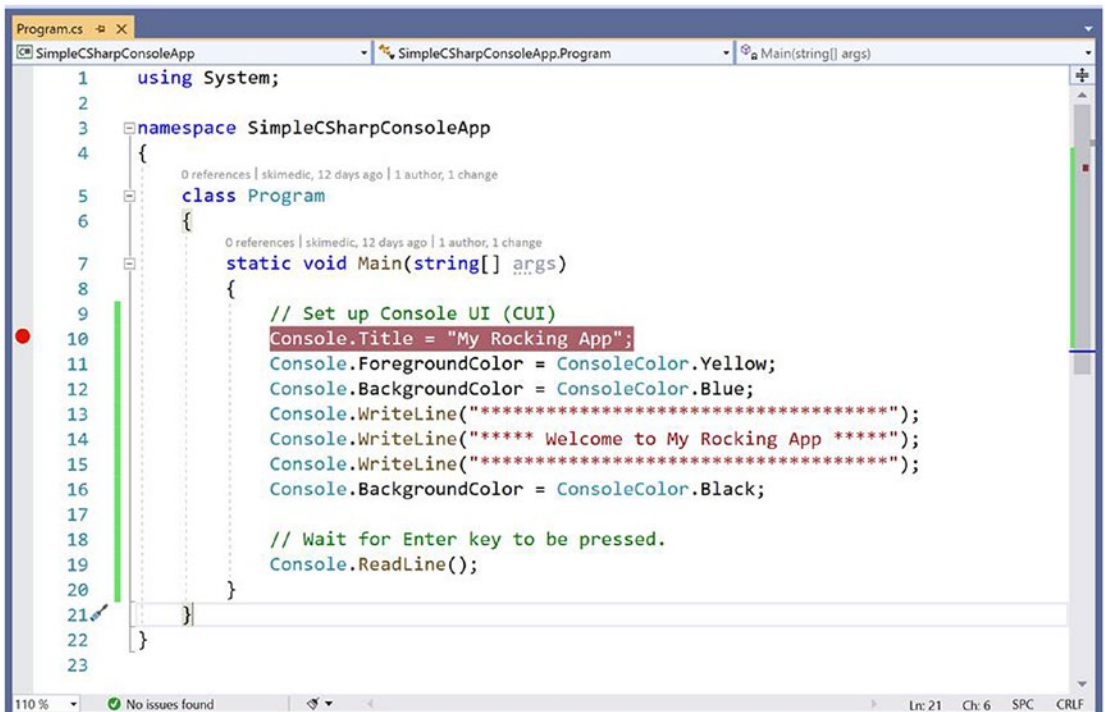
Target Framework	Version	C# Language Version Default
.NET Core	3.x	C# 8.0
.NET Core	2.x	C# 7.3
.NET Standard	2.1	C# 8.0
.NET Standard	2.0	C# 7.3
.NET Standard	1.x	C# 7.3
.NET Framework	all	C# 7.3

## Running and Debugging Your Project

To run your program and see the output, press the Ctrl+F5 keyboard command (which is also accessed from the Debug ► Start Without Debugging menu option). Once you do, you will see a Windows console window pop on the screen with your custom (and colorful) message. Be aware that when you “run” your program with Ctrl+F5, you bypass the integrated debugger.

**Note** .NET Core applications can also be compiled and executed using the CLI. To run your project, enter `dotnet run` in the same directory as the project file (`SimpleCSharpApp.csproj` in this example). The run command also automatically builds the project.

If you need to debug your code (which will certainly be important when building larger programs), your first step is to set breakpoints at the code statement you want to examine. Although there isn’t much code in this example, set a breakpoint by clicking the leftmost gray bar of the code editor (note that breakpoints are marked with a red dot icon; see Figure 2-6).



**Figure 2-6.** Setting breakpoints

If you now press the F5 key (or use the Debug ► Start Debugging menu option or click the green arrow with Start next to it in the toolbar), your program will halt at each breakpoint. As you would expect, you can interact with the debugger using the various toolbar buttons and menu options of the IDE. Once you have evaluated all breakpoints, the application will eventually terminate once `Main()` has completed.

---

**Note** Microsoft IDEs have sophisticated debuggers, and you will learn about various techniques over the chapters to come. For now, be aware that when you are in a debugging session, a large number of useful options will appear under the Debug menu. Take a moment to verify this for yourself.

---

## Solution Explorer

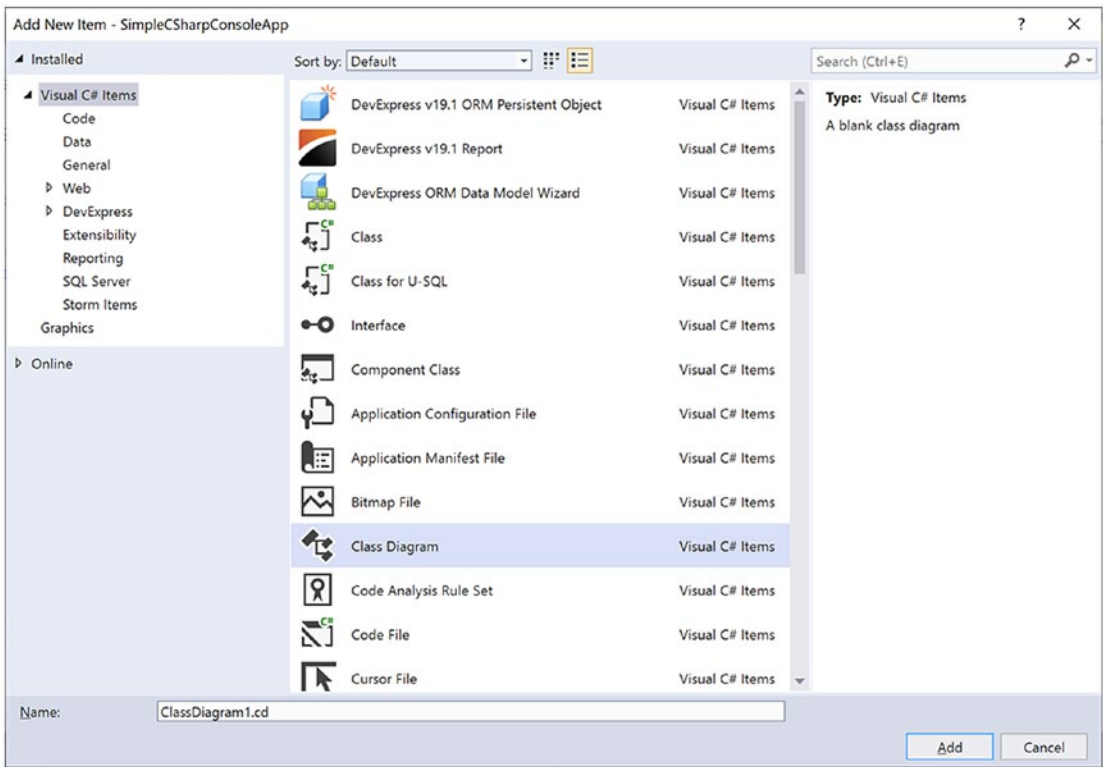
If you look at the right of the IDE, you will see a window named Solution Explorer, which shows you a few important things. First, notice that the IDE has created a solution with a single project. This can be confusing at first, as they both have been given the same name (`SimpleCSharpConsoleApp`). The idea here is that a “solution” can contain multiple projects that all work together. For example, your solution might include three class libraries, one WPF application, and one ASP.NET Core web service. The earlier chapters of this book will always have a single project; however, when you build some more complex examples, you’ll see how to add new projects to your initial solution space.

**Note** Be aware that when you select the topmost solution in the Solution Explorer window, the IDE's menu system will show you a different set of choices than when you select a project. If you ever find yourself wondering where a certain menu item has disappeared to, double-check you did not accidentally select the wrong node.

## The Visual Class Designer

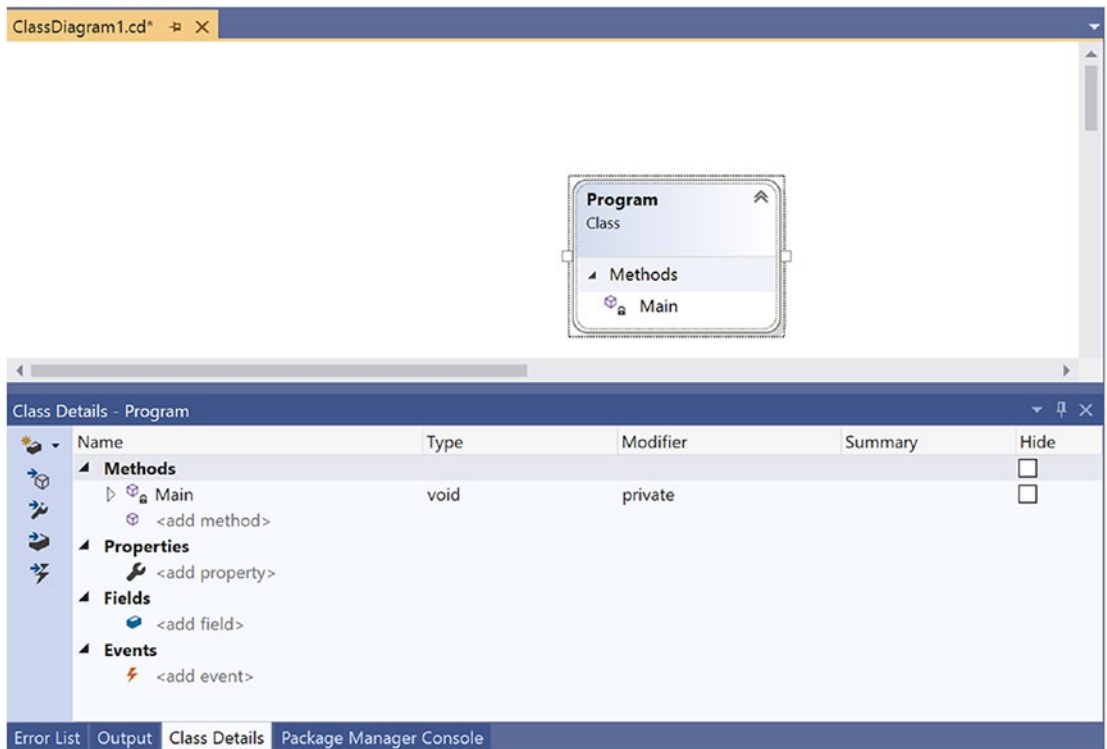
Visual Studio also gives you the ability to design classes and other types (such as interfaces or delegates) in a visual manner. The Class Designer utility allows you to view and modify the relationships of the types (classes, interfaces, structures, enumerations, and delegates) in your project. Using this tool, you are able to visually add (or remove) members to (or from) a type and have your modifications reflected in the corresponding C# file. Also, as you modify a given C# file, changes are reflected in the class diagram.

To access the visual type designer tools, the first step is to insert a new class diagram file. To do so, activate the Project ► Add New Item menu option and locate the Class Diagram type (Figure 2-7).



**Figure 2-7.** Inserting a class diagram file into the current project

Initially, the designer will be empty; however, you can drag and drop files from your Solution Explorer window on the surface. For example, once you drag `Program.cs` onto the designer, you will find a visual representation of the `Program` class. If you click the arrow icon for a given type, you can show or hide the type's members (see Figure 2-8).



**Figure 2-8.** The Class Diagram viewer

---

■ **Note** Using the Class Designer toolbar, you can fine-tune the display options of the designer surface.

---

The Class Designer utility works in conjunction with two other aspects of Visual Studio: the Class Details window (activated using the View ► Other Windows menu) and the Class Designer Toolbox (activated using the View ► Toolbox menu item). The Class Details window not only shows you the details of the currently selected item in the diagram but also allows you to modify existing members and insert new members on the fly (see Figure 2-9).

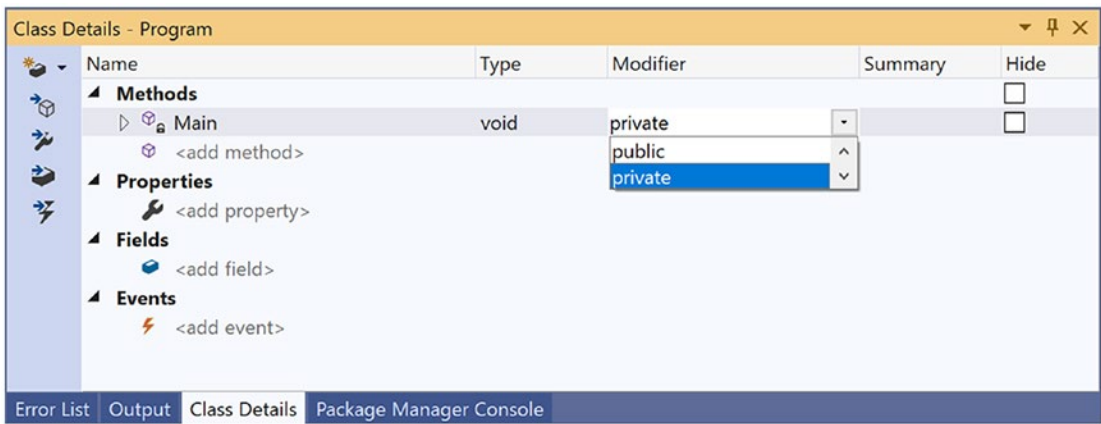


Figure 2-9. The Class Details window

The Class Designer Toolbox, which can also be activated using the View menu, allows you to insert new types (and create relationships between these types) into your project visually (see Figure 2-10). (Be aware you must have a class diagram as the active window to view this toolbox.) As you do so, the IDE automatically creates new C# type definitions in the background.

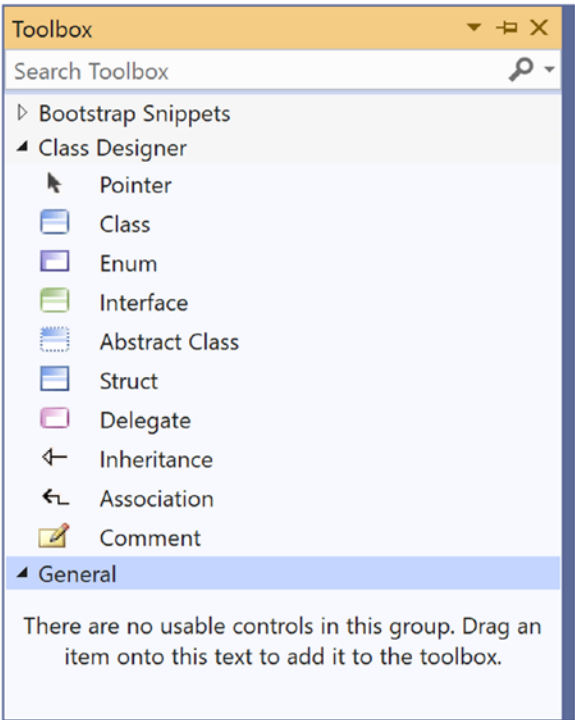
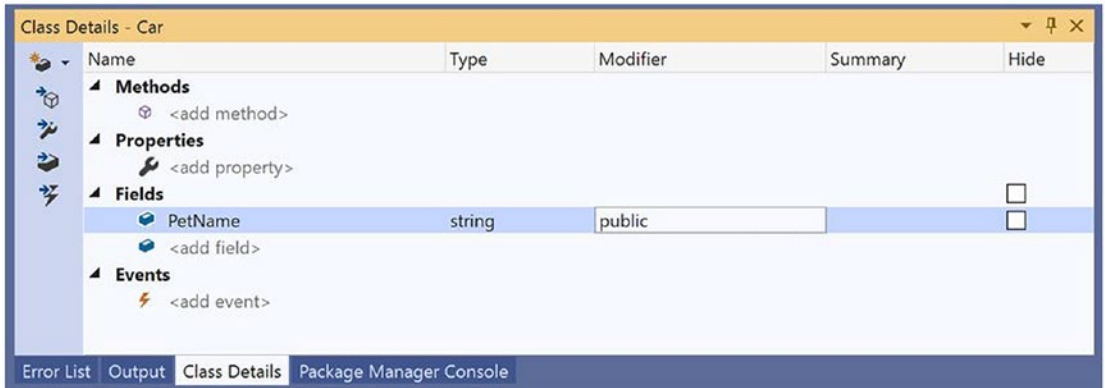


Figure 2-10. The Class Designer Toolbox



By way of example, drag a new class from the Class Designer Toolbox onto your Class Designer. Name this class `Car` in the resulting dialog box. This will result in the creation of a new C# file named `Car.cs` that is automatically added to your project. Now, using the Class Details window, add a public string field named `PetName` (see Figure 2-11).

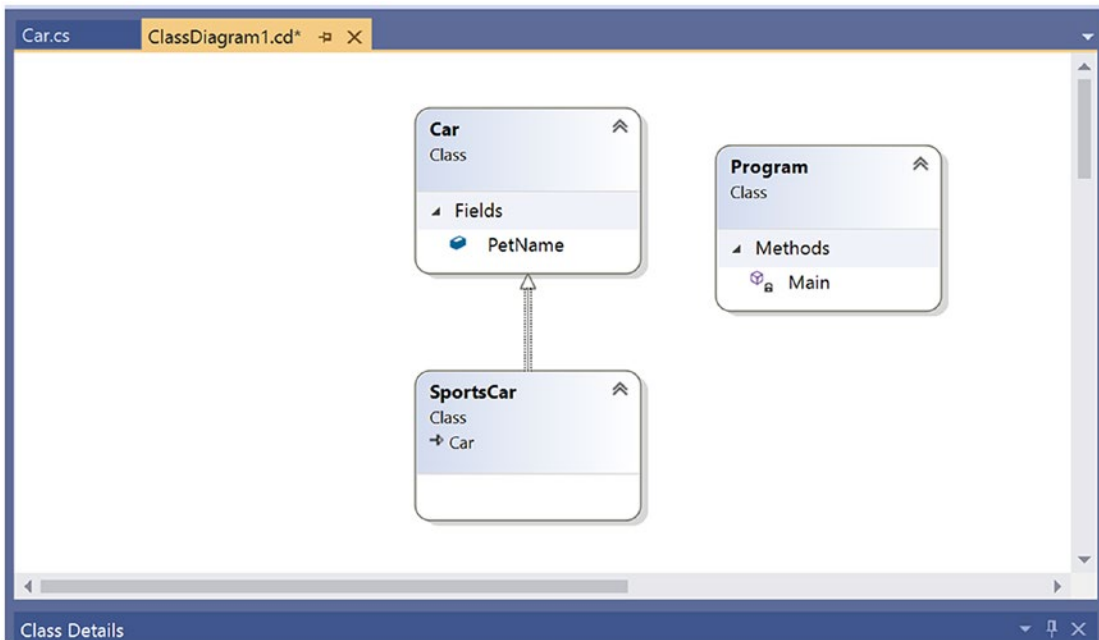


**Figure 2-11.** Adding a field with the Class Details window

If you now look at the C# definition of the `Car` class, you will see it has been updated accordingly (minus the additional code comments shown here):

```
public class Car
{
    // Public data is typically a bad idea; however,
    // it keeps this example simple.
    public string PetName;
}
```

Now, activate the designer file once again and drag another new class onto the designer and name it `SportsCar`. Select the Inheritance icon from the Class Designer Toolbox and click the top of the `SportsCar` icon. Next, click the mouse on top of the `Car` class icon. If you performed these steps correctly, you have just derived the `SportsCar` class from `Car` (see Figure 2-12).



**Figure 2-12.** Visually deriving from an existing class

---

■ **Note** The concept of inheritance will be fully examined in Chapter 6.

---

To complete this example, update the generated `SportsCar` class with a public method named `GetPetName()`, authored as follows:

```
public class SportsCar : Car
{
    public string GetPetName()
    {
        PetName = "Fred";
        return PetName;
    }
}
```

As you would expect, the designer shows the added method to the `SportsCar` class.

## The .NET Framework Documentation

The C# and .NET Core documentation is extremely good, very readable, and full of useful information. Given the huge number of predefined .NET types (which number well into the thousands), you must be willing to roll up your sleeves and dig into the provided documentation. You can view all of the Microsoft documentation at the following web address:

<https://docs.microsoft.com/en-us/dotnet/csharp/>

The areas that you will use the most in the first half of this book are the C# documentation and the .NET Core documentation, found at the following web addresses:

<https://docs.microsoft.com/en-us/dotnet/csharp/>

<https://docs.microsoft.com/en-us/dotnet/core/>

## Building .NET Core Applications on a Non-Windows OS

There are several options for building .NET applications on non-Windows operating systems. In addition to Visual Studio Code (mentioned earlier in this chapter), there is Visual Studio for the Mac (formerly Xamarin Studio) and commercial IDEs such as Rider from JetBrains. The types of applications that can be built with these development environments are limited to applications that are being developed either using .NET Core or for mobile using Xamarin.

## Summary

As you can see, you have many new toys at your disposal! The point of this chapter was to provide you with a tour of the major programming tools a C# programmer may leverage during the development process. As mentioned, if you are interested only in building .NET Core applications on a Windows development machine, your best bet is to download Visual Studio Community. As also mentioned, this edition of the book will use this particular IDE going forward. Thus, the forthcoming screenshots, menu options, and visual designers will all assume you are using Visual Studio Community.

If you want to build .NET Core applications or cross-platform mobile application on a non-Windows OS, then Visual Studio for the Mac or Visual Studio Code will be your best choice.

**PART II**



# **Core C# Programming**

## CHAPTER 3



# Core C# Programming Constructs, Part 1

This chapter begins your formal investigation of the C# programming language by presenting a number of bite-sized, stand-alone topics you must be comfortable with as you explore the .NET Core Framework. The first order of business is to understand how to build your program's *application object* and to examine the composition of an executable program's entry point: the `Main()` method. Next, you will investigate the fundamental C# data types (and their equivalent types in the `System` namespace) including an examination of the `System.String` and `System.Text.StringBuilder` classes.

After you know the details of the fundamental .NET Core data types, you will then examine a number of data type conversion techniques, including narrowing operations, widening operations, and the use of the checked and unchecked keywords.

This chapter will also examine the role of the C# `var` keyword, which allows you to *implicitly* define a local variable. As you will see later in this book, implicit typing is extremely helpful, if not occasionally mandatory, when working with the LINQ technology set. You will wrap up this chapter by quickly examining the C# keywords and operators that allow you to control the flow of an application using various looping and decision constructs.

## The Anatomy of a Simple C# Program

C# demands that all program logic be contained within a type definition (recall from Chapter 1 that *type* is a general term referring to a member of the set {class, interface, structure, enumeration, delegate}). Unlike many other languages, in C# it is not possible to create global functions or global points of data. Rather, all data members and all methods must be contained within a type definition. To get the ball rolling, create a new .NET Core C# Console Application project named `SimpleCSharpApp`. You might agree that the code within the initial `Program.cs` file is rather uneventful.

```
using System;

namespace SimpleCSharpApp
{
    class Program
    {
        static void Main(string[] args)
        {
```

```

        Console.WriteLine("Hello World!");
    }
}

```

Given this, update the `Main()` method of your `Program` class with the following code statements:

```

class Program
{
    static void Main(string[] args)
    {
        // Display a simple message to the user.
        Console.WriteLine("***** My First C# App *****");
        Console.WriteLine("Hello World!");
        Console.WriteLine();

        // Wait for Enter key to be pressed before shutting down.
        Console.ReadLine();
    }
}

```

---

■ **Note** C# is a case-sensitive programming language. Therefore, *Main* is not the same as *main*, and *Readline* is not the same as *ReadLine*. Be aware that all C# keywords are lowercase (e.g., `public`, `lock`, `class`, `dynamic`), while namespaces, types, and member names begin (by convention) with an initial capital letter and have capitalized the first letter of any embedded words (e.g., `Console.WriteLine`, `System.Windows.MessageBox`, `System.Data.SqlClient`). As a rule of thumb, whenever you receive a compiler error regarding “undefined symbols,” be sure to check your spelling and casing first!

---

The previous code contains a definition for a class type that supports a single method named `Main()`. By default, Visual Studio names the class defining `Main()` `Program`; however, you are free to change this if you so choose. Every executable C# application (console program, Windows desktop program, or Windows service) must contain a class defining a `Main()` method, which is used to signify the entry point of the application.

Formally speaking, the class that defines the `Main()` method is termed the *application object*. It is possible for a single executable application to have more than one application object (which can be useful when performing unit tests), but then the compiler must know which `Main()` method should be used as the entry point. This can be done via the `<StartupObject>` element in the project file or via the Startup Object drop-down list box, located on the Application tab of the Visual Studio project properties window.

Note that the signature of `Main()` is adorned with the `static` keyword, which will be examined in detail in Chapter 5. For the time being, simply understand that static members are scoped to the class level (rather than the object level) and can thus be invoked without the need to first create a new class instance.

In addition to the `static` keyword, this `Main()` method has a single parameter, which happens to be an array of strings (`string[] args`). Although you are not currently bothering to process this array, this parameter may contain any number of incoming command-line arguments (you’ll see how to access them momentarily). Finally, this `Main()` method has been set up with a `void` return value, meaning you do not explicitly define a return value using the `return` keyword before exiting the method scope.

The logic of the `Program` class is within `Main()`. Here, you make use of the `Console` class, which is defined within the `System` namespace. Among its set of members is the static `WriteLine()`, which, as you might assume, sends a text string and carriage return to the standard output. You also make a call to `Console.ReadLine()` to ensure the command prompt launched by the Visual Studio IDE remains visible. When running .NET Core Console apps with Visual Studio (in either Debug or Release mode), the console window remains visible by default. This behavior can be changed by enabling the setting “Automatically close the console when debugging stops” found under Tools ► Options ► Debugging. The `Console.ReadLine` method is there to keep the window open if the program is executed from Windows Explorer by double-clicking the product \*.exe file. You will learn more about the `System.Console` class shortly.

## Variations on the `Main()` Method (Updated 7.1)

By default, Visual Studio will generate a `Main()` method that has a `void` return value and an array of `string` types as the single input parameter. This is not the only possible form of `Main()`, however. It is permissible to construct your application’s entry point using any of the following signatures (assuming it is contained within a C# class or structure definition):

```
// int return type, array of strings as the parameter.
static int Main(string[] args)
{
    // Must return a value before exiting!
    return 0;
}

// No return type, no parameters.
static void Main()
{
}

// int return type, no parameters.
static int Main()
{
    // Must return a value before exiting!
    return 0;
}
```

With the release of C# 7.1, the `Main()` method can now be asynchronous. Async programming is covered in Chapter 15, but for now realize there are four additional signatures:

```
static Task Main()
static Task<int> Main()
static Task Main(string[])
static Task<int> Main(string[])
```

---

■ **Note** The `Main()` method may also be defined as `public` as opposed to `private`, which is assumed if you do not supply a specific access modifier. Visual Studio automatically defines a program’s `Main()` method as implicitly `private`.

---

Obviously, your choice of how to construct `Main()` will be based on three questions. First, do you want to return a value to the system when `Main()` has completed and your program terminates? If so, you need to return an `int` data type rather than `void`. Second, do you need to process any user-supplied, command-line parameters? If so, they will be stored in the array of `strings`. Lastly, do you need to call asynchronous code from the `Main` method. Let's examine the first two options in more detail, saving the `async` options for Chapter 15.

## Specifying an Application Error Code

While a vast majority of your `Main()` methods will return `void` as the return value, the ability to return an `int` from `Main()` keeps C# consistent with other C-based languages. By convention, returning the value 0 indicates the program has terminated successfully, while another value (such as -1) represents an error condition (be aware that the value 0 is automatically returned, even if you construct a `Main()` method prototyped to return `void`).

On the Windows operating system, an application's return value is stored within a system environment variable named `%ERRORLEVEL%`. If you were to create an application that programmatically launches another executable (a topic examined in Chapter 19), you can obtain the value of `%ERRORLEVEL%` using the `ExitCode` property of the launched process.

Given that an application's return value is passed to the system at the time the application terminates, it is obviously not possible for an application to obtain and display its final error code while running. However, to illustrate how to view this error level upon program termination, begin by updating the `Main()` method, as follows:

```
// Note we are now returning an int, rather than void.
static int Main(string[] args)
{
    // Display a message and wait for Enter key to be pressed.
    Console.WriteLine("***** My First C# App *****");
    Console.WriteLine("Hello World!");
    Console.WriteLine();
    Console.ReadLine();

    // Return an arbitrary error code.
    return -1;
}
```

Now let's capture the return value of `Main()` with the help of a batch file. Using Windows Explorer, navigate to the folder containing your project file (e.g., `C:\SimpleCSharpApp\SimpleCSharpApp`). Add a new text file (named `SimpleCSharpApp.cmd`) to that folder containing the following instructions (if you have not authored \*.cmd files before, don't concern yourself with the details):

```
@echo off
rem A batch file for SimpleCSharpApp.exe
rem which captures the app's return value.

dotnet run
@if "%ERRORLEVEL%" == "0" goto success

:fail
echo This application has failed!
echo return value = %ERRORLEVEL%
goto end
```



```
:success
    echo This application has succeeded!
    echo return value = %ERRORLEVEL%
    goto end
:end
echo All Done.
```

At this point, open a command prompt and navigate to the folder containing your new \*.cmd file. Execute the file by typing its name and pressing the Enter key. You should find the output shown next, given that your Main() method is returning -1. Had the Main() method returned 0, you would see the message “This application has succeeded!” print to the console.

---

```
***** My First C# App *****
```

```
Hello World!
```

```
This application has failed!
return value = -1
All Done.
```

---

The PowerShell equivalent of the preceding \*.cmd file is

```
dotnet run
if ($LastExitCode -eq 0) {
    Write-Host "This application has succeeded!"
} else
{
    Write-Host "This application has failed!"
}
Write-Host "All Done."
```

A vast majority (if not all) of your C# applications will use void as the return value from Main(), which, as you recall, implicitly returns the error code of zero. To this end, the Main() methods used in this text (beyond the current example) will indeed return void (and the remaining projects will certainly not need to make use of batch files to capture return codes).

## Processing Command-Line Arguments

Now that you better understand the return value of the Main() method, let’s examine the incoming array of string data. Assume that you now want to update your application to process any possible command-line parameters. One way to do so is using a C# for loop. (Note that C#’s iteration constructs will be examined in some detail near the end of this chapter.)

```
static int Main(string[] args)
{
    // Display a message and wait for Enter key to be pressed.
    Console.WriteLine("***** My First C# App *****");
    Console.WriteLine("Hello World!");
    Console.WriteLine();
}
```

```

// Process any incoming args.
for (int i = 0; i < args.Length; i++)
{
    Console.WriteLine("Arg: {0}", args[i]);
}
Console.ReadLine();
// Return an arbitrary error code.
return -1;
}

```

Here, you are checking to see whether the array of strings contains some number of items using the `Length` property of `System.Array`. As you'll see in Chapter 4, all C# arrays actually alias the `System.Array` class and, therefore, share a common set of members. As you loop over each item in the array, its value is printed to the console window. Supplying the arguments at the command line is equally simple, as shown here:

---

```
C:\SimpleCSharpApp>dotnet run /arg1 -arg2
```

```

***** My First C# App *****
Hello World!
Arg: /arg1
Arg: -arg2

```

---

As an alternative to the standard `for` loop, you may iterate over an incoming string array using the C# `foreach` keyword. Here is some sample usage (but again, you will see specifics of looping constructs later in this chapter):

```

// Notice you have no need to check the size of the array when using "foreach".
static int Main(string[] args)
{
    ...
    // Process any incoming args using foreach.
    foreach(string arg in args)
    {
        Console.WriteLine("Arg: {0}", arg);
    }
    Console.ReadLine();
    return -1;
}

```

Finally, you are also able to access command-line arguments using the static `GetCommandLineArgs()` method of the `System.Environment` type. The return value of this method is an array of strings. The first index identifies the name of the application itself, while the remaining elements in the array contain the individual command-line arguments. Note that when using this approach, it is no longer necessary to define `Main()` as taking a string array as the input parameter, although there is no harm in doing so.

```

static int Main(string[] args)
{
    ...
    // Get arguments using System.Environment.
    string[] theArgs = Environment.GetCommandLineArgs();

```

```

foreach(string arg in theArgs)
    Console.WriteLine("Arg: {0}", arg);

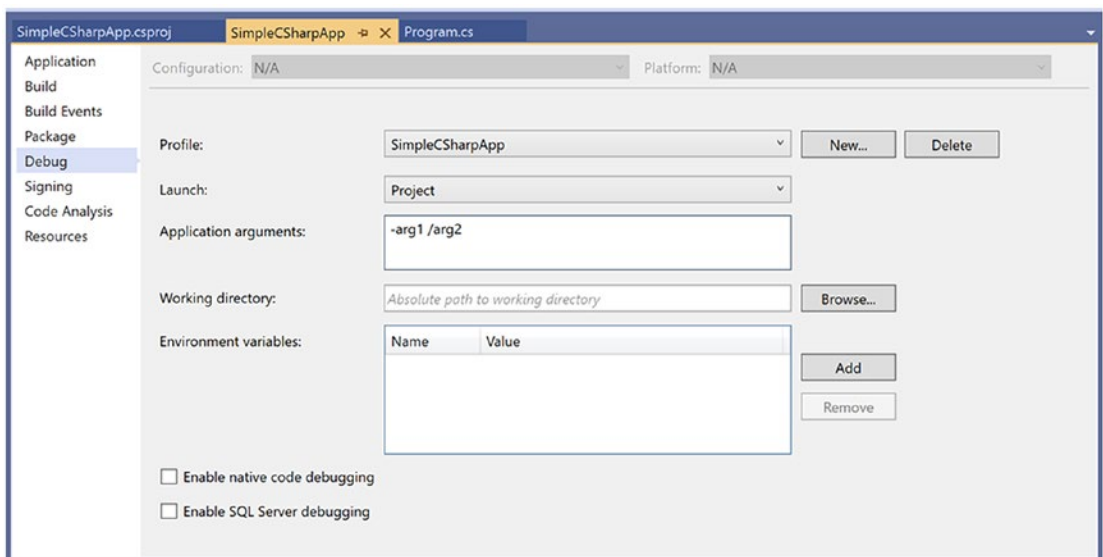
Console.ReadLine();
return -1;
}

```

Of course, it is up to you to determine which command-line arguments your program will respond to (if any) and how they must be formatted (such as with a - or / prefix). Here, I simply passed in a series of options that were printed directly to the command prompt. Assume, however, you were creating a new video game and programmed your application to process an option named `-godmode`. If the user starts your application with the flag, you know he is, in fact, *a cheater*, and you can take an appropriate course of action.

## Specifying Command-Line Arguments with Visual Studio

In the real world, an end user has the option of supplying command-line arguments when starting a program. However, during the development cycle, you might want to specify possible command-line flags for testing purposes. To do so with Visual Studio, right-click the Project name on Solution Explorer and select the Debug tab on the left side. From there, specify values using the “Application arguments” text box (see Figure 3-1) and save your changes.



**Figure 3-1.** Setting application arguments in Visual Studio

After you have established such command-line arguments, they will automatically be passed to the `Main()` method when debugging or running your application within the Visual Studio IDE.

## An Interesting Aside: Some Additional Members of the System.Environment Class

The Environment class exposes a number of extremely helpful methods beyond `GetCommandLineArgs()`. Specifically, this class allows you to obtain a number of details regarding the operating system currently hosting your .NET Core application using various static members. To illustrate the usefulness of `System.Environment`, update your `Main()` method to call a helper method named `ShowEnvironmentDetails()`.

```
static int Main(string[] args)
{
    ...
    // Helper method within the Program class.
    ShowEnvironmentDetails();

    Console.ReadLine();
    return -1;
}
```

Implement this method within your Program class to call various members of the Environment type.

```
static void ShowEnvironmentDetails()
{
    // Print out the drives on this machine,
    // and other interesting details.
    foreach (string drive in Environment.GetLogicalDrives())
    {
        Console.WriteLine("Drive: {0}", drive);
    }
    Console.WriteLine("OS: {0}", Environment.OSVersion);
    Console.WriteLine("Number of processors: {0}",
        Environment.ProcessorCount);
    Console.WriteLine(".NET Core Version: {0}",
        Environment.Version);
}
```

The following output shows a possible test run of invoking this method. Of course, if you did not specify command-line arguments via the Visual Studio Debug tab, you will not find them printed to the console.

---

```
***** My First C# App *****
```

```
Hello World!
```

```
Drive: C:\
OS: Microsoft Windows NT 6.2.9200.0
Number of processors: 16
.NET Core Version: 3.1.0
```

---

The Environment type defines members other than those shown in the previous example. Table 3-1 documents some additional properties of interest; however, be sure to check out the online documentation for full details.

**Table 3-1.** *Select Properties of System.Environment*

Property	Meaning in Life
ExitCode	Gets or sets the exit code for the application
Is64BitOperatingSystem	Returns a bool to represent whether the host machine is running a 64-bit OS
MachineName	Gets the name of the current machine
NewLine	Gets the newline symbol for the current environment
SystemDirectory	Returns the full path to the system directory
UserName	Returns the name of the user that started this application
Version	Returns a Version object that represents the version of the .NET Core platform

## The System.Console Class

Almost all the example applications created over the course of the initial chapters of this book make extensive use of the `System.Console` class. While it is true that a console user interface (CUI) may not be as enticing as a graphical user interface (GUI) or web application, restricting the early examples to console programs will allow you to keep focused on the syntax of C# and the core aspects of the .NET Core platform, rather than dealing with the complexities of building desktop GUIs or websites.

As its name implies, the `Console` class encapsulates input, output, and error-stream manipulations for console-based applications. Table 3-2 lists some (but definitely not all) members of interest. As you can see, the `Console` class does provide some members that can spice up a simple command-line application, such as the ability to change background and foreground colors and issue beep noises (in a variety of frequencies!).

**Table 3-2.** *Select Members of System.Console*

Member	Meaning in Life
Beep()	This method forces the console to emit a beep of a specified frequency and duration.
BackgroundColor	These properties set the background/foreground colors for the current output.
ForegroundColor	They may be assigned any member of the <code>ConsoleColor</code> enumeration.
BufferHeightBufferWidth	These properties control the height/width of the console's buffer area.
Title	This property gets or sets the title of the current console.
WindowHeight WindowWidth WindowTop WindowLeft	These properties control the dimensions of the console in relation to the established buffer.
Clear()	This method clears the established buffer and console display area.

## Basic Input and Output with the Console Class

In addition to the members in Table 3-2, the `Console` type defines a set of methods to capture input and output, all of which are static and are, therefore, called by prefixing the name of the class (`Console`) to the method name. As you have seen, `WriteLine()` pumps a text string (including a carriage return) to the output stream. The `Write()` method pumps text to the output stream without a carriage return. `ReadLine()` allows you to receive information from the input stream up until the Enter key is pressed, while `Read()` is used to capture a single character from the input stream.

To illustrate basic I/O using the `Console` class, create a new Console Application project named `BasicConsoleIO` and update your `Main()` method to call a helper method named `GetUserData()`.

```
class Program
{
    static void Main(string[] args)
    {
        Console.WriteLine("***** Basic Console I/O *****");
        GetUserData();
        Console.ReadLine();
    }

    private static void GetUserData()
    {
    }
}
```

---

■ **Note** Visual Studio supports a number of “code snippets” that will insert code once activated. The `cw` code snippet is quite useful during the early chapters of this text, in that it will automatically expand to `Console.WriteLine()`! To test this for yourself, type in `cw` somewhere within your `Main()` method and hit the Tab key twice (sadly, there is no code snippet for `Console.ReadLine()`). To see all code snippets, right-click in a C# code file and choose the Snippet menu option.

---

Implement this method within the `Program` class with logic that prompts the user for some bits of information and echoes each item to the standard output stream. For example, you could ask the user for a name and age (which will be treated as a text value for simplicity, rather than the expected numerical value), as follows:

```
static void GetUserData()
{
    // Get name and age.
    Console.Write("Please enter your name: ");
    string userName = Console.ReadLine();
    Console.Write("Please enter your age: ");
    string userAge = Console.ReadLine();

    // Change echo color, just for fun.
    ConsoleColor prevColor = Console.ForegroundColor;
    Console.ForegroundColor = ConsoleColor.Yellow;
```

```
// Echo to the console.
Console.WriteLine("Hello {0}! You are {1} years old.",
    userName, userAge);

// Restore previous color.
Console.ForegroundColor = prevColor;
}
```

Not surprisingly, when you run this application, the input data is printed to the console (using a custom color to boot!).

## Formatting Console Output

During these first few chapters, you might have noticed numerous occurrences of tokens such as {0} and {1} embedded within various string literals. The .NET Core platform supports a style of string formatting slightly akin to the `printf()` statement of C. Simply put, when you are defining a string literal that contains segments of data whose value is not known until runtime, you are able to specify a placeholder within the literal using this curly-bracket syntax. At runtime, the values passed into `Console.WriteLine()` are substituted for each placeholder.

The first parameter to `WriteLine()` represents a string literal that contains optional placeholders designated by {0}, {1}, {2}, and so forth. Be aware that the first ordinal number of a curly-bracket placeholder always begins with 0. The remaining parameters to `WriteLine()` are simply the values to be inserted into the respective placeholders.

---

**■ Note** If you have more uniquely numbered curly-bracket placeholders than fill arguments, you will receive a format exception at runtime. However, if you have more fill arguments than placeholders, the unused fill arguments are ignored.

---

It is permissible for a given placeholder to repeat within a given string. For example, if you are a Beatles fan and want to build the string "9, Number 9, Number 9", you would write this:

```
// John says...
Console.WriteLine("{0}, Number {0}, Number {0}", 9);
```

Also, know that it is possible to position each placeholder in any location within a string literal, and it need not follow an increasing sequence. For example, consider the following code snippet:

```
// Prints: 20, 10, 30
Console.WriteLine("{1}, {0}, {2}", 10, 20, 30);
```

Strings can also be formatted using string interpolation, which is covered later in this chapter.

## Formatting Numerical Data

If you require more elaborate formatting for numerical data, each placeholder can optionally contain various format characters. Table 3-3 shows the most common formatting options.

**Table 3-3.** .NET Core Numerical Format Characters

String Format Character	Meaning in Life
C or c	Used to format currency. By default, the flag will prefix the local cultural symbol (a dollar sign [\$] for US English).
D or d	Used to format decimal numbers. This flag may also specify the minimum number of digits used to pad the value.
E or e	Used for exponential notation. Casing controls whether the exponential constant is uppercase (E) or lowercase (e).
F or f	Used for fixed-point formatting. This flag may also specify the minimum number of digits used to pad the value.
G or g	Stands for <i>general</i> . This character can be used to format a number to fixed or exponential format.
N or n	Used for basic numerical formatting (with commas).
X or x	Used for hexadecimal formatting. If you use an uppercase X, your hex format will also contain uppercase characters.

These format characters are suffixed to a given placeholder value using the colon token (e.g., {0:C}, {1:d}, {2:X}). To illustrate, update the Main() method to call a new helper function named FormatNumericalData(). Implement this method in your Program class to format a fixed numerical value in a variety of ways.

```
// Now make use of some format tags.
static void FormatNumericalData()
{
    Console.WriteLine("The value 99999 in various formats:");
    Console.WriteLine("c format: {0:c}", 99999);
    Console.WriteLine("d9 format: {0:d9}", 99999);
    Console.WriteLine("f3 format: {0:f3}", 99999);
    Console.WriteLine("n format: {0:n}", 99999);

    // Notice that upper- or lowercasing for hex
    // determines if letters are upper- or lowercase.
    Console.WriteLine("E format: {0:E}", 99999);
    Console.WriteLine("e format: {0:e}", 99999);
    Console.WriteLine("X format: {0:X}", 99999);
    Console.WriteLine("x format: {0:x}", 99999);
}
```

The following output shows the result of calling the FormatNumericalData() method:

```
The value 99999 in various formats:
c format: $99,999.00
d9 format: 000099999
f3 format: 99999.000
n format: 99,999.00
```



```
E format: 9.999900E+004
e format: 9.999900e+004
X format: 1869F
x format: 1869f
```

You'll see additional formatting examples where required throughout this text; however, if you are interested in digging into string formatting further, look up the topic "Formatting Types" within the .NET Core documentation.

## Formatting Numerical Data Beyond Console Applications

On a final note, be aware that the use of the string formatting characters is not limited to console programs. This same formatting syntax can be used when calling the static `string.Format()` method. This can be helpful when you need to compose textual data at runtime for use in any application type (e.g., desktop GUI app, ASP.NET web app, etc.).

The `string.Format()` method returns a new string object, which is formatted according to the provided flags. The following code formats a string in hex:

```
// Using string.Format() to format a string literal.
string userMessage = string.Format("100000 in hex is {0:x}", 100000);
```

## System Data Types and Corresponding C# Keywords

Like any programming language, C# defines keywords for fundamental data types, which are used to represent local variables, class data member variables, method return values, and parameters. Unlike other programming languages, however, these keywords are much more than simple compiler-recognized tokens. Rather, the C# data type keywords are actually shorthand notations for full-blown types in the `System` namespace. Table 3-4 lists each system data type, its range, the corresponding C# keyword, and the type's compliance with the Common Language Specification (CLS). All of the system types are in the `System` namespace, left off the chart for readability.

**Table 3-4.** *The Intrinsic Data Types of C#*

C# Shorthand	CLS Compliant?	System Type	Range	Meaning in Life
<code>bool</code>	Yes	<code>Boolean</code>	true or false	Represents truth or falsity
<code>sbyte</code>	No	<code>SByte</code>	-128 to 127	Signed 8-bit number
<code>byte</code>	Yes	<code>Byte</code>	0 to 255	Unsigned 8-bit number
<code>short</code>	Yes	<code>Int16</code>	-32,768 to 32,767	Signed 16-bit number
<code>ushort</code>	No	<code>UInt16</code>	0 to 65,535	Unsigned 16-bit number
<code>int</code>	Yes	<code>Int32</code>	-2,147,483,648 to 2,147,483,647	Signed 32-bit number
<code>uint</code>	No	<code>UInt32</code>	0 to 4,294,967,295	Unsigned 32-bit number

(continued)

**Table 3-4.** (continued)

C# Shorthand	CLS Compliant?	System Type	Range	Meaning in Life
long	Yes	Int64	−9,223,372,036,854,775,808 to 9,223,372,036,854,775,807	Signed 64-bit to number
ulong	No	UInt64	0 to 18,446,744,073,709,551,615	Unsigned 64-bit number
char	Yes	Char	U+0000 to U+ffff	Single 16-bit Unicode character
float	Yes	Single	−3.4 10 <sup>38</sup> to +3.4 10 <sup>38</sup>	32-bit floating-point number
double	Yes	Double	±5.0 10 <sup>−324</sup> to ±1.7 10 <sup>308</sup>	64-bit floating-point number
decimal	Yes	Decimal	(−7.9 x 10 <sup>28</sup> to 7.9 x 10 <sup>28</sup> )/ (10 <sup>0 to 28</sup> )	128-bit signed number
string	Yes	String	Limited by system memory	Represents a set of Unicode characters
object	Yes	Object	Can store any data type in an object variable	The base class of all types in the .NET universe

■ **Note** Recall from Chapter 1 that CLS-compliant .NET Core code can be used by any other .NET Core programming language. If you expose non-CLS-compliant data from your programs, other .NET Core languages might not be able to make use of it.

## Variable Declaration and Initialization

When you are declaring a local variable (e.g., a variable within a member scope), you do so by specifying the data type, followed by the variable’s name. To begin, create a new Console Application project named BasicDataTypes. Update the Program class with the following helper method that is called from within Main():

```
static void LocalVarDeclarations()
{
    Console.WriteLine("=> Data Declarations:");
    // Local variables are declared as so:
    // dataType varName;
    int myInt;
    string myString;
    Console.WriteLine();
}
```

Be aware that it is a *compiler error* to make use of a local variable before assigning an initial value. Given this, it is good practice to assign an initial value to your local data points at the time of declaration. You may do so on a single line or by separating the declaration and assignment into two code statements.

```
static void LocalVarDeclarations()
{
    Console.WriteLine("=> Data Declarations:");
    // Local variables are declared and initialized as follows:
    // dataType varName = initialValue;
    int myInt = 0;

    // You can also declare and assign on two lines.
    string myString;
    myString = "This is my character data";

    Console.WriteLine();
}
```

It is also permissible to declare multiple variables of the same underlying type on a single line of code, as in the following three bool variables:

```
static void LocalVarDeclarations()
{
    Console.WriteLine("=> Data Declarations:");
    int myInt = 0;
    string myString;
    myString = "This is my character data";

    // Declare 3 bools on a single line.
    bool b1 = true, b2 = false, b3 = b1;
    Console.WriteLine();
}
```

Since the C# bool keyword is simply a shorthand notation for the System.Boolean structure, it is also possible to allocate any data type using its full name (of course, the same point holds true for any C# data type keyword). Here is the final implementation of LocalVarDeclarations(), which illustrates various ways to declare a local variable:

```
static void LocalVarDeclarations()
{
    Console.WriteLine("=> Data Declarations:");
    // Local variables are declared and initialized as follows:
    // dataType varName = initialValue;
    int myInt = 0;

    string myString;
    myString = "This is my character data";

    // Declare 3 bools on a single line.
    bool b1 = true, b2 = false, b3 = b1;
```

```
// Use System.Boolean data type to declare a bool.
System.Boolean b4 = false;

Console.WriteLine("Your data: {0}, {1}, {2}, {3}, {4}, {5}",
    myInt, myString, b1, b2, b3, b4);
Console.WriteLine();
}
```

## The default Literal (New 7.1)

The default literal assigns a variable the default value for its data type. This works for standard data types as well as custom classes (Chapter 5) and generic types (Chapter 10). Create a new method named `DefaultDeclarations()` and add the following code:

```
static void DefaultDeclarations()
{
    Console.WriteLine("=> Default Declarations:");
    int myInt = default;
}
```

## Intrinsic Data Types and the new Operator

All intrinsic data types support what is known as a *default constructor* (see Chapter 5). This feature allows you to create a variable using the new keyword, which automatically sets the variable to its default value:

- `bool` variables are set to `false`.
- Numeric data is set to 0 (or 0.0 in the case of floating-point data types).
- `char` variables are set to a single empty character.
- `BigInteger` variables are set to 0.
- `DateTime` variables are set to 1/1/0001 12:00:00 AM.
- Object references (including strings) are set to `null`.

---

■ **Note** The `BigInteger` data type mentioned in the previous list will be explained in just a bit.

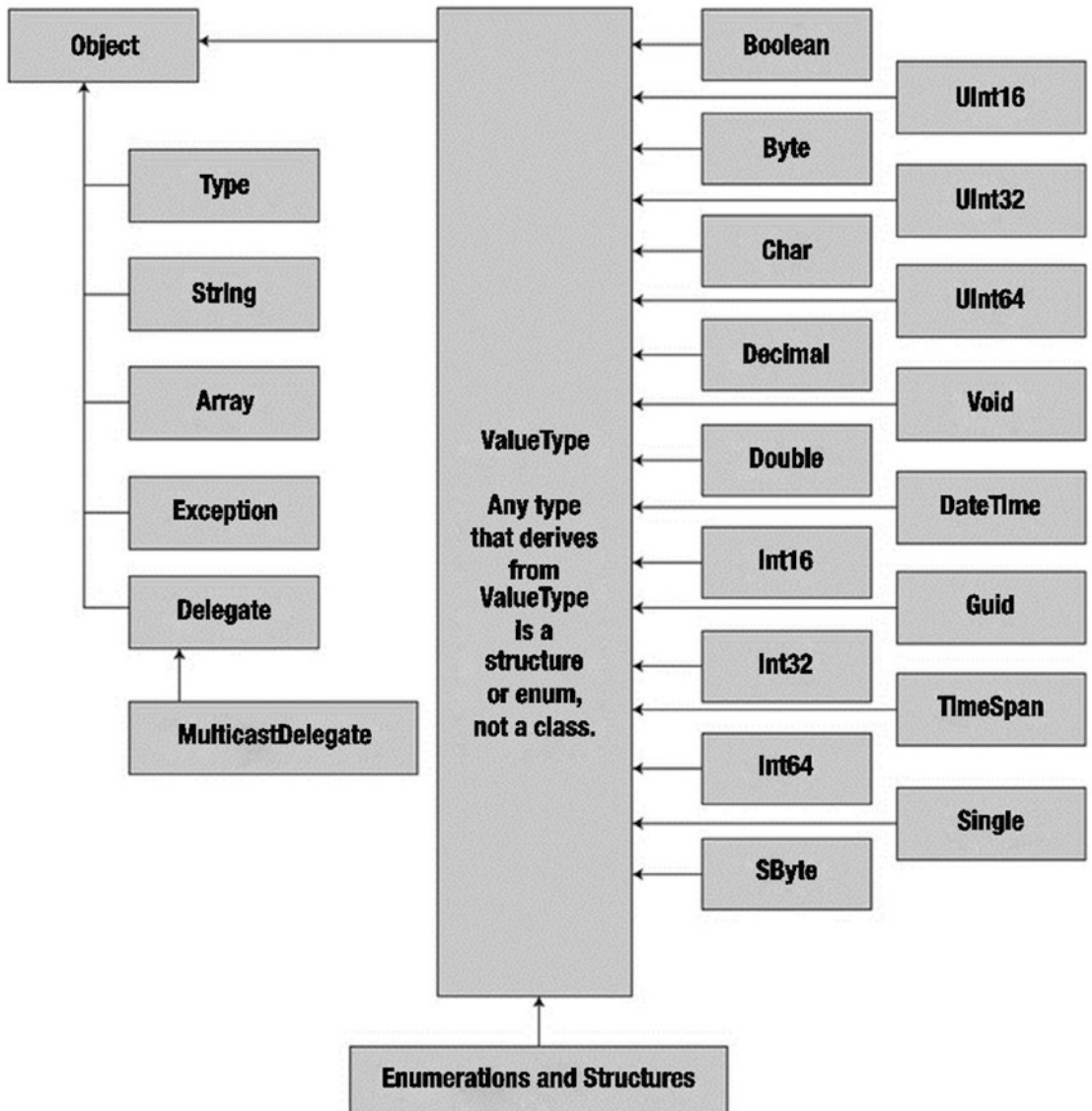
---

Although it is more cumbersome to use the new keyword when creating a basic data type variable, the following is syntactically well-formed C# code:

```
static void NewingDataTypes()
{
    Console.WriteLine("=> Using new to create variables:");
    bool b = new bool();           // Set to false.
    int i = new int();             // Set to 0.
    double d = new double();       // Set to 0.
    DateTime dt = new DateTime();  // Set to 1/1/0001 12:00:00 AM
    Console.WriteLine("{0}, {1}, {2}, {3}", b, i, d, dt);
    Console.WriteLine();
}
```

## The Data Type Class Hierarchy

It is interesting to note that even the primitive .NET Core data types are arranged in a *class hierarchy*. If you are new to the world of inheritance, you will discover the full details in Chapter 6. Until then, just understand that types at the top of a class hierarchy provide some default behaviors that are granted to the derived types. The relationship between these core system types can be understood as shown in Figure 3-2.



**Figure 3-2.** The class hierarchy of system types

Notice that each type ultimately derives from `System.Object`, which defines a set of methods (e.g., `ToString()`, `Equals()`, `GetHashCode()`) common to all types in the .NET Core base class libraries (these methods are fully detailed in Chapter 6).

Also note that many numerical data types derive from a class named `System.ValueType`. Descendants of `ValueType` are automatically allocated on the stack and, therefore, have a predictable lifetime and are quite efficient. On the other hand, types that do not have `System.ValueType` in their inheritance chain (such as `System.Type`, `System.String`, `System.Array`, `System.Exception`, and `System.Delegate`) are not allocated on the stack but on the garbage-collected heap. (You can find more information on this distinction in Chapter 4.)

Without getting too hung up on the details of `System.Object` and `System.ValueType`, just understand that because a C# keyword (such as `int`) is simply shorthand notation for the corresponding system type (in this case, `System.Int32`), the following is perfectly legal syntax, given that `System.Int32` (the C# `int`) eventually derives from `System.Object` and, therefore, can invoke any of its public members, as illustrated by this additional helper function:

```
static void ObjectFunctionality()
{
    Console.WriteLine("=> System.Object Functionality:");

    // A C# int is really a shorthand for System.Int32,
    // which inherits the following members from System.Object.
    Console.WriteLine("12.GetHashCode() = {0}", 12.GetHashCode());
    Console.WriteLine("12.Equals(23) = {0}", 12.Equals(23));
    Console.WriteLine("12.ToString() = {0}", 12.ToString());
    Console.WriteLine("12.GetType() = {0}", 12.GetType());
    Console.WriteLine();
}
```

If you were to call this method from within `Main()`, you would find the output shown here:

---

```
=> System.Object Functionality:

12.GetHashCode() = 12
12.Equals(23) = False
12.ToString() = 12
12.GetType() = System.Int32
```

---

## Members of Numerical Data Types

To continue experimenting with the intrinsic C# data types, understand that the numerical types of .NET Core support `MaxValue` and `MinValue` properties that provide information regarding the range a given type can store. In addition to the `MinValue/MaxValue` properties, a given numerical system type may define further useful members. For example, the `System.Double` type allows you to obtain the values for epsilon and infinity (which might be of interest to those of you with a mathematical flare). To illustrate, consider the following helper function:

```
static void DataTypeFunctionality()
{
    Console.WriteLine("=> Data type Functionality:");

    Console.WriteLine("Max of int: {0}", int.MaxValue);
    Console.WriteLine("Min of int: {0}", int.MinValue);
    Console.WriteLine("Max of double: {0}", double.MaxValue);
    Console.WriteLine("Min of double: {0}", double.MinValue);
    Console.WriteLine("double.Epsilon: {0}", double.Epsilon);
    Console.WriteLine("double.PositiveInfinity: {0}",
        double.PositiveInfinity);
    Console.WriteLine("double.NegativeInfinity: {0}",
        double.NegativeInfinity);
    Console.WriteLine();
}
```

When you define a literal whole number (such as 500), the runtime will default the data type to an `int`. Likewise, literal floating-point data (such as 55.333) will default to a `double`. To set the underlying data type to a `long`, use suffix `l` or `L` (4L). To declare a `float` variable, use the suffix `f` or `F` to the raw numerical value (5.3F), and use the suffix `m` or `M` to a floating-point number to declare a decimal (300.5M). This becomes more important when declaring variables implicitly, which is covered later in this chapter.

## Members of System.Boolean

Next, consider the `System.Boolean` data type. The only valid assignment a C# `bool` can take is from the set `{true | false}`. Given this point, it should be clear that `System.Boolean` does not support a `MinValue/MaxValue` property set but rather `TrueString/FalseString` (which yields the string "True" or "False", respectively). Here's an example:

```
Console.WriteLine("bool.FalseString: {0}", bool.FalseString);
Console.WriteLine("bool.TrueString: {0}", bool.TrueString);
```

## Members of System.Char

C# textual data is represented by the `string` and `char` keywords, which are simple shorthand notations for `System.String` and `System.Char`, both of which are Unicode under the hood. As you might already know, a `string` represents a contiguous set of characters (e.g., "Hello"), while the `char` can represent a single slot in a string (e.g., 'H').

The `System.Char` type provides you with a great deal of functionality beyond the ability to hold a single point of character data. Using the static methods of `System.Char`, you are able to determine whether a given character is numerical, alphabetical, a point of punctuation, or whatnot. Consider the following method:

```
static void CharFunctionality()
{
    Console.WriteLine("=> char type Functionality:");
    char myChar = 'a';
    Console.WriteLine("char.IsDigit('a'): {0}", char.IsDigit(myChar));
    Console.WriteLine("char.IsLetter('a'): {0}", char.IsLetter(myChar));
    Console.WriteLine("char.IsWhiteSpace('Hello There', 5): {0}",
        char.IsWhiteSpace("Hello There", 5));
}
```

```

Console.WriteLine("char.IsWhiteSpace('Hello There', 6): {0}",
    char.IsWhiteSpace("Hello There", 6));
Console.WriteLine("char.IsPunctuation('?'): {0}",
    char.IsPunctuation('?'));
Console.WriteLine();
}

```

As illustrated in the previous method, many members of `System.Char` have two calling conventions: a single character or a string with a numerical index that specifies the position of the character to test.

## Parsing Values from String Data

The .NET Core data types provide the ability to generate a variable of their underlying type given a textual equivalent (e.g., parsing). This technique can be extremely helpful when you want to convert some user input data (such as a selection from a GUI-based, drop-down list box) into a numerical value. Consider the following parsing logic within a method named `ParseFromStrings()`:

```

static void ParseFromStrings()
{
    Console.WriteLine("=> Data type parsing:");
    bool b = bool.Parse("True");
    Console.WriteLine("Value of b: {0}", b);
    double d = double.Parse("99.884");
    Console.WriteLine("Value of d: {0}", d);
    int i = int.Parse("8");
    Console.WriteLine("Value of i: {0}", i);
    char c = Char.Parse("w");
    Console.WriteLine("Value of c: {0}", c);
    Console.WriteLine();
}

```

## Using TryParse to Parse Values from String Data

One issue with the preceding code is that an exception will be thrown if the string cannot be cleanly converted to the correct data type. For example, the following will fail at runtime:

```
bool b = bool.Parse("Hello");
```

One solution is to wrap each call to `Parse()` in a try-catch block (exception handling is covered in detail in Chapter 7), which can add a lot of code, or use a `TryParse()` statement. The `TryParse()` statement takes an out parameter (the out modifier is covered in detail in Chapter 4) and returns a `bool` if the parsing was successful. Create a new method named `ParseFromStringWithTryParse()` and add the following code:

```

static void ParseFromStringWithTryParse()
{
    Console.WriteLine("=> Data type parsing with TryParse:");
    if (bool.TryParse("True", out bool b))
    {
        Console.WriteLine("Value of b: {0}", b);
    }
}

```



```

else
{
    Console.WriteLine("Default value of b: {0}", b);
}
string value = "Hello";
if (double.TryParse(value, out double d))
{
    Console.WriteLine("Value of d: {0}", d);
}
else
{
    Console.WriteLine("Failed to convert the input ({0}) to a double and the variable was
assigned the default {1}", value,d);
}
Console.WriteLine();
}

```

If you are new to programming and don't know how if-else statements work, they are covered later in this chapter in detail. The important item to note from the preceding example is that if a string can be converted to the requested datatype, the `TryParse()` method returns `true` and assigns the parsed value to the variable passed into the method. If the value cannot be parsed, the variable is assigned its default value, and the `TryParse()` method returns `false`.

## System.DateTime and System.TimeSpan

The `System` namespace defines a few useful data types for which there are no C# keywords, such as the `DateTime` and `TimeSpan` structures. (I'll leave the investigation of `System.Guid` and `System.Void`, as shown in Figure 3-2, to interested readers, but do be aware that these two data types in the `System` namespace are seldom useful in most applications.)

The `DateTime` type contains data that represents a specific date (month, day, year) and time value, both of which may be formatted in a variety of ways using the supplied members. The `TimeSpan` structure allows you to easily define and transform units of time using various members.

```

static void UseDatesAndTimes()
{
    Console.WriteLine("=> Dates and Times:");

    // This constructor takes (year, month, day).
    DateTime dt = new DateTime(2015, 10, 17);

    // What day of the month is this?
    Console.WriteLine("The day of {0} is {1}", dt.Date, dt.DayOfWeek);

    // Month is now December.
    dt = dt.AddMonths(2);
    Console.WriteLine("Daylight savings: {0}", dt.IsDaylightSavingTime());

    // This constructor takes (hours, minutes, seconds).
    TimeSpan ts = new TimeSpan(4, 30, 0);
    Console.WriteLine(ts);
}

```

```
// Subtract 15 minutes from the current TimeSpan and
// print the result.
Console.WriteLine(ts.Subtract(new TimeSpan(0, 15, 0)));
}
```

## The System.Numerics Namespace

The `System.Numerics` namespace defines a structure named `BigInteger`. As its name implies, the `BigInteger` data type can be used when you need to represent *humongous* numerical values, which are not constrained by a fixed upper or lower limit.

■ **Note** The `System.Numerics` namespace defines a second structure named `Complex`, which allows you to model mathematically complex numerical data (e.g., imaginary units, real data, hyperbolic tangents). Consult the .NET Core documentation if you are interested.

While many of your .NET Core applications might never need to make use of the `BigInteger` structure, if you do find the need to define a massive numerical value, your first step is to add the following using directive to the file:

```
// BigInteger lives here!  
using System.Numerics;
```

At this point, you can create a `BigInteger` variable using the new operator. Within the constructor, you can specify a numerical value, including floating-point data. However, C# implicitly types non-floating-point numbers as an `int` and floating-point numbers as a `double`. How, then, can you set `BigInteger` to a massive value while not overflowing the default data types used for raw numerical values?

The simplest approach is to establish the massive numerical value as a text literal, which can be converted into a `BigInteger` variable via the static `Parse()` method. If required, you can also pass in a byte array directly to the constructor of the `BigInteger` class.

■ **Note** After you assign a value to a `BigInteger` variable, you cannot change it, as the data is immutable. However, the `BigInteger` class defines a number of members that will return new `BigInteger` objects based on your data modifications (such as the static `Multiply()` method used in the following code sample).

In any case, after you have defined a `BigInteger` variable, you will find this class defines similar members as other intrinsic C# data types (e.g., `float`, `int`). In addition, the `BigInteger` class defines several static members that allow you to apply basic mathematical expressions (such as adding and multiplying) to `BigInteger` variables. Here is an example of working with the `BigInteger` class:

[illegible]



Here is a method that shows using the new literals with the digit separator:

```
private static void BinaryLiterals()
{
    //Updated in 7.2, Binary can begin with _
    Console.WriteLine("=> Use Binary Literals:");
    Console.WriteLine("Sixteen: {0}",0b_0001_0000);
    Console.WriteLine("Thirty Two: {0}",0b_0010_0000);
    Console.WriteLine("Sixty Four: {0}",0b_0100_0000);
}
```

## Working with String Data

System.String provides a number of methods you would expect from such a utility class, including methods that return the length of the character data, find substrings within the current string, and convert to and from uppercase/lowercase. Table 3-5 lists some (but by no means all) of the interesting members.

**Table 3-5.** Select Members of System.String

String Member	Meaning in Life
Length	This property returns the length of the current string.
Compare()	This static method compares two strings.
Contains()	This method determines whether a string contains a specific substring.
Equals()	This method tests whether two string objects contain identical character data.
Format()	This static method formats a string using other primitives (e.g., numerical data, other strings) and the {0} notation examined earlier in this chapter.
Insert()	This method inserts a string within a given string.
PadLeft() PadRight()	These methods are used to pad a string with some characters.
Remove() Replace()	These methods are used to receive a copy of a string with modifications (characters removed or replaced).
Split()	This method returns a String array containing the substrings in this instance that are delimited by elements of a specified char array or string array.
Trim()	This method removes all occurrences of a set of specified characters from the beginning and end of the current string.
ToUpper() ToLower()	These methods create a copy of the current string in uppercase or lowercase format, respectively.

## Basic String Manipulation

Working with the members of System.String is as you would expect. Simply declare a string variable and make use of the provided functionality via the dot operator. Be aware that a few of the members of System.String are static members and are, therefore, called at the class (rather than the object) level. Assume you have created a new Console Application project named FunWithStrings. Author the following method, which should be called from within Main():

```
static void BasicStringFunctionality()
{
    Console.WriteLine("=> Basic String functionality:");
    string firstName = "Freddy";
    Console.WriteLine("Value of firstName: {0}", firstName);
    Console.WriteLine("firstName has {0} characters.", firstName.Length);
    Console.WriteLine("firstName in uppercase: {0}", firstName.ToUpper());
    Console.WriteLine("firstName in lowercase: {0}", firstName.ToLower());
    Console.WriteLine("firstName contains the letter y?: {0}",
        firstName.Contains("y"));
    Console.WriteLine("firstName after replace: {0}", firstName.Replace("dy", ""));
    Console.WriteLine();
}
```

There's not too much to say here, as this method simply invokes various members, such as `ToUpper()` and `Contains()`, on a local string variable to yield various formats and transformations. Here is the initial output:

---

```
***** Fun with Strings *****
```

```
=> Basic String functionality:
Value of firstName: Freddy
firstName has 6 characters.
firstName in uppercase: FREDDY
firstName in lowercase: freddy
firstName contains the letter y?: True
firstName after replace: Fred
```

---

While this output might not seem too surprising, the output seen via calling the `Replace()` method is a bit misleading. In reality, the `firstName` variable has not changed at all; rather, you receive a new string in a modified format. You will revisit the immutable nature of strings in just a few moments.

## String Concatenation

String variables can be connected to build larger strings via the `C# +` (as well as `+=`) operator. As you might know, this technique is formally termed *string concatenation*. Consider the following new helper function:

```
static void StringConcatenation()
{
    Console.WriteLine("=> String concatenation:");
    string s1 = "Programming the ";
    string s2 = "PsychoDrill (PTP)";
    string s3 = s1 + s2;
    Console.WriteLine(s3);
    Console.WriteLine();
}
```

You might be interested to know that the C# + symbol is processed by the compiler to emit a call to the static `String.Concat()` method. Given this, it is possible to perform string concatenation by calling `String.Concat()` directly (although you really have not gained anything by doing so – in fact, you have incurred additional keystrokes!).

```
static void StringConcatenation()
{
    Console.WriteLine("=> String concatenation:");
    string s1 = "Programming the ";
    string s2 = "PsychoDrill (PTP)";
    string s3 = String.Concat(s1, s2);
    Console.WriteLine(s3);
    Console.WriteLine();
}
```

## Escape Characters

As in other C-based languages, C# string literals may contain various *escape characters*, which qualify how the character data should be printed to the output stream. Each escape character begins with a backslash, followed by a specific token. In case you are a bit rusty on the meanings behind these escape characters, Table 3-6 lists the more common options.

**Table 3-6.** *String Literal Escape Characters*

Character	Meaning in Life
\'	Inserts a single quote into a string literal.
\"	Inserts a double quote into a string literal.
\\	Inserts a backslash into a string literal. This can be quite helpful when defining file or network paths.
\a	Triggers a system alert (beep). For console programs, this can be an audio clue to the user.
\n	Inserts a new line (on Windows platforms).
\r	Inserts a carriage return.
\t	Inserts a horizontal tab into the string literal.

For example, to print a string that contains a tab between each word, you can make use of the `\t` escape character. Or assume you want to create a string literal that contains quotation marks, another that defines a directory path, and a final string literal that inserts three blank lines after printing the character data. To do so without compiler errors, you would need to make use of the `\'`, `\\`, and `\n` escape characters. Also, to annoy any person within a 10-foot radius from you, notice that I have embedded an alarm within each string literal (to trigger a beep). Consider the following:

```
static void EscapeChars()
{
    Console.WriteLine("=> Escape characters:\a");
    string strWithTabs = "Model\tColor\tSpeed\tPet Name\a ";
    Console.WriteLine(strWithTabs);
}
```

```

Console.WriteLine("Everyone loves \"Hello World\"\\a ");
Console.WriteLine("C:\\MyApp\\bin\\Debug\\a ");

// Adds a total of 4 blank lines (then beep again!).
Console.WriteLine("All finished.\\n\\n\\n\\a ");
Console.WriteLine();
}

```

## String Interpolation

The curly-bracket syntax illustrated within this chapter (`{0}`, `{1}`, etc.) has existed within the .NET platform since version 1.0. Starting with the release of C# 6, C# programmers can use an alternative syntax to build string literals that contain placeholders for variables. Formally, this is called *string interpolation*. While the output of the operation is identical to traditional string formatting syntax, this new approach allows you to directly embed the variables themselves, rather than tacking them on as a comma-delimited list.

Consider the following additional method of your Program class (`StringInterpolation()`), which builds a string variable using each approach:

```

static void StringInterpolation()
{
    // Some local variables we will plug into our larger string
    int age = 4;
    string name = "Soren";

    // Using curly-bracket syntax.
    string greeting = string.Format("Hello {0} you are {1} years old.", name, age);

    // Using string interpolation
    string greeting2 = $"Hello {name} you are {age} years old.";
}

```

In the `greeting2` variable, notice how the string you are constructing begins with a dollar sign (\$) prefix. Next, notice that the curly brackets still are used to mark a variable placeholder; however, rather than using a numerical tag, you are able to place the variable directly into the scope. The assumed advantage is that this new formatting syntax is a bit easier to read in a linear (left-to-right) fashion, given that you are not required to “jump to the end” to see the list of values to plug in at runtime.

There is another interesting aspect of this new syntax: the curly brackets used in string interpolation are a valid scope. Therefore, you can use the dot operation on the variables to change their state. Consider updates to each assembled string variable.

```

string greeting = string.Format("Hello {0} you are {1} years old.", name.ToUpper(), age);
string greeting2 = $"Hello {name.ToUpper()} you are {age} years old.";

```

Here, I have uppercased the name via a call to `ToUpper()`. Do note that in the string interpolation approach, you do *not* add a semicolon terminator when calling this method. Given this, you cannot use the curly-bracket scope as a fully blown method scope that contains numerous lines of executable code. Rather, you can invoke a single member on the object using the dot operator as well as define a simple general expression such as `{age += 1}`.

It is also worth noting that you can still use escape characters in the string literal within this new syntax. Thus, if you wanted to insert a tab, you can prefix a `\t` token as so:

```
string greeting = string.Format("\tHello {0} you are {1} years old.", name.ToUpper(), age);
string greeting2 = $" \tHello {name.ToUpper()} you are {age} years old.";
```

## Defining Verbatim Strings (Updated 8)

When you prefix a string literal with the `@` symbol, you have created what is termed a *verbatim string*. Using verbatim strings, you disable the processing of a literal's escape characters and print out a string as is. This can be most useful when working with strings representing directory and network paths. Therefore, rather than making use of `\\` escape characters, you can simply write the following:

```
// The following string is printed verbatim,
// thus all escape characters are displayed.
Console.WriteLine(@"C:\MyApp\bin\Debug");
```

Also note that verbatim strings can be used to preserve whitespace for strings that flow over multiple lines.

```
// Whitespace is preserved with verbatim strings.
string myLongString = @"This is a very
    very
        very
            long string";
Console.WriteLine(myLongString);
```

Using verbatim strings, you can also directly insert a double quote into a literal string by doubling the `"` token.

```
Console.WriteLine(@"Cerebus said ""Darrrr! Pret-ty sun-sets""");
```

Verbatim strings can also be interpolated strings, by specifying both the interpolation operator (`$`) and the verbatim operator (`@`).

```
string interp = "interpolation";
string myLongString2 = @$"This is a very
    very
        long string with {interp}";
```

New in C# 8, the order doesn't matter. Using either `$@` or `@$` will work.

## Strings and Equality

As will be fully explained in Chapter 4, a *reference type* is an object allocated on the garbage-collected managed heap. By default, when you perform a test for equality on reference types (via the C# `==` and `!=` operators), you will be returned `true` if the references are pointing to the same object in memory. However, even though the string data type is indeed a reference type, the equality operators have been redefined to compare the *values* of string objects, not the object in memory to which they refer.



```

static void StringEquality()
{
    Console.WriteLine("> String equality:");
    string s1 = "Hello!";
    string s2 = "Yo!";
    Console.WriteLine("s1 = {0}", s1);
    Console.WriteLine("s2 = {0}", s2);
    Console.WriteLine();

    // Test these strings for equality.
    Console.WriteLine("s1 == s2: {0}", s1 == s2);
    Console.WriteLine("s1 == Hello!: {0}", s1 == "Hello!");
    Console.WriteLine("s1 == HELLO!: {0}", s1 == "HELLO!");
    Console.WriteLine("s1 == hello!: {0}", s1 == "hello!");
    Console.WriteLine("s1.Equals(s2): {0}", s1.Equals(s2));
    Console.WriteLine("Yo.Equals(s2): {0}", "Yo!".Equals(s2));
    Console.WriteLine();
}

```

The C# equality operators by default perform a case-sensitive, culture-insensitive, character-by-character equality test on string objects. Therefore, "Hello!" is not equal to "HELLO!", which is also different from "hello!". Also, keeping the connection between string and `System.String` in mind, notice that you are able to test for equality using the `Equals()` method of `String` as well as the baked-in equality operators. Finally, given that every string literal (such as "Yo") is a valid `System.String` instance, you are able to access string-centric functionality from a fixed sequence of characters.

## Modifying String Comparison Behavior

As mentioned, the string equality operators (`Compare()`, `Equals()`, and `==`) as well as the `IndexOf()` function are by default case sensitive and culture insensitive. This can cause a problem if your program doesn't care about case. One way to overcome this is to convert everything to uppercase or lowercase and then compare, like this:

```

if (firstString.ToUpper() == secondString.ToUpper())
{
    //Do something
}

```

This makes a copy of each string with all lowercase letters. It's probably not an issue in most cases but could be a performance hit with a significantly large string. Even if it's not a performance issue, it is a bit of a pain to write each time. And what if you forget to call `ToUpper()`? That could lead to a hard-to-find bug in your program.

A much better practice is to use the overloads of the methods listed earlier that take a value of the `StringComparison` enumeration to control exactly how the comparisons are done. Table 3-7 describes the `StringComparison` values.

**Table 3-7.** Values of the *StringComparison* Enumeration

C# Equality/Relational Operator	Meaning in Life
CurrentCulture	Compares strings using culture-sensitive sort rules and the current culture
CurrentCultureIgnoreCase	Compares strings using culture-sensitive sort rules and the current culture and ignores the case of the strings being compared
InvariantCulture	Compares strings using culture-sensitive sort rules and the invariant culture
InvariantCultureIgnoreCase	Compares strings using culture-sensitive sort rules and the invariant culture and ignores the case of the strings being compared
Ordinal	Compares strings using ordinal (binary) sort rules
OrdinalIgnoreCase	Compares strings using ordinal (binary) sort rules and ignores the case of the strings being compared

To see the effect of using the *StringComparison* option, create a new method named *StringEqualitySpecifyingCompareRules()* and add the following code:

```
static void StringEqualitySpecifyingCompareRules()
{
    Console.WriteLine("=> String equality (Case Insensitive:");
    string s1 = "Hello!";
    string s2 = "HELLO!";
    Console.WriteLine("s1 = {0}", s1);
    Console.WriteLine("s2 = {0}", s2);
    Console.WriteLine();

    // Check the results of changing the default compare rules.
    Console.WriteLine("Default rules: s1={0},s2={1}s1.Equals(s2): {2}", s1, s2, s1.Equals(s2));
    Console.WriteLine("Ignore case: s1.Equals(s2, StringComparison.OrdinalIgnoreCase): {0}",
        s1.Equals(s2, StringComparison.OrdinalIgnoreCase));
    Console.WriteLine("Ignore case, Invariant Culture: s1.Equals(s2, StringComparison.
InvariantCultureIgnoreCase): {0}",
        s1.Equals(s2, StringComparison.InvariantCultureIgnoreCase));
    Console.WriteLine();
    Console.WriteLine("Default rules: s1={0},s2={1} s1.IndexOf(\"E\"): {2}", s1, s2,
        s1.IndexOf("E"));
    Console.WriteLine("Ignore case: s1.IndexOf(\"E\", StringComparison.OrdinalIgnoreCase):
{0}", s1.IndexOf("E",
        StringComparison.OrdinalIgnoreCase));
    Console.WriteLine("Ignore case, Invariant Culture: s1.IndexOf(\"E\", StringComparison.
InvariantCultureIgnoreCase): {0}",
        s1.IndexOf("E", StringComparison.InvariantCultureIgnoreCase));
    Console.WriteLine();
}
```

While the examples here are simple ones and use the same letters across most cultures, if your application needed to take into account different culture sets, using the *StringComparison* options is a must.

## Strings Are Immutable

One of the interesting aspects of `System.String` is that after you assign a string object with its initial value, the character data *cannot be changed*. At first glance, this might seem like a flat-out lie, given that you are always reassigning strings to new values and because the `System.String` type defines a number of methods that appear to modify the character data in one way or another (such as uppercasing and lowercasing). However, if you look more closely at what is happening behind the scenes, you will notice the methods of the string type are, in fact, returning you a new string object in a modified format.

```
static void StringsAreImmutable()
{
    // Set initial string value.
    string s1 = "This is my string.";
    Console.WriteLine("s1 = {0}", s1);

    // Uppercase s1?
    string upperString = s1.ToUpper();
    Console.WriteLine("upperString = {0}", upperString);

    // Nope! s1 is in the same format!
    Console.WriteLine("s1 = {0}", s1);
}
```

If you examine the relevant output that follows, you can verify that the original string object (`s1`) is not uppercased when calling `ToUpper()`. Rather, you are returned a *copy* of the string in a modified format.

---

```
s1 = This is my string.
upperString = THIS IS MY STRING.
s1 = This is my string.
```

---

The same law of immutability holds true when you use the C# assignment operator. To illustrate, implement the following `StringsAreImmutable2()` method:

```
static void StringsAreImmutable2()
{
    string s2 = "My other string";
    s2 = "New string value";
}
```

Now, compile your application and run `ildasm.exe` (see Chapter 1). The following output shows what you would find if you were to generate CIL code for the `StringsAreImmutable2()` method:

---

```
.method private hidebysig static void StringsAreImmutable2() cil managed
{
    // Code size          21 (0x15)
    .maxstack 1
    .locals init (string V_0)
    IL_0000: nop
    IL_0001: ldstr      "My other string"
    IL_0006: stloc.0
```

```

IL_0007: ldstr      "New string value" /* 70000B3B */
IL_000c: stloc.0
IL_000d: ldloc.0
IL_0013: nop
IL_0014: ret
} // end of method Program::StringsAreImmutable2

```

---

Although you have yet to examine the low-level details of the CIL, note the numerous calls to the `ldstr` (load string) opcode. Simply put, the `ldstr` opcode of the CIL loads a new `string` object on the managed heap. The previous `string` object that contained the value `"My other string"` will eventually be garbage collected.

So, what exactly are you to gather from this insight? In a nutshell, the `string` class can be inefficient and result in bloated code if misused, especially when performing string concatenation or working with huge amounts of text data. If you need to represent basic character data such as a US Social Security Number, first or last names, or simple bits of text used within your application, the `string` class is the perfect choice.

However, if you are building an application that makes heavy use of frequently changing textual data (such as a word processing program), it would be a bad idea to represent the word processing data using `string` objects, as you will most certainly (and often indirectly) end up making unnecessary copies of `string` data. So, what is a programmer to do? Glad you asked.

## The System.Text.StringBuilder Type

Given that the `string` type can be inefficient when used with reckless abandon, the .NET Core base class libraries provide the `System.Text` namespace. Within this (relatively small) namespace lives a class named `StringBuilder`. Like the `System.String` class, the `StringBuilder` defines methods that allow you to replace or format segments, for example. When you want to use this type in your C# code files, your first step is to make sure the following namespace is imported into your code file (this should already be the case for a new Visual Studio project):

```

// StringBuilder lives here!
using System.Text;

```

What is unique about the `StringBuilder` is that when you call members of this type, you are directly modifying the object's internal character data (making it more efficient), not obtaining a copy of the data in a modified format. When you create an instance of the `StringBuilder`, you can supply the object's initial startup values via one of many *constructors*. If you are new to the topic of constructors, simply understand that constructors allow you to create an object with an initial state when you apply the new keyword. Consider the following usage of `StringBuilder`:

```

static void FunWithStringBuilder()
{
    Console.WriteLine("=> Using the StringBuilder:");
    StringBuilder sb = new StringBuilder("**** Fantastic Games ****");
    sb.Append("\n");
    sb.AppendLine("Half Life");
    sb.AppendLine("Morrowind");
    sb.AppendLine("Deus Ex" + "2");
    sb.AppendLine("System Shock");
    Console.WriteLine(sb.ToString());
    sb.Replace("2", " Invisible War");
}

```

```

Console.WriteLine(sb.ToString());
Console.WriteLine("sb has {0} chars.", sb.Length);
Console.WriteLine();
}

```

Here, I have constructed a `StringBuilder` set to the initial value `***** Fantastic Games *****`. As you can see, I am appending to the internal buffer and am able to replace or remove characters at will. By default, a `StringBuilder` is only able to initially hold a string of 16 characters or fewer (but will expand automatically if necessary); however, this default starting value can be changed via an additional constructor argument.

```

// Make a StringBuilder with an initial size of 256.
StringBuilder sb = new StringBuilder("***** Fantastic Games *****", 256);

```

If you append more characters than the specified limit, the `StringBuilder` object will copy its data into a new instance and grow the buffer by the specified limit.

## Narrowing and Widening Data Type Conversions

Now that you understand how to work with intrinsic C# data types, let's examine the related topic of *data type conversion*. Assume you have a new Console Application project named `TypeConversions` that defines the following class:

```

class Program
{
    static void Main(string[] args)
    {
        Console.WriteLine("***** Fun with type conversions *****");

        // Add two shorts and print the result.
        short numb1 = 9, numb2 = 10;
        Console.WriteLine("{0} + {1} = {2}",
            numb1, numb2, Add(numb1, numb2));
        Console.ReadLine();
    }

    static int Add(int x, int y)
    {
        return x + y;
    }
}

```

Notice that the `Add()` method expects to be sent two `int` parameters. However, the `Main()` method is, in fact, sending in two `short` variables. While this might seem like a complete and total mismatch of data types, the program compiles and executes without error, returning the expected result of 19.

The reason the compiler treats this code as syntactically sound is because there is no possibility for loss of data. Given that the maximum value of a `short` (32,767) is well within the maximum range of an `int` (2,147,483,647), the compiler implicitly *widens* each `short` to an `int`. Formally speaking, *widening* is the term used to define an implicit *upward cast* that does not result in a loss of data.

---

■ **Note** Look up “Type Conversion Tables” in the .NET Core documentation if you want to see permissible widening (and narrowing, discussed next) conversions for each C# data type.

---

Although this implicit widening worked in your favor for the previous example, other times this “feature” can be the source of compile-time errors. For example, assume you have set values to `numb1` and `numb2` that (when added together) overflow the maximum value of a `short`. Also, assume you are storing the return value of the `Add()` method within a new local `short` variable, rather than directly printing the result to the console.

```
static void Main(string[] args)
{
    Console.WriteLine("***** Fun with type conversions *****");

    // Compiler error below!
    short numb1 = 30000, numb2 = 30000;
    short answer = Add(numb1, numb2);

    Console.WriteLine("{0} + {1} = {2}",
        numb1, numb2, answer);
    Console.ReadLine();
}
```

In this case, the compiler reports the following error:

---

```
Cannot implicitly convert type 'int' to 'short'. An explicit conversion exists (are you missing a cast?)
```

---

The problem is that although the `Add()` method is capable of returning an `int` with the value 60,000 (as this fits within the range of a `System.Int32`), the value cannot be stored in a `short`, as it overflows the bounds of this data type. Formally speaking, the CoreCLR was unable to apply a *narrowing operation*. As you can guess, narrowing is the logical opposite of widening, in that a larger value is stored within a smaller data type variable.

It is important to point out that all narrowing conversions result in a compiler error, even when you can reason that the narrowing conversion should indeed succeed. For example, the following code also results in a compiler error:

```
// Another compiler error!
static void NarrowingAttempt()
{
    byte myByte = 0;
    int myInt = 200;
    myByte = myInt;

    Console.WriteLine("Value of myByte: {0}", myByte);
}
```

Here, the value contained within the `int` variable (`myInt`) is safely within the range of a `byte`; therefore, you would expect the narrowing operation to not result in a runtime error. However, given that C# is a language built with type safety in mind, you do indeed receive a compiler error.

When you want to inform the compiler that you are willing to deal with a possible loss of data because of a narrowing operation, you must apply an *explicit cast* using the C# casting operator, `()`. Consider the following update to the Program type:

```
class Program
{
    static void Main(string[] args)
    {
        Console.WriteLine("***** Fun with type conversions *****");
        short numb1 = 30000, numb2 = 30000;

        // Explicitly cast the int into a short (and allow loss of data).
        short answer = (short)Add(numb1, numb2);

        Console.WriteLine("{0} + {1} = {2}",
            numb1, numb2, answer);
        NarrowingAttempt();
        Console.ReadLine();
    }

    static int Add(int x, int y)
    {
        return x + y;
    }

    static void NarrowingAttempt()
    {
        byte myByte = 0;
        int myInt = 200;

        // Explicitly cast the int into a byte (no loss of data).
        myByte = (byte)myInt;
        Console.WriteLine("Value of myByte: {0}", myByte);
    }
}
```

At this point, the code compiles; however, the result of the addition is completely incorrect.

---

```
***** Fun with type conversions *****
30000 + 30000 = -5536
Value of myByte: 200
```

---

As you have just witnessed, an explicit cast allows you to force the compiler to apply a narrowing conversion, even when doing so may result in a loss of data. In the case of the `NarrowingAttempt()` method, this was not a problem because the value 200 can fit snugly within the range of a byte. However, in the case of adding the two shorts within `Main()`, the end result is completely unacceptable (30,000 + 30,000 = -5536?).

If you are building an application where loss of data is always unacceptable, C# provides the checked and unchecked keywords to ensure data loss does not escape undetected.

## The checked Keyword

Let's begin by learning the role of the checked keyword. Assume you have a new method within Program that attempts to add two bytes, each of which has been assigned a value that is safely below the maximum (255). If you were to add the values of these types (casting the returned `int` to a `byte`), you would assume that the result would be the exact sum of each member.

```
static void ProcessBytes()
{
    byte b1 = 100;
    byte b2 = 250;
    byte sum = (byte)Add(b1, b2);

    // sum should hold the value 350. However, we find the value 94!
    Console.WriteLine("sum = {0}", sum);
}
```

If you were to view the output of this application, you might be surprised to find that `sum` contains the value 94 (rather than the expected 350). The reason is simple. Given that a `System.Byte` can hold a value only between 0 and 255 (inclusive, for a grand total of 256 slots), `sum` now contains the overflow value ( $350 - 256 = 94$ ). By default, if you take no corrective course of action, overflow/underflow conditions occur without error.

To handle overflow or underflow conditions in your application, you have two options. Your first choice is to leverage your wits and programming skills to handle all overflow/underflow conditions manually. Of course, the problem with this technique is the simple fact that you are human, and even your best attempts might result in errors that have escaped your eyes.

Thankfully, C# provides the checked keyword. When you wrap a statement (or a block of statements) within the scope of the checked keyword, the C# compiler emits additional CIL instructions that test for overflow conditions that may result when adding, multiplying, subtracting, or dividing two numerical data types.

If an overflow has occurred, you will receive a runtime exception: `System.OverflowException`. Chapter 7 will examine all the details of structured exception handling and the use of the `try` and `catch` keywords. Without getting too hung up on the specifics at this point, observe the following update:

```
static void ProcessBytes()
{
    byte b1 = 100;
    byte b2 = 250;

    // This time, tell the compiler to add CIL code
    // to throw an exception if overflow/underflow
    // takes place.
    try
    {
        byte sum = checked((byte)Add(b1, b2));
        Console.WriteLine("sum = {0}", sum);
    }
    catch (OverflowException ex)
    {
        Console.WriteLine(ex.Message);
    }
}
```



Notice that the return value of `Add()` has been wrapped within the scope of the `checked` keyword. Because the sum is greater than a byte, this triggers a runtime exception. Notice the error message printed out via the `Message` property.

---

Arithmetic operation resulted in an overflow.

---

If you want to force overflow checking to occur over a block of code statements, you can do so by defining a “checked scope” as follows:

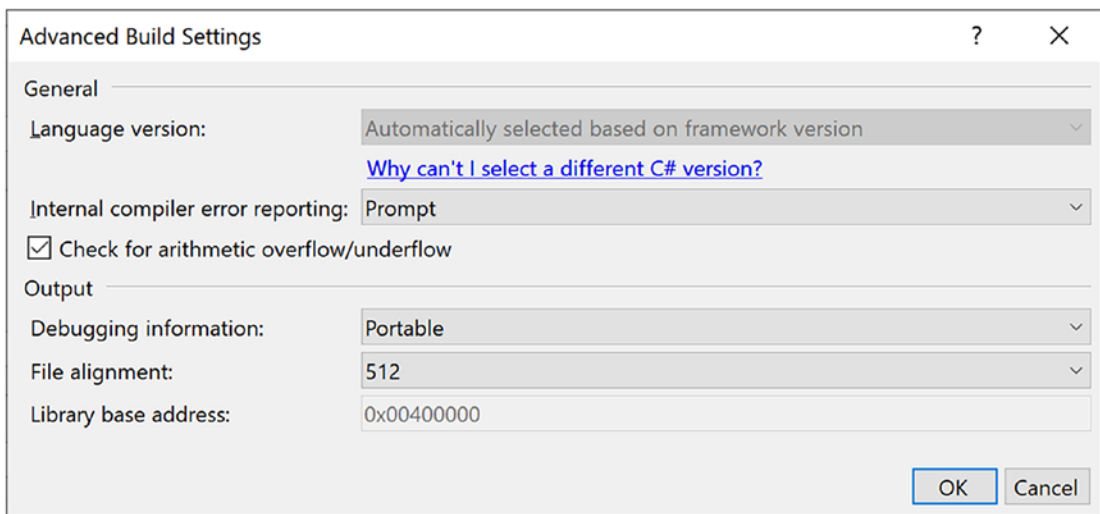
```
try
{
    checked
    {
        byte sum = (byte)Add(b1, b2);
        Console.WriteLine("sum = {0}", sum);
    }
}
catch (OverflowException ex)
{
    Console.WriteLine(ex.Message);
}
```

In either case, the code in question will be evaluated for possible overflow conditions automatically, which will trigger an overflow exception if encountered.

## Setting Project-Wide Overflow Checking

If you are creating an application that should never allow silent overflow to occur, you might find yourself in the annoying position of wrapping numerous lines of code within the scope of the `checked` keyword. As an alternative, the C# compiler supports the `/checked` flag. When enabled, all your arithmetic will be evaluated for overflow without the need to make use of the C# `checked` keyword. If overflow has been discovered, you will still receive a runtime exception.

To enable this flag using Visual Studio, open your project’s property page and click the **Advanced** button on the **Build** tab. From the resulting dialog box, select the “Check for arithmetic overflow/underflow” check box (see Figure 3-3).



**Figure 3-3.** Enabling project-wide overflow/underflow data checking

Enabling this setting can be helpful when you're creating a debug build. After all the overflow exceptions have been squashed out of the codebase, you're free to disable the /checked flag for subsequent builds (which can increase the runtime performance of your application).

## The unchecked Keyword

Now, assuming you have enabled this project-wide setting, what are you to do if you have a block of code where data loss *is* acceptable? Given that the /checked flag will evaluate all arithmetic logic, C# provides the unchecked keyword to disable the throwing of an overflow exception on a case-by-case basis. This keyword's use is identical to that of the checked keyword, in that you can specify a single statement or a block of statements.

```
// Assuming /checked is enabled,
// this block will not trigger
// a runtime exception.
unchecked
{
    byte sum = (byte)(b1 + b2);
    Console.WriteLine("sum = {0} ", sum);
}
```

So, to summarize the C# checked and unchecked keywords, remember that the default behavior of the .NET Core runtime is to ignore arithmetic overflow/underflow. When you want to selectively handle discrete statements, make use of the checked keyword. If you want to trap overflow errors throughout your application, enable the /checked flag. Finally, the unchecked keyword can be used if you have a block of code where overflow is acceptable (and thus should not trigger a runtime exception).

## Understanding Implicitly Typed Local Variables

Up until this point in the chapter, when you have been defining local variables, you've *explicitly* specified the underlying data type of each variable being declared.

```
static void DeclareExplicitVars()
{
    // Explicitly typed local variables
    // are declared as follows:
    // dataType variableName = initialValue;
    int myInt = 0;
    bool myBool = true;
    string myString = "Time, marches on...";
}
```

While many (including yours truly) would argue that it is always good practice to explicitly specify the data type of each variable, the C# language does provide for *implicitly typing* of local variables using the `var` keyword. The `var` keyword can be used in place of specifying a specific data type (such as `int`, `bool`, or `string`). When you do so, the compiler will automatically infer the underlying data type based on the initial value used to initialize the local data point.

To illustrate the role of implicit typing, create a new Console Application project named `ImplicitlyTypedLocalVars`. Notice how the local variables within the previous method can now be declared as follows:

```
static void DeclareImplicitVars()
{
    // Implicitly typed local variables
    // are declared as follows:
    // var variableName = initialValue;
    var myInt = 0;
    var myBool = true;
    var myString = "Time, marches on...";
}
```

---

■ **Note** Strictly speaking, `var` is not a C# keyword. It is permissible to declare variables, parameters, and fields named `var` without compile-time errors. However, when the `var` token is used as a data type, it is contextually treated as a keyword by the compiler.

---

In this case, the compiler is able to infer, given the initially assigned value, that `myInt` is, in fact, a `System.Int32`, `myBool` is a `System.Boolean`, and `myString` is indeed of type `System.String`. You can verify this by printing the type name via *reflection*. As you will see in much more detail in Chapter 17, *reflection* is the act of determining the composition of a type at runtime. For example, using reflection, you can determine the data type of an implicitly typed local variable. Update your method with the following code statements:

```
static void DeclareImplicitVars()
{
    // Implicitly typed local variables.
    var myInt = 0;
```

```

var myBool = true;
var myString = "Time, marches on...";

// Print out the underlying type.
Console.WriteLine("myInt is a: {0}", myInt.GetType().Name);
Console.WriteLine("myBool is a: {0}", myBool.GetType().Name);
Console.WriteLine("myString is a: {0}", myString.GetType().Name);
}

```

---

■ **Note** Be aware that you can use this implicit typing for any type including arrays, generic types (see Chapter 10), and your own custom types. You'll see other examples of implicit typing over the course of this book.

---

If you were to call the `DeclareImplicitVars()` method from within `Main()`, you'd find the output shown here:

---

```
***** Fun with Implicit Typing *****
```

```

myInt is a: Int32
myBool is a: Boolean
myString is a: String

```

---

## Declaring Numerics Implicitly

As stated earlier, whole numbers default to integers, and floating-point numbers default to doubles. Create a new method named `DeclareImplicitNumerics`, and add the following code to demonstrate implicit declaration of numerics:

```

static void DeclareImplicitNumerics()
{
    // Implicitly typed numeric variables.
    var myUInt = 0u;
    var myInt = 0;
    var myLong = 0L;
    var myDouble = 0.5;
    var myFloat = 0.5F;
    var myDecimal = 0.5M;

    // Print out the underlying type.
    Console.WriteLine("myUInt is a: {0}", myUInt.GetType().Name);
    Console.WriteLine("myInt is a: {0}", myInt.GetType().Name);
    Console.WriteLine("myLong is a: {0}", myLong.GetType().Name);
    Console.WriteLine("myDouble is a: {0}", myDouble.GetType().Name);
    Console.WriteLine("myFloat is a: {0}", myFloat.GetType().Name);
    Console.WriteLine("myDecimal is a: {0}", myDecimal.GetType().Name);
}

```

## Restrictions on Implicitly Typed Variables

There are various restrictions regarding the use of the `var` keyword. First, implicit typing applies *only* to local variables in a method or property scope. It is illegal to use the `var` keyword to define return values, parameters, or field data of a custom type. For example, the following class definition will result in various compile-time errors:

```
class ThisWillNeverCompile
{
    // Error! var cannot be used as field data!
    private var myInt = 10;

    // Error! var cannot be used as a return value
    // or parameter type!
    public var MyMethod(var x, var y){}
}
```

Also, local variables declared with the `var` keyword *must* be assigned an initial value at the exact time of declaration and *cannot* be assigned the initial value of `null`. This last restriction should make sense, given that the compiler cannot infer what sort of type in memory the variable would be pointing to based only on `null`.

```
// Error! Must assign a value!
var myData;

// Error! Must assign value at exact time of declaration!
var myInt;
myInt = 0;

// Error! Can't assign null as initial value!
var myObj = null;
```

It is permissible, however, to assign an inferred local variable to `null` after its initial assignment (provided it is a reference type).

```
// OK, if SportsCar is a reference type!
var myCar = new SportsCar();
myCar = null;
```

Furthermore, it is permissible to assign the value of an implicitly typed local variable to the value of other variables, implicitly typed or not.

```
// Also OK!
var myInt = 0;
var anotherInt = myInt;

string myString = "Wake up!";
var myData = myString;
```

Also, it is permissible to return an implicitly typed local variable to the caller, provided the method return type is the same underlying type as the `var`-defined data point.

```
static int GetAnInt()
{
    var retVal = 9;
    return retVal;
}
```

## Implicit Typed Data Is Strongly Typed Data

Be aware that implicit typing of local variables results in *strongly typed data*. Therefore, use of the `var` keyword is *not* the same technique used with scripting languages (such as JavaScript or Perl) or the COM Variant data type, where a variable can hold values of different types over its lifetime in a program (often termed *dynamic typing*).

---

■ **Note** C# does allow for dynamic typing in C# using a keyword called – surprise, surprise – `dynamic`. You will learn about this aspect of the language in [Chapter 18](#).

---

Rather, type inference keeps the strongly typed aspect of the C# language and affects only the declaration of variables at compile time. After that, the data point is treated as if it were declared with that type; assigning a value of a different type into that variable will result in a compile-time error.

```
static void ImplicitTypingIsStrongTyping()
{
    // The compiler knows "s" is a System.String.
    var s = "This variable can only hold string data!";
    s = "This is fine...";

    // Can invoke any member of the underlying type.
    string upper = s.ToUpper();

    // Error! Can't assign numerical data to a string!
    s = 44;
}
```

## Usefulness of Implicitly Typed Local Variables

Now that you have seen the syntax used to declare implicitly typed local variables, I am sure you are wondering when to make use of this construct. First, using `var` to declare local variables simply for the sake of doing so brings little to the table. Doing so can be confusing to others reading your code because it becomes harder to quickly determine the underlying data type and, therefore, more difficult to understand the overall functionality of the variable. So, if you know you need an `int`, declare an `int`!

However, as you will see beginning in [Chapter 13](#), the LINQ technology set makes use of *query expressions* that can yield dynamically created result sets based on the format of the query itself. In these cases, implicit typing is extremely helpful because you do not need to explicitly define the type that a query may return, which in some cases would be literally impossible to do. Without getting hung up on the following LINQ example code, see whether you can figure out the underlying data type of `subset`:

```
static void LinqQueryOverInts()
{
    int[] numbers = { 10, 20, 30, 40, 1, 2, 3, 8 };

    // LINQ query!
    var subset = from i in numbers where i < 10 select i;

    Console.Write("Values in subset: ");
    foreach (var i in subset)
    {
        Console.Write("{0} ", i);
    }
    Console.WriteLine();

    // Hmm...what type is subset?
    Console.WriteLine("subset is a: {0}", subset.GetType().Name);
    Console.WriteLine("subset is defined in: {0}", subset.GetType().Namespace);
}
```

You might be assuming that the `subset` data type is an array of integers. That seems to be the case, but, in fact, it is a low-level LINQ data type that you would never know about unless you have been doing LINQ for a long time or you open the compiled image in `ildasm.exe`. The good news is that when you are using LINQ, you seldom (if ever) care about the underlying type of the query's return value; you will simply assign the value to an implicitly typed local variable.

In fact, it could be argued that the *only time* you would make use of the `var` keyword is when defining data returned from a LINQ query. Remember, if you know you need an `int`, just declare an `int`! Overuse of implicit typing (via the `var` keyword) is considered by most developers to be poor style in production code.

## C# Iteration Constructs

All programming languages provide ways to repeat blocks of code until a terminating condition has been met. Regardless of which language you have used in the past, I would guess the C# iteration statements should not raise too many eyebrows and should require little explanation. C# provides the following four iteration constructs:

- `for` loop
- `foreach/in` loop
- `while` loop
- `do/while` loop

Let's quickly examine each looping construct in turn, using a new Console Application project named `IterationsAndDecisions`.

---

■ **Note** I will keep this section of the chapter short and to the point, as I am assuming you have experience using similar keywords (`if`, `for`, `switch`, etc.) in your current programming language. If you require more information, look up the topics “Iteration Statements (C# Reference),” “Jump Statements (C# Reference),” and “Selection Statements (C# Reference)” within the C# documentation.

---

## The for Loop

When you need to iterate over a block of code a fixed number of times, the `for` statement provides a good deal of flexibility. In essence, you are able to specify how many times a block of code repeats itself, as well as the terminating condition. Without belaboring the point, here is a sample of the syntax:

```
// A basic for loop.
static void ForLoopExample()
{
    // Note! "i" is only visible within the scope of the for loop.
    for(int i = 0; i < 4; i++)
    {
        Console.WriteLine("Number is: {0} ", i);
    }
    // "i" is not visible here.
}
```

All your old C, C++, and Java tricks still hold when building a C# `for` statement. You can create complex terminating conditions, build endless loops, loop in reverse (via the `--` operator), and use the `goto`, `continue`, and `break` jump keywords.

## The foreach Loop

The C# `foreach` keyword allows you to iterate over all items in a container without the need to test for an upper limit. Unlike a `for` loop, however, the `foreach` loop will walk the container only in a linear ( $n+1$ ) fashion (thus, you cannot go backward through the container, skip every third element, or whatnot).

However, when you simply need to walk a collection item by item, the `foreach` loop is the perfect choice. Here are two examples using `foreach` – one to traverse an array of strings and the other to traverse an array of integers. Notice that the data type before the `in` keyword represents the type of data in the container.

```
// Iterate array items using foreach.
static void ForEachLoopExample()
{
    string[] carTypes = {"Ford", "BMW", "Yugo", "Honda" };
    foreach (string c in carTypes)
    {
        Console.WriteLine(c);
    }

    int[] myInts = { 10, 20, 30, 40 };
    foreach (int i in myInts)
    {
        Console.WriteLine(i);
    }
}
```

The item after the `in` keyword can be a simple array (seen here) or, more specifically, any class implementing the `IEnumerable` interface. As you will see in Chapter 10, the .NET Core base class libraries ship with a number of collections that contain implementations of common abstract data types (ADTs). Any of these items (such as the generic `List<T>`) can be used within a `foreach` loop.



## Use of Implicit Typing Within foreach Constructs

It is also possible to use implicit typing within a foreach looping construct. As you would expect, the compiler will correctly infer the correct “type of type.” Recall the LINQ example method shown earlier in this chapter. Given that you don’t know the exact underlying data type of the subset variable, you can iterate over the result set using implicit typing. Make sure to add the following using statement to the top of the file:

```
using System.Linq;
static void LinqQueryOverInts()
{
    int[] numbers = { 10, 20, 30, 40, 1, 2, 3, 8 };

    // LINQ query!
    var subset = from i in numbers where i < 10 select i;
    Console.WriteLine("Values in subset: ");

    foreach (var i in subset)
    {
        Console.WriteLine("{0} ", i);
    }
}
```

## The while and do/while Looping Constructs

The while looping construct is useful should you want to execute a block of statements until some terminating condition has been reached. Within the scope of a while loop, you will need to ensure this terminating event is indeed established; otherwise, you will be stuck in an endless loop. In the following example, the message “In while loop” will be continuously printed until the user terminates the loop by entering yes at the command prompt:

```
static void WhileLoopExample()
{
    string userIsDone = "";

    // Test on a lower-class copy of the string.
    while(userIsDone.ToLower() != "yes")
    {
        Console.WriteLine("In while loop");
        Console.Write("Are you done? [yes] [no]: ");
        userIsDone = Console.ReadLine();
    }
}
```

Closely related to the while loop is the do/while statement. Like a simple while loop, do/while is used when you need to perform some action an undetermined number of times. The difference is that do/while loops are guaranteed to execute the corresponding block of code at least once. In contrast, it is possible that a simple while loop may never execute if the terminating condition is false from the onset.

```
static void DoWhileLoopExample()
{
    string userIsDone = "";

    do
    {
        Console.WriteLine("In do/while loop");
        Console.Write("Are you done? [yes] [no]: ");
        userIsDone = Console.ReadLine();
    }while(userIsDone.ToLower() != "yes"); // Note the semicolon!
}
```

## A Quick Discussion About Scope

Like all languages based on C (C#, Java, etc.), a *scope* is created using curly braces. You have already seen this in many of the examples so far, including namespaces, classes, and methods. The iteration and decision constructs also operate in a scope, as in the following example:

```
for(int i = 0; i < 4; i++)
{
    Console.WriteLine("Number is: {0} ", i);
}
```

For these constructs (both in the previous section and the next section), it is permissible to not use curly braces. In other words, the following code is *exactly* the same as the previous example:

```
for(int i = 0; i < 4; i++)
    Console.WriteLine("Number is: {0} ", i);
```

While this is permissible, it is typically not a good idea. The problem isn't the one-line statement, but the statement that goes from one line to more than one line. Without the braces, mistakes could be made when expanding the code within the iteration/decision constructs. For example, the following two examples are **not** the same:

```
for(int i = 0; i < 4; i++)
{
    Console.WriteLine("Number is: {0} ", i);
    Console.WriteLine("Number plus 1 is: {0} ", i+1)
}
for(int i = 0; i < 4; i++)
    Console.WriteLine("Number is: {0} ", i);
    Console.WriteLine("Number plus 1 is: {0} ", i+1)
```

If you are lucky (like in this example), the additional line of code generates a compilation error, since the variable *i* is only defined in the scope of the for loop. If you are unlucky, you are executing code that doesn't get flagged as a compiler error, but is a logic error, which is harder to find and debug.

## Decision Constructs and the Relational/Equality Operators

Now that you can iterate over a block of statements, the next related concept is how to control the flow of program execution. C# defines two simple constructs to alter the flow of your program, based on various contingencies:

- The if/else statement
- The switch statement

---

■ **Note** C# 7 extends the `is` expression and `switch` statements with a technique called *pattern matching*. The basics of how these extensions affect if/else and `switch` statements are shown here for completeness. These extensions will make more sense after reading Chapter 6, which covers base class/derived class rules, casting, and the standard `is` operator.

---

### The if/else Statement

First up is the if/else statement. Unlike in C and C++, the if/else statement in C# operates only on Boolean expressions, not ad hoc values such as `-1` or `0`.

### Equality and Relational Operators

C# if/else statements typically involve the use of the C# operators shown in Table 3-8 to obtain a literal Boolean value.

**Table 3-8.** C# Relational and Equality Operators

C# Equality/Relational Operator	Example Usage	Meaning in Life
<code>==</code>	<code>if(age == 30)</code>	Returns true only if each expression is the same
<code>!=</code>	<code>if("Foo" != myStr)</code>	Returns true only if each expression is different
<code>&lt;</code>	<code>if(bonus &lt; 2000)</code>	Returns true if expression A (bonus) is less than expression B (2000)
<code>&gt;</code>	<code>if(bonus &gt; 2000)</code>	Returns true if expression A (bonus) is greater than expression B (2000)
<code>&lt;=</code>	<code>if(bonus &lt;= 2000)</code>	Returns true if expression A (bonus) is less than or equal to expression B (2000)
<code>&gt;=</code>	<code>if(bonus &gt;= 2000)</code>	Returns true if expression A (bonus) is greater than or equal to expression B (2000)

Again, C and C++ programmers need to be aware that the old tricks of testing a condition for a value not equal to zero will not work in C#. Let's say you want to see whether the `string` you are working with is longer than zero characters. You might be tempted to write this:

```
static void IfElseExample()
{
    // This is illegal, given that Length returns an int, not a bool.
    string stringData = "My textual data";
    if(stringData.Length)
    {
        Console.WriteLine("string is greater than 0 characters");
    }
    else
    {
        Console.WriteLine("string is not greater than 0 characters");
    }
    Console.WriteLine();
}
```

If you want to use the `String.Length` property to determine truth or falsity, you need to modify your conditional expression to resolve to a `Boolean`.

```
// Legal, as this resolves to either true or false.
If (stringData.Length > 0)
{
    Console.WriteLine("string is greater than 0 characters");
}
```

## if/else with Pattern Matching (New 7.0)

New in C# 7.0, *pattern matching* is allowed in `if/else` statements. Pattern matching allows code to inspect an object for certain traits and properties and make decisions based on the (non-)existence of those properties and traits. Don't worry if you are new to object-oriented programming; the previous sentence will be explained in great detail in later chapters. Just know (for now) that you can check the type of an object using the `is` keyword, assign that object to a variable if the pattern matches, and then use that variable.

The `IfElsePatternMatching` method examines two object variables and determines if they are a `string` or an `int` and then prints the results to the console:

```
static void IfElsePatternMatching()
{
    Console.WriteLine("===If Else Pattern Matching ===/n");
    object testItem1 = 123;
    object testItem2 = "Hello";
    if (testItem1 is string myStringValue1)
    {
        Console.WriteLine($"{myStringValue1} is a string");
    }
    if (testItem1 is int myValue1)
    {
        Console.WriteLine($"{myValue1} is an int");
    }
}
```

```

if (testItem2 is string myStringValue2)
{
    Console.WriteLine($"{myStringValue2} is a string");
}
if (testItem2 is int myValue2)
{
    Console.WriteLine($"{myValue2} is an int");
}
Console.WriteLine();
}

```

## The Conditional Operator (Updated 7.2)

The conditional operator (`?:`), also known as the Ternary Conditional Operator, is a shorthand method of writing a simple if-else statement. The syntax works like this:

```
condition ? first_expression : second_expression;
```

The condition is the conditional test (the if part of the if-else statement). If the test passes, then the code immediately after the question mark (?) is executed. If the test does not evaluate to true, the code after the colon (the else part of the if-else statement) is executed. The previous code example can be written using the conditional operator like this:

```

private static void ExecuteIfElseUsingConditionalOperator()
{
    string stringData = "My textual data";
    Console.WriteLine(stringData.Length > 0
        ? "string is greater than 0 characters"
        : "string is not greater than 0 characters");
    Console.WriteLine();
}

```

There are some restrictions to the conditional operator. First, both types of `first_expression` and `second_expression` must be the same. Second, the conditional operator can be used only in assignment statements. The following code will result in the compiler error “Only assignment, call, increment, decrement, and new object expressions can be used as a statement”:

```

stringData.Length > 0
    ? Console.WriteLine("string is greater than 0 characters")
    : Console.WriteLine("string is not greater than 0 characters");

```

New in C# 7.2, the conditional operator can be used to return a reference to the result of the condition. Take the following example, which uses two forms of the Conditional Operator by ref:

```

private static void ConditionalRefExample()
{
    var smallArray = new int[] { 1, 2, 3, 4, 5 };
    var largeArray = new int[] { 10, 20, 30, 40, 50 };

    int index = 7;
    ref int refValue = ref ((index < 5)

```

```
        ? ref smallArray[index]
        : ref largeArray[index - 5]);
refValue = 0;

index = 2;
((index < 5)
 ? ref smallArray[index]
 : ref largeArray[index - 5]) = 100;

Console.WriteLine(string.Join(" ", smallArray));
Console.WriteLine(string.Join(" ", largeArray));
}
```

If you aren't familiar with the `ref` keyword, don't worry too much at this point, as it will be covered in depth in the next chapter. To sum up, the first example returns a *reference* to the array location checked with the condition and assigns the `refValue` variable to that reference. Think of the reference conceptually as a point to the location in the array and not the actual value of the position of the array. This allows for changing of the array's value in that position directly by changing the value assigned to the variable. The result of assigned the `refValue` variable the value of zero changes the second array's values to 10,20,**0**,40,50. The second example updates the first array's second value to 100, resulting in 1,2,**100**,4,5.

## Logical Operators

An `if` statement may be composed of complex expressions as well and can contain `else` statements to perform more complex testing. The syntax is identical to C (and C++) and Java. To build complex expressions, C# offers an expected set of logical operators, as shown in Table 3-9.

**Table 3-9.** C# Logical Operators

Operator	Example	Meaning in Life
&&	if(age == 30 && name == "Fred")	AND operator. Returns true if all expressions are true
	if(age == 30    name == "Fred")	OR operator. Returns true if at least one expression is true
!	if(!myBool)	NOT operator. Returns true if false, or false if true

■ **Note** The `&&` and `||` operators both “short-circuit” when necessary. This means that after a complex expression has been determined to be false, the remaining subexpressions will not be checked. If you require all expressions to be tested regardless, you can use the related `&` and `|` operators.

## The switch Statement

The other simple selection construct offered by C# is the `switch` statement. As in other C-based languages, the `switch` statement allows you to handle program flow based on a predefined set of choices. For example, the following `Main()` logic prints a specific string message based on one of two possible selections (the default case handles an invalid selection):

```
// Switch on a numerical value.
static void SwitchExample()
{
    Console.WriteLine("1 [C#], 2 [VB]");
    Console.Write("Please pick your language preference: ");

    string langChoice = Console.ReadLine();
    int n = int.Parse(langChoice);

    switch (n)
    {
        case 1:
            Console.WriteLine("Good choice, C# is a fine language.");
            break;
        case 2:
            Console.WriteLine("VB: OOP, multithreading, and more!");
            break;
        default:
            Console.WriteLine("Well...good luck with that!");
            break;
    }
}
```

---

■ **Note** C# demands that each case (including default) that contains executable statements have a terminating return, break, or goto to avoid falling through to the next statement.

---

One nice feature of the C# switch statement is that you can evaluate string data in addition to numeric data. In fact, all versions of C# can evaluate char, string, bool, int, long, and enum data types. As you will see in the next section, C# 7 adds additional capabilities. Here is an updated switch statement that evaluates a string variable:

```
static void SwitchOnStringExample()
{
    Console.WriteLine("C# or VB");
    Console.Write("Please pick your language preference: ");

    string langChoice = Console.ReadLine();
    switch (langChoice.ToUpper())
    {
        case "C#":
            Console.WriteLine("Good choice, C# is a fine language.");
            break;
        case "VB":
            Console.WriteLine("VB: OOP, multithreading and more!");
            break;
        default:
            Console.WriteLine("Well...good luck with that!");
            break;
    }
}
```

It is also possible to switch on an enumeration data type. As you will see in Chapter 4, the C# `enum` keyword allows you to define a custom set of name-value pairs. To whet your appetite, consider the following final helper function, which performs a switch test on the `System.DayOfWeek` enum. You'll notice some syntax I have not yet examined, but focus on the issue of switching over the enum itself; the missing pieces will be filled in over the chapters to come.

```
static void SwitchOnEnumExample()
{
    Console.Write("Enter your favorite day of the week: ");
    DayOfWeek favDay;
    try
    {
        favDay = (DayOfWeek) Enum.Parse(typeof(DayOfWeek), Console.ReadLine());
    }
    catch (Exception)
    {
        Console.WriteLine("Bad input!");
        return;
    }
    switch (favDay)
    {
        case DayOfWeek.Sunday:
            Console.WriteLine("Football!!");
            break;
        case DayOfWeek.Monday:
            Console.WriteLine("Another day, another dollar");
            break;
        case DayOfWeek.Tuesday:
            Console.WriteLine("At least it is not Monday");
            break;
        case DayOfWeek.Wednesday:
            Console.WriteLine("A fine day.");
            break;
        case DayOfWeek.Thursday:
            Console.WriteLine("Almost Friday...");
            break;
        case DayOfWeek.Friday:
            Console.WriteLine("Yes, Friday rules!");
            break;
        case DayOfWeek.Saturday:
            Console.WriteLine("Great day indeed.");
            break;
    }
    Console.WriteLine();
}
```

Falling through from one case statement to another case statement is not allowed, but what if multiple case statements should produce the same result? Fortunately, they can be combined, as the following code snippet demonstrates:



```
case DayOfWeek.Saturday:
case DayOfWeek.Sunday:
    Console.WriteLine("It's the weekend!");
    break;
```

If any code was included between the case statements, the compiler would throw an error. As long as they are consecutive statements, as shown earlier, case statements can be combined to share common code.

In addition to the return and break statements shown in the previous code samples, the switch statement also supports using a goto to exit a case condition and execute another case statement. While this is supported, it's pretty universally thought of as an anti-pattern and not generally used. Here is an example of using the goto statement in a switch block:

```
public static void SwitchWithGoto()
{
    var foo = 5;
    switch (foo)
    {
        case 1:
            //do something
            goto case 2;
        case 2:
            //do something else
            break;
        case 3:
            //yet another action
            goto default;
        default:
            //default action
            break;
    }
}
```

## Switch Statement Pattern Matching (New 7.0)

Prior to C# 7, match expressions in switch statements were limited to comparing a variable to constant values, sometimes referred to as the *constant pattern*. In C# 7, switch statements can also employ the *type pattern*, where case statements can evaluate the *type* of the variable being checked and case expressions are no longer limited to constant values. The rule that each case statement must be terminated with a return or break still applies; however, goto statements are not supported using the type pattern.

---

■ **Note** If you are new to object-oriented programming, this section might be a little confusing. It will all come together in Chapter 6, when you revisit the new pattern matching features of C# 7 in the context of classes and base classes. For now, just understand that there is a powerful new way to write switch statements.

---

Add another method named `ExecutePatternMatchingSwitch()` and add the following code:

```
static void ExecutePatternMatchingSwitch()
{
    Console.WriteLine("1 [Integer (5)], 2 [String (\"Hi\")], 3 [Decimal (2.5)]");
    Console.Write("Please choose an option: ");
    string userChoice = Console.ReadLine();
    object choice;
    //This is a standard constant pattern switch statement to set up the example
    switch (userChoice)
    {
        case "1":
            choice = 5;
            break;
        case "2":
            choice = "Hi";
            break;
        case "3":
            choice = 2.5;
            break;
        default:
            choice = 5;
            break;
    }
    //This is new the pattern matching switch statement
    switch (choice)
    {
        case int i:
            Console.WriteLine("Your choice is an integer.");
            break;
        case string s:
            Console.WriteLine("Your choice is a string.");
            break;
        case decimal d:
            Console.WriteLine("Your choice is a decimal.");
            break;
        default:
            Console.WriteLine("Your choice is something else");
            break;
    }
    Console.WriteLine();
}
```

The first switch statement is using the standard constant pattern and is included merely to set up this (very trivial) example. In the second switch statement, the variable is typed as `object` and, based on the input from the user, can be parsed into an `int`, `string`, or `decimal` data type. Based on the *type* of the variable, different case statements are matched. In addition to checking the data type, a variable is assigned in each of the case statements (except for the default case). Update the code to the following to use the values in the variables:

```
//This is new the pattern matching switch statement
switch (choice)
{
    case int i:
        Console.WriteLine("Your choice is an integer {0}.", i);
        break;
    case string s:
        Console.WriteLine("Your choice is a string. {0}", s);
        break;
    case decimal d:
        Console.WriteLine("Your choice is a decimal. {0}", d);
        break;
    default:
        Console.WriteLine("Your choice is something else");
        break;
}
```

In addition to evaluating on the type of the match expression, when clauses can be added to the case statements to evaluate conditions on the variable. In this example, in addition to checking the type, the value of the converted type is also checked for a match:

```
static void ExecutePatternMatchingSwitchWithWhen()
{
    Console.WriteLine("1 [C#], 2 [VB]");
    Console.Write("Please pick your language preference: ");

    object langChoice = Console.ReadLine();
    var choice = int.TryParse(langChoice.ToString(), out int c) ? c : langChoice;

    switch (choice)
    {
        case int i when i == 2:
        case string s when s.Equals("VB", StringComparison.OrdinalIgnoreCase):
            Console.WriteLine("VB: OOP, multithreading, and more!");
            break;
        case int i when i == 1:
        case string s when s.Equals("C#", StringComparison.OrdinalIgnoreCase):
            Console.WriteLine("Good choice, C# is a fine language.");
            break;
        default:
            Console.WriteLine("Well...good luck with that!");
            break;
    }
    Console.WriteLine();
}
```

This adds a new dimension to the switch statement as the order of the case statements is now significant. With the constant pattern, each case statement had to be unique. With the type pattern, this is no longer the case. For example, the following code will match every integer in the first case statement and will never execute the second or the third (in fact, the following code will fail to compile):

```

switch (choice)
{
    case int i:
        //do something
        break;
    case int i when i == 0:
        //do something
        break;
    case int i when i == -1:
        // do something
        break;
}

```

With the initial release of C# 7, there was a small glitch with pattern matching when using generic types. This has been resolved with C# 7.1. Generic types will be covered in [Chapter 10](#).

## Switch Expressions (New 8.0)

New in C# 8 are switch expressions, allowing the assignment of a variable in a concise statement. Consider the C# 7 version of this method that takes in a color and returns the hex value for the color name:

```

static string FromRainbowClassic(string colorBand)
{
    switch (colorBand)
    {
        case "Red":
            return "#FF0000";
        case "Orange":
            return "#FF7F00";
        case "Yellow":
            return "#FFFF00";
        case "Green":
            return "#00FF00";
        case "Blue":
            return "#0000FF";
        case "Indigo":
            return "#4B0082";
        case "Violet":
            return "#9400D3";
        default:
            return "#FFFFFF";
    }
}

```

With the new switch expressions in C# 8, the previous method can be written as follows, which is much more concise:

```

static string FromRainbow(string colorBand)
{
    return colorBand switch
    {

```

```

    "Red" => "#FF0000",
    "Orange" => "#FF7F00",
    "Yellow" => "#FFFF00",
    "Green" => "#00FF00",
    "Blue" => "#0000FF",
    "Indigo" => "#4B0082",
    "Violet" => "#9400D3",
    _ => "#FFFFFF",
};
}

```

There is a lot to unpack in that example, from the lambda ( $\Rightarrow$ ) statements to the discard ( $\_$ ). These will all be covered in later chapters, as will this example in further detail.

There is one more example before finishing the topic of switch expressions, and it involved tuples. Tuples are covered in detail in Chapter 4, so for now think of a tuple as a simple construct holding more than one value and defined with parenthesis, like this tuple that holds a string and an int:

```
(string, int)
```

In the following example, the two values passed into the `RockPaperScissors` method are converted to a tuple, and then the switch expression evaluates the two values in a single expression. This pattern allows for comparing more than one value during a switch statement.

```

//Switch expression with Tuples
static string RockPaperScissors(string first, string second)
{
    return (first, second) switch
    {
        ("rock", "paper") => "Paper wins.",
        ("rock", "scissors") => "Rock wins.",
        ("paper", "rock") => "Paper wins.",
        ("paper", "scissors") => "Scissors wins.",
        ("scissors", "rock") => "Rock wins.",
        ("scissors", "paper") => "Scissors wins.",
        (_, _) => "Tie.",
    };
}

```

To call this method, add the following lines of code to the `Main` method:

```

Console.WriteLine(RockPaperScissors("paper", "rock"));
Console.WriteLine(RockPaperScissors("scissors", "rock"));

```

This example will be revisited in Chapter 4 when tuples are introduced.

## Summary

The goal of this chapter was to expose you to numerous core aspects of the C# programming language. You examined the commonplace constructs in any application you may be interested in building. After examining the role of an application object, you learned that every C# executable program must have a type defining a `Main()` method, which serves as the program's entry point. Within the scope of `Main()`, you typically create any number of objects that work together to breathe life into your application.

Next, you dove into the details of the built-in data types of C# and came to understand that each data type keyword (e.g., `int`) is really a shorthand notation for a full-blown type in the `System` namespace (`System.Int32`, in this case). Given this, each C# data type has a number of built-in members. Along the same vein, you also learned about the role of *widening* and *narrowing*, as well as the role of the checked and unchecked keywords.

The chapter wrapped up by covering the role of implicit typing using the `var` keyword. As discussed, the most useful place for implicit typing is when working with the LINQ programming model. Finally, you quickly examined the various iteration and decision constructs supported by C#.

Now that you have an understanding of some of the basic nuts and bolts, the next chapter (Chapter 4) will complete your examination of core language features. After that, you will be well prepared to examine the object-oriented features of C# beginning in Chapter 5.

## CHAPTER 4



# Core C# Programming Constructs, Part 2

This chapter picks up where Chapter 3 left off and completes your investigation of the core aspects of the C# programming language. You will start with an investigation of the details behind manipulating arrays using the syntax of C# and get to know the functionality contained within the related `System.Array` class type.

Next, you will examine various details regarding the construction of C# methods, exploring the `out`, `ref`, and `params` keywords. Along the way, you will also examine the role of optional and named parameters. I finish the discussion on methods with a look at *method overloading*.

Next, this chapter discusses the construction of enumeration and structure types, including a fairly detailed examination of the distinction between a *value type* and a *reference type*. This chapter wraps up by examining the role of *nullable* data types and the related operators.

After you have completed this chapter, you will be in a perfect position to learn the object-oriented capabilities of C#, beginning in Chapter 5.

## Understanding C# Arrays

As I would guess you are already aware, an *array* is a set of data items, accessed using a numerical index. More specifically, an array is a set of contiguous data points of the same type (an array of ints, an array of strings, an array of `SportsCars`, etc.). Declaring, filling, and accessing an array with C# are all quite straightforward. To illustrate, create a new Console Application project named `FunWithArrays` that contains a helper method named `SimpleArrays()`, invoked from within `Main()`.

```
class Program
{
    static void Main(string[] args)
    {
        Console.WriteLine("***** Fun with Arrays *****");
        SimpleArrays();
        Console.ReadLine();
    }
    static void SimpleArrays()
    {
        Console.WriteLine("> Simple Array Creation.");
        // Create and fill an array of 3 integers
        int[] myInts = new int[3];
    }
}
```

```

    // Create a 100 item string array, indexed 0 - 99
    string[] booksOnDotNet = new string[100];
    Console.WriteLine();
}
}

```

Look closely at the previous code comments. When declaring a C# array using this syntax, the number used in the array declaration represents the total number of items, not the upper bound. Also note that the lower bound of an array always begins at 0. Thus, when you write `int[] myInts = new int[3]`, you end up with an array holding three elements, indexed at positions 0, 1, and 2.

After you have defined an array variable, you are then able to fill the elements index by index, as shown here in the updated `SimpleArrays()` method:

```

static void SimpleArrays()
{
    Console.WriteLine("=> Simple Array Creation.");
    // Create and fill an array of 3 Integers
    int[] myInts = new int[3];
    myInts[0] = 100;
    myInts[1] = 200;
    myInts[2] = 300;

    // Now print each value.
    foreach(int i in myInts)
    {
        Console.WriteLine(i);
    }
    Console.WriteLine();
}

```

---

■ **Note** Do be aware that if you declare an array but do not explicitly fill each index, each item will be set to the default value of the data type (e.g., an array of `bool`s will be set to `false` or an array of `int`s will be set to 0).

---

## C# Array Initialization Syntax

In addition to filling an array element by element, you are able to fill the items of an array using *C# array initialization syntax*. To do so, specify each array item within the scope of curly brackets (`{}`). This syntax can be helpful when you are creating an array of a known size and want to quickly specify the initial values. For example, consider the following alternative array declarations:

```

static void ArrayInitialization()
{
    Console.WriteLine("=> Array Initialization.");

    // Array initialization syntax using the new keyword.
    string[] stringArray = new string[]
    { "one", "two", "three" };
    Console.WriteLine("stringArray has {0} elements", stringArray.Length);
}

```



```
// Array initialization syntax without using the new keyword.
bool[] boolArray = { false, false, true };
Console.WriteLine("boolArray has {0} elements", boolArray.Length);

// Array initialization with new keyword and size.
int[] intArray = new int[4] { 20, 22, 23, 0 };
Console.WriteLine("intArray has {0} elements", intArray.Length);
Console.WriteLine();
}
```

Notice that when you make use of this “curly-bracket” syntax, you do not need to specify the size of the array (seen when constructing the `stringArray` variable), given that this will be inferred by the number of items within the scope of the curly brackets. Also notice that the use of the `new` keyword is optional (shown when constructing the `boolArray` type).

In the case of the `intArray` declaration, again recall the numeric value specified represents the number of elements in the array, not the value of the upper bound. If there is a mismatch between the declared size and the number of initializers (whether you have too many or too few initializers), you are issued a compile-time error. The following is an example:

```
// OOPS! Mismatch of size and elements!
int[] intArray = new int[2] { 20, 22, 23, 0 };
```

## Implicitly Typed Local Arrays

In Chapter 3, you learned about the topic of implicitly typed local variables. Recall that the `var` keyword allows you to define a variable, whose underlying type is determined by the compiler. In a similar vein, the `var` keyword can be used to define *implicitly typed local arrays*. Using this technique, you can allocate a new array variable without specifying the type contained within the array itself (note you must use the `new` keyword when using this approach).

```
static void DeclareImplicitArrays()
{
    Console.WriteLine("=> Implicit Array Initialization.");

    // a is really int[].
    var a = new[] { 1, 10, 100, 1000 };
    Console.WriteLine("a is a: {0}", a.ToString());

    // b is really double[].
    var b = new[] { 1, 1.5, 2, 2.5 };
    Console.WriteLine("b is a: {0}", b.ToString());

    // c is really string[].
    var c = new[] { "hello", null, "world" };
    Console.WriteLine("c is a: {0}", c.ToString());
    Console.WriteLine();
}
```

Of course, just as when you allocate an array using explicit C# syntax, the items in the array's initialization list must be of the same underlying type (e.g., all ints, all strings, or all `SportsCars`). Unlike what you might be expecting, an implicitly typed local array does not default to `System.Object`; thus, the following generates a compile-time error:

```
// Error! Mixed types!
var d = new[] { 1, "one", 2, "two", false };
```

## Defining an Array of Objects

In most cases, when you define an array, you do so by specifying the explicit type of item that can be within the array variable. While this seems quite straightforward, there is one notable twist. As you will come to understand in Chapter 6, `System.Object` is the ultimate base class to every type (including fundamental data types) in the .NET Core type system. Given this fact, if you were to define an array of `System.Object` data types, the subitems could be anything at all. Consider the following `ArrayOfObjects()` method (which again can be invoked from `Main()` for testing):

```
static void ArrayOfObjects()
{
    Console.WriteLine("=> Array of Objects.");

    // An array of objects can be anything at all.
    object[] myObjects = new object[4];
    myObjects[0] = 10;
    myObjects[1] = false;
    myObjects[2] = new DateTime(1969, 3, 24);
    myObjects[3] = "Form & Void";
    foreach (object obj in myObjects)
    {
        // Print the type and value for each item in array.
        Console.WriteLine("Type: {0}, Value: {1}", obj.GetType(), obj);
    }
    Console.WriteLine();
}
```

Here, as you are iterating over the contents of `myObjects`, you print the underlying type of each item using the `GetType()` method of `System.Object`, as well as the value of the current item. Without going into too much detail regarding `System.Object.GetType()` at this point in the text, simply understand that this method can be used to obtain the fully qualified name of the item (Chapter 17 examines the topic of type information and reflection services in detail). The following output shows the result of calling `ArrayOfObjects()`:

---

```
=> Array of Objects.
Type: System.Int32, Value: 10
Type: System.Boolean, Value: False
Type: System.DateTime, Value: 3/24/1969 12:00:00 AM
Type: System.String, Value: Form & Void
```

---

## Working with Multidimensional Arrays

In addition to the single-dimension arrays you have seen thus far, C# also supports two varieties of multidimensional arrays. The first of these is termed a *rectangular array*, which is simply an array of multiple dimensions, where each row is of the same length. To declare and fill a multidimensional rectangular array, proceed as follows:

```
static void RectMultidimensionalArray()
{
    Console.WriteLine("=> Rectangular multidimensional array.");
    // A rectangular MD array.
    int[,] myMatrix;
    myMatrix = new int[3,4];

    // Populate (3 * 4) array.
    for(int i = 0; i < 3; i++)
    {
        for(int j = 0; j < 4; j++)
        {
            myMatrix[i, j] = i * j;
        }
    }

    // Print (3 * 4) array.
    for(int i = 0; i < 3; i++)
    {
        for(int j = 0; j < 4; j++)
        {
            Console.Write(myMatrix[i, j] + "\t");
        }
        Console.WriteLine();
    }
    Console.WriteLine();
}
```

The second type of multidimensional array is termed a *jagged array*. As the name implies, jagged arrays contain some number of inner arrays, each of which may have a different upper limit. Here's an example:

```
static void JaggedMultidimensionalArray()
{
    Console.WriteLine("=> Jagged multidimensional array.");
    // A jagged MD array (i.e., an array of arrays).
    // Here we have an array of 5 different arrays.
    int[][] myJagArray = new int[5][];

    // Create the jagged array.
    for (int i = 0; i < myJagArray.Length; i++)
    {
        myJagArray[i] = new int[i + 7];
    }
}
```

```
// Print each row (remember, each element is defaulted to zero!).
for(int i = 0; i < 5; i++)
{
    for(int j = 0; j < myJagArray[i].Length; j++)
    {
        Console.Write(myJagArray[i][j] + " ");
    }
    Console.WriteLine();
}
Console.WriteLine();
}
```

The output of calling each of the `RectMultidimensionalArray()` and `JaggedMultidimensionalArray()` methods within `Main()` is shown next:

---

=> Rectangular multidimensional array:

```
0      0      0      0
0      1      2      3
0      2      4      6
```

=> Jagged multidimensional array:

```
0 0 0 0 0 0 0
0 0 0 0 0 0 0 0
0 0 0 0 0 0 0 0 0
0 0 0 0 0 0 0 0 0 0
0 0 0 0 0 0 0 0 0 0
```

---

## Arrays As Arguments or Return Values

After you have created an array, you are free to pass it as an argument or receive it as a member return value. For example, the following `PrintArray()` method takes an incoming array of `ints` and prints each member to the console, while the `GetStringArray()` method populates an array of `strings` and returns it to the caller:

```
static void PrintArray(int[] myInts)
{
    for(int i = 0; i < myInts.Length; i++)
    {
        Console.WriteLine("Item {0} is {1}", i, myInts[i]);
    }
}

static string[] GetStringArray()
{
    string[] theStrings = {"Hello", "from", "GetStringArray"};
    return theStrings;
}
```

These methods may be invoked as you would expect.

```
static void PassAndReceiveArrays()
{
    Console.WriteLine("=> Arrays as params and return values.");
    // Pass array as parameter.
    int[] ages = {20, 22, 23, 0} ;
    PrintArray(ages);

    // Get array as return value.
    string[] strs = GetStringArray();
    foreach(string s in strs)
    {
        Console.WriteLine(s);
    }

    Console.WriteLine();
}
```

At this point, you should feel comfortable with the process of defining, filling, and examining the contents of a C# array variable. To complete the picture, let's now examine the role of the `System.Array` class.

## The `System.Array` Base Class

Every array you create gathers much of its functionality from the `System.Array` class. Using these common members, you are able to operate on an array using a consistent object model. Table 4-1 gives a rundown of some of the more interesting members (be sure to check the documentation for full details).

**Table 4-1.** *Select Members of `System.Array`*

Member of Array Class	Meaning in Life
<code>Clear()</code>	This static method sets a range of elements in the array to empty values (0 for numbers, null for object references, false for Booleans).
<code>CopyTo()</code>	This method is used to copy elements from the source array into the destination array.
<code>Length</code>	This property returns the number of items within the array.
<code>Rank</code>	This property returns the number of dimensions of the current array.
<code>Reverse()</code>	This static method reverses the contents of a one-dimensional array.
<code>Sort()</code>	This static method sorts a one-dimensional array of intrinsic types. If the elements in the array implement the <code>IComparer</code> interface, you can also sort your custom types (see Chapters 8 and 10).

Let's see some of these members in action. The following helper method makes use of the static `Reverse()` and `Clear()` methods to pump out information about an array of `string` types to the console:

```

static void SystemArrayFunctionality()
{
    Console.WriteLine("=> Working with System.Array.");
    // Initialize items at startup.
    string[] gothicBands = {"Tones on Tail", "Bauhaus", "Sisters of Mercy"};

    // Print out names in declared order.
    Console.WriteLine("-> Here is the array:");
    for (int i = 0; i < gothicBands.Length; i++)
    {
        // Print a name.
        Console.Write(gothicBands[i] + ", ");
    }
    Console.WriteLine("\n");

    // Reverse them...
    Array.Reverse(gothicBands);
    Console.WriteLine("-> The reversed array");

    // ... and print them.
    for (int i = 0; i < gothicBands.Length; i++)
    {
        // Print a name.
        Console.Write(gothicBands[i] + ", ");
    }
    Console.WriteLine("\n");

    // Clear out all but the first member.
    Console.WriteLine("-> Cleared out all but one...");
    Array.Clear(gothicBands, 1, 2);

    for (int i = 0; i < gothicBands.Length; i++)
    {
        // Print a name.
        Console.Write(gothicBands[i] + ", ");
    }
    Console.WriteLine();
}

```

If you invoke this method from within `Main()`, you will get the output shown here:

---

```

=> Working with System.Array.
-> Here is the array:
Tones on Tail, Bauhaus, Sisters of Mercy,

-> The reversed array
Sisters of Mercy, Bauhaus, Tones on Tail,

-> Cleared out all but one...
Sisters of Mercy, , ,

```

---

Notice that many members of `System.Array` are defined as static members and are, therefore, called at the class level (e.g., the `Array.Sort()` and `Array.Reverse()` methods). Methods such as these are passed in the array you want to process. Other members of `System.Array` (such as the `Length` property) are bound at the object level; thus, you are able to invoke the member directly on the array.

## Indices and Ranges (New 8.0)

To simplify working with sequences (including arrays), C# 8 introduces two new types and two new operators for use when working with arrays:

- `System.Index` represents an index into a sequence.
- `System.Range` represents a subrange of indices.
- The index from end operator `^` specifies that the index is relative to the end of the sequence.
- The range operator `(...)` specifies the start and end of a range as its operands.

---

■ **Note** Indices and ranges can be used with arrays, strings, `Span<T>`, and `ReadOnlySpan<T>`.

---

As you have already seen, arrays are indexed beginning with zero (0). The end of a sequence is the length of the sequence - 1. The previous for loop that printed the `gothicBands` array can be updated to the following:

```
for (int i = 0; i < gothicBands.Length; i++)
{
    Index idx = i;
    // Print a name
    Console.Write(gothicBands[idx] + ", ");
}
```

The index from end operator lets you specify how many positions from the end of sequence, starting with the length. Remember that the last item in a sequence is one less than the actual length, so `^0` would actually cause an error. The following code prints the array in reverse:

```
for (int i = 1; i <= gothicBands.Length; i++)
{
    Index idx = ^i;
    // Print a name
    Console.Write(gothicBands[idx] + ", ");
}
```

The range operator specifies a start and end index, and allows for access to a sub-sequence within a list. The start of the range is inclusive and the end of the range is exclusive. For example, to pull out the first two members of the array, create ranges from 0 (the first member) to 2 (one more than the desired index position).

```
foreach (var itm in gothicBands[0..2])
{
    // Print a name
    Console.Write(itm + ", ");
}
Console.WriteLine("\n");
```

Ranges can also be passed to a sequence using the new Range data type, as shown here:

```
Range r = 0..2; //the end of the range is exclusive
foreach (var itm in gothicBands[r])
{
    // Print a name
    Console.Write(itm + ", ");
}
Console.WriteLine("\n");
```

Ranges can be defined using integers or Index variables. The same result will occur with the following code:

```
Index idx1 = 0;
Index idx2 = 2;
Range r = idx1..idx2; //the end of the range is exclusive
foreach (var itm in gothicBands[r])
{
    // Print a name
    Console.Write(itm + ", ");
}
Console.WriteLine("\n");
```

If the beginning of the range is left off, the beginning of the sequence is used. If the end of the range is left off, the length of the range is used. This does not cause an error, since the value at the end of the range is exclusive. For the previous example of three items in an array, all of the ranges represent the same subset:

```
gothicBands[..]
gothicBands[0..^0]
gothicBands[0..3]
```

## Methods

Let's examine the details of defining methods. Methods are defined by an access modifier, return type (or void for no return type), and may or may not take parameters. A method that returns a value to the caller is commonly referred to as a function, while methods that do not return a value are commonly returned to as methods.

---

■ **Note** Access modifiers for methods (and classes) are covered in Chapter 5. Method parameters are covered in the next section.

---



At this point in the text, each of your methods has followed the following basic format:

```
// Recall that static methods can be called directly
// without creating a class instance.
class Program
{
    // static returnType MethodName(parameter list) { /* Implementation */ }
    static int Add(int x, int y)
    {
        return x + y;
    }
}
```

As you will see over the next several chapters, methods can be implemented within the scope of classes, structures, or (new in C# 8) interfaces.

## Expression-Bodied Members

You already learned about simple methods that return values, such as the `Add()` method. C# 6 introduced expression-bodied members that shorten the syntax for single-line methods. For example, `Add()` can be rewritten using the following syntax:

```
static int Add(int x, int y) => x + y;
```

This is what is commonly referred to as *syntactic sugar*, meaning that the generated IL is no different. It's just another way to write the method. Some find it easier to read, and others don't, so the choice is yours (or your team's) which style you prefer.

---

■ **Note** Don't be alarmed by the `=>` operator. This is a lambda operation, which is covered in great detail in Chapter 12. That chapter also explains exactly *how* expression-bodied members work. For now, just consider them a shortcut to writing single-line statements.

---

## Local Functions (New 7.0)

A new feature introduced in C# 7.0 is the ability to create methods within methods, referred to officially as *local functions*. A local function is a function declared inside another function.

To see how this works, create a new Console Application project named `FunWithLocalFunctions`. As an example, let's say you want to extend the `Add()` example used previously to including validation of the inputs. There are many ways to accomplish this, and one simple way is to add the validation directly into the `Add()` method. Let's go with that and update the previous example to the following (the comment representing validation logic):

```
static int Add(int x, int y)
{
    //Do some validation here
    return x + y;
}
```

As you can see, there are no big changes. There's just a comment indicating that real code should do something. What if you wanted to separate the actual reason for the method (returning the sum of the arguments) from the validation of the arguments? You could create additional methods and call them from the `Add()` method. But that would require creating another method just for use by one other method. Maybe that's overkill. Local functions allow you to do the validation first and then encapsulate the real goal of the method defined inside the `AddWrapper()` method, as shown here:

```
static int AddWrapper(int x, int y)
{
    //Do some validation here
    return Add();

    int Add()
    {
        return x + y;
    }
}
```

The contained `Add()` method can be called only from the wrapping `AddWrapper()` method. So, the question I'm sure you are thinking is, "What did this buy me?" The answer for this example, quite simply, is little (if anything). This feature was added into the C# specification for custom iterator methods (Chapter 8) and asynchronous methods (Chapter 15), and you will see the benefit when you get to those topics.

## Static Local Functions (New 8.0)

An improvement to local functions that was introduced in C# 8 is the ability to declare a local function as static. In the previous example, the local `Add()` function was referencing the variables from the main function directly. This could cause unexpected side effects, since the local function can change the values of the variables.

To see this in action, create a new method call `AddWrapperWithSideEffect()`, as shown here:

```
static int AddWrapperWithSideEffect(int x, int y)
{
    //Do some validation here
    return Add();

    int Add()
    {
        x += 1;
        return x + y;
    }
}
```

Of course, this example is so simple, it probably wouldn't happen in real code. To prevent this type of mistake, add the static modifier to the local function. This prevents the local function from accessing the main method variables directly, and this causes the compiler exception CS8421 A static local function cannot contain a reference to '<variable name>'.

The improved version of the previous method is shown here:

```
static int AddWrapperWithStatic(int x, int y)
{
    //Do some validation here
    return Add(x,y);

    static int Add(int x, int y)
    {
        return x + y;
    }
}
```

## Method Parameters

Method parameters are used to pass data into a method call. Over the next several sections, you will learn the details of how methods (and their callers) treat parameters.

## Method Parameter Modifiers

The default manner in which a parameter is sent into a function is *by value*. Simply put, if you do not mark an argument with a parameter modifier, a copy of the data is passed into the function. As explained later in this chapter, exactly *what* is copied will depend on whether the parameter is a value type or a reference type.

While the definition of a method in C# is quite straightforward, you can use a handful of methods to control how arguments are passed to a method, as listed in Table 4-2.

**Table 4-2.** C# Parameter Modifiers

Parameter Modifier	Meaning in Life
(None)	If a value type parameter is not marked with a modifier, it is assumed to be passed by value, meaning the called method receives a copy of the original data. Reference types without a modifier are passed in by reference.
out	Output parameters must be assigned by the method being called and, therefore, are passed by reference. If the called method fails to assign output parameters, you are issued a compiler error.
ref	The value is initially assigned by the caller and may be optionally modified by the called method (as the data is also passed by reference). No compiler error is generated if the called method fails to assign a ref parameter.
in	New in C# 7.2, the in modifier indicates that a ref parameter is read-only by the called method.
params	This parameter modifier allows you to send in a variable number of arguments as a single logical parameter. A method can have only a single params modifier, and it must be the final parameter of the method. In reality, you might not need to use the params modifier all too often; however, be aware that numerous methods within the base class libraries do make use of this C# language feature.

To illustrate the use of these keywords, create a new Console Application project named FunWithMethods. Now, let's walk through the role of each keyword.

## The Default Parameter-Passing Behavior

When a parameter does not have a modifier, the behavior for value types is to pass in the parameter by value and for reference types is to pass in the parameter by reference.

---

■ **Note** Value types and reference types are covered later in this chapter.

---

## The Default Behavior for Value Types

The default manner in which a value type parameter is sent into a function is *by value*. Simply put, if you do not mark the argument with a modifier, a copy of the data is passed into the function. Add the following method to the Program class that operates on two numerical data types passed by value:

```
// Value type arguments are passed by value by default.
static int Add(int x, int y)
{
    int ans = x + y;
    // Caller will not see these changes
    // as you are modifying a copy of the
    // original data.
    x = 10000;
    y = 88888;
    return ans;
}
```

Numerical data falls under the category of *value types*. Therefore, if you change the values of the parameters within the scope of the member, the caller is blissfully unaware, given that you are changing the values on a *copy* of the caller's original data.

```
static void Main(string[] args)
{
    Console.WriteLine("***** Fun with Methods *****\n");

    // Pass two variables in by value.
    int x = 9, y = 10;
    Console.WriteLine("Before call: X: {0}, Y: {1}", x, y);
    Console.WriteLine("Answer is: {0}", Add(x, y));
    Console.WriteLine("After call: X: {0}, Y: {1}", x, y);
    Console.ReadLine();
}
```

As you would hope, the values of *x* and *y* remain identical before and after the call to *Add()*, as shown in the following output, as the data points were sent in by value. Thus, any changes on these parameters within the *Add()* method are not seen by the caller, as the *Add()* method is operating on a copy of the data.

---

```
***** Fun with Methods *****
```

```
Before call: X: 9, Y: 10
```

```
Answer is: 19
```

```
After call: X: 9, Y: 10
```

---

## The Default Behavior for Reference Types

The default manner in which a reference type parameter is sent into a function is *by reference for its properties, but by value for itself*. This is covered in great detail later in this chapter, after the discussion of value types and reference types.

---

■ **Note** Even though the string datatype is technically a reference type, as discussed in Chapter 3, it's a special case. When a string parameter does not have a modifier, it is passed in *by value*.

---

## The out Modifier (Updated 7.0)

Next, you have the use of *output parameters*. Methods that have been defined to take output parameters (via the out keyword) are under obligation to assign them to an appropriate value before exiting the method scope (if you fail to do so, you will receive compiler errors).

To illustrate, here is an alternative version of the Add() method that returns the sum of two integers using the C# out modifier (note the physical return value of this method is now void):

```
// Output parameters must be assigned by the called method.
static void Add(int x, int y, out int ans)
{
    ans = x + y;
}
```

Calling a method with output parameters also requires the use of the out modifier. However, the local variables that are passed as output variables are not required to be assigned before passing them in as output arguments (if you do so, the original value is lost after the call). The reason the compiler allows you to send in seemingly unassigned data is because the method being called *must* make an assignment. To call the updated Add method, create a variable of type int, and use the out modifier in the call, like this:

```
int ans;
Add(90, 90, out ans);
```

Starting with C# 7.0, out parameters do not need to be declared before using them. In other words, they can be declared inside the method call, like this:

```
Add(90, 90, out int ans);
```

The following code is an example of calling a method with an inline declaration of the out parameter:

```
static void Main(string[] args)
{
    Console.WriteLine("***** Fun with Methods *****");
    ...
    // No need to assign initial value to local variables
    // used as output parameters, provided the first time
    // you use them is as output arguments.
    // C# 7 allows for out parameters to be declared in the method call
    Add(90, 90, out int ans);
    Console.WriteLine("90 + 90 = {0}", ans);
    Console.ReadLine();
}
```

The previous example is intended to be illustrative in nature; you really have no reason to return the value of your summation using an output parameter. However, the C# out modifier does serve a useful purpose: it allows the caller to obtain multiple outputs from a single method invocation.

```
// Returning multiple output parameters.
static void FillTheseValues(out int , out string b, out bool c)
{
    a = 9;
    b = "Enjoy your string.";
    c = true;
}
```

The caller would be able to invoke the `FillTheseValues()` method. Remember that you must use the out modifier when you invoke the method, as well as when you implement the method.

```
static void Main(string[] args)
{
    Console.WriteLine("***** Fun with Methods *****");
    FillTheseValues(out int i, out string str, out bool b);

    Console.WriteLine("Int is: {0}", i);
    Console.WriteLine("String is: {0}", str);
    Console.WriteLine("Boolean is: {0}", b);
    Console.ReadLine();
}
```

---

■ **Note** C# 7 introduced tuples, which are another way to return multiple values out of a method call. You'll learn more about that later in this chapter.

---

Always remember that a method that defines output parameters must assign the parameter to a valid value before exiting the method scope. Therefore, the following code will result in a compiler error, as the output parameter has not been assigned within the method scope:

```
static void ThisWontCompile(out int a)
{
    Console.WriteLine("Error! Forgot to assign output arg!");
}
```

## Discards (New 7.0)

If you don't care about the value of an out parameter, you can use a discard as a placeholder. Discards are temporary, dummy variables that are intentionally unused. They are unassigned, don't have a value, and might not even allocate any memory. This can provide a performance benefit as well as make your code more readable. Discards can be used with out parameters, with tuples (later in this chapter), with pattern matching (Chapters 6 and 8), or even as stand-alone variables.

For example, if you want to get the value for the int in the previous example but don't care about the second two parameters, you could write the following code:

```
//This only gets the value for a, and ignores the other two parameters
FillTheseValues(out int a, out _, out _);
```

Note that the called method is still doing the work setting the values for all three parameters; it's just that the last two parameters are being *discarded* when the method call returns.

## The out Modifier in Constructors and Initializers (New 7.3)

C# 7.3 extended the allowable locations for using the out parameter. In addition to methods, parameters for constructors, field and property initializers, and query clauses can all be decorated with the out modifier. Examples of these will be examined later in this book.

## The ref Modifier

Now consider the use of the C# ref parameter modifier. Reference parameters are necessary when you want to allow a method to operate on (and usually change the values of) various data points declared in the caller's scope (such as a sorting or swapping routine). Note the distinction between output and reference parameters:

- Output parameters do not need to be initialized before they are passed to the method. The reason for this is that the method must assign output parameters before exiting.
- Reference parameters must be initialized before they are passed to the method. The reason for this is that you are passing a reference to an existing variable. If you don't assign it to an initial value, that would be the equivalent of operating on an unassigned local variable.

Let's check out the use of the ref keyword by way of a method that swaps two string variables (of course, any two data types could be used here, including int, bool, float, etc.).

```
// Reference parameters.
public static void SwapStrings(ref string s1, ref string s2)
{
    string tempStr = s1;
    s1 = s2;
    s2 = tempStr;
}
```

This method can be called as follows:

```
static void Main(string[] args)
{
    Console.WriteLine("***** Fun with Methods *****");
    ...
    string str1 = "Flip";
    string str2 = "Flop";
    Console.WriteLine("Before: {0}, {1} ", str1, str2);
    SwapStrings(ref str1, ref str2);
    Console.WriteLine("After: {0}, {1} ", str1, str2);
    Console.ReadLine();
}
```

Here, the caller has assigned an initial value to local string data (str1 and str2). After the call to SwapStrings() returns, str1 now contains the value "Flop", while str2 reports the value "Flip".

---

```
Before: Flip, Flop
After: Flop, Flip
```

---

## The in Modifier (New 7.2)

The in modifier passes a value by reference (for both value and reference types) and prevents the called method from modifying the values. This clearly states a design intent in your code, as well as potentially reducing memory pressure. When value types are passed by value, they are copied (internally) by the called method. If the object is large (such as a large struct), the extra overhead of making a copy for local use can be significant. Also, even when reference types are passed without a modifier, they can be modified by the called method. Both of these issues can be resolved using the in modifier.

Revisiting the Add method from earlier, there are two lines of code that modify the parameters, but don't effect the values for the calling method. The values aren't effected because the Add method makes a copy of the variables x and y to use locally. While the calling method doesn't have any adverse side effects, what if the Add method was changed to this code:

```
static int Add2(int x,int y)
{
    x = 10000;
    y = 88888;
    int ans = x + y;
    return ans;
}
```

Running this code then returns 98888, regardless of the numbers sent into the method. This is obviously a problem. To correct this, update the method to the following:

```
static int AddReadOnly(in int x,in int y)
{
    //Error CS8331 Cannot assign to variable 'in int' because it is a readonly variable
    //x = 10000;
    //y = 88888;
```



```
int ans = x + y;
return ans;
}
```

When the code attempts to change the values of the parameters, the compiler raises the CS8331 error, indicating that the values can't be modified because of the `in` modifier.

## The params Modifier

C# supports the use of *parameter arrays* using the `params` keyword. The `params` keyword allows you to pass into a method a variable number of identically typed parameters (or classes related by inheritance) as a *single logical parameter*. As well, arguments marked with the `params` keyword can be processed if the caller sends in a strongly typed array or a comma-delimited list of items. Yes, this can be confusing! To clear things up, assume you want to create a function that allows the caller to pass in any number of arguments and return the calculated average.

If you were to prototype this method to take an array of doubles, this would force the caller to first define the array, then fill the array, and finally pass it into the method. However, if you define `CalculateAverage` to take a `params` of `double[]` data types, the caller can simply pass a comma-delimited list of doubles. The .NET Core runtime will automatically package the set of doubles into an array of type `double` behind the scenes.

```
// Return average of "some number" of doubles.
static double CalculateAverage(params double[] values)
{
    Console.WriteLine("You sent me {0} doubles.", values.Length);

    double sum = 0;
    if(values.Length == 0)
    {
        return sum;
    }
    for (int i = 0; i < values.Length; i++)
    {
        sum += values[i];
    }
    return (sum / values.Length);
}
```

This method has been defined to take a parameter array of doubles. What this method is in fact saying is “Send me any number of doubles (including zero), and I’ll compute the average.” Given this, you can call `CalculateAverage()` in any of the following ways:

```
static void Main(string[] args)
{
    Console.WriteLine("***** Fun with Methods *****");
    ...
    // Pass in a comma-delimited list of doubles...
    double average;
    average = CalculateAverage(4.0, 3.2, 5.7, 64.22, 87.2);
    Console.WriteLine("Average of data is: {0}", average);
}
```

```

// ...or pass an array of doubles.
double[] data = { 4.0, 3.2, 5.7 };
average = CalculateAverage(data);
Console.WriteLine("Average of data is: {0}", average);

// Average of 0 is 0!
Console.WriteLine("Average of data is: {0}", CalculateAverage());
Console.ReadLine();
}

```

If you did not make use of the `params` modifier in the definition of `CalculateAverage()`, the first invocation of this method would result in a compiler error, as the compiler would be looking for a version of `CalculateAverage()` that took five double arguments.

---

■ **Note** To avoid any ambiguity, C# demands a method support only a single `params` argument, which must be the final argument in the parameter list.

---

As you might guess, this technique is nothing more than a convenience for the caller, given that the array is created by the CoreCLR as necessary. By the time the array is within the scope of the method being called, you are able to treat it as a full-blown .NET Core array that contains all the functionality of the `System.Array` base class library type. Consider the following output:

---

```

You sent me 5 doubles.
Average of data is: 32.864
You sent me 3 doubles.
Average of data is: 4.3
You sent me 0 doubles.
Average of data is: 0

```

---

## Defining Optional Parameters

C# allows you to create methods that can take *optional arguments*. This technique allows the caller to invoke a single method while omitting arguments deemed unnecessary, provided the caller is happy with the specified defaults.

To illustrate working with optional arguments, assume you have a method named `EnterLogData()`, which defines a single optional parameter.

```

static void EnterLogData(string message, string owner = "Programmer")
{
    Console.Beep();
    Console.WriteLine("Error: {0}", message);
    Console.WriteLine("Owner of Error: {0}", owner);
}

```

Here, the final string argument has been assigned the default value of "Programmer", via an assignment within the parameter definition. Given this, you can call `EnterLogData()` from within `Main()` in two ways.

```
static void Main(string[] args)
{
    Console.WriteLine("***** Fun with Methods *****");
    ...
    EnterLogData("Oh no! Grid can't find data");
    EnterLogData("Oh no! I can't find the payroll data", "CFO");

    Console.ReadLine();
}
```

Because the first invocation of `EnterLogData()` did not specify a second string argument, you would find that the programmer is the one responsible for losing data for the grid, while the CFO misplaced the payroll data (as specified by the second argument in the second method call).

One important thing to be aware of is that the value assigned to an optional parameter must be known at compile time and cannot be resolved at runtime (if you attempt to do so, you'll receive compile-time errors!). To illustrate, assume you want to update `EnterLogData()` with the following extra optional parameter:

```
// Error! The default value for an optional arg must be known
// at compile time!
static void EnterLogData(string message, string owner = "Programmer", DateTime timeStamp =
DateTime.Now)
{
    Console.Beep();
    Console.WriteLine("Error: {0}", message);
    Console.WriteLine("Owner of Error: {0}", owner);
    Console.WriteLine("Time of Error: {0}", timeStamp);
}
```

This will not compile because the value of the `Now` property of the `DateTime` class is resolved at runtime, not compile time.

---

■ **Note** To avoid ambiguity, optional parameters must always be packed onto the *end* of a method signature. It is a compiler error to have optional parameters listed before non-optional parameters.

---

## Using Named Arguments (Updated 7.2)

Another language feature found in C# is support for *named arguments*. Named arguments allow you to invoke a method by specifying parameter values in any order you choose. Thus, rather than passing parameters solely by position (as you will do in most cases), you can choose to specify each argument by name using a colon operator. To illustrate the use of named arguments, assume you have added the following method to the `Program` class:

```
static void DisplayFancyMessage(ConsoleColor textColor,
    ConsoleColor backgroundColor, string message)
{
    // Store old colors to restore after message is printed.
    ConsoleColor oldTextColor = Console.ForegroundColor;
```

```

ConsoleColor oldbackgroundColor = Console.BackgroundColor;
// Set new colors and print message.
Console.ForegroundColor = textColor;
Console.BackgroundColor = backgroundColor;
Console.WriteLine(message);
// Restore previous colors.
Console.ForegroundColor = oldTextColor;
Console.BackgroundColor = oldbackgroundColor;
}

```

Now, the way `DisplayFancyMessage()` was written, you would expect the caller to invoke this method by passing two `ConsoleColor` variables followed by a string type. However, using named arguments, the following calls are completely fine:

```

static void Main(string[] args)
{
    Console.WriteLine("***** Fun with Methods *****");
    ...
    DisplayFancyMessage(message: "Wow! Very Fancy indeed!",
        textColor: ConsoleColor.DarkRed,
        backgroundColor: ConsoleColor.White);

    DisplayFancyMessage(backgroundColor: ConsoleColor.Green,
        message: "Testing...",
        textColor: ConsoleColor.DarkBlue);
    Console.ReadLine();
}

```

The rules for using named arguments were updated slightly with C# 7.2. Prior to 7.2, if you begin to invoke a method using positional parameters, you must list them before any named parameters. With 7.2 and later versions of C#, named and unnamed parameters can be mingled as long as the parameters are in the correct position.

---

■ **Note** Just because you can mix and match named arguments with positional argument in C# 7.2 and later, it's not considered a good idea. Just because you can doesn't mean you should!

---

The following code is an example:

**// This is OK, as positional args are listed before named args.**

```

DisplayFancyMessage(ConsoleColor.Blue,
    message: "Testing...",
    backgroundColor: ConsoleColor.White);

```

**// This is OK, all arguments are in the correct order**

```

DisplayFancyMessage(textColor: ConsoleColor.White, backgroundColor: ConsoleColor.Blue,
    "Testing...");

```

**// This is an ERROR, as positional args are listed after named args.**

```
DisplayFancyMessage(message: "Testing...",
    backgroundColor: ConsoleColor.White,
    ConsoleColor.Blue);
```

This restriction aside, you might still be wondering when you would ever want to use this language feature. After all, if you need to specify three arguments to a method, why bother flipping around their positions?

Well, as it turns out, if you have a method that defines optional arguments, this feature can actually be really helpful. Assume `DisplayFancyMessage()` has been rewritten to now support optional arguments, as you have assigned fitting defaults.

```
static void DisplayFancyMessage(ConsoleColor textColor = ConsoleColor.Blue,
    ConsoleColor backgroundColor = ConsoleColor.White,
    string message = "Test Message")
{
    ...
}
```

Given that each argument has a default value, named arguments allow the caller to specify only the parameters for which they do not want to receive the defaults. Therefore, if the caller wants the value "Hello!" to appear in blue text surrounded by a white background, they can simply specify the following:

```
DisplayFancyMessage(message: "Hello!");
```

Or, if the caller wants to see "Test Message" print out with a green background containing blue text, they can invoke

```
DisplayFancyMessage(backgroundColor: ConsoleColor.Green);
```

As you can see, optional arguments and named parameters tend to work hand in hand. To wrap up your examination of building C# methods, I need to address the topic of *method overloading*.

## Understanding Method Overloading

Like other modern object-oriented languages, C# allows a method to be *overloaded*. Simply put, when you define a set of identically named methods that differ by the number (or type) of parameters, the method in question is said to be *overloaded*.

To understand why overloading is so useful, consider life as an old-school Visual Basic 6.0 (VB6) developer. Assume you are using VB6 to build a set of methods that return the sum of various incoming data types (Integers, Doubles, etc.). Given that VB6 does not support method overloading, you would be required to define a unique set of methods that essentially do the same thing (return the sum of the arguments).

### ' VB6 code examples.

```
Public Function AddInts(ByVal x As Integer, ByVal y As Integer) As Integer
    AddInts = x + y
End Function
```

```
Public Function AddDoubles(ByVal x As Double, ByVal y As Double) As Double
    AddDoubles = x + y
End Function
```

```
Public Function AddLongs(ByVal x As Long, ByVal y As Long) As Long
    AddLongs = x + y
End Function
```

Not only can code such as this become tough to maintain, but the caller must now be painfully aware of the name of each method. Using overloading, you are able to allow the caller to call a single method named `Add()`. Again, the key is to ensure that each version of the method has a distinct set of arguments (methods differing only by return type are not unique enough).

---

■ **Note** As will be explained in Chapter 10, it is possible to build generic methods that take the concept of overloading to the next level. Using generics, you can define *type placeholders* for a method implementation that are specified at the time you invoke the member in question.

---

To check this out firsthand, create a new Console Application project named `MethodOverloading`. Now, consider the following class definition:

```
// C# code.
class Program
{
    static void Main(string[] args)
    {
        // Overloaded Add() method.
        static int Add(int x, int y)
        { return x + y; }

        static double Add(double x, double y)
        { return x + y; }

        static long Add(long x, long y)
        { return x + y; }
    }
}
```

The caller can now simply invoke `Add()` with the required arguments, and the compiler is happy to comply, given that the compiler is able to resolve the correct implementation to invoke with the provided arguments.

```
static void Main(string[] args)
{
    Console.WriteLine("***** Fun with Method Overloading *****\n");

    // Calls int version of Add()
    Console.WriteLine(Add(10, 10));

    // Calls long version of Add()
    Console.WriteLine(Add(900_000_000_000, 900_000_000_000));
}
```

```
// Calls double version of Add()
Console.WriteLine(Add(4.3, 4.4));

Console.ReadLine();
}
```

The Visual Studio IDE provides assistance when calling overloaded methods to boot. When you type in the name of an overloaded method (such as your good friend `Console.WriteLine()`), IntelliSense will list each version of the method in question. Note that you are able to cycle through each version of an overloaded method using the up and down arrow keys shown in Figure 4-1.

```
static void Main(string[] args)
{
    Console.WriteLine("***** Fun with Method Overloading *****\n");

    // Calls int version of Add()
    Console.WriteLine(Add(10, 10));

    // Calls long version of Add() (using the new digit separator)
    Console.WriteLine(Add(900_000_000_000, 900_000_000_000));

    // Calls double version of Add()
    Console.WriteLine(Add(4.3, 4.4));
    Add() I
    ▲ 1 of 3 ▼ double Program.Add(double x, double y)
}
```

The screenshot shows the Visual Studio IDE with a code file. The cursor is at the end of the line `Add()`. A tooltip is visible showing the IntelliSense results for `Add()`, listing `double Program.Add(double x, double y)` as the first option.

**Figure 4-1.** Visual Studio IntelliSense for overloaded methods

If your overload has optional parameters, then the compiler will pick the method that is the best match for the calling code, based on named and/or positional arguments. Add the following method:

```
static int Add(int x, int y, int z = 0)
{
    return x + (y*z);
}
```

If the optional argument isn't passed in by the caller, the compiler will match the first signature (the one without the optional parameter). While there is a ruleset for method location, it's generally not a good idea to create methods that differ only on the optional parameters.

Finally, `in`, `ref`, and `out` are not considered as part of the signature for method overloading when more than one modifier is used. In other words, the following overloads will throw a compiler error:

```
static int Add(ref int x) { /* */ }
static int Add(out int x) { /* */ }
```

However, if only one method uses `in`, `ref`, or `out`, the compiler can distinguish between the signatures. So, this is allowed:

```
static int Add(ref int x) { /* */ }
static int Add(int x) { /* */ }
```

That wraps up the initial examination of building methods using the syntax of C#. Next, let's check out how to build and manipulate enumerations and structures.

## Understanding the enum Type

Recall from Chapter 1 that the .NET Core type system is composed of classes, structures, enumerations, interfaces, and delegates. To begin exploration of these types, let's check out the role of the *enumeration* (or simply, `enum`) using a new Console Application project named `FunWithEnums`.

---

**Note** Do not confuse the term *enum* with *enumerator*; they are completely different concepts. An `enum` is a custom data type of name-value pairs. An `enumerator` is a class or structure that implements a .NET Core interface named `IEnumerable`. Typically, this interface is implemented on collection classes, as well as the `System.Array` class. As you will see in Chapter 8, objects that support `IEnumerable` can work within the `foreach` loop.

---

When building a system, it is often convenient to create a set of symbolic names that map to known numerical values. For example, if you are creating a payroll system, you might want to refer to the type of employees using constants such as `vice president`, `manager`, `contractor`, and `grunt`. C# supports the notion of custom enumerations for this very reason. For example, here is an enumeration named `EmpTypeEnum` (you can define this in the same file as your `Program` class, right before the class definition):

```
// A custom enumeration.
enum EmpTypeEnum
{
    Manager,          // = 0
    Grunt,             // = 1
    Contractor,       // = 2
    VicePresident      // = 3
}
```

---

**Note** By convention, `enum` types are usually suffixed with `Enum`. This is not necessary, but makes for more readable code.

---

The `EmpTypeEnum` enumeration defines four named constants, corresponding to discrete numerical values. By default, the first element is set to the value zero (0), followed by an `n+1` progression. You are free to change the initial value as you see fit. For example, if it made sense to number the members of `EmpTypeEnum` as 102 through 105, you could do so as follows:



```
// Begin with 102.
enum EmpTypeEnum
{
    Manager = 102,
    Grunt,      // = 103
    Contractor, // = 104
    VicePresident // = 105
}
```

Enumerations do not necessarily need to follow a sequential ordering and do not need to have unique values. If (for some reason or another) it makes sense to establish your `EmpTypeEnum` as shown here, the compiler continues to be happy:

```
// Elements of an enumeration need not be sequential!
enum EmpType
{
    Manager = 10,
    Grunt = 1,
    Contractor = 100,
    VicePresident = 9
}
```

## Controlling the Underlying Storage for an enum

By default, the storage type used to hold the values of an enumeration is a `System.Int32` (the C# `int`); however, you are free to change this to your liking. C# enumerations can be defined in a similar manner for any of the core system types (byte, short, int, or long). For example, if you want to set the underlying storage value of `EmpTypeEnum` to be a byte rather than an `int`, you can write the following:

```
// This time, EmpTypeEnum maps to an underlying byte.
enum EmpTypeEnum : byte
{
    Manager = 10,
    Grunt = 1,
    Contractor = 100,
    VicePresident = 9
}
```

Changing the underlying type of an enumeration can be helpful if you are building a .NET Core application that will be deployed to a low-memory device and need to conserve memory wherever possible. Of course, if you do establish your enumeration to use a byte as storage, each value must be within its range! For example, the following version of `EmpTypeEnum` will result in a compiler error, as the value 999 cannot fit within the range of a byte:

```
// Compile-time error! 999 is too big for a byte!
enum EmpTypeEnum : byte
{
    Manager = 10,
    Grunt = 1,
    Contractor = 100,
    VicePresident = 999
}
```

## Declaring enum Variables

Once you have established the range and storage type of your enumeration, you can use it in place of so-called magic numbers. Because enumerations are nothing more than a user-defined data type, you are able to use them as function return values, method parameters, local variables, and so forth. Assume you have a method named `AskForBonus()`, taking an `EmpTypeEnum` variable as the sole parameter. Based on the value of the incoming parameter, you will print out a fitting response to the pay bonus request.

```
class Program
{
    static void Main(string[] args)
    {
        Console.WriteLine("**** Fun with Enums ****");
        // Make an EmpTypeEnum variable.
        EmpTypeEnum emp = EmpType.Contractor;
        AskForBonus(emp);
        Console.ReadLine();
    }

    // Enums as parameters.
    static void AskForBonus(EmpTypeEnum e)
    {
        switch (e)
        {
            case EmpType.Manager:
                Console.WriteLine("How about stock options instead?");
                break;
            case EmpType.Grunt:
                Console.WriteLine("You have got to be kidding...");
                break;
            case EmpType.Contractor:
                Console.WriteLine("You already get enough cash...");
                break;
            case EmpType.VicePresident:
                Console.WriteLine("VERY GOOD, Sir!");
                break;
        }
    }
}
```

Notice that when you are assigning a value to an enum variable, you must scope the enum name (`EmpTypeEnum`) to the value (`Grunt`). Because enumerations are a fixed set of name-value pairs, it is illegal to set an enum variable to a value that is not defined directly by the enumerated type.

```
static void ThisMethodWillNotCompile()
{
    // Error! SalesManager is not in the EmpTypeEnum enum!
    EmpTypeEnum emp = EmpType.SalesManager;

    // Error! Forgot to scope Grunt value to EmpTypeEnum enum!
    emp = Grunt;
}
```

## The System.Enum Type

The interesting thing about .NET Core enumerations is that they gain functionality from the `System.Enum` class type. This class defines a number of methods that allow you to interrogate and transform a given enumeration. One helpful method is the static `Enum.GetUnderlyingType()`, which, as the name implies, returns the data type used to store the values of the enumerated type (`System.Byte` in the case of the current `EmpTypeEnum` declaration).

```
static void Main(string[] args)
{
    Console.WriteLine("**** Fun with Enums ****");
    // Make a contractor type.
    EmpTypeEnum emp = EmpTypeEnum.Contractor;
    AskForBonus(emp);

    // Print storage for the enum.
    Console.WriteLine("EmpTypeEnum uses a {0} for storage",
        Enum.GetUnderlyingType(emp.GetType()));
    Console.ReadLine();
}
```

The `Enum.GetUnderlyingType()` method requires you to pass in a `System.Type` as the first parameter. As fully examined in Chapter 17, `Type` represents the metadata description of a given .NET Core entity.

One possible way to obtain metadata (as shown previously) is to use the `GetType()` method, which is common to all types in the .NET Core base class libraries. Another approach is to use the C# `typeof` operator. One benefit of doing so is that you do not need to have a variable of the entity you want to obtain a metadata description of.

```
// This time use typeof to extract a Type.
Console.WriteLine("EmpTypeEnum uses a {0} for storage",
    Enum.GetUnderlyingType(typeof(EmpTypeEnum)));
```

## Dynamically Discovering an enum's Name-Value Pairs

Beyond the `Enum.GetUnderlyingType()` method, all C# enumerations support a method named `ToString()`, which returns the string name of the current enumeration's value. The following code is an example:

```
static void Main(string[] args)
{
    EmpTypeEnum emp = EmpTypeEnum.Contractor;
    ...
    // Prints out "emp is a Contractor".
    Console.WriteLine("emp is a {0}.", emp.ToString());
    Console.ReadLine();
}
```

If you are interested in discovering the value of a given enumeration variable, rather than its name, you can simply cast the enum variable against the underlying storage type. The following is an example:

```
static void Main(string[] args)
{
    Console.WriteLine("**** Fun with Enums ****");
    EmpTypeEnum emp = EmpTypeEnum.Contractor;
    ...
    // Prints out "Contractor = 100".
    Console.WriteLine("{0} = {1}", emp.ToString(), (byte)emp);
    Console.ReadLine();
}
```

---

■ **Note** The static `Enum.Format()` method provides a finer level of formatting options by specifying a desired format flag. Consult the documentation for a full list of formatting flags.

---

`System.Enum` also defines another static method named `GetValues()`. This method returns an instance of `System.Array`. Each item in the array corresponds to a member of the specified enumeration. Consider the following method, which will print out each name-value pair within any enumeration you pass in as a parameter:

```
// This method will print out the details of any enum.
static void EvaluateEnum(System.Enum e)
{
    Console.WriteLine("=> Information about {0}", e.GetType().Name);

    Console.WriteLine("Underlying storage type: {0}",
        Enum.GetUnderlyingType(e.GetType()));

    // Get all name-value pairs for incoming parameter.
    Array enumData = Enum.GetValues(e.GetType());
    Console.WriteLine("This enum has {0} members.", enumData.Length);

    // Now show the string name and associated value, using the D format
    // flag (see Chapter 3).
    for(int i = 0; i < enumData.Length; i++)
    {
        Console.WriteLine("Name: {0}, Value: {0:D}",
            enumData.GetValue(i));
    }
    Console.WriteLine();
}
```

To test this new method, update your `Main()` method to create variables of several enumeration types declared in the `System` namespace (as well as an `EmpTypeEnum` enumeration for good measure). The following code is an example:

```
static void Main(string[] args)
{
    Console.WriteLine("**** Fun with Enums ****");
    ...
    EmpTypeEnum e2 = EmpType.Contractor;

    // These types are enums in the System namespace.
    DayOfWeek day = DayOfWeek.Monday;
    ConsoleColor cc = ConsoleColor.Gray;

    EvaluateEnum(e2);
    EvaluateEnum(day);
    EvaluateEnum(cc);
    Console.ReadLine();
}
```

Some partial output is shown here:

---

```
=> Information about DayOfWeek
Underlying storage type: System.Int32
This enum has 7 members.
Name: Sunday, Value: 0
Name: Monday, Value: 1
Name: Tuesday, Value: 2
Name: Wednesday, Value: 3
Name: Thursday, Value: 4
Name: Friday, Value: 5
Name: Saturday, Value: 6
```

---

As you will see over the course of this text, enumerations are used extensively throughout the .NET Core base class libraries. When you make use of any enumeration, always remember that you are able to interact with the name-value pairs using the members of `System.Enum`.

## Understanding the Structure (aka Value Type)

Now that you understand the role of enumeration types, let's examine the use of .NET Core *structures* (or simply *structs*). Structure types are well suited for modeling mathematical, geometrical, and other “atomic” entities in your application. A structure (such as an enumeration) is a user-defined type; however, structures are not simply a collection of name-value pairs. Rather, structures are types that can contain any number of data fields and members that operate on these fields.

---

■ **Note** If you have a background in OOP, you can think of a structure as a “lightweight class type,” given that structures provide a way to define a type that supports encapsulation but cannot be used to build a family of related types. When you need to build a family of related types through inheritance, you will need to make use of class types.

---

On the surface, the process of defining and using structures is simple, but as they say, the devil is in the details. To begin understanding the basics of structure types, create a new project named `FunWithStructures`. In *C#*, structures are defined using the `struct` keyword. Define a new structure named `Point`, which defines two member variables of type `int` and a set of methods to interact with said data.

```
struct Point
{
    // Fields of the structure.
    public int X;
    public int Y;

    // Add 1 to the (X, Y) position.
    public void Increment()
    {
        X++; Y++;
    }

    // Subtract 1 from the (X, Y) position.
    public void Decrement()
    {
        X--; Y--;
    }

    // Display the current position.
    public void Display()
    {
        Console.WriteLine("X = {0}, Y = {1}", X, Y);
    }
}
```

Here, you have defined your two integer fields (`X` and `Y`) using the `public` keyword, which is an access control modifier (Chapter 5 furthers this discussion). Declaring data with the `public` keyword ensures the caller has direct access to the data from a given `Point` variable (via the dot operator).

---

■ **Note** It is typically considered bad style to define public data within a class or structure. Rather, you will want to define *private* data, which can be accessed and changed using *public* properties. These details will be examined in Chapter 5.

---

Here is a `Main()` method that takes the `Point` type out for a test-drive:

```
static void Main(string[] args)
{
    Console.WriteLine("***** A First Look at Structures *****\n");

    // Create an initial Point.
    Point myPoint;
    myPoint.X = 349;
    myPoint.Y = 76;
    myPoint.Display();
}
```

```
// Adjust the X and Y values.
myPoint.Increment();
myPoint.Display();
Console.ReadLine();
}
```

The output is as you would expect.

---

\*\*\*\*\* A First Look at Structures \*\*\*\*\*

```
X = 349, Y = 76
X = 350, Y = 77
```

---

## Creating Structure Variables

When you want to create a structure variable, you have a variety of options. Here, you simply create a `Point` variable and assign each piece of public field data before invoking its members. If you do *not* assign each piece of public field data (X and Y in this case) before using the structure, you will receive a compiler error.

```
// Error! Did not assign Y value.
Point p1;
p1.X = 10;
p1.Display();

// OK! Both fields assigned before use.
Point p2;
p2.X = 10;
p2.Y = 10;
p2.Display();
```

As an alternative, you can create structure variables using the C# `new` keyword, which will invoke the structure's *default constructor*. By definition, a default constructor does not take any arguments. The benefit of invoking the default constructor of a structure is that each piece of field data is automatically set to its default value.

```
// Set all fields to default values
// using the default constructor.
Point p1 = new Point();

// Prints X=0,Y=0.
p1.Display();
```

It is also possible to design a structure with a *custom constructor*. This allows you to specify the values of field data upon variable creation, rather than having to set each data member field by field. Chapter 5 will provide a detailed examination of constructors; however, to illustrate, update the `Point` structure with the following code:

```
struct Point
{
    // Fields of the structure.
```

```

public int X;
public int Y;

// A custom constructor.
public Point(int xPos, int yPos)
{
    X = xPos;
    Y = yPos;
}
...
}

```

With this, you could now create `Point` variables, as follows:

```

// Call custom constructor.
Point p2 = new Point(50, 60);

// Prints X=50,Y=60.
p2.Display();

```

## Readonly Structs (New 7.2)

Structs can also be marked as readonly if there is a need for them to be *immutable*. Immutable objects must be set up at construction and, because they cannot be changed, can be more performant. When declaring a struct as readonly, all of the properties must also be readonly. But, you might ask, how can a property be set (as all properties must be on a struct) if it's read-only? The answer is that the value must be set during the construction of the struct.

Update the point class to the following example:

```

readonly struct ReadOnlyPoint
{
    // Fields of the structure.
    public int X {get; }
    public int Y { get; }

    // Display the current position and name.
    public void Display()
    {
        Console.WriteLine($"X = {X}, Y = {Y}");
    }

    public ReadOnlyPoint(int xPos, int yPos, string name)
    {
        X = xPos;
        Y = yPos;
    }
}

```

The Increment and Decrement methods have been removed, since the variables are read-only. Notice also the two properties, `X` and `Y`. Instead of setting them up as fields, they are created as readonly automatic properties. Automatic properties are covered in [Chapter 5](#).



## Readonly members (New 8.0)

New in C# 8.0, you can declare individual fields of a struct as `readonly`. This is more granular than making the entire struct `readonly`. The `readonly` modifier can be applied to methods, properties, and property accessors. Add the following struct code to your file, outside of the `Program` class:

```
struct PointWithReadOnly
{
    // Fields of the structure.
    public int X;
    public readonly int Y;
    public readonly string Name;

    // Display the current position and name.
    public readonly void Display()
    {
        Console.WriteLine($"X = {X}, Y = {Y}, Name = {Name}");
    }

    // A custom constructor.
    public PointWithReadOnly(int xPos, int yPos, string name)
    {
        X = xPos;
        Y = yPos;
        Name = name;
    }
}
```

To use this new struct, add the following to the `Main` method:

```
PointWithReadOnly p3 =
    new PointWithReadOnly(50,60,"Point w/RO");
p3.Display();
```

## ref Structs (New 7.2)

Also added in C# 7.2, the `ref` modifier can be used when defining a struct. This requires all instances of the struct to be stack allocated and cannot be assigned as a property of another class. The technical reason for this is that `ref` structs cannot be referenced from the heap. The difference between the stack and the heap is covered in the next section.

There are some additional limitations of `ref` structs:

- They cannot be assigned to a variable of type `object`, `dynamic`, or an interface type.
- They cannot implement interfaces.
- They cannot be used as a property of a non-`ref` struct.
- They cannot be used in `async` methods, in iterators, lambda expressions, or local functions.

The following code, which creates a simple struct and then attempts to create a property in that struct typed to a ref struct, will not compile:

```
struct NormalPoint
{
    //This does not compile
    public PointWithRef PropPointer { get; set; }
}
```

ReadOnly and ref modifiers can be combined to gain the benefits and restrictions of both.

## Disposable ref Structs (New 8.0)

As covered in the previous section, ref structs (and readonly ref structs) cannot implement an interface and therefore cannot implement `IDisposable`. New in C# 8.0, ref structs and readonly ref structs can be made disposable by adding a public void `Dispose()` method.

Add the following struct definition to the main file:

```
ref struct DisposableRefStruct
{
    public int X;
    public readonly int Y;
    public readonly void Display()
    {
        Console.WriteLine($"X = {X}, Y = {Y}");
    }
    // A custom constructor.
    public DisposableRefStruct(int xPos, int yPos)
    {
        X = xPos;
        Y = yPos;
        Console.WriteLine("Created!");
    }
    public void Dispose()
    {
        //clean up any resources here
        Console.WriteLine("Disposed!");
    }
}
```

Next, add the following to the end of the Main method to create and dispose of the new struct:

```
var s = new DisposableRefStruct(50, 60);
s.Display();
s.Dispose();
```

---

■ **Note** Object lifetime and disposing of objects is covered in depth in [Chapter 9](#).

---

To deepen your understanding of stack and heap allocation, you need to explore the distinction between a .NET Core value type and a .NET Core reference type.

## Understanding Value Types and Reference Types

---

■ **Note** The following discussion of value types and reference types assumes that you have a background in object-oriented programming. If this is not the case, you might want to skip to the “Understanding C# Nullable Types” section of this chapter and return to this section after you have read Chapters 5 and 6.

---

Unlike arrays, strings, or enumerations, C# structures do not have an identically named representation in the .NET Core library (i.e., there is no `System.Structure` class) but are implicitly derived from `System.ValueType`. The role of `System.ValueType` is to ensure that the derived type (e.g., any structure) is allocated on the *stack*, rather than the garbage-collected *heap*. Simply put, data allocated on the stack can be created and destroyed quickly, as its lifetime is determined by the defining scope. Heap-allocated data, on the other hand, is monitored by the .NET Core garbage collector and has a lifetime that is determined by a large number of factors, which will be examined in Chapter 9.

Functionally, the only purpose of `System.ValueType` is to override the virtual methods defined by `System.Object` to use value-based vs. reference-based semantics. As you might know, overriding is the process of changing the implementation of a virtual (or possibly abstract) method defined within a base class. The base class of `ValueType` is `System.Object`. In fact, the instance methods defined by `System.ValueType` are identical to those of `System.Object`.

```
// Structures and enumerations implicitly extend System.ValueType.
public abstract class ValueType : object
{
    public virtual bool Equals(object obj);
    public virtual int GetHashCode();
    public Type GetType();
    public virtual string ToString();
}
```

Given that value types are using value-based semantics, the lifetime of a structure (which includes all numerical data types [int, float], as well as any enum or structure) is predictable. When a structure variable falls out of the defining scope, it is removed from memory immediately.

```
// Local structures are popped off
// the stack when a method returns.
static void LocalValueTypes()
{
    // Recall! "int" is really a System.Int32 structure.
    int i = 0;

    // Recall! Point is a structure type.
    Point p = new Point();
} // "i" and "p" popped off the stack here!
```

## Value Types, Reference Types, and the Assignment Operator

When you assign one value type to another, a member-by-member copy of the field data is achieved. In the case of a simple data type such as `System.Int32`, the only member to copy is the numerical value. However, in the case of your `Point`, the `X` and `Y` values are copied into the new structure variable. To illustrate, create a new Console Application project named `ValueAndReferenceTypes` and then copy your previous `Point` definition into your new namespace. Next, add the following method to your `Program` type:

```
// Assigning two intrinsic value types results in
// two independent variables on the stack.
static void ValueTypeAssignment()
{
    Console.WriteLine("Assigning value types\n");

    Point p1 = new Point(10, 10);
    Point p2 = p1;

    // Print both points.
    p1.Display();
    p2.Display();

    // Change p1.X and print again. p2.X is not changed.
    p1.X = 100;
    Console.WriteLine("\n=> Changed p1.X\n");
    p1.Display();
    p2.Display();
}
```

Here, you have created a variable of type `Point` (named `p1`) that is then assigned to another `Point` (`p2`). Because `Point` is a value type, you have two copies of the `Point` type on the stack, each of which can be independently manipulated. Therefore, when you change the value of `p1.X`, the value of `p2.X` is unaffected.

---

Assigning value types

```
X = 10, Y = 10
X = 10, Y = 10
=> Changed p1.X
X = 100, Y = 10
X = 10, Y = 10
```

---

In stark contrast to value types, when you apply the assignment operator to reference types (meaning all class instances), you are redirecting what the reference variable points to in memory. To illustrate, create a new class type named `PointRef` that has the same members as the `Point` structures, beyond renaming the constructor to match the class name.

```
// Classes are always reference types.
class PointRef
{
    // Same members as the Point structure...
    // Be sure to change your constructor name to PointRef!
    public PointRef(int xPos, int yPos)
    {
```

```

        X = xPos;
        Y = yPos;
    }
}

```

Now, use your `PointRef` type within the following new method. Note that beyond using the `PointRef` class, rather than the `Point` structure, the code is identical to the `ValueTypeAssignment()` method.

```

static void ReferenceTypeAssignment()
{
    Console.WriteLine("Assigning reference types\n");
    PointRef p1 = new PointRef(10, 10);
    PointRef p2 = p1;

    // Print both point refs.
    p1.Display();
    p2.Display();

    // Change p1.X and print again.
    p1.X = 100;
    Console.WriteLine("\n=> Changed p1.X\n");
    p1.Display();
    p2.Display();
}

```

In this case, you have two references pointing to the same object on the managed heap. Therefore, when you change the value of `X` using the `p1` reference, `p2.X` reports the same value. Assuming you have called this new method within `Main()`, your output should look like the following:

---

```

Assigning reference types
X = 10, Y = 10
X = 10, Y = 10
=> Changed p1.X
X = 100, Y = 10
X = 100, Y = 10

```

---

## Value Types Containing Reference Types

Now that you have a better feeling for the basic differences between value types and reference types, let's examine a more complex example. Assume you have the following reference (class) type that maintains an informational string that can be set using a custom constructor:

```

class ShapeInfo
{
    public string InfoString;
    public ShapeInfo(string info)
    {
        InfoString = info;
    }
}

```

Now assume that you want to contain a variable of this class type within a value type named `Rectangle`. To allow the caller to set the value of the inner `ShapeInfo` member variable, you also provide a custom constructor. Here is the complete definition of the `Rectangle` type:

```
struct Rectangle
{
    // The Rectangle structure contains a reference type member.
    public ShapeInfo RectInfo;

    public int RectTop, RectLeft, RectBottom, RectRight;

    public Rectangle(string info, int top, int left, int bottom, int right)
    {
        RectInfo = new ShapeInfo(info);
        RectTop = top; RectBottom = bottom;
        RectLeft = left; RectRight = right;
    }

    public void Display()
    {
        Console.WriteLine("String = {0}, Top = {1}, Bottom = {2}, " +
            "Left = {3}, Right = {4}",
            RectInfo.infoString, RectTop, RectBottom, RectLeft, RectRight);
    }
}
```

At this point, you have contained a reference type within a value type. The million-dollar question now becomes “what happens if you assign one `Rectangle` variable to another?” Given what you already know about value types, you would be correct in assuming that the integer data (which is indeed a structure – `System.Int32`) should be an independent entity for each `Rectangle` variable. But what about the internal reference type? Will the object’s *state* be fully copied or will the reference to that object be copied? To answer this question, define the following method and invoke it from `Main()`:

```
static void ValueTypeContainingRefType()
{
    // Create the first Rectangle.
    Console.WriteLine("-> Creating r1");
    Rectangle r1 = new Rectangle("First Rect", 10, 10, 50, 50);

    // Now assign a new Rectangle to r1.
    Console.WriteLine("-> Assigning r2 to r1");
    Rectangle r2 = r1;

    // Change some values of r2.
    Console.WriteLine("-> Changing values of r2");
    r2.RectInfo.infoString = "This is new info!";
    r2.RectBottom = 4444;

    // Print values of both rectangles.
    r1.Display();
    r2.Display();
}
```

The output is shown here:

---

```
-> Creating r1
-> Assigning r2 to r1
-> Changing values of r2
String = This is new info!, Top = 10, Bottom = 50, Left = 10, Right = 50
String = This is new info!, Top = 10, Bottom = 4444, Left = 10, Right = 50
```

---

As you can see, when you change the value of the informational string using the r2 reference, the r1 reference displays the same value. By default, when a value type contains other reference types, assignment results in a copy of the references. In this way, you have two independent structures, each of which contains a reference pointing to the same object in memory (i.e., a shallow copy). When you want to perform a deep copy, where the state of internal references is fully copied into a new object, one approach is to implement the `ICloneable` interface (as you will do in Chapter 8).

## Passing Reference Types by Value

As covered earlier in the chapter, reference types or value types can be passed as parameters to methods. However, passing a reference type (e.g., a class) by reference is quite different from passing it by value. To understand the distinction, assume you have a simple `Person` class defined in a new Console Application project named `RefTypeValTypeParams`, defined as follows:

```
class Person
{
    public string personName;
    public int personAge;

    // Constructors.
    public Person(string name, int age)
    {
        personName = name;
        personAge = age;
    }
    public Person(){ }

    public void Display()
    {
        Console.WriteLine("Name: {0}, Age: {1}", personName, personAge);
    }
}
```

Now, what if you create a method that allows the caller to send in the `Person` object by value (note the lack of parameter modifiers, such as `out` or `ref`)?

```
static void SendAPersonByValue(Person p)
{
    // Change the age of "p"?
    p.personAge = 99;
```

```
// Will the caller see this reassignment?
p = new Person("Nikki", 99);
}
```

Notice how the `SendAPersonByValue()` method attempts to reassign the incoming `Person` reference to a new `Person` object, as well as change some state data. Now let's test this method using the following `Main()` method:

```
static void Main(string[] args)
{
    // Passing ref-types by value.
    Console.WriteLine("***** Passing Person object by value *****");
    Person fred = new Person("Fred", 12);
    Console.WriteLine("\nBefore by value call, Person is:");
    fred.Display();

    SendAPersonByValue(fred);
    Console.WriteLine("\nAfter by value call, Person is:");
    fred.Display();
    Console.ReadLine();
}
```

The following is the output of this call:

---

```
***** Passing Person object by value *****
```

```
Before by value call, Person is:
Name: Fred, Age: 12
```

```
After by value call, Person is:
Name: Fred, Age: 99
```

---

As you can see, the value of `personAge` has been modified. This behavior, discussed earlier, should make more sense now that the way reference types work. Given that you were able to change the state of the incoming `Person`, what was copied? The answer: a copy of the reference to the caller's object. Therefore, as the `SendAPersonByValue()` method is pointing to the same object as the caller, it is possible to alter the object's state data. What is not possible is to reassign what the reference *is pointing to*.

## Passing Reference Types by Reference

Now assume you have a `SendAPersonByReference()` method, which passes a reference type by reference (note the `ref` parameter modifier).

```
static void SendAPersonByReference(ref Person p)
{
    // Change some data of "p".
    p.personAge = 555;
```



```
// "p" is now pointing to a new object on the heap!
p = new Person("Nikki", 999);
}
```

As you might expect, this allows complete flexibility of how the callee is able to manipulate the incoming parameter. Not only can the callee change the state of the object, but if it so chooses, it may also reassign the reference to a new `Person` object. Now ponder the following updated `Main()` method:

```
static void Main(string[] args)
{
    // Passing ref-types by ref.
    Console.WriteLine("***** Passing Person object by reference *****");
    ...

    Person mel = new Person("Mel", 23);
    Console.WriteLine("Before by ref call, Person is:");
    mel.Display();

    SendAPersonByReference(ref mel);
    Console.WriteLine("After by ref call, Person is:");
    mel.Display();
    Console.ReadLine();
}
```

Notice the following output:

---

```
***** Passing Person object by reference *****
Before by ref call, Person is:
Name: Mel, Age: 23
After by ref call, Person is:
Name: Nikki, Age: 999
```

---

As you can see, an object named `Mel` returns after the call as an object named `Nikki`, as the method was able to change what the incoming reference pointed to in memory. The golden rule to keep in mind when passing reference types is the following:

- If a reference type is passed by reference, the callee may change the values of the object's state data, as well as the object it is referencing.
- If a reference type is passed by value, the callee may change the values of the object's state data but *not* the object it is referencing.

## Final Details Regarding Value Types and Reference Types

To wrap up this topic, consider the information in Table 4-3, which summarizes the core distinctions between value types and reference types.

**Table 4-3.** *Value Types and Reference Types Comparison*

Intriguing Question	Value Type	Reference Type
Where are objects allocated?	Allocated on the stack.	Allocated on the managed heap.
How is a variable represented?	Value type variables are local copies.	Reference type variables are pointing to the memory occupied by the allocated instance.
What is the base type?	Implicitly extends <code>System.ValueType</code> .	Can derive from any other type (except <code>System.ValueType</code> ), as long as that type is not “sealed” (more details on this in Chapter 6).
Can this type function as a base to other types?	No. Value types are always sealed and cannot be inherited from.	Yes. If the type is not sealed, it may function as a base to other types.
What is the default parameter-passing behavior?	Variables are passed by value (i.e., a copy of the variable is passed into the called function).	For reference types, the reference is copied by value.
Can this type override <code>System.Object.Finalize()</code> ?	No.	Yes, indirectly (more details on this in Chapter 9).
Can I define constructors for this type?	Yes, but the default constructor is reserved (i.e., your custom constructors must all have arguments).	But, of course!
When do variables of this type die?	When they fall out of the defining scope.	When the object is garbage collected (see Chapter 9).

Despite their differences, value types and reference types both have the ability to implement interfaces and may support any number of fields, methods, overloaded operators, constants, properties, and events.

## Understanding C# Nullable Types

Let’s examine the role of the *nullable data type* using a Console Application project named `NullableValueTypes` and change the solution name to `NullableTypes`. As you know, C# data types have a fixed range and are represented as a type in the `System` namespace. For example, the `System.Boolean` data type can be assigned a value from the set `{true, false}`. Now, recall that all the numerical data types (as well as the `Boolean` data type) are *value types*. Value types can never be assigned the value of `null`, as that is used to establish an empty object reference.

```
static void Main(string[] args)
{
    // Compiler errors!
    // Value types cannot be set to null!
    bool myBool = null;
    int myInt = null;
}
```

C# supports the concept of *nullable data types*. Simply put, a nullable type can represent all the values of its underlying type, plus the value null. Thus, if you declare a nullable bool, it could be assigned a value from the set {true, false, null}. This can be extremely helpful when working with relational databases, given that it is quite common to encounter undefined columns in database tables. Without the concept of a nullable data type, there is no convenient manner in C# to represent a numerical data point with no value.

To define a nullable variable type, the question mark symbol (?) is suffixed to the underlying data type. Prior to C# 8.0, this syntax was only legal when applied to value types (more on this in “Nullable Reference Types” section). Like a non-nullable variable, local nullable variables must be assigned an initial value before you can use them.

```
static void LocalNullableVariables()
{
    // Define some local nullable variables.
    int? nullableInt = 10;
    double? nullableDouble = 3.14;
    bool? nullableBool = null;
    char? nullableChar = 'a';
    int?[] arrayOfNullableInts = new int?[10];
}
```

## Nullable Value Types

In C#, the ? suffix notation is a shorthand for creating an instance of the generic System.Nullable<T> structure type. It is also used for creating nullable reference types (covered in the next section), although the behavior is a bit different. Although you will not examine generics until Chapter 10, it is important to understand that the System.Nullable<T> type provides a set of members that all nullable types can make use of.

For example, you are able to programmatically discover whether the nullable variable indeed has been assigned a null value using the HasValue property or the != operator. The assigned value of a nullable type may be obtained directly or via the Value property. In fact, given that the ? suffix is just a shorthand for using Nullable<T>, you could implement your LocalNullableVariables() method as follows:

```
static void LocalNullableVariablesUsingNullable()
{
    // Define some local nullable types using Nullable<T>.
    Nullable<int> nullableInt = 10;
    Nullable<double> nullableDouble = 3.14;
    Nullable<bool> nullableBool = null;
    Nullable<char> nullableChar = 'a';
    Nullable<int>[] arrayOfNullableInts = new Nullable<int>[10];
}
```

As stated, nullable data types can be particularly useful when you are interacting with databases, given that columns in a data table may be intentionally empty (e.g., undefined). To illustrate, assume the following class, which simulates the process of accessing a database that has a table containing two columns that may be null. Note that the GetIntFromDatabase() method is not assigning a value to the nullable integer member variable, while GetBoolFromDatabase() is assigning a valid value to the bool? member.

```
class DatabaseReader
{
    // Nullable data field.
    public int? numericValue = null;
    public bool? boolValue = true;
```

```

// Note the nullable return type.
public int? GetIntFromDatabase()
{ return numericValue; }

// Note the nullable return type.
public bool? GetBoolFromDatabase()
{ return boolValue; }
}

```

Now, assume the following `Main()` method, which invokes each member of the `DatabaseReader` class and discovers the assigned values using the `HasValue` and `Value` members, as well as using the C# equality operator (not equal, to be exact):

```

static void Main(string[] args)
{
    Console.WriteLine("***** Fun with Nullable Value Types *****\n");
    DatabaseReader dr = new DatabaseReader();

    // Get int from "database".
    int? i = dr.GetIntFromDatabase();
    if (i.HasValue)
    {
        Console.WriteLine("Value of 'i' is: {0}", i.Value);
    }
    else
    {
        Console.WriteLine("Value of 'i' is undefined.");
    }
    // Get bool from "database".
    bool? b = dr.GetBoolFromDatabase();
    if (b != null)
    {
        Console.WriteLine("Value of 'b' is: {0}", b.Value);
    }
    else
    {
        Console.WriteLine("Value of 'b' is undefined.");
    }
    Console.ReadLine();
}

```

## Nullable Reference Types (New 8.0)

A significant change in C# 8 is the support for nullable reference types. In fact, the change is so significant that the .NET Framework could not be updated to support this new feature. Hence, the decisions to only support C# 8 in .NET Core 3.0 and later and the decision that support for nullable reference types is an opt in. By default, when you create a new project in .NET Core 3.0/3.1, reference types work the same way that they did on C# 7. This is in order to prevent breaking billions of lines of code that exist in the pre-C# 8 ecosystem.

Nullable reference types follow many of the same rules as nullable value types. Non-nullable reference types must be assigned a non-null value at initialization and can't later be changed to a null value. Nullable reference types can be null, but still must be assigned something before first use (either an actual instance of something or the value of null).

Nullable reference types use the same symbol (?) to indicate that they are nullable. However, this is not a shorthand for using `System.Nullable<T>`, as only value types can be used in place of `T`. As a reminder, generics and constraints are covered in Chapter 10.

## Opting in for Nullable Reference Types

Support for nullable reference types is controlled by setting a Nullable Context. This can be as big as an entire project (by updating the project file) or as small as a few lines (by using compiler directives). There are also two contexts that can be set:

- **Nullable Annotation Context:** This enables/disables the nullable annotation (?) for nullable reference types.
- **Nullable Warning Context:** This enables/disables the compiler warnings for nullable reference types.

To see these in action, add a new console application named `NullableReferenceTypes` to your `NullableTypes` solution by right-clicking the solution name in Solution Explorer and selecting **Add ► New Project**. Open up the project file by double-clicking the project name in Solution Explorer (or by right-clicking the project name and selecting “Edit Project File”). Update the project file to support nullable reference types by adding the `<Nullable>` node (all of the available options are shown in Table 4-4).

```
<Project Sdk="Microsoft.NET.Sdk">
  <PropertyGroup>
    <OutputType>Exe</OutputType>
    <TargetFramework>netcoreapp3.1</TargetFramework>
    <Nullable>enable</Nullable>
  </PropertyGroup>
</Project>
```

**Table 4-4.** Values for Nullable in Project Files

Value	Meaning in Life
Enable	Nullable Annotations are enabled and Nullable Warnings are enabled.
Warnings	Nullable Annotations are disabled and Nullable Warnings are enabled.
Annotations	Nullable Annotations are enabled and Nullable Warnings are disabled.
Disable	Nullable Annotations are disabled and Nullable Warnings are disabled.

The `<Nullable>` element effects the entire project. To control smaller parts of the project, use the compiler directives shown in Table 4-5.

**Table 4-5.** Values for #nullable Compiler Directive

Value	Meaning in Life
Enable	Annotations are enabled and Warnings are enabled.
Disable	Annotations are disabled and Warnings are disabled.
Restore	Restores all settings to the project settings.
disable warnings	Warnings are disabled, Annotations unaffected.
enable warnings	Warnings are enabled, Annotations unaffected.
restore warnings	Warnings reset to project settings, Annotations unaffected.
disable annotations	Annotations are disabled, Warnings unaffected.
enable annotations	Annotations are enabled, Warnings unaffected.
restore annotations	Annotations reset to project settings, Warnings unaffected.

## Nullable Reference Types in Action

Largely because of the significance of the change, nullable types only throw errors when used improperly. Add the following class to the Program.cs file:

```
public class TestClass
{
    public string Name { get; set; }
    public int Age { get; set; }
}
```

As you can see, this is just a normal class. The nullability comes in when you use this class in your code. Take the following declarations:

```
string? nullableString = null;
TestClass? myNullableClass = null;
```

The project file setting makes the entire project a nullable context. The nullable context allows the declarations of the string and TestClass types to use the nullable annotation (?). The following line of code generates a warning (CS8600) due to the assignment of a null to a non-nullable type in a nullable context:

```
//Warning CS8600 Converting null literal or possible null value to non-nullable type
TestClass myNonNullableClass = myNullableClass;
```

For finer control of where the nullable contexts are in your project, you can use compiler directives (as discussed earlier) to enable or disable the context. The following code turns off the nullable context (set at the project level) and then re-enables it by restoring the project settings:

```
#nullable disable
TestClass anotherNullableClass = null;
//Warning CS8632 The annotation for nullable reference types should only be used in code
within a '#nullable' annotations
TestClass? badDefinition = null;
```

```
//Warning CS8632 The annotation for nullable reference types should only be used in code
within a '#nullable' annotations
string? anotherNullableString = null;
#nullable restore
```

To run the `NullableReferenceTypes` project, right-click the project in Solution Explorer, and select “Set as Startup Project”. This informs Visual Studio to start this project when you press F5 (or click the green run arrow).

As a final note, the nullable reference types do not have the `HasValue` and `Value` properties, as those are supplied by `System.Nullable<T>`.

## Migration Considerations

When migrating your code from C# 7 to C# 8 and you want to make use of nullable reference types, you can use a combination of the project setting and compiler directives to work through your code. A common practice is to start by enabling warnings and disabling nullable annotations for the entire project. Then, as you clean up areas of code, use the compiler directives to gradually enable the annotations.

## The Null-Coalescing Operator

The next aspect to be aware of is any variable that might have a null value can make use of the C# `??` operator, which is formally termed the *null-coalescing operator*. This operator allows you to assign a value to a nullable type if the retrieved value is in fact null. For this example, assume you want to assign a local nullable integer to 100 if the value returned from `GetIntFromDatabase()` is null (of course, this method is programmed to always return null, but I am sure you get the general idea). Move back to the `NullableValueTypes` project (and set it as the startup project), and enter the following code:

```
static void Main(string[] args)
{
    //omitted for brevity
    Console.WriteLine("***** Fun with Nullable Data *****\n");
    DatabaseReader dr = new DatabaseReader();
    ...
    // If the value from GetIntFromDatabase() is null,
    // assign local variable to 100.
    int myData = dr.GetIntFromDatabase() ?? 100;
    Console.WriteLine("Value of myData: {0}", myData);
    Console.ReadLine();
}
```

The benefit of using the `??` operator is that it provides a more compact version of a traditional `if/else` condition. However, if you want, you could have authored the following functionally equivalent code to ensure that if a value comes back as null, it will indeed be set to the value 100:

```
// Longhand notation not using ?? syntax.
int? moreData = dr.GetIntFromDatabase();
if (!moreData.HasValue)
{
    moreData = 100;
}
Console.WriteLine("Value of moreData: {0}", moreData);
```

## The Null-Coalescing Assignment Operator (New 8.0)

Building on the null-coalescing operator, C# 8 introduced the *null-coalescing assignment operator* (`??=`). This operator assigns the left-hand side to the right-hand side only if the left-hand side is null. For example, enter the following code:

```
//Null-coalescing assignment operator
int? nullableInt = null;
nullableInt ??= 12;
nullableInt ??= 14;
Console.WriteLine(nullableInt);
```

The nullableInt variable is initialized to null. The next line assigns the value of 12 to the variable since the left-hand side is indeed null. The next line does *not* assign 14 to the variable, since it isn't null.

## The Null Conditional Operator

When you are writing software, it is common to check incoming parameters, which are values returned from type members (methods, properties, indexers), against the value null. For example, let's assume you have a method that takes a string array as a single parameter. To be safe, you might want to test for null before proceeding. In that way, you will not get a runtime error if the array is empty. The following would be a traditional way to perform such a check:

```
static void TesterMethod(string[] args)
{
    // We should check for null before accessing the array data!
    if (args != null)
    {
        Console.WriteLine($"You sent me {args.Length} arguments.");
    }
}
```

Here, you use a conditional scope to ensure that the Length property of the string array will not be accessed if the array is null. If the caller failed to make an array of data and called your method like so, you are still safe and will not trigger a runtime error:

```
TesterMethod(null);
```

C#3 includes the null conditional operator token (a question mark placed after a variable type but before an access operator) to simplify the previous error checking. Rather than explicitly building a conditional statement to check for null, you can now write the following:

```
static void TesterMethod(string[] args)
{
    // We should check for null before accessing the array data!
    Console.WriteLine($"You sent me {args?.Length} arguments.");
}
```

In this case, you are not using a conditional statement. Rather, you are suffixing the `?` operator directly after the string array variable. If the variable is null, its call to the Length property will not throw a runtime error. If you want to print an actual value, you could leverage the null-coalescing operator to assign a default value as so:



```
Console.WriteLine($"You sent me {args?.Length ?? 0} arguments.");
```

There are some additional areas of coding where the C# 6.0 null conditional operator will be quite handy, especially when working with delegates and events. Those topics are addressed later in the book (see Chapter 12), and you will see many more examples.

## Tuples (New/Updated 7.0)

To wrap up this chapter, let's examine the role of tuples using a Console Application project named `FunWithTuples`. As mentioned earlier in this chapter, one way to use out parameters is to retrieve more than one value from a method call. Another way is to use a very light construct called a tuple.

Tuples are lightweight data structures that contain multiple fields. They were actually added to the language in C# 6, but in a very limited way. There was also a potentially significant problem with the C# 6 implementation: each field is implemented as a reference type, potentially creating memory and/or performance problems (from boxing/unboxing).

In C# 7, tuples use the new `ValueTuple` data type instead of reference types, potentially saving significant memory. The `ValueTuple` data type creates different structs based on the number of properties for a tuple. An additional feature added in C# 7 is that each property in a tuple can be assigned a specific name (just like variables), greatly enhancing the usability.

There are two important considerations for tuples:

- The fields are not validated.
- You cannot define your own methods.

They are really designed to just be a lightweight data transport mechanism.

## Getting Started with Tuples

Enough theory, let's write some code! To create a tuple, simply enclose the values to be assigned to the tuple in parentheses, as follows:

```
("a", 5, "c")
```

Notice that they don't all have to be the same data type. The parenthetical construct is also used to assign the tuple to a variable (or you can use the `var` keyword and the compiler will assign the data types for you). To assign the previous example to a variable, the following two lines achieve the same thing. The `values` variable will be a tuple with two string properties and an int property sandwiched in between.

```
(string, int, string) values = ("a", 5, "c");
var values = ("a", 5, "c");
```

By default, the compiler assigns each property the name `ItemX`, where `X` represents the one-based position in the tuple. For the previous example, the property names are `Item1`, `Item2`, and `Item3`. Accessing them is done as follows:

```
Console.WriteLine($"First item: {values.Item1}");
Console.WriteLine($"Second item: {values.Item2}");
Console.WriteLine($"Third item: {values.Item3}");
```

Specific names can also be added to each property in the tuple on either the right side or the left side of the statement. While it is not a compiler error to assign names on both sides of the statement, if you do, the right side will be ignored, and only the left-side names are used. The following two lines of code show setting the names on the left and the right and achieve the same end:

```
(string FirstLetter, int TheNumber, string SecondLetter) valuesWithNames = ("a", 5, "c");
var valuesWithNames2 = (FirstLetter: "a", TheNumber: 5, SecondLetter: "c");
```

Now the properties on the tuple can be accessed using the field names as well as the `ItemX` notation, as shown in the following code:

```
Console.WriteLine($"First item: {valuesWithNames.FirstLetter}");
Console.WriteLine($"Second item: {valuesWithNames.TheNumber}");
Console.WriteLine($"Third item: {valuesWithNames.SecondLetter}");
//Using the item notation still works!
Console.WriteLine($"First item: {valuesWithNames.Item1}");
Console.WriteLine($"Second item: {valuesWithNames.Item2}");
Console.WriteLine($"Third item: {valuesWithNames.Item3}");
```

Note that when setting the names on the right, you must use the keyword `var` to declare the variable. Setting the data types specifically (even without custom names) triggers the compiler to use the left side, assign the properties using the `ItemX` notation, and ignore any of the custom names set on the right. The following two examples ignore the `Custom1` and `Custom2` names:

```
(int, int) example = (Custom1:5, Custom2:7);
(int Field1, int Field2) example = (Custom1:5, Custom2:7);
```

It is also important to call out that the custom field names exist only at compile time and aren't available when inspecting the tuple at runtime using reflection (reflection is covered in [Chapter 17](#)).

Tuples can also be nested as tuples inside of tuples. Since each property in a tuple is a data type, and a tuple is a datatype, the following code is perfectly legitimate:

## Inferred Variable Names (Updated 7.1)

An update to tuples in C# 7.1 is the ability for C# to infer the variable names of tuples, as is shown here:

```
Console.WriteLine("=> Inferred Tuple Names");
var foo = new {Prop1 = "first", Prop2 = "second"};
var bar = (foo.Prop1, foo.Prop2);
Console.WriteLine($"{{bar.Prop1}};{{bar.Prop2}}");
```

## Tuple Equality/Inequality (New 7.3)

An added feature in C# 7.1 is the tuple equality (`==`) and inequality (`!=`). When testing for inequality, the comparison operators will perform implicit conversions on datatypes within the tuples, including comparing nullable and non-nullable tuples and/or properties. That means the following tests work perfectly, despite the difference between `int/long`:

```

Console.WriteLine("=> Tuples Equality/Inequality");
// lifted conversions
var left = (a: 5, b: 10);
(int? a, int? b) nullableMembers = (5, 10);
Console.WriteLine(left == nullableMembers); // Also true
// converted type of left is (long, long)
(long a, long b) longTuple = (5, 10);
Console.WriteLine(left == longTuple); // Also true
// comparisons performed on (long, long) tuples
(long a, int b) longFirst = (5, 10);
(int a, long b) longSecond = (5, 10);
Console.WriteLine(longFirst == longSecond); // Also true

```

Tuples that contain tuples can also be compared, but only if they have the same shape. You can't compare one tuple of three int properties with another tuple of two ints and a tuple.

## Tuples As Method Return Values

Earlier in this chapter, out parameters were used to return more than one value from a method call. There are additional ways to do this, such as creating a class or structure specifically to return the values. But if this class or struct is only to be used as a data transport for one method, that is extra work and extra code that doesn't need to be developed. Tuples are perfectly suited for this task, are lightweight, and are easy to declare and use.

This is one of the examples from the out parameter section. It returns three values but requires three parameters passed in as transport mechanisms for the calling code.

```

static void FillTheseValues(out int a, out string b, out bool c)
{
    a = 9;
    b = "Enjoy your string.";
    c = true;
}

```

By using a tuple, you can remove the parameters and still get the three values back.

```

static (int a,string b,bool c) FillTheseValues()
{
    return (9,"Enjoy your string.",true);
}

```

Calling this method is as simple as calling any other method.

```

var samples = FillTheseValues();
Console.WriteLine($"Int is: {samples.a}");
Console.WriteLine($"String is: {samples.b}");
Console.WriteLine($"Boolean is: {samples.c}");

```

Perhaps a better example is deconstructing a full name into its individual parts (first, middle, last). The following code takes in a full name and returns a tuple with the different parts:

```
static (string first, string middle, string last) SplitNames(string fullName)
{
    //do what is needed to split the name apart
    return ("Philip", "F", "Japikse");
}
```

## Discards with Tuples

Following up on the `SplitNames()` example, suppose you know that you need only the first and last names and don't care about the first. By providing variable names for the values you want returned and filling in the unneeded values with an underscore (`_`) placeholder, you can refine the return value like this:

```
var (first, _, last) = SplitNames("Philip F Japikse");
Console.WriteLine($"{first}:{last}");
```

The middle name value of the tuple is discarded.

## Tuple Pattern Matching Switch Expressions (New 8.0)

Now that you have a thorough understanding of tuples, it's time to revisit the switch expression with Tuples from Chapter 3. Here is the example again:

```
//Switch expression with Tuples
static string RockPaperScissors(string first, string second)
{
    return (first, second) switch
    {
        ("rock", "paper") => "Paper wins.",
        ("rock", "scissors") => "Rock wins.",
        ("paper", "rock") => "Paper wins.",
        ("paper", "scissors") => "Scissors wins.",
        ("scissors", "rock") => "Rock wins.",
        ("scissors", "paper") => "Scissors wins.",
        (_, _) => "Tie.",
    };
}
```

In this example, the two parameters are converted into a tuple as they are passed into the switch expression. The relevant values are represented in the switch expression, and any other cases are handled by the final tuple, which is composed of two discards.

The `RockPaperScissors` method signature could also be written to take in a tuple, like this:

```
static string RockPaperScissors2(
    (string first, string second) value)
{
    return value switch
    {

```

```

    //omitted for brevity
};
}

```

## Deconstructing Tuples

*Deconstructing* is the term given when separating out the properties of a tuple to be used individually. `FillTheseValues` did just that. But there is another use for this pattern that can be helpful, and that is deconstructing custom types.

Take a shorter version of the `Point` structure used earlier in this chapter. A new method named `Deconstruct()` has been added to return the individual properties of the `Point` instance as a tuple with properties named `XPos` and `YPos`.

```

struct Point
{
    // Fields of the structure.
    public int X;
    public int Y;

    // A custom constructor.
    public Point(int XPos, int YPos)
    {
        X = XPos;
        Y = YPos;
    }

    public (int XPos, int YPos) Deconstruct() => (X, Y);
}

```

Notice the new `Deconstruct()` method, shown in bold in the previous code listing. This method can be named anything, but by convention it is typically named `Deconstruct()`. This allows a single method call to get the individual values of the structure by returning a tuple.

```

Point p = new Point(7,5);
var pointValues = p.Deconstruct();
Console.WriteLine($"X is: {pointValues.XPos}");
Console.WriteLine($"Y is: {pointValues.YPos}");

```

## Deconstructing Tuples with Positional Pattern Matching (New 8.0)

When tuples have an accessible `Deconstruct` method, the deconstruction can be used in a tuple-based switch expression. Using the `Point` example, the following code uses the generated tuple and uses those values for the `when` clause of each expression:

```

static string GetQuadrant1(Point p)
{
    return p.Deconstruct() switch
    {
        (0, 0) => "Origin",
        var (x, y) when x > 0 && y > 0 => "One",
    }
}

```

```

    var (x, y) when x < 0 && y > 0 => "Two",
    var (x, y) when x < 0 && y < 0 => "Three",
    var (x, y) when x > 0 && y < 0 => "Four",
    var (_, _) => "Border",
};
}

```

If the Deconstruct method is defined with two out parameters, then the switch expression will automatically deconstruct the point. Add another Deconstruct method to the Point as follows:

```

public void Deconstruct(out int XPos, out int YPos)
    => (XPos, YPos)=(X, Y);

```

Now you can update (or add a new) GetQuadrant method to this:

```

static string GetQuadrant2(Point p)
{
    return p switch
    {
        (0, 0) => "Origin",
        var (x, y) when x > 0 && y > 0 => "One",
        var (x, y) when x < 0 && y > 0 => "Two",
        var (x, y) when x < 0 && y < 0 => "Three",
        var (x, y) when x > 0 && y < 0 => "Four",
        var (_, _) => "Border",
    };
}

```

The change is very subtle (and is highlighted in bold). Instead of calling p.Deconstruct, just the Point variable is used in the switch expression.

## Summary

This chapter began with an examination arrays. Then, we discussed the C# keywords that allow you to build custom methods. Recall that by default parameters are passed by value; however, you may pass a parameter by reference if you mark it with ref or out. You also learned about the role of optional or named parameters and how to define and invoke methods taking parameter arrays.

After you investigated the topic of method overloading, the bulk of this chapter examined several details regarding how enumerations and structures are defined in C# and represented within the .NET Core base class libraries. Along the way, you examined several details regarding value types and reference types, including how they respond when passing them as parameters to methods and how to interact with nullable data types and variables that might be null (e.g., reference type variables and nullable value type variables) using the ?, ??, ??= operators.

The final section of the chapter looked into a long-anticipated feature in C#, tuples. After getting an understanding of what they are and how they work, you used them to return multiple values from methods as well as to deconstruct custom types.

In Chapter 5, you will begin to dig into the details of object-oriented development.

**PART III**



# **Object-Oriented Programming with C#**

## CHAPTER 5



# Understanding Encapsulation

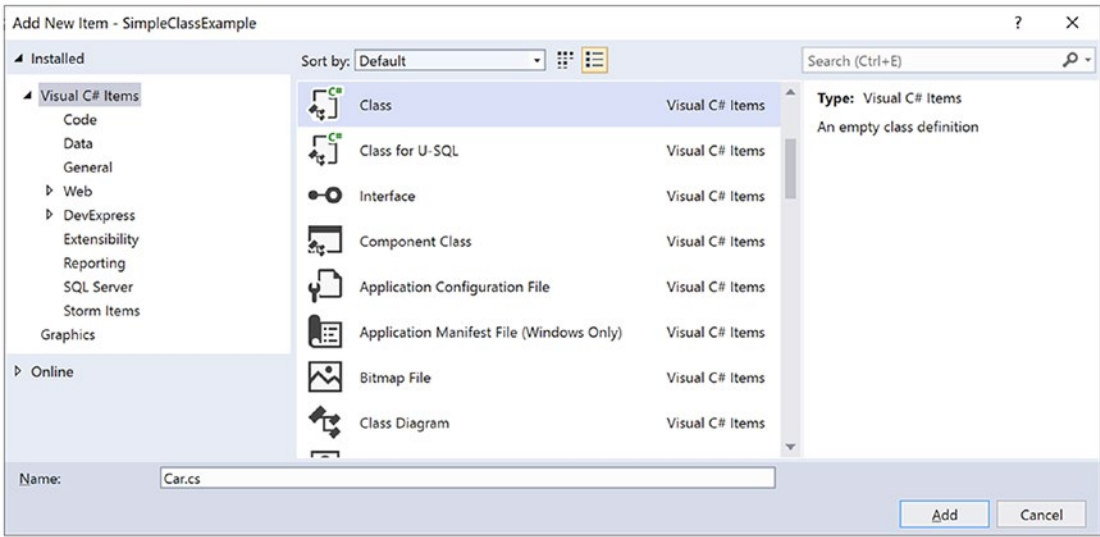
In Chapters 3 and 4, you investigated a number of core syntactical constructs that are commonplace to any .NET Core application you might be developing. Here, you will begin your examination of the object-oriented capabilities of C#. The first order of business is to examine the process of building well-defined class types that support any number of *constructors*. After you understand the basics of defining classes and allocating objects, the remainder of this chapter will examine the role of *encapsulation*. Along the way, you will learn how to define class properties and come to understand the details of the `static` keyword, object initialization syntax, read-only fields, constant data, and partial classes.

## Introducing the C# Class Type

As far as the .NET platform is concerned, the most fundamental programming construct is the *class type*. Formally, a class is a user-defined type that is composed of field data (often called *member variables*) and members that operate on this data (such as constructors, properties, methods, events, etc.). Collectively, the set of field data represents the “state” of a class instance (otherwise known as an *object*). The power of object-oriented languages, such as C#, is that by grouping data and related functionality in a unified class definition, you are able to model your software after entities in the real world.

To get the ball rolling, create a new C# Console Application project named `SimpleClassExample`. Next, insert a new class file (named `Car.cs`) into your project using the Project ► Add Class menu selection. Choose the Class icon from the resulting dialog box, as shown in Figure 5-1, and click the Add button.





**Figure 5-1.** Inserting a new C# class type

A class is defined in C# using the `class` keyword. Here is the simplest possible declaration:

```
class Car
{
}
```

After you have defined a class type, you will need to consider the set of member variables that will be used to represent its state. For example, you might decide that cars maintain an `int` data type to represent the current speed and a `string` data type to represent the car's friendly pet name. Given these initial design notes, update your `Car` class as follows:

```
class Car
{
    // The 'state' of the Car.
    public string petName;
    public int currSpeed;
}
```

Notice that these member variables are declared using the `public` access modifier. Public members of a class are directly accessible once an object of this type has been created. Recall the term *object* is used to describe an instance of a given class type created using the `new` keyword.

---

■ **Note** Field data of a class should seldom (if ever) be defined as public. To preserve the integrity of your state data, it is a far better design to define data as private (or possibly protected) and allow controlled access to the data via properties (as shown later in this chapter). However, to keep this first example as simple as possible, public data fits the bill.

---

After you have defined the set of member variables representing the state of the class, the next design step is to establish the members that model its behavior. For this example, the `Car` class will define one method named `SpeedUp()` and another named `PrintState()`. Update your class as so:

```
class Car
{
    // The 'state' of the Car.
    public string petName;
    public int currSpeed;

    // The functionality of the Car.
    // Using the expression-bodied member syntax
    public void PrintState()
        => Console.WriteLine("{0} is going {1} MPH.", petName, currSpeed);

    public void SpeedUp(int delta)
        => currSpeed += delta;
}
```

`PrintState()` is more or less a diagnostic function that will simply dump the current state of a given `Car` object to the command window. `SpeedUp()` will increase the speed of the `Car` object by the amount specified by the incoming `int` parameter. Now, update your `Main()` method in the `Program` class with the following code:

```
static void Main(string[] args)
{
    Console.WriteLine("***** Fun with Class Types *****\n");

    // Allocate and configure a Car object.
    Car myCar = new Car();
    myCar.petName = "Henry";
    myCar.currSpeed = 10;

    // Speed up the car a few times and print out the
    // new state.
    for (int i = 0; i <= 10; i++)
    {
        myCar.SpeedUp(5);
        myCar.PrintState();
    }
    Console.ReadLine();
}
```

After you run your program, you will see that the `Car` variable (`myCar`) maintains its current state throughout the life of the application, as shown in the following output:

---

```
***** Fun with Class Types *****
Henry is going 15 MPH.
Henry is going 20 MPH.
Henry is going 25 MPH.
Henry is going 30 MPH.
```

```

Henry is going 35 MPH.
Henry is going 40 MPH.
Henry is going 45 MPH.
Henry is going 50 MPH.
Henry is going 55 MPH.
Henry is going 60 MPH.
Henry is going 65 MPH.

```

---

## Allocating Objects with the new Keyword

As shown in the previous code example, objects must be allocated into memory using the new keyword. If you do not use the new keyword and attempt to use your class variable in a subsequent code statement, you will receive a compiler error. For example, the following Main() method will not compile:

```

static void Main(string[] args)
{
    Console.WriteLine("***** Fun with Class Types *****\n");

    // Compiler error! Forgot to use 'new' to create object!
    Car myCar;
    myCar.petName = "Fred";
}

```

To correctly create an object using the new keyword, you may define and allocate a Car object on a single line of code.

```

static void Main(string[] args)
{
    Console.WriteLine("***** Fun with Class Types *****\n");
    Car myCar = new Car();
    myCar.petName = "Fred";
}

```

As an alternative, if you want to define and allocate a class instance on separate lines of code, you may do so as follows:

```

static void Main(string[] args)
{
    Console.WriteLine("***** Fun with Class Types *****\n");
    Car myCar;
    myCar = new Car();
    myCar.petName = "Fred";
}

```

Here, the first code statement simply declares a reference to a yet-to-be-determined Car object. It is not until you assign a reference to an object that this reference points to a valid object in memory.

In any case, at this point you have a trivial class that defines a few points of data and some basic operations. To enhance the functionality of the current Car class, you need to understand the role of *constructors*.

## Understanding Constructors

Given that objects have state (represented by the values of an object's member variables), a programmer will typically want to assign relevant values to the object's field data before use. Currently, the `Car` class demands that the `petName` and `currSpeed` fields be assigned on a field-by-field basis. For the current example, this is not too problematic, given that you have only two public data points. However, it is not uncommon for a class to have dozens of fields to contend with. Clearly, it would be undesirable to author 20 initialization statements to set 20 points of data!

Thankfully, C# supports the use of *constructors*, which allow the state of an object to be established at the time of creation. A constructor is a special method of a class that is called indirectly when creating an object using the `new` keyword. However, unlike a “normal” method, constructors never have a return value (not even `void`) and are always named identically to the class they are constructing.

### The Role of the Default Constructor

Every C# class is provided with a “freebie” *default constructor* that you can redefine if need be. By definition, a default constructor never takes arguments. After allocating the new object into memory, the default constructor ensures that all field data of the class is set to an appropriate default value (see Chapter 3 for information regarding the default values of C# data types).

If you are not satisfied with these default assignments, you may redefine the default constructor to suit your needs. To illustrate, update your C# `Car` class as follows:

```
class Car
{
    // The 'state' of the Car.
    public string petName;
    public int currSpeed;

    // A custom default constructor.
    public Car()
    {
        petName = "Chuck";
        currSpeed = 10;
    }
    ...
}
```

In this case, you are forcing all `Car` objects to begin life named Chuck at a rate of 10 MPH. With this, you are able to create a `Car` object set to these default values as follows:

```
static void Main(string[] args)
{
    Console.WriteLine("***** Fun with Class Types *****\n");

    // Invoking the default constructor.
    Car chuck = new Car();

    // Prints "Chuck is going 10 MPH."
    chuck.PrintState();
    ...
}
```

## Defining Custom Constructors

Typically, classes define additional constructors beyond the default. In doing so, you provide the object user with a simple and consistent way to initialize the state of an object directly at the time of creation. Ponder the following update to the `Car` class, which now supports a total of three constructors:

```
class Car
{
    // The 'state' of the Car.
    public string petName;
    public int currSpeed;

    // A custom default constructor.
    public Car()
    {
        petName = "Chuck";
        currSpeed = 10;
    }

    // Here, currSpeed will receive the
    // default value of an int (zero).
    public Car(string pn)
    {
        petName = pn;
    }

    // Let caller set the full state of the Car.
    public Car(string pn, int cs)
    {
        petName = pn;
        currSpeed = cs;
    }
    ...
}
```

Keep in mind that what makes one constructor different from another (in the eyes of the C# compiler) is the number of and/or type of constructor arguments. Recall from Chapter 4, when you define a method of the same name that differs by the number or type of arguments, you have *overloaded* the method. Thus, the `Car` class has overloaded the constructor to provide a number of ways to create an object at the time of declaration. In any case, you are now able to create `Car` objects using any of the public constructors. Here's an example:

```
static void Main(string[] args)
{
    Console.WriteLine("***** Fun with Class Types *****\n");

    // Make a Car called Chuck going 10 MPH.
    Car chuck = new Car();
    chuck.PrintState();
}
```

```
// Make a Car called Mary going 0 MPH.
Car mary = new Car("Mary");
mary.PrintState();

// Make a Car called Daisy going 75 MPH.
Car daisy = new Car("Daisy", 75);
daisy.PrintState();

...
}
```

## Constructors As Expression-Bodied Members (New 7.0)

C# 7 added additional uses for the expression-bodied member style. Constructors, finalizers, and get/set accessors on properties and indexers now accept the new syntax. With this in mind, the previous constructors can be written like this:

```
// Here, currSpeed will receive the
// default value of an int (zero).
public Car(string pn) => petName = pn;
```

The second custom constructor cannot be converted to an expression, since expression-bodied members must be one-line methods.

## Constructors with out Parameters (New 7.3)

Constructors (as well as field and property initializers, covered later) can use out parameters starting with C# 7.3. For a trivial example of this, add the following constructor to the Car class:

```
public Car(string pn, int cs, out bool inDanger)
{
    petName = pn;
    currSpeed = cs;
    if (cs > 100)
    {
        inDanger = true;
    }
    else
    {
        inDanger = false;
    }
}
```

All of the rules of out parameters must be followed. In this example, the inDanger parameter must be assigned a value before the conclusion of the constructor.

## The Default Constructor Revisited

As you have just learned, all classes are provided with a free default constructor. Insert a new class into your current project named `Motorcycle`, defined like so:

```
class Motorcycle
{
    public void PopAWheelly()
    {
        Console.WriteLine("Yeeeeeee Haaaaaeewww!");
    }
}
```

Now you are able to create an instance of the `Motorcycle` type via the default constructor out of the box.

```
static void Main(string[] args)
{
    Console.WriteLine("***** Fun with Class Types *****\n");
    Motorcycle mc = new Motorcycle();
    mc.PopAWheelly();
    ...
}
```

However, as soon as you define a custom constructor with any number of parameters, the default constructor is silently removed from the class and is no longer available. Think of it this way: if you do not define a custom constructor, the C# compiler grants you a default in order to allow the object user to allocate an instance of your type with field data set to the correct default values. However, when you define a unique constructor, the compiler assumes you have taken matters into your own hands.

Therefore, if you want to allow the object user to create an instance of your type with the default constructor, as well as your custom constructor, you must *explicitly* redefine the default. To this end, understand that in a vast majority of cases, the implementation of the default constructor of a class is intentionally empty, as all you require is the ability to create an object with default values. Consider the following update to the `Motorcycle` class:

```
class Motorcycle
{
    public int driverIntensity;

    public void PopAWheelly()
    {
        for (int i = 0; i <= driverIntensity; i++)
        {
            Console.WriteLine("Yeeeeeee Haaaaaeewww!");
        }
    }

    // Put back the default constructor, which will
    // set all data members to default values.
    public Motorcycle() {}
}
```

```
// Our custom constructor.
public Motorcycle(int intensity)
{
    driverIntensity = intensity;
}
}
```

---

■ **Note** Now that you better understand the role of class constructors, here is a nice shortcut. The Visual Studio IDE provides the `ctor` code snippet. When you type **ctor** and press the Tab key twice, the IDE will automatically define a custom default constructor. You can then add custom parameters and implementation logic. Give it a try.

---

## The Role of the `this` Keyword

C# supplies a `this` keyword that provides access to the current class instance. One possible use of the `this` keyword is to resolve scope ambiguity, which can arise when an incoming parameter is named identically to a data field of the class. Of course, you could simply adopt a naming convention that does not result in such ambiguity, however; to illustrate this use of the `this` keyword, update your `Motorcycle` class with a new string field (named `name`) to represent the driver's name. Next, add a method named `SetDriverName()` implemented as follows:

```
class Motorcycle
{
    public int driverIntensity;

    // New members to represent the name of the driver.
    public string name;
    public void SetDriverName(string name) => name = name;
    ...
}
```

Although this code will compile just fine, Visual Studio will display a warning message informing you that you have assigned a variable back to itself! To illustrate, update `Main()` to call `SetDriverName()` and then print out the value of the `name` field. You might be surprised to find that the value of the `name` field is an empty string!

```
// Make a Motorcycle with a rider named Tiny?
Motorcycle c = new Motorcycle(5);
c.SetDriverName("Tiny");
c.PopAWheelie();
Console.WriteLine("Rider name is {0}", c.name); // Prints an empty name value!
```

The problem is that the implementation of `SetDriverName()` is assigning the incoming parameter *back to itself* given that the compiler assumes `name` is referring to the variable currently in the method scope rather than the `name` field at the class scope. To inform the compiler that you want to set the current object's `name` data field to the incoming `name` parameter, simply use `this` to resolve the ambiguity.

```
public void SetDriverName(string name) => this.name = name;
```

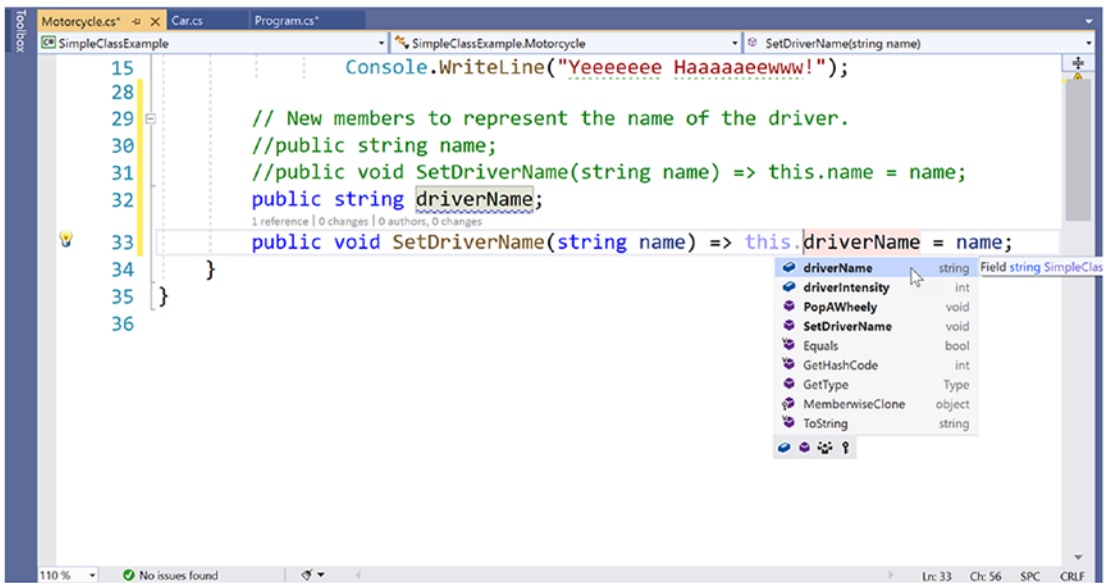


Do understand that if there is no ambiguity, you are not required to make use of the `this` keyword when a class wants to access its own data fields or members, as `this` is implied. For example, if you rename the string data member from `name` to `driverName` (which will also require you to update your `Main()` method), the use of `this` is optional as there is no longer a scope ambiguity.

```
class Motorcycle
{
    public int driverIntensity;
    public string driverName;

    public void SetDriverName(string name)
    {
        // These two statements are functionally the same.
        driverName = name;
        this.driverName = name;
    }
    ...
}
```

Even though there is little to be gained when using `this` in unambiguous situations, you might still find this keyword useful when implementing class members, as IDEs such as Visual Studio will enable IntelliSense when `this` is specified. This can be helpful when you have forgotten the name of a class member and want to quickly recall the definition, as shown in Figure 5-2.



**Figure 5-2.** The IntelliSense of `this`

---

■ **Note** A common naming convention is to start private (or internal) class-level variable names with an underscore (e.g., `_driverName`) so IntelliSense shows all of your variables at the top of the list. In our trivial example, all of the fields are public, so this naming convention wouldn't apply. Through the rest of the book you will see private and internal variables named with a leading underscore.

---

## Chaining Constructor Calls Using `this`

Another use of the `this` keyword is to design a class using a technique termed *constructor chaining*. This design pattern is helpful when you have a class that defines multiple constructors. Given that constructors often validate the incoming arguments to enforce various business rules, it can be quite common to find redundant validation logic within a class's constructor set. Consider the following updated `Motorcycle`:

```
class Motorcycle
{
    public int driverIntensity;
    public string driverName;

    public Motorcycle() { }

    // Redundant constructor logic!
    public Motorcycle(int intensity)
    {
        if (intensity > 10)
        {
            intensity = 10;
        }
        driverIntensity = intensity;
    }

    public Motorcycle(int intensity, string name)
    {
        if (intensity > 10)
        {
            intensity = 10;
        }
        driverIntensity = intensity;
        driverName = name;
    }
    ...
}
```

Here (perhaps in an attempt to ensure the safety of the rider) each constructor is ensuring that the intensity level is never greater than 10. While this is all well and good, you do have redundant code statements in two constructors. This is less than ideal, as you are now required to update code in multiple locations if your rules change (e.g., if the intensity should not be greater than 5 rather than 10).

One way to improve the current situation is to define a method in the `Motorcycle` class that will validate the incoming argument(s). If you were to do so, each constructor could make a call to this method before making the field assignment(s). While this approach does allow you to isolate the code you need to update when the business rules change, you are now dealing with the following redundancy:

```
class Motorcycle
{
    public int driverIntensity;
    public string driverName;

    // Constructors.
    public Motorcycle() { }

    public Motorcycle(int intensity)
    {
        SetIntensity(intensity);
    }

    public Motorcycle(int intensity, string name)
    {
        SetIntensity(intensity);
        driverName = name;
    }

    public void SetIntensity(int intensity)
    {
        if (intensity > 10)
        {
            intensity = 10;
        }
        driverIntensity = intensity;
    }
    ...
}
```

A cleaner approach is to designate the constructor that takes the *greatest number of arguments* as the “master constructor” and have its implementation perform the required validation logic. The remaining constructors can make use of the `this` keyword to forward the incoming arguments to the master constructor and provide any additional parameters as necessary. In this way, you need to worry only about maintaining a single constructor for the entire class, while the remaining constructors are basically empty.

Here is the final iteration of the `Motorcycle` class (with one additional constructor for the sake of illustration). When chaining constructors, note how the `this` keyword is “dangling” off the constructor’s declaration (via a colon operator) outside the scope of the constructor itself.

```
class Motorcycle
{
    public int driverIntensity;
    public string driverName;
```

```

// Constructor chaining.
public Motorcycle() {}
public Motorcycle(int intensity)
    : this(intensity, "") {}
public Motorcycle(string name)
    : this(0, name) {}

// This is the 'master' constructor that does all the real work.
public Motorcycle(int intensity, string name)
{
    if (intensity > 10)
    {
        intensity = 10;
    }
    driverIntensity = intensity;
    driverName = name;
}
...
}

```

Understand that using the `this` keyword to chain constructor calls is never mandatory. However, when you make use of this technique, you do tend to end up with a more maintainable and concise class definition. Again, using this technique, you can simplify your programming tasks, as the real work is delegated to a single constructor (typically the constructor that has the most parameters), while the other constructors simply “pass the buck.”

---

■ **Note** Recall from Chapter 4 that C# supports optional parameters. If you use optional parameters in your class constructors, you can achieve the same benefits as constructor chaining with less code. You will see how to do so in just a moment.

---

## Observing Constructor Flow

On a final note, do know that once a constructor passes arguments to the designated master constructor (and that constructor has processed the data), the constructor invoked originally by the caller will finish executing any remaining code statements. To clarify, update each of the constructors of the `Motorcycle` class with a fitting call to `Console.WriteLine()`.

```

class Motorcycle
{
    public int driverIntensity;
    public string driverName;

    // Constructor chaining.
    public Motorcycle()
    {
        Console.WriteLine("In default ctor");
    }
}

```

```

public Motorcycle(int intensity)
    : this(intensity, "")
{
    Console.WriteLine("In ctor taking an int");
}

public Motorcycle(string name)
    : this(0, name)
{
    Console.WriteLine("In ctor taking a string");
}

// This is the 'master' constructor that does all the real work.
public Motorcycle(int intensity, string name)
{
    Console.WriteLine("In master ctor ");
    if (intensity > 10)
    {
        intensity = 10;
    }
    driverIntensity = intensity;
    driverName = name;
}
...
}

```

Now, ensure your `Main()` method exercises a `Motorcycle` object as follows:

```

static void Main(string[] args)
{
    Console.WriteLine("***** Fun with class Types *****\n");

    // Make a Motorcycle.
    Motorcycle c = new Motorcycle(5);
    c.SetDriverName("Tiny");
    c.PopAWheely();
    Console.WriteLine("Rider name is {0}", c.driverName);
    Console.ReadLine();
}

```

With this, ponder the output from the previous `Main()` method.

---

```

***** Fun with Motorcycles *****

```

```

In master ctor
In ctor taking an int
Yeaaaaa Haaaaaeeww!
Yeaaaaa Haaaaaeeww!
Yeaaaaa Haaaaaeeww!

```

```

Yeeeeeee Haaaaaeewww!
Yeeeeeee Haaaaaeewww!
Yeeeeeee Haaaaaeewww!
Rider name is Tiny

```

---

As you can see, the flow of constructor logic is as follows:

- You create your object by invoking the constructor requiring a single `int`.
- This constructor forwards the supplied data to the master constructor and provides any additional startup arguments not specified by the caller.
- The master constructor assigns the incoming data to the object's field data.
- Control is returned to the constructor originally called and executes any remaining code statements.

The nice thing about using constructor chaining is that this programming pattern will work with any version of the C# language and .NET platform. However, if you are targeting .NET 4.0 and higher, you can further simplify your programming tasks by making use of optional arguments as an alternative to traditional constructor chaining.

## Revisiting Optional Arguments

In Chapter 4, you learned about optional and named arguments. Recall that optional arguments allow you to define supplied default values to incoming arguments. If the caller is happy with these defaults, they are not required to specify a unique value; however, they may do so to provide the object with custom data. Consider the following version of `Motorcycle`, which now provides a number of ways to construct objects using a *single* constructor definition:

```

class Motorcycle
{
    // Single constructor using optional args.
    public Motorcycle(int intensity = 0, string name = "")
    {
        if (intensity > 10)
        {
            intensity = 10;
        }
        driverIntensity = intensity;
        driverName = name;
    }
    ...
}

```

With this one constructor, you are now able to create a new `Motorcycle` object using zero, one, or two arguments. Recall that named argument syntax allows you to essentially skip over acceptable default settings (see Chapter 3).

```
static void MakeSomeBikes()
{
    // driverName = "", driverIntensity = 0
    Motorcycle m1 = new Motorcycle();
    Console.WriteLine("Name= {0}, Intensity= {1}",
        m1.driverName, m1.driverIntensity);

    // driverName = "Tiny", driverIntensity = 0
    Motorcycle m2 = new Motorcycle(name:"Tiny");
    Console.WriteLine("Name= {0}, Intensity= {1}",
        m2.driverName, m2.driverIntensity);

    // driverName = "", driverIntensity = 7
    Motorcycle m3 = new Motorcycle(7);
    Console.WriteLine("Name= {0}, Intensity= {1}",
        m3.driverName, m3.driverIntensity);
}
```

In any case, at this point you are able to define a class with field data (aka member variables) and various operations such as methods and constructors. Next up, let's formalize the role of the `static` keyword.

## Understanding the static Keyword

A C# class may define any number of *static members*, which are declared using the `static` keyword. When you do so, the member in question must be invoked directly from the class level, rather than from an object reference variable. To illustrate the distinction, consider your good friend `System.Console`. As you have seen, you do not invoke the `WriteLine()` method from the object level, as shown here:

```
// Compiler error! WriteLine() is not an object level method!
Console c = new Console();
c.WriteLine("I can't be printed...");
```

Instead, simply prefix the class name to the static `WriteLine()` member.

```
// Correct! WriteLine() is a static method.
Console.WriteLine("Much better! Thanks...");
```

Simply put, static members are items that are deemed (by the class designer) to be so commonplace that there is no need to create an instance of the class before invoking the member. While any class can define static members, they are quite commonly found within *utility classes*. By definition, a utility class is a class that does not maintain any object-level state and is not created with the `new` keyword. Rather, a utility class exposes all functionality as class-level (aka static) members.

For example, if you were to use the Visual Studio Object Browser (via the View ► Object Browser menu item) to view the `System` namespace, you would see that all the members of the `Console`, `Math`, `Environment`, and `GC` classes (among others) expose all their functionality via static members. These are but a few utility classes found within the .NET Core base class libraries.

Again, be aware that static members are not only found in utility classes; they can be part of any class definition at all. Just remember that static members promote a given item to the class level rather than the object level. As you will see over the next few sections, the `static` keyword can be applied to the following:

- Data of a class
- Methods of a class
- Properties of a class
- A constructor
- The entire class definition
- In conjunction with the C# `using` keyword

Let's see each of our options, beginning with the concept of static data.

---

■ **Note** You will examine the role of static properties later in this chapter while examining the properties themselves.

---

## Defining Static Field Data

Most of the time when designing a class, you define data as instance-level data or, said another way, as nonstatic data. When you define instance-level data, you know that every time you create a new object, the object maintains its own independent copy of the data. In contrast, when you define *static* data of a class, the memory is shared by all objects of that category.

To see the distinction, create a new Console Application project named `StaticDataAndMembers`. Now, insert a new class into your project named `SavingsAccount`. Begin by defining an instance-level variable (to model the current balance) and a custom constructor to set the initial balance.

```
// A simple savings account class.
class SavingsAccount
{
    // Instance-level data.
    public double currBalance;
    public SavingsAccount(double balance)
    {
        currBalance = balance;
    }
}
```

When you create `SavingsAccount` objects, memory for the `currBalance` field is allocated for each object. Thus, you could create five different `SavingsAccount` objects, each with their own unique balance. Furthermore, if you change the balance on one account, the other objects are not affected.

Static data, on the other hand, is allocated once and shared among all objects of the same class category. Add a static variable named `currInterestRate` to the `SavingsAccount` class, which is set to a default value of 0.04.

```
// A simple savings account class.
class SavingsAccount
{
    // Instance-level data.
    public double currBalance;

    // A static point of data.
    public static double currInterestRate = 0.04;
```



```

public SavingsAccount(double balance)
{
    currBalance = balance;
}
}

```

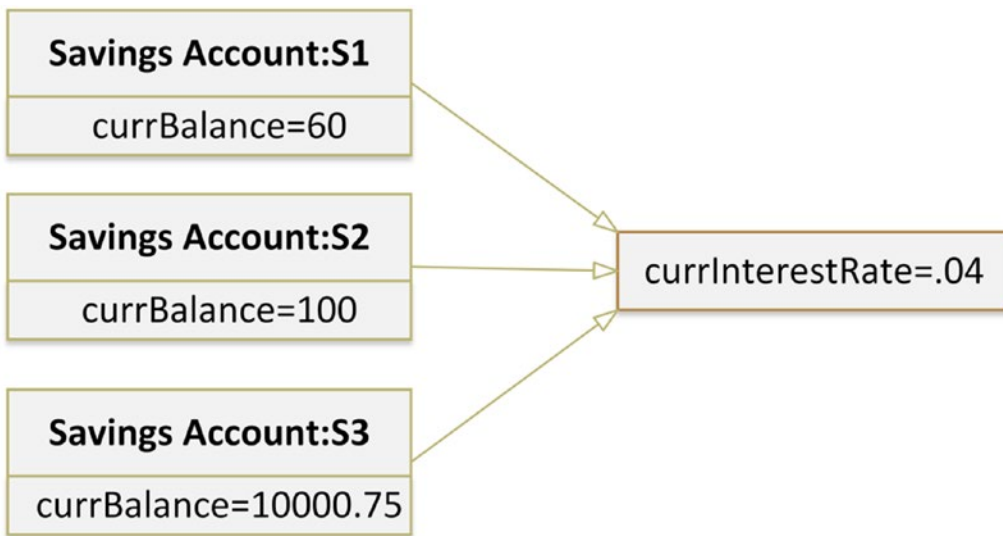
Create three instances of `SavingsAccount` in `Main()` as follows:

```

static void Main(string[] args)
{
    Console.WriteLine("***** Fun with Static Data *****\n");
    SavingsAccount s1 = new SavingsAccount(50);
    SavingsAccount s2 = new SavingsAccount(100);
    SavingsAccount s3 = new SavingsAccount(10000.75);
    Console.ReadLine();
}

```

The in-memory data allocation would look something like Figure 5-3.



**Figure 5-3.** Static data is allocated once and shared among all instances of the class

Here, the assumption is that all saving accounts should have the same interest rate. Because static data is shared by all objects of the same category, if you were to change it in any way, all objects will “see” the new value the next time they access the static data, as they are all essentially looking at the same memory location. To understand how to change (or obtain) static data, you need to consider the role of static methods.

## Defining Static Methods

Let’s update the `SavingsAccount` class to define two static methods. The first static method (`GetInterestRate()`) will return the current interest rate, while the second static method (`SetInterestRate()`) will allow you to change the interest rate.

```
// A simple savings account class.
class SavingsAccount
{
    // Instance-level data.
    public double currBalance;

    // A static point of data.
    public static double currInterestRate = 0.04;

    public SavingsAccount(double balance)
    {
        currBalance = balance;
    }

    // Static members to get/set interest rate.
    public static void SetInterestRate(double newRate)
        => currInterestRate = newRate;

    public static double GetInterestRate()
        => currInterestRate;
}
```

Now, observe the following usage:

```
static void Main(string[] args)
{
    Console.WriteLine("***** Fun with Static Data *****\n");
    SavingsAccount s1 = new SavingsAccount(50);
    SavingsAccount s2 = new SavingsAccount(100);

    // Print the current interest rate.
    Console.WriteLine("Interest Rate is: {0}", SavingsAccount.GetInterestRate());

    // Make new object, this does NOT 'reset' the interest rate.
    SavingsAccount s3 = new SavingsAccount(10000.75);
    Console.WriteLine("Interest Rate is: {0}", SavingsAccount.GetInterestRate());

    Console.ReadLine();
}
```

The output of the previous Main() is shown here:

---

```
***** Fun with Static Data *****

Interest Rate is: 0.04
Interest Rate is: 0.04
```

---

As you can see, when you create new instances of the SavingsAccount class, the value of the static data is not reset, as the CoreCLR will allocate the static data into memory exactly one time. After that point, all objects of type SavingsAccount operate on the same value for the static currInterestRate field.

When designing any C# class, one of your design challenges is to determine which pieces of data should be defined as static members and which should not. While there are no hard-and-fast rules, remember that a static data field is shared by all objects of that type. Therefore, if you are defining a point of data that *all* objects should share between them, static is the way to go.

Consider what would happen if the interest rate variable were *not* defined using the static keyword. This would mean every `SavingsAccount` object would have its own copy of the `currInterestRate` field. Now, assume you created 100 `SavingsAccount` objects and needed to change the interest rate. That would require you to call the `SetInterestRate()` method 100 times! Clearly, this would not be a useful way to model “shared data.” Again, static data is perfect when you have a value that should be common to all objects of that category.

---

■ **Note** It is a compiler error for a static member to reference nonstatic members in its implementation. On a related note, it is an error to use the `this` keyword on a static member because `this` implies an object!

---

## Defining Static Constructors

A typical constructor is used to set the value of an object’s instance-level data at the time of creation. However, what would happen if you attempted to assign the value of a static point of data in a typical constructor? You might be surprised to find that the value is reset each time you create a new object!

To illustrate, assume you have updated the `SavingsAccount` class constructor as follows (also note you are no longer assigning the `currInterestRate` field inline):

```
class SavingsAccount
{
    public double currBalance;
    public static double currInterestRate;

    // Notice that our constructor is setting
    // the static currInterestRate value.
    public SavingsAccount(double balance)
    {
        currInterestRate = 0.04; // This is static data!
        currBalance = balance;
    }
    ...
}
```

Now, assume you have authored the following code in `Main()`:

```
static void Main( string[] args )
{
    Console.WriteLine("***** Fun with Static Data *****\n");

    // Make an account.
    SavingsAccount s1 = new SavingsAccount(50);

    // Print the current interest rate.
    Console.WriteLine("Interest Rate is: {0}", SavingsAccount.GetInterestRate());
}
```

```
// Try to change the interest rate via property.
SavingsAccount.SetInterestRate(0.08);

// Make a second account.
SavingsAccount s2 = new SavingsAccount(100);

// Should print 0.08...right??
Console.WriteLine("Interest Rate is: {0}", SavingsAccount.GetInterestRate());
Console.ReadLine();
}
```

If you executed the previous `Main()` method, you would see that the `currInterestRate` variable is reset each time you create a new `SavingsAccount` object, and it is always set to `0.04`. Clearly, setting the value of static data in a normal instance-level constructor sort of defeats the whole purpose. Every time you make a new object, the class-level data is reset! One approach to setting a static field is to use member initialization syntax, as you did originally.

```
class SavingsAccount
{
    public double currBalance;

    // A static point of data.
    public static double currInterestRate = 0.04;
    ...
}
```

This approach will ensure the static field is assigned only once, regardless of how many objects you create. However, what if the value for your static data needed to be obtained at runtime? For example, in a typical banking application, the value of an interest rate variable would be read from a database or external file. Performing such tasks usually requires a method scope such as a constructor to execute the code statements.

For this reason, C# allows you to define a static constructor, which allows you to safely set the values of your static data. Consider the following update to your class:

```
class SavingsAccount
{
    public double currBalance;
    public static double currInterestRate;

    public SavingsAccount(double balance)
    {
        currBalance = balance;
    }

    // A static constructor!
    static SavingsAccount()
    {
        Console.WriteLine("In static ctor!");
        currInterestRate = 0.04;
    }
    ...
}
```

Simply put, a static constructor is a special constructor that is an ideal place to initialize the values of static data when the value is not known at compile time (e.g., you need to read in the value from an external file, read in the value from a database, generate a random number, or whatnot). If you were to rerun the previous `Main()` method, you would find the output you expect. Note that the message “In static ctor!” prints only one time, as the CoreCLR calls all static constructors before the first use (and never calls them again for that instance of the application).

---

```
***** Fun with Static Data *****
```

```
In static ctor!
Interest Rate is: 0.04
Interest Rate is: 0.08
```

---

Here are a few points of interest regarding static constructors:

- A given class may define only a single static constructor. In other words, the static constructor cannot be overloaded.
- A static constructor does not take an access modifier and cannot take any parameters.
- A static constructor executes exactly one time, regardless of how many objects of the type are created.
- The runtime invokes the static constructor when it creates an instance of the class or before accessing the first static member invoked by the caller.
- The static constructor executes before any instance-level constructors.

Given this modification, when you create new `SavingsAccount` objects, the value of the static data is preserved, as the static member is set only one time within the static constructor, regardless of the number of objects created.

## Defining Static Classes

It is also possible to apply the `static` keyword directly on the class level. When a class has been defined as static, it is not creatable using the `new` keyword, and it can contain only members or data fields marked with the `static` keyword. If this is not the case, you receive compiler errors.

---

■ **Note** Recall that a class (or structure) that exposes only static functionality is often termed a *utility class*. When designing a utility class, it is good practice to apply the `static` keyword to the class definition.

---

At first glance, this might seem like a fairly odd feature, given that a class that cannot be created does not appear all that helpful. However, if you create a class that contains nothing but static members and/or constant data, the class has no need to be allocated in the first place! To illustrate, create a new class named `TimeUtilClass` and define it as follows:

```
// Static classes can only
// contain static members!
static class TimeUtilClass
{
    public static void PrintTime()
        => Console.WriteLine(DateTime.Now.ToShortTimeString());

    public static void PrintDate()
        => Console.WriteLine(DateTime.Today.ToShortDateString());
}
```

Given that this class has been defined with the `static` keyword, you cannot create an instance of the `TimeUtilClass` using the `new` keyword. Rather, all functionality is exposed from the class level. To test this class, add the following to the `Main` method:

```
static void Main(string[] args)
{
    Console.WriteLine("***** Fun with Static Classes *****\n");

    // This is just fine.
    TimeUtilClass.PrintDate();
    TimeUtilClass.PrintTime();

    // Compiler error! Can't create instance of static classes!
    TimeUtilClass u = new TimeUtilClass ();

    Console.ReadLine();
}
```

## Importing Static Members via the C# using Keyword

C# 6 added support for importing static members with the `using` keyword. To illustrate, consider the C# file currently defining the utility class. Because you are making calls to the `WriteLine()` method of the `Console` class, as well as the `Now` and `Today` properties of the `DateTime` class, you must have a `using` statement for the `System` namespace. Since the members of these classes are all static, you could alter your code file with the following static using directives:

```
// Import the static members of Console and DateTime.
using static System.Console;
using static System.DateTime;
```

With these “static imports,” the remainder of your code file is able to directly use the static members of the `Console` and `DateTime` class, without the need to prefix the defining class. For example, you could update your utility class like so:

```
static class TimeUtilClass
{
    public static void PrintTime()
        => WriteLine(Now.ToShortTimeString());
}
```

```
public static void PrintDate()
    => WriteLine(Today.ToShortDateString());
}
```

A more realistic example of code simplification with importing static members might involve a C# class that is making substantial use of the `System.Math` class (or some other utility class). Since this class has nothing but static members, it could be somewhat easier to have a static using statement for this type and then directly call into the members of the `Math` class in your code file.

However, be aware that overuse of static import statements could result in potential confusion. First, what if multiple classes define a `WriteLine()` method? The compiler is confused and so are others reading your code. Second, unless a developer is familiar with the .NET Core code libraries, he or she might not know that `WriteLine()` is a member of the `Console` class. Unless a person were to notice the set of static imports at the top of a C# code file, they might be quite unsure where this method is actually defined. For these reasons, I will limit the use of static using statements in this text.

In any case, at this point in the chapter, you should feel comfortable defining simple class types containing constructors, fields, and various static (and nonstatic) members. Now that you have the basics of class construction under your belt, you can formally investigate the three pillars of object-oriented programming.

## Defining the Pillars of OOP

All object-oriented languages (C#, Java, C++, Visual Basic, etc.) must contend with three core principles, often called the *pillars* of object-oriented programming (OOP):

- *Encapsulation*: How does this language hide an object's internal implementation details and preserve data integrity?
- *Inheritance*: How does this language promote code reuse?
- *Polymorphism*: How does this language let you treat related objects in a similar way?

Before digging into the syntactic details of each pillar, it is important that you understand the basic role of each. Here is an overview of each pillar, which will be examined in full detail over the remainder of this chapter and the next.

## The Role of Encapsulation

The first pillar of OOP is called *encapsulation*. This trait boils down to the language's ability to hide unnecessary implementation details from the object user. For example, assume you are using a class named `DatabaseReader`, which has two primary methods, named `Open()` and `Close()`.

```
// Assume this class encapsulates the details of opening and closing a database.
DatabaseReader dbReader = new DatabaseReader();
dbReader.Open(@"C:\AutoLot.mdf");

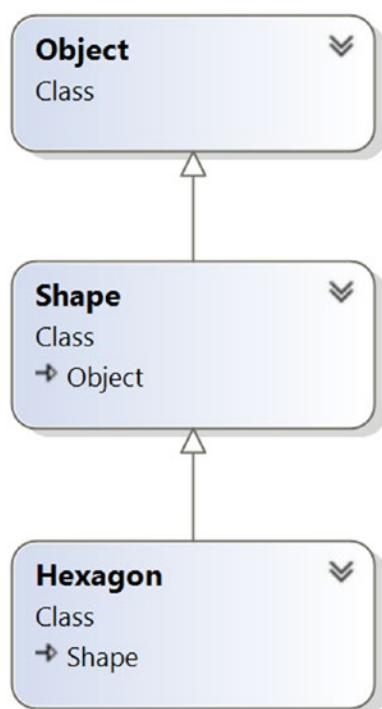
// Do something with data file and close the file.
dbReader.Close();
```

The fictitious `DatabaseReader` class encapsulates the inner details of locating, loading, manipulating, and closing a data file. Programmers love encapsulation, as this pillar of OOP keeps coding tasks simpler. There is no need to worry about the numerous lines of code that are working behind the scenes to carry out the work of the `DatabaseReader` class. All you do is create an instance and send the appropriate messages (e.g., “Open the file named `AutoLot.mdf` located on my C drive”).

Closely related to the notion of encapsulating programming logic is the idea of data protection. Ideally, an object's state data should be specified using either the `private`, `internal`, or `protected` keyword. In this way, the outside world must ask politely in order to change or obtain the underlying value. This is a good thing, as publicly declared data points can easily become corrupted (ideally by accident rather than intent!). You will formally examine this aspect of encapsulation in just a bit.

## The Role of Inheritance

The next pillar of OOP, *inheritance*, boils down to the language's ability to allow you to build new class definitions based on existing class definitions. In essence, inheritance allows you to extend the behavior of a base (or *parent*) class by inheriting core functionality into the derived subclass (also called a *child class*). Figure 5-4 shows a simple example.



**Figure 5-4.** The “is-a” relationship

You can read the diagram in Figure 5-4 as “A Hexagon is-a Shape that is-an Object.” When you have classes related by this form of inheritance, you establish “is-a” *relationships* between types. The “is-a” relationship is termed *inheritance*.

Here, you can assume that Shape defines some number of members that are common to all descendants (maybe a value to represent the color to draw the shape and other values to represent the height and width). Given that the Hexagon class extends Shape, it inherits the core functionality defined by Shape and Object, as well as defines additional hexagon-related details of its own (whatever those may be).



---

■ **Note** Under the .NET platform, `System.Object` is always the topmost parent in any class hierarchy, which defines some general functionality for all types (fully described in Chapter 6).

---

There is another form of code reuse in the world of OOP: the containment/delegation model also known as the “*has-a*” relationship or aggregation. This form of reuse is not used to establish parent-child relationships. Rather, the “has-a” relationship allows one class to define a member variable of another class and expose its functionality (if required) to the object user indirectly.

For example, assume you are again modeling an automobile. You might want to express the idea that a car “has-a” radio. It would be illogical to attempt to derive the `Car` class from a `Radio` or vice versa (a `Car` “is-a” `Radio`? I think not!). Rather, you have two independent classes working together, where the `Car` class creates and exposes the `Radio`’s functionality.

```
class Radio
{
    public void Power(bool turnOn)
    {
        Console.WriteLine("Radio on: {0}", turnOn);
    }
}

class Car
{
    // Car 'has-a' Radio.
    private Radio myRadio = new Radio();

    public void TurnOnRadio(bool onOff)
    {
        // Delegate call to inner object.
        myRadio.Power(onOff);
    }
}
```

Notice that the object user has no clue that the `Car` class is using an inner `Radio` object.

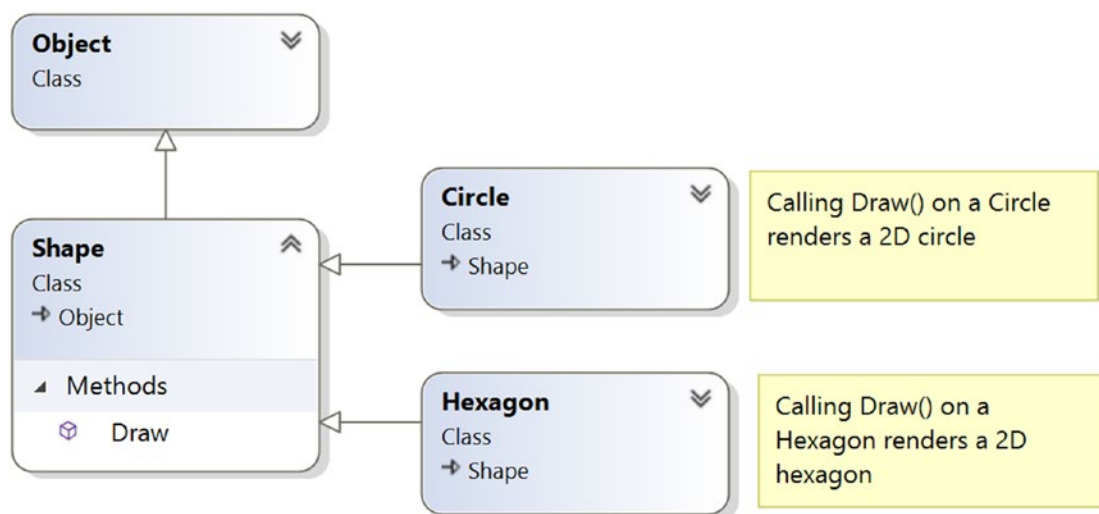
```
static void Main(string[] args)
{
    // Call is forwarded to Radio internally.
    Car viper = new Car();
    viper.TurnOnRadio(false);
}
```

## The Role of Polymorphism

The final pillar of OOP is *polymorphism*. This trait captures a language’s ability to treat related objects in a similar manner. Specifically, this tenant of an object-oriented language allows a base class to define a set of members (formally termed the *polymorphic interface*) that are available to all descendants. A class’s polymorphic interface is constructed using any number of *virtual* or *abstract* members (see Chapter 6 for full details).

In a nutshell, a *virtual member* is a member in a base class that defines a default implementation that may be changed (or more formally speaking, *overridden*) by a derived class. In contrast, an *abstract method* is a member in a base class that does not provide a default implementation but does provide a signature. When a class derives from a base class defining an abstract method, it *must* be overridden by a derived type. In either case, when derived types override the members defined by a base class, they are essentially redefining how they respond to the same request.

To preview polymorphism, let's provide some details behind the shapes hierarchy shown in Figure 5-5. Assume that the Shape class has defined a virtual method named `Draw()` that takes no parameters. Given that every shape needs to render itself in a unique manner, subclasses such as `Hexagon` and `Circle` are free to override this method to their own liking (see Figure 5-5).



**Figure 5-5.** Classical polymorphism

After a polymorphic interface has been designed, you can begin to make various assumptions in your code. For example, given that `Hexagon` and `Circle` derive from a common parent (`Shape`), an array of `Shape` types could contain anything deriving from this base class. Furthermore, given that `Shape` defines a polymorphic interface to all derived types (the `Draw()` method in this example), you can assume each member in the array has this functionality.

Consider the following `Main()` method, which instructs an array of `Shape`-derived types to render themselves using the `Draw()` method:

```

class Program
{
    static void Main(string[] args)
    {
        Shape[] myShapes = new Shape[3];
        myShapes[0] = new Hexagon();
        myShapes[1] = new Circle();
        myShapes[2] = new Hexagon();
    }
}
  
```

```
foreach (Shape s in myShapes)
{
    // Use the polymorphic interface!
    s.Draw();
}
Console.ReadLine();
}
```

This wraps up our brisk overview of the pillars of OOP. Now that you have the theory in your mind, the remainder of this chapter explores further details of how encapsulation is handled under C#. Chapter 6 will tackle the details of inheritance and polymorphism.

## C# Access Modifiers (Updated 7.2)

When working with encapsulation, you must always take into account which aspects of a type are visible to various parts of your application. Specifically, types (classes, interfaces, structures, enumerations, and delegates) as well as their members (properties, methods, constructors, and fields) are defined using a specific keyword to control how “visible” the item is to other parts of your application. Although C# defines numerous keywords to control access, they differ on where they can be successfully applied (type or member). Table 5-1 documents the role of each access modifier and where it may be applied.

**Table 5-1.** C# Access Modifiers

C# Access Modifier	May Be Applied To	Meaning in Life
public	Types or type members	Public items have no access restrictions. A public member can be accessed from an object, as well as any derived class. A public type can be accessed from other external assemblies.
private	Type members or nested types	Private items can be accessed only by the class (or structure) that defines the item.
protected	Type members or nested types	Protected items can be used by the class that defines it and any child class. They cannot be accessed from outside the inheritance chain.
internal	Types or type members	Internal items are accessible only within the current assembly. Other assemblies can be explicitly granted permission to see the internal items.
protected internal	Type members or nested types	When the protected and internal keywords are combined on an item, the item is accessible within the defining assembly, within the defining class, and by derived classes inside or outside of the defining assembly.
private protected (new 7.2)	Type members or nested types	When the private and protected keywords are combined on an item, the item is accessible within the defining class and by derived classes in the same assembly.

In this chapter, you are concerned only with the `public` and `private` keywords. Later chapters will examine the role of the `internal` and `protected internal` modifiers (useful when you build .NET Core code libraries and unit tests) and the `protected` modifier (useful when you are creating class hierarchies).

## The Default Access Modifiers

By default, type members are *implicitly private*, while types are *implicitly internal*. Thus, the following class definition is automatically set to `internal`, while the type's default constructor is automatically set to `private` (however, as you would suspect, there are few times you would want a private class constructor):

```
// An internal class with a private default constructor.
class Radio
{
    Radio(){}
}
```

If you want to be explicit, you could add these keywords yourself with no ill effect (beyond a few additional keystrokes).

```
// An internal class with a private default constructor.
internal class Radio
{
    private Radio(){}
}
```

To allow other parts of a program to invoke members of an object, you must define them with the `public` keyword (or possibly with the `protected` keyword, which you will learn about in the next chapter). As well, if you want to expose the `Radio` to external assemblies (again, useful when building .NET Core code libraries; see Chapter 16), you will need to add the `public` modifier.

```
// A public class with a public default constructor.
public class Radio
{
    public Radio(){}
}
```

## Access Modifiers and Nested Types

As mentioned in Table 5-1, the `private`, `protected`, `protected internal`, and `private protected` access modifiers can be applied to a *nested type*. Chapter 6 will examine nesting in detail. What you need to know at this point, however, is that a nested type is a type declared directly within the scope of class or structure. By way of example, here is a private enumeration (named `CarColor`) nested within a public class (named `SportsCar`):

```
public class SportsCar
{
    // OK! Nested types can be marked private.
    private enum CarColor
```

```

{
    Red, Green, Blue
}
}

```

Here, it is permissible to apply the `private` access modifier on the nested type. However, non-nested types (such as the `SportsCar`) can be defined only with the `public` or `internal` modifiers. Therefore, the following class definition is illegal:

```

// Error! Nonnested types cannot be marked private!
private class SportsCar
{
}

```

## The First Pillar: C#'s Encapsulation Services

The concept of encapsulation revolves around the notion that an object's data should not be directly accessible from an object instance. Rather, class data is defined as `private`. If the object user wants to alter the state of an object, it does so indirectly using public members. To illustrate the need for encapsulation services, assume you have created the following class definition:

```

// A class with a single public field.
class Book
{
    public int numberOfPages;
}

```

The problem with public data is that the data itself has no ability to “understand” whether the current value to which it is assigned is valid with regard to the current business rules of the system. As you know, the upper range of a C# `int` is quite large (2,147,483,647). Therefore, the compiler allows the following assignment:

```

// Humm. That is one heck of a mini-novel!
static void Main(string[] args)
{
    Book miniNovel = new Book();
    miniNovel.numberOfPages = 30_000_000;
}

```

Although you have not overflowed the boundaries of an `int` data type, it should be clear that a mini-novel with a page count of 30,000,000 pages is a bit unreasonable. As you can see, public fields do not provide a way to trap logical upper (or lower) limits. If your current system has a business rule that states a book must be between 1 and 1000 pages, you are at a loss to enforce this programmatically. Because of this, public fields typically have no place in a production-level class definition.

---

■ **Note** To be more specific, members of a class that represent an object's state should not be marked as public. As you will see later in this chapter, public constants and public read-only fields are quite useful.

---

Encapsulation provides a way to preserve the integrity of an object's state data. Rather than defining public fields (which can easily foster data corruption), you should get in the habit of defining *private data*, which is indirectly manipulated using one of two main techniques.

- You can define a pair of public accessor (get) and mutator (set) methods.
- You can define a public property.

Whichever technique you choose, the point is that a well-encapsulated class should protect its data and hide the details of how it operates from the prying eyes of the outside world. This is often termed *black-box programming*. The beauty of this approach is that an object is free to change how a given method is implemented under the hood. It does this without breaking any existing code making use of it, provided that the parameters and return values of the method remain constant.

## Encapsulation Using Traditional Accessors and Mutators

Over the remaining pages in this chapter, you will be building a fairly complete class that models a general employee. To get the ball rolling, create a new Console Application project named `EmployeeApp` and insert a new class file (named `Employee.cs`) using the Project Add class menu item. Update the `Employee` class with the following fields, methods, and constructors:

```
class Employee
{
    // Field data.
    private string _empName;
    private int _empId;
    private float _currPay;

    // Constructors.
    public Employee() {}
    public Employee(string name, int id, float pay)
    {
        _empName = name;
        _empId = id;
        _currPay = pay;
    }

    // Methods.
    public void GiveBonus(float amount) => _currPay += amount;
    public void DisplayStats()
    {
        Console.WriteLine("Name: {0}", _empName);
        Console.WriteLine("ID: {0}", _empId);
        Console.WriteLine("Pay: {0}", _currPay);
    }
}
```

Notice that the fields of the `Employee` class are currently defined using the `private` keyword. Given this, the `_empName`, `_empId`, and `_currPay` fields are not directly accessible from an object variable. Therefore, the following logic in `Main()` would result in compiler errors:

```
static void Main(string[] args)
{
    Employee emp = new Employee();
    // Error! Cannot directly access private members
    // from an object!
    emp._empName = "Marv";
}
```

If you want the outside world to interact with a worker's full name, a traditional approach (which is common in Java) is to define an accessor (get method) and a mutator (set method). The role of a get method is to return to the caller the current value of the underlying state data. A set method allows the caller to change the current value of the underlying state data, as long as the defined business rules are met.

To illustrate, let's encapsulate the `empName` field. To do so, add the following public methods to the `Employee` class. Notice that the `SetName()` method performs a test on the incoming data to ensure the string is 15 characters or less. If it is not, an error prints to the console and returns without making a change to the `empName` field.

---

■ **Note** If this were a production-level class, you would also make to check the character length for an employee's name within your constructor logic. Ignore this detail for the time being, as you will clean up this code in just a bit when you examine .NET property syntax.

---

```
class Employee
{
    // Field data.
    private string _empName;
    ...

    // Accessor (get method).
    public string GetName() => _empName;

    // Mutator (set method).
    public void SetName(string name)
    {
        // Do a check on incoming value
        // before making assignment.
        if (name.Length > 15)
        {
            Console.WriteLine("Error! Name length exceeds 15 characters!");
        }
        else
        {
            _empName = name;
        }
    }
}
```

This technique requires two uniquely named methods to operate on a single data point. To test your new methods, update your `Main()` method as follows:

```
static void Main(string[] args)
{
    Console.WriteLine("***** Fun with Encapsulation *****\n");
    Employee emp = new Employee("Marvin", 456, 30_000);
    emp.GiveBonus(1000);
    emp.DisplayStats();

    // Use the get/set methods to interact with the object's name.
    emp.SetName("Marv");
    Console.WriteLine("Employee is named: {0}", emp.GetName());
    Console.ReadLine();
}
```

Because of the code in your `SetName()` method, if you attempted to specify more than 15 characters (see the following), you would find the hard-coded error message printed to the console:

```
static void Main(string[] args)
{
    Console.WriteLine("***** Fun with Encapsulation *****\n");
    ...
    // Longer than 15 characters! Error will print to console.
    Employee emp2 = new Employee();
    emp2.SetName("Xena the warrior princess");

    Console.ReadLine();
}
```

So far, so good. You have encapsulated the private `empName` field using two public methods named `GetName()` and `SetName()`. If you were to further encapsulate the data in the `Employee` class, you would need to add various additional methods (such as `GetID()`, `SetID()`, `GetCurrentPay()`, `SetCurrentPay()`). Each of the mutator methods could have within it various lines of code to check for additional business rules. While this could certainly be done, the C# language has a useful alternative notation to encapsulate class data.

## Encapsulation Using Properties

Although you can encapsulate a piece of field data using traditional get and set methods, .NET Core languages prefer to enforce data encapsulation state data using *properties*. First, understand that properties are just a container for “real” accessor and mutator methods, named get and set, respectively. Therefore, as a class designer, you are still able to perform any internal logic necessary before making the value assignment (e.g., uppercase the value, scrub the value for illegal characters, check the bounds of a numerical value, etc.).

Here is the updated `Employee` class, now enforcing encapsulation of each field using property syntax rather than traditional get and set methods:

```
class Employee
{
    // Field data.
    private string _empName;
    private int _empId;
```



```

private float _currPay;
// Properties!
public string Name
{
    get { return _empName; }
    set
    {
        if (value.Length > 15)
        {
            Console.WriteLine("Error! Name length exceeds 15 characters!");
        }
        else
        {
            _empName = value;
        }
    }
}
// We could add additional business rules to the sets of these properties;
// however, there is no need to do so for this example.
public int Id
{
    get { return _empId; }
    set { _empId = value; }
}
public float Pay
{
    get { return _currPay; }
    set { _currPay = value; }
}
...
}

```

A C# property is composed by defining a get scope (accessor) and set scope (mutator) directly within the property itself. Notice that the property specifies the type of data it is encapsulating by what appears to be a return value. Also take note that, unlike a method, properties do not make use of parentheses (not even empty parentheses) when being defined. Consider the following commentary on your current `Id` property:

```

// The 'int' represents the type of data this property encapsulates.
public int Id // Note lack of parentheses.
{
    get { return _empId; }
    set { _empID = value; }
}

```

Within a set scope of a property, you use a token named `value`, which is used to represent the incoming value used to assign the property by the caller. This token is *not* a true C# keyword but is what is known as a *contextual keyword*. When the token `value` is within the set scope of the property, it always represents the value being assigned by the caller, and it will always be the same underlying data type as the property itself. Thus, notice how the `Name` property can still test the range of the `string` as so:

```

public string Name
{
    get { return _empName; }
    set
    {
        // Here, value is really a string.
        if (value.Length > 15)
        { Console.WriteLine("Error! Name length exceeds 15 characters!"); }
        else
        {
            empName = value;
        }
    }
}

```

After you have these properties in place, it appears to the caller that it is getting and setting a *public* point of data; however, the correct get and set block is called behind the scenes to preserve encapsulation.

```

static void Main(string[] args)
{
    Console.WriteLine("***** Fun with Encapsulation *****\n");
    Employee emp = new Employee("Marvin", 456, 30000);
    emp.GiveBonus(1000);
    emp.DisplayStats();
}

```

**// Reset and then get the Name property.**

```

emp.Name = "Marv";
Console.WriteLine("Employee is named: {0}", emp.Name);
Console.ReadLine();
}

```

Properties (as opposed to accessor and mutator methods) also make your types easier to manipulate, in that properties are able to respond to the intrinsic operators of C#. To illustrate, assume that the `Employee` class type has an internal private member variable representing the age of the employee. Here is the relevant update (notice the use of constructor chaining):

```

class Employee
{
    ...
    // New field and property.
    private int _empAge;
    public int Age
    {
        get { return _empAge; }
        set { _empAge = value; }
    }

    // Updated constructors.
    public Employee() {}
    public Employee(string name, int id, float pay)
    :this(name, 0, id, pay){}
}

```

```

public Employee(string name, int age, int id, float pay)
{
    _empName = name;
    _empId = id;
    _empAge = age;
    _currPay = pay;
}

// Updated DisplayStats() method now accounts for age.
public void DisplayStats()
{
    Console.WriteLine("Name: {0}", _empName);
    Console.WriteLine("ID: {0}", _empId);
    Console.WriteLine("Age: {0}", _empAge);
    Console.WriteLine("Pay: {0}", _currPay);
}
}

```

Now assume you have created an `Employee` object named `joe`. On his birthday, you want to increment the age by one. Using traditional accessor and mutator methods, you would need to write code such as the following:

```

Employee joe = new Employee();
joe.SetAge(joe.GetAge() + 1);

```

However, if you encapsulate `empAge` using a property named `Age`, you are able to simply write this:

```

Employee joe = new Employee();
joe.Age++;

```

## Properties As Expression-Bodied Members (New 7.0)

As mentioned previously, property get and set accessors can also be written as expression-bodied members. The rules and syntax are the same: single-line methods can be written using the new syntax. So, the `Age` property could be written like this:

```

public int Age
{
    get => empAge;
    set => empAge = value;
}

```

Both syntaxes compile down to the same IL, so which syntax you use is completely up to you. In this text, you will see a mix of both styles to keep visibility on them, not because I am adhering to a specific code style.

## Using Properties Within a Class Definition

Properties, specifically the set portion of a property, are common places to package up the business rules of your class. Currently, the `Employee` class has a `Name` property that ensures the name is no more than 15 characters. The remaining properties (`ID`, `Pay`, and `Age`) could also be updated with any relevant logic.

While this is well and good, also consider what a class constructor typically does internally. It will take the incoming parameters, check for valid data, and then make assignments to the internal private fields. Currently, your master constructor does *not* test the incoming string data for a valid range, so you could update this member as so:

```
public Employee(string name, int age, int id, float pay)
{
    // Humm, this seems like a problem...
    if (name.Length > 15)
    {
        Console.WriteLine("Error! Name length exceeds 15 characters!");
    }
    else
    {
        _empName = name;
    }
    _empId = id;
    _empAge = age;
    _currPay = pay;
}
```

I am sure you can see the problem with this approach. The `Name` property and your master constructor are performing the same error checking. If you were also making checks on the other data points, you would have a good deal of duplicate code. To streamline your code and isolate all of your error checking to a central location, you will do well if you *always* use properties within your class whenever you need to get or set the values. Consider the following updated constructor:

```
public Employee(string name, int age, int id, float pay)
{
    // Better! Use properties when setting class data.
    // This reduces the amount of duplicate error checks.
    Name = name;
    Age = age;
    ID = id;
    Pay = pay;
}
```

Beyond updating constructors to use properties when assigning values, it is good practice to use properties throughout a class implementation to ensure your business rules are always enforced. In many cases, the only time when you directly make reference to the underlying private piece of data is within the property itself. With this in mind, here is your updated `Employee` class:

```
class Employee
{
    // Field data.
    private string _empName;
```

```

private int _empId;
private float _currPay;
private int _empAge;
// Constructors.
public Employee() { }
public Employee(string name, int id, float pay)
    :this(name, 0, id, pay){}
public Employee(string name, int age, int id, float pay)
{
    Name = name;
    Age = age;
    ID = id;
    Pay = pay;
}
// Methods.
public void GiveBonus(float amount) => Pay += amount;

public void DisplayStats()
{
    Console.WriteLine("Name: {0}", Name);
    Console.WriteLine("ID: {0}", Id);
    Console.WriteLine("Age: {0}", Age);
    Console.WriteLine("Pay: {0}", Pay);
}

// Properties as before...
...
}

```

## Read-Only and Write-Only Properties

When encapsulating data, you might want to configure a *read-only property*. To do so, simply omit the set block. Likewise, if you want to have a *write-only property*, omit the get block. For example, assume you have a new property named `SocialSecurityNumber`, which encapsulates a private string variable named `empSSN`. If you want to make this a read-only property, you could write this:

```

public string SocialSecurityNumber
{
    get { return _empSSN; }
}

```

Properties that only have a get can also be simplified using expression body members. The following line is equivalent to the previous code block:

```

public string SocialSecurityNumber => _empSSN;

```

Now assume your class constructor has a new parameter to let the caller set the SSN of the object. Since the `SocialSecurityNumber` property is read-only, you cannot set the value as so:

```
public Employee(string name, int age, int id, float pay, string ssn)
{
    Name = name;
    Age = age;
    ID = id;
    Pay = pay;

    // OOPS! This is no longer possible if the property is read only.
    SocialSecurityNumber = ssn;
}
```

Unless you are willing to redesign the property as read-write, your only choice would be to use the underlying `empSSN` member variable within your constructor logic as so:

```
public Employee(string name, int age, int id, float pay, string ssn)
{
    ...
    // Check incoming ssn parameter as required and then set the value.
    empSSN = ssn;
}
```

## Mixing Private and Public Get/Set Methods on Properties

When defining properties, the access level for the get and set methods can be different. Revisiting the Social Security Number, another option for the previous example is to declare the get method as public but the set method as private, like this:

```
public string SocialSecurityNumber
{
    get => _empSSN;
    private set => _empSSN = value;
}
```

Note that this changes the property from read-only to read-write. The difference is that the write is hidden from anything outside the defining class.

## Pattern Matching with Property Patterns (New 8.0)

The property pattern enables you to match on properties of an object. To set up the example, add a new enumeration for an employee pay type, as follows:

```
public enum EmployeePayTypeEnum{
    Hourly,
    Salaried,
    Commission
}
```

Update the `Employee` class with a property for the pay type and initialize it from the constructor. The relevant code changes are listed here:

```
private EmployeePayTypeEnum _payType;
public EmployeePayTypeEnum PayType
{
    get => _payType;
    set => _payType = value;
}
public Employee(string name, int id, float pay, string empSsn)
    : this(name,0,id,pay, empSsn, EmployeePayTypeEnum.Salaried)
{
}
public Employee(string name, int age, int id,
    float pay, string empSsn, EmployeePayTypeEnum payType)
{
    Name = name;
    Id = id;
    Age = age;
    Pay = pay;
    SocialSecurityNumber = empSsn;
    PayType = payType;
}
```

Now that all of the pieces are in place, the `GiveBonus` method can be updated based on the pay type of the employee. Commissioned employees get 10% of the bonus, hourly get the equivalent of 40 hours of the prorated bonus, and salaried get the entered amount. The updated `GiveBonus` method is listed here:

```
public void GiveBonus(float amount)
{
    Pay = this switch
    {
        {PayType: EmployeePayTypeEnum.Commission }
            => Pay += .10F * amount,
        {PayType: EmployeePayTypeEnum.Hourly }
            => Pay += 40F * amount/2080F,
        {PayType: EmployeePayTypeEnum.Salaried }
            => Pay += amount,
        _ => Pay+=0
    };
}
```

As with other switch statements that use pattern matching, there must either be a catch-all case statement or the switch statement must throw an exception if none of the case statements are met.

To test this, add the following code to the `Main` method:

```
Employee emp = new Employee("Marvin",45,123,1000,"111-11-1111",EmployeePayTypeEnum.
Salaried);
Console.WriteLine(emp.Pay);
emp.GiveBonus(100);
Console.WriteLine(emp.Pay);
```

## Revisiting the static Keyword: Defining Static Properties

Earlier in this chapter, you examined the role of the `static` keyword. Now that you understand the use of C# property syntax, you can formalize static properties. In the `StaticDataAndMembers` project created earlier in this chapter, your `SavingsAccount` class had two public static methods to get and set the interest rate. However, it would be more standard to wrap this data point in a static property. Here's an example (note the use of the `static` keyword):

```
// A simple savings account class.
class SavingsAccount
{
    // Instance-level data.
    public double currBalance;

    // A static point of data.
    private static double _currInterestRate = 0.04;

    // A static property.
    public static double InterestRate
    {
        get { return _currInterestRate; }
        set { _currInterestRate = value; }
    }
    ...
}
```

If you want to use this property in place of the previous static methods, you could update your `Main()` method as so:

```
// Print the current interest rate via property.
Console.WriteLine("Interest Rate is: {0}", SavingsAccount.InterestRate);
```

## Understanding Automatic Properties

When you are building properties to encapsulate your data, it is common to find that the set scopes have code to enforce business rules of your program. However, in some cases you may not need any implementation logic beyond simply getting and setting the value. This means you can end up with a lot of code looking like the following:

```
// A Car type using standard property
// syntax.
class Car
{
    private string carName = "";
    public string PetName
    {
        get { return carName; }
        set { carName = value; }
    }
}
```



In these cases, it can become rather verbose to define private backing fields and simple property definitions multiple times. By way of an example, if you are modeling a class that requires nine private points of field data, you end up authoring nine related properties that are little more than thin wrappers for encapsulation services.

To streamline the process of providing simple encapsulation of field data, you may use *automatic property syntax*. As the name implies, this feature will offload the work of defining a private backing field and the related C# property member to the compiler using a new bit of syntax. To illustrate, create a new Console Application project named AutoProps. Now, consider the reworking of the Car class, which uses this syntax to quickly create three properties:

```
class Car
{
    // Automatic properties! No need to define backing fields.
    public string PetName { get; set; }
    public int Speed { get; set; }
    public string Color { get; set; }
}
```

---

■ **Note** Visual Studio provides the `prop` code snippet. If you type **prop** inside a class definition and press the Tab key twice, the IDE will generate starter code for a new automatic property. You can then use the Tab key to cycle through each part of the definition to fill in the details. Give it a try!

---

When defining automatic properties, you simply specify the access modifier, underlying data type, property name, and empty get/set scopes. At compile time, your type will be provided with an autogenerated private backing field and a fitting implementation of the get/set logic.

---

■ **Note** The name of the autogenerated private backing field is not visible within your C# codebase. The only way to see it is to make use of a tool such as `ildasm.exe`.

---

Since C# version 6, it is possible to define a “read-only automatic property” by omitting the set scope. Read-only autoproperties can only be set in the constructor. However, it is not possible to define a write-only property. To solidify, consider the following:

```
// Read-only property? This is OK!
public int MyReadOnlyProp { get; }

// Write only property? Error!
public int MyWriteOnlyProp { set; }
```

## Interacting with Automatic Properties

Because the compiler will define the private backing field at compile time (and given that these fields are not directly accessible in C# code), the class-defining automatic properties will always need to use property syntax to get and set the underlying value. This is important to note because many programmers make direct use of the private fields *within* a class definition, which is not possible in this case. For example, if the `Car` class were to provide a `DisplayStats()` method, it would need to implement this method using the property name.

```
class Car
{
    // Automatic properties!
    public string PetName { get; set; }
    public int Speed { get; set; }
    public string Color { get; set; }

    public void DisplayStats()
    {
        Console.WriteLine("Car Name: {0}", PetName);
        Console.WriteLine("Speed: {0}", Speed);
        Console.WriteLine("Color: {0}", Color);
    }
}
```

When you are using an object defined with automatic properties, you will be able to assign and obtain the values using the expected property syntax.

```
static void Main(string[] args)
{
    Console.WriteLine("***** Fun with Automatic Properties *****\n");

    Car c = new Car();
    c.PetName = "Frank";
    c.Speed = 55;
    c.Color = "Red";

    Console.WriteLine("Your car is named {0}? That's odd...",
        c.PetName);
    c.DisplayStats();

    Console.ReadLine();
}
```

## Automatic Properties and Default Values

When you use automatic properties to encapsulate numerical or Boolean data, you are able to use the autogenerated type properties straightaway within your codebase, as the hidden backing fields will be assigned a safe default value (false for Booleans and 0 for numerical data). However, be aware that if you use automatic property syntax to wrap another class variable, the hidden private reference type will also be set to a default value of null (which can prove problematic if you are not careful).

Let's insert into your current project a new class named `Garage`, which makes use of two automatic properties (of course, a real garage class might maintain a collection of `Car` objects; however, ignore that detail here).

```
class Garage
{
    // The hidden int backing field is set to zero!
    public int NumberOfCars { get; set; }

    // The hidden Car backing field is set to null!
    public Car MyAuto { get; set; }
}
```

Given C#'s default values for field data, you would be able to print out the value of `NumberOfCars` as is (as it is automatically assigned the value of zero), but if you directly invoke `MyAuto`, you will receive a “null reference exception” at runtime, as the `Car` member variable used in the background has not been assigned to a new object.

```
static void Main(string[] args)
{
    ...
    Garage g = new Garage();

    // OK, prints default value of zero.
    Console.WriteLine("Number of Cars: {0}", g.NumberOfCars);

    // Runtime error! Backing field is currently null!
    Console.WriteLine(g.MyAuto.PetName);
    Console.ReadLine();
}
```

To solve this problem, you could update the class constructors to ensure the object comes to life in a safe manner. Here's an example:

```
class Garage
{
    // The hidden backing field is set to zero!
    public int NumberOfCars { get; set; }
    // The hidden backing field is set to null!
    public Car MyAuto { get; set; }
    // Must use constructors to override default
    // values assigned to hidden backing fields.
    public Garage()
    {
        MyAuto = new Car();
        NumberOfCars = 1;
    }
}
```

```

public Garage(Car car, int number)
{
    MyAuto = car;
    NumberOfCars = number;
}
}

```

With this modification, you could now place a Car object into the Garage object as so:

```

static void Main(string[] args)
{
    Console.WriteLine("***** Fun with Automatic Properties *****\n");

    // Make a car.
    Car c = new Car();
    c.PetName = "Frank";
    c.Speed = 55;
    c.Color = "Red";
    c.DisplayStats();

    // Put car in the garage.
    Garage g = new Garage();
    g.MyAuto = c;
    Console.WriteLine("Number of Cars in garage: {0}", g.NumberOfCars);
    Console.WriteLine("Your car is named: {0}", g.MyAuto.PetName);

    Console.ReadLine();
}

```

## Initialization of Automatic Properties

While the previous approach works just fine, since the release of C# 6, you are provided with a language feature that can simplify how an automatic property receives its initial value assignment. Recall from the onset of this chapter, a data field of a class can be directly assigned an initial value upon declaration. Here's an example:

```

class Car
{
    private int numberOfDoors = 2;
}

```

In a similar manner, C# now allows you to assign an initial value to the underlying backing field generated by the compiler. This alleviates you from the hassle of adding additional code statements in class constructors to ensure property data comes to life as intended.

Here is an updated version of the Garage class that is initializing automatic properties to fitting values. Note you no longer need to add additional logic to your default class constructor to make safe assignments. In this iteration, you are directly assigning a new Car object to the MyAuto property.

```

class Garage
{
    // The hidden backing field is set to 1.
    public int NumberOfCars { get; set; } = 1;

    // The hidden backing field is set to a new Car object.
    public Car MyAuto { get; set; } = new Car();

    public Garage(){}
    public Garage(Car car, int number)
    {
        MyAuto = car;
        NumberOfCars = number;
    }
}

```

As you may agree, automatic properties are a nice feature of the C# programming language, as you can define a number of properties for a class using a streamlined syntax. Be aware of course that if you are building a property that requires additional code beyond getting and setting the underlying private field (such as data validation logic, writing to an event log, communicating with a database, etc.), you will be required to define a “normal” .NET property type by hand. C# automatic properties never do more than provide simple encapsulation for an underlying piece of (compiler-generated) private data.

## Understanding Object Initialization Syntax

As shown throughout this chapter, a constructor allows you to specify startup values when creating a new object. On a related note, properties allow you to get and set underlying data in a safe manner. When you are working with other people’s classes, including the classes found within the .NET Core base class library, it is not too uncommon to discover that there is not a single constructor that allows you to set every piece of underlying state data. Given this point, a programmer is typically forced to pick the best constructor possible, after which the programmer makes assignments using a handful of provided properties.

To help streamline the process of getting an object up and running, C# offers *object initializer syntax*. Using this technique, it is possible to create a new object variable and assign a slew of properties and/or public fields in a few lines of code. Syntactically, an object initializer consists of a comma-delimited list of specified values, enclosed by the { and } tokens. Each member in the initialization list maps to the name of a public field or public property of the object being initialized.

To see this syntax in action, create a new Console Application project named `ObjectInitializers`. Now, consider a simple class named `Point`, created using automatic properties (which is not mandatory for object initialization syntax but helps you write some concise code).

```

class Point
{
    public int X { get; set; }
    public int Y { get; set; }

    public Point(int xVal, int yVal)
    {
        X = xVal;
        Y = yVal;
    }
}

```

```

public Point() { }

public void DisplayStats()
{
    Console.WriteLine("[{0}, {1}]", X, Y);
}
}

```

Now consider how you can make `Point` objects using any of the following approaches:

```

static void Main(string[] args)
{
    Console.WriteLine("***** Fun with Object Init Syntax *****\n");

    // Make a Point by setting each property manually.
    Point firstPoint = new Point();
    firstPoint.X = 10;
    firstPoint.Y = 10;
    firstPoint.DisplayStats();

    // Or make a Point via a custom constructor.
    Point anotherPoint = new Point(20, 20);
    anotherPoint.DisplayStats();

    // Or make a Point using object init syntax.
    Point finalPoint = new Point { X = 30, Y = 30 };
    finalPoint.DisplayStats();
    Console.ReadLine();
}

```

The final `Point` variable is not making use of a custom constructor (as one might do traditionally) but is rather setting values to the public `X` and `Y` properties. Behind the scenes, the type's default constructor is invoked, followed by setting the values to the specified properties. To this end, object initialization syntax is just shorthand notation for the syntax used to create a class variable using a default constructor and to set the state data property by property.

## Calling Custom Constructors with Initialization Syntax

The previous examples initialized `Point` types by implicitly calling the default constructor on the type.

```

// Here, the default constructor is called implicitly.
Point finalPoint = new Point { X = 30, Y = 30 };

```

If you want to be clear about this, it is permissible to explicitly call the default constructor as follows:

```

// Here, the default constructor is called explicitly.
Point finalPoint = new Point() { X = 30, Y = 30 };

```

Do be aware that when you are constructing a type using initialization syntax, you are able to invoke *any* constructor defined by the class. Your `Point` type currently defines a two-argument constructor to set the  $(x, y)$  position. Therefore, the following `Point` declaration results in an  $X$  value of 100 and a  $Y$  value of 100, regardless of the fact that the constructor arguments specified the values 10 and 16:

```
// Calling a custom constructor.
Point pt = new Point(10, 16) { X = 100, Y = 100 };
```

Given the current definition of your `Point` type, calling the custom constructor while using initialization syntax is not terribly useful (and more than a bit verbose). However, if your `Point` type provides a new constructor that allows the caller to establish a color (via a custom enum named `PointColor`), the combination of custom constructors and object initialization syntax becomes clear. Assume you have updated `Point` as follows:

```
enum PointColor
{ LightBlue, BloodRed, Gold }

class Point
{
    public int X { get; set; }
    public int Y { get; set; }
    public PointColor Color{ get; set; }

    public Point(int xVal, int yVal)
    {
        X = xVal;
        Y = yVal;
        Color = PointColor.Gold;
    }

    public Point(PointColor ptColor)
    {
        Color = ptColor;
    }

    public Point()
        : this(PointColor.BloodRed){ }

    public void DisplayStats()
    {
        Console.WriteLine("[{0}, {1}]", X, Y);
        Console.WriteLine("Point is {0}", Color);
    }
}
```

With this new constructor, you can now create a gold point (positioned at 90, 20) as follows:

```
// Calling a more interesting custom constructor with init syntax.
Point goldPoint = new Point(PointColor.Gold){ X = 90, Y = 20 };
goldPoint.DisplayStats();
```

## Initializing Data with Initialization Syntax

As briefly mentioned earlier in this chapter (and fully examined in Chapter 6), the “has-a” relationship allows you to compose new classes by defining member variables of existing classes. For example, assume you now have a `Rectangle` class, which makes use of the `Point` type to represent its upper-left/bottom-right coordinates. Since automatic properties set all fields of class variables to `null`, you will implement this new class using “traditional” property syntax.

```
class Rectangle
{
    private Point topLeft = new Point();
    private Point bottomRight = new Point();

    public Point TopLeft
    {
        get { return topLeft; }
        set { topLeft = value; }
    }
    public Point BottomRight
    {
        get { return bottomRight; }
        set { bottomRight = value; }
    }

    public void DisplayStats()
    {
        Console.WriteLine("[TopLeft: {0}, {1}, {2} BottomRight: {3}, {4}, {5}]",
            topLeft.X, topLeft.Y, topLeft.Color,
            bottomRight.X, bottomRight.Y, bottomRight.Color);
    }
}
```

Using object initialization syntax, you could create a new `Rectangle` variable and set the inner `Points` as follows:

```
// Create and initialize a Rectangle.
Rectangle myRect = new Rectangle
{
    TopLeft = new Point { X = 10, Y = 10 },
    BottomRight = new Point { X = 200, Y = 200 }
};
```

Again, the benefit of object initialization syntax is that it basically decreases the number of keystrokes (assuming there is not a suitable constructor). Here is the traditional approach to establishing a similar `Rectangle`:

```
// Old-school approach.
Rectangle r = new Rectangle();
Point p1 = new Point();
p1.X = 10;
p1.Y = 10;
```



```

r.TopLeft = p1;
Point p2 = new Point();
p2.X = 200;
p2.Y = 200;
r.BottomRight = p2;

```

While you might feel object initialization syntax can take a bit of getting used to, once you get comfortable with the code, you'll be quite pleased at how quickly you can establish the state of a new object with minimal fuss and bother.

## Working with Constant Field Data

C# offers the `const` keyword to define constant data, which can never change after the initial assignment. As you might guess, this can be helpful when you are defining a set of known values for use in your applications that are logically connected to a given class or structure.

Assume you are building a utility class named `MyMathClass` that needs to define a value for `pi` (which you will assume to be 3.14 for simplicity). Begin by creating a new Console Application project named `ConstData`. Given that you would not want to allow other developers to change this value in code, `pi` could be modeled with the following constant:

```

namespace ConstData
{
    class MyMathClass
    {
        public const double PI = 3.14;
    }

    class Program
    {
        static void Main(string[] args)
        {
            Console.WriteLine("***** Fun with Const *****\n");
            Console.WriteLine("The value of PI is: {0}", MyMathClass.PI);
            // Error! Can't change a constant!
            // MyMathClass.PI = 3.1444;

            Console.ReadLine();
        }
    }
}

```

Notice that you are referencing the constant data defined by `MyMathClass` using a class name prefix (i.e., `MyMathClass.PI`). This is because constant fields of a class are implicitly *static*. However, it is permissible to define and access a local constant variable within the scope of a method or property. Here's an example:

```

static void LocalConstStringVariable()
{
    // A local constant data point can be directly accessed.
    const string fixedStr = "Fixed string Data";
    Console.WriteLine(fixedStr);
}

```

```
// Error!
// fixedStr = "This will not work!";
}
```

Regardless of where you define a constant piece of data, the one point to always remember is that the initial value assigned to the constant must be specified at the time you define the constant. Thus, if you were to modify your `MyMathClass` in such a way that the value of `pi` is assigned in a class constructor as follows:

```
class MyMathClass
{
    // Try to set PI in ctor?
    public const double PI;

    public MyMathClass()
    {
        // Not possible- must assign at time of declaration.
        PI = 3.14;
    }
}
```

you would receive a compile-time error. The reason for this restriction has to do with the fact the value of constant data must be known at compile time. Constructors (or any other method), as you know, are invoked at runtime.

## Understanding Read-Only Fields

Closely related to constant data is the notion of *read-only field data* (which should not be confused with a read-only property). Like a constant, a read-only field cannot be changed after the initial assignment compile-time error. However, unlike a constant, the value assigned to a read-only field can be determined at runtime and, therefore, can legally be assigned within the scope of a constructor but nowhere else.

This can be helpful when you don't know the value of a field until runtime, perhaps because you need to read an external file to obtain the value but want to ensure that the value will not change after that point. For the sake of illustration, assume the following update to `MyMathClass`:

```
class MyMathClass
{
    // Read-only fields can be assigned in ctors,
    // but nowhere else.
    public readonly double PI;

    public MyMathClass ()
    {
        PI = 3.14;
    }
}
```

Again, any attempt to make assignments to a field marked `readonly` outside the scope of a constructor results in a compiler error.

```
class MyMathClass
{
    public readonly double PI;
    public MyMathClass ()
    {
        PI = 3.14;
    }

    // Error!
    public void ChangePI()
    { PI = 3.14444; }
}
```

## Static Read-Only Fields

Unlike a constant field, read-only fields are not implicitly static. Thus, if you want to expose `PI` from the class level, you must explicitly use the `static` keyword. If you know the value of a static read-only field at compile time, the initial assignment looks similar to that of a constant (however, in this case, it would be easier to simply use the `const` keyword in the first place, as you are assigning the data field at the time of declaration).

```
class MyMathClass
{
    public static readonly double PI = 3.14;
}

class Program
{
    static void Main(string[] args)
    {
        Console.WriteLine("***** Fun with Const *****");
        Console.WriteLine("The value of PI is: {0}", MyMathClass.PI);
        Console.ReadLine();
    }
}
```

However, if the value of a static read-only field is not known until runtime, you must use a static constructor as described earlier in this chapter.

```
class MyMathClass
{
    public static readonly double PI;

    static MyMathClass()
    { PI = 3.14; }
}
```

## Understanding Partial Classes

Last but not least, it is important to understand the role of the C# `partial` keyword. A production-level class could easily consist of hundreds and hundreds (if not thousands) of lines of code within a single \*.cs file. As it turns out, when you are creating your classes, it is often the case that much of the boilerplate code can be basically ignored after it is accounted for. For example, field data, properties, and constructors tend to remain as is during production, while methods tend to be modified more often to account for updated algorithms and so forth.

In C#, you can partition a single class across multiple code files to isolate the boilerplate code from more readily useful (and complex) members. To illustrate where partial classes could be useful, open the `EmployeeApp` project you created previously in this chapter in Visual Studio, and then open the `Employee.cs` file for editing. As you recall, this single file contains code of all aspects of the class.

```
class Employee
{
    // Field Data

    // Constructors

    // Methods

    // Properties
}
```

Using partial classes, you could choose to move (for example) the properties, constructors, and field data into a new file named `Employee.Core.cs` (the name of the file is irrelevant). The first step is to add the `partial` keyword to the current class definition and cut the code to be placed into the new file.

```
// Employee.cs
partial class Employee
{
    // Methods

    // Properties
}
```

Next, assuming you have inserted a new class file into your project, you can move the data fields and properties to the new file using a simple cut-and-paste operation. In addition, you *must* add the `partial` keyword to this aspect of the class definition. Here's an example:

```
// Employee.Core.cs
partial class Employee
{
    // Field data

    // Properties
}
```

---

■ **Note** Remember that every aspect of a partial class definition must be marked with the `partial` keyword!

---

After you compile the modified project, you should see no difference whatsoever. The whole idea of a partial class is realized only during design time. After the application has been compiled, there is just a single, unified class within the assembly. The only requirement when defining partial types is that the type's name (Employee in this case) is identical and defined within the same .NET namespace.

## Use Cases for Partial Classes?

Now that you understand the mechanics of how to define a partial class, you may be wondering exactly when (and if) you will ever need to do so. To be honest, you may not need to make use of partial class definitions too often. However, Visual Studio uses them in the background all the time. For example, if you are building a graphical user interface using Windows Presentation Foundation (WPF), you will note that Visual Studio places all the designer-generated code into a dedicated partial class file, leaving you to focus on your custom programming logic (without the designer-generated code getting in the way).

More often than not, you will find partial classes to be useful when class files grow too big to be reasonably manageable. Instead of partial classes, you might consider refactoring your code into smaller, more focused classes.

## Summary

The point of this chapter was to introduce you to the role of the C# class type. As you have seen, classes can take any number of *constructors* that enable the object user to establish the state of the object upon creation. This chapter also illustrated several class design techniques (and related keywords). Recall that the `this` keyword can be used to obtain access to the current object, the `static` keyword allows you to define fields and members that are bound at the class (not object) level, and the `const` keyword (and `readonly` modifier) allows you to define a point of data that can never change after the initial assignment.

The bulk of this chapter dug into the details of the first pillar of OOP: encapsulation. You learned about the access modifiers of C# and the role of type properties, object initialization syntax, and partial classes. With this behind you, you are now able to turn to the next chapter where you will learn to build a family of related classes using inheritance and polymorphism.

## CHAPTER 6



# Understanding Inheritance and Polymorphism

Chapter 5 examined the first pillar of OOP: encapsulation. At that time, you learned how to build a single well-defined class type with constructors and various members (fields, properties, methods, constants, and read-only fields). This chapter will focus on the remaining two pillars of OOP: inheritance and polymorphism.

First, you will learn how to build families of related classes using *inheritance*. As you will see, this form of code reuse allows you to define common functionality in a parent class that can be leveraged, and possibly altered, by child classes. Along the way, you will learn how to establish a *polymorphic interface* into class hierarchies using virtual and abstract members, as well as the role of explicit casting.

The chapter will wrap up by examining the role of the ultimate parent class in the .NET base class libraries: `System.Object`.

## The Basic Mechanics of Inheritance

Recall from Chapter 5 that inheritance is an aspect of OOP that facilitates code reuse. Specifically speaking, code reuse comes in two flavors: inheritance (the “is-a” relationship) and the containment/delegation model (the “has-a” relationship). Let’s begin this chapter by examining the classical inheritance model of the “is-a” relationship.

When you establish “is-a” relationships between classes, you are building a dependency between two or more class types. The basic idea behind classical inheritance is that new classes can be created using existing classes as a starting point. To begin with a simple example, create a new Console Application project named `BasicInheritance`. Now assume you have designed a class named `Car` that models some basic details of an automobile.

```
// A simple base class.
class Car
{
    public readonly int MaxSpeed;
    private int _currSpeed;

    public Car(int max)
    {
        MaxSpeed = max;
    }
    public Car()
    {
```

```

        MaxSpeed = 55;
    }
    public int Speed
    {
        get { return _currSpeed; }
        set
        {
            _currSpeed = value;
            if (_currSpeed > MaxSpeed)
            {
                _currSpeed = MaxSpeed;
            }
        }
    }
}

```

Notice that the `Car` class is using encapsulation services to control access to the private `currSpeed` field using a public property named `Speed`. At this point, you can exercise your `Car` type as follows:

```

static void Main(string[] args)
{
    Console.WriteLine("***** Basic Inheritance *****\n");
    // Make a Car object, set max speed and current speed.
    Car myCar = new Car(80) {Speed = 50};

    // Print current speed.
    Console.WriteLine("My car is going {0} MPH", myCar.Speed);
    Console.ReadLine();
}

```

## Specifying the Parent Class of an Existing Class

Now assume you want to build a new class named `MiniVan`. Like a basic `Car`, you want to define the `MiniVan` class to support data for a maximum speed, a current speed, and a property named `Speed` to allow the object user to modify the object's state. Clearly, the `Car` and `MiniVan` classes are related; in fact, it can be said that a `MiniVan` “is-a” type of `Car`. The “is-a” relationship (formally termed *classical inheritance*) allows you to build new class definitions that extend the functionality of an existing class.

The existing class that will serve as the basis for the new class is termed a *base class*, *superclass*, or *parent class*. The role of a base class is to define all the common data and members for the classes that extend it. The extending classes are formally termed *derived* or *child* classes. In C#, you make use of the colon operator on the class definition to establish an “is-a” relationship between classes. Assume you have authored the following new `MiniVan` class:

```

// MiniVan "is-a" Car.
class MiniVan : Car
{
}

```

Currently, this new class has not defined any members whatsoever. So, what have you gained by extending your `MiniVan` from the `Car` base class? Simply put, `MiniVan` objects now have access to each public member defined within the parent class.

---

■ **Note** Although constructors are typically defined as public, a derived class never inherits the constructors of a parent class. Constructors are used to construct only the class that they are defined within, although they can be called by a derived class through constructor chaining. This will be covered shortly.

---

Given the relation between these two class types, you could now make use of the `MiniVan` class like so:

```
static void Main(string[] args)
{
    Console.WriteLine("***** Basic Inheritance *****\n");
    ...
    // Now make a MiniVan object.
    MiniVan myVan = new MiniVan {Speed = 10};
    Console.WriteLine("My van is going {0} MPH", myVan.Speed);
    Console.ReadLine();
}
```

Again, notice that although you have not added any members to the `MiniVan` class, you have direct access to the public `Speed` property of your parent class and have thus reused code. This is a far better approach than creating a `MiniVan` class that has the same members as `Car`, such as a `Speed` property. If you did duplicate code between these two classes, you would need to now maintain two bodies of code, which is certainly a poor use of your time.

Always remember that inheritance preserves encapsulation; therefore, the following code results in a compiler error, as private members can never be accessed from an object reference:

```
static void Main(string[] args)
{
    Console.WriteLine("***** Basic Inheritance *****\n");
    ...
    // Make a MiniVan object.
    MiniVan myVan = new MiniVan();
    myVan.Speed = 10;
    Console.WriteLine("My van is going {0} MPH",
        myVan.Speed);

    // Error! Can't access private members!
    myVan.currSpeed = 55;
    Console.ReadLine();
}
```

On a related note, if the `MiniVan` defined its own set of members, it would still not be able to access any private member of the `Car` base class. Remember, private members can be accessed *only* by the class that defines it. For example, the following method in `MiniVan` would result in a compiler error:

```
// MiniVan derives from Car.
class MiniVan : Car
{
    public void TestMethod()
    {
        // OK! Can access public members
    }
}
```



```

    // of a parent within a derived type.
    Speed = 10;

    // Error! Cannot access private
    // members of parent within a derived type.
    _currSpeed = 10;
}
}

```

## Regarding Multiple Base Classes

Speaking of base classes, it is important to keep in mind that C# demands that a given class have exactly *one* direct base class. It is not possible to create a class type that directly derives from two or more base classes (this technique, which is supported in unmanaged C++, is known as *multiple inheritance*, or simply *MI*). If you attempted to create a class that specifies two direct parent classes, as shown in the following code, you would receive compiler errors:

```

// Illegal! C# does not allow
// multiple inheritance for classes!
class WontWork
    : BaseClassOne, BaseClassTwo
{}

```

As you will see in Chapter 8, the .NET Core platform does allow a given class, or structure, to implement any number of discrete interfaces. In this way, a C# type can exhibit a number of behaviors while avoiding the complexities associated with MI. On a related note, while a class can have only one direct base class, it is permissible for an interface to directly derive from multiple interfaces. Using this technique, you can build sophisticated interface hierarchies that model complex behaviors (again, see Chapter 8).

## The sealed Keyword

C# supplies another keyword, *sealed*, that prevents inheritance from occurring. When you mark a class as *sealed*, the compiler will not allow you to derive from this type. For example, assume you have decided that it makes no sense to further extend the *MiniVan* class.

```

// The MiniVan class cannot be extended!
sealed class MiniVan : Car
{
}

```

If you (or a teammate) were to attempt to derive from this class, you would receive a compile-time error.

```

// Error! Cannot extend
// a class marked with the sealed keyword!
class DeluxeMiniVan
    : MiniVan
{}

```

Most often, sealing a class makes the best sense when you are designing a utility class. For example, the `System` namespace defines numerous sealed classes, such as the `String` class. Thus, just like the `MiniVan`, if you attempt to build a new class that extends `System.String`, you will receive a compile-time error.

```
// Another error! Cannot extend
// a class marked as sealed!
class MyString
    : String
{ }
```

---

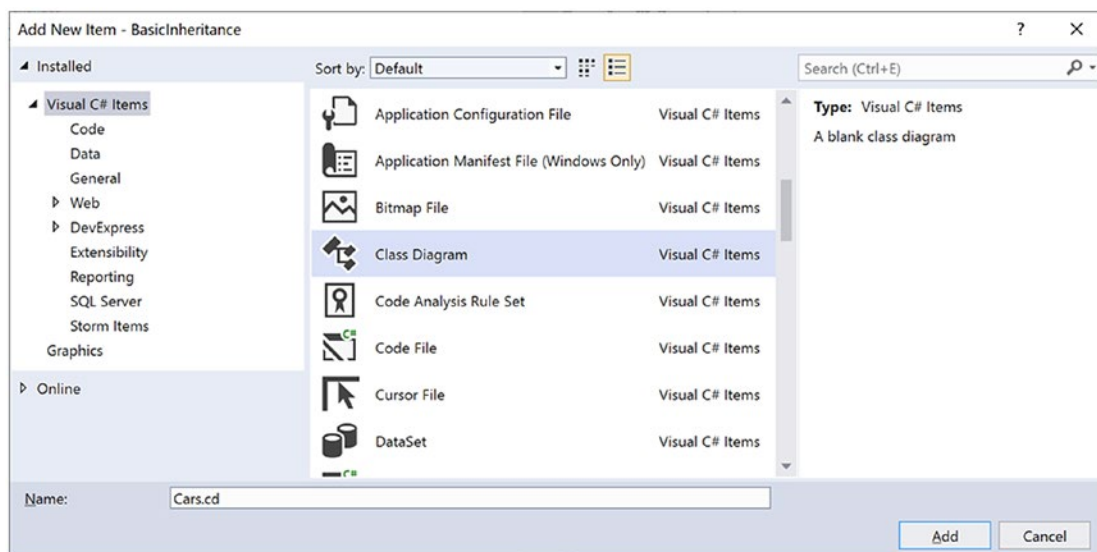
**Note** In Chapter 4, you learned that C# structures are always implicitly sealed (see Table 4-3). Therefore, you can never derive one structure from another structure, a class from a structure, or a structure from a class. Structures can be used to model only stand-alone, atomic, user-defined data types. If you want to leverage the is-a relationship, you must use classes.

---

As you would guess, there are many more details to inheritance that you will come to know during the remainder of this chapter. For now, simply keep in mind that the colon operator allows you to establish base/derived class relationships, while the `sealed` keyword prevents subsequent inheritance from occurring.

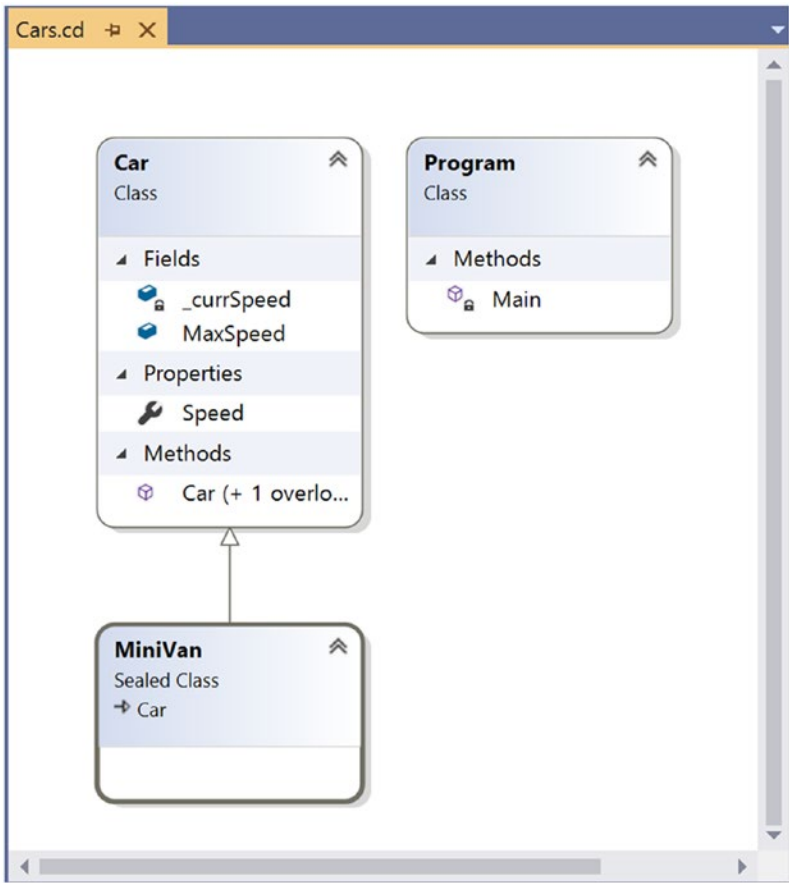
## Revisiting Visual Studio Class Diagrams

In Chapter 2, I briefly mentioned that Visual Studio allows you to establish base/derived class relationships visually at design time. To leverage this aspect of the IDE, your first step is to include a new class diagram file into your current project. To do so, access the **Project** ► **Add New Item** menu option and click the **Class Diagram** icon (in Figure 6-1, I renamed the file from `ClassDiagram1.cd` to `Cars.cd`).



**Figure 6-1.** Inserting a new class diagram

After you click the Add button, you will be presented with a blank designer surface. To add types to a class designer, simply drag each file from the Solution Explorer window onto the surface. Also recall that if you delete an item from the visual designer (simply by selecting it and pressing the Delete key), this will not destroy the associated source code but simply remove the item off the designer surface. Figure 6-2 shows the current class hierarchy.



**Figure 6-2.** The visual designer of Visual Studio

Beyond simply displaying the relationships of the types within your current application, recall from Chapter 2 that you can also create new types and populate their members using the Class Designer toolbox and Class Details window.

If you want to make use of these visual tools during the remainder of the book, feel free. However, always make sure you analyze the generated code so you have a solid understanding of what these tools have done on your behalf.

## The Second Pillar of OOP: The Details of Inheritance

Now that you have seen the basic syntax of inheritance, let's create a more complex example and get to know the numerous details of building class hierarchies. To do so, you will be reusing the `Employee` class you designed in Chapter 5. To begin, create a new C# Console Application project named `Employees`.

Next, activate the Project ➤ Add Existing Item menu option and navigate to the location of your `Employee.cs` and `Employee.Core.cs` files you created in the `EmployeeApp` example of Chapter 5. Select each of them (via a Ctrl+click) and click the Add button. Visual Studio responds by copying each file into the current project (because these are full copies, you will not need to worry about changing the original work you did in the Chapter 5 project).

Before you start to build some derived classes, you have two details to attend to. Because the original `Employee` class was created in a project named `EmployeeApp`, the class has been wrapped within an identically named `.NET Core` namespace. Chapter 16 will examine namespaces in detail; however, for simplicity, rename the current namespace (in both file locations) to `Employees` to match your new project name.

```
// Be sure to change the namespace name in both C# files!
namespace Employees
{
    partial class Employee
    {...}
}
```

The second detail is to remove any of the commented code from the different iterations of the `Employee` class from the Chapter 5 example.

---

■ **Note** As a sanity check, compile and run your new project by pressing Ctrl+F5. The program will not do anything at this point; however, this will ensure you do not have any compiler errors.

---

Your goal is to create a family of classes that model various types of employees in a company. Assume you want to leverage the functionality of the `Employee` class to create two new classes (`SalesPerson` and `Manager`). The new `SalesPerson` class “is-an” `Employee` (as is a `Manager`). Remember that under the classical inheritance model, base classes (such as `Employee`) are used to define general characteristics that are common to all descendants. Subclasses (such as `SalesPerson` and `Manager`) extend this general functionality while adding more specific functionality.

For your example, you will assume that the `Manager` class extends `Employee` by recording the number of stock options, while the `SalesPerson` class maintains the number of sales made. Insert a new class file (`Manager.cs`) that defines the `Manager` class with the following automatic property:

```
// Managers need to know their number of stock options.
class Manager : Employee
{
    public int StockOptions { get; set; }
}
```

Next, add another new class file (`SalesPerson.cs`) that defines the `SalesPerson` class with a fitting automatic property.

```
// Salespeople need to know their number of sales.
class SalesPerson : Employee
{
    public int SalesNumber { get; set; }
}
```

---

■ **Note** If you removed the default constructor during the changes to the `Employee` class in Chapter 5, make sure to add it back into the class.

---

Now that you have established an “is-a” relationship, `SalesPerson` and `Manager` have automatically inherited all public members of the `Employee` base class. To illustrate, update your `Main()` method as follows:

```
// Create a subclass object and access base class functionality.
static void Main(string[] args)
{
    Console.WriteLine("***** The Employee Class Hierarchy *****\n");
    SalesPerson fred = new SalesPerson
    {
        Age = 31, Name = "Fred", SalesNumber = 50
    };
    Console.ReadLine();
}
```

## Controlling Base Class Creation with the `base` Keyword

Currently, `SalesPerson` and `Manager` can be created only using the “freebie” default constructor (see Chapter 5). With this in mind, assume you have added a new seven-argument constructor to the `Manager` type, which is invoked as follows:

```
static void Main(string[] args)
{
    ...
    // Assume Manager has a constructor matching this signature:
    // (string fullName, int age, int empId,
    // float currPay, string ssn, int numbOfOpts)
    Manager chucky = new Manager("Chucky", 50, 92, 100000, "333-23-2322", 9000);
    Console.ReadLine();
}
```

If you look at the parameter list, you can clearly see that most of these arguments should be stored in the member variables defined by the `Employee` base class. To do so, you might implement this custom constructor on the `Manager` class as follows:

```

public Manager(string fullName, int age, int empId,
               float currPay, string ssn, int numbofOpts)
{
    // This property is defined by the Manager class.
    StockOptions = numbofOpts;

    // Assign incoming parameters using the
    // inherited properties of the parent class.
    Id = empId;
    Age = age;
    Name = fullName;
    Pay = currPay;
    PayType = EmployeePayTypeEnum.Salaried;
    // OOPS! This would be a compiler error,
    // if the SSN property were read-only!
    SocialSecurityNumber = ssn;
}

```

The first issue with this approach is that if you defined any property as read-only (e.g., the `SocialSecurityNumber` property), you are unable to assign the incoming `string` parameter to this field, as shown in the final code statement of this custom constructor.

The second issue is that you have indirectly created a rather inefficient constructor, given that under C#, unless you say otherwise, the default constructor of a base class is called automatically before the logic of the derived constructor is executed. After this point, the current implementation accesses numerous public properties of the `Employee` base class to establish its state. Thus, you have really made eight hits (six inherited properties and two constructor calls) during the creation of a `Manager` object!

To help optimize the creation of a derived class, you will do well to implement your subclass constructors to explicitly call an appropriate custom base class constructor, rather than the default. In this way, you are able to reduce the number of calls to inherited initialization members (which saves processing time). First, ensure your `Employee` parent class has the following six-argument constructor:

```

// Add to the Employee base class.
public Employee(string name, int age, int id, float pay, string empSsn, EmployeePayTypeEnum payType)
{
    Name = name;
    Id = id;
    Age = age;
    Pay = pay;
    SocialSecurityNumber = empSsn;
    PayType = payType;
}

```

Now, let's retrofit the custom constructor of the `Manager` type to call this constructor using the `base` keyword.

```

public Manager(string fullName, int age, int empId,
               float currPay, string ssn, int numbofOpts)
    : base(fullName, age, empId, currPay, ssn,
          EmployeePayTypeEnum.Salaried)
{

```

```
// This property is defined by the Manager class.
StockOptions = numbf0Opts;
}
```

Here, the `base` keyword is hanging off the constructor signature (much like the syntax used to chain constructors on a single class using the `this` keyword, as was discussed in Chapter 5), which always indicates a derived constructor is passing data to the immediate parent constructor. In this situation, you are explicitly calling the six-parameter constructor defined by `Employee` and saving yourself unnecessary calls during the creation of the child class. Additionally, you added a specific behavior to the `Manager` class, in that the `paytype` is always set to `Salaried`. The custom `SalesPerson` constructor looks almost identical, with the exception that the `pay type` is set to `Commission`.

```
// As a general rule, all subclasses should explicitly call an appropriate
// base class constructor.
public SalesPerson(string fullName, int age, int empId,
    float currPay, string ssn, int numbf0Sales)
    : base(fullName, age, empId, currPay, ssn,
        EmployeePayTypeEnum.Commission)
{
    // This belongs with us!
    SalesNumber = numbf0Sales;
}
```

---

■ **Note** You may use the `base` keyword whenever a subclass wants to access a public or protected member defined by a parent class. Use of this keyword is not limited to constructor logic. You will see examples using `base` in this manner during the examination of polymorphism, later in this chapter.

---

Finally, recall that once you add a custom constructor to a class definition, the default constructor is silently removed. Therefore, be sure to redefine the default constructor for the `SalesPerson` and `Manager` types. Here's an example:

```
// Add back the default ctor
// in the Manager class as well.
public SalesPerson() {}
```

## Keeping Family Secrets: The protected Keyword

As you already know, public items are directly accessible from anywhere, while private items can be accessed only by the class that has defined them. Recall from Chapter 5 that C# takes the lead of many other modern object languages and provides an additional keyword to define member accessibility: `protected`.

When a base class defines protected data or protected members, it establishes a set of items that can be accessed directly by any descendant. If you want to allow the `SalesPerson` and `Manager` child classes to directly access the data sector defined by `Employee`, you can update the original `Employee` class definition as follows:

```
// Protected state data.
partial class Employee
{
    // Derived classes can now directly access this information.
    protected string EmpName;
    protected int EmpId;
    protected float CurrPay;
    protected int EmpAge;
    protected string EmpSsn;
    protected EmployeePayTypeEnum EmpPayType;...
}
```

---

■ **Note** Convention is that protected members are named Pascal-Cased (EmpName) and not Underscore-Camel-Case (\_empName). This is not a requirement of the language, but a common code style. If you decide to update the names as I have done here, make sure to rename \_payType to EmpPayType, since PayType is the name of the public property.

---

The benefit of defining protected members in a base class is that derived types no longer have to access the data indirectly using public methods or properties. The possible downfall, of course, is that when a derived type has direct access to its parent's internal data, it is possible to accidentally bypass existing business rules found within public properties. When you define protected members, you are creating a level of trust between the parent class and the child class, as the compiler will not catch any violation of your type's business rules.

Finally, understand that as far as the object user is concerned, protected data is regarded as private (as the user is “outside” the family). Therefore, the following is illegal:

```
static void Main(string[] args)
{
    // Error! Can't access protected data from client code.
    Employee emp = new Employee();
    emp.empName = "Fred";
}
```

---

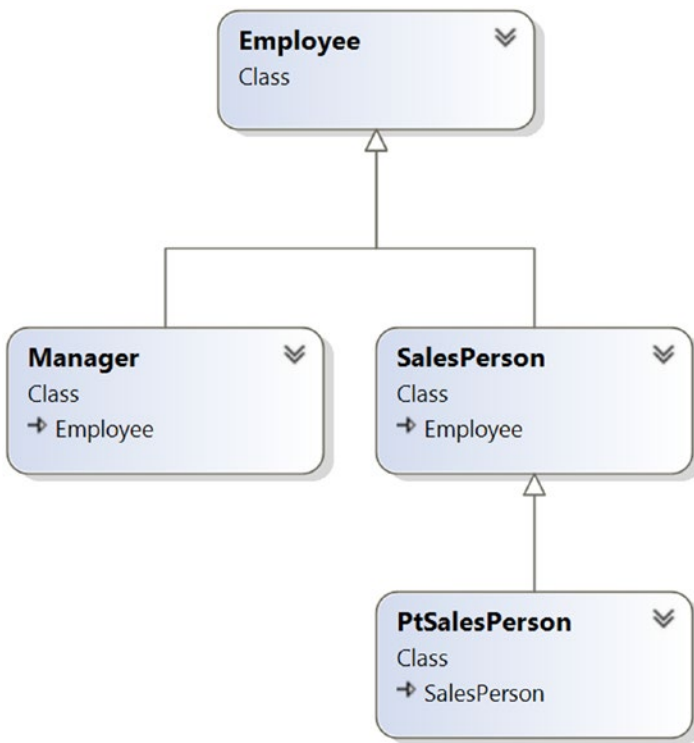
■ **Note** Although protected field data can break encapsulation, it is quite safe (and useful) to define protected methods. When building class hierarchies, it is common to define a set of methods that are only for use by derived types and are not intended for use by the outside world.

---

## Adding a sealed Class

Recall that a *sealed* class cannot be extended by other classes. As mentioned, this technique is most often used when you are designing a utility class. However, when building class hierarchies, you might find that a certain branch in the inheritance chain should be “capped off,” as it makes no sense to further extend the lineage. For example, assume you have added yet another class to your program (PtSalesPerson) that extends the existing SalesPerson type. Figure 6-3 shows the current update.





**Figure 6-3.** The *PtSalesPerson* class

*PtSalesPerson* is a class representing, of course, a part-time salesperson. For the sake of argument, let's say you want to ensure that no other developer is able to subclass from *PTSalesPerson*. (After all, how much more part-time can you get than “part-time”?) Again, to prevent others from extending a class, use the sealed keyword.

```
sealed class PtSalesPerson : SalesPerson
{
    public PtSalesPerson(string fullName, int age, int empId,
        float currPay, string ssn, int numbofSales)
        : base(fullName, age, empId, currPay, ssn, numbofSales)
    {
    }
    // Assume other members here...
}
```

## Programming for Containment/Delegation

Recall that code reuse comes in two flavors. You have just explored the classical “is-a” relationship. Before you examine the third pillar of OOP (polymorphism), let's examine the “has-a” relationship (also known as the *containment/delegation model* or *aggregation*). Assume you have created a new class that models an employee benefits package, as follows:

```
// This new type will function as a contained class.
class BenefitPackage
{
    // Assume we have other members that represent
    // dental/health benefits, and so on.
    public double ComputePayDeduction()
    {
        return 125.0;
    }
}
```

Obviously, it would be rather odd to establish an “is-a” relationship between the `BenefitPackage` class and the employee types. (Employee “is-a” `BenefitPackage`? I don’t think so.) However, it should be clear that some sort of relationship between the two could be established. In short, you would like to express the idea that each employee “has-a” `BenefitPackage`. To do so, you can update the `Employee` class definition as follows:

```
// Employees now have benefits.
partial class Employee
{
    // Contain a BenefitPackage object.
    protected BenefitPackage empBenefits = new BenefitPackage();
    ...
}
```

At this point, you have successfully contained another object. However, exposing the functionality of the contained object to the outside world requires delegation. *Delegation* is simply the act of adding public members to the containing class that use the contained object’s functionality.

For example, you could update the `Employee` class to expose the contained `empBenefits` object using a custom property, as well as make use of its functionality internally using a new method named `GetBenefitCost()`.

```
partial class Employee
{
    // Contain a BenefitPackage object.
    protected BenefitPackage EmpBenefits = new BenefitPackage();

    // Expose certain benefit behaviors of object.
    public double GetBenefitCost()
        => EmpBenefits.ComputePayDeduction();

    // Expose object through a custom property.
    public BenefitPackage Benefits
    {
        get { return EmpBenefits; }
        set { EmpBenefits = value; }
    }
    ...
}
```

In the following updated `Main()` method, notice how you can interact with the internal `BenefitsPackage` type defined by the `Employee` type:

```
static void Main(string[] args)
{
    Console.WriteLine("***** The Employee Class Hierarchy *****\n");
    ...
    Manager chucky = new Manager("Chuck", 50, 92, 100000, "333-23-2322", 9000);
    double cost = chucky.GetBenefitCost();
    Console.WriteLine($"Benefit Cost: {cost}");
    Console.ReadLine();
}
```

## Understanding Nested Type Definitions

Chapter 5 briefly mentioned the concept of nested types, which is a spin on the “has-a” relationship you have just examined. In C# (as well as other .NET languages), it is possible to define a type (enum, class, interface, struct, or delegate) directly within the scope of a class or structure. When you have done so, the nested (or “inner”) type is considered a member of the nesting (or “outer”) class and in the eyes of the runtime can be manipulated like any other member (fields, properties, methods, and events). The syntax used to nest a type is quite straightforward.

```
public class OuterClass
{
    // A public nested type can be used by anybody.
    public class PublicInnerClass {}

    // A private nested type can only be used by members
    // of the containing class.
    private class PrivateInnerClass {}
}
```

Although the syntax is fairly clear, understanding why you would want to do this might not be readily apparent. To understand this technique, ponder the following traits of nesting a type:

- Nested types allow you to gain complete control over the access level of the inner type because they may be declared privately (recall that non-nested classes cannot be declared using the `private` keyword).
- Because a nested type is a member of the containing class, it can access private members of the containing class.
- Often, a nested type is useful only as a helper for the outer class and is not intended for use by the outside world.

When a type nests another class type, it can create member variables of the type, just as it would for any point of data. However, if you want to use a nested type from outside the containing type, you must qualify it by the scope of the nesting type. Consider the following code:

```
static void Main(string[] args)
{
    // Create and use the public inner class. OK!
    OuterClass.PublicInnerClass inner;
    inner = new OuterClass.PublicInnerClass();
}
```

```
// Compiler Error! Cannot access the private class.
OuterClass.PrivateInnerClass inner2;
inner2 = new OuterClass.PrivateInnerClass();
}
```

To use this concept within the employee’s example, assume you have now nested the `BenefitPackage` directly within the `Employee` class type.

```
partial class Employee
{
    public class BenefitPackage
    {
        // Assume we have other members that represent
        // dental/health benefits, and so on.
        public double ComputePayDeduction()
        {
            return 125.0;
        }
    }
}
...
}
```

The nesting process can be as “deep” as you require. For example, assume you want to create an enumeration named `BenefitPackageLevel`, which documents the various benefit levels an employee may choose. To programmatically enforce the tight connection between `Employee`, `BenefitPackage`, and `BenefitPackageLevel`, you could nest the enumeration as follows:

```
// Employee nests BenefitPackage.
public partial class Employee
{
    // BenefitPackage nests BenefitPackageLevel.
    public class BenefitPackage
    {
        public enum BenefitPackageLevel
        {
            Standard, Gold, Platinum
        }

        public double ComputePayDeduction()
        {
            return 125.0;
        }
    }
}
...
}
```

Because of the nesting relationships, note how you are required to make use of this enumeration:

```
static void Main(string[] args)
{
    ...
    // Define my benefit level.
    Employee.BenefitPackage.BenefitPackageLevel myBenefitLevel =
        Employee.BenefitPackage.BenefitPackageLevel.Platinum;
    Console.ReadLine();
}
```

Excellent! At this point, you have been exposed to a number of keywords (and concepts) that allow you to build hierarchies of related types via classical inheritance, containment, and nested types. If the details aren't crystal clear right now, don't sweat it. You will be building a number of additional hierarchies over the remainder of this book. Next up, let's examine the final pillar of OOP: polymorphism.

## The Third Pillar of OOP: C#'s Polymorphic Support

Recall that the `Employee` base class defined a method named `GiveBonus()`, which was originally implemented as follows (before updating it to use the property pattern):

```
public partial class Employee
{
    public void GiveBonus(float amount) => _currPay += amount;
    ...
}
```

Because this method has been defined with the `public` keyword, you can now give bonuses to salespeople and managers (as well as part-time salespeople).

```
static void Main(string[] args)
{
    Console.WriteLine("***** The Employee Class Hierarchy *****\n");

    // Give each employee a bonus?
    Manager chucky = new Manager("Chucky", 50, 92, 100000, "333-23-2322", 9000);
    chucky.GiveBonus(300);
    chucky.DisplayStats();
    Console.WriteLine();

    SalesPerson fran = new SalesPerson("Fran", 43, 93, 3000, "932-32-3232", 31);
    fran.GiveBonus(200);
    fran.DisplayStats();
    Console.ReadLine();
}
```

The problem with the current design is that the publicly inherited `GiveBonus()` method operates identically for all subclasses. Ideally, the bonus of a salesperson or part-time salesperson should take into account the number of sales. Perhaps managers should gain additional stock options in conjunction with a monetary bump in salary. Given this, you are suddenly faced with an interesting question: “How can related types respond differently to the same request?” Again, glad you asked!

## The virtual and override Keywords

Polymorphism provides a way for a subclass to define its own version of a method defined by its base class, using the process termed *method overriding*. To retrofit your current design, you need to understand the meaning of the virtual and override keywords. If a base class wants to define a method that *may be* (but does not have to be) overridden by a subclass, it must mark the method with the virtual keyword.

```
partial class Employee
{
    // This method can now be "overridden" by a derived class.
    public virtual void GiveBonus(float amount)
    {
        Pay += amount;
    }
    ...
}
```

---

■ **Note** Methods that have been marked with the virtual keyword are (not surprisingly) termed *virtual methods*.

---

When a subclass wants to change the implementation details of a virtual method, it does so using the override keyword. For example, the SalesPerson and Manager could override GiveBonus() as follows (assume that PTSalesPerson will not override GiveBonus() and, therefore, simply inherits the version defined by SalesPerson):

```
class SalesPerson : Employee
{
    ...
    // A salesperson's bonus is influenced by the number of sales.
    public override void GiveBonus(float amount)
    {
        int salesBonus = 0;
        if (SalesNumber >= 0 && SalesNumber <= 100)
            salesBonus = 10;
        else
        {
            if (SalesNumber >= 101 && SalesNumber <= 200)
                salesBonus = 15;
            else
                salesBonus = 20;
        }
        base.GiveBonus(amount * salesBonus);
    }
}

class Manager : Employee
{
    ...
    public override void GiveBonus(float amount)
```

```

{
    base.GiveBonus(amount);
    Random r = new Random();
    StockOptions += r.Next(500);
}
}

```

Notice how each overridden method is free to leverage the default behavior using the base keyword.

In this way, you have no need to completely reimplement the logic behind `GiveBonus()` but can reuse (and possibly extend) the default behavior of the parent class.

Also assume that the current `DisplayStats()` method of the `Employee` class has been declared virtually.

```

public virtual void DisplayStats()
{
    Console.WriteLine("Name: {0}", Name);
    Console.WriteLine("ID: {0}", ID);
    Console.WriteLine("Age: {0}", Age);
    Console.WriteLine("Pay: {0}", Pay);
    Console.WriteLine("SSN: {0}", SocialSecurityNumber);
}

```

By doing so, each subclass can override this method to account for displaying the number of sales (for salespeople) and current stock options (for managers). For example, consider the `Manager`'s version of the `DisplayStats()` method (the `SalesPerson` class would implement `DisplayStats()` in a similar manner to show the number of sales).

```

public override void DisplayStats()
{
    base.DisplayStats();
    Console.WriteLine("Number of Stock Options: {0}", StockOptions);
}

```

Now that each subclass can interpret what these virtual methods mean for itself, each object instance behaves as a more independent entity.

```

static void Main(string[] args)
{
    Console.WriteLine("***** The Employee Class Hierarchy *****\n");

    // A better bonus system!
    Manager chucky = new Manager("Chuck", 50, 92, 100000, "333-23-2322", 9000);
    chucky.GiveBonus(300);
    chucky.DisplayStats();
    Console.WriteLine();

    SalesPerson fran = new SalesPerson("Fran", 43, 93, 3000, "932-32-3232", 31);
    fran.GiveBonus(200);
    fran.DisplayStats();
    Console.ReadLine();
}

```

The following output shows a possible test run of your application thus far:

---

```
***** The Employee Class Hierarchy *****
Name: Chucky
ID: 92
Age: 50
Pay: 100300
SSN: 333-23-2322
Number of Stock Options: 9337

Name: Fran
ID: 93
Age: 43
Pay: 5000
SSN: 932-32-3232
Number of Sales: 31
```

---

## Overriding Virtual Members Using the Visual Studio IDE

As you might have already noticed, when you are overriding a member, you must recall the type of every parameter – not to mention the method name and parameter-passing conventions (ref, out, and params). Visual Studio has a helpful feature that you can make use of when overriding a virtual member. If you type the word `override` within the scope of a class type (then hit the spacebar), IntelliSense will automatically display a list of all the overridable members defined in your parent classes, excluding methods already overridden.

When you select a member and hit the Enter key, the IDE responds by automatically filling in the method stub on your behalf. Note that you also receive a code statement that calls your parent's version of the virtual member (you are free to delete this line if it is not required). For example, if you used this technique when overriding the `DisplayStats()` method, you might find the following autogenerated code:

```
public override void DisplayStats()
{
    base.DisplayStats();
}
```

## Sealing Virtual Members

Recall that the `sealed` keyword can be applied to a class type to prevent other types from extending its behavior via inheritance. As you might remember, you sealed `PtSalesPerson` because you assumed it made no sense for other developers to extend this line of inheritance any further.

On a related note, sometimes you might not want to seal an entire class but simply want to prevent derived types from overriding particular virtual methods. For example, assume you do not want part-time salespeople to obtain customized bonuses. To prevent the `PTSalesPerson` class from overriding the virtual `GiveBonus()` method, you could effectively seal this method in the `SalesPerson` class as follows:

```
// SalesPerson has sealed the GiveBonus() method!
class SalesPerson : Employee
{
    ...
}
```



```

public override sealed void GiveBonus(float amount)
{
    ...
}
}

```

Here, `SalesPerson` has indeed overridden the virtual `GiveBonus()` method defined in the `Employee` class; however, it has explicitly marked it as sealed. Thus, if you attempted to override this method in the `PtSalesPerson` class, you would receive compile-time errors, as shown in the following code:

```

sealed class PTSalesPerson : SalesPerson
{
    ...
    // Compiler error! Can't override this method
    // in the PTSalesPerson class, as it was sealed.
    public override void GiveBonus(float amount)
    {
    }
}

```

## Understanding Abstract Classes

Currently, the `Employee` base class has been designed to supply various data members for its descendants, as well as supply two virtual methods (`GiveBonus()` and `DisplayStats()`) that may be overridden by a given descendant. While this is all well and good, there is a rather odd byproduct of the current design; you can directly create instances of the `Employee` base class.

```

// What exactly does this mean?
Employee X = new Employee();

```

In this example, the only real purpose of the `Employee` base class is to define common members for all subclasses. In all likelihood, you did not intend anyone to create a direct instance of this class, reason being that the `Employee` type itself is too general of a concept. For example, if I were to walk up to you and say “I’m an employee!”, I would bet your first question to me would be “What *kind* of employee are you?” “Are you a consultant, trainer, admin assistant, copyeditor, or White House aide?”

Given that many base classes tend to be rather nebulous entities, a far better design for this example is to prevent the ability to directly create a new `Employee` object in code. In C#, you can enforce this programmatically by using the `abstract` keyword in the class definition, thus creating an *abstract base class*.

```

// Update the Employee class as abstract
// to prevent direct instantiation.
abstract partial class Employee
{
    ...
}

```

With this, if you now attempt to create an instance of the `Employee` class, you are issued a compile-time error.

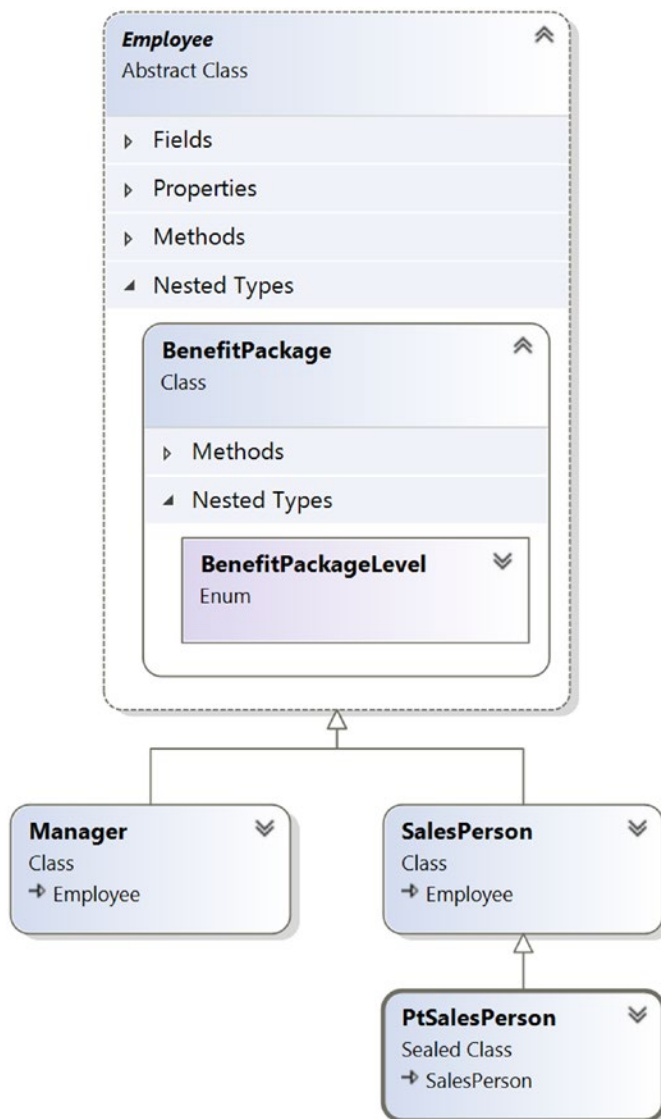
```

// Error! Cannot create an instance of an abstract class!
Employee X = new Employee();

```

At first glance, it might seem strange to define a class that you cannot directly create an instance of. Recall, however, that base classes (abstract or not) are useful, in that they contain all the common data and functionality of derived types. Using this form of abstraction, you are able to model that the “idea” of an employee is completely valid; it is just not a concrete entity. Also understand that although you cannot *directly* create an instance of an abstract class, it is still assembled in memory when derived classes are created. Thus, it is perfectly fine (and common) for abstract classes to define any number of constructors that are called *indirectly* when derived classes are allocated.

At this point, you have constructed a fairly interesting employee hierarchy. You will add a bit more functionality to this application later in this chapter when examining C# casting rules. Until then, Figure 6-4 illustrates the crux of your current design.



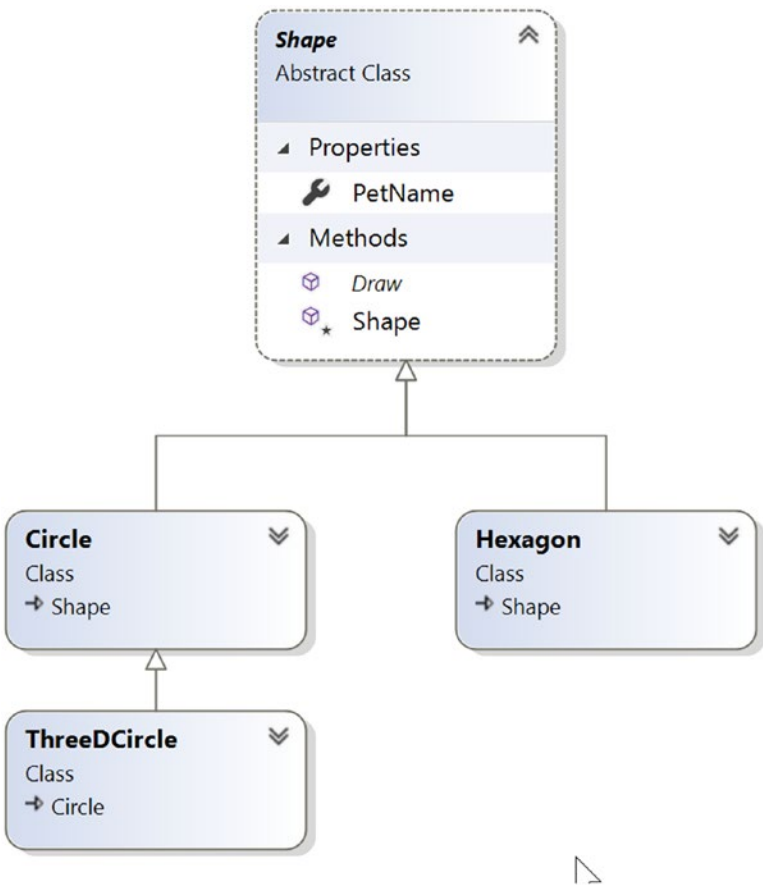
**Figure 6-4.** The Employee hierarchy

## Understanding the Polymorphic Interface

When a class has been defined as an abstract base class (via the `abstract` keyword), it may define any number of *abstract members*. Abstract members can be used whenever you want to define a member that does *not* supply a default implementation but *must* be accounted for by each derived class. By doing so, you enforce a *polymorphic interface* on each descendant, leaving them to contend with the task of providing the details behind your abstract methods.

Simply put, an abstract base class’s polymorphic interface simply refers to its set of virtual and abstract methods. This is much more interesting than first meets the eye because this trait of OOP allows you to build easily extendable and flexible software applications. To illustrate, you will be implementing (and slightly modifying) the hierarchy of shapes briefly examined in Chapter 5 during the overview of the pillars of OOP. To begin, create a new C# Console Application project named Shapes.

In Figure 6-5, notice that the `Hexagon` and `Circle` types each extend the `Shape` base class. Like any base class, `Shape` defines a number of members (a `PetName` property and `Draw()` method, in this case) that are common to all descendants.



**Figure 6-5.** The shapes hierarchy

Much like the employee hierarchy, you should be able to tell that you don't want to allow the object user to create an instance of `Shape` directly, as it is too abstract of a concept. Again, to prevent the direct creation of the `Shape` type, you could define it as an abstract class. As well, given that you want the derived types to respond uniquely to the `Draw()` method, let's mark it as `virtual` and define a default implementation. Notice that the constructor is marked as `protected` so it can only be called from derived classes.

```
// The abstract base class of the hierarchy.
abstract class Shape
{
    protected Shape(string name = "NoName")
    { PetName = name; }

    public string PetName { get; set; }

    // A single virtual method.
    public virtual void Draw()
    {
        Console.WriteLine("Inside Shape.Draw()");
    }
}
```

Notice that the virtual `Draw()` method provides a default implementation that simply prints out a message that informs you that you are calling the `Draw()` method within the `Shape` base class. Now recall that when a method is marked with the `virtual` keyword, the method provides a default implementation that all derived types automatically inherit. If a child class so chooses, it *may* override the method but does not *have* to. Given this, consider the following implementation of the `Circle` and `Hexagon` types:

```
// Circle DOES NOT override Draw().
class Circle : Shape
{
    public Circle() {}
    public Circle(string name) : base(name){}
}

// Hexagon DOES override Draw().
class Hexagon : Shape
{
    public Hexagon() {}
    public Hexagon(string name) : base(name){}
    public override void Draw()
    {
        Console.WriteLine("Drawing {0} the Hexagon", PetName);
    }
}
```

The usefulness of abstract methods becomes crystal clear when you once again remember that subclasses are *never required* to override virtual methods (as in the case of `Circle`). Therefore, if you create an instance of the `Hexagon` and `Circle` types, you'd find that the `Hexagon` understands how to "draw" itself correctly or at least print out an appropriate message to the console. The `Circle`, however, is more than a bit confused.

```
static void Main(string[] args)
{
    Console.WriteLine("***** Fun with Polymorphism *****\n");

    Hexagon hex = new Hexagon("Beth");
    hex.Draw();
    Circle cir = new Circle("Cindy");
    // Calls base class implementation!
    cir.Draw();
    Console.ReadLine();
}
```

Now consider the following output of the previous `Main()` method:

---

```
***** Fun with Polymorphism *****

Drawing Beth the Hexagon
Inside Shape.Draw()
```

---

Clearly, this is not an intelligent design for the current hierarchy. To force each child class to override the `Draw()` method, you can define `Draw()` as an abstract method of the `Shape` class, which by definition means you provide no default implementation whatsoever. To mark a method as abstract in C#, you use the `abstract` keyword. Notice that abstract members do not provide any implementation whatsoever.

```
abstract class Shape
{
    // Force all child classes to define how to be rendered.
    public abstract void Draw();
    ...
}
```

---

■ **Note** Abstract methods can be defined only in abstract classes. If you attempt to do otherwise, you will be issued a compiler error.

---

Methods marked with `abstract` are pure protocol. They simply define the name, return type (if any), and parameter set (if required). Here, the abstract `Shape` class informs the derived types that “I have a method named `Draw()` that takes no arguments and returns nothing. If you derive from me, you figure out the details.”

Given this, you are now obligated to override the `Draw()` method in the `Circle` class. If you do not, `Circle` is also assumed to be a noncreatable abstract type that must be adorned with the `abstract` keyword (which is obviously not useful in this example). Here is the code update:

```
// If we did not implement the abstract Draw() method, Circle would also be
// considered abstract, and would have to be marked abstract!
class Circle : Shape
{
    public Circle() {}
}
```

```

public Circle(string name) : base(name) {}
public override void Draw()
{
    Console.WriteLine("Drawing {0} the Circle", PetName);
}
}

```

The short answer is that you can now assume that anything deriving from `Shape` does indeed have a unique version of the `Draw()` method. To illustrate the full story of polymorphism, consider the following code:

```

static void Main(string[] args)
{
    Console.WriteLine("***** Fun with Polymorphism *****\n");

    // Make an array of Shape-compatible objects.
    Shape[] myShapes = {new Hexagon(), new Circle(), new Hexagon("Mick"),
        new Circle("Beth"), new Hexagon("Linda")};

    // Loop over each item and interact with the
    // polymorphic interface.
    foreach (Shape s in myShapes)
    {
        s.Draw();
    }
    Console.ReadLine();
}

```

Here is the output from the modified `Main()` method:

---

```

***** Fun with Polymorphism *****

Drawing NoName the Hexagon
Drawing NoName the Circle
Drawing Mick the Hexagon
Drawing Beth the Circle
Drawing Linda the Hexagon

```

---

This `Main()` method illustrates polymorphism at its finest. Although it is not possible to *directly* create an instance of an abstract base class (the `Shape`), you are able to freely store references to any subclass with an abstract base variable. Therefore, when you are creating an array of `Shapes`, the array can hold any object deriving from the `Shape` base class (if you attempt to place `Shape`-incompatible objects into the array, you receive a compiler error).

Given that all items in the `myShapes` array do indeed derive from `Shape`, you know they all support the same “polymorphic interface” (or said more plainly, they all have a `Draw()` method). As you iterate over the array of `Shape` references, it is at runtime that the underlying type is determined. At this point, the correct version of the `Draw()` method is invoked in memory.

This technique also makes it simple to safely extend the current hierarchy. For example, assume you derived more classes from the abstract `Shape` base class (`Triangle`, `Square`, etc.). Because of the polymorphic interface, the code within your `foreach` loop would not have to change in the slightest, as the compiler enforces that only `Shape`-compatible types are placed within the `myShapes` array.

## Understanding Member Shadowing

C# provides a facility that is the logical opposite of method overriding, termed *shadowing*. Formally speaking, if a derived class defines a member that is identical to a member defined in a base class, the derived class has shadowed the parent's version. In the real world, the possibility of this occurring is the greatest when you are subclassing from a class you (or your team) did not create yourself (such as when you purchase a third-party software package).

For the sake of illustration, assume you receive a class named `ThreeDCircle` from a coworker (or classmate) that defines a subroutine named `Draw()` taking no arguments.

```
class ThreeDCircle
{
    public void Draw()
    {
        Console.WriteLine("Drawing a 3D Circle");
    }
}
```

You figure that a `ThreeDCircle` “is-a” `Circle`, so you derive from your existing `Circle` type.

```
class ThreeDCircle : Circle
{
    public void Draw()
    {
        Console.WriteLine("Drawing a 3D Circle");
    }
}
```

After you recompile, you find the following warning:

---

'ThreeDCircle.Draw()' hides inherited member 'Circle.Draw()'. To make the current member override that implementation, add the `override` keyword. Otherwise add the `new` keyword.

---

The problem is that you have a derived class (`ThreeDCircle`) that contains a method that is identical to an inherited method. To address this issue, you have a few options. You could simply update the parent's version of `Draw()` using the `override` keyword (as suggested by the compiler). With this approach, the `ThreeDCircle` type is able to extend the parent's default behavior as required. However, if you don't have access to the code defining the base class (again, as would be the case in many third-party libraries), you would be unable to modify the `Draw()` method as a virtual member, as you don't have access to the code file!

As an alternative, you can include the `new` keyword to the offending `Draw()` member of the derived type (`ThreeDCircle`, in this example). Doing so explicitly states that the derived type's implementation is intentionally designed to effectively ignore the parent's version (again, in the real world, this can be helpful if external software somehow conflicts with your current software).

```
// This class extends Circle and hides the inherited Draw() method.
class ThreeDCircle : Circle
{
    // Hide any Draw() implementation above me.
```

```

public new void Draw()
{
    Console.WriteLine("Drawing a 3D Circle");
}
}

```

You can also apply the `new` keyword to any member type inherited from a base class (field, constant, static member, or property). As a further example, assume that `ThreeDCircle` wants to hide the inherited `PetName` property.

```

class ThreeDCircle : Circle
{
    // Hide the PetName property above me.
    public new string PetName { get; set; }

    // Hide any Draw() implementation above me.
    public new void Draw()
    {
        Console.WriteLine("Drawing a 3D Circle");
    }
}

```

Finally, be aware that it is still possible to trigger the base class implementation of a shadowed member using an explicit cast, as described in the next section. The following code shows an example:

```

static void Main(string[] args)
{
    ...
    // This calls the Draw() method of the ThreeDCircle.
    ThreeDCircle o = new ThreeDCircle();
    o.Draw();

    // This calls the Draw() method of the parent!
    ((Circle)o).Draw();
    Console.ReadLine();
}

```

## Understanding Base Class/Derived Class Casting Rules

Now that you can build a family of related class types, you need to learn the rules of class *casting operations*. To do so, let's return to the `Employee` hierarchy created earlier in this chapter and add some new methods to the `Program` class (if you are following along, open the `Employees` project in Visual Studio). As described later in this chapter, the ultimate base class in the system is `System.Object`. Therefore, everything “is-an” `Object` and can be treated as such. Given this fact, it is legal to store an instance of any type within an object variable.

```

static void CastingExamples()
{
    // A Manager "is-a" System.Object, so we can
    // store a Manager reference in an object variable just fine.
    object frank = new Manager("Frank Zappa", 9, 3000, 40000, "111-11-1111", 5);
}

```



In the Employees project, Managers, SalesPerson, and PtSalesPerson types all extend Employee, so you can store any of these objects in a valid base class reference. Therefore, the following statements are also legal:

```
static void CastingExamples()
{
    // A Manager "is-a" System.Object, so we can
    // store a Manager reference in an object variable just fine.
    object frank = new Manager("Frank Zappa", 9, 3000, 40000, "111-11-1111", 5);

    // A Manager "is-an" Employee too.
    Employee moonUnit = new Manager("MoonUnit Zappa", 2, 3001, 20000, "101-11-1321", 1);

    // A PtSalesPerson "is-a" SalesPerson.
    SalesPerson jill = new PtSalesPerson("Jill", 834, 3002, 100000, "111-12-1119", 90);
}
```

The first law of casting between class types is that when two classes are related by an “is-a” relationship, it is always safe to store a derived object within a base class reference. Formally, this is called an *implicit cast*, as “it just works” given the laws of inheritance. This leads to some powerful programming constructs. For example, assume you have defined a new method within your current Program class.

```
static void GivePromotion(Employee emp)
{
    // Increase pay...
    // Give new parking space in company garage...

    Console.WriteLine("{0} was promoted!", emp.Name);
}
```

Because this method takes a single parameter of type Employee, you can effectively pass any descendant from the Employee class into this method directly, given the “is-a” relationship.

```
static void CastingExamples()
{
    // A Manager "is-a" System.Object, so we can
    // store a Manager reference in an object variable just fine.
    object frank = new Manager("Frank Zappa", 9, 3000, 40000, "111-11-1111", 5);

    // A Manager "is-an" Employee too.
    Employee moonUnit = new Manager("MoonUnit Zappa", 2, 3001, 20000, "101-11-1321", 1);
    GivePromotion(moonUnit);

    // A PTSalesPerson "is-a" SalesPerson.
    SalesPerson jill = new PtSalesPerson("Jill", 834, 3002, 100000, "111-12-1119", 90);
    GivePromotion(jill);
}
```

The previous code compiles given the implicit cast from the base class type (Employee) to the derived type. However, what if you also wanted to promote Frank Zappa (currently stored in a general System.Object reference)? If you pass the frank object directly into this method, you will find a compiler error as follows:

```
object frank = new Manager("Frank Zappa", 9, 3000, 40000, "111-11-1111", 5);
// Error!
GivePromotion(frank);
```

The problem is that you are attempting to pass in a variable that is not declared as an `Employee` but a more general `System.Object`. Given that `object` is higher up the inheritance chain than `Employee`, the compiler will not allow for an implicit cast, in an effort to keep your code as type-safe as possible.

Even though you can figure out that the `object` reference is pointing to an `Employee`-compatible class in memory, the compiler cannot, as that will not be known until runtime. You can satisfy the compiler by performing an *explicit cast*. This is the second law of casting: you can, in such cases, explicitly downcast using the C# casting operator. The basic template to follow when performing an explicit cast looks something like the following:

```
(ClassIWantToCastTo)referenceIHave
```

Thus, to pass the `object` variable into the `GivePromotion()` method, you could author the following code:

```
// OK!
GivePromotion((Manager)frank);
```

## The C# as Keyword

Be aware that explicit casting is evaluated at *runtime*, not compile time. For the sake of argument, assume your `Employees` project had a copy of the `Hexagon` class created earlier in this chapter. For simplicity, you could add the following class to the current project:

```
class Hexagon
{
    public void Draw()
    {
        Console.WriteLine("Drawing a hexagon!");
    }
}
```

Although casting the `employee` object to a `shape` object makes absolutely no sense, code such as the following could compile without error:

```
// Ack! You can't cast frank to a Hexagon, but this compiles fine!
object frank = new Manager();
Hexagon hex = (Hexagon)frank;
```

However, you would receive a runtime error, or, more formally, a *runtime exception*. Chapter 7 will examine the full details of structured exception handling; however, it is worth pointing out, for the time being, that when you are performing an explicit cast, you can trap the possibility of an invalid cast using the `try` and `catch` keywords (again, see Chapter 7 for full details).

```
// Catch a possible invalid cast.
object frank = new Manager();
Hexagon hex;
try
```

```

{
    hex = (Hexagon)frank;
}
catch (InvalidCastException ex)
{
    Console.WriteLine(ex.Message);
}

```

Obviously, this is a contrived example; you would never bother casting between these types in this situation. However, assume you have an array of `System.Object` types, only a few of which contain `Employee`-compatible objects. In this case, you would like to determine whether an item in an array is compatible to begin with and, if so, perform the cast.

C# provides the `as` keyword to quickly determine at runtime whether a given type is compatible with another. When you use the `as` keyword, you are able to determine compatibility by checking against a `null` return value. Consider the following:

```

// Use "as" to test compatibility.
object[] things = new object[4];
things[0] = new Hexagon();
things[1] = false;
things[2] = new Manager();
things[3] = "Last thing";

foreach (object item in things)
{
    Hexagon h = item as Hexagon;
    if (h == null)
    {
        Console.WriteLine("Item is not a hexagon");
    }
    else
    {
        h.Draw();
    }
}

```

Here, you loop over each item in the array of objects, checking each one for compatibility with the `Hexagon` class. If (and only if!) you find a `Hexagon`-compatible object, you invoke the `Draw()` method. Otherwise, you simply report the items are not compatible.

## The C# `is` Keyword (Updated 7.0)

In addition to the `as` keyword, the C# language provides the `is` keyword to determine whether two items are compatible. Unlike the `as` keyword, however, the `is` keyword returns `false`, rather than a `null` reference, if the types are incompatible. Currently, the `GivePromotion()` method has been designed to take any possible type derived from `Employee`. Consider the following update, which now checks to see exactly which “type of employee” you have been passed:

```

static void GivePromotion(Employee emp)
{
    Console.WriteLine("{0} was promoted!", emp.Name);
    if (emp is SalesPerson)
    {
        Console.WriteLine("{0} made {1} sale(s)!", emp.Name,
            ((SalesPerson)emp).SalesNumber);
        Console.WriteLine();
    }
    else if (emp is Manager)
    {
        Console.WriteLine("{0} had {1} stock options...", emp.Name,
            ((Manager)emp).StockOptions);
        Console.WriteLine();
    }
}

```

Here, you are performing a runtime check to determine what the incoming base class reference is actually pointing to in memory. After you determine whether you received a `SalesPerson` or `Manager` type, you are able to perform an explicit cast to gain access to the specialized members of the class. Also notice that you are not required to wrap your casting operations within a `try/catch` construct, as you know that the cast is safe if you enter either `if` scope, given your conditional check.

New in C# 7.0, the `is` keyword can also assign the converted type to a variable if the cast works. This cleans up the preceding method by preventing the “double-cast” problem. In the preceding example, the first cast is done when checking to see whether the type matches, and if it does, then the variable has to be cast again. Consider this update to the preceding method:

```

static void GivePromotion(Employee emp)
{
    Console.WriteLine("{0} was promoted!", emp.Name);
    //Check if is SalesPerson, assign to variable s
    if (emp is SalesPerson s)
    {
        Console.WriteLine("{0} made {1} sale(s)!", s.Name,
            s.SalesNumber);
        Console.WriteLine();
    }
    //Check if is Manager, if it is, assign to variable m
    else if (emp is Manager m)
    {
        Console.WriteLine("{0} had {1} stock options...",
            m.Name, m.StockOptions);
        Console.WriteLine();
    }
}

```

## Discards with the is Keyword (New 7.0)

The `is` keyword can also be used in conjunction with the discard variable placeholder. If you want to create a catchall in your `if` or `switch` statement, you can do so as follows:

```
if (obj is var _)
{
    //do something
}
```

This will match everything, so be careful about the order in which you use the comparer with the `discard`. The updated `GivePromotion` method is shown here:

```
if (emp is SalesPerson s)
{
    Console.WriteLine("{0} made {1} sale(s)!", s.Name, s.SalesNumber);
    Console.WriteLine();
}
//Check if is Manager, if it is, assign to variable m
else if (emp is Manager m)
{
    Console.WriteLine("{0} had {1} stock options...", m.Name, m.StockOptions);
    Console.WriteLine();
}
else if (emp is var _)
{
    Console.WriteLine("Unable to promote {0}. Wrong employee type", emp.Name);
    Console.WriteLine();
}
```

The final `if` statement will catch any `Employee` instance that is not a `Manager`, `SalesPerson`, or `PtSalesPerson`. Remember that you can downcast to a base class, so the `PtSalesPerson` *will* register as a `SalesPerson`.

## Pattern Matching Revisited (New 7.0)

Chapter 3 introduced the C# 7 feature of pattern matching. Now that you have a firm understanding of casting, it's time for a better example. The preceding example can now be cleanly updated to use a pattern matching `switch` statement, as follows:

```
static void GivePromotion(Employee emp)
{
    Console.WriteLine("{0} was promoted!", emp.Name);
    switch (emp)
    {
        case SalesPerson s:
            Console.WriteLine("{0} made {1} sale(s)!", emp.Name,
                s.SalesNumber);
            break;
        case Manager m:
            Console.WriteLine("{0} had {1} stock options...",
```

```

        emp.Name, m.StockOptions);
    break;
}
Console.WriteLine();
}

```

When adding a **when** clause to the **case** statement, the full definition of the object *as it is cast* is available for use. For example, the `SalesNumber` property exists only on the `SalesPerson` class and not the `Employee` class. If the cast in the first case statement succeeds, the variable `s` will hold an instance of a `SalesPerson` class, so the case statement could be updated to the following:

```
case SalesPerson s when s.SalesNumber > 5:
```

These new additions to the `is` and `switch` statements provide nice improvements that help reduce the amount of code to perform matching, as the previous examples demonstrated.

## Discards with switch Statements (New 7.0)

Discards can also be used in `switch` statements, as shown in the following code:

```

switch (emp)
{
    case SalesPerson s when s.SalesNumber > 5:
        Console.WriteLine("{0} made {1} sale(s)!", emp.Name,
            s.SalesNumber);
        break;
    case Manager m:
        Console.WriteLine("{0} had {1} stock options...",
            emp.Name, m.StockOptions);
        break;
    case Employee _:
        Console.WriteLine("Unable to promote {0}. Wrong employee type", emp.Name);
        break;
}

```

Every type coming in is already an `Employee`, so the final case statement is always true. However, as discussed when pattern matching was introduced in Chapter 3, once a match is made, the `switch` statement is exited. This demonstrates the importance of getting the order correct. If the final statement was moved to the top, no `Employee` would ever be promoted.

## The Super Parent Class: System.Object

To wrap up this chapter, I'd like to examine the details of the super parent class: `Object`. As you were reading the previous section, you might have noticed that the base classes in your hierarchies (`Car`, `Shape`, `Employee`) never explicitly specify their parent classes.

```

// Who is the parent of Car?
class Car
{...}

```

In the .NET Core universe, every type ultimately derives from a base class named `System.Object`, which can be represented by the C# `object` keyword (lowercase *o*). The `Object` class defines a set of common members for every type in the framework. In fact, when you do build a class that does not explicitly define its parent, the compiler automatically derives your type from `Object`. If you want to be clear in your intentions, you are free to define classes that derive from `Object` as follows (however, again, there is no need to do so):

```
// Here we are explicitly deriving from System.Object.
class Car : object
{...}
```

Like any class, `System.Object` defines a set of members. In the following formal C# definition, note that some of these items are declared `virtual`, which specifies that a given member may be overridden by a subclass, while others are marked with `static` (and are therefore called at the class level):

```
public class Object
{
    // Virtual members.
    public virtual bool Equals(object obj);
    protected virtual void Finalize();
    public virtual int GetHashCode();
    public virtual string ToString();

    // Instance-level, nonvirtual members.
    public Type GetType();
    protected object MemberwiseClone();

    // Static members.
    public static bool Equals(object objA, object objB);
    public static bool ReferenceEquals(object objA, object objB);
}
```

Table 6-1 offers a rundown of the functionality provided by some of the methods you’re most likely to use.

**Table 6-1.** Core Members of *System.Object*

Instance Method of Object Class	Meaning in Life
<code>Equals()</code>	<p>By default, this method returns <code>true</code> only if the items being compared refer to the same item in memory. Thus, <code>Equals()</code> is used to compare object references, not the state of the object. Typically, this method is overridden to return <code>true</code> only if the objects being compared have the same internal state values (i.e., value-based semantics).</p> <p>Be aware that if you override <code>Equals()</code>, you should also override <code>GetHashCode()</code>, as these methods are used internally by <code>Hashtable</code> types to retrieve subobjects from the container.</p> <p>Also recall from Chapter 4 that the <code>ValueType</code> class overrides this method for all structures, so they work with value-based comparisons.</p>

(continued)

**Table 6-1.** (continued)

Instance Method of Object Class	Meaning in Life
Finalize()	For the time being, you can understand this method (when overridden) is called to free any allocated resources before the object is destroyed. I talk more about the CoreCLR garbage collection services in Chapter 9.
GetHashCode()	This method returns an <code>int</code> that identifies a specific object instance.
ToString()	This method returns a string representation of this object, using the <code>&lt;namespace&gt;.&lt;type name&gt;</code> format (termed the <i>fully qualified name</i> ). This method will often be overridden by a subclass to return a tokenized string of name/value pairs that represent the object's internal state, rather than its fully qualified name.
GetType()	This method returns a <code>Type</code> object that fully describes the object you are currently referencing. In short, this is a Runtime Type Identification (RTTI) method available to all objects (discussed in greater detail in Chapter 16).
MemberwiseClone()	This method exists to return a member-by-member copy of the current object, which is often used when cloning an object (see Chapter 8).

To illustrate some of the default behavior provided by the `Object` base class, create a final C# Console Application project named `ObjectOverrides`. Insert a new C# class type that contains the following empty class definition for a type named `Person`:

```
// Remember! Person extends Object.
class Person {}
```

Now, update your `Main()` method to interact with the inherited members of `System.Object` as follows:

```
class Program
{
    static void Main(string[] args)
    {
        Console.WriteLine("***** Fun with System.Object *****\n");
        Person p1 = new Person();

        // Use inherited members of System.Object.
        Console.WriteLine("ToString: {0}", p1.ToString());
        Console.WriteLine("Hash code: {0}", p1.GetHashCode());
        Console.WriteLine("Type: {0}", p1.GetType());

        // Make some other references to p1.
        Person p2 = p1;
        object o = p2;
        // Are the references pointing to the same object in memory?
        if (o.Equals(p1) && p2.Equals(o))
        {
            Console.WriteLine("Same instance!");
        }
    }
}
```



```

        Console.ReadLine();
    }
}

```

Here is the output of the current `Main()` method:

---

```
***** Fun with System.Object *****
```

```

ToString: ObjectOverrides.Person
Hash code: 58225482
Type: ObjectOverrides.Person
Same instance!

```

---

Notice how the default implementation of `ToString()` returns the fully qualified name of the current type (`ObjectOverrides.Person`). As you will see later during the examination of building custom namespaces in Chapter 15, every C# project defines a “root namespace,” which has the same name of the project itself. Here, you created a project named `ObjectOverrides`; thus, the `Person` type and the `Program` class have both been placed within the `ObjectOverrides` namespace.

The default behavior of `Equals()` is to test whether two variables are pointing to the same object in memory. Here, you create a new `Person` variable named `p1`. At this point, a new `Person` object is placed on the managed heap. `p2` is also of type `Person`. However, you are not creating a *new* instance but rather assigning this variable to reference `p1`. Therefore, `p1` and `p2` are both pointing to the same object in memory, as is the variable `o` (of type `object`, which was thrown in for good measure). Given that `p1`, `p2`, and `o` all point to the same memory location, the equality test succeeds.

Although the canned behavior of `System.Object` can fit the bill in a number of cases, it is quite common for your custom types to override some of these inherited methods. To illustrate, update the `Person` class to support some properties representing an individual’s first name, last name, and age, each of which can be set by a custom constructor.

```

// Remember! Person extends Object.
class Person
{
    public string FirstName { get; set; } = "";
    public string LastName { get; set; } = "";
    public int Age { get; set; }

    public Person(string fName, string lName, int personAge)
    {
        FirstName = fName;
        LastName = lName;
        Age = personAge;
    }
    public Person(){}
}

```

## Overriding `System.Object.ToString()`

Many classes (and structures) that you create can benefit from overriding `ToString()` in order to return a string textual representation of the type’s current state. This can be quite helpful for purposes of debugging (among other reasons). How you choose to construct this string is a matter of personal choice; however, a

recommended approach is to separate each name-value pair with semicolons and wrap the entire string within square brackets (many types in the .NET Core base class libraries follow this approach). Consider the following overridden `ToString()` for your `Person` class:

```
public override string ToString() => $"[First Name: {FirstName}; Last Name: {LastName}; Age: {Age}]";
```

This implementation of `ToString()` is quite straightforward, given that the `Person` class has only three pieces of state data. However, always remember that a proper `ToString()` override should also account for any data defined *up the chain of inheritance*.

When you override `ToString()` for a class extending a custom base class, the first order of business is to obtain the `ToString()` value from your parent using the base keyword. After you have obtained your parent's string data, you can append the derived class's custom information.

## Overriding `System.Object.Equals()`

Let's also override the behavior of `Object.Equals()` to work with value-based semantics. Recall that, by default, `Equals()` returns `true` only if the two objects being compared reference the same object instance in memory. For the `Person` class, it may be helpful to implement `Equals()` to return `true` if the two variables being compared contain the same state values (e.g., first name, last name, and age).

First, notice that the incoming argument of the `Equals()` method is a general `System.Object`. Given this, your first order of business is to ensure the caller has indeed passed in a `Person` object and, as an extra safeguard, to make sure the incoming parameter is not a `null` reference.

After you have established the caller has passed you an allocated `Person`, one approach to implement `Equals()` is to perform a field-by-field comparison against the data of the incoming object to the data of the current object.

```
public override bool Equals(object obj)
{
    if (!(obj is Person temp))
    {
        return false;
    }
    if (temp.FirstName == this.FirstName
        && temp.LastName == this.LastName
        && temp.Age == this.Age)
    {
        return true;
    }
    return false;
}
```

Here, you are examining the values of the incoming object against the values of your internal values (note the use of the `this` keyword). If the names and age of each are identical, you have two objects with the same state data and, therefore, return `true`. Any other possibility results in returning `false`.

While this approach does indeed work, you can certainly imagine how labor intensive it would be to implement a custom `Equals()` method for nontrivial types that may contain dozens of data fields. One common shortcut is to leverage your own implementation of `ToString()`. If a class has a prim-and-proper implementation of `ToString()` that accounts for all field data up the chain of inheritance, you can simply perform a comparison of the object's string data (checking for `null`).

```
// No need to cast "obj" to a Person anymore,
// as everything has a ToString() method.
public override bool Equals(object obj)
    => obj?.ToString() == ToString();
```

Notice in this case that you no longer need to check whether the incoming argument is of the correct type (a *Person*, in this example), as everything in .NET supports a `ToString()` method. Even better, you no longer need to perform a property-by-property equality check, as you are not simply testing the value returned from `ToString()`.

## Overriding `System.Object.GetHashCode()`

When a class overrides the `Equals()` method, you should also override the default implementation of `GetHashCode()`. Simply put, a *hash code* is a numerical value that represents an object as a particular state. For example, if you create two string variables that hold the value *Hello*, you would obtain the same hash code. However, if one of the string objects were in all lowercase (*hello*), you would obtain different hash codes.

By default, `System.Object.GetHashCode()` uses your object's current location in memory to yield the hash value. However, if you are building a custom type that you intend to store in a *Hashtable* type (within the `System.Collections` namespace), you should always override this member, as the *Hashtable* will be internally invoking `Equals()` and `GetHashCode()` to retrieve the correct object.

---

■ **Note** To be more specific, the `System.Collections.Hashtable` class calls `GetHashCode()` internally to gain a general idea where the object is located, but a subsequent (internal) call to `Equals()` determines the exact match.

---

Although you are not going to place your *Person* into a `System.Collections.Hashtable` in this example, for completion let's override `GetHashCode()`. There are many algorithms that can be used to create a hash code – some fancy, others not so fancy. Most of the time, you are able to generate a hash code value by leveraging the `System.String`'s `GetHashCode()` implementation.

Given that the `String` class already has a solid hash code algorithm that is using the character data of the `String` to compute a hash value, if you can identify a piece of field data on your class that should be unique for all instances (such as a Social Security number), simply call `GetHashCode()` on that point of field data. Thus, if the *Person* class defined an *SSN* property, you could author the following code:

```
// Assume we have an SSN property as so.
class Person
{
    public string SSN {get; } = "";
    public Person(string fName, string lName, int personAge,
        string ssn)
    {
        FirstName = fName;
        LastName = lName;
        Age = personAge;
        SSN = ssn;
    }
}
```

```
// Return a hash code based on unique string data.
public override int GetHashCode() => SSN.GetHashCode();
}
```

If you use a read/write property for the basis of the hash code, you will receive a warning. Once an object is created, the hash code should be immutable. In the previous example, the SSN property only has a get method, which makes the property read-only, and can only be set in the constructor.

If you cannot find a single point of unique string data but you have overridden ToString() (which satisfies the read-only convention), call GetHashCode() on your own string representation.

```
// Return a hash code based on the person's ToString() value.
public override int GetHashCode() => ToString().GetHashCode();
```

## Testing Your Modified Person Class

Now that you have overridden the virtual members of Object, update Main() to test your updates.

```
static void Main(string[] args)
{
    Console.WriteLine("***** Fun with System.Object *****\n");

    // NOTE: We want these to be identical to test
    // the Equals() and GetHashCode() methods.
    Person p1 = new Person("Homer", "Simpson", 50,
        "111-11-1111");
    Person p2 = new Person("Homer", "Simpson", 50,
        "111-11-1111");

    // Get stringified version of objects.
    Console.WriteLine("p1.ToString() = {0}", p1.ToString());
    Console.WriteLine("p2.ToString() = {0}", p2.ToString());

    // Test overridden Equals().
    Console.WriteLine("p1 = p2?: {0}", p1.Equals(p2));

    // Test hash codes.
    //still using the hash of the SSN
    Console.WriteLine("Same hash codes?: {0}", p1.GetHashCode() == p2.GetHashCode());
    Console.WriteLine();

    // Change age of p2 and test again.
    p2.Age = 45;
    Console.WriteLine("p1.ToString() = {0}", p1.ToString());
    Console.WriteLine("p2.ToString() = {0}", p2.ToString());
    Console.WriteLine("p1 = p2?: {0}", p1.Equals(p2));
    //still using the hash of the SSN
    Console.WriteLine("Same hash codes?: {0}", p1.GetHashCode() == p2.GetHashCode());
    Console.ReadLine();
}
```

The output is shown here:

---

```
***** Fun with System.Object *****
```

```
p1.ToString() = [First Name: Homer; Last Name: Simpson; Age: 50]
p2.ToString() = [First Name: Homer; Last Name: Simpson; Age: 50]
p1 = p2?: True
Same hash codes?: True
```

```
p1.ToString() = [First Name: Homer; Last Name: Simpson; Age: 50]
p2.ToString() = [First Name: Homer; Last Name: Simpson; Age: 45]
p1 = p2?: False
Same hash codes?: True
```

---

## The Static Members of System.Object

In addition to the instance-level members you have just examined, `System.Object` does define two (very helpful) static members that also test for value-based or reference-based equality. Consider the following code:

```
static void StaticMembersOfObject()
{
    // Static members of System.Object.
    Person p3 = new Person("Sally", "Jones", 4);
    Person p4 = new Person("Sally", "Jones", 4);
    Console.WriteLine("P3 and P4 have same state: {0}", object.Equals(p3, p4));
    Console.WriteLine("P3 and P4 are pointing to same object: {0}",
        object.ReferenceEquals(p3, p4));
}
```

Here, you are able to simply send in two objects (of any type) and allow the `System.Object` class to determine the details automatically.

The output is shown here:

---

```
***** Fun with System.Object *****
```

```
P3 and P4 have the same state: True
P3 and P4 are pointing to the same object: False
```

---

## Summary

This chapter explored the role and details of inheritance and polymorphism. Over these pages you were introduced to numerous new keywords and tokens to support each of these techniques. For example, recall that the colon token is used to establish the parent class of a given type. Parent types are able to define any number of virtual and/or abstract members to establish a polymorphic interface. Derived types override such members using the `override` keyword.

In addition to building numerous class hierarchies, this chapter also examined how to explicitly cast between base and derived types and wrapped up by diving into the details of the cosmic parent class in the .NET base class libraries: `System.Object`.

## CHAPTER 7



# Understanding Structured Exception Handling

In this chapter, you will learn how to handle runtime anomalies in your C# code through the use of *structured exception handling*. Not only will you examine the C# keywords that allow you to handle such matters (try, catch, throw, finally, when), but you will also come to understand the distinction between application-level and system-level exceptions, as well as the role of the `System.Exception` base class. This discussion will lead into the topic of building custom exceptions and, finally, to a quick look at some exception-centric debugging tools of Visual Studio.

## Ode to Errors, Bugs, and Exceptions

Despite what our (sometimes inflated) egos may tell us, no programmer is perfect. Writing software is a complex undertaking, and given this complexity, it is quite common for even the best software to ship with various *problems*. Sometimes the problem is caused by bad code (such as overflowing the bounds of an array). Other times, a problem is caused by bogus user input that has not been accounted for in the application's codebase (e.g., a phone number input field assigned to the value Chucky). Now, regardless of the cause of the problem, the end result is that the application does not work as expected. To help frame the upcoming discussion of structured exception handling, allow me to provide definitions for three commonly used anomaly-centric terms:

- *Bugs*: These are, simply put, errors made by the programmer. For example, suppose you are programming with unmanaged C++. If you fail to delete dynamically allocated memory, resulting in a memory leak, you have a bug.
- *User errors*: User errors, on the other hand, are typically caused by the individual running your application, rather than by those who created it. For example, an end user who enters a malformed string into a text box could very well generate an error if you fail to handle this faulty input in your codebase.
- *Exceptions*: Exceptions are typically regarded as runtime anomalies that are difficult, if not impossible, to account for while programming your application. Possible exceptions include attempting to connect to a database that no longer exists, opening a corrupted XML file, or trying to contact a machine that is currently offline. In each of these cases, the programmer (or end user) has little control over these “exceptional” circumstances.

Given these definitions, it should be clear that .NET structured *exception* handling is a technique for dealing with runtime *exceptions*. However, even for the bugs and user errors that have escaped your view, the CoreCLR will often generate a corresponding exception that identifies the problem at hand. By way of

a few examples, the .NET Core base class libraries define numerous exceptions, such as `FormatException`, `IndexOutOfRangeException`, `FileNotFoundException`, `ArgumentOutOfRangeException`, and so forth.

Within the .NET nomenclature, an *exception* accounts for bugs, bogus user input, and runtime errors, even though programmers may view each of these as a distinct issue. However, before I get too far ahead of myself, let's formalize the role of structured exception handling and check out how it differs from traditional error-handling techniques.

---

■ **Note** To make the code examples used in this book as clean as possible, I will not catch every possible exception that may be thrown by a given method in the base class libraries. In your production-level projects, you should, of course, make liberal use of the techniques presented in this chapter.

---

## The Role of .NET Exception Handling

Prior to .NET, error handling under the Windows operating system was a confused mishmash of techniques. Many programmers rolled their own error-handling logic within the context of a given application. For example, a development team could define a set of numerical constants that represented known error conditions and make use of them as method return values. By way of an example, consider the following partial C code:

```
/* A very C-style error trapping mechanism. */
#define E_FILENOTFOUND 1000

int UseFileSystem()
{
    // Assume something happens in this function
    // that causes the following return value.
    return E_FILENOTFOUND;
}

void main()
{
    int retVal = UseFileSystem();
    if(retVal == E_FILENOTFOUND)
        printf("Cannot find file...");
}
```

This approach is less than ideal, given that the constant `E_FILENOTFOUND` is little more than a numerical value and is far from being a helpful agent regarding how to deal with the problem. Ideally, you would like to wrap the error's name, a descriptive message, and other helpful information about this error condition into a single, well-defined package (which is exactly what happens under structured exception handling). In addition to a developer's ad hoc techniques, the Windows API defines hundreds of error codes that come by way of `#defines`, `HRESULTS`s, and far too many variations on the simple Boolean (`bool`, `BOOL`, `VARIANT_BOOL`, etc.).

The obvious problem with these older techniques is the tremendous lack of symmetry. Each approach is more or less tailored to a given technology, a given language, and perhaps even a given project. To put an end to this madness, the .NET platform provides a standard technique to send and trap runtime errors: structured exception handling. The beauty of this approach is that developers now have a unified approach to error handling, which is common to all languages targeting the .NET platform. Therefore, the way in which a C# programmer handles errors is syntactically similar to that of a VB programmer, or a C++ programmer using C++/CLI.

As an added bonus, the syntax used to throw and catch exceptions across assemblies and machine boundaries is identical. For example, if you use C# to build a Windows Communication Foundation (WCF) service, you can throw a SOAP fault to a remote caller, using the same keywords that allow you to throw an exception between methods in the same application.

Another bonus of .NET exceptions is that rather than receiving a cryptic numerical value, exceptions are objects that contain a human-readable description of the problem, as well as a detailed snapshot of the call stack that triggered the exception in the first place. Furthermore, you are able to give the end user help link information that points the user to a URL that provides details about the error, as well as custom programmer-defined data.

## The Building Blocks of .NET Exception Handling

Programming with structured exception handling involves the use of four interrelated entities:

- A class type that represents the details of the exception
- A member that *throws* an instance of the exception class to the caller under the correct circumstances
- A block of code on the caller's side that invokes the exception-prone member
- A block of code on the caller's side that will process (or *catch*) the exception, should it occur

The C# programming language offers five keywords (`try`, `catch`, `throw`, `finally`, and `when`) that allow you to throw and handle exceptions. The object that represents the problem at hand is a class extending `System.Exception` (or a descendent thereof). Given this fact, let's check out the role of this exception-centric base class.

## The System.Exception Base Class

All exceptions ultimately derive from the `System.Exception` base class, which in turn derives from `System.Object`. Here is the crux of this class (note that some of these members are virtual and may thus be overridden by derived classes):

```
public class Exception : ISerializable, _Exception
{
    // Public constructors
    public Exception(string message, Exception innerException);
    public Exception(string message);
    public Exception();
    ...
    // Methods
    public virtual Exception GetBaseException();
    public virtual void GetObjectData(SerializationInfo info,
        StreamingContext context);

    // Properties
    public virtual IDictionary Data { get; }
    public virtual string HelpLink { get; set; }
    public virtual Exception InnerException { get; }
    public virtual string Message { get; }
```



```
public virtual string Source { get; set; }
public virtual string StackTrace { get; }
public MethodBase TargetSite { get; }
...
}
```

As you can see, many of the properties defined by `System.Exception` are read-only in nature. This is because derived types will typically supply default values for each property. For example, the default message of the `IndexOutOfRangeException` type is “Index was outside the bounds of the array.”

**■ Note** The `Exception` class implements two .NET interfaces. Although you have yet to examine interfaces (see Chapter 8), understand that the `Exception` interface allows a .NET exception to be processed by an unmanaged codebase (such as a COM application), while the `ISerializable` interface allows an exception object to be persisted across boundaries (such as a machine boundary).

Table 7-1 describes the most important members of `System.Exception`.

**Table 7-1.** Core Members of the `System.Exception` Type

System.Exception Property	Meaning in Life
Data	This read-only property retrieves a collection of key-value pairs (represented by an object implementing <code>IDictionary</code> ) that provide additional, programmer-defined information about the exception. By default, this collection is empty.
HelpLink	This property gets or sets a URL to a help file or website describing the error in full detail.
InnerException	This read-only property can be used to obtain information about the previous exceptions that caused the current exception to occur. The previous exceptions are recorded by passing them into the constructor of the most current exception.
Message	This read-only property returns the textual description of a given error. The error message itself is set as a constructor parameter.
Source	This property gets or sets the name of the assembly, or the object, that threw the current exception.
StackTrace	This read-only property contains a string that identifies the sequence of calls that triggered the exception. As you might guess, this property is useful during debugging or if you want to dump the error to an external error log.
TargetSite	This read-only property returns a <code>MethodBase</code> object, which describes numerous details about the method that threw the exception (invoking <code>ToString()</code> will identify the method by name).

## The Simplest Possible Example

To illustrate the usefulness of structured exception handling, you need to create a class that will throw an exception under the correct (or one might say *exceptional*) circumstances. Assume you have created a new C# Console Application project (named SimpleException) that defines two class types (Car and Radio) associated by the “has-a” relationship. The Radio type defines a single method that turns the radio’s power on or off.

```
class Radio
{
    public void TurnOn(bool on)
    {
        Console.WriteLine(on ? "Jamming..." : "Quiet time...");
    }
}
```

In addition to leveraging the Radio class via containment/delegation, the Car class (shown next) is defined in such a way that if the user accelerates a Car object beyond a predefined maximum speed (specified using a constant member variable named MaxSpeed), its engine explodes, rendering the Car unusable (captured by a private bool member variable named \_carIsDead).

Beyond these points, the Car type has a few properties to represent the current speed and a user supplied “pet name,” as well as various constructors to set the state of a new Car object. Here is the complete definition (with code comments):

```
class Car
{
    // Constant for maximum speed.
    public const int MaxSpeed = 100;

    // Car properties.
    public int CurrentSpeed {get; set;} = 0;
    public string PetName {get; set;} = "";

    // Is the car still operational?
    private bool _carIsDead;

    // A car has-a radio.
    private readonly Radio _theMusicBox = new Radio();

    // Constructors.
    public Car() {}
    public Car(string name, int speed)
    {
        CurrentSpeed = speed;
        PetName = name;
    }

    public void CrankTunes(bool state)
    {
        // Delegate request to inner object.
        _theMusicBox.TurnOn(state);
    }
}
```

```
// See if Car has overheated.
public void Accelerate(int delta)
{
    if (_carIsDead)
    {
        Console.WriteLine("{0} is out of order...", PetName);
    }
    else
    {
        CurrentSpeed += delta;
        if (CurrentSpeed > MaxSpeed)
        {
            Console.WriteLine("{0} has overheated!", PetName);
            CurrentSpeed = 0;
            _carIsDead = true;
        }
        else
        {
            Console.WriteLine("=> CurrentSpeed = {0}",
                               CurrentSpeed);
        }
    }
}
}
```

Now, if you implement a `Main()` method that forces a `Car` object to exceed the predefined maximum speed (set to 100, in the `Car` class) as shown here:

```
static void Main(string[] args)
{
    Console.WriteLine("***** Simple Exception Example *****");
    Console.WriteLine("=> Creating a car and stepping on it!");
    Car myCar = new Car("Zippy", 20);
    myCar.CrankTunes(true);

    for (int i = 0; i < 10; i++)
    {
        myCar.Accelerate(10);
    }
    Console.ReadLine();
}
```

you would see the following output:

---

```
***** Simple Exception Example *****
=> Creating a car and stepping on it!
Jamming...
=> CurrentSpeed = 30
=> CurrentSpeed = 40
=> CurrentSpeed = 50
=> CurrentSpeed = 60
```

```
=> CurrentSpeed = 70
=> CurrentSpeed = 80
=> CurrentSpeed = 90
=> CurrentSpeed = 100
Zippy has overheated!
Zippy is out of order...
```

---

## Throwing a General Exception

Now that you have a functional Car class, I'll demonstrate the simplest way to throw an exception. The current implementation of `Accelerate()` simply displays an error message if the caller attempts to speed up the Car beyond its upper limit.

To retrofit this method to throw an exception if the user attempts to speed up the automobile after it has met its maker, you want to create and configure a new instance of the `System.Exception` class, setting the value of the read-only `Message` property via the class constructor. When you want to send the exception object back to the caller, use the `C# throw` keyword. Here is the relevant code update to the `Accelerate()` method:

```
// This time, throw an exception if the user speeds up beyond MaxSpeed.
public void Accelerate(int delta)
{
    if (!_carIsDead)
    {
        Console.WriteLine("{0} is out of order...", PetName);
    }
    else
    {
        CurrentSpeed += delta;
        if (CurrentSpeed >= MaxSpeed)
        {
            CurrentSpeed = 0;
            _carIsDead = true;

            // Use the "throw" keyword to raise an exception.
            throw new Exception($"{PetName} has overheated!");
        }
        Console.WriteLine("=> CurrentSpeed = {0}", CurrentSpeed);
    }
}
```

Before examining how a caller would catch this exception, let's look at a few points of interest. First, when you are throwing an exception, it is always up to you to decide exactly what constitutes the error in question and when an exception should be thrown. Here, you are making the assumption that if the program attempts to increase the speed of a Car object beyond the maximum, a `System.Exception` object should be thrown to indicate the `Accelerate()` method cannot continue (which may or may not be a valid assumption; this will be a judgment call on your part based on the application you are creating).

Alternatively, you could implement `Accelerate()` to recover automatically without needing to throw an exception in the first place. By and large, exceptions should be thrown only when a more terminal condition has been met (e.g., not finding a necessary file, failing to connect to a database, and the like) and not used a logic flow mechanism. Deciding exactly what justifies throwing an exception is a design issue you must always contend with. For the current purposes, assume that asking a doomed automobile to increase its speed is cause to throw an exception.

Secondly, notice how the the final else was removed from the method. When an exception is through (either by the framework of manually using a throw statement), control is returned to the calling method (or by the catch block in a try catch). This eliminates the need for the final else. Whether or not you leave it in for readability is up to you and your coding standards.

In any case, if you were to rerun the application at this point using the previous logic in `Main()`, the exception will eventually be thrown. As shown in the following output, the result of not handling this error is less than ideal, given you receive a verbose error dump followed by the program's termination (with your specific file path and line numbers):

---

```
***** Simple Exception Example *****
=> Creating a car and stepping on it!
Jamming...
=> CurrentSpeed = 30
=> CurrentSpeed = 40
=> CurrentSpeed = 50
=> CurrentSpeed = 60
=> CurrentSpeed = 70
=> CurrentSpeed = 80
=> CurrentSpeed = 90
=> CurrentSpeed = 100

Unhandled exception. System.Exception: Zippy has overheated!
   at SimpleException.Car.Accelerate(Int32 delta) in [path to file]\Car.cs:line 52
   at SimpleException.Program.Main(String[] args) in [path to file]\Program.cs:line 16
```

---

## Catching Exceptions

---

■ **Note** For those coming to .NET from a Java background, understand that type members are not prototyped with the set of exceptions they may throw (in other words, .NET does not support checked exceptions). For better or for worse, you are not required to handle every exception thrown from a given member.

---

Because the `Accelerate()` method now throws an exception, the caller needs to be ready to handle the exception, should it occur. When you are invoking a method that may throw an exception, you make use of a try/catch block. After you have caught the exception object, you are able to invoke the members of the exception object to extract the details of the problem.

What you do with this data is largely up to you. You might want to log this information to a report file, write the data to the event log, email a system administrator, or display the problem to the end user. Here, you will simply dump the contents to the console window:

```
// Handle the thrown exception.
static void Main(string[] args)
{
    Console.WriteLine("***** Simple Exception Example *****");
    Console.WriteLine("=> Creating a car and stepping on it!");
    Car myCar = new Car("Zippy", 20);
    myCar.CrankTunes(true);
}
```

```
// Speed up past the car's max speed to
// trigger the exception.
try
{
    for(int i = 0; i < 10; i++)
    {
        myCar. Accelerate(10);
    }
}
catch(Exception e)
{
    Console.WriteLine("\n*** Error! ***");
    Console.WriteLine("Method: {0}", e.TargetSite);
    Console.WriteLine("Message: {0}", e.Message);
    Console.WriteLine("Source: {0}", e.Source);
}
// The error has been handled, processing continues with the next statement.
Console.WriteLine("\n***** Out of exception logic *****");
Console.ReadLine();
}
```

In essence, a try block is a section of statements that may throw an exception during execution. If an exception is detected, the flow of program execution is sent to the appropriate catch block. On the other hand, if the code within a try block does not trigger an exception, the catch block is skipped entirely, and all is right with the world. The following output shows a test run of this program:

---

```
***** Simple Exception Example *****
=> Creating a car and stepping on it!
Jamming...
=> CurrentSpeed = 30
=> CurrentSpeed = 40
=> CurrentSpeed = 50
=> CurrentSpeed = 60
=> CurrentSpeed = 70
=> CurrentSpeed = 80
=> CurrentSpeed = 90
=> CurrentSpeed = 100

*** Error! ***
Method: Void Accelerate(Int32)
Message: Zippy has overheated!
Source: SimpleException

***** Out of exception logic *****
```

---

As you can see, after an exception has been handled, the application is free to continue on from the point after the catch block. In some circumstances, a given exception could be critical enough to warrant the termination of the application. However, in a good number of cases, the logic within the exception handler will ensure the application can continue on its merry way (although it could be slightly less functional, such as not being able to connect to a remote data source).

## Throw As Expression (New 7.0)

Prior to C# 7, `throw` was a statement, which meant you could throw an exception only where statements are allowed. With C# 7.0 and later, `throw` is available as an expression as well and can be called anywhere expressions are allowed.

## Configuring the State of an Exception

Currently, the `System.Exception` object configured within the `Accelerate()` method simply establishes a value exposed to the `Message` property (via a constructor parameter). As shown previously in Table 7-1, however, the `Exception` class also supplies a number of additional members (`TargetSite`, `StackTrace`, `HelpLink`, and `Data`) that can be useful in further qualifying the nature of the problem. To spruce up the current example, let's examine further details of these members on a case-by-case basis.

### The TargetSite Property

The `System.Exception.TargetSite` property allows you to determine various details about the method that threw a given exception. As shown in the previous `Main()` method, printing the value of `TargetSite` will display the return type, name, and parameter types of the method that threw the exception. However, `TargetSite` does not return just a vanilla-flavored string but rather a strongly typed `System.Reflection.MethodBase` object. This type can be used to gather numerous details regarding the offending method, as well as the class that defines the offending method. To illustrate, assume the previous catch logic has been updated as follows:

```
static void Main(string[] args)
{
    ...
    // TargetSite actually returns a MethodBase object.
    catch(Exception e)
    {
        Console.WriteLine("\n*** Error! ***");
        Console.WriteLine("Member name: {0}", e.TargetSite);
        Console.WriteLine("Class defining member: {0}",
            e.TargetSite.DeclaringType);
        Console.WriteLine("Member type: {0}",
            e.TargetSite.MemberType);
        Console.WriteLine("Message: {0}", e.Message);
        Console.WriteLine("Source: {0}", e.Source);
    }
    Console.WriteLine("\n***** Out of exception logic *****");
    Console.ReadLine();
}
```

This time, you make use of the `MethodBase.DeclaringType` property to determine the fully qualified name of the class that threw the error (`SimpleException.Car`, in this case) as well as the `MemberType` property of the `MethodBase` object to identify the type of member (such as a property vs. a method) where this exception originated. In this case, the catch logic would display the following:

---

```

*** Error! ***
Member name: Void Accelerate(Int32)
Class defining member: SimpleException.Car
Member type: Method
Message: Zippy has overheated!
Source: SimpleException

```

---

## The StackTrace Property

The `System.Exception.StackTrace` property allows you to identify the series of calls that resulted in the exception. Be aware that you never set the value of `StackTrace`, as it is established automatically at the time the exception is created. To illustrate, assume you have once again updated your catch logic.

```

catch(Exception e)
{
    ...
    Console.WriteLine("Stack: {0}", e.StackTrace);
}

```

If you were to run the program, you would find the following stack trace is printed to the console (your line numbers and file paths may differ, of course):

---

```

Stack: at SimpleException.Car.Accelerate(Int32 delta)
in [path to file]\car.cs:line 57 at SimpleException.Program.Main()
in [path to file]\Program.cs:line 20

```

---

The string returned from `StackTrace` documents the sequence of calls that resulted in the throwing of this exception. Notice how the bottommost line number of this string identifies the first call in the sequence, while the topmost line number identifies the exact location of the offending member. Clearly, this information can be quite helpful during the debugging or logging of a given application, as you are able to “follow the flow” of the error’s origin.

## The HelpLink Property

While the `TargetSite` and `StackTrace` properties allow programmers to gain an understanding of a given exception, this information is of little use to the end user. As you have already seen, the `System.Exception.Message` property can be used to obtain human-readable information that can be displayed to the current user. In addition, the `HelpLink` property can be set to point the user to a specific URL or standard help file that contains more detailed information.

By default, the value managed by the `HelpLink` property is an empty string. Update the exception using object initialization to provide a more interesting value. Here are the relevant updates to the `Car.Accelerate()` method:

```

public void Accelerate(int delta)
{
    if (_carIsDead)
    {
        Console.WriteLine("{0} is out of order...", PetName);
    }
}

```



```

else
{
    CurrentSpeed += delta;
    if (CurrentSpeed >= MaxSpeed)
    {
        CurrentSpeed = 0;
        _carIsDead = true;

        // Use the "throw" keyword to raise an exception and
        // return to the caller.
        throw new Exception($"{PetName} has overheated!")
        {
            HelpLink = "http://www.CarsRUs.com"
        };
    }
    Console.WriteLine("=> CurrentSpeed = {0}", CurrentSpeed);
}
}

```

The catch logic could now be updated to print this help link information as follows:

```

catch(Exception e)
{
    ...
    Console.WriteLine("Help Link: {0}", e.HelpLink);
}

```

## The Data Property

The Data property of `System.Exception` allows you to fill an exception object with relevant auxiliary information (such as a timestamp). The Data property returns an object implementing an interface named `IDictionary`, defined in the `System.Collections` namespace. Chapter 8 examines the role of interface-based programming, as well as the `System.Collections` namespace. For the time being, just understand that dictionary collections allow you to create a set of values that are retrieved using a specific key. Observe the next update to the `Car.Accelerate()` method:

```

public void Accelerate(int delta)
{
    if (_carIsDead)
    {
        Console.WriteLine("{0} is out of order...", PetName);
    }
    else
    {
        CurrentSpeed += delta;
        if (CurrentSpeed >= MaxSpeed)
        {
            Console.WriteLine("{0} has overheated!", PetName);
            CurrentSpeed = 0;
            _carIsDead = true;
        }
    }
}

```

```

        // Use the "throw" keyword to raise an exception
        // and return to the caller.
        throw new Exception($"{PetName} has overheated!")
        {
            HelpLink = "http://www.CarsRUs.com",
            Data = {
                {"TimeStamp", $"The car exploded at {DateTime.Now}"},
                {"Cause", "You have a lead foot."}
            }
        };
    }
    Console.WriteLine("=> CurrentSpeed = {0}", CurrentSpeed);
}
}

```

To successfully enumerate over the key-value pairs, you must first make sure to specify a using directive for the `System.Collections` namespace since you will use a `DictionaryEntry` type in the file containing the class implementing your `Main()` method.

```
using System.Collections;
```

Next, you need to update the catch logic to test that the value returned from the `Data` property is not null (the default value). After that, you use the `Key` and `Value` properties of the `DictionaryEntry` type to print the custom data to the console.

```

catch (Exception e)
{
    ...
    Console.WriteLine("\n-> Custom Data:");
    foreach (DictionaryEntry de in e.Data)
    {
        Console.WriteLine("-> {0}: {1}", de.Key, de.Value);
    }
}

```

With this, here's the final output you'd see:

---

```

***** Simple Exception Example *****
=> Creating a car and stepping on it!
Jamming...
=> CurrentSpeed = 30
=> CurrentSpeed = 40
=> CurrentSpeed = 50
=> CurrentSpeed = 60
=> CurrentSpeed = 70
=> CurrentSpeed = 80
=> CurrentSpeed = 90
*** Error! ***
Member name: Void Accelerate(Int32)
Class defining member: SimpleException.Car
Member type: Method

```

```

Message: Zippy has overheated!
Source: SimpleException
Stack: at SimpleException.Car.Accelerate(Int32 delta) ...
       at SimpleException.Program.Main(String[] args) ...
Help Link: http://www.CarsRUs.com

```

```

-> Custom Data:
-> TimeStamp: The car exploded at 3/15/2020 16:22:59
-> Cause: You have a lead foot.

```

```
***** Out of exception logic *****
```

---

The Data property is useful in that it allows you to pack in custom information regarding the error at hand, without requiring the building of a new class type to extend the Exception base class. As helpful as the Data property may be, however, it is still common for developers to build strongly typed exception classes, which handle custom data using strongly typed properties.

This approach allows the caller to catch a specific exception-derived type, rather than having to dig into a data collection to obtain additional details. To understand how to do this, you need to examine the distinction between system-level and application-level exceptions.

## System-Level Exceptions (System.SystemException)

The .NET Core base class libraries define many classes that ultimately derive from System.Exception. For example, the System namespace defines core exception objects such as ArgumentOutOfRangeException, IndexOutOfRangeException, StackOverflowException, and so forth. Other namespaces define exceptions that reflect the behavior of that namespace. For example, System.Drawing.Printing defines printing exceptions, System.IO defines input/output-based exceptions, System.Data defines database-centric exceptions, and so forth.

Exceptions that are thrown by the .NET Core platform are (appropriately) called *system exceptions*. These exceptions are generally regarded as nonrecoverable, fatal errors. System exceptions derive directly from a base class named System.SystemException, which in turn derives from System.Exception (which derives from System.Object).

```

public class SystemException : Exception
{
    // Various constructors.
}

```

Given that the System.SystemException type does not add any additional functionality beyond a set of custom constructors, you might wonder why SystemException exists in the first place. Simply put, when an exception type derives from System.SystemException, you are able to determine that the .NET Core runtime is the entity that has thrown the exception, rather than the codebase of the executing application. You can verify this quite simply using the `is` keyword.

```

// True! NullReferenceException is-a SystemException.
NullReferenceException nullRefEx = new NullReferenceException();
Console.WriteLine(
    "NullReferenceException is-a SystemException? : {0}",
    nullRefEx is SystemException);

```

## Application-Level Exceptions (System.ApplicationException)

Given that all .NET Core exceptions are class types, you are free to create your own application-specific exceptions. However, because the `System.SystemException` base class represents exceptions thrown from the CoreCLR, you might naturally assume that you should derive your custom exceptions from the `System.Exception` type. You could do this, but you could instead derive from the `System.ApplicationException` class.

```
public class ApplicationException : Exception
{
    // Various constructors.
}
```

Like `SystemException`, `ApplicationException` does not define any additional members beyond a set of constructors. Functionally, the only purpose of `System.ApplicationException` is to identify the source of the error. When you handle an exception deriving from `System.ApplicationException`, you can assume the exception was raised by the codebase of the executing application, rather than by the .NET Core base class libraries or .NET Core runtime engine.

## Building Custom Exceptions, Take 1

While you can always throw instances of `System.Exception` to signal a runtime error (as shown in the first example), it is sometimes advantageous to build a *strongly typed exception* that represents the unique details of your current problem. For example, assume you want to build a custom exception (named `CarIsDeadException`) to represent the error of speeding up a doomed automobile. The first step is to derive a new class from `System.Exception/System.ApplicationException` (by convention, all exception classes end with the `Exception` suffix; in fact, this is a .NET Core best practice).

---

■ **Note** As a rule, all custom exception classes should be defined as public classes (recall that the default access modifier of a non-nested type is internal). The reason is that exceptions are often passed outside of assembly boundaries and should therefore be accessible to the calling codebase.

---

Create a new Console Application project named `CustomException`, and copy the previous `Car.cs` and `Radio.cs` files into your new project using the Project Add Existing Item menu option (for clarity, be sure to change the namespace that defines the `Car` and `Radio` types from `SimpleException` to `CustomException`). Next, add the following class definition:

```
// This custom exception describes the details of the car-is-dead condition.
// (Remember, you can also simply extend Exception.)
public class CarIsDeadException : ApplicationException
{
}
```

As with any class, you are free to include any number of custom members that can be called within the catch block of the calling logic. You are also free to override any virtual members defined by your parent classes. For example, you could implement `CarIsDeadException` by overriding the virtual `Message` property.

As well, rather than populating a data dictionary (via the `Data` property) when throwing the exception, the constructor allows the sender to pass in a timestamp and reason for the error. Finally, the timestamp data and cause of the error can be obtained using strongly typed properties.

```

public class CarIsDeadException : ApplicationException
{
    private string _messageDetails = String.Empty;
    public DateTime ErrorTimeStamp {get; set;}
    public string CauseOfError {get; set;}

    public CarIsDeadException(){}
    public CarIsDeadException(string message,
        string cause, DateTime time)
    {
        _messageDetails = message;
        CauseOfError = cause;
        ErrorTimeStamp = time;
    }

    // Override the Exception.Message property.
    public override string Message
        => $"Car Error Message: {_messageDetails}";
}

```

Here, the `CarIsDeadException` class maintains a private field (`_messageDetails`) that represents data regarding the current exception, which can be set using a custom constructor. Throwing this exception from the `Accelerate()` method is straightforward. Simply allocate, configure, and throw a `CarIsDeadException` type rather than a `System.Exception`.

```

// Throw the custom CarIsDeadException.
public void Accelerate(int delta)
{
    ...
    throw new CarIsDeadException(
        $"{PetName} has overheated!",
        "You have a lead foot", DateTime.Now)
    {
        HelpLink = "http://www.CarsRUs.com",
    };
    ...
}

```

To catch this incoming exception, your catch scope can now be updated to catch a specific `CarIsDeadException` type (however, given that `CarIsDeadException` “is-a” `System.Exception`, it is still permissible to catch a `System.Exception` as well).

```

static void Main(string[] args)
{
    Console.WriteLine("***** Fun with Custom Exceptions *****\n");
    Car myCar = new Car("Rusty", 90);

    try
    {
        // Trip exception.
        myCar.Accelerate(50);
    }
}

```

```

catch (CarIsDeadException e)
{
    Console.WriteLine(e.Message);
    Console.WriteLine(e.ErrorTimeStamp);
    Console.WriteLine(e.CauseOfError);
}
Console.ReadLine();
}

```

So, now that you understand the basic process of building a custom exception, it's time to build on that knowledge.

## Building Custom Exceptions, Take 2

The current `CarIsDeadException` type has overridden the virtual `System.Exception.Message` property in order to configure a custom error message and has supplied two custom properties to account for additional bits of data. In reality, however, you are not required to override the virtual `Message` property, as you could simply pass the incoming message to the parent's constructor as follows:

```

public class CarIsDeadException : ApplicationException
{
    public DateTime ErrorTimeStamp { get; set; }
    public string CauseOfError { get; set; }

    public CarIsDeadException() { }

    // Feed message to parent constructor.
    public CarIsDeadException(string message, string cause, DateTime time)
        :base(message)
    {
        CauseOfError = cause;
        ErrorTimeStamp = time;
    }
}

```

Notice that this time you have *not* defined a string variable to represent the message and have *not* overridden the `Message` property. Rather, you are simply passing the parameter to your base class constructor. With this design, a custom exception class is little more than a uniquely named class deriving from `System.ApplicationException` (with additional properties if appropriate), devoid of any base class overrides.

Don't be surprised if most (if not all) of your custom exception classes follow this simple pattern. Many times, the role of a custom exception is not necessarily to provide additional functionality beyond what is inherited from the base classes but to supply a *strongly named type* that clearly identifies the nature of the error so the client can provide different handler logic for different types of exceptions.

## Building Custom Exceptions, Take 3

If you want to build a truly prim-and-proper custom exception class, you want to make sure your type adheres to .NET best practices. Specifically, this requires that your custom exception does the following:

- Derives from `Exception`/`ApplicationException`
- Is marked with the `[Serializable]` attribute
- Defines a default constructor
- Defines a constructor that sets the inherited `Message` property
- Defines a constructor to handle “inner exceptions”
- Defines a constructor to handle the serialization of your type

Now, based on your current background with .NET, you might have no experience regarding the role of attributes or object serialization, which is just fine. I’ll address these topics later (see Chapter 17 for information on attributes and Chapter 20 for details on serialization services). However, to complete your examination of building custom exceptions, here is the final iteration of `CarIsDeadException`, which accounts for each of these special constructors (the properties would be as shown in the previous example):

```
using System.Runtime.Serialization;
[Serializable]
public class CarIsDeadException : ApplicationException
{
    public CarIsDeadException(string cause, DateTime time)
        : this(cause,time,string.Empty) { }
    public CarIsDeadException(
        string cause, DateTime time, string message)
        : this(cause,time,string.Empty, null) { }
    public CarIsDeadException(string cause, DateTime time,
        string message, System.Exception inner)
        : base(message, inner)
    {
        CauseOfError = cause;
        ErrorTimeStamp = time;
    }
    protected CarIsDeadException(string cause, DateTime time,
        SerializationInfo info, StreamingContext context)
        : base(info, context)
    {
        CauseOfError = cause;
        ErrorTimeStamp = time;
    }
    // Additional custom properties and data members...
}
```

With this update to your custom exception, update the `Accelerate` method to the following:

```
throw new CarIsDeadException("You have a lead foot",
    DateTime.Now,$"{PetName} has overheated!")
{
    HelpLink = "http://www.CarsRUs.com",
};
```

Given that building custom exceptions that adhere to .NET Core best practices really differ by only their name, you will be happy to know that Visual Studio provides a code snippet template named `Exception` that will autogenerate a new exception class that adheres to .NET best practices. To activate it, type `exc` in the editor and hit the `Tab` key.

## Processing Multiple Exceptions

In its simplest form, a `try` block has a single `catch` block. In reality, though, you often run into situations where the statements within a `try` block could trigger *numerous* possible exceptions. Create a new C# Console Application project named `ProcessMultipleExceptions`; add the `Car.cs`, `Radio.cs`, and `CarIsDeadException.cs` files from the previous CustomException example into the new project (via Project ► Add Existing Item); and update your namespace names accordingly.

Now, update the `Car`'s `Accelerate()` method to also throw a predefined base class library `ArgumentOutOfRangeException` if you pass an invalid parameter (which you can assume is any value less than zero). Note the constructor of this exception class takes the name of the offending argument as the first string, followed by a message describing the error.

```
// Test for invalid argument before proceeding.
public void Accelerate(int delta)
{
    if (delta < 0)
    {
        throw new ArgumentOutOfRangeException(nameof(delta),
            "Speed must be greater than zero");
    }
    ...
}
```

---

■ **Note** The `nameof` operator returns a string representing the name of the object, in this example the variable `delta`. This is a safer way to refer to C# objects, methods, and variables when the string version is required.

---

The catch logic could now specifically respond to each type of exception.

```
static void Main(string[] args)
{
    Console.WriteLine("***** Handling Multiple Exceptions *****\n");
    Car myCar = new Car("Rusty", 90);
    try
    {
        // Trip Arg out of range exception.
        myCar.Accelerate(-10);
    }
    catch (CarIsDeadException e)
    {
        Console.WriteLine(e.Message);
    }
}
```



```

catch (ArgumentOutOfRangeException e)
{
    Console.WriteLine(e.Message);
}
Console.ReadLine();
}

```

When you are authoring multiple catch blocks, you must be aware that when an exception is thrown, it will be processed by the first appropriate catch. To illustrate exactly what the “first appropriate” catch means, assume you retrofitted the previous logic with an additional catch scope that attempts to handle all exceptions beyond `CarIsDeadException` and `ArgumentOutOfRangeException` by catching a general `System.Exception` as follows:

```

// This code will not compile!
static void Main(string[] args)
{
    Console.WriteLine("***** Handling Multiple Exceptions *****\n");
    Car myCar = new Car("Rusty", 90);

    try
    {
        // Trigger an argument out of range exception.
        myCar.Accelerate(-10);
    }
    catch(Exception e)
    {
        // Process all other exceptions?
        Console.WriteLine(e.Message);
    }
    catch (CarIsDeadException e)
    {
        Console.WriteLine(e.Message);
    }
    catch (ArgumentOutOfRangeException e)
    {
        Console.WriteLine(e.Message);
    }
    Console.ReadLine();
}

```

This exception handling logic generates compile-time errors. The problem is that the first catch block can handle *anything* derived from `System.Exception` (given the “is-a” relationship), including the `CarIsDeadException` and `ArgumentOutOfRangeException` types. Therefore, the final two catch blocks are unreachable!

The rule of thumb to keep in mind is to make sure your catch blocks are structured such that the first catch is the most specific exception (i.e., the most derived type in an exception-type inheritance chain), leaving the final catch for the most general (i.e., the base class of a given exception inheritance chain, in this case `System.Exception`).

Thus, if you want to define a catch block that will handle any errors beyond `CarIsDeadException` and `ArgumentOutOfRangeException`, you could write the following:

```
// This code compiles just fine.
static void Main(string[] args)
{
    Console.WriteLine("***** Handling Multiple Exceptions *****\n");
    Car myCar = new Car("Rusty", 90);
    try
    {
        // Trigger an argument out of range exception.
        myCar.Accelerate(-10);
    }
    catch (CarIsDeadException e)
    {
        Console.WriteLine(e.Message);
    }
    catch (ArgumentOutOfRangeException e)
    {
        Console.WriteLine(e.Message);
    }
    // This will catch any other exception
    // beyond CarIsDeadException or
    // ArgumentOutOfRangeException.
    catch (Exception e)
    {
        Console.WriteLine(e.Message);
    }
    Console.ReadLine();
}
```

---

■ **Note** Where at all possible, always favor catching specific exception classes, rather than a general `System.Exception`. Though it might appear to make life simple in the short term (you may think “Ah! This catches all the other things I don’t care about.”), in the long term you could end up with strange runtime crashes, as a more serious error was not directly dealt with in your code. Remember, a final catch block that deals with `System.Exception` tends to be very general indeed.

---

## General catch Statements

C# also supports a “general” catch scope that does not explicitly receive the exception object thrown by a given member.

```
// A generic catch.
static void Main(string[] args)
{
    Console.WriteLine("***** Handling Multiple Exceptions *****\n");
    Car myCar = new Car("Rusty", 90);
    try
    {
        myCar.Accelerate(90);
    }
}
```

```

catch
{
    Console.WriteLine("Something bad happened...");
}
Console.ReadLine();
}

```

Obviously, this is not the most informative way to handle exceptions since you have no way to obtain meaningful data about the error that occurred (such as the method name, call stack, or custom message). Nevertheless, C# does allow for such a construct, which can be helpful when you want to handle all errors in a general fashion.

## Rethrowing Exceptions

When you catch an exception, it is permissible for the logic in a `try` block to *rethrow* the exception up the call stack to the previous caller. To do so, simply use the `throw` keyword within a catch block. This passes the exception up the chain of calling logic, which can be helpful if your catch block is only able to partially handle the error at hand.

```

// Passing the buck.
static void Main(string[] args)
{
    ...
    try
    {
        // Speed up car logic...
    }
    catch(CarIsDeadException e)
    {
        // Do any partial processing of this error and pass the buck.
        throw;
    }
    ...
}

```

Be aware that, in this example code, the ultimate receiver of `CarIsDeadException` is the CoreCLR because it is the `Main()` method rethrowing the exception. Because of this, your end user is presented with a system-supplied error dialog box. Typically, you would only rethrow a partially handled exception to a caller that has the ability to handle the incoming exception more gracefully.

Notice as well that you are not explicitly rethrowing the `CarIsDeadException` object but rather making use of the `throw` keyword with no argument. You're not creating a new exception object; you're just rethrowing the original exception object (with all its original information). Doing so preserves the context of the original target.

## Inner Exceptions

As you might suspect, it is entirely possible to trigger an exception at the time you are handling another exception. For example, assume you are handling a `CarIsDeadException` within a particular catch scope and during the process you attempt to record the stack trace to a file on your C: drive named `carErrors.txt` (you must specify you are using the `System.IO` namespace to gain access to these I/O-centric types).

```

catch(CarIsDeadException e)
{
    // Attempt to open a file named carErrors.txt on the C drive.
    FileStream fs = File.Open(@"C:\carErrors.txt", FileMode.Open);
    ...
}

```

Now, if the specified file is not located on your C: drive, the call to `File.Open()` results in a `FileNotFoundException`! Later in this book, you will learn all about the `System.IO` namespace where you'll discover how to programmatically determine whether a file exists on the hard drive before attempting to open the file in the first place (thereby avoiding the exception altogether). However, to stay focused on the topic of exceptions, assume the exception has been raised.

When you encounter an exception while processing another exception, best practice states that you should record the new exception object as an “inner exception” within a new object of the same type as the initial exception. (That was a mouthful!) The reason you need to allocate a new object of the exception being handled is that the only way to document an inner exception is via a constructor parameter. Consider the following code:

```

//Place this at the top of the program.cs file
@using using System.IO;
//Update the exception handler
catch (CarIsDeadException e)
{
    try
    {
        FileStream fs =
            File.Open(@"C:\carErrors.txt", FileMode.Open);
        ...
    }
    catch (Exception e2)
    {
        //This causes a compile error-InnerException is read only
        //e.InnerException = e2;
        // Throw an exception that records the new exception,
        // as well as the message of the first exception.
        throw new CarIsDeadException(
            e.CauseOfError, e.ErrorTimeStamp, e.Message, e2); }
}

```

Notice, in this case, I have passed in the `FileNotFoundException` object as the second parameter to the `CarIsDeadException` constructor. After you have configured this new object, you throw it up the call stack to the next caller, which in this case would be the `Main()` method.

Given that there is no “next caller” after `Main()` to catch the exception, you would be again presented with an error dialog box. Much like the act of rethrowing an exception, recording inner exceptions is usually useful only when the caller has the ability to gracefully catch the exception in the first place. If this is the case, the caller’s catch logic can use the `InnerException` property to extract the details of the inner exception object.

## The finally Block

A try/catch scope may also define an optional finally block. The purpose of a finally block is to ensure that a set of code statements will *always* execute, exception (of any type) or not. To illustrate, assume you want to always power down the car's radio before exiting Main(), regardless of any handled exception.

```
static void Main(string[] args)
{
    Console.WriteLine("***** Handling Multiple Exceptions *****\n");
    Car myCar = new Car("Rusty", 90);
    myCar.CrankTunes(true);
    try
    {
        // Speed up car logic.
    }
    catch(CarIsDeadException e)
    {
        // Process CarIsDeadException.
    }
    catch(ArgumentOutOfRangeException e)
    {
        // Process ArgumentOutOfRangeException.
    }
    catch(Exception e)
    {
        // Process any other Exception.
    }
    finally
    {
        // This will always occur. Exception or not.
        myCar.CrankTunes(false);
    }
    Console.ReadLine();
}
```

If you did not include a finally block, the radio would not be turned off if an exception were encountered (which might or might not be problematic). In a more real-world scenario, when you need to dispose of objects, close a file, or detach from a database (or whatever), a finally block ensures a location for proper cleanup.

## Exception Filters

C# 6 introduced a new clause that can be placed on a catch scope, via the when keyword. When you add this clause, you have the ability to ensure that the statements within a catch block are executed only if some condition in your code holds true. This expression must evaluate to a Boolean (true or false) and can be obtained by using a simple code statement in the when definition itself or by calling an additional method in your code. In a nutshell, this approach allows you to add “filters” to your exception logic.

Consider the following modified exception logic. I have added a when clause to the CarIsDeadException handler to ensure the catch block is never executed on a Friday (a contrived example, but who wants their automobile to break down right by the weekend?). Notice that the single Boolean statement in the when clause must be wrapped in parentheses.

```

catch (CarIsDeadException e) when (e.ErrorTimeStamp.DayOfWeek != DayOfWeek.Friday)
{
    // This new line will only print if the when clause evaluates to true.
    Console.WriteLine("Catching car is dead!");

    Console.WriteLine(e.Message);
}

```

While this example is very contrived, a more likely use for the exception filter is when catch `SystemExceptions` in order to catch specific cases. For example, suppose your code is saving data to the database, a general exception is thrown. By examining the message and exception data, you can create specific handlers based on what caused the exception.

## Debugging Unhandled Exceptions Using Visual Studio

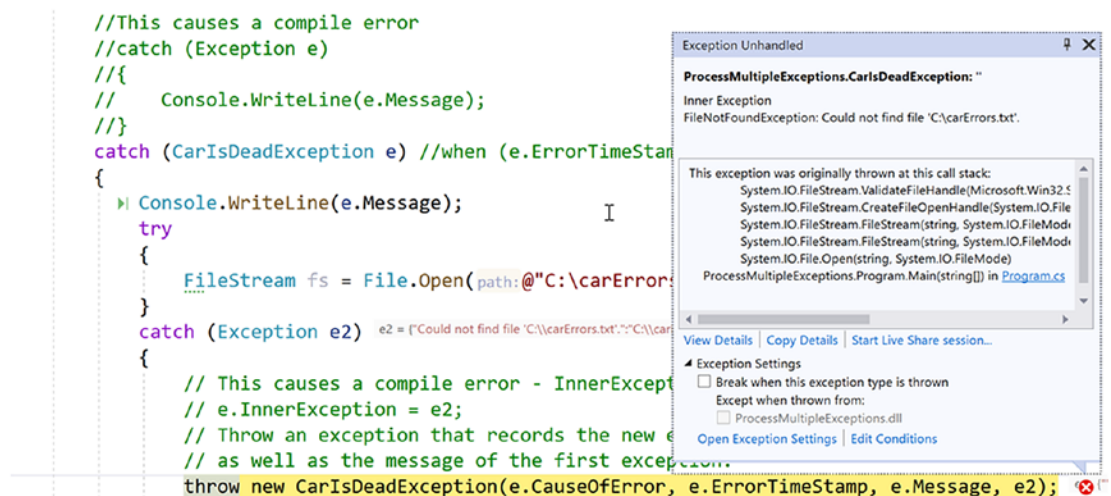
Visual Studio supplies a number of tools that help you debug unhandled exceptions. Assume you have increased the speed of a `Car` object beyond the maximum but this time did not bother to wrap your call within a try block.

```

Car myCar = new Car("Rusty", 90);
myCar.Accelerate(100);

```

If you start a debugging session within Visual Studio (using the `Debug ► Start Debugging` menu selection), Visual Studio automatically breaks at the time the uncaught exception is thrown. Better yet, you are presented with a window (see Figure 7-1) displaying the value of the `Message` property.



**Figure 7-1.** Debugging unhandled custom exceptions with Visual Studio

**Note** If you fail to handle an exception thrown by a method in the .NET base class libraries, the Visual Studio debugger breaks at the statement that called the offending method.

If you click the View Detail link, you will find the details regarding the state of the object (see Figure 7-2).

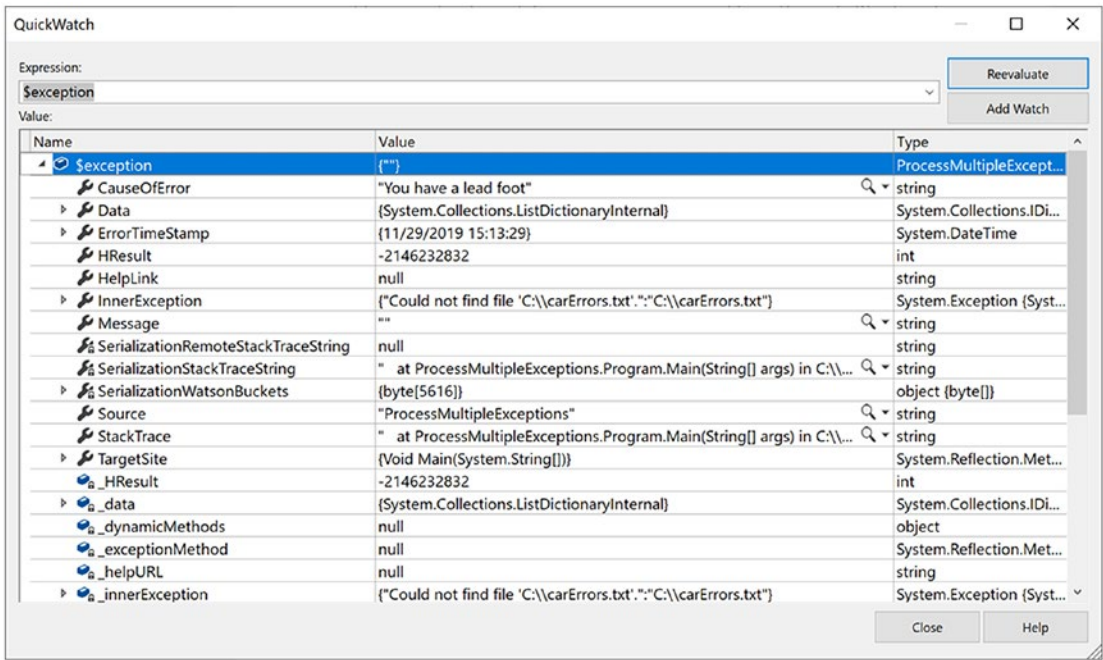


Figure 7-2. Viewing exception details

# Summary

In this chapter, you examined the role of structured exception handling. When a method needs to send an error object to the caller, it will allocate, configure, and throw a specific `System.Exception`-derived type via the `C# throw` keyword. The caller is able to handle any possible incoming exceptions using the `C# catch` keyword and an optional `finally` scope. Since `C# 6.0`, the ability to create exception filters using the optional `when` keyword was added, and `C# 7` has expanded the locations from where you can throw exceptions.

When you are creating your own custom exceptions, you ultimately create a class type deriving from `System.ApplicationException`, which denotes an exception thrown from the currently executing application. In contrast, error objects deriving from `System.SystemException` represent critical (and fatal) errors thrown by the CoreCLR. Last but not least, this chapter illustrated various tools within Visual Studio that can be used to create custom exceptions (according to .NET best practices) as well as debug exceptions.

## CHAPTER 8



# Working with Interfaces

This chapter builds upon your current understanding of object-oriented development by examining the topic of interface-based programming. Here, you'll learn how to define and implement interfaces and come to understand the benefits of building types that support multiple behaviors. Along the way, you will also examine a number of related topics, such as obtaining interface references, explicit interface implementation, and the construction of interface hierarchies. You'll also examine a number of standard interfaces defined within the .NET Core base class libraries. Also covered are the new features in C# 8 regarding interfaces, including default interface methods, static members, and access modifiers. As you will see, your custom classes and structures are free to implement these predefined interfaces to support a number of useful behaviors, such as object cloning, object enumeration, and object sorting.

## Understanding Interface Types

To begin this chapter, allow me to provide a formal definition of the *interface type*, which has changed with the introduction of C# 8.0. Prior to C# 8.0, an interface is nothing more than a named set of *abstract members*. Recall from Chapter 6 that abstract methods are pure protocol, in that they do not provide a default implementation. The specific members defined by an interface depend on the exact behavior it is modeling. Said another way, an interface expresses a *behavior* that a given class or structure may choose to support. Furthermore, as you will see in this chapter, a class or structure can support as many interfaces as necessary, thereby supporting (in essence) multiple behaviors.

The default interface methods feature, introduced in C# 8.0, allows for interface methods to contain an implementation that may or may not be overridden by the implementing class. More on this later in this chapter.

As you might guess, the .NET Core base class libraries ship with numerous predefined interface types that are implemented by various classes and structures. For example, as you will see in Chapter 21, ADO.NET ships with multiple data providers that allow you to communicate with a particular database management system. Thus, under ADO.NET, you have numerous connection objects to choose from (SqlConnection, OleDbConnection, OdbcConnection, etc.). In addition, third-party database vendors (as well as numerous open source projects) provide .NET libraries to communicate with a wide number of other databases (MySQL, Oracle, etc.), all of which contain objects implementing these interfaces.

Regardless of the fact that each connection class has a unique name, is defined within a different namespace, and (in some cases) is bundled within a different assembly, all connection classes implement a common interface named IDbConnection.

```
// The IDbConnection interface defines a common
// set of members supported by all connection objects.
public interface IDbConnection : IDisposableable
{
```



```

// Methods
IDbTransaction BeginTransaction();
IDbTransaction BeginTransaction(IsolationLevel il);
void ChangeDatabase(string databaseName);
void Close();
IDbCommand CreateCommand();
void Open();
// Properties
string ConnectionString { get; set; }
int ConnectionTimeout { get; }
string Database { get; }
ConnectionState State { get; }
}

```

---

■ **Note** By convention, .NET interfaces are prefixed with a capital letter *I*. When you are creating your own custom interfaces, it is considered a best practice to do the same.

---

Don't concern yourself with the details of what these members actually do at this point. Simply understand that the `IDbConnection` interface defines a set of members that are common to all ADO.NET connection classes. Given this, you are guaranteed that every connection object supports members such as `Open()`, `Close()`, `CreateCommand()`, and so forth. Furthermore, given that interface members are always abstract, each connection object is free to implement these methods in its own unique manner.

As you work through the remainder of this book, you'll be exposed to dozens of interfaces that ship with the .NET Core base class libraries. As you will see, these interfaces can be implemented on your own custom classes and structures to define types that integrate tightly within the framework. As well, once you understand the usefulness of the interface type, you will certainly find reasons to build your own.

## Interface Types vs. Abstract Base Classes

Given your work in Chapter 6, the interface type might seem somewhat similar to an abstract base class. Recall that when a class is marked as abstract, it *may* define any number of abstract members to provide a polymorphic interface to all derived types. However, even when a class does define a set of abstract members, it is also free to define any number of constructors, field data, nonabstract members (with implementation), and so on. Interfaces (prior to C# 8.0) contain *only* member definitions. Now, with C# 8, interfaces can contain member definitions (like abstract members), members with default implementations (like virtual methods), and static members. There are only two real differences: interfaces can't have nonstatic constructors, and a class can implement multiple interfaces. More on this second point next.

The polymorphic interface established by an abstract parent class suffers from one major limitation, in that *only derived types* support the members defined by the abstract parent. However, in larger software systems, it is common to develop multiple class hierarchies that have no common parent beyond `System.Object`. Given that abstract members in an abstract base class apply only to derived types, you have no way to configure types in different hierarchies to support the same polymorphic interface. To begin, create a new Console Application project named `CustomInterfaces`. Add the following abstract class to the project:

```

public abstract class CloneableType
{
    // Only derived types can support this
    // "polymorphic interface." Classes in other

```

```
// hierarchies have no access to this abstract
// member.
public abstract object Clone();
}
```

Given this definition, only members that extend `CloneableType` are able to support the `Clone()` method. If you create a new set of classes that do not extend this base class, you can't gain this polymorphic interface. Also, you might recall that C# does not support multiple inheritance for classes. Therefore, if you wanted to create a `MiniVan` that is-a `Car` and is-a `CloneableType`, you are unable to do so.

```
// Nope! Multiple inheritance is not possible in C#
// for classes.
public class MiniVan : Car, CloneableType
{
}
```

As you might guess, interface types come to the rescue. After an interface has been defined, it can be implemented by any class or structure, in any hierarchy, and within any namespace or any assembly (written in any .NET Core programming language). As you can see, interfaces are *highly* polymorphic. Consider the standard .NET Core interface named `ICloneable`, defined in the `System` namespace. This interface defines a single method named `Clone()`:

```
public interface ICloneable
{
    object Clone();
}
```

If you examine the .NET Core base class libraries, you'll find that a large number of seemingly unrelated types (`System.Array`, `System.Data.SqlClient.SqlConnection`, `System.OperatingSystem`, `System.String`, etc.) all implement this interface. Although these types have no common parent (other than `System.Object`), you can treat them polymorphically via the `ICloneable` interface type.

For example, if you had a method named `CloneMe` that took an `ICloneable` interface parameter, you could pass this method any object that implements said interface. Consider the following simple example that implements the `CloneMe` method as a local function:

```
static void CloneableExample()
{
    // All of these classes support the ICloneable interface.
    string myStr = "Hello";
    OperatingSystem unixOS =
        new OperatingSystem(PlatformID.Unix, new Version());

    // Therefore, they can all be passed into a method taking ICloneable.
    CloneMe(myStr);
    CloneMe(unixOS);
    static void CloneMe(ICloneable c)
    {
        // Clone whatever we get and print out the name.
        object theClone = c.Clone();
        Console.WriteLine("Your clone is a: {0}",
```

```

        theClone.GetType().Name);
    }
}

```

Update the Main method to the following:

```

static void Main(string[] args)
{
    Console.WriteLine("***** A First Look at Interfaces *****\n");
    CloneableExample();
}

```

When you run this application, the class name of each class prints to the console via the `GetType()` method you inherit from `System.Object`. As explained in Chapter 17, this method allows you to understand the composition of any type at runtime. In any case, the output of the previous program is shown next:

---

```
***** A First Look at Interfaces *****
```

```

Your clone is a: String
Your clone is a: OperatingSystem

```

---

Another limitation of abstract base classes is that *each derived type* must contend with the set of abstract members and provide an implementation. To see this problem, recall the shapes hierarchy you defined in Chapter 6. Assume you defined a new abstract method in the `Shape` base class named `GetNumberOfPoints()`, which allows derived types to return the number of points required to render the shape.

```

abstract class Shape
{
    ...
    // Every derived class must now support this method!
    public abstract byte GetNumberOfPoints();
}

```

Clearly, the only class that has any points in the first place is `Hexagon`. However, with this update, *every* derived class (`Circle`, `Hexagon`, and `ThreeDCircle`) must now provide a concrete implementation of this function, even if it makes no sense to do so. Again, the interface type provides a solution. If you define an interface that represents the behavior of “having points,” you can simply plug it into the `Hexagon` type, leaving `Circle` and `ThreeDCircle` untouched.

---

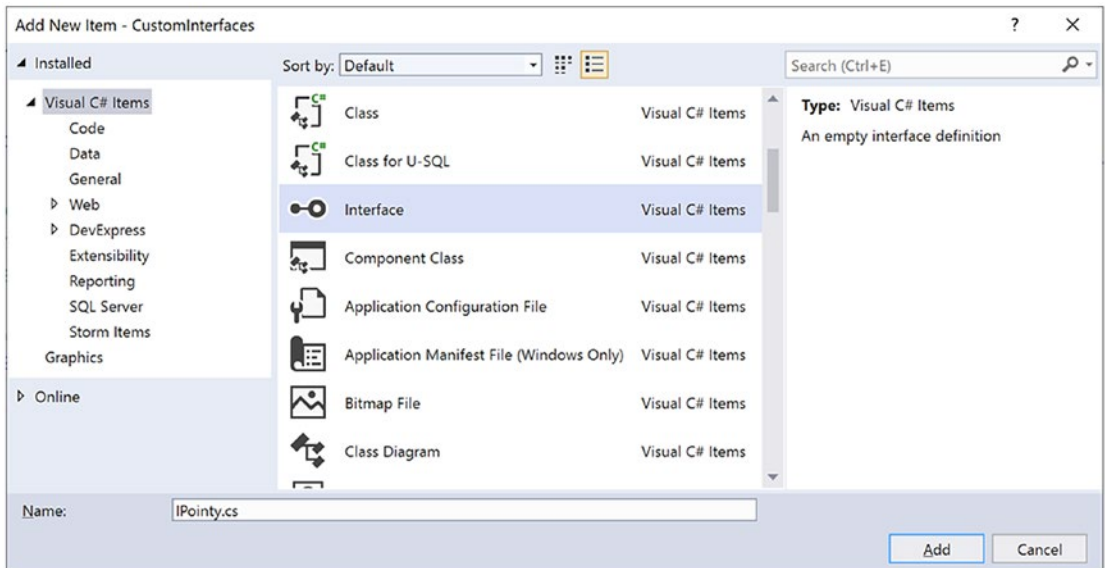
■ **Note** The changes to interfaces in C# 8 are probably the most significant changes to an existing language feature that I can recall. As described earlier, the new interface capabilities move them significantly closer to the functionality of abstract classes, with the added ability for a class to implement multiple interfaces. My advice is to tread carefully in these waters and use common sense. Just because you can do something, doesn’t mean that you should.

---

## Defining Custom Interfaces

Now that you better understand the overall role of interface types, let's see an example of defining and implementing custom interfaces. Using the Project ► Add Existing Item menu option, insert the files from the Shapes solution you created in Chapter 6: Shape.cs, Hexagon.cs, Circle.cs, and ThreeDCircle.cs. After you have done so, rename the namespace that defines your shape-centric types to CustomInterfaces (simply to avoid having to import namespace definitions in your new project).

Now, insert a new interface into your project named IPointy using the Project ► Add New Item menu option, as shown in Figure 8-1.



**Figure 8-1.** Interfaces, like classes, can be defined in any \*.cs file

At a syntactic level, an interface is defined using the C# interface keyword. Unlike a class, interfaces never specify a base class (not even System.Object; however, as you will see later in this chapter, an interface can specify base interfaces). Prior to C# 8.0, the members of an interface never specify an access modifier (as all interface members are implicitly public and abstract). New in C#, private, internal, protected, and even static members can also be defined. More on this later. To get the ball rolling, here is a custom interface defined in C#:

```
// This interface defines the behavior of "having points."
public interface IPointy
{
    // Implicitly public and abstract.
    byte GetNumberOfPoints();
}
```

Interfaces in C# 8 cannot define data fields or nonstatic constructors. Hence, the following version of `IPointy` would result in various compiler errors:

**// Ack! Errors abound!**

```
public interface IPointy
{
    // Error! Interfaces cannot have data fields!
    public int numbofPoints;
    // Error! Interfaces do not have nonstatic constructors!
    public IPointy() { numbofPoints = 0;}
}
```

In any case, this initial `IPointy` interface defines a single method. Interface types are also able to define any number of property prototypes. For example, we could update the `IPointy` interface to use a read-write property (commented out) and a read-only property. The `Points` property replaces the `GetNumberOfPoints` method:

```
// The pointy behavior as a read-only property.
public interface IPointy
{
    // Implicitly public and abstract.
    //byte GetNumberOfPoints();

    // A read-write property in an interface would look like:
    //string PropName { get; set; }

    // while a write-only property in an interface would be:
    byte Points { get; }
}
```

---

■ **Note** Interface types can also contain event (see Chapter 12) and indexer (see Chapter 11) definitions.

---

Interface types are quite useless on their own, as you can't allocate interface types as you would a class or structure.

```
// Ack! Illegal to allocate interface types.
static void Main(string[] args)
{
    IPointy p = new IPointy(); // Compiler error!
}
```

Interfaces do not bring much to the table until they are implemented by a class or structure. Here, `IPointy` is an interface that expresses the behavior of “having points.” The idea is simple: some classes in the shapes hierarchy have points (such as the `Hexagon`), while others (such as the `Circle`) do not.

## Implementing an Interface

When a class (or structure) chooses to extend its functionality by supporting interfaces, it does so using a comma-delimited list in the type definition. Be aware that the direct base class must be the first item listed after the colon operator. When your class type derives directly from `System.Object`, you are free to simply list the interface (or interfaces) supported by the class, as the C# compiler will extend your types from `System.Object` if you do not say otherwise. On a related note, given that structures always derive from `System.ValueType` (see Chapter 4), simply list each interface directly after the structure definition. Ponder the following examples:

```
// This class derives from System.Object and
// implements a single interface.
public class Pencil : IPointy
{...}

// This class also derives from System.Object
// and implements a single interface.
public class SwitchBlade : object, IPointy
{...}

// This class derives from a custom base class
// and implements a single interface.
public class Fork : Utensil, IPointy
{...}

// This struct implicitly derives from System.ValueType and
// implements two interfaces.
public struct PitchFork : ICloneable, IPointy
{...}
```

Understand that implementing an interface is an all-or-nothing proposition for interface items that do not include a default implementation. The supporting type is not able to selectively choose which members it will implement. Given that the `IPointy` interface defines a single read-only property, this is not too much of a burden. However, if you are implementing an interface that defines ten members (such as the `IDbConnection` interface shown earlier), the type is now responsible for fleshing out the details of all ten abstract members.

For this example, insert a new class type named `Triangle` that is-a `Shape` and supports `IPointy`. Note that the implementation of the read-only `Points` property (implemented using the expression-bodied member syntax) simply returns the correct number of points (3).

```
// New Shape derived class named Triangle.
class Triangle : Shape, IPointy
{
    public Triangle() { }
    public Triangle(string name) : base(name) { }
    public override void Draw()
    { Console.WriteLine("Drawing {0} the Triangle", PetName); }

    // IPointy implementation.
    //public byte Points
```

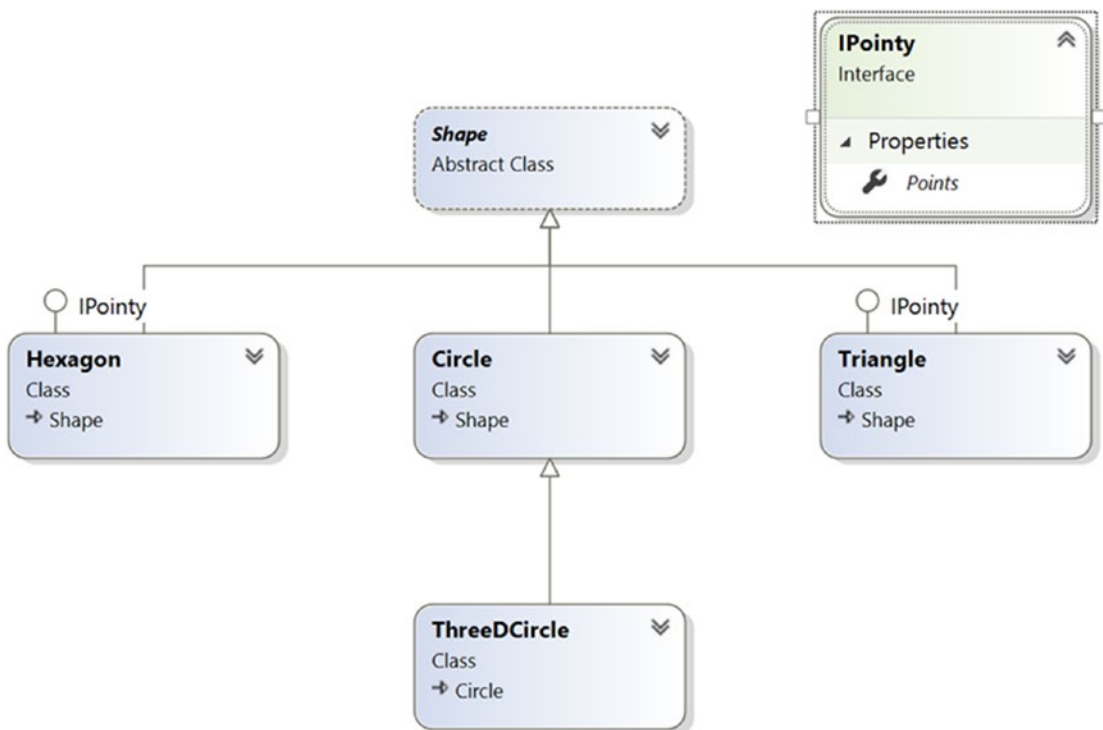
```
//{
//    get { return 3; }
//}
public byte Points => 3;
}
```

Now, update your existing Hexagon type to also support the IPointy interface type.

```
// Hexagon now implements IPointy.
class Hexagon : Shape, IPointy
{
    public Hexagon(){ }
    public Hexagon(string name) : base(name){ }
    public override void Draw()
    { Console.WriteLine("Drawing {0} the Hexagon", PetName); }

    // IPointy implementation.
    public byte Points => 6;
}
```

To sum up the story so far, the Visual Studio class diagram shown in Figure 8-2 illustrates IPointy-compatible classes using the popular “lollipop” notation. Notice again that Circle and ThreeDCircle do not implement IPointy, as this behavior makes no sense for these particular classes.



**Figure 8-2.** The shapes hierarchy, now with interfaces

---

■ **Note** To display or hide interface names in the class designer, right-click the interface icon and select the Collapse or Expand option.

---

## Invoking Interface Members at the Object Level

Now that you have some classes that support the `IPointy` interface, the next question is how you interact with the new functionality. The most straightforward way to interact with functionality supplied by a given interface is to invoke the members directly from the object level (provided the interface members are not implemented explicitly; you can find more details later in the section “Explicit Interface Implementation”). For example, consider the following `Main()` method:

```
static void Main(string[] args)
{
    Console.WriteLine("***** Fun with Interfaces *****\n");
    // Call Points property defined by IPointy.
    Hexagon hex = new Hexagon();
    Console.WriteLine("Points: {0}", hex.Points);
    Console.ReadLine();
}
```

This approach works fine in this particular case, given that you are well aware that the `Hexagon` type has implemented the interface in question and, therefore, has a `Points` property. Other times, however, you might not be able to determine which interfaces are supported by a given type. For example, suppose you have an array containing 50 `Shape`-compatible types, only some of which support `IPointy`. Obviously, if you attempt to invoke the `Points` property on a type that has not implemented `IPointy`, you would receive an error. So, how can you dynamically determine whether a class or structure supports the correct interface?

One way to determine at runtime whether a type supports a specific interface is to use an explicit cast. If the type does not support the requested interface, you receive an `InvalidCastException`. To handle this possibility gracefully, use structured exception handling as in the following example:

```
static void Main(string[] args)
{
    ...
    // Catch a possible InvalidCastException.
    Circle c = new Circle("Lisa");
    IPointy itfPt = null;
    try
    {
        itfPt = (IPointy)c;
        Console.WriteLine(itfPt.Points);
    }
    catch (InvalidCastException e)
    {
        Console.WriteLine(e.Message);
    }
    Console.ReadLine();
}
```



While you could use try/catch logic and hope for the best, it would be ideal to determine which interfaces are supported before invoking the interface members in the first place. Let's see two ways of doing so.

## Obtaining Interface References: The as Keyword

You can determine whether a given type supports an interface by using the `as` keyword, introduced in Chapter 6. If the object can be treated as the specified interface, you are returned a reference to the interface in question. If not, you receive a null reference. Therefore, be sure to check against a null value before proceeding.

```
static void Main(string[] args)
{
    ...
    // Can we treat hex2 as IPointy?
    Hexagon hex2 = new Hexagon("Peter");
    IPointy itfPt2 = hex2 as IPointy;
    if(itfPt2 != null)
    {
        Console.WriteLine("Points: {0}", itfPt2.Points);
    }
    else
    {
        Console.WriteLine("OOPS! Not pointy...");
    }
    Console.ReadLine();
}
```

Notice that when you use the `as` keyword, you have no need to use try/catch logic; if the reference is not null, you know you are calling on a valid interface reference.

## Obtaining Interface References: The is Keyword (Updated 7.0)

You may also check for an implemented interface using the `is` keyword (also first discussed in Chapter 6). If the object in question is not compatible with the specified interface, you are returned the value `false`. If you supply a variable name in the statement, the type is assigned into the variable, eliminating the need to do the type check and perform a cast. The previous example is updated here:

```
static void Main(string[] args)
{
    Console.WriteLine("***** Fun with Interfaces *****\n");
    ...
    if(hex2 is IPointy itfPt3)
    {
        Console.WriteLine("Points: {0}", itfPt3.Points);
    }
    else
    {
        Console.WriteLine("OOPS! Not pointy...");
    }
    Console.ReadLine();
}
```

## Default Implementations (New 8.0)

As mentioned earlier, C# 8.0 added the ability for interface methods and properties to have a default implementation. Add a new interface named `IRegularPointy`, to represent a regularly shaped polygon. The code is shown here:

```
interface IRegularPointy : IPointy
{
    int SideLength { get; set; }
    int NumberOfSides { get; set; }
    int Perimeter => SideLength * NumberOfSides;
}
```

Add a new class named `Square.cs` to the project, and inherit the `Shape` base class and implement the `IRegularPointy` interface, as follows:

```
class Square: Shape, IRegularPointy
{
    public Square() { }
    public Square(string name) : base(name) { }
    //Draw comes from the Shape base class
    public override void Draw()
    {
        Console.WriteLine("Drawing a square");
    }

    //This comes from the IPointy interface
    public byte Points => 4;
    //These come from the IRegularPointy interface
    public int SideLength { get; set; }
    public int NumberOfSides { get; set; }
    //Note that the Perimeter property is not implemented
}
```

Here we have unwittingly introduced the first “catch” of using default implementations in interfaces. The `Perimeter` property, defined on the `IRegularPointy` interface, is not defined in the `Square` class, making it inaccessible from an instance of `Square`. To see this in action, create a new instance of a `Square` class and output the relevant values to the console, like this:

```
static void Main(string[] args)
{
    Console.WriteLine("\n***** Fun with Interfaces *****\n");
    ...
    var sq = new Square("Boxy")
        {NumberOfSides = 4, SideLength = 4};
    sq.Draw();
    //This won't compile
    //Console.WriteLine($"{sq.PetName} has {sq.NumberOfSides} of length {sq.SideLength} and a
    perimeter of {sq.Perimeter}");
}
```

Instead, the `Square` instance must be explicitly cast to the `IRegularPointy` interface (since that is where the implementation lives), and then the `Perimeter` property can be accessed. Update the code to the following:

```
Console.WriteLine($"{sq.PetName} has {sq.NumberOfSides} of length {sq.SideLength} and a  
perimeter of {(IRegularPointy)sq}.Perimeter");
```

One option to get around this problem is to always code to the interface of a type. Change the definition of the `Square` instance to `IRegularPointy` instead of `Square`, like this:

```
IRegularPointy sq = new Square("Boxy") {NumberOfSides = 4, SideLength = 4};
```

The problem with this approach (in our particular case) is that the `Draw` method and `PetName` property are not defined on the interface, causing compilation errors.

While this is a trivial example, it does demonstrate one of the problems with default interfaces. Before using this feature in your code, make sure you measure the implications of the calling code having to know where the implementation exists.

## Static Constructors and Members (New 8.0)

Another addition to interfaces in C# 8.0 is the ability to have static constructors and members. These function the same as static members on class definitions, but defined on interfaces. Update the `IRegularPointy` interface with an example static property and a static constructor:

```
interface IRegularPointy : IPointy
{
    int SideLength { get; set; }
    int NumberOfSides { get; set; }
    int Perimeter => SideLength * NumberOfSides;

    //Static members are also allowed in C# 8
    static string ExampleProperty { get; set; }

    static IRegularPointy() => ExampleProperty = "Foo";
}
```

Static constructors have to be parameterless and can only access static properties and methods. To access the interface static property, add the following code to the `Main` method:

```
Console.WriteLine($"Example property: {IRegularPointy.ExampleProperty}");
IRegularPointy.ExampleProperty = "Updated";
Console.WriteLine($"Example property: {IRegularPointy.ExampleProperty}");
```

Notice how the static property must be invoked from the interface and not an instance variable.

## Interfaces As Parameters

Given that interfaces are valid types, you may construct methods that take interfaces as parameters, as illustrated by the `CloneMe()` method earlier in this chapter. For the current example, assume you have defined another interface named `IDraw3D`.

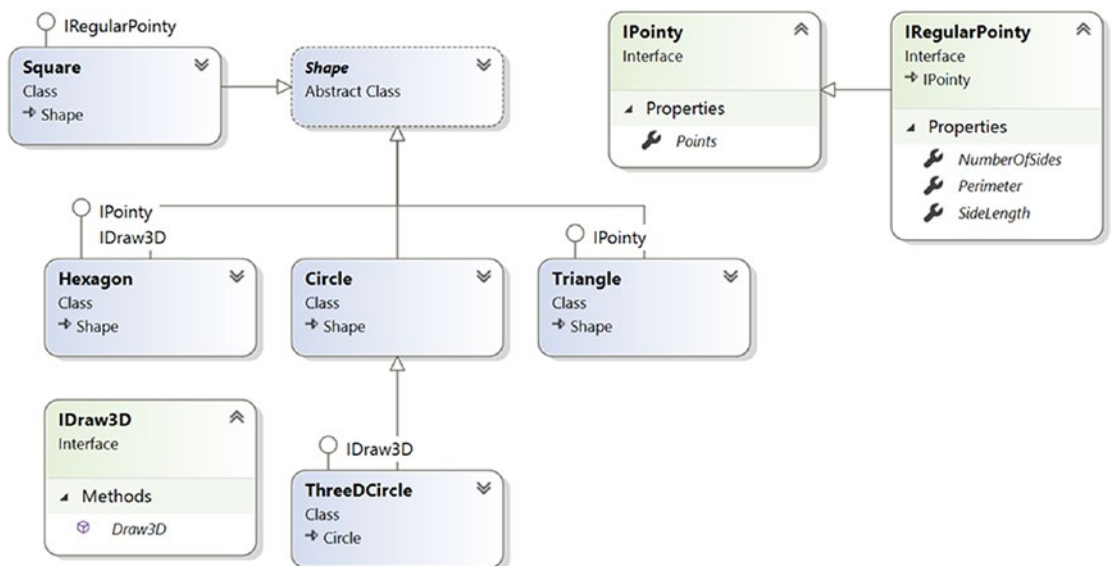
```
// Models the ability to render a type in stunning 3D.
public interface IDraw3D
{
    void Draw3D();
}
```

Next, assume that two of your three shapes (ThreeDCircle and Hexagon) have been configured to support this new behavior.

```
// Circle supports IDraw3D.
class ThreeDCircle : Circle, IDraw3D
{
    ...
    public void Draw3D()
        => Console.WriteLine("Drawing Circle in 3D!");
}

// Hexagon supports IPointy and IDraw3D.
class Hexagon : Shape, IPointy, IDraw3D
{
    ...
    public void Draw3D()
        => Console.WriteLine("Drawing Hexagon in 3D!");
}
```

Figure 8-3 presents the updated Visual Studio class diagram.



**Figure 8-3.** The updated shapes hierarchy

If you now define a method taking an `IDraw3D` interface as a parameter, you can effectively send in any object implementing `IDraw3D`. (If you attempt to pass in a type not supporting the necessary interface, you receive a compile-time error.) Consider the following method defined within your `Program` class:

```
// I'll draw anyone supporting IDraw3D.
static void DrawIn3D(IDraw3D itf3d)
{
    Console.WriteLine("-> Drawing IDraw3D compatible type");
    itf3d.Draw3D();
}
```

You could now test whether an item in the `Shape` array supports this new interface and, if so, pass it into the `DrawIn3D()` method for processing.

```
static void Main(string[] args)
{
    Console.WriteLine("***** Fun with Interfaces *****\n");
    Shape[] myShapes = { new Hexagon(), new Circle(),
        new Triangle("Joe"), new Circle("JoJo") };
    for(int i = 0; i < myShapes.Length; i++)
    {
        // Can I draw you in 3D?
        if (myShapes[i] is IDraw3D s)
        {
            DrawIn3D(s);
        }
    }
}
```

Here is the output of the updated application. Notice that only the `Hexagon` object prints out in 3D, as the other members of the `Shape` array do not implement the `IDraw3D` interface.

---

```
***** Fun with Interfaces *****
...
-> Drawing IDraw3D compatible type
Drawing Hexagon in 3D!
```

---

## Interfaces As Return Values

Interfaces can also be used as method return values. For example, you could write a method that takes an array of `Shape` objects and returns a reference to the first item that supports `IPointy`.

```
// This method returns the first object in the
// array that implements IPointy.
static IPointy FindFirstPointyShape(Shape[] shapes)
{
    foreach (Shape s in shapes)
    {
```

```

        if (s is IPointy ip)
        {
            return ip;
        }
    }
    return null;
}

```

You could interact with this method as follows:

```

static void Main(string[] args)
{
    Console.WriteLine("***** Fun with Interfaces *****\n");
    // Make an array of Shapes.
    Shape[] myShapes = { new Hexagon(), new Circle(),
                        new Triangle("Joe"), new Circle("JoJo")};

    // Get first pointy item.
    IPointy firstPointyItem = FindFirstPointyShape(myShapes);
    // To be safe, use the null conditional operator.
    Console.WriteLine("The item has {0} points",
        firstPointyItem?.Points);
    ...
}

```

## Arrays of Interface Types

Recall that the same interface can be implemented by numerous types, even if they are not within the same class hierarchy and do not have a common parent class beyond `System.Object`. This can yield some powerful programming constructs. For example, assume you have developed three new class types within your current project that model kitchen utensils (via `Knife` and `Fork` classes) and another modeling gardening equipment (à la `PitchFork`). The relevant code for the classes is shown here, and the updated class diagram is shown in Figure 8-4.

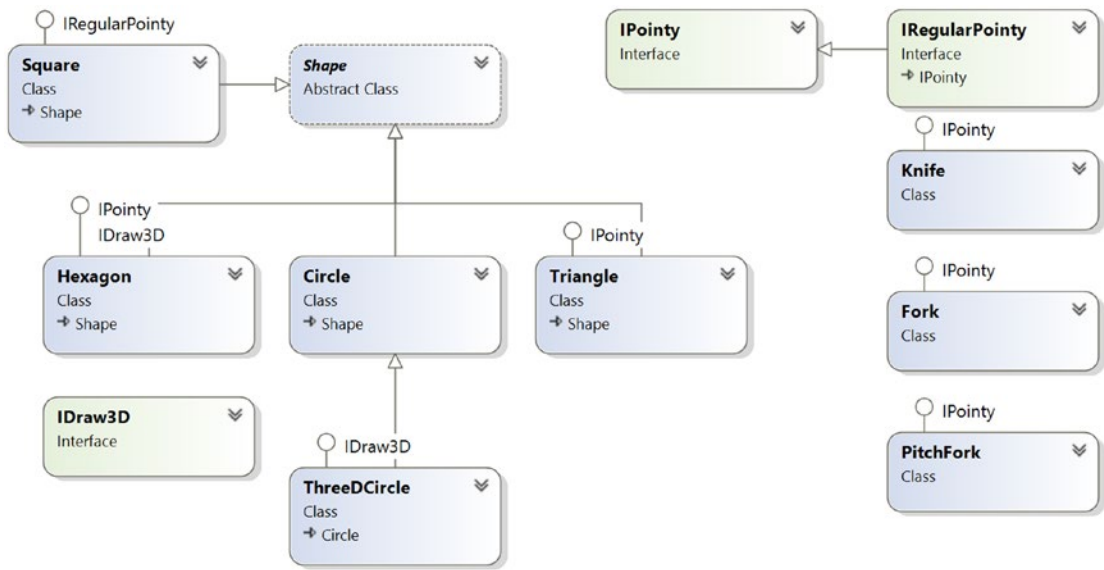
```

class Fork : IPointy
{
    public byte Points => 4;
}

class PitchFork : IPointy
{
    public byte Points => 3;
}

class Knife : IPointy
{
    public byte Points => 1;
}

```



**Figure 8-4.** Recall that interfaces can be “plugged into” any type in any part of a class hierarchy

If you defined the PitchFork, Fork, and Knife types, you could now define an array of `IPointy`-compatible objects. Given that these members all support the same interface, you can iterate through the array and treat each item as an `IPointy`-compatible object, regardless of the overall diversity of the class hierarchies.

```
static void Main(string[] args)
{
    ...
    // This array can only contain types that
    // implement the IPointy interface.
    IPointy[] myPointyObjects = {new Hexagon(), new Knife(),
        new Triangle(), new Fork(), new PitchFork()};

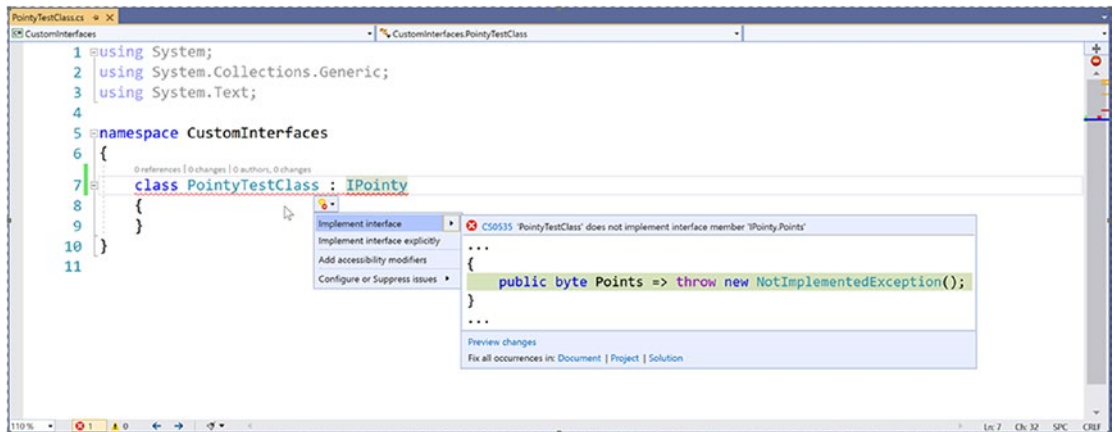
    foreach(IPointy i in myPointyObjects)
    {
        Console.WriteLine("Object has {0} points.", i.Points);
    }
    Console.ReadLine();
}
```

Just to highlight the importance of this example, remember this: when you have an array of a given interface, the array can contain any class or structure that implements that interface.

## Implementing Interfaces Using Visual Studio

Although interface-based programming is a powerful technique, implementing interfaces may entail a healthy amount of typing. Given that interfaces are a named set of abstract members, you are required to type in the definition and implementation for *each* interface method on *each* type that supports the behavior. Therefore, if you want to support an interface that defines a total of five methods and three properties, you need to account for all eight members (or else you will receive compiler errors).

As you would hope, Visual Studio supports various tools that make the task of implementing interfaces less burdensome. By way of a simple test, insert a final class into your current project named `PointyTestClass`. When you add an interface such as `IPointy` (or any interface for that matter) to a class type, you might have noticed that when you complete typing the interface's name (or when you position the mouse cursor on the interface name in the code window), Visual Studio adds a lightbulb (this can also be invoked with the CTL-Period (.) key combination). When you click the lightbulb, you will be presented with a drop-down list that allows you to implement the interface (see Figure 8-5).



**Figure 8-5.** Implementing interfaces using Visual Studio

Notice you are presented with two options, the second of which (explicit interface implementation) will be examined in the next section. For the time being, select the first option, and you'll see that Visual Studio has generated stub code for you to update (note that the default implementation throws a `System.NotImplementedException`, which can obviously be deleted).

```
namespace CustomInterfaces
{
    class PointyTestClass : IPointy
    {
        public byte Points => throw new NotImplementedException();
    }
}
```

---

■ **Note** Visual Studio also supports extract interface refactoring, available from the Extract Interface option of the Quick Actions menu. This allows you to pull out a new interface definition from an existing class definition. For example, you might be halfway through writing a class when it dawns on you that you can generalize the behavior into an interface (and thereby open up the possibility of alternative implementations).

---



## Explicit Interface Implementation

As shown earlier in this chapter, a class or structure can implement any number of interfaces. Given this, there is always the possibility you might implement interfaces that contain identical members and, therefore, have a name clash to contend with. To illustrate various manners in which you can resolve this issue, create a new Console Application project named `InterfaceNameClash`. Now design three interfaces that represent various locations to which an implementing type could render its output.

```
// Draw image to a form.
public interface IDrawToForm
{
    void Draw();
}

// Draw to buffer in memory.
public interface IDrawToMemory
{
    void Draw();
}

// Render to the printer.
public interface IDrawToPrinter
{
    void Draw();
}
```

Notice that each interface defines a method named `Draw()`, with the identical signature. If you now want to support each of these interfaces on a single class type named `Octagon`, the compiler would allow the following definition:

```
class Octagon : IDrawToForm, IDrawToMemory, IDrawToPrinter
{
    public void Draw()
    {
        // Shared drawing logic.
        Console.WriteLine("Drawing the Octagon...");
    }
}
```

Although the code compiles cleanly, you do have a possible problem. Simply put, providing a single implementation of the `Draw()` method does not allow you to take unique courses of action based on which interface is obtained from an `Octagon` object. For example, the following code will invoke the same `Draw()` method, regardless of which interface you obtain:

```
static void Main(string[] args)
{
    Console.WriteLine("***** Fun with Interface Name Clashes *****\n");
    // All of these invocations call the
    // same Draw() method!
    Octagon oct = new Octagon();
```

```

// Shorthand notation if you don't need
// the interface variable for later use.
((IDrawToPrinter)oct).Draw();

// Could also use the "is" keyword.
if (oct is IDrawToMemory dtm)
{
    dtm.Draw();
}

Console.ReadLine();
}

```

Clearly, the sort of code required to render the image to a window is quite different from the code needed to render the image to a networked printer or a region of memory. When you implement several interfaces that have identical members, you can resolve this sort of name clash using *explicit interface implementation* syntax. Consider the following update to the Octagon type:

```

class Octagon : IDrawToForm, IDrawToMemory, IDrawToPrinter
{
    // Explicitly bind Draw() implementations
    // to a given interface.
    void IDrawToForm.Draw()
    {
        Console.WriteLine("Drawing to form...");
    }
    void IDrawToMemory.Draw()
    {
        Console.WriteLine("Drawing to memory...");
    }
    void IDrawToPrinter.Draw()
    {
        Console.WriteLine("Drawing to a printer...");
    }
}

```

As you can see, when explicitly implementing an interface member, the general pattern breaks down to this:

```
returnType InterfaceName.MethodName(params){}
```

Note that when using this syntax, you do not supply an access modifier; explicitly implemented members are automatically private. For example, the following is illegal syntax:

```

// Error! No access modifier!
public void IDrawToForm.Draw()
{
    Console.WriteLine("Drawing to form...");
}

```

Because explicitly implemented members are always implicitly private, these members are no longer available from the object level. In fact, if you were to apply the dot operator to an `Octagon` type, you would find that IntelliSense does not show you any of the `Draw()` members. As expected, you must use explicit casting to access the required functionality. The previous code in `Main` is already using explicit casting, so it works with explicit interfaces:

```
static void Main(string[] args)
{
    Console.WriteLine("***** Fun with Interface Name Clashes *****\n");
    Octagon oct = new Octagon();

    // We now must use casting to access the Draw()
    // members.
    IDrawToForm itfForm = (IDrawToForm)oct;
    itfForm.Draw();

    // Shorthand notation if you don't need
    // the interface variable for later use.
    ((IDrawToPrinter)oct).Draw();

    // Could also use the "is" keyword.
    if (oct is IDrawToMemory dtm)
    {
        dtm.Draw();
    }
    Console.ReadLine();
}
```

While this syntax is quite helpful when you need to resolve name clashes, you can use explicit interface implementation simply to hide more “advanced” members from the object level. In this way, when the object user applies the dot operator, the user will see only a subset of the type’s overall functionality. However, those who require the more advanced behaviors can extract the desired interface via an explicit cast.

## Designing Interface Hierarchies

Interfaces can be arranged in an interface hierarchy. Like a class hierarchy, when an interface extends an existing interface, it inherits the abstract members defined by the parent (or parents). Prior to C# 8, derived interfaces never inherit true implementation. Rather, a derived interface simply extends its own definition with additional abstract members. In C# 8, derived interfaces inherit the default implementations as well as extend the definition, and potentially add new default implementations.

Interface hierarchies can be useful when you want to extend the functionality of an existing interface without breaking existing codebases. To illustrate, create a new Console Application project named `InterfaceHierarchy`. Now, let’s design a new set of rendering-centric interfaces such that `IDrawable` is the root of the family tree.

```
public interface IDrawable
{
    void Draw();
}
```

Given that `IDrawable` defines a basic drawing behavior, you could now create a derived interface that extends this interface with the ability to render in modified formats. Here's an example:

```
public interface IAdvancedDraw : IDrawable
{
    void DrawInBoundingBox(int top, int left, int bottom, int right);
    void DrawUpsideDown();
}
```

Given this design, if a class were to implement `IAdvancedDraw`, it would now be required to implement every member defined up the chain of inheritance (specifically, the `Draw()`, `DrawInBoundingBox()`, and `DrawUpsideDown()` methods).

```
public class BitmapImage : IAdvancedDraw
{
    public void Draw()
    {
        Console.WriteLine("Drawing...");
    }

    public void DrawInBoundingBox(int top, int left, int bottom, int right)
    {
        Console.WriteLine("Drawing in a box...");
    }

    public void DrawUpsideDown()
    {
        Console.WriteLine("Drawing upside down!");
    }
}
```

Now, when you use the `BitmapImage`, you are able to invoke each method at the object level (as they are all public), as well as extract a reference to each supported interface explicitly via casting.

```
static void Main(string[] args)
{
    Console.WriteLine("***** Simple Interface Hierarchy *****");

    // Call from object level.
    BitmapImage myBitmap = new BitmapImage();
    myBitmap.Draw();
    myBitmap.DrawInBoundingBox(10, 10, 100, 150);
    myBitmap.DrawUpsideDown();

    // Get IAdvancedDraw explicitly.
    if (myBitmap is IAdvancedDraw iAdvDraw)
    {
        iAdvDraw.DrawUpsideDown();
    }
    Console.ReadLine();
}
```

## Interface Hierarchies with Default Implementations (New 8.0)

When interface hierarchies also include default implementations, downstream interfaces can choose to carry the implementation from the base interface or create a new default implementation. Update the `IDrawable` interface to the following:

```
public interface IDrawable
{
    void Draw();
    int TimeToDraw() => 5;
}
```

Next, update the `Main` method to the following:

```
static void Main(string[] args)
{
    Console.WriteLine("***** Simple Interface Hierarchy *****");
    ...
    if (myBitmap is IAdvancedDraw iAdvDraw)
    {
        iAdvDraw.DrawUpsideDown();
        Console.WriteLine($"Time to draw: {iAdvDraw.TimeToDraw()}");
    }
    Console.ReadLine();
}
```

Not only does this code compile, but it outputs a value of 5 for the `TimeToDraw` method. This is because default implementations automatically carry forward to descendant interfaces. Casting the `BitmapImage` to the `IAdvancedDraw` interface provides access to the `TimeToDraw` method, even though the `BitmapImage` instance does not have access to the default implementation. To prove this, enter the following code and see the compile error:

```
//This does not compile
myBitmap.TimeToDraw();
```

If a downstream interface wants to provide its own default implementation, it must hide the upstream implementation. For example, if the `IAdvancedDraw` method takes 15 units to draw, update the interface to the following definition:

```
public interface IAdvancedDraw : IDrawable
{
    void DrawInBoundingBox(
        int top, int left, int bottom, int right);
    void DrawUpsideDown();
    new int TimeToDraw() => 15;
}
```

Of course, the `BitmapImage` class is also free to implement the `TimeToDraw` method. Unlike the `IAdvancedDraw` method, the class only needs to **implement** the method, not hide it.

```
public class BitmapImage : IAdvancedDraw
{
    ...
    public int TimeToDraw() => 12;
}
```

Interestingly enough, when casting the `BitmapImage` instance to either the `IAdvancedDraw` or the `IDrawable` interface, the method on the instance still is executed. Add this code to the `Main` method:

```
//Always calls method on instance:
Console.WriteLine("***** Calling Implemented TimeToDraw *****");
Console.WriteLine($"Time to draw: {myBitmap.TimeToDraw()}");
Console.WriteLine($"Time to draw: {((IDrawable) myBitmap).TimeToDraw()}");
Console.WriteLine($"Time to draw: {((IAdvancedDraw) myBitmap).TimeToDraw()}");
```

Here are the results:

---

```
***** Simple Interface Hierarchy *****
...
***** Calling Implemented TimeToDraw *****
Time to draw: 12
Time to draw: 12
Time to draw: 12
```

---

## Multiple Inheritance with Interface Types

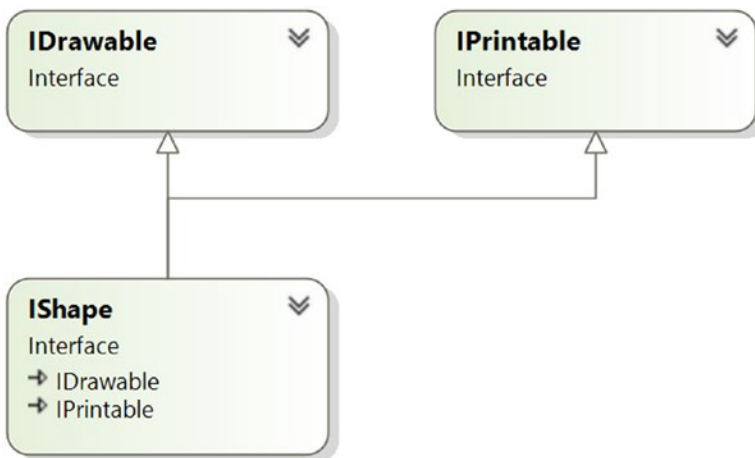
Unlike class types, an interface can extend multiple base interfaces, allowing you to design some powerful and flexible abstractions. Create a new Console Application project named `MiInterfaceHierarchy`. Here is another collection of interfaces that model various rendering and shape abstractions. Notice that the `IShape` interface is extending both `IDrawable` and `IPrintable`.

```
// Multiple inheritance for interface types is A-okay.
interface IDrawable
{
    void Draw();
}

interface IPrintable
{
    void Print();
    void Draw(); // <-- Note possible name clash here!
}

// Multiple interface inheritance. OK!
interface IShape : IDrawable, IPrintable
{
    int GetNumberOfSides();
}
```

Figure 8-6 illustrates the current interface hierarchy.



**Figure 8-6.** Unlike classes, interfaces can extend multiple interface types

At this point, the million-dollar question is “If you have a class supporting `IShape`, how many methods will it be required to implement?” The answer: it depends. If you want to provide a simple implementation of the `Draw()` method, you need to provide only three members, as shown in the following `Rectangle` type:

```
class Rectangle : IShape
{
    public int GetNumberOfSides() => 4;
    public void Draw() => Console.WriteLine("Drawing...");
    public void Print() => Console.WriteLine("Printing...");
}
```

If you’d rather have specific implementations for each `Draw()` method (which in this case would make the most sense), you can resolve the name clash using explicit interface implementation, as shown in the following `Square` type:

```
class Square : IShape
{
    // Using explicit implementation to handle member name clash.
    void IPrintable.Draw()
    {
        // Draw to printer ...
    }
    void IDrawable.Draw()
    {
        // Draw to screen ...
    }
    public void Print()
    {
        // Print ...
    }

    public int GetNumberOfSides() => 4;
}
```

Ideally, at this point you feel more comfortable with the process of defining and implementing custom interfaces using the C# syntax. To be honest, interface-based programming can take a while to get comfortable with, so if you are in fact still scratching your head just a bit, this is a perfectly normal reaction.

Do be aware, however, that interfaces are a fundamental aspect of the .NET Core Framework. Regardless of the type of application you are developing (web-based, desktop GUIs, data access libraries, etc.), working with interfaces will be part of the process. To summarize the story thus far, remember that interfaces can be extremely useful in the following cases:

- You have a single hierarchy where only a subset of the derived types supports a common behavior.
- You need to model a common behavior that is found across multiple hierarchies with no common parent class beyond `System.Object`.

Now that you have drilled into the specifics of building and implementing custom interfaces, the remainder of this chapter examines a number of predefined interfaces contained within the .NET Core base class libraries. As you will see, you can implement standard .NET Core interfaces on your custom types to ensure they integrate into the framework seamlessly.

## The IEnumerable and IEnumerator Interfaces

To begin examining the process of implementing existing .NET Core interfaces, let's first look at the role of `IEnumerable` and `IEnumerator`. Recall that C# supports a keyword named `foreach` that allows you to iterate over the contents of any array type.

```
// Iterate over an array of items.
int[] myArrayOfInts = {10, 20, 30, 40};

foreach(int i in myArrayOfInts)
{
    Console.WriteLine(i);
}
```

While it might seem that only array types can use this construct, the truth of the matter is any type supporting a method named `GetEnumerator()` can be evaluated by the `foreach` construct. To illustrate, begin by creating a new Console Application project named `CustomEnumerator`. Next, add the `Car.cs` and `Radio.cs` files defined in the `SimpleException` example of Chapter 7 (via the Project ► Add Existing Item menu option). Make sure to update the namespaces for the classes to `CustomEnumerator`.

Now, insert a new class named `Garage` that stores a set of `Car` objects within a `System.Array`.

```
// Garage contains a set of Car objects.
public class Garage
{
    private Car[] carArray = new Car[4];

    // Fill with some Car objects upon startup.
    public Garage()
    {
        carArray[0] = new Car("Rusty", 30);
        carArray[1] = new Car("Clunker", 55);
    }
}
```



```

        carArray[2] = new Car("Zippy", 30);
        carArray[3] = new Car("Fred", 30);
    }
}

```

Ideally, it would be convenient to iterate over the `Garage` object's subitems using the `foreach` construct, just like an array of data values.

```

// This seems reasonable ...
public class Program
{
    static void Main(string[] args)
    {
        Console.WriteLine("***** Fun with IEnumerable / IEnumerator *****\n");
        Garage carLot = new Garage();

        // Hand over each car in the collection?
        foreach (Car c in carLot)
        {

            Console.WriteLine("{0} is going {1} MPH",
                               c.PetName, c.CurrentSpeed);
        }
        Console.ReadLine();
    }
}

```

Sadly, the compiler informs you that the `Garage` class does not implement a method named `GetEnumerator()`. This method is formalized by the `IEnumerable` interface, which is found lurking within the `System.Collections` namespace.

---

■ **Note** In Chapter 10, you will learn about the role of generics and the `System.Collections.Generic` namespace. As you will see, this namespace contains generic versions of `IEnumerable`/`IEnumerator` that provide a more type-safe way to iterate over items.

---

Classes or structures that support this behavior advertise that they are able to expose contained items to the caller (in this example, the `foreach` keyword itself). Here is the definition of this standard interface:

```

// This interface informs the caller
// that the object's items can be enumerated.
public interface IEnumerable
{
    IEnumerator GetEnumerator();
}

```

As you can see, the `GetEnumerator()` method returns a reference to yet another interface named `System.Collections.IEnumerator`. This interface provides the infrastructure to allow the caller to traverse the internal objects contained by the `IEnumerable`-compatible container.

```
// This interface allows the caller to
// obtain a container's items.
public interface IEnumerator
{
    bool MoveNext (); // Advance the internal position of the cursor.
    object Current { get; } // Get the current item (read-only property).
    void Reset (); // Reset the cursor before the first member.
}
```

If you want to update the `Garage` type to support these interfaces, you could take the long road and implement each method manually. While you are certainly free to provide customized versions of `GetEnumerator()`, `MoveNext()`, `Current`, and `Reset()`, there is a simpler way. As the `System.Array` type (as well as many other collection classes) already implements `IEnumerable` and `IEnumerator`, you can simply delegate the request to the `System.Array` as follows (note you will need to import the `System.Collections` namespace into your code file):

```
using System.Collections;
...
public class Garage : IEnumerable
{
    // System.Array already implements IEnumerator!
    private Car[] carArray = new Car[4];

    public Garage()
    {
        carArray[0] = new Car("FeeFee", 200);
        carArray[1] = new Car("Clunker", 90);
        carArray[2] = new Car("Zippy", 30);
        carArray[3] = new Car("Fred", 30);
    }

    // Return the array object's IEnumerator.
    public IEnumerator GetEnumerator()
        => carArray.GetEnumerator();
}
```

After you have updated your `Garage` type, you can safely use the type within the C# `foreach` construct. Furthermore, given that the `GetEnumerator()` method has been defined publicly, the object user could also interact with the `IEnumerator` type.

```
// Manually work with IEnumerator.
IEnumerator i = carLot.GetEnumerator();
i.MoveNext();
Car myCar = (Car)i.Current;
Console.WriteLine("{0} is going {1} MPH", myCar.PetName, myCar.CurrentSpeed);
```

However, if you prefer to hide the functionality of `IEnumerable` from the object level, simply make use of explicit interface implementation.

```
// Return the array object's IEnumerator.
IEnumerator IEnumerable.GetEnumerator()
    => return carArray.GetEnumerator();
```

By doing so, the casual object user will not find the `Garage's GetEnumerator()` method, while the `foreach` construct will obtain the interface in the background when necessary.

## Building Iterator Methods with the `yield` Keyword

There's an alternative way to build types that work with the `foreach` loop via *iterators*. Simply put, an *iterator* is a member that specifies how a container's internal items should be returned when processed by `foreach`. To illustrate, create a new Console Application project named `CustomEnumeratorWithYield` and insert the `Car`, `Radio`, and `Garage` types from the previous example (again, renaming your namespace definitions to the current project). Now, retrofit the current `Garage` type as follows:

```
public class Garage : IEnumerable
{
    ...
    // Iterator method.

    public IEnumerator GetEnumerator()
    {
        foreach (Car c in carArray)
        {
            yield return c;
        }
    }
}
```

Notice that this implementation of `GetEnumerator()` iterates over the subitems using internal `foreach` logic and returns each `Car` to the caller using the `yield return` syntax. The `yield` keyword is used to specify the value (or values) to be returned to the caller's `foreach` construct. When the `yield return` statement is reached, the current location in the container is stored, and execution is restarted from this location the next time the iterator is called.

Iterator methods are not required to use the `foreach` keyword to return its contents. It is also permissible to define this iterator method as follows:

```
public IEnumerator GetEnumerator()
{
    yield return carArray[0];
    yield return carArray[1];
    yield return carArray[2];
    yield return carArray[3];
}
```

In this implementation, notice that the `GetEnumerator()` method is explicitly returning a new value to the caller with each pass through. Doing so for this example makes little sense, given that if you were to add more objects to the `carArray` member variable, your `GetEnumerator()` method would now be out of sync. Nevertheless, this syntax can be useful when you want to return local data from a method for processing by the `foreach` syntax.

## Guard Clauses with Local Functions (New 7.0)

None of the code in the `GetEnumerator()` method is executed until the first time that the items are iterated over (or any element is accessed). That means if there is an exception prior to the `yield` statement, it will not get thrown when the method is first called, but only when the first `MoveNext` is called.

To test this, update the `GetEnumerator` method to this:

```
public IEnumerator GetEnumerator()
{
    //This will not get thrown until MoveNext() is called
    throw new Exception("This won't get called");
    foreach (Car c in carArray)
    {
        yield return c;
    }
}
```

If you were to call the function like this and do *nothing else*, the exception will never be thrown:

```
using System.Collections;
...
static void Main(string[] args)
{
    Console.WriteLine("***** Fun with the Yield Keyword *****\n");
    Garage carLot = new Garage();
    IEnumerator carEnumerator = carLot.GetEnumerator();

    Console.ReadLine();
}
```

It's not until `MoveNext()` is called that the code will execute and the exception is thrown. Depending on the needs of your program, that might be perfectly fine. But it might not. Your `GetEnumerator` method might have a *guard clause* that needs to execute when the method is first called. For example, suppose that the list is gathered from a database. You might want to check that the database connection can be opened at the time the method is *called*, not when the list is iterated over. Or you might want to check the input parameters to the `Iterator` method (covered next) for validity.

Recall from Chapter 4 the C# 7 local function feature; local functions are private functions inside other functions. By moving the `yield return` into a local function that is returned from the main body of the method. The code in the main method (before the local function is returned) is executed immediately. The local function is executed when `MoveNext` is called.

Update the method to this:

```
public IEnumerator GetEnumerator()
```

```
{
    //This will get thrown immediately
    throw new Exception("This will get called");

    return ActualImplementation();

    //this is the local function and the actual IEnumerator implementation
    IEnumerator ActualImplementation()
    {
        foreach (Car c in carArray)
```

```

    {
        yield return c;
    }
}

```

Test this by updating the Main method to this:

```

static void Main(string[] args)
{
    Console.WriteLine("***** Fun with the Yield Keyword *****\n");
    Garage carLot = new Garage();
    try
    {
        //Error at this time
        var carEnumerator = carLot.GetEnumerator();
    }
    catch (Exception e)
    {
        Console.WriteLine($"Exception occurred on GetEnumerator");
    }
    Console.ReadLine();
}

```

With the update to the GetEnumerator method, the exception is thrown immediately instead of when MoveNext is called.

## Building a Named Iterator

It is also interesting to note that the yield keyword can technically be used within any method, regardless of its name. These methods (which are technically called *named iterators*) are also unique in that they can take any number of arguments. When building a named iterator, be aware that the method will return the IEnumerable interface, rather than the expected IEnumerator-compatible type. To illustrate, you could add the following method to the Garage type (using a local function to encapsulate the iteration functionality):

```

public IEnumerable GetTheCars(bool returnReversed)
{
    //do some error checking here
    return ActualImplementation();

    IEnumerable ActualImplementation()
    {
        // Return the items in reverse.
        if (returnReversed)
        {
            for (int i = carArray.Length; i != 0; i--)
            {
                yield return carArray[i - 1];
            }
        }
    }
}

```

```

else
{
    // Return the items as placed in the array.
    foreach (Car c in carArray)
    {
        yield return c;
    }
}
}
}

```

Notice that the new method allows the caller to obtain the subitems in sequential order, as well as in reverse order, if the incoming parameter has the value `true`. You could now interact with your new method as follows (be sure to comment out the `throw new exception` statement in the `GetEnumerator` method):

```

static void Main(string[] args)
{
    Console.WriteLine("***** Fun with the Yield Keyword *****\n");
    Garage carLot = new Garage();

    // Get items using GetEnumerator().
    foreach (Car c in carLot)
    {
        Console.WriteLine("{0} is going {1} MPH",
            c.PetName, c.CurrentSpeed);
    }

    Console.WriteLine();

    // Get items (in reverse!) using named iterator.
    foreach (Car c in carLot.GetTheCars(true))
    {
        Console.WriteLine("{0} is going {1} MPH",
            c.PetName, c.CurrentSpeed);
    }
    Console.ReadLine();
}

```

As you might agree, named iterators are helpful constructs, in that a single custom container can define multiple ways to request the returned set.

So, to wrap up this look at building enumerable objects, remember that for your custom types to work with the C# `foreach` keyword, the container must define a method named `GetEnumerator()`, which has been formalized by the `IEnumerable` interface type. The implementation of this method is typically achieved by simply delegating it to the internal member that is holding onto the subobjects; however, it is also possible to use the `yield return` syntax to provide multiple “named iterator” methods.

## The ICloneable Interface

As you might recall from Chapter 6, `System.Object` defines a method named `MemberwiseClone()`. This method is used to obtain a *shallow copy* of the current object. Object users do not call this method directly, as it is protected. However, a given object may call this method itself during the *cloning* process. To illustrate, create a new Console Application project named `CloneablePoint` that defines a class named `Point`.

```
// A class named Point.
public class Point
{
    public int X {get; set;}
    public int Y {get; set;}

    public Point(int xPos, int yPos) { X = xPos; Y = yPos;}
    public Point(){}

    // Override Object.ToString().
    public override string ToString() => $"X = {X}; Y = {Y}";
}
```

Given what you already know about reference types and value types (see Chapter 4), you are aware that if you assign one reference variable to another, you have two references pointing to the same object in memory. Thus, the following assignment operation results in two references to the same `Point` object on the heap; modifications using either reference affect the same object on the heap:

```
static void Main(string[] args)
{
    Console.WriteLine("***** Fun with Object Cloning *****\n");
    // Two references to same object!
    Point p1 = new Point(50, 50);
    Point p2 = p1;
    p2.X = 0;
    Console.WriteLine(p1);
    Console.WriteLine(p2);
    Console.ReadLine();
}
```

When you want to give your custom type the ability to return an identical copy of itself to the caller, you may implement the standard `ICloneable` interface. As shown at the start of this chapter, this type defines a single method named `Clone()`.

```
public interface ICloneable
{
    object Clone();
}
```

Obviously, the implementation of the `Clone()` method varies among your classes. However, the basic functionality tends to be the same: copy the values of your member variables into a new object instance of the same type and return it to the user. To illustrate, ponder the following update to the `Point` class:

```
// The Point now supports "clone-ability."
public class Point : ICloneable
{
    public int X { get; set; }
    public int Y { get; set; }

    public Point(int xPos, int yPos) { X = xPos; Y = yPos; }
    public Point() { }

    // Override Object.ToString().
    public override string ToString() => $"X = {X}; Y = {Y}";

    // Return a copy of the current object.
    public object Clone() => new Point(this.X, this.Y);
}
```

In this way, you can create exact stand-alone copies of the `Point` type, as illustrated by the following code:

```
static void Main(string[] args)
{
    Console.WriteLine("***** Fun with Object Cloning *****\n");
    ...
    // Notice Clone() returns a plain object type.
    // You must perform an explicit cast to obtain the derived type.
    Point p3 = new Point(100, 100);
    Point p4 = (Point)p3.Clone();

    // Change p4.X (which will not change p3.X).
    p4.X = 0;

    // Print each object.
    Console.WriteLine(p3);
    Console.WriteLine(p4);
    Console.ReadLine();
}
```

While the current implementation of `Point` fits the bill, you can streamline things just a bit. Because the `Point` type does not contain any internal reference type variables, you could simplify the implementation of the `Clone()` method as follows:

```
// Copy each field of the Point member by member.
public object Clone() => this.MemberwiseClone();
```

Be aware, however, that if the `Point` did contain any reference type member variables, `MemberwiseClone()` would copy the references to those objects (i.e., a *shallow copy*). If you want to support a true *deep copy*, you will need to create a new instance of any reference type variables during the cloning process. Let's see an example next.



## A More Elaborate Cloning Example

Now assume the `Point` class contains a reference type member variable of type `PointDescription`. This class maintains a point's friendly name as well as an identification number expressed as a `System.Guid` (a globally unique identifier [GUID] is a statistically unique 128-bit number). Here is the implementation:

```
// This class describes a point.
public class PointDescription
{
    public string PetName {get; set;}
    public Guid PointID {get; set;}

    public PointDescription()
    {
        PetName = "No-name";
        PointID = Guid.NewGuid();
    }
}
```

The initial updates to the `Point` class itself included modifying `ToString()` to account for these new bits of state data, as well as defining and creating the `PointDescription` reference type. To allow the outside world to establish a pet name for the `Point`, you also update the arguments passed into the overloaded constructor.

```
public class Point : ICloneable
{
    public int X { get; set; }
    public int Y { get; set; }
    public PointDescription desc = new PointDescription();

    public Point(int xPos, int yPos, string petName)
    {
        X = xPos; Y = yPos;
        desc.PetName = petName;
    }
    public Point(int xPos, int yPos)
    {
        X = xPos; Y = yPos;
    }
    public Point() { }

    // Override Object.ToString().
    public override string ToString()
        => $"X = {X}; Y = {Y}; Name = {desc.PetName};\nID = {desc.PointID}\n";

    // Return a copy of the current object.
    public object Clone() => this.MemberwiseClone();
}
```

Notice that you did not yet update your `Clone()` method. Therefore, when the object user asks for a clone using the current implementation, a shallow (member-by-member) copy is achieved. To illustrate, assume you have updated `Main()` as follows:

```
static void Main(string[] args)
{
    Console.WriteLine("***** Fun with Object Cloning *****\n");
    ...
    Console.WriteLine("Cloned p3 and stored new Point in p4");
    Point p3 = new Point(100, 100, "Jane");
    Point p4 = (Point)p3.Clone();

    Console.WriteLine("Before modification:");
    Console.WriteLine("p3: {0}", p3);
    Console.WriteLine("p4: {0}", p4);
    p4.desc.PetName = "My new Point";
    p4.X = 9;

    Console.WriteLine("\nChanged p4.desc.petName and p4.X");
    Console.WriteLine("After modification:");
    Console.WriteLine("p3: {0}", p3);
    Console.WriteLine("p4: {0}", p4);
    Console.ReadLine();
}
```

Notice in the following output that while the value types have indeed been changed, the internal reference types maintain the same values, as they are “pointing” to the same objects in memory (specifically, note that the pet name for both objects is now “My new Point”).

---

```
***** Fun with Object Cloning *****

Cloned p3 and stored new Point in p4
Before modification:
p3: X = 100; Y = 100; Name = Jane;
ID = 133d66a7-0837-4bd7-95c6-b22ab0434509

p4: X = 100; Y = 100; Name = Jane;
ID = 133d66a7-0837-4bd7-95c6-b22ab0434509

Changed p4.desc.petName and p4.X
After modification:
p3: X = 100; Y = 100; Name = My new Point;
ID = 133d66a7-0837-4bd7-95c6-b22ab0434509

p4: X = 9; Y = 100; Name = My new Point;
ID = 133d66a7-0837-4bd7-95c6-b22ab0434509
```

---

To have your `Clone()` method make a complete deep copy of the internal reference types, you need to configure the object returned by `MemberwiseClone()` to account for the current point's name (the `System.Guid` type is in fact a structure, so the numerical data is indeed copied). Here is one possible implementation:

```
// Now we need to adjust for the PointDescription member.
public object Clone()
{
    // First get a shallow copy.
    Point newPoint = (Point)this.MemberwiseClone();

    // Then fill in the gaps.
    PointDescription currentDesc = new PointDescription();
    currentDesc.PetName = this.desc.PetName;
    newPoint.desc = currentDesc;
    return newPoint;
}
```

If you rerun the application once again and view the output (shown next), you see that the `Point` returned from `Clone()` does copy its internal reference type member variables (note the pet name is now unique for both `p3` and `p4`).

---

\*\*\*\*\* Fun with Object Cloning \*\*\*\*\*

Cloned p3 and stored new Point in p4  
 Before modification:  
 p3: X = 100; Y = 100; Name = Jane;  
 ID = 51f64f25-4b0e-47ac-ba35-37d263496406

p4: X = 100; Y = 100; Name = Jane;  
 ID = 0d3776b3-b159-490d-b022-7f3f60788e8a

Changed p4.desc.petName and p4.X  
 After modification:  
 p3: X = 100; Y = 100; Name = Jane;  
 ID = 51f64f25-4b0e-47ac-ba35-37d263496406

p4: X = 9; Y = 100; Name = My new Point;  
 ID = 0d3776b3-b159-490d-b022-7f3f60788e8a

---

To summarize the cloning process, if you have a class or structure that contains nothing but value types, implement your `Clone()` method using `MemberwiseClone()`. However, if you have a custom type that maintains other reference types, you might want to create a new object that takes into account each reference type member variable in order to get a “deep copy.”

## The IComparable Interface

The `System.IComparable` interface specifies a behavior that allows an object to be sorted based on some specified key. Here is the formal definition:

```
// This interface allows an object to specify its
// relationship between other like objects.
public interface IComparable
{
    int CompareTo(object o);
}
```

---

■ **Note** The generic version of this interface (`IComparable<T>`) provides a more type-safe manner to handle comparisons between objects. You'll examine generics in [Chapter 10](#).

---

Create a new Console Application project named `ComparableCar` and copy the `Car` and `Radio` classes from the `SimpleException` example in [Chapter 7](#). Update the `Car` class by adding a new property to represent a unique ID for each car and a modified constructor:

```
public class Car
{
    ...
    public int CarID {get; set;}
    public Car(string name, int currSp, int id)
    {
        CurrentSpeed = currSp;
        PetName = name;
        CarID = id;
    }
    ...
}
```

Now assume you have an array of `Car` objects as follows:

```
static void Main(string[] args)
{
    Console.WriteLine("***** Fun with Object Sorting *****\n");

    // Make an array of Car objects.
    Car[] myAutos = new Car[5];
    myAutos[0] = new Car("Rusty", 80, 1);
    myAutos[1] = new Car("Mary", 40, 234);
    myAutos[2] = new Car("Viper", 40, 34);
    myAutos[3] = new Car("Mel", 40, 4);
    myAutos[4] = new Car("Chuck", 40, 5);

    Console.ReadLine();
}
```

The `System.Array` class defines a static method named `Sort()`. When you invoke this method on an array of intrinsic types (`int`, `short`, `string`, etc.), you are able to sort the items in the array in numeric/alphabetic order, as these intrinsic data types implement `IComparable`. However, what if you were to send an array of `Car` types into the `Sort()` method as follows?

```
// Sort my cars? Not yet!  
Array.Sort(myAutos);
```

If you run this test, you would get a runtime exception, as the `Car` class does not support the necessary interface. When you build custom types, you can implement `IComparable` to allow arrays of your types to be sorted. When you flesh out the details of `CompareTo()`, it will be up to you to decide what the baseline of the ordering operation will be. For the `Car` type, the internal `CarID` seems to be the logical candidate.

```
// The iteration of the Car can be ordered  
// based on the CarID.  
public class Car : IComparable  
{  
    ...  
    // IComparable implementation.  
    int IComparable.CompareTo(object obj)  
    {  
        if (obj is Car temp)  
        {  
            if (this.CarID > temp.CarID)  
            {  
                return 1;  
            }  
            if (this.CarID < temp.CarID)  
            {  
                return -1;  
            }  
            return 0;  
        }  
        throw new ArgumentException("Parameter is not a Car!");  
    }  
}
```

As you can see, the logic behind `CompareTo()` is to test the incoming object against the current instance based on a specific point of data. The return value of `CompareTo()` is used to discover whether this type is less than, greater than, or equal to the object it is being compared with (see Table 8-1).

**Table 8-1.** *CompareTo Return Values*

Return Value	Description
Any number less than zero	This instance comes before the specified object in the sort order.
Zero	This instance is equal to the specified object.
Any number greater than zero	This instance comes after the specified object in the sort order.

You can streamline the previous implementation of `CompareTo()` given that the C# `int` data type (which is just a shorthand notation for the CoreCLR `System.Int32`) implements `IComparable`. You could implement the Car's `CompareTo()` as follows:

```
int IComparable.CompareTo(object obj)
{
    if (obj is Car temp)
    {
        return this.CarID.CompareTo(temp.CarID);
    }
    throw new ArgumentException("Parameter is not a Car!");
}
```

In either case, so that your `Car` type understands how to compare itself to like objects, you can write the following user code:

```
// Exercise the IComparable interface.
static void Main(string[] args)
{
    // Make an array of Car objects.
    ...
    // Display current array.
    Console.WriteLine("Here is the unordered set of cars:");
    foreach(Car c in myAutos)
    {
        Console.WriteLine("{0} {1}", c.CarID, c.PetName);
    }

    // Now, sort them using IComparable!
    Array.Sort(myAutos);
    Console.WriteLine();

    // Display sorted array.
    Console.WriteLine("Here is the ordered set of cars:");
    foreach(Car c in myAutos)
    {
        Console.WriteLine("{0} {1}", c.CarID, c.PetName);
    }
    Console.ReadLine();
}
```

Here is the output from the previous `Main()` method:

---

```
***** Fun with Object Sorting *****
```

```
Here is the unordered set of cars:
```

```
1 Rusty
234 Mary
34 Viper
4 Mel
5 Chucky
```

Here is the ordered set of cars:

```
1 Rusty
4 Mel
5 Chucky
34 Viper
234 Mary
```

---

## Specifying Multiple Sort Orders with IComparer

In this version of the Car type, you used the car's ID as the base for the sort order. Another design might have used the pet name of the car as the basis for the sorting algorithm (to list cars alphabetically). Now, what if you wanted to build a Car that could be sorted by ID *as well as* by pet name? If this is the type of behavior you are interested in, you need to make friends with another standard interface named `Comparer`, defined within the `System.Collections` namespace as follows:

```
// A general way to compare two objects.
interface IComparer
{
    int Compare(object o1, object o2);
}
```

---

■ **Note** The generic version of this interface (`Comparer<T>`) provides a more type-safe manner to handle comparisons between objects. You'll examine generics in [Chapter 10](#).

---

Unlike the `IComparable` interface, `Comparer` is typically *not* implemented on the type you are trying to sort (i.e., the Car). Rather, you implement this interface on any number of helper classes, one for each sort order (pet name, car ID, etc.). Currently, the Car type already knows how to compare itself against other cars based on the internal car ID. Therefore, allowing the object user to sort an array of Car objects by pet name will require an additional helper class that implements `Comparer`. Here's the code (be sure to import the `System.Collections` namespace in the code file):

```
// This helper class is used to sort an array of Cars by pet name.
public class PetNameComparer : IComparer
{
    // Test the pet name of each object.
    int IComparer.Compare(object o1, object o2)
    {
        if (o1 is Car t1 && o2 is Car t2)
        {
            return string.Compare(t1.PetName, t2.PetName,
                StringComparison.OrdinalIgnoreCase);
        }
        else
        {
            throw new ArgumentException("Parameter is not a Car!");
        }
    }
}
```

The object user code is able to use this helper class. `System.Array` has a number of overloaded `Sort()` methods, one that just happens to take an object implementing `IComparer`.

```
static void Main(string[] args)
{
    ...
    // Now sort by pet name.
    Array.Sort(myAutos, new PetNameComparer());

    // Dump sorted array.
    Console.WriteLine("Ordering by pet name:");
    foreach(Car c in myAutos)
    {
        Console.WriteLine("{0} {1}", c.CarID, c.PetName);
    }
    ...
}
```

## Custom Properties and Custom Sort Types

It is worth pointing out that you can use a custom static property to help the object user along when sorting your `Car` types by a specific data point. Assume the `Car` class has added a static read-only property named `SortByPetName` that returns an instance of an object implementing the `IComparer` interface (`PetNameComparer`, in this case; be sure to import `System.Collections`).

```
// We now support a custom property to return
// the correct IComparer interface.
public class Car : IComparable
{
    ...
    // Property to return the PetNameComparer.
    public static IComparer SortByPetName
        => (IComparer)new PetNameComparer();}
```

The object user code can now sort by pet name using a strongly associated property, rather than just “having to know” to use the stand-alone `PetNameComparer` class type.

```
// Sorting by pet name made a bit cleaner.
Array.Sort(myAutos, Car.SortByPetName);
```

Ideally, at this point you not only understand how to define and implement your own interfaces but also understand their usefulness. To be sure, interfaces are found within every major .NET Core namespace, and you will continue working with various standard interfaces in the remainder of this book.

## Summary

An interface can be defined as a named collection of *abstract members*. It is common to regard an interface as a behavior that may be supported by a given type. When two or more classes implement the same interface, you can treat each type the same way (interface-based polymorphism) even if the types are defined within unique class hierarchies.



C# provides the `interface` keyword to allow you to define a new interface. As you have seen, a type can support as many interfaces as necessary using a comma-delimited list. Furthermore, it is permissible to build interfaces that derive from multiple base interfaces.

In addition to building your custom interfaces, the .NET Core libraries define a number of standard (i.e., framework-supplied) interfaces. As you have seen, you are free to build custom types that implement these predefined interfaces to gain a number of desirable traits such as cloning, sorting, and enumerating.

## CHAPTER 9



# Understanding Object Lifetime

At this point in the book, you have learned a great deal about how to build custom class types using C#. Now you will see how the CoreCLR manages allocated class instances (aka objects) via *garbage collection* (GC). C# programmers never directly deallocate a managed object from memory (recall there is no `delete` keyword in the C# language). Rather, .NET Core objects are allocated to a region of memory termed the *managed heap*, where they will be automatically destroyed by the garbage collector “sometime in the future.”

After you have looked at the core details of the collection process, you’ll learn how to programmatically interact with the garbage collector using the `System.GC` class type (which is something you will typically not be required to do for a majority of your projects). Next, you’ll examine how the virtual `System.Object.Finalize()` method and `IDisposable` interface can be used to build classes that release internal *unmanaged resources* in a predictable and timely manner.

You will also delve into some functionality of the garbage collector introduced in .NET 4.0, including background garbage collections and lazy instantiation using the generic `System.Lazy<>` class. By the time you have completed this chapter, you will have a solid understanding of how .NET Core objects are managed by the CoreCLR.

## Classes, Objects, and References

To frame the topics covered in this chapter, it is important to further clarify the distinction between classes, objects, and reference variables. Recall that a class is nothing more than a blueprint that describes how an instance of this type will look and feel in memory. Classes, of course, are defined within a code file (which in C# takes a \*.cs extension by convention). Consider the following simple `Car` class defined within a new C# Console Application project named `SimpleGC`:

```
// Car.cs
public class Car
{
    public int CurrentSpeed {get; set;}
    public string PetName {get; set;}

    public Car(){}
    public Car(string name, int speed)
    {
        PetName = name;
        CurrentSpeed = speed;
    }
}
```

```

public override string ToString()
    => $"{PetName} is going {CurrentSpeed} MPH";
}
}

```

After a class has been defined, you may allocate any number of objects using the C# `new` keyword. Understand, however, that the `new` keyword returns a *reference* to the object on the heap, not the actual object. If you declare the reference variable as a local variable in a method scope, it is stored on the stack for further use in your application. When you want to invoke members on the object, apply the C# dot operator to the stored reference, like so:

```

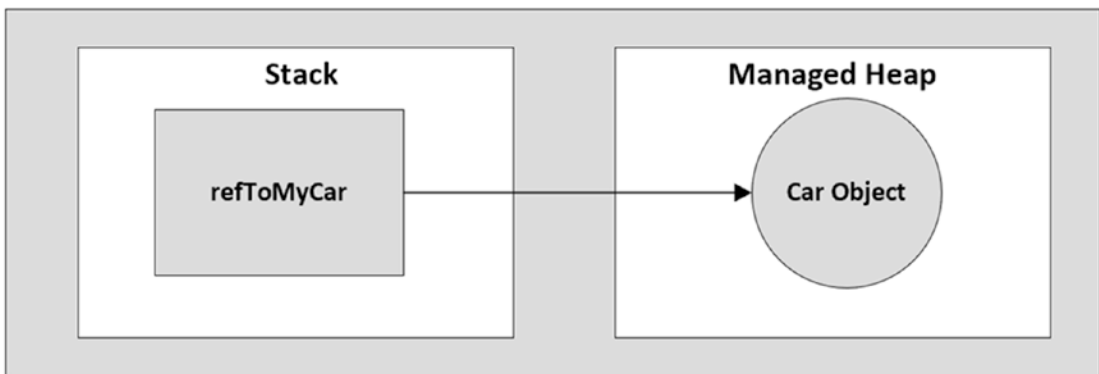
class Program
{
    static void Main(string[] args)
    {
        Console.WriteLine("***** GC Basics *****");

        // Create a new Car object on the managed heap.
        // We are returned a reference to the object
        // ("refToMyCar").
        Car refToMyCar = new Car("Zippy", 50);

        // The C# dot operator (.) is used to invoke members
        // on the object using our reference variable.
        Console.WriteLine(refToMyCar.ToString());
        Console.ReadLine();
    }
}

```

Figure 9-1 illustrates the class, object, and reference relationship.



**Figure 9-1.** *References to objects on the managed heap*

---

■ **Note** Recall from Chapter 4 that structures are *value types* that are always allocated directly on the stack and are never placed on the .NET Core managed heap. Heap allocation occurs only when you are creating instances of classes.

---

## The Basics of Object Lifetime

When you are building your C# applications, you are correct to assume that the .NET Core runtime environment will take care of the managed heap without your direct intervention. In fact, the golden rule of .NET Core memory management is simple.

---

■ **Rule** Allocate a class instance onto the managed heap using the `new` keyword and forget about it.

---

Once instantiated, the garbage collector will destroy an object when it is no longer needed. The next obvious question, of course, is “How does the garbage collector determine when an object is no longer needed?” The short (i.e., incomplete) answer is that the garbage collector removes an object from the heap only if it is *unreachable* by any part of your codebase. Assume you have a method in your `Program` class that allocates a local `Car` object as follows:

```
static void MakeACar()
{
    // If myCar is the only reference to the Car object, it *may* be destroyed when this
    method returns.
    Car myCar = new Car();
}
```

Notice that this `Car` reference (`myCar`) has been created directly within the `MakeACar()` method and has not been passed outside of the defining scope (via a return value or `ref/out` parameters). Thus, once this method call completes, the `myCar` reference is no longer reachable, and the associated `Car` object is now a candidate for garbage collection. Understand, however, that you can’t guarantee that this object will be reclaimed from memory immediately after `MakeACar()` has completed. All you can assume at this point is that when the CoreCLR performs the next garbage collection, the `myCar` object could be safely destroyed.

As you will most certainly discover, programming in a garbage-collected environment greatly simplifies your application development. In stark contrast, C++ programmers are painfully aware that if they fail to manually delete heap-allocated objects, memory leaks are never far behind. In fact, tracking down memory leaks is one of the most time-consuming (and tedious) aspects of programming in unmanaged environments. By allowing the garbage collector to take charge of destroying objects, the burden of memory management has been lifted from your shoulders and placed onto those of the CoreCLR.

## The CIL of new

When the C# compiler encounters the `new` keyword, it emits a CIL `newobj` instruction into the method implementation. If you compile the current example code and investigate the resulting assembly using `ildasm.exe`, you’d find the following CIL statements within the `MakeACar()` method:

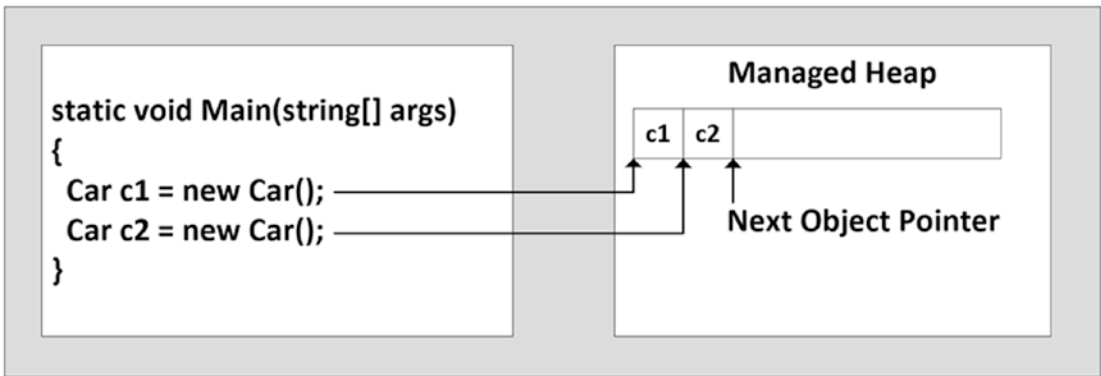
```
method private hidebysig static void MakeACar() cil managed
{
    // Code size      8 (0x8)
    .maxstack 1
    .locals init (class SimpleGC.Car V_0)
    IL_0000: nop
    IL_0001: newobj instance void SimpleGC.Car::.ctor()
    IL_0006: stloc.0
    IL_0007: ret
} // end of method Program::MakeACar
```

Before you examine the exact rules that determine when an object is removed from the managed heap, let's check out the role of the CIL `newobj` instruction in a bit more detail. First, understand that the managed heap is more than just a random chunk of memory accessed by the CoreCLR. The .NET Core garbage collector is quite a tidy housekeeper of the heap, given that it will compact empty blocks of memory (when necessary) for the purposes of optimization.

To aid in this endeavor, the managed heap maintains a pointer (commonly referred to as the *next object pointer* or *new object pointer*) that identifies exactly where the next object will be located. That said, the `newobj` instruction tells the CoreCLR to perform the following core operations:

1. Calculate the total amount of memory required for the object to be allocated (including the memory required by the data members and the base classes).
2. Examine the managed heap to ensure that there is indeed enough room to host the object to be allocated. If there is, the specified constructor is called, and the caller is ultimately returned a reference to the new object in memory, whose address just happens to be identical to the last position of the next object pointer.
3. Finally, before returning the reference to the caller, advance the next object pointer to point to the next available slot on the managed heap.

Figure 9-2 illustrates the basic process.



**Figure 9-2.** The details of allocating objects onto the managed heap

As your application is busy allocating objects, the space on the managed heap may eventually become full. When processing the `newobj` instruction, if the CoreCLR determines that the managed heap does not have sufficient memory to allocate the requested type, it will perform a garbage collection in an attempt to free up memory. Thus, the next rule of garbage collection is also quite simple.

---

■ **Rule** If the managed heap does not have sufficient memory to allocate a requested object, a garbage collection will occur.

---

Exactly *how* this garbage collection occurs, however, depends on which type of garbage collection your application uses. You'll look at the differences a bit later in this chapter.

## Setting Object References to null

C/C++ programmers often set pointer variables to null to ensure they are no longer referencing unmanaged memory. Given this, you might wonder what the end result is of assigning object references to null under C#. For example, assume the `MakeACar()` subroutine has now been updated as follows:

```
static void MakeACar()
{
    Car myCar = new Car();
    myCar = null;
}
```

When you assign object references to null, the compiler generates CIL code that ensures the reference (`myCar`, in this example) no longer points to any object. If you once again made use of `ildasm.exe` to view the CIL code of the modified `MakeACar()`, you would find the `ldnull` opcode (which pushes a null value on the virtual execution stack) followed by a `stloc.0` opcode (which sets the null reference on the variable).

```
.method private hidebysig static void MakeACar() cil managed
{
    // Code size      10 (0xa)
    .maxstack 1
    .locals init (class SimpleGC.Car V_0)
    IL_0000: nop
    IL_0001: newobj instance void SimpleGC.Car::.ctor()
    IL_0006: stloc.0
    IL_0007: ldnull
    IL_0008: stloc.0
    IL_0009: ret
} // end of method Program::MakeACar
```

What you must understand, however, is that assigning a reference to null does not in any way force the garbage collector to fire up at that exact moment and remove the object from the heap. The only thing you have accomplished is explicitly clipping the connection between the reference and the object it previously pointed to. Given this point, setting references to null under C# is far less consequential than doing so in other C-based languages; however, doing so will certainly not cause any harm.

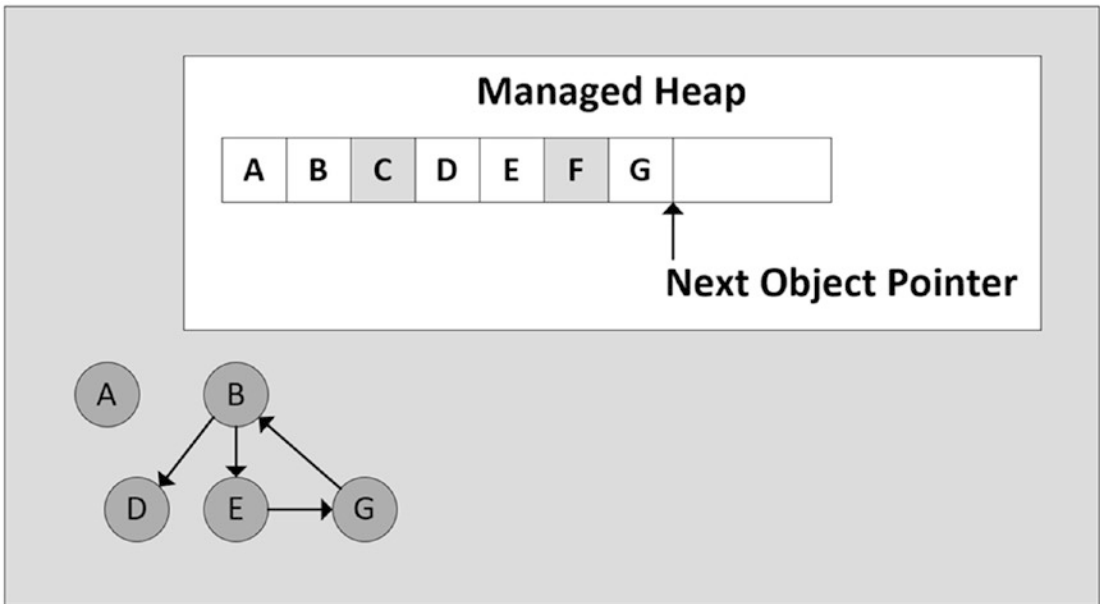
## Determining If an Object Is Live

Now, back to the topic of how the garbage collector determines when an object is no longer needed. The garbage collector uses the following information to determine whether an object is live or not:

- *Stack Roots*: Stack variables provided by the compiler and stack walker
- *Garbage collection handles*: Handles that point to managed objects that can be referenced from code or the runtime
- *Static data*: Static objects in application domains that can reference other objects

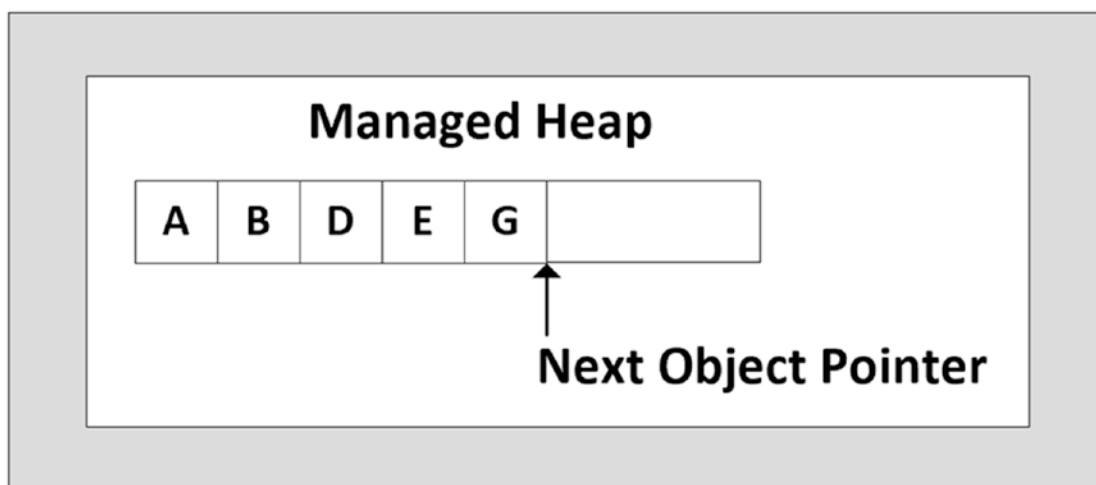
During a garbage collection process, the runtime will investigate objects on the managed heap to determine whether they are still reachable by the application. To do so, the CoreCLR will build an *object graph*, which represents each reachable object on the heap. Object graphs are explained in some detail during the discussion of object serialization in Chapter 20. For now, just understand that object graphs are used to document all reachable objects. As well, be aware that the garbage collector will never graph the same object twice, thus avoiding the nasty circular reference count found in COM programming.

Assume the managed heap contains a set of objects named A, B, C, D, E, F, and G. During garbage collection, these objects (as well as any internal object references they may contain) are examined. After the graph has been constructed, unreachable objects (which you can assume are objects C and F) are marked as garbage. Figure 9-3 diagrams a possible object graph for the scenario just described (you can read the directional arrows using the phrase *depends on* or *requires*; for example, E depends on G and B, A depends on nothing, etc.).



**Figure 9-3.** Object graphs are constructed to determine which objects are reachable by application roots

After objects have been marked for termination (C and F in this case – as they are not accounted for in the object graph), they are swept from memory. At this point, the remaining space on the heap is compacted, which in turn causes the CoreCLR to modify the set of underlying pointers to refer to the correct memory location (this is done automatically and transparently). Last but not least, the next object pointer is readjusted to point to the next available slot. Figure 9-4 illustrates the resulting readjustment.



**Figure 9-4.** A clean and compacted heap

---

■ **Note** Strictly speaking, the garbage collector uses two distinct heaps, one of which is specifically used to store large objects. This heap is less frequently consulted during the collection cycle, given possible performance penalties involved with relocating large objects. In .NET Core, the large heap can be compacted on demand or when optional hard limits for absolute or percentage memory usage is reached.

---

## Understanding Object Generations

When the CoreCLR is attempting to locate unreachable objects, it does not literally examine every object placed on the managed heap. Doing so, obviously, would involve considerable time, especially in larger (i.e., real-world) applications.

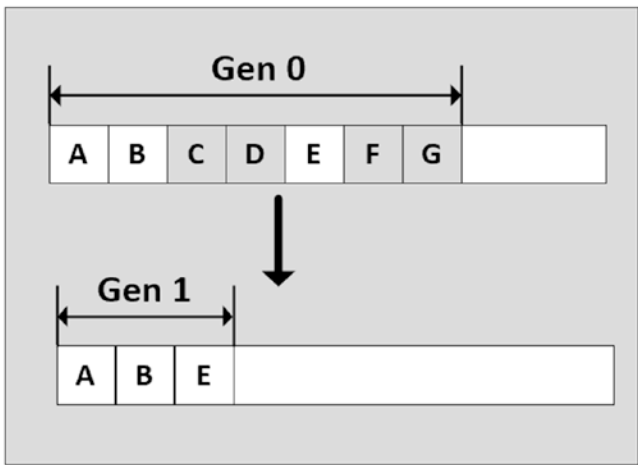
To help optimize the process, each object on the heap is assigned to a specific “generation.” The idea behind generations is simple: the longer an object has existed on the heap, the more likely it is to stay there. For example, the class that defined the main window of a desktop application will be in memory until the program terminates. Conversely, objects that have only recently been placed on the heap (such as an object allocated within a method scope) are likely to be unreachable rather quickly. Given these assumptions, each object on the heap belongs to a collection in one of the following generations:

- *Generation 0:* Identifies a newly allocated object that has never been marked for collection (with the exception of large objects, which are initially placed in a generation 2 collection). Most objects are reclaimed for garbage collection in generation 0 and do now survive to generation 1.
- *Generation 1:* Identifies an object that has survived a garbage collection. This generation also serves as a buffer between short-lived objects and long-lived objects.
- *Generation 2:* Identifies an object that has survived more than one sweep of the garbage collector or a significantly large object that started in a generation 2 collection.



■ **Note** Generations 0 and 1 are termed *ephemeral generations*. As explained in the next section, you will see that the garbage collection process does treat ephemeral generations differently.

The garbage collector will investigate all generation 0 objects first. If marking and sweeping (or said more plainly, getting rid of) these objects results in the required amount of free memory, any surviving objects are promoted to generation 1. To see how an object’s generation affects the collection process, ponder Figure 9-5, which diagrams how a set of surviving generation 0 objects (A, B, and E) are promoted once the required memory has been reclaimed.



**Figure 9-5.** Generation 0 objects that survive a garbage collection are promoted to generation 1

If all generation 0 objects have been evaluated but additional memory is still required, generation 1 objects are then investigated for reachability and collected accordingly. Surviving generation 1 objects are then promoted to generation 2. If the garbage collector *still* requires additional memory, generation 2 objects are evaluated. At this point, if a generation 2 object survives a garbage collection, it remains a generation 2 object, given the predefined upper limit of object generations.

The bottom line is that by assigning a generational value to objects on the heap, newer objects (such as local variables) will be removed quickly, while older objects (such as a program’s main window) are not “bothered” as often.

Garbage collection is triggered when the system has low physical memory, memory allocated on the managed heap rises above an acceptable threshold, or `GC.Collect` is called in the application code.

If this all seems a bit wonderful and better than having to manage memory yourself, remember that the process of garbage collection is not without some cost. The timing of garbage collection and what gets collected when is typically out of the developers’ controls, although it can certainly be influenced for good or bad. And when garbage collection is executing, CPU cycles are being used and can have an effect on the performance of the application. The next sections examine the different types of garbage collection.

## Ephemeral Generations and Segments

As mentioned earlier, generations 0 and 1 are short-lived, and are known as ephemeral generations. These generations are allocated in a memory segment known as the ephemeral segment. As garbage collection occurs, new segments acquired by the garbage collection become new ephemeral segments, and the segment containing objects surviving past generation 1 becomes the new generation 2 segment.

The size of the ephemeral segment varies on a number of factors, such as the garbage collection type (covered next) and the bitness of the system. Table 9-1 shows the different sizes of the ephemeral segments.

**Table 9-1.** Ephemeral Segment Sizes

Garbage Collection Type	32-bit	64-bit
Workstation	16 MB	256 MB
Server	64 MB	4 GB
Server with > 4 logical CPUs	32 MB	2 GB
Server with > 8 logical CPUs	16 MB	1 GB

## Garbage Collection Types

There are two types of garbage collection provided by the runtime:

- *Workstation garbage collection:* This is designed for client applications and is the default for stand-alone applications. Workstation GC can be background (covered next) or non-concurrent.
- *Server garbage collection:* This is designed for server applications that require high throughput and scalability. Server GC can be background or non-concurrent, just like workstation GC.

---

■ **Note** The names are indicative of the default settings for workstation and server applications, but the method of garbage collection is configurable through the machine’s runtimeconfig.json or system environment variables. Unless the computer only has one processor, then it will always use workstation garbage collection.

---

Workstation GC occurs on the same thread that triggered the garbage collection and remains at the same priority as when it was triggered. This can cause competition with other threads in the application. Server GC occurs on multiple dedicated threads that are set to the `THREAD_PRIORITY_HIGHEST` priority level (threading is covered in Chapter 15). Each CPU gets a dedicated heap and dedicated thread to perform garbage collection. This can lead to server garbage collection becoming very resource intensive.

## Background Garbage Collection

Beginning with .NET 4.0 (and continuing in .NET Core), the garbage collector is able to deal with thread suspension when it cleans up objects on the managed heap, using *background garbage collection*. Despite its name, this does not mean that all garbage collection now takes place on additional background threads of execution. Rather, if a background garbage collection is taking place for objects living in a nonephemeral generation, the .NET Core runtime is now able to collect objects on the ephemeral generations using a dedicated background thread.

On a related note, the .NET 4.0 and higher garbage collection have been improved to further reduce the amount of time a given thread involved with garbage collection details must be suspended. The end result of these changes is that the process of cleaning up unused objects living in generation 0 or generation 1 has been optimized and can result in better runtime performance of your programs (which is really important for real-time systems that require small, and predictable, GC stop time).

Do understand, however, that the introduction of this new garbage collection model has no effect on how you build your .NET Core applications. For all practical purposes, you can simply allow the garbage collector to perform its work without your direct intervention (and be happy that the folks at Microsoft are improving the collection process in a transparent manner).

## The System.GC Type

The `mscorlib.dll` assembly provides a class type named `System.GC` that allows you to programmatically interact with the garbage collector using a set of static members. Now, do be aware that you will seldom (if ever) need to make use of this class directly in your code. Typically, the only time you will use the members of `System.GC` is when you are creating classes that make internal use of *unmanaged resources*. This could be the case if you are building a class that makes calls into the Windows C-based API using the .NET Core platform invocation protocol or perhaps because of some very low-level and complicated COM interop logic. Table 9-2 provides a rundown of some of the more interesting members (consult the .NET Framework SDK documentation for complete details).

**Table 9-2.** *Select Members of the System.GC Type*

System.GC Member	Description
AddMemoryPressure() RemoveMemoryPressure()	Allows you to specify a numerical value that represents the calling object’s “urgency level” regarding the garbage collection process. Be aware that these methods should alter pressure <i>in tandem</i> and, thus, never remove more pressure than the total amount you have added.
Collect()	Forces the GC to perform a garbage collection. This method has been overloaded to specify a generation to collect, as well as the mode of collection (via the <code>GC.CollectMode</code> enumeration).
CollectionCount()	Returns a numerical value representing how many times a given generation has been swept.
GetGeneration()	Returns the generation to which an object currently belongs.
GetTotalMemory()	Returns the estimated amount of memory (in bytes) currently allocated on the managed heap. A Boolean parameter specifies whether the call should wait for garbage collection to occur before returning.
MaxGeneration	Returns the maximum number of generations supported on the target system. Under Microsoft’s .NET 4.0, there are three possible generations: 0, 1, and 2.
SuppressFinalize()	Sets a flag indicating that the specified object should not have its <code>Finalize()</code> method called.
WaitForPendingFinalizers()	Suspends the current thread until all finalizable objects have been finalized. This method is typically called directly after invoking <code>GC.Collect()</code> .

To illustrate how the `System.GC` type can be used to obtain various garbage collection-centric details, update your main method of the SimpleGC project to the following, which makes use of several members of GC:

```
static void Main(string[] args)
{
    Console.WriteLine("***** Fun with System.GC *****");
}
```

```
// Print out estimated number of bytes on heap.
Console.WriteLine("Estimated bytes on heap: {0}",
    GC.GetTotalMemory(false));

// MaxGeneration is zero based, so add 1 for display
// purposes.
Console.WriteLine("This OS has {0} object generations.\n",
    (GC.MaxGeneration + 1));

Car refToMyCar = new Car("Zippy", 100);
Console.WriteLine(refToMyCar.ToString());

// Print out generation of refToMyCar object.
Console.WriteLine("Generation of refToMyCar is: {0}",
    GC.GetGeneration(refToMyCar));
Console.ReadLine();
}
```

After running this, you should see output similar to this:

---

```
***** Fun with System.GC *****
Estimated bytes on heap: 75760
This OS has 3 object generations.

Zippy is going 100 MPH
Generation of refToMyCar is: 0
```

---

You will explore more of the methods from Table 9-2 in the next section.

## Forcing a Garbage Collection

Again, the whole purpose of the garbage collector is to manage memory on your behalf. However, in some rare circumstances, it may be beneficial to programmatically force a garbage collection using `GC.Collect()`. Here are two common situations where you might consider interacting with the collection process:

- Your application is about to enter into a block of code that you don't want interrupted by a possible garbage collection.
- Your application has just finished allocating an extremely large number of objects and you want to remove as much of the acquired memory as soon as possible.

If you determine it could be beneficial to have the garbage collector check for unreachable objects, you could explicitly trigger a garbage collection, as follows:

```
static void Main(string[] args)
{
    ...
    // Force a garbage collection and wait for
    // each object to be finalized.
    GC.Collect();
}
```

```

    GC.WaitForPendingFinalizers();
    ...
}

```

When you manually force a garbage collection, you should always make a call to `GC.WaitForPendingFinalizers()`. With this approach, you can rest assured that all *finalizable objects* (described in the next section) have had a chance to perform any necessary cleanup before your program continues. Under the hood, `GC.WaitForPendingFinalizers()` will suspend the calling thread during the collection process. This is a good thing, as it ensures your code does not invoke methods on an object currently being destroyed!

The `GC.Collect()` method can also be supplied a numerical value that identifies the oldest generation on which a garbage collection will be performed. For example, to instruct the CoreCLR to investigate only generation 0 objects, you would write the following:

```

static void Main(string[] args)
{
    ...
    // Only investigate generation 0 objects.
    GC.Collect(0);
    GC.WaitForPendingFinalizers();
    ...
}

```

As well, the `Collect()` method can also be passed in a value of the `GCCollectionMode` enumeration as a second parameter, to fine-tune exactly how the runtime should force the garbage collection. This enum defines the following values:

```

public enum GCCollectionMode
{
    Default, // Forced is the current default.
    Forced, // Tells the runtime to collect immediately!
    Optimized // Allows the runtime to determine whether the current time is optimal to
               reclaim objects.
}

```

As with any garbage collection, calling `GC.Collect()` promotes surviving generations. To illustrate, assume that your `Main()` method has been updated as follows:

```

static void Main(string[] args)
{
    Console.WriteLine("***** Fun with System.GC *****");

    // Print out estimated number of bytes on heap.
    Console.WriteLine("Estimated bytes on heap: {0}",
        GC.GetTotalMemory(false));

    // MaxGeneration is zero based.
    Console.WriteLine("This OS has {0} object generations.\n",
        (GC.MaxGeneration + 1));
    Car refToMyCar = new Car("Zippy", 100);
    Console.WriteLine(refToMyCar.ToString());
}

```

```
// Print out generation of refToMyCar.
Console.WriteLine("\nGeneration of refToMyCar is: {0}",
    GC.GetGeneration(refToMyCar));

// Make a ton of objects for testing purposes.
object[] tonsOfObjects = new object[50000];
for (int i = 0; i < 50000; i++)
{
    tonsOfObjects[i] = new object();
}

// Collect only gen 0 objects.
Console.WriteLine("Force Garbage Collection");
GC.Collect(0, GCCollectionMode.Forced);
GC.WaitForPendingFinalizers();

// Print out generation of refToMyCar.
Console.WriteLine("Generation of refToMyCar is: {0}",
    GC.GetGeneration(refToMyCar));

// See if tonsOfObjects[9000] is still alive.
if (tonsOfObjects[9000] != null)
{
    Console.WriteLine("Generation of tonsOfObjects[9000] is: {0}", GC.GetGeneration(tonsOf
        Objects[9000]));
}
else
{
    Console.WriteLine("tonsOfObjects[9000] is no longer alive.");
}

// Print out how many times a generation has been swept.
Console.WriteLine("\nGen 0 has been swept {0} times",
    GC.CollectionCount(0));
Console.WriteLine("Gen 1 has been swept {0} times",
    GC.CollectionCount(1));
Console.WriteLine("Gen 2 has been swept {0} times",
    GC.CollectionCount(2));
Console.ReadLine();
}
```

Here, I have purposely created a large array of object types (50,000 to be exact) for testing purposes. Here is the output from the program:

---

```
***** Fun with System.GC *****
Estimated bytes on heap: 75760
This OS has 3 object generations.

Zippy is going 100 MPH
Generation of refToMyCar is: 0
Forcing Garbage Collection
```

```
Generation of refToMyCar is: 1
Generation of tonsOfObjects[9000] is: 1
```

```
Gen 0 has been swept 1 times
Gen 1 has been swept 0 times
Gen 2 has been swept 0 times
```

---

At this point, I hope you feel more comfortable regarding the details of object lifetime. In the next section, you'll examine the garbage collection process a bit further by addressing how you can build *finalizable objects*, as well as *disposable objects*. Be aware that the following techniques are typically necessary only if you are building C# classes that maintain internal unmanaged resources.

## Building Finalizable Objects

In Chapter 6, you learned that the supreme base class of .NET Core, `System.Object`, defines a virtual method named `Finalize()`. The default implementation of this method does nothing whatsoever.

```
// System.Object
public class Object
{
    ...
    protected virtual void Finalize() {}
}
```

When you override `Finalize()` for your custom classes, you establish a specific location to perform any necessary cleanup logic for your type. Given that this member is defined as `protected`, it is not possible to directly call an object's `Finalize()` method from a class instance via the dot operator. Rather, the *garbage collector* will call an object's `Finalize()` method (if supported) before removing the object from memory.

---

■ **Note** It is illegal to override `Finalize()` on structure types. This makes perfect sense given that structures are value types, which are never allocated on the heap to begin with and, therefore, are not garbage collected! However, if you create a structure that contains unmanaged resources that need to be cleaned up, you can implement the `IDisposable` interface (described shortly). Remember from Chapter 4 that ref structs and readonly ref structs can't implement an interface, but can implement a `Dispose` method.

---

Of course, a call to `Finalize()` will (eventually) occur during a “natural” garbage collection or possibly when you programmatically force a collection via `GC.Collect()`. In prior versions of .NET (not .NET Core), each object's finalizer is called on application shutdown. In .NET Core, there isn't any way to force the finalizer to be executed, even when the app is shut down.

Now, despite what your developer instincts may tell you, the vast majority of your C# classes will not require any explicit cleanup logic or a custom finalizer. The reason is simple: if your classes are just making use of other managed objects, everything will eventually be garbage collected. The only time you would need to design a class that can clean up after itself is when you are using *unmanaged* resources (such as raw OS file handles, raw unmanaged database connections, chunks of unmanaged memory, or other unmanaged resources). Under the .NET Core platform, unmanaged resources are obtained by directly calling into the API of the operating system using Platform Invocation Services (PInvoke) or as a result of some elaborate COM interoperability scenarios. Given this, consider the next rule of garbage collection.

---

■ **Rule** The only compelling reason to override `Finalize()` is if your C# class is using unmanaged resources via `Pinvoke` or complex COM interoperability tasks (typically via various members defined by the `System.Runtime.InteropServices.Marshal` type). The reason is that under these scenarios you are manipulating memory that the CoreCLR cannot manage.

---

## Overriding `System.Object.Finalize()`

In the rare case that you do build a C# class that uses unmanaged resources, you will obviously want to ensure that the underlying memory is released in a predictable manner. Suppose you have created a new C# Console Application project named `SimpleFinalize` and inserted a class named `MyResourceWrapper` that uses an unmanaged resource (whatever that might be) and you want to override `Finalize()`. The odd thing about doing so in C# is that you can't do it using the expected `override` keyword.

```
class MyResourceWrapper
{
    // Compile-time error!
    protected override void Finalize(){ }
}
```

Rather, when you want to configure your custom C# class types to override the `Finalize()` method, you make use of a (C++-like) destructor syntax to achieve the same effect. The reason for this alternative form of overriding a virtual method is that when the C# compiler processes the finalizer syntax, it automatically adds a good deal of required infrastructure within the implicitly overridden `Finalize()` method (shown in just a moment).

C# finalizers look similar to constructors, in that they are named identically to the class they are defined within. In addition, finalizers are prefixed with a tilde symbol (`~`). Unlike a constructor, however, a finalizer never takes an access modifier (they are implicitly protected), never takes parameters, and can't be overloaded (only one finalizer per class).

The following is a custom finalizer for `MyResourceWrapper` that will issue a system beep when invoked. Obviously, this example is only for instructional purposes. A real-world finalizer would do nothing more than free any unmanaged resources and would *not* interact with other managed objects, even those referenced by the current object, as you can't assume they are still alive at the point the garbage collector invokes your `Finalize()` method.

```
// Override System.Object.Finalize() via finalizer syntax.
using System;
...
class MyResourceWrapper
{
    // Clean up unmanaged resources here.
    // Beep when destroyed (testing purposes only!)
    ~MyResourceWrapper() => Console.Beep();
}
```

If you were to examine this C# destructor using `ildasm.exe`, you would see that the compiler inserts some necessary error-checking code. First, the code statements within the scope of your `Finalize()` method are placed within a try block (see Chapter 7). The related finally block ensures that your base classes' `Finalize()` method will always execute, regardless of any exceptions encountered within the try scope.



```
.method family hidebysig virtual instance void
    Finalize() cil managed
{
    .override [System.Runtime]System.Object::Finalize
    // Code size          17 (0x11)
    .maxstack 1
    .try
    {
        IL_0000: call void [System.Console]System.Console::Beep()
        IL_0005: nop
        IL_0006: leave.s IL_0010
    } // end .try
    finally
    {
        IL_0008: ldarg.0
        IL_0009: call instance void
            [System.Runtime]System.Object::Finalize()
        IL_000e: nop
        IL_000f: endfinally
    } // end handler
    IL_0010: ret
} // end of method MyResourceWrapper::Finalize
```

If you then tested the `MyResourceWrapper` type, you would find that a system beep occurs when the finalizer executes.

```
static void Main(string[] args)
{
    Console.WriteLine("***** Fun with Finalizers *****\n");
    Console.WriteLine("Hit return to create the objects ");
    Console.WriteLine("then force the GC to invoke Finalize()");
    //Depending on the power of your system,
    //you might need to increase these values
    CreateObjects(1_000_000);
    //Artificially inflate the memory pressure
    GC.AddMemoryPressure(2147483647);
    GC.Collect(0, GCCollectionMode.Forced);
    GC.WaitForPendingFinalizers();
    Console.ReadLine();
}
private static void CreateObjects(int count)
{
    MyResourceWrapper[] tonsOfObjects =
        new MyResourceWrapper[count];
    for (int i = 0; i < count; i++)
    {
        tonsOfObjects[i] = new MyResourceWrapper();
    }
    tonsOfObjects = null;
}
```

---

■ **Note** The only way to guarantee that this small console app will force a garbage collection in .NET Core is to create a huge amount of the objects in memory and then set them to null. If you run this sample app, make sure to hit the Ctrl+C key combination to stop the program execution and all of the beeping!

---

## Detailing the Finalization Process

Not to beat a dead horse, but always remember that the role of the `Finalize()` method is to ensure that a .NET Core object can clean up unmanaged resources when it is garbage collected. Thus, if you are building a class that does not make use of unmanaged memory (by far the most common case), finalization is of little use. In fact, if at all possible, you should design your types to avoid supporting a `Finalize()` method for the simple reason that finalization takes time.

When you allocate an object onto the managed heap, the runtime automatically determines whether your object supports a custom `Finalize()` method. If so, the object is marked as *finalizable*, and a pointer to this object is stored on an internal queue named the *finalization queue*. The finalization queue is a table maintained by the garbage collector that points to every object that must be finalized before it is removed from the heap.

When the garbage collector determines it is time to free an object from memory, it examines each entry on the finalization queue and copies the object off the heap to yet another managed structure termed the *finalization reachable table* (often abbreviated as *freachable* and pronounced “eff-reachable”). At this point, a separate thread is spawned to invoke the `Finalize()` method for each object on the *freachable* table *at the next garbage collection*. Given this, it will take, at the least, two garbage collections to truly finalize an object.

The bottom line is that while finalization of an object does ensure an object can clean up unmanaged resources, it is still nondeterministic in nature and, because of the extra behind-the-curtains processing, considerably slower.

## Building Disposable Objects

As you have seen, finalizers can be used to release unmanaged resources when the garbage collector kicks in. However, given that many unmanaged objects are “precious items” (such as raw database or file handles), it could be valuable to release them as soon as possible instead of relying on a garbage collection to occur. As an alternative to overriding `Finalize()`, your class could implement the `IDisposable` interface, which defines a single method named `Dispose()` as follows:

```
public interface IDisposable
{
    void Dispose();
}
```

When you do implement the `IDisposable` interface, the assumption is that when the *object user* is finished using the object, the object user manually calls `Dispose()` before allowing the object reference to drop out of scope. In this way, an object can perform any necessary cleanup of unmanaged resources without incurring the hit of being placed on the finalization queue and without waiting for the garbage collector to trigger the class’s finalization logic.

---

■ **Note** Non-ref structures and class types can both implement `IDisposable` (unlike overriding `Finalize()`, which is reserved for class types), as the object user (not the garbage collector) invokes the `Dispose()` method. Disposable ref structs were covered in Chapter 4.

---

To illustrate the use of this interface, create a new C# Console Application project named `SimpleDispose`. Here is an updated `MyResourceWrapper` class that now implements `IDisposable`, rather than overriding `System.Object.Finalize()`:

```
// Implementing IDisposable.
class MyResourceWrapper : IDisposable
{
    // The object user should call this method
    // when they finish with the object.
    public void Dispose()
    {
        // Clean up unmanaged resources...
        // Dispose other contained disposable objects...
        // Just for a test.
        Console.WriteLine("***** In Dispose! *****");
    }
}
```

Notice that a `Dispose()` method not only is responsible for releasing the type's unmanaged resources but can also call `Dispose()` on any other contained disposable methods. Unlike with `Finalize()`, it is perfectly safe to communicate with other managed objects within a `Dispose()` method. The reason is simple: the garbage collector has no clue about the `IDisposable` interface and will never call `Dispose()`. Therefore, when the object user calls this method, the object is still living a productive life on the managed heap and has access to all other heap-allocated objects. The calling logic, shown here, is straightforward:

```
class Program
{
    static void Main(string[] args)
    {
        Console.WriteLine("***** Fun with Dispose *****\n");
        // Create a disposable object and call Dispose()
        // to free any internal resources.
        MyResourceWrapper rw = new MyResourceWrapper();
        rw.Dispose();
        Console.ReadLine();
    }
}
```

Of course, before you attempt to call `Dispose()` on an object, you will want to ensure the type supports the `IDisposable` interface. While you will typically know which base class library types implement `IDisposable` by consulting the documentation, a programmatic check can be accomplished using the `is` or `as` keywords discussed in Chapter 6.

```

class Program
{
    static void Main(string[] args)
    {
        Console.WriteLine("***** Fun with Dispose *****\n");
        MyResourceWrapper rw = new MyResourceWrapper();
        if (rw is IDisposable)
        {
            rw.Dispose();
        }
        Console.ReadLine();
    }
}

```

This example exposes yet another rule regarding memory management.

---

**■ Rule** It is a good idea to call `Dispose()` on any object you directly create if the object supports `IDisposable`. The assumption you should make is that if the class designer chose to support the `Dispose()` method, the type has some cleanup to perform. If you forget, memory will eventually be cleaned up (so don't panic), but it could take longer than necessary.

---

There is one caveat to the previous rule. A number of types in the base class libraries that do implement the `IDisposable` interface provide a (somewhat confusing) alias to the `Dispose()` method, in an attempt to make the disposal-centric method sound more natural for the defining type. By way of an example, while the `System.IO.FileStream` class implements `IDisposable` (and therefore supports a `Dispose()` method), it also defines the following `Close()` method that is used for the same purpose:

```

// Assume you have imported
// the System.IO namespace...
static void DisposeFileStream()
{
    FileStream fs = new FileStream("myFile.txt", FileMode.OpenOrCreate);

    // Confusing, to say the least!
    // These method calls do the same thing!
    fs.Close();
    fs.Dispose();
}

```

While it does feel more natural to “close” a file rather than “dispose” of one, this doubling up of cleanup methods can be confusing. For the few types that do provide an alias, just remember that if a type implements `IDisposable`, calling `Dispose()` is always a safe course of action.

## Reusing the C# using Keyword

When you are handling a managed object that implements `IDisposable`, it is quite common to make use of structured exception handling to ensure the type's `Dispose()` method is called in the event of a runtime exception, like so:

```
static void Main(string[] args)
{
    Console.WriteLine("***** Fun with Dispose *****\n");
    MyResourceWrapper rw = new MyResourceWrapper ();
    try
    {
        // Use the members of rw.
    }
    finally
    {
        // Always call Dispose(), error or not.
        rw.Dispose();
    }
}
```

While this is a fine example of defensive programming, the truth of the matter is that few developers are thrilled by the prospects of wrapping every disposable type within a try/finally block just to ensure the `Dispose()` method is called. To achieve the same result in a much less obtrusive manner, C# supports a special bit of syntax that looks like this:

```
static void Main(string[] args)
{
    Console.WriteLine("***** Fun with Dispose *****\n");
    // Dispose() is called automatically when the using scope exits.
    using(MyResourceWrapper rw = new MyResourceWrapper())
    {
        // Use rw object.
    }
}
```

If you looked at the following CIL code of the `Main()` method using `ildasm.exe`, you would find the using syntax does indeed expand to try/finally logic, with the expected call to `Dispose()`:

```
.method private hidebysig static void
    Main(string[] args) cil managed
{
    ...
    .try
    {
    ...
    } // end .try
    finally
    {
    ...
        IL_001a: callvirt instance void
            [System.Runtime]System.IDisposable::Dispose()
    ...
    } // end handler
    ...
} // end of method Program::Main
```

---

■ **Note** If you attempt to “use” an object that does not implement `IDisposable`, you will receive a compiler error.

---

While this syntax does remove the need to manually wrap disposable objects within `try/finally` logic, the `C#` `using` keyword unfortunately now has a double meaning (importing namespaces and invoking a `Dispose()` method). Nevertheless, when you are working with types that support the `IDisposable` interface, this syntactical construct will ensure that the object “being used” will automatically have its `Dispose()` method called once the using block has exited.

Also, be aware that it is possible to declare multiple objects *of the same type* within a using scope. As you would expect, the compiler will inject code to call `Dispose()` on each declared object.

```
static void Main(string[] args)
{
    Console.WriteLine("***** Fun with Dispose *****\n");

    // Use a comma-delimited list to declare multiple objects to dispose.
    using(MyResourceWrapper rw = new MyResourceWrapper(), rw2 = new MyResourceWrapper())
    {
        // Use rw and rw2 objects.
    }
}
```

## Using Declarations (New 8.0)

New in `C# 8.0` is the addition of using declarations. A using declaration is a variable declaration preceded by the `using` keyword. This is functionally the same as the syntax covered in the last question, with the exception of the explicit code block marked by braces (`{}`).

Add the following method to your class:

```
private static void UsingDeclaration()
{
    //This variable will be in scope until the end of the method
    using var rw = new MyResourceWrapper();
    //Do something here
    Console.WriteLine("About to dispose.");
    //Variable is disposed at this point.
}
```

Next, add the following call to the `Main` method:

```
static void Main(string[] args)
{
    Console.WriteLine("***** Fun with Dispose *****\n");
    ...
    Console.WriteLine("Demonstrate using declarations");
    UsingDeclaration();
    Console.ReadLine();
}
```

If you examine the new method with ILDASM, you will (as you might expect) find the same code as before:

```
.method private hidebysig static
    void UsingDeclaration() cil managed
{
...
    .try
    {
...
    } // end .try
    finally
    {
        IL_0018: callvirt instance void
            [System.Runtime]System.IDisposable::Dispose()
...
    } // end handler
    IL_001f: ret
} // end of method Program::UsingDeclaration
```

This new feature is essentially compiler magic, saving a few keystrokes. Be careful when using it, as the new syntax is not as explicit as the previous syntax.

## Building Finalizable and Disposable Types

At this point, you have seen two different approaches to constructing a class that cleans up internal unmanaged resources. On the one hand, you can use a finalizer. Using this technique, you have the peace of mind that comes with knowing the object cleans itself up when garbage collected (whenever that may be) without the need for user interaction. On the other hand, you can implement `IDisposable` to provide a way for the object user to clean up the object as soon as it is finished. However, if the caller forgets to call `Dispose()`, the unmanaged resources may be held in memory indefinitely.

As you might suspect, it is possible to blend both techniques into a single class definition. By doing so, you gain the best of both models. If the object user does remember to call `Dispose()`, you can inform the garbage collector to bypass the finalization process by calling `GC.SuppressFinalize()`. If the object user forgets to call `Dispose()`, the object will eventually be finalized and have a chance to free up the internal resources. The good news is that the object's internal unmanaged resources will be freed one way or another.

Here is the next iteration of `MyResourceWrapper`, which is now finalizable and disposable, defined in a C# Console Application project named `FinalizableDisposableClass`:

```
// A sophisticated resource wrapper.
public class MyResourceWrapper : IDisposable
{
    // The garbage collector will call this method if the object user forgets to call Dispose().
    ~MyResourceWrapper()
    {
        // Clean up any internal unmanaged resources.
        // Do not call Dispose() on any managed objects.
    }
    // The object user will call this method to clean up resources ASAP.
    public void Dispose()
```

```

{
    // Clean up unmanaged resources here.
    // Call Dispose() on other contained disposable objects.
    // No need to finalize if user called Dispose(), so suppress finalization.
    GC.SuppressFinalize(this);
}
}

```

Notice that this `Dispose()` method has been updated to call `GC.SuppressFinalize()`, which informs the CoreCLR that it is no longer necessary to call the destructor when this object is garbage collected, given that the unmanaged resources have already been freed via the `Dispose()` logic.

## A Formalized Disposal Pattern

The current implementation of `MyResourceWrapper` does work fairly well; however, you are left with a few minor drawbacks. First, the `Finalize()` and `Dispose()` methods each have to clean up the same unmanaged resources. This could result in duplicate code, which can easily become a nightmare to maintain. Ideally, you would define a private helper function that is called by either method.

Next, you'd like to make sure that the `Finalize()` method does not attempt to dispose of any managed objects, while the `Dispose()` method should do so. Finally, you'd also like to be certain the object user can safely call `Dispose()` multiple times without error. Currently, the `Dispose()` method has no such safeguards.

To address these design issues, Microsoft defined a formal, prim-and-proper disposal pattern that strikes a balance between robustness, maintainability, and performance. Here is the final (and annotated) version of `MyResourceWrapper`, which makes use of this official pattern:

```

class MyResourceWrapper : IDisposable
{
    // Used to determine if Dispose() has already been called.
    private bool disposed = false;

    public void Dispose()
    {
        // Call our helper method.
        // Specifying "true" signifies that the object user triggered the cleanup.
        Cleanup(true);

        // Now suppress finalization.
        GC.SuppressFinalize(this);
    }

    private void Cleanup(bool disposing)
    {
        // Be sure we have not already been disposed!
        if (!this.disposed)
        {
            // If disposing equals true, dispose all managed resources.
            if (disposing)
            {
                // Dispose managed resources.
            }
        }
    }
}

```



```

        // Clean up unmanaged resources here.
    }
    disposed = true;
}
~MyResourceWrapper()
{
    // Call our helper method.
    // Specifying "false" signifies that the GC triggered the cleanup.
    Cleanup(false);
}
}

```

Notice that `MyResourceWrapper` now defines a private helper method named `Cleanup()`. By specifying `true` as an argument, you indicate that the object user has initiated the cleanup, so you should clean up all managed *and* unmanaged resources. However, when the garbage collector initiates the cleanup, you specify `false` when calling `Cleanup()` to ensure that internal disposable objects are *not* disposed (as you can't assume they are still in memory!). Last but not least, the `bool` member variable (`disposed`) is set to `true` before exiting `Cleanup()` to ensure that `Dispose()` can be called numerous times without error.

---

■ **Note** After an object has been “disposed,” it's still possible for the client to invoke members on it, as it is still in memory. Therefore, a robust resource wrapper class would also need to update each member of the class with additional coding logic that says, in effect, “If I am disposed, do nothing and return from the member.”

---

To test the final iteration of `MyResourceWrapper`, update `Main()` as follows:

```

static void Main(string[] args)
{
    Console.WriteLine("***** Dispose() / Destructor Combo Platter *****");

    // Call Dispose() manually. This will not call the finalizer.
    MyResourceWrapper rw = new MyResourceWrapper();
    rw.Dispose();

    // Don't call Dispose(). This will trigger the finalizer when the object gets garbage
    collected.
    MyResourceWrapper rw2 = new MyResourceWrapper();
}

```

Notice that you are explicitly calling `Dispose()` on the `rw` object, so the destructor call is suppressed. However, you have “forgotten” to call `Dispose()` on the `rw2` object; no worries, the finalizer will still execute when the object is garbage collected.

That concludes your investigation of how the CoreCLR manages your objects via garbage collection. While there are additional (somewhat esoteric) details regarding the collection process I haven't covered here (such as weak references and object resurrection), you are now in a perfect position for further exploration on your own. To wrap this chapter up, you will examine a programming feature called *lazy instantiation* of objects.

## Understanding Lazy Object Instantiation

When you are creating classes, you might occasionally need to account for a particular member variable in code, which might never actually be needed, in that the object user might not call the method (or property) that makes use of it. Fair enough. However, this can be problematic if the member variable in question requires a large amount of memory to be instantiated.

For example, assume you are writing a class that encapsulates the operations of a digital music player. In addition to the expected methods, such as `Play()`, `Pause()`, and `Stop()`, you also want to provide the ability to return a collection of `Song` objects (via a class named `AllTracks`), which represents every single digital music file on the device.

If you'd like to follow along, create a new Console Application project named `LazyObjectInstantiation`, and define the following class types:

**// Represents a single song.**

```
class Song
{
    public string Artist { get; set; }
    public string TrackName { get; set; }
    public double TrackLength { get; set; }
}
```

**// Represents all songs on a player.**

```
class AllTracks
{
    // Our media player can have a maximum
    // of 10,000 songs.
    private Song[] _allSongs = new Song[10000];

    public AllTracks()
    {
        // Assume we fill up the array
        // of Song objects here.
        Console.WriteLine("Filling up the songs!");
    }
}
```

**// The MediaPlayer has-an AllTracks object.**

```
class MediaPlayer
{
    // Assume these methods do something useful.
    public void Play() { /* Play a song */ }
    public void Pause() { /* Pause the song */ }
    public void Stop() { /* Stop playback */ }
    private AllTracks _allSongs = new AllTracks();

    public AllTracks GetAllTracks()
    {
        // Return all of the songs.
        return _allSongs;
    }
}
```

The current implementation of `MediaPlayer` assumes that the object user will want to obtain a list of songs via the `GetAllTracks()` method. Well, what if the object user does *not* need to obtain this list? In the current implementation, the `AllTracks` member variable will still be allocated, thereby creating 10,000 `Song` objects in memory, as follows:

```
static void Main(string[] args)
{
    Console.WriteLine("***** Fun with Lazy Instantiation *****\n");

    // This caller does not care about getting all songs,
    // but indirectly created 10,000 objects!
    MediaPlayer myPlayer = new MediaPlayer();
    myPlayer.Play();

    Console.ReadLine();
}
```

Clearly, you would rather not create 10,000 objects that nobody will use, as that will add a good deal of stress to the .NET Core garbage collector. While you could manually add some code to ensure the `_allSongs` object is created only if used (perhaps using the factory method design pattern), there is an easier way.

The base class libraries provide a useful generic class named `Lazy<>`, defined in the `System` namespace of `mscorlib.dll`. This class allows you to define data that will *not* be created unless your codebase actually uses it. As this is a generic class, you must specify the type of item to be created on first use, which can be any type with the .NET Core base class libraries or a custom type you have authored yourself. To enable lazy instantiation of the `AllTracks` member variable, you can simply update the `MediaPlayer` code to this:

```
// The MediaPlayer has-an Lazy<AllTracks> object.
class MediaPlayer
{
    ...
    private Lazy<AllTracks> _allSongs = new Lazy<AllTracks>();
    public AllTracks GetAllTracks()
    {
        // Return all of the songs.
        return _allSongs.Value;
    }
}
```

Beyond the fact that you are now representing the `AllTracks` member variable as a `Lazy<>` type, notice that the implementation of the previous `GetAllTracks()` method has also been updated. Specifically, you must use the read-only `Value` property of the `Lazy<>` class to obtain the actual stored data (in this case, the `AllTracks` object that is maintaining the 10,000 `Song` objects).

With this simple update, notice how the following updated `Main()` method will indirectly allocate the `Song` objects only if `GetAllTracks()` is indeed called:

```
static void Main(string[] args)
{
    Console.WriteLine("***** Fun with Lazy Instantiation *****\n");

    // No allocation of AllTracks object here!
    MediaPlayer myPlayer = new MediaPlayer();
    myPlayer.Play();
}
```

```
// Allocation of AllTracks happens when you call GetAllTracks().
MediaPlayer yourPlayer = new MediaPlayer();
AllTracks yourMusic = yourPlayer.GetAllTracks();

Console.ReadLine();
}
```

---

■ **Note** Lazy object instantiation is useful not only to decrease allocation of unnecessary objects. You can also use this technique if a given member has expensive creation code, such as invoking a remote method, communication with a relational database, or whatnot.

---

## Customizing the Creation of the Lazy Data

When you declare a `Lazy<>` variable, the actual internal data type is created using the default constructor, like so:

```
// Default constructor of AllTracks is called when the Lazy<>
// variable is used.
private Lazy<AllTracks> _allSongs = new Lazy<AllTracks>();
```

While this might be fine in some cases, what if the `AllTracks` class had some additional constructors and you want to ensure the correct one is called? Furthermore, what if you have some extra work to do (beyond simply creating the `AllTracks` object) when the `Lazy<>` variable is made? As luck would have it, the `Lazy<>` class allows you to specify a generic delegate as an optional parameter, which will specify a method to call during the creation of the wrapped type.

The generic delegate in question is of type `System.Func<>`, which can point to a method that returns the same data type being created by the related `Lazy<>` variable and can take up to 16 arguments (which are typed using generic type parameters). In most cases, you will not need to specify any parameters to pass to the method pointed to by `Func<>`. Furthermore, to greatly simplify the use of the required `Func<>`, I recommend using a lambda expression (see Chapter 12 to learn or review the delegate/lambda relationship).

With this in mind, the following is a final version of `MediaPlayer` that adds a bit of custom code when the wrapped `AllTracks` object is created. Remember, this method must return a new instance of the type wrapped by `Lazy<>` before exiting, and you can use any constructor you choose (here, you are still invoking the default constructor of `AllTracks`).

```
class MediaPlayer
{
...
    // Use a lambda expression to add additional code
    // when the AllTracks object is made.
    private Lazy<AllTracks> _allSongs =
        new Lazy<AllTracks>( () =>
        {
            Console.WriteLine("Creating AllTracks object!");
            return new AllTracks();
        }
    );
}
```

```

public AllTracks GetAllTracks()
{
    // Return all of the songs.
    return _allSongs.Value;
}
}

```

Sweet! I hope you can see the usefulness of the `Lazy<>` class. Essentially, this generic class allows you to ensure expensive objects are allocated only when the object user requires them.

## Summary

The point of this chapter was to demystify the garbage collection process. As you saw, the garbage collector will run only when it is unable to acquire the necessary memory from the managed heap (or when the developer calls `GC.Collect()`). When a collection does occur, you can rest assured that Microsoft's collection algorithm has been optimized by the use of object generations, secondary threads for the purpose of object finalization, and a managed heap dedicated to hosting large objects.

This chapter also illustrated how to programmatically interact with the garbage collector using the `System.GC` class type. As mentioned, the only time you will really need to do so is when you are building finalizable or disposable class types that operate on unmanaged resources.

Recall that finalizable types are classes that have provided a destructor (effectively overriding the `Finalize()` method) to clean up unmanaged resources at the time of garbage collection. Disposable objects, on the other hand, are classes (or non-ref structures) that implement the `IDisposable` interface, which should be called by the object user when it is finished using said objects. Finally, you learned about an official “disposal” pattern that blends both approaches.

This chapter wrapped up with a look at a generic class named `Lazy<>`. As you saw, you can use this class to delay the creation of an expensive (in terms of memory consumption) object until the caller actually requires it. By doing so, you can help reduce the number of objects stored on the managed heap and also ensure expensive objects are created only when actually required by the caller.

**PART IV**



# **Advanced C# Programming**

## CHAPTER 10



# Collections and Generics

Any application you create with the .NET Core platform will need to contend with the issue of maintaining and manipulating a set of data points in memory. These data points can come from any variety of locations including a relational database, a local text file, an XML document, a web service call, or perhaps user-provided input.

When the .NET platform was first released, programmers frequently used the classes of the `System.Collections` namespace to store and interact with bits of data used within an application. In .NET 2.0, the C# programming language was enhanced to support a feature termed *generics*; and with this change, a new namespace was introduced in the base class libraries: `System.Collections.Generic`.

This chapter will provide you with an overview of the various collection (generic and nongeneric) namespaces and types found within the .NET Core base class libraries. As you will see, generic containers are often favored over their nongeneric counterparts because they typically provide greater type safety and performance benefits. After you've learned how to create and manipulate the generic items found in the framework, the remainder of this chapter will examine how to build your own generic methods and generic types. As you do this, you will learn about the role of *constraints* (and the corresponding C# `where` keyword), which allow you to build extremely type-safe classes.

## The Motivation for Collection Classes

The most primitive container you could use to hold application data is undoubtedly the array. As you saw in Chapter 4, C# arrays allow you to define a set of identically typed items (including an array of `System.Object`, which essentially represents an array of any type of data) of a fixed upper limit. Also recall from Chapter 4 that all C# array variables gather a good deal of functionality from the `System.Array` class. By way of a quick review, consider the following `Main()` method, which creates an array of textual data and manipulates its contents in various ways:

```
static void Main(string[] args)
{
    // Make an array of string data.
    string[] strArray = {"First", "Second", "Third" };

    // Show number of items in array using Length property.
    Console.WriteLine("This array has {0} items.", strArray.Length);
    Console.WriteLine();

    // Display contents using enumerator.
    foreach (string s in strArray)
```

```

{
    Console.WriteLine("Array Entry: {0}", s);
}
Console.WriteLine();

// Reverse the array and print again.
Array.Reverse(strArray);
foreach (string s in strArray)
{
    Console.WriteLine("Array Entry: {0}", s);
}

Console.ReadLine();
}

```

While basic arrays can be useful to manage small amounts of fixed-size data, there are many other times where you require a more flexible data structure, such as a dynamically growing and shrinking container or a container that can hold objects that meet only a specific criteria (e.g., only objects deriving from a specific base class or only objects implementing a particular interface). When you make use of a simple array, always remember they are created with a “fixed size.” If you make an array of three items, you get only three items; therefore, the following code would result in a runtime exception (an `IndexOutOfRangeException`, to be exact):

```

static void Main(string[] args)
{
    // Make an array of string data.
    string[] strArray = { "First", "Second", "Third" };

    // Try to add a new item at the end?? Runtime error!
    strArray[3] = "new item?";
    ...
}

```

---

■ **Note** It is actually possible to change the size of an array using the generic `Resize(<T>)` method. However, this will result in a copy of the data into a new array object and could be inefficient.

---

To help overcome the limitations of a simple array, the .NET Core base class libraries ship with a number of namespaces containing *collection classes*. Unlike a simple C# array, collection classes are built to dynamically resize themselves on the fly as you insert or remove items. Moreover, many of the collection classes offer increased type safety and are highly optimized to process the contained data in a memory-efficient manner. As you read over this chapter, you will quickly notice that a collection class can belong to one of two broad categories:

- Nongeneric collections (primarily found in the `System.Collections` namespace)
- Generic collections (primarily found in the `System.Collections.Generic` namespace)

Nongeneric collections are typically designed to operate on `System.Object` types and are, therefore, loosely typed containers (however, some nongeneric collections do operate only on a specific type of data, such as `string` objects). In contrast, generic collections are much more type-safe, given that you



must specify the “type of type” they contain upon creation. As you will see, the telltale sign of any generic item is the “type parameter” marked with angled brackets (e.g., `List<T>`). You will examine the details of generics (including the many benefits they provide) a bit later in this chapter. For now, let’s examine some of the key nongeneric collection types in the `System.Collections` and `System.Collections.Specialized` namespaces.

## The `System.Collections` Namespace

When the .NET platform was first released, programmers frequently used the nongeneric collection classes found within the `System.Collections` namespace, which contains a set of classes used to manage and organize large amounts of in-memory data. Table 10-1 documents some of the more commonly used collection classes of this namespace and the core interfaces they implement.

**Table 10-1.** *Useful Types of `System.Collections`*

<b>System.Collections Class</b>	<b>Meaning in Life</b>	<b>Key Implemented Interfaces</b>
<code>ArrayList</code>	Represents a dynamically sized collection of objects listed in sequential order	<code>IList</code> , <code>ICollection</code> , <code>IEnumerable</code> , and <code>ICloneable</code>
<code>BitArray</code>	Manages a compact array of bit values, which are represented as <code>Booleans</code> , where <code>true</code> indicates that the bit is on (1) and <code>false</code> indicates the bit is off (0)	<code>ICollection</code> , <code>IEnumerable</code> , and <code>ICloneable</code>
<code>Hashtable</code>	Represents a collection of key-value pairs that are organized based on the hash code of the key	<code>IDictionary</code> , <code>ICollection</code> , <code>IEnumerable</code> , and <code>ICloneable</code>
<code>Queue</code>	Represents a standard first-in, first-out (FIFO) collection of objects	<code>ICollection</code> , <code>IEnumerable</code> , and <code>ICloneable</code>
<code>SortedList</code>	Represents a collection of key-value pairs that are sorted by the keys and are accessible by key and by index	<code>IDictionary</code> , <code>ICollection</code> , <code>IEnumerable</code> , and <code>ICloneable</code>
<code>Stack</code>	A last-in, first-out (LIFO) stack providing push and pop (and peek) functionality	<code>ICollection</code> , <code>IEnumerable</code> , and <code>ICloneable</code>

The interfaces implemented by these collection classes provide huge insights into their overall functionality. Table 10-2 documents the overall nature of these key interfaces, some of which you worked with firsthand in Chapter 8.

**Table 10-2.** *Key Interfaces Supported by Classes of System.Collections*

System.Collections Interface	Meaning in Life
ICollection	Defines general characteristics (e.g., size, enumeration, and thread safety) for all nongeneric collection types
ICloneable	Allows the implementing object to return a copy of itself to the caller
IDictionary	Allows a nongeneric collection object to represent its contents using key-value pairs
IEnumerable	Returns an object implementing the IEnumerator interface (see next table entry)
IEnumerator	Enables foreach-style iteration of collection items
IList	Provides behavior to add, remove, and index items in a sequential list of objects

## An Illustrative Example: Working with the ArrayList

Based on your experience, you might have some firsthand experience using (or implementing) some of these classic data structures such as stacks, queues, and lists. If this is not the case, I'll provide some further details on their differences when you examine their generic counterparts a bit later in this chapter. Until then, here is a `Main()` method making use of an `ArrayList` object:

```
// You must import System.Collections to access the ArrayList.
static void Main(string[] args)
{
    ArrayList strArray = new ArrayList();
    strArray.AddRange(new string[] { "First", "Second", "Third" });

    // Show number of items in ArrayList.
    Console.WriteLine("This collection has {0} items.", strArray.Count);
    Console.WriteLine();

    // Add a new item and display current count.
    strArray.Add("Fourth!");
    Console.WriteLine("This collection has {0} items.", strArray.Count);

    // Display contents.
    foreach (string s in strArray)
    {
        Console.WriteLine("Entry: {0}", s);
    }
    Console.WriteLine();
}
```

Notice that you can add (or remove) items on the fly and the container automatically resizes itself accordingly.

As you would guess, the `ArrayList` class has many useful members beyond the `Count` property and `AddRange()` and `Add()` methods, so be sure you consult the .NET Core documentation for full details. On a related note, the other classes of `System.Collections` (`Stack`, `Queue`, etc.) are also fully documented in the .NET Core help system.

However, it is important to point out that a majority of your .NET Core projects will most likely *not* make use of the collection classes in the `System.Collections` namespace! To be sure, these days it is far more common to make use of the generic counterpart classes found in the `System.Collections.Generic` namespace. Given this point, I won't comment on (or provide code examples for) the remaining nongeneric classes found in `System.Collections`.

## A Survey of `System.Collections.Specialized` Namespace

`System.Collections` is not the only .NET Core namespace that contains nongeneric collection classes. The `System.Collections.Specialized` namespace defines a number of (pardon the redundancy) specialized collection types. Table 10-3 documents some of the more useful types in this particular collection-centric namespace, all of which are nongeneric.

**Table 10-3.** *Useful Classes of `System.Collections.Specialized`*

<code>System.Collections.Specialized</code> Type	Meaning in Life
<code>HybridDictionary</code>	This class implements <code>IDictionary</code> by using a <code>ListDictionary</code> while the collection is small and then switching to a <code>Hashtable</code> when the collection gets large.
<code>ListDictionary</code>	This class is useful when you need to manage a small number of items (ten or so) that can change over time. This class makes use of a singly linked list to maintain its data.
<code>StringCollection</code>	This class provides an optimal way to manage large collections of string data.
<code>BitVector32</code>	This class provides a simple structure that stores Boolean values and small integers in 32 bits of memory.

Beyond these concrete class types, this namespace also contains many additional interfaces and abstract base classes that you can use as a starting point for creating custom collection classes. While these “specialized” types might be just what your projects require in some situations, I won't comment on their usage here. Again, in many cases, you will likely find that the `System.Collections.Generic` namespace provides classes with similar functionality and additional benefits.

---

■ **Note** There are two additional collection-centric namespaces (`System.Collections.ObjectModel` and `System.Collections.Concurrent`) in the .NET Core base class libraries. You will examine the former namespace later in this chapter, after you are comfortable with the topic of generics. `System.Collections.Concurrent` provides collection classes well suited to a multithreaded environment (see Chapter 15 for information on multithreading).

---

## The Problems of Nongeneric Collections

While it is true that many successful .NET and .NET Core applications have been built over the years using these nongeneric collection classes (and interfaces), history has shown that use of these types can result in a number of issues.

The first issue is that using the `System.Collections` and `System.Collections.Specialized` classes can result in some poorly performing code, especially when you are manipulating numerical data (e.g., value types). As you'll see momentarily, the CoreCLR must perform a number of memory transfer operations when you store structures in any nongeneric collection class prototyped to operate on `System.Objects`, which can hurt runtime execution speed.

The second issue is that most of the nongeneric collection classes are not type-safe because (again) they were developed to operate on `System.Objects`, and they could therefore contain anything at all. If a developer needed to create a highly type-safe collection (e.g., a container that can hold objects implementing only a certain interface), the only real choice was to create a new collection class by hand. Doing so was not too labor intensive, but it was a tad on the tedious side.

Before you look at how to use generics in your programs, you'll find it helpful to examine the issues of nongeneric collection classes a bit closer; this will help you better understand the problems generics intended to solve in the first place. If you want to follow along, create a new Console Application project named `IssuesWithNonGenericCollections`. Next, make sure you import the `System.Collections` namespace to the top of your C# code file.

```
using System.Collections;
```

## The Issue of Performance

As you might recall from Chapter 4, the .NET Core platform supports two broad categories of data: value types and reference types. Given that .NET Core defines two major categories of types, you might occasionally need to represent a variable of one category as a variable of the other category. To do so, C# provides a simple mechanism, termed *boxing*, to store the data in a value type within a reference variable. Assume that you have created a local variable of type `int` in a method called `SimpleBoxUnboxOperation`. If, during the course of your application, you were to represent this value type as a reference type, you would *box* the value, as follows:

```
static void SimpleBoxUnboxOperation()
{
    // Make a ValueType (int) variable.
    int myInt = 25;

    // Box the int into an object reference.
    object boxedInt = myInt;
}
```

Boxing can be formally defined as the process of explicitly assigning a value type to a `System.Object` variable. When you box a value, the CoreCLR allocates a new object on the heap and copies the value type's value (25, in this case) into that instance. What is returned to you is a reference to the newly allocated heap-based object.

The opposite operation is also permitted through *unboxing*. Unboxing is the process of converting the value held in the object reference back into a corresponding value type on the stack. Syntactically speaking, an unboxing operation looks like a normal casting operation. However, the semantics are quite different. The CoreCLR begins by verifying that the receiving data type is equivalent to the boxed type, and if so, it

copies the value back into a local stack-based variable. For example, the following unboxing operations work successfully, given that the underlying type of the boxedInt is indeed an int:

```
static void SimpleBoxUnboxOperation()
{
    // Make a ValueType (int) variable.
    int myInt = 25;

    // Box the int into an object reference.
    object boxedInt = myInt;

    // Unbox the reference back into a corresponding int.
    int unboxedInt = (int)boxedInt;
}
```

When the C# compiler encounters boxing/unboxing syntax, it emits CIL code that contains the box/unbox op codes. If you were to examine your compiled assembly using `ildasm.exe`, you would find the following:

```
.method private hidebysig static
    void SimpleBoxUnboxOperation() cil managed
{
    .maxstack 1
    .locals init (int32 V_0, object V_1, int32 V_2)
    IL_0000: nop
    IL_0001: ldc.i4.s 25
    IL_0003: stloc.0
    IL_0004: ldloc.0
    IL_0005: box [System.Runtime]System.Int32
    IL_000a: stloc.1
    IL_000b: ldloc.1
    IL_000c: unbox.any [System.Runtime]System.Int32
    IL_0011: stloc.2
    IL_0012: ret
} // end of method Program::SimpleBoxUnboxOperation
```

Remember that unlike when performing a typical cast, you *must* unbox into an appropriate data type. If you attempt to unbox a piece of data into the incorrect data type, an `InvalidCastException` exception will be thrown. To be perfectly safe, you should wrap each unboxing operation in try/catch logic; however, this would be quite labor intensive to do for every unboxing operation. Consider the following code update, which will throw an error because you're attempting to unbox the boxed int into a long:

```
static void SimpleBoxUnboxOperation()
{
    // Make a ValueType (int) variable.
    int myInt = 25;

    // Box the int into an object reference.
    object boxedInt = myInt;
```

```

// Unbox in the wrong data type to trigger
// runtime exception.
try
{
    long unboxedLong = (long)boxedInt;
}
catch (InvalidCastException ex)
{
    Console.WriteLine(ex.Message);
}
}

```

At first glance, boxing/unboxing might seem like a rather uneventful language feature that is more academic than practical. After all, you will seldom need to store a local value type in a local object variable, as shown here. However, it turns out that the boxing/unboxing process is quite helpful because it allows you to assume everything can be treated as a `System.Object`, while the CoreCLR takes care of the memory-related details on your behalf.

Let's look at a practical use of these techniques. Let's examine the `System.Collections.ArrayList` class and use it to hold onto a batch of numeric (stack-allocated) data. The relevant members of the `ArrayList` class are listed as follows. Notice that they are prototyped to operate on `System.Object` data. Now consider the `Add()`, `Insert()`, and `Remove()` methods, as well as the class indexer.

```

public class ArrayList : IList, ICloneable
{
    ...
    public virtual int Add(object? value);
    public virtual void Insert(int index, object? value);
    public virtual void Remove(object? obj);
    public virtual object? this[int index] {get; set; }
}

```

`ArrayList` has been built to operate on objects, which represent data allocated on the heap, so it might seem strange that the following code compiles and executes without throwing an error:

```

static void WorkWithArrayList()
{
    // Value types are automatically boxed when
    // passed to a method requesting an object.
    ArrayList myInts = new ArrayList();
    myInts.Add(10);
    myInts.Add(20);
    myInts.Add(35);
}

```

Although you pass in numerical data directly into methods requiring an object, the runtime automatically boxes the stack-based data on your behalf. Later, if you want to retrieve an item from the `ArrayList` using the type indexer, you must unbox the heap-allocated object into a stack-allocated integer using a casting operation. Remember that the indexer of the `ArrayList` is returning `System.Objects`, not `System.Int32s`.

```

static void WorkWithArrayList()
{
    // Value types are automatically boxed when
    // passed to a member requesting an object.
    ArrayList myInts = new ArrayList();
    myInts.Add(10);
    myInts.Add(20);
    myInts.Add(35);

    // Unboxing occurs when an object is converted back to
    // stack-based data.
    int i = (int)myInts[0];

    // Now it is reboxed, as WriteLine() requires object types!
    Console.WriteLine("Value of your int: {0}", i);
}

```

Again, note that the stack-allocated `System.Int32` is boxed prior to the call to `ArrayList.Add()`, so it can be passed in the required `System.Object`. Also note that the `System.Object` is unboxed back into a `System.Int32` once it is retrieved from the `ArrayList` via the casting operation, only to be boxed *again* when it is passed to the `Console.WriteLine()` method, as this method is operating on `System.Object` variables.

Boxing and unboxing are convenient from a programmer's viewpoint, but this simplified approach to stack/heap memory transfer comes with the baggage of performance issues (in both speed of execution and code size) and a lack of type safety. To understand the performance issues, ponder these steps that must occur to box and unbox a simple integer:

1. A new object must be allocated on the managed heap.
2. The value of the stack-based data must be transferred into that memory location.
3. When unboxed, the value stored on the heap-based object must be transferred back to the stack.
4. The now unused object on the heap will (eventually) be garbage collected.

Although this particular `WorkWithArrayList()` method won't cause a major bottleneck in terms of performance, you could certainly feel the impact if an `ArrayList` contained thousands of integers that your program manipulates on a somewhat regular basis. In an ideal world, you could manipulate stack-based data in a container without any performance issues. Ideally, it would be nice if you did not have to bother plucking data from this container using `try/catch` scopes (this is exactly what generics let you achieve).

## The Issue of Type Safety

I touched on the issue of type safety when covering unboxing operations. Recall that you must unbox your data into the same data type it was declared as before boxing. However, there is another aspect of type safety you must keep in mind in a generic-free world: the fact that a majority of the classes of `System.Collections` can typically hold anything whatsoever because their members are prototyped to operate on `System.Object`s. For example, this method builds an `ArrayList` of random bits of unrelated data:

```

static void ArrayListOfRandomObjects()
{
    // The ArrayList can hold anything at all.
    ArrayList allMyObjects = new ArrayList();
}

```

```

    allMyObjects.Add(true);
    allMyObjects.Add(new OperatingSystem(PlatformID.MacOSX, new Version(10, 0)));
    allMyObjects.Add(66);
    allMyObjects.Add(3.14);
}

```

In some cases, you will require an extremely flexible container that can hold literally anything (as shown here). However, most of the time you desire a *type-safe* container that can operate only on a particular type of data point. For example, you might need a container that can hold only database connections, bitmaps, or IPPointy-compatible objects.

Prior to generics, the only way you could address this issue of type safety was to create a custom (strongly typed) collection class manually. Assume you want to create a custom collection that can contain only objects of type `Person`.

```

public class Person
{
    public int Age {get; set;}
    public string FirstName {get; set;}
    public string LastName {get; set;}

    public Person(){}
    public Person(string firstName, string lastName, int age)
    {
        Age = age;
        FirstName = firstName;
        LastName = lastName;
    }

    public override string ToString()
    {
        return $"Name: {FirstName} {LastName}, Age: {Age}";
    }
}

```

To build a collection that can hold only `Person` objects, you could define a `System.Collections.ArrayList` member variable within a class named `PersonCollection` and configure all members to operate on strongly typed `Person` objects, rather than on `System.Object` types. Here is a simple example (a production-level custom collection could support many additional members and might extend an abstract base class from the `System.Collections` or `System.Collections.Specialized` namespace):

```

public class PersonCollection : IEnumerable
{
    private ArrayList arPeople = new ArrayList();

    // Cast for caller.
    public Person GetPerson(int pos) => (Person)arPeople[pos];

    // Insert only Person objects.
    public void AddPerson(Person p)
    { arPeople.Add(p); }
}

```



```

public void ClearPeople()
{ arPeople.Clear(); }

public int Count => arPeople.Count;

// Foreach enumeration support.
IEnumerator IEnumerable.GetEnumerator() => arPeople.GetEnumerator();
}

```

Notice that the `PersonCollection` class implements the `IEnumerable` interface, which allows a `foreach`-like iteration over each contained item. Also notice that your `GetPerson()` and `AddPerson()` methods have been prototyped to operate only on `Person` objects, not `bitmaps`, `strings`, `database connections`, nor other items. With these types defined, you are now assured of type safety, given that the C# compiler will be able to determine any attempt to insert an incompatible data type.

```

static void UsePersonCollection()
{
    Console.WriteLine("***** Custom Person Collection *****\n");
    PersonCollection myPeople = new PersonCollection();
    myPeople.AddPerson(new Person("Homer", "Simpson", 40));
    myPeople.AddPerson(new Person("Marge", "Simpson", 38));
    myPeople.AddPerson(new Person("Lisa", "Simpson", 9));
    myPeople.AddPerson(new Person("Bart", "Simpson", 7));
    myPeople.AddPerson(new Person("Maggie", "Simpson", 2));

    // This would be a compile-time error!
    // myPeople.AddPerson(new Car());

    foreach (Person p in myPeople)
        Console.WriteLine(p);
}

```

While custom collections do ensure type safety, this approach leaves you in a position where you must create an (almost identical) custom collection for each unique data type you want to contain. Thus, if you need a custom collection that can operate only on classes deriving from the `Car` base class, you need to build a highly similar collection class.

```

public class CarCollection : IEnumerable
{
    private ArrayList arCars = new ArrayList();

    // Cast for caller.
    public Car GetCar(int pos) => (Car) arCars[pos];

    // Insert only Car objects.
    public void AddCar(Car c)
    { arCars.Add(c); }

    public void ClearCars()
    { arCars.Clear(); }
}

```

```

public int Count => arCars.Count;

// Foreach enumeration support.
IEnumerator IEnumerable.GetEnumerator() => arCars.GetEnumerator();
}

```

However, a custom collection class does nothing to solve the issue of boxing/unboxing penalties. Even if you were to create a custom collection named `IntCollection` that you designed to operate only on `System.Int32` items, you would have to allocate some type of object to hold the data (e.g., `System.Array` and `ArrayList`).

```

public class IntCollection : IEnumerable
{
    private ArrayList arInts = new ArrayList();

    // Get an int (performs unboxing!).
    public int GetInt(int pos) => (int)arInts[pos];

    // Insert an int (performs boxing)!
    public void AddInt(int i)
    { arInts.Add(i); }

    public void ClearInts()
    { arInts.Clear(); }

    public int Count => arInts.Count;

    IEnumerator IEnumerable.GetEnumerator() => arInts.GetEnumerator();
}

```

Regardless of which type you might choose to hold the integers, you cannot escape the boxing dilemma using nongeneric containers.

## A First Look at Generic Collections

When you use generic collection classes, you rectify all the previous issues, including boxing/unboxing penalties and a lack of type safety. Also, the need to build a custom (generic) collection class becomes quite rare. Rather than having to build unique classes that can contain people, cars, and integers, you can use a generic collection class and specify the type of type.

Consider the following method, which uses the generic `List<T>` class (in the `System.Collections.Generic` namespace) to contain various types of data in a strongly typed manner (don't fret the details of generic syntax at this time):

```

using System.Collections.Generic;
...
static void UseGenericList()
{
    Console.WriteLine("***** Fun with Generics *****\n");

    // This List<> can hold only Person objects.
    List<Person> morePeople = new List<Person>();
}

```

```

morePeople.Add(new Person ("Frank", "Black", 50));
Console.WriteLine(morePeople[0]);

// This List<T> can hold only integers.
List<int> moreInts = new List<int>();
moreInts.Add(10);
moreInts.Add(2);
int sum = moreInts[0] + moreInts[1];

// Compile-time error! Can't add Person object
// to a list of ints!
// moreInts.Add(new Person());
}

```

The first `List<T>` object can contain only `Person` objects. Therefore, you do not need to perform a cast when plucking the items from the container, which makes this approach more type-safe. The second `List<T>` can contain only integers, all of which are allocated on the stack; in other words, there is no hidden boxing or unboxing as you found with the nongeneric `ArrayList`. Here is a short list of the benefits generic containers provide over their nongeneric counterparts:

- Generics provide better performance because they do not result in boxing or unboxing penalties when storing value types.
- Generics are type-safe because they can contain only the type of type you specify.
- Generics greatly reduce the need to build custom collection types because you specify the “type of type” when creating the generic container.

## The Role of Generic Type Parameters

You can find generic classes, interfaces, structures, and delegates throughout the .NET Core base class libraries, and these might be part of any .NET Core namespace. Also be aware that generics have far more uses than simply defining a collection class. To be sure, you will see many different generics used in the remainder of this book for various reasons.

---

■ **Note** Only classes, structures, interfaces, and delegates can be written generically; enum types cannot.

---

When you see a generic item listed in the .NET Core documentation or the Visual Studio Object Browser, you will notice a pair of angled brackets with a letter or other token sandwiched within. Figure 10-1 shows the Visual Studio Object Browser displaying a number of generic items located within the `System.Collections.Generic` namespace, including the highlighted `List<T>` class.

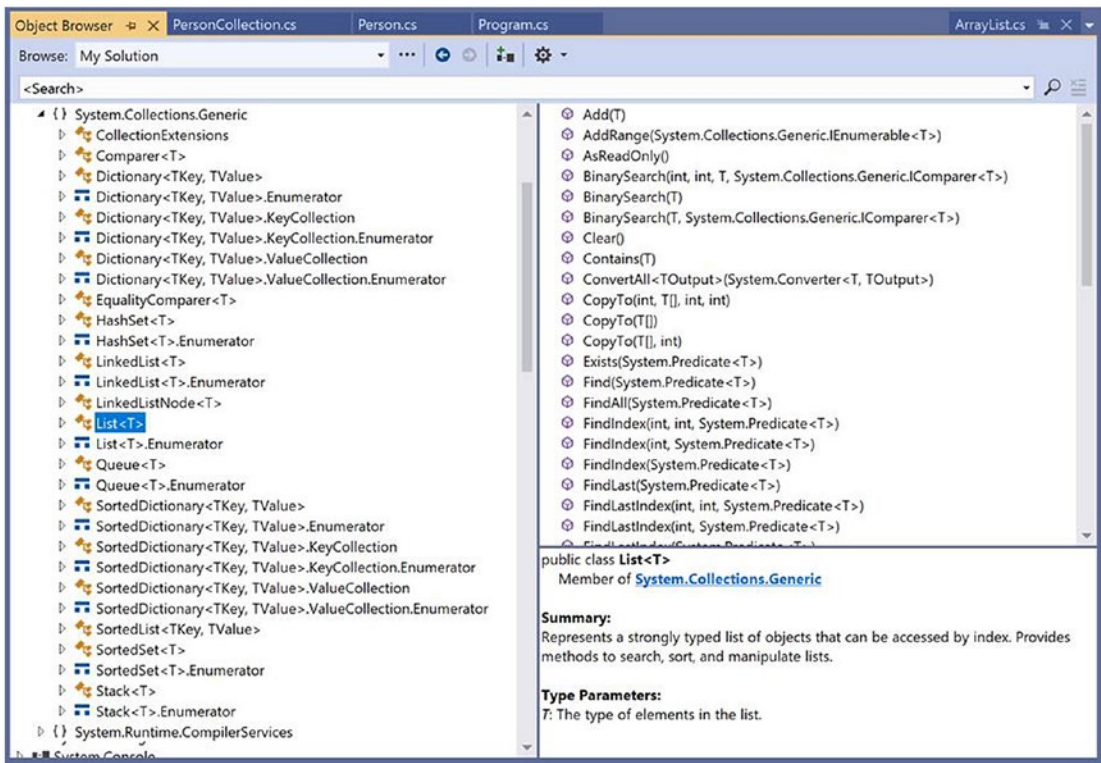


Figure 10-1. Generic items supporting type parameters

Formally speaking, you call these tokens *type parameters*; however, in more user-friendly terms, you can simply call them *placeholders*. You can read the symbol `<T>` as “of T.” Thus, you can read `IEnumerable<T>` as “IEnumerable of T” or, to say it another way, “IEnumerable of type T.”

**Note** The name of a type parameter (placeholder) is irrelevant, and it is up to the developer who created the generic item. However, typically *T* is used to represent types, *TKey* or *K* is used for keys, and *TValue* or *V* is used for values.

When you create a generic object, implement a generic interface, or invoke a generic member, it is up to you to supply a value to the type parameter. You’ll see many examples in this chapter and throughout the remainder of the text. However, to set the stage, let’s see the basics of interacting with generic types and members.

## Specifying Type Parameters for Generic Classes/Structures

When you create an instance of a generic class or structure, you specify the type parameter when you declare the variable and when you invoke the constructor. As you saw in the preceding code example, `UseGenericList()` defined two `List<T>` objects.

```
// This List<> can hold only Person objects.
List<Person> morePeople = new List<Person>();
// This List<> can hold only integers.
List<int> moreInts = new List<int>();
```

You can read the first line in the preceding snippet as “a List<> of T, where T is of type Person.” Or, more simply, you can read it as “a list of person objects.” After you specify the type parameter of a generic item, it cannot be changed (remember, generics are all about type safety). When you specify a type parameter for a generic class or structure, all occurrences of the placeholder(s) are now replaced with your supplied value.

If you were to view the full declaration of the generic List<T> class using the Visual Studio Object Browser, you would see that the placeholder T is used throughout the definition of the List<T> type. Here is a partial listing (note the items in **bold**):

```
// A partial listing of the List<T> class.
namespace System.Collections.Generic
{
    public class List<T> : IList<T>, IList, IReadOnlyList<T>
    {
    ...
        public void Add(T item);
        public void AddRange(IEnumerable<T> collection);
        public ReadOnlyCollection<TT item);
        public bool Contains(T item);
        public void CopyTo(T[] array);
        public int FindIndex(System.Predicate<T> match);
        public T FindLast(System.Predicate<T> match);
        public bool Remove(T item);
        public int RemoveAll(System.Predicate<T> match);
        public T[] ToArray();
        public bool TrueForAll(System.Predicate<T> match);
        public T this[int index] { get; set; }
    }
}
```

When you create a List<T> specifying Person objects, it is as if the List<T> type were defined as follows:

```
namespace System.Collections.Generic
{
    public class List<Person>
        : IList<Person>, IList, IReadOnlyList<Person>
    {
    ...
        public void Add(Person item);
        public void AddRange(IEnumerable<Person> collection);
        public ReadOnlyCollection<Person> AsReadOnly();
        public int BinarySearch(Person item);
        public bool Contains(Person item);
        public void CopyTo(Person[] array);
        public int FindIndex(System.Predicate<Person> match);
        public Person FindLast(System.Predicate<Person> match);
```

```

    public bool Remove(Person item);
    public int RemoveAll(System.Predicate<Person> match);
    public Person[] ToArray();
    public bool TrueForAll(System.Predicate<Person> match);
    public Person this[int index] { get; set; }
}

```

Of course, when you create a generic `List<T>` variable, the compiler does not literally create a new implementation of the `List<T>` class. Rather, it will address only the members of the generic type you actually invoke.

## Specifying Type Parameters for Generic Members

It is fine for a nongeneric class or structure to support generic properties. In these cases, you would also need to specify the placeholder value at the time you invoke the method. For example, `System.Array` supports a several generic methods. Specifically, the nongeneric static `Sort()` method now has a generic counterpart named `Sort<T>()`. Consider the following code snippet, where `T` is of type `int`:

```

int[] myInts = { 10, 4, 2, 33, 93 };

// Specify the placeholder to the generic
// Sort<>() method.
Array.Sort<int>(myInts);

foreach (int i in myInts)
{
    Console.WriteLine(i);
}

```

## Specifying Type Parameters for Generic Interfaces

It is common to implement generic interfaces when you build classes or structures that need to support various framework behaviors (e.g., cloning, sorting, and enumeration). In Chapter 8, you learned about a number of nongeneric interfaces, such as `IComparable`, `IEnumerable`, `IEnumerator`, and `IComparer`. Recall that the nongeneric `IComparable` interface was defined like this:

```

public interface IComparable
{
    int CompareTo(object obj);
}

```

In Chapter 8, you also implemented this interface on your `Car` class to enable sorting in a standard array. However, the code required several runtime checks and casting operations because the parameter was a general `System.Object`.

```

public class Car : IComparable
{
    ...
    // IComparable implementation.
}

```

```

int IComparable.CompareTo(object obj)
{
    if (obj is Car temp)
    {
        return this.CarID.CompareTo(temp.CarID);
    }
    throw new ArgumentException("Parameter is not a Car!");
}
}

```

Now assume you use the generic counterpart of this interface.

```

public interface IComparable<T>
{
    int CompareTo(T obj);
}

```

In this case, your implementation code will be cleaned up considerably.

```

public class Car : IComparable<Car>
{
    ...
    // IComparable<T> implementation.
    int IComparable<Car>.CompareTo(Car obj)
    {
        if (this.CarID > obj.CarID)
        {
            return 1;
        }
        if (this.CarID < obj.CarID)
        {
            return -1;
        }
        return 0;
    }
}

```

Here, you do not need to check whether the incoming parameter is a *Car* because it can *only* be a *Car*! If someone were to pass in an incompatible data type, you would get a compile-time error. Now that you have a better handle on how to interact with generic items, as well as the role of type parameters (aka placeholders), you're ready to examine the classes and interfaces of the `System.Collections.Generic` namespace.

## The System.Collections.Generic Namespace

When you are building a .NET Core application and need a way to manage in-memory data, the classes of `System.Collections.Generic` will most likely fit the bill. At the opening of this chapter, I briefly mentioned some of the core nongeneric interfaces implemented by the nongeneric collection classes. Not too surprisingly, the `System.Collections.Generic` namespace defines generic replacements for many of them.

In fact, you can find a number of the generic interfaces that extend their nongeneric counterparts. This might seem odd; however, by doing so, implementing classes will also support the legacy functionality found in their nongeneric siblings. For example, `IEnumerable<T>` extends `IEnumerable`. Table 10-4 documents the core generic interfaces you’ll encounter when working with the generic collection classes.

**Table 10-4.** *Key Interfaces Supported by Classes of `System.Collections.Generic`*

System.Collections.Generic Interface	Meaning in Life
<code>ICollection&lt;T&gt;</code>	Defines general characteristics (e.g., size, enumeration, and thread safety) for all generic collection types.
<code>IComparer&lt;T&gt;</code>	Defines a way to compare to objects.
<code>IDictionary&lt;TKey, TValue&gt;</code>	Allows a generic collection object to represent its contents using key-value pairs.
<code>IEnumerable&lt;T&gt;/IEnumerable&lt;T&gt;</code>	Returns the <code>IEnumerator&lt;T&gt;</code> interface for a given object. <code>IEnumerator</code> (new in C# 8.0) is covered in Chapter 15.
<code>IEnumerator&lt;T&gt;</code>	Enables foreach-style iteration over a generic collection.
<code>IList&lt;T&gt;</code>	Provides behavior to add, remove, and index items in a sequential list of objects.
<code>ISet&lt;T&gt;</code>	Provides the base interface for the abstraction of sets.

The `System.Collections.Generic` namespace also defines several classes that implement many of these key interfaces. Table 10-5 describes some commonly used classes of this namespace, the interfaces they implement, and their basic functionality.

**Table 10-5.** *Classes of `System.Collections.Generic`*

Generic Class	Supported Key Interfaces	Meaning in Life
<code>Dictionary&lt;TKey, TValue&gt;</code>	<code>ICollection&lt;T&gt;</code> , <code>IDictionary&lt;TKey, TValue&gt;</code> , <code>IEnumerable&lt;T&gt;</code>	This represents a generic collection of keys and values.
<code>LinkedList&lt;T&gt;</code>	<code>ICollection&lt;T&gt;</code> , <code>IEnumerator&lt;T&gt;</code>	This represents a doubly linked list.
<code>List&lt;T&gt;</code>	<code>ICollection&lt;T&gt;</code> , <code>IEnumerator&lt;T&gt;</code> , <code>IList&lt;T&gt;</code>	This is a dynamically resizable sequential list of items.
<code>Queue&lt;T&gt;</code>	<code>ICollection</code> (Not a typo! This is the nongeneric collection interface), <code>IEnumerator&lt;T&gt;</code>	This is a generic implementation of a first-in, first-out list.
<code>SortedDictionary&lt;TKey, TValue&gt;</code>	<code>ICollection&lt;T&gt;</code> , <code>IDictionary&lt;TKey, TValue&gt;</code> , <code>IEnumerator&lt;T&gt;</code>	This is a generic implementation of a sorted set of key-value pairs.
<code>SortedSet&lt;T&gt;</code>	<code>ICollection&lt;T&gt;</code> , <code>IEnumerator&lt;T&gt;</code> , <code>ISet&lt;T&gt;</code>	This represents a collection of objects that is maintained in sorted order with no duplication.
<code>Stack&lt;T&gt;</code>	<code>ICollection</code> (Not a typo! This is the nongeneric collection interface), <code>IEnumerator&lt;T&gt;</code>	This is a generic implementation of a last-in, first-out list.



The `System.Collections.Generic` namespace also defines many auxiliary classes and structures that work in conjunction with a specific container. For example, the `LinkedListNode<T>` type represents a node within a generic `LinkedList<T>`, the `KeyNotFoundException` exception is raised when attempting to grab an item from a container using a nonexistent key, and so forth. Be sure to consult the .NET Core documentation for full details of the `System.Collections.Generic` namespace.

In any case, your next task is to learn how to use some of these generic collection classes. Before you do, however, allow me to illustrate a C# language feature (first introduced in .NET 3.5) that simplifies the way you populate generic (and nongeneric) collection containers with data.

## Understanding Collection Initialization Syntax

In Chapter 4, you learned about *object initialization syntax*, which allows you to set properties on a new variable at the time of construction. Closely related to this is *collection initialization syntax*. This C# language feature makes it possible to populate many containers (such as `ArrayList` or `List<T>`) with items by using syntax similar to what you use to populate a basic array. Create a new .NET Core Console application named `FunWithCollectionInitialization`.

---

**Note** You can apply collection initialization syntax only to classes that support an `Add()` method, which is formalized by the `ICollection<T>/ICollection` interfaces.

---

Consider the following examples:

```
// Init a standard array.
int[] myArrayOfInts = { 0, 1, 2, 3, 4, 5, 6, 7, 8, 9 };

// Init a generic List<> of ints.
List<int> myGenericList = new List<int> { 0, 1, 2, 3, 4, 5, 6, 7, 8, 9 };

// Init an ArrayList with numerical data.
ArrayList myList = new ArrayList { 0, 1, 2, 3, 4, 5, 6, 7, 8, 9 };
```

If your container is managing a collection of classes or a structure, you can blend object initialization syntax with collection initialization syntax to yield some functional code. You might recall the `Point` class from Chapter 5, which defined two properties named `X` and `Y`. If you wanted to build a generic `List<T>` of `Point` objects, you could write the following:

```
List<Point> myListOfPoints = new List<Point>
{
    new Point { X = 2, Y = 2 },
    new Point { X = 3, Y = 3 },
    new Point { X = 4, Y = 4 }
};

foreach (var pt in myListOfPoints)
{
    Console.WriteLine(pt);
}
```

Again, the benefit of this syntax is that you save yourself numerous keystrokes. While the nested curly brackets can become difficult to read if you don't mind your formatting, imagine the amount of code that would be required to fill the following `List<T>` of `Rectangles` if you did not have collection initialization syntax.

```
List<Rectangle> myListOfRects = new List<Rectangle>
{
    new Rectangle {
        Height = 90, Width = 90,
        Location = new Point { X = 10, Y = 10 }},
    new Rectangle {
        Height = 50, Width = 50,
        Location = new Point { X = 2, Y = 2 }},
};
foreach (var r in myListOfRects)
{
    Console.WriteLine(r);
}
```

## Working with the `List<T>` Class

Create a new Console Application project named `FunWithGenericCollections`. Add a using statement for the `System.Collections.Generic` namespace:

```
using System.Collections.Generic;
```

The first generic class you will examine is `List<T>`, which you've already seen once or twice in this chapter. The `List<T>` class is bound to be your most frequently used type in the `System.Collections.Generic` namespace because it allows you to resize the contents of the container dynamically. To illustrate the basics of this type, ponder the following method in your `Program` class, which leverages `List<T>` to manipulate the set of `Person` objects shown earlier in this chapter; you might recall that these `Person` objects defined three properties (`Age`, `FirstName`, and `LastName`) and a custom `ToString()` implementation:

```
static void UseGenericList()
{
    // Make a List of Person objects, filled with
    // collection/object init syntax.
    List<Person> people = new List<Person>()
    {
        new Person {FirstName= "Homer", LastName="Simpson", Age=47},
        new Person {FirstName= "Marge", LastName="Simpson", Age=45},
        new Person {FirstName= "Lisa", LastName="Simpson", Age=9},
        new Person {FirstName= "Bart", LastName="Simpson", Age=8}
    };

    // Print out # of items in List.
    Console.WriteLine("Items in list: {0}", people.Count);
}
```

```

// Enumerate over list.
foreach (Person p in people)
{
    Console.WriteLine(p);
}

// Insert a new person.
Console.WriteLine("\n->Inserting new person.");
people.Insert(2, new Person { FirstName = "Maggie", LastName = "Simpson", Age = 2 });
Console.WriteLine("Items in list: {0}", people.Count);

// Copy data into a new array.
Person[] arrayOfPeople = people.ToArray();
foreach (Person p in arrayOfPeople)
{
    Console.WriteLine("First Names: {0}", p.FirstName);
}
}

```

Here, you use collection initialization syntax to populate your `List<T>` with objects, as a shorthand notation for calling `Add()` *multiple* times. After you print out the number of items in the collection (as well as enumerate over each item), you invoke `Insert()`. As you can see, `Insert()` allows you to plug a new item into the `List<T>` at a specified index.

Finally, notice the call to the `ToArray()` method, which returns an array of `Person` objects based on the contents of the original `List<T>`. From this array, you loop over the items again using the array's indexer syntax. If you call this method from within `Main()`, you get the following output:

---

```
***** Fun with Generic Collections *****
```

```

Items in list: 4
Name: Homer Simpson, Age: 47
Name: Marge Simpson, Age: 45
Name: Lisa Simpson, Age: 9
Name: Bart Simpson, Age: 8

```

```

->Inserting new person.
Items in list: 5
First Names: Homer
First Names: Marge
First Names: Maggie
First Names: Lisa
First Names: Bart

```

---

The `List<T>` class defines many additional members of interest, so be sure to consult the documentation for more information. Next, let's look at a few more generic collections, specifically `Stack<T>`, `Queue<T>`, and `SortedSet<T>`. This should get you in a great position to understand your basic choices regarding how to hold your custom application data.

## Working with the Stack<T> Class

The `Stack<T>` class represents a collection that maintains items using a last-in, first-out manner. As you might expect, `Stack<T>` defines members named `Push()` and `Pop()` to place items onto or remove items from the stack. The following method creates a stack of `Person` objects:

```
static void UseGenericStack()
{
    Stack<Person> stackOfPeople = new Stack<Person>();
    stackOfPeople.Push(new Person { FirstName = "Homer", LastName = "Simpson", Age = 47 });
    stackOfPeople.Push(new Person { FirstName = "Marge", LastName = "Simpson", Age = 45 });
    stackOfPeople.Push(new Person { FirstName = "Lisa", LastName = "Simpson", Age = 9 });

    // Now look at the top item, pop it, and look again.
    Console.WriteLine("First person is: {0}", stackOfPeople.Peek());
    Console.WriteLine("Popped off {0}", stackOfPeople.Pop());
    Console.WriteLine("\nFirst person is: {0}", stackOfPeople.Peek());
    Console.WriteLine("Popped off {0}", stackOfPeople.Pop());
    Console.WriteLine("\nFirst person item is: {0}", stackOfPeople.Peek());
    Console.WriteLine("Popped off {0}", stackOfPeople.Pop());

    try
    {
        Console.WriteLine("\nnFirst person is: {0}", stackOfPeople.Peek());
        Console.WriteLine("Popped off {0}", stackOfPeople.Pop());
    }
    catch (InvalidOperationException ex)
    {
        Console.WriteLine("\nError! {0}", ex.Message);
    }
}
```

Here, you build a stack that contains three people, added in the order of their first names: Homer, Marge, and Lisa. As you peek into the stack, you will always see the object at the top first; therefore, the first call to `Peek()` reveals the third `Person` object. After a series of `Pop()` and `Peek()` calls, the stack eventually empties, at which time additional `Peek()` and `Pop()` calls raise a system exception. You can see the output for this here:

---

```
***** Fun with Generic Collections *****
```

```
First person is: Name: Lisa Simpson, Age: 9
Popped off Name: Lisa Simpson, Age: 9
```

```
First person is: Name: Marge Simpson, Age: 45
Popped off Name: Marge Simpson, Age: 45
```

```
First person item is: Name: Homer Simpson, Age: 47
Popped off Name: Homer Simpson, Age: 47
```

```
Error! Stack empty.
```

---

## Working with the Queue<T> Class

Queues are containers that ensure items are accessed in a first-in, first-out manner. Sadly, we humans are subject to queues all day long: lines at the bank, lines at the movie theater, and lines at the morning coffeehouse. When you need to model a scenario in which items are handled on a first-come, first-served basis, you will find the Queue<T> class fits the bill. In addition to the functionality provided by the supported interfaces, Queue defines the key members shown in Table 10-6.

**Table 10-6.** *Members of the Queue<T> Type*

Select Member of Queue<T>	Meaning in Life
Dequeue()	Removes and returns the object at the beginning of the Queue<T>
Enqueue()	Adds an object to the end of the Queue<T>
Peek()	Returns the object at the beginning of the Queue<T> without removing it

Now let's put these methods to work. You can begin by leveraging your Person class again and building a Queue<T> object that simulates a line of people waiting to order coffee.

```
static void UseGenericQueue()
{
    // Make a Q with three people.
    Queue<Person> peopleQ = new Queue<Person>();
    peopleQ.Enqueue(new Person {FirstName= "Homer", LastName="Simpson", Age=47});
    peopleQ.Enqueue(new Person {FirstName= "Marge", LastName="Simpson", Age=45});
    peopleQ.Enqueue(new Person {FirstName= "Lisa", LastName="Simpson", Age=9});

    // Peek at first person in Q.
    Console.WriteLine("{0} is first in line!", peopleQ.Peek().FirstName);

    // Remove each person from Q.
    GetCoffee(peopleQ.Dequeue());
    GetCoffee(peopleQ.Dequeue());
    GetCoffee(peopleQ.Dequeue());
    // Try to de-Q again?
    try
    {
        GetCoffee(peopleQ.Dequeue());
    }
    catch(InvalidOperationException e)
    {
        Console.WriteLine("Error! {0}", e.Message);
    }
    //Local helper function
    static void GetCoffee(Person p)
    {
        Console.WriteLine("{0} got coffee!", p.FirstName);
    }
}
```

Here, you insert three items into the `Queue<T>` class using its `Enqueue()` method. The call to `Peek()` allows you to view (but not remove) the first item currently in the `Queue`. Finally, the call to `Dequeue()` removes the item from the line and sends it into the `GetCoffee()` helper function for processing. Note that if you attempt to remove items from an empty queue, a runtime exception is thrown. Here is the output you receive when calling this method:

---

```
***** Fun with Generic Collections *****
```

```
Homer is first in line!
Homer got coffee!
Marge got coffee!
Lisa got coffee!
Error! Queue empty.
```

---

## Working with the `SortedSet<T>` Class

The `SortedSet<T>` class is useful because it automatically ensures that the items in the set are sorted when you insert or remove items. However, you do need to inform the `SortedSet<T>` class exactly *how* you want it to sort the objects, by passing in as a constructor argument an object that implements the generic `IComparer<T>` interface.

Begin by creating a new class named `SortPeopleByAge`, which implements `IComparer<T>`, where `T` is of type `Person`. Recall that this interface defines a single method named `Compare()`, where you can author whatever logic you require for the comparison. Here is a simple implementation of this class:

```
class SortPeopleByAge : IComparer<Person>
{
    public int Compare(Person firstPerson, Person secondPerson)
    {
        if (firstPerson?.Age > secondPerson?.Age)
        {
            return 1;
        }
        if (firstPerson?.Age < secondPerson?.Age)
        {
            return -1;
        }
        return 0;
    }
}
```

Now add the following new method that demonstrates using the `SortedSet<Person>`:

```
static void UseSortedSet()
{
    // Make some people with different ages.
    SortedSet<Person> setOfPeople = new SortedSet<Person>(new SortPeopleByAge())
    {
        new Person {FirstName= "Homer", LastName="Simpson", Age=47},
        new Person {FirstName= "Marge", LastName="Simpson", Age=45},
        new Person {FirstName= "Lisa", LastName="Simpson", Age=9},
    }
```

```

    new Person {FirstName= "Bart", LastName="Simpson", Age=8}
};

// Note the items are sorted by age!
foreach (Person p in setOfPeople)
{
    Console.WriteLine(p);
}
    Console.WriteLine();

// Add a few new people, with various ages.
setOfPeople.Add(new Person { FirstName = "Saku", LastName = "Jones", Age = 1 });
setOfPeople.Add(new Person { FirstName = "Mikko", LastName = "Jones", Age = 32 });

// Still sorted by age!
foreach (Person p in setOfPeople)
{
    Console.WriteLine(p);
}
}

```

When you run your application, the listing of objects is now always ordered based on the value of the `Age` property, regardless of the order you inserted or removed objects.

---

\*\*\*\*\* Fun with Generic Collections \*\*\*\*\*

```

Name: Bart Simpson, Age: 8
Name: Lisa Simpson, Age: 9
Name: Marge Simpson, Age: 45
Name: Homer Simpson, Age: 47

```

```

Name: Saku Jones, Age: 1
Name: Bart Simpson, Age: 8
Name: Lisa Simpson, Age: 9
Name: Mikko Jones, Age: 32
Name: Marge Simpson, Age: 45
Name: Homer Simpson, Age: 47

```

---

## Working with the Dictionary<TKey, TValue> Class

Another handy generic collection is the `Dictionary<TKey, TValue>` type, which allows you to hold any number of objects that may be referred to via a unique key. Thus, rather than obtaining an item from a `List<T>` using a numerical identifier (e.g., “Give me the second object”), you could use the unique text key (e.g., “Give me the object I keyed as Homer”).

Like other collection objects, you can populate a `Dictionary<TKey, TValue>` by calling the generic `Add()` method manually. However, you can also fill a `Dictionary<TKey, TValue>` using collection initialization syntax. Do be aware that when you are populating this collection object, key names must be unique. If you mistakenly specify the same key multiple times, you will receive a runtime exception.

Consider the following method that fills a `Dictionary<K,V>` with various objects. Notice when you create the `Dictionary<TKey,TValue>` object, you specify the key type (`TKey`) and underlying object type (`TValue`) as constructor arguments. In this example, you are using a `string` data type as the key and a `Person` type as the value. Also note that you can combine object initialization syntax with collection initialization syntax.

```
private static void UseDictionary()
{
    // Populate using Add() method
    Dictionary<string, Person> peopleA = new Dictionary<string, Person>();
    peopleA.Add("Homer", new Person { FirstName = "Homer", LastName = "Simpson", Age = 47
});
    peopleA.Add("Marge", new Person { FirstName = "Marge", LastName = "Simpson", Age = 45
});
    peopleA.Add("Lisa", new Person { FirstName = "Lisa", LastName = "Simpson", Age = 9 });

    // Get Homer.
    Person homer = peopleA["Homer"];
    Console.WriteLine(homer);

    // Populate with initialization syntax.
    Dictionary<string, Person> peopleB = new Dictionary<string, Person>()
    {
        { "Homer", new Person { FirstName = "Homer", LastName = "Simpson", Age = 47 } },
        { "Marge", new Person { FirstName = "Marge", LastName = "Simpson", Age = 45 } },
        { "Lisa", new Person { FirstName = "Lisa", LastName = "Simpson", Age = 9 } }
    };

    // Get Lisa.
    Person lisa = peopleB["Lisa"];
    Console.WriteLine(lisa);
}
```

It is also possible to populate a `Dictionary<TKey,TValue>` using a related initialization syntax introduced with the current version of .NET that is specific to this type of container (not surprisingly termed *dictionary initialization*). Similar to the syntax used to populate the `peopleB` object in the previous code example, you still define an initialization scope for the collection object; however, you can use the indexer to specify the key and assign this to a new object as so:

```
// Populate with dictionary initialization syntax.
Dictionary<string, Person> peopleC = new Dictionary<string, Person>()
{
    ["Homer"] = new Person { FirstName = "Homer", LastName = "Simpson", Age = 47 },
    ["Marge"] = new Person { FirstName = "Marge", LastName = "Simpson", Age = 45 },
    ["Lisa"] = new Person { FirstName = "Lisa", LastName = "Simpson", Age = 9 }
};
```

## The System.Collections.ObjectModel Namespace

Now that you understand how to work with the major generic classes, we will briefly examine an additional collection-centric namespace, `System.Collections.ObjectModel`. This is a relatively small namespace, which contains a handful of classes. Table 10-7 documents the two classes that you should most certainly be aware of.



**Table 10-7.** *Useful Members of `System.Collections.ObjectModel`*

<b>System.Collections.ObjectModel Type</b>	<b>Meaning in Life</b>
<code>ObservableCollection&lt;T&gt;</code>	Represents a dynamic data collection that provides notifications when items get added, when items get removed, or when the whole list is refreshed
<code>ReadOnlyObservableCollection&lt;T&gt;</code>	Represents a read-only version of <code>ObservableCollection&lt;T&gt;</code>

The `ObservableCollection<T>` class is useful, in that it has the ability to inform external objects when its contents have changed in some way (as you might guess, working with `ReadOnlyObservableCollection<T>` is similar but read-only in nature).

## Working with `ObservableCollection<T>`

Create a new Console Application project named `FunWithObservableCollections` and import the `System.Collections.ObjectModel` namespace into your initial C# code file. In many ways, working with `ObservableCollection<T>` is identical to working with `List<T>`, given that both of these classes implement the same core interfaces. What makes the `ObservableCollection<T>` class unique is that this class supports an event named `CollectionChanged`. This event will fire whenever a new item is inserted, a current item is removed (or relocated), or the entire collection is modified.

Like any event, `CollectionChanged` is defined in terms of a delegate, which in this case is `NotifyCollectionChangedEventHandler`. This delegate can call any method that takes an object as the first parameter and takes a `NotifyCollectionChangedEventArgs` as the second. Consider the following `Main()` method, which populates an observable collection containing `Person` objects and wires up the `CollectionChanged` event:

```
class Program
{
    static void Main(string[] args)
    {
        // Make a collection to observe
        //and add a few Person objects.
        ObservableCollection<Person> people = new ObservableCollection<Person>()
        {
            new Person{ FirstName = "Peter", LastName = "Murphy", Age = 52 },
            new Person{ FirstName = "Kevin", LastName = "Key", Age = 48 },
        };

        // Wire up the CollectionChanged event.
        people.CollectionChanged += people_CollectionChanged;
    }

    static void people_CollectionChanged(object sender, System.Collections.Specialized.
    NotifyCollectionChangedEventArgs e)
    {
        throw new NotImplementedException();
    }
}
```

The incoming `NotifyCollectionChangedEventArgs` parameter defines two important properties, `OldItems` and `NewItems`, which will give you a list of items that were currently in the collection before the event fired and the new items that were involved in the change. However, you will want to examine these lists only under the correct circumstances. Recall that the `CollectionChanged` event can fire when items are added, removed, relocated, or reset. To discover which of these actions triggered the event, you can use the `Action` property of `NotifyCollectionChangedEventArgs`. The `Action` property can be tested against any of the following members of the `NotifyCollectionChangedAction` enumeration:

```
public enum NotifyCollectionChangedAction
{
    Add = 0,
    Remove = 1,
    Replace = 2,
    Move = 3,
    Reset = 4,
}
```

Here is an implementation of the `CollectionChanged` event handler that will traverse the old and new sets when an item has been inserted into or removed from the collection at hand (notice the added using for `System.Collections.Specialized`):

```
using System.Collections.Specialized;
...
static void people_CollectionChanged(object sender,
    NotifyCollectionChangedEventArgs e)
{
    // What was the action that caused the event?
    Console.WriteLine("Action for this event: {0}", e.Action);

    // They removed something.
    if (e.Action == NotifyCollectionChangedAction.Remove)
    {
        Console.WriteLine("Here are the OLD items:");
        foreach (Person p in e.OldItems)
        {
            Console.WriteLine(p.ToString());
        }
        Console.WriteLine();
    }

    // They added something.
    if (e.Action == NotifyCollectionChangedAction.Add)
    {
        // Now show the NEW items that were inserted.
        Console.WriteLine("Here are the NEW items:");
        foreach (Person p in e.NewItems)
        {
            Console.WriteLine(p.ToString());
        }
    }
}
```

Now, update your `Main()` method to add and remove an item:

```
// Now add a new item.
people.Add(new Person("Fred", "Smith", 32));
// Remove an item.
people.RemoveAt(0);
```

When you run the program, you will see output similar to the following:

---

```
Action for this event: Add
Here are the NEW items:
Name: Fred Smith, Age: 32

Action for this event: Remove
Here are the OLD items:
Name: Peter Murphy, Age: 52
```

---

That wraps up the examination of the various collection-centric namespaces. To conclude the chapter, you will now examine how you can build your own custom generic methods and custom generic types.

## Creating Custom Generic Methods

While most developers typically use the existing generic types within the base class libraries, it is also possible to build your own generic members and custom generic types. Let's look at how to incorporate custom generics into your own projects. The first step is to build a generic swap method. Begin by creating a new console application named `CustomGenericMethods`.

When you build custom generic methods, you achieve a supercharged version of traditional method overloading. In Chapter 2, you learned that overloading is the act of defining multiple versions of a single method, which differ by the number of, or type of, parameters.

While overloading is a useful feature in an object-oriented language, one problem is that you can easily end up with a ton of methods that essentially do the same thing. For example, assume you need to build some methods that can switch two pieces of data using a simple swap routine. You might begin by authoring a new method that can operate on integers, like this:

```
// Swap two integers.
static void Swap(ref int a, ref int b)
{
    int temp = a;
    a = b;
    b = temp;
}
```

So far, so good. But now assume you also need to swap two `Person` objects; this would require authoring a new version of `Swap()`.

```
// Swap two Person objects.
static void Swap(ref Person a, ref Person b)
{
    Person temp = a;
    a = b;
    b = temp;
}
```

No doubt, you can see where this is going. If you also needed to swap floating-point numbers, bitmaps, cars, buttons, and whatnot, you would have to build even more methods, which would become a maintenance nightmare. You could build a single (nongeneric) method that operated on object parameters, but then you face all the issues you examined earlier in this chapter, including boxing, unboxing, a lack of type safety, explicit casting, and so on.

Whenever you have a group of overloaded methods that differ only by incoming arguments, this is your clue that generics could make your life easier. Consider the following generic `Swap<T>` method that can swap any two `T`s:

```
// This method will swap any two items.
// as specified by the type parameter <T>.
static void Swap<T>(ref T a, ref T b)
{
    Console.WriteLine("You sent the Swap() method a {0}", typeof(T));
    T temp = a;
    a = b;
    b = temp;
}
```

Notice how a generic method is defined by specifying the type parameters after the method name but before the parameter list. Here, you state that the `Swap<T>()` method can operate on any two parameters of type `<T>`. To spice things up a bit, you also print out the type name of the supplied placeholder to the console using C#'s `typeof()` operator. Now consider the following `Main()` method, which swaps integers and strings:

```
static void Main(string[] args)
{
    Console.WriteLine("***** Fun with Custom Generic Methods *****\n");

    // Swap 2 ints.
    int a = 10, b = 90;
    Console.WriteLine("Before swap: {0}, {1}", a, b);
    Swap<int>(ref a, ref b);
    Console.WriteLine("After swap: {0}, {1}", a, b);
    Console.WriteLine();

    // Swap 2 strings.
    string s1 = "Hello", s2 = "There";
    Console.WriteLine("Before swap: {0} {1}!", s1, s2);
    Swap<string>(ref s1, ref s2);
    Console.WriteLine("After swap: {0} {1}!", s1, s2);

    Console.ReadLine();
}
```

The output looks like this:

---

```
***** Fun with Custom Generic Methods *****
```

```
Before swap: 10, 90
You sent the Swap() method a System.Int32
After swap: 90, 10
```

```
Before swap: Hello There!
You sent the Swap() method a System.String
After swap: There Hello!
```

---

The major benefit of this approach is that you have only one version of `Swap<T>()` to maintain, yet it can operate on any two items of a given type in a type-safe manner. Better yet, stack-based items stay on the stack, while heap-based items stay on the heap!

## Inference of Type Parameters

When you invoke generic methods such as `Swap<T>`, you can optionally omit the type parameter if (and only if) the generic method requires arguments because the compiler can infer the type parameter based on the member parameters. For example, you could swap two `System.Boolean` values by adding the following code to `Main()`:

```
// Compiler will infer System.Boolean.
bool b1 = true, b2 = false;
Console.WriteLine("Before swap: {0}, {1}", b1, b2);
Swap(ref b1, ref b2);
Console.WriteLine("After swap: {0}, {1}", b1, b2);
```

Even though the compiler is able to discover the correct type parameter based on the data type used to declare `b1` and `b2`, you should get in the habit of always specifying the type parameter explicitly.

```
Swap<string>(ref b1, ref b2);
```

This makes it clear to your fellow programmers that this method is indeed generic. Moreover, inference of type parameters works only if the generic method has at least one parameter. For example, assume you have the following generic method in your `Program` class:

```
static void DisplayBaseClass<T>()
{
    // BaseType is a method used in reflection,
    // which will be examined in Chapter 17
    Console.WriteLine("Base class of {0} is: {1}.", typeof(T), typeof(T).BaseType);
}
```

In this case, you must supply the type parameter upon invocation.

```
static void Main(string[] args)
{
    ...
```

```

// Must supply type parameter if
// the method does not take params.
DisplayBaseClass<int>();
DisplayBaseClass<string>();

// Compiler error! No params? Must supply placeholder!
// DisplayBaseClass();
Console.ReadLine();
}

```

Of course, generic methods do not need to be static as they are in these examples. All of the rules and options for nongeneric methods also apply.

## Creating Custom Generic Structures and Classes

Now that you understand how to define and invoke generic methods, it's time to turn your attention to the construction of a generic structure (the process of building a generic class is identical) within a new Console Application project named `GenericPoint`. Assume you have built a generic `Point` structure that supports a single type parameter that represents the underlying storage for the (x, y) coordinates. The caller can then create `Point<T>` types as follows:

```

// Point using ints.
Point<int> p = new Point<int>(10, 10);

// Point using double.
Point<double> p2 = new Point<double>(5.4, 3.3);

// Point using strings.
Point<string> p3 = new Point<string>("i", "3i");

```

Creating a point using strings might seem a bit odd at first, but consider the case of imaginary numbers. Then it might make sense to use strings for the values of X and Y of a point. Regardless, it demonstrates the power of generics. Here is the complete definition of `Point<T>`:

```

// A generic Point structure.
public struct Point<T>
{
    // Generic state data.
    private T _xPos;
    private T _yPos;

    // Generic constructor.
    public Point(T xVal, T yVal)
    {
        _xPos = xVal;
        _yPos = yVal;
    }

    // Generic properties.
    public T X

```

```

{
    get => _xPos;
    set => _xPos = value;
}

public T Y
{
    get => _yPos;
    set => _yPos = value;
}

public override string ToString() => $"[{_xPos}, {_yPos}]";
}

```

As you can see, `Point<T>` leverages its type parameter in the definition of the field data, constructor arguments, and property definitions.

## Default Value Expressions with Generics

With the introduction of generics, the C# `default` keyword has been given a dual identity. In addition to its use within a `switch` construct, it can also be used to set a type parameter to its default value. This is helpful because a generic type does not know the actual placeholders up front, which means it cannot safely assume what the default value will be. The defaults for a type parameter are as follows:

- Numeric values have a default value of 0.
- Reference types have a default value of `null`.
- Fields of a structure are set to 0 (for value types) or `null` (for reference types).

To reset an instance of `Point<T>`, you could set the `X` and `Y` values to 0 directly. This assumes the caller will supply only numerical data. What about the string version? This is where the `default(T)` syntax comes in handy. The `default` keyword resets a variable to the default value for the variable's datatype. Add a method called `ResetPoint` as follows:

```

// Reset fields to the default value of the type parameter.
// The "default" keyword is overloaded in C#.
// When used with generics, it represents the default
// value of a type parameter.
public void ResetPoint()
{
    _xPos = default(T);
    _yPos = default(T);
}

```

Now that you have the `ResetPoint` method in place, you can fully exercise the methods of `Point<T>` struct.

```

static void Main(string[] args)
{
    Console.WriteLine("***** Fun with Generic Structures *****\n");
    // Point using ints.
    Point<int> p = new Point<int>(10, 10);
}

```

```

Console.WriteLine("p.ToString()={0}", p.ToString());
p.ResetPoint();
Console.WriteLine("p.ToString()={0}", p.ToString());
Console.WriteLine();

// Point using double.
Point<double> p2 = new Point<double>(5.4, 3.3);
Console.WriteLine("p2.ToString()={0}", p2.ToString());
p2.ResetPoint();
Console.WriteLine("p2.ToString()={0}", p2.ToString());
Console.WriteLine();

// Point using strings.
Point<string> p3 = new Point<string>("i", "3i");
Console.WriteLine("p3.ToString()={0}", p3.ToString());
p3.ResetPoint();
Console.WriteLine("p3.ToString()={0}", p3.ToString());
Console.ReadLine();
}

```

Here is the output:

---

```
***** Fun with Generic Structures *****
```

```

p.ToString()=[10, 10]
p.ToString()=[0, 0]

p2.ToString()=[5.4, 3.3]
p2.ToString()=[0, 0]

p3.ToString()=[i, 3i]
p3.ToString()=[, ]

```

---

## Default Literal Expressions (New 7.1)

In addition to setting the default value of a property, C# 7.1 introduced default literal expressions. This eliminates the need to specifying the type of the variable in the default statement. Update the `ResetPoint` method to the following:

```

public void ResetPoint()
{
    _xPos = default;
    _yPos = default;
}

```

The default expression isn't limited to just simple variables, but can also be applied to complex types. For example, to create and initialize the `Point` structure, you can write the following:



```
Point<string> p4 = default;
Console.WriteLine("p4.ToString()={0}", p4.ToString());
Console.WriteLine();
Point<int> p5 = default;
Console.WriteLine("p5.ToString()={0}", p5.ToString());
```

## Pattern Matching with Generics (New 7.1)

Another update in C# 7.1 is the ability to pattern match on generics. Take the following method, which checks the `Point` instance for the datatype that it is based on (arguably incomplete, but enough to show the concept):

```
static void PatternMatching<T>(Point<T> p)
{
    switch (p)
    {
        case Point<string> pString:
            Console.WriteLine("Point is based on strings");
            return;
        case Point<int> pInt:
            Console.WriteLine("Point is based on ints");
            return;
    }
}
```

To exercise the pattern matching code, add the following lines to the `Main` method (updates in bold):

```
Point<string> p4 = default;
Point<int> p5 = default;
PatternMatching(p4);
PatternMatching(p5);
```

## Constraining Type Parameters

As this chapter illustrates, any generic item has at least one type parameter that you need to specify at the time you interact with the generic type or member. This alone allows you to build some type-safe code; however, you can also use the `where` keyword to get extremely specific about what a given type parameter must look like.

Using this keyword, you can add a set of constraints to a given type parameter, which the C# compiler will check at compile time. Specifically, you can constrain a type parameter as described in Table 10-8.

**Table 10-8.** Possible Constraints for Generic Type Parameters

Generic Constraint	Meaning in Life
where T : struct	The type parameter <T> must have System.ValueType in its chain of inheritance (i.e., <T> must be a structure).
where T : class	The type parameter <T> must not have System.ValueType in its chain of inheritance (i.e., <T> must be a reference type).
where T : new()	The type parameter <T> must have a default constructor. This is helpful if your generic type must create an instance of the type parameter because you cannot assume you know the format of custom constructors. Note that this constraint must be listed last on a multi-constrained type.
where T : NameOfBaseClass	The type parameter <T> must be derived from the class specified by NameOfBaseClass.
where T : NameOfInterface	The type parameter <T> must implement the interface specified by NameOfInterface. You can separate multiple interfaces as a comma-delimited list.

Unless you need to build some extremely type-safe custom collections, you might never need to use the `where` keyword in your C# projects. Regardless, the following handful of (partial) code examples illustrate how to work with the `where` keyword.

### Examples Using the `where` Keyword

Begin by assuming that you have created a custom generic class, and you want to ensure that the type parameter has a default constructor. This could be useful when the custom generic class needs to create instances of the `T` because the default constructor is the only constructor that is potentially common to all types. Also, constraining `T` in this way lets you get compile-time checking; if `T` is a reference type, the programmer remembered to redefine the default in the class definition (you might recall that the default constructor is removed in classes when you define your own).

```
// MyGenericClass derives from object, while
// contained items must have a default ctor.
public class MyGenericClass<T> where T : new()
{
    ...
}
```

Notice that the `where` clause specifies which type parameter is being constrained, followed by a colon operator. After the colon operator, you list each possible constraint (in this case, a default constructor). Here is another example:

```
// MyGenericClass derives from object, while
// contained items must be a class implementing IDrawable
// and must support a default ctor.
public class MyGenericClass<T> where T : class, IDrawable, new()
{
    ...
}
```

In this case, `T` has three requirements. It must be a reference type (not a structure), as marked with the `class` token. Second, `T` must implement the `IDrawable` interface. Third, it must also have a default constructor. Multiple constraints are listed in a comma-delimited list; however, you should be aware that the `new()` constraint must always be listed last! Thus, the following code will not compile:

```
// Error! new() constraint must be listed last!
public class MyGenericClass<T> where T : new(), class, IDrawable
{
    ...
}
```

If you ever create a custom generic collection class that specifies multiple type parameters, you can specify a unique set of constraints for each, using separate `where` clauses.

```
// <K> must extend SomeBaseClass and have a default ctor,
// while <T> must be a structure and implement the
// generic IComparable interface.
public class MyGenericClass<K, T> where K : SomeBaseClass, new()
    where T : struct, IComparable<T>
{
    ...
}
```

You will rarely encounter cases where you need to build a complete custom generic collection class; however, you can use the `where` keyword on generic methods as well. For example, if you want to specify that your generic `Swap<T>()` method can operate only on structures, you would update the method like this:

```
// This method will swap any structure, but not classes.
static void Swap<T>(ref T a, ref T b) where T : struct
{
    ...
}
```

Note that if you were to constrain the `Swap()` method in this manner, you would no longer be able to swap string objects (as is shown in the sample code) because `string` is a reference type.

## The Lack of Operator Constraints

I want to make one more comment about generic methods and constraints as this chapter draws to a close. It might come as a surprise to you to find out that when creating generic methods, you will get a compiler error if you apply any C# operators (`+`, `-`, `*`, `==`, etc.) on the type parameters. For example, imagine the usefulness of a class that can add, subtract, multiply, and divide generic types.

```
// Compiler error! Cannot apply
// operators to type parameters!
public class BasicMath<T>
{
    public T Add(T arg1, T arg2)
    { return arg1 + arg2; }
    public T Subtract(T arg1, T arg2)
    { return arg1 - arg2; }
```

```

public T Multiply(T arg1, T arg2)
{ return arg1 * arg2; }
public T Divide(T arg1, T arg2)
{ return arg1 / arg2; }
}

```

Unfortunately, the preceding `BasicMath` class will not compile. While this might seem like a major restriction, you need to remember that generics are generic. Of course, the numerical data can work just fine with the binary operators of C#. However, for the sake of argument, if `<T>` were a custom class or structure type, the compiler could assume the class supports the `+`, `-`, `*`, and `/` operators. Ideally, C# would allow a generic type to be constrained by supported operators, as in this example:

```

// Illustrative code only!
public class BasicMath<T> where T : operator +, operator -,
    operator *, operator /
{
    public T Add(T arg1, T arg2)
    { return arg1 + arg2; }
    public T Subtract(T arg1, T arg2)
    { return arg1 - arg2; }
    public T Multiply(T arg1, T arg2)
    { return arg1 * arg2; }
    public T Divide(T arg1, T arg2)
    { return arg1 / arg2; }
}

```

Alas, operator constraints are not supported under the current version of C#. However, it is possible (albeit it requires a bit more work) to achieve the desired effect by defining an interface that supports these operators (C# interfaces can define operators!) and then specifying an interface constraint of the generic class. In any case, this wraps up this book's initial look at building custom generic types. In Chapter 12, I will pick up the topic of generics once again in the course of examining the delegate type.

## Summary

This chapter began by examining the nongeneric collection types of `System.Collections` and `System.Collections.Specialized`, including the various issues associated with many nongeneric containers, including a lack of type safety and the runtime overhead of boxing and unboxing operations. As mentioned, for these very reasons, modern-day .NET programs will typically make use of the generic collection classes found in `System.Collections.Generic` and `System.Collections.ObjectModel`.

As you have seen, a generic item allows you to specify placeholders (type parameters) that you specify at the time of object creation (or invocation, in the case of generic methods). While you will most often simply use the generic types provided in the .NET base class libraries, you will also be able to create your own generic types (and generic methods). When you do so, you have the option of specifying any number of constraints (using the `where` keyword) to increase the level of type safety and ensure that you perform operations on types of a *known quantity* that are guaranteed to exhibit certain basic capabilities.

As a final note, remember that generics are found in numerous locations within the .NET base class libraries. Here, you focused specifically on generic collections. However, as you work through the remainder of this book (and when you dive into the platform on your own terms), you will certainly find generic classes, structures, and delegates located in a given namespace. As well, be on the lookout for generic members of a nongeneric class!

## CHAPTER 11



# Advanced C# Language Features

In this chapter, you'll deepen your understanding of the C# programming language by examining a number of more advanced topics. To begin, you'll learn how to implement and use an *indexer method*. This C# mechanism enables you to build custom types that provide access to internal subitems using an array-like syntax. After you learn how to build an indexer method, you'll see how to overload various operators (+, -, <, >, etc.) and how to create custom explicit and implicit conversion routines for your types (and you'll learn why you might want to do this).

Next, you'll examine topics that are particularly useful when working with LINQ-centric APIs (though you can use them outside of the context of LINQ) – specifically extension methods and anonymous types.

To wrap things up, you'll learn how to create an “unsafe” code context to directly manipulate unmanaged pointers. While it is certainly true that using pointers in C# applications is a fairly infrequent activity, understanding how to do so can be helpful in some circumstances that involve complex interoperability scenarios.

## Understanding Indexer Methods

As a programmer, you are certainly familiar with the process of accessing individual items contained within a simple array using the index operator ([ ]). Here's an example:

```
static void Main(string[] args)
{
    // Loop over incoming command-line arguments
    // using index operator.
    for(int i = 0; i < args.Length; i++)
    {
        Console.WriteLine("Args: {0}", args[i]);
    }

    // Declare an array of local integers.
    int[] myInts = { 10, 9, 100, 432, 9874};

    // Use the index operator to access each element.
    for(int j = 0; j < myInts.Length; j++)
    {
        Console.WriteLine("Index {0} = {1} ", j, myInts[j]);
    }
    Console.ReadLine();
}
```

This code is by no means a major news flash. However, the C# language provides the capability to design custom classes and structures that may be indexed just like a standard array, by defining an *indexer method*. This particular feature is most useful when you are creating custom collection classes (generic or nongeneric).

Before examining how to implement a custom indexer, let's begin by seeing one in action. Assume you have added support for an indexer method to the custom `PersonCollection` type developed in Chapter 9 (specifically, the `IssuesWithNonGenericCollections` project). While you have not yet added the indexer, observe the following usage within a new Console Application project named `SimpleIndexer`:

```
// Indexers allow you to access items in an array-like fashion.
class Program
{
    static void Main(string[] args)
    {
        Console.WriteLine("***** Fun with Indexers *****\n");

        PersonCollection myPeople = new PersonCollection();

        // Add objects with indexer syntax.
        myPeople[0] = new Person("Homer", "Simpson", 40);
        myPeople[1] = new Person("Marge", "Simpson", 38);
        myPeople[2] = new Person("Lisa", "Simpson", 9);
        myPeople[3] = new Person("Bart", "Simpson", 7);
        myPeople[4] = new Person("Maggie", "Simpson", 2);

        // Now obtain and display each item using indexer.
        for (int i = 0; i < myPeople.Count; i++)
        {
            Console.WriteLine("Person number: {0}", i);
            Console.WriteLine("Name: {0} {1}",
                myPeople[i].FirstName, myPeople[i].LastName);
            Console.WriteLine("Age: {0}", myPeople[i].Age);
            Console.WriteLine();
        }
    }
}
```

As you can see, indexers allow you to manipulate the internal collection of subobjects just like a standard array. Now for the big question: how do you configure the `PersonCollection` class (or any custom class or structure) to support this functionality? An indexer is represented as a slightly modified C# property definition. In its simplest form, an indexer is created using the `this[]` syntax. Here is the required update for the `PersonCollection` class:

```
// Add the indexer to the existing class definition.
public class PersonCollection : IEnumerable
{
    private ArrayList arPeople = new ArrayList();
    ...
    // Custom indexer for this class.
    public Person this[int index]
    {

```

```

    get => (Person)arPeople[index];
    set => arPeople.Insert(index, value);
}
}

```

Apart from using the `this` keyword with the brackets, the indexer looks just like any other C# property declaration. For example, the role of the `get` scope is to return the correct object to the caller. Here, you are doing so by delegating the request to the indexer of the `ArrayList` object, as this class also supports an indexer. The `set` scope is in charge of adding new `Person` objects; this is achieved by calling the `Insert()` method of the `ArrayList`.

Indexers are yet another form of syntactic sugar, given that this functionality can also be achieved using “normal” public methods such as `AddPerson()` or `GetPerson()`. Nevertheless, when you support indexer methods on your custom collection types, they integrate well into the fabric of the .NET Core base class libraries.

While creating indexer methods is quite commonplace when you are building custom collections, do remember that generic types give you this functionality out of the box. Consider the following method, which uses a generic `List<T>` of `Person` objects. Note that you can simply use the indexer of `List<T>` directly. Here’s an example:

```

using System.Collections.Generic;
static void UseGenericListOfPeople()
{
    List<Person> myPeople = new List<Person>();
    myPeople.Add(new Person("Lisa", "Simpson", 9));
    myPeople.Add(new Person("Bart", "Simpson", 7));

    // Change first person with indexer.
    myPeople[0] = new Person("Maggie", "Simpson", 2);

    // Now obtain and display each item using indexer.
    for (int i = 0; i < myPeople.Count; i++)
    {
        Console.WriteLine("Person number: {0}", i);
        Console.WriteLine("Name: {0} {1}", myPeople[i].FirstName, myPeople[i].LastName);
        Console.WriteLine("Age: {0}", myPeople[i].Age);
        Console.WriteLine();
    }
}

```

## Indexing Data Using String Values

The current `PersonCollection` class defined an indexer that allowed the caller to identify subitems using a numerical value. Understand, however, that this is not a requirement of an indexer method. Suppose you’d prefer to contain the `Person` objects using a `System.Collections.Generic.Dictionary<TKey, TValue>` rather than an `ArrayList`. Given that `Dictionary` types allow access to the contained types using a key (such as a person’s first name), you could define an indexer as follows:

```

using System.Collections;
using System.Collections.Generic;
public class PersonCollectionStringIndexer : IEnumerable
{
    private Dictionary<string, Person> listPeople = new Dictionary<string, Person>();
}

```

```
// This indexer returns a person based on a string index.
public Person this[string name]
{
    get => (Person)listPeople[name];
    set => listPeople[name] = value;
}
public void ClearPeople()
{ listPeople.Clear(); }

public int Count => listPeople.Count;

IEnumerator IEnumerable.GetEnumerator() => listPeople.GetEnumerator();
}
```

The caller would now be able to interact with the contained Person objects, as shown here:

```
static void Main(string[] args)
{
    Console.WriteLine("***** Fun with Indexers *****\n");

    PersonCollectionStringIndexer myPeopleStrings =
        new PersonCollectionStringIndexer();

    myPeopleStrings["Homer"] =
        new Person("Homer", "Simpson", 40);
    myPeopleStrings["Marge"] =
        new Person("Marge", "Simpson", 38);

    // Get "Homer" and print data.
    Person homer = myPeopleStrings["Homer"];
    Console.ReadLine();
}
```

Again, if you were to use the generic `Dictionary<TKey, TValue>` type directly, you'd gain the indexer method functionality out of the box, without building a custom, nongeneric class supporting a string indexer. Nevertheless, do understand that the data type of any indexer will be based on how the supporting collection type allows the caller to retrieve subitems.

## Overloading Indexer Methods

Indexer methods may be overloaded on a single class or structure. Thus, if it makes sense to allow the caller to access subitems using a numerical index *or* a string value, you might define multiple indexers for a single type. By way of example, in ADO.NET (.NET's native database-access API), the `DataSet` class supports a property named `Tables`, which returns to you a strongly typed `DataTableCollection` type. As it turns out, `DataTableCollection` defines *three* indexers to get and set `DataTable` objects – one by ordinal position and the others by a friendly string moniker and optional containing namespace, as shown here:

```
public sealed class DataTableCollection : InternalDataCollectionBase
{
    ...
    // Overloaded indexers!
    public DataTable this[int index] { get; }
}
```



```

public DataTable this[string name] { get; }
public DataTable this[string name, string tableNamespace] { get; }
}

```

It is common for types in the base class libraries to support indexer methods. So be aware, even if your current project does not require you to build custom indexers for your classes and structures, that many types already support this syntax.

## Indexers with Multiple Dimensions

You can also create an indexer method that takes multiple parameters. Assume you have a custom collection that stores subitems in a 2D array. If this is the case, you may define an indexer method as follows:

```

public class SomeContainer
{
    private int[,] my2DintArray = new int[10, 10];

    public int this[int row, int column]
    { /* get or set value from 2D array */ }
}

```

Again, unless you are building a highly stylized custom collection class, you won't have much need to build a multidimensional indexer. Still, once again ADO.NET showcases how useful this construct can be. The ADO.NET `DataTable` is essentially a collection of rows and columns, much like a piece of graph paper or the general structure of a Microsoft Excel spreadsheet.

While `DataTable` objects are typically populated on your behalf using a related “data adapter,” the following code illustrates how to manually create an in-memory `DataTable` containing three columns (for the first name, last name, and age of each record). Notice how once you have added a single row to the `DataTable`, you use a multidimensional indexer to drill into each column of the first (and only) row. (If you are following along, you'll need to import the `System.Data` namespace into your code file.)

```

static void MultiIndexerWithDataTable()
{
    // Make a simple DataTable with 3 columns.
    DataTable myTable = new DataTable();
    myTable.Columns.Add(new DataColumn("FirstName"));
    myTable.Columns.Add(new DataColumn("LastName"));
    myTable.Columns.Add(new DataColumn("Age"));

    // Now add a row to the table.
    myTable.Rows.Add("Mel", "Appleby", 60);

    // Use multidimension indexer to get details of first row.
    Console.WriteLine("First Name: {0}", myTable.Rows[0][0]);
    Console.WriteLine("Last Name: {0}", myTable.Rows[0][1]);
    Console.WriteLine("Age : {0}", myTable.Rows[0][2]);
}

```

Do be aware that you'll take a rather deep dive into ADO.NET beginning with Chapter 21, so if some of the previous code seems unfamiliar, fear not. The main point of this example is that indexer methods can support multiple dimensions and, if used correctly, can simplify the way you interact with contained subobjects in custom collections.

## Indexer Definitions on Interface Types

Indexers can be defined on a given .NET Core interface type to allow supporting types to provide a custom implementation. Here is a simple example of an interface that defines a protocol for obtaining string objects using a numerical indexer:

```
public interface IStringContainer
{
    string this[int index] { get; set; }
}
```

With this interface definition, any class or structure that implements this interface must now support a read-write indexer that manipulates subitems using a numerical value. Here is a partial implementation of such a class:

```
class SomeClass : IStringContainer
{
    private List<string> myStrings = new List<string>();

    public string this[int index]
    {
        get => myStrings[index];
        set => myStrings.Insert(index, value);
    }
}
```

That wraps up the first major topic of this chapter. Now let's examine a language feature that lets you build custom classes or structures that respond uniquely to the intrinsic operators of C#. Next, allow me to introduce the concept of *operator overloading*.

## Understanding Operator Overloading

C#, like any programming language, has a canned set of tokens that are used to perform basic operations on intrinsic types. For example, you know that the + operator can be applied to two integers to yield a larger integer.

```
// The + operator with ints.
int a = 100;
int b = 240;
int c = a + b; // c is now 340
```

Once again, this is no major news flash, but have you ever stopped and noticed how the same + operator can be applied to most intrinsic C# data types? For example, consider this code:

```
// + operator with strings.
string s1 = "Hello";
string s2 = " world!";
string s3 = s1 + s2; // s3 is now "Hello World!"
```

In essence, the + operator functions in specific ways based on the supplied data types (strings or integers, in this case). When the + operator is applied to numerical types, the result is the summation of the operands. However, when the + operator is applied to string types, the result is string concatenation.

The C# language gives you the capability to build custom classes and structures that also respond uniquely to the same set of basic tokens (such as the + operator). While not every possible C# operator can be overloaded, many can, as shown in Table 11-1.

**Table 11-1.** *Overloadability of C# Operators*

C# Operator	Overloadability
+, -, !, ~, ++, --, true, false	These unary operators can be overloaded.
+, -, *, /, %, &,  , ^, <, >	These binary operators can be overloaded.
==, !=, <, >, <=, >=	These comparison operators can be overloaded. C# demands that “like” operators (i.e., < and >, <= and >=, == and !=) are overloaded together.
[]	The [] operator cannot be overloaded. As you saw earlier in this chapter, however, the indexer construct provides the same functionality.
()	The () operator cannot be overloaded. As you will see later in this chapter, however, custom conversion methods provide the same functionality.
+=, -=, *=, /=, %=, &=,  =, ^=, <<=, >>=	Shorthand assignment operators cannot be overloaded; however, you receive them as a freebie when you overload the related binary operator.

## Overloading Binary Operators

To illustrate the process of overloading binary operators, assume the following simple Point class is defined in a new Console Application project named OverloadedOps:

```
// Just a simple, everyday C# class.
public class Point
{
    public int X {get; set;}
    public int Y {get; set;}

    public Point(int xPos, int yPos)
    {
        X = xPos;
        Y = yPos;
    }
    public override string ToString()
        => $"[{this.X}, {this.Y}]";
}
```

Now, logically speaking, it makes sense to “add” Points together. For example, if you added together two Point variables, you should receive a new Point that is the summation of the X and Y values. Of course, it might also be helpful to subtract one Point from another. Ideally, you would like to be able to author the following code:

```
// Adding and subtracting two points?
static void Main(string[] args)
{
    Console.WriteLine("***** Fun with Overloaded Operators *****\n");

    // Make two points.
    Point ptOne = new Point(100, 100);
    Point ptTwo = new Point(40, 40);
    Console.WriteLine("ptOne = {0}", ptOne);
    Console.WriteLine("ptTwo = {0}", ptTwo);

    // Add the points to make a bigger point?
    Console.WriteLine("ptOne + ptTwo: {0} ", ptOne + ptTwo);

    // Subtract the points to make a smaller point?
    Console.WriteLine("ptOne - ptTwo: {0} ", ptOne - ptTwo);
    Console.ReadLine();
}
```

However, as your Point now stands, you will receive compile-time errors, as the Point type does not know how to respond to the + or - operator. To equip a custom type to respond uniquely to intrinsic operators, C# provides the operator keyword, which you can use only in conjunction with the static keyword. When you overload a binary operator (such as + and -), you will most often pass in two arguments that are the same type as the defining class (a Point in this example), as illustrated in the following code update:

```
// A more intelligent Point type.
public class Point
{
    ...
    // Overloaded operator +.
    public static Point operator + (Point p1, Point p2)
        => new Point(p1.X + p2.X, p1.Y + p2.Y);

    // Overloaded operator -.
    public static Point operator - (Point p1, Point p2)
        => new Point(p1.X - p2.X, p1.Y - p2.Y);
}
```

The logic behind operator + is simply to return a new Point object based on the summation of the fields of the incoming Point parameters. Thus, when you write `pt1 + pt2`, under the hood you can envision the following hidden call to the static operator + method:

```
// Pseudo-code: Point p3 = Point.operator+ (p1, p2)
```

```
Point p3 = p1 + p2;
```

Likewise,  $p1 - p2$  maps to the following:

```
// Pseudo-code: Point p4 = Point.operator- (p1, p2)
```

```
Point p4 = p1 - p2;
```

With this update, your program now compiles, and you find you are able to add and subtract `Point` objects, as shown in the following output:

---

```
***** Fun with Overloaded Operators *****
```

```
ptOne = [100, 100]
ptTwo = [40, 40]
ptOne + ptTwo: [140, 140]
ptOne - ptTwo: [60, 60]
```

---

When you are overloading a binary operator, you are not required to pass in two parameters of the same type. If it makes sense to do so, one of the arguments can differ. For example, here is an overloaded operator `+` that allows the caller to obtain a new `Point` that is based on a numerical adjustment:

```
public class Point
{
    ...
    public static Point operator + (Point p1, int change)
        => new Point(p1.X + change, p1.Y + change);

    public static Point operator + (int change, Point p1)
        => new Point(p1.X + change, p1.Y + change);
}
```

Notice that you need *both* versions of the method if you want the arguments to be passed in either order (i.e., you can't just define one of the methods and expect the compiler to automatically support the other one). You are now able to use these new versions of operator `+` as follows:

```
// Prints [110, 110].
Point biggerPoint = ptOne + 10;
Console.WriteLine("ptOne + 10 = {0}", biggerPoint);

// Prints [120, 120].
Console.WriteLine("10 + biggerPoint = {0}", 10 + biggerPoint);
Console.WriteLine();
```

## And What of the `+=` and `-=` Operators?

If you are coming to C# from a C++ background, you might lament the loss of overloading the shorthand assignment operators (`+=`, `-=`, etc.). Don't despair. In terms of C#, the shorthand assignment operators are automatically simulated if a type overloads the related binary operator. Thus, given that the `Point` structure has already overloaded the `+` and `-` operators, you can write the following:

```
// Overloading binary operators results in a freebie shorthand operator.
static void Main(string[] args)
{
    ...
    // Freebie +=
    Point ptThree = new Point(90, 5);
    Console.WriteLine("ptThree = {0}", ptThree);
    Console.WriteLine("ptThree += ptTwo: {0}", ptThree += ptTwo);

    // Freebie -=
    Point ptFour = new Point(0, 500);
    Console.WriteLine("ptFour = {0}", ptFour);
    Console.WriteLine("ptFour -= ptThree: {0}", ptFour -= ptThree);
    Console.ReadLine();
}
```

## Overloading Unary Operators

C# also allows you to overload various unary operators, such as ++ and --. When you overload a unary operator, you also must use the static keyword with the operator keyword; however, in this case you simply pass in a single parameter that is the same type as the defining class/structure. For example, if you were to update the Point with the following overloaded operators:

```
public class Point
{
    ...
    // Add 1 to the X/Y values for the incoming Point.
    public static Point operator ++(Point p1)
        => new Point(p1.X+1, p1.Y+1);

    // Subtract 1 from the X/Y values for the incoming Point.
    public static Point operator --(Point p1)
        => new Point(p1.X-1, p1.Y-1);
}
```

you could increment and decrement Point's x and y values like this:

```
static void Main(string[] args)
{
    ...
    // Applying the ++ and -- unary operators to a Point.
    Point ptFive = new Point(1, 1);
    Console.WriteLine("++ptFive = {0}", ++ptFive); // [2, 2]
    Console.WriteLine("--ptFive = {0}", --ptFive); // [1, 1]

    // Apply same operators as postincrement/decrement.
    Point ptSix = new Point(20, 20);
    Console.WriteLine("ptSix++ = {0}", ptSix++); // [20, 20]
    Console.WriteLine("ptSix-- = {0}", ptSix--); // [21, 21]
    Console.ReadLine();
}
```

```
}
```

Notice in the preceding code example you are applying the custom ++ and -- operators in two different manners. In C++, it is possible to overload pre- and post-increment/decrement operators separately. This is not possible in C#. However, the return value of the increment/decrement is automatically handled “correctly” free of charge (i.e., for an overloaded ++ operator, pt++ has the value of the unmodified object as its value within an expression, while ++pt has the new value applied before use in the expression).

## Overloading Equality Operators

As you might recall from Chapter 6, `System.Object.Equals()` can be overridden to perform value-based (rather than referenced-based) comparisons between reference types. If you choose to override `Equals()` (and the often related `System.Object.GetHashCode()` method), it is trivial to overload the equality operators (`==` and `!=`). To illustrate, here is the updated `Point` type:

```
// This incarnation of Point also overloads the == and != operators.
public class Point
{
    ...
    public override bool Equals(object o)
        => o.ToString() == this.ToString();

    public override int GetHashCode()
        => this.ToString().GetHashCode();

    // Now let's overload the == and != operators.
    public static bool operator ==(Point p1, Point p2)
        => p1.Equals(p2);

    public static bool operator !=(Point p1, Point p2)
        => !p1.Equals(p2);
}
```

Notice how the implementation of `operator ==` and `operator !=` simply makes a call to the overridden `Equals()` method to get the bulk of the work done. Given this, you can now exercise your `Point` class as follows:

```
// Make use of the overloaded equality operators.
static void Main(string[] args)
{
    ...
    Console.WriteLine("ptOne == ptTwo : {0}", ptOne == ptTwo);
    Console.WriteLine("ptOne != ptTwo : {0}", ptOne != ptTwo);
    Console.ReadLine();
}
```

As you can see, it is quite intuitive to compare two objects using the well-known `==` and `!=` operators, rather than making a call to `Object.Equals()`. If you do overload the equality operators for a given class, keep in mind that C# demands that if you override the `==` operator, you *must* also override the `!=` operator (if you forget, the compiler will let you know).

## Overloading Comparison Operators

In Chapter 8, you learned how to implement the `Comparable` interface to compare the relationship between two like objects. You can, in fact, also overload the comparison operators (`<`, `>`, `<=`, and `>=`) for the same class. As with the equality operators, C# demands that if you overload `<`, you must also overload `>`. The same holds true for the `<=` and `>=` operators. If the `Point` type overloaded these comparison operators, the object user could now compare `Points`, as follows:

```
// Using the overloaded < and > operators.
static void Main(string[] args)
{
    ...
    Console.WriteLine("ptOne < ptTwo : {0}", ptOne < ptTwo);
    Console.WriteLine("ptOne > ptTwo : {0}", ptOne > ptTwo);
    Console.ReadLine();
}
```

Assuming you have implemented the `Comparable` interface (or better yet, the generic equivalent), overloading the comparison operators is trivial. Here is the updated class definition:

```
// Point is also comparable using the comparison operators.
public class Point : Comparable<Point>
{
    ...
    public int CompareTo(Point other)
    {
        if (this.X > other.X && this.Y > other.Y)
        {
            return 1;
        }
        if (this.X < other.X && this.Y < other.Y)
        {
            return -1;
        }
        return 0;
    }
    public static bool operator <(Point p1, Point p2)
        => p1.CompareTo(p2) < 0;

    public static bool operator >(Point p1, Point p2)
        => p1.CompareTo(p2) > 0;

    public static bool operator <=(Point p1, Point p2)
        => p1.CompareTo(p2) <= 0;

    public static bool operator >=(Point p1, Point p2)
        => p1.CompareTo(p2) >= 0;
}
```



## Final Thoughts Regarding Operator Overloading

As you have seen, C# provides the capability to build types that can respond uniquely to various intrinsic, well-known operators. Now, before you go and retrofit all your classes to support such behavior, you must be sure that the operators you are about to overload make some sort of logical sense in the world at large.

For example, let's say you overloaded the multiplication operator for the `MiniVan` class. What exactly would it mean to multiply two `MiniVan` objects? Not much. In fact, it would be confusing for teammates to see the following use of `MiniVan` objects:

```
// Huh?! This is far from intuitive...
MiniVan newVan = myVan * yourVan;
```

Overloading operators is generally useful only when you're building atomic data types. Text, points, rectangles, fractions, and hexagons make good candidates for operator overloading. People, managers, cars, database connections, and web pages do not. As a rule of thumb, if an overloaded operator makes it *harder* for the user to understand a type's functionality, don't do it. Use this feature wisely.

## Understanding Custom Type Conversions

Let's now examine a topic closely related to operator overloading: custom type conversions. To set the stage for the discussion, let's quickly review the notion of explicit and implicit conversions between numerical data and related class types.

### Recall: Numerical Conversions

In terms of the intrinsic numerical types (`sbyte`, `int`, `float`, etc.), an *explicit conversion* is required when you attempt to store a larger value in a smaller container, as this could result in a loss of data. Basically, this is your way to tell the compiler, "Leave me alone, I know what I am trying to do." Conversely, an *implicit conversion* happens automatically when you attempt to place a smaller type in a destination type that will not result in a loss of data.

```
static void Main()
{
    int a = 123;
    long b = a;          // Implicit conversion from int to long.
    int c = (int) b;     // Explicit conversion from long to int.
}
```

### Recall: Conversions Among Related Class Types

As shown in Chapter 6, class types may be related by classical inheritance (the "is-a" relationship). In this case, the C# conversion process allows you to cast up and down the class hierarchy. For example, a derived class can always be implicitly cast to a base type. However, if you want to store a base class type in a derived variable, you must perform an explicit cast, like so:

```
// Two related class types.
class Base{}
class Derived : Base{}
```

```

class Program
{
    static void Main(string[] args)
    {
        // Implicit cast between derived to base.
        Base myBaseType;
        myBaseType = new Derived();
        // Must explicitly cast to store base reference
        // in derived type.
        Derived myDerivedType = (Derived)myBaseType;
    }
}

```

This explicit cast works because the `Base` and `Derived` classes are related by classical inheritance. However, what if you have two class types in *different hierarchies* with no common parent (other than `System.Object`) that require conversions? Given that they are not related by classical inheritance, typical casting operations offer no help (and you would get a compiler error to boot!).

On a related note, consider value types (structures). Assume you have two structures named `Square` and `Rectangle`. Given that structures cannot leverage classic inheritance (as they are always sealed), you have no natural way to cast between these seemingly related types.

While you could create helper methods in the structures (such as `Rectangle.ToSquare()`), C# lets you build custom conversion routines that allow your types to respond to the `()` casting operator. Therefore, if you configured the structures correctly, you would be able to use the following syntax to explicitly convert between them as follows:

```

// Convert a Rectangle to a Square!
Rectangle rect = new Rectangle
{
    Width = 3;
    Height = 10;
}
Square sq = (Square)rect;

```

## Creating Custom Conversion Routines

Begin by creating a new Console Application project named `CustomConversions`. C# provides two keywords, `explicit` and `implicit`, that you can use to control how your types respond during an attempted conversion. Assume you have the following structure definitions:

```

public struct Rectangle
{
    public int Width {get; set;}
    public int Height {get; set;}

    public Rectangle(int w, int h)
    {
        Width = w;
        Height = h;
    }
}

```

```

public void Draw()
{
    for (int i = 0; i < Height; i++)
    {
        for (int j = 0; j < Width; j++)
        {
            Console.Write("*");
        }
        Console.WriteLine();
    }
}

public override string ToString()
    => $"[Width = {Width}; Height = {Height}]";
}

public struct Square
{
    public int Length {get; set;}
    public Square(int l) : this()
    {
        Length = l;
    }

    public void Draw()
    {
        for (int i = 0; i < Length; i++)
        {
            for (int j = 0; j < Length; j++)
            {
                Console.Write("*");
            }
            Console.WriteLine();
        }
    }

    public override string ToString() => $"[Length = {Length}]";

    // Rectangles can be explicitly converted into Squares.
    public static explicit operator Square(Rectangle r)
    {
        Square s = new Square {Length = r.Height};
        return s;
    }
}

```

Notice that this iteration of the `Square` type defines an explicit conversion operator. Like the process of overloading an operator, conversion routines make use of the C# operator keyword, in conjunction with the explicit or implicit keyword, and must be defined as static. The incoming parameter is the entity you are converting *from*, while the operator type is the entity you are converting *to*.

In this case, the assumption is that a square (being a geometric pattern in which all sides are of equal length) can be obtained from the height of a rectangle. Thus, you are free to convert a `Rectangle` into a `Square`, as follows:

```
static void Main(string[] args)
{
    Console.WriteLine("***** Fun with Conversions *****\n");
    // Make a Rectangle.
    Rectangle r = new Rectangle(15, 4);
    Console.WriteLine(r.ToString());
    r.Draw();

    Console.WriteLine();

    // Convert r into a Square,
    // based on the height of the Rectangle.
    Square s = (Square)r;
    Console.WriteLine(s.ToString());
    s.Draw();
    Console.ReadLine();
}
```

You can see the output here:

---

```
***** Fun with Conversions *****
```

```
[Width = 15; Height = 4]
```

```
*****
*****
*****
*****
```

```
[Length = 4]
```

```
****
****
****
****
```

---

While it may not be all that helpful to convert a `Rectangle` into a `Square` within the same scope, assume you have a function that has been designed to take `Square` parameters.

```
// This method requires a Square type.
static void DrawSquare(Square sq)
{
    Console.WriteLine(sq.ToString());
    sq.Draw();
}
```

Using your explicit conversion operation on the `Square` type, you can now pass in `Rectangle` types for processing using an explicit cast, like so:

```
static void Main(string[] args)
{
    ...
    // Convert Rectangle to Square to invoke method.
    Rectangle rect = new Rectangle(10, 5);
    DrawSquare((Square)rect);
    Console.ReadLine();
}
```

## Additional Explicit Conversions for the Square Type

Now that you can explicitly convert `Rectangles` into `Squares`, let's examine a few additional explicit conversions. Given that a square is symmetrical on all sides, it might be helpful to provide an explicit conversion routine that allows the caller to cast from an integer type into a `Square` (which, of course, will have a side length equal to the incoming integer). Likewise, what if you were to update `Square` such that the caller can cast *from* a `Square` into an `int`? Here is the calling logic:

```
static void Main(string[] args)
{
    ...
    // Converting an int to a Square.
    Square sq2 = (Square)90;
    Console.WriteLine("sq2 = {0}", sq2);

    // Converting a Square to an int.
    int side = (int)sq2;
    Console.WriteLine("Side length of sq2 = {0}", side);
    Console.ReadLine();
}
```

and here is the update to the `Square` class:

```
public struct Square
{
    ...
    public static explicit operator Square(int sideLength)
    {
        Square newSq = new Square {Length = sideLength};
        return newSq;
    }

    public static explicit operator int (Square s) => s.Length;
}
```

To be honest, converting from a `Square` into an integer may not be the most intuitive (or useful) operation (after all, chances are you could just pass such values to a constructor). However, it does point out an important fact regarding custom conversion routines: the compiler does not care what you convert to or from, as long as you have written syntactically correct code.

Thus, as with overloading operators, just because you *can* create an explicit cast operation for a given type does not mean you *should*. Typically, this technique will be most helpful when you're creating structure types, given that they are unable to participate in classical inheritance (where casting comes for free).

## Defining Implicit Conversion Routines

So far, you have created various custom *explicit* conversion operations. However, what about the following *implicit* conversion?

```
static void Main(string[] args)
{
    ...
    Square s3 = new Square {Length = 83};

    // Attempt to make an implicit cast?
    Rectangle rect2 = s3;

    Console.ReadLine();
}
```

This code will not compile, given that you have not provided an implicit conversion routine for the `Rectangle` type. Now here is the catch: it is illegal to define explicit and implicit conversion functions on the same type if they do not differ by their return type or parameter set. This might seem like a limitation; however, the second catch is that when a type defines an *implicit* conversion routine, it is legal for the caller to make use of the *explicit* cast syntax!

Confused? To clear things up, let's add an implicit conversion routine to the `Rectangle` structure using the C# `implicit` keyword (note that the following code assumes the width of the resulting `Rectangle` is computed by multiplying the side of the `Square` by 2):

```
public struct Rectangle
{
    ...
    public static implicit operator Rectangle(Square s)
    {
        Rectangle r = new Rectangle
        {
            Height = s.Length,
            Width = s.Length * 2 // Assume the length of the new Rectangle with (Length x 2).
        };
        return r;
    }
}
```

With this update, you are now able to convert between types, as follows:

```
static void Main(string[] args)
{
    ...
    // Implicit cast OK!
    Square s3 = new Square { Length= 7};
```

```

Rectangle rect2 = s3;
Console.WriteLine("rect2 = {0}", rect2);

// Explicit cast syntax still OK!
Square s4 = new Square {Length = 3};
Rectangle rect3 = (Rectangle)s4;

Console.WriteLine("rect3 = {0}", rect3);
Console.ReadLine();
}

```

That wraps up your look at defining custom conversion routines. As with overloaded operators, remember that this bit of syntax is simply a shorthand notation for “normal” member functions, and in this light, it is always optional. When used correctly, however, custom structures can be used more naturally, as they can be treated as true class types related by inheritance.

## Understanding Extension Methods

.NET 3.5 introduced the concept of *extension methods*, which allow you to add new methods or properties to a class or structure, without modifying the original type in any direct manner. So, where might this be helpful? Consider the following possibilities.

First, say you have a given class that is in production. It becomes clear over time that this class should support a handful of new members. If you modify the current class definition directly, you risk the possibility of breaking backward compatibility with older codebases making use of it, as they might not have been compiled with the latest and greatest class definition. One way to ensure backward compatibility is to create a new derived class from the existing parent; however, now you have two classes to maintain. As we all know, code maintenance is the least glamorous part of a software engineer’s job description.

Now consider this situation. Let’s say you have a structure (or maybe a sealed class) and want to add new members so that it behaves polymorphically in your system. Since structures and sealed classes cannot be extended, your only choice is to add the members to the type, once again risking backward compatibility!

Using extension methods, you are able to modify types without subclassing and without modifying the type directly. The catch is that the new functionality is offered to a type only if the extension methods have been referenced for use in your current project.

## Defining Extension Methods

When you define extension methods, the first restriction is that they must be defined within a static class (see Chapter 5); therefore, each extension method must be declared with the `static` keyword. The second point is that all extension methods are marked as such by using the `this` keyword as a modifier on the first (and only the first) parameter of the method in question. The “this qualified” parameter represents the item being extended.

To illustrate, create a new Console Application project named `ExtensionMethods`. Now, assume you are authoring a class named `MyExtensions` that defines two extension methods. The first method allows any object to use a new method named `DisplayDefiningAssembly()` that makes use of types in the `System.Reflection` namespace to display the name of the assembly containing the type in question.

---

■ **Note** You will formally examine the reflection API in Chapter 17. If you are new to the topic, simply understand that reflection allows you to discover the structure of assemblies, types, and type members at runtime.

---

The second extension method, named `ReverseDigits()`, allows any `int` to obtain a new version of itself where the value is reversed digit by digit. For example, if an integer with the value 1234 called `ReverseDigits()`, the integer returned is set to the value 4321. Consider the following class implementation (be sure to import the `System.Reflection` namespace if you are following along):

```
static class MyExtensions
{
    // This method allows any object to display the assembly
    // it is defined in.
    public static void DisplayDefiningAssembly(this object obj)
    {
        Console.WriteLine("{0} lives here: => {1}\n",
            obj.GetType().Name,
            Assembly.GetAssembly(obj.GetType()).GetName().Name);
    }

    // This method allows any integer to reverse its digits.
    // For example, 56 would return 65.
    public static int ReverseDigits(this int i)
    {
        // Translate int into a string, and then
        // get all the characters.
        char[] digits = i.ToString().ToCharArray();

        // Now reverse items in the array.
        Array.Reverse(digits);

        // Put back into string.
        string newDigits = new string(digits);

        // Finally, return the modified string back as an int.
        return int.Parse(newDigits);
    }
}
```

Again, note how the first parameter of each extension method has been qualified with the `this` keyword, before defining the parameter type. It is always the case that the first parameter of an extension method represents the type being extended. Given that `DisplayDefiningAssembly()` has been prototyped to extend `System.Object`, every type now has this new member, as `Object` is the parent to all types in the .NET Core platform. However, `ReverseDigits()` has been prototyped to extend only integer types; therefore, if anything other than an integer attempts to invoke this method, you will receive a compile-time error.



---

■ **Note** Understand that a given extension method can have multiple parameters, but *only* the first parameter can be qualified with `this`. The additional parameters would be treated as normal incoming parameters for use by the method.

---

## Invoking Extension Methods

Now that you have these extension methods in place, consider the following `Main()` method that applies the extension method to various types in the base class libraries:

```
static void Main(string[] args)
{
    Console.WriteLine("***** Fun with Extension Methods *****\n");

    // The int has assumed a new identity!
    int myInt = 12345678;
    myInt.DisplayDefiningAssembly();

    // So has the DataSet!
    System.Data.DataSet d = new System.Data.DataSet();
    d.DisplayDefiningAssembly();

    // Use new integer functionality.
    Console.WriteLine("Value of myInt: {0}", myInt);
    Console.WriteLine("Reversed digits of myInt: {0}",
        myInt.ReverseDigits());

    Console.ReadLine();
}
```

Here is the output:

---

```
***** Fun with Extension Methods *****

Int32 lives here: => mscorlib

DataSet lives here: => System.Data

Value of myInt: 12345678
Reversed digits of myInt: 87654321
```

---

## Importing Extension Methods

When you define a class containing extension methods, it will no doubt be defined within a namespace. If this namespace is different from the namespace using the extension methods, you will need to make use of the expected C# `using` keyword. When you do, your code file has access to all extension methods for

the type being extended. This is important to remember because if you do not explicitly import the correct namespace, the extension methods are not available for that C# code file.

In effect, although it can appear on the surface that extension methods are global in nature, they are in fact limited to the namespaces that define them or the namespaces that import them. Thus, if you wrap the `MyExtensions` class into a namespace named `MyExtensionMethods`, as follows:

```
namespace MyExtensionMethods
{
    static class MyExtensions
    {
        ...
    }
}
```

other namespaces in the project would need to explicitly import the `MyExtensionMethods` namespace to gain the extension methods defined by your class.

---

**■ Note** It is common practice to not only isolate extension methods into a dedicated namespace but to isolate them into a dedicated class library. In this way, new applications can “opt in” to extensions by explicitly referencing the correct library and importing the namespace. Chapter 16 will examine the details of building and using custom .NET class libraries.

---

## Extending Types Implementing Specific Interfaces

At this point, you have seen how to extend classes (and, indirectly, structures that follow the same syntax) with new functionality via extension methods. It is also possible to define an extension method that can only extend a class or structure that implements the correct interface. For example, you could say something to the effect of “If a class or structure implements `IEnumerable<T>`, then that type gets the following new members.” Of course, it is possible to demand that a type support any interface at all, including your own custom interfaces.

To illustrate, create a new Console Application project named `InterfaceExtensions`. The goal here is to add a new method to any type that implements `IEnumerable`, which would include any array and many nongeneric collection classes (recall from Chapter 10 that the generic `IEnumerable<T>` interface extends the nongeneric `IEnumerable` interface). Add the following extension class to your new project:

```
static class AnnoyingExtensions
{
    public static void PrintDataAndBeep(
        this System.Collections.IEnumerable iterator)
    {
        foreach (var item in iterator)
        {
            Console.WriteLine(item);
            Console.Beep();
        }
    }
}
```

Given that the `PrintDataAndBeep()` method can be used by any class or structure that implements `IEnumerable`, you could test via the following `Main()` method:

```
using System.Collections.Generic;
static void Main( string[] args )
{
    Console.WriteLine("***** Extending Interface Compatible Types *****\n");

    // System.Array implements IEnumerable!
    string[] data =
        { "Wow", "this", "is", "sort", "of", "annoying",
          "but", "in", "a", "weird", "way", "fun!" };
    data.PrintDataAndBeep();

    Console.WriteLine();

    // List<T> implements IEnumerable!
    List<int> myInts = new List<int>() {10, 15, 20};
    myInts.PrintDataAndBeep();

    Console.ReadLine();
}
```

That wraps up your examination of C# extension methods. Remember that this particular language feature can be useful whenever you want to extend the functionality of a type but do not want to subclass (or cannot subclass if the type is sealed), for the purposes of polymorphism. As you will see later in the text, extension methods play a key role for LINQ APIs. In fact, you will see that under the LINQ APIs, one of the most common items being extended is a class or structure implementing (surprise!) the generic version of `IEnumerable`.

## Understanding Anonymous Types

As an object-oriented programmer, you know the benefits of defining classes to represent the state and functionality of a given item you are attempting to model. To be sure, whenever you need to define a class that is intended to be reused across projects and that provides numerous bits of functionality through a set of methods, events, properties, and custom constructors, creating a new C# class is common practice.

However, there are other times when you would like to define a class simply to model a set of encapsulated (and somehow related) data points without any associated methods, events, or other specialized functionality. Furthermore, what if this type is to be used only by a handful of methods in your program? It would be rather a bother to define a full class definition as shown next when you know full well this class will be used in only a handful of places. To accentuate this point, here is the rough outline of what you might need to do when you need to create a “simple” data type that follows typical value-based semantics:

```
class SomeClass
{
    // Define a set of private member variables...

    // Make a property for each member variable...
```

```
// Override ToString() to account for key member variables...

// Override GetHashCode() and Equals() to work with value-based equality...
}
```

As you can see, it is not necessarily so simple. Not only do you need to author a fair amount of code, but you have another class to maintain in your system. For temporary data such as this, it would be useful to whip up a custom data type on the fly. For example, let's say you need to build a custom method that receives a set of incoming parameters. You would like to take these parameters and use them to create a new data type for use in this method scope. Further, you would like to quickly print out this data using the typical `ToString()` method and perhaps use other members of `System.Object`. You can do this very thing using anonymous type syntax.

## Defining an Anonymous Type

When you define an anonymous type, you do so by using the `var` keyword (see Chapter 3) in conjunction with object initialization syntax (see Chapter 5). You must use the `var` keyword because the compiler will automatically generate a new class definition at compile time (and you never see the name of this class in your C# code). The initialization syntax is used to tell the compiler to create private backing fields and (read-only) properties for the newly created type.

To illustrate, create a new Console Application project named `AnonymousTypes`. Now, add the following method to your `Program` class, which composes a new type, on the fly, using the incoming parameter data:

```
static void BuildAnonType( string make, string color, int currSp )
{
    // Build anon type using incoming args.
    var car = new { Make = make, Color = color, Speed = currSp };

    // Note you can now use this type to get the property data!
    Console.WriteLine("You have a {0} {1} going {2} MPH", car.Color, car.Make, car.Speed);

    // Anon types have custom implementations of each virtual
    // method of System.Object. For example:
    Console.WriteLine("ToString() == {0}", car.ToString());
}
```

You can call this method from `Main()`, as expected. However, do note that an anonymous type can also be created using hard-coded values, as shown here:

```
static void Main(string[] args)
{
    Console.WriteLine("***** Fun with Anonymous Types *****\n");

    // Make an anonymous type representing a car.
    var myCar = new { Color = "Bright Pink", Make = "Saab", CurrentSpeed = 55 };

    // Now show the color and make.
    Console.WriteLine("My car is a {0} {1}.", myCar.Color, myCar.Make);
}
```

```
// Now call our helper method to build anonymous type via args.
BuildAnonType("BMW", "Black", 90);

Console.ReadLine();
}
```

So, at this point, simply understand that anonymous types allow you to quickly model the “shape” of data with very little overhead. This technique is little more than a way to whip up a new data type on the fly, which supports bare-bones encapsulation via properties and acts according to value-based semantics. To understand that last point, let’s see how the C# compiler builds out anonymous types at compile time and, specifically, how it overrides the members of `System.Object`.

## The Internal Representation of Anonymous Types

All anonymous types are automatically derived from `System.Object` and, therefore, support each of the members provided by this base class. Given this, you could invoke `ToString()`, `GetHashCode()`, `Equals()`, or `GetType()` on the implicitly typed `myCar` object. Assume your `Program` class defines the following static helper function:

```
static void ReflectOverAnonymousType(object obj)
{
    Console.WriteLine("obj is an instance of: {0}",
        obj.GetType().Name);
    Console.WriteLine("Base class of {0} is {1}",
        obj.GetType().Name, obj.GetType().BaseType);
    Console.WriteLine("obj.ToString() == {0}", obj.ToString());
    Console.WriteLine("obj.GetHashCode() == {0}",
        obj.GetHashCode());
    Console.WriteLine();
}
```

Now assume you invoke this method from `Main()`, passing in the `myCar` object as the parameter, like so:

```
static void Main(string[] args)
{
    Console.WriteLine("***** Fun with Anonymous Types *****\n");

    // Make an anonymous type representing a car.
    var myCar = new {Color = "Bright Pink", Make = "Saab",
        CurrentSpeed = 55};

    // Reflect over what the compiler generated.
    ReflectOverAnonymousType(myCar);
    ...

    Console.ReadLine();
}
```

The output will look similar to the following:

---

```
***** Fun with Anonymous Types *****
```

```
obj is an instance of: <>f__AnonymousType0`3
Base class of <>f__AnonymousType0`3 is System.Object
obj.ToString() = { Color = Bright Pink, Make = Saab, CurrentSpeed = 55 }
obj.GetHashCode() = -1648810448
```

---

First, notice that, in this example, the `myCar` object is of type `<>f__AnonymousType0`3` (your name may differ). Remember that the assigned type name is completely determined by the compiler and is not directly accessible in your C# codebase.

Perhaps most important, notice that each name-value pair defined using the object initialization syntax is mapped to an identically named read-only property and a corresponding private read-only backing field. The following C# code approximates the compiler-generated class used to represent the `myCar` object (which again can be verified using `ildasm.exe`):

```
internal sealed class <>f__AnonymousType0<<Color>j__TPar,
    <Make>j__TPar, <CurrentSpeed>j__TPar>
{
    // Read-only fields.
    private readonly <Color>j__TPar <Color>i__Field;
    private readonly <CurrentSpeed>j__TPar <CurrentSpeed>i__Field;
    private readonly <Make>j__TPar <Make>i__Field;

    // Default constructor.
    public <>f__AnonymousType0(<Color>j__TPar Color,
        <Make>j__TPar Make, <CurrentSpeed>j__TPar CurrentSpeed);
    // Overridden methods.
    public override bool Equals(object value);
    public override int GetHashCode();
    public override string ToString();

    // Read-only properties.
    public <Color>j__TPar Color { get; }
    public <CurrentSpeed>j__TPar CurrentSpeed { get; }
    public <Make>j__TPar Make { get; }
}
```

## The Implementation of ToString() and GetHashCode()

All anonymous types automatically derive from `System.Object` and are provided with an overridden version of `Equals()`, `GetHashCode()`, and `ToString()`. The `ToString()` implementation simply builds a string from each name-value pair. Here's an example:

```
public override string ToString()
{
    StringBuilder builder = new StringBuilder();
    builder.Append("{ Color = ");
    builder.Append(this.<Color>i__Field);
```

```

builder.Append(", Make = ");
builder.Append(this.<Make>i__Field);
builder.Append(", CurrentSpeed = ");
builder.Append(this.<CurrentSpeed>i__Field);
builder.Append(" }");
return builder.ToString();
}

```

The `GetHashCode()` implementation computes a hash value using each anonymous type's member variables as input to the `System.Collections.Generic.EqualityComparer<T>` type. Using this implementation of `GetHashCode()`, two anonymous types will yield the same hash value if (and only if) they have the same set of properties that have been assigned the same values. Given this implementation, anonymous types are well suited to be contained within a `Hashtable` container.

## The Semantics of Equality for Anonymous Types

While the implementation of the overridden `ToString()` and `GetHashCode()` methods is fairly straightforward, you might be wondering how the `Equals()` method has been implemented. For example, if you were to define two “anonymous cars” variables that specify the same name-value pairs, would these two variables be considered equal? To see the results firsthand, update your `Program` type with the following new method:

```

static void EqualityTest()
{
    // Make 2 anonymous classes with identical name/value pairs.
    var firstCar = new { Color = "Bright Pink", Make = "Saab",
        CurrentSpeed = 55 };
    var secondCar = new { Color = "Bright Pink", Make = "Saab",
        CurrentSpeed = 55 };

    // Are they considered equal when using Equals()?
    if (firstCar.Equals(secondCar))
    {
        Console.WriteLine("Same anonymous object!");
    }
    else
    {
        Console.WriteLine("Not the same anonymous object!");
    }

    // Are they considered equal when using ==?
    if (firstCar == secondCar)
    {
        Console.WriteLine("Same anonymous object!");
    }
    else
    {
        Console.WriteLine("Not the same anonymous object!");
    }
}

```

```

// Are these objects the same underlying type?
if (firstCar.GetType().Name == secondCar.GetType().Name)
{
    Console.WriteLine("We are both the same type!");
}
else
{
    Console.WriteLine("We are different types!");
}

// Show all the details.
Console.WriteLine();
ReflectOverAnonymousType(firstCar);
ReflectOverAnonymousType(secondCar);
}

```

Assuming you have called this method from within `Main()`, here is the (somewhat surprising) output:

---

```

My car is a Bright Pink Saab.
You have a Black BMW going 90 MPH
ToString() == { Make = BMW, Color = Black, Speed = 90 }

Same anonymous object!
Not the same anonymous object!
We are both the same type!

obj is an instance of: <>f__AnonymousType0`3
Base class of <>f__AnonymousType0`3 is System.Object
obj.ToString() == { Color = Bright Pink, Make = Saab, CurrentSpeed = 55 }
obj.GetHashCode() == -925496951

obj is an instance of: <>f__AnonymousType0`3
Base class of <>f__AnonymousType0`3 is System.Object
obj.ToString() == { Color = Bright Pink, Make = Saab, CurrentSpeed = 55 }
obj.GetHashCode() == -925496951

```

---

When you run this test code, you will see that the first conditional test where you call `Equals()` returns `true` and, therefore, the message “Same anonymous object!” prints out to the screen. This is because the compiler-generated `Equals()` method uses value-based semantics when testing for equality (e.g., checking the value of each field of the objects being compared).

However, the second conditional test, which makes use of the C# equality operator (`==`), prints out “Not the same anonymous object!” This might seem at first glance to be a bit counterintuitive. This result is because anonymous types do *not* receive overloaded versions of the C# equality operators (`==` and `!=`). Given this, when you test for equality of anonymous types using the C# equality operators (rather than the `Equals()` method), the *references*, not the values maintained by the objects, are being tested for equality.

Last but not least, in the final conditional test (where you examine the underlying type name), you find that the anonymous types are instances of the same compiler-generated class type (in this example, `<>f__AnonymousType0`3`) because `firstCar` and `secondCar` have the same properties (`Color`, `Make`, and `CurrentSpeed`).



This illustrates an important but subtle point: the compiler will generate a new class definition only when an anonymous type contains *unique* names of the anonymous type. Thus, if you declare identical anonymous types (again, meaning the same names) within the same assembly, the compiler generates only a single anonymous type definition.

## Anonymous Types Containing Anonymous Types

It is possible to create an anonymous type that is composed of other anonymous types. For example, assume you want to model a purchase order that consists of a timestamp, a price point, and the automobile purchased. Here is a new (slightly more sophisticated) anonymous type representing such an entity:

```
// Make an anonymous type that is composed of another.
var purchaseItem = new {
    TimeBought = DateTime.Now,
    ItemBought = new {Color = "Red", Make = "Saab", CurrentSpeed = 55},
    Price = 34.000};

ReflectOverAnonymousType(purchaseItem);
```

At this point, you should understand the syntax used to define anonymous types, but you might still be wondering exactly where (and when) to use this new language feature. To be blunt, anonymous type declarations should be used sparingly, typically only when making use of the LINQ technology set (see Chapter 13). You would never want to abandon the use of strongly typed classes/structures simply for the sake of doing so, given anonymous types' numerous limitations, which include the following:

- You don't control the name of the anonymous type.
- Anonymous types always extend `System.Object`.
- The fields and properties of an anonymous type are always read-only.
- Anonymous types cannot support events, custom methods, custom operators, or custom overrides.
- Anonymous types are always implicitly sealed.
- Anonymous types are always created using the default constructor.

However, when programming with the LINQ technology set, you will find that in many cases this syntax can be helpful when you want to quickly model the overall *shape* of an entity rather than its functionality.

## Working with Pointer Types

And now for the final topic of the chapter, which most likely will be the least used of all C# features for the vast majority of your .NET projects.

---

■ **Note** In the examples that follow, I'm assuming you have some background in C++ pointer manipulation. If this is not true, feel free to skip this topic entirely. Using pointers will not be a common task for the vast majority of C# applications.

---

In Chapter 4, you learned that the .NET Core platform defines two major categories of data: value types and reference types. Truth be told, however, there is a third category: *pointer types*. To work with pointer types, you get specific operators and keywords that allow you to bypass the CoreCLR’s memory management scheme and take matters into your own hands (see Table 11-2).

**Table 11-2.** *Pointer-Centric C# Operators and Keywords*

Operator/ Keyword	Meaning in Life
*	This operator is used to create a pointer variable (i.e., a variable that represents a direct location in memory). As in C++, this same operator is used for pointer indirection.
&	This operator is used to obtain the address of a variable in memory.
->	This operator is used to access fields of a type that is represented by a pointer (the unsafe version of the C# dot operator).
[ ]	This operator (in an unsafe context) allows you to index the slot pointed to by a pointer variable (if you’re a C++ programmer, you will recall the interplay between a pointer variable and the [ ] operator).
++, --	In an unsafe context, the increment and decrement operators can be applied to pointer types.
+, -	In an unsafe context, the addition and subtraction operators can be applied to pointer types.
==, !=, <, >, <=, =>	In an unsafe context, the comparison and equality operators can be applied to pointer types.
stackalloc	In an unsafe context, the stackalloc keyword can be used to allocate C# arrays directly on the stack.
fixed	In an unsafe context, the fixed keyword can be used to temporarily fix a variable so that its address can be found.

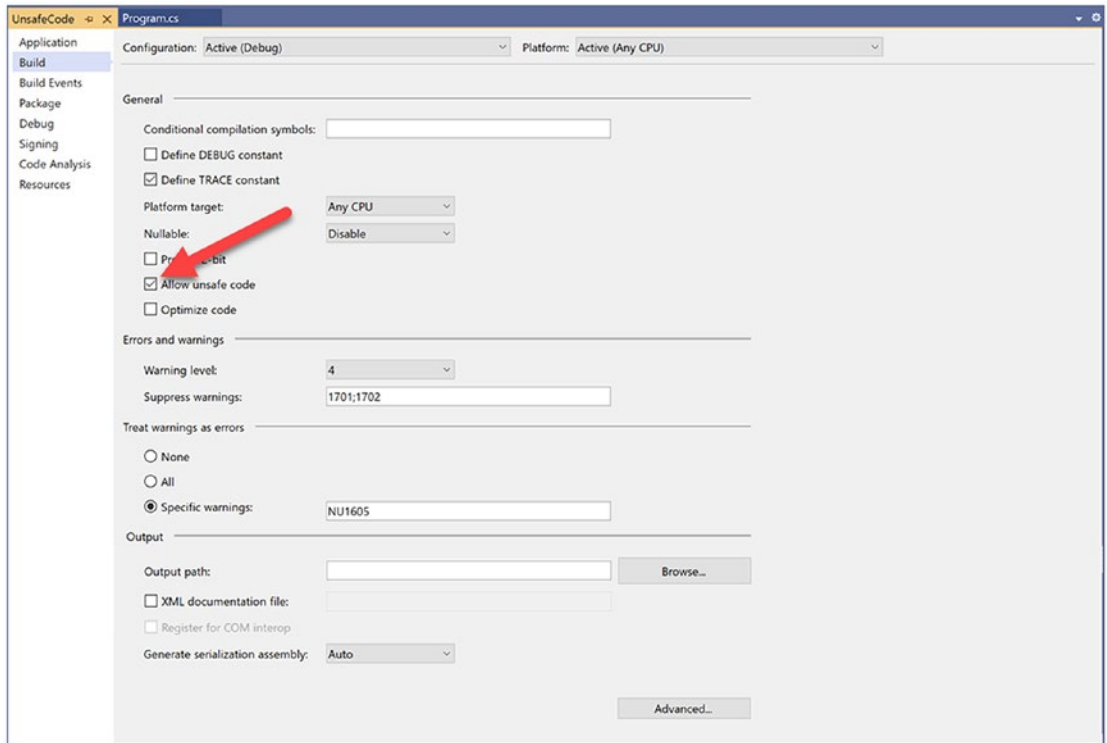
Now, before digging into the details, let me again point out that you will *seldom if ever* need to make use of pointer types. Although C# does allow you to drop down to the level of pointer manipulations, understand that the .NET Core runtime has absolutely no clue of your intentions. Thus, if you mismanage a pointer, you are the one in charge of dealing with the consequences. Given these warnings, when exactly would you need to work with pointer types? There are two common situations:

- You are looking to optimize select parts of your application by directly manipulating memory outside the management of the CoreCLR.
- You are calling methods of a C-based .dll or COM server that demand pointer types as parameters. Even in this case, you can often bypass pointer types in favor of the System.IntPtr type and members of the System.Runtime.InteropServices.Marshal type.

In the event that you do decide to make use of this C# language feature, you are required to inform the C# compiler (csc.exe) of your intentions by enabling your project to support “unsafe code.” To do so at the command line, simply supply the following /unsafe flag as an argument:

```
csc /unsafe *.cs
```

From Visual Studio, you will need to access your project's Properties page and select the Allow unsafe code box on the Build tab (see Figure 11-1). To experiment with pointer types, create a new Console Application project named UnsafeCode, and make sure you enable the Allow unsafe code setting.



**Figure 11-1.** Enabling unsafe code using Visual Studio

## The unsafe Keyword

When you want to work with pointers in C#, you must specifically declare a block of “unsafe code” using the `unsafe` keyword (any code that is not marked with the `unsafe` keyword is considered “safe” automatically). For example, the following `Program` class declares a scope of unsafe code within the safe `Main()` method:

```
class Program
{
    static void Main(string[] args)
    {
        unsafe
        {
            // Work with pointer types here!
        }
        // Can't work with pointers here!
    }
}
```

In addition to declaring a scope of unsafe code within a method, you can build structures, classes, type members, and parameters that are “unsafe.” Here are a few examples to gnaw on (no need to define the `Node` or `Node2` types in your current project):

```
// This entire structure is "unsafe" and can
// be used only in an unsafe context.
unsafe struct Node
{
    public int Value;
    public Node* Left;
    public Node* Right;
}

// This struct is safe, but the Node2* members
// are not. Technically, you may access "Value" from
// outside an unsafe context, but not "Left" and "Right".
public struct Node2
{
    public int Value;

    // These can be accessed only in an unsafe context!
    public unsafe Node2* Left;
    public unsafe Node2* Right;
}
```

Methods (static or instance level) may be marked as unsafe as well. For example, assume you know that a particular static method will make use of pointer logic. To ensure that this method can be called only from an unsafe context, you could define the method as follows:

```
static unsafe void SquareIntPtr(int* myIntPtr)
{
    // Square the value just for a test.
    *myIntPtr *= *myIntPtr;
}
```

The configuration of your method demands that the caller invoke `SquareIntPtr()` as follows:

```
static void Main(string[] args)
{
    unsafe
    {
        int myInt = 10;

        // OK, because we are in an unsafe context.
        SquareIntPtr(&myInt);
        Console.WriteLine("myInt: {0}", myInt);
    }

    int myInt2 = 5;
```

```
// Compiler error! Must be in unsafe context!
SquareIntPtr(&myInt2);
Console.WriteLine("myInt: {0}", myInt2);
}
```

If you would rather not force the caller to wrap the invocation within an unsafe context, you could update `Main()` with the `unsafe` keyword. In this case, the following code would compile:

```
static unsafe void Main(string[] args)
{
    int myInt2 = 5;
    SquareIntPtr(&myInt2);
    Console.WriteLine("myInt: {0}", myInt2);
}
```

If you run this version of the `Main()` method, you will see the following output:

---

```
myInt: 25
```

---

## Working with the \* and & Operators

After you have established an unsafe context, you are then free to build pointers to data types using the `*` operator and obtain the address of what is being pointed to using the `&` operator. Unlike in C or C++, in C# the `*` operator is applied to the underlying type only, not as a prefix to each pointer variable name. For example, consider the following code, which illustrates both the correct and incorrect ways to declare pointers to integer variables:

```
// No! This is incorrect under C#!
int *pi, *pj;

// Yes! This is the way of C#.
int* pi, pj;
```

Consider the following unsafe method:

```
static unsafe void PrintValueAndAddress()
{
    int myInt;

    // Define an int pointer, and
    // assign it the address of myInt.
    int* ptrToMyInt = &myInt;

    // Assign value of myInt using pointer indirection.
    *ptrToMyInt = 123;

    // Print some stats.
    Console.WriteLine("Value of myInt {0}", myInt);
    Console.WriteLine("Address of myInt {0:X}", (int)&ptrToMyInt);
}
```

If you run this method from the unsafe block of main, you will see the following output:

---

```
**** Print Value And Address ****
Value of myInt 123
Address of myInt 90F7E698
```

---

## An Unsafe (and Safe) Swap Function

Of course, declaring pointers to local variables simply to assign their value (as in the previous example) is never required and not altogether useful. To illustrate a more practical example of unsafe code, assume you want to build a swap function using pointer arithmetic.

```
public unsafe static void UnsafeSwap(int* i, int* j)
{
    int temp = *i;
    *i = *j;
    *j = temp;
}
```

Very C-like, don't you think? However, given your work previously, you should be aware that you could write the following safe version of your swap algorithm using the C# `ref` keyword:

```
public static void SafeSwap(ref int i, ref int j)
{
    int temp = i;
    i = j;
    j = temp;
}
```

The functionality of each method is identical, thus reinforcing the point that direct pointer manipulation is not a mandatory task under C#. Here is the calling logic using a safe `Main()`, with an unsafe context:

```
static void Main(string[] args)
{
    Console.WriteLine("***** Calling method with unsafe code *****");

    // Values for swap.
    int i = 10, j = 20;

    // Swap values "safely."
    Console.WriteLine("\n***** Safe swap *****");
    Console.WriteLine("Values before safe swap: i = {0}, j = {1}", i, j);
    SafeSwap(ref i, ref j);
    Console.WriteLine("Values after safe swap: i = {0}, j = {1}", i, j);

    // Swap values "unsafely."
    Console.WriteLine("\n***** Unsafe swap *****");
    Console.WriteLine("Values before unsafe swap: i = {0}, j = {1}", i, j);
    unsafe { UnsafeSwap(&i, &j); }
```

```

    Console.WriteLine("Values after unsafe swap: i = {0}, j = {1}", i, j);
    Console.ReadLine();
}

```

## Field Access via Pointers (the -> Operator)

Now assume you have defined a simple, safe `Point` structure, as follows:

```

struct Point
{
    public int x;
    public int y;

    public override string ToString() => $"({x}, {y})";
}

```

If you declare a pointer to a `Point` type, you will need to make use of the pointer field-access operator (represented by `->`) to access its public members. As shown in Table 11-2, this is the unsafe version of the standard (safe) dot operator (`.`). In fact, using the pointer indirection operator (`*`), it is possible to dereference a pointer to (once again) apply the dot operator notation. Check out the unsafe method:

```

static unsafe void UsePointerToPoint()
{
    // Access members via pointer.
    Point point;
    Point* p = &point;
    p->x = 100;
    p->y = 200;
    Console.WriteLine(p->ToString());

    // Access members via pointer indirection.
    Point point2;
    Point* p2 = &point2;
    (*p2).x = 100;
    (*p2).y = 200;
    Console.WriteLine((*p2).ToString());
}

```

## The `stackalloc` Keyword

In an unsafe context, you may need to declare a local variable that allocates memory directly from the call stack (and is, therefore, not subject to .NET Core garbage collection). To do so, C# provides the `stackalloc` keyword, which is the C# equivalent to the `_alloca` function of the C runtime library. Here is a simple example:

```

static unsafe void UnsafeStackAlloc()
{
    char* p = stackalloc char[256];
    for (int k = 0; k < 256; k++)

```

```

{
    p[k] = (char)k;
}
}

```

## Pinning a Type via the fixed Keyword

As you saw in the previous example, allocating a chunk of memory within an unsafe context may be facilitated via the `stackalloc` keyword. By the very nature of this operation, the allocated memory is cleaned up as soon as the allocating method has returned (as the memory is acquired from the stack). However, assume a more complex example. During our examination of the `->` operator, you created a value type named `Point`. Like all value types, the allocated memory is popped off the stack once the executing scope has terminated. For the sake of argument, assume `Point` was instead defined as a *reference* type, like so:

```

class PointRef // <= Renamed and retyped.
{
    public int x;
    public int y;
    public override string ToString() => $"({x}, {y})";
}

```

As you are aware, if the caller declares a variable of type `Point`, the memory is allocated on the garbage-collected heap. The burning question then becomes “What if an unsafe context wants to interact with this object (or any object on the heap)?” Given that garbage collection can occur at any moment, imagine the problems encountered when accessing the members of `Point` at the very point in time such a sweep of the heap is underway. Theoretically, it is possible that the unsafe context is attempting to interact with a member that is no longer accessible or has been repositioned on the heap after surviving a generational sweep (which is an obvious problem).

To lock a reference type variable in memory from an unsafe context, C# provides the `fixed` keyword. The `fixed` statement sets a pointer to a managed type and “pins” that variable during the execution of the code. Without `fixed`, pointers to managed variables would be of little use, since garbage collection could relocate the variables unpredictably. (In fact, the C# compiler will not allow you to set a pointer to a managed variable except in a `fixed` statement.)

Thus, if you create a `PointRef` object and want to interact with its members, you must write the following code (or receive a compiler error):

```

public unsafe static void UseAndPinPoint()
{
    PointRef pt = new PointRef
    {
        x = 5,
        y = 6
    };

    // Pin pt in place so it will not
    // be moved or GC-ed.
    fixed (int* p = &pt.x)
    {
        // Use int* variable here!
    }
}

```



```
// pt is now unpinned, and ready to be GC-ed once
// the method completes.
Console.WriteLine ("Point is: {0}", pt);
}
```

In a nutshell, the `fixed` keyword allows you to build a statement that locks a reference variable in memory, such that its address remains constant for the duration of the statement (or scope block). Any time you interact with a reference type from within the context of unsafe code, pinning the reference is a must.

## The sizeof Keyword

The final unsafe-centric C# keyword to consider is `sizeof`. As in C++, the C# `sizeof` keyword is used to obtain the size in bytes of an *intrinsic data type*, but not a custom type, unless within an unsafe context. For example, the following method does not need to be declared “unsafe” as all arguments to the `sizeof` keyword are intrinsic types:

```
static void UseSizeOfOperator()
{
    Console.WriteLine("The size of short is {0}.", sizeof(short));
    Console.WriteLine("The size of int is {0}.", sizeof(int));
    Console.WriteLine("The size of long is {0}.", sizeof(long));
}
```

However, if you want to get the size of your custom `Point` structure, you need to update this method as so (note the `unsafe` keyword has been added):

```
unsafe static void UseSizeOfOperator()
{
    ...
    Unsafe {
        Console.WriteLine("The size of Point is {0}.", sizeof(Point));
    }
}
```

That wraps up the look at some of the more advanced features of the C# programming language. To make sure we are all on the same page here, I again must say that a majority of your .NET projects might never need to directly use these features (especially pointers). Nevertheless, as you will see in later chapters, some topics are quite useful, if not required, when working with the LINQ APIs, most notably extension methods and anonymous types.

## Summary

The purpose of this chapter was to deepen your understanding of the C# programming language. First, you investigated various advanced type construction techniques (indexer methods, overloaded operators, and custom conversion routines).

Next, you examined the role of extension methods and anonymous types. As you'll see in some detail in Chapter 13, these features are useful when working with LINQ-centric APIs (though you can use them anywhere in your code, should they be useful). Recall that anonymous methods allow you to quickly model the “shape” of a type, while extension methods allow you to tack on new functionality to types, without the need to subclass.

You spent the remainder of this chapter examining a small set of lesser-known keywords (`sizeof`, `unsafe`, etc.) and during the process learned how to work with raw pointer types. As stated throughout the examination of pointer types, the vast majority of your C# applications will never need to use them.

## CHAPTER 12



# Delegates, Events, and Lambda Expressions

Up to this point in the text, most of the applications you have developed added various bits of code to `Main()`, which, in some way or another, sent requests *to* a given object. However, many applications require that an object be able to communicate *back to* the entity that created it using a callback mechanism. While callback mechanisms can be used in any application, they are especially critical for graphical user interfaces in that controls (such as a button) need to invoke external methods under the correct circumstances (when the button is clicked, when the mouse enters the button surface, etc.).

Under the .NET Core platform, the *delegate* type is the preferred means of defining and responding to callbacks within applications. Essentially, the .NET Core delegate type is a type-safe object that “points to” a method or a list of methods that can be invoked at a later time. Unlike a traditional C++ function pointer, however, delegates are classes that have built-in support for multicasting.

---

■ **Note** In prior versions of .NET, delegates exposed asynchronous method invocation with `BeginInvoke/EndInvoke`. While these are still generated by the compiler, they are not supported under .NET Core. This is because the `IAsyncResult/BeginInvoke` pattern used by delegates has been replaced by the task-based async pattern. For more on asynchronous execution, see Chapter 15.

---

In this chapter, you will learn how to create and manipulate delegate types, and then you’ll investigate the C# event keyword, which streamlines the process of working with delegate types. Along the way, you will also examine several delegate- and event-centric language features of C#, including anonymous methods and method group conversions.

I wrap up this chapter by examining *lambda expressions*. Using the C# lambda operator (`=>`), you can specify a block of code statements (and the parameters to pass to those code statements) wherever a strongly typed delegate is required. As you will see, a lambda expression is little more than an anonymous method in disguise and provides a simplified approach to working with delegates. In addition, this same operation (as of .NET 4.6 and later) can be used to implement a single-statement method or property using a concise syntax.

## Understanding the Delegate Type

Before formally defining delegates, let's gain a bit of perspective. Historically, the Windows API made frequent use of C-style function pointers to create entities termed *callback functions*, or simply *callbacks*. Using callbacks, programmers were able to configure one function to report back to (call back) another function in the application. With this approach, Windows developers were able to handle button clicking, mouse moving, menu selecting, and general bidirectional communications between two entities in memory.

In the .NET and .NET Core Frameworks, callbacks are accomplished in a type-safe and object-oriented manner using *delegates*. In essence, a delegate is a type-safe object that points to another method (or possibly a list of methods) in the application, which can be invoked at a later time. Specifically, a delegate maintains three important pieces of information:

- The *address* of the method on which it makes calls
- The *parameters* (if any) of this method
- The *return type* (if any) of this method

---

■ **Note** .NET Core delegates can point to either static or instance methods.

---

After a delegate object has been created and given the necessary information, it may dynamically invoke the method(s) it points to at runtime.

## Defining a Delegate Type in C#

When you want to create a delegate type in C#, you use the `delegate` keyword. The name of your delegate type can be whatever you desire. However, you must define the delegate to match the signature of the method(s) it will point to. For example, the following delegate type (named `BinaryOp`) can point to any method that returns an integer and takes two integers as input parameters (you will build and use this delegate yourself a bit later in this chapter, so hang tight for now):

```
// This delegate can point to any method,
// taking two integers and returning an integer.
public delegate int BinaryOp(int x, int y);
```

When the C# compiler processes delegate types, it automatically generates a sealed class deriving from `System.MulticastDelegate`. This class (in conjunction with its base class, `System.Delegate`) provides the necessary infrastructure for the delegate to hold onto a list of methods to be invoked at a later time. For example, if you were to examine the `BinaryOp` delegate using `ildasm.exe`, you would find the details as shown here (you will build this full example in just a moment if you want to check for yourself):

```
// -----
//      TypDefName: SimpleDelegate.BinaryOp
//      Extends    : System.MulticastDelegate
//      Method #1
//      -----
//      MethodName: .ctor
//      ReturnType: Void
//      2 Arguments
//      Argument #1: Object
//      Argument #2: I (native int)
```

```
//      Method #2 (06000002)
//      -----
//      MethodName: Invoke
//      ReturnType: I4 (int32)
//      2 Arguments
//          Argument #1: I4 (int32)
//          Argument #2: I4 (int32)
//
//      Method #3
//      -----
//      MethodName: BeginInvoke
//      ReturnType: Class System.IAsyncResult
//      4 Arguments
//          Argument #1: I4 (int32)
//          Argument #2: I4 (int32)
//          Argument #3: Class System.AsyncCallback
//          Argument #4: Object
//
//      Method #4
//      -----
//      MethodName: EndInvoke
//      ReturnType: I4 (int32)
//      1 Arguments
//          Argument #1: Class System.IAsyncResult
```

As you can see, the compiler-generated `BinaryOp` class defines three public methods. `Invoke()` is the key method in .NET Core, as it is used to invoke each method maintained by the delegate object in a *synchronous* manner, meaning the caller must wait for the call to complete before continuing on its way. Strangely enough, the synchronous `Invoke()` method may not need to be called explicitly from your C# code. As you will see in just a bit, `Invoke()` is called behind the scenes when you use the appropriate C# syntax.

---

■ **Note** While the `BeginInvoke()` and `EndInvoke()` are generated, they are not supported when running your code under .NET Core. This can be frustrating, since you will not receive a compiler error, but a runtime error if you use them.

---

Now, how exactly does the compiler know how to define the `Invoke()` method? To understand the process, here is the crux of the compiler-generated `BinaryOp` class type (bold italic marks the items specified by the defined delegate type):

```
sealed class BinaryOp : System.MulticastDelegate
{
    public int Invoke(int x, int y);
}
```

First, notice that the parameters and return type defined for the `Invoke()` method exactly match the definition of the `BinaryOp` delegate.

Let's see another example. Assume you have defined a delegate type that can point to any method returning a string and receiving three `System.Boolean` input parameters.

```
public delegate string MyDelegate (bool a, bool b, bool c);
```

This time, the compiler-generated class breaks down as follows:

```
sealed class MyDelegate : System.MulticastDelegate
{
    public string Invoke(bool a, bool b, bool c);
}
```

Delegates can also “point to” methods that contain any number of out or ref parameters (as well as array parameters marked with the `params` keyword). For example, assume the following delegate type:

```
public delegate string MyOtherDelegate(
    out bool a, ref bool b, int c);
```

The signature of the `Invoke()` method looks as you would expect.

To summarize, a C# delegate type definition results in a sealed class with a compiler-generated method whose parameter and return types are based on the delegate's declaration. The following pseudocode approximates the basic pattern:

```
// This is only pseudo-code!
public sealed class DelegateName : System.MulticastDelegate
{
    public delegateReturnValue Invoke(allDelegateInputRefAndOutParams);
}
```

## The `System.MulticastDelegate` and `System.Delegate` Base Classes

So, when you build a type using the C# `delegate` keyword, you are indirectly declaring a class type that derives from `System.MulticastDelegate`. This class provides descendants with access to a list that contains the addresses of the methods maintained by the delegate object, as well as several additional methods (and a few overloaded operators) to interact with the invocation list. Here are some select members of `System.MulticastDelegate`:

```
public abstract class MulticastDelegate : Delegate
{
    // Returns the list of methods "pointed to."
    public sealed override Delegate[] GetInvocationList();

    // Overloaded operators.
    public static bool operator ==
        (MulticastDelegate d1, MulticastDelegate d2);
    public static bool operator !=
        (MulticastDelegate d1, MulticastDelegate d2);

    // Used internally to manage the list of methods maintained by the delegate.
    private IntPtr _invocationCount;
    private object _invocationList;
}
```

`System.MulticastDelegate` obtains additional functionality from its parent class, `System.Delegate`. Here is a partial snapshot of the class definition:

```
public abstract class Delegate : ICloneable, ISerializable
{
    // Methods to interact with the list of functions.
    public static Delegate Combine(params Delegate[] delegates);
    public static Delegate Combine(Delegate a, Delegate b);
    public static Delegate Remove(
        Delegate source, Delegate value);
    public static Delegate RemoveAll(
        Delegate source, Delegate value);

    // Overloaded operators.
    public static bool operator ==(Delegate d1, Delegate d2);
    public static bool operator !=(Delegate d1, Delegate d2);

    // Properties that expose the delegate target.
    public MethodInfo Method { get; }
    public object Target { get; }
}
```

Now, understand that you can never directly derive from these base classes in your code (it is a compiler error to do so). Nevertheless, when you use the `delegate` keyword, you have indirectly created a class that “is-a” `MulticastDelegate`. Table 12-1 documents the core members common to all delegate types.

**Table 12-1.** *Select Members of `System.MulticastDelegate`/`System.Delegate`*

Member	Meaning in Life
<code>Method</code>	This property returns a <code>System.Reflection.MethodInfo</code> object that represents details of a static method maintained by the delegate.
<code>Target</code>	If the method to be called is defined at the object level (rather than a static method), <code>Target</code> returns an object that represents the method maintained by the delegate. If the value returned from <code>Target</code> equals <code>null</code> , the method to be called is a static member.
<code>Combine()</code>	This static method adds a method to the list maintained by the delegate. In C#, you trigger this method using the overloaded <code>+=</code> operator as a shorthand notation.
<code>GetInvocationList()</code>	This method returns an array of <code>System.Delegate</code> objects, each representing a particular method that may be invoked.
<code>Remove()</code> <code>RemoveAll()</code>	These static methods remove a method (or all methods) from the delegate’s invocation list. In C#, the <code>Remove()</code> method can be called indirectly using the overloaded <code>-=</code> operator.

## The Simplest Possible Delegate Example

To be sure, delegates can cause some confusion when encountered for the first time. Thus, to get the ball rolling, let's take a look at a simple console application program (named SimpleDelegate) that makes use of the BinaryOp delegate type you've seen previously. Here is the complete code, with analysis to follow:

```
namespace SimpleDelegate
{
    // This delegate can point to any method,
    // taking two integers and returning an integer.
    public delegate int BinaryOp(int x, int y);

    // This class contains methods BinaryOp will
    // point to.
    public class SimpleMath
    {
        public static int Add(int x, int y) => x + y;
        public static int Subtract(int x, int y) => x - y;
    }

    class Program
    {
        static void Main(string[] args)
        {
            Console.WriteLine("***** Simple Delegate Example *****\n");

            // Create a BinaryOp delegate object that
            // "points to" SimpleMath.Add().
            BinaryOp b = new BinaryOp(SimpleMath.Add);

            // Invoke Add() method indirectly using delegate object.
            Console.WriteLine("10 + 10 is {0}", b(10, 10));
            Console.ReadLine();
        }
    }
}
```

Again, notice the format of the BinaryOp delegate type declaration; it specifies that BinaryOp delegate objects can point to any method taking two integers and returning an integer (the actual name of the method pointed to is irrelevant). Here, you have created a class named SimpleMath, which defines two static methods that match the pattern defined by the BinaryOp delegate.

When you want to assign the target method to a given delegate object, simply pass in the name of the method to the delegate's constructor.

```
// Create a BinaryOp delegate object that
// "points to" SimpleMath.Add().
BinaryOp b = new BinaryOp(SimpleMath.Add);
```



At this point, you are able to invoke the member pointed to using a syntax that looks like a direct function invocation.

```
// Invoke() is really called here!
Console.WriteLine("10 + 10 is {0}", b(10, 10));
```

Under the hood, the runtime actually calls the compiler-generated `Invoke()` method on your `MulticastDelegate`-derived class. You can verify this for yourself if you open your assembly in `ildasm.exe` and examine the CIL code within the `Main()` method.

```
.method private hidebysig static void Main(string[] args) cil managed
{
    ...
    callvirt instance int32 SimpleDelegate.BinaryOp::Invoke(int32, int32)
}
```

C# does not require you to explicitly call `Invoke()` within your codebase. Because `BinaryOp` can point to methods that take two arguments, the following code statement is also permissible:

```
Console.WriteLine("10 + 10 is {0}", b.Invoke(10, 10));
```

Recall that .NET Core delegates are *type-safe*. Therefore, if you attempt to create a delegate object pointing to a method that does not match the pattern, you receive a compile-time error. To illustrate, assume the `SimpleMath` class now defines an additional method named `SquareNumber()`, which takes a single integer as input.

```
public class SimpleMath
{
    public static int SquareNumber(int a) => a * a;
}
```

Given that the `BinaryOp` delegate can point *only* to methods that take two integers and return an integer, the following code is illegal and will not compile:

```
// Compiler error! Method does not match delegate pattern!
BinaryOp b2 = new BinaryOp(SimpleMath.SquareNumber);
```

## Investigating a Delegate Object

Let's spice up the current example by creating a static method (named `DisplayDelegateInfo()`) within the `Program` class. This method will print out the names of the methods maintained by a delegate object, as well as the name of the class defining the method. To do this, you will iterate over the `System.Delegate` array returned by `GetInvocationList()`, invoking each object's `Target` and `Method` properties.

```
static void DisplayDelegateInfo(Delagate delObj)
{
    // Print the names of each member in the
    // delegate's invocation list.
    foreach (Delegate d in delObj.GetInvocationList())
    {
```

```

        Console.WriteLine("Method Name: {0}", d.Method);
        Console.WriteLine("Type Name: {0}", d.Target);
    }
}

```

Assuming you have updated your `Main()` method to actually call this new helper method, as shown here:

```

BinaryOp b = new BinaryOp(SimpleMath.Add);
DisplayDelegateInfo(b);

```

you would find the output shown next:

---

```

***** Simple Delegate Example *****

```

```

Method Name: Int32 Add(Int32, Int32)
Type Name:
10 + 10 is 20

```

---

Notice that the name of the target class (`SimpleMath`) is currently *not* displayed when calling the `Target` property. The reason has to do with the fact that your `BinaryOp` delegate is pointing to a *static method* and, therefore, there is no object to reference! However, if you update the `Add()` and `Subtract()` methods to be nonstatic (simply by deleting the static keywords), you could create an instance of the `SimpleMath` class and specify the methods to invoke using the object reference.

```

static void Main(string[] args)
{
    Console.WriteLine("***** Simple Delegate Example *****\n");

    // Delegates can also point to instance methods as well.
    SimpleMath m = new SimpleMath();
    BinaryOp b = new BinaryOp(m.Add);

    // Show information about this object.
    DisplayDelegateInfo(b);

    Console.WriteLine("10 + 10 is {0}", b(10, 10));
    Console.ReadLine();
}

```

In this case, you would find the output shown here:

---

```

***** Simple Delegate Example *****

```

```

Method Name: Int32 Add(Int32, Int32)
Type Name: SimpleDelegate.SimpleMath
10 + 10 is 20

```

---

## Sending Object State Notifications Using Delegates

Clearly, the previous SimpleDelegate example was intended to be purely illustrative in nature, given that there would be no compelling reason to define a delegate simply to add two numbers. To provide a more realistic use of delegate types, let's use delegates to define a Car class that has the ability to inform external entities about its current engine state. To do so, you will take the following steps:

1. Define a new delegate type that will be used to send notifications to the caller.
2. Declare a member variable of this delegate in the Car class.
3. Create a helper function on the Car that allows the caller to specify the method to call back on.
4. Implement the Accelerate() method to invoke the delegate's invocation list under the correct circumstances.

To begin, create a new Console Application project named CarDelegate. Now, define a new Car class that looks initially like this:

```
public class Car
{
    // Internal state data.
    public int CurrentSpeed { get; set; }
    public int MaxSpeed { get; set; } = 100;
    public string PetName { get; set; }

    // Is the car alive or dead?
    private bool _carIsDead;

    // Class constructors.
    public Car() {}
    public Car(string name, int maxSp, int currSp)
    {
        CurrentSpeed = currSp;
        MaxSpeed = maxSp;
        PetName = name;
    }
}
```

Now, consider the following updates, which address the first three points:

```
public class Car
{
    ...
    // 1) Define a delegate type.
    public delegate void CarEngineHandler(string msgForCaller);

    // 2) Define a member variable of this delegate.
    private CarEngineHandler _listOfHandlers;
```

```
// 3) Add registration function for the caller.
public void RegisterWithCarEngine(CarEngineHandler methodToCall)
{
    _listOfHandlers = methodToCall;
}
}
```

Notice in this example that you define the delegate types directly within the scope of the `Car` class, which is certainly not necessary but does help enforce the idea that the delegate works naturally with this particular class. The delegate type, `CarEngineHandler`, can point to any method taking a single string as input and void as a return value.

Next, note that you declare a private member variable of your delegate type (named `_listOfHandlers`) and a helper function (named `RegisterWithCarEngine()`) that allows the caller to assign a method to the delegate's invocation list.

---

■ **Note** Strictly speaking, you could have defined your delegate member variable as public, therefore avoiding the need to create additional registration methods. However, by defining the delegate member variable as private, you are enforcing encapsulation services and providing a more type-safe solution. You'll revisit the risk of public delegate member variables later in this chapter when you look at the C# event keyword.

---

At this point, you need to create the `Accelerate()` method. Recall, the point here is to allow a `Car` object to send engine-related messages to any subscribed listener. Here is the update:

```
// 4) Implement the Accelerate() method to invoke the delegate's
// invocation list under the correct circumstances.
public void Accelerate(int delta)
{
    // If this car is "dead," send dead message.
    if (_carIsDead)
    {
        _listOfHandlers?.Invoke("Sorry, this car is dead...");
    }
    else
    {
        CurrentSpeed += delta;
        // Is this car "almost dead"?
        if (10 == (MaxSpeed - CurrentSpeed))
        {
            _listOfHandlers?.Invoke("Careful buddy! Gonna blow!");
        }
        if (CurrentSpeed >= MaxSpeed)
        {
            _carIsDead = true;
        }
    }
}
```

```

    else
    {
        Console.WriteLine("CurrentSpeed = {0}", CurrentSpeed);
    }
}
}

```

Notice that you are using the null propagation syntax when attempting to invoke the methods maintained by the `listOfHandlers` member variable. The reason is that it will be the job of the caller to allocate these objects by calling the `RegisterWithCarEngine()` helper method. If the caller does not call this method and you attempt to invoke the delegate's invocation list, you will trigger a `NullReferenceException` at runtime. Now that you have the delegate infrastructure in place, observe the updates to the `Program` class:

```

class Program
{
    static void Main(string[] args)
    {
        Console.WriteLine("** Delegates as event enablers **\n");

        // First, make a Car object.
        Car c1 = new Car("SlugBug", 100, 10);

        // Now, tell the car which method to call
        // when it wants to send us messages.
        c1.RegisterWithCarEngine(
            new Car.CarEngineHandler(OnCarEngineEvent));

        // Speed up (this will trigger the events).
        Console.WriteLine("***** Speeding up *****");
        for (int i = 0; i < 6; i++)
        {
            c1.Accelerate(20);
        }
        Console.ReadLine();
    }

    // This is the target for incoming events.
    public static void OnCarEngineEvent(string msg)
    {
        Console.WriteLine("\n*** Message From Car Object ***");
        Console.WriteLine("=> {0}", msg);
        Console.WriteLine("*****\n");
    }
}

```

The `Main()` method begins by simply making a new `Car` object. Since you are interested in hearing about the engine events, the next step is to call your custom registration function, `RegisterWithCarEngine()`. Recall that this method expects to be passed an instance of the nested `CarEngineHandler` delegate, and as with any delegate, you specify a “method to point to” as a constructor parameter. The trick in this example is that the method in question is located back in the `Program` class!

Again, notice that the `OnCarEngineEvent()` method is a dead-on match to the related delegate, in that it takes a `string` as input and returns `void`. Consider the output of the current example:

---

```
***** Delegates as event enablers *****
***** Speeding up *****
CurrentSpeed = 30
CurrentSpeed = 50
CurrentSpeed = 70

***** Message From Car Object *****
=> Careful buddy! Gonna blow!
*****
CurrentSpeed = 90
***** Message From Car Object *****
=> Sorry, this car is dead...
*****
```

---

## Enabling Multicasting

Recall that .NET Core delegates have the built-in ability to *multicast*. In other words, a delegate object can maintain a list of methods to call, rather than just a single method. When you want to add multiple methods to a delegate object, you simply use the overloaded `+=` operator, rather than a direct assignment. To enable multicasting on the `Car` class, you could update the `RegisterWithCarEngine()` method, like so:

```
public class Car
{
    // Now with multicasting support!
    // Note we are now using the += operator, not
    // the assignment operator (=).
    public void RegisterWithCarEngine(
        CarEngineHandler methodToCall)
    {
        _listOfHandlers += methodToCall;
    }
    ...
}
```

When you use the `+=` operator on a delegate object, the compiler resolves this to a call on the static `Delegate.Combine()` method. In fact, you could call `Delegate.Combine()` directly; however, the `+=` operator offers a simpler alternative. There is no need to modify your current `RegisterWithCarEngine()` method, but here is an example of using `Delegate.Combine()` rather than the `+=` operator:

```
public void RegisterWithCarEngine( CarEngineHandler methodToCall )
{
    if (_listOfHandlers == null)
    {
        _listOfHandlers = methodToCall;
    }
}
```

```

else
{
    _listOfHandlers =
        Delegate.Combine(_listOfHandlers, methodToCall)
            as CarEngineHandler;
}
}

```

In any case, the caller can now register multiple targets for the same callback notification. Here, the second handler prints the incoming message in uppercase, just for display purposes:

```

class Program
{
    static void Main(string[] args)
    {
        Console.WriteLine("***** Delegates as event enablers *****\n");

        // First, make a Car object.
        Car c1 = new Car("SlugBug", 100, 10);

        // Register multiple targets for the notifications.
        c1.RegisterWithCarEngine(
            new Car.CarEngineHandler(OnCarEngineEvent));
        c1.RegisterWithCarEngine(
            new Car.CarEngineHandler(OnCarEngineEvent2));

        // Speed up (this will trigger the events).
        Console.WriteLine("***** Speeding up *****");
        for (int i = 0; i < 6; i++)
        {
            c1.Accelerate(20);
        }
        Console.ReadLine();
    }
    // We now have TWO methods that will be called by the Car
    // when sending notifications.
    public static void OnCarEngineEvent(string msg)
    {
        Console.WriteLine("\n*** Message From Car Object ***");
        Console.WriteLine("=> {0}", msg);
        Console.WriteLine("*****\n");
    }

    public static void OnCarEngineEvent2(string msg)
    {
        Console.WriteLine("=> {0}", msg.ToUpper());
    }
}

```

## Removing Targets from a Delegate's Invocation List

The `Delegate` class also defines a static `Remove()` method that allows a caller to dynamically remove a method from a delegate object's invocation list. This makes it simple to allow the caller to “unsubscribe” from a given notification at runtime. While you could call `Delegate.Remove()` directly in code, C# developers can use the `-=` operator as a convenient shorthand notation. Let's add a new method to the `Car` class that allows a caller to remove a method from the invocation list.

```
public class Car
{
    ...
    public void UnRegisterWithCarEngine(CarEngineHandler methodToCall)
    {
        _listOfHandlers -= methodToCall;
    }
}
```

With the current updates to the `Car` class, you could stop receiving the engine notification on the second handler by updating `Main()` as follows:

```
static void Main(string[] args)
{
    Console.WriteLine("***** Delegates as event enablers *****\n");

    // First, make a Car object.
    Car c1 = new Car("SlugBug", 100, 10);
    c1.RegisterWithCarEngine(
        new Car.CarEngineHandler(OnCarEngineEvent));

    // This time, hold onto the delegate object,
    // so we can unregister later.
    Car.CarEngineHandler handler2 =
        new Car.CarEngineHandler(OnCarEngineEvent2);
    c1.RegisterWithCarEngine(handler2);

    // Speed up (this will trigger the events).
    Console.WriteLine("***** Speeding up *****");
    for (int i = 0; i < 6; i++)
    {
        c1.Accelerate(20);
    }

    // Unregister from the second handler.
    c1.UnRegisterWithCarEngine(handler2);

    // We won't see the "uppercase" message anymore!
    Console.WriteLine("***** Speeding up *****");
    for (int i = 0; i < 6; i++)
    {
        c1.Accelerate(20);
    }

    Console.ReadLine();
}
```



One difference in `Main()` is that this time you are creating a `Car.CarEngineHandler` object and storing it in a local variable so you can use this object to unregister with the notification later. Thus, the second time you speed up the `Car` object, you no longer see the uppercase version of the incoming message data, as you have removed this target from the delegate's invocation list.

## Method Group Conversion Syntax

In the previous `CarDelegate` example, you explicitly created instances of the `Car.CarEngineHandler` delegate object to register and unregister with the engine notifications.

```
static void Main(string[] args)
{
    Console.WriteLine("***** Delegates as event enablers *****\n");

    Car c1 = new Car("SlugBug", 100, 10);
    c1.RegisterWithCarEngine(new Car.CarEngineHandler(OnCarEngineEvent));

    Car.CarEngineHandler handler2 =
    new Car.CarEngineHandler(OnCarEngineEvent2);
    c1.RegisterWithCarEngine(handler2);
    ...
}
```

To be sure, if you need to call any of the inherited members of `MulticastDelegate` or `Delegate`, manually creating a delegate variable is the most straightforward way of doing so. However, in most cases, you don't really need to hang onto the delegate object. Rather, you typically need to use the delegate object only to pass in the method name as a constructor parameter.

As a simplification, *C#* provides a shortcut termed *method group conversion*. This feature allows you to supply a direct method name, rather than a delegate object, when calling methods that take delegates as arguments.

---

■ **Note** As you will see later in this chapter, you can also use method group conversion syntax to simplify how you register with a C# event.

---

To illustrate, consider the following updates to the `Program` class, which uses method group conversion to register and unregister from the engine notifications:

```
static void Main(string[] args)
{
    ...
    Console.WriteLine("***** Method Group Conversion *****\n");
    Car c2 = new Car();

    // Register the simple method name.
    c2.RegisterWithCarEngine(OnCarEngineEvent);
}
```

```

Console.WriteLine("***** Speeding up *****");
for (int i = 0; i < 6; i++)
{
    c2.Accelerate(20);
}

// Unregister the simple method name.
c2.UnRegisterWithCarEngine(OnCarEngineEvent);

// No more notifications!
for (int i = 0; i < 6; i++)
{
    c2.Accelerate(20);
}

Console.ReadLine();
}

```

Notice that you are not directly allocating the associated delegate object but rather simply specifying a method that matches the delegate's expected signature (a method returning void and taking a single string, in this case). Understand that the C# compiler is still ensuring type safety. Thus, if the `OnCarEngineEvent()` method did not take a string and return void, you would be issued a compiler error.

## Understanding Generic Delegates

In Chapter 10, I mentioned that C# allows you to define generic delegate types. For example, assume you want to define a delegate type that can call any method returning void and receiving a single parameter. If the argument in question may differ, you could model this using a type parameter. To illustrate, consider the following code within a new Console Application project named `GenericDelegate`:

```

namespace GenericDelegate
{
    // This generic delegate can represent any method
    // returning void and taking a single parameter of type T.
    public delegate void MyGenericDelegate<T>(T arg);

    class Program
    {
        static void Main(string[] args)
        {
            Console.WriteLine("***** Generic Delegates *****\n");

            // Register targets.
            MyGenericDelegate<string> strTarget =
                new MyGenericDelegate<string>(StringTarget);
            strTarget("Some string data");

            //Using the method group conversion syntax
            MyGenericDelegate<int> intTarget = IntTarget;
            intTarget(9);
            Console.ReadLine();
        }
    }
}

```

```

static void StringTarget(string arg)
{
    Console.WriteLine("arg in uppercase is: {0}", arg.ToUpper());
}

static void IntTarget(int arg)
{
    Console.WriteLine("++arg is: {0}", ++arg);
}
}
}

```

Notice that `MyGenericDelegate<T>` defines a single type parameter that represents the argument to pass to the delegate target. When creating an instance of this type, you are required to specify the value of the type parameter, as well as the name of the method the delegate will invoke. Thus, if you specified a string type, you send a string value to the target method.

```

// Create an instance of MyGenericDelegate<T>
// with string as the type parameter.
MyGenericDelegate<string> strTarget = StringTarget;
strTarget("Some string data");

```

Given the format of the `strTarget` object, the `StringTarget()` method must now take a single string as a parameter.

```

static void StringTarget(string arg)
{
    Console.WriteLine(
        "arg in uppercase is: {0}", arg.ToUpper());
}

```

## The Generic Action<> and Func<> Delegates

Over the course of this chapter, you have seen that when you want to use delegates to enable callbacks in your applications, you typically follow the steps shown here:

1. Define a custom delegate that matches the format of the method being pointed to.
2. Create an instance of your custom delegate, passing in a method name as a constructor argument.
3. Invoke the method indirectly, via a call to `Invoke()` on the delegate object.

When you take this approach, you typically end up with a number of custom delegates that might never be used beyond the current task at hand (e.g., `MyGenericDelegate<T>`, `CarEngineHandler`, etc.). While it may certainly be the case that you do indeed need to have a custom, uniquely named delegate type for your project, other times the exact *name* of the delegate type is irrelevant. In many cases, you simply want “some delegate” that takes a set of arguments and possibly has a return value other than void. In these cases, you can use the framework’s built-in `Action<>` and `Func<>` delegate types. To illustrate their usefulness, create a new Console Application project named `ActionAndFuncDelegates`.

The generic `Action<>` delegate is defined in the `System` namespace, and you can use this generic delegate to “point to” a method that takes up to 16 *arguments* (that ought to be enough!) and returns `void`. Now recall, because `Action<>` is a generic delegate, you will need to specify the underlying types of each parameter as well.

Update your `Program` class to define a new static method that takes three (or so) unique parameters. Here’s an example:

```
// This is a target for the Action<> delegate.
static void DisplayMessage(string msg, ConsoleColor txtColor, int printCount)
{
    // Set color of console text.
    ConsoleColor previous = Console.ForegroundColor;
    Console.ForegroundColor = txtColor;

    for (int i = 0; i < printCount; i++)
    {
        Console.WriteLine(msg);
    }

    // Restore color.
    Console.ForegroundColor = previous;
}
```

Now, rather than building a custom delegate manually to pass the program’s flow to the `DisplayMessage()` method, you can use the out-of-the-box `Action<>` delegate, as so:

```
static void Main(string[] args)
{
    Console.WriteLine("***** Fun with Action and Func *****");

    // Use the Action<> delegate to point to DisplayMessage.
    Action<string, ConsoleColor, int> actionTarget =
        DisplayMessage;
    actionTarget("Action Message!", ConsoleColor.Yellow, 5);

    Console.ReadLine();
}
```

As you can see, using the `Action<>` delegate saves you the bother of defining a custom delegate type. However, recall that the `Action<>` delegate type can point only to methods that take a `void` return value. If you want to point to a method that does have a return value (and don’t want to bother writing the custom delegate yourself), you can use `Func<>`.

The generic `Func<>` delegate can point to methods that (like `Action<>`) take up to 16 parameters and a custom return value. To illustrate, add the following new method to the `Program` class:

```
// Target for the Func<> delegate.
static int Add(int x, int y)
{
    return x + y;
}
```

Earlier in the chapter, I had you build a custom `BinaryOp` delegate to “point to” addition and subtraction methods. However, you can simplify your efforts using a version of `Func<>` that takes a total of three type parameters. Be aware that the *final* type parameter of `Func<>` is *always* the return value of the method. Just to solidify that point, assume the `Program` class also defines the following method:

```
static string SumToString(int x, int y)
{
    return (x + y).ToString();
}
```

Now, the `Main()` method can call each of these methods, as so:

```
Func<int, int, int> funcTarget = Add;
int result = funcTarget.Invoke(40, 40);
Console.WriteLine("40 + 40 = {0}", result);

Func<int, int, string> funcTarget2 = SumToString;
string sum = funcTarget2(90, 300);
Console.WriteLine(sum);
```

In any case, given that `Action<>` and `Func<>` can save you the step of manually defining a custom delegate, you might be wondering if you should use them all the time. The answer, like so many aspects of programming, is “it depends.” In many cases, `Action<>` and `Func<>` will be the preferred course of action (no pun intended). However, if you need a delegate that has a custom name that you feel helps better capture your problem domain, building a custom delegate is as simple as a single code statement. You’ll see both approaches as you work over the remainder of this text.

---

■ **Note** Many important .NET Core APIs make considerable use of `Action<>` and `Func<>` delegates, including the parallel programming framework and LINQ (among others).

---

That wraps up our initial look at the delegate type. Next, let’s move on to the related topic of the C# event keyword.

## Understanding C# Events

Delegates are fairly interesting constructs, in that they enable objects in memory to engage in a two-way conversation. However, working with delegates in the raw can entail the creation of some boilerplate code (defining the delegate, declaring necessary member variables, creating custom registration and unregistration methods to preserve encapsulation, etc.).

Moreover, when you use delegates in the raw as your application’s callback mechanism, if you do not define a class’s delegate member variables as `private`, the caller will have direct access to the delegate objects. In this case, the caller could reassign the variable to a new delegate object (effectively deleting the current list of functions to call), and, worse yet, the caller would be able to directly invoke the delegate’s invocation list. To illustrate this problem, consider the following reworking (and simplification) of the `Car` class from the previous `CarDelegate` example:

```

public class Car
{
    public delegate void CarEngineHandler(string msgForCaller);

    // Now a public member!
    public CarEngineHandler ListOfHandlers;

    // Just fire out the Exploded notification.
    public void Accelerate(int delta)
    {
        if (ListOfHandlers != null)
        {
            ListOfHandlers("Sorry, this car is dead...");
        }
    }
}

```

Notice that you no longer have private delegate member variables encapsulated with custom registration methods. Because these members are indeed public, the caller can directly access the `ListOfHandlers` member variable and reassign this type to new `CarEngineHandler` objects and invoke the delegate whenever it so chooses.

```

static void Main(string[] args)
{
    Console.WriteLine("***** Agh! No Encapsulation! *****\n");
    // Make a Car.
    Car myCar = new Car();
    // We have direct access to the delegate!
    myCar.ListOfHandlers = CallWhenExploded;
    myCar.Accelerate(10);

    // We can now assign to a whole new object...
    // confusing at best.
    myCar.ListOfHandlers = CallHereToo;
    myCar.Accelerate(10);

    // The caller can also directly invoke the delegate!
    myCar.ListOfHandlers.Invoke("hee, hee, hee...");
    Console.ReadLine();
}

static void CallWhenExploded(string msg)
{
    Console.WriteLine(msg);
}

static void CallHereToo(string msg)
{
    Console.WriteLine(msg);
}

```

Exposing public delegate members breaks encapsulation, which not only can lead to code that is hard to maintain (and debug) but could also open your application to possible security risks! Here is the output of the current example:

---

```
***** Agh! No Encapsulation! *****
```

```
Sorry, this car is dead...
Sorry, this car is dead...
hee, hee, hee...
```

---

Obviously, you would not want to give other applications the power to change what a delegate is pointing to or to invoke the members without your permission. Given this, it is common practice to declare private delegate member variables.

## The C# event Keyword

As a shortcut, so you don't have to build custom methods to add or remove methods to a delegate's invocation list, C# provides the event keyword. When the compiler processes the event keyword, you are automatically provided with registration and unregistration methods, as well as any necessary member variables for your delegate types. These delegate member variables are *always* declared private, and, therefore, they are not directly exposed from the object firing the event. To be sure, the event keyword can be used to simplify how a custom class sends out notifications to external objects.

Defining an event is a two-step process. First, you need to define a delegate type (or reuse an existing one) that will hold the list of methods to be called when the event is fired. Next, you declare an event (using the C# event keyword) in terms of the related delegate type.

To illustrate the event keyword, create a new console application named CarEvents. In this iteration of the Car class, you will define two events named AboutToBlow and Exploded. These events are associated to a single delegate type named CarEngineHandler. Here are the initial updates to the Car class:

```
public class Car
{
    // This delegate works in conjunction with the
    // Car's events.
    public delegate void CarEngineHandler(string msg);

    // This car can send these events.
    public event CarEngineHandler Exploded;
    public event CarEngineHandler AboutToBlow;
    ...
}
```

Sending an event to the caller is as simple as specifying the event by name, along with any required parameters as defined by the associated delegate. To ensure that the caller has indeed registered with the event, you will want to check the event against a null value before invoking the delegate's method set. With these points in mind, here is the new iteration of the Car's Accelerate() method:

```
public void Accelerate(int delta)
{
    // If the car is dead, fire Exploded event.
```

```

if (_carIsDead)
{
    Exploded?.Invoke("Sorry, this car is dead...");
}
else
{
    CurrentSpeed += delta;

    // Almost dead?
    if (10 == MaxSpeed - CurrentSpeed)
    {
        AboutToBlow?.Invoke("Careful buddy! Gonna blow!");
    }

    // Still OK!
    if (CurrentSpeed >= MaxSpeed)
    {
        _carIsDead = true;
    }
    else
    {
        Console.WriteLine("CurrentSpeed = {0}", CurrentSpeed);
    }
}
}

```

With this, you have configured the car to send two custom events without having to define custom registration functions or declare delegate member variables. You will see the usage of this new automobile in just a moment, but first let's check the event architecture in a bit more detail.

## Events Under the Hood

When the compiler processes the C# event keyword, it generates two hidden methods, one having an `add_` prefix and the other having a `remove_` prefix. Each prefix is followed by the name of the C# event. For example, the `Exploded` event results in two hidden methods named `add_Exploded()` and `remove_Exploded()`. If you were to check out the CIL instructions behind `add_AboutToBlow()`, you would find a call to the `Delegate.Combine()` method. Consider the partial CIL code:

```

.method public hidebysig specialname instance void add_AboutToBlow(class CarEvents.Car/
CarEngineHandler 'value') cil managed
{
...
    IL_000b: call class [System.Runtime]System.Delegate
[System.Runtime]System.Delegate::Combine(class [System.Runtime]System.Delegate,
class [System.Runtime]System.Delegate)
...
} // end of method Car::add_AboutToBlow

```



As you would expect, `remove_AboutToBlow()` will call `Delegate.Remove()` on your behalf.

```
.method public hidebysig specialname instance void remove_AboutToBlow
(class CarEvents.Car/CarEngineHandler 'value') cil managed
    IL_000b: call class [System.Runtime]System.Delegate
    [System.Runtime]System.Delegate::Remove(class [System.Runtime]System.Delegate,
    class [System.Runtime]System.Delegate)
...
}
```

Finally, the CIL code representing the event itself makes use of the `.addon` and `.removeon` directives to map the names of the correct `add_XXX()` and `remove_XXX()` methods to invoke.

```
.event CarEvents.Car/CarEngineHandler AboutToBlow
{
    .addon instance void CarEvents.Car::add_AboutToBlow
    (class CarEvents.Car/CarEngineHandler)
    .removeon instance void CarEvents.Car::remove_AboutToBlow
    (class CarEvents.Car/CarEngineHandler)
} // end of event Car::AboutToBlow
```

Now that you understand how to build a class that can send C# events (and are aware that events are little more than a typing time-saver), the next big question is how to listen to the incoming events on the caller's side.

## Listening to Incoming Events

C# events also simplify the act of registering the caller-side event handlers. Rather than having to specify custom helper methods, the caller simply uses the `+=` and `-=` operators directly (which triggers the correct `add_XXX()` or `remove_XXX()` method in the background). When you want to register with an event, follow the pattern shown here:

```
// NameOfObject.NameOfEvent +=
//     new RelatedDelegate(functionToCall);
//
Car.CarEngineHandler d =
    new Car.CarEngineHandler(CarExplodedEventHandler);
myCar.Exploded += d;
```

When you want to detach from a source of events, use the `-=` operator, using the following pattern:

```
// NameOfObject.NameOfEvent -=
//     new RelatedDelegate(functionToCall);
//
myCar.Exploded -= d;
```

Note that you can also use the method group conversion syntax with events as well:

```
Car.CarEngineHandler d = CarExplodedEventHandler;
myCar.Exploded += d;
```

Given these very predictable patterns, here is the refactored `Main()` method, now using the C# event registration syntax:

```
static void Main(string[] args)
{
    Console.WriteLine("***** Fun with Events *****\n");
    Car c1 = new Car("SlugBug", 100, 10);

    // Register event handlers.
    c1.AboutToBlow += CarIsAlmostDoomed;
    c1.AboutToBlow += CarAboutToBlow;

    Car.CarEngineHandler d = CarExploded;
    c1.Exploded += d;

    Console.WriteLine("***** Speeding up *****");
    for (int i = 0; i < 6; i++)
    {
        c1.Accelerate(20);
    }

    // Remove CarExploded method
    // from invocation list.
    c1.Exploded -= d;

    Console.WriteLine("\n***** Speeding up *****");
    for (int i = 0; i < 6; i++)
    {
        c1.Accelerate(20);
    }
    Console.ReadLine();
}

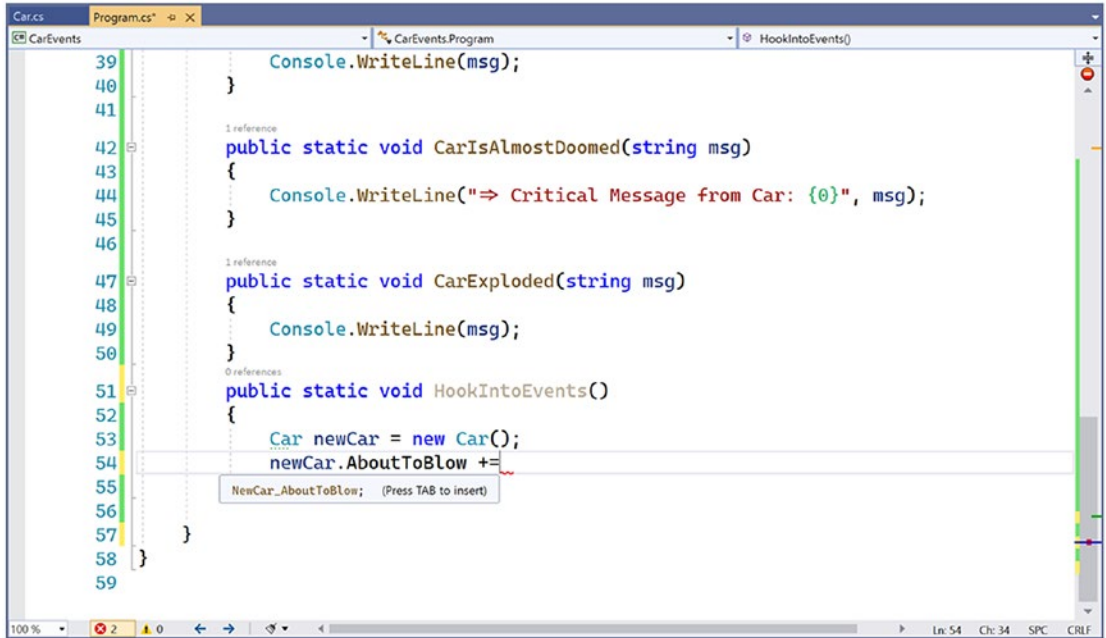
public static void CarAboutToBlow(string msg)
{
    Console.WriteLine(msg);
}

public static void CarIsAlmostDoomed(string msg)
{
    Console.WriteLine("=> Critical Message from Car: {0}", msg);
}

public static void CarExploded(string msg)
{ Console.WriteLine(msg); }
```

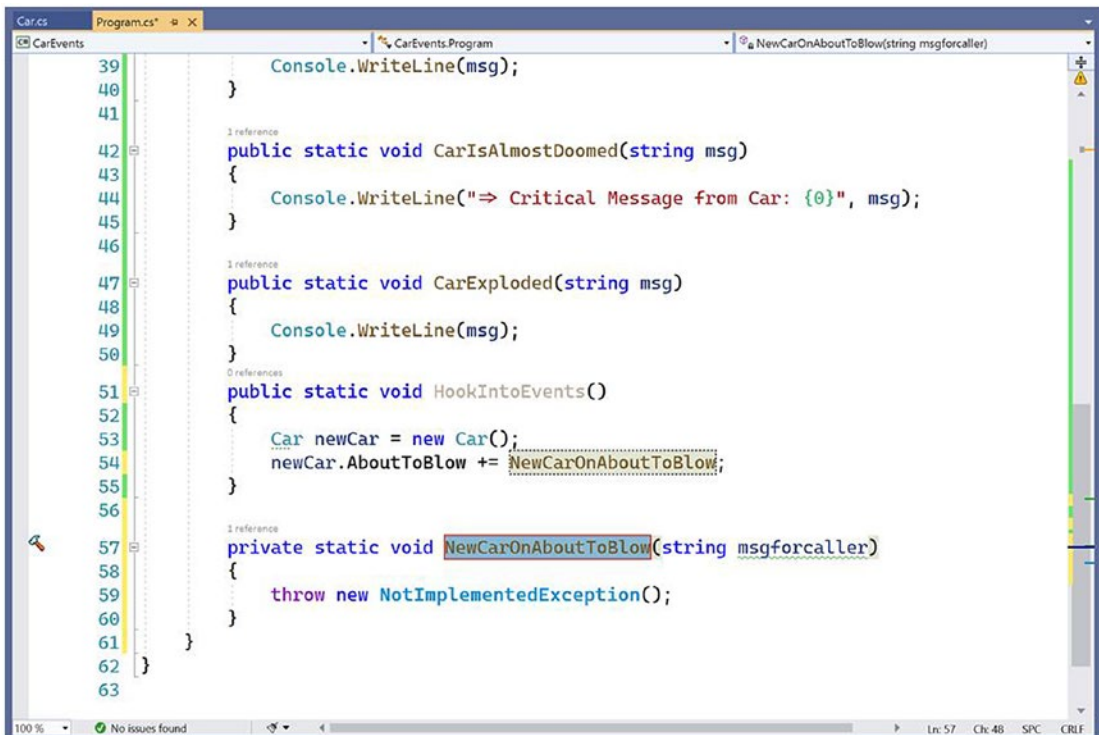
## Simplifying Event Registration Using Visual Studio

Visual Studio offers assistance with the process of registering event handlers. When you apply the `+=` syntax during event registration, you will find an IntelliSense window displayed, inviting you to hit the Tab key to autocomplete the associated delegate instance (see Figure 12-1), which is captured using *method group conversion syntax*.



**Figure 12-1.** Delegate selection IntelliSense

After you hit the Tab key, the IDE will generate the new method automatically, as shown in Figure 12-2.



**Figure 12-2.** Delegate target format IntelliSense

Note the stub code is in the correct format of the delegate target (note that this method has been declared static because the event was registered within a static method).

```
static void NewCar_AboutToBlow(string msg)
{
    throw new NotImplementedException();
}
```

IntelliSense is available to all .NET Core events in the base class libraries. This IDE feature is a massive time-saver, given that it saves you from having to search the help system to figure out both the correct delegate to use with a particular event and the format of the delegate target method.

## Creating Custom Event Arguments

Truth be told, there is one final enhancement you could make to the current iteration of the Car class that mirrors Microsoft's recommended event pattern. As you begin to explore the events sent by a given type in the base class libraries, you will find that the first parameter of the underlying delegate is a `System.Object`, while the second parameter is a descendant of `System.EventArgs`.

The `System.Object` argument represents a reference to the object that sent the event (such as the Car), while the second parameter represents information regarding the event at hand. The `System.EventArgs` base class represents an event that is not sending any custom information.

```
public class EventArgs
{
    public static readonly EventArgs Empty;
    public EventArgs();
}
```

For simple events, you can pass an instance of `EventArgs` directly. However, when you want to pass along custom data, you should build a suitable class deriving from `EventArgs`. For this example, assume you have a class named `CarEventArgs`, which maintains a string representing the message sent to the receiver.

```
public class CarEventArgs : EventArgs
{
    public readonly string msg;
    public CarEventArgs(string message)
    {
        msg = message;
    }
}
```

With this, you would now update the `CarEngineHandler` delegate type definition as follows (the events would be unchanged):

```
public class Car
{
    public delegate void CarEngineHandler(object sender, CarEventArgs e);
    ...
}
```

Here, when firing the events from within the `Accelerate()` method, you would now need to supply a reference to the current `Car` (via the `this` keyword) and an instance of the `CarEventArgs` type. For example, consider the following partial update:

```
public void Accelerate(int delta)
{
    // If the car is dead, fire Exploded event.
    if (carIsDead)
    {
        Exploded?.Invoke(this, new CarEventArgs("Sorry, this car is dead..."));
    }
    ...
}
```

On the caller's side, all you would need to do is update your event handlers to receive the incoming parameters and obtain the message via the read-only field. Here's an example:

```
public static void CarAboutToBlow(object sender, CarEventArgs e)
{
    Console.WriteLine($"{sender} says: {msg}");
}
```

If the receiver wants to interact with the object that sent the event, you can explicitly cast the `System.Object`. From this reference, you can make use of any public member of the object that sent the event notification.

```
public static void CarAboutToBlow(object sender, CarEventArgs e)
{
    // Just to be safe, perform a
    // runtime check before casting.
    if (sender is Car c)
    {
        Console.WriteLine(
            $"Critical Message from {c.PetName}: {e.msg}");
    }
}
```

## The Generic EventHandler<T> Delegate

Given that so many custom delegates take an object as the first parameter and an `EventArgs` descendant as the second, you could further streamline the previous example by using the generic `EventHandler<T>` type, where `T` is your custom `EventArgs` type. Consider the following update to the `Car` type (notice how you no longer need to define a custom delegate type at all):

```
public class Car
{
    ...
    public event EventHandler<CarEventArgs> Exploded;
    public event EventHandler<CarEventArgs> AboutToBlow;
}
```

The `Main()` method could then use `EventHandler<CarEventArgs>` anywhere you previously specified `CarEventHandler` (or, once again, use method group conversion).

```
static void Main(string[] args)
{
    Console.WriteLine("***** Prim and Proper Events *****\n");

    // Make a car as usual.
    Car c1 = new Car("SlugBug", 100, 10);

    // Register event handlers.
    c1.AboutToBlow += CarIsAlmostDoomed;
    c1.AboutToBlow += CarAboutToBlow;

    EventHandler<CarEventArgs> d = CarExploded;
    c1.Exploded += d;
    ...
}
```

Great! At this point, you have seen the core aspects of working with delegates and events in the C# language. While you could use this information for just about all your callback needs, you will wrap up this chapter with a look at some final simplifications, specifically anonymous methods and lambda expressions.

## Understanding C# Anonymous Methods

As you have seen, when a caller wants to listen to incoming events, it must define a custom method in a class (or structure) that matches the signature of the associated delegate. Here's an example:

```
class Program
{
    static void Main(string[] args)
    {
        SomeType t = new SomeType();

        // Assume "SomeDelegate" can point to methods taking no
        // args and returning void.
        t.SomeEvent += new SomeDelegate(MyEventHandler);
    }

    // Typically only called by the SomeDelegate object.
    public static void MyEventHandler()
    {
        // Do something when event is fired.
    }
}
```

When you think about it, however, methods such as `MyEventHandler()` are seldom intended to be called by any part of the program other than the invoking delegate. As far as productivity is concerned, it is a bit of a bother (though in no way a showstopper) to manually define a separate method to be called by the delegate object.

To address this point, it is possible to associate an event directly to a block of code statements at the time of event registration. Formally, such code is termed an *anonymous method*. To illustrate the syntax, check out the following updates to the `Main()` method, which handles the events sent from the `Car` class using anonymous methods, rather than specifically named event handlers:

```
class Program
{
    static void Main(string[] args)
    {
        Console.WriteLine("***** Anonymous Methods *****\n");
        Car c1 = new Car("SlugBug", 100, 10);

        // Register event handlers as anonymous methods.
        c1.AboutToBlow += delegate
        {
            Console.WriteLine("Eek! Going too fast!");
        };

        c1.AboutToBlow += delegate(object sender, CarEventArgs e)
        {
            Console.WriteLine("Message from Car: {0}", e.msg);
        };
    }
}
```

```

    c1.Exploded += delegate(object sender, CarEventArgs e)
    {
        Console.WriteLine("Fatal Message from Car: {0}", e.msg);
    };

    // This will eventually trigger the events.
    for (int i = 0; i < 6; i++)
    {
        c1.Accelerate(20);
    }
    Console.ReadLine();
}
}

```

---

■ **Note** The final curly bracket of an anonymous method must be terminated by a semicolon. If you fail to do so, you are issued a compilation error.

---

Again, notice that the Program type no longer needs to define specific static event handlers such as CarAboutToBlow() or CarExploded(). Rather, the unnamed (aka anonymous) methods are defined inline at the time the caller is handling the event using the += syntax. The basic syntax of an anonymous method matches the following pseudocode:

```

class Program
{
    static void Main(string[] args)
    {
        SomeType t = new SomeType();
        t.SomeEvent += delegate (optionallySpecifiedDelegateArgs)
        { /* statements */ };
    }
}

```

When handling the first AboutToBlow event within the previous Main() method, notice that you are not specifying the arguments passed from the delegate.

```

c1.AboutToBlow += delegate
{
    Console.WriteLine("Eek! Going too fast!");
};

```

Strictly speaking, you are not required to receive the incoming arguments sent by a specific event. However, if you want to make use of the possible incoming arguments, you will need to specify the parameters prototyped by the delegate type (as shown in the second handling of the AboutToBlow and Exploded events). Here's an example:

```

c1.AboutToBlow += delegate(object sender, CarEventArgs e)
{
    Console.WriteLine("Critical Message from Car: {0}", e.msg);
};

```



## Accessing Local Variables

Anonymous methods are interesting, in that they are able to access the local variables of the method that defines them. Formally speaking, such variables are termed *outer variables* of the anonymous method. A few important points about the interaction between an anonymous method scope and the scope of the defining method should be mentioned:

- An anonymous method cannot access `ref` or `out` parameters of the defining method.
- An anonymous method cannot have a local variable with the same name as a local variable in the outer method.
- An anonymous method can access instance variables (or static variables, as appropriate) in the outer class scope.
- An anonymous method can declare local variables with the same name as outer class member variables (the local variables have a distinct scope and hide the outer class member variables).

Assume your `Main()` method defined a local integer named `aboutToBlowCounter`. Within the anonymous methods that handle the `AboutToBlow` event, you will increment this counter by one and print out the tally before `Main()` completes.

```
static void Main(string[] args)
{
    Console.WriteLine("***** Anonymous Methods *****\n");
    int aboutToBlowCounter = 0;

    // Make a car as usual.
    Car c1 = new Car("SlugBug", 100, 10);

    // Register event handlers as anonymous methods.
    c1.AboutToBlow += delegate
    {
        aboutToBlowCounter++;
        Console.WriteLine("Eek! Going too fast!");
    };

    c1.AboutToBlow += delegate(object sender, CarEventArgs e)
    {
        aboutToBlowCounter++;
        Console.WriteLine("Critical Message from Car: {0}", e.msg);
    };

    // This will eventually trigger the events.
    for (int i = 0; i < 6; i++)
    {
        c1.Accelerate(20);
    }

    Console.WriteLine("AboutToBlow event was fired {0} times.",
        aboutToBlowCounter);
    Console.ReadLine();
}
```

After you run this updated `Main()` method, you will find the final `Console.WriteLine()` reports the `AboutToBlow` event was fired twice.

## Understanding Lambda Expressions

To conclude your look at the .NET Core event architecture, you will examine C# *lambda expressions*. As just explained, C# supports the ability to handle events “inline” by assigning a block of code statements directly to an event using anonymous methods, rather than building a stand-alone method to be called by the underlying delegate. Lambda expressions are nothing more than a concise way to author anonymous methods and ultimately simplify how you work with the .NET Core delegate type.

To set the stage for your examination of lambda expressions, create a new Console Application project named `LambdaExpressions`. To begin, consider the `FindAll()` method of the generic `List<T>` class. This method can be called when you need to extract a subset of items from the collection and is prototyped like so:

```
// Method of the System.Collections.Generic.List<T>
class public List<T> FindAll(Predicate<T> match)
```

As you can see, this method returns a new `List<T>` that represents the subset of data. Also notice that the sole parameter to `FindAll()` is a generic delegate of type `System.Predicate<T>`. This delegate type can point to any method returning a `bool` and takes a single type parameter as the only input parameter.

```
// This delegate is used by FindAll() method
// to extract out the subset.
public delegate bool Predicate<T>(T obj);
```

When you call `FindAll()`, each item in the `List<T>` is passed to the method pointed to by the `Predicate<T>` object. The implementation of said method will perform some calculations to see whether the incoming data matches the necessary criteria and will return `true` or `false`. If this method returns `true`, the item will be added to the new `List<T>` that represents the subset (got all that?).

Before you see how lambda expressions can simplify working with `FindAll()`, let’s work the problem out in longhand notation, using the delegate objects directly. Add a method (named `TraditionalDelegateSyntax()`) within your `Program` type that interacts with the `System.Predicate<T>` type to discover the even numbers in a `List<T>` of integers.

```
using System;
using System.Collections.Generic;
class Program
{
    static void Main(string[] args)
    {
        Console.WriteLine("***** Fun with Lambdas *****\n");
        TraditionalDelegateSyntax();
        Console.ReadLine();
    }

    static void TraditionalDelegateSyntax()
    {
        // Make a list of integers.
        List<int> list = new List<int>();
        list.AddRange(new int[] { 20, 1, 4, 8, 9, 44 });
```

```

// Call FindAll() using traditional delegate syntax.
Predicate<int> callback = IsEvenNumber;
List<int> evenNumbers = list.FindAll(callback);

Console.WriteLine("Here are your even numbers:");
foreach (int evenNumber in evenNumbers)
{
    Console.Write("{0}\t", evenNumber);
}
Console.WriteLine();
}

// Target for the Predicate<> delegate.
static bool IsEvenNumber(int i)
{
    // Is it an even number?
    return (i % 2) == 0;
}
}

```

Here, you have a method (`IsEvenNumber()`) that is in charge of testing the incoming integer parameter to see whether it is even or odd via the C# modulo operator, `%`. If you execute your application, you will find the numbers 20, 4, 8, and 44 print to the console.

While this traditional approach to working with delegates behaves as expected, the `IsEvenNumber()` method is invoked only in limited circumstances – specifically when you call `FindAll()`, which leaves you with the baggage of a full method definition. While you could make this a local function, if you were to instead use an anonymous method, your code would clean up considerably. Consider the following new method of the `Program` class:

```

static void AnonymousMethodSyntax()
{
    // Make a list of integers.
    List<int> list = new List<int>();
    list.AddRange(new int[] { 20, 1, 4, 8, 9, 44 });

    // Now, use an anonymous method.
    List<int> evenNumbers =
        list.FindAll(delegate(int i) { return (i % 2) == 0; } );

    Console.WriteLine("Here are your even numbers:");
    foreach (int evenNumber in evenNumbers)
    {
        Console.Write("{0}\t", evenNumber);
    }
    Console.WriteLine();
}

```

In this case, rather than directly creating a `Predicate<T>` delegate object and then authoring a stand-alone method, you are able to inline a method anonymously. While this is a step in the right direction, you are still required to use the `delegate` keyword (or a strongly typed `Predicate<T>`), and you must ensure that the parameter `list` is a dead-on match.

```
List<int> evenNumbers = list.FindAll(
    delegate(int i)
    {
        return (i % 2) == 0;
    }
);
```

*Lambda expressions* can be used to simplify the call to `FindAll()` even more. When you use lambda syntax, there is no trace of the underlying delegate object whatsoever. Consider the following new method to the `Program` class:

```
static void LambdaExpressionSyntax()
{
    // Make a list of integers.
    List<int> list = new List<int>();
    list.AddRange(new int[] { 20, 1, 4, 8, 9, 44 });

    // Now, use a C# lambda expression.
    List<int> evenNumbers = list.FindAll(i => (i % 2) == 0);

    Console.WriteLine("Here are your even numbers:");
    foreach (int evenNumber in evenNumbers)
    {
        Console.Write("{0}\t", evenNumber);
    }
    Console.WriteLine();
}
```

In this case, notice the rather strange statement of code passed into the `FindAll()` method, which is in fact a lambda expression. In this iteration of the example, there is no trace whatsoever of the `Predicate<T>` delegate (or the `delegate` keyword, for that matter). All you have specified is the lambda expression.

```
i => (i % 2) == 0
```

Before I break this syntax down, first understand that lambda expressions can be used anywhere you would have used an anonymous method or a strongly typed delegate (typically with far fewer keystrokes). Under the hood, the C# compiler translates the expression into a standard anonymous method making use of the `Predicate<T>` delegate type (which can be verified using `ildasm.exe` or `reflector.exe`). Specifically, the following code statement:

```
// This lambda expression...
List<int> evenNumbers = list.FindAll(i => (i % 2) == 0);
```

is compiled into the following approximate C# code:

```
// ...becomes this anonymous method.
List<int> evenNumbers = list.FindAll(delegate (int i)
{
    return (i % 2) == 0;
});
```

## Dissecting a Lambda Expression

A lambda expression is written by first defining a parameter list, followed by the `=>` token (C#'s token for the lambda operator found in the *lambda calculus*), followed by a set of statements (or a single statement) that will process these arguments. From a high level, a lambda expression can be understood as follows:

```
ArgumentsToProcess => StatementsToProcessThem
```

Within the `LambdaExpressionSyntax()` method, things break down like so:

```
// "i" is our parameter list.
// "(i % 2) == 0" is our statement set to process "i".
List<int> evenNumbers = list.FindAll(i => (i % 2) == 0);
```

The parameters of a lambda expression can be explicitly or implicitly typed. Currently, the underlying data type representing the `i` parameter (an integer) is determined implicitly. The compiler is able to figure out that `i` is an integer based on the context of the overall lambda expression and the underlying delegate. However, it is also possible to explicitly define the type of each parameter in the expression by wrapping the data type and variable name in a pair of parentheses, as follows:

```
// Now, explicitly state the parameter type.
List<int> evenNumbers = list.FindAll((int i) => (i % 2) == 0);
```

As you have seen, if a lambda expression has a single, implicitly typed parameter, the parentheses may be omitted from the parameter list. If you want to be consistent regarding your use of lambda parameters, you can *always* wrap the parameter list within parentheses, leaving you with this expression:

```
List<int> evenNumbers = list.FindAll((i) => (i % 2) == 0);
```

Finally, notice that currently the expression has not been wrapped in parentheses (you have of course wrapped the modulo statement to ensure it is executed first before the test for equality). Lambda expressions do allow for the statement to be wrapped as follows:

```
// Now, wrap the expression as well.
List<int> evenNumbers = list.FindAll((i) => ((i % 2) == 0));
```

Now that you have seen the various ways to build a lambda expression, how can you read this lambda statement in human-friendly terms? Leaving the raw mathematics behind, the following explanation fits the bill:

```
// My list of parameters (in this case, a single integer named i)
// will be processed by the expression (i % 2) == 0.
List<int> evenNumbers = list.FindAll((i) => ((i % 2) == 0));
```

## Processing Arguments Within Multiple Statements

The first lambda expression was a single statement that ultimately evaluated to a Boolean. However, as you know, many delegate targets must perform a number of code statements. For this reason, C# allows you to build lambda expressions using multiple statement blocks. When your expression must process the parameters using multiple lines of code, you can do so by denoting a scope for these statements using the expected curly brackets. Consider the following example update to the `LambdaExpressionSyntax()` method:

```
static void LambdaExpressionSyntax()
{
    // Make a list of integers.
    List<int> list = new List<int>();
    list.AddRange(new int[] { 20, 1, 4, 8, 9, 44 });

    // Now process each argument within a group of
    // code statements.
    List<int> evenNumbers = list.FindAll((i) =>
    {
        Console.WriteLine("value of i is currently: {0}", i);
        bool isEven = ((i % 2) == 0);
        return isEven;
    });

    Console.WriteLine("Here are your even numbers:");
    foreach (int evenNumber in evenNumbers)
    {
        Console.WriteLine("{0}\t", evenNumber);
    }
    Console.WriteLine();
}
```

In this case, the parameter `list` (again, a single integer named `i`) is being processed by a set of code statements. Beyond the calls to `Console.WriteLine()`, the modulo statement has been broken into two code statements for increased readability. Assuming each of the methods you've looked at in this section is called from within `Main()`:

```
static void Main(string[] args)
{
    Console.WriteLine("***** Fun with Lambdas *****\n");
    TraditionalDelegateSyntax();
    AnonymousMethodSyntax();
    Console.WriteLine();
    LambdaExpressionSyntax();
    Console.ReadLine();
}
```

you will find the following output:

---

```
***** Fun with Lambdas *****
Here are your even numbers:
20      4      8      44
Here are your even numbers:
20      4      8      44
value of i is currently: 20
value of i is currently: 1
value of i is currently: 4
value of i is currently: 8
value of i is currently: 9
value of i is currently: 44
Here are your even numbers:
20      4      8      44
```

---

## Lambda Expressions with Multiple (or Zero) Parameters

The lambda expressions you have seen in this chapter so far processed a single parameter. This is not a requirement, however, as a lambda expression may process multiple arguments (or none). To illustrate the first scenario of multiple arguments, add the following incarnation of the `SimpleMath` type:

```
public class SimpleMath
{
    public delegate void MathMessage(string msg, int result);
    private MathMessage _mmDelegate;

    public void SetMathHandler(MathMessage target)
    {
        _mmDelegate = target;
    }

    public void Add(int x, int y)
    {
        _mmDelegate?.Invoke("Adding has completed!", x + y);
    }
}
```

Notice that the `MathMessage` delegate type is expecting two parameters. To represent them as a lambda expression, the `Main()` method might be written as follows:

```
static void Main(string[] args)
{
    // Register with delegate as a lambda expression.
    SimpleMath m = new SimpleMath();
    m.SetMathHandler((msg, result) =>
        {Console.WriteLine("Message: {0}, Result: {1}", msg, result)});
}
```

```
// This will execute the lambda expression.
m.Add(10, 10);
Console.ReadLine();
}
```

Here, you are leveraging type inference, as the two parameters have not been strongly typed for simplicity. However, you could call `SetMathHandler()`, as follows:

```
m.SetMathHandler((string msg, int result) =>
    {Console.WriteLine("Message: {0}, Result: {1}", msg, result)});
```

Finally, if you are using a lambda expression to interact with a delegate taking no parameters at all, you may do so by supplying a pair of empty parentheses as the parameter. Thus, assuming you have defined the following delegate type:

```
public delegate string VerySimpleDelegate();
```

you could handle the result of the invocation as follows:

```
// Prints "Enjoy your string!" to the console.
VerySimpleDelegate d = new VerySimpleDelegate( () => {return "Enjoy your string!";} );
Console.WriteLine(d());
```

Using the new expression syntax, the previous line can be written like this:

```
VerySimpleDelegate d2 =
    new VerySimpleDelegate(() => "Enjoy your string!");
```

which can also be shortened to

```
VerySimpleDelegate d3 = () => "Enjoy your string!";
```

## Retrofitting the CarEvents Example Using Lambda Expressions

Given that the whole reason for lambda expressions is to provide a clean, concise manner to define an anonymous method (and therefore indirectly a manner to simplify working with delegates), let's retrofit the `CarEventArgs` project created earlier in this chapter. Here is a simplified version of that project's `Program` class, which makes use of lambda expression syntax (rather than the raw delegates) to hook into each event sent from the `Car` object:

```
static void Main(string[] args)
{
    Console.WriteLine("***** More Fun with Lambdas *****\n");

    // Make a car as usual.
    Car c1 = new Car("SlugBug", 100, 10);

    // Hook into events with lambdas!
    c1.AboutToBlow += (sender, e)
        => { Console.WriteLine(e.msg); };
    c1.Exploded += (sender, e) => { Console.WriteLine(e.msg); };
```



```
// Speed up (this will generate the events).
Console.WriteLine("\n***** Speeding up *****");
for (int i = 0; i < 6; i++)
{
    c1.Accelerate(20);
}
Console.ReadLine();
}
```

## Lambdas and Expression-Bodied Members (Updated 7.0)

Now that you understand lambda expressions and how they work, it should be much clearer how expression-bodied members work under the covers. As mentioned in Chapter 4, as of C# 6, it is permissible to use the `=>` operator to simplify member implementations. Specifically, if you have a method or property (in addition to a custom operator or conversion routine; see Chapter 11) that consists of exactly a single line of code in the implementation, you are not required to define a scope via curly bracket. You can instead leverage the lambda operator and write an expression-bodied member. In C# 7, you can also use this syntax for class constructors, finalizers (covered in Chapter 9), and get and set accessors on property members.

Be aware, however, this new shortened syntax can be used anywhere at all, even when your code has nothing to do with delegates or events. So, for example, if you were to build a trivial class to add two numbers, you might write the following:

```
class SimpleMath
{
    public int Add(int x, int y)
    {
        return x + y;
    }

    public void PrintSum(int x, int y)
    {
        Console.WriteLine(x + y);
    }
}
```

Alternatively, you could now write code like the following:

```
class SimpleMath
{
    public int Add(int x, int y) => x + y;
    public void PrintSum(int x, int y) => Console.WriteLine(x + y);
}
```

Ideally, at this point you can see the overall role of lambda expressions and understand how they provide a “functional manner” to work with anonymous methods and delegate types. Although the lambda operator (`=>`) might take a bit to get used to, always remember a lambda expression can be broken down to the following simple equation:

```
ArgumentsToProcess => StatementsToProcessThem
```

Or, if using the `=>` operator to implement a single-line type member, it would be like this:

```
TypeMember => SingleCodeStatement
```

It is worth pointing out that the LINQ programming model also makes substantial use of lambda expressions to help simplify your coding efforts. You will examine LINQ beginning in Chapter 13.

## Summary

In this chapter, you examined a number of ways in which multiple objects can partake in a bidirectional conversation. First, you looked at the C# `delegate` keyword, which is used to indirectly construct a class derived from `System.MulticastDelegate`. As you saw, a delegate object maintains the method to call when told to do so.

You then examined the C# `event` keyword, which, when used in conjunction with a delegate type, can simplify the process of sending your event notifications to waiting callers. As shown via the resulting CIL, the .NET event model maps to hidden calls on the `System.Delegate/System.MulticastDelegate` types. In this light, the C# `event` keyword is purely optional, in that it simply saves you some typing time. As well, you have seen that the C# 6.0 null conditional operator simplifies how you safely fire events to any interested party.

This chapter also explored a C# language feature termed *anonymous methods*. Using this syntactic construct, you are able to directly associate a block of code statements to a given event. As you have seen, anonymous methods are free to ignore the parameters sent by the event and have access to the “outer variables” of the defining method. You also examined a simplified way to register events using *method group conversion*.

Finally, you wrapped things up by looking at the C# *lambda operator*, `=>`. As shown, this syntax is a great shorthand notation for authoring anonymous methods, where a stack of arguments can be passed into a group of statements for processing. Any method in the .NET Core platform that takes a delegate object as an argument can be substituted with a related lambda expression, which will typically simplify your codebase quite a bit.

## CHAPTER 13



# LINQ to Objects

Regardless of the type of application you are creating using the .NET Core platform, your program will certainly need to access some form of data as it executes. To be sure, data can be found in numerous locations, including XML files, relational databases, in-memory collections, and primitive arrays. Historically speaking, based on the location of said data, programmers needed to make use of different and unrelated APIs. The Language Integrated Query (LINQ) technology set, introduced initially in .NET 3.5, provides a concise, symmetrical, and strongly typed manner to access a wide variety of data stores. In this chapter, you will begin your investigation of LINQ by focusing on LINQ to Objects.

Before you dive into LINQ to Objects proper, the first part of this chapter quickly reviews the key C# programming constructs that enable LINQ. As you work through this chapter, you will find that implicitly typed local variables, object initialization syntax, lambda expressions, extension methods, and anonymous types will be quite useful (if not occasionally mandatory).

After this supporting infrastructure is reviewed, the remainder of the chapter will introduce you to the LINQ programming model and its role in the .NET platform. Here, you will come to learn the role of query operators and query expressions, which allow you to define statements that will interrogate a data source to yield the requested result set. Along the way, you will build numerous LINQ examples that interact with data contained within arrays as well as various collection types (both generic and nongeneric) and understand the assemblies, namespaces, and types that represent the LINQ to Objects API.

---

■ **Note** The information in this chapter is the foundation for future sections and chapters of this book, including Parallel LINQ (Chapter 15) and Entity Framework Core (Chapters 22 and 23).

---

## LINQ-Specific Programming Constructs

From a high level, LINQ can be understood as a strongly typed query language, embedded directly into the grammar of C#. Using LINQ, you can build any number of expressions that have a look and feel similar to that of a database SQL query. However, a LINQ query can be applied to any number of data stores, including stores that have nothing to do with a literal relational database.

---

■ **Note** Although LINQ queries can look similar to SQL queries, the syntax is *not* identical. In fact, many LINQ queries seem to be the exact opposite format of a similar database query! If you attempt to map LINQ directly to SQL, you will surely become frustrated. To keep your sanity, I recommend you try your best to regard LINQ queries as unique statements, which just “happen to look” similar to SQL.

---

When LINQ was first introduced to the .NET platform in version 3.5, the C# and VB languages were each expanded with a large number of new programming constructs used to support the LINQ technology set. Specifically, the C# language uses the following core LINQ-centric features:

- Implicitly typed local variables
- Object/collection initialization syntax
- Lambda expressions
- Extension methods
- Anonymous types

These features have already been explored in detail within various chapters of the text. However, to get the ball rolling, let's quickly review each feature in turn, just to make sure we are all in the proper mind-set.

---

■ **Note** Because the following sections are reviews of material covered elsewhere in the book, I have not included a C# code project for this content.

---

## Implicit Typing of Local Variables

In Chapter 3, you learned about the `var` keyword of C#. This keyword allows you to define a local variable without explicitly specifying the underlying data type. The variable, however, is strongly typed, as the compiler will determine the correct data type based on the initial assignment. Recall this code example from Chapter 3:

```
static void DeclareImplicitVars()
{
    // Implicitly typed local variables.
    var myInt = 0;
    var myBool = true;
    var myString = "Time, marches on...";

    // Print out the underlying type.
    Console.WriteLine("myInt is a: {0}", myInt.GetType().Name);
    Console.WriteLine("myBool is a: {0}",
        myBool.GetType().Name);
    Console.WriteLine("myString is a: {0}",
        myString.GetType().Name);
}
```

This language feature is helpful, and often mandatory, when using LINQ. As you will see during this chapter, many LINQ queries will return a sequence of data types, which are not known until compile time. Given that the underlying data type is not known until the application is compiled, you obviously can't declare a variable explicitly!

## Object and Collection Initialization Syntax

Chapter 5 explored the role of object initialization syntax, which allows you to create a class or structure variable and to set any number of its public properties in one fell swoop. The end result is a compact (yet still easy on the eyes) syntax that can be used to get your objects ready for use. Also recall from Chapter 9, the C# language allows you to use a similar syntax to initialize collections of objects. Consider the following code snippet, which uses collection initialization syntax to fill a `List<T>` of `Rectangle` objects, each of which maintains two `Point` objects to represent an (x,y) position:

```
List<Rectangle> myListOfRects = new List<Rectangle>
{
    new Rectangle {TopLeft = new Point { X = 10, Y = 10 },
                  BottomRight = new Point { X = 200, Y = 200}},
    new Rectangle {TopLeft = new Point { X = 2, Y = 2 },
                  BottomRight = new Point { X = 100, Y = 100}},
    new Rectangle {TopLeft = new Point { X = 5, Y = 5 },
                  BottomRight = new Point { X = 90, Y = 75}}
};
```

While you are never required to use collection/object initialization syntax, doing so results in a more compact codebase. Furthermore, this syntax, when combined with implicit typing of local variables, allows you to declare an anonymous type, which is useful when creating a LINQ projection. You'll learn about LINQ projections later in this chapter.

## Lambda Expressions

The C# lambda operator (`=>`) was fully explored in Chapter 12. Recall that this operator allows you to build a lambda expression, which can be used any time you invoke a method that requires a strongly typed delegate as an argument. Lambdas greatly simplify how you work with delegates, in that they reduce the amount of code you have to author by hand. Recall that a lambda expression can be broken down into the following usage:

```
( ArgumentsToProcess ) => { StatementsToProcessThem }
```

In Chapter 12, I walked you through how to interact with the `FindAll()` method of the generic `List<T>` class using three different approaches. After working with the raw `Predicate<T>` delegate and a C# anonymous method, you eventually arrived with the following (extremely concise) iteration that used the following lambda expression:

```
static void LambdaExpressionSyntax()
{
    // Make a list of integers.
    List<int> list = new List<int>();
    list.AddRange(new int[] { 20, 1, 4, 8, 9, 44 });

    // C# lambda expression.
    List<int> evenNumbers = list.FindAll(i => (i % 2) == 0);
}
```

```

Console.WriteLine("Here are your even numbers:");
foreach (int evenNumber in evenNumbers)
{
    Console.Write("{0}\t", evenNumber);
}
Console.WriteLine();
}

```

Lambdas will be useful when working with the underlying object model of LINQ. As you will soon find out, the C# LINQ query operators are simply a shorthand notation for calling true-blue methods on a class named `System.Linq.Enumerable`. These methods typically always require delegates (the `Func<>` delegate in particular) as parameters, which are used to process your data to yield the correct result set. Using lambdas, you can streamline your code and allow the compiler to infer the underlying delegate.

## Extension Methods

C# extension methods allow you to tack on new functionality to existing classes without the need to subclass. As well, extension methods allow you to add new functionality to sealed classes and structures, which could never be subclassed in the first place. Recall from Chapter 11, when you author an extension method, the first parameter is qualified with the `this` keyword and marks the type being extended. Also recall that extension methods must always be defined within a static class and must, therefore, also be declared using the `static` keyword. Here's an example:

```

namespace MyExtensions
{
    static class ObjectExtensions
    {
        // Define an extension method to System.Object.
        public static void DisplayDefiningAssembly(
            this object obj)
        {
            Console.WriteLine("{0} lives here:\n\t->{1}\n", obj.GetType().Name,
                Assembly.GetAssembly(obj.GetType()));
        }
    }
}

```

To use this extension, an application must import the namespace defining the extension (and possibly add a reference to the external assembly). At this point, simply import the defining namespace and code away.

```

static void Main(string[] args)
{
    // Since everything extends System.Object, all classes and structures
    // can use this extension.
    int myInt = 12345678;
    myInt.DisplayDefiningAssembly();

    System.Data.DataSet d = new System.Data.DataSet();
    d.DisplayDefiningAssembly();
    Console.ReadLine();
}

```

When you are working with LINQ, you will seldom, if ever, be required to manually build your own extension methods. However, as you create LINQ query expressions, you will actually be making use of numerous extension methods already defined by Microsoft. In fact, each C# LINQ query operator is a shorthand notation for making a manual call on an underlying extension method, typically defined by the `System.Linq.Enumerable` utility class.

## Anonymous Types

The final C# language feature I'd like to quickly review is that of anonymous types, which was explored in Chapter 11. This feature can be used to quickly model the “shape” of data by allowing the compiler to generate a new class definition at compile time, based on a supplied set of name-value pairs. Recall that this type will be composed using value-based semantics, and each virtual method of `System.Object` will be overridden accordingly. To define an anonymous type, declare an implicitly typed variable and specify the data's shape using object initialization syntax.

```
// Make an anonymous type that is composed of another.
var purchaseItem = new {
    TimeBought = DateTime.Now,
    ItemBought =
        new {Color = "Red", Make = "Saab", CurrentSpeed = 55},
    Price = 34.000};
```

LINQ makes frequent use of anonymous types when you want to project new forms of data on the fly. For example, assume you have a collection of `Person` objects and want to use LINQ to obtain information on the age and Social Security number of each. Using a LINQ projection, you can allow the compiler to generate a new anonymous type that contains your information.

## Understanding the Role of LINQ

That wraps up the quick review of the C# language features that allow LINQ to work its magic. However, why have LINQ in the first place? Well, as software developers, it is hard to deny that the vast majority of our programming time is spent obtaining and manipulating data. When speaking of “data,” it is easy to immediately envision information contained within relational databases. However, another popular location for data is within XML documents or simple text files.

Data can be found in numerous places beyond these two common homes for information. For instance, say you have an array or generic `List<T>` type containing 300 integers and you want to obtain a subset that meets a given criterion (e.g., only the odd or even members in the container, only prime numbers, only nonrepeating numbers greater than 50). Or perhaps you are making use of the reflection APIs and need to obtain only metadata descriptions for each class deriving from a particular parent class within an array of `Types`. Indeed, data is *everywhere*.

Prior to .NET 3.5, interacting with a particular flavor of data required programmers to use very diverse APIs. Consider, for example, Table 13-1, which illustrates several common APIs used to access various types of data (I'm sure you can think of many other examples).

**Table 13-1.** *Ways to Manipulate Various Types of Data*

The Data You Want	How to Obtain It
Relational data	System.Data.dll, System.Data.SqlClient.dll, etc.
XML document data	System.Xml.dll
Metadata tables	The System.Reflection namespace
Collections of objects	System.Array and the System.Collections/System.Collections.Generic namespaces

Of course, nothing is wrong with these approaches to data manipulation. In fact, you can (and will) certainly make direct use of ADO.NET, the XML namespaces, reflection services, and the various collection types. However, the basic problem is that each of these APIs is an island unto itself, which offers little in the way of integration. True, it is possible (for example) to save an ADO.NET DataSet as XML and then manipulate it via the System.Xml namespaces, but nonetheless, data manipulation remains rather asymmetrical.

The LINQ API is an attempt to provide a consistent, symmetrical manner in which programmers can obtain and manipulate “data” in the broad sense of the term. Using LINQ, you are able to create directly within the C# programming language constructs called *query expressions*. These query expressions are based on numerous query operators that have been intentionally designed to look and feel similar (but not quite identical) to a SQL expression.

The twist, however, is that a query expression can be used to interact with numerous types of data – even data that has nothing to do with a relational database. Strictly speaking, “LINQ” is the term used to describe this overall approach to data access. However, based on where you are applying your LINQ queries, you will encounter various terms, such as the following:

- *LINQ to Objects*: This term refers to the act of applying LINQ queries to arrays and collections.
- *LINQ to XML*: This term refers to the act of using LINQ to manipulate and query XML documents.
- *LINQ to Entities*: This aspect of LINQ allows you to make use of LINQ queries within the ADO.NET Entity Framework (EF) Core API.
- *Parallel LINQ (aka PLINQ)*: This allows for parallel processing of data returned from a LINQ query.

Today, LINQ is an integral part of the .NET Core base class libraries, managed languages, and Visual Studio itself.

## LINQ Expressions Are Strongly Typed

It is also important to point out that a LINQ query expression (unlike a traditional SQL statement) is *strongly typed*. Therefore, the C# compiler will keep you honest and make sure that these expressions are syntactically well formed. Tools such as Visual Studio can use metadata for useful features such as IntelliSense, autocompletion, and so forth.



## The Core LINQ Assemblies

When you opt to compile against .NET 3.5 or higher (including .NET Core and .NET Standard), each of the project templates will automatically reference the key LINQ assemblies. You will encounter additional LINQ libraries over the remainder of this book.

To work with LINQ to Objects, you must make sure that every C# code file that contains LINQ queries imports the `System.Linq` namespace. If you do not do so, you will run into a number of problems. So make sure the following using statement is in each code file that uses LINQ:

```
using System.Linq;
```

## Applying LINQ Queries to Primitive Arrays

To begin examining LINQ to Objects, let's build an application that will apply LINQ queries to various array objects. Create a Console Application project named `LinqOverArray`, and define a static helper method within the `Program` class named `QueryOverStrings()`. In this method, create a `string` array containing six or so items of your liking (here, I listed a batch of video games in my library). Make sure to have at least two entries that contain numerical values and a few that have embedded spaces.

```
static void QueryOverStrings()
{
    // Assume we have an array of strings.
    string[] currentVideoGames = {"Morrowind", "Uncharted 2", "Fallout 3", "Daxter", "System Shock 2"};
}
```

Now, update `Main()` to invoke `QueryOverStrings()`.

```
static void Main(string[] args)
{
    Console.WriteLine("***** Fun with LINQ to Objects *****\n");
    QueryOverStrings();
    Console.ReadLine();
}
```

When you have any array of data, it is common to extract a subset of items based on a given requirement. Maybe you want to obtain only the subitems that contain a number (e.g., `System Shock 2`, `Uncharted 2`, and `Fallout 3`), have more or less than some number of characters, or don't contain embedded spaces (e.g., `Morrowind` or `Daxter`). While you could certainly perform such tasks using members of the `System.Array` type and a bit of elbow grease, LINQ query expressions can greatly simplify the process.

Going on the assumption that you want to obtain from the array only items that contain an embedded blank space and you want these items listed in alphabetical order, you could build the following LINQ query expression:

```
static void QueryOverStrings()
{
    // Assume we have an array of strings.
    string[] currentVideoGames = {"Morrowind", "Uncharted 2", "Fallout 3", "Daxter", "System Shock 2"};

    // Build a query expression to find the items in the array
    // that have an embedded space.
```

```

IEnumerable<string> subset =
    from g in currentVideoGames
    where g.Contains(" ")
    orderby g
    select g;

// Print out the results.
foreach (string s in subset)
{
    Console.WriteLine("Item: {0}", s);
}
}

```

Notice that the query expression created here makes use of the `from`, `in`, `where`, `orderby`, and `select` LINQ query operators. You will dig into the formalities of query expression syntax later in this chapter. However, even now you should be able to read this statement roughly as “Give me the items inside of `currentVideoGames` that contain a space, ordered alphabetically.”

Here, each item that matches the search criteria has been given the name `g` (as in “game”); however, any valid C# variable name would do.

```

IEnumerable<string> subset =
    from game in currentVideoGames
    where game.Contains(" ")
    orderby game
    select game;

```

Notice that the returned sequence is held in a variable named `subset`, typed as a type that implements the generic version of `IEnumerable<T>`, where `T` is of type `System.String` (after all, you are querying an array of strings). After you obtain the result set, you then simply print out each item using a standard `foreach` construct. If you run your application, you will find the following output:

---

```

***** Fun with LINQ to Objects *****
Item: Fallout 3
Item: System Shock 2
Item: Uncharted 2

```

---

## Once Again, Using Extension Methods

The LINQ syntax used earlier (and the rest of this chapter) is referred to as LINQ *query expressions*, which is a format that is similar to SQL but (somewhat annoying) different. There is another syntax that uses extension methods. Most LINQ statements can be written using either format; however, some of the more complex queries will require using query expressions.

Create a new method named `QueryOverStringsWithExtensionMethods()` and enter the following code:

```

static void QueryOverStringsWithExtensionMethods()
{
    // Assume we have an array of strings.
    string[] currentVideoGames = {"Morrowind", "Uncharted 2", "Fallout 3", "Daxter", "System Shock 2"};
}

```

```
// Build a query expression to find the items in the array
// that have an embedded space.
IEnumerable<string> subset =
currentVideoGames.Where(g => g.Contains(" ")).OrderBy(g => g).Select(g => g);

// Print out the results.
foreach (string s in subset)
{
    Console.WriteLine("Item: {0}", s);
}
}
```

Everything is the same as the previous method, except for the line in bold. This is using the extension method syntax. This syntax uses lambda expressions within each method to define the operation. For example, the lambda in the `Where()` method defines the condition (where a value contains a space). Just as in the query expression syntax, the letter used to indicate the value being evaluated in the lambda is random; I could have used `v` for video games.

While the results are the same (running this method produces the same output as the previous method using the query expression), you will see soon that the *type* of the result set is slightly different. For most (if not practically all) scenarios, this difference doesn't cause any issues, and the formats can be used interchangeably.

## Once Again, Without LINQ

To be sure, LINQ is never mandatory. If you so choose, you could have found the same result set by forgoing LINQ altogether and making use of programming primitives such as `if` statements and `for` loops. Here is a method that yields the same result as the `QueryOverStrings()` method but in a much more verbose manner:

```
static void QueryOverStringsLongHand()
{
    // Assume we have an array of strings.
    string[] currentVideoGames = {"Morrowind", "Uncharted 2", "Fallout 3", "Daxter", "System Shock 2"};

    string[] gamesWithSpaces = new string[5];

    for (int i = 0; i < currentVideoGames.Length; i++)
    {
        if (currentVideoGames[i].Contains(" "))
        {
            gamesWithSpaces[i] = currentVideoGames[i];
        }
    }

    // Now sort them.
    Array.Sort(gamesWithSpaces);
}
```

```
// Print out the results.
foreach (string s in gamesWithSpaces)
{
    if( s != null)
    {
        Console.WriteLine("Item: {0}", s);
    }
}
Console.WriteLine();
}
```

While I am sure you can think of ways to tweak the previous method, the fact remains that LINQ queries can be used to radically simplify the process of extracting new subsets of data from a source. Rather than building nested loops, complex if/else logic, temporary data types, and so on, the C# compiler will perform the dirty work on your behalf, once you create a fitting LINQ query.

## Reflecting Over a LINQ Result Set

Now, assume the Program class defines an additional helper function named `ReflectOverQueryResults()` that will print out various details of the LINQ result set (note the parameter is a `System.Object` to account for multiple types of result sets).

```
static void ReflectOverQueryResults(object resultSet, string queryType = "Query
Expressions")
{
    Console.WriteLine($"***** Info about your query using {queryType} *****");
    Console.WriteLine("resultSet is of type: {0}", resultSet.GetType().Name);
    Console.WriteLine("resultSet location: {0}", resultSet.GetType().Assembly.GetName().Name);
}
```

Update the core of `QueryOverStrings()` method to the following:

```
// Build a query expression to find the items in the array
// that have an embedded space.
IEnumerable<string> subset =
    from g in currentVideoGames
    where g.Contains(" ")
    orderby g
    select g;
```

### **ReflectOverQueryResults(subset);**

```
// Print out the results.
foreach (string s in subset)
{
    Console.WriteLine("Item: {0}", s);
}
```

When you run the application, you will see the subset variable is really an instance of the generic `OrderedEnumerable<TElement, TKey>` type (represented as `OrderedEnumerable`2`), which is an internal abstract type residing in the `System.Linq.dll` assembly.

---

```
***** Info about your query using Query Expressions*****
resultSet is of type: OrderedEnumerable`2
resultSet location: System.Linq
```

---

Make the same change to the `QueryOverStringsWithExtensionMethods()` method, with the exception of adding "Extension Methods" for the second parameter.

```
// Build a query expression to find the items in the array
// that have an embedded space.
IEnumerable<string> subset =
    currentVideoGames
        .Where(g => g.Contains(" "))
        .OrderBy(g => g)
        .Select(g => g);
```

**ReflectOverQueryResults(subset, "Extension Methods");**

```
// Print out the results.
foreach (string s in subset)
{
    Console.WriteLine("Item: {0}", s);
}
```

When you run the application, you will see the subset variable is an instance of type `SelectIPartitionIterator`. If you remove `Select(g=>g)` from the query, you will be back to having an instance of type `OrderedEnumerable<TElement, TKey>`. What does this all mean? For the overwhelming majority of developers, not much (if anything). They both derive from `IEnumerable<T>`, both can be iterated over in the same manner, and both can create a list or an array from their values.

---

```
***** Info about your query using Extension Methods *****
resultSet is of type: SelectIPartitionIterator`2
resultSet location: System.Linq
```

---

## LINQ and Implicitly Typed Local Variables

While the current sample program makes it relatively easy to determine that the result set can be captured as an enumeration of the string object (e.g., `IEnumerable<string>`), I would guess that it is *not* clear that subset is really of type `OrderedEnumerable<TElement, TKey>`.

Given that LINQ result sets can be represented using a good number of types in various LINQ-centric namespaces, it would be tedious to define the proper type to hold a result set, because in many cases the underlying type may not be obvious or even directly accessible from your codebase (and as you will see, in some cases the type is generated at compile time).

To further accentuate this point, consider the following additional helper method defined within the Program class (which I assume you will invoke from within the Main() method):

```
static void QueryOverInts()
{
    int[] numbers = {10, 20, 30, 40, 1, 2, 3, 8};

    // Print only items less than 10.
    IEnumerable<int> subset = from i in numbers where i < 10 select i;

    foreach (int i in subset)
    {
        Console.WriteLine("Item: {0}", i);
    }
    ReflectOverQueryResults(subset);
}
```

In this case, the subset variable is a completely different underlying type. This time, the type implementing the IEnumerable<int> interface is a low-level class named WhereArrayIterator<T>.

---

```
Item: 1
Item: 2
Item: 3
Item: 8
```

```
***** Info about your query *****
resultSet is of type: WhereArrayIterator`1
resultSet location: System.Linq
```

---

Given that the exact underlying type of a LINQ query is certainly not obvious, these first examples have represented the query results as an IEnumerable<T> variable, where T is the type of data in the returned sequence (string, int, etc.). However, this is still rather cumbersome. To add insult to injury, given that IEnumerable<T> extends the nongeneric IEnumerable interface, it would also be permissible to capture the result of a LINQ query as follows:

```
System.Collections.IEnumerable subset =
    from i in numbers
    where i < 10
    select i;
```

Thankfully, implicit typing cleans things up considerably when working with LINQ queries.

```
static void QueryOverInts()
{
    int[] numbers = {10, 20, 30, 40, 1, 2, 3, 8};

    // Use implicit typing here...
    var subset = from i in numbers where i < 10 select i;

    // ...and here.
    foreach (var i in subset)
```

```

{
    Console.WriteLine("Item: {0} ", i);
}
ReflectOverQueryResults(subset);
}

```

As a rule of thumb, you will always want to make use of implicit typing when capturing the results of a LINQ query. Just remember, however, that (in a vast majority of cases) the *real* return value is a type implementing the generic `IEnumerable<T>` interface.

Exactly what this type is under the covers (`OrderedEnumerable<TElement, TKey>`, `WhereArrayIterator<T>`, etc.) is irrelevant and not necessary to discover. As shown in the previous code example, you can simply use the `var` keyword within a `foreach` construct to iterate over the fetched data.

## LINQ and Extension Methods

Although the current example does not have you author any extension methods directly, you are in fact using them seamlessly in the background. LINQ query expressions can be used to iterate over data containers that implement the generic `IEnumerable<T>` interface. However, the `System.Array` class type (used to represent the array of strings and array of integers) does *not* implement this contract.

```

// The System.Array type does not seem to implement the
// correct infrastructure for query expressions!
public abstract class Array : ICloneable, IList,
    IStructuralComparable, IStructuralEquatable
{
    ...
}

```

While `System.Array` does not directly implement the `IEnumerable<T>` interface, it indirectly gains the required functionality of this type (as well as many other LINQ-centric members) via the static `System.Linq.Enumerable` class type.

This utility class defines a good number of generic extension methods (such as `Aggregate<T>()`, `First<T>()`, `Max<T>()`, etc.), which `System.Array` (and other types) acquires in the background. Thus, if you apply the dot operator on the `currentVideoGames` local variable, you will find a good number of members *not* found within the formal definition of `System.Array`.

## The Role of Deferred Execution

Another important point regarding LINQ query expressions is that they are not actually evaluated until you iterate over the sequence. Formally speaking, this is termed *deferred execution*. The benefit of this approach is that you are able to apply the same LINQ query multiple times to the same container and rest assured you are obtaining the latest and greatest results. Consider the following update to the `QueryOverInts()` method:

```

static void QueryOverInts()
{
    int[] numbers = { 10, 20, 30, 40, 1, 2, 3, 8 };

    // Get numbers less than ten.
    var subset = from i in numbers where i < 10 select i;
}

```

```

// LINQ statement evaluated here!
foreach (var i in subset)
{
    Console.WriteLine("{0} < 10", i);
}
Console.WriteLine();
// Change some data in the array.
numbers[0] = 4;

// Evaluated again!
foreach (var j in subset)
{
    Console.WriteLine("{0} < 10", j);
}

Console.WriteLine();
ReflectOverQueryResults(subset);
}

```

If you were to execute the program yet again, you would find the following output. Notice that the second time you iterate over the requested sequence, you find an additional member, as you set the first item in the array to be a value less than ten.

---

```

1 < 10
2 < 10
3 < 10
8 < 10

4 < 10
1 < 10
2 < 10
3 < 10
8 < 10

```

---

One useful aspect of Visual Studio is that if you set a breakpoint before the evaluation of a LINQ query, you are able to view the contents during a debugging session. Simply locate your mouse cursor over the LINQ result set variable (subset in Figure 13-1). When you do, you will be given the option of evaluating the query at that time by expanding the Results View option.



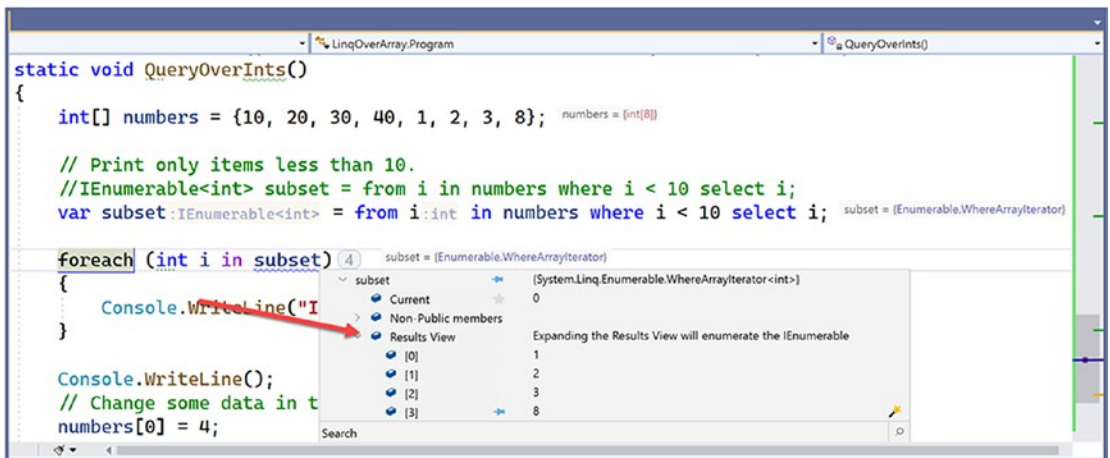


Figure 13-1. Debugging LINQ expressions

## The Role of Immediate Execution

When you need to evaluate a LINQ expression from outside the confines of `foreach` logic, you are able to call any number of extension methods defined by the `Enumerable` type such as `ToArray<T>()`, `ToDictionary<TSource, TKey>()`, and `ToList<T>()`. These methods will cause a LINQ query to execute at the exact moment you call them to obtain a snapshot of the data. After you have done so, the snapshot of data may be independently manipulated.

```
static void ImmediateExecution()
{
    int[] numbers = { 10, 20, 30, 40, 1, 2, 3, 8 };

    // Get data RIGHT NOW as int[].
    int[] subsetAsIntArray =
        (from i in numbers where i < 10 select i).ToArray<int>();

    // Get data RIGHT NOW as List<int>.
    List<int> subsetAsListOfInts =
        (from i in numbers where i < 10 select i).ToList<int>();
}
```

Notice that the entire LINQ expression is wrapped within parentheses to cast it into the correct underlying type (whatever that might be) in order to call the extension methods of `Enumerable`.

Also recall from Chapter 10 that when the C# compiler can unambiguously determine the type parameter of a generic, you are not required to specify the type parameter. Thus, you could also call `ToArray<T>()` (or `ToList<T>()` for that matter) as follows:

```
int[] subsetAsIntArray =
    (from i in numbers where i < 10 select i).ToArray();
```

The usefulness of immediate execution is obvious when you need to return the results of a LINQ query to an external caller. And, as luck would have it, this happens to be the next topic of this chapter.

## Returning the Result of a LINQ Query

It is possible to define a field within a class (or structure) whose value is the result of a LINQ query. To do so, however, you cannot make use of implicit typing (as the `var` keyword cannot be used for fields), and the target of the LINQ query cannot be instance-level data; therefore, it must be static. Given these limitations, you will seldom need to author code like the following:

```
class LINQBasedFieldsAreClunky
{
    private static string[] currentVideoGames =
        {"Morrowind", "Uncharted 2",
         "Fallout 3", "Daxter", "System Shock 2"};

    // Can't use implicit typing here! Must know type of subset!
    private IEnumerable<string> subset =
        from g in currentVideoGames
        where g.Contains(" ")
        orderby g
        select g;

    public void PrintGames()
    {
        foreach (var item in subset)
        {
            Console.WriteLine(item);
        }
    }
}
```

More often than not, LINQ queries are defined within the scope of a method or property. Moreover, to simplify your programming, the variable used to hold the result set will be stored in an implicitly typed local variable using the `var` keyword. Now, recall from Chapter 3 that implicitly typed variables cannot be used to define parameters, return values, or fields of a class or structure.

Given this point, you might wonder exactly how you could return a query result to an external caller. The answer is: it depends. If you have a result set consisting of strongly typed data, such as an array of strings or a `List<T>` of Cars, you could abandon the use of the `var` keyword and use a proper `IEnumerable<T>` or `IEnumerable` type (again, as `IEnumerable<T>` extends `IEnumerable`). Consider the following example for a new console application named `LinqRetVal`:

```
using System.Collections.Generic;
using System.Linq;
class Program
{
    static void Main(string[] args)
    {
        Console.WriteLine("***** LINQ Return Values *****\n");
        IEnumerable<string> subset = GetStringSubset();

        foreach (string item in subset)
        {
            Console.WriteLine(item);
        }
    }
}
```

```

    Console.ReadLine();
}
static IEnumerable<string> GetStringSubset()
{
    string[] colors = {"Light Red", "Green", "Yellow", "Dark Red", "Red", "Purple"};

    // Note subset is an IEnumerable<string>-compatible object.
    IEnumerable<string> theRedColors = from c in colors where c.Contains("Red") select c;

    return theRedColors;
}
}

```

The results are as expected.

---

```

Light Red
Dark Red
Red

```

---

## Returning LINQ Results via Immediate Execution

This example works as expected, only because the return value of `GetStringSubset()` and the LINQ query within this method has been strongly typed. If you used the `var` keyword to define the `subset` variable, it would be permissible to return the value *only* if the method is still prototyped to return `IEnumerable<string>` (and if the implicitly typed local variable is in fact compatible with the specified return type).

Because it is a bit inconvenient to operate on `IEnumerable<T>`, you could make use of immediate execution. For example, rather than returning `IEnumerable<string>`, you could simply return a `string[]`, provided that you transform the sequence to a strongly typed array. Consider this new method of the `Program` class, which does this very thing:

```

static string[] GetStringSubsetAsArray()
{
    string[] colors = {"Light Red", "Green", "Yellow", "Dark Red", "Red", "Purple"};

    var theRedColors = from c in colors where c.Contains("Red") select c;

    // Map results into an array.
    return theRedColors.ToArray();
}

```

With this, the caller can be blissfully unaware that their result came from a LINQ query and simply work with the array of strings as expected. Here's an example:

```

foreach (string item in GetStringSubsetAsArray())
{
    Console.WriteLine(item);
}

```

Immediate execution is also critical when attempting to return to the caller the results of a LINQ projection. You'll examine this topic a bit later in the chapter. Next up, let's look at how to apply LINQ queries to generic and nongeneric collection objects.

## Applying LINQ Queries to Collection Objects

Beyond pulling results from a simple array of data, LINQ query expressions can also manipulate data within members of the `System.Collections.Generic` namespace, such as the `List<T>` type. Create a new Console Application project named `LinqOverCollections`, and define a basic `Car` class that maintains a current speed, color, make, and pet name, as shown in the following code:

```
class Car
{
    public string PetName {get; set;} = "";
    public string Color {get; set;} = "";
    public int Speed {get; set;}
    public string Make {get; set;} = "";
}
```

Now, within your `Main()` method, define a local `List<T>` variable of type `Car`, and make use of object initialization syntax to fill the list with a handful of new `Car` objects.

```
using System.Collections.Generic;
using System.Linq;
static void Main(string[] args)
{
    Console.WriteLine("***** LINQ over Generic Collections *****\n");

    // Make a List<> of Car objects.
    List<Car> myCars = new List<Car>() {
        new Car{ PetName = "Henry", Color = "Silver", Speed = 100, Make = "BMW"},
        new Car{ PetName = "Daisy", Color = "Tan", Speed = 90, Make = "BMW"},
        new Car{ PetName = "Mary", Color = "Black", Speed = 55, Make = "VW"},
        new Car{ PetName = "Clunker", Color = "Rust", Speed = 5, Make = "Yugo"},
        new Car{ PetName = "Melvin", Color = "White", Speed = 43, Make = "Ford"}
    };

    Console.ReadLine();
}
```

## Accessing Contained Subobjects

Applying a LINQ query to a generic container is no different from doing so with a simple array, as LINQ to Objects can be used on any type implementing `IEnumerable<T>`. This time, your goal is to build a query expression to select only the `Car` objects within the `myCars` list, where the speed is greater than 55.

After you get the subset, you will print out the name of each Car object by calling the `PetName` property. Assume you have the following helper method (taking a `List<Car>` parameter), which is called from within `Main()`:

```
static void GetFastCars(List<Car> myCars)
{
    // Find all Car objects in the List<>, where the Speed is
    // greater than 55.
    var fastCars = from c in myCars where c.Speed > 55 select c;

    foreach (var car in fastCars)
    {
        Console.WriteLine("{0} is going too fast!", car.PetName);
    }
}
```

Notice that your query expression is grabbing only those items from the `List<T>` where the `Speed` property is greater than 55. If you run the application, you will find that Henry and Daisy are the only two items that match the search criteria.

If you want to build a more complex query, you might want to find only the BMWs that have a `Speed` value greater than 90. To do so, simply build a compound Boolean statement using the C# `&&` operator.

```
static void GetFastBMWs(List<Car> myCars)
{
    // Find the fast BMWs!
    var fastCars = from c in myCars where c.Speed > 90 && c.Make == "BMW" select c;
    foreach (var car in fastCars)
    {
        Console.WriteLine("{0} is going too fast!", car.PetName);
    }
}
```

In this case, the only pet name printed out is Henry.

## Applying LINQ Queries to Nongeneric Collections

Recall that the query operators of LINQ are designed to work with any type implementing `IEnumerable<T>` (either directly or via extension methods). Given that `System.Array` has been provided with such necessary infrastructure, it might surprise you that the legacy (nongeneric) containers within `System.Collections` have not. Thankfully, it is still possible to iterate over data contained within nongeneric collections using the generic `Enumerable.Of<T>()` extension method.

When calling `Of<T>()` from a nongeneric collection object (such as the `ArrayList`), simply specify the type of item within the container to extract a compatible `IEnumerable<T>` object. In code, you can store this data point using an implicitly typed variable.

Consider the following new method, which fills an `ArrayList` with a set of Car objects (be sure to import the `System.Collections` namespace into your `Program.cs` file):

```
static void LINQOverArrayList()
{
    Console.WriteLine("***** LINQ over ArrayList *****");
}
```

```
// Here is a nongeneric collection of cars.
ArrayList myCars = new ArrayList() {
    new Car{ PetName = "Henry", Color = "Silver", Speed = 100, Make = "BMW"},
    new Car{ PetName = "Daisy", Color = "Tan", Speed = 90, Make = "BMW"},
    new Car{ PetName = "Mary", Color = "Black", Speed = 55, Make = "VW"},
    new Car{ PetName = "Clunker", Color = "Rust", Speed = 5, Make = "Yugo"},
    new Car{ PetName = "Melvin", Color = "White", Speed = 43, Make = "Ford"}
};

// Transform ArrayList into an IEnumerable<T>-compatible type.
var myCarsEnum = myCars.OfType<Car>();

// Create a query expression targeting the compatible type.
var fastCars = from c in myCarsEnum where c.Speed > 55 select c;

foreach (var car in fastCars)
{
    Console.WriteLine("{0} is going too fast!", car.PetName);
}
}
```

Similar to the previous examples, this method, when called from `Main()`, will display only the names Henry and Daisy, based on the format of the LINQ query.

## Filtering Data Using `OfType<T>()`

As you know, nongeneric types are capable of containing any combination of items, as the members of these containers (again, such as the `ArrayList`) are prototyped to receive `System.Objects`. For example, assume an `ArrayList` contains a variety of items, only a subset of which are numerical. If you want to obtain a subset that contains only numerical data, you can do so using `OfType<T>()` since it filters out each element whose type is different from the given type during the iterations.

```
static void OfTypeAsFilter()
{
    // Extract the ints from the ArrayList.
    ArrayList myStuff = new ArrayList();
    myStuff.AddRange(new object[] { 10, 400, 8, false, new Car(), "string data" });
    var myInts = myStuff.OfType<int>();

    // Prints out 10, 400, and 8.
    foreach (int i in myInts)
    {
        Console.WriteLine("Int value: {0}", i);
    }
}
```

At this point, you have had a chance to apply LINQ queries to arrays, generic collections, and nongeneric collections. These containers held both C# primitive types (integers, string data) as well as custom classes. The next task is to learn about many additional LINQ operators that can be used to build more complex and useful queries.

# Investigating the C# LINQ Query Operators

C# defines a good number of query operators out of the box. Table 13-2 documents some of the more commonly used query operators. In addition to the partial list of operators shown in Table 13-2, the `System.Linq.Enumerable` class provides a set of methods that do not have a direct C# query operator shorthand notation but are instead exposed as extension methods. These generic methods can be called to transform a result set in various manners (`Reverse<>()`, `ToArray<>()`, `ToList<>()`, etc.). Some are used to extract singletons from a result set, others perform various set operations (`Distinct<>()`, `Union<>()`, `Intersect<>()`, etc.), and still others aggregate results (`Count<>()`, `Sum<>()`, `Min<>()`, `Max<>()`, etc.).

**Table 13-2.** Common LINQ Query Operators

Query Operators	Meaning in Life
from, in	Used to define the backbone for any LINQ expression, which allows you to extract a subset of data from a fitting container.
Where	Used to define a restriction for which items to extract from a container.
Select	Used to select a sequence from the container.
join, on, equals, into	Performs joins based on specified key. Remember, these “joins” do not need to have anything to do with data in a relational database.
orderby, ascending, descending	Allows the resulting subset to be ordered in ascending or descending order.
groupby	Yields a subset with data grouped by a specified value.

To begin digging into more intricate LINQ queries, create a new Console Application project named `FunWithLinqExpressions`. Next, you need to define an array or collection of some sample data. For this project, you will make an array of `ProductInfo` objects, defined in the following code:

```
class ProductInfo
{
    public string Name {get; set;} = "";
    public string Description {get; set;} = "";
    public int NumberInStock {get; set;} = 0;

    public override string ToString()
        => $"Name={Name}, Description={Description}, Number in Stock={NumberInStock}";
}
```

Now populate an array with a batch of `ProductInfo` objects within your `Main()` method.

```
static void Main(string[] args)
{
    Console.WriteLine("***** Fun with Query Expressions *****\n");

    // This array will be the basis of our testing...
    ProductInfo[] itemsInStock = new[] {
        new ProductInfo{ Name = "Mac's Coffee", Description = "Coffee with TEETH", NumberInStock
            = 24},
        new ProductInfo{ Name = "Milk Maid Milk", Description = "Milk cow's love", NumberInStock = 100},
    }
```

```

    new ProductInfo{ Name = "Pure Silk Tofu", Description = "Bland as Possible",
    NumberInStock = 120},
    new ProductInfo{ Name = "Crunchy Pops", Description = "Cheezy, peppery goodness",
    NumberInStock = 2},
    new ProductInfo{ Name = "RipOff Water", Description = "From the tap to your wallet",
    NumberInStock = 100},
    new ProductInfo{ Name = "Classic Valpo Pizza", Description = "Everyone loves
    pizza!", NumberInStock = 73}
};

// We will call various methods here!
Console.ReadLine();
}

```

## Basic Selection Syntax

Because the syntactical correctness of a LINQ query expression is validated at compile time, you need to remember that the ordering of these operators is critical. In the simplest terms, every LINQ query expression is built using the `from`, `in`, and `select` operators. Here is the general template to follow:

```

var result =
    from matchingItem in container
    select matchingItem;

```

The item after the `from` operator represents an item that matches the LINQ query criteria, which can be named anything you choose. The item after the `in` operator represents the data container to search (an array, collection, XML document, etc.).

Here is a simple query, doing nothing more than selecting every item in the container (similar in behavior to a database `Select *` SQL statement). Consider the following:

```

static void SelectEverything(ProductInfo[] products)
{
    // Get everything!
    Console.WriteLine("All product details:");
    var allProducts = from p in products select p;

    foreach (var prod in allProducts)
    {
        Console.WriteLine(prod.ToString());
    }
}

```

To be honest, this query expression is not entirely useful, given that your subset is identical to that of the data in the incoming parameter. If you want, you could extract only the `Name` values of each car using the following selection syntax:

```

static void ListProductNames(ProductInfo[] products)
{
    // Now get only the names of the products.
    Console.WriteLine("Only product names:");
    var names = from p in products select p.Name;
}

```



```

foreach (var n in names)
{
    Console.WriteLine("Name: {0}", n);
}
}

```

## Obtaining Subsets of Data

To obtain a specific subset from a container, you can use the `where` operator. When doing so, the general template now becomes the following code:

```

var result =
    from item
    in container
    where BooleanExpression
    select item;

```

Notice that the `where` operator expects an expression that resolves to a Boolean. For example, to extract from the `ProductInfo[]` argument only the items that have more than 25 items on hand, you could author the following code:

```

static void GetOverstock(ProductInfo[] products)
{
    Console.WriteLine("The overstock items!");

    // Get only the items where we have more than
    // 25 in stock.
    var overstock =
        from p
        in products
        where p.NumberInStock > 25
        select p;

    foreach (ProductInfo c in overstock)
    {
        Console.WriteLine(c.ToString());
    }
}

```

As shown earlier in this chapter, when you are building a `where` clause, it is permissible to make use of any valid C# operators to build complex expressions. For example, recall this query that extracts out only the BMWs going at least 100 MPH:

```

// Get BMWs going at least 100 MPH.
var onlyFastBMWs =
    from c
    in myCars
    where c.Make == "BMW" && c.Speed >= 100
    select c;

```

## Projecting New Data Types

It is also possible to project new forms of data from an existing data source. Let's assume you want to take the incoming `ProductInfo[]` parameter and obtain a result set that accounts only for the name and description of each item. To do so, you can define a select statement that dynamically yields a new anonymous type.

```
static void GetNamesAndDescriptions(ProductInfo[] products)
{
    Console.WriteLine("Names and Descriptions:");
    var nameDesc =
        from p
        in products
        select new { p.Name, p.Description };

    foreach (var item in nameDesc)
    {
        // Could also use Name and Description properties
        // directly.
        Console.WriteLine(item.ToString());
    }
}
```

Always remember that when you have a LINQ query that makes use of a projection, you have no way of knowing the underlying data type, as this is determined at compile time. In these cases, the `var` keyword is mandatory. As well, recall that you cannot create methods with implicitly typed return values. Therefore, the following method would not compile:

```
static var GetProjectedSubset(ProductInfo[] products)
{
    var nameDesc =
        from p in products select new { p.Name, p.Description };
    return nameDesc; // Nope!
}
```

When you need to return projected data to a caller, one approach is to transform the query result into a `System.Array` object using the `ToArray()` extension method. Thus, if you were to update your query expression as follows:

```
// Return value is now an Array.
static Array GetProjectedSubset(ProductInfo[] products)
{
    var nameDesc =
        from p in products select new { p.Name, p.Description };

    // Map set of anonymous objects to an Array object.
    return nameDesc.ToArray();
}
```

you could invoke and process the data from `Main()` as follows:

```
Array objs = GetProjectedSubset(itemsInStock);
foreach (object o in objs)
{
    Console.WriteLine(o); // Calls ToString() on each anonymous object.
}
```

Note that you must use a literal `System.Array` object and cannot make use of the C# array declaration syntax, given that you don't know the underlying type of type because you are operating on a compiler-generated anonymous class! Also note that you are not specifying the type parameter to the generic `ToArray<T>()` method, as you once again don't know the underlying data type until compile time, which is too late for your purposes.

The obvious problem is that you lose any strong typing, as each item in the `Array` object is assumed to be of type `Object`. Nevertheless, when you need to return a LINQ result set that is the result of a projection operation to an anonymous type, transforming the data into an `Array` type (or another suitable container via other members of the `Enumerable` type) is mandatory.

## Projecting to Different Data Types

In addition to projecting into anonymous types, you can also project the results of your LINQ query into another concrete type. This allows for static typing and using `IEnumerable<T>` as the result set. To start, create a smaller version of the `ProductInfo` class:

```
class ProductInfoSmall
{
    public string Name {get; set;} = "";
    public string Description {get; set;} = "";
    public override string ToString()
        => $"Name={Name}, Description={Description}";
}
```

The next change is to project the query results into a collection of `ProductInfoSmall` objects, instead of anonymous types. Add the following method to your class:

```
static void GetNamesAndDescriptionsTyped(
    ProductInfo[] products)
{
    Console.WriteLine("Names and Descriptions:");
    IEnumerable<ProductInfoSmall> nameDesc =
        from p
        in products
        select new ProductInfoSmall
            { Name=p.Name, Description=p.Description };

    foreach (ProductInfoSmall item in nameDesc)
    {
        Console.WriteLine(item.ToString());
    }
}
```

With LINQ projections, you have choices and which method you use (anonymous or strong-typed objects). Which decision you make depends entirely on your business need.

## Obtaining Counts Using Enumerable

When you are projecting new batches of data, you may need to discover exactly how many items have been returned into the sequence. Any time you need to determine the number of items returned from a LINQ query expression, simply use the `Count()` extension method of the `Enumerable` class. For example, the following method will find all string objects in a local array that have a length greater than six characters:

```
static void GetCountFromQuery()
{
    string[] currentVideoGames = {"Morrowind", "Uncharted 2", "Fallout 3", "Daxter", "System Shock 2"};

    // Get count from the query.
    int numb = (from g in currentVideoGames where g.Length > 6 select g).Count();

    // Print out the number of items.
    Console.WriteLine("{0} items honor the LINQ query.", numb);
}
```

## Reversing Result Sets

You can reverse the items within a result set quite simply using the `Reverse<>()` extension method of the `Enumerable` class. For example, the following method selects all items from the incoming `ProductInfo[]` parameter, in reverse:

```
static void ReverseEverything(ProductInfo[] products)
{
    Console.WriteLine("Product in reverse:");
    var allProducts = from p in products select p;
    foreach (var prod in allProducts.Reverse())
    {
        Console.WriteLine(prod.ToString());
    }
}
```

## Sorting Expressions

As you have seen over this chapter's initial examples, a query expression can take an `orderby` operator to sort items in the subset by a specific value. By default, the order will be ascending; thus, ordering by a string would be alphabetical, ordering by numerical data would be lowest to highest, and so forth. If you need to view the results in a descending order, simply include the descending operator. Ponder the following method:

```
static void AlphabetizeProductNames(ProductInfo[] products)
{
    // Get names of products, alphabetized.
    var subset = from p in products orderby p.Name select p;
```

```

Console.WriteLine("Ordered by Name:");
foreach (var p in subset)
{
    Console.WriteLine(p.ToString());
}
}

```

Although ascending order is the default, you are able to make your intentions clear by using the ascending operator.

```
var subset = from p in products orderby p.Name ascending select p;
```

If you want to get the items in descending order, you can do so via the descending operator.

```
var subset = from p in products orderby p.Name descending select p;
```

## LINQ As a Better Venn Diagramming Tool

The `Enumerable` class supports a set of extension methods that allows you to use two (or more) LINQ queries as the basis to find unions, differences, concatenations, and intersections of data. First, consider the `Except()` extension method, which will return a LINQ result set that contains the difference between two containers, which, in this case, is the value Yugo:

```

static void DisplayDiff()
{
    List<string> myCars =
        new List<String> { "Yugo", "Aztec", "BMW" };
    List<string> yourCars =
        new List<String> { "BMW", "Saab", "Aztec" };

    var carDiff =
        (from c in myCars select c)
        .Except(from c2 in yourCars select c2);

    Console.WriteLine("Here is what you don't have, but I do:");
    foreach (string s in carDiff)
    {
        Console.WriteLine(s); // Prints Yugo.
    }
}

```

The `Intersect()` method will return a result set that contains the common data items in a set of containers. For example, the following method returns the sequence Aztec and BMW:

```

static void DisplayIntersection()
{
    List<string> myCars = new List<String> { "Yugo", "Aztec", "BMW" };
    List<string> yourCars = new List<String> { "BMW", "Saab", "Aztec" };

    // Get the common members.
    var carIntersect =
        (from c in myCars select c)
        .Intersect(from c2 in yourCars select c2);
}

```

```

Console.WriteLine("Here is what we have in common:");
foreach (string s in carIntersect)
{
    Console.WriteLine(s); // Prints Aztec and BMW.
}
}

```

The `Union()` method, as you would guess, returns a result set that includes all members of a batch of LINQ queries. Like any proper union, you will not find repeating values if a common member appears more than once. Therefore, the following method will print out the values Yugo, Aztec, BMW, and Saab:

```

static void DisplayUnion()
{
    List<string> myCars =
        new List<String> { "Yugo", "Aztec", "BMW" };
    List<string> yourCars =
        new List<String> { "BMW", "Saab", "Aztec" };

    // Get the union of these containers.
    var carUnion =
        (from c in myCars select c)
        .Union(from c2 in yourCars select c2);

    Console.WriteLine("Here is everything:");
    foreach (string s in carUnion)
    {
        Console.WriteLine(s); // Prints all common members.
    }
}

```

Finally, the `Concat()` extension method returns a result set that is a direct concatenation of LINQ result sets. For example, the following method prints out the results Yugo, Aztec, BMW, BMW, Saab, and Aztec:

```

static void DisplayConcat()
{
    List<string> myCars =
        new List<String> { "Yugo", "Aztec", "BMW" };
    List<string> yourCars =
        new List<String> { "BMW", "Saab", "Aztec" };

    var carConcat =
        (from c in myCars select c)
        .Concat(from c2 in yourCars select c2);

    // Prints:
    // Yugo Aztec BMW BMW Saab Aztec.
    foreach (string s in carConcat)
    {
        Console.WriteLine(s);
    }
}

```

## Removing Duplicates

When you call the `Concat()` extension method, you could very well end up with redundant entries in the fetched result, which could be exactly what you want in some cases. However, in other cases, you might want to remove duplicate entries in your data. To do so, simply call the `Distinct()` extension method, as shown here:

```
static void DisplayConcatNoDups()
{
    List<string> myCars =
        new List<String> { "Yugo", "Aztec", "BMW" };
    List<string> yourCars =
        new List<String> { "BMW", "Saab", "Aztec" };

    var carConcat =
        (from c in myCars select c)
        .Concat(from c2 in yourCars select c2);

    // Prints:
    // Yugo Aztec BMW Saab.
    foreach (string s in carConcat.Distinct())
    {
        Console.WriteLine(s);
    }
}
```

## LINQ Aggregation Operations

LINQ queries can also be designed to perform various aggregation operations on the result set. The `Count()` extension method is one such aggregation example. Other possibilities include obtaining an average, maximum, minimum, or sum of values using the `Max()`, `Min()`, `Average()`, or `Sum()` members of the `Enumerable` class. Here is a simple example:

```
static void AggregateOps()
{
    double[] winterTemps = { 2.0, -21.3, 8, -4, 0, 8.2 };

    // Various aggregation examples.
    Console.WriteLine("Max temp: {0}",
        (from t in winterTemps select t).Max());

    Console.WriteLine("Min temp: {0}",
        (from t in winterTemps select t).Min());

    Console.WriteLine("Average temp: {0}",
        (from t in winterTemps select t).Average());

    Console.WriteLine("Sum of all temps: {0}",
        (from t in winterTemps select t).Sum());
}
```

These examples should give you enough knowledge to feel comfortable with the process of building LINQ query expressions. While there are additional operators you have not yet examined, you will see further examples later in this text when you learn about related LINQ technologies. To wrap up your first look at LINQ, the remainder of this chapter will dive into the details between the C# LINQ query operators and the underlying object model.

## The Internal Representation of LINQ Query Statements

At this point, you have been introduced to the process of building query expressions using various C# query operators (such as `from`, `in`, `where`, `orderby`, and `select`). Also, you discovered that some functionality of the LINQ to Objects API can be accessed only when calling extension methods of the `Enumerable` class. The truth of the matter, however, is that when compiled, the C# compiler actually translates all C# LINQ operators into calls on methods of the `Enumerable` class.

A great many of the methods of `Enumerable` have been prototyped to take delegates as arguments. In particular, many methods require a generic delegate named `Func<>`, which was introduced to you during your examination of generic delegates in Chapter 10. Consider the `Where()` method of `Enumerable`, which is called on your behalf when you use the C# `where` LINQ query operator.

**// Overloaded versions of the `Enumerable.Where<T>()` method.**

**// Note the second parameter is of type `System.Func<>`.**

```
public static IEnumerable<TSource> Where<TSource>(
    this IEnumerable<TSource> source,
    System.Func<TSource,int,bool> predicate)
```

```
public static IEnumerable<TSource> Where<TSource>(
    this IEnumerable<TSource> source,
    System.Func<TSource,bool> predicate)
```

The `Func<>` delegate (as the name implies) represents a pattern for a given function with a set of up to 16 arguments and a return value. If you were to examine this type using the Visual Studio Object Browser, you would notice various forms of the `Func<>` delegate. Here's an example:

**// The various formats of the `Func<>` delegate.**

```
public delegate TResult Func<T1,T2,T3,T4,TResult>(T1 arg1, T2 arg2, T3 arg3, T4 arg4)
```

```
public delegate TResult Func<T1,T2,T3,TResult>(T1 arg1, T2 arg2, T3 arg3)
```

```
public delegate TResult Func<T1,T2,TResult>(T1 arg1, T2 arg2)
```

```
public delegate TResult Func<T1,TResult>(T1 arg1)
```

```
public delegate TResult Func<TResult>()
```

Given that many members of `System.Linq.Enumerable` demand a delegate as input, when invoking them, you can either manually create a new delegate type and author the necessary target methods, make use of a C# anonymous method, or define a proper lambda expression. Regardless of which approach you take, the end result is identical.

While it is true that making use of C# LINQ query operators is far and away the simplest way to build a LINQ query expression, let's walk through each of these possible approaches, just so you can see the connection between the C# query operators and the underlying `Enumerable` type.



## Building Query Expressions with Query Operators (Revisited)

To begin, create a new Console Application project named `LinqUsingEnumerable`. The `Program` class will define a series of static helper methods (each of which is called within the `Main()` method) to illustrate the various manners in which you can build LINQ query expressions.

The first method, `QueryStringsWithOperators()`, offers the most straightforward way to build a query expression and is identical to the code shown in the `LinqOverArray` example earlier in this chapter.

```
using System.Linq;
static void QueryStringWithOperators()
{
    Console.WriteLine("***** Using Query Operators *****");

    string[] currentVideoGames = {"Morrowind", "Uncharted 2", "Fallout 3", "Daxter", "System
    Shock 2"};

    var subset = from game in currentVideoGames
        where game.Contains(" ") orderby game select game;

    foreach (string s in subset)
    {
        Console.WriteLine("Item: {0}", s);
    }
}
```

The obvious benefit of using C# query operators to build query expressions is that the `Func<>` delegates and calls on the `Enumerable` type are out of sight and out of mind, as it is the job of the C# compiler to perform this translation. To be sure, building LINQ expressions using various query operators (`from`, `in`, `where`, or `orderby`) is the most common and straightforward approach.

## Building Query Expressions Using the Enumerable Type and Lambda Expressions

Keep in mind that the LINQ query operators used here are simply shorthand versions for calling various extension methods defined by the `Enumerable` type. Consider the following `QueryStringsWithEnumerableAndLambdas()` method, which is processing the local string array now making direct use of the `Enumerable` extension methods:

```
static void QueryStringsWithEnumerableAndLambdas()
{
    Console.WriteLine("***** Using Enumerable / Lambda Expressions *****");

    string[] currentVideoGames = {"Morrowind", "Uncharted 2", "Fallout 3", "Daxter", "System
    Shock 2"};

    // Build a query expression using extension methods
    // granted to the Array via the Enumerable type.
    var subset = currentVideoGames
        .Where(game => game.Contains(" "))
        .OrderBy(game => game).Select(game => game);
}
```

```
// Print out the results.
foreach (var game in subset)
{
    Console.WriteLine("Item: {0}", game);
}
Console.WriteLine();
}
```

Here, you begin by calling the `Where()` extension method on the `currentVideoGames` string array. Recall that the `Array` class receives this via an extension method granted by `Enumerable`. The `Enumerable.Where()` method requires a `System.Func<T1, TResult>` delegate parameter. The first type parameter of this delegate represents the `IEnumerable<T>`-compatible data to process (an array of strings in this case), while the second type parameter represents the method result data, which is obtained from a single statement fed into the lambda expression.

The return value of the `Where()` method is hidden from view in this code example, but under the covers you are operating on an `OrderedEnumerable` type. From this object, you call the generic `OrderBy()` method, which also requires a `Func<>` delegate parameter. This time, you are simply passing each item in turn via a fitting lambda expression. The end result of calling `OrderBy()` is a new ordered sequence of the initial data.

Last but not least, you call the `Select()` method off the sequence returned from `OrderBy()`, which results in the final set of data that is stored in an implicitly typed variable named `subset`.

To be sure, this “longhand” LINQ query is a bit more complex to tease apart than the previous C# LINQ query operator example. Part of the complexity is, no doubt, due to the chaining together of calls using the dot operator. Here is the same query, with each step broken into discrete chunks (as you might guess, you could break down the overall query in various manners):

```
static void QueryStringsIEnumerableAndLambdas2()
{
    Console.WriteLine("***** Using Enumerable / Lambda Expressions *****");

    string[] currentVideoGames = {"Morrowind", "Uncharted 2", "Fallout 3", "Daxter", "System Shock 2"};

    // Break it down!
    var gamesWithSpaces = currentVideoGames.Where(game => game.Contains(" "));
    var orderedGames = gamesWithSpaces.OrderBy(game => game);
    var subset = orderedGames.Select(game => game);

    foreach (var game in subset)
    {
        Console.WriteLine("Item: {0}", game);
    }
    Console.WriteLine();
}
```

As you might agree, building a LINQ query expression using the methods of the `Enumerable` class directly is much more verbose than making use of the C# query operators. As well, given that the methods of `Enumerable` require delegates as parameters, you will typically need to author lambda expressions to allow the input data to be processed by the underlying delegate target.

## Building Query Expressions Using the Enumerable Type and Anonymous Methods

Given that C# lambda expressions are simply shorthand notations for working with anonymous methods, consider the third query expression created within the `QueryStringsWithAnonymousMethods()` helper function, shown here:

```
static void QueryStringsWithAnonymousMethods()
{
    Console.WriteLine("***** Using Anonymous Methods *****");

    string[] currentVideoGames = {"Morrowind", "Uncharted 2", "Fallout 3", "Daxter",
    "System Shock 2"};

    // Build the necessary Func<> delegates using anonymous methods.
    Func<string, bool> searchFilter = delegate(string game) { return game.Contains(" "); };
    Func<string, string> itemToProcess = delegate(string s) { return s; };

    // Pass the delegates into the methods of Enumerable.
    var subset = currentVideoGames.Where(searchFilter).OrderBy(itemToProcess).
    Select(itemToProcess);

    // Print out the results.
    foreach (var game in subset)
    {
        Console.WriteLine("Item: {0}", game);
    }
    Console.WriteLine();
}
```

This iteration of the query expression is even more verbose, because you are manually creating the `Func<>` delegates used by the `Where()`, `OrderBy()`, and `Select()` methods of the `Enumerable` class. On the plus side, the anonymous method syntax does keep all the delegate processing contained within a single method definition. Nevertheless, this method is functionally equivalent to the `QueryStringsWithEnumerableAndLambdas()` and `QueryStringsWithOperators()` methods created in the previous sections.

## Building Query Expressions Using the Enumerable Type and Raw Delegates

Finally, if you want to build a query expression using the *really verbose approach*, you could avoid the use of lambdas/anonymous method syntax and directly create delegate targets for each `Func<>` type. Here is the final iteration of your query expression, modeled within a new class type named `VeryComplexQueryExpression`:

```
class VeryComplexQueryExpression
{
    public static void QueryStringsWithRawDelegates()
    {
        Console.WriteLine("***** Using Raw Delegates *****");
        string[] currentVideoGames = {"Morrowind", "Uncharted 2", "Fallout 3", "Daxter",
        "System Shock 2"};
```

```

// Build the necessary Func<> delegates.
Func<string, bool> searchFilter =
    new Func<string, bool>(Filter);
Func<string, string> itemToProcess =
    new Func<string, string>(ProcessItem);

// Pass the delegates into the methods of Enumerable.
var subset =
    currentVideoGames
        .Where(searchFilter)
        .OrderBy(itemToProcess)
        .Select(itemToProcess);

// Print out the results.
foreach (var game in subset)
{
    Console.WriteLine("Item: {0}", game);
}
Console.WriteLine();
}

// Delegate targets.
public static bool Filter(string game)
{
    return game.Contains(" ");
}
public static string ProcessItem(string game)
{
    return game;
}
}

```

You can test this iteration of your string-processing logic by calling this method within the `Main()` method of the `Program` class, as follows:

```
VeryComplexQueryExpression.QueryStringsRawDelegates();
```

If you were to now run the application to test each possible approach, it should not be too surprising that the output is identical, regardless of the path taken. Keep the following points in mind regarding how LINQ query expressions are represented under the covers:

- Query expressions are created using various C# query operators.
- Query operators are simply shorthand notations for invoking extension methods defined by the `System.Linq.Enumerable` type.
- Many methods of `Enumerable` require delegates (`Func<>` in particular) as parameters.
- Any method requiring a delegate parameter can instead be passed a lambda expression.

- Lambda expressions are simply anonymous methods in disguise (which greatly improve readability).
- Anonymous methods are shorthand notations for allocating a raw delegate and manually building a delegate target method.

Whew! That might have been a bit deeper under the hood than you wanted to have gone, but I hope this discussion has helped you understand what the user-friendly C# query operators are actually doing behind the scenes.

## Summary

LINQ is a set of related technologies that attempts to provide a single, symmetrical manner to interact with diverse forms of data. As explained over the course of this chapter, LINQ can interact with any type implementing the `IEnumerable<T>` interface, including simple arrays as well as generic and nongeneric collections of data.

As you have seen, working with LINQ technologies is accomplished using several C# language features. For example, given that LINQ query expressions can return any number of result sets, it is common to make use of the `var` keyword to represent the underlying data type. As well, lambda expressions, object initialization syntax, and anonymous types can all be used to build functional and compact LINQ queries.

More importantly, you have seen how the C# LINQ query operators are simply shorthand notations for making calls on static members of the `System.Linq.Enumerable` type. As shown, most members of `Enumerable` operate on `Func<T>` delegate types, which can take literal method addresses, anonymous methods, or lambda expressions as input to evaluate the query.

## CHAPTER 14



# Processes, AppDomains, and Load Contexts

In this chapter, you'll drill deep into the details of how an assembly is hosted by the runtime and come to understand the relationship between processes, application domains, and object contexts.

In a nutshell, *application domains* (or simply *AppDomains*) are logical subdivisions within a given process that host a set of related .NET Core assemblies. As you will see, an AppDomain is further subdivided into *contextual boundaries*, which are used to group like-minded .NET Core objects. Using the notion of context, the runtime is able to ensure that objects with special requirements are handled appropriately.

While it is true that many of your day-to-day programming tasks might not involve directly working with processes, AppDomains, or object contexts, understanding these topics is important when working with numerous .NET Core APIs, including multithreading, parallel processing, and object serialization.

## The Role of a Windows Process

The concept of a “process” existed within Windows-based operating systems well before the release of the .NET/.NET Core platforms. In simple terms, a *process* is a running program. However, formally speaking, a process is an operating system–level concept used to describe a set of resources (such as external code libraries and the primary thread) and the necessary memory allocations used by a running application. For each .NET Core application loaded into memory, the OS creates a separate and isolated process for use during its lifetime.

Using this approach to application isolation, the result is a much more robust and stable runtime environment, given that the failure of one process does not affect the functioning of another. Furthermore, data in one process cannot be directly accessed by another process, unless you make use of specific tools such as System.IO.Pipes or the MemoryMappedFile class. Given these points, you can regard the process as a fixed, safe boundary for a running application.

Every Windows process is assigned a unique process identifier (PID) and may be independently loaded and unloaded by the OS as necessary (as well as programmatically). As you might be aware, the Processes tab of the Windows Task Manager utility (activated via the Ctrl+Shift+Esc keystroke combination on Windows) allows you to view various statistics regarding the processes running on a given machine. The Details tab allows you to view the assigned PID and image name (see Figure 14-1).

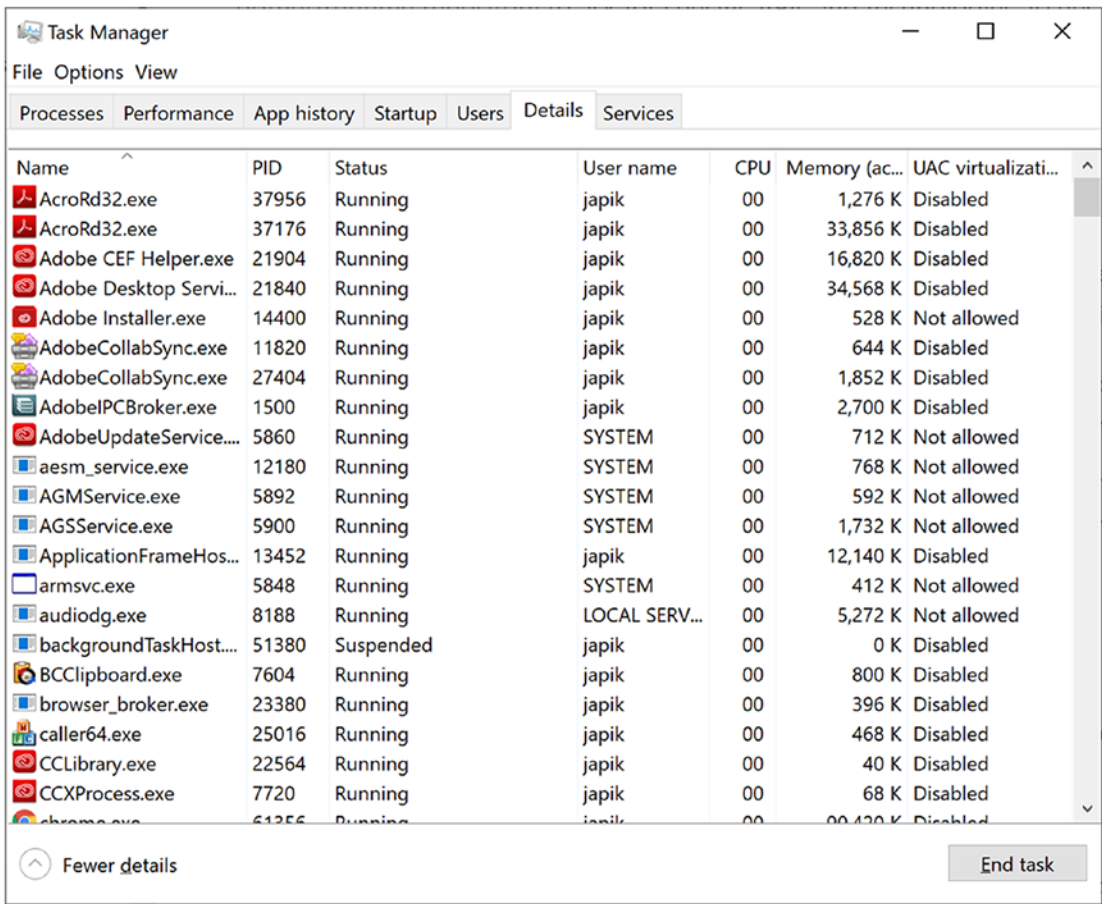


Figure 14-1. The Windows Task Manager

## The Role of Threads

Every Windows process contains an initial “thread” that functions as the entry point for the application. Chapter 15 examines the details of building multithreaded applications under the .NET Core platform; however, to facilitate the topics presented here, you need a few working definitions. First, a *thread* is a path of execution within a process. Formally speaking, the first thread created by a process’s entry point is termed the *primary thread*. Any .NET Core program (console application, Windows service, WPF application, etc.) marks its entry point with the `Main()` method. When this method is invoked, the primary thread is created automatically.

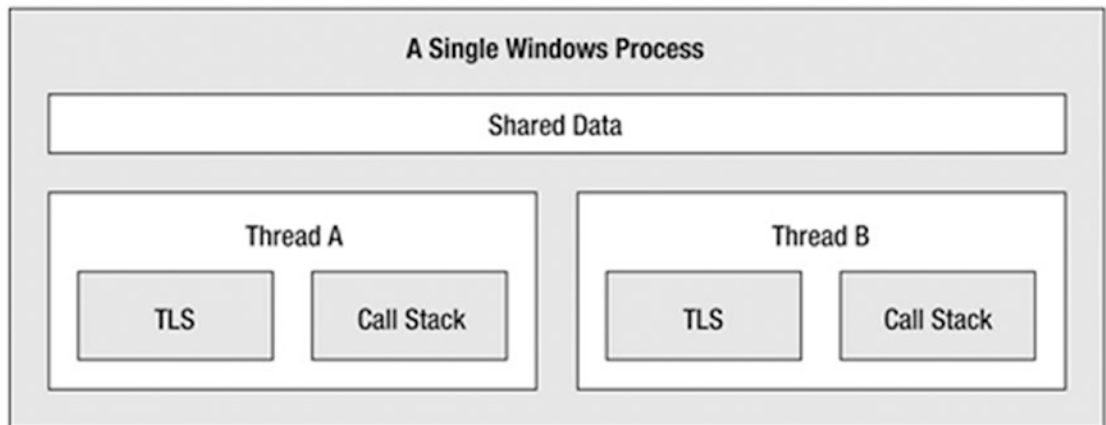
Processes that contain a single primary thread of execution are intrinsically *thread-safe*, given the fact that there is only one thread that can access the data in the application at a given time. However, a single-threaded process (especially one that is GUI based) will often appear a bit unresponsive to the user if this single thread is performing a complex operation (such as printing out a lengthy text file, performing a mathematically intensive calculation, or attempting to connect to a remote server located thousands of miles away).

Given this potential drawback of single-threaded applications, the operating systems that are supported by .NET Core (as well as the .NET Core platform) make it possible for the primary thread to spawn additional secondary threads (also termed *worker threads*) using a handful of API functions such as `CreateThread`.

Each thread (primary or secondary) becomes a unique path of execution in the process and has concurrent access to all shared points of data within the process.

As you might have guessed, developers typically create additional threads to help improve the program's overall responsiveness. Multithreaded processes provide the illusion that numerous activities are happening at more or less the same time. For example, an application may spawn a worker thread to perform a labor-intensive unit of work (again, such as printing a large text file). As this secondary thread is churning away, the main thread is still responsive to user input, which gives the entire process the potential of delivering greater performance. However, this may not actually be the case: using too many threads in a single process can actually *degrade* performance, as the CPU must switch between the active threads in the process (which takes time).

On some machines, multithreading is most commonly an illusion provided by the OS. Machines that host a single (non-hyperthreaded) CPU do not have the ability to literally handle multiple threads at the same time. Rather, a single CPU will execute one thread for a unit of time (called a *time slice*) based in part on the thread's priority level. When a thread's time slice is up, the existing thread is suspended to allow another thread to perform its business. For a thread to remember what was happening before it was kicked out of the way, each thread is given the ability to write to Thread Local Storage (TLS) and is provided with a separate call stack, as illustrated in Figure 14-2.



**Figure 14-2.** The Windows process/thread relationship

If the subject of threads is new to you, don't sweat the details. At this point, just remember that a thread is a unique path of execution within a Windows process. Every process has a primary thread (created via the executable's entry point) and may contain additional threads that have been programmatically created.

## Interacting with Processes Using .NET Core

Although processes and threads are nothing new, the manner in which you interact with these primitives under the .NET Core platform has changed quite a bit (for the better). To pave the way to understanding the world of building multithreaded assemblies (see Chapter 15), let's begin by checking out how to interact with processes using the .NET Core base class libraries.

The `System.Diagnostics` namespace defines a number of types that allow you to programmatically interact with processes and various diagnostic-related types such as the system event log and performance counters. In this chapter, you are concerned with only the process-centric types defined in Table 14-1.



**Table 14-1.** *Select Members of the System.Diagnostics Namespace*

Process-Centric Types of the System.Diagnostics Namespace	Meaning in Life
Process	The Process class provides access to local and remote processes and also allows you to programmatically start and stop processes.
ProcessModule	This type represents a module (*.dll or *.exe) that is loaded into a particular process. Understand that the ProcessModule type can represent <i>any</i> module – COM-based, .NET-based, or traditional C-based binaries.
ProcessModuleCollection	This provides a strongly typed collection of ProcessModule objects.
ProcessStartInfo	This specifies a set of values used when starting a process via the Process.Start() method.
ProcessThread	This type represents a thread within a given process. Be aware that ProcessThread is a type used to diagnose a process's thread set and is not used to spawn new threads of execution within a process.
ProcessThreadCollection	This provides a strongly typed collection of ProcessThread objects.

The System.Diagnostics.Process class allows you to analyze the processes running on a given machine (local or remote). The Process class also provides members that allow you to programmatically start and terminate processes, view (or modify) a process's priority level, and obtain a list of active threads and/or loaded modules within a given process. Table 14-2 lists some of the key properties of System.Diagnostics.Process.

**Table 14-2.** *Select Properties of the Process Type*

Property	Meaning in Life
ExitTime	This property gets the timestamp associated with the process that has terminated (represented with a DateTime type).
Handle	This property returns the handle (represented by an IntPtr) associated to the process by the OS. This can be useful when building .NET applications that need to communicate with unmanaged code.
Id	This property gets the PID for the associated process.
MachineName	This property gets the name of the computer the associated process is running on.
MainWindowTitle	MainWindowTitle gets the caption of the main window of the process (if the process does not have a main window, you receive an empty string).
Modules	This property provides access to the strongly typed ProcessModuleCollection type, which represents the set of modules (*.dll or *.exe) loaded within the current process.
ProcessName	This property gets the name of the process (which, as you would assume, is the name of the application itself).
Responding	This property gets a value indicating whether the user interface of the process is responding to user input (or is currently “hung”).
StartTime	This property gets the time that the associated process was started (via a DateTime type).
Threads	This property gets the set of threads that are running in the associated process (represented via a collection of ProcessThread objects).

In addition to the properties just examined, `System.Diagnostics.Process` also defines a few useful methods (see Table 14-3).

**Table 14-3.** *Select Methods of the Process Type*

Method	Meaning in Life
<code>CloseMainWindow()</code>	This method closes a process that has a user interface by sending a close message to its main window.
<code>GetCurrentProcess()</code>	This static method returns a new <code>Process</code> object that represents the currently active process.
<code>GetProcesses()</code>	This static method returns an array of new <code>Process</code> objects running on a given machine.
<code>Kill()</code>	This method immediately stops the associated process.
<code>Start()</code>	This method starts a process.

## Enumerating Running Processes

To illustrate the process of manipulating `Process` objects (pardon the redundancy), create a C# Console Application project named `ProcessManipulator` that defines the following static helper method within the `Program` class (be sure you import the `System.Diagnostics` and `System.Linq` namespaces in your code file):

```
static void ListAllRunningProcesses()
{
    // Get all the processes on the local machine, ordered by
    // PID.
    var runningProcs =
        from proc
        in Process.GetProcesses(".")
        orderby proc.Id
        select proc;

    // Print out PID and name of each process.
    foreach(var p in runningProcs)
    {
        string info = $"-> PID: {p.Id}\tName: {p.ProcessName}";
        Console.WriteLine(info);
    }
    Console.WriteLine("*****\n");
}
```

The static `Process.GetProcesses()` method returns an array of `Process` objects that represent the running processes on the target machine (the dot notation shown here represents the local computer). After you have obtained the array of `Process` objects, you are able to invoke any of the members listed in

Tables 14-2 and 14-3. Here, you are simply displaying the PID and the name of each process, ordered by PID. Update the `Main()` method as follows:

```
static void Main(string[] args)
{
    Console.WriteLine("***** Fun with Processes *****\n");
    ListAllRunningProcesses();
    Console.ReadLine();
}
```

When you run the application, you will see the names and PIDs for all processes on your local computer. Here is some partial output from my current machine (your output will most likely be different):

---

```
***** Fun with Processes *****

-> PID: 0      Name: Idle
-> PID: 4      Name: System
-> PID: 104    Name: Secure System
-> PID: 176    Name: Registry
-> PID: 908    Name: svchost
-> PID: 920    Name: smss
-> PID: 1016   Name: csrss
-> PID: 1020   Name: NVDisplay.Container
-> PID: 1104   Name: wininit
-> PID: 1112   Name: csrss
*****
```

---

## Investigating a Specific Process

In addition to obtaining a complete list of all running processes on a given machine, the static `Process.GetProcessById()` method allows you to obtain a single `Process` object via the associated PID. If you request access to a nonexistent PID, an `ArgumentException` exception is thrown. For example, if you were interested in obtaining a `Process` object representing a process with the PID of 987, you could write the following code:

```
// If there is no process with the PID of 987, a runtime exception will be thrown.
static void GetSpecificProcess()
{
    Process theProc = null;
    try
    {
        theProc = Process.GetProcessById(987);
    }
    catch(ArgumentException ex)
    {
        Console.WriteLine(ex.Message);
    }
}
```

At this point, you have learned how to get a list of all processes, as well as a specific process on a machine via a PID lookup. While it is somewhat useful to discover PIDs and process names, the `Process` class also allows you to discover the set of current threads and libraries used within a given process. Let's see how to do so.

## Investigating a Process's Thread Set

The set of threads is represented by the strongly typed `ProcessThreadCollection` collection, which contains some number of individual `ProcessThread` objects. To illustrate, add the following additional static helper function to your current application:

```
static void EnumThreadsForPid(int pID)
{
    Process theProc = null;
    try
    {
        theProc = Process.GetProcessById(pID);
    }
    catch (ArgumentException ex)
    {
        Console.WriteLine(ex.Message);
        return;
    }

    // List out stats for each thread in the specified process.
    Console.WriteLine(
        "Here are the threads used by: {0}", theProc.ProcessName);
    ProcessThreadCollection theThreads = theProc.Threads;

    foreach (ProcessThread pt in theThreads)
    {
        string info =
            $"-> Thread ID: {pt.Id}\tStart Time: {pt.StartTime.ToShortTimeString()}\tPriority: "
            + "{pt.PriorityLevel}";
        Console.WriteLine(info);
    }
    Console.WriteLine("*****\n");
}
```

As you can see, the `Threads` property of the `System.Diagnostics.Process` type provides access to the `ProcessThreadCollection` class. Here, you are printing the assigned thread ID, start time, and priority level of each thread in the process specified by the client. Now, update your program's `Main()` method to prompt the user for a PID to investigate, as follows:

```
static void Main(string[] args)
{
    ...
    // Prompt user for a PID and print out the set of active threads.
    Console.WriteLine("***** Enter PID of process to investigate *****");
    Console.Write("PID: ");
    string pID = Console.ReadLine();
    int theProcID = int.Parse(pID);

    EnumThreadsForPid(theProcID);
    Console.ReadLine();
}
```

When you run your program, you can now enter the PID of any process on your machine and see the threads used in the process. The following output shows a partial list of the threads used by PID 61356 on my machine, which happens to be hosting Chrome:

```
***** Enter PID of process to investigate *****
PID: 61356
Here are the threads used by: chrome
-> Thread ID: 27068   Start Time: 04:34 PM   Priority: Normal
-> Thread ID: 40072   Start Time: 04:34 PM   Priority: Normal
-> Thread ID: 60516   Start Time: 04:34 PM   Priority: Normal
-> Thread ID: 33568   Start Time: 04:34 PM   Priority: Normal
-> Thread ID: 11568   Start Time: 04:34 PM   Priority: Normal
-> Thread ID: 7564    Start Time: 04:34 PM   Priority: Normal
-> Thread ID: 34904   Start Time: 04:34 PM   Priority: Normal
-> Thread ID: 40344   Start Time: 04:34 PM   Priority: Normal
-> Thread ID: 34060   Start Time: 04:34 PM   Priority: Normal
-> Thread ID: 52780   Start Time: 04:34 PM   Priority: Normal
-> Thread ID: 56156   Start Time: 04:34 PM   Priority: Normal
-> Thread ID: 2004    Start Time: 04:34 PM   Priority: Normal
-> Thread ID: 28968   Start Time: 04:34 PM   Priority: Lowest
-> Thread ID: 23156   Start Time: 04:34 PM   Priority: Normal
-> Thread ID: 31000   Start Time: 04:34 PM   Priority: Normal
-> Thread ID: 22536   Start Time: 04:34 PM   Priority: Normal
-> Thread ID: 10272   Start Time: 04:34 PM   Priority: Normal
*****
```

The `ProcessThread` type has additional members of interest beyond `Id`, `StartTime`, and `PriorityLevel`. Table 14-4 documents some members of interest.

**Table 14-4.** *Select Members of the `ProcessThread` Type*

Member	Meaning in Life
<code>CurrentPriority</code>	Gets the current priority of the thread
<code>Id</code>	Gets the unique identifier of the thread
<code>IdealProcessor</code>	Sets the preferred processor for this thread to run on
<code>PriorityLevel</code>	Gets or sets the priority level of the thread
<code>ProcessorAffinity</code>	Sets the processors on which the associated thread can run
<code>StartAddress</code>	Gets the memory address of the function that the operating system called that started this thread
<code>StartTime</code>	Gets the time that the operating system started the thread
<code>ThreadState</code>	Gets the current state of this thread
<code>TotalProcessorTime</code>	Gets the total amount of time that this thread has spent using the processor
<code>WaitReason</code>	Gets the reason that the thread is waiting

Before you read any further, be aware that the `ProcessThread` type is *not* the entity used to create, suspend, or kill threads under the .NET Core platform. Rather, `ProcessThread` is a vehicle used to obtain diagnostic information for the active Windows threads within a running process. Again, you will investigate how to build multithreaded applications using the `System.Threading` namespace in Chapter 15.

## Investigating a Process's Module Set

Next up, let's check out how to iterate over the number of loaded modules that are hosted within a given process. When talking about processes, a *module* is a general term used to describe a given \*.dll (or the \*.exe itself) that is hosted by a specific process. When you access the `ProcessModuleCollection` via the `Process.Modules` property, you are able to enumerate over *all modules* hosted within a process: .NET Core-based, COM-based, or traditional C-based libraries. Ponder the following additional helper function that will enumerate the modules in a specific process based on the PID:

```
static void EnumModsForPid(int pID)
{
    Process theProc = null;
    try
    {
        theProc = Process.GetProcessById(pID);
    }
    catch (ArgumentException ex)
    {
        Console.WriteLine(ex.Message);
        return;
    }

    Console.WriteLine("Here are the loaded modules for: {0}",
        theProc.ProcessName);
    ProcessModuleCollection theMods = theProc.Modules;
    foreach (ProcessModule pm in theMods)
    {
        string info = $"-> Mod Name: {pm.ModuleName}";
        Console.WriteLine(info);
    }
    Console.WriteLine("*****\n");
}
```

To see some possible output, let's check out the loaded modules for the process hosting the current example program (`ProcessManipulator`). To do so, run the application, identify the PID assigned to `ProcessManipulator.exe` (via the Task Manager), and pass this value to the `EnumModsForPid()` method (be sure to update your `Main()` method accordingly). Once you do, you might be surprised to see the list of \*.dlls used for a simple Console Application project (`GDI32.dll`, `USER32.dll`, `ole32.dll`, etc.). The following output is a partial listing of modules loaded (edited for brevity):

Here are (some of) the loaded modules for: ProcessManipulator

```
-> Mod Name: ProcessManipulator.exe
-> Mod Name: ntdll.dll
-> Mod Name: KERNEL32.DLL
-> Mod Name: KERNELBASE.dll
-> Mod Name: USER32.dll
-> Mod Name: win32u.dll
-> Mod Name: GDI32.dll
-> Mod Name: gdi32full.dll
-> Mod Name: msvcrt.dll
-> Mod Name: coreclr.dll
-> Mod Name: ole32.dll
-> Mod Name: OLEAUT32.dll
-> Mod Name: bcrypt.dll
-> Mod Name: System.Memory.dll
-> Mod Name: Microsoft.Win32.Primitives.dll
-> Mod Name: System.Resources.ResourceManager.dll
-> Mod Name: System.Runtime.InteropServices.dll
-> Mod Name: System.Collections.NonGeneric.dll
-> Mod Name: System.Collections.dll
*****
```

---

## Starting and Stopping Processes Programmatically

The final aspects of the `System.Diagnostics.Process` class examined here are the `Start()` and `Kill()` methods. As you can gather by their names, these members provide a way to programmatically launch and terminate a process, respectively. For example, consider the following static `StartAndKillProcess()` helper method:

---

■ **Note** Depending on your operating system's security settings, you might need to be running Visual Studio with Administrator rights to start new processes.

---

```
static void StartAndKillProcess()
{
    Process ffProc = null;

    // Launch Firefox, and go to Facebook!
    try
    {
        ffProc = Process.Start(@"C:\Program Files\Mozilla Firefox\firefox.exe",
                                "www.facebook.com");
    }
    catch (InvalidOperationException ex)
    {
        Console.WriteLine(ex.Message);
    }
}
```

```

Console.Write("--> Hit enter to kill {0}...",
    ffProc.ProcessName);
Console.ReadLine();

// Kill all of the firefox.exe processes.
try
{
    foreach (var p in Process.GetProcessesByName("FireFox"))
    {
        p.Kill(true);
    }
}
catch (InvalidOperationException ex)
{
    Console.WriteLine(ex.Message);
}
}

```

The static `Process.Start()` method has been overloaded a few times. At a minimum, you will need to specify the path and file name of the process you want to launch. This example uses a variation of the `Start()` method that allows you to specify any additional arguments to pass into the program's entry point, in this case, the web page to load.

After you call the `Start()` method, you are returned a reference to the newly activated process. When you want to terminate the process, simply call the instance-level `Kill()` method. In this example, since `FireFox` launches a lot of processes, you are looping through to kill all of the launched processes. You are also wrapping the calls to `Start()` and `Kill()` within a `try/catch` block to handle any `InvalidOperationException` errors. This is especially important when calling the `Kill()` method, as this error will be raised if the process has already been terminated prior to calling `Kill()`.

---

■ **Note** In prior versions of the .NET Framework, the `Process.Start` method allowed for either the full path and filename or the operating system shortcut (e.g. "firefox") of the process to start. With .NET Core and the cross-platform support, you must specify the full path and filename. Operating system associations can be leveraged using the `ProcessStartInfo`, covered in the next two sections.

---

## Controlling Process Startup Using the `ProcessStartInfo` Class

The `Start()` method also allows you to pass in a `System.Diagnostics.ProcessStartInfo` type to specify additional bits of information regarding how a given process should come to life. Here is a partial definition of `ProcessStartInfo` (see the documentation for full details):

```

public sealed class ProcessStartInfo : object
{
    public ProcessStartInfo();
    public ProcessStartInfo(string fileName);
    public ProcessStartInfo(string fileName, string arguments);
    public string Arguments { get; set; }
    public bool CreateNoWindow { get; set; }
    public StringDictionary EnvironmentVariables { get; }
}

```



```

public bool ErrorDialog { get; set; }
public IntPtr ErrorDialogParentHandle { get; set; }
public string FileName { get; set; }
public bool LoadUserProfile { get; set; }
public SecureString Password { get; set; }
public bool RedirectStandardError { get; set; }
public bool RedirectStandardInput { get; set; }
public bool RedirectStandardOutput { get; set; }
public Encoding StandardErrorEncoding { get; set; }
public Encoding StandardOutputEncoding { get; set; }
public bool UseShellExecute { get; set; }
public string Verb { get; set; }
public string[] Verbs { get; }
public ProcessWindowStyle WindowStyle { get; set; }
public string WorkingDirectory { get; set; }
}

```

To illustrate how to fine-tune your process startup, here is a modified version of `StartAndKillProcess()`, which will load Firefox and navigate to [www.facebook.com](http://www.facebook.com), using the windows association "firefox":

```

static void StartAndKillProcess()
{
    Process ffProc = null;

    // Launch Firefox, and go to Facebook, with maximized window.
    try
    {
        ProcessStartInfo startInfo = new
            ProcessStartInfo("FireFox", "www.facebook.com");
        startInfo.UseShellExecute = true;
        ffProc = Process.Start(startInfo);
    }
    catch (InvalidOperationException ex)
    {
        Console.WriteLine(ex.Message);
    }
    ...
}

```

In .NET Core, the `UseShellExecute` property defaults to false, while in prior versions of .NET, the `UseShellExecute` property defaults to true. This is the reason that the previous version of process start

```
Process.Start("firefox")
```

no longer works without using `ProcessStartInfo` and setting the `UseShellExecute` property to true.

## Leveraging OS Verbs with ProcessStartInfo

In addition to using the OS shortcuts to launch applications, you can also take advantage of file associations with `ProcessStartInfo`. On Windows, if you right-click a Word document, there are options to edit or print the document. Let's use the `ProcessStartInfo` to determine the verbs available and then use them to manipulate the process.

Create a new method with the following code:

```
static void UseApplicationVerbs()
{
    int i = 0;
    //adjust this path and name to a document on your machine
    ProcessStartInfo si =
        new ProcessStartInfo(@"..\..\..\..\TestPage.docx");
    foreach (var verb in si.Verbs)
    {
        Console.WriteLine($" {i++}. {verb}");
    }
    si.WindowStyle = ProcessWindowStyle.Maximized;
    si.Verb = "Edit";
    si.UseShellExecute = true;
    Process.Start(si);
}
```

When you run this code, the first part prints out all of the available verbs for a Word document, as the following shows:

---

```
***** Fun with Processes *****
```

```
0. Edit
1. OnenotePrintto
2. Open
3. OpenAsReadOnly
4. Print
5. Printto
6. ViewProtected
```

---

After setting the `WindowStyle` to maximized, the verb is set to `Edit`, which opens the document in edit mode. If you set the verb to `Print`, the document will be sent straight to the printer.

Now that you understand the role of Windows processes and how to interact with them from C# code, you are ready to investigate the concept of a .NET application domain.

## Understanding .NET Application Domains

Under the .NET and .NET Core platforms, executables are not hosted directly within a Windows process, as is the case in traditional unmanaged applications. Rather, .NET and .NET Core executables are hosted by a logical partition within a process called an *application domain*. This partition of a traditional Windows process offers several benefits, some of which are as follows:

- AppDomains are a key aspect of the OS-neutral nature of the .NET Core platform, given that this logical division abstracts away the differences in how an underlying OS represents a loaded executable.
- AppDomains are far less expensive in terms of processing power and memory than a full-blown process. Thus, the CoreCLR is able to load and unload application domains much quicker than a formal process and can drastically improve scalability of server applications.

AppDomains are fully and completely isolated from other AppDomains within a process. Given this fact, be aware that an application running in one AppDomain is unable to obtain data of any kind (global variables or static fields) within another AppDomain, unless they use a distributed programming protocol.

---

■ **Note** Support for AppDomains is changed in .NET Core. In .NET Core, there is exactly one AppDomain. Creation of AppDomains is no longer supported because they require runtime support and are generally expensive to create. The `ApplicationLoadContext` (covered later in this chapter) provides assembly isolation in .NET Core.

---

## The System.AppDomain Class

The `AppDomain` class is largely deprecated with .NET Core. Most of the remaining support is designed to make migrating from .NET 4.x to .NET Core. The remaining features can still provide value, as covered in the next two sections.

## Interacting with the Default Application Domain

Your application has access to the default application domain using the static `AppDomain.CurrentDomain` property. After you have this access point, you are able to use the methods and properties of `AppDomain` to perform some runtime diagnostics.

To learn how to interact with the default application domain, begin by creating a new Console Application project named `DefaultAppDomainApp`. Now, update your `Program` class with the following logic, which will simply display some details about the default application domain, using a number of members of the `AppDomain` class:

```
class Program
{
    static void Main(string[] args)
    {
        Console.WriteLine("***** Fun with the default AppDomain *****\n");
        DisplayDADStats();
        Console.ReadLine();
    }
}
```

```

private static void DisplayDADStats()
{
    // Get access to the AppDomain for the current thread.
    AppDomain defaultAD = AppDomain.CurrentDomain;
    // Print out various stats about this domain.
    Console.WriteLine("Name of this domain: {0}",
        defaultAD.FriendlyName);
    Console.WriteLine("ID of domain in this process: {0}",
        defaultAD.Id);
    Console.WriteLine("Is this the default domain?: {0}",
        defaultAD.IsDefaultAppDomain());
    Console.WriteLine("Base directory of this domain: {0}",
        defaultAD.BaseDirectory);
    Console.WriteLine("Setup Information for this domain:");
    Console.WriteLine("\t Application Base: {0}",
        defaultAD.SetupInformation.ApplicationBase);
    Console.WriteLine("\t Target Framework: {0}",
        defaultAD.SetupInformation.TargetFrameworkName);
}
}

```

The output of this example is shown here:

---

```

***** Fun with the default AppDomain *****

```

```

Name of this domain: DefaultAppDomainApp
ID of domain in this process: 1
Is this the default domain?: True
Base directory of this domain: C:\GitHub\Books\csharp8-wf\Code\Chapter_14\
DefaultAppDomainApp\DefaultAppDomainApp\bin\Debug\netcoreapp3.1\
Setup Information for this domain:
    Application Base: C:\GitHub\Books\csharp8-wf\Code\Chapter_14\DefaultAppDomainApp\
DefaultAppDomainApp\bin\Debug\netcoreapp3.1\
    Target Framework: .NETCoreApp,Version=v3.1

```

---

Notice that the name of the default application domain will be identical to the name of the executable that is contained within it (DefaultAppDomainApp.exe, in this example). Also notice that the base directory value, which will be used to probe for externally required private assemblies, maps to the current location of the deployed executable.

## Enumerating Loaded Assemblies

It is also possible to discover all the loaded .NET Core assemblies within a given application domain using the instance-level `GetAssemblies()` method. This method will return to you an array of `Assembly` objects (covered in Chapter 17). For now, just add the following namespace to your code file:

```
using System.Reflection;
```

To illustrate, define a new method named `ListAllAssembliesInAppDomain()` within the `Program` class. This helper method will obtain all loaded assemblies and print the friendly name and version of each.

```
static void ListAllAssembliesInAppDomain()
{
    // Get access to the AppDomain for the current thread.
    AppDomain defaultAD = AppDomain.CurrentDomain;

    // Now get all loaded assemblies in the default AppDomain.
    Assembly[] loadedAssemblies = defaultAD.GetAssemblies();
    Console.WriteLine("***** Here are the assemblies loaded in {0} *****\n",
        defaultAD.FriendlyName);
    foreach(Assembly a in loadedAssemblies)
    {
        Console.WriteLine($"-> Name, Version: {a.GetName().Name}:{a.GetName().Version}" );
    }
}
```

Assuming you have updated your `Main()` method to call this new member, you will see that the application domain hosting your executable is currently making use of the following .NET Core libraries:

---

```
** Here are the assemblies loaded in DefaultAppDomainApp **

-> Name, Version: System.Private.CoreLib:4.0.0.0
-> Name, Version: DefaultAppDomainApp:1.0.0.0
-> Name, Version: System.Runtime:4.2.2.0
-> Name, Version: System.Console:4.1.2.0
-> Name, Version: System.Threading:4.1.2.0
-> Name, Version: System.Runtime.Extensions:4.2.2.0
-> Name, Version: System.Text.Encoding.Extensions:4.1.2.0
```

---

Now understand that the list of loaded assemblies can change at any time as you author new C# code. For example, assume you have updated your `ListAllAssembliesInAppDomain()` method to make use of a LINQ query, which will order the loaded assemblies by name, as follows:

```
using System.Linq;
static void ListAllAssembliesInAppDomain()
{
    // Get access to the AppDomain for the current thread.
    AppDomain defaultAD = AppDomain.CurrentDomain;

    // Now get all loaded assemblies in the default AppDomain.
    var loadedAssemblies =
        defaultAD.GetAssemblies().OrderBy(x=>x.GetName().Name);
    Console.WriteLine("***** Here are the assemblies loaded in {0} *****\n",
        defaultAD.FriendlyName);
    foreach(Assembly a in loadedAssemblies)
    {
        Console.WriteLine($"-> Name, Version: {a.GetName().Name}:{a.GetName().Version}" );
    }
}
```

If you were to run the program once again, you would see that `System.Linq.dll` has also been loaded into memory.

---

```
** Here are the assemblies loaded in DefaultAppDomainApp **
```

```
-> Name, Version: DefaultAppDomainApp:1.0.0.0
-> Name, Version: System.Console:4.1.2.0
-> Name, Version: System.Linq:4.2.2.0
-> Name, Version: System.Private.CoreLib:4.0.0.0
-> Name, Version: System.Runtime:4.2.2.0
-> Name, Version: System.Runtime.Extensions:4.2.2.0
-> Name, Version: System.Text.Encoding.Extensions:4.1.2.0
-> Name, Version: System.Threading:4.1.2.0
```

---

## Assembly Isolation with Application Load Contexts

As you have just seen, AppDomains are logical partitions used to host .NET Core assemblies. Additionally, an application domain may be further subdivided into numerous load context boundaries. Conceptually, a load context creates a scope for loading, resolving, and potentially unloading a set of assemblies. In a nutshell, a .NET Core load context provides a way for a single AppDomain to establish a “specific home” for a given object.

---

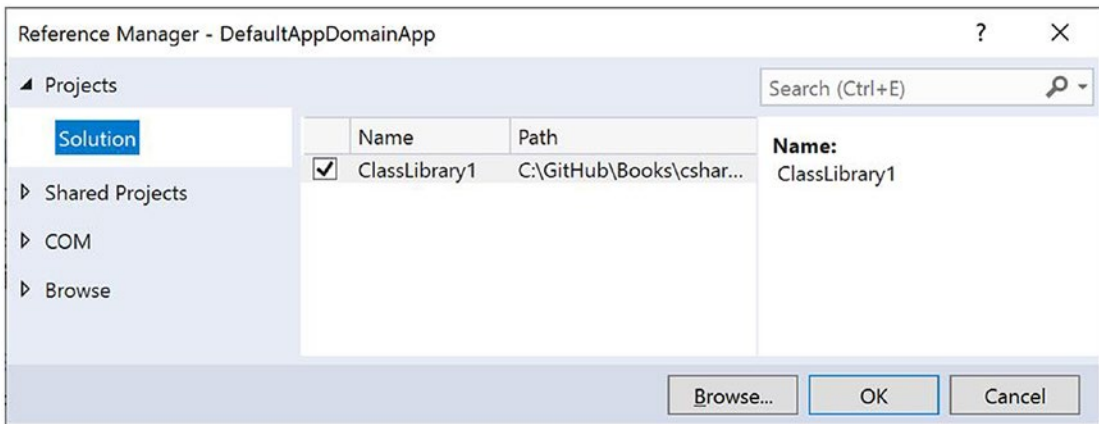
■ **Note** While understanding processes and application domains is quite important, most .NET Core applications will never demand that you work with object contexts. I’ve included this overview material just to paint a more complete picture.

---

The `AssemblyLoadContext` class provides the capability to load additional assemblies into their own contexts. To demonstrate, first add another project to your solution. You can do this by right-clicking the solution node in Solution Explorer, selecting **Add ► New Project**, and adding a .NET Core class library into your project named `ClassLibrary1`. In this class library, add our base `Car` class, as follows:

```
public class Car
{
    public string PetName { get; set; }
    public string Make { get; set; }
    public int Speed { get; set; }
}
```

Add a reference to this new project by right-clicking the `DefaultAppDomainApp` project, and select **Add ► References**. Select the **Projects ► Solution** option in the left rail, and select the `ClassLibrary1` check box, as shown in Figure 14-3.



**Figure 14-3.** Adding the Project Reference

With this new assembly in place, add the following using statements:

```
using System.IO;
using System.Runtime.Loader;
```

Then add another method to your Program class as follows:

```
static void LoadAdditionalAssembliesDifferentContexts()
{
    var path =
        Path.Combine(AppDomain.CurrentDomain.BaseDirectory,
            "ClassLibrary1.dll");
    AssemblyLoadContext lc1 =
        new AssemblyLoadContext("NewContext1", false);
    var cl1 = lc1.LoadFromAssemblyPath(path);
    var c1 = cl1.CreateInstance("ClassLibrary1.Car");

    AssemblyLoadContext lc2 =
        new AssemblyLoadContext("NewContext2", false);
    var cl2 = lc2.LoadFromAssemblyPath(path);
    var c2 = cl2.CreateInstance("ClassLibrary1.Car");
    Console.WriteLine("*** Loading Additional Assemblies in Different Contexts ***");
    Console.WriteLine($"Assembly1 Equals(Assembly2) {cl1.Equals(cl2)}");
    Console.WriteLine($"Assembly1 == Assembly2 {cl1 == cl2}");
    Console.WriteLine($"Class1.Equals(Class2) {c1.Equals(c2)}");
    Console.WriteLine($"Class1 == Class2 {c1 == c2}");
}
```

The first line uses the static Path.Combine method to build up the directory for the ClassLibrary1 assembly.

---

**Note** You might be wondering why you created a reference for an assembly that will be loaded dynamically. This is to make sure that when the project builds, the `ClassLibrary1` assembly builds as well, and is located in the same directory as the `DefaultAppDomainApp`.

---

Next, the code creates a new `AssemblyLoadContext` with the name `NewContext1` and does not support unloading. This `LoadContext` is used to load the `ClassLibrary1` assembly and then create an instance of a `Car` class. If some of this code is new to you, it will be explained more fully in Chapter 19. The process is repeated with a new `AssemblyLoadContext`, and then the assemblies and classes are compared for equality. When you run this new method, you will see the following output:

---

```
*** Loading Additional Assemblies in Different Contexts ***
Assembly1.Equals(Assembly2) False
Assembly1 == Assembly2 False
Class1.Equals(Class2) False
Class1 == Class2 False
```

---

This demonstrates that the same assembly has been loaded twice into the app domain. The classes are also different, as should be expected.

Next, add a new method that will load the assembly from the same `AssemblyLoadContext`:

```
static void LoadAdditionalAssembliesSameContext()
{
    var path =
        Path.Combine(AppDomain.CurrentDomain.BaseDirectory,
            "ClassLibrary1.dll");
    AssemblyLoadContext lc1 =
        new AssemblyLoadContext(null, false);
    var cl1 = lc1.LoadFromAssemblyPath(path);
    var c1 = cl1.CreateInstance("ClassLibrary1.Car");
    var cl2 = lc1.LoadFromAssemblyPath(path);
    var c2 = cl2.CreateInstance("ClassLibrary1.Car");
    Console.WriteLine("*** Loading Additional Assemblies in Same Context ***");
    Console.WriteLine($"Assembly1.Equals(Assembly2) {cl1.Equals(cl2)}");
    Console.WriteLine($"Assembly1 == Assembly2 {cl1 == cl2}");
    Console.WriteLine($"Class1.Equals(Class2) {c1.Equals(c2)}");
    Console.WriteLine($"Class1 == Class2 {c1 == c2}");
}
```

The main difference in this code is that only one `AssemblyLoadContext` is created. Now, when the `ClassLibrary1` assembly is loaded twice, the second assembly is simply a pointer to the first instance of the assembly. Running the code produces the following output:

---

```
*** Loading Additional Assemblies in Same Context ***
Assembly1.Equals(Assembly2) True
Assembly1 == Assembly2 True
Class1.Equals(Class2) False
Class1 == Class2 False
```

---



## Summarizing Processes, AppDomains, and Load Contexts

At this point, you should have a much better idea about how a .NET Core assembly is hosted by the runtime. If the previous pages have seemed to be a bit too low level for your liking, fear not. For the most part, .NET Core automatically deals with the details of processes, application domains, and load contexts on your behalf. The good news, however, is that this information provides a solid foundation for understanding multithreaded programming under the .NET Core platform.

## Summary

The point of this chapter was to examine exactly how a .NET Core application is hosted by the .NET Core platform. As you have seen, the long-standing notion of a Windows process has been altered under the hood to accommodate the needs of the CoreCLR. A single process (which can be programmatically manipulated via the `System.Diagnostics.Process` type) is now composed of an application domain, which represents isolated and independent boundaries within a process.

An application domain is capable of hosting and executing any number of related assemblies. Furthermore, a single application domain can contain any number of load contexts for further assembly isolation. Using this additional level of type isolation, the CoreCLR can ensure that special-need objects are handled correctly.

## CHAPTER 15



# Multithreaded, Parallel, and Async Programming

Nobody enjoys working with an application that is sluggish during its execution. Moreover, nobody enjoys starting a task in an application (perhaps initiated by clicking a toolbar item) that prevents other parts of the program from being as responsive as possible. Before the release of .NET (and .NET Core), building applications that had the ability to perform multiple tasks typically required authoring complex C++ code that used the Windows threading APIs. Thankfully, the .NET/.NET Core platform provides a number of ways for you to build software that can perform complex operations on unique paths of execution, with far fewer pain points.

This chapter begins by defining the overall nature of a “multithreaded application.” Next, you’ll be introduced to the original threading namespace that has shipped since .NET 1.0, specifically `System.Threading`. Here, you’ll examine numerous types (`Thread`, `ThreadStart`, etc.) that allow you to explicitly create additional threads of execution and synchronize your shared resources, which helps ensure that multiple threads can share data in a nonvolatile manner.

The remaining parts of this chapter will examine three more recent techniques .NET Core developers can use to build multithreaded software, specifically the Task Parallel Library (TPL), Parallel LINQ (PLINQ), and the new (as of C# 6) intrinsic asynchronous keywords of C# (`async` and `await`). As you will see, these features can dramatically simplify how you can build responsive multithreaded software applications.

## The Process/AppDomain/Context/Thread Relationship

In Chapter 14, a *thread* was defined as a path of execution within an executable application. While many .NET Core applications can live happy and productive single-threaded lives, an assembly’s primary thread (spawned by the runtime when `Main()` executes) may create secondary threads of execution at any time to perform additional units of work. By creating additional threads, you can build more responsive (but not necessarily faster executing on single-core machines) applications.

The `System.Threading` namespace was released with .NET 1.0 and offers one approach to build multithreaded applications. The `Thread` class is perhaps the core type, as it represents a given thread. If you want to programmatically obtain a reference to the thread currently executing a given member, simply call the static `Thread.CurrentThread` property, like so:

```
static void ExtractExecutingThread()
{
    // Get the thread currently
    // executing this method.
    Thread currThread = Thread.CurrentThread;
}
```

Under the .NET Core platform, there is *not* a direct one-to-one correspondence between application domains and threads. In fact, a given AppDomain can have numerous threads executing within it at any given time. When you want to programmatically gain access to the AppDomain that is hosting the current thread, call the static `Thread.GetDomain()` method, like so:

```
static void ExtractAppDomainHostingThread()
{
    // Obtain the AppDomain hosting the current thread.
    AppDomain ad = Thread.GetDomain();
}
```

A single thread may also be moved into a particular execution context at any given time, and it may be relocated within a new execution context at the whim of the CoreCLR. When you want to obtain the current execution context a thread happens to be executing in, use the static `Thread.CurrentThread.ExecutionContext` property, like so:

```
static void ExtractCurrentThreadExecutionContext()
{
    // Obtain the execution context under which the
    // current thread is operating.
    ExecutionContext ctx =
        Thread.CurrentThread.ExecutionContext;
}
```

Again, the CoreCLR is the entity that is in charge of moving threads into (and out of) execution contexts. As a .NET Core developer, you can usually remain blissfully unaware where a given thread ends up. Nevertheless, you should be aware of the various ways of obtaining the underlying primitives.

## The Problem of Concurrency

One of the many “joys” (read: painful aspects) of multithreaded programming is that you have little control over how the underlying operating system or the CoreCLR uses its threads. For example, if you craft a block of code that creates a new thread of execution, you cannot guarantee that the thread executes immediately. Rather, such code only instructs the OS/CoreCLR to execute the thread as soon as possible (which is typically when the thread scheduler gets around to it).

Furthermore, given that threads can be moved between application and contextual boundaries as required by the CoreCLR, you must be mindful of which aspects of your application are *thread-volatile* (e.g., subject to multithreaded access) and which operations are *atomic* (thread-volatile operations are the dangerous ones!).

To illustrate the problem, assume a thread is invoking a method of a specific object. Now assume that this thread is instructed by the thread scheduler to suspend its activity to allow another thread to access the same method of the same object.

If the original thread was not completely finished with its operation, the second incoming thread may be viewing an object in a partially modified state. At this point, the second thread is basically reading bogus data, which is sure to give way to extremely odd (and hard to find) bugs, which are even harder to replicate and debug.

Atomic operations, on the other hand, are always safe in a multithreaded environment. Sadly, there are few operations in the .NET Core base class libraries that are guaranteed to be atomic. Even the act of assigning a value to a member variable is not atomic! Unless the .NET Core documentation specifically says an operation is atomic, you must assume it is thread-volatile and take precautions.

## The Role of Thread Synchronization

At this point, it should be clear that multithreaded programs are in themselves quite volatile, as numerous threads can operate on the shared resources at (more or less) the same time. To protect an application's resources from possible corruption, .NET Core developers must use any number of threading primitives (such as locks, monitors, and the [Synchronization] attribute or language keyword support) to control access among the executing threads.

Although the .NET Core platform cannot make the difficulties of building robust multithreaded applications completely disappear, the process has been simplified considerably. Using types defined within the `System.Threading` namespace, the Task Parallel Library (TPL), and the C# `async` and `await` language keywords, you are able to work with multiple threads with minimal fuss and bother.

Before diving into the `System.Threading` namespace, the TPL, and the C# `async` and `await` keywords, you will begin by examining how the .NET Core delegate type can be used to invoke a method in an asynchronous manner. While it is most certainly true that since .NET 4.6 the new C# `async` and `await` keywords offer a simpler alternative to asynchronous delegates, it is still important that you know how to interact with code using this approach (trust me; there is a ton of code in production that uses asynchronous delegates).

## The System.Threading Namespace

Under the .NET and .NET Core platforms, the `System.Threading` namespace provides a number of types that enable the direct construction of multithreaded applications. In addition to providing types that allow you to interact with a particular CoreCLR thread, this namespace defines types that allow access to the CoreCLR-maintained thread pool, a simple (non-GUI-based) `Timer` class, and numerous types used to provide synchronized access to shared resources. Table 15-1 lists some of the important members of this namespace. (Be sure to consult the .NET Core SDK documentation for full details.)

**Table 15-1.** Core Types of the `System.Threading` Namespace

Type	Meaning in Life
<code>Interlocked</code>	This type provides atomic operations for variables that are shared by multiple threads.
<code>Monitor</code>	This type provides the synchronization of threading objects using locks and wait/signals. The C# <code>lock</code> keyword uses a <code>Monitor</code> object under the hood.
<code>Mutex</code>	This synchronization primitive can be used for synchronization between application domain boundaries.
<code>ParameterizedThreadStart</code>	This delegate allows a thread to call methods that take any number of arguments.
<code>Semaphore</code>	This type allows you to limit the number of threads that can access a resource, or a particular type of resource, concurrently.
<code>Thread</code>	This type represents a thread that executes within the CoreCLR. Using this type, you are able to spawn additional threads in the originating <code>AppDomain</code> .
<code>ThreadPool</code>	This type allows you to interact with the CoreCLR-maintained thread pool within a given process.

(continued)

**Table 15-1.** *(continued)*

Type	Meaning in Life
ThreadPriority	This enum represents a thread’s priority level (Highest, Normal, etc.).
ThreadStart	This delegate is used to specify the method to call for a given thread. Unlike the ParameterizedThreadStart delegate, targets of ThreadStart must always have the same prototype.
ThreadState	This enum specifies the valid states a thread may take (Running, Aborted, etc.).
Timer	This type provides a mechanism for executing a method at specified intervals.
TimerCallback	This delegate type is used in conjunction with Timer types.

## The System.Threading.Thread Class

The most primitive of all types in the `System.Threading` namespace is `Thread`. This class represents an object-oriented wrapper around a given path of execution within a particular `AppDomain`. This type also defines a number of methods (both static and instance level) that allow you to create new threads within the current `AppDomain`, as well as to suspend, stop, and destroy a particular thread. Consider the list of core static members in [Table 15-2](#).

**Table 15-2** *Key Static Members of the Thread Type*

Static Member	Meaning in Life
ExecutionContext	This read-only property returns information relevant to the logical thread of execution, including security, call, synchronization, localization, and transaction contexts.
CurrentThread	This read-only property returns a reference to the currently running thread.
Sleep()	This method suspends the current thread for a specified time.

The `Thread` class also supports several instance-level members, some of which are shown in [Table 15-3](#).

**Table 15-3.** *Select Instance-Level Members of the Thread Type*

Instance-Level Member	Meaning in Life
IsAlive	Returns a Boolean that indicates whether this thread has been started (and has not yet terminated or aborted).
IsBackground	Gets or sets a value indicating whether this thread is a “background thread” (more details in just a moment).
Name	Allows you to establish a friendly text name of the thread.
Priority	Gets or sets the priority of a thread, which may be assigned a value from the <code>ThreadPriority</code> enumeration.
ThreadState	Gets the state of this thread, which may be assigned a value from the <code>ThreadState</code> enumeration.

*(continued)*

**Table 15-3.** (continued)

Instance-Level Member	Meaning in Life
Abort()	Instructs the CoreCLR to terminate the thread as soon as possible.
Interrupt()	Interrupts (e.g., wakes) the current thread from a suitable wait period.
Join()	Blocks the calling thread until the specified thread (the one on which Join() is called) exits.
Resume()	Resumes a thread that has been previously suspended.
Start()	Instructs the CoreCLR to execute the thread ASAP.
Suspend()	Suspends the thread. If the thread is already suspended, a call to Suspend() has no effect.

---

■ **Note** Aborting or suspending an active thread is generally considered a bad idea. When you do so, there is a chance (however small) that a thread could “leak” its workload when disturbed or terminated.

---

## Obtaining Statistics About the Current Thread of Execution

Recall that the entry point of an executable assembly (i.e., the Main() method) runs on the primary thread of execution. To illustrate the basic use of the Thread type, assume you have a new Console Application project named ThreadStats. As you know, the static Thread.CurrentThread property retrieves a Thread object that represents the currently executing thread. Once you have obtained the current thread, you are able to print out various statistics, like so:

```
// Be sure to import the System.Threading namespace.
using System.Threading;
static void Main(string[] args)
{
    Console.WriteLine("***** Primary Thread stats *****\n");

    // Obtain and name the current thread.
    Thread primaryThread = Thread.CurrentThread;
    primaryThread.Name = "ThePrimaryThread";

    // Print out some stats about this thread.
    Console.WriteLine("ID of current thread: {0}",
        primaryThread.ManagedThreadId);
    Console.WriteLine("Thread Name: {0}",
        primaryThread.Name);
    Console.WriteLine("Has thread started?: {0}",
        primaryThread.IsAlive);
    Console.WriteLine("Priority Level: {0}",
        primaryThread.Priority);
    Console.WriteLine("Thread State: {0}",
        primaryThread.ThreadState);
    Console.ReadLine();
}
```

Here is the current output:

```
***** Primary Thread stats *****
ID of current thread: 1
Thread Name: ThePrimaryThread
Has thread started?: True
Priority Level: Normal
Thread State: Running
```

## The Name Property

While this code is more or less self-explanatory, do notice that the Thread class supports a property called Name. If you do not set this value, Name will return an empty string. However, once you assign a friendly string moniker to a given Thread object, you can greatly simplify your debugging endeavors. If you are using Visual Studio, you may access the Threads window during a debugging session (select Debug ► Windows ► Threads when the program is running). As you can see from Figure 15-1, you can quickly identify the thread you want to diagnose.

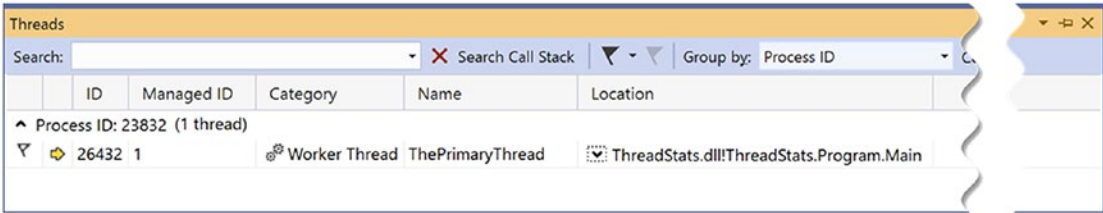


Figure 15-1. Debugging a thread with Visual Studio

## The Priority Property

Next, notice that the Thread type defines a property named Priority. By default, all threads have a priority level of Normal. However, you can change this at any point in the thread's lifetime using the ThreadPriority property and the related System.Threading.ThreadPriority enumeration, like so:

```
public enum ThreadPriority
{
    Lowest,
    BelowNormal,
    Normal, // Default value.
    AboveNormal,
    Highest
}
```

If you were to assign a thread's priority level to a value other than the default (ThreadPriority.Normal), understand that you would have no direct control over when the thread scheduler switches between threads. In reality, a thread's priority level offers a hint to the CoreCLR regarding the importance of the thread's activity. Thus, a thread with the value ThreadPriority.Highest is not necessarily guaranteed to be given the highest precedence.

Again, if the thread scheduler is preoccupied with a given task (e.g., synchronizing an object, switching threads, or moving threads), the priority level will most likely be altered accordingly. However, all things being equal, the CoreCLR will read these values and instruct the thread scheduler how to best allocate time slices. Threads with an identical thread priority should each receive the same amount of time to perform their work.

In most cases, you will seldom (if ever) need to directly alter a thread's priority level. In theory, it is possible to jack up the priority level on a set of threads, thereby preventing lower-priority threads from executing at their required levels (so use caution).

## Manually Creating Secondary Threads

When you want to programmatically create additional threads to carry on some unit of work, follow this predictable process when using the types of the `System.Threading` namespace:

1. Create a method to be the entry point for the new thread.
2. Create a new `ParameterizedThreadStart` (or `ThreadStart`) delegate, passing the address of the method defined in step 1 to the constructor.
3. Create a `Thread` object, passing the `ParameterizedThreadStart/ThreadStart` delegate as a constructor argument.
4. Establish any initial thread characteristics (name, priority, etc.).
5. Call the `Thread.Start()` method. This starts the thread at the method referenced by the delegate created in step 2 as soon as possible.

As stated in step 2, you may use two distinct delegate types to “point to” the method that the secondary thread will execute. The `ThreadStart` delegate can point to any method that takes no arguments and returns nothing. This delegate can be helpful when the method is designed to simply run in the background without further interaction.

The limitation of `ThreadStart` is that you are unable to pass in parameters for processing. However, the `ParameterizedThreadStart` delegate type allows a single parameter of type `System.Object`. Given that anything can be represented as a `System.Object`, you can pass in any number of parameters via a custom class or structure. Do note, however, that the `ThreadStart` and `ParameterizedThreadStart` delegates can only point to methods that return `void`.

## Working with the ThreadStart Delegate

To illustrate the process of building a multithreaded application (as well as to demonstrate the usefulness of doing so), assume you have a Console Application project (`SimpleMultiThreadApp`) that allows the end user to choose whether the application will perform its duties using the single primary thread or whether it will split its workload using two separate threads of execution.

Assuming you have imported the `System.Threading` namespace, your first step is to define a method to perform the work of the (possible) secondary thread. To keep focused on the mechanics of building multithreaded programs, this method will simply print out a sequence of numbers to the console window, pausing for approximately two seconds with each pass. Here is the full definition of the `Printer` class:

```
public class Printer
{
    public void PrintNumbers()
    {
```



```

// Display Thread info.
Console.WriteLine("-> {0} is executing PrintNumbers()",
    Thread.CurrentThread.Name);

// Print out numbers.
Console.Write("Your numbers: ");
for(int i = 0; i < 10; i++)
{
    Console.Write("{0}, ", i);
    Thread.Sleep(2000);
}
Console.WriteLine();
}
}

```

Now, within `Main()`, you will first prompt the user to determine whether one or two threads will be used to perform the application's work. If the user requests a single thread, you will simply invoke the `PrintNumbers()` method within the primary thread. However, if the user specifies two threads, you will create a `ThreadStart` delegate that points to `PrintNumbers()`, pass this delegate object into the constructor of a new `Thread` object, and call `Start()` to inform the CoreCLR this thread is ready for processing. Here is the complete implementation of `Main()`:

```

static void Main(string[] args)
{
    Console.WriteLine("***** The Amazing Thread App *****\n");
    Console.Write("Do you want [1] or [2] threads? ");
    string threadCount = Console.ReadLine();

    // Name the current thread.
    Thread primaryThread = Thread.CurrentThread;
    primaryThread.Name = "Primary";

    // Display Thread info.
    Console.WriteLine("-> {0} is executing Main()",
        Thread.CurrentThread.Name);

    // Make worker class.
    Printer p = new Printer();

    switch(threadCount)
    {
        case "2":
            // Now make the thread.
            Thread backgroundThread =
                new Thread(new ThreadStart(p.PrintNumbers));
            backgroundThread.Name = "Secondary";
            backgroundThread.Start();
            break;
        case "1":
            p.PrintNumbers();
            break;
    }
}

```

```

    default:
        Console.WriteLine("I don't know what you want...you get 1 thread.");
        goto case "1";
    }
    // Do some additional work.
    Console.WriteLine("This is on the main thread, and we are finished.");
    Console.ReadLine();
}

```

Now, if you run this program with a single thread, you will find that the final message box will not display the message until the entire sequence of numbers has printed to the console. As you are explicitly pausing for approximately two seconds after each number is printed, this will result in a less-than-stellar end-user experience. However, if you select two threads, the message box displays instantly, given that a unique `Thread` object is responsible for printing the numbers to the console.

## Working with the `ParameterizedThreadStart` Delegate

Recall that the `ThreadStart` delegate can point only to methods that return `void` and take no arguments. While this might fit the bill in some cases, if you want to pass data to the method executing on the secondary thread, you will need to use the `ParameterizedThreadStart` delegate type. To illustrate, create a new Console Application project named `AddWithThreads` and import the `System.Threading` namespace. Now, given that `ParameterizedThreadStart` can point to any method taking a `System.Object` parameter, you will create a custom type containing the numbers to be added, like so:

```

class AddParams
{
    public int a, b;

    public AddParams(int numb1, int numb2)
    {
        a = numb1;
        b = numb2;
    }
}

```

Next, create a static method in the `Program` class that will take an `AddParams` parameter and print the sum of the two numbers involved, as follows:

```

static void Add(object data)
{
    if (data is AddParams ap)
    {
        Console.WriteLine("ID of thread in Add(): {0}",
            Thread.CurrentThread.ManagedThreadId);

        Console.WriteLine("{0} + {1} is {2}",
            ap.a, ap.b, ap.a + ap.b);
    }
}

```

The code within `Main()` is straightforward. Simply use `ParameterizedThreadStart` rather than `ThreadStart`, like so:

```
static void Main(string[] args)
{
    Console.WriteLine("***** Adding with Thread objects *****");
    Console.WriteLine("ID of thread in Main(): {0}",
        Thread.CurrentThread.ManagedThreadId);

    // Make an AddParams object to pass to the secondary thread.
    AddParams ap = new AddParams(10, 10);
    Thread t = new Thread(new ParameterizedThreadStart(Add));
    t.Start(ap);

    // Force a wait to let other thread finish.
    Thread.Sleep(5);
    Console.ReadLine();
}
```

## The AutoResetEvent Class

In these first few examples, there isn't a clean way to know when the secondary thread has completed its work. In the last example, `Sleep` was called with an arbitrary time to let the other thread finish. One simple and thread-safe way to force a thread to wait until another is completed is to use the `AutoResetEvent` class. In the thread that needs to wait (such as a `Main()` method), create an instance of this class and pass in `false` to the constructor to signify you have not yet been notified. Then, at the point at which you are willing to wait, call the `WaitOne()` method. Here is the update to the `Program` class, which will do this very thing using a static-level `AutoResetEvent` member variable:

```
class Program
{
    private static AutoResetEvent _waitHandle =
        new AutoResetEvent(false);

    static void Main(string[] args)
    {
        Console.WriteLine("***** Adding with Thread objects *****");
        Console.WriteLine("ID of thread in Main(): {0}",
            Thread.CurrentThread.ManagedThreadId);
        AddParams ap = new AddParams(10, 10);
        Thread t = new Thread(new ParameterizedThreadStart(Add));
        t.Start(ap);

        // Wait here until you are notified!
        _waitHandle.WaitOne();
        Console.WriteLine("Other thread is done!");

        Console.ReadLine();
    }
    ...
}
```

When the other thread is completed with its workload, it will call the `Set()` method on the same instance of the `AutoResetEvent` type.

```
static void Add(object data)
{
    if (data is AddParams ap)
    {
        Console.WriteLine("ID of thread in Add(): {0}",
            Thread.CurrentThread.ManagedThreadId);

        Console.WriteLine("{0} + {1} is {2}",
            ap.a, ap.b, ap.a + ap.b);

        // Tell other thread we are done.
        _waitHandle.Set();
    }
}
```

## Foreground Threads and Background Threads

Now that you have seen how to programmatically create new threads of execution using the `System.Threading` namespace, let's formalize the distinction between foreground threads and background threads:

- *Foreground threads* have the ability to prevent the current application from terminating. The CoreCLR will not shut down an application (which is to say, unload the hosting `AppDomain`) until all foreground threads have ended.
- *Background threads* (sometimes called *daemon threads*) are viewed by the CoreCLR as expendable paths of execution that can be ignored at any point in time (even if they are currently laboring over some unit of work). Thus, if all foreground threads have terminated, any and all background threads are automatically killed when the application domain unloads.

It is important to note that foreground and background threads are *not* synonymous with primary and worker threads. By default, every thread you create via the `Thread.Start()` method is automatically a foreground thread. Again, this means that the `AppDomain` will not unload until all threads of execution have completed their units of work. In most cases, this is exactly the behavior you require.

For the sake of argument, however, assume that you want to invoke `Printer.PrintNumbers()` on a secondary thread that should behave as a background thread. Again, this means that the method pointed to by the `Thread` type (via the `ThreadStart` or `ParameterizedThreadStart` delegate) should be able to halt safely as soon as all foreground threads are done with their work. Configuring such a thread is as simple as setting the `IsBackground` property to `true`, like so:

```
static void Main(string[] args)
{
    Console.WriteLine("***** Background Threads *****\n");
    Printer p = new Printer();
    Thread bgThread =
        new Thread(new ThreadStart(p.PrintNumbers));
```

```
// This is now a background thread.
bgroundThread.IsBackground = true;
bgroundThread.Start();
}
```

Notice that this `Main()` method is *not* making a call to `Console.ReadLine()` to force the console to remain visible until you press the Enter key. Thus, when you run the application, it will shut down immediately because the `Thread` object has been configured as a background thread. Given that the `Main()` method triggers the creation of the primary *foreground* thread, as soon as the logic in `Main()` completes, the `AppDomain` unloads before the secondary thread is able to complete its work.

However, if you comment out the line that sets the `IsBackground` property, you will find that each number prints to the console, as all foreground threads must finish their work before the `AppDomain` is unloaded from the hosting process.

For the most part, configuring a thread to run as a background type can be helpful when the worker thread in question is performing a noncritical task that is no longer needed when the main task of the program is finished. For example, you could build an application that pings an email server every few minutes for new emails, updates current weather conditions, or performs some other noncritical task.

## The Issue of Concurrency

When you build multithreaded applications, your program needs to ensure that any piece of shared data is protected against the possibility of numerous threads changing its value. Given that all threads in an `AppDomain` have concurrent access to the shared data of the application, imagine what might happen if multiple threads were accessing the same point of data. As the thread scheduler will force threads to suspend their work at random, what if thread A is kicked out of the way before it has fully completed its work? Thread B is now reading unstable data.

To illustrate the problem of concurrency, let's build another Console Application project named `MultiThreadedPrinting`. This application will once again use the `Printer` class created previously, but this time the `PrintNumbers()` method will force the current thread to pause for a randomly generated amount of time.

```
using System.Threading;
public class Printer
{
    public void PrintNumbers()
    {
        // Display Thread info.
        Console.WriteLine("-> {0} is executing PrintNumbers()",
            Thread.CurrentThread.Name);

        // Print out numbers.
        for (int i = 0; i < 10; i++)
        {
            // Put thread to sleep for a random amount of time.
            Random r = new Random();
            Thread.Sleep(1000 * r.Next(5));
            Console.Write("{0}, ", i);
        }
        Console.WriteLine();
    }
}
```

The `Main()` method is responsible for creating an array of ten (uniquely named) `Thread` objects, each of which is making calls on the *same instance* of the `Printer` object as follows:

```
class Program
{
    static void Main(string[] args)
    {
        Console.WriteLine("*****Synchronizing Threads *****\n");

        Printer p = new Printer();

        // Make 10 threads that are all pointing to the same
        // method on the same object.
        Thread[] threads = new Thread[10];
        for (int i = 0; i < 10; i++)
        {
            threads[i] = new Thread(new ThreadStart(p.PrintNumbers))
            {
                Name = $"Worker thread #{i}"
            };
        }
        // Now start each one.
        foreach (Thread t in threads)
        {
            t.Start();
        }
        Console.ReadLine();
    }
}
```

Before looking at some test runs, let's recap the problem. The primary thread within this `AppDomain` begins life by spawning ten secondary worker threads. Each worker thread is told to make calls on the `PrintNumbers()` method on the *same* `Printer` instance. Given that you have taken no precautions to lock down this object's shared resources (the console), there is a good chance that the current thread will be kicked out of the way before the `PrintNumbers()` method is able to print the complete results. Because you don't know exactly when (or if) this might happen, you are bound to get unpredictable results. For example, you might find the output shown here:

---

```
*****Synchronizing Threads *****
```

```
-> Worker thread #3 is executing PrintNumbers()
-> Worker thread #0 is executing PrintNumbers()
-> Worker thread #1 is executing PrintNumbers()
-> Worker thread #2 is executing PrintNumbers()
-> Worker thread #4 is executing PrintNumbers()
-> Worker thread #5 is executing PrintNumbers()
-> Worker thread #6 is executing PrintNumbers()
-> Worker thread #7 is executing PrintNumbers()
-> Worker thread #8 is executing PrintNumbers()
-> Worker thread #9 is executing PrintNumbers()
```

```

0, 0, 0, 0, 1, 0, 1, 0, 1, 0, 0, 0, 1, 0, 1, 1, 2, 3, 1, 2, 2, 2, 1, 2, 1, 1, 2, 2, 3, 3, 4,
3, 3, 2, 2, 3, 4, 3, 4, 5, 4, 5, 4, 4, 3, 6, 7, 2, 3, 4, 4, 4, 5, 6, 5, 3, 5, 8, 9,
6, 7, 4, 5, 6, 6, 5, 5, 5, 8, 5, 6, 7, 8, 7, 7, 6, 6, 6, 8, 9,
8, 7, 7, 7, 7, 9,
6, 8, 9,
8, 9,
9, 9,

8, 8, 7, 8, 9,
9,
9,

```

---

Now run the application a few more times and examine the output. It will most likely be different each time.

---

■ **Note** If you are unable to generate unpredictable outputs, increase the number of threads from 10 to 100 (for example) or introduce another call to `Thread.Sleep()` within your program. Eventually, you will encounter the concurrency issue.

---

There are clearly some problems here. As each thread is telling the `Printer` to print the numerical data, the thread scheduler is happily swapping threads in the background. The result is inconsistent output. What you need is a way to programmatically enforce synchronized access to the shared resources. As you would guess, the `System.Threading` namespace provides a number of synchronization-centric types. The C# programming language also provides a particular keyword for the very task of synchronizing shared data in multithreaded applications.

## Synchronization Using the C# `lock` Keyword

The first technique you can use to synchronize access to shared resources is the C# `lock` keyword. This keyword allows you to define a scope of statements that must be synchronized between threads. By doing so, incoming threads cannot interrupt the current thread, thus preventing it from finishing its work. The `lock` keyword requires you to specify a *token* (an object reference) that must be acquired by a thread to enter within the lock scope. When you are attempting to lock down a *private* instance-level method, you can simply pass in a reference to the current type, as follows:

```

private void SomePrivateMethod()
{
    // Use the current object as the thread token.
    lock(this)
    {
        // All code within this scope is thread safe.
    }
}

```

However, if you are locking down a region of code within a *public* member, it is safer (and a best practice) to declare a private object member variable to serve as the lock token, like so:

```
public class Printer
{
    // Lock token.
    private object threadLock = new object();

    public void PrintNumbers()
    {
        // Use the lock token.
        lock (threadLock)
        {
            ...
        }
    }
}
```

In any case, if you examine the `PrintNumbers()` method, you can see that the shared resource the threads are competing to gain access to is the console window. Therefore, if you scope all interactions with the Console type within a lock scope, as follows:

```
public void PrintNumbers()
{
    // Use the private object lock token.
    lock (threadLock)
    {
        // Display Thread info.
        Console.WriteLine("-> {0} is executing PrintNumbers()",
            Thread.CurrentThread.Name);
        // Print out numbers.
        Console.Write("Your numbers: ");
        for (int i = 0; i < 10; i++)
        {
            Random r = new Random();
            Thread.Sleep(1000 * r.Next(5));
            Console.Write("{0}, ", i);
        }
        Console.WriteLine();
    }
}
```

you have effectively designed a method that will allow the current thread to complete its task. Once a thread enters into a lock scope, the lock token (in this case, a reference to the current object) is inaccessible by other threads until the lock is released after the lock scope has exited. Thus, if thread A has obtained the lock token, other threads are unable to enter *any scope* that uses the same lock token until thread A relinquishes the lock token.

---

■ **Note** If you are attempting to lock down code in a static method, simply declare a private static object member variable to serve as the lock token.

---



If you now run the application, you can see that each thread has ample opportunity to finish its business.

---

```
*****Synchronizing Threads *****
-> Worker thread #0 is executing PrintNumbers()
Your numbers: 0, 1, 2, 3, 4, 5, 6, 7, 8, 9,
-> Worker thread #1 is executing PrintNumbers()
Your numbers: 0, 1, 2, 3, 4, 5, 6, 7, 8, 9,
-> Worker thread #3 is executing PrintNumbers()
Your numbers: 0, 1, 2, 3, 4, 5, 6, 7, 8, 9,
-> Worker thread #2 is executing PrintNumbers()
Your numbers: 0, 1, 2, 3, 4, 5, 6, 7, 8, 9,
-> Worker thread #4 is executing PrintNumbers()
Your numbers: 0, 1, 2, 3, 4, 5, 6, 7, 8, 9,
-> Worker thread #5 is executing PrintNumbers()
Your numbers: 0, 1, 2, 3, 4, 5, 6, 7, 8, 9,
-> Worker thread #7 is executing PrintNumbers()
Your numbers: 0, 1, 2, 3, 4, 5, 6, 7, 8, 9,
-> Worker thread #6 is executing PrintNumbers()
Your numbers: 0, 1, 2, 3, 4, 5, 6, 7, 8, 9,
-> Worker thread #8 is executing PrintNumbers()
Your numbers: 0, 1, 2, 3, 4, 5, 6, 7, 8, 9,
-> Worker thread #9 is executing PrintNumbers()
Your numbers: 0, 1, 2, 3, 4, 5, 6, 7, 8, 9,
```

---

## Synchronization Using the System.Threading.Monitor Type

The C# lock statement is really just a shorthand notation for working with the `System.Threading.Monitor` class. Once processed by the C# compiler, a lock scope actually resolves to the following (which you can verify using `ildasm.exe`):

```
public void PrintNumbers()
{
    Monitor.Enter(threadLock);
    try
    {
        // Display Thread info.
        Console.WriteLine("-> {0} is executing PrintNumbers()",
            Thread.CurrentThread.Name);

        // Print out numbers.
        Console.Write("Your numbers: ");
        for (int i = 0; i < 10; i++)
        {
            Random r = new Random();
            Thread.Sleep(1000 * r.Next(5));
            Console.Write("{0}, ", i);
        }
    }
}
```

```

        Console.WriteLine();
    }
    finally
    {
        Monitor.Exit(threadLock);
    }
}

```

First, notice that the `Monitor.Enter()` method is the ultimate recipient of the thread token you specified as the argument to the lock keyword. Next, all code within a lock scope is wrapped within a try block. The corresponding finally block ensures that the thread token is released (via the `Monitor.Exit()` method), regardless of any possible runtime exception. If you were to modify the `MultiThreadPrinting` program to make direct use of the `Monitor` type (as just shown), you would find the output is identical.

Now, given that the lock keyword seems to require less code than making explicit use of the `System.Threading.Monitor` type, you might wonder about the benefits of using the `Monitor` type directly. The short answer is control. If you use the `Monitor` type, you are able to instruct the active thread to wait for some duration of time (via the static `Monitor.Wait()` method), inform waiting threads when the current thread is completed (via the static `Monitor.Pulse()` and `Monitor.PulseAll()` methods), and so on.

As you would expect, in a great number of cases, the C# lock keyword will fit the bill. However, if you are interested in checking out additional members of the `Monitor` class, consult the .NET Core documentation.

## Synchronization Using the `System.Threading.Interlocked` Type

Although it is always hard to believe, until you look at the underlying CIL code, assignments and simple arithmetic operations are *not atomic*. For this reason, the `System.Threading` namespace provides a type that allows you to operate on a single point of data atomically with less overhead than with the `Monitor` type. The `Interlocked` class defines the key static members shown in Table 15-4.

**Table 15-4.** Select Static Members of the `System.Threading.Interlocked` Type

Member	Meaning in Life
<code>CompareExchange()</code>	Safely tests two values for equality and, if equal, exchanges one of the values with a third
<code>Decrement()</code>	Safely decrements a value by 1
<code>Exchange()</code>	Safely swaps two values
<code>Increment()</code>	Safely increments a value by 1

Although it might not seem like it from the onset, the process of atomically altering a single value is quite common in a multithreaded environment. Assume you have a method named `AddOne()` that increments an integer member variable named `intVal`. Rather than writing synchronization code such as the following:

```

public void AddOne()
{
    lock(myLockToken)
    {
        intVal++;
    }
}

```

you can simplify your code via the static `Interlocked.Increment()` method. Simply pass in the variable to increment by reference. Do note that the `Increment()` method not only adjusts the value of the incoming parameter but also returns the new value.

```
public void AddOne()
{
    int newVal = Interlocked.Increment(ref intVal);
}
```

In addition to `Increment()` and `Decrement()`, the `Interlocked` type allows you to atomically assign numerical and object data. For example, if you want to assign the value of a member variable to the value 83, you can avoid the need to use an explicit lock statement (or explicit `Monitor` logic) and use the `Interlocked.Exchange()` method, like so:

```
public void SafeAssignment()
{
    Interlocked.Exchange(ref myInt, 83);
}
```

Finally, if you want to test two values for equality and change the point of comparison in a thread-safe manner, you are able to leverage the `Interlocked.CompareExchange()` method as follows:

```
public void CompareAndExchange()
{
    // If the value of i is currently 83, change i to 99.
    Interlocked.CompareExchange(ref i, 99, 83);
}
```

## Programming with Timer Callbacks

Many applications have the need to call a specific method during regular intervals of time. For example, you might have an application that needs to display the current time on a status bar via a given helper function. As another example, you might want to have your application call a helper function every so often to perform noncritical background tasks such as checking for new email messages. For situations such as these, you can use the `System.Threading.Timer` type in conjunction with a related delegate named `TimerCallback`.

To illustrate, assume you have a Console Application project (`TimerApp`) that will print the current time every second until the user presses a key to terminate the application. The first obvious step is to write the method that will be called by the `Timer` type (be sure to import `System.Threading` into your code file).

```
class Program
{
    static void PrintTime(object state)
    {
        Console.WriteLine("Time is: {0}",
            DateTime.Now.ToLongTimeString());
    }

    static void Main(string[] args)
    {
    }
}
```

Notice the `PrintTime()` method has a single parameter of type `System.Object` and returns `void`. This is not optional, given that the `TimerCallback` delegate can only call methods that match this signature. The value passed into the target of your `TimerCallback` delegate can be any type of object (in the case of the email example, this parameter might represent the name of the Microsoft Exchange Server to interact with during the process). Also note that given that this parameter is indeed a `System.Object`, you are able to pass in multiple arguments using a `System.Array` or custom class/structure.

The next step is to configure an instance of the `TimerCallback` delegate and pass it into the `Timer` object. In addition to configuring a `TimerCallback` delegate, the `Timer` constructor allows you to specify the optional parameter information to pass into the delegate target (defined as a `System.Object`), the interval to poll the method, and the amount of time to wait (in milliseconds) before making the first call. Here's an example:

```
static void Main(string[] args)
{
    Console.WriteLine("***** Working with Timer type *****\n");

    // Create the delegate for the Timer type.
    TimerCallback timeCB = new TimerCallback(PrintTime);

    // Establish timer settings.
    Timer t = new Timer(
        timeCB,      // The TimerCallback delegate object.
        null,        // Any info to pass into the called method (null for no info).
        0,           // Amount of time to wait before starting (in milliseconds).
        1000);       // Interval of time between calls (in milliseconds).

    Console.WriteLine("Hit Enter key to terminate...");
    Console.ReadLine();
}
```

In this case, the `PrintTime()` method will be called roughly every second and will pass in no additional information to said method. Here is the output:

---

```
***** Working with Timer type *****

Hit key to terminate...
Time is: 6:51:48 PM
Time is: 6:51:49 PM
Time is: 6:51:50 PM
Time is: 6:51:51 PM
Time is: 6:51:52 PM
Press any key to continue . . .
```

---

If you did want to send in some information for use by the delegate target, simply substitute the `null` value of the second constructor parameter with the appropriate information, like so:

```
// Establish timer settings.
Timer t = new Timer(timeCB, "Hello From Main", 0, 1000);
```

You can then obtain the incoming data as follows:

```
static void PrintTime(object state)
{
    Console.WriteLine("Time is: {0}, Param is: {1}",
        DateTime.Now.ToLongTimeString(), state.ToString());
}
```

## Using a Stand-Alone Discard

In the previous example, the `Timer` variable isn't used in any execution path, so it can be replaced with a `discard`, as follows:

```
var _ = new Timer(
    timeCB, // The TimerCallback delegate object.
    null,   // Any info to pass into the called method
            // (null for no info).
    0,      // Amount of time to wait before starting
            //(in milliseconds).
    1000);  // Interval of time between calls
            //(in milliseconds).
```

## Understanding the ThreadPool

The next thread-centric topic you will examine in this chapter is the role of the runtime thread pool. There is a cost with starting a new thread, so for purposes of efficiency, the thread pool holds onto created (but inactive) threads until needed. To allow you to interact with this pool of waiting threads, the `System.Threading` namespace provides the `ThreadPool` class type.

If you want to queue a method call for processing by a worker thread in the pool, you can use the `ThreadPool.QueueUserWorkItem()` method. This method has been overloaded to allow you to specify an optional `System.Object` for custom state data in addition to an instance of the `WaitCallback` delegate.

```
public static class ThreadPool
{
    ...
    public static bool QueueUserWorkItem(WaitCallback callBack);
    public static bool QueueUserWorkItem(WaitCallback callBack,
                                         object state);
}
```

The `WaitCallback` delegate can point to any method that takes a `System.Object` as its sole parameter (which represents the optional state data) and returns nothing. Do note that if you do not provide a `System.Object` when calling `QueueUserWorkItem()`, the CoreCLR automatically passes a null value. To illustrate queuing methods for use by the CoreCLR thread pool, ponder the following program, which uses the `Printer` type once again. In this case, however, you are not manually creating an array of `Thread` objects; rather, you are assigning members of the pool to the `PrintNumbers()` method.

```

class Program
{
    static void Main(string[] args)
    {
        Console.WriteLine("***** Fun with the CoreCLR Thread Pool *****\n");

        Console.WriteLine("Main thread started. ThreadID = {0}",
            Thread.CurrentThread.ManagedThreadId);

        Printer p = new Printer();

        WaitCallback workItem = new WaitCallback(PrintTheNumbers);

        // Queue the method ten times.
        for (int i = 0; i < 10; i++)
        {
            ThreadPool.QueueUserWorkItem(workItem, p);
        }
        Console.WriteLine("All tasks queued");
        Console.ReadLine();
    }
    static void PrintTheNumbers(object state)
    {
        Printer task = (Printer)state;
        task.PrintNumbers();
    }
}

```

At this point, you might be wondering if it would be advantageous to use the CoreCLR-maintained thread pool rather than explicitly creating `Thread` objects. Consider these benefits of leveraging the thread pool:

- The thread pool manages threads efficiently by minimizing the number of threads that must be created, started, and stopped.
- By using the thread pool, you can focus on your business problem rather than the application's threading infrastructure.

However, using manual thread management is preferred in some cases. Here's an example:

- If you require foreground threads or must set the thread priority. Pooled threads are *always* background threads with default priority (`ThreadPriority.Normal`).
- If you require a thread with a fixed identity in order to abort it, suspend it, or discover it by name.

That wraps up your investigation of the `System.Threading` namespace. To be sure, understanding the topics presented thus far in the chapter (especially during your examination of concurrency issues) will be extremely valuable when creating a multithreaded application. Given this foundation, you will now turn your attention to a number of new thread-centric topics that were introduced in .NET 4.0 and carried forward to .NET Core. To begin, you will examine the role of an alternative threading model, the Task Parallel Library.

## Parallel Programming Using the Task Parallel Library (TPL)

At this point in the chapter, you have examined the `System.Threading` namespace objects that allow you to build multithreaded software. Beginning with the release of .NET 4.0, Microsoft introduced a new approach to multithreaded application development using a parallel programming library termed the *Task Parallel Library* (TPL). Using the types of `System.Threading.Tasks`, you can build fine-grained, scalable parallel code without having to work directly with threads or the thread pool.

This is not to say, however, that you will not use the types of `System.Threading` when you use the TPL. In reality, these two threading toolkits can work together quite naturally. This is especially true in that the `System.Threading` namespace still provides a majority of the synchronization primitives you examined previously (Monitor, Interlocked, etc.). This being said, you will quite likely find that you will favor working with the TPL rather than the original `System.Threading` namespace, given that the same set of tasks can be performed in a more straightforward manner.

### The System.Threading.Tasks Namespace

Collectively speaking, the types of `System.Threading.Tasks` are referred to as the *Task Parallel Library*. The TPL will automatically distribute your application's workload across available CPUs dynamically, using the runtime thread pool. The TPL handles the partitioning of the work, thread scheduling, state management, and other low-level details. The end result is that you can maximize the performance of your .NET Core applications while being shielded from many of complexities of directly working with threads.

### The Role of the Parallel Class

A key class of the TPL is `System.Threading.Tasks.Parallel`. This class supports a number of methods that allow you to iterate over a collection of data (specifically, an object implementing `IEnumerable<T>`) in a parallel fashion. This class supports two primary static methods, `Parallel.For()` and `Parallel.ForEach()`, each of which defines numerous overloaded versions.

These methods allow you to author a body of code statements that will be processed in a parallel manner. In concept, these statements are the same sort of logic you would write in a normal looping construct (via the `for` or `foreach` C# keywords). The benefit is that the `Parallel` class will pluck threads from the thread pool (and manage concurrency) on your behalf.

Both of these methods require you to specify an `IEnumerable`- or `IEnumerable<T>`-compatible container that holds the data you need to process in a parallel manner. The container could be a simple array, a nongeneric collection (such as `ArrayList`), a generic collection (such as `List<T>`), or the results of a LINQ query.

In addition, you will need to use the `System.Func<T>` and `System.Action<T>` delegates to specify the target method that will be called to process the data. You've already encountered the `Func<T>` delegate in Chapter 13, during your investigation of LINQ to Objects. Recall that `Func<T>` represents a method that can have a given return value and a varied number of arguments. The `Action<T>` delegate is similar to `Func<T>`, in that it allows you to point to a method taking some number of parameters. However, `Action<T>` specifies a method that can only return void.

While you could call the `Parallel.For()` and `Parallel.ForEach()` methods and pass a strongly typed `Func<T>` or `Action<T>` delegate object, you can simplify your programming by using a fitting C# anonymous method or lambda expression.

## Data Parallelism with the Parallel Class

The first way to use the TPL is to perform *data parallelism*. Simply put, this term refers to the task of iterating over an array or collection in a parallel manner using the `Parallel.For()` or `Parallel.ForEach()` method. Assume you need to perform some labor-intensive file I/O operations. Specifically, you need to load a large number of \*.jpg files into memory, flip them upside down, and save the modified image data to a new location.

In this example, you will see how to perform the same overall task using a graphical user interface so you can examine the use of “anonymous delegates” to allow secondary threads to update the primary user interface thread (aka the UI thread).

---

■ **Note** When you are building a multithreaded graphical user interface (GUI) application, secondary threads can never directly access user interface controls. The reason is that controls (buttons, text boxes, labels, progress bars, etc.) have thread affinity with the thread that created them. In the following example, I’ll illustrate one way to allow secondary threads to access UI items in a thread-safe manner. You’ll see a more simplified approach when you examine the C# `async` and `await` keywords.

---

To illustrate, create a new Windows Presentation Foundation application (the template is abbreviated to WPF App (.NET Core)) named `DataParallelismWithForEach`.

---

■ **Note** Windows Presentation Foundation (WPF) will be covered in detail in Chapters 24–28. If you haven’t worked with WPF, everything you need for this example is listed here. If you would rather just follow along with a completed solution, you can find `DataParallelismWithForEach` in the Chapter 15 folder.

---

Double-click the `MainWindow.xaml` file in Solution Explorer, and replace all of the XAML with the following:

```
<Window x:Class="DataParallelismWithForEach.MainWindow"
        xmlns="http://schemas.microsoft.com/winfx/2006/xaml/presentation"
        xmlns:x="http://schemas.microsoft.com/winfx/2006/xaml"
        xmlns:d="http://schemas.microsoft.com/expression/blend/2008"
        xmlns:mc="http://schemas.openxmlformats.org/markup-compatibility/2006"
        xmlns:local="clr-namespace:DataParallelismWithForEach"
        mc:Ignorable="d"
        Title="Fun with TPL" Height="400" Width="800">
  <Grid>
    <Grid.RowDefinitions>
      <RowDefinition Height="Auto"/>
      <RowDefinition Height="*/>
      <RowDefinition Height="Auto"/>
    </Grid.RowDefinitions>
    <Label Grid.Row="0" Grid.Column="0">
      Feel free to type here while the images are processed...
    </Label>
    <TextBox Grid.Row="1" Grid.Column="0" Margin="10,10,10,10"/>
    <Grid Grid.Row="2" Grid.Column="0">
```



```

<Grid.ColumnDefinitions>
  <ColumnDefinition Width="Auto"/>
  <ColumnDefinition Width="*/>
  <ColumnDefinition Width="Auto"/>
</Grid.ColumnDefinitions>
  <Button Name="cmdCancel" Grid.Row="0" Grid.Column="0" Margin="10,10,0,10"
    Click="cmdCancel_Click">
    Cancel
  </Button>
  <Button Name="cmdProcess" Grid.Row="0" Grid.Column="2" Margin="0,10,10,10"
    Click="cmdProcess_Click">
    Click to Flip Your Images!
  </Button>
</Grid>
</Grid>
</Window>

```

Again, don't worry about what the markup means or how it works; you will spend plenty of time with WPF shortly. The GUI of the application consists of a multiline `TextBox` and a single `Button` (named `cmdProcess`). The purpose of the text area is to allow you to enter data while the work is being performed in the background, thus illustrating the nonblocking nature of the parallel task.

For this example, an additional NuGet package (`System.Drawing.Common`) is required. To add it to your project, enter the following line (all on one line) in the command line (in the same directory as your solution file) or Package Manager Console in Visual Studio:

```
dotnet add DataParallelismWithForEach package System.Drawing.Common
```

Double-click the `MainWindow.xaml.cs` file (you might have to expand the node by `MainWindow.xaml`), and add the following using statements to the top of the file:

```

// Be sure you have these namespaces! (System.Threading.Tasks should already be there from
the default template)
using System.Drawing;
using System.Threading.Tasks;
using System.Threading;
using System.IO;

```

---

■ **Note** You should update the string passed into the following `Directory.GetFiles()` method call to point to a path on your computer that has some image files (such as a personal folder of family pictures). I've included some sample images (that ship with the Windows operating system) in the `Solution` directory for your convenience. Alternatively, you can copy the `TestPictures` directory into the `bin\Debug` directory under this project and leave the strings as they are.

---

```

public partial class MainWindow : Window
{
  public MainWindow()
  {
    InitializeComponent();
  }
}

```

```

private void cmdCancel_Click(object sender, EventArgs e)
{
    // This will be updated shortly
}

private void cmdProcess_Click(object sender, EventArgs e)
{
    ProcessFiles();
    this.Title = "Processing Complete";
}

private void ProcessFiles()
{
    // Load up all *.jpg files, and make a new folder for the
    // modified data.
    //Get the directory path where the file is executing
    var basePath = Directory.GetCurrentDirectory();
    var pictureDirectory =
        Path.Combine(basePath, "TestPictures");
    var outputDirectory =
        Path.Combine(basePath, "ModifiedPictures");
    Directory.CreateDirectory(outputDirectory);
    string[] files = Directory.GetFiles(pictureDirectory,
        "*.jpg", SearchOption.AllDirectories);

    // Process the image data in a blocking manner.
    foreach (string currentFile in files)
    {
        string filename =
            System.IO.Path.GetFileName(currentFile);
        using (Bitmap bitmap = new Bitmap(currentFile))
        {
            bitmap.RotateFlip(RotateFlipType.Rotate180FlipNone);
            bitmap.Save(System.IO.Path.Combine(
                outputDirectory, filename));
            // Print out the ID of the thread processing the current image.
            this.Title = $"Processing {filename} on thread {Thread.CurrentThread.ManagedThreadId}";
        }
    }
}

```

---

■ **Note** If you receive an error that Path is an ambiguous reference between System.IO.Path and System.Windows.Shapes.Path, either remove the using for System.Windows.Shapes or add System.IO to Path: System.IO.Path.Combine(...).

---

Notice that the `ProcessFiles()` method will rotate each `*.jpg` file under the specified directory, which currently contains three files (again, be sure to update the path sent into `Directory.GetFiles()` as necessary). Currently, all the work is happening on the primary thread of the executable. Therefore, if the button is clicked, the program will appear to hang. Furthermore, the caption of the window will also report that the same primary thread is processing the file, as we have only a single thread of execution.

To process the files on as many CPUs as possible, you can rewrite the current `foreach` loop to use `Parallel.ForEach()`. Recall that this method has been overloaded numerous times; however, in the simplest form, you must specify the `IEnumerable<T>`-compatible object that contains the items to process (that would be the files string array) and an `Action<T>` delegate that points to the method that will perform the work.

Here is the relevant update, using the C# lambda operator in place of a literal `Action<T>` delegate object. Notice that you are currently *commenting out* the line of code that displayed the ID of the thread executing the current image file. See the next section to find out the reason why.

```
// Process the image data in a parallel manner!
Parallel.ForEach(files, currentFile =>
{
    string filename = Path.GetFileName(currentFile);

    using (Bitmap bitmap = new Bitmap(currentFile))
    {
        bitmap.RotateFlip(RotateFlipType.Rotate180FlipNone);
        bitmap.Save(Path.Combine(outputDirectory, filename));

        // This code statement is now a problem! See next section.
        // this.Title = $"Processing {filename} on thread
        // {Thread.CurrentThread.ManagedThreadId}"
        // Thread.CurrentThread.ManagedThreadId);
    }
});
```

## Accessing UI Elements on Secondary Threads

You'll notice that I've commented out the previous line of code that updated the caption of the main window with the ID of the currently executing thread. As noted previously, GUI controls have "thread affinity" with the thread that created them. If secondary threads attempt to access a control they did not directly create, you are bound to run into runtime errors when debugging your software. On the flip side, if you were to *run* the application (via `Ctrl+F5`), you might not ever find any problems whatsoever with the original code.

---

■ **Note** Let me reiterate the previous point: when you debug (F5) a multithreaded application, Visual Studio is often able to catch errors that arise when a secondary thread is "touching" a control created on the primary thread. However, oftentimes when you run (`Ctrl+F5`) the application, the application could appear to run correctly (or it might error straightaway). Until you take precautions (examined next), your application has the potential of raising a runtime error under such circumstances.

---

One approach that you can use to allow these secondary threads to access the controls in a thread-safe manner is yet another delegate-centric technique, specifically an *anonymous delegate*. The `Control` parent class in WPF defines a `Dispatcher` object, which manages the work items for a thread. This object has a method named `Invoke()`, which takes a `System.Delegate` as input. You can call this method when you are in a coding context involving secondary threads to provide a thread-safe manner to update the UI of the given control. Now, while you could write all of the required delegate code directly, most developers use expression syntax as a simple alternative. Here is the relevant update to the content with the previously commented-out code statement:

```
using (Bitmap bitmap = new Bitmap(currentFile))
{
    bitmap.RotateFlip(RotateFlipType.Rotate180FlipNone);
    bitmap.Save(Path.Combine(outputDirectory, filename));

    // Eek! This will not work anymore!
    //this.Title = $"Processing {filename} on thread {Thread.CurrentThread.ManagedThreadId}";

    // Invoke on the Form object, to allow secondary threads to access controls
    // in a thread-safe manner.
    Dispatcher?.Invoke(() =>
    {
        this.Title =
            $"Processing {filename} on thread {Thread.CurrentThread.ManagedThreadId}";
    }
    );
}
```

Now, if you run the program, the TPL will indeed distribute the workload to multiple threads from the thread pool, using as many CPUs as possible. However, you will not see the window's caption display the name of each unique thread, and you won't see anything if you type in the text box until all the images have been processed! The reason is that the primary UI thread is still blocked, waiting for all the other threads to finish up their business.

## The Task Class

The `Task` class allows you to easily invoke a method on a secondary thread and can be used as a simple alternative to working with asynchronous delegates. Update the `Click` handler of your `Button` control as so:

```
private void cmdProcess_Click(object sender, EventArgs e)
{
    // Start a new "task" to process the files.
    Task.Factory.StartNew(() => ProcessFiles());
    //Can also be written this way
    //Task.Factory.StartNew(ProcessFiles);
}
```

The `Factory` property of `Task` returns a `TaskFactory` object. When you call its `StartNew()` method, you pass in an `Action<T>` delegate (here, hidden away with a fitting lambda expression) that points to the method to invoke in an asynchronous manner. With this small update, you will now find that the window's title will show which thread from the thread pool is processing a given file, and better yet, the text area is able to receive input, as the UI thread is no longer blocked.

## Handling Cancellation Request

One improvement you can make to the current example is to provide a way for the user to stop the processing of the image data, via a second (aptly named) Cancel button. Thankfully, the `Parallel.For()` and `Parallel.ForEach()` methods both support cancellation through the use of *cancellation tokens*. When you invoke methods on `Parallel`, you can pass in a `ParallelOptions` object, which in turn contains a `CancellationTokenSource` object.

First, define the following new private member variable in your Form-derived class of type `CancellationTokenSource` named `_cancelToken`:

```
public partial class MainWindow :Window
{
    // New Window-level variable.
    private CancellationTokenSource _cancelToken = new CancellationTokenSource();
    ...
}
```

Update the Cancel button Click event to the following code:

```
private void cmdCancel_Click(object sender, EventArgs e)
{
    // This will be used to tell all the worker threads to stop!
    _cancelToken.Cancel();
}
```

Now, the real modifications need to occur within the `ProcessFiles()` method. Consider the final implementation:

```
private void ProcessFiles()
{
    // Use ParallelOptions instance to store the CancellationToken.
    ParallelOptions parOpts = new ParallelOptions();
    parOpts.CancellationToken = _cancelToken.Token;
    parOpts.MaxDegreeOfParallelism = System.Environment.ProcessorCount;

    // Load up all *.jpg files, and make a new folder for the modified data.
    string[] files = Directory.GetFiles(@"\TestPictures", "*.jpg",
    SearchOption.AllDirectories);
    string outputDirectory = @"\ModifiedPictures";
    Directory.CreateDirectory(outputDirectory);

    try
    {
        // Process the image data in a parallel manner!
        Parallel.ForEach(files, parOpts, currentFile =>
        {
            parOpts
                .CancellationToken.ThrowIfCancellationRequested();
```

```

string filename = Path.GetFileName(currentFile);
using (Bitmap bitmap = new Bitmap(currentFile))
{
    bitmap.RotateFlip(RotateFlipType.Rotate180FlipNone);
    bitmap.Save(Path.Combine(outputDirectory, filename));
    Dispatcher?.Invoke(() =>
    {
        this.Title =
            $"Processing {filename} on thread {Thread.CurrentThread.ManagedThreadId}";
    });
}
});
Dispatcher?.Invoke(()=>this.Title = "Done!");
}
catch (OperationCanceledException ex)
{
    Dispatcher?.Invoke(()=>this.Title = ex.Message);
}
}

```

Notice that you begin the method by configuring a `ParallelOptions` object, setting the `CancellationToken` property to use the `CancellationTokenSource` token. Also note that when you call the `Parallel.ForEach()` method, you pass in the `ParallelOptions` object as the second parameter.

Within the scope of the looping logic, you make a call to `ThrowIfCancellationRequested()` on the token, which will ensure if the user clicks the Cancel button, all threads will stop, and you will be notified via a runtime exception. When you catch the `OperationCanceledException` error, you will set the text of the main window to the error message.

## Task Parallelism Using the Parallel Class

In addition to data parallelism, the TPL can also be used to easily fire off any number of asynchronous tasks using the `Parallel.Invoke()` method. This approach is a bit more straightforward than using members from `System.Threading`; however, if you require more control over the way tasks are executed, you could forgo use of `Parallel.Invoke()` and use the `Task` class directly, as you did in the previous example.

To illustrate task parallelism, create a new console application called `MyEBookReader` and be sure the `System.Threading`, `System.Text`, `System.Threading.Tasks`, `System.Linq`, and `System.Net` namespaces are imported at the top of `Program.cs` (this example is a modification of a useful example in the .NET Core documentation). Here, you will fetch a publicly available ebook from Project Gutenberg ([www.gutenberg.org](http://www.gutenberg.org)) and then perform a set of lengthy tasks in parallel.

The book is downloaded in the `GetBook()` method, shown here:

```

private static string _theEBook = "";
static void Main(string[] args)
{
    GetBook();
    Console.WriteLine("Downloading book...");
    Console.ReadLine();
}
static void GetBook()
{
    WebClient wc = new WebClient();

```

```

wc.DownloadStringCompleted += (s, eArgs) =>
{
    _theEBook = eArgs.Result;
    Console.WriteLine("Download complete.");
    GetStats();
};

// The Project Gutenberg EBook of A Tale of Two Cities, by Charles Dickens
// You might have to run it twice if you've never visited the site before, since the first
// time you visit there is a message box that pops up, and breaks this code.
wc.DownloadStringAsync(new Uri("http://www.gutenberg.org/files/98/98-8.txt"));
}

```

The `WebClient` class is a member of `System.Net`. This class provides a number of methods for sending data to and receiving data from a resource identified by a URI. As it turns out, many of these methods have an asynchronous version, such as `DownloadStringAsync()`. This method will spin up a new thread from the CoreCLR thread pool automatically. When the `WebClient` is done obtaining the data, it will fire the `DownloadStringCompleted` event, which you are handling here using a C# lambda expression. If you were to call the synchronous version of this method (`DownloadString()`), the “Downloading” message wouldn’t show until the download was complete.

Next, the `GetStats()` method is implemented to extract the individual words contained in the `theEBook` variable and then pass the string array to a few helper functions for processing as follows:

```

static void GetStats()
{
    // Get the words from the ebook.
    string[] words = _theEBook.Split(new char[]
    { ' ', '\u000A', ',', '.', ';', ':', '-', '?', '/' },
    StringSplitOptions.RemoveEmptyEntries);

    // Now, find the ten most common words.
    string[] tenMostCommon = FindTenMostCommon(words);

    // Get the longest word.
    string longestWord = FindLongestWord(words);

    // Now that all tasks are complete, build a string to show all stats.
    StringBuilder bookStats = new StringBuilder("Ten Most Common Words are:\n");
    foreach (string s in tenMostCommon)
    {
        bookStats.AppendLine(s);
    }

    bookStats.AppendFormat("Longest word is: {0}", longestWord);
    bookStats.AppendLine();
    Console.WriteLine(bookStats.ToString(), "Book info");
}

```

The `FindTenMostCommon()` method uses a LINQ query to obtain a list of string objects that occur most often in the string array, while `FindLongestWord()` locates, well, the longest word.

```
private static string[] FindTenMostCommon(string[] words)
{
    var frequencyOrder = from word in words
                          where word.Length > 6
                          group word by word into g
                          orderby g.Count() descending
                          select g.Key;
    string[] commonWords = (frequencyOrder.Take(10)).ToArray();
    return commonWords;
}
private static string FindLongestWord(string[] words)
{
    return (from w in words orderby w.Length descending select w).FirstOrDefault();
}
```

If you were to run this project, performing all of the tasks could take a significant amount of time, based on the CPU count of your machine and overall processor speed. Eventually, you should see the output shown here:

---

```
Downloading book...
Download complete.
Ten Most Common Words are:
Defarge
himself
Manette
through
nothing
business
another
looking
prisoner
Cruncher
Longest word is: undistinguishable
```

---

You can help ensure that your application uses all available CPUs on the host machine by invoking the `FindTenMostCommon()` and `FindLongestWord()` methods in parallel. To do so, modify your `GetStats()` method as so:

```
static void GetStats()
{
    // Get the words from the ebook.
    string[] words = _theEBook.Split(
        new char[] { ' ', '\u000A', ',', '.', ';', ':', '-', '?', '/' },
        StringSplitOptions.RemoveEmptyEntries);
    string[] tenMostCommon = null;
    string longestWord = string.Empty;

    Parallel.Invoke(
        () =>
        {
            // Now, find the ten most common words.
```



```
        tenMostCommon = FindTenMostCommon(words);
    },
    () =>
    {
        // Get the longest word.
        longestWord = FindLongestWord(words);
    });

    // Now that all tasks are complete, build a string to show all stats.
    ...
}
```

The `Parallel.Invoke()` method expects a parameter array of `Action<>` delegates, which you have supplied indirectly using lambda expressions. Again, while the output is identical, the benefit is that the TPL will now use all possible processors on the machine to invoke each method in parallel if possible.

## Parallel LINQ Queries (PLINQ)

To wrap up your look at the TPL, be aware that there is another way you can incorporate parallel tasks into your .NET Core applications. If you choose, you can use a set of extension methods that allow you to construct a LINQ query that will perform its workload in parallel (if possible). Fittingly, LINQ queries that are designed to run in parallel are termed *PLINQ queries*.

Like parallel code authored using the `Parallel` class, PLINQ has the option of ignoring your request to process the collection in parallel if need be. The PLINQ framework has been optimized in numerous ways, which includes determining whether a query would, in fact, perform faster in a synchronous manner.

At runtime, PLINQ analyzes the overall structure of the query, and if the query is likely to benefit from parallelization, it will run concurrently. However, if parallelizing a query would hurt performance, PLINQ just runs the query sequentially. If PLINQ has a choice between a potentially expensive parallel algorithm or an inexpensive sequential algorithm, it chooses the sequential algorithm by default.

The necessary extension methods are found within the `ParallelEnumerable` class of the `System.Linq` namespace. Table 15-5 documents some useful PLINQ extensions.

**Table 15-5.** *Select Members of the `ParallelEnumerable` Class*

Member	Meaning in Life
<code>AsParallel()</code>	Specifies that the rest of the query should be parallelized, if possible
<code>WithCancellation()</code>	Specifies that PLINQ should periodically monitor the state of the provided cancellation token and cancel execution if it is requested
<code>WithDegreeOfParallelism()</code>	Specifies the maximum number of processors that PLINQ should use to parallelize the query
<code>ForAll()</code>	Enables results to be processed in parallel without first merging back to the consumer thread, as would be the case when enumerating a LINQ result using the <code>foreach</code> keyword

To see PLINQ in action, create a console application named `PLINQDataProcessingWithCancellation` and import the `System.Linq`, `System.Threading`, and `System.Threading.Tasks` namespaces (if not already there). When processing starts, the program will fire off a new `Task`, which executes a LINQ query that investigates a large array of integers, looking for only the items where `x % 3 == 0` is true. Here is a *nonparallel* version of the query:

```
class Program
{
    static void Main(string[] args)
    {
        Console.WriteLine("Start any key to start processing");
        Console.ReadKey();

        Console.WriteLine("Processing");
        Task.Factory.StartNew(ProcessIntData);
        Console.ReadLine();
    }

    static void ProcessIntData()
    {
        // Get a very large array of integers.
        int[] source = Enumerable.Range(1, 10_000_000).ToArray();
        // Find the numbers where num % 3 == 0 is true, returned
        // in descending order.
        int[] modThreeIsZero = (
            from num in source
            where num % 3 == 0
            orderby num descending
            select num).ToArray();
        Console.WriteLine($"Found { modThreeIsZero.Count()} numbers that match query!");
    }
}
```

## Opting in to a PLINQ Query

If you want to inform the TPL to execute this query in parallel (if possible), you will want to use the `AsParallel()` extension method as so:

```
int[] modThreeIsZero = (
    from num in source.AsParallel()
    where num % 3 == 0
    orderby num descending select num).ToArray();
```

Notice how the overall format of the LINQ query is identical to what you saw in previous chapters. However, by including a call to `AsParallel()`, the TPL will attempt to pass the workload off to an available CPU.

## Cancelling a PLINQ Query

It is also possible to use a `CancellationTokenSource` object to inform a PLINQ query to stop processing under the correct conditions (typically because of user intervention). Declare a class-level `CancellationTokenSource` object named `_cancelToken` and update the `Main()` method to take input from the user. Here is the relevant code update:

```
class Program
{
    static CancellationTokenSource _cancelToken =
        new CancellationTokenSource();

    static void Main(string[] args)
    {
        do
        {
            Console.WriteLine("Start any key to start processing");
            Console.ReadKey();
            Console.WriteLine("Processing");
            Task.Factory.StartNew(ProcessIntData);
            Console.Write("Enter Q to quit: ");
            string answer = Console.ReadLine();
            // Does user want to quit?
            if (answer.Equals("Q",
                StringComparison.OrdinalIgnoreCase))
            {
                _cancelToken.Cancel();
                break;
            }
        } while (true);
        Console.ReadLine();
    }
}
```

Now, inform the PLINQ query that it should be on the lookout for an incoming cancellation request by chaining on the `WithCancellation()` extension method and passing in the token. In addition, you will want to wrap this PLINQ query in a proper try/catch scope and deal with the possible exception. Here is the final version of the `ProcessIntData()` method:

```
static void ProcessIntData()
{
    // Get a very large array of integers.
    int[] source = Enumerable.Range(1, 10_000_000).ToArray();
    // Find the numbers where num % 3 == 0 is true, returned
    // in descending order.
    int[] modThreeIsZero = null;
    try
    {
        modThreeIsZero = (from num in source.AsParallel().WithCancellation(_cancelToken.Token)
            where num % 3 == 0
            orderby num descending
            select num).ToArray();
    }
```

```

        Console.WriteLine();
        Console.WriteLine($"Found {modThreeIsZero.Count()} numbers that match query!");
    }
    catch (OperationCanceledException ex)
    {
        Console.WriteLine(ex.Message);
    }
}

```

When running this, you will want to hit Q and enter pretty quickly to actually see the message from the cancellation token. On my development machine, I had about 1 (one) second to quit before it finished on its own.

## Async Calls with the `async/await` (Updated 7.0/7.1)

I have covered a lot of material in this (rather lengthy) chapter. To be sure, building, debugging, and understanding complex multithreaded applications are challenging in any framework. While the TPL, PLINQ, and the delegate type can simplify matters to some extent (especially when compared to other platforms and languages), developers are still required to be fairly savvy with the ins and outs of various advanced techniques.

Since the release of .NET 4.5 (and into .NET Core), the C# programming language has been updated with two new keywords that further simplify the process of authoring asynchronous code. In contrast to all the examples in this chapter, when you use the new `async` and `await` keywords, the compiler will generate a good deal of threading code on your behalf, using numerous members of the `System.Threading` and `System.Threading.Tasks` namespaces.

### A First Look at the C# `async` and `await` Keywords

The `async` keyword of C# is used to qualify that a method, lambda expression, or anonymous method should be called in an asynchronous manner *automatically*. Yes, it's true. Simply by marking a method with the `async` modifier, the CoreCLR will create a new thread of execution to handle the task at hand. Furthermore, when you are calling an `async` method, the `await` keyword will *automatically* pause the current thread from any further activity until the task is complete, leaving the calling thread free to continue on its merry way.

To illustrate, create a console application named `FunWithCSharpAsync` and import the `System.Threading`, `System.Threading.Tasks`, and `System.Collections.Generic` namespaces into `Program.cs`. Add a method named `DoWork()`, which forces the calling thread to wait for five seconds. Here is the story thus far:

```

class Program
{
    static void Main(string[] args)
    {
        Console.WriteLine(" Fun With Async ==>");
        Console.WriteLine(DoWork());
        Console.WriteLine("Completed");
        Console.ReadLine();
    }
    static string DoWork()

```

```

{
    Thread.Sleep(5_000);
    return "Done with work!";
}
}

```

Now, given your work in this chapter, you know that if you were to run the program, you would need to wait five seconds before anything else can happen. If this was a graphical application, the entire screen would be locked until the work was completed.

If you were to use any of the previous techniques shown in this chapter to make your program more responsive, you would have a good deal of work ahead of you. However, since .NET 4.5, you can author the following C# codebase:

```

static async Task Main(string[] args)
{
    ...
    string message = await DoWorkAsync();
    Console.WriteLine(message);
    ...
}

static string DoWork()
{
    Thread.Sleep(5_000);
    return "Done with work!";
}

static async Task<string> DoWorkAsync()
{
    return await Task.Run(() =>
    {
        Thread.Sleep(5_000);
        return "Done with work!";
    });
}

```

---

■ **Note** The ability to decorate the Main method with `async` is new as of C# 7.1.

---

Notice the `await` keyword *before* naming the method that will be called in an asynchronous manner. This is important: if you decorate a method with the `async` keyword but do not have at least one internal `await`-centric method call, you have essentially built a synchronous method call (in fact, you will be given a compiler warning to this effect).

Now, notice that you are required to use the `Task` class from the `System.Threading.Tasks` namespace to refactor your `Main()` and `DoWork()` methods (the latter is added as `DoWorkAsync()`). Basically, rather than returning a specific return value straightaway (a `string` object in the current example), you return a `Task<T>` object, where the generic type parameter `T` is the underlying, actual return value (with me so far?). If the method does not have a return value (as in the `Main` method), then instead of `Task<T>` you just use `Task`.

The implementation of `DoWorkAsync()` now directly returns a `Task<T>` object, which is the return value of `Task.Run()`. The `Run()` method takes a `Func<>` or `Action<>` delegate, and as you know by this point in the text, you can simplify your life by using a lambda expression. Basically, your new version of `DoWorkAsync()` is essentially saying the following:

*When you call me, I will run a new task. This task will cause the calling thread to sleep for five seconds, and when it is done, it gives me a string return value. I'll put this string in a new `Task<string>` object and return it to the caller.*

Having translated this new implementation of `DoWorkAsync()` into more natural (poetic) language, you gain some insight into the real role of the `await` token. This keyword will always modify a method that returns a `Task` object. When the flow of logic reaches the `await` token, the calling thread is suspended in this method until the call completes. If you were to run this version of the application, you would find that the `Completed` message shows before the `Done with work!` message. If this were a graphical application, the user could continue to use the UI while the `DoWorkAsync()` method executes.

## Naming Conventions for Asynchronous Methods

Of course, you noticed the name change from `DoWork()` to `DoWorkAsync()`, but why the change? Let's say that the new version of the method was still named `DoWork()`; however, the calling code has been implemented as so:

```
//Oops! No await keyword here!
string message = DoWork();
```

Notice you did indeed mark the method with the `async` keyword, but you neglected to use the `await` keyword as a decorator before the `DoWork()` method call. At this point, you will have compiler errors, as the return value of `DoWork()` is a `Task` object, which you are attempting to assign directly to a string variable. Remember, the `await` token is in charge of extracting the internal return value contained in the `Task` object. Since you have not used this token, you have a type mismatch.

---

■ **Note** An “awaitable” method is simply a method that returns a `Task<T>`.

---

Given that methods that return `Task` objects can now be called in a nonblocking manner via the `async` and `await` tokens, Microsoft recommends (as a best practice) that any method returning a `Task` be marked with an `Async` suffix. In this way, developers who know the naming convention receive a visual reminder that the `await` keyword is required, if they intend to invoke the method within an asynchronous context.

---

■ **Note** Event handlers for GUI controls (such as a button `Click` handler) that use the `async/await` keywords do not follow this naming convention (by convention – pardon the redundancy!).

---

## Async Methods Returning Void

Currently, your `DoWorkAsync()` method is returning a `Task`, which contains “real data” for the caller that will be obtained transparently via the `await` keyword. However, what if you want to build an asynchronous method that returns `void` (as in the `Main` method)? In this case, you use the nongeneric `Task` class and omit any `return` statement, like so:

```
static async Task MethodReturningVoidAsync()
{
    await Task.Run(() => { /* Do some work here... */
                          Thread.Sleep(4_000);
                        });
    Console.WriteLine("Void method completed");
}
```

The caller of this method would then use the `await` and `async` keywords as so:

```
await MethodReturningVoidAsync();
Console.WriteLine("Void method complete");
```

## Async Methods with Multiple Awaits

It is completely permissible for a single `async` method to have multiple `await` contexts within its implementation. The following is perfectly acceptable code:

```
static async Task MultipleAwaits()
{
    await Task.Run(() => { Thread.Sleep(2_000); });
    Console.WriteLine("Done with first task!");

    await Task.Run(() => { Thread.Sleep(2_000); });
    Console.WriteLine("Done with second task!");

    await Task.Run(() => { Thread.Sleep(2_000); });
    Console.WriteLine("Done with third task!");
}
```

Again, here each task is not doing much more than suspending the current thread for a spell; however, any unit of work could be represented by these tasks (calling a web service, reading a database, or what have you).

Another option is to not `await` each task, but wait them all together. This is a more likely scenario, where there are three things (check email, update server, download files) that must be done, can be done in parallel, but must be completed as a batch. Here is the code updated using the `Task.WhenAll()` method:

```
static async Task MultipleAwaits()
{
    var task1 = Task.Run(() =>
    {
        Thread.Sleep(2_000);
        Console.WriteLine("Done with first task!");
    });
```

```

var task2=Task.Run(() =>
{
    Thread.Sleep(1_000);
    Console.WriteLine("Done with second task!");
});

var task3 = Task.Run(() =>
{
    Thread.Sleep(1_000);
    Console.WriteLine("Done with third task!");
});
await Task.WhenAll(task1,task2,task3);
}

```

When you run the program now, you see that the three tasks fire in order of the lowest Sleep time.

---

```

Fun With Async ==>
Done with work!
Void method completed
Done with second task!
Done with third task!
Done with first task!
Completed

```

---

There is also a `WhenAny`, which returns the task that completed. To demonstrate `WhenAny`, change the last line of the `MultipleAwaits` to this:

```
await Task.WhenAny(task1,task2,task3);
```

When you do this, the output changes to this:

---

```

Fun With Async ==>
Done with work!
Void method completed
Done with second task!
Completed
Done with third task!
Done with first task!

```

---

## Calling Async Methods from Non-async Methods

Each of the previous examples used the `async` keyword to return the thread to calling code while the `async` method executes. In review, you can only use the `await` keyword in a method marked `async`. What if you can't (or don't want to) mark a method `async`?

Fortunately, there are other ways to call `async` methods. If you just don't use the `await` keyword, code in that method continues past the `async` method without returning to the caller. If you needed to actually wait for your `async` method to complete (which is what happens when you use the `await` keyword), there are two approaches.



The first is to simply use the `Result` property on the `Task<T>` or `Wait` on `Task/Task<T>` methods. (Remember that a method that returns a value must return `Task<T>` when `async`, and a method without a return value returns `Task` when `async`). If the method fails, an `AggregateException` is returned.

You can also call `GetAwaiter().GetResult()`, which accomplishes the same thing as the `await` keyword in an `async` method, and propagates exceptions the same manner as `async/await`. However, these methods are marked in the documentation as “not for external use”, which means they might change or go away at some point in the future. The `GetAwaiter().GetResult()` methods work on both methods with a return value and methods without a return value.

---

■ **Note** Whether you use `Result` or `GetAwaiter().GetResult()` on `Task<T>` is up to you, and most developers decide based on the exception handling. If your method returns `Task`, you must use `GetAwaiter().GetResult()` or `Wait()`.

---

For example, you could call the `DoWorkAsync()` method like this:

```
Console.WriteLine(DoWorkAsync().Result);
Console.WriteLine(DoWorkAsync().GetAwaiter().GetResult());
```

To halt execution until an `async` method returns with a `void` return type, simply call `Wait()` on the `Task`, like this:

```
MethodReturningVoidAsync().Wait();
```

## Await in catch and finally Blocks

C# 6 introduced the ability to place `await` calls in `catch` and `finally` blocks. The method itself must be `async` to do this. The following code example demonstrates the capability:

```
static async Task<string> MethodWithTryCatch()
{
    try
    {
        //Do some work
        return "Hello";
    }
    catch (Exception ex)
    {
        await LogTheErrors();
        throw;
    }
    finally
    {
        await DoMagicCleanUp();
    }
}
```

## Generalized Async Return Types (New 7.0)

Prior to C# 7, the only return options for async methods were `Task`, `Task<T>`, and `void`. C# 7 enables additional return types, as long as they follow the async pattern. One concrete example is `ValueTask`. To see this in action, create code like this:

```
static async ValueTask<int> ReturnAnInt()
{
    await Task.Delay(1_000);
    return 5;
}
```

All of the same rules apply; it's just a `Task` for value types instead of forcing allocation of an object on the heap.

## Local Functions (New 7.0)

Local functions were introduced in Chapter 4 and used in Chapter 8 with iterators. They can also be beneficial for async methods. To demonstrate the benefit, you need to first see the problem. Add a new method named `MethodWithProblems()` and add the following code:

```
static async Task MethodWithProblems(int firstParam, int secondParam)
{
    Console.WriteLine("Enter");
    await Task.Run(() =>
    {
        //Call long running method
        Thread.Sleep(4_000);
        Console.WriteLine("First Complete");
        //Call another long running method that fails because
        //the second parameter is out of range
        Console.WriteLine("Something bad happened");
    });
}
```

The scenario is that the second long-running task fails because of invalid input data. You can (and should) add checks to the beginning of the method, but since the entire method is asynchronous, there's no guarantee when the checks will be executed. It would be better for the checks to happen right away before the calling code moves on. In the following update, the checks are done in a synchronous manner, and then the private function is executed asynchronously.

```
static async Task MethodWithProblemsFixed(int firstParam, int secondParam)
{
    Console.WriteLine("Enter");
    if (secondParam < 0)
    {
        Console.WriteLine("Bad data");
        return;
    }
}
```

```

await actualImplementation();

async Task actualImplementation()
{
    await Task.Run(() =>
    {
        //Call long running method
        Thread.Sleep(4_000);
        Console.WriteLine("First Complete");
        //Call another long running method that fails because
        //the second parameter is out of range
        Console.WriteLine("Something bad happened");
    });
}
}

```

## Cancelling Async/Await Operations

Cancellation is also possible with the async/await pattern and much simpler than with `Parallel.ForEach`. To demonstrate, we will use the same WPF project from earlier in the chapter. You can either reuse that project or add a new WPF App (.NET Core) to the solution by right-clicking the solution name in Solution Explorer and select **Add ► Project** and name it `PictureHandlerWithAsyncAwait`. Make sure to set the new project as the startup project by right-clicking the new project name and select **Set as StartUp Project**. Add the `System.Drawing.Common` NuGet package (the following command line must be entered on one line):

```
dotnet add PictureHandlerWithAsyncAwait package System.Drawing.Common
```

Replace the XAML exactly the same as the previous WPF project, except change the Title to “Picture Handler with Async/Await”.

In the `MainWindow.xaml.cs` file, make sure that the following usings are in place:

```

using System;
using System.IO;
using System.Threading;
using System.Threading.Tasks;
using System.Windows;
using System.Drawing;

```

Next, add a class-level variable for the `CancellationToken` and add the Cancel button event handler:

```

private CancellationTokenSource _cancelToken = null;
private void cmdCancel_Click(object sender, EventArgs e)
{
    _cancelToken.Cancel();
}

```

The process is the same as the previous example: get the picture directory, create the output directory, and get the picture files, rotate them, and save them to the new directory. Instead of using `Parallel.ForEach`, this new version will use async methods to do the work, and the method signatures accept a `CancellationToken` as a parameter. Enter the following code:

```
private async void cmdProcess_Click(object sender, EventArgs e)
{
    _cancellationToken = new CancellationTokenSource();
    var basePath = Directory.GetCurrentDirectory();
    var pictureDirectory =
        Path.Combine(basePath, "TestPictures");
    var outputDirectory =
        Path.Combine(basePath, "ModifiedPictures");
    Directory.CreateDirectory(outputDirectory);
    string[] files = Directory.GetFiles(
        pictureDirectory, "*.jpg", SearchOption.AllDirectories);
    try
    {
        foreach(string file in files)
        {
            try
            {
                await ProcessFile(
                    file, outputDirectory, _cancellationToken.Token);
            }
            catch (OperationCanceledException ex)
            {
                Console.WriteLine(ex);
                throw;
            }
        }
    }
    catch (OperationCanceledException ex)
    {
        Console.WriteLine(ex);
        throw;
    }
    catch (Exception ex)
    {
        Console.WriteLine(ex);
        throw;
    }
    _cancellationToken = null;
    this.Title = "Processing complete";
}
```

After the initial setup, the code loops through the files and calls `ProcessFile` asynchronously for each file. The call to `ProcessFile` is wrapped in a try-catch block, and the `CancellationToken` is passed into the `ProcessFile` method. If `Cancel()` is executed on the `CancellationTokenSource` (such as when the user clicks the Cancel button), an `OperationCanceledException` is thrown.

---

■ **Note** The try-catch code can be anywhere in the calling chain (as you shall soon see). Whether to place it at the first call or in the asynchronous method itself is a matter of pure preference and application needs.

---

The final method to add is the `ProcessFile` method.

```
private async Task ProcessFile(string currentFile,
    string outputDirectory, CancellationToken token)
{
    string filename = Path.GetFileName(currentFile);
    using (Bitmap bitmap = new Bitmap(currentFile))
    {
        try
        {
            await Task.Run(() =>
            {
                bitmap.RotateFlip(RotateFlipType.Rotate180FlipNone);
                bitmap.Save(
                    Path.Combine(outputDirectory, filename));
                Dispatcher?.Invoke(() =>
                {
                    this.Title = $"Processing {filename}";
                });
            }, token);
        }
        catch (OperationCanceledException ex)
        {
            Console.WriteLine(ex);
            throw;
        }
    }
}
```

This method uses another overload of the `Task.Run` command, taking in the `CancellationToken` as a parameter. The `Task.Run` command is wrapped in a try-catch block (just like the calling code) in case the user clicks the Cancel button.

## Asynchronous Streams (New 8.0)

New in C# 8.0, streams (covered later in Chapter 20) can be created and consumed asynchronously. A method that returns an asynchronous stream

- Is declared with the `async` modifier
- Returns an `IAsyncEnumerable<T>`
- Contains `yield return` statements (covered in Chapter 8) to return successive elements in the asynchronous stream

Take the following example:

```
public static async IEnumerable<int> GenerateSequence()
{
    for (int i = 0; i < 20; i++)
    {
        await Task.Delay(100);
        yield return i;
    }
}
```

The method is declared as `async`, returns an `IEnumerable<int>`, and uses the `yield return` to return integers in from a sequence. To call this method, add the following to your `Main` method:

```
await foreach (var number in GenerateSequence())
{
    Console.WriteLine(number);
}
```

## Wrapping Up `async` and `await`

This section contained a lot of examples; here are the key points of this section:

- Methods (as well as lambda expressions or anonymous methods) can be marked with the `async` keyword to enable the method to do work in a nonblocking manner.
- Methods (as well as lambda expressions or anonymous methods) marked with the `async` keyword will run synchronously until the `await` keyword is encountered.
- A single `async` method can have multiple `await` contexts.
- When the `await` expression is encountered, the calling thread is suspended until the awaited task is complete. In the meantime, control is returned to the caller of the method.
- The `await` keyword will hide the returned `Task` object from view, appearing to directly return the underlying return value. Methods with no return value simply return `void`.
- Parameter checking and other error handling should be done in the main section of the method, with the actual `async` portion moved to a private function.
- For stack variables, the `ValueTask` is more efficient than the `Task` object, which might cause boxing and unboxing.
- As a naming convention, methods that are to be called asynchronously should be marked with the `Async` suffix.

## Summary

This chapter began by examining the role of the `System.Threading` namespace. As you learned, when an application creates additional threads of execution, the result is that the program in question is able to carry out numerous tasks at (what appears to be) the same time. You also examined several manners in which you can protect thread-sensitive blocks of code to ensure that shared resources do not become unusable units of bogus data.

This chapter then examined some new models for working with multithreaded development introduced with .NET 4.0, specifically the Task Parallel Library and PLINQ. I wrapped things up by covering the role of the `async` and `await` keywords. As you have seen, these keywords are using many types of the TPL framework in the background; however, the compiler does a majority of the work to create the complex threading and synchronization code on your behalf.

**PART V**



# **Programming with .NET Core Assemblies**





# Building and Configuring Class Libraries

For most of the examples so far in this book, you have created “stand-alone” executable applications, in which all the programming logic was packaged within a single executable file (\*.exe). These executable assemblies were using little more than the .NET Core base class libraries. While some simple .NET Core programs may be constructed using nothing more than the base class libraries, chances are it will be commonplace for you (or your teammates) to isolate reusable programming logic into *custom* class libraries (\*.dll files) that can be shared among applications.

In this chapter, you’ll start by learning the details of partitioning types into .NET Core namespaces. After this, you will take a deep look at class libraries in .NET Core, the difference between a .NET Core and .NET Standard, application configuration, and packaging your libraries into reusable NuGet packages.

## Defining Custom Namespaces

Before diving into the aspects of library deployment and configuration, the first task is to learn the details of packaging your custom types into .NET Core namespaces. Up to this point in the text, you’ve been building small test programs that leverage existing namespaces in the .NET Core universe (System, in particular). However, when you build larger applications with many types, it can be helpful to group your related types into custom namespaces. In C#, this is accomplished using the namespace keyword. Explicitly defining custom namespaces is even more important when creating shared assemblies, as other developers will need to reference the library and import your custom namespaces to use your types. Custom namespaces also prevent name collisions by segregating your custom classes from other custom classes that might have the same name.

To investigate the issues firsthand, begin by creating a new .NET Core Console Application project named CustomNamespaces. Now, assume you are developing a collection of geometric classes named Square, Circle, and Hexagon. Given their similarities, you would like to group them together into a unique namespace called MyShapes within the CustomNamespaces.exe assembly. You have two basic approaches. First, you can choose to define all classes in a single C# file. The other option is to keep each type in its own file and have a namespace defined in each file.

While the C# compiler has no problems with a single C# code file containing multiple types, this can be problematic when working in a team environment. If you are working on the Circle type, and your coworker needs to work on the Hexagon class, you would have to take turns working in the monolithic file or face difficult to resolve (well, at least time-consuming) merge conflicts. As an alternative, you can split a single

namespace across multiple C# files. To ensure each type is packaged into the same logical group, simply wrap the given class definitions in the same namespace scope, like so:

#### **// Circle.cs**

```
using System;

namespace MyShapes
{
    // Circle class
    public class Circle { /* Interesting methods... */ }
}
```

#### **// Hexagon.cs**

```
using System;

namespace MyShapes
{
    // Hexagon class
    public class Hexagon { /* More interesting methods... */ }
}
```

#### **// Square.cs**

```
using System;

namespace MyShapes
{
    // Square class
    public class Square { /* Even more interesting methods...*/ }
}
```

---

■ **Guidance** It is considered a best practice to have only one class in each code file. While many of the earlier examples did not do this, that was for simplicity in teaching. Moving forward in this book, my intention is to always separate each class into its own file.

---

In both cases, notice how the `MyShapes` namespace acts as the conceptual “container” of these classes. When another namespace (such as `CustomNamespaces`) wants to use types in a separate namespace, you use the `using` keyword, just as you would when using namespaces of the .NET Core base class libraries, as follows:

```
// Bring in a namespace from the base class libraries.
using System;
// Make use of types defined the MyShapes namespace.
using MyShapes;

namespace CustomNamespaces
{
    public class Program
    {
        static void Main(string[] args)
```

```

    {
        Hexagon h = new Hexagon();
        Circle c = new Circle();
        Square s = new Square();
    }
}

```

For this particular example, the assumption is that the C# file (or files) that defines the `MyShapes` namespace is part of the same Console Application project that contains the file defining the `CustomNamespaces` namespace; in other words, all the files are used to compile a single assembly. If you defined the `MyShapes` namespace within an external assembly, you would also need to add a reference to that library before you could compile successfully. You'll learn all the details of building applications that use external libraries during the course of this chapter.

## Resolving Name Clashes with Fully Qualified Names

Technically speaking, you are not required to use the C# `using` keyword when referring to types defined in external namespaces. You could use the *fully qualified name* of the type, which, as you may recall from Chapter 1, is the type's name prefixed with the defining namespace. Here's an example:

```

// Note we are not importing MyShapes anymore!
using System;

namespace CustomNamespaces
{
    public class Program
    {
        static void Main(string[] args)
        {
            MyShapes.Hexagon h = new MyShapes.Hexagon();
            MyShapes.Circle c = new MyShapes.Circle();
            MyShapes.Square s = new MyShapes.Square();
        }
    }
}

```

Typically, there is no need to use a fully qualified name. Not only does it require a greater number of keystrokes, it also makes no difference whatsoever in terms of code size or execution speed. In fact, in CIL code, types are *always* defined with the fully qualified name. In this light, the C# `using` keyword is simply a typing time-saver.

However, fully qualified names can be helpful (and sometimes necessary) to avoid potential name clashes when using multiple namespaces that contain identically named types. Assume you have a new namespace termed `My3DShapes`, which defines the following three classes, capable of rendering a shape in stunning 3D:

```

// Another shape-centric namespace.
using System;
namespace My3DShapes
{
    // 3D Circle class.
    public class Circle { }
}

```

```
// 3D Hexagon class.
public class Hexagon { }

// 3D Square class.
public class Square { }
}
```

If you update the Program class as shown next, you are issued a number of compile-time errors, because both namespaces define identically named classes:

```
// Ambiguities abound!
using System;
using MyShapes;
using My3DShapes;

namespace CustomNamespaces
{
    public class Program
    {
        static void Main(string[] args)
        {
            // Which namespace do I reference?
            Hexagon h = new Hexagon(); // Compiler error!
            Circle c = new Circle();   // Compiler error!
            Square s = new Square();    // Compiler error!
        }
    }
}
```

The ambiguity can be resolved using the type's fully qualified name, like so:

```
// We have now resolved the ambiguity.
static void Main(string[] args)
{
    My3DShapes.Hexagon h = new My3DShapes.Hexagon();
    My3DShapes.Circle c = new My3DShapes.Circle();
    MyShapes.Square s = new MyShapes.Square();
}
```

## Resolving Name Clashes with Aliases

The C# using keyword also lets you create an alias for a type's fully qualified name. When you do so, you define a token that is substituted for the type's full name at compile time. Defining aliases provides a second way to resolve name clashes. Here's an example:

```
using System;
using MyShapes;
using My3DShapes;

// Resolve the ambiguity using a custom alias.
using The3DHexagon = My3DShapes.Hexagon;
```

```

namespace CustomNamespaces
{
    class Program
    {
        static void Main(string[] args)
        {
            // This is really creating a My3DShapes.Hexagon class.
            The3DHexagon h2 = new The3DHexagon();
        }
    }
}

```

This alternative using syntax also lets you create an alias for a lengthy namespace. One of the longer base class library namespaces is `System.Runtime.Serialization.Formatters.Binary`, which contains a member named `BinaryFormatter`. If you want, you can create an instance of the `BinaryFormatter` as follows:

```
using bfHome = System.Runtime.Serialization.Formatters.Binary;
```

```

namespace MyApp
{
    class Program
    {
        static void Main(string[] args)
        {
            bfHome.BinaryFormatter b = new bfHome.BinaryFormatter();
            ...
        }
    }
}

```

as well as with a traditional using directive:

```
using System.Runtime.Serialization.Formatters.Binary;
```

```

namespace MyApp
{
    class ShapeTester
    {
        static void Main(string[] args)
        {
            BinaryFormatter b = new BinaryFormatter();
            ...
        }
    }
}

```

At this point in the game, there is no need to concern yourself with what the `BinaryFormatter` class is used for (you'll examine this class in [Chapter 20](#)). For now, simply remember that the C# `using` keyword can be used to define aliases for lengthy fully qualified names or, more commonly, to resolve name clashes that can arise when importing multiple namespaces that define identically named types.

---

■ **Note** Be aware that overuse of C# aliases can result in a confusing codebase. If other programmers on your team are unaware of your custom aliases, they could assume the aliases refer to types in the base class libraries and become quite confused when they can't find these tokens in the documentation!

---

## Creating Nested Namespaces

When organizing your types, you are free to define namespaces within other namespaces. The base class libraries do so in numerous places to provide deeper levels of type organization. For example, the `IO` namespace is nested within `System` to yield `System.IO`.

The .NET Core project templates add the initial code into a namespace named after the assembly. This base namespace is referred to as the root namespace. In this example, the root namespace created by the .NET Core template is `CustomNamespaces`, and shown here:

```
namespace CustomNamespaces
{
    class Program
    {
        ...
    }
}
```

To nest the `MyShapes` and `My3DShapes` namespaces inside the root namespace, there are two options. The first is to simply nest the namespace keyword, like this:

```
namespace CustomNamespaces
{
    namespace MyShapes
    {
        // Circle class
        public class Circle
        {
            /* Interesting methods... */
        }
    }
}
```

The other option (and more common) is to use “dot notation” in the namespace definition, like this:

```
namespace CustomNamespaces.MyShapes
{
    // Circle class
    public class Circle
    {
        /* Interesting methods... */
    }
}
```

Namespaces do not have to directly contain any types. This allows developers to use namespaces to provide a further level of scope.

Given that you have now nested the `My3DShapes` namespace within the `CustomNamespaces` root namespace, you need to update any existing using directives and type aliases, like so (assuming you have updated all of the sample classes to be nested under the root namespace):

```
using The3DHexagon = CustomNamespaces.My3DShapes.Hexagon;
using CustomNamespaces.MyShapes;
```

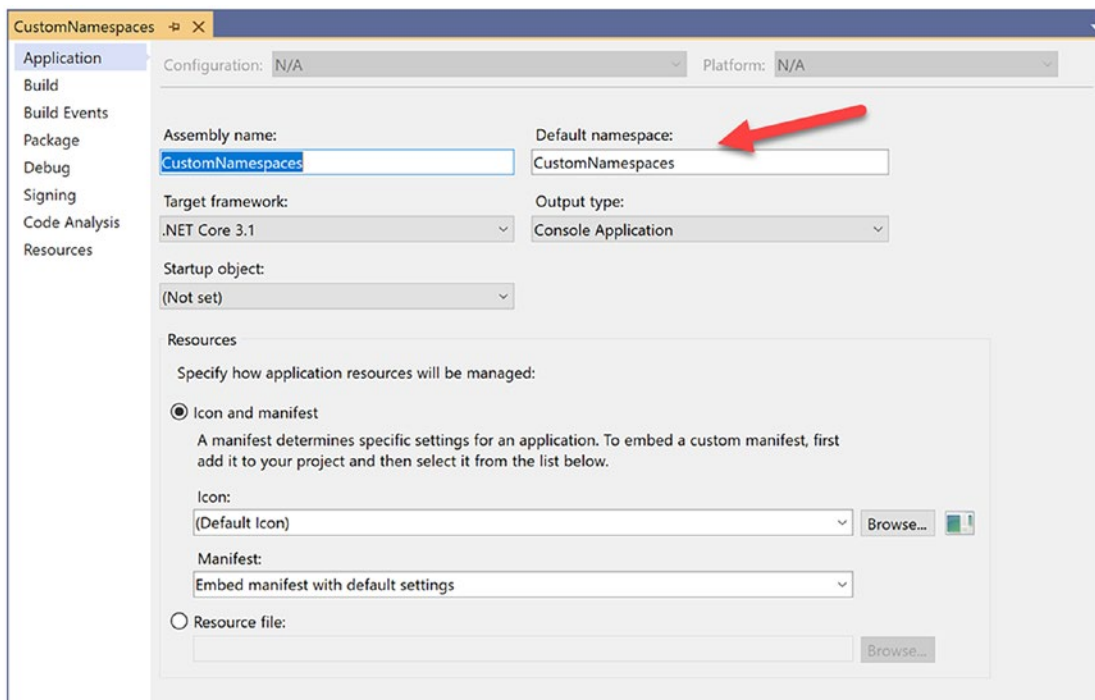
---

■ **Guidance** A common practice is to group files in a namespace by directory. As shown, where a file lives in the directory structure has no impact on namespaces. However, it does make the namespace structure more clear (and concrete) to other developers. Due to this, many developers and code linting tools expect the namespaces to match the folder structures.

---

## Change the Root Namespace of Visual Studio

As mentioned, when you create a new C# project using Visual Studio (or the .NET Core CLI), the name of your application's root namespace will be identical to the project name. From this point on, when you insert new code files using the Project ► Add New Item menu selection, types will automatically be wrapped within the root namespace. If you want to change the name of the root namespace, simply access the "Default namespace" option using the Application tab of the project's properties window (see Figure 16-1).



**Figure 16-1.** Configuring the default namespace

---

■ **Note** The Visual Studio property pages still refer to the root namespace as the “Default namespace”. You will see next why I refer to it as the “Root namespace”.

---

If not using Visual Studio (or even with Visual Studio), you can also configure the root namespace by updating the project (\*.csproj) file. With .NET Core projects, editing the project file is as easy as double-clicking the project file in Solution Explorer (or right-clicking the project file in Solution Explorer and selecting “Edit project file”). Once the file is open, update the main PropertyGroup by adding in the RootNamespace node, like this:

```
<Project Sdk="Microsoft.NET.Sdk">

  <PropertyGroup>
    <OutputType>Exe</OutputType>
    <TargetFramework>netcoreapp3.1</TargetFramework>
    <RootNamespace>CustomNamespaces2</RootNamespace>
  </PropertyGroup>

</Project>
```

So far, so good. Now that you have seen some details regarding how to package your custom types into well-organized namespaces, let’s quickly review the benefits and format of the .NET Core assembly. After this, you will delve into the details of creating, deploying, and configuring your custom class libraries.

## The Role of .NET Core Assemblies

.NET Core applications are constructed by piecing together any number of *assemblies*. Simply put, an assembly is a versioned, self-describing binary file hosted by the CoreCLR. Now, despite that .NET Core assemblies have the same file extensions (\*.exe or \*.dll) as previous Windows binaries, they have little in common under the hood with those files. Before unpacking that last statement, let’s consider some of the benefits provided by the assembly format.

### Assemblies Promote Code Reuse

As you have built your Console Application projects over the previous chapters, it might have seemed that *all* the applications’ functionality was contained within the executable assembly you were constructing. In reality, your applications were leveraging numerous types contained within the always-accessible .NET Core base class libraries.

As you might know, a *code library* (also termed a *class library*) is a \*.dll that contains types intended to be used by external applications. When you are creating executable assemblies, you will no doubt be leveraging numerous system-supplied and custom code libraries as you create your application. Do be aware, however, that a code library need not take a \*.dll file extension. It is perfectly possible (although certainly not common) for an executable assembly to use types defined within an external executable file. In this light, a referenced \*.exe can also be considered a code library.



Regardless of how a code library is packaged, the .NET Core platform allows you to reuse types in a language-independent manner. For example, you could create a code library in C# and reuse that library in any other .NET Core programming language. It is possible not only to allocate types across languages but also to derive from them. A base class defined in C# could be extended by a class authored in Visual Basic. Interfaces defined in F# can be implemented by structures defined in C# and so forth. The point is that when you begin to break apart a single monolithic executable into numerous .NET assemblies, you achieve a *language-neutral* form of code reuse.

## Assemblies Establish a Type Boundary

Recall that a type's *fully qualified name* is composed by prefixing the type's namespace (e.g., `System`) to its name (e.g., `Console`). Strictly speaking, however, the assembly in which a type resides further establishes a type's identity. For example, if you have two uniquely named assemblies (say, `MyCars.dll` and `YourCars.dll`) that both define a namespace (`CarLibrary`) containing a class named `SportsCar`, they are considered unique types in the .NET Core universe.

## Assemblies Are Versionable Units

.NET Core assemblies are assigned a four-part numerical version number of the form `<major>.<minor>.<build>.<revision>`. (If you do not explicitly provide a version number, the assembly is automatically assigned a version of 1.0.0.0, given the default .NET Core project settings.) This number, in conjunction with an optional *public key value*, allows multiple versions of the same assembly to coexist in harmony on a single machine. Formally speaking, assemblies that provide public key information are termed *strongly named*. As you will see in this chapter, by using a strong name, the CoreCLR is able to ensure that the correct version of an assembly is loaded on behalf of the calling client.

## Assemblies Are Self-Describing

Assemblies are regarded as *self-describing*, in part because they record in the assembly's *manifest* every external assembly they must have access to in order to function correctly. Recall from Chapter 1 that a manifest is a blob of metadata that describes the assembly itself (name, version, required external assemblies, etc.).

In addition to manifest data, an assembly contains metadata that describes the composition (member names, implemented interfaces, base classes, constructors, etc.) of every contained type. Because an assembly is documented in such detail, the CoreCLR does *not* consult the Windows system registry to resolve its location (quite the radical departure from Microsoft's legacy COM programming model). This separation from the registry is one of the factors that enables .NET Core applications to run on other operating systems besides Windows as well as supporting multiple versions of .NET Core on the same machine.

As you will discover during this chapter, the CoreCLR makes use of an entirely new scheme to resolve the location of external code libraries.

## Understanding the Format of a .NET Core Assembly

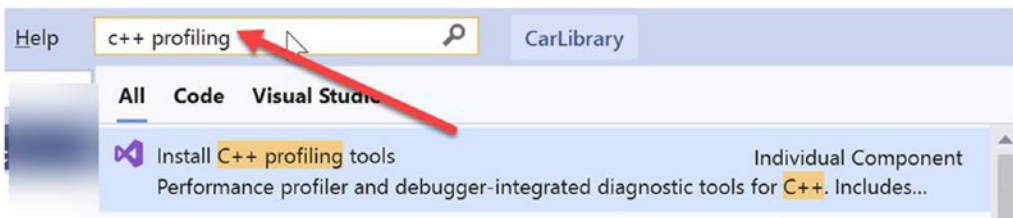
Now that you've learned about several benefits provided by the .NET Core assembly, let's shift gears and get a better idea of how an assembly is composed under the hood. Structurally speaking, a .NET Core assembly (\*.dll or \*.exe) consists of the following elements:

- An operating system (e.g. Windows) file header
- A CLR file header
- CIL code
- Type metadata
- An assembly manifest
- Optional embedded resources

While the first two elements (the operating system and CLR headers) are blocks of data you can typically always ignore, they do deserve some brief consideration. Here's an overview of each element.

## Installing the C++ Profiling Tools

The next few sections use a utility call `dumpbin.exe`, and it ships with the C++ profiling tools. To install them, type C++ profiling tools in the quick search bar, and click the prompt to install the tools, as shown in Figure 16-2.



**Figure 16-2.** Installing the C++ profiling tools from Quick Launch

This will bring up the Visual Studio installer with the Alternatively, you can launch the Visual Studio installer yourself and select the components shown in Figure 16-3.

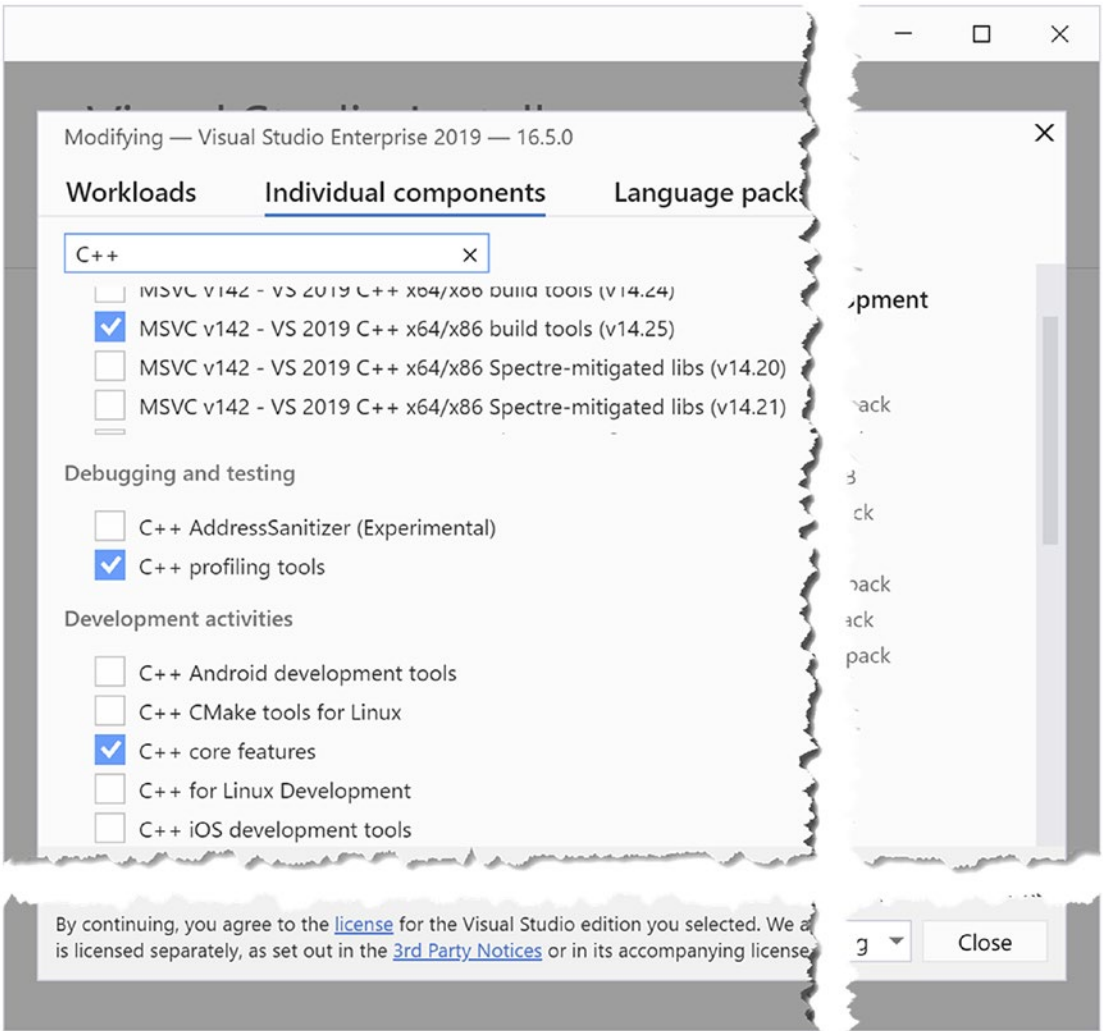


Figure 16-3. Installing the C++ profiling tools

## The Operating System (Windows) File Header

The operating system file header establishes the fact that the assembly can be loaded and manipulated by the target operating system (in the following example, Windows). This header data also identifies the kind of application (console-based, GUI-based, or \*.dll code library) to be hosted by the operating system.

Open the CarLibrary.dll file (in the book's repo or created later in this chapter) using the `dumpbin.exe` utility (via the developer command prompt) with the `/headers` flag as so:

```
dumpbin /headers CarLibrary.dll
```

This displays the assembly's operating system header information (shown in the following when built for Windows). Here is the (partial) Windows header information for the CarLibrary.dll:

---

```
Dump of file carlibrary.dll
```

```
PE signature found
```

```
File Type: DLL
```

```
FILE HEADER VALUES
```

```
    14C machine (x86)
```

```
    3 number of sections
```

```
A6F7A030 time date stamp
```

```
    0 file pointer to symbol table
```

```
    0 number of symbols
```

```
    E0 size of optional header
```

```
    2022 characteristics
```

```
        Executable
```

```
        Application can handle large (>2GB) addresses
```

```
        DLL
```

```
...
```

---

Now, remember that the vast majority of .NET Core programmers will never need to concern themselves with the format of the header data embedded in a .NET Core assembly. Unless you happen to be building a new .NET Core language compiler (where you *would* care about such information), you are free to remain blissfully unaware of the grimy details of the header data. Do be aware, however, that this information is used under the covers when the operating system loads the binary image into memory.

## The CLR File Header

The CLR header is a block of data that all .NET Core assemblies must support (and do support, courtesy of the C# compiler) to be hosted by the CoreCLR. In a nutshell, this header defines numerous flags that enable the runtime to understand the layout of the managed file. For example, flags exist that identify the location of the metadata and resources within the file, the version of the runtime the assembly was built against, the value of the (optional) public key, and so forth. Execute `dumpbin.exe` again with the `/clrheader` flag:

```
dumpbin /clrheader CarLibrary.dll
```

You are presented with the internal CLR header information for a given .NET Core assembly, as shown here:

---

Dump of file CarLibrary.dll

File Type: DLL

clr Header:

```

48 cb
2.05 runtime version
2160 [ AB4] RVA [size] of MetaData Directory
  1 flags
    IL Only
  0 entry point token
  0 [  0] RVA [size] of Resources Directory
  0 [  0] RVA [size] of StrongNameSignature Directory
  0 [  0] RVA [size] of CodeManagerTable Directory
  0 [  0] RVA [size] of VTableFixups Directory
  0 [  0] RVA [size] of ExportAddressTableJumps Directory
  0 [  0] RVA [size] of ManagedNativeHeader Directory

```

Summary

```

2000 .reloc
2000 .rsrc
2000 .text

```

---

Again, as a .NET Core developer, you will not need to concern yourself with the gory details of an assembly's CLR header information. Just understand that every .NET Core assembly contains this data, which is used behind the scenes by the .NET Core runtime as the image data loads into memory. Now turn your attention to some information that is much more useful in your day-to-day programming tasks.

## CIL Code, Type Metadata, and the Assembly Manifest

At its core, an assembly contains CIL code, which, as you recall, is a platform- and CPU-agnostic intermediate language. At runtime, the internal CIL is compiled on the fly using a just-in-time (JIT) compiler, according to platform- and CPU-specific instructions. Given this design, .NET Core assemblies can indeed execute on a variety of architectures, devices, and operating systems. (Although you can live a happy and productive life without understanding the details of the CIL programming language, Chapter 19 offers an introduction to the syntax and semantics of CIL.)

An assembly also contains metadata that completely describes the format of the contained types, as well as the format of external types referenced by this assembly. The .NET Core runtime uses this metadata to resolve the location of types (and their members) within the binary, lay out types in memory, and facilitate remote method invocations. You'll check out the details of the .NET metadata format in Chapter 17 during your examination of reflection services.

An assembly must also contain an associated *manifest* (also referred to as *assembly metadata*). The manifest documents each *module* within the assembly, establishes the version of the assembly, and also documents any *external* assemblies referenced by the current assembly. As you will see over the course of this chapter, the CLR makes extensive use of an assembly's manifest during the process of locating external assembly references.

## Optional Assembly Resources

Finally, a .NET Core assembly may contain any number of embedded resources, such as application icons, image files, sound clips, or string tables. In fact, the .NET Core platform supports *satellite assemblies* that contain nothing but localized resources. This can be useful if you want to partition your resources based on a specific culture (English, German, etc.) for the purposes of building international software. The topic of building satellite assemblies is outside the scope of this text. Consult the .NET Core documentation for information on satellite assemblies and localization if you are interested.

## Class Libraries vs. Console Applications

So far in this book, the examples were almost exclusively .NET Core Console applications. If you are reading this book as a current .NET developer, these are similar to .NET console applications, with the main difference being the configuration process (to be covered later) and, of course, that they run on .NET Core. Console applications have a single entry point (Main), can interact with the console, and can be launched directly from the operating system. Another difference between .NET Core and .NET console applications is that console applications in .NET Core are launched using the .NET Core Application Host and not *directly* from the operating system.

Class libraries, on the other hand, don't have an entry point and therefore cannot be launched directly. They are used to encapsulate logic, custom types, and so on and pulled into (known as referenced by) other class libraries and/or console applications. In other words, class libraries are used to contain the things talked about in "The Role of .NET Core Assemblies" section.

## .NET Standard vs. .NET Core Class Libraries

.NET Core class libraries run on .NET Core, and .NET class libraries run on .NET. Pretty straightforward. However, there is a problem with this. Assume you have a large .NET codebase in your organization, with (potentially) years of development behind you and your team. There is probably a significant amount of shared code leveraged by the applications you and your team have built over the years. Perhaps it's centralized logging, reporting, or domain-specific functionality.

Now you (and your organization) want to move to .NET Core for all new development. What about all of that shared code? Rewriting it all in .NET Core would be bad enough, but that also means you would have to support two versions (one in .NET and one in .NET Core). That would bring productivity to a screeching halt.

Fortunately, the builders of .NET Core thought through this scenario. .NET Standard is a new type of class library project that was introduced with .NET Core, and can be referenced by .NET as well as .NET Core applications.

Each .NET Standard version defines a common set of APIs that must be supported by all .NET versions (.NET, .NET Core, Xamarin, etc.) to conform to the standard. For example, if you were to build a class library as a .NET Standard 2.0 project, it can be referenced by .NET 4.61+ and .NET Core 2.0+ (plus various versions of Xamarin, Mono, Universal Windows Platform, and Unity).

This means you could move the code from your .NET class libraries into .NET Standard 2.0 class libraries, and they can be shared by .NET Core and .NET applications. Much better than supporting duplicate copies of the same code, one for each framework.

If this sounds too good to be true, there is indeed a catch. Each .NET Standard version represents the lowest common denominator for the frameworks. That means the lower the version, the less that you can do in your class library. While .NET Core 3.1 can reference a .NET Standard 2.0 library, you cannot use a significant number of C# 8 in a .NET Standard 2.0 library. You must use .NET Standard 2.1 for full C# 8 support. And .NET 4.8 (the latest/last version of the original .NET framework) only goes up to .NET Standard 2.0.

Still a good mechanism for leveraging existing code in newer applications, but not a silver bullet.

## Configuring Applications

While it is possible to keep all of the information needed by your .NET Core application in the source code, being able to change certain values at runtime is vitally important in most applications of significance. This is typically done through a configuration file that is shipped with your application.

---

■ **Note** The previous .NET framework relied mostly on XML files named `app.config` (or `web.config` for ASP.NET applications). While XML-based configuration files can still be used, the main method for configuring .NET Core applications is with JSON (JavaScript Object Notation) files as shown in this section. Configuration will be addressed in depth in the chapters in WPF and ASP.NET Core.

---

To illustrate the process, create a new .NET Core Console application named `FunWithConfiguration`. Add the following package reference to your project:

```
dotnet add package Microsoft.Extensions.Configuration.Json
```

This adds a reference for the JSON file-based .NET Core configuration subsystem (and its dependencies) into your project. To leverage this, first add a new JSON file into your project named `appsettings.json`. Update the project file to make sure the file is always copied to the output directory when the project is built:

```
<ItemGroup>
  <None Update="appsettings.json">
    <CopyToOutputDirectory>Always</CopyToOutputDirectory>
  </None>
</ItemGroup>
```

Finally, update the file to match the following:

```
{
  "CarName": "Suzy"
}
```

---

■ **Note** If you are not familiar with JSON, it is a name-value pair format with each object enclosed in curly braces. The entire file is read in as an object, and subobjects are also marked with curly braces. Later in this book, you will work with more complex JSON files.

---

The final step is you read in the configuration file and get the `CarName` value. Update the using statements in `Program.cs` to the following:

```
using System;
using System.IO;
using Microsoft.Extensions.Configuration;
```

Update the Main method to the following:

```
static void Main(string[] args)
{
    IConfiguration config = new ConfigurationBuilder()
        .SetBasePath(Directory.GetCurrentDirectory())
        .AddJsonFile("appsettings.json", true, true)
        .Build();
}
```

The new configuration system starts with a `ConfigurationBuilder`. This allows you to add multiple files, set properties (such as where the configuration files are located), and then finally build the configuration into an instance of `IConfiguration`.

Once you have an instance of `IConfiguration`, you call it much the same way as in .NET 4.8. Add the following to the bottom of the Main method, and when you run the app, you will see the value written to the console:

```
Console.WriteLine($"My car's name is {config["CarName"]}");
Console.ReadLine();
```

In addition to JSON files, there are configuration packages for supporting environment variables, Azure Key Vault, command-line arguments, and many more. Reference the .NET Core documentation for more information.

## Building and Consuming a .NET Core Class Library

To begin exploring the world of .NET Core class libraries, you'll first create a \*.dll assembly (named `CarLibrary`) that contains a small set of public types. While you can create new projects using Visual Studio (as shown in Chapter 2), the .NET Core Command Line Interface (CLI) can also be used to create projects and solutions, add projects to a solution, add references between projects, and add NuGet packages to projects. And it works across all of the operating systems supported by .NET Core (Windows, macOS, Linux).

To get started using the CLI, create a new directory on your hard drive for the project. Open a command window in this directory, and enter the following command (all on one line):

```
dotnet new classlib -f netcoreapp3.1 -n CarLibrary -o CarLibrary
```

This creates a new .NET Core 3.1 (-f) class library named `CarLibrary` (-n) in the subdirectory named `CarLibrary` (-o). The output (-o) location is optional – if left off, the project will be created in a subdirectory with the same name as the project name. One difference between using the CLI and Visual Studio is that Visual Studio (by default) creates a new solution file at the same time as creating the project (and with the same name as the first project, unless you change it). To create a solution file with the CLI, enter the following command:

```
dotnet new sln -n FunWithClassLibraries
```

This creates a new solution named (-n) `FunWithClassLibraries`. The next step is to add the `CarLibrary` project to the `FunWithClassLibraries` solution. To do this, enter the following command:

```
dotnet sln add CarLibrary
```



This adds the project named CarLibrary to the solution file located in the same directory where the command was run.

---

■ **Note** The .NET Core CLI has a very good help system. To get help for any command, add -h to the command. For example, to see all of the templates listed, type `dotnet new -h`. To get more information about creating a class library, type `dotnet new classlib -h`.

---

Now that you have created your project and solution, you can open in Visual Studio (or Visual Studio Code) to begin building the classes. After opening up the solution, delete the autogenerated file `Class1.cs`.

The design of your automobile library begins with an abstract base class named `Car` that defines various state data via automatic property syntax. This class also has a single abstract method named `TurboBoost()`, which uses a custom enumeration (`EngineState`) representing the current condition of the car's engine. Insert a new C# class file into your project, named `Car.cs`, which contains the following code:

```
using System;

namespace CarLibrary
{
    // Represents the state of the engine.
    public enum EngineState
    {
        EngineAlive,
        EngineDead
    }

    // The abstract base class in the hierarchy.
    public abstract class Car
    {
        public string PetName {get; set;}
        public int CurrentSpeed {get; set;}
        public int MaxSpeed {get; set;}

        protected EngineState State = EngineState.EngineAlive;
        public EngineState EngineState => State;
        public abstract void TurboBoost();

        public Car(){}
        public Car(string name, int maxSpeed, int currentSpeed)
        {
            PetName = name;
            MaxSpeed = maxSpeed;
            CurrentSpeed = currentSpeed;
        }
    }
}
```

Now assume you have two direct descendants of the `Car` type named `MiniVan` and `SportsCar`. Each overrides the abstract `TurboBoost()` method by displaying an appropriate message via console message. Insert two new C# class files into your project, named `MiniVan.cs` and `SportsCar.cs`, respectively. Update the code in each file with the relevant code:

```
//SportsCar.cs
using System;
namespace CarLibrary
{
    public class SportsCar : Car
    {
        public SportsCar(){ }
        public SportsCar(
            string name, int maxSpeed, int currentSpeed)
            : base (name, maxSpeed, currentSpeed){ }

        public override void TurboBoost()
        {
            Console.WriteLine("Ramming speed! Faster is better...");
        }
    }
}

//MiniVan.cs
using System;
namespace CarLibrary
{
    public class MiniVan : Car
    {
        public MiniVan(){ }
        public MiniVan(
            string name, int maxSpeed, int currentSpeed)
            : base (name, maxSpeed, currentSpeed){ }

        public override void TurboBoost()
        {
            // Minivans have poor turbo capabilities!
            State = EngineState.EngineDead;
            Console.WriteLine("Eek! Your engine block exploded!");
        }
    }
}
```

## Exploring the Manifest

Before using `CarLibrary.dll` from a client application, let's check out how the code library is composed under the hood. Assuming you have compiled this project and run `ildasm.exe` against the compiled assembly. If you don't have `ildasm.exe` (covered earlier in this book), it is also located in the [Chapter 16](#) directory of this book's repository.

The Manifest section of the disassembled results starts with `//Metadata version: 4.0.30319`. Immediately following is the list of all external assemblies required by the class library, as shown here:

```
// Metadata version: v4.0.30319
.assembly extern System.Runtime
{
    .publickeytoken = (B0 3F 5F 7F 11 D5 0A 3A )
    .ver 4:2:2:0
}
.assembly extern System.Diagnostics.Debug
{
    .publickeytoken = (B0 3F 5F 7F 11 D5 0A 3A )
    .ver 4:1:2:0
}
.assembly extern System.Console
{
    .publickeytoken = (B0 3F 5F 7F 11 D5 0A 3A )
    .ver 4:1:2:0
}
```

Each `.assembly extern` block is qualified by the `.publickeytoken` and `.ver` directives. The `.publickeytoken` instruction is present only if the assembly has been configured with a *strong name* (more details on strong names in the section “Understanding Strong Names” later in this chapter). The `.ver` token defines (of course) the numerical version identifier of the referenced assembly.

After the external references, you will find a number of `.custom` tokens that identify assembly-level attributes (some system generated, but also copyright information, company name, assembly version, etc.). Here is a (very) partial listing of this particular chunk of manifest data:

```
.assembly CarLibrary
{
...
    .custom instance void ... TargetFrameworkAttribute ...
    .custom instance void ... AssemblyCompanyAttribute ...
    .custom instance void ... AssemblyConfigurationAttribute ...
    .custom instance void ... AssemblyFileVersionAttribute ...
    .custom instance void ... AssemblyProductAttribute ...
    .custom instance void ... AssemblyTitleAttribute ...
.module CarLibrary.dll
```

These settings can be set either using the Visual Studio property pages or by editing the project file and adding in the correct elements. To edit in Visual Studio, right-click the project in Solution Explorer, select Properties, and navigate to the Package menu in the left rail of the window. This brings up the dialog window shown in Figure 16-4.

Configuration: N/A Platform: N/A

☐ Generate NuGet package on build

☐ Require license acceptance

Package id: CarLibrary

Package version: 1.0.0.3

Authors: Phil Japikse

Company: Apress

Product: Pro C# 8

Description: This is an awesome library for cars.

Copyright: Copyright 2017

Licensing:

Expression: ☐

File: ☐  Browse...

Project URL:

Icon File:  Browse...

Repository URL:

Repository type:

Tags:

Release notes:

Assembly neutral language: (None)

Assembly version: 1 0 0 1

Assembly file version: 1 0 0 2

**Figure 16-4.** Editing assembly information using Visual Studio's Properties window

Another way to add the metadata to your assembly is directly in the \*.csproj project file. The following update to the main PropertyGroup in the project file does the same thing as filling in the form shown in Figure 16-4.

```
<PropertyGroup>
  <TargetFramework>netcoreapp3.1</TargetFramework>
  <Copyright>Copyright 2017</Copyright>
  <Authors>Phil Japikse</Authors>
  <Company>Apress</Company>
  <Product>Pro C# 8</Product>
  <PackageId>CarLibrary</PackageId>
  <Description>This is an awesome library for cars.</Description>
  <AssemblyVersion>1.0.0.1</AssemblyVersion>
  <FileVersion>1.0.0.2</FileVersion>
  <Version>1.0.0.3</Version>
</PropertyGroup>
```

---

■ **Note** Don't worry about the rest of the entries from Figure 16-4. I will cover generating NuGet packages from assemblies later in this chapter.

---

## Exploring the CIL

Recall that an assembly does not contain platform-specific instructions; rather, it contains platform-agnostic Common Intermediate Language (CIL) instructions. When the .NET Core runtime loads an assembly into memory, the underlying CIL is compiled (using the JIT compiler) into instructions that can be understood by the target platform. For example, the `TurboBoost()` method of the `SportsCar` class is represented by the following CIL:

```
.method public hidebysig virtual instance void TurboBoost() cil managed
{
    .maxstack 8
    IL_0000: nop
    IL_0001: ldstr "Ramming speed! Faster is better..."
    IL_0006: call void [System.Console]System.Console::WriteLine(string)
    IL_000b: nop
    IL_000c: ret
}
// end of method SportsCar::TurboBoost
```

Most .NET Core developers don't need to be deeply concerned with the details of CIL on a daily basis. Chapter 19 provides more details on its syntax and semantics, which can be helpful when you are building more complex applications that require advanced services, such as runtime construction of assemblies.

## Exploring the Type Metadata

Before you build some applications that use your custom .NET library, examine the metadata for the types within the `CarLibrary.dll` assembly. For an example, here is the `TypeDef` for the `EngineState` enum:

```
TypeDef #1 (02000002)
-----
TypeDefName: CarLibrary.EngineState (02000002)
Flags       : [Public] [AutoLayout] [Class] [Sealed] [AnsiClass] (00000101)
Extends     : 0100000E [TypeRef] System.Enum
Field #1 (04000001)
-----
Field Name: value__ (04000001)
Flags      : [Public] [SpecialName] [RTSpecialName] (00000606)
CallConvtn: [FIELD]
Field type: I4

Field #2 (04000002)
-----
Field Name: EngineAlive (04000002)
Flags      : [Public] [Static] [Literal] [HasDefault] (00008056)
DefltValue: (I4) 0
CallConvtn: [FIELD]
Field type: ValueClass CarLibrary.EngineState
```

Field #3 (04000003)

```
-----
Field Name: EngineDead (04000003)
Flags      : [Public] [Static] [Literal] [HasDefault] (00008056)
DefltValue: (I4) 1
CallCnvtn: [FIELD]
Field type: ValueClass CarLibrary.EngineState
```

As explained in the next chapter, an assembly's metadata is an important element of the .NET Core platform and serves as the backbone for numerous technologies (object serialization, late binding, extendable applications, etc.). In any case, now that you have looked inside the `CarLibrary.dll` assembly, you can build some client applications that use your types.

## Building a C# Client Application

Because each of the `CarLibrary` types has been declared using the `public` keyword, other .NET Core applications are able to use them as well. Recall that you may also define types using the C# `internal` keyword (in fact, this is the default C# access mode). Internal types can be used only by the assembly in which they are defined. External clients can neither see nor create types marked with the `internal` keyword.

---

■ **Note** The exception to this rule is when an assembly explicitly allows access to another assembly using the `InternalsVisibleTo` attribute, covered shortly.

---

To use your library's functionality, create a new C# Console Application project named `CSharpCarClient` in the same solution as the `CarLibrary`. Again, you can do this using Visual Studio (right-click the solution, select **Add ► New Project**) or using the command line (three lines, each executed separately).

```
dotnet new console -n CSharpCarClient -f netcoreapp3.1
dotnet add CSharpCarClient reference CarLibrary
dotnet sln add CSharpCarClient
```

The previous commands created the console application, added a project reference to the `CarLibrary` project for the new project, and added it to your solution.

---

■ **Note** The `add reference` command creates a *project* reference. This is convenient for development, as the `CSharpCarClient` will always be using the latest version of the `CarLibrary`. You can also reference an assembly *directly*. Direct references are created by referencing the compiled class library.

---

If you still had the solution open in Visual Studio, you'll notice that the new project shows up in Solution Explorer without any intervention on your part.

The final change to make is to right-click the `CSharpCarClient` in Solution Explorer and select "Set as Startup Project". If you are not using Visual Studio, you can run the new project by executing "dotnet run" in the project directory.

---

■ **Note** You can set the project reference in Visual Studio as well by right-clicking the CSharpCarClient project in solution explorer, select Add ► Reference, and select the CarLibrary project from the project's node.

---

At this point, you can build your client application to use the external types. Update your initial C# file as follows:

```
using System;
// Don't forget to import the CarLibrary namespace!
using CarLibrary;

namespace CSharpCarClient
{
    public class Program
    {
        static void Main(string[] args)
        {
            Console.WriteLine("***** C# CarLibrary Client App *****");
            // Make a sports car.
            SportsCar viper = new SportsCar("Viper", 240, 40);
            viper.TurboBoost();

            // Make a minivan.
            MiniVan mv = new MiniVan();
            mv.TurboBoost();

            Console.WriteLine("Done. Press any key to terminate");
            Console.ReadLine();
        }
    }
}
```

This code looks just like the code of the other applications developed thus far in the book. The only point of interest is that the C# client application is now using types defined within a separate custom library. Run your program and verify that you see the display of messages.

You might be wondering exactly what happened when you referenced the CarLibrary project. When a *project reference* is made, the solution build order is adjusted so that dependent projects (CarLibrary in this example) build first, and then the output from that build is copied into the output directory of the parent project (CSharpCarLibrary). The compiled client library references the compiled class library. When the client project is rebuilt, so is the dependent library, and the new version is once again copied to the target folder.

When a *direct reference* is made, the compiled library is also copied to the output directory of the client library, but at the time the reference is made. The .NET Core framework watches the compiled assembly, and if it changes, the new copy is copied into the target folder. But if the client project is rebuilt, it does not rebuild the dependent project. In short, if you are developing dependent libraries (as is probably true with any significant software project), it is best to reference the project and not the project output.

---

■ **Note** If you are using Visual Studio, you can click the “Show All Files” button in Solution Explorer, and you can see all of the output files and verify that the compiled CarLibrary is there.

---

## Building a Visual Basic Client Application

Recall that the .NET Core platform allows developers to share compiled code across programming languages. To illustrate the language-agnostic attitude of the .NET Core platform, let's create another Console Application project (VisualBasicCarClient), this time using Visual Basic (note that each of commands is a one-line command):

```
dotnet new console -n VisualBasicCarClient -f netcoreapp3.1 -lang vb
dotnet add VisualBasicCarClient reference CarLibrary
dotnet sln add VisualBasicCarClient
```

Like C#, Visual Basic allows you to list each namespace used within the current file. However, Visual Basic offers the `Imports` keyword rather than the C# `using` keyword, so add the following `Imports` statement within the `Program.vb` code file:

```
Imports CarLibrary
Module Program
    Sub Main()
    End Sub
End Module
```

Notice that the `Main()` method is defined within a Visual Basic module type. In a nutshell, modules are a Visual Basic notation for defining a class that can contain only static methods (much like a C# static class). In any case, to exercise the `MiniVan` and `SportsCar` types using the syntax of Visual Basic, update your `Main()` method as follows:

```
Sub Main()
    Console.WriteLine("***** VB CarLibrary Client App *****")
    ' Local variables are declared using the Dim keyword.
    Dim myMiniVan As New MiniVan()
    myMiniVan.TurboBoost()

    Dim mySportsCar As New SportsCar()
    mySportsCar.TurboBoost()
    Console.ReadLine()
End Sub
```

When you compile and run your application (make sure to set the `VisualBasicCarClient` as the startup project in Visual Studio), you will once again find a series of message boxes displayed. Furthermore, this new client application has its own local copy of `CarLibrary.dll` located under the `bin\Debug\netcoreapp3.1` folder.

## Cross-Language Inheritance in Action

An enticing aspect of .NET Core development is the notion of *cross-language inheritance*. To illustrate, let's create a new Visual Basic class that derives from `SportsCar` (which was authored using C#). First, add a new class file to your current Visual Basic application (by selecting the Project ► Add Class menu option) named `PerformanceCar.vb`. Update the initial class definition by deriving from the `SportsCar` type using the `Inherits` keyword. Then, override the abstract `TurboBoost()` method using the `Overrides` keyword, like so:



```
Imports CarLibrary
' This VB class is deriving from the C# SportsCar.
Public Class PerformanceCar
    Inherits SportsCar
    Public Overrides Sub TurboBoost()
        Console.WriteLine("Zero to 60 in a cool 4.8 seconds...")
    End Sub
End Class
```

To test this new class type, update the module's `Main()` method as follows:

```
Sub Main()
...
    Dim dreamCar As New PerformanceCar()

    ' Use Inherited property.
    dreamCar.PetName = "Hank"
    dreamCar.TurboBoost()
    Console.ReadLine()
End Sub
```

Notice that the `dreamCar` object is able to invoke any public member (such as the `PetName` property) found up the chain of inheritance, regardless of the fact that the base class was defined in a completely different language and in a completely different assembly! The ability to extend classes across assembly boundaries in a language-independent manner is a natural aspect of the .NET development cycle. This makes it easy to use compiled code written by individuals who would rather not build their shared code with C#.

## Exposing internal Types to Other Assemblies

As mentioned earlier, internal classes are only visible to other objects in the project where they defined. The sidebar note teased about an exception to this, and now is the time to investigate this.

Begin by adding a new class named `MyInternalClass` to the `CarLibrary` project, and update the code to the following:

```
namespace CarLibrary
{
    internal class MyInternalClass
    {
    }
}
```

---

■ **Note** Why expose internal types at all? This is usually done for unit and integration testing. Developers want to be able to test their code but not necessarily expose it beyond the borders of the assembly.

---

## Using an Assembly Attribute

Chapter 17 will cover attributes in depth, but for now open up the `Car.cs` class in the `CarLibrary` project, and add the following attribute and using statement:

```
using System.Runtime.CompilerServices;
[assembly:InternalsVisibleTo("CSharpCarClient")]
namespace CarLibrary
{
}
```

The `InternalsVisibleTo` attribute takes the name of the project that is allowed to see into the class that has the attribute set. Note that other projects cannot “ask” for this permission; it has to be granted by the project holding the internal types.

---

■ **Note** Previous versions of .NET leveraged the `AssemblyInfo.cs` class, which still exists in .NET Core, but is autogenerated and not meant for developer consumption.

---

Now you can update the `CSharpCarClient` project by adding the following code to the `Main` method:

```
var internalClassInstance = new MyInternalClass();
```

This works perfectly. Now try to do the same thing in the `VisualBasicCarClient` `Main` method:

```
'Will not compile
'Dim internalClassInstance = New MyInternalClass()
```

Because the `VisualBasicCarClient` library was not granted permission to see the internals, the previous line of code will not compile.

## Using the Project File

Another way to accomplish the same thing (and could be argued is more of the .NET Core way to do it) is to use the updated capabilities in the .NET Core project file.

Comment out the attribute you just added, and open the project file for `CarLibrary`. Add the following `ItemGroup` in the project file:

```
<ItemGroup>
  <AssemblyAttribute Include="System.Runtime.CompilerServices.InternalsVisibleToAttribute">
    <_Parameter1>CSharpCarClient</_Parameter1>
  </AssemblyAttribute>
</ItemGroup>
```

This accomplishes the same thing as using the attribute on a class and, in my opinion, is a better solution, since other developers will see it right in the project file instead of having to know where to look throughout the project.

## NuGet and .NET Core

NuGet is the package manager for .NET and .NET Core. It is a mechanism to share software in a format that .NET Core applications understand and is the default mechanism for loading .NET Core and its related framework pieces (ASP.NET Core, EF Core, etc.). Many organizations package their standard assemblies for cross-cutting concerns (like logging and error reporting) into NuGet packages for consumption into their line-of-business applications.

## Packaging Assemblies with NuGet

To see this in action, we will turn the CarLibrary into a NuGet package and then reference it from the two client applications.

---

■ **Note** In the repo for this chapter, there is another solution (FunWithNuGet) that you can use for the section.

---

The NuGet Package properties can be accessed from the project's property pages. Right-click the CarLibrary project and select Properties. Navigate to the Package page, and see the values that we entered before to customize the assembly. There are additional properties that can be set for the NuGet package (i.e., license agreement acceptance, project information, such as URL and repository location).

For this example, we don't need to set any additional properties except to check the "Generate NuGet package on build" check box. This will cause the package to be rebuilt every time the software is built. By default, the package will be created in the bin/Debug or bin/Release folder, depending on which configuration is selected.

Packages can also be created from the command line, and the CLI provides more options than Visual Studio. For example, to build the package and place it in a directory called Publish, enter the following commands (in the CarLibrary project directory). The first command builds the assembly, and the second packages up the NuGet package.

```
dotnet build -c Release
dotnet pack -o .\Publish -c Debug
```

---

■ **Note** Debug is the default configuration, so it's not necessary, but is included to make it clear what the intent is.

---

The CarLibrary.1.0.0.3.nupkg file is now in the Publish directory. To see its contents, open the file with any Zip utility (such as 7-Zip), and you can see the entire content, which includes the assembly, but also additional metadata.

## Referencing NuGet Packages

You might be wondering where the packages that were added in the previous examples actually came from. The location of NuGet packages is controlled by an XML-based file named NuGet.Config. On Windows, this file is located in the %appdata%\NuGet directory. This is the main file. Open it up, and you will see several package sources:

```
<?xml version="1.0" encoding="utf-8"?>
<configuration>
  <packageSources>
    <add key="nuget.org" value="https://api.nuget.org/v3/index.json" protocolVersion="3" />
```

```

    <add key="Microsoft Visual Studio Offline Packages" value="C:\Program Files (x86)\
    Microsoft SDKs\NuGetPackages\" />
  </packageSources>
</configuration>

```

The previous file listing shows two sources. The first points to NuGet.org, which is the largest NuGet package repository in the world. The second is on your local drive and is used by Visual Studio as a cache of packages.

The import item to note is that NuGet.Config files are *additive*. To add additional sources without changing the list for the entire system, you can add additional NuGet.Config files. Each file is valid for the directory that it's placed in as well as any subdirectory. Add a new file named NuGet.Config into the solution directory, and update the contents to this:

```

<?xml version="1.0" encoding="utf-8"?>
<configuration>
  <packageSources>
    <add key="local-packages" value=".\\CarLibrary\Publish" />
  </packageSources>
</configuration>

```

Remove the project references from the CSharpCarClient and the VisualBasicCarClient project, and then add package references like this (from the solution directory):

```

dotnet add CSharpCarClient package CarLibrary
dotnet add VisualBasicCarClient package CarLibrary

```

Once the references are set, build the solution and take a look at the output in the target directories (bin\Debug\netcoreapp3.1), and you will see the CarLibrary.dll in the directory and not the CarLibrary.nupkg file. This is because .NET Core unpacks the contents and adds in the assemblies contained as direct references.

Now set one of the clients as the startup project and run the application, and it works exactly like before.

Next, update the version number of the CarLibrary to 1.0.0.4, and repackage it. In the Publish directory, there are now two CarLibrary NuGet packages. If you rerun the add package commands, the project will be updated to use the new version. If the older version was preferred, the add package command allows for adding version numbers for a specific package.

## How .NET Core Locates Assemblies

So far in this book, all of the assemblies that you have built were directly related (except for the NuGet example you just completed). You either added a project reference or a direct reference between projects. In these cases (as well as the NuGet example), the dependent assembly was copied directly into the target directory of the client application. Locating the dependent assembly isn't an issue, since they reside on the disk right next to the application that needs them.

But what about the .NET Core framework? How are those located? Previous versions of .NET installed the framework files into the Global Assembly Cache (GAC), and all .NET applications knew how to locate the framework files.

However, the GAC prevents the side-by-side capabilities in .NET Core, so there isn't a single repository of runtime and framework files. Instead, the files that make up the framework are installed together in "C:\Program Files\dotnet" (on Windows), separated by version. Based on the version of the application (as specified in the csproj file), the necessary runtime and framework files are loaded for an application from the specified version's directory.

Specifically, when a version of the runtime is started, the runtime host provides a set of *probing paths* that it will use to find an application's dependencies. There are five probing properties (each of them optional) as listed in Table 16-1.

**Table 16-1.** *Application Probing Properties*

Option	Meaning in Life
TRUSTED_PLATFORM_ASSEMBLIES	List of platform and application assembly file paths
PLATFORM_RESOURCE_ROOTS	List of directory paths to search for satellite resource assemblies
NATIVE_DLL_SEARCH_DIRECTORIES	List of directory paths to search for unmanaged (native) libraries
APP_PATHS	List of directory paths to search for managed assemblies
APP_NI_PATHS	List of directory paths to search for native images of managed assemblies

To see the default paths for these, create a new .NET Core Console application named `FunWithProbingPaths`. Update the `Main` method to the following:

```
static void Main(string[] args)
{
    Console.WriteLine("*** Fun with Probing Paths ***");
    Console.WriteLine($"TRUSTED_PLATFORM_ASSEMBLIES: ");
    //Use ':' on non-Windows platforms
    var list = AppContext.GetData("TRUSTED_PLATFORM_ASSEMBLIES")
        .ToString().Split(';');
    foreach (var dir in list)
    {
        Console.WriteLine(dir);
    }
    Console.WriteLine();
    Console.WriteLine($"PLATFORM_RESOURCE_ROOTS: {AppContext.GetData(
        "PLATFORM_RESOURCE_ROOTS")}");
    Console.WriteLine();
    Console.WriteLine($"NATIVE_DLL_SEARCH_DIRECTORIES: {AppContext.GetData(
        "NATIVE_DLL_SEARCH_DIRECTORIES")}");
    Console.WriteLine();
    Console.WriteLine($"APP_PATHS: {AppContext.GetData("APP_PATHS")}");
    Console.WriteLine();
    Console.WriteLine($"APP_NI_PATHS: {AppContext.GetData("APP_NI_PATHS")}");
    Console.WriteLine();
    Console.ReadLine();
}
```

When you run this app, you will see the vast majority of the values come from the `TRUSTED_PLATFORM_ASSEMBLIES` variable. In addition to the assembly that is created for this project in the target directory, you will see a list of base class libraries from the current runtime directory, `C:\Program Files\dotnet\shared\Microsoft.NETCore.App\3.1.2` (your version number might be different).

Each of the files that are directly referenced by your application is added to the list as well as any runtime files that are required for your application. The list of runtime libraries is populated by one or more \*.deps.json files that are loaded with the .NET Core runtime. There are several in the installation directory for the SDK (used for building the software) and the runtime (used for running the software). With our simple example, the only file used is the Microsoft.NETCore.App.deps.json.

As your application grows in complexity, so will the list of files in TRUSTED\_PLATFORM\_ASSEMBLIES. For example, if you add a reference to the Microsoft.EntityFrameworkCore package, the list of required assemblies grows. To demonstrate this, enter the following command in Package Manager Console (in the same directory as the \*.csproj file):

```
dotnet add package Microsoft.EntityFrameworkCore
```

Once you have added the package, rerun the application, and notice how many more files are listed. Even though you only added one new reference, the Microsoft.EntityFrameworkCore package has its dependencies, which get added into the trusted file list.

## Summary

This chapter examined the role of .NET Core class libraries (aka .NET \*.dlls). As you have seen, class libraries are .NET Core binaries that contain logic intended to be reused across a variety of projects.

You learned the details of partitioning types into .NET Core namespaces and the difference between a .NET Core and .NET Standard, got started with application configuration, and dove deep into the composition of class libraries. Finally, you learned how to package your applications using NuGet.

## CHAPTER 17



# Type Reflection, Late Binding, and Attribute-Based Programming

As shown in Chapter 16, assemblies are the basic unit of deployment in the .NET Core universe. Using the integrated Object Browser of Visual Studio (and numerous other IDEs), you are able to examine the types within a project's referenced set of assemblies. Furthermore, external tools such as `ildasm.exe` allow you to peek into the underlying CIL code, type metadata, and assembly manifest for a given .NET Core binary. In addition to this design-time investigation of .NET Core assemblies, you are also able to *programmatically* obtain this same information using the `System.Reflection` namespace. To this end, the first task of this chapter is to define the role of reflection and the necessity of .NET Core metadata.

The remainder of the chapter examines a number of closely related topics, all of which hinge upon reflection services. For example, you'll learn how a .NET Core client may employ dynamic loading and late binding to activate types it has no compile-time knowledge of. You'll also learn how to insert custom metadata into your .NET Core assemblies through the use of system-supplied and custom attributes. To put all of these (seemingly esoteric) topics into perspective, the chapter closes by demonstrating how to build several "snap-in objects" that you can plug into an extendable console application.

## The Necessity of Type Metadata

The ability to fully describe types (classes, interfaces, structures, enumerations, and delegates) using metadata is a key element of the .NET Core platform. Many .NET Core technologies, like object serialization, require the ability to discover the format of types at runtime. Furthermore, cross-language interoperability, numerous compiler services, and an IDE's IntelliSense capabilities all rely on a concrete description of *type*.

Recall that the `ildasm.exe` utility allows you to view an assembly's type metadata. In the generated `CarLibrary.il` file (from Chapter 16), navigate to the `METAINFO` section to see all of the `CarLibrary`'s metadata. A small snippet is included here:

```
// ==== M E T A I N F O ===  
  
// =====  
// ScopeName : CarLibrary.dll  
// MVID      : {469494FE-CEB1-4DE0-9D60-EDA067D309EE}  
// =====  
// Global functions  
// -----  
//
```

```
// Global fields
// -----
//
// Global MemberRefs
// -----
//
// TypeDef #1 (02000002)
// -----
//   TypDefName: CarLibrary.EngineState (02000002)
//   Flags      : [Public] [AutoLayout] [Class] [Sealed] [AnsiClass] (00000101)
//   Extends    : 0100000E [TypeRef] System.Enum
//   Field #1 (04000001)
//   -----
//     Field Name: value__ (04000001)
//     Flags      : [Public] [SpecialName] [RTSpecialName] (00000606)
//     CallConvtn: [FIELD]
//     Field type: I4
//
```

As you can see, the .NET Core type metadata is verbose (the actual binary format is much more compact). In fact, if I were to list the entire metadata description representing the `CarLibrary.dll` assembly, it would span several pages. Given that this act would be a woeful waste of paper, let's just glimpse into some key metadata descriptions of the `CarLibrary.dll` assembly.

---

■ **Note** Don't be too concerned with the exact syntax of every piece of .NET Core metadata in the next few sections. The bigger point to absorb is that .NET Core metadata is very descriptive and lists each internally defined (and externally referenced) type found within a given codebase.

---

## Viewing (Partial) Metadata for the EngineState Enumeration

Each type defined within the current assembly is documented using a `TypeDef #n` token (where `TypeDef` is short for *type definition*). If the type being described uses a type defined within a separate .NET Core assembly, the referenced type is documented using a `TypeRef #n` token (where `TypeRef` is short for *type reference*). A `TypeRef` token is a pointer (if you will) to the referenced type's full metadata definition in an external assembly. In a nutshell, .NET Core metadata is a set of tables that clearly mark all type definitions (`TypeDefs`) and referenced types (`TypeRefs`), all of which can be examined using `ildasm.exe`.

As far as `CarLibrary.dll` goes, one `TypeDef` is the metadata description of the `CarLibrary.EngineState` enumeration (your number may differ; `TypeDef` numbering is based on the order in which the C# compiler processes the file).

```
// TypeDef #1 (02000002)
// -----
//   TypDefName: CarLibrary.EngineState (02000002)
//   Flags      : [Public] [AutoLayout] [Class] [Sealed] [AnsiClass] (00000101)
//   Extends    : 0100000E [TypeRef] System.Enum
//   Field #1 (04000001)
//   -----
//     Field Name: value__ (04000001)
```



```
//      Flags      : [Public] [SpecialName] [RTSpecialName] (00000606)
//      CallCnvtn: [FIELD]
//      Field type: I4
//
//      Field #2 (04000002)
//      -----
//      Field Name: EngineAlive (04000002)
//      Flags      : [Public] [Static] [Literal] [HasDefault] (00008056)
//      DefltValue: (I4) 0
//      CallCnvtn: [FIELD]
//      Field type: ValueClass CarLibrary.EngineState
//
// ...
```

Here, the `TypDefName` token is used to establish the name of the given type, which in this case is the custom `CarLibrary.EngineState` enum. The `Extends` metadata token is used to document the base type of a given .NET Core type (in this case, the referenced type, `System.Enum`). Each field of an enumeration is marked using the `Field #n` token. For brevity, I have simply listed only part of the metadata.

## Viewing (Partial) Metadata for the Car Type

Here is a partial dump of the `Car` class that illustrates the following:

- How fields are defined in terms of .NET Core metadata
- How methods are documented via .NET Core metadata
- How an automatic property is represented in .NET Core metadata

```
// TypeDef #3 (02000004)
// -----
//      TypDefName: CarLibrary.Car (02000004)
//      Flags      : [Public] [AutoLayout] [Class] [Abstract] [AnsiClass]
//                  [BeforeFieldInit] (00100081)
//      Extends    : 0100000F [TypeRef] System.Object
//      Field #1 (04000009)
//      -----
//      Field Name: <PetName>k__BackingField (04000009)
//      Flags      : [Private] (00000001)
//      CallCnvtn: [FIELD]
//      Field type: String
//
// ...

Method #1 (06000001)
-----
Method Name: get_PetName (06000001)
Flags      : [Public] [HideBySig] [ReuseSlot] [SpecialName] (00000886)
RVA        : 0x000020d0
ImplFlags  : [IL] [Managed] (00000000)
CallCnvtn: [DEFAULT]
hasThis
ReturnType: String
No arguments.
```

```

...

// Method #2 (06000002)
// -----
//   MethodName: set_PetName (06000002)
//   Flags      : [Public] [HideBySig] [ReuseSlot] [SpecialName] (00000886)
//   RVA        : 0x00002058
//   ImplFlags  : [IL] [Managed] (00000000)
//   CallConvtn: [DEFAULT]
//   hasThis
//   ReturnType: Void
//   1 Arguments
//     Argument #1: String
//   1 Parameters
//     (1) ParamToken : (08000001) Name : value flags: [none] (00000000)
...

// Property #1 (17000001)
// -----
//   Prop.Name : PetName (17000001)
//   Flags      : [none] (00000000)
//   CallConvtn: [PROPERTY]
//   hasThis
//   ReturnType: String
//   No arguments.
//   DefltValue:
//   Setter     : (06000002) set_PetName
//   Getter     : (06000001) get_PetName
//   0 Others
...

```

First, note that the `Car` class metadata marks the type's base class (`System.Object`) and includes various flags that describe how this type was constructed (e.g., `[Public]`, `[Abstract]`, and `whatnot`). Methods (such as the `Car`'s constructor) are described in regard to their parameters, return value, and name.

Note how an automatic property results in a compiler-generated private backing field (which was named `<PetName>k__BackingField`) and two compiler-generated methods (in the case of a read-write property) named, in this example, `get_PetName()` and `set_PetName()`. Finally, the actual property is mapped to the internal `get/set` methods using the .NET Core metadata `Getter/Setter` tokens.

## Examining a TypeRef

Recall that an assembly's metadata will describe not only the set of internal types (`Car`, `EngineState`, etc.) but also any external types the internal types reference. For example, given that `CarLibrary.dll` has defined two enumerations, you find a `TypeRef` block for the `System.Enum` type, as follows:

```

// TypeRef #14 (0100000e)
// -----
// Token:           0x0100000e
// ResolutionScope: 0x23000001
// TypeRefName:     System.Enum

```

## Documenting the Defining Assembly

The CarLibrary.il file also allows you to view the .NET Core metadata that describes the assembly itself using the Assembly token. The following is a partial dump of the manifest of CarLibrary.dll:

```
// Assembly
// -----
//   Token: 0x20000001
//   Name : CarLibrary
//   Public Key   :
//   Hash Algorithm : 0x00008004
//   Version: 1.0.0.1
//   Major Version: 0x00000001
//   Minor Version: 0x00000000
//   Build Number: 0x00000000
//   Revision Number: 0x00000001
//   Locale: <null>
//   Flags : [none] (00000000)
```

## Documenting Referenced Assemblies

In addition to the Assembly token and the set of TypeDef and TypeRef blocks, .NET Core metadata also makes use of AssemblyRef #n tokens to document each external assembly. Given that each .NET Core assembly references the System.Runtime base class library assembly, you find an AssemblyRef for the System.Runtime assembly, as shown in the following code:

```
// AssemblyRef #1 (23000001)
// -----
//   Token: 0x23000001
//   Public Key or Token: b0 3f 5f 7f 11 d5 0a 3a
//   Name: System.Runtime
//   Version: 4.2.2.0
//   Major Version: 0x00000004
//   Minor Version: 0x00000002
//   Build Number: 0x00000002
//   Revision Number: 0x00000000
//   Locale: <null>
//   HashValue Blob:
//   Flags: [none] (00000000)
```

## Documenting String Literals

The final point of interest regarding .NET Core metadata is the fact that every string literal in your codebase is documented under the User Strings token.

```
// User Strings
// -----
// 70000001 : (23) L"CarLibrary Version 2.0!"
// 70000031 : (13) L"Quiet time..."
// 7000004d : (11) L"Jamming {0}"
```

```
// 70000065 : (32) L"Eek! Your engine block exploded!"
// 700000a7 : (34) L"Ramming speed! Faster is better..."
```

■ **Note** As illustrated in this last metadata listing, always be aware that all strings are clearly documented in the assembly metadata. This could have huge security consequences if you were to use string literals to capture passwords, credit card numbers, or other sensitive information.

The next question on your mind may be (in the best-case scenario) “How can I leverage this information in my applications?” or (in the worst-case scenario) “Why should I care about metadata?” To address both points of view, allow me to introduce .NET Core reflection services. Be aware that the usefulness of the topics presented over the pages that follow may be a bit of a head-scratcher until this chapter’s endgame. So hang tight.

■ **Note** You will also find a number of CustomAttribute tokens displayed by the MetaInfo section, which documents the attributes applied within the codebase. You’ll learn about the role of .NET Core attributes later in this chapter.

# Understanding Reflection

In the .NET Core universe, *reflection* is the process of runtime type discovery. Using reflection services, you are able to programmatically obtain the same metadata information generated by ildasm.exe using a friendly object model. For example, through reflection, you can obtain a list of all types contained within a given \*.dll or \*.exe assembly, including the methods, fields, properties, and events defined by a given type. You can also dynamically discover the set of interfaces supported by a given type, the parameters of a method, and other related details (base classes, namespace information, manifest data, etc.).

Like any namespace, System.Reflection (which is defined in System.Runtime.dll) contains a number of related types. Table 17-1 lists some of the core items you should be familiar with.

**Table 17-1.** A Sampling of Members of the System.Reflection Namespace

Type	Meaning in Life
Assembly	This abstract class contains a number of members that allow you to load, investigate, and manipulate an assembly.
AssemblyName	This class allows you to discover numerous details behind an assembly’s identity (version information, culture information, etc.).
EventInfo	This abstract class holds information for a given event.
FieldInfo	This abstract class holds information for a given field.
MemberInfo	This is the abstract base class that defines common behaviors for the EventInfo, FieldInfo, MethodInfo, and PropertyInfo types.
MethodInfo	This abstract class contains information for a given method.
Module	This abstract class allows you to access a given module within a multiframe assembly.
ParameterInfo	This class holds information for a given parameter.
PropertyInfo	This abstract class holds information for a given property.

To understand how to leverage the `System.Reflection` namespace to programmatically read .NET Core metadata, you need to first come to terms with the `System.Type` class.

## The System.Type Class

The `System.Type` class defines a number of members that can be used to examine a type's metadata, a great number of which return types from the `System.Reflection` namespace. For example, `Type.GetMethods()` returns an array of `MethodInfo` objects, `Type.GetFields()` returns an array of `FieldInfo` objects, and so on. The complete set of members exposed by `System.Type` is quite expansive; however, Table 17-2 offers a partial snapshot of the members supported by `System.Type` (see the .NET Core documentation for full details).

**Table 17-2.** *Select Members of System.Type*

Member	Meaning in Life
<code>IsAbstract</code>	These properties (among others) allow you to discover a number of basic traits about the Type you are referring to (e.g., if it is an abstract entity, an array, a nested class, etc.).
<code>IsArray</code>	
<code>IsClass</code>	
<code>IsCOMObject</code>	
<code>IsEnum</code>	
<code>IsGenericTypeDefinition</code>	
<code>IsGenericParameter</code>	
<code>IsInterface</code>	
<code>IsPrimitive</code>	
<code>IsNestedPrivate</code>	
<code>IsNestedPublic</code>	
<code>IsSealed</code>	
<code>IsValueType</code>	
<code>GetConstructors()</code>	These methods (among others) allow you to obtain an array representing the items (interface, method, property, etc.) you are interested in. Each method returns a related array (e.g., <code>GetFields()</code> returns a <code>FieldInfo</code> array, <code>GetMethods()</code> returns a <code>MethodInfo</code> array, etc.). Be aware that each of these methods has a singular form (e.g., <code>GetMethod()</code> , <code>GetProperty()</code> , etc.) that allows you to retrieve a specific item by name, rather than an array of all related items.
<code>GetEvents()</code>	
<code>GetFields()</code>	
<code>GetInterfaces()</code>	
<code>GetMembers()</code>	
<code>GetMethods()</code>	
<code>GetNestedTypes()</code>	
<code>GetProperties()</code>	
<code>FindMembers()</code>	This method returns a <code>MemberInfo</code> array based on search criteria.
<code>GetType()</code>	This static method returns a <code>Type</code> instance given a string name.
<code>InvokeMember()</code>	This method allows “late binding” for a given item. You’ll learn about late binding later in this chapter.

## Obtaining a Type Reference Using System.Object.GetType()

You can obtain an instance of the `Type` class in a variety of ways. However, the one thing you cannot do is directly create a `Type` object using the `new` keyword, as `Type` is an abstract class. Regarding your first choice, recall that `System.Object` defines a method named `GetType()`, which returns an instance of the `Type` class that represents the metadata for the current object.

```
// Obtain type information using a SportsCar instance.
SportsCar sc = new SportsCar();
Type t = sc.GetType();
```

Obviously, this approach will work only if you have compile-time knowledge of the type you want to reflect over (`SportsCar` in this case) and currently have an instance of the type in memory. Given this restriction, it should make sense that tools such as `ildasm.exe` do not obtain type information by directly calling `System.Object.GetType()` for each type, given that `ildasm.exe` was not compiled against your custom assemblies.

## Obtaining a Type Reference Using `typeof()`

The next way to obtain type information is using the C# `typeof` operator, like so:

```
// Get the type using typeof.
Type t = typeof(SportsCar);
```

Unlike `System.Object.GetType()`, the `typeof` operator is helpful, in that you do not need to first create an object instance to extract type information. However, your codebase must still have compile-time knowledge of the type you are interested in examining, as `typeof` expects the strongly typed name of the type.

## Obtaining a Type Reference Using `System.Type.GetType()`

To obtain type information in a more flexible manner, you may call the static `GetType()` member of the `System.Type` class and specify the fully qualified string name of the type you are interested in examining. Using this approach, you do *not* need to have compile-time knowledge of the type you are extracting metadata from, given that `Type.GetType()` takes an instance of the omnipresent `System.String`.

---

■ **Note** When I say you do not need compile-time knowledge when calling `Type.GetType()`, I am referring to the fact that this method can take any string value whatsoever (rather than a strongly typed variable). Of course, you would still need to know the name of the type in a “stringified” format!

---

The `Type.GetType()` method has been overloaded to allow you to specify two Boolean parameters, one of which controls whether an exception should be thrown if the type cannot be found, and the other of which establishes the case sensitivity of the string. To illustrate, ponder the following:

```
// Obtain type information using the static Type.GetType() method
// (don't throw an exception if SportsCar cannot be found and ignore case).
Type t = Type.GetType("CarLibrary.SportsCar", false, true);
```

In the previous example, notice that the string you are passing into `GetType()` makes no mention of the assembly containing the type. In this case, the assumption is that the type is defined within the currently executing assembly. However, when you want to obtain metadata for a type within an external assembly, the string parameter is formatted using the type’s fully qualified name, followed by a comma, followed by the friendly name (the assembly name without any version information) of the assembly containing the type, like so:

```
// Obtain type information for a type within an external assembly.
Type t = Type.GetType("CarLibrary.SportsCar, CarLibrary");
```

As well, do know that the string passed into `Type.GetType()` may specify a plus token (+) to denote a *nested type*. Assume you want to obtain type information for an enumeration (`SpyOptions`) nested within a class named `JamesBondCar`. To do so, you would write the following:

```
// Obtain type information for a nested enumeration
// within the current assembly.
Type t = Type.GetType("CarLibrary.JamesBondCar+SpyOptions");
```

## Building a Custom Metadata Viewer

To illustrate the basic process of reflection (and the usefulness of `System.Type`), let's create a Console Application project named `MyTypeViewer`. This program will display details of the methods, properties, fields, and supported interfaces (in addition to some other points of interest) for any type within `System.Runtime.dll` (recall all .NET Core applications have automatic access to this core framework class library) or a type within `MyTypeViewer` itself. Once the application has been created, be sure to import the `System.Reflection` namespace.

```
// Need to import this namespace to do any reflection!
using System.Reflection;
```

## Reflecting on Methods

The `Program` class will be updated to define a number of static methods, each of which takes a single `System.Type` parameter and returns `void`. First you have `ListMethods()`, which (as you might guess) prints the name of each method defined by the incoming type. Notice how `Type.GetMethods()` returns an array of `System.Reflection.MethodInfo` objects, which can be enumerated over using a standard `foreach` loop, as follows:

```
// Display method names of type.
static void ListMethods(Type t)
{
    Console.WriteLine("***** Methods *****");
    MethodInfo[] mi = t.GetMethods();
    foreach(MethodInfo m in mi)
    {
        Console.WriteLine("->{0}", m.Name);
    }
    Console.WriteLine();
}
```

Here, you are simply printing the name of the method using the `MethodInfo.Name` property. As you might guess, `MethodInfo` has many additional members that allow you to determine whether the method is static, virtual, generic, or abstract. As well, the `MethodInfo` type allows you to obtain the method's return value and parameter set. You'll spruce up the implementation of `ListMethods()` in just a bit.

If you wanted, you could also build a fitting LINQ query to enumerate the names of each method. Recall from Chapter 13, LINQ to Objects allows you to build strongly typed queries that can be applied to in-memory object collections. As a good rule of thumb, whenever you find blocks of looping or decision

programming logic, you could make use of a related LINQ query. For example, you could rewrite the previous method as so (make sure to add the using for System.Linq):

```
using System.Linq;
static void ListMethods(Type t)
{
    Console.WriteLine("***** Methods *****");
    var methodNames = from n in t.GetMethods() select n.Name;
    foreach (var name in methodNames)
    {
        Console.WriteLine("->{0}", name);
    }
    Console.WriteLine();
}
```

## Reflecting on Fields and Properties

The implementation of `ListFields()` is similar. The only notable difference is the call to `Type.GetFields()` and the resulting `FieldInfo` array. Again, to keep things simple, you are printing out only the name of each field using a LINQ query.

```
// Display field names of type.
static void ListFields(Type t)
{
    Console.WriteLine("***** Fields *****");
    var fieldNames = from f in t.GetFields() select f.Name;
    foreach (var name in fieldNames)
    {
        Console.WriteLine("->{0}", name);
    }
    Console.WriteLine();
}
```

The logic to display a type's properties is similar.

```
// Display property names of type.
static void ListProps(Type t)
{
    Console.WriteLine("***** Properties *****");
    var propNames = from p in t.GetProperties() select p.Name;
    foreach (var name in propNames)
    {
        Console.WriteLine("->{0}", name);
    }
    Console.WriteLine();
}
```



## Reflecting on Implemented Interfaces

Next, you will author a method named `ListInterfaces()` that will print the names of any interfaces supported on the incoming type. The only point of interest here is that the call to `GetInterfaces()` returns an array of `System.Type`s! This should make sense given that interfaces are, indeed, types.

```
// Display implemented interfaces.
static void ListInterfaces(Type t)
{
    Console.WriteLine("***** Interfaces *****");
    var ifaces = from i in t.GetInterfaces() select i;
    foreach(Type i in ifaces)
    {
        Console.WriteLine("->{0}", i.Name);
    }
}
```

---

■ **Note** Be aware that a majority of the “get” methods of `System.Type` (`GetMethods()`, `GetInterfaces()`, etc.) have been overloaded to allow you to specify values from the `BindingFlags` enumeration. This provides a greater level of control on exactly what should be searched for (e.g., only static members, only public members, include private members, etc.). Consult the documentation for details.

---

## Displaying Various Odds and Ends

Last but not least, you have one final helper method that will simply display various statistics (indicating whether the type is generic, what the base class is, whether the type is sealed, etc.) regarding the incoming type.

```
// Just for good measure.
static void ListVariousStats(Type t)
{
    Console.WriteLine("***** Various Statistics *****");
    Console.WriteLine("Base class is: {0}", t.BaseType);
    Console.WriteLine("Is type abstract? {0}", t.IsAbstract);
    Console.WriteLine("Is type sealed? {0}", t.IsSealed);
    Console.WriteLine("Is type generic? {0}", t.IsGenericTypeDefinition);
    Console.WriteLine("Is type a class type? {0}", t.IsClass);
    Console.WriteLine();
}
```

## Implementing Main()

The `Main()` method of the `Program` class prompts the user for the fully qualified name of a type. Once you obtain this string data, you pass it into the `Type.GetType()` method and send the extracted `System.Type` into each of your helper methods. This process repeats until the user presses Q to terminate the application.

```

static void Main(string[] args)
{
    Console.WriteLine("***** Welcome to MyTypeViewer *****");
    string typeName = "";

    do
    {
        Console.WriteLine("\nEnter a type name to evaluate");
        Console.Write("or enter Q to quit: ");

        // Get name of type.
        typeName = Console.ReadLine();

        // Does user want to quit?
        if (typeName.Equals("Q", StringComparison.OrdinalIgnoreCase))
        {
            break;
        }

        // Try to display type.
        try
        {
            Type t = Type.GetType(typeName);
            Console.WriteLine("");
            ListVariousStats(t);
            ListFields(t);
            ListProps(t);
            ListMethods(t);
            ListInterfaces(t);
        }
        catch
        {
            Console.WriteLine("Sorry, can't find type");
        }
    } while (true);
}

```

At this point, `MyTypeViewer.exe` is ready to take a test-drive. For example, run your application and enter the following fully qualified names (be aware that the manner in which you invoked `Type.GetType()` requires case-sensitive string names):

- `System.Int32`
- `System.Collections.ArrayList`
- `System.Threading.Thread`
- `System.Void`
- `System.IO.BinaryWriter`
- `System.Math`
- `MyTypeViewer.Program`

For example, here is some partial output when specifying `System.Math`:

---

```
***** Welcome to MyTypeViewer *****

Enter a type name to evaluate
or enter Q to quit: System.Math

***** Various Statistics *****
Base class is: System.Object
Is type abstract? True
Is type sealed? True
Is type generic? False
Is type a class type? True

***** Fields *****
->PI
->E

***** Properties *****

***** Methods *****
->Acos
->Asin
->Atan
->Atan2
->Ceiling
->Cos
...
```

---

## Reflecting on Static Types

If you enter `System.Console` in the previous method, an exception will be thrown in the first helper method because the value for `t` will be null. Static types can't be loaded using the `Type.GetType(typeName)` method. Instead, you have to use another mechanism, the `typeof` function from `System.Type`. Update the program to handle the `System.Console` special case like this:

```
Type t = Type.GetType(typeName);
if (t == null && typeName.Equals("System.Console",
    StringComparison.OrdinalIgnoreCase))
{
    t = typeof(System.Console);
}
```

## Reflecting on Generic Types

When you call `Type.GetType()` to obtain metadata descriptions of generic types, you must make use of a special syntax involving a “backtick” character (```) followed by a numerical value that represents the number of type parameters the type supports. For example, if you want to print out the metadata description of `System.Collections.Generic.List<T>`, you would need to pass the following string into your application:

```
System.Collections.Generic.List`1
```

Here, you are using the numerical value of 1, given that `List<T>` has only one type parameter. However, if you want to reflect over `Dictionary<TKey, TValue>`, you would supply the value 2, like so:

```
System.Collections.Generic.Dictionary`2
```

## Reflecting on Method Parameters and Return Values

So far, so good! Let’s make a minor enhancement to the current application. Specifically, you will update the `ListMethods()` helper function to list not only the name of a given method but also the return type and incoming parameter types. The `MethodInfo` type provides the `ReturnType` property and `GetParameters()` method for these tasks. In the following modified code, notice that you are building a string that contains the type and name of each parameter using a nested `foreach` loop (without the use of LINQ):

```
static void ListMethods(Type t)
{
    Console.WriteLine("***** Methods *****");
    MethodInfo[] mi = t.GetMethods();
    foreach (MethodInfo m in mi)
    {
        // Get return type.
        string retVal = m.ReturnType.FullName;
        string paramInfo = "( ";
        // Get params.
        foreach (ParameterInfo pi in m.GetParameters())
        {
            paramInfo += string.Format("{0} {1} ", pi.ParameterType, pi.Name);
        }
        paramInfo += " )";

        // Now display the basic method sig.
        Console.WriteLine("->{0} {1} {2}", retVal, m.Name, paramInfo);
    }
    Console.WriteLine();
}
```

If you now run this updated application, you will find that the methods of a given type are much more detailed. If you enter your good friend `System.Object` as input to the program, the following methods will display:

---

```
***** Methods *****
->System.Type GetType ( )
->System.String ToString ( )
->System.Boolean Equals ( System.Object obj )
```

```
->System.Boolean Equals ( System.Object objA System.Object objB )
->System.Boolean ReferenceEquals ( System.Object objA System.Object objB )
->System.Int32 GetHashCode ( )
```

---

The current implementation of `ListMethods()` is helpful, in that you can directly investigate each parameter and method return type using the `System.Reflection` object model. As an extreme shortcut, be aware that all of the `XXXInfo` types (`MethodInfo`, `PropertyInfo`, `EventInfo`, etc.) have overridden `ToString()` to display the signature of the item requested. Thus, you could also implement `ListMethods()` as follows (once again using LINQ, where you simply select all `MethodInfo` objects, rather than only the `Name` values):

```
static void ListMethods(Type t)
{
    Console.WriteLine("***** Methods *****");
    var methodNames = from n in t.GetMethods() select n;
    foreach (var name in methodNames)
    {
        Console.WriteLine("->{0}", name);
    }
    Console.WriteLine();
}
```

Interesting stuff, huh? Clearly, the `System.Reflection` namespace and `System.Type` class allow you to reflect over many other aspects of a type beyond what `MyTypeViewer` is currently displaying. As you would hope, you can obtain a type's events, get the list of any generic parameters for a given member, and glean dozens of other details.

Nevertheless, at this point you have created a (somewhat capable) object browser. The major limitation, of course, is that you have no way to reflect beyond the current assembly (`MyTypeViewer`) or the always-accessible `mscorlib.dll`. This begs the question "How can I build applications that can load (and reflect over) assemblies not referenced at compile time?" Glad you asked.

## Dynamically Loading Assemblies

There will be times when you need to load assemblies on the fly programmatically, even if there is no record of said assembly in the manifest. Formally speaking, the act of loading external assemblies on demand is known as a *dynamic load*.

`System.Reflection` defines a class named `Assembly`. Using this class, you are able to dynamically load an assembly, as well as discover properties about the assembly itself. Using the `Assembly` type, you are able to dynamically load assemblies, as well as load an assembly located at an arbitrary location. In essence, the `Assembly` class provides methods (`Load()` and `LoadFrom()`, in particular) that allow you to programmatically load assemblies off disk.

To illustrate dynamic loading, create a new Console Application project named `ExternalAssemblyReflector`. Your task is to construct a `Main()` method that prompts for the name of an assembly (minus any extension) to load dynamically. You will pass the `Assembly` reference into a helper method named `DisplayTypes()`, which will simply print the names of each class, interface, structure, enumeration, and delegate it contains. The code is refreshingly simple.

```
using System;
using System.Collections.Generic;
using System.Linq;
using System.Text;
```

```

using System.Reflection;
using System.IO; // For FileNotFoundException definition.

namespace ExternalAssemblyReflector
{
    class Program
    {
        static void DisplayTypesInAsm(Assembly asm)
        {
            Console.WriteLine("\n***** Types in Assembly *****");
            Console.WriteLine("->{0}", asm.FullName);
            Type[] types = asm.GetTypes();
            foreach (Type t in types)
            {
                Console.WriteLine("Type: {0}", t);
            }
            Console.WriteLine("");
        }

        static void Main(string[] args)
        {
            Console.WriteLine("***** External Assembly Viewer *****");
            string asmName = "";
            Assembly asm = null;
            do
            {
                Console.WriteLine("\nEnter an assembly to evaluate");
                Console.Write("or enter Q to quit: ");
                // Get name of assembly.
                asmName = Console.ReadLine();
                // Does user want to quit?
                if (asmName.Equals("Q", StringComparison.OrdinalIgnoreCase))
                {
                    break;
                }

                // Try to load assembly.
                try
                {
                    asm = Assembly.LoadFrom(asmName);
                    DisplayTypesInAsm(asm);
                }
                catch
                {
                    Console.WriteLine("Sorry, can't find assembly.");
                }
            } while (true);
        }
    }
}

```

If you want to reflect over `CarLibrary.dll`, you will need to copy the `CarLibrary.dll` binary (from the previous chapter) to the `\bin\Debug\netcoreapp3.1` directory of the `ExternalAssemblyReflector` application to run this program. Once you do, you will find output similar to the following:

---

```
***** External Assembly Viewer *****

Enter an assembly to evaluate
or enter Q to quit: CarLibrary

***** Types in Assembly *****
->CarLibrary, Version=1.0.0.1, Culture=neutral, PublicKeyToken=null
Type: CarLibrary.MyInternalClass
Type: CarLibrary.EngineState
Type: CarLibrary.MusicMedia
Type: CarLibrary.Car
Type: CarLibrary.Minivan
Type: CarLibrary.SportsCar
```

---

The `LoadFrom` method can also take an absolute path to the assembly you want to view (e.g., `C:\MyApp\MyAsm.dll`). With this method, you can pass in a full path to your Console Application project. Thus, if `CarLibrary.dll` was located under `C:\MyCode`, you could enter `C:\MyCode\CarLibrary` (note that the extension is optional).

## Reflecting on Framework Assemblies

The `Assembly.Load()` method has been overloaded a number of times. One variation allows you to specify a culture value (for localized assemblies), as well as a version number and public key token value (for framework assemblies). Collectively speaking, the set of items identifying an assembly is termed the *display name*. The format of a display name is a comma-delimited string of name-value pairs that begins with the friendly name of the assembly, followed by optional qualifiers (that may appear in any order). Here is the template to follow (optional items appear in parentheses):

```
Name (,Version = major.minor.build.revision) (,Culture = culture token) (,PublicKeyToken=
public key token)
```

When you're crafting a display name, the convention `PublicKeyToken=null` indicates that binding and matching against a nonstrongly named assembly is required. Additionally, `Culture=""` indicates matching against the default culture of the target machine. Here's an example:

```
// Load version 1.0.0.0 of CarLibrary using the default culture.
Assembly a =
    Assembly.Load("CarLibrary, Version=1.0.0.0, PublicKeyToken=null, Culture=\"\");
```

Also be aware that the `System.Reflection` namespace supplies the `AssemblyName` type, which allows you to represent the preceding string information in a handy object variable. Typically, this class is used in conjunction with `System.Version`, which is an OO wrapper around an assembly's version number. Once you have established the display name, it can then be passed into the overloaded `Assembly.Load()` method, like so:

```
// Make use of AssemblyName to define the display name.
AssemblyName asmName;
asmName = new AssemblyName();
asmName.Name = "CarLibrary";
Version v = new Version("1.0.0.0");
asmName.Version = v;
Assembly a = Assembly.Load(asmName);
```

To load a framework assembly, the `Assembly.Load()` parameter should specify a `PublicKeyToken` value, although with .NET Core it's not required. For example, assume you have a new Console Application project named `FrameworkAssemblyViewer` that has a reference to the `Microsoft.EntityFrameworkCore` package and you want to load it to inspect it. Given that the number of types in this assembly is quite large, the following application prints out only the names of public enums, using a simple LINQ query:

```
using System;
using System.Linq;
using System.Reflection;

public class Program
{
    private static void DisplayInfo(Assembly a)
    {
        Console.WriteLine("***** Info about Assembly *****");
        Console.WriteLine($"Asm Name: {a.GetName().Name}");
        Console.WriteLine($"Asm Version: {a.GetName().Version}");
        Console.WriteLine($"Asm Culture: {a.GetName().CultureInfo.DisplayName}");
        Console.WriteLine("\nHere are the public enums:");

        // Use a LINQ query to find the public enums.
        Type[] types = a.GetTypes();
        var publicEnums =
            from pe in types
            where pe.IsEnum && pe.IsPublic
            select pe;

        foreach (var pe in publicEnums)
        {
            Console.WriteLine(pe);
        }
    }

    static void Main(string[] args)
    {
        Console.WriteLine("***** The Framework Assembly Reflector App *****\n");
    }
}
```



```

// Load Microsoft.EntityFrameworkCore.dll
var displayName =
"Microsoft.EntityFrameworkCore, Version=3.1.3.0, Culture=\","", PublicKeyToken=adb9793829ddae60";
Assembly asm = Assembly.Load(displayName);
DisplayInfo(asm);
Console.WriteLine("Done!");
Console.ReadLine();
}
}

```

At this point, you should understand how to use some of the core members of the `System.Reflection` namespace to discover metadata at runtime. Of course, I realize despite the “cool factor,” you likely will not need to build custom object browsers at your place of employment too often. Do recall, however, that reflection services are the foundation for a number of common programming activities, including late binding.

## Understanding Late Binding

Simply put, *late binding* is a technique in which you are able to create an instance of a given type and invoke its members at runtime without having hard-coded compile-time knowledge of its existence. When you are building an application that binds late to a type in an external assembly, you have no reason to set a reference to the assembly; therefore, the caller’s manifest has no direct listing of the assembly.

At first glance, it is not easy to see the value of late binding. It is true that if you can “bind early” to an object (e.g., add an assembly reference and allocate the type using the C# `new` keyword), you should opt to do so. For one reason, early binding allows you to determine errors at compile time, rather than at runtime. Nevertheless, late binding does have a critical role in any extendable application you may be building. You will have a chance to build such an “extendable” program at the end of this chapter, in the section “Building an Extendable Application.” Until then, let’s examine the role of the `Activator` class.

## The System.Activator Class

The `System.Activator` class is the key to the .NET Core late-binding process. For the next example, you are interested only in the `Activator.CreateInstance()` method, which is used to create an instance of a type through late binding. This method has been overloaded numerous times to provide a good deal of flexibility. The simplest variation of the `CreateInstance()` member takes a valid `Type` object that describes the entity you want to allocate into memory on the fly.

Create a new Console Application project named `LateBindingApp` and import the `System.IO` and `System.Reflection` namespaces via the C# `using` keyword. Now, update the `Program` class as follows:

```

// This program will load an external library,
// and create an object using late binding.
public class Program
{
    static void Main(string[] args)
    {
        Console.WriteLine("***** Fun with Late Binding *****");
        // Try to load a local copy of CarLibrary.
        Assembly a = null;
        try
        {

```

```

        a = Assembly.LoadFrom("CarLibrary");
    }
    catch(FileNotFoundException ex)
    {
        Console.WriteLine(ex.Message);
        return;
    }
    if(a != null)
    {
        CreateUsingLateBinding(a);
    }
    Console.ReadLine();
}

static void CreateUsingLateBinding(Assembly asm)
{
    try
    {
        // Get metadata for the Minivan type.
        Type miniVan = asm.GetType("CarLibrary.Minivan");

        // Create a Minivan instance on the fly.
        object obj = Activator.CreateInstance(miniVan);
        Console.WriteLine("Created a {0} using late binding!", obj);
    }
    catch(Exception ex)
    {
        Console.WriteLine(ex.Message);
    }
}
}

```

Now, before you run this application, you will need to manually place a copy of `CarLibrary.dll` into the `bin\Debug\netcoreapp3.1` folder of this new application. If you didn't do the Chapter 16 samples, there is a copy of the `CarLibrary.dll` file in this chapter's code sample. The reason is that you are calling `Assembly.LoadFrom`; therefore, the CLR will probe only in the client folder. (If you want, you could also enter a path to the assembly; however, in this example, there is no need to do so.)

---

■ **Note** Don't add a reference to `CarLibrary.dll` using Visual Studio for this example! That will record this library in the client's manifest. The whole point of late binding is that you are trying to create an object that is not known at compile time.

---

Notice that the `Activator.CreateInstance()` method returns a `System.Object` rather than a strongly typed `Minivan`. Therefore, if you apply the dot operator on the `obj` variable, you will fail to see any members of the `Minivan` class. At first glance, you might assume you can remedy this problem with an explicit cast, like so:

```

// Cast to get access to the members of Minivan?
// Nope! Compiler error!
object obj = (Minivan)Activator.CreateInstance(minivan);

```

However, because your program has not added a reference to `CarLibrary.dll`, you cannot use the `C#` `using` keyword to import the `CarLibrary` namespace, and therefore, you can't use a `MiniVan` during the casting operation! Remember that the whole point of late binding is to create instances of objects for which there is no compile-time knowledge. Given this, how can you invoke the underlying methods of the `MiniVan` object stored in the `System.Object` reference? The answer, of course, is by using reflection.

## Invoking Methods with No Parameters

Assume you want to invoke the `TurboBoost()` method of the `MiniVan`. As you recall, this method will set the state of the engine to “dead” and display an informational message box. The first step is to obtain a `MethodInfo` object for the `TurboBoost()` method using `Type.GetMethod()`. From the resulting `MethodInfo`, you are then able to call `MiniVan.TurboBoost` using `Invoke()`. `MethodInfo.Invoke()` requires you to send in all parameters that are to be given to the method represented by `MethodInfo`. These parameters are represented by an array of `System.Object` types (as the parameters for a given method could be any number of various entities).

Given that `TurboBoost()` does not require any parameters, you can simply pass `null` (meaning “this method has no parameters”). Update your `CreateUsingLateBinding()` method as follows:

```
static void CreateUsingLateBinding(Assembly asm)
{
    try
    {
        // Get metadata for the Minivan type.
        Type miniVan = asm.GetType("CarLibrary.Minivan");

        // Create the Minivan on the fly.
        object obj = Activator.CreateInstance(miniVan);
        Console.WriteLine($"Created a {obj} using late binding!");
        // Get info for TurboBoost.
        MethodInfo mi = miniVan.GetMethod("TurboBoost");

        // Invoke method ('null' for no parameters).
        mi.Invoke(obj, null);
    }
    catch(Exception ex)
    {
        Console.WriteLine(ex.Message);
    }
}
```

At this point, you will see the message in the console that your engine exploded.

## Invoking Methods with Parameters

When you want to use late binding to invoke a method requiring parameters, you should package up the arguments as a loosely typed array of objects. Recall that version 2.0.0.0 of `CarLibrary.dll` defined the following method in the `Car` class:

```
public void TurnOnRadio(bool musicOn, MusicMedia mm)
{
    public void TurnOnRadio(bool musicOn, MusicMedia mm)
        => MessageBox.Show(musicOn ? $"Jamming {mm}" : "Quiet time...");
}
```

This method takes two parameters: a Boolean representing if the automobile's music system should be turned on or off and an enum representing the type of music player. Recall this enum was structured as so:

```
public enum MusicMedia
{
    musicCd,      // 0
    musicTape,    // 1
    musicRadio,   // 2
    musicMp3      // 3
}
```

Here is a new method of the `Program` class, which invokes `TurnOnRadio()`. Notice that you are using the underlying numerical values of the `MusicMedia` enumeration to specify a “radio” media player.

```
static void InvokeMethodWithArgsUsingLateBinding(Assembly asm)
{
    try
    {
        // First, get a metadata description of the sports car.
        Type sport = asm.GetType("CarLibrary.SportsCar");

        // Now, create the sports car.
        object obj = Activator.CreateInstance(sport);
        // Invoke TurnOnRadio() with arguments.
        MethodInfo mi = sport.GetMethod("TurnOnRadio");
        mi.Invoke(obj, new object[] { true, 2 });
    }
    catch (Exception ex)
    {
        Console.WriteLine(ex.Message);
    }
}
```

Ideally, at this point, you can see the relationships among reflection, dynamic loading, and late binding. To be sure, the reflection API provides many additional features beyond what has been covered here, but you should be in good shape to dig into more details if you are interested.

Again, you still might wonder exactly *when* you should use these techniques in your own applications. The conclusion of this chapter should shed light on this issue; however, the next topic under investigation is the role of .NET Core attributes.

## Understanding the Role of .NET Attributes

As illustrated at the beginning of this chapter, one role of a .NET Core compiler is to generate metadata descriptions for all defined and referenced types. In addition to this standard metadata contained within any assembly, the .NET Core platform provides a way for programmers to embed additional metadata into an assembly using *attributes*. In a nutshell, attributes are nothing more than code annotations that can be applied to a given type (class, interface, structure, etc.), member (property, method, etc.), assembly, or module.

.NET Core attributes are class types that extend the abstract `System.Attribute` base class. As you explore the .NET Core namespaces, you will find many predefined attributes that you are able to use in your applications. Furthermore, you are free to build custom attributes to further qualify the behavior of your types by creating a new type deriving from `Attribute`.

The .NET Core base class library provides a number of attributes in various namespaces. Table 17-3 gives a snapshot of some – but by *absolutely* no means all – predefined attributes.

**Table 17-3.** *A Tiny Sampling of Predefined Attributes*

Attribute	Meaning in Life
[CLSCompliant]	Enforces the annotated item to conform to the rules of the Common Language Specification (CLS). Recall that CLS-compliant types are guaranteed to be used seamlessly across all .NET Core programming languages.
[DllImport]	Allows .NET Core code to make calls to any unmanaged C- or C++-based code library, including the API of the underlying operating system.
[Obsolete]	Marks a deprecated type or member. If other programmers attempt to use such an item, they will receive a compiler warning describing the error of their ways.
[Serializable]	Marks a class or structure as being “serializable,” meaning it is able to persist its current state into a stream.
[NonSerialized]	Specifies that a given field in a class or structure should not be persisted during the serialization process.

Understand that when you apply attributes in your code, the embedded metadata is essentially useless until another piece of software explicitly reflects over the information. If this is not the case, the blurb of metadata embedded within the assembly is ignored and completely harmless.

## Attribute Consumers

As you would guess, the .NET Core Framework ships with numerous utilities that are indeed on the lookout for various attributes. The C# compiler (`csc.exe`) itself has been preprogrammed to discover the presence of various attributes during the compilation cycle. For example, if the C# compiler encounters the [CLSCompliant] attribute, it will automatically check the attributed item to ensure it is exposing only CLS-compliant constructs. By way of another example, if the C# compiler discovers an item attributed with the [Obsolete] attribute, it will display a compiler warning in the Visual Studio Error List window.

In addition to development tools, numerous methods in the .NET Core base class libraries are preprogrammed to reflect over specific attributes. For example, if you want to persist the state of an object to file, all you are required to do is annotate your class or structure with the [Serializable] attribute. If the `Serialize()` method of the `BinaryFormatter` class encounters this attribute, the object is automatically persisted to file in a compact binary format.

Finally, you are free to build applications that are programmed to reflect over your own custom attributes, as well as any attribute in the .NET Core base class libraries. By doing so, you are essentially able to create a set of “keywords” that are understood by a specific set of assemblies.

## Applying Attributes in C#

To illustrate the process of applying attributes in C#, create a new Console Application project named `ApplyingAttributes`. Assume you want to build a class named `Motorcycle` that can be persisted in a binary format. To do so, simply apply the `[Serializable]` attribute to the class definition. If you have a field that should not be persisted, you may apply the `[NonSerialized]` attribute.

```
// This class can be saved to disk.
[Serializable]
public class Motorcycle
{
    // However, this field will not be persisted.
    [NonSerialized]
    float weightOfCurrentPassengers;
    // These fields are still serializable.
    bool hasRadioSystem;
    bool hasHeadSet;
    bool hasSissyBar;
}
```

---

■ **Note** An attribute applies to the “very next” item. For example, the only nonserialized field of the `Motorcycle` class is `weightOfCurrentPassengers`. The remaining fields are serializable given that the entire class has been annotated with `[Serializable]`.

---

At this point, don’t concern yourself with the actual process of object serialization (Chapter 20 examines the details). Just notice that when you want to apply an attribute, the name of the attribute is sandwiched between square brackets.

Once this class has been compiled, you can view the extra metadata using `ildasm.exe`.

```
// TypeDef #1 (02000002)
// -----
// TypDefName: ApplyingAttributes.Motorcycle (02000002)
// Flags      : [Public] [AutoLayout] [Class] [Serializable] [AnsiClass]
//             [BeforeFieldInit] (00102001)
// Extends    : 0100000C [TypeRef] System.Object
// Field #1 (04000001)
// -----
// Field Name: weightOfCurrentPassengers (04000001)
// Flags      : [Private] [NotSerialized] (00000081)
// CallCnvtn: [FIELD]
// Field type: R4
```

As you might guess, a single item can be attributed with multiple attributes. Assume you have a legacy C# class type (`HorseAndBuggy`) that was marked as serializable but is now considered obsolete for current development. Rather than deleting the class definition from your codebase (and risk breaking existing software), you can mark the class with the `[Obsolete]` attribute. To apply multiple attributes to a single item, simply use a comma-delimited list, like so:

```
[Serializable, Obsolete("Use another vehicle!")]
public class HorseAndBuggy
{
    // ...
}
```

As an alternative, you can also apply multiple attributes on a single item by stacking each attribute as follows (the end result is identical):

```
[Serializable]
[Obsolete("Use another vehicle!")]
public class HorseAndBuggy
{
    // ...
}
```

## C# Attribute Shorthand Notation

If you were consulting the .NET Core documentation, you might have noticed that the actual class name of the `[Obsolete]` attribute is `ObsoleteAttribute`, not `Obsolete`. As a naming convention, all .NET Core attributes (including custom attributes you may create yourself) are suffixed with the `Attribute` token. However, to simplify the process of applying attributes, the C# language does not require you to type in the `Attribute` suffix. Given this, the following iteration of the `HorseAndBuggy` type is identical to the previous (it just involves a few more keystrokes):

```
[SerializableAttribute]
[ObsoleteAttribute("Use another vehicle!")]
public class HorseAndBuggy
{
    // ...
}
```

Be aware that this is a courtesy provided by C#. Not all .NET Core languages support this shorthand attribute syntax.

## Specifying Constructor Parameters for Attributes

Notice that the `[Obsolete]` attribute is able to accept what appears to be a constructor parameter. If you view the formal definition of the `[Obsolete]` attribute by right-clicking the item in the code editor and selecting the `Go To Definition` menu option, you will find that this class indeed provides a constructor receiving a `System.String`.

```
public sealed class ObsoleteAttribute : Attribute
{
    public ObsoleteAttribute(string message, bool error);
```

```

public ObsoleteAttribute(string message);
public ObsoleteAttribute();
public bool IsError { get; }
public string? Message { get; }
}

```

Understand that when you supply constructor parameters to an attribute, the attribute is *not* allocated into memory until the parameters are reflected upon by another type or an external tool. The string data defined at the attribute level is simply stored within the assembly as a blurb of metadata.

## The Obsolete Attribute in Action

Now that `HorseAndBuggy` has been marked as obsolete, if you were to allocate an instance of this type:

```

static void Main(string[] args)
{
    HorseAndBuggy mule = new HorseAndBuggy();
}

```

you would find that a compiler warning is issued. The warning is specifically CS0618, and the message includes the information passed into the attribute:

‘HorseAndBuggy’ is obsolete: ‘Use another vehicle!’

Visual Basic also helps with IntelliSense, which gets its information through reflection. Figure 17-1 shows the results of the `Obsolete` attribute in Visual Studio:



**Figure 17-1.** Attributes in action in Visual Studio

Ideally, at this point, you should understand the following key points regarding .NET Core attributes:

- Attributes are classes that derive from `System.Attribute`.
- Attributes result in embedded metadata.
- Attributes are basically useless until another agent reflects upon them.
- Attributes are applied in C# using square brackets.

Next up, let’s examine how you can build your own custom attributes and a piece of custom software that reflects over the embedded metadata.



## Building Custom Attributes

The first step in building a custom attribute is to create a new class deriving from `System.Attribute`. Keeping in step with the automobile theme used throughout this book, assume you have created a new C# Class Library project named `AttributedCarLibrary` (name the solution `FunWithAttributes`).

---

■ **Note** If you are not familiar with changing the solution name, that will be covered later in this chapter.

---

This assembly will define a handful of vehicles, each of which is described using a custom attribute named `VehicleDescriptionAttribute`, as follows:

```
// A custom attribute.
public sealed class VehicleDescriptionAttribute : System.Attribute
{
    public string Description { get; set; }

    public VehicleDescriptionAttribute(string description)
        => Description = description;
    public VehicleDescriptionAttribute(){ }
}
```

As you can see, `VehicleDescriptionAttribute` maintains a piece of string data manipulated using an automatic property (`Description`). Beyond the fact that this class derived from `System.Attribute`, there is nothing unique to this class definition.

---

■ **Note** For security reasons, it is considered a .NET best practice to design all custom attributes as sealed. In fact, Visual Studio provides a code snippet named `Attribute` that will dump out a new `System.Attribute`-derived class into your code window. You can expand any snippet by typing its name and pressing the `Tab` key.

---

## Applying Custom Attributes

Given that `VehicleDescriptionAttribute` is derived from `System.Attribute`, you are now able to annotate your vehicles as you see fit. For testing purposes, add the following class definitions to your new class library:

```
// All classes in one file for simplicity
// Assign description using a "named property."
[Serializable]
[VehicleDescription(Description = "My rocking Harley")]
public class Motorcycle
{
}

[Serializable]
[Obsolete ("Use another vehicle!")]
[VehicleDescription("The old gray mare, she ain't what she used to be...")]
public class HorseAndBuggy
```

```

{
}

[VehicleDescription("A very long, slow, but feature-rich auto")]
public class Winnebago
{
}

```

## Named Property Syntax

Notice that the description of the `Motorcycle` is assigned a description using a new bit of attribute syntax termed a *named property*. In the constructor of the first `[VehicleDescription]` attribute, you set the underlying string data by using the `Description` property. If this attribute is reflected upon by an external agent, the value is fed into the `Description` property (named property syntax is legal only if the attribute supplies a writable .NET Core property).

In contrast, the `HorseAndBuggy` and `Winnebago` types are not using named property syntax and are simply passing the string data via the custom constructor. In any case, once you compile the `AttributedCarLibrary` assembly, you can use `ildasm.exe` to view the injected metadata descriptions for your type. For example, the following shows the embedded description of the `Winnebago` class:

```

// CustomAttribute #1 (0c000010)
// -----
//   CustomAttribute Type: 06000008
//   CustomAttributeName: AttributedCarLibrary.VehicleDescriptionAttribute :: instance void
//   .ctor(class System.String)
//   Length: 45
//   Value : 01 00 28 41 20 76 65 72 79 20 6c 6f 6e 67 2c 20 > (A very long, <
//           : 73 6c 6f 77 2c 20 62 75 74 20 66 65 61 74 75 72 >slow, but feature<
//           : 65 2d 72 69 63 68 20 61 75 74 6f 00 00 >e-rich auto <
//   ctor args: ("A very long, slow, but feature-rich auto")

```

## Restricting Attribute Usage

By default, custom attributes can be applied to just about any aspect of your code (methods, classes, properties, etc.). Thus, if it made sense to do so, you could use `VehicleDescription` to qualify methods, properties, or fields (among other things).

```

[VehicleDescription("A very long, slow, but feature-rich auto")]
public class Winnebago
{
    [VehicleDescription("My rocking CD player")]
    public void PlayMusic(bool On)
    {
        ...
    }
}

```

In some cases, this is exactly the behavior you require. Other times, however, you may want to build a custom attribute that can be applied only to select code elements. If you want to constrain the scope of a custom attribute, you will need to apply the `[AttributeUsage]` attribute on the definition of your custom

attribute. The `[AttributeUsage]` attribute allows you to supply any combination of values (via an OR operation) from the `AttributeTargets` enumeration, like so:

```
// This enumeration defines the possible targets of an attribute.
public enum AttributeTargets
{
    All, Assembly, Class, Constructor,
    Delegate, Enum, Event, Field, GenericParameter,
    Interface, Method, Module, Parameter,
    Property, ReturnValue, Struct
}
```

Furthermore, `[AttributeUsage]` also allows you to optionally set a named property (`AllowMultiple`) that specifies whether the attribute can be applied more than once on the same item (the default is `false`). As well, `[AttributeUsage]` allows you to establish whether the attribute should be inherited by derived classes using the `Inherited` named property (the default is `true`).

To establish that the `[VehicleDescription]` attribute can be applied only once on a class or structure, you can update the `VehicleDescriptionAttribute` definition as follows:

```
// This time, we are using the AttributeUsage attribute
// to annotate our custom attribute.
[AttributeUsage(AttributeTargets.Class | AttributeTargets.Struct, Inherited = false)]
public sealed class VehicleDescriptionAttribute : System.Attribute
{
    ...
}
```

With this, if a developer attempted to apply the `[VehicleDescription]` attribute on anything other than a class or structure, they are issued a compile-time error.

## Assembly-Level Attributes

It is also possible to apply attributes on all types within a given assembly using the `[assembly:]` tag. For example, assume you want to ensure that every public member of every public type defined within your assembly is CLS compliant. To do so, simply add the following assembly-level attribute at the top of any C# source code file. Be aware that all assembly- or module-level attributes must be listed outside the scope of any namespace scope! I recommend adding a new file to your project named `AssemblyAttributes.cs` (not `AssemblyInfo.cs`, since that is autogenerated) and placing your assembly-level attributes in there.

---

■ **Note** There isn't technical reason for using a separate file, it's purely for supportability of your code. Putting all of the assembly attributes in a separate file makes it very clear that your project uses assembly-level attributes and where they are.

---

If you add assembly- or module-level attributes to your project, here is one recommended file layout to follow:

```
// List "using" statements first.
using System;
using System.Collections.Generic;
```

```
using System.Linq;
using System.Text;

// Now list any assembly- or module-level attributes.
// Enforce CLS compliance for all public types in this
// assembly.
[assembly: CLSCompliant(true)]
```

If you now add a bit of code that falls outside the CLS specification (such as an exposed point of unsigned data), you will be issued a compiler warning:

```
// Ulong types don't jibe with the CLS.
public class Winnebago
{
    public ulong notCompliant;
}
```

---

■ **Note** There are two significant changes in .NET Core. The first is that the `AssemblyInfo.cs` file is now autogenerated from the project properties and is not recommended for customization. The second (and very related) change is that many of the prior assembly-level attributes (`Version`, `Company`, etc.) have been replaced with properties in the project file.

---

## Using the Project File for Assembly Attributes

As seen in Chapter 16 with the `InternalsVisibleToAttribute`, assembly attributes can also be added to the project file. There is a catch, in that only single string parameter attributes can be used this way. This is true for all of the properties that can be set on the `Package` tab in the project properties.

---

■ **Note** At the time of this writing, there is an active discussion on the MSBuild GitHub repo regarding adding capability for non-string parameters support. This would enable the `CLSCompliant` attribute to be added using the project file instead of a `*.cs` file.

---

Go ahead and set some of the properties (such as `Authors`, `Description`) by right-clicking the project in Solution Explorer, selecting `Properties`, and then clicking `Package`. Also, add the `InternalsVisibleToAttribute` as you did in Chapter 16. Your project file will now look something like this:

```
<Project Sdk="Microsoft.NET.Sdk">

  <PropertyGroup>
    <OutputType>Library</OutputType>
    <TargetFramework>netcoreapp3.1</TargetFramework>
    <Authors>Philip Japikse</Authors>
    <Description>This is a sample car library</Description>
  </PropertyGroup>
  <ItemGroup>
```

```

    <AssemblyAttribute Include="System.Runtime.CompilerServices.
InternalsVisibleToAttribute">
        <_Parameter1>CSharpCarClient</_Parameter1>
    </AssemblyAttribute>
</ItemGroup>
</Project>

```

After you compile your project, navigate to the `\obj\Debug\netcoreapp3.1` directory, and look for the `AttributedCarLibrary.AssemblyInfo.cs` file. Open that, and you will see those properties as attributes (unfortunately, not very readable in this format):

```

using System;
using System.Reflection;

[assembly: System.Runtime.CompilerServices.InternalsVisibleToAttribute("CSharpCarClient")]
[assembly: System.Reflection.AssemblyCompanyAttribute("Philip Japikse")]
[assembly: System.Reflection.AssemblyConfigurationAttribute("Debug")]
[assembly: System.Reflection.AssemblyDescriptionAttribute("This is a sample car library")]
[assembly: System.Reflection.AssemblyFileVersionAttribute("1.0.0.0")]
[assembly: System.Reflection.AssemblyInformationalVersionAttribute("1.0.0")]
[assembly: System.Reflection.AssemblyProductAttribute("AttributedCarLibrary")]
[assembly: System.Reflection.AssemblyTitleAttribute("AttributedCarLibrary")]
[assembly: System.Reflection.AssemblyVersionAttribute("1.0.0.0")]

```

As a final closing remark on assembly attributes, you can turn off the generation of the `AssemblyInfo.cs` class if you want to manage the process yourself.

## Reflecting on Attributes Using Early Binding

Remember that an attribute is quite useless until another piece of software reflects over its values. Once a given attribute has been discovered, that piece of software can take whatever course of action necessary. Now, like any application, this “other piece of software” could discover the presence of a custom attribute using either early binding or late binding. If you want to make use of early binding, you’ll require the client application to have a compile-time definition of the attribute in question (`VehicleDescriptionAttribute`, in this case). Given that the `AttributedCarLibrary` assembly has defined this custom attribute as a public class, early binding is the best option.

To illustrate the process of reflecting on custom attributes, add a new C# Console Application project named `VehicleDescriptionAttributeReader` to the solution. Next, add a reference to the `AttributedCarLibrary` project and make the new console application the startup project in Visual Studio (right-click the project in Solution Explorer, select “Set as Startup Project”). Finally, update your initial `*.cs` file with the following code:

```

using System;
using AttributedCarLibrary;

namespace VehicleDescriptionAttributeReader
{
    class Program
    {
        static void Main(string[] args)

```

```

    {
        Console.WriteLine("***** Value of VehicleDescriptionAttribute *****\n");
        ReflectOnAttributesUsingEarlyBinding();
        Console.ReadLine();
    }

    private static void ReflectOnAttributesUsingEarlyBinding()
    {
        // Get a Type representing the Winnebago.
        Type t = typeof(Winnebago);

        // Get all attributes on the Winnebago.
        object[] customAtts = t.GetCustomAttributes(false);

        // Print the description.
        foreach (VehicleDescriptionAttribute v in customAtts)
        {
            Console.WriteLine("-> {0}\n", v.Description);
        }
    }
}

```

The `Type.GetCustomAttributes()` method returns an object array that represents all the attributes applied to the member represented by the `Type` (the Boolean parameter controls whether the search should extend up the inheritance chain). Once you have obtained the list of attributes, iterate over each `VehicleDescriptionAttribute` class and print out the value obtained by the `Description` property.

## Reflecting on Attributes Using Late Binding

The previous example used early binding to print out the vehicle description data for the `Winnebago` type. This was possible because the `VehicleDescriptionAttribute` class type was defined as a public member in the `AttributedCarLibrary` assembly. It is also possible to make use of dynamic loading and late binding to reflect over attributes.

Add a new project called `VehicleDescriptionAttributeReaderLateBinding` to the solution, set it as the startup project, and copy `AttributedCarLibrary.dll` to the project's `\bin\Debug\netcoreapp3.1` directory. Now, update your `Program` class as follows:

```

using System;
using System.Reflection;

namespace VehicleDescriptionAttributeReaderLateBinding
{
    class Program
    {
        static void Main(string[] args)
        {
            Console.WriteLine("***** Value of VehicleDescriptionAttribute *****\n");
            ReflectAttributesUsingLateBinding();
            Console.ReadLine();
        }
    }
}

```

```

private static void ReflectAttributesUsingLateBinding()
{
    try
    {
        // Load the local copy of AttributedCarLibrary.
        Assembly asm =
            Assembly.LoadFrom("AttributedCarLibrary");

        // Get type info of VehicleDescriptionAttribute.
        Type vehicleDesc = asm.GetType(
            "AttributedCarLibrary.VehicleDescriptionAttribute");

        // Get type info of the Description property.
        PropertyInfo propDesc =
            vehicleDesc.GetProperty("Description");

        // Get all types in the assembly.
        Type[] types = asm.GetTypes();

        // Iterate over each type and obtain any VehicleDescriptionAttributes.
        foreach (Type t in types)
        {
            object[] objs =
                t.GetCustomAttributes(vehicleDesc, false);

            // Iterate over each VehicleDescriptionAttribute and print
            // the description using late binding.
            foreach (object o in objs)
            {
                Console.WriteLine("-> {0}: {1}\n", t.Name,
                    propDesc.GetValue(o, null));
            }
        }
    }
    catch (Exception ex)
    {
        Console.WriteLine(ex.Message);
    }
}
}

```

If you were able to follow along with the examples in this chapter, this code should be (more or less) self-explanatory. The only point of interest is the use of the `PropertyInfo.GetValue()` method, which is used to trigger the property's accessor. Here is the output of the current example:

---

```
***** Value of VehicleDescriptionAttribute *****
-> Motorcycle: My rocking Harley

-> HorseAndBuggy: The old gray mare, she ain't what she used to be...

-> Winnebago: A very long, slow, but feature-rich auto
```

---

## Putting Reflection, Late Binding, and Custom Attributes in Perspective

Even though you have seen numerous examples of these techniques in action, you may still be wondering when to make use of reflection, dynamic loading, late binding, and custom attributes in your programs. To be sure, these topics can seem a bit on the academic side of programming (which may or may not be a bad thing, depending on your point of view). To help map these topics to a real-world situation, you need a solid example. Assume for the moment that you are on a programming team that is building an application with the following requirement:

- The product must be extendable by the use of additional third-party tools.

What exactly is meant by *extendable*? Well, consider the Visual Studio IDE. When this application was developed, various “hooks” were inserted into the codebase to allow other software vendors to “snap” (or plug in) custom modules into the IDE. Obviously, the Visual Studio development team had no way to set references to external .NET assemblies it had not developed yet (thus, no early binding), so how exactly would an application provide the required hooks? Here is one possible way to solve this problem:

1. First, an extendable application must provide some input mechanism to allow the user to specify the module to plug in (such as a dialog box or command-line flag). This requires *dynamic loading*.
2. Second, an extendable application must be able to determine whether the module supports the correct functionality (such as a set of required interfaces) to be plugged into the environment. This requires *reflection*.
3. Finally, an extendable application must obtain a reference to the required infrastructure (such as a set of interface types) and invoke the members to trigger the underlying functionality. This may require *late binding*.

Simply put, if the extendable application has been preprogrammed to query for specific interfaces, it is able to determine at runtime whether the type can be activated. Once this verification test has been passed, the type in question may support additional interfaces that provide a polymorphic fabric to their functionality. This is the exact approach taken by the Visual Studio team and, despite what you might be thinking, is not at all difficult!



## Building an Extendable Application

In the sections that follow, I will take you through an example that illustrates the process of building an application that can be augmented by the functionality of external assemblies. To serve as a road map, the extendable application entails the following assemblies:

- `CommonSnappableTypes.dll`: This assembly contains type definitions that will be used by each snap-in object and will be directly referenced by the Windows Forms application.
- `CSharpSnapIn.dll`: A snap-in written in C#, which leverages the types of `CommonSnappableTypes.dll`.
- `VbSnapIn.dll`: A snap-in written in Visual Basic, which leverages the types of `CommonSnappableTypes.dll`.
- `MyExtendableApp.exe`: A console application that may be extended by the functionality of each snap-in.

This application will use dynamic loading, reflection, and late binding to dynamically gain the functionality of assemblies it has no prior knowledge of.

---

■ **Note** You might be thinking to yourself, “My boss has never asked me to build a console application,” and you are probably correct! The overwhelming majority of user-facing applications built with C# are either smart client (WinForms or WPF) or Web (ASP.NET Core). We are using console applications to allow you, the reader, to focus on the specific concepts of the example, in this case dynamic loading, reflection, and late binding. Later in this book, you will explore “real” user-facing applications using WPF and ASP.NET Core.

---

## Building the Multiproject ExtendableApp Solution

Up to this point in this book, most of the applications have been stand-alone projects, with a few exceptions (like the previous one). This was done to keep the examples simple and focused. However, in real-world development, more often than not, you will be working with multiple projects together. Recall that, by default, Visual Studio names the solution the same as the first project created in that solution. However, you can easily change the name of the solution as shown in Figure 17-2.

To create the `ExtendableApp` solution, start by selecting **File** ► **New Project** to load the New Project dialog. Select **Class Library**, and enter the name **CommonSnappableTypes**. Before you click OK, enter the solution name **ExtendableApp**, as shown in Figure 17-2.

**Configure your new project**

Class Library (.NET Core) C# Windows Linux macOS Library

Project name: CommonSnappableTypes

Location: C:\GitHub\Books\csharp8-wf\Code\Chapter\_17

Solution: Create new solution

Solution name: ExtendableApp

☐ Place solution and project in the same directory

Back Create

**Figure 17-2.** Creating the *CommonSnappableTypes* project and the *ExtendableApp* solution

Throughout the rest of this example, you will add the additional projects into the *ExtendableApp* solution.

As a reminder, you can do the exact same process through the .NET Core Command Line Interface:

```
dotnet new sln -n ExtendableApp
dotnet new classlib -n CommonSnappableTypes -f netcoreapp3.1
dotnet sln add CommonSnappableTypes
```

## Building CommonSnappableTypes.dll

Delete the default *Class1.cs* file and add a new interface file named *IAppFunctionality.cs* and update it to the following:

```
namespace CommonSnappableTypes
{
    public interface IAppFunctionality
    {
        void DoIt();
    }
}
```

Add a class file named `CompanyInfoAttribute.cs` and update it to the following:

```
namespace CommonSnappableTypes
{
    [AttributeUsage(AttributeTargets.Class)]
    public sealed class CompanyInfoAttribute : System.Attribute
    {
        public string CompanyName { get; set; }
        public string CompanyUrl { get; set; }
    }
}
```

The `IAppFunctionality` interface provides a polymorphic interface for all snap-ins that can be consumed by the extendable application. Given that this example is purely illustrative, you supply a single method named `DoIt()`.

The `CompanyInfoAttribute` type is a custom attribute that can be applied on any class type that wants to be snapped into the container. As you can tell by the definition of this class, `[CompanyInfo]` allows the developer of the snap-in to provide some basic details about the component's point of origin.

## Adding Projects to the Solution

Next up, you need to create a type that implements the `IAppFunctionality` interface. To add another project into the solution, right-click the `ExtendableApp` name in Solution Explorer (or click **File** ► **Add** ► **New Project**) and select **Add** ► **New Project**. When adding another project into an existing solution, the **Add New Project** dialog box is a little different now; as you can see, the solution options are no longer there, just the project information (name and location). Name the Class Library project `CSharpSnapIn` and click **Create**.

Next, add a reference to the `CommandSnappableTypes` project from the `CSharpSnapIn` project. To do this in Visual Studio, right-click the `CSharpSnapin` project and select **Add** ► **Project Reference**. In the **Reference Manager** dialog, select **Projects** ► **Solution** from the left (if not already selected) and check the box next to `CommonSnappableTypes`.

To do the same thing from the command line, enter the following commands:

```
dotnet new classlib -n CSharpSnapin -f netcoreapp3.1
dotnet sln add CSharpSnapin
dotnet add CSharpSnapin reference CommonSnappableTypes
```

## Building the C# Snap-In

Now that you have the reference in place, delete the `Class1.cs` file in the project, add a new file named `CSharpModule.cs`, and update the code to match the following (make sure to add the `using` statement for `CommonSnappableTypes`):

```
using System;
using CommonSnappableTypes;

namespace CSharpSnapIn
{
    [CompanyInfo(CompanyName = "FooBar", CompanyUrl = "www.FooBar.com")]
    public class CSharpModule : IAppFunctionality
```

```

{
    void IAppFunctionality.DoIt()
    {
        Console.WriteLine("You have just used the C# snap-in!");
    }
}
}

```

Notice that I chose to make use of explicit interface implementation (see Chapter 8) when supporting the `IAppFunctionality` interface. This is not required; however, the idea is that the only part of the system that needs to directly interact with this interface type is the hosting application. By explicitly implementing this interface, the `DoIt()` method is not directly exposed from the `CSharpModule` type.

## Building the Visual Basic Snap-In

Now, to simulate the role of a third-party vendor that prefers Visual Basic over C#, add a new Visual Basic class library (`VbSnapIn`) that references the `CommonSnappableTypes` project, just like the previous `CSharpSnapIn` project.

From the .NET Core CLI, you can also specify language type (C# is the default):

```

dotnet new classlib -n VBSnapin -lang vb -f netcoreapp3.1
dotnet sln add VBSnapIn
dotnet add VBSnapin reference CommonSnappableTypes

```

Delete the `Class1.vb` file and add a new one named `VbModule.vb`. The code is (again) intentionally simple.

```

Imports CommonSnappableTypes

<CompanyInfo(CompanyName:="Chucky's Software", CompanyUrl:="www.ChuckySoft.com")>
Public Class VbSnapIn
    Implements IAppFunctionality

    Public Sub DoIt() Implements CommonSnappableTypes.IAppFunctionality.DoIt
        Console.WriteLine("You have just used the VB snap in!")
    End Sub
End Class

```

Notice that applying attributes in the syntax of Visual Basic requires angle brackets (`< >`) rather than square brackets (`[ ]`). Also notice that the `Implements` keyword is used to implement interface types on a given class or structure.

## Create the Console Application

The final project to add is a new C# console application (`MyExtendableApp`). When there is more than one project in a solution, Visual Studio needs to be informed about which project (or projects; multiproject starts will be covered later in this book) should be run when you click Run. By default, it's the first project added to your solution. You need the `MyExtendableApp` project to be first. Setting the startup project is simple. Right-click the `MyExtendableApp` project in Solution Explorer and select `Set as StartUp Project`.

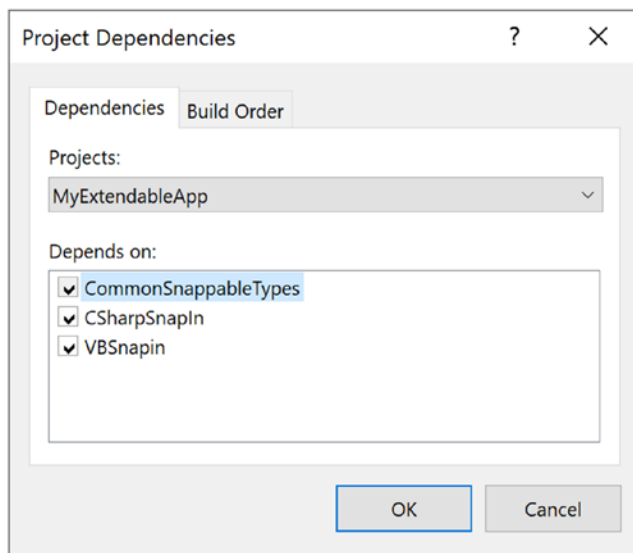
■ **Note** If you right-click the `ExtendableApp` solution instead of one of the projects, the context menu option displayed is `Set StartUp Projects`. In addition to having just one project execute when you click `Run`, you can set up multiple projects to execute. This will be demonstrated in later chapters.

After adding the `MyExtendableApp` console application to the solution and setting it as the startup project, add a reference to the `CommonSnappableTypes` project but *not* the `CSharpSnapIn.dll` or `VbSnapIn.dll` project.

## Setting Project Build Dependencies

When Visual Studio is given the command to run a solution, the startup projects and all referenced projects are built if any changes are detected; however, any unreferenced projects are *not* built. This can be changed by setting project dependencies. To do this, right-click the solution in Solution Explorer, select “Project Build Order...”, and, in the resulting dialog, select the `Dependencies` tab and change the `Project` to `MyExtendableApp`.

Notice that the `CommonSnappableTypes` project is already selected and the check box is disabled. This is because it is referenced directly. Select the `CSharpSnapIn` and `VbSnapIn` project check boxes as well, as shown in Figure 17-3.



**Figure 17-3.** Accessing the Project Build Order context menu

Now, each time the `MyExtendableApp` project is built, the `CSharpSnapIn` and `VbSnapIn` projects build as well.

## Adding PostBuild Events

When projects are built (either from Visual Studio or the command line), there are events that can be hooked into. For example, we want to copy the two snap-in assemblies into the console app target directory after every successful build.

To do this, we are going to take advantage of several built-in macros. Open the project properties for the CSharpSnapin (right-click Solution Explorer, select Properties) and navigate to the Build Events page.

Click the Edit Post-build button, and then click Macros>>. Here are several macros that are path related. The advantage of using these macros is that they are machine independent. For example, I am working in a directory call c-sharp-wf\code\chapter17. You might be (and probably are) using a different directory. By using the macros, MSBuild will always use the correct path relative to the \*.csproj files.

In the PostBuild box, enter (all on one line)

```
copy $(TargetPath) $(SolutionDir)MyExtendableApp\$(OutDir)$(TargetFileName) /Y
```

Now, edit the CSharpSnapIn Project file by double-clicking the project in Solution Explorer. Notice the new Target element that comes straight from the property page. Copy that element, and edit the VbSnapIn project file. Paste the contents in

```
<Target Name="PostBuild" AfterTargets="PostBuildEvent">
  <Exec Command="copy $(TargetPath) $(SolutionDir)MyExtendableApp\$(OutDir)$(TargetFileName)
/Y" />
</Target>
```

Now when the VB project is built, it will copy its assembly into the MyExtendableApp's target directory as well.

## Adding the Code for the ExtendableApp

Begin by updating the using statements at the top of the Program.cs class to the following:

```
using System;
using System.Linq;
using System.Reflection;
using CommonSnappableTypes;
```

The LoadExternalModule() method performs the following tasks:

- Dynamically loads the selected assembly into memory
- Determines whether the assembly contains any types implementing IAppFunctionality
- Creates the type using late binding

If a type implementing IAppFunctionality is found, the DoIt() method is called and then sent to the DisplayCompanyData() method to output additional information from the reflected type.

```
private static void LoadExternalModule(string assemblyName)
{
    Assembly theSnapInAsm = null;
    try
    {
```

```

        // Dynamically load the selected assembly.
        theSnapInAsm = Assembly.LoadFrom(assemblyName);
    }
    catch (Exception ex)
    {
        Console.WriteLine($"An error occurred loading the snapin: {ex.Message}");
        return;
    }

    // Get all IAppFunctionality compatible classes in assembly.
    var theClassTypes = theSnapInAsm
        .GetTypes()
        .Where(t => t.IsClass && (t.GetInterface("IAppFunctionality") != null))
        .ToList();
    if (!theClassTypes.Any())
    {
        Console.WriteLine("Nothing implements IAppFunctionality!");
    }

    // Now, create the object and call DoIt() method.
    foreach (Type t in theClassTypes)
    {
        // Use late binding to create the type.
        IAppFunctionality itfApp = (IAppFunctionality) theSnapInAsm.CreateInstance(t.FullName,
            true);
        itfApp?.DoIt();
        // Show company info.
        DisplayCompanyData(t);
    }
}

```

The final task is to display the metadata provided by the [CompanyInfo] attribute. Create the `DisplayCompanyData()` method as follows. Notice this method takes a single `System.Type` parameter.

```

private static void DisplayCompanyData(Type t)
{
    // Get [CompanyInfo] data.
    var compInfo = t
        .GetCustomAttributes(false)
        .Where(ci => (ci is CompanyInfoAttribute));
    // Show data.
    foreach (CompanyInfoAttribute c in compInfo)
    {
        Console.WriteLine($"More info about {c.CompanyName} can be found at {c.CompanyUrl}");
    }
}

```

Finally, update the `Main()` method to the following:

```

static void Main(string[] args)
{
    Console.WriteLine("***** Welcome to MyTypeViewer *****");
    string typeName = "";
}

```

```

do
{
    Console.WriteLine("\nEnter a snapin to load");
    Console.Write("or enter Q to quit: ");

    // Get name of type.
    typeName = Console.ReadLine();

    // Does user want to quit?
    if (typeName.Equals("Q", StringComparison.OrdinalIgnoreCase))
    {
        break;
    }
    // Try to display type.
    try
    {
        LoadExternalModule(typeName);
    }
    catch (Exception ex)
    {
        Console.WriteLine("Sorry, can't find snapin");
    }
}
while (true);
}

```

Excellent! That wraps up the example application. I hope you can see that the topics presented in this chapter can be quite helpful in the real world and are not limited to the tool builders of the world.

---

■ **Note** Previous editions of this book used a Windows Forms–based example here. With the move to .NET Core, I replaced it with a console app to keep the cross-platform functionality of this sample. Windows Forms and WPF, both included with .NET Core 3.0 and above, are still Windows only and not cross-platform.

---

## Summary

Reflection is an interesting aspect of a robust OO environment. In the world of .NET Core, the keys to reflection services revolve around the `System.Type` class and the `System.Reflection` namespace. As you have seen, reflection is the process of placing a type under the magnifying glass at runtime to understand the who, what, where, when, why, and how of a given item.

Late binding is the process of creating an instance of a type and invoking its members without prior knowledge of the specific names of said members. Late binding is often a direct result of *dynamic loading*, which allows you to load a .NET Core assembly into memory programmatically. As shown during this chapter's extendable application example, this is a powerful technique used by tool builders as well as tool consumers.

This chapter also examined the role of attribute-based programming. When you adorn your types with attributes, the result is the augmentation of the underlying assembly metadata.



## CHAPTER 18



# Dynamic Types and the Dynamic Language Runtime

NET 4.0 introduced a new keyword to the C# language, specifically, `dynamic`. This keyword allows you to incorporate scripting-like behaviors into the strongly typed world of type safety, semicolons, and curly brackets. Using this loose typing, you can greatly simplify some complex coding tasks and also gain the ability to interoperate with a number of dynamic languages which are .NET Core savvy.

In this chapter, you will be introduced to the C# `dynamic` keyword and understand how loosely typed calls are mapped to the correct in-memory object using the Dynamic Language Runtime (DLR). After you understand the services provided by the DLR, you will see examples of using dynamic types to streamline how you can perform late-bound method calls (via reflection services) and to easily communicate with legacy COM libraries.

---

**Note** Don't confuse the C# `dynamic` keyword with the concept of a *dynamic assembly* (see Chapter 19). While you could use the `dynamic` keyword when building a dynamic assembly, these are ultimately two independent concepts.

---

## The Role of the C# `dynamic` Keyword

In Chapter 3, you learned about the `var` keyword, which allows you to define local variables in such a way that the underlying datatype is determined at compile time, based on the initial assignment (recall that this is termed *implicit typing*). Once this initial assignment has been made, you have a strongly typed variable, and any attempt to assign an incompatible value will result in a compiler error.

To begin your investigation into the C# `dynamic` keyword, create a new Console Application project named `DynamicKeyword`. Now, author the following method in your `Program` class, and verify that the final code statement will indeed trigger a compile-time error if uncommented:

```
static void ImplicitlyTypedVariable()
{
    // a is of type List<int>.
    var a = new List<int> {90};
    // This would be a compile-time error!
    // a = "Hello";
}
```

Using implicit typing simply for the sake of doing so is considered by some to be bad style (if you know you need a `List<int>`, just declare a `List<int>`). However, as you saw in Chapter 13, implicit typing is useful with LINQ, as many LINQ queries return enumerations of anonymous classes (via projections) that you cannot directly declare in your C# code. However, even in such cases, the implicitly typed variable is, in fact, strongly typed.

On a related note, as you learned in Chapter 6, `System.Object` is the topmost parent class in the .NET Core Framework and can represent anything at all. Again, if you declare a variable of type `object`, you have a strongly typed piece of data; however, what it points to in memory can differ based on your assignment of the reference. To gain access to the members the object reference is pointing to in memory, you need to perform an explicit cast.

Assume you have a simple class named `Person` that defines two automatic properties (`FirstName` and `LastName`) both encapsulating a `string`. Now, observe the following code:

```
static void UseObjectVariable()
{
    // Assume we have a class named Person.
    object o = new Person() { FirstName = "Mike", LastName = "Larson" };

    // Must cast object as Person to gain access
    // to the Person properties.
    Console.WriteLine("Person's first name is {0}", ((Person)o).FirstName);
}
```

Now, back to the `dynamic` keyword. From a high level, you can consider the `dynamic` keyword a specialized form of `System.Object`, in that any value can be assigned to a `dynamic` data type. At first glance, this can appear horribly confusing, as it appears you now have three ways to define data whose underlying type is not directly indicated in your codebase. For example, this method

```
static void PrintThreeStrings()
{
    var s1 = "Greetings";
    object s2 = "From";
    dynamic s3 = "Minneapolis";

    Console.WriteLine("s1 is of type: {0}", s1.GetType());
    Console.WriteLine("s2 is of type: {0}", s2.GetType());
    Console.WriteLine("s3 is of type: {0}", s3.GetType());
}
```

would print out the following if invoked from `Main()`:

---

```
s1 is of type: System.String
s2 is of type: System.String
s3 is of type: System.String
```

---

What makes a `dynamic` variable vastly different from a variable declared implicitly or via a `System.Object` reference is that it is *not strongly typed*. Said another way, `dynamic` data is not *statically typed*. As far as the C# compiler is concerned, a data point declared with the `dynamic` keyword can be assigned any initial value at all and can be reassigned to any new (and possibly unrelated) value during its lifetime. Consider the following method and the resulting output:

```
static void ChangeDynamicDataType()
{
    // Declare a single dynamic data point
    // named "t".
    dynamic t = "Hello!";
    Console.WriteLine("t is of type: {0}", t.GetType());

    t = false;
    Console.WriteLine("t is of type: {0}", t.GetType());

    t = new List<int>();
    Console.WriteLine("t is of type: {0}", t.GetType());
}
```

---

```
t is of type: System.String
t is of type: System.Boolean
t is of type: System.Collections.Generic.List`1[System.Int32]
```

---

At this point in your investigation, do be aware that the previous code would compile and execute identically if you were to declare the `t` variable as a `System.Object`. However, as you will soon see, the `dynamic` keyword offers many additional features.

## Calling Members on Dynamically Declared Data

Given that a dynamic variable can take on the identity of any type on the fly (just like a variable of type `System.Object`), the next question on your mind might be about calling members on the dynamic variable (properties, methods, indexers, register with events, etc.). Well, syntactically speaking, it will again look no different. Just apply the dot operator to the dynamic data variable, specify a public member, and supply any arguments (if required).

However (and this is a very big “however”), the validity of the members you specify will not be checked by the compiler! Remember, unlike a variable defined as a `System.Object`, dynamic data is not statically typed. It is not until runtime that you will know whether the dynamic data you invoked supports a specified member, whether you passed in the correct parameters, whether you spelled the member correctly, and so on. Thus, as strange as it might seem, the following method compiles perfectly:

```
static void InvokeMembersOnDynamicData()
{
    dynamic textData1 = "Hello";
    Console.WriteLine(textData1.ToUpper());

    // You would expect compiler errors here!
    // But they compile just fine.
    Console.WriteLine(textData1.toupper());
    Console.WriteLine(textData1.Foo(10, "ee", DateTime.Now));
}
```

Notice the second call to `WriteLine()` attempts to call a method named `toupper()` on the dynamic data point (note the incorrect casing – it should be `ToUpper()`). As you can see, `textData1` is of type `string`, and therefore, you know it does not have a method of this name in all lowercase letters. Furthermore, `string` certainly does not have a method named `Foo()` that takes an `int`, `string`, and `DateTime` object!

Nevertheless, the C# compiler is satisfied. However, if you invoke this method from within `Main()`, you will get runtime errors similar to the following output:

---

```
Unhandled Exception: Microsoft.CSharp.RuntimeBinder.RuntimeBinderException:
'string' does not contain a definition for 'toupper'
```

---

Another obvious distinction between calling members on dynamic data and strongly typed data is that when you apply the dot operator to a piece of dynamic data, you will *not* see the expected Visual Studio IntelliSense. The IDE will allow you to enter any member name you could dream up.

It should make sense that IntelliSense is not possible with dynamic data. However, remember that this means you need to be extremely careful when you are typing C# code on such data points. Any misspelling or incorrect capitalization of a member will throw a runtime error, specifically an instance of the `RuntimeBinderException` class.

The `RuntimeBinderException` represents an error that will be thrown if you attempt to invoke a member on a dynamic data type which does not actually exist (as in the case of the `toupper()` and `Foo()` methods). This same error will be raised if you specify the wrong parameter data to a member that does exist.

Because dynamic data is so volatile, whenever you are invoking members on a variable declared with the C# dynamic keyword, you could wrap the calls within a proper try/catch block and handle the error in a graceful manner, like so:

```
static void InvokeMembersOnDynamicData()
{
    dynamic testData1 = "Hello";

    try
    {
        Console.WriteLine(textData1.ToUpper());
        Console.WriteLine(textData1.toupper());
        Console.WriteLine(textData1.Foo(10, "ee", DateTime.Now));
    }
    catch (Microsoft.CSharp.RuntimeBinder.RuntimeBinderException ex)
    {
        Console.WriteLine(ex.Message);
    }
}
```

If you call this method again, you will find the call to `ToUpper()` (note the capital *T* and *U*) works correctly; however, you then find the error data displayed to the console.

---

```
HELLO
'string' does not contain a definition for 'toupper'
```

---

Of course, the process of wrapping all dynamic method invocations in a try/catch block is rather tedious. As long as you watch your spelling and parameter passing, this is not required. However, catching exceptions is handy when you might not know in advance if a member will be present on the target type.

## The Scope of the dynamic Keyword

Recall that implicitly typed data (declared with the `var` keyword) is possible only for local variables in a member scope. The `var` keyword can never be used as a return value, a parameter, or a member of a class/structure. This is not the case with the `dynamic` keyword, however. Consider the following class definition:

```
class VeryDynamicClass
{
    // A dynamic field.
    private static dynamic _myDynamicField;

    // A dynamic property.
    public dynamic DynamicProperty { get; set; }

    // A dynamic return type and a dynamic parameter type.
    public dynamic DynamicMethod(dynamic dynamicParam)
    {
        // A dynamic local variable.
        dynamic dynamicLocalVar = "Local variable";

        int myInt = 10;

        if (dynamicParam is int)
        {
            return dynamicLocalVar;
        }
        else
        {
            return myInt;
        }
    }
}
```

You could now invoke the public members as expected; however, as you are operating on dynamic methods and properties, you cannot be completely sure what the data type will be! To be sure, the `VeryDynamicClass` definition might not be useful in a real-world application, but it does illustrate the scope of where you can apply this C# keyword.

## Limitations of the dynamic Keyword

While a great many things can be defined using the `dynamic` keyword, there are some limitations regarding its usage. While they are not showstoppers, do know that a dynamic data item cannot make use of lambda expressions or C# anonymous methods when calling a method. For example, the following code will always result in errors, even if the target method does indeed take a delegate parameter that takes a string value and returns void:

```
dynamic a = GetDynamicObject();

// Error! Methods on dynamic data can't use lambdas!
a.Method(arg => Console.WriteLine(arg));
```

To circumvent this restriction, you will need to work with the underlying delegate directly, using the techniques described in Chapter 12. Another limitation is that a dynamic point of data cannot understand any extension methods (see Chapter 11). Unfortunately, this would also include any of the extension methods that come from the LINQ APIs. Therefore, a variable declared with the `dynamic` keyword has limited use within LINQ to Objects and other LINQ technologies.

```
dynamic a = GetDynamicObject();

// Error! Dynamic data can't find the Select() extension method!
var data = from d in a select d;
```

## Practical Uses of the `dynamic` Keyword

Given that dynamic data is not strongly typed, not checked at compile time, has no ability to trigger IntelliSense, and cannot be the target of a LINQ query, you are absolutely correct to assume that using the `dynamic` keyword just for the sake of doing so is a poor programming practice.

However, in a few circumstances, the `dynamic` keyword can radically reduce the amount of code you need to author by hand. Specifically, if you are building a .NET Core application that makes heavy use of late binding (via reflection), the `dynamic` keyword can save you typing time. As well, if you are building a .NET Core application that needs to communicate with legacy COM libraries (such as Microsoft Office products), you can greatly simplify your codebase via the `dynamic` keyword. By way of a final example, web applications built using ASP.NET Core frequently use the `ViewBag` type, which can also be accessed in a simplified manner using the `dynamic` keyword.

---

■ **Note** COM interaction is strictly a Windows paradigm and removes the cross-platform capabilities of your application.

---

Like any “shortcut,” you need to weigh the pros and cons. The use of the `dynamic` keyword is a trade-off between brevity of code and type safety. While C# is a strongly typed language at its core, you can opt in (or opt out) of dynamic behaviors on a call-by-call basis. Always remember that you never need to use the `dynamic` keyword. You could always get to the same end result by authoring alternative code by hand (and typically much more of it).

## The Role of the Dynamic Language Runtime

Now that you better understand what “dynamic data” is all about, let’s learn how it is processed. Since the release of .NET 4.0, the Common Language Runtime (CLR) was supplemented with a complementary runtime environment named the Dynamic Language Runtime. The concept of a “dynamic runtime” is certainly not new. In fact, many programming languages such as JavaScript, LISP, Ruby, and Python have used it for years. In a nutshell, a dynamic runtime allows a dynamic language the ability to discover types completely at runtime with no compile-time checks.

---

■ **Note** While a lot of the DLR was ported to .NET Core (starting with 3.0), feature parity between the DLR in .NET Core 3.1 and .NET 4.8 hasn’t been achieved. Many new features are expected to come to the DLR in .NET Core 5, also known as .NET 5.

---

If you have a background in strongly typed languages (including C#, without dynamic types), the notion of such a runtime might seem undesirable. After all, you typically want to receive compile-time errors, not runtime errors, wherever possible. Nevertheless, dynamic languages/runtimes do provide some interesting features, including the following:

- An extremely flexible codebase. You can refactor code without making numerous changes to data types.
- A simple way to interoperate with diverse object types built in different platforms and programming languages.
- A way to add or remove members to a type, in memory, at runtime.

One role of the DLR is to enable various dynamic languages to run with the .NET runtime and give them a way to interoperate with other .NET code. These languages live in a dynamic universe, where type is discovered solely at runtime. And yet, these languages have access to the richness of the .NET base class libraries. Even better, their codebases can interoperate with C# (or vice versa), thanks to the inclusion of the `dynamic` keyword.

---

■ **Note** This chapter will not address how the DLR can be used to integrate with dynamic languages.

---

## The Role of Expression Trees

The DLR makes use of *expression trees* to capture the meaning of a dynamic call in neutral terms. For example, take the following C# code:

```
dynamic d = GetSomeData();
d.SuperMethod(12);
```

In this example, the DLR will automatically build an expression tree that says, in effect, “Call the method named `SuperMethod` on object `d`, passing in the number 12 as an argument.” This information (formally termed the *payload*) is then passed to the correct runtime binder, which again could be the C# dynamic binder or even (as explained shortly) legacy COM objects.

From here, the request is mapped into the required call structure for the target object. The nice thing about these expression trees (beyond that you don’t need to manually create them) is that this allows you to write a fixed C# code statement and not worry about what the underlying target actually is.

## Dynamic Runtime Lookup of Expression Trees

As explained, the DLR will pass the expression trees to a target object; however, this dispatching will be influenced by a few factors. If the dynamic data type is pointing in memory to a COM object, the expression tree is sent to a low-level COM interface named `IDispatch`. As you might know, this interface was COM’s way of incorporating its own set of dynamic services. COM objects, however, can be used in a .NET application without the use of the DLR or C# `dynamic` keyword. Doing so, however (as you will see), tends to result in much more complex C# coding.

If the dynamic data is not pointing to a COM object, the expression tree may be passed to an object implementing the `IDynamicObject` interface. This interface is used behind the scenes to allow a language, such as IronRuby, to take a DLR expression tree and map it to Ruby specifics.

Finally, if the dynamic data is pointing to an object that is *not* a COM object and does *not* implement `IDynamicObject`, the object is a normal, everyday .NET object. In this case, the expression tree is dispatched to the C# runtime binder for processing. The process of mapping the expression tree to .NET specifics involves reflection services.

After the expression tree has been processed by a given binder, the dynamic data will be resolved to the real in-memory data type, after which the correct method is called with any necessary parameters. Now, let's see a few practical uses of the DLR, beginning with the simplification of late-bound .NET calls.

## Simplifying Late-Bound Calls Using Dynamic Types

One instance where you might decide to use the `dynamic` keyword is when you are working with reflection services, specifically when making late-bound method calls. In Chapter 17, you saw a few examples of when this type of method call can be useful, most commonly when you are building some type of extensible application. At that time, you learned how to use the `Activator.CreateInstance()` method to create an object, for which you have no compile-time knowledge of (beyond its display name). You can then make use of the types of the `System.Reflection` namespace to invoke members via late binding. Recall the following example from Chapter 17:

```
static void CreateUsingLateBinding(Assembly asm)
{
    try
    {
        // Get metadata for the Minivan type.
        Type miniVan = asm.GetType("CarLibrary.Minivan");

        // Create the Minivan on the fly.
        object obj = Activator.CreateInstance(miniVan);

        // Get info for TurboBoost.
        MethodInfo mi = miniVan.GetMethod("TurboBoost");

        // Invoke method ("null" for no parameters).
        mi.Invoke(obj, null);
    }
    catch (Exception ex)
    {
        Console.WriteLine(ex.Message);
    }
}
```

While this code works as expected, you might agree it is a bit clunky. You have to manually make use of the `MethodInfo` class, manually query the metadata, and so forth. The following is a version of this same method, now using the C# `dynamic` keyword and the DLR:

```
static void InvokeMethodWithDynamicKeyword(Assembly asm)
{
    try
    {
        // Get metadata for the Minivan type.
        Type miniVan = asm.GetType("CarLibrary.Minivan");
```



```

// Create the Minivan on the fly and call method!
dynamic obj = Activator.CreateInstance(miniVan);
obj.TurboBoost();
}
catch (Exception ex)
{
    Console.WriteLine(ex.Message);
}
}

```

By declaring the `obj` variable using the `dynamic` keyword, the heavy lifting of reflection is done on your behalf, courtesy of the DRL.

## Leveraging the dynamic Keyword to Pass Arguments

The usefulness of the DLR becomes even more obvious when you need to make late-bound calls on methods that take parameters. When you use “longhand” reflection calls, arguments need to be packaged up as an array of objects, which are passed to the `Invoke()` method of `MethodInfo`.

To illustrate using a fresh example, begin by creating a new C# Console Application project named `LateBindingWithDynamic`. Next, add a Class Library project to the current solution (using the File ► Add ► New Project menu option) named `MathLibrary` (make sure `LateBindingWithDynamic` is still the StartUp project). Rename the initial `Class1.cs` file of the `MathLibrary` project to `SimpleMath.cs`, and implement the class like so:

```

public class SimpleMath
{
    public int Add(int x, int y)
    {
        return x + y;
    }
}

```

Update the `MathLibrary.csproj` file with the following (to copy the compiled assembly to the `LateBindingWithDynamic` target directory):

```

<Target Name="PostBuild" AfterTargets="PostBuildEvent">
    <Exec Command="copy $(TargetPath) $(SolutionDir)LateBindingWithDynamic\$(OutDir)$(TargetFileName) /Y" />
</Target>

```

---

■ **Note** If this project item is new to you, review this technique in Chapter 17 for full details.

---

Now, import the `System.Reflection` and `Microsoft.CSharp.RuntimeBinder` namespaces into the `Program.cs` file of your Console Application project. Next, add the following method to the `Program` class, which invokes the `Add()` method using typical reflection API calls:

```

private static void AddWithReflection()
{
    Assembly asm = Assembly.LoadFrom("MathLibrary");
    try

```

```

{
    // Get metadata for the SimpleMath type.
    Type math = asm.GetType("MathLibrary.SimpleMath");

    // Create a SimpleMath on the fly.
    object obj = Activator.CreateInstance(math);

    // Get info for Add.
    MethodInfo mi = math.GetMethod("Add");

    // Invoke method (with parameters).
    object[] args = { 10, 70 };
    Console.WriteLine("Result is: {0}", mi.Invoke(obj, args));
}
catch (Exception ex)
{
    Console.WriteLine(ex.Message);
}
}

```

Now, consider the simplification of the previous logic with the `dynamic` keyword, via the following new method:

```

private static void AddWithDynamic()
{
    Assembly asm = Assembly.LoadFrom("MathLibrary");

    try
    {
        // Get metadata for the SimpleMath type.
        Type math = asm.GetType("MathLibrary.SimpleMath");

        // Create a SimpleMath on the fly.
        dynamic obj = Activator.CreateInstance(math);

        // Note how easily we can now call Add().
        Console.WriteLine("Result is: {0}", obj.Add(10, 70));
    }
    catch (RuntimeBinderException ex)
    {
        Console.WriteLine(ex.Message);
    }
}

```

Not too shabby! If you call both methods from the `Main()` method, you'll see identical output. However, when using the `dynamic` keyword, you saved yourself quite a bit of work. With dynamically defined data, you no longer need to manually package up arguments as an array of objects, query the assembly metadata, or other such details. If you are building an application that makes heavy use of dynamic loading/late binding, I am sure you can see how these code savings would add up over time.

## Simplifying COM Interoperability Using Dynamic Data (Windows Only)

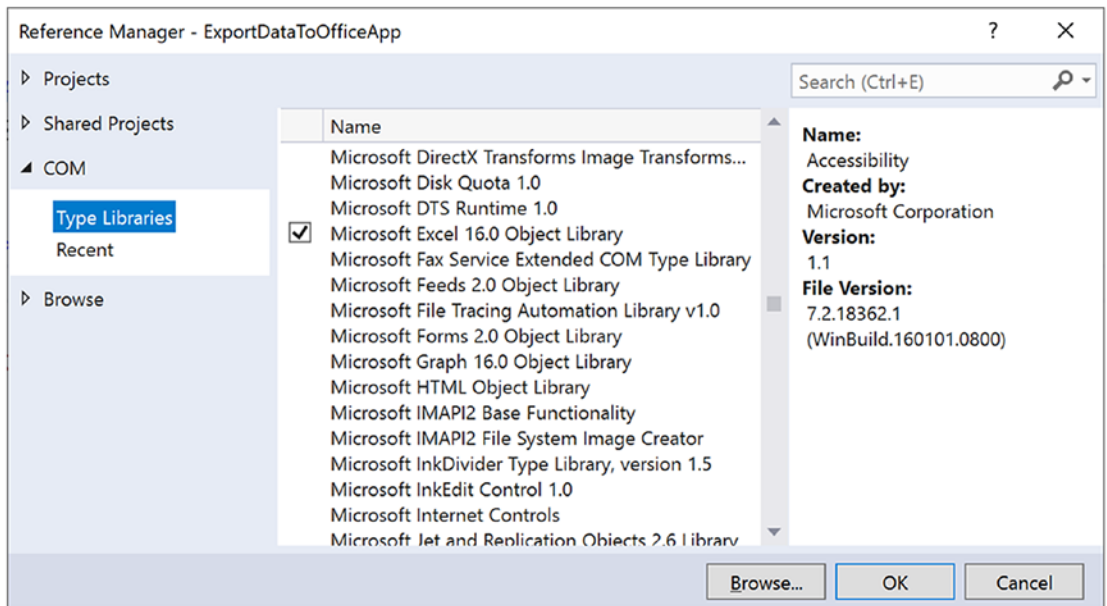
Let's see another useful case for the `dynamic` keyword within the context of a COM interoperability project. Now, if you don't have much background in COM development, do be aware for this next example that a compiled COM library contains metadata, just like a .NET Core library; however, the format is completely different. Because of this, if a .NET Core program needs to communicate with a COM object, the first order of business is to generate what is known as an *interop assembly* (described in the following paragraphs). Doing so is quite straightforward.

---

■ **Note** If you did not install the Visual Studio Tools for Office (VSTO) individual component or “Office/SharePoint development” workload, you will need to do so to complete this section. You can rerun the installer to select the missing component, or you can use the Visual Studio Quick Launch (Ctrl+Q). Type **Visual Studio Tools for Office** in the Quick Launch, and select the Install option.

---

First, create a new console application named `ExportDataToOfficeApp`, activate the Add COM Reference dialog box, select the COM tab, and find the COM library you want to use (see Figure 18-1).



**Figure 18-1.** The COM tab of the Add Reference dialog box will show you all registered COM libraries on your machine

---

■ **Note** Be aware that several important Microsoft object models (including Office products) are currently accessible only through COM interoperability. Thus, even if you do not have direct experience building COM applications, you might need to consume them from a .NET Core program.

---

Once you select a COM library, the IDE will respond by generating a new assembly that contains .NET descriptions of COM metadata. Formally speaking, these are termed *interoperability assemblies* (or simply, *interop assemblies*). Interop assemblies do not contain any implementation code, except for a small amount that helps translate COM events to .NET Core events. However, these interop assemblies are useful, in that they shield your .NET Core codebase from the complex underbelly of COM internals.

In your C# code, you can directly program against the interop assembly, which maps .NET Core data types into COM types and vice versa. Behind the scenes, data is marshaled between the .NET Core and COM applications using a Runtime Callable Wrapper (RCW), which is basically a dynamically generated proxy. This RCW proxy will marshal and transform .NET Core data types into COM types and map any COM return values into .NET Core equivalents.

## The Role of Primary Interop Assemblies

Many COM libraries created by COM library vendors (such as the Microsoft COM libraries that allow access to the object model of Microsoft Office products) provide an “official” interoperability assembly termed a *primary interop assembly* (PIA). PIAs are optimized interop assemblies, which clean up (and possibly extend) the code typically generated when referencing a COM library using the Add Reference dialog box.

Examine the project in Solution Explorer after making the reference to the Microsoft Excel 16.0 Object Library. Under the Dependencies node, you will see a new node (COM) with an item named Interop.Microsoft.Office.Interop.Excel. This is the generated interop file.

## Embedding Interop Metadata

Before the release of .NET 4.0, when a C# application made use of a COM library (PIA or not), you needed to ensure the client machine had a copy of the interop assembly on their computer. Not only did this increase the size of your application installer package, but the install script had to check that the PIA assemblies were indeed present and, if not, install a copy to the Global Assembly Cache (GAC).

---

■ **Note** The Global Assembly Cache was the central repository for .NET framework assemblies. It is no longer used in .NET Core.

---

However, with .NET 4.0 and higher, you can now embed the interoperability data directly within your compiled application. When you do so, you are no longer required to ship a copy of the interoperability assembly along with your .NET Core application, as the necessary interoperability metadata is hard-coded in your program. With .NET Core, embedding the PIA is required.

To embed the PIA, either set the “Embed Interop Types” property through Solution Explorer or update the property in the project file, as follows:

```
<ItemGroup>
  <COMReference Include="Microsoft.Office.Excel.dll">
    <Guid>00020813-0000-0000-c000-000000000046</Guid>
    <VersionMajor>1</VersionMajor>
    <VersionMinor>9</VersionMinor>
    <WrapperTool>tlbimp</WrapperTool>
    <Lcid>0</Lcid>
    <Isolated>>false</Isolated>
```

```

<EmbedInteropTypes>true</EmbedInteropTypes>
<Private>true</Private>
</COMReference>
</ItemGroup>

```

The C# compiler will include only the parts of the interop library you are actually using. Thus, if the real interop library has .NET Core descriptions of hundreds of COM objects, you will bring in only the definitions of the subset you are really using in your C# code. Beyond reducing the size of the application you need to ship to the client, you also have an easier installation path, as you don't need to install any missing PIAs on the target machine.

## Common COM Interop Pain Points

Many COM libraries defined methods that took optional arguments, which were not supported in C# until .NET 3.5. This required you to specify the value `Type.Missing` for every occurrence of the optional argument. Thankfully, with .NET 3.5 and beyond (including .NET Core), the `Type.Missing` values will be inserted at compile time if you don't specify a specific value.

On a related note, many COM methods provided support for named arguments, which, as you recall from Chapter 4, allows you to pass values to members in any order you require. Given that C# supports this same feature, it is simple to “skip” over a set of optional arguments you don't care about and set only the few you do.

Another common COM interop pain point has to do with the fact that many COM methods were designed to take and return a particular data type, termed the `Variant`. Much like the C# `dynamic` keyword, a `Variant` data type could be assigned to any type of COM data on the fly (strings, interface references, numerical values, etc.). Before you had the `dynamic` keyword, passing or receiving `Variant` data points required some hoop jumping, typically by way of numerous casting operations.

When you set the `Embed Interop Types` property to `True`, all COM `Variant` types are automatically mapped to `dynamic` data. This will not only reduce the need to extraneous casting operations when working with underlying COM `Variant` data types but will also further hide some COM complexities, such as working with COM indexers.

An additional pain point when working with COM Interop and .NET Core 3.1 is the lack of build and runtime support. The .NET Core 3.1 version of MSBuild cannot resolve interop libraries, so the .NET Core projects using COM interop can't be built or run using the .NET Core CLI. They must be built using Visual Studio and either executed with Visual Studio or by using the Visual Studio built assembly.

## COM Interop Using C# Dynamic Data

To showcase how C# optional arguments, named arguments, and the `dynamic` keyword all work together to simplify COM interop, you will now build an application that uses the Microsoft Office object model. Add a new class name `Car.cs` that contains the following code:

```

namespace ExportDataToOfficeApp
{
    public class Car
    {
        public string Make { get; set; }
        public string Color { get; set; }
        public string PetName { get; set; }
    }
}

```

Next, create a list of `Car` records in the `Main()` method of `Program.cs`, as follows (make sure to add using statement for `System.Collections.Generic`):

```
List<Car> carsInStock = new List<Car>
{
    new Car {Color="Green", Make="VW", PetName="Mary"},
    new Car {Color="Red", Make="Saab", PetName="Mel"},
    new Car {Color="Black", Make="Ford", PetName="Hank"},
    new Car {Color="Yellow", Make="BMW", PetName="Davie"}
};
```

Add the following namespace alias to the form's primary code file. This is not mandatory to define an alias when interacting with COM libraries. However, by doing so, you have a handy qualifier for all the imported COM objects, which helps if some of these COM objects have names that would clash with your .NET types.

```
// Create an alias to the Excel object model.
using Excel = Microsoft.Office.Interop.Excel;
```

Because you imported the COM library using Visual Studio, the PIA has been automatically configured so that the used metadata will be embedded into the .NET Core application. Therefore, all COM Variant data types are realized as dynamic data types. Furthermore, you can use C# optional arguments and named arguments. This being said, consider the following implementation of `ExportToExcel()`:

```
static void ExportToExcel(List<Car> carsInStock)
{
    // Load up Excel, then make a new empty workbook.
    Excel.Application excelApp = new Excel.Application();
    excelApp.Workbooks.Add();

    // This example uses a single workSheet.
    Excel._Worksheet workSheet = excelApp.ActiveSheet;

    // Establish column headings in cells.
    workSheet.Cells[1, "A"] = "Make";
    workSheet.Cells[1, "B"] = "Color";
    workSheet.Cells[1, "C"] = "Pet Name";

    // Now, map all data in List<Car> to the cells of the spreadsheet.
    int row = 1;
    foreach (Car c in carsInStock)
    {
        row++;
        workSheet.Cells[row, "A"] = c.Make;
        workSheet.Cells[row, "B"] = c.Color;
        workSheet.Cells[row, "C"] = c.PetName;
    }

    // Give our table data a nice look and feel.
    workSheet.Range["A1"].AutoFormat(Excel.XlRangeAutoFormat.xlRangeAutoFormatClassic2);
}
```

```

// Save the file, quit Excel, and display message to user.
workSheet.SaveAs($"{Environment.CurrentDirectory}\Inventory.xlsx");
excelApp.Quit();
Console.WriteLine("The Inventory.xlsx file has been saved to your app folder");
}

```

This method begins by loading Excel into memory; however, you won't see it visible on your computer desktop. For this application, you are interested only in using the internal Excel object model. However, if you do want to actually display the UI of Excel, update your method with this additional line of code:

```

static void ExportToExcel(List<Car> carsInStock)
{
    // Load up Excel, then make a new empty workbook.
    Excel.Application excelApp = new Excel.Application();

    // Go ahead and make Excel visible on the computer.
    excelApp.Visible = true;
    ...
}

```

After you create an empty worksheet, you add three columns that are named similar to the properties of the Car class. Then, you fill the cells with the data of the List<Car> and save your file under the (hard-coded) name Inventory.xlsx.

At this point, if you run your application, add a few new records, and export your data to Excel, you will then be able to open the Inventory.xlsx file, which will be saved to the \bin\Debug\netcoreapp3.1 folder of your project.

While it doesn't appear that any dynamic data was used in the preceding code, know that the DLR provided significant assistance. Without the DLR, the code would have to be writing like this:

```

static void ExportToExcelManual(List<Car> carsInStock)
{
    Excel.Application excelApp = new Excel.Application();
    // Must mark missing params!
    excelApp.Workbooks.Add(Type.Missing);
    // Must cast Object as _Worksheet!
    Excel._Worksheet workSheet =
        (Excel._Worksheet)excelApp.ActiveSheet;
    // Must cast each Object as Range object then call low-level Value2 property!
    ((Excel.Range)excelApp.Cells[1, "A"]).Value2 = "Make";
    ((Excel.Range)excelApp.Cells[1, "B"]).Value2 = "Color";
    ((Excel.Range)excelApp.Cells[1, "C"]).Value2 = "Pet Name";
    int row = 1;
    foreach (Car c in carsInStock)
    {
        row++;
        // Must cast each Object as Range and call low-level Value2 prop!
        ((Excel.Range)workSheet.Cells[row, "A"]).Value2 = c.Make;
        ((Excel.Range)workSheet.Cells[row, "B"]).Value2 = c.Color;
        ((Excel.Range)workSheet.Cells[row, "C"]).Value2 = c.PetName;
    }
}

```

```
// Must call get_Range method and then specify all missing args!
excelApp.get_Range("A1", Type.Missing).AutoFormat(
    Excel.XlRangeAutoFormat.xlRangeAutoFormatClassic2,
    Type.Missing, Type.Missing, Type.Missing,
    Type.Missing, Type.Missing, Type.Missing);
// Must specify all missing optional args!
workSheet.SaveAs(
    $"{Environment.CurrentDirectory}\InventoryManual.xlsx",
    Type.Missing, Type.Missing, Type.Missing,
    Type.Missing, Type.Missing, Type.Missing,
    Type.Missing, Type.Missing, Type.Missing);
excelApp.Quit();
Console.WriteLine("The InventoryManual.xlsx file has been saved to your app folder");
}
```

That wraps up your look at the C# dynamic keyword and the DLR. I hope you can see how these features can simplify complex programming tasks and (perhaps more importantly) understand the trade-offs. When you opt into dynamic data, you do lose a good amount of type safety, and your codebase is prone to many more runtime errors.

While there is certainly more to say about the DLR, this chapter has tried to focus on topics that are practical and useful in your day-to-day programming. If you want to learn more about advanced features of the Dynamic Language Runtime, such as integrating with scripting languages, be sure to consult the .NET Core SDK documentation (look up the topic “Dynamic Language Runtime Overview” to get started).

## Summary

The dynamic keyword allows you to define data whose true identity is not known until runtime. When processed by the Dynamic Language Runtime, the automatically created “expression tree” will be passed to the correct dynamic language binder, where the payload will be unpackaged and sent to the correct object member.

Using dynamic data and the DLR, a number of complex C# programming tasks can be radically simplified, especially the act of incorporating COM libraries into your .NET Core applications. As you saw in this chapter, this provides a number of further simplifications to COM interop (which have nothing to do with dynamic data), such as embedding COM interop data into your applications, optional arguments, and named arguments.

While these features can certainly simplify your code, always remember that dynamic data makes your C# code much less type-safe and open to runtime errors. Be sure you weigh the pros and cons of using dynamic data in your C# projects, and test accordingly!





# Understanding CIL and the Role of Dynamic Assemblies

When you are building a full-scale .NET Core application, you will most certainly use C# (or a similar managed language such as Visual Basic), given its inherent productivity and ease of use. However, as you learned in the beginning of this book, the role of a managed compiler is to translate \*.cs code files into terms of CIL code, type metadata, and an assembly manifest. As it turns out, CIL is a full-fledged .NET Core programming language, with its own syntax, semantics, and compiler (ilasm.exe).

In this chapter, you will be given a tour of .NET Core's mother tongue. Here, you will understand the distinction between a CIL *directive*, CIL *attribute*, and CIL *opcode*. You will then learn about the role of round-trip engineering of a .NET Core assembly and various CIL programming tools. The remainder of the chapter will then walk you through the basics of defining namespaces, types, and members using the grammar of CIL. The chapter will wrap up with an examination of the role of the `System.Reflection.Emit` namespace and explain how it is possible to construct an assembly (with CIL instructions) dynamically at runtime.

Of course, few programmers will ever need to work with raw CIL code on a day-to-day basis. Therefore, I will start this chapter by examining a few reasons why getting to know the syntax and semantics of this low-level .NET Core language might be worth your while.

## Motivations for Learning the Grammar of CIL

CIL is the true mother tongue of the .NET Core platform. When you build a .NET Core assembly using your managed language of choice (C#, VB, F#, etc.), the associated compiler translates your source code into terms of CIL. Like any programming language, CIL provides numerous structural and implementation-centric tokens. Given that CIL is just another .NET Core programming language, it should come as no surprise that it is possible to build your .NET Core assemblies directly using CIL and the CIL compiler (ilasm.exe).

---

**Note** The `ildasm.exe` program no longer ships with the .NET Core runtime, but must be compiled from the CoreCLR/Core Runtime sources, which can be located at <https://github.com/dotnet/coreclr> (.NET Core 3.1) or <https://github.com/dotnet/runtime> (.NET 5). The home page for the .NET 5 repo has platform-specific instructions to build the tool. I have included `ildasm.exe` in the Chapter 19 folder of this book's GIT repo.

---

Now while it is true that few (if any!) programmers would choose to build an entire .NET Core application directly with CIL, CIL is still an extremely interesting intellectual pursuit. Simply put, the more you understand the grammar of CIL, the better able you are to move into the realm of advanced .NET Core development. By way of some concrete examples, individuals who possess an understanding of CIL are capable of the following:

- Disassembling an existing .NET Core assembly, editing the CIL code, and recompiling the updated codebase into a modified .NET Core binary. For example, there are some scenarios where you might need to modify CIL to interoperate with some advanced COM features.
- Building dynamic assemblies using the `System.Reflection.Emit` namespace. This API allows you to generate an in-memory .NET Core assembly, which can optionally be persisted to disk. This is a useful technique for the tool builders of the world who need to generate assemblies on the fly.
- Understanding aspects of the CTS that are not supported by higher-level managed languages but do exist at the level of CIL. To be sure, CIL is the only .NET Core language that allows you to access every aspect of the CTS. For example, using raw CIL, you are able to define global-level members and fields (which are not permissible in C#).

Again, to be perfectly clear, if you choose *not* to concern yourself with the details of CIL code, you are still absolutely able to gain mastery of C# and the .NET Core base class libraries. In many ways, knowledge of CIL is analogous to a C (and C++) programmer's understanding of assembly language. Those who know the ins and outs of the low-level "goo" are able to create rather advanced solutions for the task at hand and gain a deeper understanding of the underlying programming (and runtime) environment. So, if you are up for the challenge, let's begin to examine the details of CIL.

---

■ **Note** Understand that this chapter is not intended to be a comprehensive treatment of the syntax and semantics of CIL.

---

## Examining CIL Directives, Attributes, and Opcodes

When you begin to investigate low-level languages such as CIL, you are guaranteed to find new (and often intimidating-sounding) names for familiar concepts. For example, at this point in the text, if you were shown the following set of items:

```
{new, public, this, base, get, set, explicit, unsafe, enum, operator, partial}
```

you would most certainly understand them to be keywords of the C# language (which is correct). However, if you look more closely at the members of this set, you might be able to see that while each item is indeed a C# keyword, it has radically different semantics. For example, the `enum` keyword defines a `System.Enum`-derived type, while the `this` and `base` keywords allow you to reference the current object or the object's parent class, respectively. The `unsafe` keyword is used to establish a block of code that cannot be directly monitored by the CLR, while the `operator` keyword allows you to build a hidden (specially named) method that will be called when you apply a specific C# operator (such as the plus sign).

In stark contrast to a higher-level language such as C#, CIL does not just simply define a general set of keywords per se. Rather, the token set understood by the CIL compiler is subdivided into the following three broad categories based on semantics:

- CIL directives
- CIL attributes
- CIL operation codes (opcodes)

Each category of CIL token is expressed using a particular syntax, and the tokens are combined to build a valid .NET assembly.

## The Role of CIL Directives

First up, there is a set of well-known CIL tokens that are used to describe the overall structure of a .NET assembly. These tokens are called *directives*. CIL directives are used to inform the CIL compiler how to define the namespaces(s), type(s), and member(s) that will populate an assembly.

Directives are represented syntactically using a single dot (.) prefix (e.g., `.namespace`, `.class`, `.publickeytoken`, `.method`, `.assembly`, etc.). Thus, if your \*.il file (the conventional extension for a file containing CIL code) has a single `.namespace` directive and three `.class` directives, the CIL compiler will generate an assembly that defines a single .NET Core namespace containing three .NET Core class types.

## The Role of CIL Attributes

In many cases, CIL directives in and of themselves are not descriptive enough to fully express the definition of a given .NET type or type member. Given this fact, many CIL directives can be further specified with various CIL *attributes* to qualify how a directive should be processed. For example, the `.class` directive can be adorned with the `public` attribute (to establish the type visibility), the `extends` attribute (to explicitly specify the type's base class), and the `implements` attribute (to list the set of interfaces supported by the type).

---

■ **Note** Don't confuse a .NET attribute (see Chapter 17) with that of a CIL attribute, which are two very different concepts.

---

## The Role of CIL Opcodes

Once a .NET Core assembly, namespace, and type set have been defined in terms of CIL using various directives and related attributes, the final remaining task is to provide the type's implementation logic. This is a job for *operation codes*, or simply *opcodes*. In the tradition of other low-level languages, many CIL opcodes tend to be cryptic and completely unpronounceable by us mere humans. For example, if you need to load a string variable into memory, you don't use a friendly opcode named `LoadString` but rather `ldstr`.

Now, to be fair, some CIL opcodes do map quite naturally to their C# counterparts (e.g., `box`, `unbox`, `throw`, and `sizeof`). As you will see, the opcodes of CIL are always used within the scope of a member's implementation, and unlike CIL directives, they are never written with a dot prefix.

## The CIL Opcode/CIL Mnemonic Distinction

As just explained, opcodes such as `ldstr` are used to implement the members of a given type. In reality, however, tokens such as `ldstr` are *CIL mnemonics* for the actual *binary CIL opcodes*. To clarify the distinction, assume you have authored the following method in C#:

```
static int Add(int x, int y)
{
    return x + y;
}
```

The act of adding two numbers is expressed in terms of the CIL opcode `0X58`. In a similar vein, subtracting two numbers is expressed using the opcode `0X59`, and the act of allocating a new object on the managed heap is achieved using the `0X73` opcode. Given this reality, understand that the “CIL code” processed by a JIT compiler is actually nothing more than blobs of binary data.

Thankfully, for each binary opcode of CIL, there is a corresponding mnemonic. For example, the `add` mnemonic can be used rather than `0X58`, `sub` rather than `0X59`, and `newobj` rather than `0X73`. Given this opcode/mnemonic distinction, realize that CIL decompilers such as `ildasm.exe` translate an assembly’s binary opcodes into their corresponding CIL mnemonics. For example, here would be the CIL presented by `ildasm.exe` for the previous C# `Add()` method (your exact output may differ based on your version of .NET Core):

```
.method private hidebysig static int32 Add(int32 x,
    int32 y) cil managed
{
    // Code size 9 (0x9)
    .maxstack 2
    .locals init ([0] int32 int32 V_0)
    IL_0000: nop
    IL_0001: ldarg.0
    IL_0002: ldarg.1
    IL_0003: add
    IL_0004: stloc.0
    IL_0005: br.s IL_0007
    IL_0007: ldloc.0
    IL_0008: ret
}
```

Unless you’re building some extremely low-level .NET Core software (such as a custom managed compiler), you’ll never need to concern yourself with the literal numeric binary opcodes of CIL. For all practical purposes, when .NET Core programmers speak about “CIL opcodes,” they’re referring to the set of friendly string token mnemonics (as I’ve done within this text and will do for the remainder of this chapter) rather than the underlying numerical values.

## Pushing and Popping: The Stack-Based Nature of CIL

Higher-level .NET Core languages (such as C#) attempt to hide low-level CIL grunge from view as much as possible. One aspect of .NET Core development that is particularly well hidden is that CIL is a stack-based programming language. Recall from the examination of the collection namespaces (see Chapter 10) that the `Stack<T>` class can be used to push a value onto a stack as well as pop the topmost value off of the stack for use. Of course, CIL developers do not use an object of type `Stack<T>` to load and unload the values to be evaluated; however, the same pushing and popping mind-set still applies.

Formally speaking, the entity used to hold a set of values to be evaluated is termed the *virtual execution stack*. As you will see, CIL provides a number of opcodes that are used to push a value onto the stack; this process is termed *loading*. As well, CIL defines a number of additional opcodes that transfer the topmost value on the stack into memory (such as a local variable) using a process termed *storing*.

In the world of CIL, it is impossible to access a point of data directly, including locally defined variables, incoming method arguments, or field data of a type. Rather, you are required to explicitly load the item onto the stack, only to then pop it off for later use (keep this point in mind, as it will help explain why a given block of CIL code can look a bit redundant).

---

■ **Note** Recall that CIL is not directly executed but compiled on demand. During the compilation of CIL code, many of these implementation redundancies are optimized away. Furthermore, if you enable the code optimization option for your current project (using the Build tab of the Visual Studio Project Properties window), the compiler will also remove various CIL redundancies.

---

To understand how CIL leverages a stack-based processing model, consider a simple C# method, `PrintMessage()`, which takes no arguments and returns `void`. Within the implementation of this method, you will simply print the value of a local string variable to the standard output stream, like so:

```
public void PrintMessage()
{
    string myMessage = "Hello.";
    Console.WriteLine(myMessage);
}
```

If you were to examine how the C# compiler translates this method in terms of CIL, you would first find that the `PrintMessage()` method defines a storage slot for a local variable using the `.locals` directive. The local string is then loaded and stored in this local variable using the `ldstr` (load string) and `stloc.0` opcodes (which can be read as “store the current value in a local variable at storage slot zero”).

The value (again, at index 0) is then loaded into memory using the `ldloc.0` (“load the local argument at index 0”) opcode for use by the `System.Console.WriteLine()` method invocation (specified using the `call` opcode). Finally, the function returns via the `ret` opcode. Here is the (annotated) CIL code for the `PrintMessage()` method (note that I’ve removed the `nop` opcodes from this listing, for brevity):

```
.method public hidebysig instance void PrintMessage() cil managed
{
    .maxstack 1
    // Define a local string variable (at index 0).
    .locals init ([0] string V_0)

    // Load a string onto the stack with the value "Hello."
    ldstr " Hello."

    // Store string value on the stack in the local variable.
    stloc.0

    // Load the value at index 0.
    ldloc.0
```

```
// Call method with current value.
call void [System.Console]System.Console::WriteLine(string)
ret
}
```

---

■ **Note** As you can see, CIL supports code comments using the double-slash syntax (as well as the `/*...*/` syntax, for that matter). As in C#, code comments are completely ignored by the CIL compiler.

---

Now that you have the basics of CIL directives, attributes, and opcodes, let's see a practical use of CIL programming, beginning with the topic of round-trip engineering.

## Understanding Round-Trip Engineering

You are aware of how to use `ildasm.exe` to view the CIL code generated by the C# compiler (see Chapter 1). What you might not know, however, is that `ildasm.exe` allows you to dump the CIL contained within an assembly loaded into `ildasm.exe` to an external file. Once you have the CIL code at your disposal, you are free to edit and recompile the codebase using the CIL compiler, `ilasm.exe`.

Formally speaking, this technique is termed *round-trip engineering*, and it can be useful under select circumstances, such as the following:

- You need to modify an assembly for which you no longer have the source code.
- You are working with a less-than-perfect .NET Core language compiler that has emitted ineffective (or flat-out incorrect) CIL code, and you want to modify the codebase.
- You are constructing a COM interoperability library and want to account for some COM IDL attributes that have been lost during the conversion process (such as the `COM [helpstring]` attribute).

To illustrate the process of round-tripping, begin by creating a new C# .NET Core Console application named `RoundTrip` using the .NET Core Command Line Interface (CLI):

```
dotnet new console -n RoundTrip -f netcoreapp3.1
```

Update the `Main` method to the following:

```
// A simple C# console app.
using System;

static void Main(string[] args)
{
    Console.WriteLine("Hello CIL code!");
    Console.ReadLine();
}
}
```

Compile your program using the .NET Core CLI:

```
dotnet build
```

---

■ **Note** Recall from Chapter 1 that all .NET Core assemblies (class libraries or console apps) are compiled to assemblies that have a \*.dll extension. They are executed using the .NET Core CLI. New in .NET Core 3 (and later), the dotnet.exe file is copied into the output directory and renamed to match the assembly name. So while it *looks* like your project was compiled to RoundTrip.exe, it was compiled to RoundTrip.dll with dotnet.exe copied to RoundTrip.exe.

---

Now, open RoundTrip.dll with ildasm.exe and, using the File ► Dump menu option, save the raw CIL code to a new \*.il file (HelloProgram.il) in the same folder containing your compiled assembly (all the default values of the resulting dialog box are fine as is).

---

■ **Note** ildasm.exe will also generate a \*.res file when dumping the contents of an assembly to file. These resource files can be ignored (and deleted) throughout this chapter, as you will not be using them. This file contains some low-level CLR security information (among other things).

---

Now you are able to view RoundTrip.il using your text editor of choice. Here is the (slightly reformatted and annotated) result:

**// Referenced assemblies.**

```
.assembly extern System.Runtime
{
    .publickeytoken = (B0 3F 5F 7F 11 D5 0A 3A)
    .ver 4:2:2:0
}
.assembly extern System.Console
{
    .publickeytoken = (B0 3F 5F 7F 11 D5 0A 3A )
    .ver 4:1:2:0
}
```

**// Our assembly.**

```
.assembly RoundTrip
{
    /**** TargetFrameworkAttribute data removed for clarity! ****/

    .hash algorithm 0x00008004
    .ver 1:0:0:0
}
.module RoundTrip.dll
.imagebase 0x00400000
.file alignment 0x00000200
.stackreserve 0x00100000
.subsystem 0x0003
.corflags 0x00000001
```

**// Definition of Program class.**

```
.class private auto ansi beforefieldinit RoundTrip.Program
    extends [System.Runtime]System.Object
{
    .method private hidebysig static void Main(string[] args) cil managed
    {
        // Marks this method as the entry point of the executable.
        .entrypoint
        .maxstack 8
        IL_0000: nop
        IL_0001: ldstr "Hello CIL code!"
        IL_0006: call void [System.Console]System.Console::WriteLine(string)
        IL_000b: nop
        IL_000c: call string [System.Console]System.Console::ReadLine()
        IL_0011: pop
        IL_0012: ret
    } //end of method Program::Main

    // The default constructor.
    .method public hidebysig specialname rtspecialname
        instance void .ctor() cil managed
    {
        .maxstack 8
        IL_0000: ldarg.0
        IL_0001: call instance void [System.Runtime]System.Object::.ctor()
        IL_0006: ret
    } //end of method Program::.ctor
} //end of class RoundTrip.Program
```

First, notice that the \*.il file opens by declaring each externally referenced assembly the current assembly is compiled against. If your class library used additional types within other referenced assemblies (beyond System.Runtime and System.Console), you would find additional .assembly extern directives.

Next, you find the formal definition of your RoundTrip.dll assembly, described using various CIL directives (such as .module, .imagebase, etc.).

After documenting the externally referenced assemblies and defining the current assembly, you find a definition of the Program type. Note that the .class directive has various attributes (many of which are actually optional) such as extends, shown here, which marks the base class of the type:

```
.class private auto ansi beforefieldinit RoundTrip.Program
    extends [System.Runtime]System.Object
{ ... }
```

The bulk of the CIL code represents the implementation of the class's default constructor and the Main() method, both of which are defined (in part) with the .method directive. Once the members have been defined using the correct directives and attributes, they are implemented using various opcodes.

It is critical to understand that when interacting with .NET Core types (such as System.Console) in CIL, you will *always* need to use the type's fully qualified name. Furthermore, the type's fully qualified name must *always* be prefixed with the friendly name of the defining assembly (in square brackets). Consider the following CIL implementation of Main():



```
.method private hidebysig static void Main(string[] args) cil managed
{
    .entrypoint
    .maxstack 8
    IL_0000: nop
    IL_0001: ldstr "Hello CIL code!"
    IL_0006: call void [System.Console]System.Console::WriteLine(string)
    IL_000b: nop
    IL_000c: call string [System.Console]System.Console::ReadLine()
    IL_0011: pop
    IL_0012: ret
}
```

The implementation of the default constructor in terms of CIL code makes use of yet another “load-centric” instruction (`ldarg.0`). In this case, the value loaded onto the stack is not a custom variable specified by you but the current object reference (more details on this later). Also note that the default constructor explicitly makes a call to the base class constructor, as follows (which, in this case, is your good friend `System.Object`):

```
.method public hidebysig specialname rtspecialname
    instance void .ctor() cil managed
{
    .maxstack 8
    IL_0000: ldarg.0
    IL_0001: call instance void [System.Runtime]System.Object::.ctor()
    IL_0006: ret
}
```

## The Role of CIL Code Labels

One thing you certainly have noticed is that each line of implementation code is prefixed with a token of the form `IL_XXX:` (e.g., `IL_0000:`, `IL_0001:`, etc.). These tokens are called *code labels* and may be named in any manner you choose (provided they are not duplicated within the same member scope). When you dump an assembly to file using `ildasm.exe`, it will automatically generate code labels that follow an `IL_XXX:` naming convention. However, you may change them to reflect a more descriptive marker. Here’s an example:

```
.method private hidebysig static void Main(string[] args) cil managed
{
    .entrypoint
    .maxstack 8
    Nothing_1: nop
    Load_String: ldstr "Hello CIL code!"
    PrintToConsole: call void [System.Console]System.Console::WriteLine(string)
    Nothing_2: nop
    WaitFor_KeyPress: call string [System.Console]System.Console::ReadLine()
    RemoveValueFromStack: pop
    Leave_Function: ret
}
```

The truth of the matter is that most code labels are completely optional. The only time code labels are truly mandatory is when you are authoring CIL code that makes use of various branching or looping constructs, as you can specify where to direct the flow of logic via these code labels. For the current example, you can remove these autogenerated labels altogether with no ill effect, like so:

```
.method private hidebysig static void Main(string[] args) cil managed
{
    .entrypoint
    .maxstack 8
    nop
    ldstr "Hello CIL code!"
    call void [System.Console]System.Console::WriteLine(string)
    nop
    call string [System.Console]System.Console::ReadLine()
    pop
    ret
}
```

## Interacting with CIL: Modifying an \*.il File

Now that you have a better understanding of how a basic CIL file is composed, let's complete the round-tripping experiment. The goal here is quite simple: change the message that is output to the console. You can do more, such as add assembly references or create new classes and methods, but we'll keep it simple.

To make the change, you need to alter the current implementation of the `Main()` method. Locate this method within the \*.il file and change the message to "Hello from altered CIL Code!"

In effect, you have just updated the CIL code to correspond to the following C# class definition:

```
static void Main(string[] args)
{
    Console.WriteLine("Hello from altered CIL code!");
    Console.ReadLine();
}
```

## Compiling CIL Code

Prior versions of .NET allowed you to compile \*.il files using `ilasm.exe`. This has changed in .NET Core. To compile \*.il files, you have to use a `Microsoft.NET.Sdk.IL` project type, and at the time of this writing, this is not part of the standard SDK.

Start by creating a new directory on your machine. In this directory, create a `global.json` file. The `global.json` file applies to the current directory and all subdirectories below the file. It is used to define which SDK version you will use when running .NET Core Command Line Interface (CLI) commands. Update the files to the following:

```
{
  "msbuild-sdks": {
    "Microsoft.NET.Sdk.IL": "3.0.0-preview1-27101-02"
  }
}
```

---

■ **Note** The current version (at the time of this writing) is still a preview version. Update your version to match the version at this URL: <https://dotnet.myget.org/feed/dotnet-core/package/nuget/Microsoft.NET.Sdk.IL>.

---

Next, add a NuGet.config to add in the additional MyGet location for the IL SDK and to confirm the location of the .NET Core NuGet feed. Update the file to the following:

```
<?xml version="1.0" encoding="utf-8"?>
<configuration>
  <packageSources>
    <add key="nuget.org" value="https://www.nuget.org/api/v3/index.json" />
    <add key="DotnetCore" value="https://dotnet.myget.org/F/dotnet-core/api/v3/index.json" />
  </packageSources>
</configuration>
```

The final setup step is to create the project file. Create a file named RoundTrip.ilproj and update it to the following:

```
<Project Sdk="Microsoft.NET.Sdk.IL">
  <PropertyGroup>
    <OutputType>Exe</OutputType>
    <TargetFramework>netcoreapp3.1</TargetFramework>
  <MicrosoftNetCoreIlasmPackageVersion>3.0.0-preview1-27101-02</MicrosoftNetCoreIlasmPackageVersion>
</PropertyGroup>
</Project>
```

Finally, copy in your updated RoundTrip.il file into the directory. Compile the assembly using the .NET Core CLI:

```
dotnet build
```

You will find the resulting files in the usual bin\debug\netcoreapp3.1 folder. At this point, you can run your new application. Sure enough, you will see the updated message displaying in the console window. While the output of this simple example is not all that spectacular, it does illustrate one practical use of programming in CIL: round-tripping.

## Understanding CIL Directives and Attributes

Now that you have seen how to convert .NET Core assemblies into IL and compile IL into assemblies, you can get down to the business of checking out the syntax and semantics of CIL itself. The next sections will walk you through the process of authoring a custom namespace containing a set of types. However, to keep things simple, these types will not contain any implementation logic for their members (yet). After you understand how to create empty types, you can then turn your attention to the process of defining “real” members using CIL opcodes.

## Specifying Externally Referenced Assemblies in CIL

In a new directory, copy the `global.json` and `NuGet.config` files from the previous example. Create a new project file named `CILTypes.ilproj`, and update it to the following:

```
<Project Sdk="Microsoft.NET.Sdk.IL">
  <PropertyGroup>
    <TargetFramework>netcoreapp3.1</TargetFramework>
    <MicrosoftNetCoreIlasmPackageVersion>3.0.0-preview1-27101-02</MicrosoftNetCoreIlasmPackageVersion>
  </PropertyGroup>
</Project>
```

Next, create a new file named `CILTypes.il` using your editor of choice. The first task a CIL project will require is to list the set of external assemblies used by the current assembly. For this example, you will only use types found within `System.Runtime.dll`. To do so, the `.assembly` directive will be qualified using the external attribute. When you are referencing a strongly named assembly, such as `System.Runtime.dll`, you'll want to specify the `.publickeytoken` and `.ver` directives as well, like so:

```
.assembly extern System.Runtime
{
  .publickeytoken = (B0 3F 5F 7F 11 D5 0A 3A )
  .ver 4:2:2:0
}
```

## Defining the Current Assembly in CIL

The next order of business is to define the assembly you are interested in building using the `.assembly` directive. At the simplest level, an assembly can be defined by specifying the friendly name of the binary, like so:

```
// Our assembly.
.assembly CILTypes { }
```

While this indeed defines a new .NET Core assembly, you will typically place additional directives within the scope of the assembly declaration. For this example, update your assembly definition to include a version number of 1.0.0.0 using the `.ver` directive (note that each numerical identifier is separated by *colons*, not the C#-centric dot notation), as follows:

```
// Our assembly.
.assembly CILTypes
{
  .ver 1:0:0:0
}
```

Given that the `CILTypes` assembly is a single-file assembly, you will finish up the assembly definition using the following single `.module` directive, which marks the official name of your .NET binary, `CILTypes.dll`:

```
.assembly CILTypes
{
  .ver 1:0:0:0
}
```

```
// The module of our single-file assembly.
.module CILTypes.dll
```

In addition to `.assembly` and `.module` are CIL directives that further qualify the overall structure of the .NET binary you are composing. Table 19-1 lists a few of the more common assembly-level directives.

**Table 19-1.** *Additional Assembly-Centric Directives*

Directive	Meaning in Life
<code>.mresources</code>	If your assembly uses internal resources (such as bitmaps or string tables), this directive is used to identify the name of the file that contains the resources to be embedded.
<code>.subsystem</code>	This CIL directive is used to establish the preferred UI that the assembly wants to execute within. For example, a value of 2 signifies that the assembly should run within a GUI application, whereas a value of 3 denotes a console executable.

## Defining Namespaces in CIL

Now that you have defined the look and feel of your assembly (and the required external references), you can create a .NET Core namespace (MyNamespace) using the `.namespace` directive, like so:

```
// Our assembly has a single namespace.
.namespace MyNamespace {}
```

Like C#, CIL namespace definitions can be nested within further namespaces. There is no need to define a root namespace here; however, for the sake of argument, assume you want to create the following root namespace named MyCompany:

```
.namespace MyCompany
{
    .namespace MyNamespace {}
}
```

Like C#, CIL allows you to define a nested namespace as follows:

```
// Defining a nested namespace.
.namespace MyCompany.MyNamespace {}
```

## Defining Class Types in CIL

Empty namespaces are not very interesting, so let's now check out the process of defining a class type using CIL. Not surprisingly, the `.class` directive is used to define a new class. However, this simple directive can be adorned with numerous additional attributes, to further qualify the nature of the type. To illustrate, add a public class to your namespace named MyBaseClass. As in C#, if you do not specify an explicit base class, your type will automatically be derived from `System.Object`.

```
.namespace MyNamespace
{
    // System.Object base class assumed.
    .class public MyBaseClass {}
}
```

When you are building a class type that derives from any class other than `System.Object`, you use the `extends` attribute. Whenever you need to reference a type defined within the same assembly, CIL demands that you also use the fully qualified name (however, if the base type is within the same assembly, you can omit the assembly's friendly name prefix). Therefore, the following attempt to extend `MyBaseClass` results in a compiler error:

```
// This will not compile!
.namespace MyNamespace
{
    .class public MyBaseClass {}

    .class public MyDerivedClass
        extends MyBaseClass {}
}
```

To correctly define the parent class of `MyDerivedClass`, you must specify the full name of `MyBaseClass` as follows:

```
// Better!
.namespace MyNamespace
{
    .class public MyBaseClass {}

    .class public MyDerivedClass
        extends MyNamespace.MyBaseClass {}
}
```

In addition to the `public` and `extends` attributes, a CIL class definition may take numerous additional qualifiers that control the type's visibility, field layout, and so on. Table 19-2 illustrates some (but not all) of the attributes that may be used in conjunction with the `.class` directive.

**Table 19-2.** Various Attributes Used in Conjunction with the `.class` Directive

Attributes	Meaning in Life
public,private,nested assembly, nested famandassem,nested family, nested famorassem,nested public, nested private	CIL defines various attributes that are used to specify the visibility of a given type. As you can see, raw CIL offers numerous possibilities other than those offered by C#. Refer to ECMA 335 for details if you are interested.
abstract,sealed	These two attributes may be tacked onto a <code>.class</code> directive to define an abstract class or sealed class, respectively.
auto,sequential,explicit	These attributes are used to instruct the CLR how to lay out field data in memory. For class types, the default layout flag ( <code>auto</code> ) is appropriate. Changing this default can be helpful if you need to use <code>P/Invoke</code> to call into unmanaged C code.
extends,implements	These attributes allow you to define the base class of a type (via <code>extends</code> ) or implement an interface on a type (via <code>implements</code> ).

## Defining and Implementing Interfaces in CIL

As odd as it might seem, interface types are defined in CIL using the `.class` directive. However, when the `.class` directive is adorned with the `interface` attribute, the type is realized as a CTS interface type. Once an interface has been defined, it may be bound to a class or structure type using the CIL `implements` attribute, like so:

```
.namespace MyNamespace
{
    // An interface definition.
    .class public interface IMyInterface {}

    // A simple base class.
    .class public MyBaseClass {}

    // MyDerivedClass now implements IMyInterface,
    // and extends MyBaseClass.
    .class public MyDerivedClass
        extends MyNamespace.MyBaseClass
        implements MyNamespace.IMyInterface {}
}
```

---

■ **Note** The `extends` clause must precede the `implements` clause. As well, the `implements` clause can incorporate a comma-separated list of interfaces.

---

As you recall from Chapter 10, interfaces can function as the base interface to other interface types in order to build interface hierarchies. However, contrary to what you might be thinking, the `extends` attribute cannot be used to derive interface A from interface B. The `extends` attribute is used only to qualify a type's base class. When you want to extend an interface, you will use the `implements` attribute yet again. Here's an example:

```
// Extending interfaces in terms of CIL.
.class public interface IMyInterface {}

.class public interface IMyOtherInterface
    implements MyNamespace.IMyInterface {}
```

## Defining Structures in CIL

The `.class` directive can be used to define a CTS structure if the type extends `System.ValueType`. As well, the `.class` directive must be qualified with the `sealed` attribute (given that structures can never be a base structure to other value types). If you attempt to do otherwise, `ilasm.exe` will issue a compiler error.

```
// A structure definition is always sealed.
.class public sealed MyStruct
    extends [System.Runtime]System.ValueType{}
```

Do be aware that CIL provides a shorthand notation to define a structure type. If you use the value attribute, the new type will derive the type from `[System.Runtime]System.ValueType` automatically. Therefore, you could define `MyStruct` as follows:

```
// Shorthand notation for declaring a structure.
.class public sealed value MyStruct{}
```

## Defining Enums in CIL

.NET Core enumerations (as you recall) derive from `System.Enum`, which is a `System.ValueType` (and therefore must also be sealed). When you want to define an enum in terms of CIL, simply extend `[System.Runtime]System.Enum`, like so:

```
// An enum.
.class public sealed MyEnum
    extends [System.Runtime]System.Enum{}
```

Like a structure definition, enumerations can be defined with a shorthand notation using the enum attribute. Here's an example:

```
// Enum shorthand.
.class public sealed enum MyEnum{}
```

You'll see how to specify the name-value pairs of an enumeration in just a moment.

## Defining Generics in CIL

Generic types also have a specific representation in the syntax of CIL. Recall from Chapter 10 that a given generic type or generic member may have one or more type parameters. For example, the `List<T>` type has a single type parameter, while `Dictionary<TKey, TValue>` has two. In terms of CIL, the number of type parameters is specified using a backward-leaning single tick (```), followed by a numerical value representing the number of type parameters. Like C#, the actual value of the type parameters is encased within angled brackets.

---

■ **Note** On most keyboards, you can find the ``` character on the key above the Tab key (and to the left of the 1 key).

---

For example, assume you want to create a `List<T>` variable, where `T` is of type `System.Int32`. In C#, you would type the following:

```
void SomeMethod()
{
    List<int> myInts = new List<int>();
}
```



In CIL, you would author the following (which could appear in any CIL method scope):

```
// In C#: List<int> myInts = new List<int>();
newobj instance void class [System.Collections]
    System.Collections.Generic.List`1<int32>::.ctor()
```

Notice that this generic class is defined as `List`1<int32>`, as `List<T>` has a single type parameter. However, if you needed to define a `Dictionary<string, int>` type, you would do so as follows:

```
// In C#: Dictionary<string, int> d = new Dictionary<string, int>();
newobj instance void class [System.Collections]
    System.Collections.Generic.Dictionary`2<string,int32>
        ::.ctor()
```

As another example, if you have a generic type that uses another generic type as a type parameter, you would author CIL code such as the following:

```
// In C#: List<List<int>> myInts = new List<List<int>>();
newobj instance void class [mscorlib]
    System.Collections.Generic.List`1<class
        [System.Collections]
        System.Collections.Generic.List`1<int32>>
        ::.ctor()
```

## Compiling the CILTypes.il File

Even though you have not yet added any members or implementation code to the types you have defined, you are able to compile this \*.il file into a .NET Core DLL assembly (which you must do, as you have not specified a `Main()` method). Open a command prompt and enter the following command:

```
dotnet build
```

After you have done so, you can now open your compiled assembly into `ildasm.exe` to verify the creation of each type. To understand how to populate a type with content, you first need to examine the fundamental data types of CIL.

## .NET Base Class Library, C#, and CIL Data Type Mappings

Table 19-3 illustrates how a .NET base class type maps to the corresponding C# keyword and how each C# keyword maps into raw CIL. As well, Table 19-3 documents the shorthand constant notations used for each CIL type. As you will see in just a moment, these constants are often referenced by numerous CIL opcodes.

**Table 19-3.** Mapping .NET Base Class Types to C# Keywords and C# Keywords to CIL

.NET Core Base Class Type	C# Keyword	CIL Representation	CIL Constant Notation
System.SByte	Sbyte	int8	I1
System.Byte	Byte	unsigned int8	U1
System.Int16	Short	int16	I2
System.UInt16	Ushort	unsigned int16	U2
System.Int32	Int	int32	I4
System.UInt32	UInt	unsigned int32	U4
System.Int64	Long	int64	I8
System.UInt64	Ulong	unsigned int64	U8
System.Char	Char	char	CHAR
System.Single	Float	float32	R4
System.Double	Double	float64	R8
System.Boolean	Bool	bool	BOOLEAN
System.String	String	string	N/A
System.Object	Object	object	N/A
System.Void	Void	void	VOID

■ **Note** The `System.IntPtr` and `System.UIntPtr` types map to native `int` and native `unsigned int` (this is good to know, as many of COM interoperability and P/Invoke scenarios use these extensively).

## Defining Type Members in CIL

As you are already aware, .NET Core types may support various members. Enumerations have some set of name-value pairs. Structures and classes may have constructors, fields, methods, properties, static members, and so on. Over the course of this book’s first 18 chapters, you have already seen partial CIL definitions for the items previously mentioned, but nevertheless, here is a quick recap of how various members map to CIL primitives.

### Defining Field Data in CIL

Enumerations, structures, and classes can all support field data. In each case, the `.field` directive will be used. For example, let’s breathe some life into the skeleton `MyEnum` enumeration and define the following three name-value pairs (note the values are specified within parentheses):

```
.class public sealed enum MyEnum
{
    .field public static literal valuetype
        MyNamespace.MyEnum A = int32(0)
    .field public static literal valuetype
        MyNamespace.MyEnum B = int32(1)
```

```
.field public static literal valuetype
  MyNamespace.MyEnum C = int32(2)
}
```

Fields that reside within the scope of a .NET Core System.Enum-derived type are qualified using the `static` and `literal` attributes. As you would guess, these attributes set up the field data to be a fixed value accessible from the type itself (e.g., `MyEnum.A`).

---

■ **Note** The values assigned to an enum value may also be in hexadecimal with a `0x` prefix.

---

Of course, when you want to define a point of field data within a class or structure, you are not limited to a point of public static literal data. For example, you could update `MyBaseClass` to support two points of private, instance-level field data, set to default values:

```
.class public MyBaseClass
{
  .field private string stringField = "hello!"
  .field private int32 intField = int32(42)
}
```

As in C#, class field data will automatically be initialized to an appropriate default value. If you want to allow the object user to supply custom values at the time of creation for each of these points of private field data, you (of course) need to create custom constructors.

## Defining Type Constructors in CIL

The CTS supports both instance-level and class-level (static) constructors. In terms of CIL, instance-level constructors are represented using the `.ctor` token, while a static-level constructor is expressed via `.cctor` (class constructor). Both of these CIL tokens must be qualified using the `rtspecialname` (return type special name) and `specialname` attributes. Simply put, these attributes are used to identify a specific CIL token that can be treated in unique ways by a given .NET Core language. For example, in C#, constructors do not define a return type; however, in terms of CIL, the return value of a constructor is indeed `void`.

```
.class public MyBaseClass
{
  .field private string stringField
  .field private int32 intField

  .method public hidebysig specialname rtspecialname
    instance void .ctor(string s, int32 i) cil managed
  {
    // TODO: Add implementation code...
  }
}
```

Note that the `.ctor` directive has been qualified with the `instance` attribute (as it is not a static constructor). The `cil managed` attributes denote that the scope of this method contains CIL code, rather than unmanaged code, which may be used during platform invocation requests.

## Defining Properties in CIL

Properties and methods also have specific CIL representations. By way of an example, if `MyBaseClass` were updated to support a public property named `TheString`, you would author the following CIL (note again the use of the `specialname` attribute):

```
.class public MyBaseClass
{
...
.method public hidebysig specialname
    instance string get_TheString() cil managed
    {
        // TODO: Add implementation code...
    }

.method public hidebysig specialname
    instance void set_TheString(string 'value') cil managed
    {
        // TODO: Add implementation code...
    }

.property instance string TheString()
    {
        .get instance string
            MyNamespace.MyBaseClass::get_TheString()
        .set instance void
            MyNamespace.MyBaseClass::set_TheString(string)
    }
}
```

In terms of CIL, a property maps to a pair of methods that take `get_` and `set_` prefixes. The `.property` directive makes use of the related `.get` and `.set` directives to map property syntax to the correct “specially named” methods.

---

■ **Note** Notice that the incoming parameter to the `set` method of a property is placed in single quotation marks, which represents the name of the token to use on the right side of the assignment operator within the method scope.

---

## Defining Member Parameters

In a nutshell, specifying arguments in CIL is (more or less) identical to doing so in C#. For example, each argument is defined by specifying its data type, followed by the parameter name. Furthermore, like C#, CIL provides a way to define input, output, and pass-by-reference parameters. As well, CIL allows you to define a parameter array argument (aka the C# `params` keyword), as well as optional parameters.

To illustrate the process of defining parameters in raw CIL, assume you want to build a method that takes an `int32` (by value), an `int32` (by reference), a `[mscorlib]System.Collection.ArrayList`, and a single output parameter (of type `int32`). In terms of C#, this method would look something like the following:

```
public static void MyMethod(int inputInt,
    ref int refInt, ArrayList ar, out int outputInt)
{
    outputInt = 0; // Just to satisfy the C# compiler...
}
```

If you were to map this method into CIL terms, you would find that C# reference parameters are marked with an ampersand (&) suffixed to the parameter's underlying data type (`int32&`).

Output parameters also use the & suffix, but they are further qualified using the CIL `[out]` token. Also notice that if the parameter is a reference type (in this case, the `[mscorlib]System.Collections.ArrayList` type), the class token is prefixed to the data type (not to be confused with the `.class` directive!).

```
.method public hidebysig static void MyMethod(int32 inputInt,
    int32& refInt,
    class [System.Runtime.Extensions]System.Collections.ArrayList ar,
    [out] int32& outputInt) cil managed
{
    ...
}
```

## Examining CIL Opcodes

The final aspect of CIL code you'll examine in this chapter has to do with the role of various operational codes (opcodes). Recall that an opcode is simply a CIL token used to build the implementation logic for a given member. The complete set of CIL opcodes (which is fairly large) can be grouped into the following broad categories:

- Opcodes that control program flow
- Opcodes that evaluate expressions
- Opcodes that access values in memory (via parameters, local variables, etc.)

To provide some insight to the world of member implementation via CIL, Table 19-4 defines some of the more useful opcodes that are directly related to member implementation logic, grouped by related functionality.

**Table 19-4.** *Various Implementation-Specific CIL Opcodes*

Opcodes	Meaning in Life
add, sub, mul, div, rem	These CIL opcodes allow you to add, subtract, multiply, and divide two values (rem returns the remainder of a division operation).
and, or, not, xor	These CIL opcodes allow you to perform bit-wise operations on two values.
ceq, cgt, clt	These CIL opcodes allow you to compare two values on the stack in various manners. Here are some examples: ceq: Compare for equality cgt: Compare for greater than clt: Compare for less than
box, unbox	These CIL opcodes are used to convert between reference types and value types.
ret	This CIL opcode is used to exit a method and return a value to the caller (if necessary).
beq, bgt, ble, blt, switch	These CIL opcodes (in addition to many other related opcodes) are used to control branching logic within a method. Here are some examples: beq: Break to code label if equal bgt: Break to code label if greater than ble: Break to code label if less than or equal to blt: Break to code label if less than All the branch-centric opcodes require that you specify a CIL code label to jump to if the result of the test is true.
call	This CIL opcode is used to call a member on a given type.
newarr, newobj	These CIL opcodes allow you to allocate a new array or new object type into memory (respectively).

The next broad category of CIL opcodes (a subset of which is shown in Table 19-5) is used to load (push) arguments onto the virtual execution stack. Note how these load-specific opcodes take an ld (load) prefix.

**Table 19-5.** *The Primary Stack-Centric Opcodes of CIL*

Opcode	Meaning in Life
ldarg (with numerous variations)	Loads a method's argument onto the stack. In addition to the general ldarg (which works in conjunction with a given index that identifies the argument), there are numerous other variations. For example, ldarg opcodes that have a numerical suffix (ldarg.0) hard-code which argument to load. As well, variations of the ldarg opcode allow you to hard-code the data type using the CIL constant notation shown in Table 19-4 (ldarg_I4, for an int32), as well as the data type and value (ldarg_I4_5, to load an int32 with the value of 5).
ldc (with numerous variations)	Loads a constant value onto the stack.
ldfld (with numerous variations)	Loads the value of an instance-level field onto the stack.
ldloc (with numerous variations)	Loads the value of a local variable onto the stack.
ldobj	Obtains all the values gathered by a heap-based object and places them on the stack.
ldstr	Loads a string value onto the stack.

In addition to the set of load-specific opcodes, CIL provides numerous opcodes that *explicitly* pop the topmost value off the stack. As shown over the first few examples in this chapter, popping a value off the stack typically involves storing the value into temporary local storage for further use (such as a parameter for an upcoming method invocation). Given this, note how many opcodes that pop the current value off the virtual execution stack take an `st` (store) prefix. Table 19-6 hits the highlights.

**Table 19-6.** *Various Pop-Centric Opcodes*

Opcode	Meaning in Life
<code>pop</code>	Removes the value currently on top of the evaluation stack but does not bother to store the value
<code>starg</code>	Stores the value on top of the stack into the method argument at a specified index
<code>stloc</code> (with numerous variations)	Pops the current value from the top of the evaluation stack and stores it in a local variable list at a specified index
<code>stobj</code>	Copies a value of a specified type from the evaluation stack into a supplied memory address
<code>stsfld</code>	Replaces the value of a static field with a value from the evaluation stack

Do be aware that various CIL opcodes will *implicitly* pop values off the stack to perform the task at hand. For example, if you are attempting to subtract two numbers using the `sub` opcode, it should be clear that `sub` will have to pop off the next two available values before it can perform the calculation. Once the calculation is complete, the result of the value (surprise, surprise) is pushed onto the stack once again.

## The `.maxstack` Directive

When you write method implementations using raw CIL, you need to be mindful of a special directive named `.maxstack`. As its name suggests, `.maxstack` establishes the maximum number of variables that may be pushed onto the stack at any given time during the execution of the method. The good news is that the `.maxstack` directive has a default value (8), which should be safe for a vast majority of methods you might be authoring. However, if you want to be explicit, you are able to manually calculate the number of local variables on the stack and define this value explicitly, like so:

```
.method public hidebysig instance void
    Speak() cil managed
{
    // During the scope of this method, exactly
    // 1 value (the string literal) is on the stack.
    .maxstack 1
    ldstr "Hello there..."
    call void [mscorlib]System.Console::WriteLine(string)
    ret
}
```

## Declaring Local Variables in CIL

Let's first check out how to declare a local variable. Assume you want to build a method in CIL named `MyLocalVariables()` that takes no arguments and returns `void`. Within the method, you want to define three local variables of types `System.String`, `System.Int32`, and `System.Object`. In C#, this member would appear as follows (recall that locally scoped variables do not receive a default value and should be set to an initial state before further use):

```
public static void MyLocalVariables()
{
    string myStr = "CIL code is fun!";
    int myInt = 33;
    object myObj = new object();
}
```

If you were to construct `MyLocalVariables()` directly in CIL, you could author the following:

```
.method public hidebysig static void
    MyLocalVariables() cil managed
{
    .maxstack 8
    // Define three local variables.
    .locals init (string myStr, int32 myInt, object myObj)
    // Load a string onto the virtual execution stack.
    ldstr "CIL code is fun!"
    // Pop off current value and store in local variable [0].
    stloc.0

    // Load a constant of type "i4"
    // (shorthand for int32) set to the value 33.
    ldc.i4.s 33
    // Pop off current value and store in local variable [1].
    stloc.1

    // Create a new object and place on stack.
    newobj instance void [mscorlib]System.Object::.ctor()
    // Pop off current value and store in local variable [2].
    stloc.2
    ret
}
```

As you can see, the first step taken to allocate local variables in raw CIL is to use the `.locals` directive, which is paired with the `init` attribute. As you can see, each variable is identified by its data type and an optional variable name. After the local variables have been defined, you load a value onto the stack (using the various load-centric opcodes) and store the value within the local variable (using the various storage-centric opcodes).



## Mapping Parameters to Local Variables in CIL

You have already seen how to declare local variables in raw CIL using the `.locals init` directive; however, you have yet to see exactly how to map incoming parameters to local methods. Consider the following static C# method:

```
public static int Add(int a, int b)
{
    return a + b;
}
```

This innocent-looking method has a lot to say in terms of CIL. First, the incoming arguments (a and b) must be pushed onto the virtual execution stack using the `ldarg` (load argument) opcode. Next, the `add` opcode will be used to pop the next two values off the stack and find the summation and store the value on the stack yet again. Finally, this sum is popped off the stack and returned to the caller via the `ret` opcode. If you were to disassemble this C# method using `ildasm.exe`, you would find numerous additional tokens injected by the build process, but the crux of the CIL code is quite simple.

```
.method public hidebysig static int32 Add(int32 a,
    int32 b) cil managed
{
    .maxstack 2
    ldarg.0 // Load "a" onto the stack.
    ldarg.1 // Load "b" onto the stack.
    add     // Add both values.
    ret
}
```

## The Hidden `this` Reference

Notice that the two incoming arguments (a and b) are referenced within the CIL code using their indexed position (index 0 and index 1), given that the virtual execution stack begins indexing at position 0.

One thing to be mindful of when you are examining or authoring CIL code is that every nonstatic method that takes incoming arguments automatically receives an implicit additional parameter, which is a reference to the current object (similar to the C# `this` keyword). Given this, if the `Add()` method were defined as *nonstatic*, like so:

```
// No longer static!
public int Add(int a, int b)
{
    return a + b;
}
```

the incoming a and b arguments are loaded using `ldarg.1` and `ldarg.2` (rather than the expected `ldarg.0` and `ldarg.1` opcodes). Again, the reason is that slot 0 actually contains the implicit `this` reference. Consider the following pseudocode:

```
// This is JUST pseudocode!
.method public hidebysig static int32 AddTwoIntParams(
    MyClass_HiddenThisPointer this, int32 a, int32 b) cil managed
```

```

{
    ldarg.0 // Load MyClass_HiddenThisPointer onto the stack.
    ldarg.1 // Load "a" onto the stack.
    ldarg.2 // Load "b" onto the stack.
    ...
}

```

## Representing Iteration Constructs in CIL

Iteration constructs in the C# programming language are represented using the `for`, `foreach`, `while`, and `do` keywords, each of which has a specific representation in CIL. Consider the following classic `for` loop:

```

public static void CountToTen()
{
    for(int i = 0; i < 10; i++)
    {
    }
}

```

Now, as you may recall, the `br` opcodes (`br`, `blt`, etc.) are used to control a break in flow when some condition has been met. In this example, you have set up a condition in which the `for` loop should break out of its cycle when the local variable `i` is equal to or greater than the value of 10. With each pass, the value of 1 is added to `i`, at which point the test condition is yet again evaluated.

Also recall that when you use any of the CIL branching opcodes, you will need to define a specific code label (or two) that marks the location to jump to when the condition is indeed true. Given these points, ponder the following (edited) CIL code generated via `ildasm.exe` (including the autogenerated code labels):

```

.method public hidebysig static void CountToTen() cil managed
{
    .maxstack 2
    .locals init (int32 V_0, bool V_1)
    IL_0000: ldc.i4.0      // Load this value onto the stack.
    IL_0001: stloc.0      // Store this value at index "0".
    IL_0002: br.s IL_000b // Jump to IL_0008.
    IL_0003: ldloc.0      // Load value of variable at index 0.
    IL_0004: ldc.i4.1      // Load the value "1" on the stack.
    IL_0005: add         // Add current value on the stack at index 0.
    IL_0006: stloc.0
    IL_0007: ldloc.0      // Load value at index "0".
    IL_0008: ldc.i4.s 10  // Load value of "10" onto the stack.
    IL_0009: clt         // check less than value on the stack
    IL_000a: stloc.1      // Store result at index "1"
    IL_000b: ldloc.1      // Load value at index "1"
    IL_000c: brtrue.s IL_0002 // if true jump back to IL_0002
    IL_000d: ret
}

```

In a nutshell, this CIL code begins by defining the local `int32` and loading it onto the stack. At this point, you jump back and forth between code labels `IL_0008` and `IL_0004`, each time bumping the value of `i` by 1 and testing to see whether `i` is still less than the value 10. If so, you exit the method.

## The Final Word on CIL

Now that you see the process for creating an executable from an \*.IL file, you are probably thinking “that is an awful lot of work,” and then wondering “what’s the benefit.” For the vast majority, you will never create a .NET Core executable from IL. However, being able to understand IL can be very helpful if you are trying to dig into an assembly that you don’t have the source code for.

That being said, there are also commercial projects that can take a .NET Core assembly and reverse engineer it into source code. If you’ve ever used one of these tools, now you know how they work!

## Understanding Dynamic Assemblies

To be sure, the process of building a complex .NET Core application in CIL would be quite the labor of love. On the one hand, CIL is an extremely expressive programming language that allows you to interact with all the programming constructs allowed by the CTS. On the other hand, authoring raw CIL is tedious, error-prone, and painful. While it is true that knowledge is power, you might indeed wonder just how important it is to commit the laws of CIL syntax to memory. The answer is “it depends.” To be sure, most of your .NET Core programming endeavors will not require you to view, edit, or author CIL code. However, with the CIL primer behind you, you are now ready to investigate the world of dynamic assemblies (as opposed to static assemblies) and the role of the `System.Reflection.Emit` namespace.

The first question you may have is “What exactly is the difference between static and dynamic assemblies?” By definition, *static assemblies* are .NET binaries loaded directly from disk storage, meaning they are located somewhere on your hard drive in a physical file (or possibly a set of files in the case of a multifile assembly) at the time the CLR requests them. As you might guess, every time you compile your C# source code, you end up with a static assembly.

A *dynamic assembly*, on the other hand, is created in memory, on the fly, using the types provided by the `System.Reflection.Emit` namespace. The `System.Reflection.Emit` namespace makes it possible to create an assembly and its modules, type definitions, and CIL implementation logic *at runtime*. After you have done so, you are then free to save your in-memory binary to disk. This, of course, results in a new static assembly. To be sure, the process of building a dynamic assembly using the `System.Reflection.Emit` namespace does require some level of understanding regarding the nature of CIL opcodes.

Although creating dynamic assemblies is a fairly advanced (and uncommon) programming task, they can be useful under various circumstances. Here’s an example:

- You are building a .NET programming tool that needs to generate assemblies on demand based on user input.
- You are building a program that needs to generate proxies to remote types on the fly, based on the obtained metadata.
- You want to load a static assembly and dynamically insert new types into the binary image.

This being said, let’s check out the types within `System.Reflection.Emit`.

## Exploring the System.Reflection.Emit Namespace

Creating a dynamic assembly requires you to have some familiarity with CIL opcodes, but the types of the `System.Reflection.Emit` namespace hide the complexity of CIL as much as possible. For example, rather than directly specifying the necessary CIL directives and attributes to define a class type, you can simply use the `TypeBuilder` class. Likewise, if you want to define a new instance-level constructor, you have no need to emit the `specialname`, `rtspecialname`, or `.ctor` token; rather, you can use the `ConstructorBuilder`. Table 19-7 documents the key members of the `System.Reflection.Emit` namespace.

**Table 19-7.** *Select Members of the System.Reflection.Emit Namespace*

Members	Meaning in Life
AssemblyBuilder	Used to create an assembly (*.dll or *.exe) at runtime. *.exes must call the ModuleBuilder.SetEntryPoint() method to set the method that is the entry point to the module. If no entry point is specified, a *.dll will be generated.
ModuleBuilder	Used to define the set of modules within the current assembly.
EnumBuilder	Used to create a .NET enumeration type.
TypeBuilder	May be used to create classes, interfaces, structures, and delegates within a module at runtime.
MethodBuilder LocalBuilder PropertyBuilder FieldBuilder ConstructorBuilder CustomAttributeBuilder ParameterBuilder EventBuilder	Used to create type members (such as methods, local variables, properties, constructors, and attributes) at runtime.
ILGenerator	Emits CIL opcodes into a given type member.
OpCodes	Provides numerous fields that map to CIL opcodes. This type is used in conjunction with the various members of System.Reflection.Emit.ILGenerator.

In general, the types of the System.Reflection.Emit namespace allow you to represent raw CIL tokens programmatically during the construction of your dynamic assembly. You will see many of these members in the example that follows; however, the ILGenerator type is worth checking out straightaway.

## The Role of the System.Reflection.Emit.ILGenerator

As its name implies, the ILGenerator type’s role is to inject CIL opcodes into a given type member. However, you cannot directly create ILGenerator objects, as this type has no public constructors; rather, you receive an ILGenerator type by calling specific methods of the builder-centric types (such as the MethodBuilder and ConstructorBuilder types). Here’s an example:

```
// Obtain an ILGenerator from a ConstructorBuilder
// object named "myCtorBuilder".
ConstructorBuilder myCtorBuilder = /* */;
ILGenerator myCILGen = myCtorBuilder.GetILGenerator();
```

Once you have an ILGenerator in your hands, you are then able to emit the raw CIL opcodes using any number of methods. Table 19-8 documents some (but not all) methods of ILGenerator.

**Table 19-8.** *Various Methods of ILGenerator*

Method	Meaning in Life
BeginCatchBlock()	Begins a catch block
BeginExceptionBlock()	Begins an exception scope for an exception
BeginFinallyBlock()	Begins a finally block
BeginScope()	Begins a lexical scope
DeclareLocal()	Declares a local variable
DefineLabel()	Declares a new label
Emit()	Is overloaded numerous times to allow you to emit CIL opcodes
EmitCall()	Pushes a call or callvirt opcode into the CIL stream
EmitWriteLine()	Emits a call to Console.WriteLine() with different types of values
EndExceptionBlock()	Ends an exception block
EndScope()	Ends a lexical scope
ThrowException()	Emits an instruction to throw an exception
UsingNamespace()	Specifies the namespace to be used in evaluating locals and watches for the current active lexical scope

The key method of `ILGenerator` is `Emit()`, which works in conjunction with the `System.Reflection.Emit.OpCodes` class type. As mentioned earlier in this chapter, this type exposes a good number of read-only fields that map to raw CIL opcodes. The full set of these members are all documented within online help, and you will see various examples in the pages that follow.

## Emitting a Dynamic Assembly

To illustrate the process of defining a .NET Core assembly at runtime, let's walk through the process of creating a single-file dynamic assembly. Within this assembly is a class named `HelloWorld`. The `HelloWorld` class supports a default constructor and a custom constructor that is used to assign the value of a private member variable (the `message`) of type `string`. In addition, `HelloWorld` supports a public instance method named `SayHello()`, which prints a greeting to the standard I/O stream, and another instance method named `GetMsg()`, which returns the internal private string. In effect, you are going to programmatically generate the following class type:

```
// This class will be created at runtime
// using System.Reflection.Emit.
public class HelloWorld
{
    private string theMessage;
    HelloWorld() {}
    HelloWorld(string s) {theMessage = s;}
}
```

```

public string GetMsg() {return theMessage;}
public void SayHello()
{
    System.Console.WriteLine("Hello from the HelloWorld class!");
}
}

```

Assume you have created a new Console Application project named `DynamicAsmBuilder` and you add the `System.Reflection.Emit` NuGet package. Next, import the `System.Reflection` and `System.Reflection.Emit` namespaces. Define a static method named `CreateMyAsm()` in the `Program` class. This single method is in charge of the following:

- Defining the characteristics of the dynamic assembly (name, version, etc.)
- Implementing the `HelloClass` type
- Returning the `AssemblyBuilder` to the calling method

Here is the complete code, with analysis to follow:

```

public static AssemblyBuilder CreateMyAsm()
{
    // Establish general assembly characteristics.
    AssemblyName assemblyName = new AssemblyName
    {
        Name = "MyAssembly",
        Version = new Version("1.0.0.0")
    };

    // Create new assembly.
    var builder = AssemblyBuilder.DefineDynamicAssembly(
        assemblyName, AssemblyBuilderAccess.Run);

    // Define the name of the module.
    ModuleBuilder module =
        builder.DefineDynamicModule("MyAssembly");
    // Define a public class named "HelloWorld".
    TypeBuilder helloWorldClass =
        module.DefineType("MyAssembly.HelloWorld",
            TypeAttributes.Public);

    // Define a private String variable named "theMessage".
    FieldBuilder msgField = helloWorldClass.DefineField(
        "theMessage",
        Type.GetType("System.String"),
        attributes: FieldAttributes.Private);

    // Create the custom ctor.
    Type[] constructorArgs = new Type[1];
    constructorArgs[0] = typeof(string);
    ConstructorBuilder constructor =
        helloWorldClass.DefineConstructor(
            MethodAttributes.Public,

```

```

        CallingConventions.Standard,
        constructorArgs);
ILGenerator constructorIl = constructor.GetILGenerator();
constructorIl.Emit(OpCodes.Ldarg_0);
Type objectClass = typeof(object);
ConstructorInfo superConstructor =
    objectClass.GetConstructor(new Type[0]);
constructorIl.Emit(OpCodes.Call, superConstructor);
constructorIl.Emit(OpCodes.Ldarg_0);
constructorIl.Emit(OpCodes.Ldarg_1);
constructorIl.Emit(OpCodes.Stfld, msgField);
constructorIl.Emit(OpCodes.Ret);

// Create the default ctor.
helloWorldClass.DefineDefaultConstructor(
    MethodAttributes.Public);
// Now create the GetMsg() method.
MethodBuilder getMsgMethod = helloWorldClass.DefineMethod(
    "GetMsg",
    MethodAttributes.Public,
    typeof(string),
    null);
ILGenerator methodIl = getMsgMethod.GetILGenerator();
methodIl.Emit(OpCodes.Ldarg_0);
methodIl.Emit(OpCodes.Ldfld, msgField);
methodIl.Emit(OpCodes.Ret);

// Create the SayHello method.
MethodBuilder sayHiMethod = helloWorldClass.DefineMethod(
    "SayHello", MethodAttributes.Public, null, null);
methodIl = sayHiMethod.GetILGenerator();
methodIl.EmitWriteLine("Hello from the HelloWorld class!");
methodIl.Emit(OpCodes.Ret);

// "Bake" the class HelloWorld.
// (Baking is the formal term for emitting the type.)
helloWorldClass.CreateType();

return builder;
}

```

## Emitting the Assembly and Module Set

The method body begins by establishing the minimal set of characteristics about your assembly, using the `AssemblyName` and `Version` types (defined in the `System.Reflection` namespace). Next, you obtain an `AssemblyBuilder` type via the static `AssemblyBuilder.DefineDynamicAssembly()` method.

When calling `DefineDynamicAssembly()`, you must specify the access mode of the assembly you want to define, the most common values of which are shown in Table 19-9.

**Table 19-9.** *Common Values of the `AssemblyBuilderAccess` Enumeration*

Value	Meaning in Life
<code>RunAndCollect</code>	The assembly will be immediately unloaded and its memory reclaimed once it is no longer accessible.
<code>Run</code>	Represents that a dynamic assembly can be executed in memory but not saved to disk.

The next task is to define the module set (and its name) for your new assembly. Once the `DefineDynamicModule()` method has returned, you are provided with a reference to a valid `ModuleBuilder` type.

```
// Create new assembly.
var builder = AssemblyBuilder.DefineDynamicAssembly(
    assemblyName, AssemblyBuilderAccess.Run);
```

## The Role of the `ModuleBuilder` Type

`ModuleBuilder` is the key type used during the development of dynamic assemblies. As you would expect, `ModuleBuilder` supports a number of members that allow you to define the set of types contained within a given module (classes, interfaces, structures, etc.) as well as the set of embedded resources (string tables, images, etc.) contained within. Table 19-10 describes two of the creation-centric methods. (Do note that each method will return to you a related type that represents the type you want to construct.)

**Table 19-10.** *Select Members of the `ModuleBuilder` Type*

Method	Meaning in Life
<code>DefineEnum()</code>	Used to emit a .NET enum definition
<code>DefineType()</code>	Constructs a <code>TypeBuilder</code> , which allows you to define value types, interfaces, and class types (including delegates)

The key member of the `ModuleBuilder` class to be aware of is `DefineType()`. In addition to specifying the name of the type (via a simple string), you will also use the `System.Reflection.TypeAttributes` enum to describe the format of the type itself. Table 19-11 lists some (but not all) of the key members of the `TypeAttributes` enumeration.



**Table 19-11.** *Select Members of the TypeAttributes Enumeration*

Member	Meaning in Life
Abstract	Specifies that the type is abstract
Class	Specifies that the type is a class
Interface	Specifies that the type is an interface
NestedAssembly	Specifies that the class is nested with assembly visibility and is thus accessible only by methods within its assembly
NestedFamANDAssem	Specifies that the class is nested with assembly and family visibility and is thus accessible only by methods lying in the intersection of its family and assembly
NestedFamily	Specifies that the class is nested with family visibility and is thus accessible only by methods within its own type and any subtypes
NestedFamORAssem	Specifies that the class is nested with family or assembly visibility and is thus accessible only by methods lying in the union of its family and assembly
NestedPrivate	Specifies that the class is nested with private visibility
NestedPublic	Specifies that the class is nested with public visibility
NotPublic	Specifies that the class is not public
Public	Specifies that the class is public
Sealed	Specifies that the class is concrete and cannot be extended
Serializable	Specifies that the class can be serialized

## Emitting the HelloWorld Type and the String Member Variable

Now that you have a better understanding of the role of the `ModuleBuilder.CreateType()` method, let's examine how you can emit the public `HelloWorld` class type and the private string variable.

**// Define a public class named "HelloWorld".**

```
TypeBuilder helloWorldClass =
    module.DefineType("MyAssembly.HelloWorld",
        TypeAttributes.Public);
```

**// Define a private String variable named "theMessage".**

```
FieldBuilder msgField = helloWorldClass.DefineField(
    "theMessage",
    Type.GetType("System.String"),
    attributes: FieldAttributes.Private);
```

Notice how the `TypeBuilder.DefineField()` method provides access to a `FieldBuilder` type. The `TypeBuilder` class also defines other methods that provide access to other “builder” types. For example, `DefineConstructor()` returns a `ConstructorBuilder`, `DefineProperty()` returns a `PropertyBuilder`, and so forth.

## Emitting the Constructors

As mentioned earlier, the `TypeBuilder.DefineConstructor()` method can be used to define a constructor for the current type. However, when it comes to implementing the constructor of `HelloClass`, you need to inject raw CIL code into the constructor body, which is responsible for assigning the incoming parameter to the internal private string. To obtain an `ILGenerator` type, you call the `GetILGenerator()` method from the respective “builder” type you have reference to (in this case, the `ConstructorBuilder` type).

The `Emit()` method of the `ILGenerator` class is the entity in charge of placing CIL into a member implementation. `Emit()` itself makes frequent use of the `OpCodes` class type, which exposes the opcode set of CIL using read-only fields. For example, `OpCodes.Ret` signals the return of a method call, `OpCodes.Stfld` makes an assignment to a member variable, and `OpCodes.Call` is used to call a given method (in this case, the base class constructor). That said, ponder the following constructor logic:

```
// Create the custom ctor taking single string arg.
Type[] constructorArgs = new Type[1];
constructorArgs[0] = typeof(string);
ConstructorBuilder constructor =
    helloWorldClass.DefineConstructor(
        MethodAttributes.Public,
        CallingConventions.Standard,
        constructorArgs);
//Emit the necessary CIL into the ctor
ILGenerator constructorIl = constructor.GetILGenerator();
constructorIl.Emit(OpCodes.Ldarg_0);
Type objectClass = typeof(object);
ConstructorInfo superConstructor =
    objectClass.GetConstructor(new Type[0]);
constructorIl.Emit(OpCodes.Call, superConstructor);
//Load this pointer onto the stack
constructorIl.Emit(OpCodes.Ldarg_0);
constructorIl.Emit(OpCodes.Ldarg_1);
//Load argument on virtual stack and store in msdField
constructorIl.Emit(OpCodes.Stfld, msgField);
constructorIl.Emit(OpCodes.Ret);
```

Now, as you are well aware, as soon as you define a custom constructor for a type, the default constructor is silently removed. To redefine the no-argument constructor, simply call the `DefineDefaultConstructor()` method of the `TypeBuilder` type as follows:

```
// Create the default ctor.
helloWorldClass.DefineDefaultConstructor(
    MethodAttributes.Public);
```

## Emitting the SayHello() Method

Last but not least, let’s examine the process of emitting the `SayHello()` method. The first task is to obtain a `MethodBuilder` type from the `helloWorldClass` variable. After you do this, you define the method and obtain the underlying `ILGenerator` to inject the CIL instructions, like so:

```
// Create the SayHello method.
MethodBuilder sayHiMethod = helloWorldClass.DefineMethod(
```

```
"SayHello", MethodAttributes.Public, null, null);
methodIl = sayHiMethod.GetILGenerator();
```

### **//Write to the console**

```
methodIl.EmitWriteLine("Hello from the HelloWorld class!");
methodIl.Emit(OpCodes.Ret);
```

Here you have established a public method (`MethodAttributes.Public`) that takes no parameters and returns nothing (marked by the null entries contained in the `DefineMethod()` call). Also note the `EmitWriteLine()` call. This helper member of the `ILGenerator` class automatically writes a line to the standard output with minimal fuss and bother.

## Using the Dynamically Generated Assembly

Now that you have the logic in place to create your assembly, all that's needed is to execute the generated code. The logic in `Main()` calls the `CreateMyAsm()` method, getting a reference to the created `AssemblyBuilder`.

Next, you will exercise some late binding (see Chapter 17) to create an instance of the `HelloWorld` class and interact with its members. Update your `Main()` method as follows:

```
static void Main(string[] args)
{
    Console.WriteLine("***** The Amazing Dynamic Assembly Builder App *****");
    // Create the assembly builder using our helper f(x).
    AssemblyBuilder builder = CreateMyAsm();

    // Get the HelloWorld type.
    Type hello = builder.GetType("MyAssembly.HelloWorld");

    // Create HelloWorld instance and call the correct ctor.
    Console.Write("-> Enter message to pass HelloWorld class: ");
    string msg = Console.ReadLine();
    object[] ctorArgs = new object[1];
    ctorArgs[0] = msg;
    object obj = Activator.CreateInstance(hello, ctorArgs);

    // Call SayHello and show returned string.
    Console.WriteLine("-> Calling SayHello() via late binding.");
    MethodInfo mi = hello.GetMethod("SayHello");
    mi.Invoke(obj, null);

    // Invoke method.
    mi = hello.GetMethod("GetMsg");
    Console.WriteLine(mi.Invoke(obj, null));
}
```

In effect, you have just created a .NET Core assembly that is able to create and execute .NET Core assemblies at runtime! That wraps up the examination of CIL and the role of dynamic assemblies. I hope this chapter has deepened your understanding of the .NET Core type system, the syntax and semantics of CIL, and how the C# compiler processes your code at compile time.

## Summary

This chapter provided an overview of the syntax and semantics of CIL. Unlike higher-level managed languages such as C#, CIL does not simply define a set of keywords but provides directives (used to define the structure of an assembly and its types), attributes (which further qualify a given directive), and opcodes (which are used to implement type members).

You were introduced to a few CIL-centric programming tools and learned how to alter the contents of a .NET assembly with new CIL instructions using round-trip engineering. After this point, you spent time learning how to establish the current (and referenced) assembly, namespaces, types, and members. I wrapped up with a simple example of building a .NET code library and executable using little more than CIL, command-line tools, and a bit of elbow grease.

Finally, you took an introductory look at the process of creating a *dynamic assembly*. Using the `System.Reflection.Emit` namespace, it is possible to define a .NET Core assembly in memory at runtime. As you have seen firsthand, using this particular API requires you to know the semantics of CIL code in some detail. While the need to build dynamic assemblies is certainly not a common task for most .NET Core applications, it can be useful for those of you who need to build support tools and other programming utilities.

## PART VI



# File and Data Handling

## CHAPTER 20



# File I/O and Object Serialization

When you create desktop applications, the ability to save information between user sessions is commonplace. This chapter examines a number of I/O-related topics as seen through the eyes of the .NET Core Framework. The first order of business is to explore the core types defined in the `System.IO` namespace and learn how to modify a machine's directory and file structure programmatically. The next task is to explore various ways to read from and write to character-based, binary-based, string-based, and memory-based data stores.

After you learn how to manipulate files and directories using the core I/O types, you will examine the related topic of *object serialization*. You can use object serialization to persist and retrieve the state of an object to (or from) any `System.IO.Stream`-derived type.

---

■ **Note** To ensure you can run each of the examples in this chapter, start Visual Studio with administrative rights (just right-click the Visual Studio icon and select Run as Administrator. If you do not do so, you may encounter runtime security exceptions when accessing the computer file system).

---

## Exploring the System.IO Namespace

In the framework of .NET Core, the `System.IO` namespace is the region of the base class libraries devoted to file-based (and memory-based) input and output (I/O) services. Like any namespace, `System.IO` defines a set of classes, interfaces, enumerations, structures, and delegates, most of which you can find in `mscorlib.dll`. In addition to the types contained within `mscorlib.dll`, the `System.dll` assembly defines additional members of the `System.IO` namespace.

Many of the types within the `System.IO` namespace focus on the programmatic manipulation of physical directories and files. However, additional types provide support to read data from and write data to string buffers, as well as raw memory locations. Table 20-1 outlines the core (nonabstract) classes, providing a road map of the functionality in `System.IO`.

**Table 20-1.** Key Members of the *System.IO* Namespace

Nonabstract I/O Class Type	Meaning in Life
BinaryReader BinaryWriter	These classes allow you to store and retrieve primitive data types (integers, Booleans, strings, and whatnot) as a binary value.
BufferedStream	This class provides temporary storage for a stream of bytes that you can commit to storage at a later time.
Directory DirectoryInfo	You use these classes to manipulate a machine’s directory structure. The <i>Directory</i> type exposes functionality using <i>static members</i> , while the <i>DirectoryInfo</i> type exposes similar functionality from a valid <i>object reference</i> .
DriveInfo	This class provides detailed information regarding the drives that a given machine uses.
File FileInfo	You use these classes to manipulate a machine’s set of files. The <i>File</i> type exposes functionality using <i>static members</i> , while the <i>FileInfo</i> type exposes similar functionality from a valid <i>object reference</i> .
FileStream	This class gives you random file access (e.g., seeking capabilities) with data represented as a stream of bytes.
FileSystemWatcher	This class allows you to monitor the modification of external files in a specified directory.
MemoryStream	This class provides random access to streamed data stored in memory rather than in a physical file.
Path	This class performs operations on <i>System.String</i> types that contain file or directory path information in a platform-neutral manner.
StreamWriter StreamReader	You use these classes to store (and retrieve) textual information to (or from) a file. These types do not support random file access.
StringWriter StringReader	Like the <i>StreamReader/StreamWriter</i> classes, these classes also work with textual information. However, the underlying storage is a string buffer rather than a physical file.

In addition to these concrete class types, *System.IO* defines a number of enumerations, as well as a set of abstract classes (e.g., *Stream*, *TextReader*, and *TextWriter*), that define a shared polymorphic interface to all descendants. You will read about many of these types in this chapter.

## The Directory(Info) and File(Info) Types

*System.IO* provides four classes that allow you to manipulate individual files, as well as interact with a machine’s directory structure. The first two types, *Directory* and *File*, expose creation, deletion, copying, and moving operations using various static members. The closely related *FileInfo* and *DirectoryInfo* types expose similar functionality as instance-level methods (therefore, you must allocate them with the new keyword). The *Directory* and *File* classes directly extend *System.Object*, while *DirectoryInfo* and *FileInfo* derive from the abstract *FileSystemInfo* type.

`FileInfo` and `DirectoryInfo` typically serve as better choices for obtaining full details of a file or directory (e.g., time created or read/write capabilities) because their members tend to return strongly typed objects. In contrast, the `Directory` and `File` class members tend to return simple string values rather than strongly typed objects. This is only a guideline, however; in many cases, you can get the same work done using `File/FileInfo` or `Directory/DirectoryInfo`.

## The Abstract `FileSystemInfo` Base Class

The `DirectoryInfo` and `FileInfo` types receive many behaviors from the abstract `FileSystemInfo` base class. For the most part, you use the members of the `FileSystemInfo` class to discover general characteristics (such as time of creation, various attributes, etc.) about a given file or directory. Table 20-2 lists some core properties of interest.

**Table 20-2.** *FileSystemInfo Properties*

Property	Meaning in Life
Attributes	Gets or sets the attributes associated with the current file that are represented by the <code>FileAttributes</code> enumeration (e.g., is the file or directory read-only, encrypted, hidden, or compressed?)
CreationTime	Gets or sets the time of creation for the current file or directory
Exists	Determines whether a given file or directory exists
Extension	Retrieves a file's extension
FullName	Gets the full path of the directory or file
LastAccessTime	Gets or sets the time the current file or directory was last accessed
LastWriteTime	Gets or sets the time when the current file or directory was last written to
Name	Obtains the name of the current file or directory

`FileSystemInfo` also defines the `Delete()` method. This is implemented by derived types to delete a given file or directory from the hard drive. Also, you can call `Refresh()` prior to obtaining attribute information to ensure that the statistics regarding the current file (or directory) are not outdated.

## Working with the `DirectoryInfo` Type

The first creatable I/O-centric type you will examine is the `DirectoryInfo` class. This class contains a set of members used for creating, moving, deleting, and enumerating over directories and subdirectories. In addition to the functionality provided by its base class (`FileSystemInfo`), `DirectoryInfo` offers the key members detailed in Table 20-3.



**Table 20-3.** *Key Members of the DirectoryInfo Type*

Member	Meaning in Life
Create() CreateSubdirectory()	Creates a directory (or set of subdirectories) when given a path name
Delete()	Deletes a directory and all its contents
GetDirectories()	Returns an array of DirectoryInfo objects that represent all subdirectories in the current directory
GetFiles()	Retrieves an array of FileInfo objects that represent a set of files in the given directory
MoveTo()	Moves a directory and its contents to a new path
Parent	Retrieves the parent directory of this directory
Root	Gets the root portion of a path

You begin working with the DirectoryInfo type by specifying a particular directory path as a constructor parameter. Use the dot (.) notation if you want to obtain access to the current working directory (the directory of the executing application). Here are some examples:

```
// Bind to the current working directory.
DirectoryInfo dir1 = new DirectoryInfo(".");
// Bind to C:\Windows,
// using a verbatim string.
DirectoryInfo dir2 = new DirectoryInfo(@"C:\Windows");
```

In the second example, you assume that the path passed into the constructor (C:\Windows) already exists on the physical machine. However, if you attempt to interact with a nonexistent directory, a System.IO.DirectoryNotFoundException is thrown. Thus, if you specify a directory that is not yet created, you need to call the Create() method before proceeding, like so:

```
// Bind to a nonexistent directory, then create it.
DirectoryInfo dir3 = new DirectoryInfo(@"C:\MyCode\Testing");
dir3.Create();
```

The path syntax used in the previous example is Windows-centric. If you are developing .NET Core applications for different platforms, you should use the Path.VolumeSeparatorChar and Path.DirectorySeparatorChar constructs, which will yield the appropriate characters based on the platform. Update the previous code to the following:

```
DirectoryInfo dir3 = new DirectoryInfo(
    $"{Path.VolumeSeparatorChar}{Path.DirectorySeparatorChar}MyCode{
    Path.DirectorySeparatorChar}Testing");
```

After you create a DirectoryInfo object, you can investigate the underlying directory contents using any of the properties inherited from FileSystemInfo. To see this in action, create a new Console Application project named DirectoryApp and update your C# file to import System and System.IO. Update your Program class with the following new static method that creates a new DirectoryInfo object mapped to C:\Windows (adjust your path if need be), which displays a number of interesting statistics:

```

class Program
{
    static void Main(string[] args)
    {
        Console.WriteLine("***** Fun with Directory(Info) *****\n");
        ShowWindowsDirectoryInfo();
        Console.ReadLine();
    }

    static void ShowWindowsDirectoryInfo()
    {
        // Dump directory information. If you are not on Windows, plug in another directory
        DirectoryInfo dir = new DirectoryInfo($"{Path.VolumeSeparatorChar}
        {Path.DirectorySeparatorChar}Windows");
        Console.WriteLine("***** Directory Info *****");
        Console.WriteLine("FullName: {0}", dir.FullName);
        Console.WriteLine("Name: {0}", dir.Name);
        Console.WriteLine("Parent: {0}", dir.Parent);
        Console.WriteLine("Creation: {0}", dir.CreationTime);
        Console.WriteLine("Attributes: {0}", dir.Attributes);
        Console.WriteLine("Root: {0}", dir.Root);
        Console.WriteLine("*****\n");
    }
}

```

While your output might differ, you should see something similar to the following:

---

```

***** Fun with Directory(Info) *****

***** Directory Info *****
FullName: C:\Windows
Name: Windows
Parent:
Creation: 3/19/2019 00:37:22
Attributes: Directory
Root: C:\
*****

```

---

## Enumerating Files with the DirectoryInfo Type

In addition to obtaining basic details of an existing directory, you can extend the current example to use some methods of the `DirectoryInfo` type. First, you can leverage the `GetFiles()` method to obtain information about all `*.jpg` files located in the `C:\Windows\Web\Wallpaper` directory.

---

■ **Note** If you are not on a Windows machine, retrofit this code to read files of a directory on your machine. Remember to use the `Path.VolumeSeparatorChar` and `Path.DirectorySeparatorChar` values to make your code cross-platform compatible.

---

The `GetFiles()` method returns an array of `FileInfo` objects, each of which exposes details of a particular file (you will learn the full details of the `FileInfo` type later in this chapter). Assume that you have the following static method of the `Program` class, which you call from `Main()`:

```
static void DisplayImageFiles()
{
    DirectoryInfo dir = new
        DirectoryInfo(@"C:\Windows\Web\Wallpaper");
    // Get all files with a *.jpg extension.
    FileInfo[] imageFiles =
        dir.GetFiles("*.jpg", SearchOption.AllDirectories);

    // How many were found?
    Console.WriteLine("Found {0} *.jpg files\n", imageFiles.Length);

    // Now print out info for each file.
    foreach (FileInfo f in imageFiles)
    {
        Console.WriteLine("*****");
        Console.WriteLine("File name: {0}", f.Name);
        Console.WriteLine("File size: {0}", f.Length);
        Console.WriteLine("Creation: {0}", f.CreationTime);
        Console.WriteLine("Attributes: {0}", f.Attributes);
        Console.WriteLine("*****\n");
    }
}
```

Notice that you specify a search option when you call `GetFiles()`; you do this to look within all subdirectories of the root. After you run the application, you will see a listing of all files that match the search pattern.

## Creating Subdirectories with the `DirectoryInfo` Type

You can programmatically extend a directory structure using the `DirectoryInfo.CreateSubdirectory()` method. This method can create a single subdirectory, as well as multiple nested subdirectories, in a single function call. This method illustrates how to do so, extending the directory structure of the application execution directory (denoted with the `"."`) with some custom subdirectories:

```
static void ModifyAppDirectory()
{
    DirectoryInfo dir = new DirectoryInfo(".");

    // Create \MyFolder off application directory.
    dir.CreateSubdirectory("MyFolder");

    // Create \MyFolder2\Data off application directory.
    dir.CreateSubdirectory(
        $"MyFolder2{Path.DirectorySeparatorChar}Data");
}
```

You are not required to capture the return value of the `CreateSubdirectory()` method, but you should be aware that a `DirectoryInfo` object representing the newly created item is passed back on successful execution. Consider the following update to the previous method:

```
static void ModifyAppDirectory()
{
    DirectoryInfo dir = new DirectoryInfo(".");

    // Create \MyFolder off initial directory.
    dir.CreateSubdirectory("MyFolder");

    // Capture returned DirectoryInfo object.
    DirectoryInfo myDataFolder = dir.CreateSubdirectory(
        $"{Path.DirectorySeparatorChar}Data");

    // Prints path to ..\MyFolder2\Data.
    Console.WriteLine("New Folder is: {0}", myDataFolder);
}
```

If you call this method from within `Main()` and examine your Windows directory using Windows Explorer, you will see that the new subdirectories are present and accounted for.

## Working with the Directory Type

You have seen the `DirectoryInfo` type in action; now you're ready to learn about the `Directory` type. For the most part, the static members of `Directory` mimic the functionality provided by the instance-level members defined by `DirectoryInfo`. Recall, however, that the members of `Directory` typically return string data rather than strongly typed `FileInfo`/`DirectoryInfo` objects.

Now let's look at some functionality of the `Directory` type. This final helper function displays the names of all drives mapped to the current computer (using the `Directory.GetLogicalDrives()` method) and uses the static `Directory.Delete()` method to remove the `\MyFolder` and `\MyFolder2\Data` subdirectories created previously.

```
static void FunWithDirectoryType()
{
    // List all drives on current computer.
    string[] drives = Directory.GetLogicalDrives();
    Console.WriteLine("Here are your drives:");
    foreach (string s in drives)
    {
        Console.WriteLine("--> {0} ", s);
    }

    // Delete what was created.
    Console.WriteLine("Press Enter to delete directories");
    Console.ReadLine();
    try
    {
        Directory.Delete("MyFolder");
    }
```

```

    // The second parameter specifies whether you
    // wish to destroy any subdirectories.
    Directory.Delete("MyFolder2", true);
}
catch (IOException e)
{
    Console.WriteLine(e.Message);
}
}

```

## Working with the DriveInfo Class Type

The `System.IO` namespace provides a class named `DriveInfo`. Like `Directory.GetLogicalDrives()`, the static `DriveInfo.GetDrives()` method allows you to discover the names of a machine's drives. Unlike `Directory.GetLogicalDrives()`, however, `DriveInfo` provides numerous other details (e.g., the drive type, available free space, and volume label). Consider the following `Program` class defined within a new Console Application project named `DriveInfoApp` (don't forget to import `System.IO`):

```

class Program
{
    static void Main(string[] args)
    {
        Console.WriteLine("***** Fun with DriveInfo *****\n");

        // Get info regarding all drives.
        DriveInfo[] myDrives = DriveInfo.GetDrives();
        // Now print drive stats.
        foreach(DriveInfo d in myDrives)
        {
            Console.WriteLine("Name: {0}", d.Name);
            Console.WriteLine("Type: {0}", d.DriveType);

            // Check to see whether the drive is mounted.
            if(d.IsReady)
            {
                Console.WriteLine("Free space: {0}", d.TotalFreeSpace);
                Console.WriteLine("Format: {0}", d.DriveFormat);
                Console.WriteLine("Label: {0}", d.VolumeLabel);
            }
            Console.WriteLine();
        }
        Console.ReadLine();
    }
}

```

Here is some possible output:

---

```
***** Fun with DriveInfo *****
```

```
Name: C:\
Type: Fixed
Free space: 284131119104
Format: NTFS
Label: OS
```

```
Name: M:\
Type: Network
Free space: 4711871942656
Format: NTFS
Label: DigitalMedia
```

---

At this point, you have investigated some core behaviors of the `Directory`, `DirectoryInfo`, and `DriveInfo` classes. Next, you'll learn how to create, open, close, and destroy the files that populate a given directory.

## Working with the FileInfo Class

As shown in the previous `DirectoryApp` example, the `FileInfo` class allows you to obtain details regarding existing files on your hard drive (e.g., time created, size, and file attributes) and aids in the creation, copying, moving, and destruction of files. In addition to the set of functionality inherited by `FileSystemInfo`, you can find some core members unique to the `FileInfo` class, which you can see described in Table 20-4.

**Table 20-4.** *FileInfo Core Members*

Member	Meaning in Life
<code>AppendText()</code>	Creates a <code>StreamWriter</code> object (described later) that appends text to a file
<code>CopyTo()</code>	Copies an existing file to a new file
<code>Create()</code>	Creates a new file and returns a <code>FileStream</code> object (described later) to interact with the newly created file
<code>CreateText()</code>	Creates a <code>StreamWriter</code> object that writes a new text file
<code>Delete()</code>	Deletes the file to which a <code>FileInfo</code> instance is bound
<code>Directory</code>	Gets an instance of the parent directory
<code>DirectoryName</code>	Gets the full path to the parent directory
<code>Length</code>	Gets the size of the current file
<code>MoveTo()</code>	Moves a specified file to a new location, providing the option to specify a new file name
<code>Name</code>	Gets the name of the file
<code>Open()</code>	Opens a file with various read/write and sharing privileges
<code>OpenRead()</code>	Creates a read-only <code>FileStream</code> object
<code>OpenText()</code>	Creates a <code>StreamReader</code> object (described later) that reads from an existing text file
<code>OpenWrite()</code>	Creates a write-only <code>FileStream</code> object

Note that a majority of the methods of the `FileInfo` class return a specific I/O-centric object (e.g., `FileStream` and `StreamWriter`) that allows you to begin reading and writing data to (or reading from) the associated file in a variety of formats. You will check out these types in just a moment; however, before you see a working example, you'll find it helpful to examine various ways to obtain a file handle using the `FileInfo` class type.

## The `FileInfo.Create()` Method

One way you can create a file handle is to use the `FileInfo.Create()` method, like so:

```
static void Main(string[] args)
{
    var fileName = $"C{Path.VolumeSeparatorChar}{Path.DirectorySeparatorChar}Test.dat";
    // Make a new file on the C drive.
    FileInfo f = new FileInfo(fileName);
    FileStream fs = f.Create();

    // Use the FileStream object...

    // Close down file stream.
    fs.Close();
}
```

---

■ **Note** These examples require running Visual Studio (or Visual Studio Code) as an Administrator.

---

Notice that the `FileInfo.Create()` method returns a `FileStream` object, which exposes synchronous and asynchronous write/read operations to/from the underlying file (more details in a moment). Be aware that the `FileStream` object returned by `FileInfo.Create()` grants full read/write access to all users.

Also notice that after you finish with the current `FileStream` object, you must ensure you close down the handle to release the underlying unmanaged stream resources. Given that `FileStream` implements `IDisposable`, you can use the C# using scope to allow the compiler to generate the teardown logic (see Chapter 8 for details), like so:

```
static void Main(string[] args)
{
    var fileName = $"C{Path.VolumeSeparatorChar}{Path.DirectorySeparatorChar}Test.dat";
    ...
    // Defining a using scope for file I/O
    FileInfo f = new FileInfo(fileName);
    using (FileStream fs = f.Create())
    {
        // Use the FileStream object...
    }
    f.Delete();
}
```

---

■ **Note** Almost all of these examples in this chapter include using statements. I could have used the new using declaration syntax, but chose not to in this rewrite to keep the examples focused on the System.IO components that we are examining.

---

## The FileInfo.Open() Method

You can use the `FileInfo.Open()` method to open existing files, as well as to create new files with far more precision than you can with `FileInfo.Create()`. This works because `Open()` typically takes several parameters to qualify exactly how to iterate the file you want to manipulate. Once the call to `Open()` completes, you are returned a `FileStream` object. Consider the following logic:

```
static void Main(string[] args)
{
    var fileName = $"C:{Path.VolumeSeparatorChar}{Path.DirectorySeparatorChar}Test.dat";
    ...
    // Make a new file via FileInfo.Open().
    FileInfo f2 = new FileInfo(fileName);
    using(FileStream fs2 = f2.Open(FileMode.OpenOrCreate,
        FileAccess.ReadWrite, FileShare.None))
    {
        // Use the FileStream object...
    }
    f2.Delete();
}
```

This version of the overloaded `Open()` method requires three parameters. The first parameter of the `Open()` method specifies the general flavor of the I/O request (e.g., make a new file, open an existing file, and append to a file), which you specify using the `FileMode` enumeration (see Table 20-5 for details), like so:

```
public enum FileMode
{
    CreateNew,
    Create,
    Open,
    OpenOrCreate,
    Truncate,
    Append
}
```



**Table 20-5.** *Members of the FileMode Enumeration*

Member	Meaning in Life
CreateNew	Informs the OS to make a new file. If it already exists, an IOException is thrown.
Create	Informs the OS to make a new file. If it already exists, it will be overwritten.
Open	Opens an existing file. If the file does not exist, a FileNotFoundException is thrown.
OpenOrCreate	Opens the file if it exists; otherwise, a new file is created.
Truncate	Opens an existing file and truncates the file to 0 bytes in size.
Append	Opens a file, moves to the end of the file, and begins write operations (you can use this flag only with a write-only stream). If the file does not exist, a new file is created.

You use the second parameter of the `Open()` method, a value from the `FileAccess` enumeration, to determine the read/write behavior of the underlying stream, as follows:

```
public enum FileAccess
{
    Read,
    Write,
    ReadWrite
}
```

Finally, the third parameter of the `Open()` method, `FileShare`, specifies how to share the file among other file handlers. Here are the core names:

```
public enum FileShare
{
    None,
    Read,
    Write,
    ReadWrite,
    Delete,
    Inheritable
}
```

## The FileInfo.OpenRead() and FileInfo.OpenWrite() Methods

The `FileInfo.Open()` method allows you to obtain a file handle in a flexible manner, but the `FileInfo` class also provides members named `OpenRead()` and `OpenWrite()`. As you might imagine, these methods return a properly configured read-only or write-only `FileStream` object, without the need to supply various enumeration values. Like `FileInfo.Create()` and `FileInfo.Open()`, `OpenRead()` and `OpenWrite()` return a `FileStream` object.

Note that the `OpenRead()` method requires the file to already exist. The following code creates the file and then closes the `FileStream` so it can be used by the `OpenRead` method:

```
f3.Create().Close();
```

Here are the full examples:

```
static void Main(string[] args)
{
    var fileName = $"{Path.VolumeSeparatorChar}{Path.DirectorySeparatorChar}Test.dat";
    ...
    // Get a FileStream object with read-only permissions.
    FileInfo f3 = new FileInfo(fileName);
    //File must exist before using OpenRead
    f3.Create().Close();
    using(FileStream readOnlyStream = f3.OpenRead())
    {
        // Use the FileStream object...
    }
    f3.Delete();

    // Now get a FileStream object with write-only permissions.
    FileInfo f4 = new FileInfo(fileName);
    using(FileStream writeOnlyStream = f4.OpenWrite())
    {
        // Use the FileStream object...
    }
    f4.Delete();
}
```

## The FileInfo.OpenText() Method

Another open-centric member of the `FileInfo` type is `OpenText()`. Unlike `Create()`, `Open()`, `OpenRead()`, or `OpenWrite()`, the `OpenText()` method returns an instance of the `StreamReader` type, rather than a `FileStream` type. Assuming you have a file named `boot.ini` on your `C:` drive, the following snippet gives you access to its contents:

```
static void Main(string[] args)
{
    var fileName = $"{Path.VolumeSeparatorChar}{Path.DirectorySeparatorChar}Test.dat";
    ...
    // Get a StreamReader object.
    //If not on a Windows machine, change the file name accordingly
    FileInfo f5 = new FileInfo(fileName);
    //File must exist before using OpenRead
    f5.Create().Close();
    using(StreamReader sreader = f5.OpenText())
    {
        // Use the StreamReader object...
    }
    f5.Delete();
}
```

As you will see shortly, the `StreamReader` type provides a way to read character data from the underlying file.

## The FileInfo.CreateText() and FileInfo.AppendText() Methods

The final two FileInfo methods of interest at this point are CreateText() and AppendText(). Both return a StreamWriter object, as shown here:

```
static void Main(string[] args)
{
    var fileName = $"{Path.VolumeSeparatorChar}{Path.DirectorySeparatorChar}Test.dat";
    ...
    FileInfo f6 = new FileInfo(fileName);
    using(StreamWriter swriter = f6.CreateText())
    {
        // Use the StreamWriter object...
    }
    f6.Delete();
    FileInfo f7 = new FileInfo(fileName);
    using(StreamWriter swriterAppend = f7.AppendText())
    {
        // Use the StreamWriter object...
    }
    f7.Delete();
}
```

As you might guess, the StreamWriter type provides a way to write character data to the underlying file.

## Working with the File Type

The File type uses several static members to provide functionality almost identical to that of the FileInfo type. Like FileInfo, File supplies AppendText(), Create(), CreateText(), Open(), OpenRead(), OpenWrite(), and OpenText() methods. In many cases, you can use the File and FileInfo types interchangeably. Note that OpenText() and OpenRead() require the file to already exist. To see this in action, you can simplify each of the previous FileStream examples by using the File type instead, like so:

```
static void Main(string[] args)
{
    var fileName = $"{Path.VolumeSeparatorChar}{Path.DirectorySeparatorChar}Test.dat";
    ...
    //Using File instead of FileInfo
    using (FileStream fs8 = File.Create(fileName))
    {
        // Use the FileStream object...
    }
    File.Delete(fileName);
    // Make a new file via FileInfo.Open().
    using(FileStream fs9 = File.Open(fileName,
        FileMode.OpenOrCreate, FileAccess.ReadWrite,
        FileShare.None))
    {
        // Use the FileStream object...
    }
}
```

```

// Get a FileStream object with read-only permissions.
using(FileStream readOnlyStream = File.OpenRead(fileName))
{}
File.Delete(fileName);
// Get a FileStream object with write-only permissions.
using(FileStream writeOnlyStream = File.OpenWrite(fileName))
{}
// Get a StreamReader object.
using(StreamReader sreader = File.OpenText(fileName))
{}
File.Delete(fileName);
// Get some StreamWriters.
using(StreamWriter swriter = File.CreateText(fileName))
{}
File.Delete(fileName);

using(StreamWriter swriterAppend =
    File.AppendText(fileName))
{}
File.Delete(fileName);
}

```

## Additional File-Centric Members

The `File` type also supports a few members, shown in Table 20-6, which can greatly simplify the processes of reading and writing textual data.

**Table 20-6.** *Methods of the File Type*

Method	Meaning in Life
<code>ReadAllBytes()</code>	Opens the specified file, returns the binary data as an array of bytes, and then closes the file
<code>ReadAllLines()</code>	Opens a specified file, returns the character data as an array of strings, and then closes the file
<code>ReadAllText()</code>	Opens a specified file, returns the character data as a <code>System.String</code> , and then closes the file
<code>WriteAllBytes()</code>	Opens the specified file, writes out the byte array, and then closes the file
<code>WriteAllLines()</code>	Opens a specified file, writes out an array of strings, and then closes the file
<code>WriteAllText()</code>	Opens a specified file, writes the character data from a specified string, and then closes the file

You can use these methods of the `File` type to read and write batches of data in only a few lines of code. Even better, each of these members automatically closes down the underlying file handle. For example, the following console program (named `SimpleFileIO`) persists the string data into a new file on the C: drive (and reads it into memory) with minimal fuss (this example assumes you have imported `System.IO`):

```

class Program
{
    static void Main(string[] args)
    {
        Console.WriteLine("***** Simple I/O with the File Type *****\n");
        string[] myTasks = {
            "Fix bathroom sink", "Call Dave",
            "Call Mom and Dad", "Play Xbox One"};

        // Write out all data to file on C drive.
        File.WriteAllLines(@"tasks.txt", myTasks);

        // Read it all back and print out.
        foreach (string task in File.ReadAllLines(@"tasks.txt"))
        {
            Console.WriteLine("TODO: {0}", task);
        }
        Console.ReadLine();
        File.Delete("tasks.txt");
    }
}

```

The lesson here is that when you want to obtain a file handle quickly, the `File` type will save you some keystrokes. However, one benefit of creating a `FileInfo` object first is that you can investigate the file using the members of the abstract `FileSystemInfo` base class.

## The Abstract Stream Class

At this point, you have seen many ways to obtain `FileStream`, `StreamReader`, and `StreamWriter` objects, but you have yet to read data from or write data to a file using these types. To understand how to do this, you'll need to familiarize yourself with the concept of a *stream*. In the world of I/O manipulation, a *stream* represents a chunk of data flowing between a source and a destination. Streams provide a common way to interact with a *sequence of bytes*, regardless of what kind of device (e.g., file, network connection, or printer) stores or displays the bytes in question.

The abstract `System.IO.Stream` class defines several members that provide support for synchronous and asynchronous interactions with the storage medium (e.g., an underlying file or memory location).

---

■ **Note** The concept of a stream is not limited to file I/O. To be sure, the .NET Core libraries provide stream access to networks, memory locations, and other stream-centric abstractions.

---

Again, `Stream` descendants represent data as a raw stream of bytes; therefore, working directly with raw streams can be quite cryptic. Some `Stream`-derived types support *seeking*, which refers to the process of obtaining and adjusting the current position in the stream. Table 20-7 helps you understand the functionality provided by the `Stream` class by describing its core members.

**Table 20-7.** *Abstract Stream Members*

Member	Meaning in Life
CanRead CanWrite CanSeek	Determines whether the current stream supports reading, seeking, and/or writing.
Close()	Closes the current stream and releases any resources (such as sockets and file handles) associated with the current stream. Internally, this method is aliased to the <code>Dispose()</code> method; therefore, <i>closing a stream</i> is functionally equivalent to <i>disposing a stream</i> .
Flush()	Updates the underlying data source or repository with the current state of the buffer and then clears the buffer. If a stream does not implement a buffer, this method does nothing.
Length	Returns the length of the stream in bytes.
Position	Determines the position in the current stream.
Read() ReadByte() ReadAsync()	Reads a sequence of bytes (or a single byte) from the current stream and advances the current position in the stream by the number of bytes read.
Seek()	Sets the position in the current stream.
SetLength()	Sets the length of the current stream.
Write() WriteByte() WriteAsync()	Writes a sequence of bytes (or a single byte) to the current stream and advances the current position in this stream by the number of bytes written.

## Working with FileStreams

The `FileStream` class provides an implementation for the abstract `Stream` members in a manner appropriate for file-based streaming. It is a fairly primitive stream; it can read or write only a single byte or an array of bytes. However, you will not often need to interact directly with the members of the `FileStream` type. Instead, you will probably use various *stream wrappers*, which make it easier to work with textual data or .NET Core types. Nevertheless, you will find it helpful to experiment with the synchronous read/write capabilities of the `FileStream` type.

Assume you have a new Console Application project named `FileStreamApp` (and verify that `System.IO` and `System.Text` are imported into your initial C# code file). Your goal is to write a simple text message to a new file named `myMessage.dat`. However, given that `FileStream` can operate only on raw bytes, you will be required to encode the `System.String` type into a corresponding byte array. Fortunately, the `System.Text` namespace defines a type named `Encoding` that provides members that encode and decode strings to (or from) an array of bytes.

Once encoded, the byte array is persisted to file with the `FileStream.Write()` method. To read the bytes back into memory, you must reset the internal position of the stream (using the `Position` property) and call the `ReadByte()` method. Finally, you display the raw byte array and the decoded string to the console. Here is the complete `Main()` method:

```
// Don't forget to import the System.Text and System.IO namespaces.
static void Main(string[] args)
{
    Console.WriteLine("***** Fun with FileStreams *****\n");
```

```

// Obtain a FileStream object.
using(FileStream fStream = File.Open("myMessage.dat",
    FileMode.Create))
{
    // Encode a string as an array of bytes.
    string msg = "Hello!";
    byte[] msgAsByteArray = Encoding.Default.GetBytes(msg);

    // Write byte[] to file.
    fStream.Write(msgAsByteArray, 0, msgAsByteArray.Length);

    // Reset internal position of stream.
    fStream.Position = 0;

    // Read the bytes from file and display to console.
    Console.WriteLine("Your message as an array of bytes: ");
    byte[] bytesFromFile = new byte[msgAsByteArray.Length];
    for (int i = 0; i < msgAsByteArray.Length; i++)
    {
        bytesFromFile[i] = (byte)fStream.ReadByte();
        Console.WriteLine(bytesFromFile[i]);
    }

    // Display decoded messages.
    Console.WriteLine("\nDecoded Message: ");
    Console.WriteLine(Encoding.Default.GetString(bytesFromFile));
}
Console.ReadLine();
File.Delete("myMessage.dat");
}

```

This example populates the file with data, but it also punctuates the major downfall of working directly with the `FileStream` type: it demands to operate on raw bytes. Other `Stream`-derived types operate in a similar manner. For example, if you want to write a sequence of bytes to a region of memory, you can allocate a `MemoryStream`.

As mentioned previously, the `System.IO` namespace provides several *reader* and *writer* types that encapsulate the details of working with `Stream`-derived types.

## Working with StreamWriters and StreamReaders

The `StreamWriter` and `StreamReader` classes are useful whenever you need to read or write character-based data (e.g., strings). Both of these types work by default with Unicode characters; however, you can change this by supplying a properly configured `System.Text.Encoding` object reference. To keep things simple, assume that the default Unicode encoding fits the bill.

`StreamReader` derives from an abstract type named `TextReader`, as does the related `StringReader` type (discussed later in this chapter). The `TextReader` base class provides a limited set of functionality to each of these descendants; specifically, it provides the ability to read and peek into a character stream.

The `StreamWriter` type (as well as `StringWriter`, which you will examine later in this chapter) derives from an abstract base class named `TextWriter`. This class defines members that allow derived types to write textual data to a given character stream.

To aid in your understanding of the core writing capabilities of the `StreamWriter` and `StringWriter` classes, Table 20-8 describes the core members of the abstract `TextWriter` base class.

**Table 20-8.** *Core Members of TextWriter*

Member	Meaning in Life
<code>Close()</code>	This method closes the writer and frees any associated resources. In the process, the buffer is automatically flushed (again, this member is functionally equivalent to calling the <code>Dispose()</code> method).
<code>Flush()</code>	This method clears all buffers for the current writer and causes any buffered data to be written to the underlying device; however, it does not close the writer.
<code>NewLine</code>	This property indicates the newline constant for the derived writer class. The default line terminator for the Windows OS is a carriage return, followed by a line feed ( <code>\r\n</code> ).
<code>Write()</code> <code>WriteAsync()</code>	This overloaded method writes data to the text stream without a newline constant.
<code>WriteLine()</code> <code>WriteLineAsync()</code>	This overloaded method writes data to the text stream with a newline constant.

■ **Note** The last two members of the `TextWriter` class probably look familiar to you. If you recall, the `System.Console` type has `Write()` and `WriteLine()` members that push textual data to the standard output device. In fact, the `Console.In` property wraps a `TextReader`, and the `Console.Out` property wraps a `TextWriter`.

The derived `StreamWriter` class provides an appropriate implementation for the `Write()`, `Close()`, and `Flush()` methods, and it defines the additional `AutoFlush` property. When set to `true`, this property forces `StreamWriter` to flush all data every time you perform a write operation. Be aware that you can gain better performance by setting `AutoFlush` to `false`, provided you always call `Close()` when you finish writing with a `StreamWriter`.

## Writing to a Text File

To see the `StreamWriter` type in action, create a new Console Application project named `StreamWriterReaderApp` and import `System.IO` and `System.Text`. The following `Main()` method creates a new file named `reminders.txt` in the current execution folder, using the `File.CreateText()` method. Using the obtained `StreamWriter` object, you can add some textual data to the new file.

```
static void Main(string[] args)
{
    Console.WriteLine("***** Fun with StreamWriter / StreamReader *****\n");

    // Get a StreamWriter and write string data.
    using (StreamWriter writer = File.CreateText("reminders.txt"))
    {
        writer.WriteLine("Don't forget Mother's Day this year...");
        writer.WriteLine("Don't forget Father's Day this year...");
    }
}
```



```
        writer.WriteLine("Don't forget these numbers:");
        for(int i = 0; i < 10; i++)
        {
            writer.Write(i + " ");
        }

        // Insert a new line.
        writer.Write(writer.NewLine);
    }
    Console.WriteLine("Created file and wrote some thoughts...");
    Console.ReadLine();
    //File.Delete("reminders.txt");
}
```

After you run this program, you can examine the contents of this new file. You will find this file under the bin\Debug\netcoreapp3.1 folder of your current application because you did not specify an absolute path at the time you called CreateText().

## Reading from a Text File

Next, you will learn to read data from a file programmatically by using the corresponding StreamReader type. Recall that this class derives from the abstract TextReader, which offers the functionality described in Table 20-9.

Table 20-9. TextReader Core Members

Member	Meaning in Life
Peek()	Returns the next available character (expressed as an integer) without actually changing the position of the reader. A value of -1 indicates you are at the end of the stream.
Read() ReadAsync()	Reads data from an input stream.
ReadBlock() ReadBlockAsync()	Reads a specified maximum number of characters from the current stream and writes the data to a buffer, beginning at a specified index.
ReadLine() ReadLineAsync()	Reads a line of characters from the current stream and returns the data as a string (a null string indicates EOF).
ReadToEnd() ReadToEndAsync()	Reads all characters from the current position to the end of the stream and returns them as a single string.

If you now extend the current sample application to use a StreamReader, you can read in the textual data from the reminders.txt file, as shown here:

```
static void Main(string[] args)
{
    Console.WriteLine("***** Fun with StreamWriter / StreamReader *****\n");
    ...
    // Now read data from file.
    Console.WriteLine("Here are your thoughts:\n");
}
```

```

using(StreamReader sr = File.OpenText("reminders.txt"))
{
    string input = null;
    while ((input = sr.ReadLine()) != null)
    {
        Console.WriteLine (input);
    }
}
Console.ReadLine();
}

```

After you run the program, you will see the character data in `reminders.txt` displayed to the console.

## Directly Creating StreamWriter/StreamReader Types

One of the confusing aspects of working with the types within `System.IO` is that you can often achieve an identical result using different approaches. For example, you have already seen that you can use the `CreateText()` method to obtain a `StreamWriter` with the `File` or `FileInfo` type. It so happens that you can work with `StreamWriters` and `StreamReaders` another way: by creating them directly. For example, you could retrofit the current application as follows:

```

static void Main(string[] args)
{
    Console.WriteLine("***** Fun with StreamWriter / StreamReader *****\n");

    // Get a StreamWriter and write string data.
    using(StreamWriter writer = new StreamWriter("reminders.txt"))
    {
        ...
    }

    // Now read data from file.
    using(StreamReader sr = new StreamReader("reminders.txt"))
    {
        ...
    }
}

```

Although it can be a bit confusing to see so many seemingly identical approaches to file I/O, keep in mind that the end result is greater flexibility. In any case, you are now ready to examine the role of the `StringWriter` and `StringReader` classes, given that you have seen how to move character data to and from a given file using the `StreamWriter` and `StreamReader` types.

## Working with StringWriters and StringReaders

You can use the `StringWriter` and `StringReader` types to treat textual information as a stream of in-memory characters. This can prove helpful when you would like to append character-based information to an underlying buffer. The following Console Application project (named `StringReaderWriterApp`) illustrates this by writing a block of string data to a `StringWriter` object, rather than to a file on the local hard drive (don't forget to import `System.IO` and `System.Text`):

```

static void Main(string[] args)
{
    Console.WriteLine("***** Fun with StringWriter / StringReader *****\n");

    // Create a StringWriter and emit character data to memory.
    using(StringWriter strWriter = new StringWriter())
    {
        strWriter.WriteLine("Don't forget Mother's Day this year...");
        // Get a copy of the contents (stored in a string) and dump
        // to console.
        Console.WriteLine("Contents of StringWriter:\n{0}", strWriter);
    }
    Console.ReadLine();
}

```

StringWriter and StreamWriter both derive from the same base class (TextWriter), so the writing logic is more or less identical. However, given the nature of StringWriter, you should also be aware that this class allows you to use the following GetStringBuilder() method to extract a System.Text.StringBuilder object:

```

using (StringWriter strWriter = new StringWriter())
{
    strWriter.WriteLine("Don't forget Mother's Day this year...");
    Console.WriteLine("Contents of StringWriter:\n{0}", strWriter);

    // Get the internal StringBuilder.
    StringBuilder sb = strWriter.GetStringBuilder();
    sb.Insert(0, "Hey!! ");
    Console.WriteLine("-> {0}", sb.ToString());
    sb.Remove(0, "Hey!! ".Length);
    Console.WriteLine("-> {0}", sb.ToString());
}

```

When you want to read from a stream of character data, you can use the corresponding StringReader type, which (as you would expect) functions identically to the related StreamReader class. In fact, the StringReader class does nothing more than override the inherited members to read from a block of character data, rather than from a file, as shown here:

```

using (StringWriter strWriter = new StringWriter())
{
    strWriter.WriteLine("Don't forget Mother's Day this year...");
    Console.WriteLine("Contents of StringWriter:\n{0}", strWriter);

    // Read data from the StringWriter.
    using (StringReader strReader = new StringReader(strWriter.ToString()))
    {
        string input = null;
    }
}

```

```

while ((input = strReader.ReadLine()) != null)
{
    Console.WriteLine(input);
}
}

```

## Working with BinaryWriters and BinaryReaders

The final writer/reader sets you will examine in this section are `BinaryReader` and `BinaryWriter`. Both derive directly from `System.Object`. These types allow you to read and write discrete data types to an underlying stream in a compact binary format. The `BinaryWriter` class defines a highly overloaded `Write()` method to place a data type in the underlying stream. In addition to the `Write()` member, `BinaryWriter` provides additional members that allow you to get or set the `Stream`-derived type; it also offers support for random access to the data (see Table 20-10).

**Table 20-10.** *BinaryWriter Core Members*

Member	Meaning in Life
<code>BaseStream</code>	This read-only property provides access to the underlying stream used with the <code>BinaryWriter</code> object.
<code>Close()</code>	This method closes the binary stream.
<code>Flush()</code>	This method flushes the binary stream.
<code>Seek()</code>	This method sets the position in the current stream.
<code>Write()</code>	This method writes a value to the current stream.

The `BinaryReader` class complements the functionality offered by `BinaryWriter` with the members described in Table 20-11.

**Table 20-11.** *BinaryReader Core Members*

Member	Meaning in Life
<code>BaseStream</code>	This read-only property provides access to the underlying stream used with the <code>BinaryReader</code> object.
<code>Close()</code>	This method closes the binary reader.
<code>PeekChar()</code>	This method returns the next available character without advancing the position in the stream.
<code>Read()</code>	This method reads a given set of bytes or characters and stores them in the incoming array.
<code>ReadXXXX()</code>	The <code>BinaryReader</code> class defines numerous read methods that grab the next type from the stream (e.g., <code>ReadBoolean()</code> , <code>ReadByte()</code> , and <code>ReadInt32()</code> ).

The following example (a Console Application project named `BinaryWriterReader` with using `System.IO`) writes a number of data types to a new `*.dat` file:

```
static void Main(string[] args)
{
    Console.WriteLine("***** Fun with Binary Writers / Readers *****\n");

    // Open a binary writer for a file.
    FileInfo f = new FileInfo("BinFile.dat");
    using(BinaryWriter bw = new BinaryWriter(f.OpenWrite()))
    {
        // Print out the type of BaseStream.
        // (System.IO.FileStream in this case).
        Console.WriteLine("Base stream is: {0}", bw.BaseStream);

        // Create some data to save in the file.
        double aDouble = 1234.67;
        int anInt = 34567;
        string aString = "A, B, C";

        // Write the data.
        bw.Write(aDouble);
        bw.Write(anInt);
        bw.Write(aString);
    }
    Console.WriteLine("Done!");
    Console.ReadLine();
}
```

Notice how the `FileStream` object returned from `FileInfo.OpenWrite()` is passed to the constructor of the `BinaryWriter` type. Using this technique makes it easy to *layer in* a stream before writing out the data. Note that the constructor of `BinaryWriter` takes any `Stream`-derived type (e.g., `FileStream`, `MemoryStream`, or `BufferedStream`). Thus, writing binary data to memory instead is as simple as supplying a valid `MemoryStream` object.

To read the data out of the `BinFile.dat` file, the `BinaryReader` type provides a number of options. Here, you call various read-centric members to pluck each chunk of data from the file stream:

```
static void Main(string[] args)
{
    ...
    FileInfo f = new FileInfo("BinFile.dat");
    ...
    // Read the binary data from the stream.
    using(BinaryReader br = new BinaryReader(f.OpenRead()))
    {
        Console.WriteLine(br.ReadDouble());
        Console.WriteLine(br.ReadInt32());
        Console.WriteLine(br.ReadString());
    }
    Console.ReadLine();
}
```

## Watching Files Programmatically

Now that you have a better handle on the use of various readers and writers, you'll look at the role of the `FileSystemWatcher` class. This type can be quite helpful when you want to monitor (or “watch”) files on your system programmatically. Specifically, you can instruct the `FileSystemWatcher` type to monitor files for any of the actions specified by the `System.IO.NotifyFilters` enumeration.

```
public enum NotifyFilters
{
    Attributes, CreationTime,
    DirectoryName, FileName,
    LastAccess, LastWrite,
    Security, Size
}
```

To begin working with the `FileSystemWatcher` type, you need to set the `Path` property to specify the name (and location) of the directory that contains the files you want to monitor, as well as the `Filter` property that defines the file extensions of the files you want to monitor.

At this point, you may choose to handle the `Changed`, `Created`, and `Deleted` events, all of which work in conjunction with the `FileSystemEventHandler` delegate. This delegate can call any method matching the following pattern:

```
// The FileSystemEventHandler delegate must point  
// to methods matching the following signature.  
void MyNotificationHandler(object source, FileSystemEventArgs e)
```

You can also handle the `Renamed` event using the `RenamedEventHandler` delegate type, which can call methods that match the following signature:

```
// The RenamedEventHandler delegate must point  
// to methods matching the following signature.  
void MyRenamedHandler(object source, RenamedEventArgs e)
```

While you could use the traditional delegate/event syntax to handle each event, we will use the new lambda expression syntax.

Next, let's look at the process of watching a file. The following Console Application project (named `MyDirectoryWatcher` and with a `using` for `System.IO`) monitors the `*.txt` files in the `bin\debug\netcoreapp3.1` directory and prints messages when files are created, deleted, modified, or renamed:

```
static void Main(string[] args)
{
    Console.WriteLine("***** The Amazing File Watcher App *****\n");
    // Establish the path to the directory to watch.
    FileSystemWatcher watcher = new FileSystemWatcher();
    try
    {
        watcher.Path = @".";
    }
    catch (ArgumentException ex)
    {
        Console.WriteLine(ex.Message);
    }
}
```

```

    return;
}
// Set up the things to be on the lookout for.
watcher.NotifyFilter = NotifyFilters.LastAccess
    | NotifyFilters.LastWrite
    | NotifyFilters.FileName
    | NotifyFilters.DirectoryName;

// Only watch text files.
watcher.Filter = "*.txt";

// Add event handlers.
// Specify what is done when a file is changed, created, or deleted.
watcher.Changed += (s, e) =>
    Console.WriteLine($"File: {e.FullPath} {e.ChangeType}!");
watcher.Created += (s, e) =>
    Console.WriteLine($"File: {e.FullPath} {e.ChangeType}!");
watcher.Deleted += (s, e) =>
    Console.WriteLine($"File: {e.FullPath} {e.ChangeType}!");
// Specify what is done when a file is renamed.
watcher.Renamed += (s, e) =>
    Console.WriteLine($"File: {e.OldFullPath} renamed to {e.FullPath}");
// Begin watching the directory.
watcher.EnableRaisingEvents = true;

// Wait for the user to quit the program.
Console.WriteLine(@"Press 'q' to quit app.");
// Raise some events.
using (var sw = File.CreateText("Test.txt"))
{
    sw.Write("This is some text");
}
File.Move("Test.txt", "Test2.txt");
File.Delete("Test2.txt");

while(Console.Read() != 'q');
}

```

When you run this program, the last lines will create, change, rename, and then delete a text file, raising the events along the way. You can also navigate to the `bin\debug\netcoreapp3.1` directory and play with files (with the `*.txt` extension) and raise additional events.

---

```
***** The Amazing File Watcher App *****
```

```

Press 'q' to quit app.
File: .\Test.txt Created!
File: .\Test.txt Changed!
File: .\Test.txt renamed to .\Test2.txt
File: .\Test2.txt Deleted!

```

---

That wraps up this chapter's look at fundamental I/O operations within the .NET Core platform. While you will certainly use these techniques in many of your applications, you might also find that *object serialization* services can greatly simplify how you persist large amounts of data.

## Understanding Object Serialization

The term *serialization* describes the process of persisting (and possibly transferring) the state of an object into a stream (e.g., file stream and memory stream). The persisted data sequence contains all the necessary information you need to reconstruct (or *deserialize*) the state of the object for use later. Using this technology makes it trivial to save vast amounts of data (in various formats). In many cases, saving application data using serialization services results in less code than using the readers/writers you find in the `System.IO` namespace.

For example, assume you want to create a GUI-based desktop application that provides a way for end users to save their preferences (e.g., window color and font size). To do this, you might define a class named `UserPrefs` that encapsulates 20 or so pieces of field data. Now, if you were to use a `System.IO.BinaryWriter` type, you would need to save each field of the `UserPrefs` object *manually*. Likewise, if you were to load the data from a file back into memory, you would need to use a `System.IO.BinaryReader` and (once again) *manually* read in each value to reconfigure a new `UserPrefs` object.

This is all doable, but you can save yourself a good amount of time by marking the `UserPrefs` class with the `[Serializable]` attribute, like so:

```
[Serializable]
public class UserPrefs
{
    public string WindowColor;
    public int FontSize;
}
```

Doing this means that you can persist the entire state of the object with only a few lines of code. Without getting hung up on the details for the time being, consider the following `Main()` method:

```
static void Main(string[] args)
{
    UserPrefs userData= new UserPrefs();
    userData.WindowColor = "Yellow";
    userData.FontSize = 50;

    // The BinaryFormatter persists state data in a binary format.
    // You would need to import System.Runtime.Serialization.Formatters.Binary
    // to gain access to BinaryFormatter.
    BinaryFormatter binFormat = new BinaryFormatter();

    // Store object in a local file.
    using(Stream fStream = new FileStream("user.dat",
        FileMode.Create, FileAccess.Write, FileShare.None))
    {
        binFormat.Serialize(fStream, userData);
    }
    Console.ReadLine();
}
```



.NET Core object serialization makes it easy to persist objects; however, the processes used behind the scenes are quite sophisticated. For example, when an object is persisted to a stream, all associated data (e.g., base class data and contained objects) is automatically serialized as well. Therefore, if you attempt to persist a derived class, all data up the chain of inheritance comes along for the ride. As you will see, you use an object graph to represent a set of interrelated objects.

.NET Core serialization services also allow you to persist an object graph in a variety of formats. The previous code example uses the `BinaryFormatter` type; therefore, the state of the `UserPrefs` object is persisted as a compact binary format. You can also persist an object graph into XML format using another formatter. These formats can be quite helpful when you need to ensure that your persisted objects travel well across operating systems, languages, and architectures.

Finally, understand that you can persist an object graph into *any* `System.IO.Stream`-derived type. In the previous example, you used the `FileStream` type to persist a `UserPrefs` object into a local file. However, if you would rather store an object to a specific region of memory, you could use a `MemoryStream` type instead. All that matters is that the sequence of data correctly represents the state of objects within the graph.

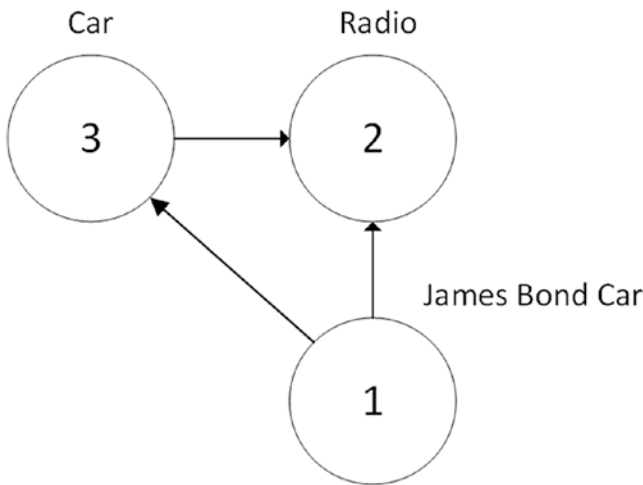
## The Role of Object Graphs

As mentioned previously, the CoreCLR will account for all related objects to ensure that data is persisted correctly when an object is serialized. This set of related objects is referred to as an *object graph*. Object graphs provide a simple way to document how a set of items refer to each other. Be aware that object graphs are *not* denoting OOP *is-a* or *has-a* relationships. Rather, you can read the arrows in an object diagram as “requires” or “depends on.”

Each object in an object graph is assigned a unique numerical value. Keep in mind that the numbers assigned to the members in an object graph are arbitrary and have no real meaning to the outside world.

Once you assign all objects a numerical value, the object graph can record each object’s set of dependencies.

For example, assume you have created a set of classes that model some automobiles (of course). You have a base class named `Car`, which *has-a* `Radio`. Another class named `JamesBondCar` extends the `Car` base type. Figure 20-1 shows a possible object graph that models these relationships.



**Figure 20-1.** A simple object graph

When reading object graphs, you can use the phrase *depends on* or *refers to* when connecting the arrows. Thus, in Figure 20-1, you can see that the Car refers to the Radio class (given the *has-a* relationship). JamesBondCar refers to Car (given the *is-a* relationship), as well as to Radio (it inherits this protected member variable).

Of course, the CLR does not paint pictures in memory to represent a graph of related objects. Rather, the relationship documented in Figure 20-1 is represented by a mathematical formula that looks something like this:

```
[Car 3, ref 2], [Radio 2], [JamesBondCar 1, ref 3, ref 2]
```

If you parse this formula, you can see that object 3 (the Car) has a dependency on object 2 (the Radio). Object 2, the Radio, is a lone wolf and requires nobody. Finally, object 1 (the JamesBondCar) has a dependency on object 3, as well as object 2. In any case, when you serialize or deserialize an instance of JamesBondCar, the object graph ensures that the Radio and Car types also participate in the process.

The beautiful thing about the serialization process is that the graph representing the relationships among your objects is established automatically behind the scenes. As you will see later in this chapter, however, you can become more involved in the construction of a given object graph by customizing the serialization process using attributes and interfaces.

---

■ **Note** Strictly speaking, the `XmlSerializer` type (described later in this chapter) does not persist state using object graphs; however, this type still serializes and deserializes related objects in a predictable manner.

---

## Configuring Objects for Serialization

To make an object available to .NET Core serialization services, all you need to do is decorate each related class (or structure) with the `[Serializable]` attribute. If you determine that a given type has some member data that should not (or perhaps cannot) participate in the serialization scheme, you can mark such fields with the `[NonSerialized]` attribute. This can be helpful if you want to reduce the size of the persisted data and you have member variables in a serializable class that do not need to be remembered (e.g., fixed values, random values, and transient data).

## Defining Serializable Types

To get the ball rolling, create a new Console Application project named `SimpleSerialize`. Update the namespaces to the following:

```
using System;
using System.Collections.Generic;
using System.IO;
using System.Runtime.Serialization.Formatters.Binary;
using System.Xml.Serialization;
```

Insert a new class named `Radio`, which has been marked `[Serializable]`, excluding a single member variable (`radioID`) that has been marked `[NonSerialized]` and will, therefore, not be persisted into the specified data stream.

```
[Serializable]
public class Radio
{
    public bool HasTweeters;
    public bool HasSubWoofers;
    public double[] StationPresets;

    [NonSerialized]
    public string RadioID = "XF-552RR6";
}
```

Next, insert two additional class types to represent the `JamesBondCar` and `Car` classes, both of which are also marked `[Serializable]` and define the following pieces of field data:

```
[Serializable]
public class Car
{
    public Radio TheRadio = new Radio();
    public bool IsHatchBack;
}

[Serializable]
public class JamesBondCar : Car
{
    public bool CanFly;
    public bool CanSubmerge;
}
```

Be aware that you cannot inherit the `[Serializable]` attribute from a parent class. Therefore, if you derive a class from a type marked `[Serializable]`, the child class must be marked `[Serializable]` as well, or it cannot be persisted. In fact, all objects in an object graph must be marked with the `[Serializable]` attribute. If you attempt to serialize a nonserializable object using the `BinaryFormatter`, you will receive a `SerializationException` at runtime.

## Public Fields, Private Fields, and Public Properties

Notice that in each of these classes you define the field data as public; this helps keep the example simple. Of course, private data exposed using public properties would be preferable from an OO point of view. Also, for the sake of simplicity, this example does not define any custom constructors on these types; therefore, all unassigned field data will receive the expected default values.

OO design principles aside, you might wonder how the various formatters expect a type's field data to be defined in order to be serialized into a stream. The answer is that it depends. If you persist an object's state using the `BinaryFormatter`, it makes absolutely no difference. This type is programmed to serialize *all* serializable fields of a type, regardless of whether they are public fields, private fields, or private fields exposed through public properties. Recall, however, that if you have points of data that you do not want to be persisted into the object graph, you can selectively mark public or private fields as `[NonSerialized]`, as you did with the string field of the `Radio` type.

The situation is quite different if you use the `XmlSerializer` type, however. This type will *only* serialize public data fields or private data exposed by public properties. Private data not exposed from properties will be ignored. For example, consider the following serializable `Person` type:

```
[Serializable]
public class Person
{
    // A public field.
    public bool IsAlive = true;

    // A private field.
    private int PersonAge = 21;

    // Public property/private data.
    private string _fName = string.Empty;
    public string FirstName
    {
        get { return _fName; }
        set { _fName = value; }
    }
}
```

If you processed the preceding with the `BinaryFormatter`, you would find that the `IsAlive`, `PersonAge`, and `_fName` fields are saved into the selected stream. However, the `XmlSerializer` would *not* save the value of `PersonAge` because this piece of private data is not encapsulated by a public type property. If you wanted to persist the age of the person with the `XmlSerializer`, you would need to define the field publicly or encapsulate the private member using a public property.

## Choosing a Serialization Formatter

After you configure your types to participate in the .NET Core serialization scheme by applying the necessary attributes, your next step is to choose which format (binary or XML) you should use when persisting your object's state. Each possibility is represented by the following classes:

- `BinaryFormatter`
- `XmlSerializer`

---

■ **Note** You might be wondering why JavaScript Object Notation (JSON) isn't on this list. The process of serializing to JSON and deserializing from JSON is different enough that it will be covered in [Chapter 30](#).

---

The `BinaryFormatter` type serializes your object's state to a stream using a compact binary format. This type is defined within the `System.Runtime.Serialization.Formatters.Binary` namespace. If you want to gain access to this type, you can specify the following C# using directive:

```
// Gain access to the BinaryFormatter in mscorlib.dll.
using System.Runtime.Serialization.Formatters.Binary;
```

If you want to persist a tree of objects as an XML document, you can use the `XmlSerializer` type. To use this type, you need to specify that you are using the `System.Xml.Serialization` namespace:

```
// Defined within System.Xml.dll.
using System.Xml.Serialization;
```

## The IFormatter and IRemotingFormatter Interfaces

Regardless of which formatter you choose to use, be aware that all of them derive directly from `System.Object`, so they do *not* share a common set of members from a serialization-centric base class. The `BinaryFormatter` implements the `IFormatter` interface although, strange as it might seem, the `XmlSerializer` does not.

`System.Runtime.Serialization.IFormatter` defines the core `Serialize()` and `Deserialize()` methods, which do the work to move your object graphs into and out of a specific stream. Beyond these members, `IFormatter` defines the following few properties that the implementing type uses behind the scenes:

```
public interface IFormatter
{
    SerializationBinder Binder { get; set; }
    StreamingContext Context { get; set; }
    ISurrogateSelector SurrogateSelector { get; set; }
    object Deserialize(Stream serializationStream);
    void Serialize(Stream serializationStream, object graph);
}
```

Although you might not need to interact directly with this interface for most of your serialization endeavors, recall that interface-based polymorphism allows you to hold an instance of `BinaryFormatter` using an `IFormatter` reference. Therefore, if you want to build a method that can serialize an object graph using another implementation of `IFormatter`, you could write the following:

```
static void SerializeObjectGraph(IFormatter itfFormat, Stream destStream, object graph)
{
    itfFormat.Serialize(destStream, graph);
}
```

## Type Fidelity Among the Formatters

The most obvious difference among the formatters is how the object graph is persisted to the stream (binary or XML). You should also be aware of a few more subtle points of distinction, specifically, how the formatters contend with *type fidelity*. When you use the `BinaryFormatter` type, it will persist not only the field data of the objects in the object graph but also each type's fully qualified name and the full name of the defining assembly (name, version, public key token, and culture). These extra points of data make the `BinaryFormatter` an ideal choice when you want to transport objects by value (e.g., as a full copy) across machine boundaries for .NET Core-centric applications.

However, the `XmlSerializer` does *not* attempt to preserve full type fidelity; therefore, it does not record the type's fully qualified name or assembly of origin. This might seem like a limitation at first glance, but XML serialization is used by classic .NET web services (and can be used for ASP.NET Core services as well, although JSON is much more common), which can be called from clients on any platform (not just .NET/.NET Core). This means that there is no point serializing full .NET/.NET Core type metadata. Here is a possible XML representation of the `Person` type (remember that private data is not exposed by the `XmlSerializer`, only data that is accessible publicly):

```
<?xml version="1.0"?>
<Person xmlns:xsi="http://www.w3.org/2001/XMLSchema-instance"
        xmlns:xsd="http://www.w3.org/2001/XMLSchema">
```

```
<isAlive>true</isAlive>
<FirstName>James</FirstName>
</Person>
```

If you want to persist an object's state in a manner that can be used by any operating system (e.g., Windows, macOS, and various Linux distributions), application framework (e.g., .NET, Java Enterprise Edition, and COM), or programming language, you do not want to maintain full type fidelity because you cannot assume all possible recipients can understand .NET-specific data types. Given this, the `XmlSerializer` (or using the JSON serializer, covered with ASP.NET Core later in this book) are ideal choices when you need to ensure as broad a reach as possible for the persisted tree of objects.

## Exploring the `BinaryFormatter`

You can use the `BinaryFormatter` type to illustrate how easy it is to persist an instance of the `JamesBondCar` to a physical file. Again, the two key methods of the `BinaryFormatter` type to be aware of are `Serialize()` and `Deserialize()`:

- `Serialize()`: Persists an object graph to a specified stream as a sequence of bytes
- `Deserialize()`: Converts a persisted sequence of bytes to an object graph

## Serializing Objects

Assume you have created an instance of `JamesBondCar`, an instance of a person, and want to persist your spymobile and the spy into respective \*.dat files. You can achieve this by creating an instance of the `System.IO.FileStream` type to create your file, then create an instance of the `BinaryFormatter`, and pass in the `FileStream` and object graph to persist. Consider the following `Main()` method:

```
// Be sure to import the System.Runtime.Serialization.Formatters.Binary
// and System.IO namespaces.
static void Main(string[] args)
{
    Console.WriteLine("***** Fun with Object Serialization *****\n");

    // Make a JamesBondCar and set state.
    JamesBondCar jbc = new JamesBondCar
    {
        CanFly = true,
        CanSubmerge = false,
        TheRadio =
        {
            StationPresets = new double[] {89.3, 105.1, 97.1},
            HasTweeters = true
        }
    };

    Person p = new Person
    {
        FirstName = "James",
        IsAlive = true
    };
}
```

```

// Now save the car to a specific file in a binary format.
SaveAsBinaryFormat(jbc, "CarData.dat");
Console.WriteLine("=> Saved car in binary format!");
Console.ReadLine();

// Now save the spy to a specific file in a binary format.
SaveAsBinaryFormat(jbc, "PersonData.dat");
Console.WriteLine("=> Saved person in binary format!");
Console.ReadLine();
}

```

You implement the `SaveAsBinaryFormat()` method (using generics to enable passing in the person and the car) like this:

```

static void SaveAsBinaryFormat<T>(T objGraph, string fileName)
{
    // Save object to a file in binary.
    BinaryFormatter binFormat = new BinaryFormatter();
    using(Stream fStream = new FileStream(fileName,
        FileMode.Create, FileAccess.Write, FileShare.None))
    {
        binFormat.Serialize(fStream, objGraph);
    }
}

```

The `BinaryFormatter.Serialize()` method is the member responsible for composing the object graph and moving the byte sequence to some `Stream`-derived type. In this case, the stream happens to be a physical file. You could also serialize your object types to any `Stream`-derived type, such as a memory location or network stream.

After you run your program, you can view the contents of the `CarData.dat` and `PersonData.dat` files that represent the instances by navigating to the `\bin\Debug\netcoreapp3.1` folder of the current project. Note that depending on your editor of choice, the file probably won't be very readable.

## Deserializing Objects

Now suppose you want to read the persisted `JamesBondCar` from the binary file back into an object variable. After you open `CarData.dat` programmatically (with the `File.OpenRead()` method), you can call the `Deserialize()` method of the `BinaryFormatter`. Be aware that `Deserialize()` returns a general `System.Object` type, so you need to impose an explicit cast, as shown here:

```

static T LoadFromBinaryFile<T>(string fileName)
{
    BinaryFormatter binFormat = new BinaryFormatter();
    T dataFromDisk = default;
    // Read the JamesBondCar from the binary file.
    using (Stream fStream = File.OpenRead(fileName))
    {
        dataFromDisk = (T)binFormat.Deserialize(fStream);
    }
    return dataFromDisk;
}

```

---

■ **Note** Generics were covered in depth in Chapter 10.

---

Notice that when you call `Deserialize()`, you pass the `Stream`-derived type that represents the location of the persisted object graph. Once you cast the object back into the correct type, you will find the state data has been retained from the point at which you saved the object.

## Serializing Objects Using the `XmlSerializer`

The `System.Xml.dll` provides another formatter, `System.Xml.Serialization.XmlSerializer`. You can use this formatter to persist the *public* state of a given object as pure XML. Working with this type is a bit different from working with the `BinaryFormatter` type. Consider the following code, which assumes you have imported the `System.Xml.Serialization` namespace:

```
static void SaveAsXmlFormat<T>(T objGraph, string fileName)
{
    // Save object to a file in XML format.
    XmlSerializer xmlFormat = new XmlSerializer(typeof(T));
    using (Stream fStream = new FileStream(fileName,
        FileMode.Create, FileAccess.Write, FileShare.None))
    {
        xmlFormat.Serialize(fStream, objGraph);
    }
}
```

Add the following methods to your `Main` method:

```
SaveAsXmlFormat(jbc, "CarData.xml");
Console.WriteLine("=> Saved car in XML format!");

SaveAsXmlFormat(p, "PersonData.xml");
Console.WriteLine("=> Saved person in XML format!");
```

The key difference is that the `XmlSerializer` type requires you to specify type information that represents the class you want to serialize. If you were to look within the newly generated `CarData.xml` file, you would find the XML data shown here:

```
<?xml version="1.0"?>
<JamesBondCar xmlns:xsi="http://www.w3.org/2001/XMLSchema-instance"
xmlns:xsd="http://www.w3.org/2001/XMLSchema" xmlns="http://www.MyCompany.com">
  <TheRadio>
    <HasTweeters>true</HasTweeters>
    <HasSubWoofers>false</HasSubWoofers>
    <StationPresets>
      <double>89.3</double>
      <double>105.1</double>
      <double>97.1</double>
    </StationPresets>
    <RadioId>XF-552RR6</RadioId>
  </TheRadio>
```



```
<IsHatchBack>false</IsHatchBack>
<CanFly>true</CanFly>
<CanSubmerge>false</CanSubmerge>
</JamesBondCar>
```

■ **Note** The `XmlSerializer` demands that all serialized types in the object graph support a default constructor (so be sure to add it back if you define custom constructors). If this is not the case, you will receive an `InvalidOperationException` at runtime.

## Controlling the Generated XML Data

If you have a background in XML technologies, you know that it is often critical to ensure the data within an XML document conforms to a set of rules that establish the *validity* of the data. Understand that a *valid* XML document does not have anything to do with the syntactic well-being of the XML elements (e.g., all opening elements must have a closing element). Rather, valid documents conform to agreed-upon formatting rules (e.g., field `X` must be expressed as an attribute and not a subelement), which are typically defined by an XML schema or document-type definition (DTD) file.

By default, `XmlSerializer` serializes all public fields/properties as XML elements, rather than as XML attributes. If you want to control how the `XmlSerializer` generates the resulting XML document, you can decorate types with any number of additional .NET attributes from the `System.Xml.Serialization` namespace. Table 20-12 documents some (but not all) of the .NET Core attributes that influence how XML data is encoded to a stream.

**Table 20-12.** *Select Attributes of the System.Xml.Serialization Namespace*

.NET Attribute	Meaning in Life
[XmlAttribute]	You can use this .NET attribute on a public field or property in a class to tell <code>XmlSerializer</code> to serialize the data as an XML attribute (rather than as a subelement).
[XmlElement]	The field or property will be serialized as an XML element named as you so choose.
[XmlAttribute]	This attribute provides the element name of an enumeration member.
[XmlRoot]	This attribute controls how the root element will be constructed (namespace and element name).
[XmlText]	The property or field will be serialized as XML text (i.e., the content between the start tag and the end tag of the root element).
[XmlType]	This attribute provides the name and namespace of the XML type.

This simple example illustrates how the field data of `JamesBondCar` is currently persisted as XML:

```
<?xml version="1.0" encoding="utf-8"?>
<JamesBondCar xmlns:xsi="http://www.w3.org/2001/XMLSchema-instance"
  xmlns:xsd="http://www.w3.org/2001/XMLSchema">
...
  <canFly>true</canFly>
  <canSubmerge>false</canSubmerge>
</JamesBondCar>
```

If you want to specify a custom XML namespace that qualifies the `JamesBondCar` and encodes the `canFly` and `canSubmerge` values as XML attributes, you can do so by modifying the C# definition of `JamesBondCar`, like so:

```
[Serializable, XmlRoot(Namespace = "http://www.MyCompany.com")]
public class JamesBondCar : Car
{
    [XmlAttribute]
    public bool CanFly;
    [XmlAttribute]
    public bool CanSubmerge;
}
```

This yields the following XML document (note the opening `<JamesBondCar>` element):

```
<?xml version="1.0"?">
<JamesBondCar xmlns:xsi="http://www.w3.org/2001/XMLSchema-instance"
               xmlns:xsd="http://www.w3.org/2001/XMLSchema"
               CanFly="true" CanSubmerge="false"
               xmlns="http://www.MyCompany.com">
...
</JamesBondCar>
```

Of course, you can use many other .NET Core attributes to control how the `XmlSerializer` generates the resulting XML document. For full details, look up the `System.Xml.Serialization` namespace in the .NET Core SDK documentation.

## Serializing Collections of Objects

Now that you have seen how to persist a single object to a stream, you're ready to examine how to save a set of objects. As you might have noticed, the `Serialize()` method of the `IFormatter` interface does not provide a way to specify an arbitrary number of objects as input (only a single `System.Object`). On a related note, the return value of `Deserialize()` is, again, a single `System.Object` (the same basic limitation holds true for `XmlSerializer`).

```
public interface IFormatter
{
    ...
    object Deserialize(Stream serializationStream);
    void Serialize(Stream serializationStream, object graph);
}
```

Recall that the `System.Object` represents a complete tree of objects. Given this, if you pass in an object that has been marked as `[Serializable]` and contains other `[Serializable]` objects, the entire set of objects is persisted in a single method call. As luck would have it, most of the types you find in the `System.Collections` and `System.Collections.Generic` namespaces have already been marked as `[Serializable]`. Therefore, if you would like to persist a set of objects, simply add the desired set to the container (such as a normal array, an `ArrayList`, or a `List<T>`) and serialize the object to your stream of choice.

Now assume that you want to update the `JamesBondCar` class with a two-argument constructor so you can set a few pieces of state data (note that you add back the default constructor as required by the `XmlSerializer`).

```
[Serializable,
 XmlRoot(Namespace = "http://www.MyCompany.com")]
public class JamesBondCar : Car
{
    public JamesBondCar(bool skyWorthy, bool seaWorthy)
    {
        CanFly = skyWorthy;
        CanSubmerge = seaWorthy;
    }
    // The XmlSerializer demands a default constructor!
    public JamesBondCar(){}
    ...
}
```

With this, you can now persist any number of JamesBondCars.

```
static void SaveListOfCarsAsXml()
{
    // Now persist a List<T> of JamesBondCars.
    List<JamesBondCar> myCars = new List<JamesBondCar>
    {
        new JamesBondCar(true, true),
        new JamesBondCar(true, false),
        new JamesBondCar(false, true),
        new JamesBondCar(false, false)
    };

    using(Stream fStream = new FileStream("CarCollection.xml",
        FileMode.Create, FileAccess.Write, FileShare.None))
    {
        XmlSerializer xmlFormat = new XmlSerializer(typeof(List<JamesBondCar>));
        xmlFormat.Serialize(fStream, myCars);
    }
    Console.WriteLine("=> Saved list of cars!");
}
```

You use `XmlSerializer` here, so you are required to specify type information for each of the subobjects within the root object (`List<JamesBondCar>`, in this case). The logic is more straightforward if you were to use the `BinaryFormatter` type instead, as shown here:

```
static void SaveListOfCarsAsBinary()
{
    // Save ArrayList object (myCars) as binary.
    List<JamesBondCar> myCars = new List<JamesBondCar>
    {
        new JamesBondCar(true, true),
        new JamesBondCar(true, false),
        new JamesBondCar(false, true),
        new JamesBondCar(false, false)
    };
};
```

```

BinaryFormatter binFormat = new BinaryFormatter();
using(Stream fStream = new FileStream("AllMyCars.dat",
    FileMode.Create, FileAccess.Write, FileShare.None))
{
    binFormat.Serialize(fStream, myCars);
}
Console.WriteLine("=> Saved list of cars in binary!");
}

```

To wrap it all up, add the following lines to the Main method to exercise these new functions:

```

SaveListOfCarsAsXml();
SaveListOfCarsAsBinary();

```

## Customizing the Binary Serialization Process

In a majority of cases, the default serialization scheme provided by the .NET Core platform will be exactly what you require. Simply apply the [Serializable] attribute to your related types and pass the tree of objects to your formatter of choice for processing. In some cases, however, you might want to become more involved with how a tree is constructed and handled during the serialization process. For example, perhaps you have a business rule that says all field data must be persisted using a particular format, or perhaps you need to add additional bits of data to the stream that do not map directly to fields in the object being persisted (e.g., timestamps and unique identifiers).

When you want to become more involved with the process of object serialization, the System.Runtime.Serialization namespace provides several types that allow you to do so. Table 20-13 describes some of the core types you should be aware of.

**Table 20-13.** *System.Runtime.Serialization Namespace Core Types*

Type	Meaning in Life
ISerializable	You can implement this interface on a [Serializable] type to control its serialization and deserialization.
ObjectIDGenerator	This type generates IDs for members in an object graph.
[OnDeserialized]	This attribute allows you to specify a method that will be called immediately after the object has been deserialized.
[OnDeserializing]	This attribute allows you to specify a method that will be called before the deserialization process.
[OnSerialized]	This attribute allows you to specify a method that will be called immediately after the object has been serialized.
[OnSerializing]	This attribute allows you to specify a method that will be called before the serialization process.
[OptionalField]	This attribute allows you to define a field on a type that can be missing from the specified stream.
[SerializationInfo]	In essence, this class is a <i>property bag</i> that maintains name-value pairs representing the state of an object during the serialization process.

## A Deeper Look at Object Serialization

Before you examine various ways that you can customize the serialization process, you will find it helpful to take a deeper look at what takes place behind the scenes. When the `BinaryFormatter` serializes an object graph, it is in charge of transmitting the following information into the specified stream:

- The fully qualified name of the objects in the graph (e.g., `MyApp.JamesBondCar`)
- The name of the assembly defining the object graph (e.g., `MyApp.exe`)
- An instance of the `SerializationInfo` class that contains all stateful data maintained by the members in the object graph

During the deserialization process, the `BinaryFormatter` uses this same information to build an identical copy of the object, using the information extracted from the underlying stream.

---

■ **Note** Recall that the `XmlSerializer` does not persist a type's fully qualified name or the name of the defining assembly; this behavior helps keep the state of the object as mobile as possible. This type is concerned only with persisting exposed public data.

---

Beyond moving the required data into and out of a stream, formatters also analyze the members in the object graph for the following pieces of infrastructure:

- A check is made to determine whether the object is marked with the `[Serializable]` attribute. If the object is not, a `SerializationException` is thrown.
- If the object is marked `[Serializable]`, a check is made to determine whether the object implements the `ISerializable` interface. If this is the case, `GetObjectData()` is called on the object.
- If the object does not implement `ISerializable`, the default serialization process is used, serializing all fields not marked as `[NonSerialized]`.

In addition to determining whether the type supports `ISerializable`, formatters are also responsible for discovering whether the types in question support members that have been adorned with the `[OnSerializing]`, `[OnSerialized]`, `[OnDeserializing]`, or `[OnDeserialized]` attributes. You'll examine the role of these attributes momentarily, but first you need to look at the role of `ISerializable`.

## Customizing Serialization Using `ISerializable`

Objects that are marked `[Serializable]` have the option of implementing the `ISerializable` interface. Doing so lets you get “involved” with the serialization process and perform any pre- or post-data formatting.

The `ISerializable` interface is quite simple, given that it defines only a single method, `GetObjectData()`.

```
// When you wish to tweak the serialization process,
// implement ISerializable.
public interface ISerializable
{
    void GetObjectData(SerializationInfo info,
        StreamingContext context);
}
```

The `GetObjectData()` method is called automatically by a given formatter during the serialization process. The implementation of this method populates the incoming `SerializationInfo` parameter with a series of name-value pairs that (typically) map to the field data of the object being persisted. `SerializationInfo` defines numerous variations on the overloaded `AddValue()` method, as well as a small set of properties that allow the type to get and set the type's name, defining assembly, and member count. Here is a partial snapshot:

```
public sealed class SerializationInfo
{
    public SerializationInfo(Type type, IFormatterConverter converter);
    public string AssemblyName { get; set; }
    public string FullTypeName { get; set; }
    public int MemberCount { get; }
    public void AddValue(string name, short value);
    public void AddValue(string name, ushort value);
    public void AddValue(string name, int value);
    ...
}
```

Types that implement the `ISerializable` interface must also define a special constructor that takes the following signature:

```
// You must supply a custom constructor with this signature
// to allow the runtime engine to set the state of your object.
[Serializable]
class SomeClass : ISerializable
{
    protected SomeClass (SerializationInfo si, StreamingContext ctx) {...}
    ...
}
```

Notice that the visibility of this constructor is set as *protected*. This is permissible because the formatter will have access to this member, regardless of its visibility. These special constructors tend to be marked as *protected* (or *private* for that matter) to ensure that the casual object user can never create an object in this manner. The first parameter of this constructor is an instance of the `SerializationInfo` type (which you've seen previously).

The second parameter of this special constructor is a `StreamingContext` type, which contains information regarding the source of the bits. The most informative member of `StreamingContext` is the `State` property, which represents a value from the `StreamingContextStates` enumeration. The values of this enumeration represent the basic composition of the current stream. You will seldom need to deal with this enumeration directly. Nevertheless, here are the possible names of the `StreamingContextStates` enum (not all are supported by .NET Core):

```
public enum StreamingContextStates
{
    CrossProcess,
    CrossMachine,
    File,
    Persistence,
    Remoting,
    Other,
}
```

```

Clone,
CrossAppDomain,
All
}

```

Now let's look at how to customize the serialization process using `ISerializable`. Assume you have a new Console Application project (named `CustomSerialization`) that defines a class type containing two points of string data. Also assume that you must ensure that the string objects are serialized to the stream in all uppercase and deserialized from the stream in lowercase. To account for such rules, you could implement `ISerializable` like this (be sure to import the `System.Runtime.Serialization` namespace):

```

[Serializable]
class StringData : ISerializable
{
    private string _dataItemOne = "First data block";
    private string _dataItemTwo = "More data";

    public StringData(){}
    protected StringData(SerializationInfo si, StreamingContext ctx)
    {
        // Rehydrate member variables from stream.
        _dataItemOne = si?.GetString("First_Item")?.ToLower();
        _dataItemTwo = si?.GetString("dataItemTwo")?.ToLower();
    }

    void ISerializable.GetObjectData(SerializationInfo info, StreamingContext ctx)
    {
        // Fill up the SerializationInfo object with the formatted data.
        info.AddValue("First_Item", _dataItemOne.ToUpper());
        info.AddValue("dataItemTwo", _dataItemTwo.ToUpper());
    }
}

```

Notice that when you fill the `SerializationInfo` type with the `GetObjectData()` method, you are *not* required to name the data points identically to the type's internal member variables. This can obviously be helpful if you need to further decouple the type's data from the persisted format. Be aware, however, that you will need to obtain the values from the special, protected constructor using the same names assigned within `GetObjectData()`.

To test your customization, assume that you want to persist an instance of `MyStringData` using a `BinaryFormatter` (add the `System.Runtime.Serialization.Formatters.Binary` and `System.IO` using statements), as follows:

```

static void Main(string[] args)
{
    Console.WriteLine("***** Fun with Custom Serialization *****");

    // Recall that this type implements ISerializable.
    StringData myData = new StringData();
}

```

```
// Save to a local file in Binary format.
BinaryFormatter binFormat = new BinaryFormatter();
using(Stream fStream = new FileStream("MyData.dat",
    FileMode.Create, FileAccess.Write, FileShare.None))
{
    binFormat.Serialize(fStream, myData);
}
Console.ReadLine();
}
```

When you view the resulting \*.dat file, you will see that the string fields have been persisted in uppercase.

## Customizing Serialization Using Attributes

Although implementing the `ISerializable` interface is one way to customize the serialization process, the preferred way to customize the serialization process is to define methods that are attributed with any of the new serialization-centric attributes: `[OnSerializing]`, `[OnSerialized]`, `[OnDeserializing]`, or `[OnDeserialized]`. Using these attributes is less cumbersome than implementing `ISerializable` because you do not need to interact manually with an incoming `SerializationInfo` parameter. Instead, you can modify your state data directly, while the formatter operates on the type.

---

■ **Note** You can find these serialization attributes defined in the `System.Runtime.Serialization` namespace.

---

When you define methods decorated with these attributes, you must define the methods so they receive a `StreamingContext` parameter and return nothing (otherwise, you will receive a runtime exception). Note that you are not required to account for each of the serialization-centric attributes, and you can simply contend with the stages of serialization you want to intercept. The following snippet illustrates this. Here, a new `[Serializable]` type has the same requirements as `StringData`, but this time you account for using the `[OnSerializing]` and `[OnDeserialized]` attributes:

```
[Serializable]
class MoreData
{
    private string _dataItemOne = "First data block";
    private string _dataItemTwo = "More data";

    [OnSerializing]
    private void OnSerializing(StreamingContext context)
    {
        // Called during the serialization process.
        _dataItemOne = _dataItemOne.ToUpper();
        _dataItemTwo = _dataItemTwo.ToUpper();
    }
}
```



**[OnDeserialized]**

```
private void OnDeserialized(StreamingContext context)
{
    // Called when the deserialization process is complete.
    _dataItemOne = _dataItemOne.ToLower();
    _dataItemTwo = _dataItemTwo.ToLower();
}
}
```

If you were to serialize this new type, you would again find that the data has been persisted as uppercase and deserialized as lowercase.

With this example behind you, your exploration of the core details of object serialization services, including various ways to customize the process, is complete. As you have seen, the serialization and deserialization process makes it easy to persist large amounts of data, and it can be less labor intensive than working with the various reader/writer classes of the `System.IO` namespace.

## Summary

You began this chapter by examining the use of the `Directory(Info)` and `File(Info)` types. As you learned, these classes allow you to manipulate a physical file or directory on your hard drive. Next, you examined a number of classes derived from the abstract `Stream` class. Given that `Stream`-derived types operate on a raw stream of bytes, the `System.IO` namespace provides numerous reader/writer types (e.g., `StreamWriter`, `StringWriter`, and `BinaryWriter`) that simplify the process. Along the way, you also checked out the functionality provided by `DriveType`, learned how to monitor files using the `FileSystemWatcher` type, and saw how to interact with streams in an asynchronous manner.

This chapter also introduced you to the topic of object serialization services. As you have seen, the .NET Core platform uses an object graph to account for the full set of related objects that you want to persist to a stream. As long as each member in the object graph has been marked with the `[Serializable]` attribute, the data is persisted using the selected format (binary or XML).

You also learned that it is possible to customize the out-of-the-box serialization process using two possible approaches. First, you learned how to implement the `ISerializable` interface (and support a special private constructor), which enables you to become more involved with how formatters persist the supplied data. Second, you learned about a set of .NET Core attributes that simplify the process of custom serialization. All you need to do is apply the `[OnSerializing]`, `[OnSerialized]`, `[OnDeserializing]`, or `[OnDeserialized]` attribute on members that take a `StreamingContext` parameter, and the formatters will invoke them accordingly.

## CHAPTER 21



# Data Access with ADO.NET

The .NET Core platform defines a number of namespaces that allow you to interact with relational database systems. Collectively speaking, these namespaces are known as ADO.NET. In this chapter, you'll learn about the overall role of ADO.NET and the core types and namespaces, and then you'll move on to the topic of ADO.NET data providers. The .NET Core platform supports numerous data providers (both provided as part of the .NET Core Framework and available from third-party sources), each of which is optimized to communicate with a specific database management system (e.g., Microsoft SQL Server, Oracle, and MySQL).

After you understand the common functionality provided by various data providers, you will then look at the data provider factory pattern. As you will see, using types within the `System.Data` namespaces (including `System.Data.Common` and provider-specific namespaces like `Microsoft.Data.SqlClient`, `System.Data.Odbc`, and (for Windows only) `System.Data.OleDb`), you can build a single codebase that can dynamically pick and choose the underlying data provider without the need to recompile or redeploy the application's codebase.

Next, you will learn how to work directly with the SQL Server database provider, creating and opening connections to retrieve data, and then move on to inserting, updating, and deleting data, followed by examining the topic of database transactions. Finally, you will execute SQL Server's bulk copy feature using ADO.NET to load a list of records into the database.

---

■ **Note** This chapter focuses on the raw ADO.NET. Starting with Chapter 22, I cover Entity Framework (EF) Core, Microsoft's object-relational mapping (ORM) framework. Since Entity Framework Core uses ADO.NET for data access under the covers, a solid understanding of how ADO.NET works is vital when troubleshooting data access. There are also scenarios that aren't solved by EF Core (such as executing a SQL bulk copy), and you will need to know ADO.NET to solve those issues.

---

## ADO.NET vs. ADO

If you have a background in Microsoft's previous COM-based data access model (Active Data Objects [ADO]) and are just starting to work with the .NET Core platform, you need to understand that ADO.NET has little to do with ADO beyond the letters *A*, *D*, and *O*. While it is true that there is some relationship between the two systems (e.g., each has the concept of connection and command objects), some familiar ADO types (e.g., the `Recordset`) no longer exist. Furthermore, you can find many new types that have no direct equivalent under classic ADO (e.g., the data adapter).

# Understanding ADO.NET Data Providers

ADO.NET does not provide a single set of objects that communicate with multiple database management systems (DBMSs). Rather, ADO.NET supports multiple *data providers*, each of which is optimized to interact with a specific DBMS. The first benefit of this approach is that you can program a specific data provider to access any unique features of a particular DBMS. The second benefit is that a specific data provider can connect directly to the underlying engine of the DBMS in question without an intermediate mapping layer standing between the tiers.

Simply put, a data provider is a set of types defined in a given namespace that understand how to communicate with a specific type of data source. Regardless of which data provider you use, each defines a set of class types that provide core functionality. Table 21-1 documents some of the core base classes and the key interfaces they implement.

**Table 21-1.** *The Core Objects of an ADO.NET Data Provider*

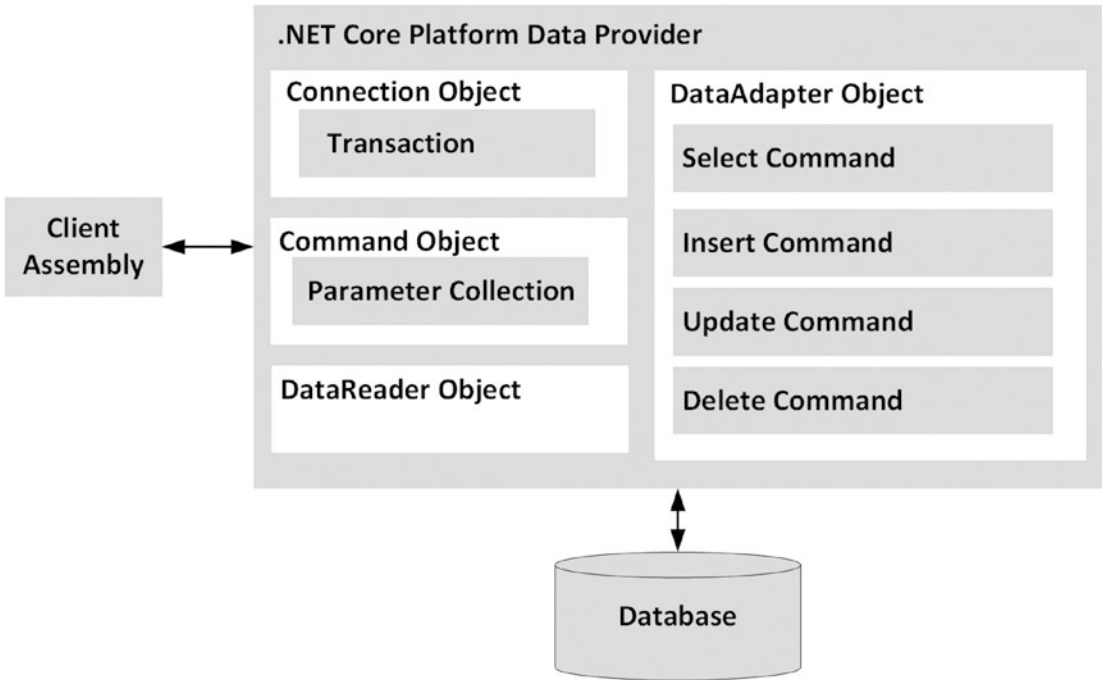
Base Class	Relevant Interfaces	Meaning in Life
DbConnection	IDbConnection	Provides the ability to connect to and disconnect from the data store. Connection objects also provide access to a related transaction object.
DbCommand	IDbCommand	Represents a SQL query or a stored procedure. Command objects also provide access to the provider's data reader object.
DbDataReader	IDataReader, IDataRecord	Provides forward-only, read-only access to data using a server-side cursor.
DbDataAdapter	IDataAdapter, IDbDataAdapter	Transfers DataSets between the caller and the data store. Data adapters contain a connection and a set of four internal command objects used to select, insert, update, and delete information from the data store.
DbParameter	IDataParameter, IDbDataParameter	Represents a named parameter within a parameterized query.
DbTransaction	IDbTransaction	Encapsulates a database transaction.

Although the specific names of these core classes will differ among data providers (e.g., SqlConnection vs. OleDbConnection), each class derives from the same base class (DbConnection, in the case of connection objects) that implements identical interfaces (e.g., IDbConnection). Given this, you would be correct to assume that after you learn how to work with one data provider, the remaining providers prove quite straightforward.

■ **Note** When you refer to a connection object under ADO.NET, you're actually referring to a specific DbConnection-derived type; there is no class literally named *Connection*. The same idea holds true for a *command object*, *data adapter object*, and so forth. As a naming convention, the objects in a specific data provider are prefixed with the name of the related DBMS (e.g., SqlConnection, OleDbConnection, and OleDbDataReader).

Figure 21-1 shows the big picture behind ADO.NET data providers. The client assembly can be any type of .NET Core application: console program, Windows Forms, Windows Presentation Foundation, ASP.NET Core, .NET Core code library, and so on.

A data provider will supply you with other types beyond the objects shown in Figure 21-1; however, these core objects define a common baseline across all data providers.



**Figure 21-1.** ADO.NET data providers provide access to a given DBMS

## ADO.NET Data Providers

As with all of .NET Core, data providers ship as NuGet packages. There are several supported by Microsoft as well as a multitude of third-party providers available. Table 21-2 documents some of the data providers supported by Microsoft.

**Table 21-2.** Some of the Microsoft-Supported Data Providers

Data Provider	Namespace/NuGet Package Name
Microsoft SQL Server	Microsoft.Data.SqlClient
ODBC	System.Data.Odbc
OLE DB (Windows only)	System.Data.OleDb

■ **Note** The data access platform in .NET Core is Entity Framework (EF) Core, covered in subsequent chapters. EF Core also uses the provider patterns and has a much richer provider ecosystem than raw ADO.NET. As this chapter is focused on vanilla ADO.NET, only a few of the providers will be used.

The Microsoft SQL Server data provider offers direct access to Microsoft SQL Server data stores – and *only* SQL Server data stores (including SQL Azure). The `Microsoft.Data.SqlClient` namespace contains the types used by the SQL Server provider.

■ **Note** While `System.Data.SqlClient` is still supported, all development effort for interaction with SQL Server (and SQL Azure) is focused on the new `Microsoft.Data.SqlClient` provider library.

The ODBC provider (`System.Data.Odbc`) provides access to ODBC connections. The ODBC types defined within the `System.Data.Odbc` namespace are typically useful only if you need to communicate with a given DBMS for which there is no custom .NET Core data provider. This is true because ODBC is a widespread model that provides access to a number of data stores.

The OLE DB data provider, which is composed of the types defined in the `System.Data.OleDb` namespace, allows you to access data located in any data store that supports the classic COM-based OLE DB protocol. Due to the dependence on COM, this provider will only work on the Windows operating system and should be considered deprecated in the cross-platform world of .NET Core.

## The Types of the System.Data Namespace

Of all the ADO.NET namespaces, `System.Data` is the lowest common denominator. This namespace contains types that are shared among all ADO.NET data providers, regardless of the underlying data store. In addition to a number of database-centric exceptions (e.g., `NotNullAllowedException`, `RowNotFoundException`, and `MissingPrimaryKeyException`), `System.Data` contains types that represent various database primitives (e.g., tables, rows, columns, and constraints), as well as the common interfaces implemented by data provider objects. Table 21-3 lists some of the core types you should be aware of.

**Table 21-3.** Core Members of the `System.Data` Namespace

Type	Meaning in Life
Constraint	Represents a constraint for a given <code>DataColumn</code> object
DataColumn	Represents a single column within a <code>DataTable</code> object
DataRelation	Represents a parent-child relationship between two <code>DataTable</code> objects
DataRow	Represents a single row within a <code>DataTable</code> object
DataSet	Represents an in-memory cache of data consisting of any number of interrelated <code>DataTable</code> objects
DataTable	Represents a tabular block of in-memory data
DataTableReader	Allows you to treat a <code>DataTable</code> as a fire-hose cursor (forward-only, read-only data access)
DataRowView	Represents a customized view of a <code>DataRow</code> for sorting, filtering, searching, editing, and navigation
IDataAdapter	Defines the core behavior of a data adapter object
IDataParameter	Defines the core behavior of a parameter object
IDataReader	Defines the core behavior of a data reader object

(continued)

**Table 21-3.** (continued)

Type	Meaning in Life
IDbCommand	Defines the core behavior of a command object
IDbDataAdapter	Extends IDataAdapter to provide additional functionality of a data adapter object
IDbTransaction	Defines the core behavior of a transaction object

Your next task is to examine the core interfaces of `System.Data` at a high level; this can help you understand the common functionality offered by any data provider. You will also learn specific details throughout this chapter; however, for now it's best to focus on the overall behavior of each interface type.

## The Role of the IDbConnection Interface

The `IDbConnection` type is implemented by a data provider's *connection object*. This interface defines a set of members used to configure a connection to a specific data store. It also allows you to obtain the data provider's transaction object. Here is the formal definition of `IDbConnection`:

```
public interface IDbConnection : IDisposable
{
    string ConnectionString { get; set; }
    int ConnectionTimeout { get; }
    string Database { get; }
    ConnectionState State { get; }

    IDbTransaction BeginTransaction();
    IDbTransaction BeginTransaction(IsolationLevel il);
    void ChangeDatabase(string databaseName);
    void Close();
    IDbCommand CreateCommand();
    void Open();
}
```

---

■ **Note** Like many other types in the .NET Core base class libraries, the `Close()` method is functionally equivalent to calling the `Dispose()` method directly or indirectly within C# by using scope (see [Chapter 9](#)).

---

## The Role of the IDbTransaction Interface

The overloaded `BeginTransaction()` method defined by `IDbConnection` provides access to the provider's *transaction object*. You can use the members defined by `IDbTransaction` to interact programmatically with a transactional session and the underlying data store.

```
public interface IDbTransaction : IDisposable
{
    IDbConnection Connection { get; }
    IsolationLevel IsolationLevel { get; }

    void Commit();
    void Rollback();
}
```

## The Role of the IDbCommand Interface

Next up is the IDbCommand interface, which will be implemented by a data provider's *command object*. Like other data access object models, command objects allow programmatic manipulation of SQL statements, stored procedures, and parameterized queries. Command objects also provide access to the data provider's data reader type through the overloaded ExecuteReader() method.

```
public interface IDbCommand : IDisposable
{
    string CommandText { get; set; }
    int CommandTimeout { get; set; }
    CommandType CommandType { get; set; }
    IDbConnection Connection { get; set; }
    IDbTransaction Transaction { get; set; }
    IDataParameterCollection Parameters { get; }
    UpdateRowSource UpdatedRowSource { get; set; }

    void Prepare();
    void Cancel();
    IDbDataParameter CreateParameter();
    int ExecuteNonQuery();
    IDataReader ExecuteReader();
    IDataReader ExecuteReader(CommandBehavior behavior);
    object ExecuteScalar();
}
```

## The Role of the IDbDataParameter and IDataParameter Interfaces

Notice that the Parameters property of IDbCommand returns a strongly typed collection that implements IDataParameterCollection. This interface provides access to a set of IDbDataParameter-compliant class types (e.g., parameter objects).

```
public interface IDbDataParameter : IDataParameter
{
    byte Precision { get; set; }
    byte Scale { get; set; }
    int Size { get; set; }
}
```

IDbDataParameter extends the IDataParameter interface to obtain the following additional behaviors:

```
public interface IDataParameter
{
    DbType DbType { get; set; }
    ParameterDirection Direction { get; set; }
    bool IsNullable { get; }
    string ParameterName { get; set; }
    string SourceColumn { get; set; }
    DataRowVersion SourceVersion { get; set; }
    object Value { get; set; }
}
```

As you will see, the functionality of the IDbDataParameter and IDataParameter interfaces allows you to represent parameters within a SQL command (including stored procedures) through specific ADO.NET parameter objects, rather than through hard-coded string literals.

## The Role of the IDbDataAdapter and IDataAdapter Interfaces

You use *data adapters* to push and pull DataSets to and from a given data store. The IDbDataAdapter interface defines the following set of properties that you can use to maintain the SQL statements for the related select, insert, update, and delete operations:

```
public interface IDbDataAdapter : IDataAdapter
{
    IDbCommand SelectCommand { get; set; }
    IDbCommand InsertCommand { get; set; }
    IDbCommand UpdateCommand { get; set; }
    IDbCommand DeleteCommand { get; set; }
}
```

In addition to these four properties, an ADO.NET data adapter picks up the behavior defined in the base interface, IDataAdapter. This interface defines the key function of a data adapter type: the ability to transfer DataSets between the caller and underlying data store using the Fill() and Update() methods. The IDataAdapter interface also allows you to map database column names to more user-friendly display names with the TableMappings property.

```
public interface IDataAdapter
{
    MissingMappingAction MissingMappingAction { get; set; }
    MissingSchemaAction MissingSchemaAction { get; set; }
    ITableMappingCollection TableMappings { get; }

    DataTable[] FillSchema(DataSet dataSet,
        SchemaType schemaType);
    int Fill(DataSet dataSet);
    IDataParameter[] GetFillParameters();
    int Update(DataSet dataSet);
}
```



## The Role of the IDataReader and IDataRecord Interfaces

The next key interface to be aware of is `IDataReader`, which represents the common behaviors supported by a given data reader object. When you obtain an `IDataReader`-compatible type from an ADO.NET data provider, you can iterate over the result set in a forward-only, read-only manner.

```
public interface IDataReader : IDisposable, IDataRecord
{
    int Depth { get; }
    bool IsClosed { get; }
    int RecordsAffected { get; }

    void Close();
    DataTable GetSchemaTable();
    bool NextResult();
    bool Read();
}
```

Finally, `IDataReader` extends `IDataRecord`, which defines many members that allow you to extract a strongly typed value from the stream, rather than casting the generic `System.Object` retrieved from the data reader's overloaded indexer method. Here is the `IDataRecord` interface definition:

```
public interface IDataRecord
{
    int FieldCount { get; }
    object this[ int i ] { get; }
    object this[ string name ] { get; }
    string GetName(int i);
    string GetDataTypeName(int i);
    Type GetFieldType(int i);
    object GetValue(int i);
    int GetValues(object[] values);
    int GetOrdinal(string name);
    bool GetBoolean(int i);
    byte GetByte(int i);
    long GetBytes(int i, long fieldOffset, byte[] buffer,
        int bufferoffset, int length);
    char GetChar(int i);
    long GetChars(int i, long fieldoffset, char[] buffer,
        int bufferoffset, int length);
    Guid GetGuid(int i);
    short GetInt16(int i);
    int GetInt32(int i);
    long GetInt64(int i);
    float GetFloat(int i);
    double GetDouble(int i);
    string GetString(int i);
    Decimal GetDecimal(int i);
    DateTime GetDateTime(int i);
    IDataReader GetData(int i);
    bool IsDBNull(int i);
}
```

---

■ **Note** You can use the `IDataReader.IsDBNull()` method to discover programmatically whether a specified field is set to `null` before obtaining a value from the data reader (to avoid triggering a runtime exception). Also recall that C# supports nullable data types (see Chapter 4), which are ideal for interacting with data columns that could be `null` in the database table.

---

## Abstracting Data Providers Using Interfaces

At this point, you should have a better idea of the common functionality found among all .NET Core data providers. Recall that even though the exact names of the implementing types will differ among data providers, you can program against these types in a similar manner – that’s the beauty of interface-based polymorphism. For example, if you define a method that takes an `IDbConnection` parameter, you can pass in any ADO.NET connection object, like so:

```
public static void OpenConnection(IDbConnection cn)
{
    // Open the incoming connection for the caller.
    connection.Open();
}
```

---

■ **Note** Interfaces are not strictly required; you can achieve the same level of abstraction using abstract base classes (such as `DbConnection`) as parameters or return values.

---

The same holds true for member return values. Create a new .NET Core Console application named `MyConnectionFactory`. Add the following NuGet packages to the project (the `OleDb` package is only valid on Windows):

```
Microsoft.Data.SqlClient
System.Data.Common
System.Data.Odbc
System.Data.OleDb
```

The following code example allows you to obtain a specific connection object based on the value of a custom enumeration. For diagnostic purposes, you simply print the underlying connection object using reflection services.

```
using System;
using System.Data;
using System.Data.Odbc;
using System.Data.OleDb;
using Microsoft.Data.SqlClient;
```

```

namespace MyConnectionFactory
{
    //OleDb (a windows only COM based library) is not supported in .NET Core
    enum DataProviderEnum
    {
        SqlServer,
#ifdef PC
        OleDb,
#endif
        Odbc,
        None
    }

    class Program
    {
        static void Main(string[] args)
        {
            Console.WriteLine("**** Very Simple Connection Factory ****\n");
            Setup(DataProviderEnum.SqlServer);
#ifdef PC
            Setup(DataProviderEnum.OleDb); //Not supported on macOS
#endif
            Setup(DataProviderEnum.Odbc);
            Setup(DataProviderEnum.None);
            Console.ReadLine();
        }

        private static void Setup(DataProviderEnum provider)
        {
            // Get a specific connection.
            IDbConnection myConnection = GetConnection(provider);
            Console.WriteLine($"Your connection is a {myConnection?.GetType().Name ??
                "unrecognized type"}");
            // Open, use and close connection...
        }

        // This method returns a specific connection object
        // based on the value of a DataProvider enum.
        static IDbConnection GetConnection(
            DataProviderEnum dataProvider)
        => dataProvider switch
        {
            DataProviderEnum.SqlServer => new SqlConnection(),
#ifdef PC
            //Not supported on macOS
            DataProviderEnum.OleDb => new OleDbConnection(),
#endif
            DataProviderEnum.Odbc => new OdbcConnection(),
            _ => null,
        };
    }
}

```

The `#if PC` and `#endif` lines define compiler constants. If you are using a Windows-based machine and would like to enable the OleDb code, add the following to your project file:

```
<PropertyGroup Condition="'$(Configuration)|$(Platform)'=='Debug|AnyCPU'">
  <DefineConstants>TRACE;PC</DefineConstants>
</PropertyGroup>
```

The previous update to your project file enables the code block between the `#if` and `#endif` statements.

The benefit of working with the general interfaces of `System.Data` (or, for that matter, the abstract base classes of `System.Data.Common`) is that you have a much better chance of building a flexible codebase that can evolve over time. For example, today you might be building an application that targets Microsoft SQL Server; however, it's possible your company could switch to a different database months down the road. If you build a solution that hard-codes the Microsoft SQL Server-specific types of `System.Data.SqlClient`, you would obviously need to edit, recompile, and redeploy the assembly should the back-end database management system change.

At this point, you have authored some (very simple) ADO.NET code that allows you to create different types of provider-specific connection object. However, obtaining a connection object is only one aspect of working with ADO.NET. To make a worthwhile data provider factory library, you would also have to account for command objects, data readers, transaction objects, and other data-centric types. Building such a code library would not necessarily be difficult, but it would require a considerable amount of code and time.

Since the release of .NET 2.0, the kind folks in Redmond have built this exact functionality directly into the .NET base class libraries. This functionality has been significantly updated for .NET Core.

You will examine this formal API in just a moment; however, first you need to create a custom database to use throughout this chapter (and for many chapters to come).

## Setting Up SQL Server and Azure Data Studio

As you work through this chapter, you will execute queries against a simple SQL Server test database named `AutoLot`. In keeping with the automotive theme used throughout this book, this database will contain four interrelated tables (`Inventory`, `Orders`, `Customers`, and `CreditRisks`) that contain various bits of data representing order information for a fictional automobile sales company. Before getting into the database details, you must set up SQL Server and a SQL Server IDE.

---

■ **Note** If you are using a Windows-based development machine and installed Visual Studio 2019, you also have an instance of SQL Server Express (called `localdb`) installed, which can be used for all of the examples in this book. If you are content to use that version, please skip to the section “Installing Azure Data Studio”.

---

## Installing Docker

If you are using a non-Windows-based development machine and do not have an instance of SQL Server available for the samples, you can run SQL Server inside a Docker container on your Mac- or Linux-based workstation. Docker also works on Windows machines, so you are welcome to run the examples in this book using Docker regardless of your operating system of choice.

---

■ **Note** Containerization is a very large topic, and there just isn't space in this book to get into the deep details of containers or Docker. This book will cover just enough so you can work through all of the examples.

---

Docker Desktop can be downloaded from [www.docker.com/get-started](https://www.docker.com/get-started). Download and install the appropriate version (Windows, Mac, Linux) for your workstation (you will need a free DockerHub user account). Make sure you select Linux containers when prompted.

---

■ **Note** The container choice (Windows or Linux) is the operating system running inside the container, not the operating system of your workstation.

---

## Pulling the Image and Running SQL Server 2019

Containers are based on images, and each image is a layered set that builds up the final product. To get the image needed to run SQL Server 2019 in a container, open a cmd window and enter the following command:

```
docker pull mcr.microsoft.com/mssql/server:2019-latest
```

Once you have the image loaded onto your machine, you need to start SQL Server. To do that, enter the following command (all on one line):

```
docker run -e "ACCEPT_EULA=Y" -e "SA_PASSWORD=P@ssw0rd" -p 5433:1433 --name AutoLot -d mcr.microsoft.com/mssql/server:2019-latest
```

The previous command accepts the end user license agreement, sets the password (in real life, you need to use a strong password), sets the port mapping (port 5433 on your machine maps to the default port for SQL Server in the container (1433), then names the database (AutoLot), and finally informs Docker to use the previously downloaded image.

---

■ **Note** These are not settings you want to use for real development. For information on changing the SA password and to see a tutorial, go to <https://docs.microsoft.com/en-us/sql/linux/quickstart-install-connect-docker?view=sql-server-ver15&pivots=csi-bash>.

---

To confirm that it is running, enter the command "docker ps -a" (without the quotes) in your command prompt. You will see output similar to the following (some columns omitted for brevity):

---

```
C:\Users\japik>docker ps -a
CONTAINER ID IMAGE
STATUS      PORTS      NAMES
347475cfb823 mcr.microsoft.com/mssql/server:2019-latest
Up 6 minutes 0.0.0.0:5433->1433/tcp  AutoLot
```

---

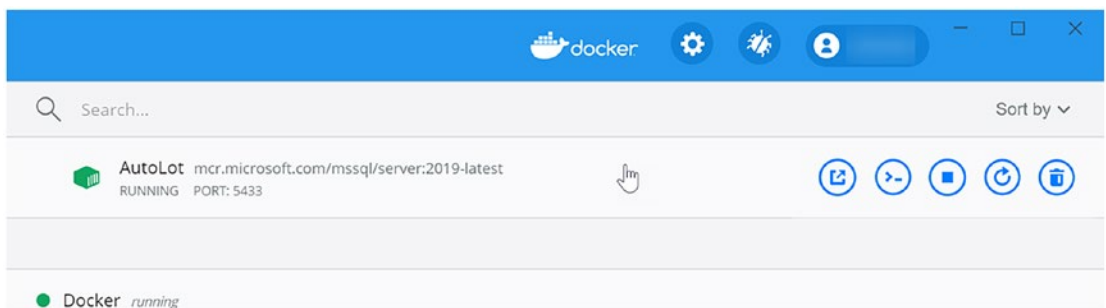
To stop the container, enter "docker stop 34747" (without the quotes), where the numbers 34747 are the first five characters of the container id. To restart the container, enter "docker start 34747" (without the quotes), again updating the command with the beginning of your container's id.

---

■ **Note** You can also use the container's name (AutoLot in this example) with the Docker CLI commands, for example, "docker start AutoLot" (without the quotes).

---

If you want to use the Docker Dashboard, right-click the Docker whale (in your system tray), select Dashboard, and you should see the image running on port 5433. Hover over the image name with your mouse, and you will see the commands to stop, start, and delete (among others) as shown in Figure 21-2.



**Figure 21-2.** Docker Dashboard

## Installing SQL Server 2019

A special instance of SQL Server (named (localdb)\mssqllocaldb) is installed with Visual Studio 2019. If you choose not to use SQL Server Express LocalDB (or Docker) and you are using a Windows machine, you can install SQL Server 2019 Developer Edition. SQL Server 2019 Developer Edition is free and can be downloaded from the SQL Server home page at Microsoft.com. At the time of this writing, that page is at this page (if it has changed, just search for SQL Server 2019 Developer Edition download):

<https://www.microsoft.com/en-us/sql-server/sql-server-downloads>

If you have another edition (e.g., Express), you can use that instance with this book as well; you will just need to change your connection screen appropriately.

## Installing a SQL Server IDE

Azure Data Studio is a new IDE for use with SQL Server. It's free and cross-platform, so it will work on Windows, Mac, or Linux. It can be downloaded from here:

<https://docs.microsoft.com/en-us/sql/ssms/download-sql-server-management-studio-ssms?view=sql-server-ver15>

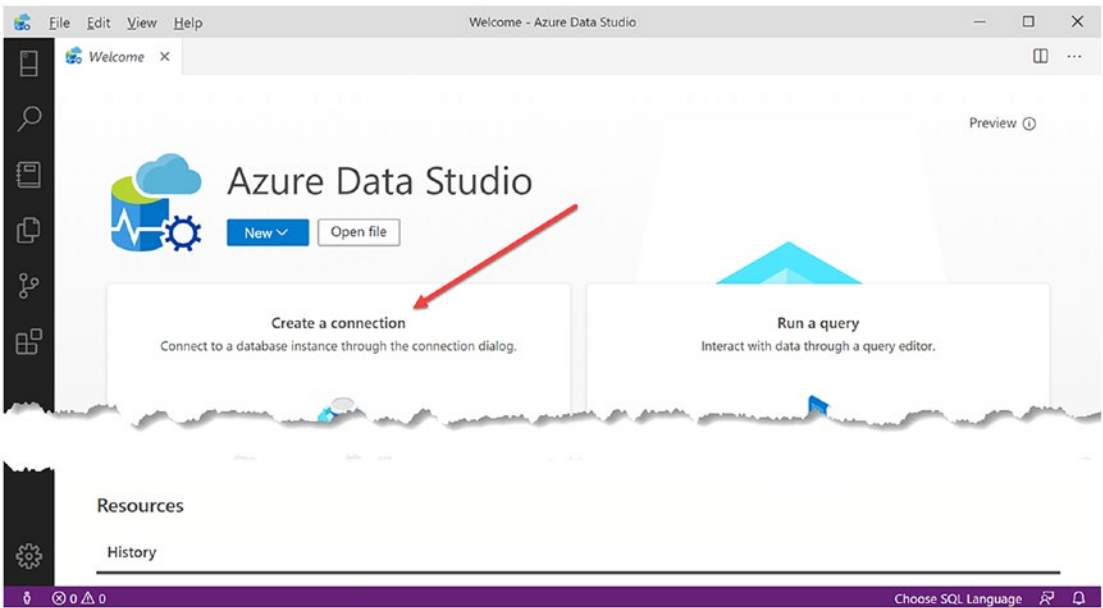
**Note** If you are using a Windows machine and prefer to use SQL Server Management Studio (SSMS), you can download the latest copy from here: <https://docs.microsoft.com/en-us/sql/ssms/download-sql-server-management-studio-ssms?view=sql-server-ver15>.

## Connecting to SQL Server

Once you have Azure Data Studio or SSMS installed, it's time to connect to your database instance. The following sections cover connection to either SQL Server in a Docker or LocalDb. If you are using another instance of SQL Server, please update the connection string used in the following sections accordingly.

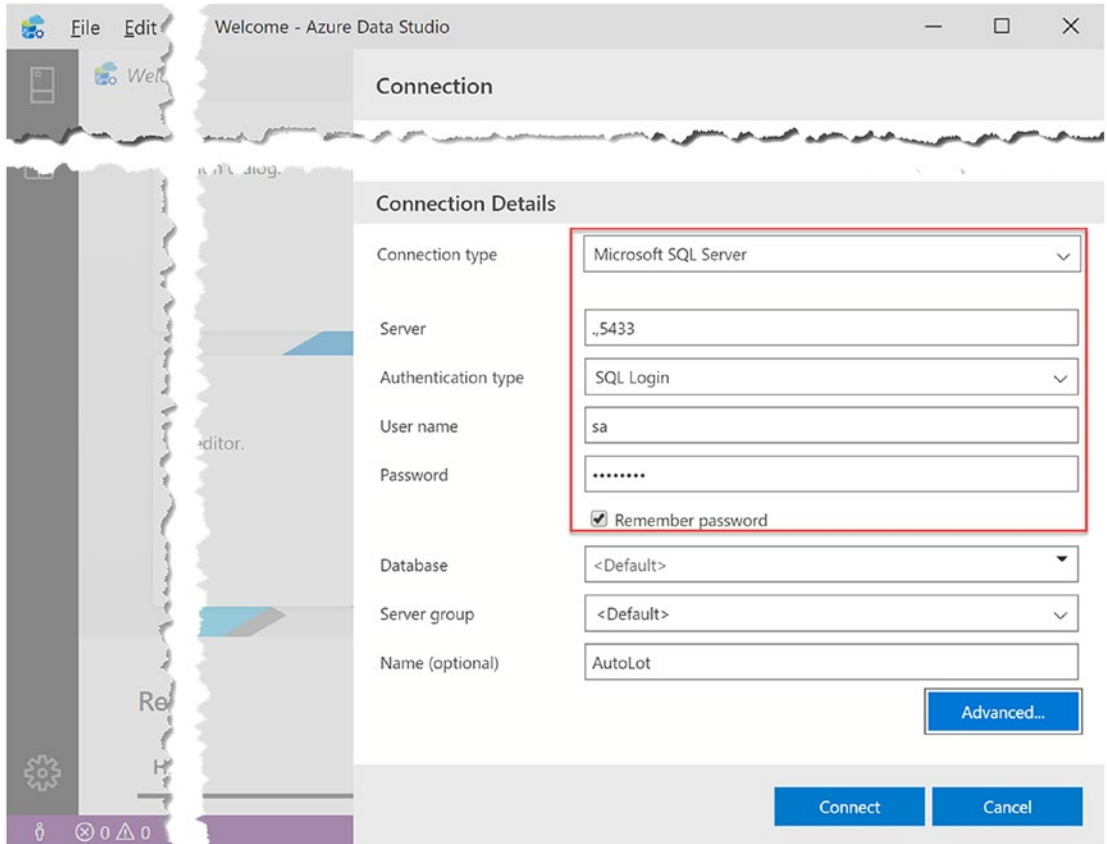
## Connecting to SQL Server in a Docker Container

To connect to your SQL Server instance running in a Docker container, first make sure it is up and running. Next, click the Create a connection in Azure Data Studio, as shown in Figure 21-3.



**Figure 21-3.** Creating a connection in Azure Data Studio

In the Connection Details dialog, update the Server to `.,5433` (without the quotes). The dot indicates the current host, and the `,5433` is the port that you indicated when creating the SQL Server instance in the Docker container. The user name is `sa` (without the quotes), and the password is the same one that you entered when creating the SQL Server instance. The name is optional, but allows you to quickly select this connection in subsequent Azure Data Studio sessions. All of this is shown in Figure 21-4.

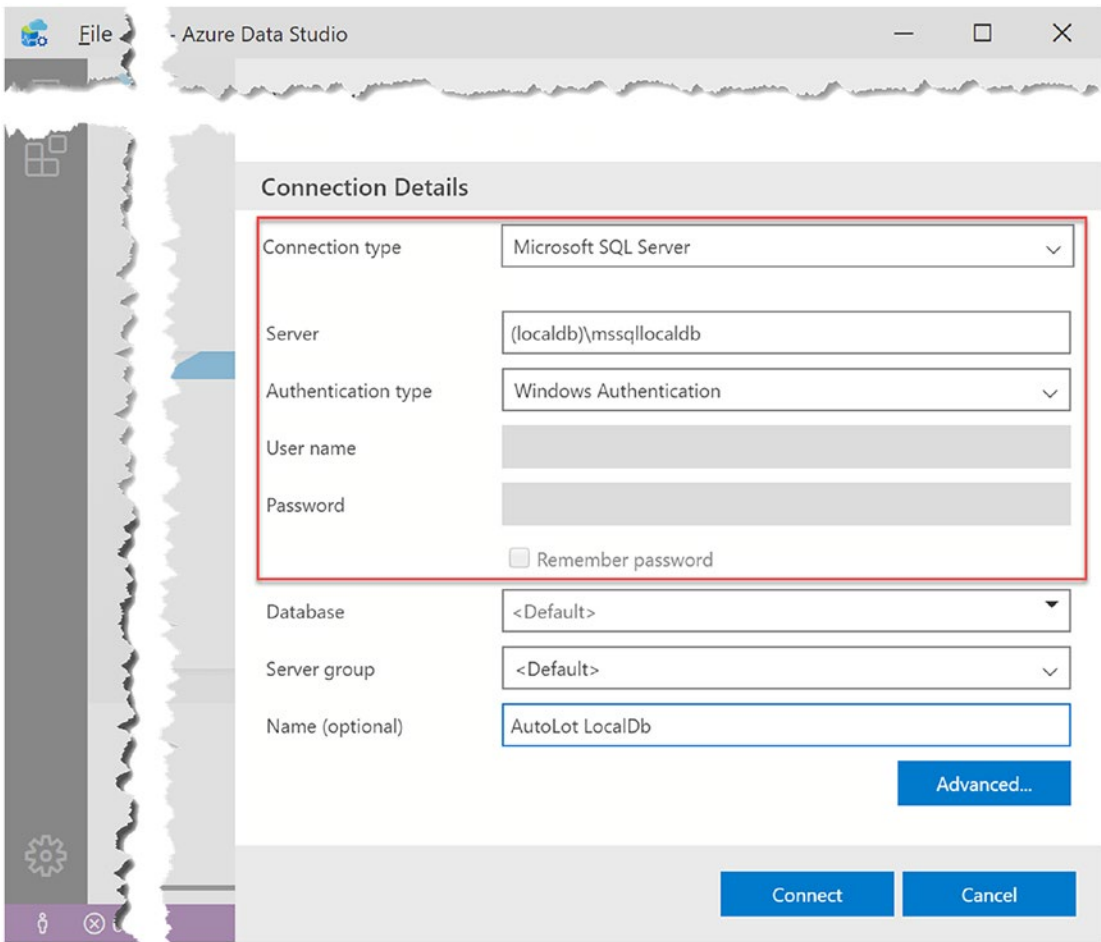


**Figure 21-4.** Setting the connection options for Docker SQL Server

## Connecting to SQL Server LocalDb

To connect to the Visual Studio installed version of SQL Server Express LocalDb, update the connection information to the following, shown in Figure 21-5.





**Figure 21-5.** Setting the connection options for SQL Server LocalDb

When connecting to LocalDb, you can use Windows Authentication, since the instance is running on the same machine as Azure Data Studio and the same security context as the current logged in user.

### Connecting to Any Other SQL Server Instance

If you are connecting to any other SQL Server instance, update the connection properties accordingly.

## Restoring the AutoLot Database Backup

Instead of building the database from scratch, you can use either SSMS or Azure Data Studio to restore one of the supplied backups contained in the chapter’s files in the repository. There are two backups supplied: the one named AutoLotWindows.bak is designed for use on a Windows machine (LocalDb, Windows Server, etc.), and the AutoLotDocker.bak is designed for use in a Docker container.

## Copying the Backup File to Your Container

If you are using SQL Server in a Docker container, you first have to copy the backup file to the container. Fortunately, the Docker CLI provides a mechanism for working with a container's file system. First, create a new directory for the backup using the following command:

```
docker exec -it AutoLot mkdir var/opt/mssql/backup
```

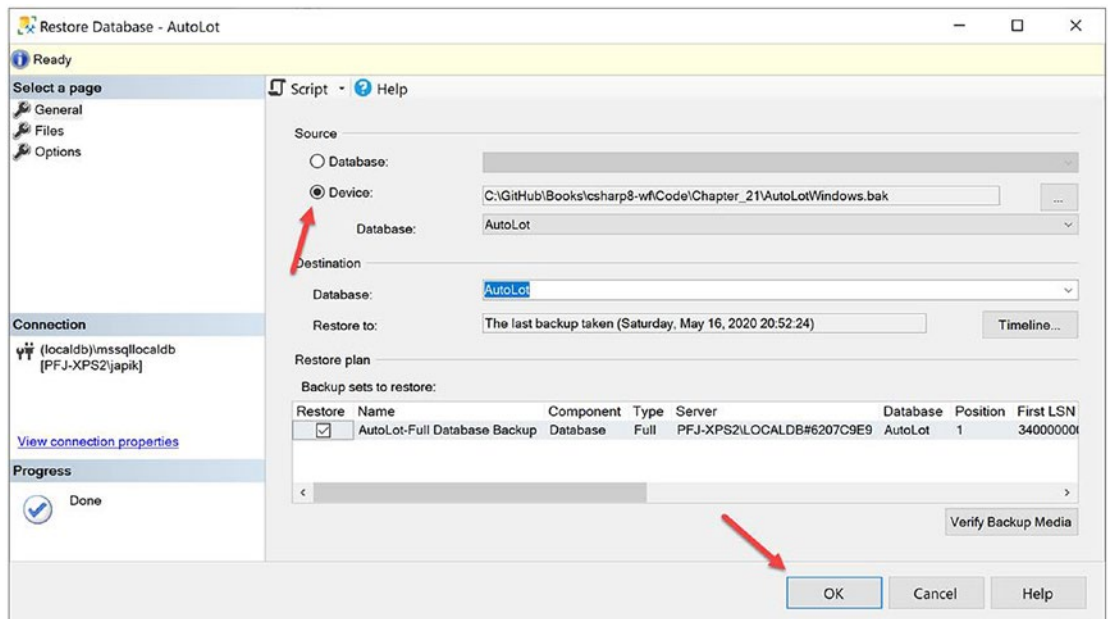
The path structure must match the containers operating system (in this case Ubuntu), even if your host machine is Windows based. Next, copy the backup to your new directory using the following command:

```
docker cp .\AutoLotDocker.bak AutoLot:var/opt/mssql/backup
```

Note that the source directory structure matches the host machine (in my example, Windows), while the target is the container name and then the directory path (in the target OS format).

## Restoring the Database with SSMS

To restore the database using SSMS, right-click the Databases node in Object Explorer. Select Restore Database.... Select Device and click the ellipses. This will bring on the Select Backup Device dialog. Keep the Backup media type as file, then click Add, navigate to the AutoLotWindows.bak file (either on your operating system or the container specific path), and then click OK. When you are back on the main restore screen, click OK as shown in Figure 21-6.



**Figure 21-6.** Restoring the database with SSMS (with the Windows version selected)

If you are using SQL Server in a Docker container and selected the `AutoLotWindows.bak` file, there is another setting that must be changed. Select the `Files` page, and then check the “Relocate all files to folder” option, which will move the files to the correct path in the container. This is shown in Figure 21-7.

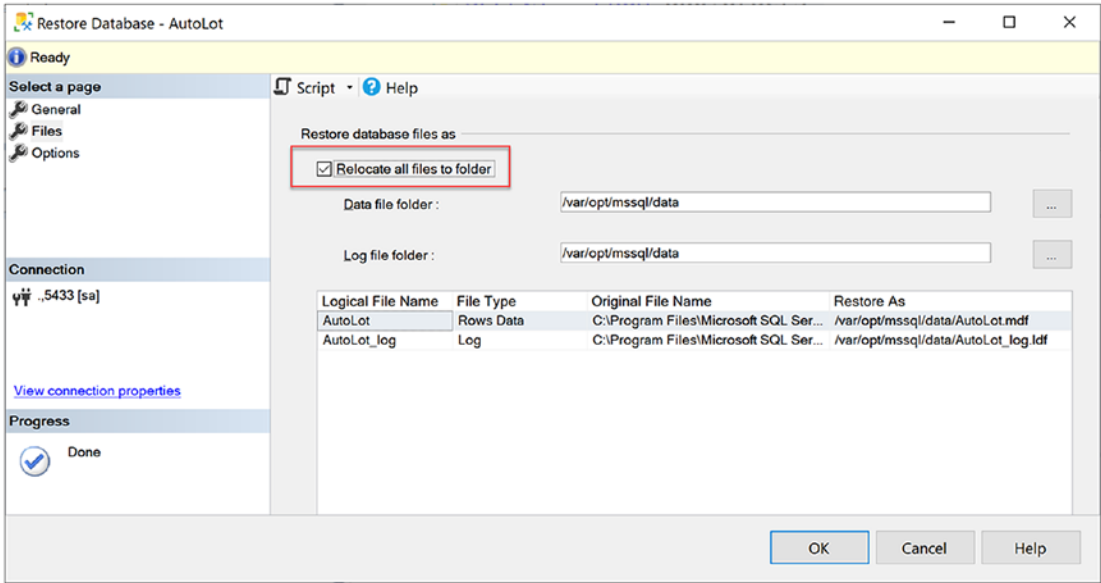
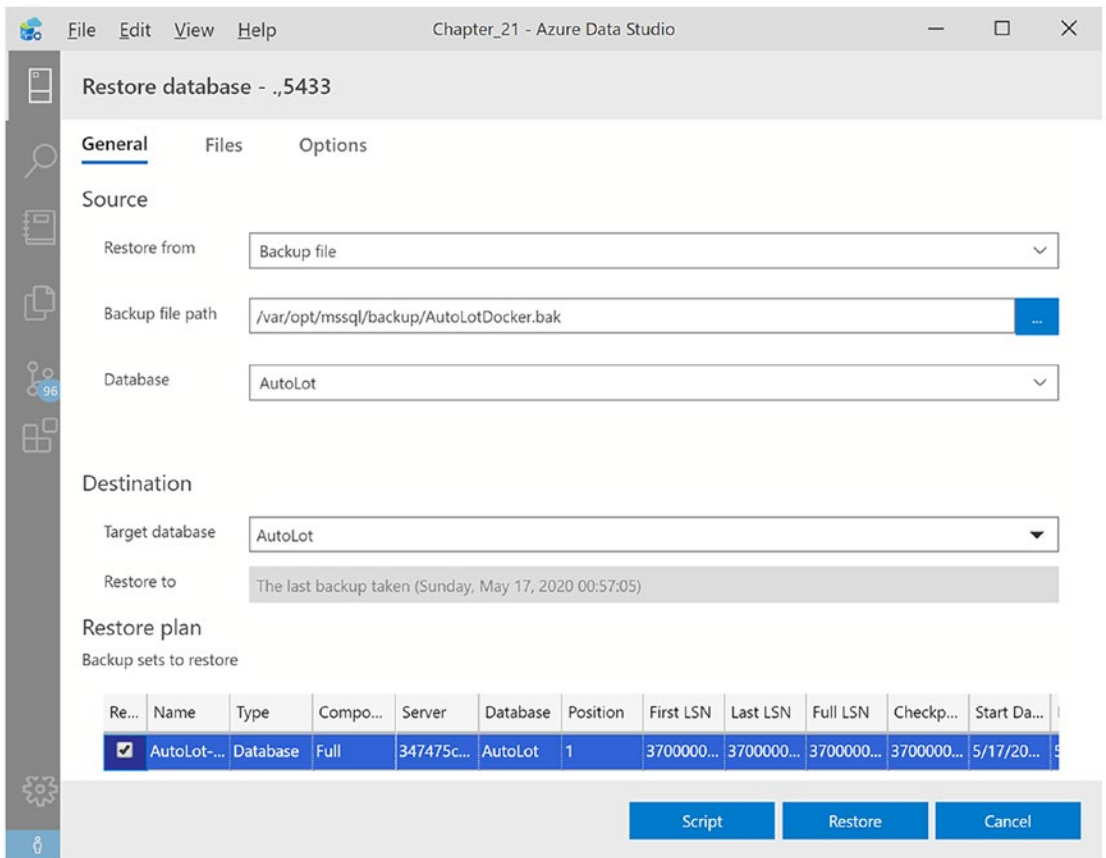


Figure 21-7. Changing the destination file locations

■ **Note** Anytime you are using a backup created on a different OS than the target, check the `Files` page to make sure the pathing is correct.

## Restoring the Database with Azure Data Studio

To restore the database using Azure Data Studio, click `View`, then select the `Command Palette` (or press `Ctrl+Shift+P`), and select `Restore`. Select “Backup file” as the `Restore from` option, and then the file you just copied. The target database and related fields will be filled in for you, as shown in Figure 21-8.



**Figure 21-8.** Restoring the database using Azure Data Studio

Azure Data Studio also has a Files tab that you can use to correct the file paths if you have a backup built on another operating system than the target.

## Creating the AutoLot Database

This entire section is devoted to creating the AutoLot database using Azure Data Studio. If you are using SSMS, you can follow along with these steps using either the SQL scripts discussed here or using the GUI tools. If you restored the backup, you can skip ahead to the section “The ADO.NET Data Provider Factory Model”.

### Creating the Database

To create the AutoLot database, connect to your database server using Azure Data Studio. Open a new query by clicking File ► New Query (or by pressing Ctrl+N) and enter the following command text:

```
CREATE DATABASE AutoLot;
go
ALTER DATABASE [AutoLot] SET RECOVERY SIMPLE
GO
```

Other than changing the recovery mode to simple, this creates the AutoLot database with all of the defaults. Click Run (or press F5) to create the database.

## Creating the Inventory Table

Next up is the Inventory table. Open a new query and enter the following SQL, which will create the table with four columns and also create the primary key:

```
USE [AutoLot]
GO
CREATE TABLE [dbo].[Inventory](
    [Id] [int] IDENTITY(1,1) NOT NULL,
    [Make] [nvarchar](50) NULL,
    [Color] [nvarchar](50) NULL,
    [PetName] [nvarchar](50) NULL,
    CONSTRAINT [PK_Inventory] PRIMARY KEY CLUSTERED
(
    [Id] ASC
)WITH (PAD_INDEX = OFF, STATISTICS_NORECOMPUTE = OFF, IGNORE_DUP_KEY = OFF, ALLOW_ROW_LOCKS
= ON, ALLOW_PAGE_LOCKS = ON) ON [PRIMARY]
) ON [PRIMARY]
GO
```

Click Run (or press F5) to create the Inventory table.

## Adding Test Records to the Inventory Table

To add records to your first table, create a new query and execute the following SQL statements to add seven records into the Inventory table:

```
USE [AutoLot]
GO
SET IDENTITY_INSERT [dbo].[Inventory] ON
GO
INSERT INTO [dbo].[Inventory] ([Id], [Make], [Color], [PetName]) VALUES
(1, N'VW', N'Black', N'Zippy')
INSERT INTO [dbo].[Inventory] ([Id], [Make], [Color], [PetName]) VALUES
(2, N'Ford', N'Rust', N'Rusty')
INSERT INTO [dbo].[Inventory] ([Id], [Make], [Color], [PetName]) VALUES
(3, N'Saab', N'Black', N'Mel')
INSERT INTO [dbo].[Inventory] ([Id], [Make], [Color], [PetName]) VALUES
(4, N'Yugo', N'Yellow', N'Clunker')
INSERT INTO [dbo].[Inventory] ([Id], [Make], [Color], [PetName]) VALUES
(5, N'BMW', N'Black', N'Bimmer')
INSERT INTO [dbo].[Inventory] ([Id], [Make], [Color], [PetName]) VALUES
(6, N'BMW', N'Green', N'Hank')
INSERT INTO [dbo].[Inventory] ([Id], [Make], [Color], [PetName]) VALUES
(7, N'BMW', N'Pink', N'Pinky')
SET IDENTITY_INSERT [dbo].[Inventory] OFF
GO
```

Click Run (or press F5) to insert the records.

## Authoring the GetPetName() Stored Procedure

Later in this chapter, you will learn how to use ADO.NET to invoke stored procedures. As you might already know, stored procedures are code routines stored within a database that do something. Like C# methods, stored procedures can return data or just operate on data without returning anything. You will add a single stored procedure that will return an automobile's pet name, based on the supplied Car Id. To do so, create a new query window and enter the following SQL command:

```
USE [AutoLot]
GO
CREATE PROCEDURE [dbo].[GetPetName]
@carID int,
@petName nvarchar(50) output
AS
SELECT @petName = PetName from dbo.Inventory where Id = @carID
GO
```

---

■ **Note** Stored procedures do not have to return data using output parameters, as shown here; however, doing things this way sets the stage for material covered later in this chapter.

---

Click Run (or press F5) to create the stored procedure.

## Creating the Customers Table

The AutoLot database needs two additional tables: Customers and Orders. The Customers table (as the name suggests) will contain a list of customers. Create a new query and enter the following SQL commands:

```
USE [AutoLot]
GO
CREATE TABLE [dbo].[Customers](
    [Id] [int] IDENTITY(1,1) NOT NULL,
    [FirstName] [nvarchar](50) NULL,
    [LastName] [nvarchar](50) NULL,
    PRIMARY KEY CLUSTERED
(
    [ID] ASC
)WITH (PAD_INDEX = OFF, STATISTICS_NORECOMPUTE = OFF, IGNORE_DUP_KEY = OFF, ALLOW_ROW_LOCKS
= ON, ALLOW_PAGE_LOCKS = ON) ON [PRIMARY]
) ON [PRIMARY]
GO
```

Click Run (or press F5) to create the Customers table.

## Adding Test Records to the Customers Table

To add records to the Customers table, create a new query and execute the following SQL statements:

```
USE AutoLot
GO
SET IDENTITY_INSERT [dbo].[Customers] ON
INSERT INTO [dbo].[Customers] ([Id], [FirstName], [LastName]) VALUES (1, N'Dave', N'Brenner')
INSERT INTO [dbo].[Customers] ([Id], [FirstName], [LastName]) VALUES (2, N'Matt', N'Walton')
INSERT INTO [dbo].[Customers] ([Id], [FirstName], [LastName]) VALUES (3, N'Steve', N'Hagen')
INSERT INTO [dbo].[Customers] ([Id], [FirstName], [LastName]) VALUES (4, N'Pat', N'Walton')
SET IDENTITY_INSERT [dbo].[Customers] OFF
GO
```

Click Run (or press F5) to insert the records.

## Creating the Orders Table

You will use your final table, Orders, to represent the automobile a given customer purchased. Create a new query, enter the following code, and click Run (or press F5):

```
USE [AutoLot]
GO
CREATE TABLE [dbo].[Orders](
    [Id] [int] IDENTITY(1,1) NOT NULL,
    [CustomerId] [int] NOT NULL,
    [CarId] [int] NOT NULL,
    PRIMARY KEY CLUSTERED
(
    [Id] ASC
)WITH (PAD_INDEX = OFF, STATISTICS_NORECOMPUTE = OFF, IGNORE_DUP_KEY = OFF, ALLOW_ROW_LOCKS
= ON, ALLOW_PAGE_LOCKS = ON) ON [PRIMARY]
) ON [PRIMARY]
GO
```

## Adding Test Records to the Orders Table

Now add data to your Orders table. You haven't created any table relationships yet, so you will have to manually make sure you enter values that exist in each table. Create a new query, enter the following SQL, and click Run (or press F5):

```
USE AutoLot
GO
SET IDENTITY_INSERT [dbo].[Orders] ON
INSERT INTO [dbo].[Orders] ([Id], [CustomerId], [CarId]) VALUES (1, 1, 5)
INSERT INTO [dbo].[Orders] ([Id], [CustomerId], [CarId]) VALUES (2, 2, 1)
INSERT INTO [dbo].[Orders] ([Id], [CustomerId], [CarId]) VALUES (3, 3, 4)
INSERT INTO [dbo].[Orders] ([Id], [CustomerId], [CarId]) VALUES (4, 4, 7)
SET IDENTITY_INSERT [dbo].[Orders] OFF
GO
```

## Creating the CreditRisk Table

You will use your final table, *Orders*, to represent the automobile a given customer purchased. Create a new query, enter the following code, and click Run (or press F5):

```
USE [AutoLot]
GO
/***** Object: Table [dbo].[CreditRisks]    Script Date: 5/12/2020 11:30:22 *****/
SET ANSI_NULLS ON
GO
SET QUOTED_IDENTIFIER ON
GO
CREATE TABLE [dbo].[CreditRisks](
    [Id] [int] IDENTITY(1,1) NOT NULL,
    [CustomerId] [int] NOT NULL,
    [FirstName] [nvarchar](50) NULL,
    [LastName] [nvarchar](50) NULL,
    PRIMARY KEY CLUSTERED
(
    [Id] ASC
)WITH (PAD_INDEX = OFF, STATISTICS_NORECOMPUTE = OFF, IGNORE_DUP_KEY = OFF, ALLOW_ROW_LOCKS
= ON, ALLOW_PAGE_LOCKS = ON) ON [PRIMARY]
) ON [PRIMARY]
GO
```

## Creating the Table Relationships

The final step is to create the foreign keys between the *Orders* table and the *Inventory* and *Customers* table. Open a new Query and add the following SQL text, and then press F5 to execute:

```
USE [AutoLot]
GO
ALTER TABLE [dbo].[Orders] WITH CHECK ADD CONSTRAINT [FK_Orders_Customers] FOREIGN
KEY([CustomerId])
REFERENCES [dbo].[Customers] ([Id])
ON UPDATE CASCADE
ON DELETE CASCADE
GO
ALTER TABLE [dbo].[Orders] CHECK CONSTRAINT [FK_Orders_Customers]
GO
ALTER TABLE [dbo].[Orders] WITH CHECK ADD CONSTRAINT [FK_Orders_Inventory] FOREIGN
KEY([CarId])
REFERENCES [dbo].[Inventory] ([Id])
GO
ALTER TABLE [dbo].[Orders] CHECK CONSTRAINT [FK_Orders_Inventory]
GO
ALTER TABLE [dbo].[CreditRisks] WITH CHECK ADD CONSTRAINT [FK_CreditRisks_Customers]
FOREIGN KEY([CustomerId])
REFERENCES [dbo].[Customers] ([Id])
ON UPDATE CASCADE
```



```
ON DELETE CASCADE
GO
```

---

■ **Note** If you are wondering why there are columns for `FirstName` and `LastName` *and* a relationship to the customer table, it's merely for demo purposes. I could think up a creative reason for it, but at the end of the day, it sets up Chapter 23 nicely.

---

With this, the `AutoLot` database is complete! Of course, this is a far cry from a real-world corporate database, but it will serve your needs for this chapter. Now that you have a database to test with, you can dive into the details of the ADO.NET data provider factory model.

## The ADO.NET Data Provider Factory Model

The .NET Core data provider factory pattern allows you to build a single codebase using generalized data access types. To understand the data provider factory implementation, recall from Table 21-1 that the classes within a data provider all derive from the same base classes defined within the `System.Data.Common` namespace:

- `DbCommand`: The abstract base class for all command classes
- `DbConnection`: The abstract base class for all connection classes
- `DbDataAdapter`: The abstract base class for all data adapter classes
- `DbDataReader`: The abstract base class for all data reader classes
- `DbParameter`: The abstract base class for all parameter classes
- `DbTransaction`: The abstract base class for all transaction classes

Each of the .NET Core-compliant data providers contains a class type that derives from `System.Data.Common.DbProviderFactory`. This base class defines several methods that retrieve provider-specific data objects. Here are the members of `DbProviderFactory`:

```
public abstract class DbProviderFactory
{
    ..public virtual bool CanCreateDataAdapter { get; };
    ..public virtual bool CanCreateCommandBuilder { get; };
    public virtual DbCommand CreateCommand();
    public virtual DbCommandBuilder CreateCommandBuilder();
    public virtual DbConnection CreateConnection();
    public virtual DbConnectionStringBuilder
        CreateConnectionStringBuilder();
    public virtual DbDataAdapter CreateDataAdapter();
    public virtual DbParameter CreateParameter();
    public virtual DbDataSourceEnumerator
        CreateDataSourceEnumerator();
}
```

To obtain the `DbProviderFactory`-derived type for your data provider, each provider provides a static property used to return the correct type. To return the SQL Server version of the `DbProviderFactory`, use the following code:

```
static void Main(string[] args)
{
    // Get the factory for the SQL data provider.
    DbProviderFactory sqlFactory =
        Microsoft.Data.SqlClient.SqlClientFactory.Instance;
}
```

To make the program more versatile, you can create a `DbProviderFactory` factory that returns a specific flavor of a `DbProviderFactory` based on a setting in the `appsettings.json` file for the application. You will learn how to do this shortly; for the moment, you can obtain the associated provider-specific data objects (e.g., connections, commands, and data readers) once you have obtained the factory for your data provider.

## A Complete Data Provider Factory Example

For a complete example, create a new C# Console Application project (named `DataProviderFactory`) that prints out the automobile inventory of the `AutoLot` database. For this initial example, you will hard-code the data access logic directly within the `DataProviderFactory.exe` assembly (to keep things simple). As you progress through this chapter, you will see better ways to do this.

---

Entity Framework Core simplifies much of what we are accomplishing in this chapter. You will use EF Core for data access starting with the next chapter and for the rest of this book.

---

Begin by adding a new `ItemGroup` and the `Microsoft.Extensions.Configuration.Json`, `System.Data.Common`, `System.Data.Odbc`, `System.Data.OleDb`, and `Microsoft.Data.SqlClient` packages to the project file like this:

```
<ItemGroup>
  <PackageReference Include="Microsoft.Extensions.Configuration.Json" Version="3.1.3" />
  <PackageReference Include="System.Data.Common" Version="4.3.0" />
  <PackageReference Include="System.Data.Odbc" Version="4.7.0" />
  <PackageReference Include="System.Data.OleDb" Version="4.7.0" />
  <PackageReference Include="Microsoft.Data.SqlClient" Version="1.1.2" />
</ItemGroup>
```

Add a new JSON file named `appsettings.json` to the project and update its contents to this (update the connection strings based on your specific environment):

```
{
  "ProviderName": "SqlServer",
  //"ProviderName": "OleDb",
  //"ProviderName": "Odbc",
  "SqlServer": {
    // for localdb use @"Data Source=(localdb)\mssqllocaldb;Integrated Security=true;
    Initial Catalog=AutoLot"
```

```

    "ConnectionString": "Data Source=.,5433;User Id=sa;Password=P@sswOrd;Initial
    Catalog=AutoLot"
  },
  "Odbc": {
    // for localdb use @"Driver={ODBC Driver 17 for SQL Server};Server=(localdb)\mssqllocal
    db;Database=AutoLot;Trusted_Connection=Yes";
    "ConnectionString": "Driver={ODBC Driver 17 for SQL Server};Server=localhost,5433;
    Database=AutoLot;Uid=sa;Pwd=P@sswOrd;"
  },
  "OleDb": {
    // if localdb use @"Provider=SQLNCLI11;Data Source=(localdb)\mssqllocaldb;Initial
    Catalog=AutoLot;Integrated Security=SSPI"),
    "ConnectionString": "Provider=SQLNCLI11;Data Source=.,5433;User Id=sa;Password=P@sswOrd;
    Initial Catalog=AutoLot;"
  }
}

```

The final change is to inform MSBuild to copy the JSON file to the output directory on every build. Update the project file by adding the following:

```

<ItemGroup>
  <None Update="appsettings.json">
    <CopyToOutputDirectory>Always</CopyToOutputDirectory>
  </None>
</ItemGroup>

```

---

■ **Note** The `CopyToOutputDirectory` is whitespace sensitive. Make sure it is all on one line without any spaces around the word `Always`.

---

Now that you have a proper `appsettings.json`, you can read in the `provider` and `connectionString` values using .NET Core configuration. Start by updating the using statements at the top of `Program.cs` to the following:

```

using System;
using System.Data.Common;
using System.Data.Odbc;
using System.Data.OleDb;
using System.IO;
using Microsoft.Data.SqlClient;
using Microsoft.Extensions.Configuration;

```

Add the following code to read the configuration, set the `DataProviderEnum` to the correct value, get the connection string, and return an instance of the `DbProviderFactory`:

```
enum DataProviderEnum
{
    SqlServer,
#if PC
    OleDb,
#endif
    Odbc
}

static DbProviderFactory GetDbProviderFactory(
    DataProviderEnum provider) => provider switch
{
    DataProviderEnum.SqlServer
        => Microsoft.Data.SqlClient.SqlClientFactory.Instance,
    DataProviderEnum.Odbc
        => System.Data.Odbc.OdbcFactory.Instance,
#if PC
    DataProviderEnum.OleDb
        => System.Data.OleDb.OleDbFactory.Instance,
#endif
    _ => null
};

static (DataProviderEnum Provider, string ConnectionString)
    GetProviderFromConfiguration()
{
    IConfiguration config = new ConfigurationBuilder()
        .SetBasePath(Directory.GetCurrentDirectory())
        .AddJsonFile("appsettings.json", true, true)
        .Build();
    var providerName = config["ProviderName"];
    if (Enum.TryParse<DataProviderEnum>
        (providerName, out DataProviderEnum provider))
    {
        return (provider, config["${providerName}:ConnectionString"]);
    }
    throw new Exception(
        "Invalid data provider value supplied.");
}
```

Assuming you have imported the `System.Data`, `System.Data.Common`, and static `System.Console` namespaces, you can update your `Main()` method like this:

```
static void Main(string[] args)
{
    Console.WriteLine("***** Fun with Data Provider Factories *****\n");
    var (provider, connectionString)=
        GetProviderFromConfiguration();
```

```

DbProviderFactory factory = GetDbProviderFactory(provider);
// Now get the connection object.
using (DbConnection connection = factory.CreateConnection())
{
    if (connection == null)
    {
        Console.WriteLine($"Unable to create the connection object");
        return;
    }

    Console.WriteLine(
        $"Your connection is a: {connection.GetType().Name}");
    connection.ConnectionString = connectionString;
    connection.Open();
    // Make command object.
    DbCommand command = factory.CreateCommand();
    if (command == null)
    {
        Console.WriteLine($"Unable to create the command object");
        return;
    }
    Console.WriteLine(
        $"Your command object is a: {command.GetType().Name}");
    command.Connection = connection;
    command.CommandText = "Select * From Inventory";
    // Print out data with data reader.
    using (DbDataReader dataReader = command.ExecuteReader())
    {
        Console.WriteLine(
            $"Your data reader is a: {dataReader.GetType().Name}");
        Console.WriteLine("\n***** Current Inventory *****");
        while (dataReader.Read())
        {
            Console.WriteLine($"-> Car #{dataReader["Id"]} is a {dataReader["Make"]}");
        }
    }
}

Console.ReadLine();
}

```

Notice that, for diagnostic purposes, you use reflection services to print the name of the underlying connection, command, and data reader. If you run this application, you will find the following current data in the Inventory table of the AutoLot database printed to the console:

---

```

***** Fun with Data Provider Factories *****
Your connection object is a: SqlConnection
Your command object is a: SqlCommand
Your data reader object is a: SqlDataReader

```

```

***** Current Inventory *****
-> Car #1 is a VW.
-> Car #2 is a Ford.
-> Car #3 is a Saab.
-> Car #4 is a Yugo.
-> Car #5 is a BMW.
-> Car #6 is a BMW.
-> Car #7 is a BMW.

```

---

Now change the settings file to specify a different provider. The code will pick up the related connection string and produce the same output as before, except for the type specific information.

Of course, based on your experience with ADO.NET, you might be a bit unsure exactly what the connection, command, and data reader objects actually *do*. Don't sweat the details for the time being (quite a few pages remain in this chapter, after all!). At this point, it's enough to know that you can use the ADO.NET data provider factory model to build a single codebase that can consume various data providers in a declarative manner.

## A Potential Drawback with the Data Provider Factory Model

Although this is a powerful model, you must make sure that the codebase uses only types and methods common to all providers through the members of the abstract base classes. Therefore, when authoring your codebase, you are limited to the members exposed by `DbConnection`, `DbCommand`, and the other types of the `System.Data.Common` namespace.

Given this, you might find that this generalized approach prevents you from directly accessing some of the bells and whistles of a particular DBMS. If you must be able to invoke specific members of the underlying provider (e.g., `SqlConnection`), you can do so using an explicit cast, as in this example:

```

if (connection is SqlConnection sqlConnection)
{
    // Print out which version of SQL Server is used.
    WriteLine(sqlConnection.ServerVersion);
}

```

When doing this, however, your codebase becomes a bit harder to maintain (and less flexible) because you must add a number of runtime checks. Nevertheless, if you need to build ADO.NET data access libraries in the most flexible way possible, the data provider factory model provides a great mechanism for doing so.

---

■ **Note** Entity Framework Core and its support for dependency injection greatly simplifies building data access libraries that need to access disparate data sources.

---

With this first example behind you, you can now dive into the details of working with ADO.NET.

## Diving Deeper into Connections, Commands, and DataReaders

As shown in the previous example, ADO.NET allows you to interact with a database using the connection, command, and data reader objects of your data provider. Now you'll create an expanded example to get a deeper understanding of these objects in ADO.NET.

In the previous example demonstrated, you need to perform the following steps when you want to connect to a database and read the records using a data reader object:

1. Allocate, configure, and open your connection object.
2. Allocate and configure a command object, specifying the connection object as a constructor argument or with the `Connection` property.
3. Call `ExecuteReader()` on the configured command class.
4. Process each record using the `Read()` method of the data reader.

To get the ball rolling, create a new Console Application project named `AutoLot.DataReader`, add the `Microsoft.Data.SqlClient` package, and import the `Microsoft.Data.SqlClient` namespace. Here is the complete code within `Main()` (analysis will follow):

```
class Program
{
    static void Main(string[] args)
    {
        Console.WriteLine("***** Fun with Data Readers *****\n");

        // Create and open a connection.
        using (SqlConnection connection = new SqlConnection())
        {
            connection.ConnectionString =
                @"Data Source=.,5433;User Id=sa;Password=P@ssw0rd;Initial Catalog=AutoLot";
            connection.Open();

            // Create a SQL command object.
            string sql = "Select * From Inventory";
            SqlCommand myCommand = new SqlCommand(sql, connection);

            // Obtain a data reader a la ExecuteReader().
            using (SqlDataReader myDataReader = myCommand.ExecuteReader())
            {
                // Loop over the results.
                while (myDataReader.Read())
                {
                    Console.WriteLine($"-> Make: {myDataReader["Make"]}, PetName: {myDataReader["PetName"]}, Color: {myDataReader["Color"]}");
                }
            }
        }
        Console.ReadLine();
    }
}
```

# Working with Connection Objects

The first step to take when working with a data provider is to establish a session with the data source using the connection object (which, as you recall, derives from `DbConnection`). .NET Core connection objects are provided with a formatted *connection string*; this string contains a number of name-value pairs, separated by semicolons. You use this information to identify the name of the machine you want to connect to, the required security settings, the name of the database on that machine, and other data provider-specific information.

As you can infer from the preceding code, the `Initial Catalog` name refers to the database you want to establish a session with. The `Data Source` name identifies the name of the machine that maintains the database. I am using "., 5433", which refers to the host machine (the period) and port 5433, which is my Docker containers instance of SQL Server. If you were using a different instance, you define the property as `machinename\instance`. For example, `MYSERVER\SQLSERVER2016` means `MYSERVER` is the name of the server and `SQLSERVER2016` is the name of the instance. If the machine is local to the development, you can use a period (.) or the token (local) for the server name. If the SQL Server instance is the default instance, the instance name is left off. For example, if you created `AutoLot` on a Microsoft SQL Server installation set up as the default instance on your local computer, you would use "`Data Source=(local)`".

Beyond this, you can supply any number of tokens that represent security credentials. If `Integrated Security` is set to `true`, current Windows account credentials are used for authentication and authorization.

After you establish your connection string, you can use a call to `Open()` to establish a connection with the DBMS. In addition to the `ConnectionString`, `Open()`, and `Close()` members, a connection object provides a number of members that let you configure additional settings regarding your connection, such as timeout settings and transactional information. Table 21-4 lists some (but not all) members of the `DbConnection` base class.

**Table 21-4.** *Members of the DbConnection Type*

Member	Meaning in Life
<code>BeginTransaction()</code>	You use this method to begin a database transaction.
<code>ChangeDatabase()</code>	You use this method to change the database on an open connection.
<code>ConnectionTimeout</code>	This read-only property returns the amount of time to wait while establishing a connection before terminating and generating an error (the default value is provider dependent). If you would like to change the default, specify a <code>Connect Timeout</code> segment in the connection string (e.g., <code>Connect Timeout=30</code> ).
<code>Database</code>	This read-only property gets the name of the database maintained by the connection object.
<code>DataSource</code>	This read-only property gets the location of the database maintained by the connection object.
<code>GetSchema()</code>	This method returns a <code>DataTable</code> object that contains schema information from the data source.
<code>State</code>	This read-only property gets the current state of the connection, which is represented by the <code>ConnectionState</code> enumeration.



The properties of the `DbConnection` type are typically read-only in nature and are useful only when you want to obtain the characteristics of a connection at runtime. When you need to override default settings, you must alter the connection string itself. For example, the following connection string sets the connection timeout setting from the default (15 seconds for SQL Server) to 30 seconds:

```
using(SqlConnection connection = new SqlConnection())
{
    connection.ConnectionString =
        @"Data Source=.,5433;User Id=sa;Password=P@ssw0rd;Initial Catalog=AutoLot;Connect
        Timeout=30";
    connection.Open();
}
```

The following code outputs details about the `SqlConnection` that it passed into it:

```
static void ShowConnectionStatus(SqlConnection connection)
{
    // Show various stats about current connection object.
    Console.WriteLine("***** Info about your connection *****");
    Console.WriteLine($"Database location:
        {connection.DataSource}");
    Console.WriteLine($"Database name: {connection.Database}");
    Console.WriteLine($"Timeout:
        {connection.ConnectionTimeout}");
    Console.WriteLine($"Connection state:
        {connection.State}\n");
}
```

While most of these properties are self-explanatory, the `State` property is worth a special mention. You can assign this property any value of the `ConnectionState` enumeration, as shown here:

```
public enum ConnectionState
{
    Broken,
    Closed,
    Connecting,
    Executing,
    Fetching,
    Open
}
```

However, the only valid `ConnectionState` values are `ConnectionState.Open`, `ConnectionState.Connecting`, and `ConnectionState.Closed` (the remaining members of this enum are reserved for future use). Also, it is always safe to close a connection, even if the connection state is currently `ConnectionState.Closed`.

## Working with `ConnectionStringBuilder` Objects

Working with connection strings programmatically can be cumbersome because they are often represented as string literals, which are difficult to maintain and error-prone at best. The .NET Core-compliant data providers support *connection string builder objects*, which allow you to establish the name-value pairs using strongly typed properties. Consider the following update to the current `Main()` method:

```

var connectionStringBuilder = new SqlConnectionStringBuilder
{
    InitialCatalog = "AutoLot",
    DataSource = ".,5433",
    UserID = "sa",
    Password = "P@ssw0rd",
    ConnectTimeout = 30
};
connection.ConnectionString =
    connectionStringBuilder.ConnectionString;

```

In this iteration, you create an instance of `SqlConnectionStringBuilder`, set the properties accordingly, and obtain the internal string using the `ConnectionString` property. Also note that you use the default constructor of the type. If you so choose, you can also create an instance of your data provider's connection string builder object by passing in an existing connection string as a starting point (this can be helpful when you read these values dynamically from an external source). Once you have hydrated the object with the initial string data, you can change specific name-value pairs using the related properties.

## Working with Command Objects

Now that you understand better the role of the connection object, the next order of business is to check out how to submit SQL queries to the database in question. The `SqlCommand` type (which derives from `DbCommand`) is an OO representation of a SQL query, table name, or stored procedure. You specify the type of command using the `CommandType` property, which can take any value from the `CommandType` enum, as shown here:

```

public enum CommandType
{
    StoredProcedure,
    TableDirect,
    Text // Default value.
}

```

When you create a command object, you can establish the SQL query as a constructor parameter or directly by using the `CommandText` property. Also when you create a command object, you need to specify the connection you want to use. Again, you can do so as a constructor parameter or by using the `Connection` property. Consider this code snippet:

```

// Create command object via ctor args.
string sql = "Select * From Inventory";
SqlCommand myCommand = new SqlCommand(sql, connection);
// Create another command object via properties.
SqlCommand testCommand = new SqlCommand();
testCommand.Connection = connection;
testCommand.CommandText = sql;

```

Realize that, at this point, you have not actually submitted the SQL query to the AutoLot database but instead prepared the state of the command object for future use. Table 21-5 highlights some additional members of the `DbCommand` type.

**Table 21-5.** *Members of the DbCommand Type*

Member	Meaning in Life
CommandTimeout	Gets or sets the time to wait while executing the command before terminating the attempt and generating an error. The default is 30 seconds.
Connection	Gets or sets the DbConnection used by this instance of the DbCommand.
Parameters	Gets the collection of DbParameter objects used for a parameterized query.
Cancel()	Cancels the execution of a command.
ExecuteReader()	Executes a SQL query and returns the data provider's DbDataReader object, which provides forward-only, read-only access for the result of the query.
ExecuteNonQuery()	Executes a SQL nonquery (e.g., an insert, update, delete, or create table).
ExecuteScalar()	A lightweight version of the ExecuteReader() method that was designed specifically for singleton queries (e.g., obtaining a record count).
Prepare()	Creates a prepared (or compiled) version of the command on the data source. As you might know, a <i>prepared query</i> executes slightly faster and is useful when you need to execute the same query multiple times (typically with different parameters each time).

## Working with Data Readers

After you establish the active connection and SQL command, the next step is to submit the query to the data source. As you might guess, you have a number of ways to do this. The DbDataReader type (which implements IDataReader) is the simplest and fastest way to obtain information from a data store. Recall that data readers represent a read-only, forward-only stream of data returned one record at a time. Given this, data readers are useful only when submitting SQL selection statements to the underlying data store.

Data readers are useful when you need to iterate over large amounts of data quickly and you do not need to maintain an in-memory representation. For example, if you request 20,000 records from a table to store in a text file, it would be rather memory intensive to hold this information in a DataSet (because a DataSet holds the entire result of the query in memory at the same time).

A better approach is to create a data reader that spins over each record as rapidly as possible. Be aware, however, that data reader objects (unlike data adapter objects, which you'll examine later) maintain an open connection to their data source until you explicitly close the connection.

You obtain data reader objects from the command object using a call to ExecuteReader(). The data reader represents the current record it has read from the database. The data reader has an indexer method (e.g., [] syntax in C#) that allows you to access a column in the current record. You can access the column either by name or by zero-based integer.

The following use of the data reader leverages the Read() method to determine when you have reached the end of your records (using a false return value). For each incoming record that you read from the database, you use the type indexer to print out the make, pet name, and color of each automobile. Also note that you call Close() as soon as you finish processing the records, which frees up the connection object.s

```
tatic void Main(string[] args)
{
    ...
    // Obtain a data reader via ExecuteReader().
    using(SqlDataReader myDataReader = myCommand.ExecuteReader())
```

```

{
    // Loop over the results.
    while (myDataReader.Read())
    {
        WriteLine($"-> Make: { myDataReader["Make"]}, PetName: { myDataReader["PetName"]},
            Color: { myDataReader["Color"]}.");
    }
}
ReadLine();
}

```

In the preceding snippet, you overload the indexer of a data reader object to take either a string (representing the name of the column) or an int (representing the column's ordinal position). Thus, you can clean up the current reader logic (and avoid hard-coded string names) with the following update (note the use of the `FieldCount` property):

```

while (myDataReader.Read())
{
    for (int i = 0; i < myDataReader.FieldCount; i++)
    {
        Console.Write(i != myDataReader.FieldCount - 1
            ? $"{myDataReader.GetName(i)} = {myDataReader.GetValue(i)}, "
            : $"{myDataReader.GetName(i)} = {myDataReader.GetValue(i)} ");
    }
    Console.WriteLine();
}

```

If you compile and run your project at this point, you should see a list of all automobiles in the Inventory table of the AutoLot database. The following output shows the modified output:

---

```

***** Fun with Data Readers *****
***** Info about your connection *****
Database location: .,5433
Database name: AutoLot
Timeout: 30
Connection state: Open

Id = 1, Make = VW, Color = Black, PetName = Zippy
Id = 2, Make = Ford, Color = Rust, PetName = Rusty
Id = 3, Make = Saab, Color = Black, PetName = Mel
Id = 4, Make = Yugo, Color = Yellow, PetName = Clunker
Id = 5, Make = BMW, Color = Black, PetName = Bimmer
Id = 6, Make = BMW, Color = Green, PetName = Hank
Id = 7, Make = BMW, Color = Pink, PetName = Pinky

```

---

## Obtaining Multiple Result Sets Using a Data Reader

Data reader objects can obtain multiple result sets using a single command object. For example, if you want to obtain all rows from the Inventory table, as well as all rows from the Customers table, you can specify both SQL Select statements using a semicolon delimiter, like so:

```
string sql = "Select * From Inventory;Select * from Customers";
```

After you obtain the data reader, you can iterate over each result set using the `NextResult()` method. Note that you are always returned the first result set automatically. Thus, if you want to read over the rows of each table, you can build the following iteration construct:

```
do
{
    while (myDataReader.Read())
    {
        for (int i = 0; i < myDataReader.FieldCount; i++)
        {
            Console.Write(i != myDataReader.FieldCount - 1
                ? $"{myDataReader.GetName(i)} = {myDataReader.GetValue(i)}, "
                : $"{myDataReader.GetName(i)} = {myDataReader.GetValue(i)} ");
        }
        Console.WriteLine();
    }
    Console.WriteLine();
} while (myDataReader.NextResult());
```

At this point, you should be more aware of the functionality data reader objects bring to the table. Always remember that a data reader can process only SQL Select statements; you cannot use them to modify an existing database table using Insert, Update, or Delete requests. Modifying an existing database requires additional investigation of command objects.

## Working with Create, Update, and Delete Queries

The `ExecuteReader()` method extracts a data reader object that allows you to examine the results of a SQL Select statement using a forward-only, read-only flow of information. However, when you want to submit SQL statements that result in the modification of a given table (or any other nonquery SQL statement, such as creating tables or granting permissions), you call the `ExecuteNonQuery()` method of your command object. This single method performs inserts, updates, and deletes based on the format of your command text.

---

■ **Note** Technically speaking, a *nonquery* is a SQL statement that does not return a result set. Thus, Select statements are queries, while Insert, Update, and Delete statements are not. Given this, `ExecuteNonQuery()` returns an `int` that represents the number of rows affected, not a new set of records.

---

All of the database interaction examples in this chapter so far have only opened connections and used them to retrieve data. This is just one part of working with a database; a data access framework would not be of much use unless it also fully supported Create, Read, Update, and Delete (CRUD) functionality. Next, you will learn how to do this using calls to `ExecuteNonQuery()`.

Begin by creating a new C# Class Library project named *AutoLot.DAL* (short for *AutoLot data access layer*), delete the default class file, and add the *Microsoft.Data.SqlClient* package to the project file, like this:

```
<ItemGroup>
  <PackageReference Include="Microsoft.Data.SqlClient" Version="1.1.2" />
</ItemGroup>
```

Before building the class that will conduct the data operations, we will first create an C# class that represents the *Car* table.

## Create the Car Model

Modern data access libraries use classes (commonly called *models or entities*) that are used to represent and transport the data from the database. You will see in the next chapter that the concept is a foundation of ORMs like the Entity Framework Core, but now, you are just going to create one model to represent a row in the *Inventory* table. Add a new folder to your project named *Models*, and add a new public class named *Car*. Update the code to the following:

```
public class Car
{
    public int Id { get; set; }
    public string Color { get; set; }
    public string Make { get; set; }
    public string PetName { get; set; }
}
```

This class will be used shortly.

## Adding the InventoryDAL Class

Next, add a new folder named *DataOperations*. In this new folder, add a new class named *InventoryDAL.cs* and change the class to *public*. This class will define various members to interact with the *Inventory* table of the *AutoLot* database. Finally, import the following namespaces:

```
using System;
using System.Collections.Generic;
using System.Data;
using AutoLot.DAL.Models;
using Microsoft.Data.SqlClient;
```

## Adding Constructors

Create a constructor that takes a string parameter (`connectionString`) and assigns the value to a class-level variable. Next, create a parameterless constructor that passes a default connection string to the other constructor. This enables the calling code to change the connection string if necessary from the default. The relevant code is as follows:

```
private readonly string _connectionString;
public InventoryDAL() : this(
    @"Data Source=.,5433;User Id=sa;Password=P@ssw0rd;Initial Catalog=AutoLot")
{
}
public InventoryDAL(string connectionString)
    => _connectionString = connectionString;
```

## Opening and Closing the Connection

Next, add a class-level variable to hold a connection that will be used by the data access code. Also, add two methods, one to open the connection (`OpenConnection()`) and the other to close the connection (`CloseConnection()`). In the `CloseConnection()` method, check the state of the connection, and if it's not closed, then call `Close()` on the connection. The code listing follows:

```
private SqlConnection _sqlConnection = null;
private void OpenConnection()
{
    _sqlConnection = new SqlConnection
    {
        ConnectionString = _connectionString
    };
    _sqlConnection.Open();
}
private void CloseConnection()
{
    if (_sqlConnection?.State != ConnectionState.Closed)
    {
        _sqlConnection?.Close();
    }
}
```

For the sake of brevity, most of the methods in the `InventoryDAL` class will not test for possible exceptions, nor will it throw custom exceptions to report various issues with the execution (e.g., a malformed connection string). If you were to build an industrial-strength data access library, you would absolutely want to use structured exception handling techniques (as covered in [Chapter 7](#)) to account for any runtime anomalies.

## Adding IDisposable

Add the IDisposable interface to the class definition, like this:

```
public class InventoryDAL : IDisposable
{
    ...
}
```

Next, implement the disposable pattern, calling Dispose on the SqlConnection object:

```
bool _disposed = false;
protected virtual void Dispose(bool disposing)
{
    if (_disposed)
    {
        return;
    }
    if (disposing)
    {
        _sqlConnection.Dispose();
    }
    _disposed = true;
}
public void Dispose()
{
    Dispose(true);
    GC.SuppressFinalize(this);
}
```

## Adding the Selection Methods

You start by combining what you already know about Command objects, DataReaders, and generic collections to get all of the records from the Inventory table. As you saw earlier in this chapter, a data provider's data reader object allows for a selection of records using a read-only, forward-only mechanism using the Read() method. In this example, the CommandBehavior property on the DataReader is set to automatically close the connection when the reader is closed. The GetAllInventory() method returns a List<Car> to represent all the data in the Inventory table:

```
public List<Car> GetAllInventory()
{
    OpenConnection();
    // This will hold the records.
    List<Car> inventory = new List<Car>();

    // Prep command object.
    string sql = "Select * From Inventory";
    using SqlCommand command =
        new SqlCommand(sql, _sqlConnection)
```



```

    {
        CommandType = CommandType.Text
    };
    command.CommandType = CommandType.Text;
    SqlDataReader dataReader =
        command.ExecuteReader(CommandBehavior.CloseConnection);
    while (dataReader.Read())
    {
        inventory.Add(new Car
        {
            Id = (int)dataReader["Id"],
            Color = (string)dataReader["Color"],
            Make = (string)dataReader["Make"],
            PetName = (string)dataReader["PetName"]
        });
    }
    dataReader.Close();
    return inventory;
}

```

The next selection method gets a single car based on the CarId:

```

public Car GetCar(int id)
{
    OpenConnection();
    Car car = null;
    //This should use parameters for security reasons
    string sql = $"Select * From Inventory where Id = {id}";
    using SqlCommand command =
        new SqlCommand(sql, _sqlConnection)
        {
            CommandType = CommandType.Text
        };
    SqlDataReader dataReader =
        command.ExecuteReader(CommandBehavior.CloseConnection);
    while (dataReader.Read())
    {
        car = new Car
        {
            Id = (int) dataReader["Id"],
            Color = (string) dataReader["Color"],
            Make = (string) dataReader["Make"],
            PetName = (string) dataReader["PetName"]
        };
    }
    dataReader.Close();
    return car;
}

```

---

■ **Note** It's generally a bad practice to accept user input into raw SQL statements as is done here. Later in this chapter, this code will be updated to use parameters.

---

## Inserting a New Car

Inserting a new record into the Inventory table is as simple as formatting the SQL Insert statement (based on user input), opening the connection, calling the `ExecuteNonQuery()` using your command object, and closing the connection. You can see this in action by adding a public method to your `InventoryDAL` type named `InsertAuto()` that takes three parameters that map to the non-identity columns of the Inventory table (Color, Make, and PetName). You use these arguments to format a string type to insert the new record. Finally, use your `SqlConnection` object to execute the SQL statement.

```
public void InsertAuto(string color, string make, string petName)
{
    OpenConnection();
    // Format and execute SQL statement.
    string sql = $"Insert Into Inventory (Make, Color, PetName) Values ('{make}', '{color}', '{petName}');";
    // Execute using our connection.
    using (SqlCommand command = new SqlCommand(sql, _sqlConnection))
    {
        command.CommandType = CommandType.Text;
        command.ExecuteNonQuery();
    }
    CloseConnection();
}
```

This previous method takes three string values and works as long as the calling code passes the strings in the correct order. A better method uses the `Car` model to make a strongly typed method, ensuring all the properties are passed into the method in the correct order.

## Create the Strongly Type `InsertCar()` Method

Add another `InsertAuto()` method that takes a `Car` model as a parameter to your `InventoryDAL` class. Also add a `using` for `AutoLot.DAL.Models` to the top of the class, as shown here:

```
public void InsertAuto(Car car)
{
    OpenConnection();
    // Format and execute SQL statement.
    string sql = "Insert Into Inventory (Make, Color, PetName) Values " +
        $"('{car.Make}', '{car.Color}', '{car.PetName}')";

    // Execute using our connection.
    using (SqlCommand command = new SqlCommand(sql, _sqlConnection))
    {
        command.CommandType = CommandType.Text;
        command.ExecuteNonQuery();
    }
    CloseConnection();
}
```

Defining classes that represent records in a relational database is a common way to build a data access library.

## Adding the Deletion Logic

Deleting an existing record is as simple as inserting a new record. Unlike when you created the code for `InsertAuto()`, this time you will learn about an important `try/catch` scope that handles the possibility of attempting to delete a car that is currently on order for an individual in the `Customers` table. The default `INSERT` and `UPDATE` options for foreign keys default to preventing the deletion of related records in linked tables. When this happens, a `SqlException` is thrown. A real program would handle that error intelligently; however, in this sample, you are just throwing a new exception. Add the following method to the `InventoryDAL` class type:

```
public void DeleteCar(int id)
{
    OpenConnection();
    // Get ID of car to delete, then do so.
    string sql = $"Delete from Inventory where Id = '{id}'";
    using (SqlCommand command = new SqlCommand(sql, _sqlConnection))
    {
        try
        {
            command.CommandType = CommandType.Text;
            command.ExecuteNonQuery();
        }
        catch (SqlException ex)
        {
            Exception error = new Exception("Sorry! That car is on order!", ex);
            throw error;
        }
    }
    CloseConnection();
}
```

## Adding the Update Logic

When it comes to the act of updating an existing record in the `Inventory` table, the first thing you must decide is what you want to allow the caller to change, whether it's the car's color, the pet name, the make, or all of these. One way to give the caller complete flexibility is to define a method that takes a `string` type to represent any sort of SQL statement, but that is risky at best.

Ideally, you want to have a set of methods that allow the caller to update a record in a variety of ways. However, for this simple data access library, you will define a single method that allows the caller to update the pet name of a given automobile, like so:

```
public void UpdateCarPetName(int id, string newPetName)
{
    OpenConnection();
    // Get ID of car to modify the pet name.
    string sql = $"Update Inventory Set PetName = '{newPetName}' Where Id = '{id}'";
    using (SqlCommand command = new SqlCommand(sql, _sqlConnection))
    {
        command.ExecuteNonQuery();
    }
    CloseConnection();
}
```

# Working with Parameterized Command Objects

Currently, the insert, update, and delete logic for the InventoryDAL type uses hard-coded string literals for each SQL query. With *parameterized queries*, SQL parameters are objects, rather than simple blobs of text. Treating SQL queries in a more object-oriented manner helps reduce the number of typos (given strongly typed properties); plus, parameterized queries typically execute much faster than a literal SQL string because they are parsed exactly once (rather than each time the SQL string is assigned to the CommandText property). Parameterized queries also help protect against SQL injection attacks (a well-known data access security issue).

To support parameterized queries, ADO.NET command objects maintain a collection of individual parameter objects. By default, this collection is empty, but you can insert any number of parameter objects that map to a *placeholder parameter* in the SQL query. When you want to associate a parameter within a SQL query to a member in the command object's parameters collection, you can prefix the SQL text parameter with the @ symbol (at least when using Microsoft SQL Server; not all DBMSs support this notation).

## Specifying Parameters Using the DbParameter Type

Before you build a parameterized query, you need to familiarize yourself with the DbParameter type (which is the base class to a provider's specific parameter object). This class maintains a number of properties that allow you to configure the name, size, and data type of the parameter, as well as other characteristics, including the parameter's direction of travel. Table 21-6 describes some key properties of the DbParameter type.

**Table 21-6.** Key Members of the DbParameter Type

Property	Meaning in Life
DbType	Gets or sets the native data type of the parameter, represented as a CLR data type.
Direction	Gets or sets whether the parameter is input-only, output-only, bidirectional, or a return value parameter.
IsNullable	Gets or sets whether the parameter accepts null values.
ParameterName	Gets or sets the name of the DbParameter.
Size	Gets or sets the maximum parameter size of the data in bytes; this is useful only for textual data.
Value	Gets or sets the value of the parameter.

Now let's look at how to populate a command object's collection of DBParameter-compatible objects by reworking the InventoryDAL methods to use parameters.

## Update the GetCar Method

The original implementation of the GetCar method used C# string interpolation when building the SQL string to retrieve the car data. To update this method, create an instance of SqlParameter with the appropriate values, as follows:

```
SqlParameter param = new SqlParameter
{
    ParameterName = "@carId",
    Value = id,
    SqlDbType = SqlDbType.Int,
    Direction = ParameterDirection.Input
};
```

The ParameterName must match the name used in the SQL query (you'll update that next), the type must match the database column type, and the direction is dependent on whether the parameter is used to send data *into* the query (ParameterDirection.Input) or if it is meant to return data *from* the query (ParameterDirection.Output). Parameters can also be defined as input/output or as return values (e.g., from a stored procedure).

Next, update the SQL string to use the parameter name ("@carId") instead of the C# string interpolation construct ("{id}").

```
string sql = "Select * From Inventory where Id = @carId";
```

The final update is to add the new parameter to the Parameters collection of the command object:

```
command.Parameters.Add(param);
```

## Update the DeleteCar Method

Likewise, the original implementation of the DeleteCar method used C# string interpolation. To update this method, create an instance of SqlParameter with the appropriate values, as follows:

```
SqlParameter param = new SqlParameter
{
    ParameterName = "@carId",
    Value = id,
    SqlDbType = SqlDbType.Int,
    Direction = ParameterDirection.Input
};
```

Next, update the SQL string to use the parameter name ("@carId").

```
string sql = "Delete from Inventory where Id = @carId";
```

The final update is to add the new parameter to the Parameters collection of the command object:

```
command.Parameters.Add(param);
```

## Update the UpdateCarPetName Method

This method requires two parameters, one for the car Id and the other for the new PetName. The first parameter is created just like the two previous examples (with the exception of a different variable name), and the second creates a parameter that maps to the database NVarChar type (the PetName field type from the Inventory table). Notice that a Size is set. It's important this size matches your database field size so as to not create problems when executing the command.

```
SqlParameter paramId = new SqlParameter
{
    ParameterName = "@carId",
    Value = id,
    SqlDbType = SqlDbType.Int,
    Direction = ParameterDirection.Input
};
SqlParameter paramName = new SqlParameter
{
    ParameterName = "@petName",
    Value = newPetName,
    SqlDbType = SqlDbType.NVarChar,
    Size = 50,
    Direction = ParameterDirection.Input
};
```

Next, update the SQL string to use the parameters:

```
string sql = $"Update Inventory Set PetName = @petName Where Id = @carId";
```

The final update is to add the new parameters to the Parameters collection of the command object:

```
command.Parameters.Add(paramId);
command.Parameters.Add(paramName);
```

## Update the InsertAuto Method

Add the following version of the InsertAuto() method to leverage parameter objects:

```
public void InsertAuto(Car car)
{
    OpenConnection();
    // Note the "placeholders" in the SQL query.
    string sql = "Insert Into Inventory" +
        "(Make, Color, PetName) Values" +
        "(@Make, @Color, @PetName)";

    // This command will have internal parameters.
    using (SqlCommand command = new SqlCommand(sql, _sqlConnection))
    {
        // Fill params collection.
        SqlParameter parameter = new SqlParameter
```

```

    {
        ParameterName = "@Make",
        Value = car.Make,
        SqlDbType = SqlDbType.NVarChar,
        Size = 50,
        Direction = ParameterDirection.Input
    };
    command.Parameters.Add(parameter);

    parameter = new SqlParameter
    {
        ParameterName = "@Color",
        Value = car.Color,
        SqlDbType = SqlDbType.NVarChar,
        Size = 50,
        Direction = ParameterDirection.Input
    };
    command.Parameters.Add(parameter);

    parameter = new SqlParameter
    {
        ParameterName = "@PetName",
        Value = car.PetName,
        SqlDbType = SqlDbType.NVarChar,
        Size = 50,
        Direction = ParameterDirection.Input
    };
    command.Parameters.Add(parameter);

    command.ExecuteNonQuery();
    CloseConnection();
}
}

```

While building a parameterized query often requires more code, the end result is a more convenient way to tweak SQL statements programmatically, as well as to achieve better overall performance. They also are extremely helpful when you want to trigger a stored procedure.

## Executing a Stored Procedure

Recall that a *stored procedure* is a named block of SQL code stored in the database. You can construct stored procedures so they return a set of rows or scalar data types or do anything else that makes sense (e.g., insert, update, or delete records); you can also have them take any number of optional parameters. The end result is a unit of work that behaves like a typical method, except that it is located on a data store rather than a binary business object. Currently, your AutoLot database defines a single stored procedure named `GetPetName`.

Now consider the following final method (for now) of the `InventoryDAL` type, which invokes your stored procedure:

```
public string LookUpPetName(int carId)
{
    OpenConnection();
    string carPetName;

    // Establish name of stored proc.
    using (SqlCommand command = new SqlCommand("GetPetName", _sqlConnection))
    {
        command.CommandType = CommandType.StoredProcedure;

        // Input param.
        SqlParameter param = new SqlParameter
        {
            ParameterName = "@carId",
            SqlDbType = SqlDbType.Int,
            Value = carId,
            Direction = ParameterDirection.Input
        };
        command.Parameters.Add(param);

        // Output param.
        param = new SqlParameter
        {
            ParameterName = "@petName",
            SqlDbType = SqlDbType.NVarChar,
            Size = 50,
            Direction = ParameterDirection.Output
        };
        command.Parameters.Add(param);

        // Execute the stored proc.
        command.ExecuteNonQuery();

        // Return output param.
        carPetName = (string)command.Parameters["@petName"].Value;
        CloseConnection();
    }
    return carPetName;
}
```

One important aspect of invoking a stored procedure is to keep in mind that a command object can represent a SQL statement (the default) or the name of a stored procedure. When you want to inform a command object that it will be invoking a stored procedure, you pass in the name of the procedure (as a constructor argument or by using the `CommandText` property) and must set the `CommandType` property to the value `CommandType.StoredProcedure`. (If you fail to do this, you will receive a runtime exception because the command object is expecting a SQL statement by default.)

Next, notice that the `Direction` property of the `@petName` parameter is set to `ParameterDirection.Output`. As before, you add each parameter object to the command object's parameters collection.



After the stored procedure completes with a call to `ExecuteNonQuery()`, you can obtain the value of the output parameter by investigating the command object's parameter collection and casting accordingly.

```
// Return output param.
carPetName = (string)command.Parameters["@petName"].Value;
```

At this point, you have an extremely simple data access library that you can use to build a client to display and edit your data. You have not yet examined how to build graphical user interfaces, so next you will test your data library from a new console application.

## Creating a Console-Based Client Application

Add a new console application (named `AutoLot.Client`) to the `AutoLot.DAL` solution. Set the new project as the startup project (by right-clicking the project in Solution Explorer and selecting `Set as StartUp Project`) and add a reference to the `AutoLot.DAL` project. Add the following using statements to the top of `Program.cs`:

```
using AutoLot.DAL.DataOperations;
using AutoLot.DAL.Models;
```

Replace the `Main()` method with the following code to exercise `AutoLot.DAL`:

```
class Program
{
    static void Main(string[] args)
    {
        InventoryDAL dal = new InventoryDAL();
        var list = dal.GetAllInventory();
        Console.WriteLine(" ***** All Cars ***** ");
        Console.WriteLine("Id\tMake\tColor\tPet Name");
        foreach (var itm in list)
        {
            Console.WriteLine($"{itm.Id}\t{itm.Make}\t{itm.Color}\t{itm.PetName}");
        }
        Console.WriteLine();
        var car = dal.GetCar(list.OrderBy(x=>x.Color).Select(x => x.Id).First());
        Console.WriteLine(" ***** First Car By Color ***** ");
        Console.WriteLine("CarId\tMake\tColor\tPet Name");
        Console.WriteLine($"{car.Id}\t{car.Make}\t{car.Color}\t{car.PetName}");

        try
        {
            dal.DeleteCar(5);
            Console.WriteLine("Car deleted.");
        }
        catch (Exception ex)
        {
            Console.WriteLine($"An exception occurred: {ex.Message}");
        }
    }
}
```

```

dal.InsertAuto(new Car {Color="Blue",Make="Pilot",PetName = "TowMonster"});
list = dal.GetAllInventory();
var newCar = list.First(x => x.PetName == "TowMonster");
Console.WriteLine(" ***** New Car ***** ");
Console.WriteLine("CarId\tMake\tColor\tPet Name");
Console.WriteLine($"{newCar.Id}\t{newCar.Make}\t{newCar.Color}\t{newCar.PetName}");
dal.DeleteCar(newCar.Id);
var petName = dal.LookUpPetName(car.Id);
Console.WriteLine(" ***** New Car ***** ");
Console.WriteLine($"Car pet name: {petName}");
Console.Write("Press enter to continue...");
Console.ReadLine();
}
}

```

## Understanding Database Transactions

Let's wrap up this examination of ADO.NET by taking a look at the concept of a database transaction. Simply put, a *transaction* is a set of database operations that must either *all* succeed or *all* fail as a collective unit. As you might imagine, transactions are quite important to ensure that table data is safe, valid, and consistent.

Transactions are important when a database operation involves interacting with multiple tables or multiple stored procedures (or a combination of database atoms). The classic transaction example involves the process of transferring monetary funds between two bank accounts. For example, if you were to transfer \$500 from your savings account into your checking account, the following steps should occur in a transactional manner:

1. The bank should remove \$500 from your savings account.
2. The bank should add \$500 to your checking account.

It would be an extremely bad thing if the money were removed from the savings account but not transferred to the checking account (because of some error on the bank's part) because then you would be out \$500! However, if these steps are wrapped up into a database transaction, the DBMS ensures that all related steps occur as a single unit. If any part of the transaction fails, the entire operation is *rolled back* to the original state. On the other hand, if all steps succeed, the transaction is *committed*.

---

■ **Note** You might be familiar with the acronym ACID from looking at transactional literature. This represents the four key properties of a prim-and-proper transaction: *atomic* (all or nothing), *consistent* (data remains stable throughout the transaction), *isolated* (transactions do not step on each other's feet), and *durable* (transactions are saved and logged).

---

It turns out that the .NET Core platform supports transactions in a variety of ways. This chapter will look at the transaction object of your ADO.NET data provider (SqlTransaction, in the case of Microsoft.Data.SqlClient).

In addition to the baked-in transactional support within the .NET base class libraries, it is possible to use the SQL language of your database management system. For example, you could author a stored procedure that uses the BEGIN TRANSACTION, ROLLBACK, and COMMIT statements.

## Key Members of an ADO.NET Transaction Object

All of transactions we will use implement the `IDbTransaction` interface. Recall from the beginning of this chapter that `IDbTransaction` defines a handful of members as follows:

```
public interface IDbTransaction : IDisposable
{
    IDbConnection Connection { get; }
    IsolationLevel IsolationLevel { get; }

    void Commit();
    void Rollback();
}
```

Notice the `Connection` property, which returns a reference to the connection object that initiated the current transaction (as you'll see, you obtain a transaction object from a given connection object). You call the `Commit()` method when each of your database operations has succeeded. Doing this causes each of the pending changes to be persisted in the data store. Conversely, you can call the `Rollback()` method in the event of a runtime exception, which informs the DBMS to disregard any pending changes, leaving the original data intact.

---

■ **Note** The `IsolationLevel` property of a transaction object allows you to specify how aggressively a transaction should be guarded against the activities of other parallel transactions. By default, transactions are isolated completely until committed.

---

Beyond the members defined by the `IDbTransaction` interface, the `SqlTransaction` type defines an additional member named `Save()`, which allows you to define *save points*. This concept allows you to roll back a failed transaction up until a named point, rather than rolling back the entire transaction. Essentially, when you call `Save()` using a `SqlTransaction` object, you can specify a friendly string moniker. When you call `Rollback()`, you can specify this same moniker as an argument to perform an effective *partial rollback*. Calling `Rollback()` with no arguments causes all the pending changes to be rolled back.

## Adding a Transaction Method to InventoryDAL

Now let's look at how you work with ADO.NET transactions programmatically. Begin by opening the `AutoLot.DAL` code library project you created earlier and add a new public method named `ProcessCreditRisk()` to the `InventoryDAL` class to deal with perceived credit risks. (Note that this example avoids using a parameterized query to keep the implementation simple; however, you'd want to use such a query for a production-level method).

```
public void ProcessCreditRisk(bool throwEx, int customerId)
{
    OpenConnection();
    // First, look up current name based on customer ID.
    string fName;
    string lName;
```

```

var cmdSelect = new SqlCommand(
    "Select * from Customers where Id = @customerId",
    _sqlConnection);
SqlParameter paramId = new SqlParameter
{
    ParameterName = "@customerId",
    SqlDbType = SqlDbType.Int,
    Value = customerId,
    Direction = ParameterDirection.Input
};
cmdSelect.Parameters.Add(paramId);
using (var dataReader = cmdSelect.ExecuteReader())
{
    if (dataReader.HasRows)
    {
        dataReader.Read();
        fName = (string) dataReader["FirstName"];
        lName = (string) dataReader["LastName"];
    }
    else
    {
        CloseConnection();
        return;
    }
}
cmdSelect.Parameters.Clear();
// Create command objects that represent each step of the operation.
var cmdRemove = new SqlCommand(
    "Delete from Customers where Id = @customerId",
    _sqlConnection);
cmdRemove.Parameters.Add(paramId);
var cmdInsert = new SqlCommand(
    "Insert Into CreditRisks (CustomerId,FirstName, LastName) Values(@customerId,
    @FirstName, @LastName)",
    _sqlConnection);
SqlParameter parameterId2 = new SqlParameter
{
    ParameterName = "@CustomerId",
    SqlDbType = SqlDbType.Int,
    Value = customerId,
    Direction = ParameterDirection.Input
};
SqlParameter parameterFirstName = new SqlParameter
{
    ParameterName = "@FirstName",
    Value = fName,
    SqlDbType = SqlDbType.NVarChar,
    Size = 50,
    Direction = ParameterDirection.Input
};

```

```

SqlParameter parameterLastName = new SqlParameter
{
    ParameterName = "@LastName",
    Value = lName,
    SqlDbType = SqlDbType.NVarChar,
    Size = 50,
    Direction = ParameterDirection.Input
};

cmdInsert.Parameters.Add(parameterId2);
cmdInsert.Parameters.Add(parameterFirstName);
cmdInsert.Parameters.Add(parameterLastName);
// We will get this from the connection object.
SqlTransaction tx = null;
try
{
    tx = _sqlConnection.BeginTransaction();
    // Enlist the commands into this transaction.
    cmdInsert.Transaction = tx;
    cmdRemove.Transaction = tx;
    // Execute the commands.
    cmdInsert.ExecuteNonQuery();
    cmdRemove.ExecuteNonQuery();
    // Simulate error.
    if (throwEx)
    {
        throw new Exception("Sorry! Database error! Tx failed...");
    }
    // Commit it!
    tx.Commit();
}
catch (Exception ex)
{
    Console.WriteLine(ex.Message);
    // Any error will roll back transaction. Using the new conditional access operator to
    // check for null.
    tx?.Rollback();
}
finally
{
    CloseConnection();
}
}

```

Here, you use an incoming `bool` parameter to represent whether you will throw an arbitrary exception when you attempt to process the offending customer. This allows you to simulate an unforeseen circumstance that will cause the database transaction to fail. Obviously, you do this here only for illustrative purposes; a true database transaction method would not want to allow the caller to force the logic to fail on a whim!

Note that you use two `SqlCommand` objects to represent each step in the transaction you will kick off. After you obtain the customer's first and last names based on the incoming `customerID` parameter, you can obtain a valid `SqlTransaction` object from the connection object using `BeginTransaction()`. Next, and most importantly, you must *enlist each command object* by assigning the `Transaction` property to the transaction object you have just obtained. If you fail to do so, the `Insert/Delete` logic will not be under a transactional context.

After you call `ExecuteNonQuery()` on each command, you throw an exception if (and only if) the value of the `bool` parameter is `true`. In this case, all pending database operations are rolled back. If you do not throw an exception, both steps will be committed to the database tables once you call `Commit()`.

## Testing Your Database Transaction

Select one of the customers you added to the `Customers` table (e.g., Dave Benner, `Id = 1`). Next, add a new method to `Program.cs` in the `AutoLot.Client` project named `MoveCustomer()`.

```
public static void MoveCustomer()
{
    Console.WriteLine("***** Simple Transaction Example *****\n");

    // A simple way to allow the tx to succeed or not.
    bool throwEx = true;
    Console.Write("Do you want to throw an exception (Y or N): ");
    var userAnswer = Console.ReadLine();
    if (string.IsNullOrEmpty(userAnswer) || userAnswer.Equals("N", StringComparison.
OrdinalIgnoreCase))
    {
        throwEx = false;
    }
    var dal = new InventoryDAL();
    // Process customer 1 - enter the id for the customer to move.
    dal.ProcessCreditRisk(throwEx, 1);
    Console.WriteLine("Check CreditRisk table for results");
    Console.ReadLine();
}
```

If you were to run your program and elect to throw an exception, you would find that the customer is *not* removed from the `Customers` table because the entire transaction has been rolled back. However, if you did not throw an exception, you would find that the customer is no longer in the `Customers` table and has been placed in the `CreditRisks` table instead.

## Executing Bulk Copies with ADO.NET

In cases where you need to load lots of records into the database, the methods shown so far would be rather inefficient. SQL Server has a feature called *bulk copy* that is designed specifically for this scenario, and it's wrapped up in ADO.NET with the `SqlBulkCopy` class. This section of the chapter shows how to do this with ADO.NET.

## Exploring the SqlBulkCopy Class

The `SqlBulkCopy` class has one method, `WriteToServer()` (and the async version `WriteToServerAsync()`), that processes a list of records and writes the data to the database more efficiently than writing a series of insert statements and running them with a `Command` object. The `WriteToServer` overloads take a `DataTable`, a `DataReader`, or an array of `DataRow`s.

To keep with the theme of this chapter, you are going to use the `DataReader` version. For that, you need to create a custom data reader.

## Creating a Custom Data Reader

You want your custom data reader to be generic and hold a list of the models that you want to import. Begin by creating a new folder in the `AutoLot.DAL` project named `BulkImport`, and in the folder, create a new generic interface named `IMyDataReader` that implements `IDataReader`, like this:

```
using System.Collections.Generic;
using System.Data;
public interface IMyDataReader<T> : IDataReader
{
    List<T> Records { get; set; }
}
```

Next comes the task of implementing the custom data reader. As you have already seen, data readers have lots of moving parts. The good news for you is that, for `SqlBulkCopy`, you have to implement only a handful of them. Create a new generic class named `MyDataReader` and have it implement `IMyDataReader`. Add the two constructors and the `Records` property:

```
public sealed class MyDataReader<T> : IMyDataReader<T>
{
    public List<T> Records { get; set; }
    public MyDataReader()
    {
    }
    public MyDataReader(List<T> records) : this()
    {
        Records = records
    }
}
```

Also, update the using statements to the following:

```
using System;
using System.Collections.Generic;
using System.Data;
using System.Linq;
using System.Reflection;
```

Have Visual Studio or Visual Studio Code implement all the methods for you (or copy them from the following), and you will have your starting point for the custom data reader. The only methods that need to be implemented for this scenario are detailed in [Table 21-7](#).

**Table 21-7.** *Key Methods of `IDataReader` for `SqlBulkCopy`*

Method	Meaning in Life
<code>Read</code>	Gets the next record; returns true if there is another record or returns false if at the end of the list
<code>FieldCount</code>	Gets the total number of fields in the data source
<code>GetName</code>	Gets the name of a field based on the ordinal position
<code>GetOrdinal</code>	Gets the ordinal position of the field based on the name of a field
<code>GetValue</code>	Gets the value of a field based on the ordinal position

Starting with the `Read()` method, return false if the reader is at the end of the list, and return true (and increment a class-level counter) if the reader is not at the end of the list. Add a class-level variable to hold the current index of the `List<T>` and update the `Read()` method like this:

```
public class MyDataReader<T> : IMyDataReader<T>
{
    ...
    private int _currentIndex = -1;
    public bool Read()
    {
        if (_currentIndex + 1 >= Records.Count)
        {
            return false;
        }
        _currentIndex++;
        return true;
    }
}
```

Each of the get methods and the `FieldCount` methods requires an intimate knowledge of the specific model to be loaded. An example of the `GetValue()` method (using the `Car` model) would be as follows:

```
public object GetValue(int i)
{
    Car currentRecord = Records[_currentIndex] as Car;
    switch (i)
    {
        case 0: return currentRecord.Id;
        case 1: return currentRecord.Color;
        case 2: return currentRecord.Make;
        case 3: return currentRecord.PetName;
        default: return string.Empty;
    }
}
```

The database has only four tables, but that means you still have four variations of the data reader. Imagine if you had a real production database with many more tables! You can do better than this using reflection (covered in Chapter 17) and LINQ to Objects (covered in Chapter 13).



Update the parameterless constructor to get all the properties of the generic type and create a Dictionary from those properties. This dictionary ties the name of each property to its index. Also add two class-level variables to hold the values gathered in the constructor. The added code is as follows:

```
private readonly PropertyInfo[] _propertyInfos;
private readonly Dictionary<string, int> _nameDictionary;

public MyDataReader()
{
    _propertyInfos = typeof(T).GetProperties();
    _nameDictionary = _propertyInfos
        .Select((x, index) => new { x.Name, index })
        .ToDictionary(pair => pair.Name, pair => pair.index);
}
```

Now, the following methods can be implemented generically, using the reflected information:

```
public int FieldCount => _propertyInfos.Length;
public string GetName(int i)
    => i >= 0 && i < FieldCount ? _propertyInfos[i].Name : string.Empty;
public int GetOrdinal(string name)
    => _nameDictionary.ContainsKey(name) ? _nameDictionary[name] : -1;

public object GetValue(int i)
    => _propertyInfos[i].GetValue(Records[_currentIndex]);
```

The remainder of the methods that have to be present (but not implemented) are listed here for reference:

```
public string GetDataTypeName(int i) => throw new NotImplementedException();
public Type GetFieldType(int i) => throw new NotImplementedException();
public int GetValues(object[] values) => throw new NotImplementedException();
public bool GetBoolean(int i) => throw new NotImplementedException();
public byte GetByte(int i) => throw new NotImplementedException();
public long GetBytes(int i, long fieldOffset, byte[] buffer, int bufferoffset, int length)
    => throw new NotImplementedException();
public char GetChar(int i) => throw new NotImplementedException();
public long GetChars(int i, long fieldOffset, char[] buffer, int bufferoffset, int length)
    => throw new NotImplementedException();
public Guid GetGuid(int i) => throw new NotImplementedException();
public short GetInt16(int i) => throw new NotImplementedException();
public int GetInt32(int i) => throw new NotImplementedException();
public long GetInt64(int i) => throw new NotImplementedException();
public float GetFloat(int i) => throw new NotImplementedException();
public double GetDouble(int i) => throw new NotImplementedException();
public string GetString(int i) => throw new NotImplementedException();
public decimal GetDecimal(int i) => throw new NotImplementedException();
public DateTime GetDateTime(int i) => throw new NotImplementedException();
public IDataReader GetData(int i) => throw new NotImplementedException();
public bool IsDBNull(int i) => throw new NotImplementedException();
object IDataRecord.this[int i] => throw new NotImplementedException();
object IDataRecord.this[string name] => throw new NotImplementedException();
public void Close() => throw new NotImplementedException();
```

```

public DataTable GetSchemaTable() => throw new NotImplementedException();
public bool NextResult() => throw new NotImplementedException();
public int Depth { get; }
public bool IsClosed { get; }
public int RecordsAffected { get; }

```

## Executing the Bulk Copy

Add a new public static class named `ProcessBulkImport.cs` to the `BulkImport` folder. Add the following using statements to the top of the file:

```

using System;
using System.Collections.Generic;
using System.Data;
using System.Linq;
using Microsoft.Data.SqlClient;

```

Add the code to handle opening and closing connections (similar to the code in the `InventoryDAL` class), as follows:

```

private const string ConnectionString =
    @"Data Source=.,5433;User Id=sa;Password=P@ssw0rd;Initial Catalog=AutoLot";
private static SqlConnection _sqlConnection = null;

private static void OpenConnection()
{
    _sqlConnection = new SqlConnection
    {
        ConnectionString = ConnectionString
    };
    _sqlConnection.Open();
}

private static void CloseConnection()
{
    if (_sqlConnection?.State != ConnectionState.Closed)
    {
        _sqlConnection?.Close();
    }
}

```

The `SqlBulkCopy` class requires the name (and schema, if different than `dbo`) to process the records. After creating a new `SqlBulkCopy` instance (passing in the connection object), set the `DestinationTableName` property. Then, create a new instance of the custom data reader holding the list to be bulk copied, and call `WriteToServer`. The `ExecuteBulkImport` method is shown here:

```

public static void ExecuteBulkImport<T>(IEnumerable<T> records, string tableName)
{
    OpenConnection();
    using (SqlConnection conn = _sqlConnection)

```

```

{
    SqlBulkCopy bc = new SqlBulkCopy(conn)
    {
        DestinationTableName = tableName
    };
    var dataReader = new MyDataReader<T>(records.ToList());
    try
    {
        bc.WriteToServer(dataReader);
    }
    catch (Exception ex)
    {
        //Should do something here
    }
    finally
    {
        CloseConnection();
    }
}
}

```

## Testing the Bulk Copy

Back in the `AutoLot.Client` project, add the following using statement to `Program.cs`:

```
using AutoLot.DAL.BulkImport;
```

Add a new method to `Program.cs` named `DoBulkCopy.cs`. Create a list of `Car` objects, and pass that (and the name of the table) into the `ExecuteBulkImport` method. The rest of the code displays the results of the bulk copy:

```

public static void DoBulkCopy()
{
    Console.WriteLine(" ***** Do Bulk Copy ***** ");
    var cars = new List<Car>
    {
        new Car() {Color = "Blue", Make = "Honda", PetName = "MyCar1"},
        new Car() {Color = "Red", Make = "Volvo", PetName = "MyCar2"},
        new Car() {Color = "White", Make = "VW", PetName = "MyCar3"},
        new Car() {Color = "Yellow", Make = "Toyota", PetName = "MyCar4"}
    };
    ProcessBulkImport.ExecuteBulkImport(cars, "Inventory");
    InventoryDAL dal = new InventoryDAL();
    var list = dal.GetAllInventory();
    Console.WriteLine(" ***** All Cars ***** ");
    Console.WriteLine("CarId\tMake\tColor\tPet Name");
    foreach (var itm in list)

```

```

{
    Console.WriteLine(
        $"{itm.Id}\t{itm.Make}\t{itm.Color}\t{itm.PetName}");
}
Console.WriteLine();
}

```

While adding four new cars doesn't show the merits of the work involved in using the `SqlBulkCopy` class, imagine trying to load *thousands* of records. I have done this with customers, and the load time has been mere seconds, where looping through each record took hours! As with everything in .NET, this is just another tool to keep in your toolbox to use when it makes the most sense.

## Summary

ADO.NET is the native data access technology of the .NET Core platform. In this chapter, you began by learning the role of data providers, which are essentially concrete implementations of several abstract base classes (in the `System.Data.Common` namespace) and interface types (in the `System.Data` namespace). You also saw that it is possible to build a provider-neutral codebase using the ADO.NET data provider factory model.

You also learned that you can use connection objects, transaction objects, command objects, and data reader objects to select, update, insert, and delete records. Also, recall that command objects support an internal parameter collection, which you can use to add some type safety to your SQL queries; these also prove quite helpful when triggering stored procedures.

Next, you learned how to safeguard your data manipulation code with transactions and wrapped up the chapter with a look at using the `SqlBulkCopy` class to load large amounts of data into SQL Server using ADO.NET.

## CHAPTER 22



# Introducing Entity Framework Core

The previous chapter examined the fundamentals of ADO.NET. ADO.NET has enabled .NET programmers to work with relational data (in a relatively straightforward manner) since the initial release of the .NET platform. However, Microsoft introduced a new component of the ADO.NET API called the *Entity Framework* (or simply, *EF*) in .NET 3.5 Service Pack 1.

The overarching goal of EF is to allow you to interact with data from relational databases using an object model that maps directly to the business objects (or domain objects) in your application. For example, rather than treating a batch of data as a collection of rows and columns, you can operate on a collection of strongly typed objects termed *entities*. These entities are also natively LINQ aware, and you can query against them using the same LINQ grammar you learned about in Chapter 13.

Like the .NET Core framework, Entity Framework Core is a complete rewrite of Entity Framework 6. It is built on top of the .NET Core framework, enabling EF Core to run on multiple platforms. Rewriting EF Core has enabled the team to add new features and performance improvements to EF Core that couldn't be reasonably implemented in EF 6.

Recreating an entire framework from scratch requires a hard look at which features will be supported in the new framework and which features will be left behind. One of the features of EF 6 that is not in EF Core (and not likely to ever be added) is support for the Entity Designer. EF Core only supports the Code First development paradigm. If you are currently using Code First, you can safely ignore the previous sentence.

With each release, EF Core has added more features that existed in EF 6 as well as brand new features that never existed in EF 6. The 3.1 release significantly shortened the list of essential features that are missing from EF Core (as compared to EF 6). In fact, for most projects, EF Core has everything you need.

This chapter and the next will introduce you to data access using the Entity Framework Core. You will learn about creating a domain model, mapping model classes to the database, and the role of the *DbContext* class. You will also learn about navigation properties, transactions, and concurrency checking.

By the time you complete these chapters, you will have the final version of the data access layer for our AutoLot database. Before we get into EF Core, let's talk about object-relational mappers in general.

## Object-Relational Mappers

ADO.NET provides you with a fabric that lets you select, insert, update, and delete data with connections, commands, and data readers. While this is all well and good, these aspects of ADO.NET force you to treat the fetched data in a manner that is tightly coupled to the physical database schema. Recall, for example, when getting records from the database, you typically iterate over each record by specifying column names to a data reader.

When you use ADO.NET, you must always be mindful of the physical structure of the back-end database. You must know the schema of each data table, author potentially complex SQL queries to interact with said data table(s), and so forth. This can force you to author some fairly verbose C# code because C# itself does not speak the language of the database schema directly.

To make matters worse, the way in which a physical database is usually constructed is squarely focused on database constructs such as foreign keys, views, stored procedures, and data normalization, not object-oriented programming.

The availability of *object-relational mapping* frameworks (commonly referred to as ORMs) in .NET greatly enhanced the data access story by managing the bulk of Create, Read, Update, and Delete (CRUD) data access tasks for the developer. The developer creates a mapping between the .NET objects and the relational database, and the ORM manages connections, query generation, change tracking, and persisting the data. This leaves the developer free to focus on the business needs of the application.

---

■ **Note** It is important to remember that ORMs are not magical unicorns riding in on rainbows. Every decision involves trade-offs. ORMs reduce the amount of work for developers creating data access layers, but can also introduce performance and scaling issues if used improperly. Use ORMs for CRUD operations, and use the power of your database for set-based operations.

---

Even though the different ORMs might have different names, they all essentially have the same pieces and parts and strive for the same goal – to make data access operations easier. Entities (sometimes called models) are the C# classes that are mapped to the database tables. A `DbSet` is a specialized collection type that contains one or more entities. The `ChangeTracker` keeps track of the entities in a `DbSet` and any changes that are made to them, and the `DbContext` is the brains/ringleader of the operation. All of these will be explored in this and the next chapter.

---

■ **Note** EF Core can be used with existing databases as well as blank and/or new databases. Both mechanisms are called “Code First,” which is probably not the best name. Entity classes and the derived `DbContext` can be scaffolded from an existing database, and databases can be created and updated from entity classes. You will use both of these approaches in these chapters.

---

## Understanding the Role of the Entity Framework Core

EF Core is simply another approach to the data access APIs and is not necessarily intended to completely replace using ADO.NET directly from C# code. However, once you spend some time working with EF, you will quickly find yourself preferring this rich object model over creating all of your data access code from scratch. EF Core is another tool in your toolbox, and only you can decide what approach works best for your project.

## The Building Blocks of the Entity Framework

EF (at its core) uses the ADO.NET infrastructure you have already examined in the previous chapter. Like any ADO.NET interaction, EF uses an ADO.NET data provider to communicate with the data store. However, the data provider must be updated so it supports a new set of services before it can interact with the EF API. As you might expect, the Microsoft SQL Server data provider has been updated with the necessary infrastructure, which is accounted for when using the `System.Data.Entity.dll` assembly.

---

■ **Note** Many third-party databases (e.g., Oracle and MySQL) provide EF-aware data providers. If you are not using SQL Server, consult your database vendor for details or navigate to <https://docs.microsoft.com/en-us/dotnet/framework/data/adonet/ado-net-overview> for a list of known ADO.NET data providers.

---

In addition to adding the necessary bits to the Microsoft SQL Server data provider, the `System.Data.Entity.dll` assembly contains various namespaces that account for the EF services themselves. The first key piece of the EF API to concentrate on is the `DbContext` class. You will create a derived, model-specific context when you use EF for your data access libraries.

## Entities

The strongly typed classes mentioned previously (and demonstrated with the `Car` class in the previous chapter) are officially called *entities*. Entities are a conceptual model of a physical database that maps to your business domain. Formally speaking, this model is termed an *entity data model* (EDM). The EDM is a client-side set of classes that are mapped to a physical database by Entity Framework Core convention and configuration. You should understand that the entities need not map directly to the database schema, and typically they don't. You are free to structure your entity classes to fit your application needs and then map your unique entities to your database schema.

---

■ **Note** Some people refer to the POCO classes as *models* and the collection of these classes as the *object graph*. When the model classes are instantiated with data from the data store, they are then referred to as *entities*. In reality, the terms are pretty much used interchangeably, and both will be used throughout this text.

---

For example, take the simple `Inventory` table in the `AutoLot` database and the `Car` model class from the previous chapter. Through model configuration, you inform EF Core that the `Car` model represents the `Inventory` table. This loose coupling means you can shape the entities so they closely model your business domain.

EF Core examines the configuration of your entities and your context class to take the client-side representation of the `Inventory` table (here, a class named `Car`) and map it back to the correct columns of the `Inventory` table. This mapping is accomplished using data annotations (C# attributes on your entity) and a fluent API in the `DbContext`.

## Entity Framework Data Annotations

Data annotations are C# attributes that are used to shape your entities. Table 22-1 lists some of the most commonly used data annotations for defining how your entity classes and properties map to database tables and fields. There are many more annotations that you can use to refine your model and add validations, as you will see throughout the rest of this chapter and book.

**Table 22-1.** *Data Annotations Supported by the Entity Framework*

Data Annotation	Meaning in Life
Table	Defines the schema and table name for the entity.
Column	Defines the column name for the model property.
Key	Defines the primary key for the model. Key fields are implicitly also [Required].
Required	Declares the property as not nullable in the database.
ForeignKey	Declares a property that is used as the foreign key for a navigation property.
InverseProperty	Declares the navigation property on the other end of a relationship.
StringLength	Specifies the max length for a string property.
TimeStamp	Declares a type as a rowversion in SQL Server and adds concurrency checks to database operations involving the entity.
ConcurrencyCheck	Flags field to be used in concurrency checking when executing updates and deletes.
DatabaseGenerated	Specifies if the field is database generated or not. Takes a DatabaseGeneratedOption value of Computed, Identity, or None.
DataType	Provides for a more specific definition of a field than the intrinsic datatype.
NotMapped	Excludes the property or class in regard to database fields and tables.

The following code shows the Car class and the data annotations that shape it in the database:

```
[Table("Inventory",Schema = "dbo")]
public partial class Car
{
    [Key, DatabaseGenerated(DatabaseGeneratedOption.Identity)]
    public int Id { get; set; }
    [StringLength(50)]
    public string Make { get; set; }
    [StringLength(50)]
    public string Color { get; set; }
    [StringLength(50)]
    public string PetName { get; set; }
    [InverseProperty("Car")]
    public virtual IEnumerable<Orders> Orders { get; set; } = new List<Orders>();
}
```

The Table attribute maps the Car class to the Inventory table (in the dbo schema) in the database. The Id field is declared the primary key and is set as an identity column. The three text fields are set to a max string length of 50 characters. The InverseProperty attribute is explained in the next section.

---

■ **Note** EF Core is full of conventions that are used when shaping the database. I prefer to explicitly use data annotations and the fluent API so there isn't any confusion or doubt as to what the shape of the database will be.

---



## Navigation Properties and Foreign Keys

*Navigation properties* represent how model classes relate to each other and enable code to traverse the object model. On the database side, navigation properties are translated into foreign key relationships between tables. One-to-one and one-to-many relationships are directly supported in EF Core. Many-to-many relationships are supported if using a join entity in between the two tables, but will be supported directly in EF Core 5 (the next release of EF Core).

To create a one-to-many relationship, the class on the one side adds a `List<T>` of the child. On the many side, the class adds a property of the parent type as well as a property of the same type as the parent's primary key. For example, the `Inventory` and `Order` tables have a foreign key relationship. The following code shows the navigation properties in action:

```
public partial class Order
{
    ...
    public int CarId { get; set; }

    [ForeignKey(nameof(CarId))]
    [InverseProperty(nameof(Inventory.Orders))]
    public virtual Car CarNavigation { get; set; }
    ...
}
[Table("Inventory", Schema = "dbo")]
public partial class Car
{
    ...
    [InverseProperty(nameof(Order.CarNavigation))]
    public virtual IEnumerable<Order> Orders { get; set; } = new List<Order>();
}
```

The `ForeignKey` annotation lets EF Core know which property is the backing field for the navigation property. By convention, `<TypeName>Id` would automatically be set, but here I am explicitly setting the property.

The `Inverse Property` informs EF Core of how the tables relate. In this example, it's pretty obvious. But that annotation comes in handy (and can be required) when there are a lot of different relations, especially when a single table relates to another table more than once.

## The Fluent API

The Fluent API configures the application entities through C# code. The methods are exposed by the `ModelBuilder` instance available in the `DbContext` `OnModelCreating` method. The Fluent API is the most powerful of the configuration methods and overrides any data annotations or conventions that are in conflict. Some of the configuration options are only available using the Fluent API, such as complex keys and indices. This will be examined shortly.

## The DbContext Class

The `DbContext` doesn't get used directly, but through classes that inherit from the `DbContext` class. The entities that are mapped to the database are added as `DbSet<T>` properties on the derived class. The `OnModelCreating` method is used to further define the mappings between the entities and the database.

The `SaveChanges` method persists all of the changes to the database in an implicit transaction. Table 22-2 shows some of the more commonly used members of the `DbContext`.

**Table 22-2.** *Common Members of `DbContext`*

Member of <code>DbContext</code>	Meaning in Life
<code>Database</code>	Provides access to database-related information and functionality, including execution of SQL statements.
<code>Model</code>	The metadata about the shape of entities, the relationships between them, and how they map to the database. <b>Note:</b> This property is usually not interacted with directly.
<code>ChangeTracker</code>	Provides access to information and operations for entity instances this context is tracking.
<code>DbSet&lt;T&gt;</code>	Used to query and save instances of application entities. LINQ queries against <code>DbSet&lt;T&gt;</code> properties are translated into SQL queries.
<code>EntryEntry&lt;TEntity&gt;</code>	Provides access to change tracking information and operations (such as changing the <code>EntityState</code> ) for the entity. Can also be called on an untracked entity to change the state to tracked.
<code>SaveChangesSaveChangesAsync</code>	Saves all entity changes to the database and returns the number of records affected.
<code>OnConfiguring</code>	A builder used to create or modify options for the context. Executes each time a <code>DbContext</code> instance is created. <b>Note:</b> It is recommended not to use this, and instead use the <code>DbContextOptions</code> to configure the context at runtime, and use an instance of the <code>IDesignTimeDbContextFactory</code> at design time.
<code>OnModelCreating</code>	Called when a model has been initialized, but before it's finalized. Methods from the Fluent API are placed in this method to finalize the shape of the model.

## Transaction Support

EF Core wraps each call to `SaveChanges/SaveChangesAsync` in a transaction. The isolation level of these automatic transactions is the same as the default isolation level for the database. For more control, you can enlist the derived `DbContext` into an explicit transaction as well.

## The `DbContextOptions` Class

The `DbContextOptions` class is used to configure an instance of a derived `DbContext` class and is injected into the derived `DbContext` class with constructor injection. The options are created using a `DbContextOptionsBuilder`, as the `DbContextOptions` class is not meant to be directly constructed in your code.

## The DbSet<T> Class

For each entity in your object model, you add a property of type `DbSet<T>`. The `DbSet<T>` is a specialized collection property used to interact with the database provider to get, add, update, or delete records in the database.

Each `DbSet<T>` provides a number of core services to each collection, such as creating, deleting, and finding records in the represented table. Table 22-3 describes some of the core members of the `DbSet<T>` class.

**Table 22-3.** Common Members of `DbSet<T>`

Member of <code>DbSet&lt;T&gt;</code>	Meaning in Life
Add/AddRange	Begins tracking the entity/entities in the Added state. Item(s) will be added when <code>SaveChanges</code> is called. Async versions are available as well.
Find	Searches for the entity in the <code>ChangeTracker</code> by primary key. If not found, the data store is queried for the object. An async version is available as well.
Update/UpdateRange	Begins tracking the entity/entities in the Modified state. Item(s) will be updated when <code>SaveChanges</code> is called. Async versions are available as well.
Remove/RemoveRange	Begins tracking the entity/entities in the Deleted state. Item(s) will be removed when <code>SaveChanges</code> is called. Async versions are available as well.
Attach/AttachRange	Begins tracking the entity/entities in the Unchanged state. No operation will execute when <code>SaveChanges</code> is called. Async versions are available as well.

■ **Note** All of the methods in Table 22-3 can be called directly on the derived `DbContext` class in addition to the `DbSet<T>` properties. My preference is to only use the methods exposed by the `DbSet<T>` properties, as the code is easier to read and maintain.

`DbSet<T>` implements `IQueryable<T>`, and is typically the target of LINQ to Entity queries. `DbSet<T>` supports the same extension methods you learned about in Chapter 13, such as `ForEach()`, `Select()`, and `All()`.

## Query Types

Query types are `DbSet<T>` collections that are used to represent views or tables without a primary key. Prior versions of EF Core used `DbQuery<T>` for these, but now they are just `DbSet<T>` types updated through the fluent API.

## The DbChangeTracker

The `DbChangeTracker` automatically tracks the state for any object loaded into a `DbSet<T>` within a `DbContext`. In the previous examples, while inside the `using` statement, any changes to the data will be tracked and saved when `SaveChanges` is called on the `AutoLotEntities` class. Table 22-4 lists the possible values for the state of an object.

**Table 22-4.** Entity State Enumeration Values

Value	Meaning in Life
Added	The entity is being tracked but does not yet exist in the database.
Deleted	The entity is being tracked and is marked for deletion from the database.
Detached	The entity is not being tracked by the context.
Modified	The entry is being tracked and has been changed.
Unchanged	The entity is being tracked, exists in the database, and has not been modified.

If you need to check the state of an object, use the following code:

```
EntityState state = context.Entry(entity).State;
```

## Database Providers

EF Core uses a provider model to allow use with different databases. Each provider must implement the base functionality, but can also add database-specific functionality. The list of supported providers (both free and commercial) grows with every release. The current support providers can be found here: <https://docs.microsoft.com/en-us/ef/core/providers/>.

## Query Execution

Data retrieval Queries are created with `DbSet<T>` LINQ methods (or the `FromSql` method). The LINQ query is changed to the database-specific language (e.g., T-SQL) by the database provider’s LINQ translation engine and executed server side. Multi-record (or potential multi-record) LINQ queries are not executed until the query is iterated over (e.g., using a `foreach`) or bound to a control for display (like a data grid). This deferred execution allows building up queries in code without suffering performance issues from chattiness with the database.

Single record queries (such as when using `FirstOrDefault`) execute immediately on calling the action (such as `FirstOrDefault`), and `Create`, `Update`, and `Delete` statements are executed immediately when the `DbContext.SaveChanges` method is executed.

## Mixed Client-Server Evaluation

Prior versions of EF Core introduced the ability to mix server-side and client-side execution. This meant that a C# function could be used in the middle of a LINQ statement and essentially negate what I described in the previous paragraph. The part up to the C# function would execute server-side, but then all of the results (at that point of the query) are brought back client-side, and then the rest of the query would execute as LINQ to Objects. This ended up causing more problems than it solved, and with the release of EF Core 3.1, this functionality was changed. Now, only the final node of a LINQ statement can execute client-side.

## Tracking vs. NoTracking Queries

When data is read from the database into a `DbSet<T>`, the entities (by default) are tracked by the change tracker. This is typically what you want in your application. However, there might be times when you need to get some data from the database, but you don’t want it to be tracked by the change tracker. The reason might

be performance (tracking original and current values for a large set of records can add memory pressure) or maybe you know those records will never be changed by the part of the application that needs the data.

To load data into a `DbSet<T>` without adding the data to the Change Tracker, add `AsNoTracking` into the LINQ statement. This signals EF Core to retrieve the data without adding it into the `ChangeTracker`.

## Notable EF Core Features

The list of features being added to EF Core with every release is significant, and many of the EF 6 features have now been replicated in EF Core. While there isn't enough space in this book to cover everything in EF Core, the following sections cover some of the more beneficial features (in no particular order).

### Concurrency Checking

Concurrency issues arise when two separate processes (users or systems) attempt to update the same record at roughly the same time. For example, User 1 and User 2 both get the data for Customer A. User 1 updates the address and saves the change. User 2 updates the credit rating and attempts to save the same record. If the save for User 2 works, the changes from User 1 will be reverted, since the address was changed after User 2 retrieved the record. Another option is to fail the save for User 2, in which case User 1's changes are persisted, but User 2's changes are not.

How this situation is handled depends on the requirements for the application. Solutions range from doing nothing (second update overwrites the first), optimistic concurrency (the second update fails), to more complicated solutions such as checking individual fields. Except for the choice of doing nothing (universally considered a bad programming idea), the developer needs to know when concurrency issues arise so they can be coded correctly.

Fortunately, many modern databases have tooling to help the development team handle concurrency issues. SQL Server has a built-in datatype called `timestamp`, a synonym for `rowversion`. If a column is defined with a datatype of `timestamp`, then when a record is added to the database, the value for the column is created by SQL Server, and when a record is updated, the value for the column is updated as well. The value is virtually guaranteed to be unique and controlled by SQL Server.

EF Core can leverage the SQL Server `timestamp` datatype by implementing a `Timestamp` property on an entity (represented as `byte[]` in C#). Entity properties defined with the `Timestamp` attribute or Fluent API designation are added to the where clause when updating or deleting records. Instead of just using the primary key value(s), the generated SQL adds the value of the timestamp property to the where clause. This limits the results to those records where the primary key and the timestamp values match. If another user (or the system) has updated the record, the timestamp values will not match since SQL Server will have updated the column's value, and the update or delete statement won't affect any records.

When the number of records affected by calling `SaveChanges` is different than the number of records the `ChangeTracker` expected to be changed, EF Core throws a `DbUpdateConcurrencyException` and rolls the entire transaction back. The `DbUpdateConcurrencyException` contains information for all of the records that did not persist, including the original values (when the entity was loaded from the database) and the current values (as the user/system updated them). There is also a method to get the current database values (this requires another call to the server). With this wealth of information, the developer can then handle the concurrency error as the application requires.

### Connection Resiliency

Transient errors are difficult to debug and more difficult to replicate. Fortunately, many database providers have a built-in retry mechanism for glitches in the system (tempdb issues, user limits, etc.) connectivity that can be leveraged by EF Core. For SQL Server, the `SqlServerRetryingExecutionStrategy` catches errors

that are transient (as defined by the SQL Server team), and if enabled on the derived `DbContext` through the `DbContextOptions`, EF Core automatically retries the operation until the maximum retry limit is reached. The maximum number of retries and the time limit between retries can be configured per the application's requirements. If the retry limit is reached without the operation completing, EF Core will notify the application of the connection problems by throwing a `RetryLimitExceededException`. This exception, when handled by the developer, can relay the pertinent information to the user, providing a better experience.

## Eager Loading

Eager loading is the term for loading related records from multiple tables in one database call. This is analogous to creating a query in T-SQL linking two or more tables with joins. When entities have navigation properties and those properties are used in the LINQ queries, the translation engine uses joins to get data from the related tables and loads the corresponding entities. This is much more efficient than executing one query to get the data from one table and then running additional queries for each of the related tables.

The `Include` and `ThenInclude` methods are used to traverse the navigation properties in LINQ queries. If some of the related records are already being tracked by EF Core, the entity instances will be wired up to the related records and not create duplicate instances.

---

■ **Note** Lazy loading has been re-introduced into EF Core with version 2.1. Lazy loading should be used cautiously, as it can cause performance degradation of your application, especially web-based applications. For this reason, lazy loading is disabled by default in EF Core, unlike EF 6, where it was enabled by default.

---

## Explicit Loading

Explicit loading is loading data along a navigation property after the core object is already loaded. This process involves executing an additional database call to get the related data. This can be useful if your application selectively needs to get the related records and not pull all of the related records perhaps based on some user action.

## Global Query Filters

Global query filters enable a where clause to be added into all LINQ queries for a particular entity. For example, a common database design pattern is to use soft deletes instead of hard deletes. A field is added to the table to indicate the deleted status of the record. If the record is “deleted”, the value is set to true (or 1), but not removed from the database. This is called a soft delete.

To filter out the soft-deleted records from normal operations, every where clause (selects, updates, and deletes) must check the value of this field. Remembering to include this filter in every where clause for every query can be time-consuming, if not problematic.

Global query filters are model-level filters that are applied to every query involving that model. For the soft delete example described earlier, you set a filter on the model class to exclude the soft-deleted records. Any queries created by EF Core involving those entities (even when eager loading the entity as a related record to another entity) will have the filter applied. No longer do you have to remember to include the where clause in every query.

If you need to see the filtered records, add `IgnoreQueryFilters` into the LINQ the query, which disables the global query filters for every model in the LINQ query.

## Raw SQL Queries with LINQ

Sometimes getting the correct LINQ statement for a complicated query can be harder than just writing the SQL directly. Fortunately, EF Core has a mechanism to allow raw SQL statements to be executed on a `DbSet<T>`. The `FromSqlRaw` and `FromSqlRawInterpolated` methods take in a string that becomes the base of the LINQ query. This query is executed server-side.

If the statement in the `FromSql` method is non-terminating (e.g. neither a stored procedure, user-defined function, nor end with a semicolon), then additional LINQ statements can be added to the query. The additional LINQ statements, such as `Include`, `OrderBy`, or `Where` clauses, will be combined with the original `FromSql` call, and the entire query is executed server-side.

## Parameter Passing with String Interpolation

Starting with EF Core version 2.0, when C# string interpolation is used with LINQ, the C# variables in the interpolated string are translated into SQL parameters. This is a great addition for security, as all raw queries should be parameterized to help prevent SQL injection attacks.

## Batching of Statements

EF Core has significantly improved the performance when saving changes to the database by executing the statements in batches, unlike EF 6, which creates a separate query for each change being persisted. In traditional data centers where the database and the web servers are physically located next to each other and the servers are a sunk cost, this is a non-factor. However, the costing model for many cloud services can be based on the number of transactions and not transaction size. Sending that many small transactions with each call to `SaveChanges` can be cost-prohibitive. Even if cost isn't an issue, sending all of the changes in individual trips across the wire can create significant performance issues.

EF Core batches the create, update, and delete statements using table-valued parameters. The number of batches depends on a variety of factors, including the number of changes, the size of the tables and the data, and many more. The batch size can also be configured through the `DbContextOptions`, but the recommendation is to let EF Core calculate the batch size for most (if not all) situations.

## Owned Object Types

Using a C# class as a property on an entity to define a collection of properties for another entity was first introduced in version 2.0, but became much more usable in version 2.1. When types marked with the `[Owned]` attribute are added as a property of an entity, EF Core will add all of the properties from the `[Owned]` entity class to the owning entity. This increases the possibility of C# code reuse.

The default column names from the owned type will be formatted as `OwnedTypeName_OwnedPropertyName` (e.g., `Details_Description`). The default names can be changed using the Fluent API.

## Attach New and Existing Entities

EF Core supports adding a mixture of new and existing entities into the `ChangeTracker`, as long as the entities support generated keys. When adding an object graph (the ones added directly to the `DbSet<T>` and the entities referenced through navigation properties) by calling `DbSet<T>.Attach`, the entities with a key value are marked as `Unchanged`, and the entities without a key value are marked as `Added`. When adding the object graph by calling `DbSet<T>.Update`, those with a key value are marked as `Modified` instead of `Unchanged`.

## Database Function Mapping

SQL Server scalar user-defined functions (UDFs) can be mapped to C# methods, similar to mapping entities to database tables. The mapped C# method can then be used in a LINQ query and the function gets translated into SQL and executed server-side.

## The EF Core Global Tool CLI Commands

The dotnet-ef global CLI tool EF Core tooling contains the commands needed to scaffold existing databases into code, to create/remove migrations (changes in the data structure based on the entities), and to operate on a database (update, drop, etc.).

Before you can use the dotnet-ef global tooling, it must be installed with the following command:

```
dotnet tool install --global dotnet-ef
```

The three main commands in the EF Core global tool are shown in Table 22-5. Each main command has additional sub-commands. As with the all of the .NET Core commands, each command has a rich help system that can be accessed by entering -h along with the command.

**Table 22-5.** EF Core Tooling Commands

Command	Meaning in Life
Database	Commands to manage the database. Sub-commands include drop and update.
DbContext	Commands to manage the DbContext types. Sub-commands include scaffold, list, and info.
Migrations	Commands to manage migrations. Sub-commands include add, list, remove, and script.

The EF Core commands execute on .NET Core project files (and not solution files). The target project needs to reference the EF Core tooling NuGet package `Microsoft.EntityFrameworkCore.Design`. The commands operate on the project file located in the same directory where the commands are run or a project file in another directory if referenced through the command-line options.

For the EF Core CLI commands that need an instance of a derived `DbContext` class, if there is only one in the project, that one will be used. If there are more than one, then the `DbContext` needs to be specified. The derived `DbContext` class will be instantiated using an instance of a class implementing the `IDesignTimeDbContextFactory<TContext>` interface if one can be located in scope. If the tooling cannot find one, the context will be instantiated using the parameterless constructor of the derived context. If neither exists, the command will fail.

## The Database Commands

The database commands are used to drop or update a database. The drop command deletes the database if it exists. The update command updates the database using migrations.

## The Database Update Command

The update command takes one argument (the migration name) and several parameters, all optional. If the command is executed without a migration name, the command updates the database to the most recent migration, creating the database if necessary. If a migration is named, the database will be updated to that



migration. All previous migrations that have not yet been applied will be applied as well. As migrations are applied, their names are stored in the `__EFMigrationsHistory` table.

If the named migration has a timestamp that is earlier than other applied migrations, all of the later migrations are rolled back. If a 0 (zero) is passed in as the named migration, all migrations are reverted, leaving an empty database (except for the `__EFMigrationsHistory` table).

The optional parameters set the context, the project, or the startup project, among other options.

## The DbContext Commands

The `DbContext` commands `list` and `info` operate on derived `DbContext` classes in your project. The `info` command provides details about the specified derived `DbContext` class, including the connection string, provider name, database name, and data source. The `list` command lists the full name of any derived `DbContext` classes located in the project. The `scaffold` command is used to reverse engineer an existing database.

## The DbContext Scaffold Command

The `scaffold` command creates the C# classes (derived `DbContext` and entities) complete with data annotations and Fluent API commands from an existing database. There are two required arguments, the database connection string and the fully qualified provider (e.g., `Microsoft.EntityFrameworkCore.SqlServer`). The options available include selecting specific schemas and tables, the created context class name, the output directory, and many more.

## The Migrations Commands

The `migrations` command is used to add, remove, list, and script migrations. The `add` command creates a new migration based on the changes from the previous migration. The `remove` command first checks if the last migration in the project has been applied to the database and, if not, deletes the migration file and its designer and then rolls back the snapshot class to the previous migration. The `list` command lists all of the migrations in the project.

The `script` command creates a SQL script based on the specified migrations. The command takes two named migrations, the `from` and the `to`. If no migrations are named, the script created will be the cumulative total of all of the migrations. If named migrations are provided, the script will contain the changes between the two migrations (inclusive). Running the script will also update the `__EFMigrationsHistory` table.

## Start the AutoLot.Dal Project

The rest of this chapter will start by recreating the AutoLot database from Chapter 21 in code and examining the results. Then the data access layer will be refactored and improved until we have the final version that will be used throughout the rest of this book.

---

■ **Note** The next chapter will examine CRUD operations using the AutoLot data access layer as well as build custom, strongly typed repositories.

---

Create a new .NET Core class library named `AutoLot.Dal` and delete the default class created with the template. Add the following NuGet packages to the project:

```
Microsoft.EntityFrameworkCore.SqlServer
```

```
Microsoft.EntityFrameworkCore.Design
```

Next, open Package Manager Console and change to the `AutoLot.Dal` project directory. Use the EF Core CLI tools to scaffold the `AutoLot` database into the entities and `DbContext`-derived class with the following command (all on one line):

```
dotnet ef dbcontext scaffold "server=.,5433;Database=AutoLot;User Id=sa;Password=
P@ssWord;" Microsoft.EntityFrameworkCore.SqlServer -d -c ApplicationDbContext --context-dir
EfStructures -o Entities -f
```

The previous command scaffolds the database located at the provided connection string (this is the connection string for the Docker container used in Chapter 21) using the SQL Server database provider. The `-d` flag is to prioritize data annotations where possible (over the fluent API). The `-c` names the context, `--context-dir` indicates the directory (in the current project) for the derived `DbContext` class, and the `-o` is the output directory for the entities. The `-f` forces the regeneration of all of the code, replacing what might exist in the target directories.

---

■ **Note** There are many additional options that can be set when scaffolding a database. To learn more, execute `dotnet ef dbcontext scaffold -h`.

---

## The Entities

In the `Entities` directory, you will find four files, one for each table in the database. Note that the names match the database exactly (this will be fixed in the next chapter). All four files are listed here:

```
public partial class CreditRisks
{
    [Key]
    public int Id { get; set; }
    public int CustomerId { get; set; }
    [StringLength(50)]
    public string FirstName { get; set; }
    [StringLength(50)]
    public string LastName { get; set; }
    [ForeignKey(nameof(CustomerId))]
    [InverseProperty(nameof(Customers.CreditRisks))]
    public virtual Customers Customer { get; set; }
}

public partial class Customers
{
    public Customers()
    {
        CreditRisks = new HashSet<CreditRisks>();
    }
}
```

```

        Orders = new HashSet<Orders>();
    }
    [Key]
    public int Id { get; set; }
    [StringLength(50)]
    public string FirstName { get; set; }
    [StringLength(50)]
    public string LastName { get; set; }
    [InverseProperty("Customer")]
    public virtual ICollection<CreditRisks> CreditRisks { get; set; }
    [InverseProperty("Customer")]
    public virtual ICollection<Orders> Orders { get; set; }
}

public partial class Inventory
{
    public Inventory()
    {
        Orders = new HashSet<Orders>();
    }
    [Key]
    public int Id { get; set; }
    [StringLength(50)]
    public string Make { get; set; }
    [StringLength(50)]
    public string Color { get; set; }
    [StringLength(50)]
    public string PetName { get; set; }
    [InverseProperty("Car")]
    public virtual ICollection<Orders> Orders { get; set; }
}

public partial class Orders
{
    [Key]
    public int Id { get; set; }
    public int CustomerId { get; set; }
    public int CarId { get; set; }
    [ForeignKey(nameof(CarId))]
    [InverseProperty(nameof(Inventory.Orders))]
    public virtual Inventory Car { get; set; }
    [ForeignKey(nameof(CustomerId))]
    [InverseProperty(nameof(Customers.Orders))]
    public virtual Customers Customer { get; set; }
}

```

Notice how the navigation properties were created as virtual properties. This is to support lazy loading (not covered in this book). The data annotations and navigation properties were covered earlier in this chapter.

## The ApplicationDbContext

In the EfStructures directory, you will find a single file, ApplicationDbContext. The file is listed here:

```
public partial class ApplicationDbContext : DbContext
{
    public ApplicationDbContext()
    {
    }

    public ApplicationDbContext(DbContextOptions<ApplicationDbContext> options)
        : base(options)
    {
    }

    public virtual DbSet<CreditRisks> CreditRisks { get; set; }
    public virtual DbSet<Customers> Customers { get; set; }
    public virtual DbSet<Inventory> Inventory { get; set; }
    public virtual DbSet<Orders> Orders { get; set; }

    protected override void OnConfiguring(DbContextOptionsBuilder optionsBuilder)
    {
        if (!optionsBuilder.IsConfigured)
        {
#warning To protect potentially sensitive information in your connection string, you should
move it out of source code. See http://go.microsoft.com/fwlink/?LinkId=723263 for guidance
on storing connection strings.
            optionsBuilder.UseSqlServer("server=.,5433;Database=AutoLot;User Id=sa;Password=
P@sswOrd;");
        }
    }

    protected override void OnModelCreating(ModelBuilder modelBuilder)
    {
        modelBuilder.Entity<CreditRisks>(entity =>
        {
            entity.HasOne(d => d.Customer)
                .WithMany(p => p.CreditRisks)
                .HasForeignKey(d => d.CustomerId)
                .HasConstraintName("FK_CreditRisks_Customers");
        });

        modelBuilder.Entity<Orders>(entity =>
        {
            entity.HasOne(d => d.Car)
                .WithMany(p => p.Orders)
                .HasForeignKey(d => d.CarId)
                .OnDelete(DeleteBehavior.ClientSetNull)
                .HasConstraintName("FK_Orders_Inventory");
        });
    }
}
```

```

        entity.HasOne(d => d.Customer)
            .WithMany(p => p.Orders)
            .HasForeignKey(d => d.CustomerId)
            .HasConstraintName("FK_Orders_Customers");
    });

    OnModelCreatingPartial(modelBuilder);
}
partial void OnModelCreatingPartial(ModelBuilder modelBuilder);
}

```

The file starts with a parameterless constructor. Delete that, as we won't need it. The next constructor takes an instance of the `DbContextOptions` object. This is the constructor that we will be using shortly. More on `DbContextOptions` shortly.

Next are the `DbSet<T>` properties, one for each of our entities. They are also marked virtual to support lazy loading.

The `OnConfiguring` override is a catchall to allow for default configuration of the `ApplicationDbContext` in case one wasn't supplied into the constructor. This is commonly considered a bad practice, since the connection string is hard-coded into the class. Delete this method, as it won't be needed either.

The next method is the `OnModelCreating` override. This is the method that houses the fluent API code. The `CreditRisk` table adds a constraint name to the relationship, but otherwise the data annotations accomplished the same result. What's more interesting to us is the code for the `Orders` table, shown again here:

```

entity.HasOne(d => d.Car)
    .WithMany(p => p.Orders)
    .HasForeignKey(d => d.CarId)
    .OnDelete(DeleteBehavior.ClientSetNull)
    .HasConstraintName("FK_Orders_Inventory");

entity.HasOne(d => d.Customer)
    .WithMany(p => p.Orders)
    .HasForeignKey(d => d.CustomerId)
    .HasConstraintName("FK_Orders_Customers");

```

They both configure the cascade behaviors for the relationships. In the former, if a `Car` (Inventory record) is deleted, the related record in the `Orders` tables will be set to null. However, the `CarId` field is required (not null), so instead an exception is thrown. This is an example of a configuration property that isn't always apparent to those reading the code. In the second, the default is used, which is cascade delete. However, it's only the default because the `CustomerId` record is also not null. Update the code block to the following so it is more clear to the reader:

```

entity.HasOne(d => d.CustomerNavigation)
    .WithMany(p => p.Orders)
    .HasForeignKey(d => d.CustomerId)
    .OnDelete(DeleteBehavior.Cascade)
    .HasConstraintName("FK_Orders_Customers");

```

## Cleaning Up the Entities

Before we start using these entities to access the data, we are going to clean them up and run our first migration. The first step is to rename all of the entity classes. Database tables are usually pluralized, but entities are typically singular.

---

■ **Note** Changing the pluralization on scaffolding is possible by implementing an `IPluralizer` or using Brice Lams package: <https://github.com/bricelam/EFCore.Pluralizer>.

---

You'll notice that this caused a few compile-time problems. We are going to fix those now. First, in the `CreditRisk` entity, the navigation property for the `Customer` record is also named `Customer`. It's a problem to have property names and classes (and namespaces for that matter) collide like this. So, to fix it, I name my singular navigation properties as `<ClassName>Navigation`. The updated `CreditRisk` class is as follows:

```
using System.ComponentModel.DataAnnotations.Schema;
using AutoLot.Dal.Entities.Base;
public partial class CreditRisk
{
    [Key]
    public int Id { get; set; }
    public int CustomerId { get; set; }
    [StringLength(50)]
    public string FirstName { get; set; }
    [StringLength(50)]
    public string LastName { get; set; }

    [ForeignKey(nameof(CustomerId))]
    [InverseProperty(nameof(Customer.CreditRisks))]
    public virtual Customer CustomerNavigation { get; set; }
}
```

Next up is the `Customer` class. While there aren't any name clashes, notice that the collection properties are defined as `ICollection<T>` and initialized as `HashSet<T>`. I prefer to use the lower `IEnumerable<T>` (since `IQueryable<T>` and `ICollection<T>` both derive from `IEnumerable<T>`). Change the types to `IEnumerable<T>` and initialize them as `new List<T>` using property initializers. Then you can delete the constructor and its code. The final issue are the magic strings used in the `InverseProperties`. Update these to use the `nameof` method, for the final result shown here (this will not compile until we finish all of the cleanup):

```
using System.Collections.Generic;
using System.ComponentModel.DataAnnotations;
using System.ComponentModel.DataAnnotations.Schema;
using AutoLot.Dal.Entities.Base;
public partial class Customer
{
    [Key]
    public int Id { get; set; }
    [StringLength(50)]
```

```

public string FirstName { get; set; }
[StringLength(50)]
public string LastName { get; set; }

[InverseProperty(nameof(CreditRisk.CustomerNavigation))]
public virtual IEnumerable<CreditRisk> CreditRisks { get; set; } = new List<CreditRisk>();

[InverseProperty(nameof(Order.CustomerNavigation))]
public virtual IEnumerable<Order> Orders { get; set; } = new List<Order>();
}

```

Next, we will clean up the Order class. Change the names for the Inventory and Customer navigation properties to CarNavigation and CustomerNavigation, respectively. Change the inverse property for the CarNavigation from Inventory.Orders to Car.Orders (we will be renaming the Inventory class to Car), and change the type from Inventory to Car, as follows:

```

using System.ComponentModel.DataAnnotations.Schema;
using AutoLot.Dal. Entities.Base;
public partial class Order
{
    [Key]
    public int Id { get; set; }
    public int CustomerId { get; set; }
    public int CarId { get; set; }

    [ForeignKey(nameof(CarId))]
    [InverseProperty(nameof(Car.Orders))]
    public virtual Car CarNavigation { get; set; }
    [ForeignKey(nameof(CustomerId))]
    [InverseProperty(nameof(Customer.Orders))]
    public virtual Customer CustomerNavigation { get; set; }
}

```

Finally, update the Inventory class name to Car. This involves adding the Table attribute to map the class to the Inventory table and deleting the constructor. Update the Orders property to IEnumerable<Order>, use property initialization to set the property to a new List<Car>, and update the InverseProperty to use the nameof function:

```

using System.Collections.Generic;
using System.ComponentModel.DataAnnotations;
using System.ComponentModel.DataAnnotations.Schema;
using AutoLot.Dal. Entities.Base;
[Table("Inventory", Schema = "dbo")]
public partial class Car
{
    [Key]
    public int Id { get; set; }
    [StringLength(50)]
    public string Make { get; set; }
    [StringLength(50)]

```

```

public string Color { get; set; }
[StringLength(50)]
public string PetName { get; set; }
[InverseProperty(nameof(Order.CarNavigation))]
public virtual IEnumerable<Order> Orders { get; set; } = new List<Order>();
}

```

For this one, you also need to update the `ApplicationDbContext`. Update the `DbSet<Car>` to the following:

```

public virtual DbSet<Car> Cars {get; set; }

```

## Cleaning Up the ApplicationDbContext

The changes to the entities also affect the `ApplicationDbContext`. We already removed some unwanted code, and now we need to update the changes to reflect the updated entities. Open up the `ApplicationDbContext` file and make all of the class names singular and change `Inventory` to `Car` (keep the property names as plural, since they reflect collections of the entities):

```

public virtual DbSet<CreditRisk> CreditRisks { get; set; }
public virtual DbSet<Customer> Customers { get; set; }
public virtual DbSet<Car> Inventory { get; set; }
public virtual DbSet<Order> Orders { get; set; }

```

Next, update the class names in the `OnModelCreating`. You will need to make the classes singular and add “Navigation” to the navigation properties:

```

modelBuilder.Entity<CreditRisk>(entity =>
{
    entity.HasOne(d => d.CustomerNavigation)
        .WithMany(p => p.CreditRisks)
        .HasForeignKey(d => d.CustomerId)
        .HasConstraintName("FK_CreditRisks_Customers");
});

```

```

modelBuilder.Entity<Order>(entity =>
{
    entity.HasOne(d => d.CarNavigation)
        .WithMany(p => p.Orders)
        .HasForeignKey(d => d.CarId)
        .OnDelete(DeleteBehavior.ClientSetNull)
        .HasConstraintName("FK_Orders_Inventory");

    entity.HasOne(d => d.CustomerNavigation)
        .WithMany(p => p.Orders)
        .HasForeignKey(d => d.CustomerId)
        .HasConstraintName("FK_Orders_Customers");
});

```



## Add the Base Entity Class

All of the entities have an `Id` property that is the primary key, and they all need to have a `TimeStamp` field added. This fits perfectly with creating a base class. In EF Core, a base class seamlessly becomes part of the table that is represented by the downstream class. Add a new folder named `Base` to the `Entities` folder, and add a new class named `BaseEntity` into that folder. Update the class to match the following:

```
using System.ComponentModel.DataAnnotations;
using System.ComponentModel.DataAnnotations.Schema;
namespace AutoLot.Dal.Entities.Base
{
    public abstract class BaseEntity
    {
        [Key, DatabaseGenerated(DatabaseGeneratedOption.Identity)]
        public int Id { get; set; }
        [Timestamp]
        public byte[] TimeStamp { get; set; }
    }
}
```

Next, update each of the classes to inherit from the `BaseEntity` and delete their `Id` properties. Here is the partial `Car` class listing to demonstrate:

```
public partial class Car : BaseEntity
{
    [Key] public int Id { get; set; } (Delete this line)
    [StringLength(50)] public string Make { get; set; }
    ...
}
```

## Add the Owned Property

EF Core introduced a feature where you can encapsulate common properties into a class for reuse in different entities. These “owned” classes are incorporated in the table as if they are part of the original class, with the exception of the default column naming convention. More on that shortly.

Create a new folder named `Owned` under the `Entities` folder. In this folder, add a new class named `Person.cs`. Add the following namespaces:

```
using System.ComponentModel.DataAnnotations;
using Microsoft.EntityFrameworkCore;
```

Update the code to the following (note the `[Owned]` attribute):

```
[Owned]
public class Person
{
    [StringLength(50)]
    public string FirstName { get; set; }
    [StringLength(50)]
    public string LastName { get; set; }
}
```

Now, the `FirstName` and `LastName` properties in the `CreditRisk` and `Customer` classes can be replaced with the following code (be sure to add in the `AutoLot.Dal.Entities.Owned` namespace):

```
public Person PersonalInformation { get; set; } = new Person();
```

When you apply this change to the database, the columns will be named after the `<OwnedClass_PropertyName>_<PropertyName>`. In this example, the columns will be named `PersonalInformation_FirstName` and `PersonalInformation_LastName`. That might be fine, but by using the fluent API, you can adjust the names to go back to `FirstName` and `LastName`.

Open the `ApplicationDbContext` and navigate to the `OnModelCreating` method. In the `CreditRisk` configuration, add the following code (highlighted in bold):

```
modelBuilder.Entity<CreditRisk>(entity =>
{
    entity.HasOne(d => d.CustomerNavigation)
        .WithMany(p => p.CreditRisks)
        .HasForeignKey(d => d.CustomerId)
        .HasConstraintName("FK_CreditRisks_Customers");
    entity.OwnsOne(o => o.PersonalInformation,
        pd =>
        {
            pd.Property(p => p.FirstName).HasColumnName(nameof(Person.FirstName));
            pd.Property(p => p.LastName).HasColumnName(nameof(Person.LastName));
        });
});
```

Next, add a configuration block for the `Customer` class, and add the same code:

```
modelBuilder.Entity<Customer>(entity =>
{
    entity.OwnsOne(o => o.PersonalInformation,
        pd =>
        {
            pd.Property(p => p.FirstName).HasColumnName(nameof(Person.FirstName));
            pd.Property(p => p.LastName).HasColumnName(nameof(Person.LastName));
        });
});
```

## Add the ApplicationDbContextFactory

When the EF Core CLI is executed to work with commands that need a context instance, the CLI will look for a class that derives from `IDesignTimeDbContextFactory<TContext>`. If this isn't found, the CLI will attempt to directly create the instance using the default constructor. The problem with the default constructor is that it relies on the `OnConfiguring` override, which we have deleted from our context.

The main advantage of creating a context factory is that it is *only* used by the EF Core CLI, so you can safely hard-code your development connection string without risk of effecting any other databases.

Create a new class named `ApplicationDbContextFactory` in the `EfStructures` folder. Inherit `IDesignTimeDbContextFactory<ApplicationDbContext>`, and add the following using statements to the top of the file:

```
using System;
using Microsoft.EntityFrameworkCore;
using Microsoft.EntityFrameworkCore.Design;
```

Implement the `CreateDbContext` method as follows:

```
public ApplicationDbContext CreateDbContext(string[] args)
{
    var optionsBuilder = new DbContextOptionsBuilder<ApplicationDbContext>();
    var connectionString = @"server=.,5433;Database=AutoLotFinal;User Id=sa;Password=
P@sswOrd;";
    optionsBuilder.UseSqlServer(connectionString);
    Console.WriteLine(connectionString);
    return new ApplicationDbContext(optionsBuilder.Options);
}
```

The `CreateDbContext` takes a single parameter that is not used at this time, but is reserved for future use. In the method, create an instance of the `DbContextOptionsBuilder` typed to the `ApplicationDbContext`. After setting the connection string (note the database name change to `AutoLotFinal`), you call `UseSqlServer(connectionString)`. This is another example of the opt-in nature of all of the .NET Core frameworks. You have to enable which database provider you want the `DbContext` class to use. The next line prints the connection string to the console (not needed, but helpful for troubleshooting). Finally, a new instance of the `ApplicationDbContext` is created using the `DbContextOptions` and returned to the caller.

## Update the Database

Over this section, quite a few changes have been made to the entities. It's now time to apply the changes to the database. If you didn't change the database name in the `ApplicationDbContextFactory` connection string setting, you should drop the current `AutoLot` database in preparation for creating the updated one.

---

■ **Note** You don't have to drop the database every time you run a migration, but blending scaffolding and migrations can be tricky. More on how migrations work shortly.

---

## Create the Initial Migration

You have to use the .NET Core CLI (and the EF Core global tool) to create and apply migrations. Open a command prompt in the same directory as the `AutoLot.Dal` project, and run the following command:

```
dotnet ef migrations add Initial -o EfStructures\Migrations -c AutoLot.Dal.EfStructures.
ApplicationDbContext
```

This adds a migration named `Initial` and places the created files in the `EfStructures\Migrations` folder (creating the folder if it doesn't already exist), using the `ApplicationDbContext`.

---

■ **Note** The EF Core commands will not save edited files (unlike building the project in Visual Studio), so you must save all files and build the solution before running any CLI commands.

---

This creates three files in the target directory. The name argument for the migration is used as the C# class name of the migration and as part of the file name. The rest of the file name is the timestamp (YYYYMMDDHHMMSS) when the migration was created. The full name (timestamp plus migration name) class name is placed in the migration class designer in the Migration attribute. The timestamp is used by EF Core to run the migrations in the proper order.

```
20200529024239_Initial.cs (your timestamp value will be different)
20200529024239_Initial.Designer.cs (your timestamp value will be different)
ApplicationDbContextModelSnapshot.cs
```

---

■ **Note** In Visual Studio, the three files will appear as two files, since the Visual Studio Solution Explorer collapses the migration file and the migration designer together.

---

The 20200529024239\_Initial.cs file contains two methods, Up and Down. The Up method applies the changes to the database, while the Down method rolls the changes back. The MigrationBuilder instance passed into the Up and Down methods provides the API to directly interact with the database, as well as an option to execute raw SQL statements (which you will do in the next chapter). Part of the Up method and the entire Down method are shown here:

```
public partial class Initial : Migration
{
    protected override void Up(MigrationBuilder migrationBuilder)
    {
        migrationBuilder.EnsureSchema(name: "dbo");

        migrationBuilder.CreateTable(
            name: "Customers",
            columns: table => new
            {
                Id = table.Column<int>(nullable: false)
                    .Annotation("SqlServer:Identity", "1, 1"),
                TimeStamp = table.Column<byte[]>(rowVersion: true, nullable: true),
                FirstName = table.Column<string>(maxLength: 50, nullable: true),
                LastName = table.Column<string>(maxLength: 50, nullable: true)
            },
            constraints: table =>
            {
                table.PrimaryKey("PK_Customers", x => x.Id);
            }
        );
    }

    protected override void Down(MigrationBuilder migrationBuilder)
    {
        migrationBuilder.DropTable(name: "CreditRisks");
        migrationBuilder.DropTable(name: "Orders");
        migrationBuilder.DropTable(name: "Inventory", schema: "dbo");
        migrationBuilder.DropTable(name: "Customers");
    }
}
```

The `EnsureSchema` method will check for the existence of the schema and create it if it doesn't exist. Notice that the `down` method does not remove the schema, as EF Core doesn't check to see if it's no longer used. If you need to completely clean the database, you can edit the `down` method to remove the schema.

The `20200529024239_Initial.Designer.cs` class is the cumulative shape of the database, including this migration and all previous migrations (in this case, there aren't any other migrations). The `ApplicationDbContextModelSnapshot.cs` class is the current shape of the database based on all of the migrations (again, in this example, there is only one migration).

## Apply the Migration

Once the migration is created, it needs to be applied to the database. Migrations can be manually applied using the `dotnet ef database update` command, or migrations can be applied through code. Applying a migration will check to see if the database exists and create it if it doesn't. Next, the migration system checks the `__EFMigrationHistory` table for the latest migration that was applied. If this table doesn't exist, it will be created.

The timestamp in the file name (and in the attribute in the related designer class) is used to determine the order that the migrations will be applied. If the database update command is executed with a specific migration name, the migrations applied after that specified migration will be rolled back in reverse order. Again, the rollback process executes the `Down` method in a migration class. If the specified migration has not been applied, any unapplied migrations (up to and including the specified migration) are applied in order. Finally, the `__EFMigrationsHistory` table, which tracks applied migrations, is updated accordingly.

If you do not specify a migration name, all migrations will be applied. If you specify 0 (zero) for the name, all migrations are rolled back. To apply the `Initial` migration you just created, enter the following command into the command prompt:

```
dotnet ef database update Initial -c AutoLot.Dal.EfStructures.ApplicationDbContext
```

---

■ **Note** Strictly speaking, since there is only one `DbContext` in the `AutoLot.Dal` project and you are updating to the latest migration, you could have just typed `"dotnet ef database update"`. The context class is optional when there is only one `DbContext` class, and the migration name is optional if you are updating to the latest migration.

---

When applying the command, you will see the connection string output to the command window (due to the `Console.WriteLine` call added to the `ApplicationDbContextFactory`), and if all is successful, a message that states

Done.

Somewhat anticlimactic, considering all of the work that was put in up to this point!

## Remove a Migration

If you want to remove a migration, first roll back to an earlier migration or use `"dotnet ef database update 0"` to roll all migrations back. You can't remove a migration that has been applied to the database.

Once a migration has been unapplied (or has never been applied), you can remove them, one at a time, starting with the most recent migration. You remove the last migration using the `"dotnet ef migrations remove"` command. This process will revert the `ApplicationDbContextModelSnapshot` to match the prior migration's designer class and then remove the migration from the project.

---

■ **Note** Although it might be tempting, don't remove migrations by deleting them using the file system. This will force you to rebuild all of your migrations since the ModelSnapshot and designer files will be out of sync.

---

## The Final Entity Updates

There are just a few more changes to make to the data model. First, we will create a Make class to further normalize the data. Then, we will make additional fields required in the classes. First, the Make entity.

### Add the Make Entity

Currently, the Make property is just a string in the Inventory table. A better design is to have a Makes table and build a foreign key relationship between the Makes table and the Inventory table. Add a new class named Make in the Entities directory. Add the following using statements to the top of the class:

```
using System.Collections.Generic;
using System.ComponentModel.DataAnnotations;
using System.ComponentModel.DataAnnotations.Schema;
using AutoLot.Dal.Entities.Base;
```

Make sure the class is public and inherits from BaseEntity. Then update the code to have a Name property and a Cars navigation property:

```
public class Make : BaseEntity
{
    [StringLength(50)]
    public string Name { get; set; }
    [InverseProperty(nameof(Car.MakeNavigation))]
    public IEnumerable<Car> Cars { get; set; } = new List<Car>();
}
```

Update the Car class to leverage this new relationship:

```
public partial class Car : BaseEntity
{
    [Required]
    public int MakeId { get; set; }
    [ForeignKey(nameof(MakeId))]
    [InverseProperty(nameof(Make.Cars))]
    public Make MakeNavigation { get; set; }
    ...
}
```

Finally, add another DbSet<T> property to the ApplicationDbContext for the Make class:

```
public virtual DbSet<Make> Makes { get; set; }
```

---

■ **Note** If an entity class doesn't have a `Table` attribute or fluent API configuration for the table name, the convention for the table name is the name of the `DbSet<T>` property. In this case, the table will be named `Makes`.

---

Now create another migration and apply to the database (make sure you build your project first). Each command must be on its own line (and consist of just one line):

```
dotnet ef migrations add AddMakeTable -o EfStructures\Migrations -c AutoLot.Dal.
EfStructures.ApplicationDbContext
```

```
dotnet ef database update AddMakeTable -c AutoLot.Dal.EfStructures.ApplicationDbContext
```

When you create this migration, you will get a warning that there might be a loss of data. That is due to a column (`Make`) being dropped from the `Car` table. This is what we expected (and wanted), so continue on and apply the migration.

## Add a Global Query Filter on the Car Entity

Add a global query filter to the `Car` entity that will filter based on `MakeId`. This goes along with the fact that most dealerships only sell one brand of car. All of the default queries that involve the `Car` entity will be filtered on `MakeId`, unless `IgnoreQueryFilters` is used in the LINQ statement. The `MakeId` will be assigned as a property on the `ApplicationDbContext`.

Add a public property name `MakeId` to the top of the `ApplicationDbContext` class:

```
public int MakeId { get; set; }
```

Next, add a configuration block for the `Car` class in the `OnModelCreating` override. In this block, call the `HasQueryFilter` fluent API method, and assign the query filter:

```
modelBuilder.Entity<Car>(entity => {
    entity.HasQueryFilter(c => c.MakeId == MakeId);
});
```

## Update the Required Fields

The `PetName` and `Color` properties on the `Car` class and the `Name` on the `Make` class are optional because strings are nullable types. To make them non-nullable in the database, we can either add the `Required` data annotation or turn on C# 8 nullability. In our case, we will do both. Enabling nullability will fix the database side, but ASP.NET Core needs the `Required` attribute for its validation system.

Open the `AutoLot.Dal` project file, and enable C# 8 nullability, like this:

```
<PropertyGroup>
  <TargetFramework>netcoreapp3.1</TargetFramework>
  <Nullable>enable</Nullable>
</PropertyGroup>
```

This also changes the `TimeStamp` property to be non-nullable in SQL Server, so we will want to revert that back to nullable. Recall that when nullability is enabled, reference types are made nullable just like value types by adding a question mark (?) to the type declaration. Update the `BaseEntity` class like this:

```
[Timestamp]
public byte[]? TimeStamp { get; set; }
```

Now add a new migration and apply it to the database (remember that each command must be a single line – the line breaks because of the size of this page):

```
dotnet ef migrations add AddRequired -o EfStructures\Migrations -c AutoLot.Dal.EfStructures.
ApplicationDbContext
```

```
dotnet ef database update AddRequired -c AutoLot.Dal.EfStructures.ApplicationDbContext
```

Next, update the `PetName`, `Color` (in `Car`), and `Name` (in `Make`) by adding the `Required` attribute:

```
public partial class Car : BaseEntity
{
    ...
    [StringLength(50),Required]
    public string Color { get; set; }
    [StringLength(50),Required]
    public string PetName { get; set; }
    ...
}

public class Make : BaseEntity
{
    [StringLength(50),Required]
    public string Name { get; set; }
    ...
}
```

One last change, that doesn't affect EF Core, but does affect ASP.NET Core. ASP.NET Core also honors nullability, so all of the single navigation properties either need to be initialized (like the lists) or set as nullable types. To fix this, make the following code changes:

```
public partial class Car : BaseEntity
{
    ...
    [ForeignKey(nameof(MakeId))]
    [InverseProperty(nameof(Make.Cars))]
    public Make? MakeNavigation { get; set; }
    ...
}

public partial class CreditRisk : BaseEntity
{
    ...
    [ForeignKey(nameof(CustomerId))]
    [InverseProperty(nameof(Customer.CreditRisks))]
```



```

    public virtual Customer? CustomerNavigation { get; set; }
}
public partial class Order : BaseEntity
{
    ...
    [ForeignKey(nameof(CarId))]
    [InverseProperty(nameof(Car.Orders))]
    public virtual Car? CarNavigation { get; set; }

    [ForeignKey(nameof(CustomerId))]
    [InverseProperty(nameof(Customer.Orders))]
    public virtual Customer? CustomerNavigation { get; set; }
}

```

## Create a Unique Index on Order

Creating constraints (unique, indices, etc.) is done through the fluent API. To create a unique constraint on the Order table that uses the CarId and the CustomerId, update the Order configuration block to the following:

```

modelBuilder.Entity<Order>(entity =>
{
    ...
    entity.HasIndex(cr => new { cr.CustomerId, cr.CarId }).IsUnique(true);
});

```

Create a new migration and apply it to the database:

```
dotnet ef migrations add UniqueIndex -o EfStructures\Migrations -c AutoLot.Dal.EfStructures.
ApplicationDbContext
```

```
dotnet ef database update UniqueIndex -c AutoLot.Dal.EfStructures.ApplicationDbContext
```

## Add the View and ViewModel

The final change to our database will be to add a T-SQL View to retrieve the Order records with Customer, Car, and Make details and a ViewModel to receive the data.

### Add the View

We will apply this view to the database using a migration, even though we have to roll the migration by hand. The reason to do this (instead of just opening Azure Data Studio and running the T-SQL code) is to keep with the one-stop process of updating the database. This way, developers don't have to run the migrations and then run some other scripts to get the project current.

Start by creating a new migration, but don't apply it yet. The Up and Down methods will be empty, since there aren't any model changes. Then we will write the code to add the view to the database in the Up method and add the code to drop the view in the Down method.

```
dotnet ef migrations add SQL -o EfStructures\Migrations -c AutoLot.Dal.EfStructures.
ApplicationDbContext
```

Now, add a new class named `MigrationHelper` in the `EfStructures` folder. Add a using statement for `Microsoft.EntityFrameworkCore.Migrations`, make the class static, and add the following methods, which use the `MigrationBuilder` to execute SQL statements against the database:

```
public static class MigrationHelpers
{
    public static void CreateView(MigrationBuilder migrationBuilder)
    {
        var sql = @"
CREATE VIEW [dbo].[CustomerOrderView]
AS
SELECT dbo.Customers.FirstName, dbo.Customers.LastName, dbo.Inventory.Color, dbo.Inventory.
PetName, dbo.Makes.Name AS Make
FROM    dbo.Orders
INNER JOIN dbo.Customers ON dbo.Orders.CustomerId = dbo.Customers.Id
INNER JOIN dbo.Inventory ON dbo.Orders.CarId = dbo.Inventory.Id
INNER JOIN dbo.Makes ON dbo.Makes.Id = dbo.Inventory.MakeId ";
        migrationBuilder.Sql(sql);
    }
    public static void DropView(MigrationBuilder migrationBuilder)
    {
        var sql = @"DROP VIEW [dbo].[ CustomerOrderView]";
        migrationBuilder.Sql(sql);
    }
}
```

Next, update the `Up` and `Down` methods in the `20200529142150_SQL.cs` class (your timestamp will be different) to call these helper methods:

```
public partial class SQL : Migration
{
    protected override void Up(MigrationBuilder migrationBuilder)
    {
        MigrationHelpers.CreateView(migrationBuilder);
    }

    protected override void Down(MigrationBuilder migrationBuilder)
    {
        MigrationHelpers.DropView(migrationBuilder);
    }
}
```

Now when you apply the migration, the view will be created. If you roll back the migration (by applying an earlier migration), the view will be dropped.

## Add the ViewModel

There are a variety of definitions for the term “ViewModel”. The one that I will use here (and throughout the rest of the book unless called out differently) is a transport mechanism for data that is based on a subset of a model or multiple entities combined together.

---

■ **Note** In the world of Windows Presentation Foundation (WPF), `ViewModel` takes on extra meaning when using the MVVM pattern.

---

Add a new folder named `ViewModels` in the `AutoLot.Dal` project. In this folder, add a class named `CustomerOrderViewModel.cs`, and add the following using statement to the file:

```
using System.ComponentModel.DataAnnotations.Schema;
```

Next, update the code to the following:

```
public class CustomerOrderViewModel
{
    public string FirstName { get; set; }
    public string LastName { get; set; }
    public string Color { get; set; }
    public string PetName { get; set; }
    public string Make { get; set; }

    [NotMapped]
    public string FullDetail => $"{FirstName} {LastName} ordered a {Color} {Make} named {PetName}";
    public override string ToString() => FullDetail;
}
```

The first five properties represent the data coming from the view. The `FullDetail` property is decorated with the `NotMapped` data annotation. This informs EF Core that this property is not to be included in the database. The `ToString` override and the other properties coming from `System.Object` are always ignored by EF Core.

## Add the ViewModel to the ApplicationDbContext

The final step is to register the `CustomerOrderViewModel` with the `ApplicationDbContext` so that LINQ queries can be used to get the data. Add a using statement for `AutoLot.Dal.ViewModels` to the `ApplicationDbContext`, and then add the `DbSet<T>` property:

```
public virtual DbSet<CustomerOrderViewModel> CustomerOrderViewModels { get; set; }
```

Next, we have to make sure to let EF Core know that this doesn't represent a table that can have its data updated, but a view that is read-only. This is done through the fluent API. Add the following to the `OnModelCreating` method:

```
modelBuilder.Entity<CustomerOrderViewModel>(entity =>
{
    entity.HasNoKey().ToView("CustomerOrderView", "dbo");
});
```

The `HasNoKey` method is what lets EF Core know that this entity represents read-only data. This could be a table without a primary key or (as in our case) a view.

# Automatic Database and Migration Handling

Recall from Table 22-2 that the DbContext exposes a Database property. This represents a database façade that contains a host of properties and methods, including methods to drop and create the database as well as run migrations. The three methods related to these operations are listed in Table 22-6.

Table 22-6. Programmatically Working with the Database

Member of Database	Meaning in Life
EnsureDeleted	Drops the database if it exists. Does nothing if it doesn't.
EnsureCreated	Creates the database if it doesn't exist. Does nothing if it doesn't. Creates the tables and columns based on the classes reachable from the DbSet<T> properties. Does not apply any migrations. <b>Note</b> This should not be used in conjunction with migrations.
Migrate	Creates the database if it doesn't exist. Applies all migrations to the database.

As mentioned in the table, the EnsureCreated method will create the database if it doesn't exist and then creates the tables, columns, and indices based on the entity model. It does not apply any migrations. If you are using migrations (as we are), this will cause a multitude of issues. Whenever you are working with migrations, you should always use the Migration method to programmatically create the database.

## Drop and Recreate the Database

During development, it can be beneficial to drop and recreate the development database and then seed it with sample data. This creates an environment where testing (manual or automated) can be executed without fear of ruining other tests due to changing the data. The next section covers seeding the database, but before running the seed methods, the database needs to be cleaned, either by dropping it and recreating it or by deleting all of the records.

Create a new folder named Initialization in the AutoLot.Dal project. In this folder, create a new class named SampleDataInitializer.cs. At the top of the file, update the using statements to the following:

```
using System;
using System.Collections.Generic;
using System.Linq;
using AutoLot.Dal.EfStructures;
using AutoLot.Dal.Entities.Base;
using Microsoft.EntityFrameworkCore;
using Microsoft.EntityFrameworkCore.Storage;
```

Make the class public and static and add a method named DropAndCreateDatabase that takes an instance of the ApplicationDbContext as an argument. In this method, call EnsureDeleted and Migrate using the Database property of the injected ApplicationDbContext, as shown here:

```
public static void DropAndCreateDatabase(ApplicationDbContext context)
{
    context.Database.EnsureDeleted();
    context.Database.Migrate();
}
```

## Data Initialization

A data seeding mechanism was added in EF Core 2.1, but this process is tied into the migration system and is difficult to work with. Instead, we are going to build our own data seeding system that can be run on demand. The `SampleDataInitializer` class that you created in the last section will contain all of the code used to create, load, and clean the database. Another file will hold all of the sample data, which you will create now.

### Create the Sample Data

Add a new file named `SampleData.cs` to the `Initialization` folder. Make the class public and static and update the using statements to the following:

```
using System.Collections.Generic;
using AutoLot.Dal.Entities;
using AutoLot.Dal.Entities.Owned;
```

The file consists of five static functions that create the sample data:

```
public static class SampleData
{
    public static List<Customer> Customers =>
        new List<Customer>
        {
            new Customer {Id = 1, PersonalInformation = new Person{FirstName = "Dave", LastName =
                "Brenner"}},
            new Customer {Id = 2, PersonalInformation = new Person{FirstName = "Matt", LastName =
                "Walton"}},
            new Customer {Id = 3, PersonalInformation = new Person{FirstName = "Steve", LastName =
                "Hagen"}},
            new Customer {Id = 4, PersonalInformation = new Person{FirstName = "Pat", LastName =
                "Walton"}},
            new Customer {Id = 5, PersonalInformation = new Person{FirstName = "Bad", LastName =
                "Customer"}},
        };

    public static List<Make> Makes => new List<Make>
    {
        new Make {Id = 1, Name = "VW"},
        new Make {Id = 2, Name = "Ford"},
        new Make {Id = 3, Name = "Saab"},
        new Make {Id = 4, Name = "Yugo"},
        new Make {Id = 5, Name = "BMW"},
        new Make {Id = 6, Name = "Pinto"},
    };

    public static List<Car> Inventory => new List<Car>
    {
        new Car {Id = 1, MakeId = 1, Color = "Black", PetName = "Zippy"},
        new Car {Id = 2, MakeId = 2, Color = "Rust", PetName = "Rusty"},
        new Car {Id = 3, MakeId = 3, Color = "Black", PetName = "Mel"},
        new Car {Id = 4, MakeId = 4, Color = "Yellow", PetName = "Clunker"},
    };
}
```

```

        new Car {Id = 5, MakeId = 5, Color = "Black", PetName = "Bimmer"},
        new Car {Id = 6, MakeId = 5, Color = "Green", PetName = "Hank"},
        new Car {Id = 7, MakeId = 5, Color = "Pink", PetName = "Pinky"},
        new Car {Id = 8, MakeId = 6, Color = "Black", PetName = "Pete"},
        new Car {Id = 9, MakeId = 4, Color = "Brown", PetName = "Brownie"},
    };

    public static List<Order> Orders => new List<Order>
    {
        new Order {Id = 1, CustomerId = 1, CarId = 5},
        new Order {Id = 2, CustomerId = 2, CarId = 1},
        new Order {Id = 3, CustomerId = 3, CarId = 4},
        new Order {Id = 4, CustomerId = 4, CarId = 7},
    };

    public static List<CreditRisk> CreditRisks => new List<CreditRisk>
    {
        new CreditRisk
        {
            Id = 1,
            CustomerId = Customers[4].Id,
            PersonalInformation = new Person{
                FirstName = Customers[4].PersonalInformation.FirstName,
                LastName = Customers[4].PersonalInformation.LastName
            }
        }
    };
}

```

## Load or Delete the Sample Data

The next step is to create the methods that add the sample data to the database as well as remove them.

## Delete the Data and Reseed the Identity Columns

Open the `StoreDataInitializer.cs` class and add a method named `ResetIdentity`. This method reseeds the identity column for all tables in the database. This method leverages the `Model` property of the `ApplicationDbContext` to then get the actual schema and table name, since the DBCC `CheckIdent` function requires the database names, and can't use the C# class name that they are mapped to:

```

internal static void ResetIdentity(ApplicationDbContext context)
{
    foreach (var entity in context.Model.GetEntityTypes())
    {
        if (entity.FindPrimaryKey() == null)
        {
            continue;
        }
    }
}

```

```

        var tableName = entity.GetTableName();
        var schemaName = entity.GetSchema();
        context.Database.ExecuteSqlRaw($"DBCC CHECKIDENT ({schemaName}.{tableName}\",
        RESEED, 1);");
    }
}

```

---

■ **Note** The `ExecuteSqlRaw` method of the database façade should be used carefully to prevent potential SQL Injection attacks.

---

The next method clears the data from the database and reseeds the identity columns. The string array makes sure the tables are cleared in the proper order.

```

internal static void ClearData(ApplicationDbContext context)
{
    var entities = new[] {
        typeof(Order).FullName,
        typeof(Customer).FullName,
        typeof(Car).FullName,
        typeof(Make).FullName,
        typeof(CreditRisk).FullName
    };
    foreach (var entityName in entities)
    {
        var entity = context.Model.FindEntityType(entityName);
        var tableName = entity.GetTableName();
        var schemaName = entity.GetSchema();
        context.Database.ExecuteSqlRaw($"DELETE FROM {schemaName}.{tableName}");
        context.Database.ExecuteSqlRaw($"DBCC CHECKIDENT ({schemaName}.{tableName}\",
        RESEED, 1);");
    }
}

```

## Load the Data into the Database

The internal `SeedData` method adds the data from the `SampleData` methods into an instance of the `ApplicationDbContext` and then persists the data to the database.

```

internal static void SeedData(ApplicationDbContext context)
{
    ProcessInsert(context, context.Customers, SampleData.Customers);
    ProcessInsert(context, context.Makes, SampleData.Makes);
    ProcessInsert(context, context.Cars, SampleData.Inventory);
    ProcessInsert(context, context.Orders, SampleData.Orders);
    ProcessInsert(context, context.CreditRisks, SampleData.CreditRisks);
}

```

```

static void ProcessInsert<TEntity>(
    ApplicationDbContext context,
    DbSet<TEntity> table,
    List<TEntity> records) where TEntity : BaseEntity
{
    //Check if any records exist
    if (!table.Any())
    {
        //Create an execution strategy to hold the explicit transaction
        IExecutionStrategy strategy = context.Database.CreateExecutionStrategy();
        strategy.Execute(() =>
        {
            using var transaction = context.Database.BeginTransaction();
            try
            {
                var metaData = context.Model.FindEntityType(typeof(TEntity).FullName);
                context.Database.ExecuteSqlRaw(
                    $"SET IDENTITY_INSERT {metaData.GetSchema()}.{metaData.GetTableName()} ON");
                table.AddRange(records);
                context.SaveChanges();
                context.Database.ExecuteSqlRaw(
                    $"SET IDENTITY_INSERT {metaData.GetSchema()}.{metaData.GetTableName()} OFF");
                transaction.Commit();
            }
            catch (Exception)
            {
                transaction.Rollback();
            }
        });
    }
}

```

The `SeedData` method uses a local function to process the data. This method uses a lot of code that will be explained in greater detail in the next chapter. It first checks to see if the table has any records and, if not, proceeds to process the sample data. An `ExecutionStrategy` is created from the database façade, and this is used to create an explicit transaction, which is needed to turn identity insert on and off. The records are added, and if all is successful, the transaction is committed; otherwise, it's rolled back.

The two methods are public and used to reset the database. `InitializeData` drops and recreates the database before seeding it, and the `ClearDatabase` method just deletes all of the records, resets the identity, and then seeds the data.

```

public static void InitializeData(ApplicationDbContext context)
{
    DropAndCreateDatabase(context);
    SeedData(context);
}

```



```
public static void ClearAndReseedDatabase(ApplicationDbContext context)
{
    context.Database.Migrate();
    ClearData(context);
    SeedData(context);
}
```

## Splitting the Entities and ViewModels from the Data Access Layer

Currently, the data access layer is all-in-one project, with all the EF Core code and the entities grouped together. While that is sufficient for some applications, more often it's beneficial to split them apart. Fortunately, this is extremely simple.

Add a new .NET Core class library project named `AutoLot.Dal.Models` to your solution and delete the generated `Class1.cs` class. Add the `Microsoft.EntityFrameworkCore.Abstractions` NuGet Package, and enable C# 8 nullability for the new project:

```
<PropertyGroup>
  <TargetFramework>netcoreapp3.1</TargetFramework>
  <Nullable>enable</Nullable>
</PropertyGroup>
```

Move the `Entities` and `ViewModels` folders into the new project. Clean up the namespaces, and you now have better separation of concerns.

## Summary

This chapter started the journey into Entity Framework Core. This chapter examined EF Core fundamentals, how queries execute, and the EF Core Command Line Interface. Then you scaffolded your `AutoLot` database from [Chapter 21](#) into entities and a derived `DbContext` class.

The rest of the chapter focused on building the core of the `AutoLot` data access layer. The entities (and their data annotations) and the view model were first scaffolded from an existing data and then updated to match the current requirements. It also examined how relationships and database constraints are configured using the fluent API. Migrations were created to apply the entities to the database and used to create SQL Server objects (in `AutoLot` that was a view).

In the next chapter, you will conduct a deep dive into Create, Read, Update, and Delete (CRUD) operations and finish the data access layer by implementing a repository pattern in `AutoLot.Dal`.

## CHAPTER 23



# Finishing the Data Access Layer

The previous chapter built the core parts of the AutoLot data access layer – the `ApplicationDbContext`, the entities and view model, and the data initialization code. This chapter starts by examining Create, Read, Update, and Delete (CRUD) operations using Entity Framework Core and wraps up by creating a set of strongly typed repositories to make writing your data access code even easier.

## Test-Driving the AutoLot Data Access Layer

Before examining CRUD operations, we are going to set up an integration test platform using xUnit, a unit testing framework. Start by adding a new xUnit Test Project named `AutoLot.Dal.Tests`. In Visual Studio, this project type is named “xUnit Test Project (.NET Core)”. Make sure to select the C# version. From the .NET Core Command Line Interface (CLI), the template is named “xUnit”. Make sure to add the project to the solution if you use the .NET Core CLI.

---

■ **Note** Unit tests are designed to test a single unit of code. What we will be doing throughout this chapter is technically creating *Integration* tests, since we are testing the C# code *and* EF Core, all of the way to the database.

---

## Configure the Project

Add the `Microsoft.EntityFrameworkCore.SqlServer` and `Microsoft.Extensions.Configuration.Json` NuGet packages to the test project, and make sure all of the NuGet packages are up to date. Next, add project references to `AutoLot.Models` and `AutoLot.Dal`.

Then add a JSON file named `appsettings.json` to the project, and add your connection string information into the JSON file (update your connection string from what is listed here as necessary):

```
{
  "ConnectionStrings": {
    "AutoLotFinal": "server=.,5433;Database=AutoLotFinal;User Id=sa;Password=P@ssw0rd;"
  }
}
```

It's important to use the "ConnectionStrings" element name since there is built-in support for it in the .NET Core configuration system. Also, update project file to have the settings file copied to the output folder on every build. Do that by adding the following ItemGroup to the AutoLot.Dal.Tests.csproj file:

```
<ItemGroup>
  <None Update="appsettings.json">
    <CopyToOutputDirectory>Always</CopyToOutputDirectory>
  </None>
</ItemGroup>
```

## Add the TestHelper Class

The TestHelper class will handle the application configuration as well as creating a new instance of the ApplicationDbContext. Add a new public static class named TestHelpers.cs in the root of the project. Update the using statements to the following:

```
using System.IO;
using AutoLot.Dal.EfStructures;
using Microsoft.EntityFrameworkCore;
using Microsoft.EntityFrameworkCore.Storage;
using Microsoft.Extensions.Configuration;
```

Add two public static methods to create instances of the IConfiguration and ApplicationDbContext classes. Add the following code to the class:

```
public static IConfiguration GetConfiguration() =>
    new ConfigurationBuilder()
        .SetBasePath(Directory.GetCurrentDirectory())
        .AddJsonFile("appsettings.json", true, true)
        .Build();

public static ApplicationDbContext GetContext(
    IConfiguration configuration)
{
    var optionsBuilder =
        new DbContextOptionsBuilder<ApplicationDbContext>();
    var connectionString = configuration
        .GetConnectionString("AutoLotFinal");
    optionsBuilder.UseSqlServer(connectionString,
        sqlOptions => sqlOptions.EnableRetryOnFailure());
    return new ApplicationDbContext(optionsBuilder.Options);
}
```

The only new code in the preceding block is the call to **EnableRetryOnFailure** (in bold). This opts in to the SQL Server Retrying Execution Strategy, which will automatically retry operations that failed due to transient errors.

Add another static method that will create a new instance of the ApplicationDbContext using the same connection and transaction as the original one passed in. This shows another mechanism of configuring a derived DbContext:

```

public static ApplicationDbContext GetSecondContext(
    ApplicationDbContext oldContext,
    IDbContextTransaction trans)
{
    var optionsBuilder =
        new DbContextOptionsBuilder<ApplicationDbContext>();
    optionsBuilder.UseSqlServer(
        oldContext.Database.GetDbConnection(),
        sqlServerOptions =>
            sqlServerOptions.EnableRetryOnFailure());
    var context =
        new ApplicationDbContext(optionsBuilder.Options);
    context.Database.UseTransaction(trans.GetDbTransaction());
    return context;
}

```

## Add the BaseTest Class

Now add a new folder named Base to the project, and add a new class file named BaseTest.cs to that folder. Update the using statements to the following:

```

using System;
using System.Data;
using AutoLot.Dal.EfStructures;
using Microsoft.EntityFrameworkCore;
using Microsoft.EntityFrameworkCore.Storage;
using Microsoft.Extensions.Configuration;

```

Make the class abstract and implement *IDisposable*. Add two protected readonly properties to hold the *IConfiguration* and *ApplicationDbContext* instances:

```

public abstract class BaseTest : IDisposable
{
    protected readonly IConfiguration Configuration;
    protected readonly ApplicationDbContext Context;

    public virtual void Dispose()
    {
    }
}

```

The xUnit test framework provides a mechanism to run code before and after *each* test is executed. Test classes (called *Fixtures*) that implement the *IDisposable* pattern will execute the code in the class constructor (in this case, the base class constructor and the derived class constructor) before each test is run, and the code in the *Dispose* method (in both the derived class and the base class) is run after each test is run.

Add a protected constructor. In the constructor, you will create an instance of *IConfiguration* and an instance of the *ApplicationDbContext* using the *TestHelper* class: `protected BaseTest()`

```
{
    Configuration = TestHelpers.GetConfiguration();
    Context = TestHelpers.GetContext(Configuration);
}
```

Update the Dispose method to dispose of the instance of the ApplicationDbContext:

```
public void Dispose()
{
    Context.Dispose();
}
```

## Add the Transacted Methods

The final two methods in the BaseTest class will enable running tests in a transaction. The methods will take an Action delegate as a single parameter, create an explicit transaction, execute the Action, and then roll back the transaction. Since the ApplicationDbContext is configured to enable retry on transient errors, the entire process must be executed from the execution strategy.

The ExecuteInATransaction executes using a single instance of an ApplicationDbContext. The ExecuteInASharedTransaction allows for multiple ApplicationDbContext instances to share a transaction. More on the use of these methods later in this chapter. For now, add the following code into your BaseTest class:

```
protected void ExecuteInATransaction(Action actionToExecute)
{
    var strategy = Context.Database.CreateExecutionStrategy();
    strategy.Execute(() =>
    {
        using var trans = Context.Database.BeginTransaction();
        actionToExecute();
        trans.Rollback();
    });
}

protected void ExecuteInASharedTransaction(
    Action<IDbContextTransaction> actionToExecute)
{
    var strategy = Context.Database.CreateExecutionStrategy();
    strategy.Execute(() =>
    {
        using IDbContextTransaction trans =
            Context.Database.BeginTransaction(
                IsolationLevel.ReadUncommitted);
        actionToExecute(trans);
        trans.Rollback();
    });
}
```

## Add the EnsureDatabase Class

The xUnit test framework provides a mechanism for running code before and after any of the tests are run. Normally, this isn't considered a best practice, but in our case, we want to ensure that the database is created and loaded with data before any tests are run. Running the initialization code before every test would slow down the test execution. Test classes that implement `IClassFixture<T>` will have the constructor code of `T` executed before any tests are run and the `Dispose` code run after all tests are completed.

Add a new public sealed class named `EnsureAutoLotDatabaseTestFixture.cs` to the `Base` directory and implement `IDisposable`. Add the following using statements:

```
using System;
using AutoLot.Dal.Initialization;
```

The constructor code is similar to the `BaseTest` class, except this class calls the `ClearAndReseedDatabase` method from the `SampleDataInitializer`:

```
public sealed class EnsureAutoLotDatabaseTestFixture :
    IDisposable
{
    public EnsureAutoLotDatabaseTestFixture()
    {
        var configuration = TestHelpers.GetConfiguration();
        var context = TestHelpers.GetContext(configuration);
        SampleDataInitializer.ClearAndReseedDatabase(context);
        context.Dispose();
    }

    public void Dispose()
    {
    }
}
```

## Add the TestFixture Classes

Due to space limitations, we won't be testing all of the entities, but enough to demonstrate the concepts for this chapter. Add a new folder named `ContextTests` in the `AutoLot.Dal.Tests` folder, and add two files named `CarTests.cs` and `CustomerTests.cs` to this folder. Add the following using statements to both files:

```
using System.Collections.Generic;
using System.Linq;
using AutoLot.Dal.Models.Entities;
using AutoLot.Dal.Tests.Base;
using Microsoft.EntityFrameworkCore;
using Xunit;
```

Depending on the capabilities of the test runner, xUnit tests are run in serial within a test fixture (class), but in parallel across test fixtures. This can be problematic when executing integration tests that interact with a database. This can be changed by specifying a `Collection` name to the test fixtures. All tests in fixtures that share the same `Collection` name will be run in serial. Add the `Collection` attribute to the top of both classes:

```
[Collection("Integration Tests")]
```

Next, inherit from the `BaseTest` and implement the `IClassFixture` interface in both classes:

```
[Collection("Integration Tests")]
public class CustomerTests : BaseTest,
    IClassFixture<EnsureAutoLotDatabaseTestFixture>
{
}

[Collection("Integration Tests")]
public class CarTests : BaseTest,
    IClassFixture<EnsureAutoLotDatabaseTestFixture>
{
}
```

## Fact and Theory Methods

Parameterless test methods are referred to as Facts (and use the `Fact` attribute). Tests that take parameters are referred to as Theories (and use the `Theory` attribute) and can run multiple iterations with different values passed into the parameters.

## Reading Records

Creating entity instances from database data typically involves executing a LINQ statement against the `DbSet<T>` properties. The LINQ statements are converted to SQL by the database provider and the LINQ translation engine, and the appropriate data is read from the database. Data can also be loaded using the `FromSqlRaw` or `FromSqlInterpolated` methods using raw SQL strings. Entities loaded into the `DbSet<T>` collections are added to the `ChangeTracker` by default, but can be added without tracking (covered shortly). Data loaded in keyless `DbSet<T>` collections are never tracked.

If related entities are already loaded into the `DbSet<T>`, EF Core will wire up the new instances along the navigation properties. For example, if the `Cars` are loaded into the `DbSet<Car>` collection and then the related `Orders` are loaded into the `DbSet<Order>` of the same `ApplicationDbContext` instance, the `Car.Orders` navigation property will return the related `Order` entities without re-querying the database.

## Entity State

When an entity is created by reading data from the database, the `EntityState` is set to `Unchanged`.

## LINQ Queries

The `DbSet<T>` collection type implements (among other interfaces) `IQueryable<T>` and `IEnumerable<T>`. This allows C# LINQ commands to be used to create queries to get data from the database. While all C# LINQ statements are available for use with the `DbSet<T>` collection type, some LINQ statements might not be supported by the database provider. Unsupported LINQ statements cannot be translated into the database provider's language, and execute client-side. Unless the non-translatable statement is the very last statement of the LINQ command, an exception will be thrown.

---

■ **Note** This book is not a complete LINQ reference, but shows just a few examples. For more examples of LINQ queries, Microsoft has published 101 LINQ samples at <https://code.msdn.microsoft.com/101-LINQ-Samples-3fb9811b>.

---

## LINQ Execution

As a reminder, when using LINQ to query the database for a list of entities, the query isn't executed until the query is iterated over, converted to a `List<T>`, or bound to a list control (like a data grid). For single record queries, the statement is executed when the single record call is added to the LINQ statement.

## Get All Records

To get all of the records for a table, simply use the `DbSet<T>` property directly. Since we defined them as `IEnumerable`, you should call `ToList()` to convert them to a `List<T>`. In the `CustomerTests` class, add the following Fact:

```
[Fact]
public void ShouldGetAllOfTheCustomers()
{
    var cars = Context.Customers.ToList();
    Assert.Equal(5, cars.Count);
}
```

The line in bold gets all of the values from the `DbSet<Customer>` property (the `ToList()` executes the query against the database). This gets translated into

Select \* from dbo.Customers

The final line of the method asserts that the number of records returned matches our expectation.

## Global Query Filters

One catch to the preceding query is if there is a global query filter on the entity. Open the `CarTests.cs` class and add the following test:

```
[Fact]
public void ShouldReturnNoCarsWithQueryFilterNotSet()
{
    var cars = Context.Cars.ToList();
    Assert.Empty(cars);
}
```



You might expect that there would be cars returned and not an empty list, or maybe the database doesn't have records. What has happened is that the query filter on the Car entity excluded all of the cars. It is in the ApplicationDbContext OnModelCreating override, and is listed here for reference:

```
modelBuilder.Entity<Car>(entity => {
    entity.HasQueryFilter(c => c.MakeId == MakeId);
});
```

The MakeId property wasn't set on the ApplicationDbContext and defaults to zero (0). The filter excludes all records that don't have a MakeId equal to zero, which, in our data, excludes all records.

## Disable the Query Filters

To disable global query filters, add the IgnoreQueryFilters method to the LINQ query. This disables all filters on all entities in the query. If there was more than one filter on the entity and some of the filters are required, they must be reapplied using Where methods.

Add the following test to the CarTests class, which disables the query filter and returns all records:

```
[Fact]
public void ShouldGetAllOfTheCars()
{
    var cars = Context.Cars.IgnoreQueryFilters().ToList();
    Assert.Equal(9, cars.Count);
}
```

## Use the Query Filters

To use the query filter on the Car entity in our example, the MakeId on the ApplicationDbContext must be set prior to executing a query. The following Theory uses the InlineData attribute to pass values into the test's parameters. The first is the Make Id and the second is the expected number of Cars with that make.

```
[Theory]
[InlineData(1, 1)]
[InlineData(2, 1)]
[InlineData(3, 1)]
[InlineData(4, 2)]
[InlineData(5, 3)]
[InlineData(6, 1)]
public void ShouldGetTheCarsByMake(
    int makeId, int expectedCount)
{
    Context.MakeId = makeId;
    var cars = Context.Cars.ToList();
    Assert.Equal(expectedCount, cars.Count);
}
```

The query filters are also applied when using FromSqlRaw or FromSqlInterpolated. Both of these methods will be covered shortly, but here are the tests showing that the query filters are still in action:

```

[Fact]
public void ShouldNotGetTheCarsUsingFromSql()
{
    var entity =
        Context.Model.FindEntityType($"{typeof(Car).FullName}");
    var tableName = entity.GetTableName();
    var schemaName = entity.GetSchema();
    var cars = Context.Cars
        .FromSqlRaw($"Select * from {schemaName}.{tableName}")
        .ToList();
    Assert.Empty(cars);
}

[Fact]
public void ShouldGetTheCarsUsingFromSqlWithIgnoreQueryFilters()
{
    var entity =
        Context.Model.FindEntityType($"{typeof(Car).FullName}");
    var tableName = entity.GetTableName();
    var schemaName = entity.GetSchema();
    var cars = Context.Cars
        .FromSqlRaw($"Select * from {schemaName}.{tableName}")
        .IgnoreQueryFilters()
        .ToList();
    Assert.Equal(9, cars.Count);
}

[Theory]
[InlineData(1, 1)]
[InlineData(2, 1)]
[InlineData(3, 1)]
[InlineData(4, 2)]
[InlineData(5, 3)]
[InlineData(6, 1)]
public void ShouldGetTheCarsByMakeUsingFromSql(int makeId, int expectedCount)
{
    Context.MakeId = makeId;
    var entity =
        Context.Model.FindEntityType($"{typeof(Car).FullName}");
    var tableName = entity.GetTableName();
    var schemaName = entity.GetSchema();
    var cars = Context.Cars
        .FromSqlRaw($"Select * from {schemaName}.{tableName}")
        .ToList();
    Assert.Equal(expectedCount, cars.Count);
}

```

## Retrieve a Single Record

There are two main methods for returning just a single record with a query, `First` and `Single`. Both return the first record that matches the query conditions (based on sorting statements or database order if no sorting is specified). With `Single`, if there is more than one record that matches the query, an exception is thrown. Execution occurs immediately when the `First` or `Single` methods are called.

The `First/Single` methods throw an exception if no records can be located that match the query. There are additional variations of the methods, including `FirstOrDefault` and `SingleOrDefault`. When the `-OrDefault` versions are used, the default value for the type is returned when no data is returned by the query.

### Using First

When using the parameterless form of `First` and `FirstOrDefault`, the first record (based on database order or any preceding where clauses) will be returned. Both methods can also take an `Expression<Func<Customer, bool>>` (a lambda) to narrow down the result set. Filtering is covered in the next section “Filter and Sort Records”. Add the following tests into the `CustomerTests` class to demonstrate using `First()`:

```
[Fact]
public void FirstGetFirstMatchingRecord()
{
    //Gets the first record, database order
    var customer = Context.Customers.First();
    Assert.Equal(1,customer.Id);
}

[Fact]
public void FirstShouldThrowExceptionIfNoneMatch()
{
    //Filters based on Id. Throws due to no match
    Assert.Throws<InvalidOperationException>(
        ()=> Context.Customers.First(x=>x.Id == 10));
}

[Fact]
public void FirstOrDefaultShouldReturnDefaultIfNoneMatch()
{
    //Expression<Func<Customer>> is a lambda expression
    Expression<Func<Customer, bool>> expression = x=>x.Id == 10;
    //Returns null when nothing is found
    var customer = Context.Customers.FirstOrDefault(expression);
    Assert.Null(customer);
}
```

For the preceding examples that have the lambda, the equivalent SQL statement is as follows:

```
Select * from dbo.Customers where Id = 10
```

## Using Single

When using the parameterless form of `Single` and `SingleOrDefault`, the first record (based on database order or any preceding where clauses) will be returned. Both methods can also take an `Expression<Func<Customer, bool>>` to narrow down the result set. If more than one record matches the query, `Single` and `SingleOrDefault` throw an exception. If no records match the statement, `Single` throws an exception.

Add the following tests into the `CustomerTests` class to demonstrate using `Single()`:

```
[Fact]
public void GetOneMatchingRecordWithSingle()
{
    //Gets the first record, database order
    var customer = Context.Customers.Single(x=>x.Id == 1);
    Assert.Equal(1,customer.Id);
}
[Fact]
public void SingleShouldThrowExceptionIfNoneMatch()
{
    //Filters based on Id. Throws due to no match
    Assert.Throws<InvalidOperationException>(
        ()=> Context.Customers.Single(x=>x.Id == 10));
}
[Fact]
public void SingleShouldThrowExceptionIfMoreThenOneMatch()
{
    //Filters based on Id. Throws due to no match
    Assert.Throws<InvalidOperationException>(()=> Context.Customers.Single());
}
[Fact]
public void SingleOrDefaultShouldReturnDefaultIfNoneMatch()
{
    //Expression<Func<Customer>> is a lambda expression
    Expression<Func<Customer, bool>> expression = x=>x.Id == 10;
    //Returns null when nothing is found
    var customer =
        Context.Customers.SingleOrDefault(expression);
    Assert.Null(customer);
}
```

## Filter Records

The `Where` method is used to filter records from the `DbSet<T>`. Just like with `First[OrDefault]` and `Single[OrDefault]`, the where clause is specified with a lambda. Unlike the prior examples, multiple `Where` methods can be fluently chained to dynamically build the query. Chained `Where` methods are always combined as *and* clauses. To create an *or* statement, use the same `Where` clause.

You've already seen some filtering in action with the `First/Single` examples. When accessing properties of `Owned` tables, they must be accessed through the `Owned` property name on the entity and then the property. For example, to get to the `LastName` of a `Customer`, use the following code:

```
Var fName = customerInstance.PersonalInformation.LastName
```

Add the following tests that demonstrate various record filters:

```
[Fact]
public void ShouldGetCustomersWithLastNameWithW()
{
    var customers =
        Context.Customers.Where(x =>
            x.PersonalInformation.LastName.StartsWith("W"))
            .ToList();
    Assert.Equal(2, customers.Count);
}

[Fact]
public void ShouldGetCustomersWithLastNameWithWAndFirstNameM()
{
    var customers =
        Context.Customers.Where(x =>
            x.PersonalInformation.LastName.StartsWith("W"))
            .Where(x =>
                x.PersonalInformation.FirstName.StartsWith("M"))
            .ToList();
    Assert.Single(customers);
}

[Fact]
public void ShouldGetCustomersWithLastNameWithWOrH()
{
    var customers =
        Context.Customers.Where(x =>
            x.PersonalInformation.LastName.StartsWith("W") ||
            x.PersonalInformation.LastName.StartsWith("H"))
            .ToList();
    Assert.Equal(3, customers.Count);
}
```

## Sort Records

The `OrderBy` and `OrderByDescending` methods set the sort for the query, ascending and descending, respectively. If subsequent sorts are required, use the `ThenBy` and `ThenByDescending` methods. Sorting is shown in the following code:

```
[Fact]
public void ShouldSortByFirstNameThenLastName()
{
    var customers = Context.Customers
        .OrderBy(x => x.PersonalInformation.LastName)
        .ThenBy(x => x.PersonalInformation.FirstName).ToList();
}
```

## Load Related Data Eagerly

Entities that are linked through navigation properties can be instantiated in one query using eager loading. The `Include` and `ThenInclude` methods create joins between tables in the query. `Include` works on the principal entity (the `DbSet<T>`), and the `ThenInclude` method uses the entity from the previous `Include` as the principal entity.

Relationships that are required will use an Inner Join, while optional relationships will use a Left Join. Add the following tests to the `CarTests.cs` class:

```
[Fact]
public void ShouldGetAllOfTheCarsWithMakes()
{
    var cars = Context.Cars.IgnoreQueryFilters()
        .Include(c => c.MakeNavigation)
        .ToList();
    Assert.Equal(9, cars.Count);
}

[Fact]
public void ShouldGetCarsOnOrderWithRelatedProperties()
{
    var cars = Context.Cars.IgnoreQueryFilters()
        .Where(c => c.Orders.Any())
        .Include(c => c.MakeNavigation)
        .Include(c => c.Orders)
        .ThenInclude(o => o.CustomerNavigation)
        .ToList();
    Assert.Equal(4, cars.Count);
    cars.ForEach(c =>
    {
        Assert.NotNull(c.MakeNavigation);
        Assert.NotNull(c.Orders.ToList()[0].CustomerNavigation);
    });
}
```

The first test adds the `MakeNavigation` property to the results, performing an inner join with the following SQL being executed:

```
SELECT [i].[Id], [i].[Color], [i].[MakeId], [i].[PetName], [i].[TimeStamp], [m].[Id], [m].[Name], [m].[TimeStamp]
FROM [dbo].[Inventory] AS [i]
INNER JOIN [Makes] AS [m] ON [i].[MakeId] = [m].[Id]
```

The second uses two sets of related data. The first is getting the `Make` information (same as the previous test), while the second is getting the `Orders` and then the `Customers` attached to the `Orders`. The entire test is also filtering out the `Car` records that have any orders. The optional relationships generate left joins.

## Load Related Data Explicitly

If the related data needs to be loaded after loading the principle entity, the related entities can be retrieved from the database with subsequent database calls. This is triggered using the `Entry` method on the derived `DbContext`. When loading entities on the many end of a one-to-many relationship, use the `Collection` method on the `Entry` result. To load entities on the one end of a one-to-many (or in a one-to-one relationship), use the `Reference` method. The following code shows both options for loading related data:

```
[Fact]
public void ShouldGetRelatedInformationExplicitly()
{
    var car = Context.Cars.IgnoreQueryFilters()
        .First(x => x.Id == 1);
    Assert.Null(car.MakeNavigation);
    Context.Entry(car).Reference(c=>c.MakeNavigation).Load();
    Assert.NotNull(car.MakeNavigation);

    Assert.Empty(car.Orders);
    Context.Entry(car).Collection(c=>c.Orders).Load();
    Assert.Single(car.Orders);
}
```

Database execution occurs when the `Load` method is called.

## NoTracking Queries

The entities instantiated from the database with LINQ or `FromSql` method calls are added to the `ChangeTracker` by default. If the data is used in a read-only manner, excluding entities from the `ChangeTracker` can provide a slight performance benefit. To disable tracking, add the `AsNoTracking` method to the LINQ statement, as shown here:

```
context.Customers.AsNoTracking().ToList();
```

To disable tracking for the entire `ApplicationDbContext`, set the `QueryTrackingBehavior` on the `ChangeTracker`, as shown here:

```
context.ChangeTracker.QueryTrackingBehavior=
    QueryTrackingBehavior.NoTracking
```

## SQL Queries with LINQ

If the LINQ statement for a particular query is overly complicated or testing reveals the performance is less than desired, data can be retrieved using a raw SQL statement using the `FromSqlRaw` or `FromSqlInterpolated` methods of the `DbSet<T>` collection type. The SQL statement can be a T-SQL select statement, stored procedure, or table-valued function. If the query is an open query (T-SQL statement without a termination semicolon), then additional LINQ statements can be added to the `FromSql` method and all of the code is executed server-side. If the query is termination, it must be executed first, and then subsequent calls will be executed client-side as LINQ to objects.

FromSqlRaw executes the query exactly as it is typed. FromSqlInterpolated uses C# string interpolation and then turns the interpolated values into parameters. The three following tests (two that were shown before) show examples from using both of these methods:

```
[Fact]
public void ShouldNotGetTheCarsUsingFromSql()
{
    var entity = Context.Model
        .FindEntityType($"{typeof(Car).FullName}");
    var tableName = entity.GetTableName();
    var schemaName = entity.GetSchema();
    var cars = Context.Cars
        .FromSqlRaw($"Select * from {schemaName}.{tableName}")
        .ToList();
    Assert.Empty(cars);
}

[Fact]
public void ShouldGetTheCarsUsingFromSqlWithIgnoreQueryFilters()
{
    var entity = Context.Model
        .FindEntityType($"{typeof(Car).FullName}");
    var tableName = entity.GetTableName();
    var schemaName = entity.GetSchema();
    var cars = Context.Cars
        .FromSqlRaw($"Select * from {schemaName}.{tableName}")
        .IgnoreQueryFilters()
        .ToList();
    Assert.Equal(9, cars.Count);
}

[Fact]
public void ShouldGetOneCarUsingInterpolation()
{
    var carId = 1;
    var car = Context.Cars
        .FromSqlInterpolated(
            $"Select * from dbo.Inventory where Id = {carId}")
        .Include(x=>x.MakeNavigation)
        .IgnoreQueryFilters()
        .First();
    Assert.Equal("Black", car.Color);
    Assert.Equal("VW", car.MakeNavigation.Name);
}
```

There are some rules when using the FromSql method. The columns returned from the SQL statement have to match the mapped columns on the model, all columns must be returned, and related data cannot be returned.

With an open-ended query, related data can be loaded with additional LINQ methods, as shown in the third test.



## Creating Records

Records are added to the database by creating them in code, adding them to the property `DbSet<T>`, and calling `SaveChanges` on the context. When `SaveChanges` is executed, the `ChangeTracker` reports all of the added entities and EF Core (along with the database provider) creates the appropriate SQL statement(s) to insert the record(s).

As a reminder, `SaveChanges` executes in an implicit transaction, unless an explicit transaction is used. If the save was successful, the server-generated values are then queried to set the values on the entities.

## Entity State

When an entity is created but not yet added to the `DbSet<T>` property, the `EntityState` is set to `Detached`. Once a new entity is added to a `DbSet<T>`, the `EntityState` is set to `Added`. After `SaveChanges` executes successfully, the `EntityState` is set to `Unchanged`.

## Adding Single Records

The following test demonstrates adding a single record into the `Inventory` table:

```
[Fact]
public void ShouldAddACar()
{
    ExecuteInATransaction(RunTheTest);

    void RunTheTest()
    {
        var car = new Car
        {
            Color = "Yellow",
            MakeId = 1,
            PetName = "Herbie"
        };
        var carCount = Context.Cars.IgnoreQueryFilters().Count();
        Context.Cars.Add(car);
        Context.SaveChanges();
        var newCarCount =
            Context.Cars.IgnoreQueryFilters().Count();
        Assert.Equal(carCount+1,newCarCount);
    }
}
```

This example uses the `ExecuteInATransaction` method built earlier in this chapter to keep the state of the database the same after as it was before the test was run.

## Adding Multiple Records at Once

To insert multiple records in a single transaction, use the `AddRange` method of the `DbSet<T>`, as shown in this test:

```
[Fact]
public void ShouldAddMultipleCars()
{
    ExecuteInATransaction(RunTheTest);

    void RunTheTest()
    {
        var cars = new List<Car>
        {
            new Car
            {
                Color = "Yellow",
                MakeId = 1,
                PetName = "Herbie"
            },
            new Car
            {
                Color = "White",
                MakeId = 2,
                PetName = "Mach 5"
            },
        };
        var carCount = Context.Cars.IgnoreQueryFilters().Count();
        Context.Cars.AddRange(cars);
        Context.SaveChanges();
        var newCarCount =
            Context.Cars.IgnoreQueryFilters().Count();
        Assert.Equal(carCount + 2, newCarCount);
    }
}
```

This example inserted multiple Car records, but you aren't limited to a single entity. You can add a Car and a Customer at the same time just as easily.

## Server-Side Computed Columns

Database columns that have values set server-side, such as sequences, timestamps, and computed columns, should not have their values set with C#. When the entity is successfully saved to the database, EF Core populates the entities' server-side computed properties as part of the call to `SaveChanges`.

As with all other C# class properties, the columns marked as server generated have their initial values set to their C# defaults (e.g., 0 (zero) for numeric values, null for the `byte[]`, etc.) when a new instance is created. Once the entity is successfully saved, the default values are replaced with the database-generated value.

## Adding an Object Graph

When adding an entity to the database, child records can be added in the same call without specifically adding them into their own `DbSet<T>` as long as they are added into the collection property for the parent record. For example, a new Make entity is created, and a child Car record is added to the Cars property on

the Make. When the Make entity is added to the `DbSet<Make>` property, EF Core automatically starts tracking the child Car record as well, without having to add it into the `DbSet<Car>` property explicitly. Executing `SaveChanges` saves the Make and Car together. The following test demonstrates this:

```
[Fact]
public void ShouldAddAnObjectGraph()
{
    ExecuteInATransaction(RunTheTest);

    void RunTheTest()
    {
        var make = new Make {Name = "Honda"};
        var car = new Car
        {
            Color = "Yellow",
            MakeId = 1,
            PetName = "Herbie"
        };
        //Cast the Cars property to List<Car> from IEnumerable<Car>
        ((List<Car>)make.Cars).Add(car);
        Context.Makes.Add(make);
        var carCount = Context.Cars.IgnoreQueryFilters().Count();
        var makeCount =
            Context.Makes.IgnoreQueryFilters().Count();
        Context.SaveChanges();
        var newCarCount =
            Context.Cars.IgnoreQueryFilters().Count();
        var newMakeCount =
            Context.Makes.IgnoreQueryFilters().Count();
        Assert.Equal(carCount+1,newCarCount);
        Assert.Equal(makeCount+1,newMakeCount);
    }
}
```

When adding an object graph, the navigation properties of the root entity must be used and not those of the child entity. The top-down navigation prevents recursion issues.

## Updating Records

Records are updated by loading them into the `DbSet<T>` as a tracked entity, changed through code, and then calling `SaveChanges` on the context. When `SaveChanges` is executed, the `ChangeTracker` reports all of the modified entities and EF Core (along with the database provider) creates the appropriate SQL statement(s) to update the record(s). Records can be updated one at a time (calling `Update`) or in batches (calling `UpdateRange`).

## Entity State

When a tracked entity is edited, the `EntityState` is set to `Modified`. After the changes are successfully saved, the state is returned to `Unchanged`.

## Updating Tracked Entities

Updating a single record is much like adding a single record. Load the record from the database into a tracked entity, make some changes, and call `SaveChanges`. The following code only updates one record, but the same process works with multiple records.

```
[Fact]
public void ShouldUpdateACar()
{
    ExecuteInASharedTransaction(RunTheTest);

    void RunTheTest(IDbContextTransaction trans)
    {
        var car =
            Context.Cars.IgnoreQueryFilters().First(c => c.Id == 1);
        Assert.Equal("Black", car.Color);
        car.Color = "White";
        Context.SaveChanges();
        Assert.Equal("White", car.Color);
        var context2 =
            TestHelpers.GetSecondContext(Context, trans);
        var car2 = context2.Cars.IgnoreQueryFilters()
            .First(c => c.Id == 1);
        Assert.Equal("White", car2.Color);
    }
}
```

The prior code uses a shared transaction across two instances of `ApplicationDbContext`. This is to ensure that the test is valid and not just checking the tracked entity in the first `ApplicationDbContext`.

## Updating Non-tracked Entities

Untracked entities can also update database records, although doing this is a lot more uncommon than the previous example. Create an instance of the class you want to update, and set the values on that object.

The next order of business is to start tracking this entity, and there are two ways to do that. The first is to call `Update` on the `DbSet<T>` property. The second is to set the `EntityState` to `Modified`. Either way, `SaveChanges` must still be called for the values to persist.

The following example reads a record in as non-tracked, creates a new instance of the `Car` class from this record, and changes one property (`Color`). Then it either sets the state or uses the `Update` method on the `DbSet<T>`. The `Update` method also changes the state to `Modified`. The test then calls `SaveChanges`. All of the extra contexts are there to ensure the test is accurate and there isn't any crossover between contexts.

```
[Fact]
public void ShouldUpdateACarUsingState()
{
    ExecuteInASharedTransaction(RunTheTest);
```

```

void RunTheTest(IDbContextTransaction trans)
{
    var car = Context.Cars
        .IgnoreQueryFilters().AsNoTracking()
        .First(c => c.Id == 1);
    Assert.Equal("Black", car.Color);
    var updatedCar = new Car
    {
        Color = "White", //Original is Black
        Id = car.Id,
        MakeId = car.MakeId,
        PetName = car.PetName,
        TimeStamp = car.TimeStamp
    };
    var context2 =
        TestHelpers.GetSecondContext(Context, trans);
    //Either call Update or modify the state
    context2.Entry(updatedCar).State = EntityState.Modified;
    //context2.Cars.Update(updatedCar);
    context2.SaveChanges();
    var context3 =
        TestHelpers.GetSecondContext(Context, trans);
    var car2 = context3.Cars
        .IgnoreQueryFilters().First(c => c.Id == 1);
    Assert.Equal("White", car2.Color);
}
}

```

## Concurrency Checking

Last chapter mentioned concurrency checking, but now it's time to see it in action. As a reminder, when an entity has a `TimeStamp` property defined, the value of that property is used in the `where` clause when changes (updates or deletes) are persisted to the database. Instead of just searching for the primary key, the `TimeStamp` value is added to the query, like this example:

```

UPDATE [dbo].[Inventory] SET [PetName] = @p0
WHERE [Id] = @p1 AND [TimeStamp] = @p2;

```

The `ChangeTracker` compares the number of effected records (as returned by SQL Server) with the number of records the `ChangeTracker` marked as `Modified`. If those numbers are not equal, EF Core will throw a `DbUpdateConcurrencyException`. This exception provides access to the entities that failed to update, their original property values (when the entity was loaded from the database) and the current entity values. The following test shows an example of creating a concurrency exception, catching it, and using the `Entries` to get the original values, current values, and the values that are currently stored in the database. Getting the current values requires another database call (you will need to add in a `using` for Microsoft.EntityFrameworkCore.ChangeTracking).

```

[Fact]
public void ShouldThrowConcurrencyException()
{
    ExecuteInATransaction(RunTheTest);
}

```

```

void RunTheTest()
{
    var car = Context.Cars.IgnoreQueryFilters().First();
    //Update the database outside of the context
    Context.Database.ExecuteSqlInterpolated(
        $"Update dbo.Inventory set Color='Pink' where Id = {car.Id}");
    car.Color = "Yellow";
    var ex = Assert.Throws<DbUpdateConcurrencyException>(
        () => Context.SaveChanges());
    var entry = ex.Entries[0];
    PropertyValues originalProps = entry.OriginalValues;
    PropertyValues currentProps = entry.CurrentValues;
    //This needs another database call
    PropertyValues databaseProps = entry.GetDatabaseValues();
}
}

```

## Deleting Records

When a tracked entity is deleted, an EF Core (along with the database provider) creates the appropriate SQL statement(s) to delete the record(s) when `SaveChanges` is called. Records can be deleted one at a time (calling `Remove`) or in batches (calling `RemoveRange`). The removal process will cause cascade effects on navigation properties based on the rules configured in the `OnModelCreating` (or by EF Core conventions).

## Entity State

When a tracked entity is removed, the `EntityState` is set to `Deleted`. After the delete statement is successfully executed, the entity is removed from the `ChangeTracker` and its state is changed to `Detached`.

## Deleting Tracked Records

The delete process mirrors the update process. Once an entity is tracked, call `Remove` on that instance, and then call `SaveChanges` to remove the record from the database.

```

[Fact]
public void ShouldRemoveACar()
{
    ExecuteInATransaction(RunTheTest);

    void RunTheTest()
    {
        var carCount = Context.Cars.IgnoreQueryFilters().Count();
        var car = Context.Cars
            .IgnoreQueryFilters().First(c => c.Id == 2);
        Context.Cars.Remove(car);
        Context.SaveChanges();
        var newCarCount = Context.Cars
            .IgnoreQueryFilters().Count();
    }
}

```

```

    Assert.Equal(carCount - 1, newCarCount);
    Assert.Equal(
        EntityState.Detached,
        Context.Entry(car).State);
}
}

```

After `SaveChanges` is called, the entity instance still exists, but is no longer in the `ChangeTracker`. When checking the `EntityState`, the state will be `Detached`.

## Updating Non-tracked Entities

Untracked entities can also update database records, although doing this is a lot more uncommon than the previous example. Create an instance of the class you want to update, and set the values on that object.

The next order of business is to start tracking this entity, and there are two ways to do that. The first is to call `Update` on the `DbSet<T>` property. The second is to set the `EntityState` to `Modified`. Either way, `SaveChanges` must still be called for the values to persist.

The following example reads a record in as non-tracked, creates a new instance of the `Car` class from this record, and changes one property (`Color`). Then it either sets the state or uses the `Update` method on the `DbSet<T>`. The `Update` method also changes the state to `Modified`. The test then calls `SaveChanges`. All of the extra contexts are there to ensure the test is accurate and there isn't any crossover between contexts.

```

[Fact]
public void ShouldRemoveACarUsingState()
{
    ExecuteInASharedTransaction(RunTheTest);

    void RunTheTest(IDbContextTransaction trans)
    {
        var carCount = Context.Cars
            .IgnoreQueryFilters().Count();
        var car = Context.Cars
            .IgnoreQueryFilters().AsNoTracking()
            .First(c => c.Id == 2);
        var context2 =
            TestHelpers.GetSecondContext(Context, trans);
        //Either call Update or modify the state
        context2.Entry(car).State = EntityState.Deleted;
        //context2.Cars.Remove(car);
        context2.SaveChanges();
        var newCarCount = Context.Cars
            .IgnoreQueryFilters().Count();
        Assert.Equal(carCount - 1, newCarCount);
        Assert.Equal(
            EntityState.Detached,
            Context.Entry(car).State);
    }
}

```

## Catching Cascade Delete Failures

EF Core will throw a `DbUpdateException` when an attempt to delete a record fails due to the cascade rules. The following test shows this in action:

```
[Fact]
public void ShouldFailToRemoveACar()
{
    ExecuteInATransaction(RunTheTest);

    void RunTheTest()
    {
        var car = Context.Cars
            .IgnoreQueryFilters().First(c => c.Id == 1);
        Context.Cars.Remove(car);
        Assert.Throws<DbUpdateException>(
            ()=>Context.SaveChanges());
    }
}
```

## Concurrency Checking

Delete also uses concurrency checking if the entity has a `TimeStamp` property. See the section on “Concurrency Checking” in the “Updating Records” section for more information.

## Adding Repositories for Code Reuse

A common data access design pattern is the *repository pattern*. As described by Martin Fowler ([www.martinfowler.com/eaCatalog/repository.html](http://www.martinfowler.com/eaCatalog/repository.html)), the core of this pattern is to mediate between the domain and data mapping layers. This helps to eliminate duplication of code. Having specific repositories and interfaces is also needed to use the repositories with the dependency injection framework in ASP.NET Core.

Each of the entities in the AutoLot data access layer will have a strongly typed repo to encapsulate all of the data access work. To start, create a folder named `Repos` in the `AutoLot.Dal` project to hold all of the classes.

---

■ **Note** This next section is not meant to be (nor does it pretend to be) a literal interpretation of Mr. Fowler’s design pattern. If you are interested in the original pattern that motivated my code, you can find more information on the repository pattern on Martin Fowler’s website at [www.martinfowler.com/eaCatalog/repository.html](http://www.martinfowler.com/eaCatalog/repository.html).

---



## Adding the IRepo Interface

My version of the pattern starts with an interface that exposes the vast majority of the standard methods you will use in a data access library. Start by adding a new folder in the `AutoLot.Dal` project named `Repos`, and in that folder, make a new folder named `Base`. Add a new interface into the `Repos\Base` folder named `IRepo`. Update the using statements to the following:

```
using System.Collections.Generic;
```

The full interface is listed here:

```
public interface IRepo<T> : IDisposable
{
    int Add(T entity, bool persist = true);
    int AddRange(IEnumerable<T> entities, bool persist = true);
    int Update(T entity, bool persist = true);
    int UpdateRange(
        IEnumerable<T> entities, bool persist = true);
    int Delete(int id, byte[] timeStamp, bool persist = true);
    int Delete(T entity, bool persist = true);
    int DeleteRange(
        IEnumerable<T> entities, bool persist = true);
    T Find(int? id);
    T FindAsNoTracking(int id);
    T FindIgnoreQueryFilters(int id);

    IEnumerable<T> GetAll();
    IEnumerable<T> GetAllIgnoreQueryFilters();
    void ExecuteQuery(
        string sql, object[] sqlParametersObjects);
    int SaveChanges();
}
```

## Adding the BaseRepo

Next, add another class to the `Repos\Base` directory named `BaseRepo`. This class will implement the `IRepo` interface and provide the core functionality for type-specific repos (coming next). Update the using statements to the following:

```
using System;
using System.Collections.Generic;
using System.Linq;
using AutoLot.Dal.EfStructures;
using AutoLot.Dal.Models.Entities.Base;
using Microsoft.Data.SqlClient;
using Microsoft.EntityFrameworkCore;
using Microsoft.EntityFrameworkCore.Storage;
```

Make the class generic with type `T` and constrain the type to `BaseEntity` and `new()`, which limits the types to classes that have a parameterless constructor. Implement the `IRepo<T>` interface, as follows:

```
public abstract class BaseRepo<T> : IRepo<T> where T : BaseEntity, new()
```

The repo needs an instance of the `ApplicationDbContext` class in order to operate on the database and entities in the object model. This will be passed in through dependency injection for typical use. The ASP.NET Core dependency injection framework handles construction and disposal of resources, negating the need to directly dispose of the `ApplicationDbContext` instance when used with ASP.NET Core. Create a constructor that takes an instance of the `ApplicationDbContext` class and assigns it to a public class-level variable as follows:

```
public ApplicationDbContext Context { get; }
protected BaseRepo(ApplicationDbContext context)
{
    Context = context;
}
```

Another constructor takes an instance of `DbContextOptions` for direct instantiation of the `ApplicationDbContext`. Since this instance is not managed by the DI framework, a class-level variable is set to indicate that the `ApplicationDbContext` should be disposed when the repo is disposed. This constructor calls into the previous constructor, passing in a new instance of the `ApplicationDbContext` class. The `Dispose` method disposed of the context class if created by the repo. Add the following constructor and variable to the class:

```
private readonly bool _disposeContext;
protected BaseRepo(DbContextOptions<ApplicationDbContext> options)
    : this(new ApplicationDbContext(options))
{
    _disposeContext = true;
}
public virtual void Dispose()
{
    if (_disposeContext)
    {
        Context.Dispose();
    }
}
```

The `DbSet<T>` properties of the `ApplicationDbContext` can be referenced by using the `Context.Set<T>` method. Create a public property named `Table` of type `DbSet<T>` and set the value in the initial constructor. The code up to this point is listed here, complete with the dispose pattern:

```
public abstract class BaseRepo<T>
    : IRepo<T> where T : BaseEntity, new()
{
    private bool _isDisposed;
    private readonly bool _disposeContext;
    public DbSet<T> Table { get; }
    public ApplicationDbContext Context { get; }
```

```

protected BaseRepo(ApplicationDbContext context)
{
    Context = context;
    Table = Context.Set<T>();
}

protected BaseRepo(
    DbContextOptions<ApplicationDbContext> options)
    : this(new ApplicationDbContext(options))
{
    _disposeContext = true;
}

public void Dispose()
{
    Dispose(true);
    GC.SuppressFinalize(this);
}

protected virtual void Dispose(bool disposing)
{
    if (_isDisposed)
    {
        return;
    }
    if (disposing)
    {
        if (_disposeContext)
        {
            Context.Dispose();
        }
    }
    _isDisposed = true;
}

~BaseRepo()
{
    Dispose(false);
}
}

```

## Implement the SaveChanges Method

A significant advantage to encapsulating the `DbSet<T>` operations in a repository class is wrapping the call to `ApplicationDbContext.SaveChanges`. This enables centralized error handling and logging. The following code wraps the `Context.SaveChanges` call to encapsulate error handling. Add the following code to the `BaseRepo` class:

```

public int SaveChanges()
{
    try
    {
        return Context.SaveChanges();
    }
    catch (DbUpdateConcurrencyException ex)
    {
        //A concurrency error occurred
        //Should log and handle intelligently
        throw;
    }
    catch (RetryLimitExceededException ex)
    {
        //DbResiliency retry limit exceeded
        //Should log and handle intelligently
        throw;
    }
    catch (DbUpdateException ex)
    {
        //Should log and handle intelligently
        throw;
    }
    catch (Exception ex)
    {
        //Should log and handle intelligently
        throw;
    }
}

```

## Implement the Common Read Methods

The next series of methods returns records using LINQ statements. The `Find` method takes the primary key value(s) and searches the `ChangeTracker` first. If the entity is found, that instance gets returned. If not, the record is retrieved from the database.

```
public virtual T Find(int? id) => Table.Find(id);
```

The two additional `Find` methods extend the `Find` base method. The next method demonstrates retrieving a record but not adding it to the `ChangeTracker` using `AsNoTracking`. Note that this method uses the `Where` method and not the `Find` method, so it does not search the `ChangeTracker` for the instance, it always queries the database. Add the following code to the class:

```

public virtual T FindAsNoTracking(int id) =>
    Table.Where(x => x.Id == id).AsNoTracking().FirstOrDefault();

```

The next variation removes the query filters from the entity and then uses the shorthand version (skipping the `Where` method) to get the `FirstOrDefault`. Add the following to the class:

```
public T FindIgnoreQueryFilters(int id) =>
    Table.IgnoreQueryFilters().FirstOrDefault(x => x.Id == id);
```

The `GetAll` methods return all of the records from the table. The first retrieves them in database order, and the second takes turns of any query filters:

```
public virtual IEnumerable<T> GetAll() => Table;
public virtual IEnumerable<T> GetAllIgnoreQueryFilters()
    => Table.IgnoreQueryFilters();
```

The `ExecuteQuery` method is there to execute stored procedures:

```
public void ExecuteQuery(
    string sql, object[] sqlParametersObjects)
    => Context.Database.ExecuteSqlRaw(
        sql, sqlParametersObjects);
```

## The Add, Update, and Delete Methods

The next block of code to be added wraps the matching `Create`, `Update`, and `Remove` functions on the specific `DbSet<T>` property. The `persist` parameter determines whether the repo executes `SaveChanges` immediately when the `Create/Update/Delete` repository methods are called. All of the methods are marked `virtual` to allow for downstream overriding. Add the following code to your class:

```
public virtual int Add(T entity, bool persist = true)
{
    Table.Add(entity);
    return persist ? SaveChanges() : 0;
}
public virtual int AddRange(IEnumerable<T> entities, bool persist = true)
{
    Table.AddRange(entities);
    return persist ? SaveChanges() : 0;
}
public virtual int Update(T entity, bool persist = true)
{
    Table.Update(entity);
    return persist ? SaveChanges() : 0;
}
public virtual int UpdateRange(IEnumerable<T> entities, bool persist = true)
{
    Table.UpdateRange(entities);
    return persist ? SaveChanges() : 0;
}
```

```

public virtual int Delete(T entity, bool persist = true)
{
    Table.Remove(entity);
    return persist ? SaveChanges() : 0;
}
public virtual int DeleteRange(IEnumerable<T> entities, bool persist = true)
{
    Table.RemoveRange(entities);
    return persist ? SaveChanges() : 0;
}

```

There is one more Delete method that doesn't follow the same pattern. This method uses EntityState to conduct the delete operation, which is used fairly often in ASP.NET Core operations to cut down on the network traffic. It is listed here:

```

public int Delete(
    int id, byte[] timeStamp, bool persist = true)
{
    Context.Entry(new T {Id = id, TimeStamp = timeStamp})
        .State = EntityState.Deleted;
    return SaveChanges();
}

```

This concludes the BaseRepo class, and now it's time to build the entity-specific repos.

## Entity-Specific Repo Interfaces

Each entity will have a strongly typed repository derived from BaseRepo<T> and an Interface that implements IRepo<T>. Add a new folder named Interfaces under the Repos directory in the AutoLot.Dal project. In this new directory, add six interfaces:

```

ICarRepo.cs
ICreditRiskRepo.cs
ICustomerRepo.cs
IMakelRepo.cs
IOrderRepo.cs

```

The next sections complete the interfaces.

## The Car Repository Interface

Open the ICarRepo.cs interface. Add the following using statements to the top of the file:

```

using System.Collections.Generic;
using AutoLot.Dal.Models.Entities;
using AutoLot.Dal.Repos.Base;

```

Change the interface to public and implement `IRepo<Category>` as follows:

```
public interface ICarRepo : IRepo<Car>
{
    IEnumerable<Car> GetAllBy(int makeId);
}
```

This completes the interface as all of the necessary API endpoints are covered in the base class.

## The Credit Risk Interface

Open the `ICreditRiskRepo.cs` interface. Add the following using statements to the top of the file:

```
using AutoLot.Dal.Models.Entities;
using AutoLot.Dal.Repos.Base;
```

Change the interface to public and implement `IRepo<CreditRisk>` as follows:

```
public interface ICreditRiskRepo : IRepo<CreditRisk>
{
}
```

This completes the interface as all of the necessary API endpoints are covered in the base class.

## The Customer Repository Interface

Open the `ICustomerRepo.cs` interface. Add the following using statements to the top of the file:

```
using AutoLot.Dal.Models.Entities;
using AutoLot.Dal.Repos.Base;
```

Change the interface to public and implement `IRepo<Customer>` as follows:

```
public interface ICustomerRepo : IRepo<Customer>
{
}
```

This completes the interface as all of the necessary API endpoints are covered in the base class.

## The Make Repository Interface

Open the `IMakeRepo.cs` interface. Add the following using statements to the top of the file:

```
using AutoLot.Dal.Models.Entities;
using AutoLot.Dal.Repos.Base;
```

Change the interface to public and implement `IRepo<Make>` as follows:

```
public interface IMakeRepo : IRepo<Make>
{
}
```

This completes the interface as all of the necessary API endpoints are covered in the base class.

## The Order Repository Interface

Open the `IOrderRepo.cs` interface. Add the following using statements to the top of the file:

```
using AutoLot.Dal.Models.Entities;
using AutoLot.Dal.Repos.Base
```

Change the interface to public and implement `IRepo<Order>` as follows:

```
public interface IOrderRepo : IRepo<Order>
{
}
```

This completes the interface as all of the necessary API endpoints are covered in the base class.

## Implement the Entity-Specific Repositories

The implemented repositories gain most of their functionality from the base class. This section covers the functionality added to or overridden from the base repository. In the `Repos` directory of the `AutoLot.Dal` project, add the six repo classes:

```
CarRepo.cs
CreditRiskRepo.cs
CustomerRepo.cs
MakeRepo.cs
OrderRepo.cs
```

The next sections complete the repositories.

## The Car Repository

Open the `CarRepo.cs` class and add the following using statements to the top of the file:

```
using System.Collections.Generic;
using System.Linq;
using AutoLot.Dal.EfStructures;
using AutoLot.Dal.Models.Entities;
using AutoLot.Dal.Repos.Base;
using AutoLot.Dal.Repos.Interfaces;
using Microsoft.EntityFrameworkCore;
```



Change the class to public, inherit from `BaseRepo<Car>`, and implement `ICarRepo`:

```
public class CarRepo : BaseRepo<Car>, ICarRepo
{
}
```

Each of the repositories must implement the two constructors from the `BaseRepo`:

```
public CarRepo(ApplicationDbContext context) : base(context)
{
}
internal CarRepo(DbContextOptions<ApplicationDbContext> options) : base(options)
{
}
```

Add an override for `GetAllIgnoreQueryFilters` to include the `MakeNavigation` property and order by the `PetName`:

```
public override IEnumerable<Car> GetAllIgnoreQueryFilters()
=> Table
    .Include(c => c.MakeNavigation)
    .OrderBy(o => o.PetName)
    .IgnoreQueryFilters();
```

Implement the `GetAllBy` method. This method must set the query filter on the context before executing. Include the `Make navigation` property and sort by `PetName`:

```
public IEnumerable<Car> GetAllBy(int makeId)
{
    Context.MakeId = makeId;
    return Table
        .Include(c => c.MakeNavigation)
        .OrderBy(c => c.PetName);
}
```

Add an override for `Find` to include the `MakeNavigation` property and ignore query filters:

```
public override Car Find(int? id)
=> Table
    .IgnoreQueryFilters()
    .Where(x => x.Id == id)
    .Include(m => m.MakeNavigation)
    .FirstOrDefault();
```

## The CreditRisk Repository

Open the `CreditRiskRepo.cs` class and add the following using statements to the top of the file:

```
using AutoLot.Dal.EfStructures;
using AutoLot.Dal.Models.Entities;
using AutoLot.Dal.Repos.Base;
```

```
using AutoLot.Dal.Repos.Interfaces;
using Microsoft.EntityFrameworkCore;
```

Change the class to public, inherit from `BaseRepo<CreditRisk>`, implement `ICreditRiskRepo`, and add the two required constructors:

```
public class CreditRiskRepo : BaseRepo<CreditRisk>, ICreditRiskRepo
{
    public CreditRiskRepo(ApplicationDbContext context) : base(context)
    {
    }
    internal CreditRiskRepo(
        DbContextOptions<ApplicationDbContext> options)
        : base(options)
    {
    }
}
```

## The Customer Repository

Open the `CustomerRepo.cs` class and add the following using statements to the top of the file:

```
using System.Collections.Generic;
using System.Linq;
using AutoLot.Dal.EfStructures;
using AutoLot.Dal.Models.Entities;
using AutoLot.Dal.Repos.Base;
using AutoLot.Dal.Repos.Interfaces;
using Microsoft.EntityFrameworkCore;
```

Change the class to public, inherit from `BaseRepo<Customer>`, implement `ICustomerRepo`, and add the two required constructors:

```
public class CustomerRepo : BaseRepo<Customer>, ICustomerRepo
{
    public CustomerRepo(ApplicationDbContext context)
        : base(context)
    {
    }
    internal CustomerRepo(
        DbContextOptions<ApplicationDbContext> options)
        : base(options)
    {
    }
}
```

The final step is to add the method that returns all Customer records with their Orders sorted by LastName. Add the following method to the class:

```
public override IEnumerable<Customer> GetAll()
    => Table
        .Include(c => c.Orders)
        .OrderBy(o => o.PersonalInformation.LastName);
```

## The Make Repository

Open the MakeRepo.cs class and add the following using statements to the top of the file:

```
using System.Collections.Generic;
using System.Linq;
using AutoLot.Dal.EfStructures;
using AutoLot.Dal.Models.Entities;
using AutoLot.Dal.Repos.Base;
using AutoLot.Dal.Repos.Interfaces;
using Microsoft.EntityFrameworkCore;
```

Change the class to public, inherit from BaseRepo<Make>, implement IMakeRepo, and add the two required constructors:

```
public class MakeRepo : BaseRepo<Make>, IMakeRepo
{
    public MakeRepo(ApplicationDbContext context)
        : base(context)
    {
    }

    internal MakeRepo(
        DbContextOptions<ApplicationDbContext> options)
        : base(options)
    {
    }
}
```

The final method is to override the GetAll method to sort the Makes by Name:

```
public override IEnumerable<Make> GetAll()
    => Table.OrderBy(m => m.Name);
```

## The Order Repository

Open the `OrderRepo.cs` class and add the following using statements to the top of the file:

```
using AutoLot.Dal.EfStructures;
using AutoLot.Dal.Models.Entities;
using AutoLot.Dal.Repos.Base;
using AutoLot.Dal.Repos.Interfaces;
using Microsoft.EntityFrameworkCore;
```

Change the class to public, inherit from `BaseRepo<Order>`, and implement `IOrderRepo`:

```
public class OrderRepo : BaseRepo<Order>, IOrderRepo
{
    public OrderRepo(ApplicationDbContext context)
        : base(context)
    {
    }

    internal OrderRepo(
        DbContextOptions<ApplicationDbContext> options)
        : base(options)
    {
    }
}
```

This completes the repositories and therefore the entire data access library that you will use to explore Windows Presentation Foundation as well as ASP.NET Core.

## Summary

Over the past two chapters, you went on a tour of data manipulation using Entity Framework Core. Entity Framework Core (and other ORMS) provides value in getting projects to market faster, but it is still vital to understand the inner workings on ADO.NET. To be sure, you have only scratched the surface of all the topics found within the ADO.NET technology set.

This chapter started by setting up a test framework for the data access library using xUnit. Then, you explored the different mechanisms to query data as well as Create, Update, and Delete data.

This chapter wrapped up the creation of the entity-specific repositories that you will use through the remaining chapters of this book.

**PART VII**



# **Windows Client Development**



# Introducing Windows Presentation Foundation and XAML

When version 1.0 of the .NET platform was released, programmers who needed to build graphical desktop applications made use of two APIs named Windows Forms and GDI+, packaged up primarily in the `System.Windows.Forms.dll` and `System.Drawing.dll` assemblies. While Windows Forms and GDI+ are still viable APIs for building traditional desktop GUIs, Microsoft shipped an alternative GUI desktop API named Windows Presentation Foundation (WPF) beginning with the release of .NET 3.0.

This initial WPF chapter begins by examining the motivation behind this new GUI framework, which will help you see the differences between the Windows Forms/GDI+ and WPF programming models. Next, you will come to know the role of several important classes, including `Application`, `Window`, `ContentControl`, `Control`, `UIElement`, and `FrameworkElement`.

This chapter will then introduce you to an XML-based grammar named *Extensible Application Markup Language* (XAML; pronounced “zammel”). Here, you will learn the syntax and semantics of XAML (including attached property syntax and the role of type converters and markup extensions).

This chapter wraps up by investigating the integrated WPF designers of Visual Studio by building your first WPF application. During this time, you will learn to intercept keyboard and mouse activities, define application-wide data, and perform other common WPF tasks.

---

■ **Note** This version of the book uses the .NET Core version of Windows Presentation Foundation that was released to Long-Term Support with version 3.1. WPF is still only available on Windows machines.

---

## The Motivation Behind WPF

Over the years, Microsoft has created numerous graphical user interface toolkits (raw C/C++/Windows API development, VB6, MFC, etc.) to build desktop executables. Each of these APIs provided a codebase to represent the basic aspects of a GUI application, including main windows, dialog boxes, controls, menu systems, and other basic necessities. With the initial release of the .NET platform, the Windows Forms API quickly became the preferred model for UI development, given its simple yet very powerful object model.

While many full-featured desktop applications have been successfully created using Windows Forms, the fact of the matter is that this programming model is rather *asymmetrical*. Simply put, `System.Windows.Forms.dll` and `System.Drawing.dll` do not provide direct support for many additional technologies required to build a feature-rich desktop application. To illustrate this point, consider the ad hoc nature of GUI desktop development before the release of WPF (see Table 24-1).

**Table 24-1.** *Pre-WPF Solutions to Desired Functionalities*

Desired Functionality	Technology
Building windows with controls	Windows Forms
2D graphics support	GDI+ (System.Drawing.dll)
3D graphics support	DirectX APIs
Support for streaming video	Windows Media Player APIs
Support for flow-style documents	Programmatic manipulation of PDF files

As you can see, a Windows Forms developer must pull in types from a number of unrelated APIs and object models. While it is true that making use of these diverse APIs might look similar syntactically (it is just C# code, after all), you might also agree that each technology requires a radically different mind-set. For example, the skills required to create a 3D rendered animation using DirectX are completely different from those used to bind data to a grid. To be sure, it is difficult for a Windows Forms programmer to master the diverse nature of each API.

## Unifying Diverse APIs

WPF was purposely created to merge these previously unrelated programming tasks into a single unified object model. Thus, if you need to author a 3D animation, you have no need to manually program against the DirectX API (although you could) because 3D functionality is baked directly into WPF. To see how well things have cleaned up, consider Table 24-2, which illustrates the desktop development model ushered in as of .NET 3.0.

**Table 24-2.** *.NET 3.0 Solutions to Desired Functionalities*

Desired Functionality	Technology
Building forms with controls	WPF
2D graphics support	WPF
3D graphics support	WPF
Support for streaming video	WPF
Support for flow-style documents	WPF

The obvious benefit here is that .NET programmers now have a single, *symmetrical* API for all common GUI desktop programming needs. After you become comfortable with the functionality of the key WPF assemblies and the grammar of XAML, you'll be amazed how quickly you can create sophisticated UIs.

## Providing a Separation of Concerns via XAML

Perhaps one of the most compelling benefits is that WPF provides a way to cleanly separate the look and feel of a GUI application from the programming logic that drives it. Using XAML, it is possible to define the UI of an application via XML *markup*. This markup (ideally generated using tools such as Microsoft Visual Studio or Blend for Visual Studio) can then be connected to a related C# code file to provide the guts of the program's functionality.

---

■ **Note** XAML is not limited to WPF applications. Any application can use XAML to describe a tree of .NET objects, even if they have nothing to do with a visible user interface.

---

As you dig into WPF, you might be surprised how much flexibility this “desktop markup” provides. XAML allows you to define not only simple UI elements (buttons, grids, list boxes, etc.) in markup but also interactive 2D and 3D graphics, animations, data-binding logic, and multimedia functionality (such as video playback).

XAML also makes it easy to customize how a control should render out its visual appearance. For example, defining a circular button control that animates your company logo requires just a few lines of markup. As shown in Chapter 27, WPF controls can be modified through styles and templates, which allow you to change the overall look and feel of an application with minimum fuss and bother. Unlike Windows Forms development, the only compelling reason to build a custom WPF control from the ground up is if you need to change the *behaviors* of a control (e.g., add custom methods, properties, or events; subclass an existing control to override virtual members). If you simply need to change the *look and feel* of a control (again, such as a circular animated button), you can do so entirely through markup.

## Providing an Optimized Rendering Model

GUI toolkits such as Windows Forms, MFC, or VB6 performed all graphical rendering requests (including the rendering of UI elements such as buttons and list boxes) using a low-level, C-based API (GDI), which has been part of the Windows OS for years. GDI provides adequate performance for typical business applications or simple graphical programs; however, if a UI application needed to tap into high-performance graphics, DirectX was required.

The WPF programming model is quite different, in that GDI is *not* used when rendering graphical data. All rendering operations (e.g., 2D graphics, 3D graphics, animations, control rendering, etc.) now make use of the DirectX API. The first obvious benefit is that your WPF applications will automatically take advantage of hardware and software optimizations. As well, WPF applications can tap into very rich graphical services (blur effects, anti-aliasing, transparency, etc.) without the complexity of programming directly against the DirectX API.

---

■ **Note** Although WPF does push all rendering requests to the DirectX layer, I don’t want to suggest that a WPF application will perform as fast as building an application using unmanaged C++ and DirectX directly. Although significant performance advances have been made in WPF with every release, if you are intending to build a desktop application that requires the fastest possible execution speed (such as a 3D video game), unmanaged C++ and DirectX are still the best approach.

---

## Simplifying Complex UI Programming

To recap the story thus far, Windows Presentation Foundation (WPF) is an API for building desktop applications that integrates various desktop APIs into a single object model and provides a clean separation of concerns via XAML. In addition to these major points, WPF applications also benefit from a simple way to integrate services into your programs, which historically were quite complex to account for. The following is a quick rundown of the core WPF features:

- A number of layout managers (far more than Windows Forms) to provide extremely flexible control over the placement and repositioning of content.
- Use of an enhanced data-binding engine to bind content to UI elements in a variety of ways.



- A built-in style engine, which allows you to define “themes” for a WPF application.
- Use of vector graphics, which allows content to be automatically resized to fit the size and resolution of the screen hosting the application.
- Support for 2D and 3D graphics, animations, and video and audio playback.
- A rich typography API, such as support for XML Paper Specification (XPS) documents, fixed documents (WYSIWYG), flow documents, and document annotations (e.g., a Sticky Notes API).
- Support for interoperating with legacy GUI models (e.g., Windows Forms, ActiveX, and Win32 HWNDs). For example, you can incorporate custom Windows Forms controls into a WPF application and vice versa.

Now that you have some idea of what WPF brings to the table, let’s look at the various types of applications that can be created using this API. Many of these features will be explored in detail in the chapters to come.

## Investigating the WPF Assemblies

WPF is ultimately little more than a collection of types bundled within .NET Core assemblies. Table 24-3 describes the key assemblies used to build WPF applications, each of which must be referenced when creating a new project. As you would hope, Visual Studio WPF projects reference these required assemblies automatically.

**Table 24-3.** Core WPF Assemblies

Assembly	Meaning in Life
PresentationCore	This assembly defines numerous namespaces that constitute the foundation of the WPF GUI layer. For example, this assembly contains support for the WPF Ink API, animation primitives, and numerous graphical rendering types.
PresentationFramework	This assembly contains a majority of the WPF controls, the Application and Window classes, support for interactive 2D graphics, and numerous types used in data binding.
System.Xaml.dll	This assembly provides namespaces that allow you to program against a XAML document at runtime. By and large, this library is useful only if you are authoring WPF support tools or need absolute control over XAML at runtime.
WindowsBase.dll	This assembly defines types that constitute the infrastructure of the WPF API, including those representing WPF threading types, security types, various type converters, and support for <i>dependency properties</i> and <i>routed events</i> (described in Chapter 27).

Collectively, these four assemblies define a number of new namespaces and hundreds of new .NET Core classes, interfaces, structures, enumerations, and delegates. Table 24-4 describes the role of some (but certainly not all) of the important namespaces.

**Table 24-4.** *Core WPF Namespaces*

Namespace	Meaning in Life
System.Windows	This is the root namespace of WPF. Here, you will find core classes (such as <code>Application</code> and <code>Window</code> ) that are required by any WPF desktop project.
System.Windows.Controls	This contains all of the expected WPF widgets, including types to build menu systems, tooltips, and numerous layout managers.
System.Windows.Data	This contains types to work with the WPF data-binding engine, as well as support for data-binding templates.
System.Windows.Documents	This contains types to work with the documents API, which allows you to integrate PDF-style functionality into your WPF applications, via the XML Paper Specification (XPS) protocol.
System.Windows.Ink	This provides support for the Ink API, which allows you to capture input from a stylus or mouse, respond to input gestures, and so forth. This is useful for Tablet PC programming; however, any WPF can make use of this API.
System.Windows.Markup	This namespace defines a number of types that allow XAML markup (and the equivalent binary format, BAML) to be parsed and processed programmatically.
System.Windows.Media	This is the root namespace to several media-centric namespaces. Within these namespaces you will find types to work with animations, 3D rendering, text rendering, and other multimedia primitives.
System.Windows.Navigation	This namespace provides types to account for the navigation logic employed by XAML browser applications (XBAPs) as well as standard desktop applications that require a navigational page model.
System.Windows.Shapes	This defines classes that allow you to render interactive 2D graphics that automatically respond to mouse input.

To begin your journey into the WPF programming model, you'll examine two members of the `System.Windows` namespace that are commonplace to any traditional desktop development effort: `Application` and `Window`.

---

■ **Note** If you have created desktop UIs using the Windows Forms API, be aware that the `System.Windows.Forms.*` and `System.Drawing.*` assemblies are not related to WPF. These libraries represent the original .NET GUI toolkit, Windows Forms/GDI+.

---

## The Role of the Application Class

The `System.Windows.Application` class represents a global instance of a running WPF application. This class supplies a `Run()` method (to start the application), a series of events that you are able to handle in order to interact with the application's lifetime (such as `Startup` and `Exit`). Table 24-5 details some of the key properties.

**Table 24-5.** *Key Properties of the Application Type*

Property	Meaning in Life
Current	This static property allows you to gain access to the running <code>Application</code> object from anywhere in your code. This can be helpful when a window or dialog box needs to gain access to the <code>Application</code> object that created it, typically to access application-wide variables and functionality.
MainWindow	This property allows you to programmatically get or set the main window of the application.
Properties	This property allows you to establish and obtain data that is accessible throughout all aspects of a WPF application (windows, dialog boxes, etc.).
StartupUri	This property gets or sets a URI that specifies a window or page to open automatically when the application starts.
Windows	This property returns a <code>WindowCollection</code> type, which provides access to each window created from the thread that created the <code>Application</code> object. This can be helpful when you want to iterate over each open window of an application and alter its state (such as minimizing all windows).

## Constructing an Application Class

Any WPF application will need to define a class that extends `Application`. Within this class, you will define your program's entry point (the `Main()` method), which creates an instance of this subclass and typically handles the `Startup` and `Exit` events (as necessary). Here is an example:

```
// Define the global application object
// for this WPF program.
class MyApp : Application
{
    [STAThread]
    static void Main(string[] args)
    {
        // Create the application object.
        MyApp app = new MyApp();

        // Register the Startup/Exit events.
        app.Startup += (s, e) => { /* Start up the app */ };
        app.Exit += (s, e) => { /* Exit the app */ };
    }
}
```

Within the `Startup` handler, you will most often process any incoming command-line arguments and launch the main window of the program. The `Exit` handler, as you would expect, is where you can author any necessary shutdown logic for the program (e.g., save user preferences, write to the Windows registry).

**■ Note** The `Main()` method of a WPF application must be attributed with the `[STAThread]` attribute, which ensures any legacy COM objects used by your application are thread-safe. If you do not annotate `Main()` in this way, you will encounter a runtime exception.

## Enumerating the Windows Collection

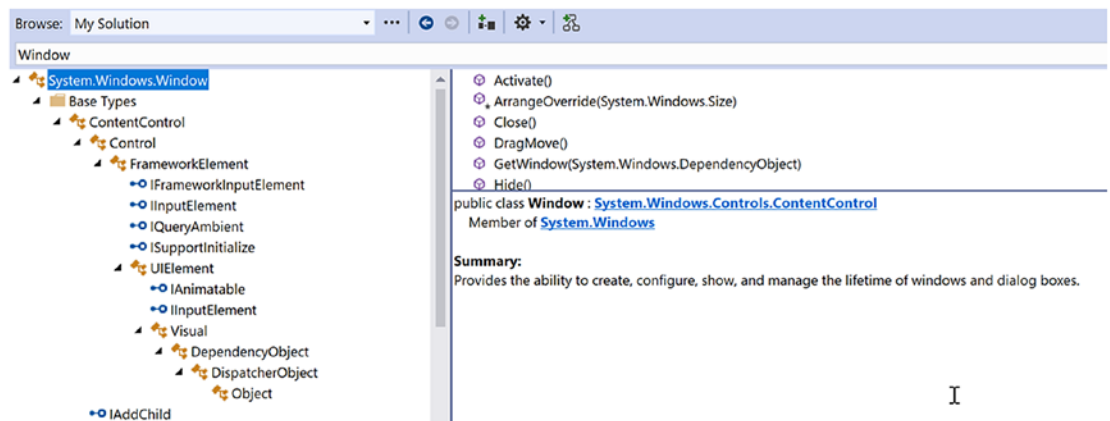
Another interesting property exposed by `Application` is `Windows`, which provides access to a collection representing each window loaded into memory for the current WPF application. As you create new `Window` objects, they are automatically added into the `Application.Windows` collection. Here is an example method that will minimize each window of the application (perhaps in response to a given keyboard gesture or menu option triggered by the end user):

```
static void MinimizeAllWindows()
{
    foreach (Window wnd in Application.Current.Windows)
    {
        wnd.WindowState = WindowState.Minimized;
    }
}
```

You'll build some WPF applications shortly, but until then, let's check out the core functionality of the `Window` type and learn about a number of important WPF base classes in the process.

## The Role of the Window Class

The `System.Windows.Window` class (located in the `PresentationFramework.dll` assembly) represents a single window owned by the `Application`-derived class, including any dialog boxes displayed by the main window. Not surprisingly, `Window` has a series of parent classes, each of which brings more functionality to the table. Consider Figure 24-1, which shows the inheritance chain (and implemented interfaces) for `System.Windows.Window` as seen through the Visual Studio Object Browser.



**Figure 24-1.** The hierarchy of the `Window` class

You'll come to understand the functionality provided by many of these base classes as you progress through this chapter and the chapters to come. However, to whet your appetite, the following sections present a breakdown of the functionality provided by each base class (consult the .NET Framework 4.7 SDK documentation for full details).

## The Role of System.Windows.Controls.ContentControl

The direct parent of `Window` is `ContentControl`, which is quite possibly the most enticing of all WPF classes. This base class provides derived types with the ability to host a single piece of *content*, which, simply put, refers to the visual data placed within the interior of the control's surface area via the `Content` property. The WPF content model makes it very simple to customize the basic look and feel of a content control.

For example, when you think of a typical “button” control, you tend to assume that the content is a simple string literal (OK, Cancel, Abort, etc.). If you are using XAML to describe a WPF control and the value you want to assign to the `Content` property can be captured as a simple string, you may set the `Content` property within the element's opening definition as so (don't fret over the exact markup at this point):

```
<!-- Setting the Content value in the opening element -->
<Button Height="80" Width="100" Content="OK"/>
```

---

■ **Note** The `Content` property can also be set in C# code, which allows you to change the interior of a control at runtime.

---

However, content can be almost anything. For example, let's say you want to have a “button” that has something more interesting than a simple string, perhaps a custom graphic and a blurb of text. In other UI frameworks such as Windows Forms, you would be required to build a custom control, which could entail quite a bit of code and a whole new class to maintain. With the WPF content model, there is no need to do so.

When you want to assign the `Content` property to a value that cannot be captured as a simple array of characters, you can't assign it using an attribute in the control's opening definition. Rather, you must define the content data *implicitly*, within the element's scope. For example, the following `<Button>` contains a `<StackPanel>` as content, which itself contains some unique data (an `<Ellipse>` and `<Label>`, to be exact):

```
<!-- Implicitly setting the Content property with complex data -->
<Button Height="80" Width="100">
  <StackPanel>
    <Ellipse Fill="Red" Width="25" Height="25"/>
    <Label Content="OK!"/>
  </StackPanel>
</Button>
```

You can also make use of XAML's *property-element syntax* to set complex content. Consider the following functionally equivalent `<Button>` definition, which sets the `Content` property explicitly using property-element syntax (again, you'll find more information on XAML later in this chapter, so don't sweat the details just yet):

```
<!-- Setting the Content property using property-element syntax -->
<Button Height="80" Width="100">
  <Button.Content>
    <StackPanel>
      <Ellipse Fill="Red" Width="25" Height="25"/>
      <Label Content="OK!"/>
    </StackPanel>
  </Button.Content>
</Button>
```

Do be aware that not every WPF element derives from `ContentControl` and, therefore, not all controls support this unique content model (however, most do). As well, some WPF controls add a few refinements to the basic content model you have just examined. Chapter 25 will examine the role of WPF content in much more detail.

## The Role of `System.Windows.Controls.Control`

Unlike `ContentControl`, all WPF controls share the `Control` base class as a common parent. This base class provides numerous core members that account for basic UI functionality. For example, `Control` defines properties to establish the control's size, opacity, tab order logic, the display cursor, background color, and so forth. Furthermore, this parent class provides support for *templating services*. As explained in Chapter 27, WPF controls can completely change the way they render their appearance using templates and styles. Table 24-6 documents some key members of the `Control` type, grouped by related functionality.

**Table 24-6.** *Key Members of the Control Type*

Members	Meaning in Life
Background, Foreground, BorderBrush, BorderThickness, Padding, HorizontalContentAlignment, VerticalContentAlignment	These properties allow you to set basic settings regarding how the control will be rendered and positioned.
FontFamily, FontSize, FontStretch, FontWeight	These properties control various font-centric settings.
IsTabStop, TabIndex	These properties are used to establish tab order among controls on a window.
MouseDoubleClick, PreviewMouseDoubleClick	These events handle the act of double-clicking a widget.
Template	This property allows you to get and set the control's template, which can be used to change the rendering output of the widget.

## The Role of `System.Windows.FrameworkElement`

This base class provides a number of members that are used throughout the WPF framework, such as support for storyboarding (used within animations) and support for data binding, as well as the ability to name a member (via the `Name` property), obtain any resources defined by the derived type, and establish the overall dimensions of the derived type. Table 24-7 hits the highlights.

**Table 24-7.** *Key Members of the FrameworkElement Type*

Members	Meaning in Life
ActualHeight, ActualWidth, MaxHeight, MaxWidth, MinHeight, MinWidth, Height, Width	These properties control the size of the derived type.
ContextMenu	Gets or sets the pop-up menu associated with the derived type.
Cursor	Gets or sets the mouse cursor associated with the derived type.
HorizontalAlignment, VerticalAlignment	Gets or sets how the type is positioned within a container (such as a panel or list box).
Name	Allows to you assign a name to the type in order to access its functionality in a code file.
Resources	Provides access to any resources defined by the type (see Chapter 29 for an examination of the WPF resource system).
ToolTip	Gets or sets the tooltip associated with the derived type.

## The Role of System.Windows.UIElement

Of all the types within a Window’s inheritance chain, the UIElement base class provides the greatest amount of functionality. The key task of UIElement is to provide the derived type with numerous events to allow the derived type to receive focus and process input requests. For example, this class provides numerous events to account for drag-and-drop operations, mouse movement, keyboard input, stylus input, and touch.

Chapter 25 digs into the WPF event model in detail; however, many of the core events will look quite familiar (MouseMove, KeyUp, MouseDown, MouseEnter, MouseLeave, etc.). In addition to defining dozens of events, this parent class provides a number of properties to account for control focus, enabled state, visibility, and hit-testing logic, as shown in Table 24-8.

**Table 24-8.** *Key Members of the UIElement Type*

Members	Meaning in Life
Focusable, IsFocused	These properties allow you to set focus on a given derived type.
IsEnabled	This property allows you to control whether a given derived type is enabled or disabled.
IsMouseDirectlyOver, IsMouseOver	These properties provide a simple way to perform hit-testing logic.
IsVisible, Visibility	These properties allow you to work with the visibility setting of a derived type.
RenderTransform	This property allows you to establish a transformation that will be used to render the derived type.

## The Role of System.Windows.Media.Visual

The `Visual` class type provides core rendering support in WPF, which includes hit-testing of graphical data, coordinate transformation, and bounding box calculations. In fact, the `Visual` class interacts with the underlying DirectX subsystem to actually draw data on the screen. As you will examine in Chapter 26, WPF provides three possible manners in which you can render graphical data, each of which differs in terms of functionality and performance. Use of the `Visual` type (and its children, such as `DrawingVisual`) provides the most lightweight way to render graphical data, but it also entails the greatest amount of manual code to account for all the required services. Again, more details to come in Chapter 28.

## The Role of System.Windows.DependencyObject

WPF supports a particular flavor of .NET properties termed *dependency properties*. Simply put, this style of property provides extra code to allow the property to respond to several WPF technologies such as styles, data binding, animations, and so forth. For a type to support this new property scheme, it will need to derive from the `DependencyObject` base class. While dependency properties are a key aspect of WPF development, much of the time their details are hidden from view. Chapter 25 dives further into the details of dependency properties.

## The Role of System.Windows.Threading.DispatcherObject

The final base class of the `Window` type (beyond `System.Object`, which I assume needs no further explanation at this point in the book) is `DispatcherObject`. This type provides one property of interest, `Dispatcher`, which returns the associated `System.Windows.Threading.Dispatcher` object. The `Dispatcher` class is the entry point to the event queue of the WPF application, and it provides the basic constructs for dealing with concurrency and threading.

## Understanding the Syntax of WPF XAML

Production-level WPF applications will typically make use of dedicated tools to generate the necessary XAML. As helpful as these tools are, it is a good idea to have an understanding of the overall structure of XAML markup. To help in your learning process, allow me to introduce a popular (and free) tool that allows you to easily experiment with XAML.

## Introducing Kaxaml

When you are first learning the grammar of XAML, it can be helpful to use a free tool named *Kaxaml*. You can obtain this popular XAML editor/parser from <https://github.com/punker76/kaxaml>.

---

**Note** For many editions of this book, I've pointed users to [www.kaxaml.com](http://www.kaxaml.com), but unfortunately, that site has been retired. Jan Karger (<https://github.com/punker76>) has forked the old code and has done some work on improving it. You can find his version of the tool on GitHub <https://github.com/punker76/kaxaml>. Much respect and thanks to the original developers of Kaxaml and to Jan for keeping it alive; it's a great tool and has helped countless developers learn XAML.

---



Kaxaml is helpful, in that it has no clue about C# source code, event handlers, or implementation logic. It is a much more straightforward way to test XAML snippets than using a full-blown Visual Studio WPF project template. As well, Kaxaml has a number of integrated tools, such as a color chooser, a XAML snippet manager, and even an “XAML scrubber” option that will format your XAML based on your settings. When you first open Kaxaml, you will find simple markup for a <Page> control, as follows:

```
<Page
  xmlns="http://schemas.microsoft.com/winfx/2006/xaml/presentation"
  xmlns:x="http://schemas.microsoft.com/winfx/2006/xaml">
  <Grid>

  </Grid>
</Page>
```

Like a Window, a Page contains various layout managers and controls. However, unlike a Window, Page objects cannot run as stand-alone entities. Rather, they must be placed inside a suitable host such as a NavigationWindow or a Frame. The good news is that you can type identical markup within a <Page> or <Window> scope.

---

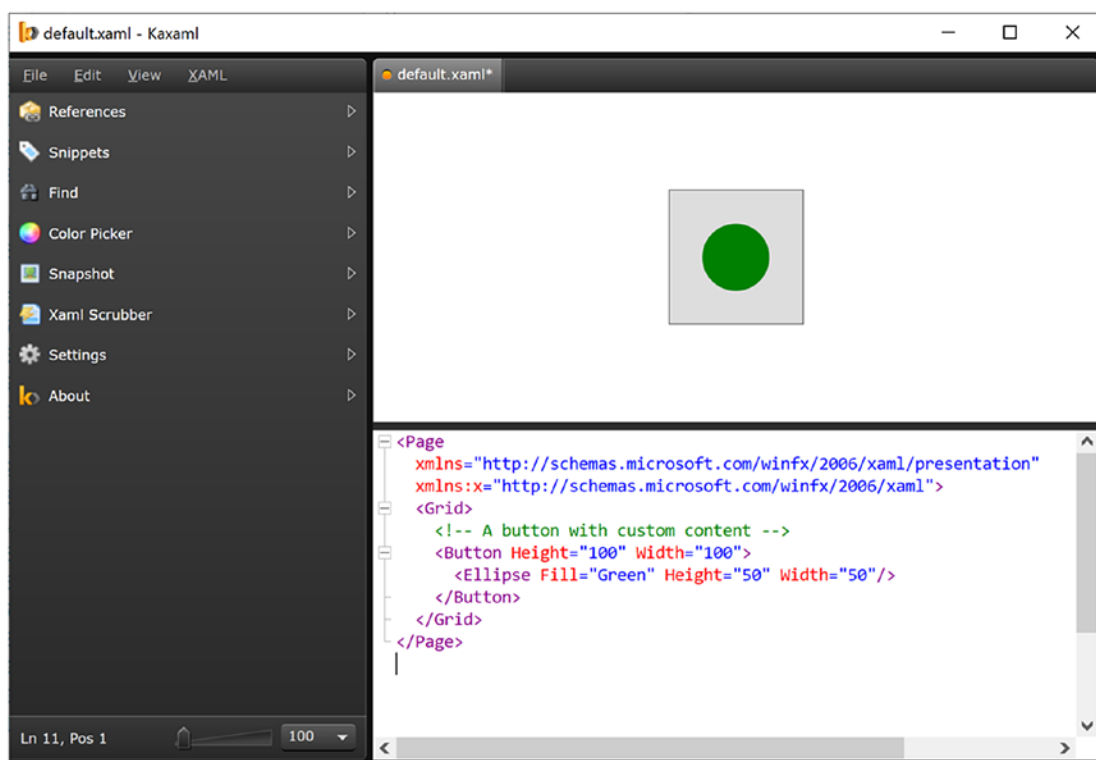
■ **Note** If you change the <Page> and </Page> elements in the Kaxaml markup window to <Window> and </Window>, you can press the F5 key to load a new window onto the screen.

---

As an initial test, enter the following markup into the XAML pane at the bottom of the tool:

```
<Page
  xmlns="http://schemas.microsoft.com/winfx/2006/xaml/presentation"
  xmlns:x="http://schemas.microsoft.com/winfx/2006/xaml">
  <Grid>
    <!-- A button with custom content -->
    <Button Height="100" Width="100">
      <Ellipse Fill="Green" Height="50" Width="50"/>
    </Button>
  </Grid>
</Page>
```

You should now see your page render at the upper part of the Kaxaml editor (see Figure 24-2).



**Figure 24-2.** Kaxaml is a helpful (and free) tool used to learn the grammar of XAML

As you work with Kaxaml, remember that this tool does not allow you to author any markup that entails code compilation (however, using `x:Class` is allowed). This includes defining an `x:Class` attribute (for specifying a code file), entering event handler names in markup, or using any XAML keywords that also entail code compilation (such as `FieldModifier` or `ClassModifier`). Any attempt to do so will result in a markup error.

## XAML XML Namespaces and XAML “Keywords”

The root element of a WPF XAML document (such as a `<Window>`, `<Page>`, `<UserControl>`, or `<Application>` definition) will almost always make reference to the following two predefined XML namespaces:

```

<Page
  xmlns="http://schemas.microsoft.com/winfx/2006/xaml/presentation"
  xmlns:x="http://schemas.microsoft.com/winfx/2006/xaml">
  <Grid>

  </Grid>
</Page>
  
```

The first XML namespace, <http://schemas.microsoft.com/winfx/2006/xaml/presentation>, maps a slew of WPF .NET namespaces for use by the current \*.xaml file (System.Windows, System.Windows.Controls, System.Windows.Data, System.Windows.Ink, System.Windows.Media, System.Windows.Navigation, etc.).

This one-to-many mapping is actually hard-coded within the WPF assemblies (WindowsBase.dll, PresentationCore.dll, and PresentationFramework.dll) using the assembly-level [XmlnsDefinition] attribute. For example, if you open the Visual Studio Object Browser and select the PresentationCore.dll assembly, you will see listings such as the following, which essentially imports System.Windows:

```
[assembly: XmlnsDefinition("http://schemas.microsoft.com/winfx/2006/xaml/presentation",
    "System.Windows")]
```

The second XML namespace, <http://schemas.microsoft.com/winfx/2006/xaml>, is used to include XAML-specific “keywords” (for lack of a better term) as well as the inclusion of the System.Windows.Markup namespace, as follows:

```
[assembly: XmlnsDefinition("http://schemas.microsoft.com/winfx/2006/xaml",
    "System.Windows.Markup")]
```

One rule of any well-formed XML document (remember, XAML is an XML-based grammar) is that the opening root element designates one XML namespace as the *primary namespace*, which typically is the namespace that contains the most commonly used items. If a root element requires the inclusion of additional secondary namespaces (as seen here), they must be defined using a unique tag prefix (to resolve any possible name clashes). As a convention, the prefix is simply x; however, this can be any unique token you require, such as XamlSpecificStuff.

```
<Page
  xmlns="http://schemas.microsoft.com/winfx/2006/xaml/presentation"
  xmlns:XamlSpecificStuff="http://schemas.microsoft.com/winfx/2006/xaml">
  <Grid>
    <!-- A button with custom content -->
    <Button XamlSpecificStuff:Name="button1" Height="100" Width="100">
      <Ellipse Fill="Green" Height="50" Width="50"/>
    </Button>
  </Grid>
</Page>
```

The obvious downside of defining wordy XML namespace prefixes is you are required to type XamlSpecificStuff each time your XAML file needs to refer to one of the items defined within this XAML-centric XML namespace. Given that XamlSpecificStuff requires many additional keystrokes, just stick with x.

In any case, beyond the x:Name, x:Class, and x:Code keywords, the <http://schemas.microsoft.com/winfx/2006/xaml> XML namespace also provides access to additional XAML keywords, the most common of which are shown in Table 24-9.

**Table 24-9.** XAML Keywords

XAML Keyword	Meaning in Life
x:Array	Represents a .NET array type in XAML.
x:ClassModifier	Allows you to define the visibility of the C# class (internal or public) denoted by the Class keyword.
x:FieldModifier	Allows you to define the visibility of a type member (internal, public, private, or protected) for any named subelement of the root (e.g., a <Button> within a <Window> element). A <i>named element</i> is defined using the Name XAML keyword.
x:Key	Allows you to establish a key value for a XAML item that will be placed into a dictionary element.
x:Name	Allows you to specify the generated C# name of a given XAML element.
x:Null	Represents a null reference.
x:Static	Allows you to make reference to a static member of a type.
x:Type	The XAML equivalent of the C# typeof operator (it will yield a System.Type based on the supplied name).
x:TypeArguments	Allows you to establish an element as a generic type with a specific type parameter (e.g., List<int> vs. List<bool>).

In addition to these two necessary XML namespace declarations, it is possible, and sometimes necessary, to define additional tag prefixes in the opening element of a XAML document. You will typically do so whenever you need to describe in XAML a .NET Core class defined in an external assembly.

For example, say you have built a few custom WPF controls and packaged them in a library named `MyControls.dll`. Now, if you want to create a new Window that uses these controls, you can establish a custom XML namespace that maps to your library using the `clr-namespace` and `assembly` tokens. Here is some example markup that creates a tag prefix named `myCtrls`, which can be used to access controls in your library:

```
<Window x:Class="WpfApplication1.MainWindow"
  xmlns="http://schemas.microsoft.com/winfx/2006/xaml/presentation"
  xmlns:x="http://schemas.microsoft.com/winfx/2006/xaml"
  xmlns:myCtrls="clr-namespace:MyControls;assembly=MyControls"
  Title="MainWindow" Height="350" Width="525">
  <Grid>
    <myCtrls:MyCustomControl />
  </Grid>
</Window>
```

The `clr-namespace` token is assigned to the name of the .NET Core namespace in the assembly, while the `assembly` token is set to the friendly name of the external \*.dll assembly. You can use this syntax for any external .NET Core library you would like to manipulate in markup. While there is no need to do so at the current time, future chapters will require you to define custom XML namespace declarations to describe types in markup.

---

■ **Note** If you need to define a class in markup that is part of the current assembly but in a different .NET Core namespace, your `xmlns` tag prefix is defined without the `assembly=` attribute, like so:

```
xmlns:myCtrls="clr-namespace:SomeNamespaceInMyApp".
```

---

## Controlling Class and Member Variable Visibility

You will see many of these keywords in action where required in the chapters to come; however, by way of a simple example, consider the following XAML <Window> definition that makes use of the `ClassModifier` and `FieldModifier` keywords, as well as `x:Name` and `x:Class` (remember that `kaxaml.exe` will not allow you to make use of any XAML keyword that entails code compilation, such as `x:Code`, `x:FieldModifier`, or `x:ClassModifier`):

```
<!-- This class will now be declared internal in the *.g.cs file -->
<Window x:Class="MyWPFApp.MainWindow" x:ClassModifier="internal"
  xmlns="http://schemas.microsoft.com/winfx/2006/xaml/presentation"
  xmlns:x="http://schemas.microsoft.com/winfx/2006/xaml">

  <!-- This button will be public in the *.g.cs file -->
  <Button x:Name="myButton" x:FieldModifier="public" Content="OK"/>
</Window>
```

By default, all C#/XAML type definitions are public, while members default to internal. However, based on your XAML definition, the resulting autogenerated file contains an internal class type with a public `Button` variable.

```
internal partial class MainWindow :
System.Windows.Window,
    System.Windows.Markup.IComponentConnector
{
    public System.Windows.Controls.Button myButton;
    ...
}
```

## XAML Elements, XAML Attributes, and Type Converters

After you have established your root element and any required XML namespaces, your next task is to populate the root with a *child element*. In a real-world WPF application, the child will be a layout manager (such as a `Grid` or `StackPanel`) that contains, in turn, any number of additional UI elements that describe the user interface. The next chapter examines these layout managers in detail, so for now just assume that your <Window> type will contain a single `Button` element.

As you have already seen over the course of this chapter, XAML *elements* map to a class or structure type within a given .NET Core namespace, while the *attributes* within the opening element tag map to properties or events of the type. To illustrate, enter the following <Button> definition into `Kaxaml`:

```
<Page
  xmlns="http://schemas.microsoft.com/winfx/2006/xaml/presentation"
  xmlns:x="http://schemas.microsoft.com/winfx/2006/xaml">
  <Grid>
    <!-- Configure the look and feel of a Button -->
    <Button Height="50" Width="100" Content="OK!"
      FontSize="20" Background="Green" Foreground="Yellow"/>
  </Grid>
</Page>
```

Notice that the values assigned to each property have been captured as a simple text value. This may seem like a complete mismatch of data types because if you were to make this `Button` in C# code, you would *not* assign string objects to these properties but would make use of specific data types. For example, here is the same button authored in code:

```
public void MakeAButton()
{
    Button myBtn = new Button();
    myBtn.Height = 50;
    myBtn.Width = 100;
    myBtn.FontSize = 20;
    myBtn.Content = "OK!";
    myBtn.Background = new SolidColorBrush(Colors.Green);
    myBtn.Foreground = new SolidColorBrush(Colors.Yellow);
}
```

As it turns out, WPF ships with a number of *type converter* classes, which will be used to transform simple text values into the correct underlying data type. This process happens transparently (and automatically).

While this is all well and good, there will be many times when you need to assign a much more complex value to a XAML attribute, which cannot be captured as a simple string. For example, let's say you want to build a custom brush to set the `Background` property of the `Button`. If you are building the brush in code, it is quite straightforward, as shown here:

```
public void MakeAButton()
{
    ...
    // A fancy brush for the background.
    LinearGradientBrush fancyBrush =
        new LinearGradientBrush(Colors.DarkGreen, Colors.LightGreen, 45);
    myBtn.Background = fancyBrush;
    myBtn.Foreground = new SolidColorBrush(Colors.Yellow);
}
```

How, can you represent your complex brush as a string? Well, you can't! Thankfully, XAML provides a special syntax that can be used whenever you need to assign a property value to a complex object, termed *property-element syntax*.

## Understanding XAML Property-Element Syntax

*Property-element syntax* allows you to assign complex objects to a property. Here is a XAML description for a `Button` that makes use of a `LinearGradientBrush` to set its `Background` property:

```
<Button Height="50" Width="100" Content="OK!"
        FontSize="20" Foreground="Yellow">
  <Button.Background>
    <LinearGradientBrush>
      <GradientStop Color="DarkGreen" Offset="0"/>
      <GradientStop Color="LightGreen" Offset="1"/>
    </LinearGradientBrush>
  </Button.Background>
</Button>
```

Notice that within the scope of the `<Button>` and `</Button>` tags, you have defined a subscope named `<Button.Background>`. Within this scope, you have defined a custom `<LinearGradientBrush>`. (Don't worry about the exact code for the brush; you'll learn about WPF graphics in Chapter 28).

Generally speaking, any property can be set using property-element syntax, which always breaks down to the following pattern:

```
<DefiningClass>
  <DefiningClass.PropertyOnDefiningClass>
    <!-- Value for Property here! -->
  </DefiningClass.PropertyOnDefiningClass>
</DefiningClass>
```

While any property *could* be set using this syntax, if you can capture a value as a simple string, you will save yourself typing time. For example, here is a much more verbose way to set the `Width` of your `Button`:

```
<Button Height="50" Content="OK!"
        FontSize="20" Foreground="Yellow">
...
  <Button.Width>
    100
  </Button.Width>
</Button>
```

## Understanding XAML Attached Properties

In addition to property-element syntax, XAML defines a special syntax used to set a value to an *attached property*. Essentially, an attached property allows a child element to set the value for a property that is actually defined in a parent element. The general template to follow looks like this:

```
<ParentElement>
  <ChildElement ParentElement.PropertyOnParent = "Value">
</ParentElement>
```

The most common use of attached property syntax is to position UI elements within one of the WPF layout manager classes (`Grid`, `DockPanel`, etc.). The next chapter dives into these panels in some detail; for now, enter the following in Kaxaml:

```
<Page
  xmlns="http://schemas.microsoft.com/winfx/2006/xaml/presentation"
  xmlns:x="http://schemas.microsoft.com/winfx/2006/xaml">
  <Canvas Height="200" Width="200" Background="LightBlue">
    <Ellipse Canvas.Top="40" Canvas.Left="40" Height="20" Width="20" Fill="DarkBlue"/>
  </Canvas>
</Page>
```

Here, you have defined a `Canvas` layout manager that contains an `Ellipse`. Notice that the `Ellipse` is able to inform its parent (the `Canvas`) where to position its top/left position using attached property syntax.

There are a few items to be aware of regarding attached properties. First and foremost, this is not an all-purpose syntax that can be applied to *any* property of *any* parent. For example, the following XAML cannot be parsed without error:

```
<!-- Error! Set Background property on Canvas via attached property? -->
<Canvas Height="200" Width="200">
    <Ellipse Canvas.Background="LightBlue"
              Canvas.Top="40" Canvas.Left="90"
              Height="20" Width="20" Fill="DarkBlue"/>
</Canvas>
```

In reality, attached properties are a specialized form of a WPF-specific concept termed a *dependency property*. Unless a property was implemented in a specific manner, you cannot set its value using attached property syntax. You will explore dependency properties in a detail in Chapter 25.

---

■ **Note** Visual Studio has IntelliSense, which will show you valid attached properties that can be set by a given element.

---

## Understanding XAML Markup Extensions

As explained, property values are most often represented using a simple string or via property-element syntax. There is, however, another way to specify the value of a XAML attribute, using *markup extensions*. Markup extensions allow a XAML parser to obtain the value for a property from a dedicated, external class. This can be beneficial given that some property values require a number of code statements to execute to figure out the value.

Markup extensions provide a way to cleanly extend the grammar of XAML with new functionality. A markup extension is represented internally as a class that derives from `MarkupExtension`. Note that the chances of you ever needing to build a custom markup extension will be slim to none. However, a subset of XAML keywords (such as `x:Array`, `x:Null`, `x:Static`, and `x:Type`) are markup extensions in disguise!

A markup extension is sandwiched between curly brackets, like so:

```
<Element PropertyToSet = "{MarkupExtension}"/>
```

To see some markup extensions in action, author the following into `Kaxaml`:

```
<Page
  xmlns="http://schemas.microsoft.com/winfx/2006/xaml/presentation"
  xmlns:x="http://schemas.microsoft.com/winfx/2006/xaml"
  xmlns:CorLib="clr-namespace:System;assembly=mscorlib">

  <StackPanel>
    <!-- The Static markup extension lets us obtain a value
         from a static member of a class -->
    <Label Content = "{x:Static CorLib:Environment.OSVersion}"/>
    <Label Content = "{x:Static CorLib:Environment.ProcessorCount}"/>
```



```

<!-- The Type markup extension is a XAML version of
      the C# typeof operator -->
<Label Content="{x:Type Button}" />
<Label Content="{x:Type CorLib:Boolean}" />

<!-- Fill a ListBox with an array of strings! -->
<ListBox Width="200" Height="50">
  <ListBox.ItemsSource>
    <x:Array Type="CorLib:String">
      <CorLib:String>Sun Kil Moon</CorLib:String>
      <CorLib:String>Red House Painters</CorLib:String>
      <CorLib:String>Besnard Lakes</CorLib:String>
    </x:Array>
  </ListBox.ItemsSource>
</ListBox>
</StackPanel>
</Page>

```

First, notice that the <Page> definition has a new XML namespace declaration, which allows you to gain access to the System namespace of mscorlib.dll. With this XML namespace established, you first make use of the x:Static markup extension and grab values from OSVersion and ProcessorCount of the System.Environment class.

The x:Type markup extension allows you to gain access to the metadata description of the specified item. Here, you are simply assigning the fully qualified names of the WPF Button and System.Boolean types.

The most interesting part of this markup is the ListBox. Here, you are setting the ItemsSource property to an array of strings declared entirely in markup! Notice here how the x:Array markup extension allows you to specify a set of subitems within its scope:

```

<x:Array Type="CorLib:String">
  <CorLib:String>Sun Kil Moon</CorLib:String>
  <CorLib:String>Red House Painters</CorLib:String>
  <CorLib:String>Besnard Lakes</CorLib:String>
</x:Array>

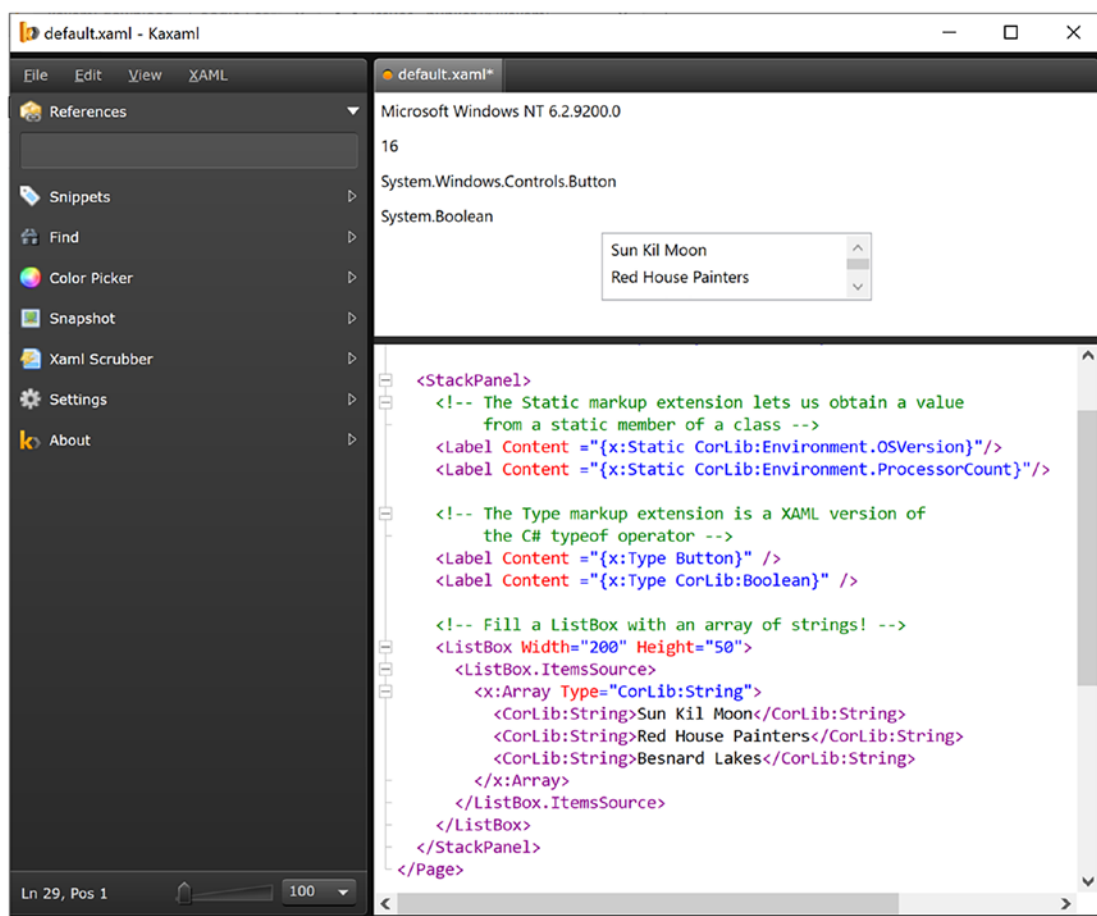
```

---

■ **Note** The previous XAML example is used only to illustrate a markup extension in action. As you will see in Chapter 25, there are much easier ways to populate ListBox controls!

---

Figure 24-3 shows the markup of this <Page> in Kaxaml.



**Figure 24-3.** Markup extensions allow you to set values via the functionality of a dedicated class

You have now seen numerous examples that showcase each of the core aspects of the XAML syntax. As you might agree, XAML is interesting, in that it allows you to describe a tree of .NET objects in a declarative manner. While this is extremely helpful when configuring graphical user interfaces, do remember that XAML can describe *any* type from *any* assembly, provided it is a nonabstract type containing a default constructor.

## Building WPF Applications Using Visual Studio

Let's examine how Visual Studio can simplify the construction of WPF programs.

---

■ **Note** Here, I will point out some key features of using Visual Studio to build WPF applications. Forthcoming chapters will illustrate additional aspects of the IDE where necessary.

---

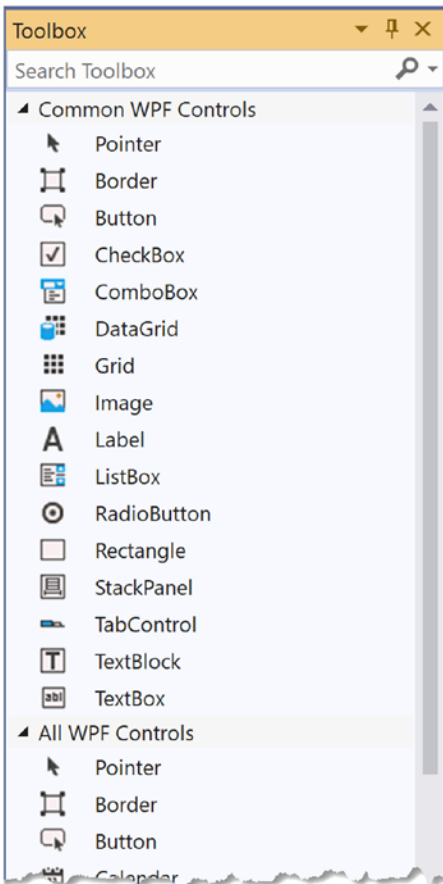
## The WPF Project Templates

The New Project dialog box of Visual Studio defines a set of WPF project templates, including a WPF App, WPF Custom Control Library, and WPF User Control Library.

Beyond setting the project SDK to Microsoft.NET.Sdk.WindowsDesktop, you will be provided with initial Window- and Application-derived classes, each represented using a XAML and C# code file.

## The Toolbox and XAML Designer/Editor

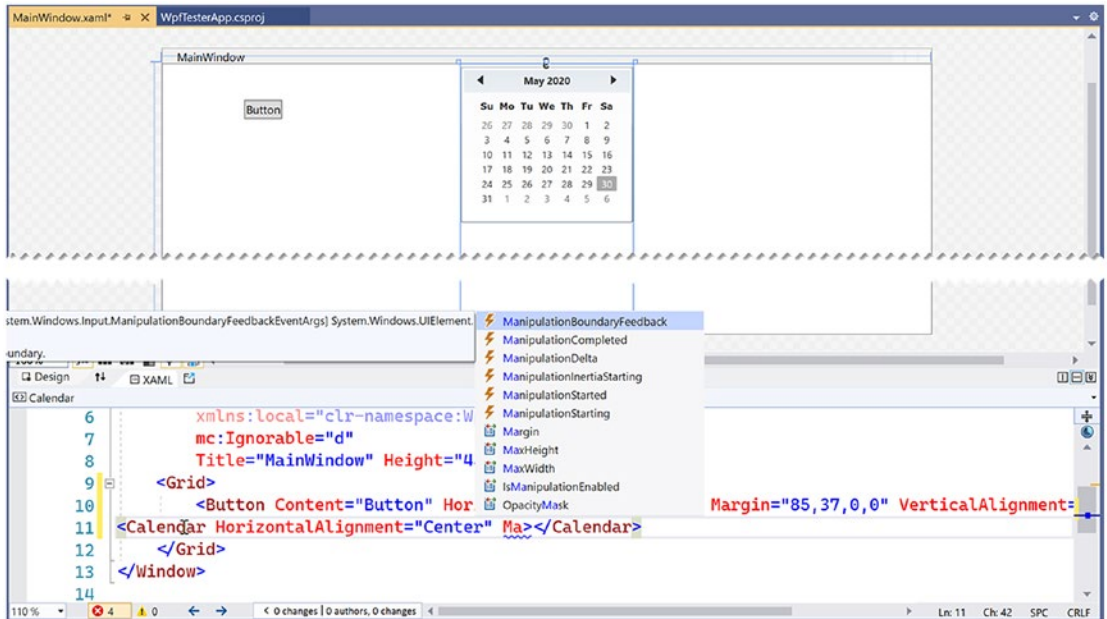
Visual Studio provides a Toolbox (which you can open via the View menu) that contains numerous WPF controls. The top part of the panel holds the most commonly used controls, and the bottom contains all of the controls (see Figure 24-4).



**Figure 24-4.** The Toolbox contains the WPF controls that can be placed on the designer surface

Using a standard drag-and-drop operation, you can place any of these controls onto the window's designer surface or drag the control into the XAML markup editor at the bottom of the designer. When you do, the initial XAML will be authored on your behalf. Use your mouse to drag a Button control and a Calendar control onto the designer surface. After you have done so, notice how you can relocate and resize your controls (and be sure to examine the resulting XAML generated based on your edits).

In addition to building the UI via the mouse and toolbox, you can manually enter your markup using the integrated XAML editor. As you can see in Figure 24-5, you do get IntelliSense support, which can help simplify the authoring of the markup. For example, try to add the Background property to the opening `<Window>` element.



**Figure 24-5.** The WPF Window designer

Take a few moments to add some property values directly in the XAML editor. Be sure you take the time to become comfortable using this aspect of the WPF designer.

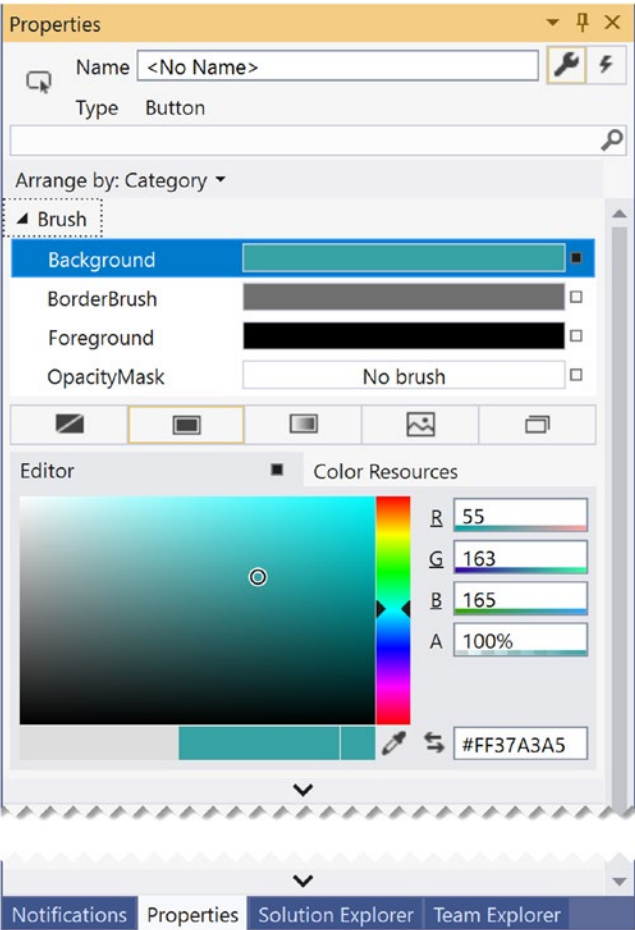
## Setting Properties Using the Properties Window

After you have placed some controls onto your designer (or manually defined them in the editor), you can then make use of the Properties window to set property values for the selected control, as well as rig up event handlers for the selected control. By way of a simple test, select your `Button` control on the designer. Now, use the Properties window to change the Background color of the `Button` using the integrated Brushes editor (see Figure 24-6; you will learn more about the Brushes editor in Chapter 26, during your examination of WPF graphics).

---

■ **Note** The Properties window provides a Search text area at the top. Type in the name of a property you would like to set to quickly find the item in question.

---



**Figure 24-6.** The Properties window can be used to configure the UI of a WPF control

After you have finished tinkering with the Brushes editor, check out the generated markup. It might look something like this:

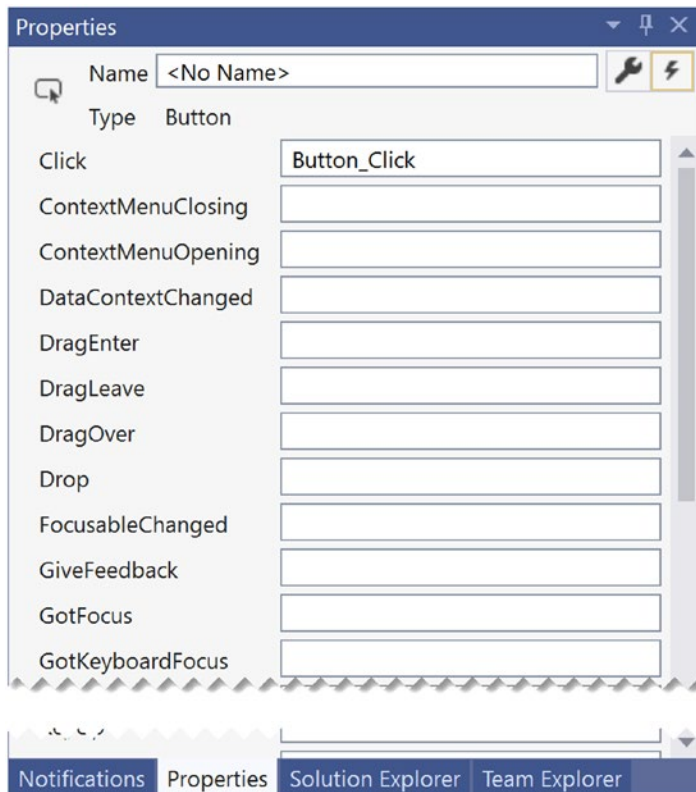
```
<Button Content="Button" HorizontalAlignment="Left" Margin="10,10,0,0"
VerticalAlignment="Top" Width="75">
  <Button.Background>
    <LinearGradientBrush EndPoint="0.5,1" StartPoint="0.5,0">
      <GradientStop Color="Black" Offset="0"/>
      <GradientStop Color="#FFE90E0E" Offset="1"/>
      <GradientStop Color="#FF1F4CE3"/>
    </LinearGradientBrush>
  </Button.Background>
</Button>
```

## Handling Events Using the Properties Window

If you want to handle events for a given control, you can also make use of the Properties window, but this time you need to click the Events button at the upper right of the Properties window (look for the lightning bolt icon). Ensure that the button is selected on your designer, and locate the Click event. Once you do, double-click directly on the Click event entry. This will cause Visual Studio to automatically build an event handler that takes the following general form:

*NameOfControl\_NameOfEvent*

Since you did not rename your button, the Properties window shows that it generated an event handler named `Button_Click` (see Figure 24-7).



**Figure 24-7.** Handling events using the Properties window

As well, Visual Studio generated the corresponding C# event handler in your window's code file. Here, you can add any sort of code that must execute when the button is clicked. For a quick test, just enter the following code statement:

```
private void Button_Click(object sender, RoutedEventArgs e)
{
    MessageBox.Show("You clicked the button!");
}
```

## Handling Events in the XAML Editor

You can also handle events directly in the XAML editor. By way of an example, place your mouse within the `<Window>` element and type in the `MouseMove` event, followed by the equal sign. Once you do, you will see that Visual Studio displays any compatible handlers in your code file (if they exist), as well as the `Create` method option (see Figure 24-8).



**Figure 24-8.** Handling events using the XAML editor

Let the IDE create the `MouseMove` event handler, enter the following code, and then run the application to see the end result:

```
private void MainWindow_MouseMove (object sender, MouseEventArgs e)
{
    this.Title = e.GetPosition(this).ToString();
}
```

---

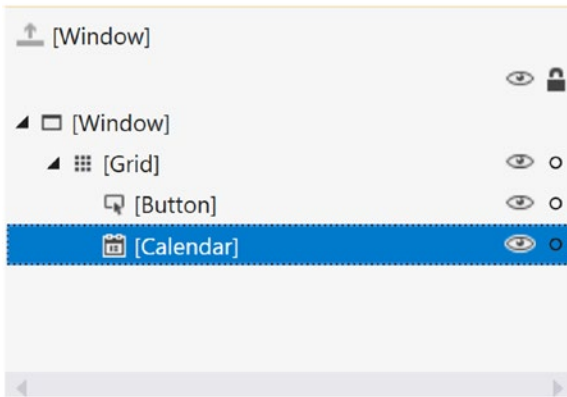
■ **Note** Chapter 28 covers MVVM and the Command pattern, which is a much better way to handle click events in enterprise applications. But if you need only a simple app, handling click events with a straight event handler is perfectly acceptable.

---

## The Document Outline Window

When you work with any XAML-based project, you will certainly make use of a healthy amount of markup to represent your UIs. When you begin to work with more complex XAML, it can be useful to visualize the markup in order to quickly select an item to edit on the Visual Studio designer.

Currently, your markup is quite tame because you have defined only a few controls within the initial `<Grid>`. Nevertheless, locate the Document Outline window in your IDE, mounted by default on the left side of Visual Studio (if you cannot locate it, simply activate it using the **View** ► **Other Windows** menu option). Now, make sure your XAML designer is the active window in the IDE (rather than the C# code file), and you will notice the Document Outline window displays the nested elements (see Figure 24-9).

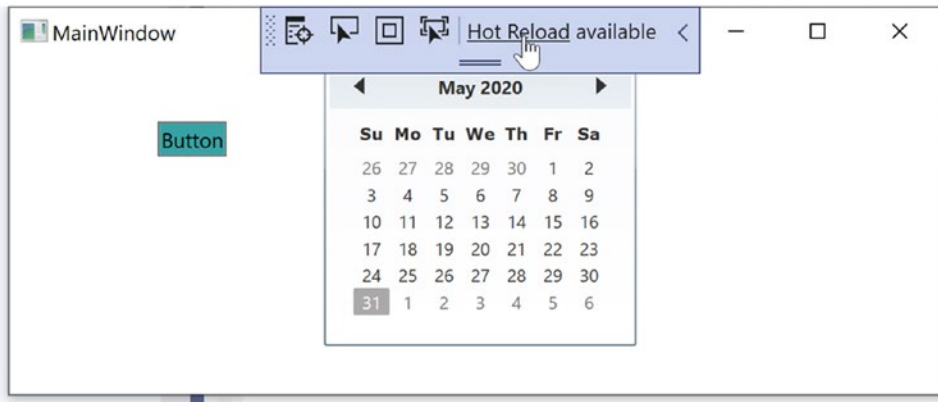


**Figure 24-9.** Visualizing your XAML via the Document Outline window

This tool also provides a way to temporarily hide a given item (or set of items) on the designer as well as lock items to prevent additional edits from taking place. In the next chapter, you will see how the Document Outline window also provides many other features to group selected items into new layout managers (among other features).

## Enable or Disable the XAML Debugger

When you run the application, you will see the `MainWindow` on the screen. You will also see the interactive debugger, as shown in Figure 24-10.



**Figure 24-10.** XAML UI debugging

If you want to turn this off, you will find the entries for XAML debugging under **Tools > Options > Debugging > General**. Deselect the boxes to prevent the debugger window from overlaying your windows. Figure 24-11 shows the entries.



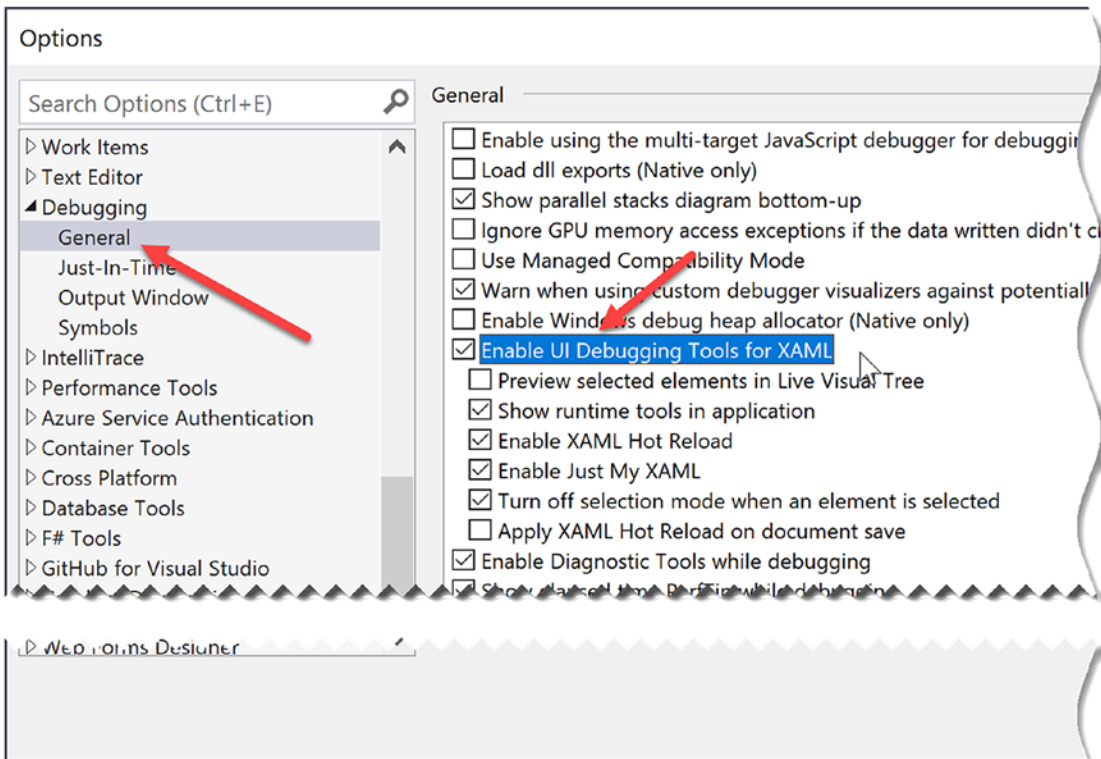


Figure 24-11. XAML UI debugging

## Examining the App.xaml File

How did the project know what window to launch? Even more intriguing, if you examine the code files in your application, you will also see that there isn't a `Main()` method anywhere to be found. You've learned throughout this book that applications must have an entry point, so how does .NET know how to launch your app? Fortunately, both of these plumbing items are handled for you through the Visual Studio templates and the WPF framework.

To solve the riddle of which window to launch, the `App.xaml` file defines an application class through markup. In addition to the namespace definitions, it defines application properties such as the `StartupUri`, application-wide resources (covered in Chapter 27), and specific handlers for application events such as `Startup` and `Exit`. The `StartupUri` indicates which window to load on startup. Open the `App.xaml` file and examine the markup, shown here:

```
<Application x:Class="WpfTesterApp.App"
    xmlns="http://schemas.microsoft.com/winfx/2006/xaml/presentation"
    xmlns:x="http://schemas.microsoft.com/winfx/2006/xaml"
    xmlns:local="clr-namespace:WpfTesterApp"
    StartupUri="MainWindow.xaml">
    <Application.Resources>
    </Application.Resources>
</Application>
```

Using the XAML designer and using Visual Studio code completion, add handlers for the Startup and Exit events. Your updated XAML should look like this (notice the change in bold):

```
<Application x:Class="WpfTesterApp.App"
    xmlns="http://schemas.microsoft.com/winfx/2006/xaml/presentation"
    xmlns:x="http://schemas.microsoft.com/winfx/2006/xaml"
    xmlns:local="clr-namespace:WpfTesterApp"
    StartupUri="MainWindow.xaml" Startup="App_OnStartup" Exit="App_OnExit">
    <Application.Resources>
    </Application.Resources>
</Application>
```

If you look at the App.xaml.cs file, it should look like this:

```
public partial class App : Application
{
    private void App_OnStartup(object sender, StartupEventArgs e)
    {
    }
    private void App_OnExit(object sender, ExitEventArgs e)
    {
    }
}
```

Note that the class is marked as partial. In fact, all the code-behind windows for XAML files are marked partial. That is key to solving the riddle of where the Main() method lives. But first, you need to examine what happens when msbuild.exe processes XAML files.

## Mapping the Window XAML Markup to C# Code

When msbuild.exe processed your \*.csproj file, it produced three files for each XAML file in your project with the form of \*.g.cs (where g denotes *generated*), \*.g.i.cs (where *i* denotes *IntelliSense*), and \*.baml (for Binary Application Markup Language). These are saved into the \obj\Debug directory (and can be viewed in Solution Explorer by clicking the Show All Files button). You might have to hit the Refresh button in Solution Explorer to see them since they are not part of the actual project, but build artifacts.

To make the most sense of the process, it's helpful to provide names for your controls. Go ahead and provide names for the Button and Calendar controls, as follows:

```
<Button Name="ClickMe" Content="Button" HorizontalAlignment="Left" Margin="10,10,0,0"
    VerticalAlignment="Top" Width="75" Click="Button_Click">
//omitted for brevity
</Button>
<Calendar Name="MyCalendar" HorizontalAlignment="Left" Margin="10,41,0,0"
    VerticalAlignment="Top"/>
```

Now rebuild your solution (or project) and refresh the files in Solution Explorer. If you open the MainWindow.g.cs file into a text editor, you will find a class named MainWindow, which extends the Window base class. The name of this class is a direct result of the x:Class attribute in the <Window> start tag.

This class defines a private member variable of type `bool` (named `_contentLoaded`), which was not directly accounted for in the XAML markup. This data member is used to determine (and ensure) the content of the window is assigned only once. This class also contains a member variable of type `System.Windows.Controls.Button`, named `ClickMe`. The name of the control is based on the `x:Name` (or the shorthand form `Name`) attribute value within the opening `<Button>` declaration. What you don't see is a variable for the `Calendar` control. This is because `msbuild.exe` creates a variable for each *named* control in your XAML that has related code in the code-behind. If there isn't any code, there isn't any need for a variable. To make matters more confusing, if you hadn't named the `Button` control, there wouldn't be a variable for it either. This is part of the magic of WPF and is tied into the `IComponentConnector` interface implementation.

The compiler-generated class also explicitly implements the WPF `IComponentConnector` interface defined in the `System.Windows.Markup` namespace. This interface defines a single method called `Connect()`, which has been implemented to prep each control defined in the markup and rig up the event logic as specified within the original `MainWindow.xaml` file. You can see the handler being set up for the `ClickMe` click event. Before the method completes, the `_contentLoaded` member variable is set to `true`. Here is the crux of the method:

```
void System.Windows.Markup.IComponentConnector.Connect(int connectionId, object target)
{
    switch (connectionId)
    {
        case 1:
            this.ClickMe = ((System.Windows.Controls.Button)(target));
            #line 11 "..\..\MainWindow.xaml"
            this.ClickMe.Click += new System.Windows.RoutedEventHandler(this.Button_Click);
            #line default
            #line hidden
            return;
        }
        this._contentLoaded = true;
    }
}
```

To show the effects of unnamed controls with code, add an event handler for the `SelectedDatesChanged` event on the calendar. Rebuild the application, refresh the files, and reload the `MainWindow.g.cs` file. In the `Connect()` method, you now see the following code block:

```
#line 20 "..\..\MainWindow.xaml"
this.MyCalendar.SelectedDatesChanged += new
    System.EventHandler<System.Windows.Controls.SelectionChangedEventArgs>(
        this.MyCalendar_OnSelectedDatesChanged);
```

This tells the framework that the control on line 20 of the XAML file has `SelectedDatesChanged` event handler assigned, as shown in the preceding code.

Last but not least, the `MainWindow` class defines and implements a method named `InitializeComponent()`. You might expect that this method contains code that sets up the look and feel of each control by setting various properties (`Height`, `Width`, `Content`, etc.). However, this is not the case! How then do the controls take on the correct UI? The logic with `InitializeComponent()` resolves the location of an embedded assembly resource that is named identical to the original `*.xaml` file, like so:

```

public void InitializeComponent() {
    if (_contentLoaded) {
        return;
    }
    _contentLoaded = true;
    System.Uri resourceLocator = new System.Uri("/WpfTesterApp;component/mainwindow.xaml",
        System.UriKind.Relative);
    #line 1 "..\\..\\MainWindow.xaml"
    System.Windows.Application.LoadComponent(this, resourceLocator);
    #line default
    #line hidden
}

```

At this point, the question becomes “what exactly is this embedded resource?”

## The Role of BAML

As you might have guessed from the name, Binary Application Markup Language (BAML) is a compact, binary representation of the original XAML data. This \*.baml file is embedded as a resource (via a generated \*.g.resources file) into the compiled assembly. This BAML resource contains all the data needed to establish the look and feel of the UI widgets (again, such as the Height and Width properties).

The important takeaway here is to understand that a WPF application contains within itself a binary representation (the BAML) of the markup. At runtime, this BAML will be plucked out of the resource container and used to make sure all windows and controls are initialized to the correct look and feel.

Also, remember that the name of these binary resources are *identical* to the name of the stand-alone \*.xaml files you authored. However, this does not imply in any way that you must distribute the loose \*.xaml files with your compiled WPF program. Unless you build a WPF application that will dynamically load and parse \*.xaml files at runtime, you will never need to ship the original markup.

## Solving the Mystery of Main()

Now that you know how the MSBuild process works, open the App.g.cs file. Here you will find the autogenerated Main() method that initializes and runs your application object.

```

public static void Main() {
    WpfTesterApp.App app = new WpfTesterApp.App();
    app.InitializeComponent();
    app.Run();
}

```

The InitializeComponent() method configures the application properties, including the StartupUri and the event handlers for the Startup and Exit events.

```

public void InitializeComponent() {
    #line 5 "..\\..\\App.xaml"
    this.Startup += new System.Windows.StartupEventHandler(this.App_OnStartup);
    #line default
    #line hidden
    #line 5 "..\\..\\App.xaml"
    this.Exit += new System.Windows.ExitEventHandler(this.App_OnExit);
    #line default
}

```

```

#line hidden
#line 5 "..\..\App.xaml"
this.StartupUri = new System.Uri("MainWindow.xaml", System.UriKind.Relative);
#line default
#line hidden
}

```

## Interacting with Application-Level Data

Recall that the `Application` class defines a property named `Properties`, which allows you to define a collection of name-value pairs via a type indexer. Because this indexer has been defined to operate on type `System.Object`, you are able to store any sort of item within this collection (including your custom classes) to be retrieved at a later time using a friendly moniker. Using this approach, it is simple to share data across all windows in a WPF application.

To illustrate, you will update the current `Startup` event handler to check the incoming command-line arguments for a value named `/GODMODE` (a common cheat code for many PC video games). If you find this token, you will establish a `bool` value set to `true` within the `properties` collection of the same name (otherwise, you will set the value to `false`).

This sounds simple enough, but how are you going to pass the incoming command-line arguments (typically obtained from the `Main()` method) to your `Startup` event handler? One approach is to call the static `Environment.GetCommandLineArgs()` method. However, these same arguments are automatically added to the incoming `StartupEventArgs` parameter and can be accessed via the `Args` property. That being said, here is the first update to the current codebase:

```

private void App_OnStartup(object sender, StartupEventArgs e)
{
    Application.Current.Properties["GodMode"] = false;
    // Check the incoming command-line arguments and see if they
    // specified a flag for /GODMODE.
    foreach (string arg in e.Args)
    {
        if (arg.Equals("/godmode", StringComparison.OrdinalIgnoreCase))
        {
            Application.Current.Properties["GodMode"] = true;
            break;
        }
    }
}

```

Application-wide data can be accessed from anywhere within the WPF application. All you are required to do is obtain an access point to the global application object (via `Application.Current`) and investigate the collection. For example, you could update the `Click` event handler of the `Button` as so:

```

private void Button_Click(object sender, RoutedEventArgs e)
{
    // Did user enable /godmode?
    if ((bool)Application.Current.Properties["GodMode"])
    {
        MessageBox.Show("Cheater!");
    }
}

```

With this, if you enter the `/godmode` command-line argument into the Debug tab in the project properties and then run the program, you will be shamed and the program will exit. You can also run the program from a command line by entering the following command (open a command prompt and navigate to the `bin/debug` directory):

```
WpfAppAllCode.exe /godmode
```

You will see the shameful message box displayed when terminating the application.

---

■ **Note** Recall that you can supply command-line arguments within Visual Studio. Simply double-click the Properties icon within Solution Explorer, click the Debug tab from the resulting editor, and enter `/godmode` within the “Command line arguments” editor.

---

## Handling the Closing of a Window Object

End users can shut down a window by using numerous built-in system-level techniques (e.g., clicking the X close button on the window’s frame) or by indirectly calling the `Close()` method in response to some user interaction element (e.g., File ► Exit). In either case, WPF provides two events that you can intercept to determine whether the user is *truly* ready to shut down the window and remove it from memory. The first event to fire is `Closing`, which works in conjunction with the `CancelEventHandler` delegate.

This delegate expects target methods to take `System.ComponentModel.CancelEventArgs` as the second parameter. `CancelEventArgs` provides the `Cancel` property, which when set to `true` will prevent the window from actually closing (this is handy when you have asked the user if he really wants to close the window or if perhaps he would like to save his work first).

If the user does indeed want to close the window, `CancelEventArgs.Cancel` can be set to `false` (which is the default setting). This will then cause the `Closed` event to fire (which works with the `System.EventHandler` delegate), making it the point at which the window is about to be closed for good.

Update the `MainWindow` class to handle these two events by adding these code statements to the current constructor, like so:

```
public MainWindow()
{
    InitializeComponent();
    this.Closed+=MainWindow_Closed;
    this.Closing += MainWindow_Closing;
}
```

Now, implement the corresponding event handlers as so:

```
private void MainWindow_Closing(object sender, System.ComponentModel.CancelEventArgs e)
{
    // See if the user really wants to shut down this window.
    string msg = "Do you want to close without saving?";
    MessageBoxResult result = MessageBox.Show(msg,
        "My App", MessageBoxButton.YesNo, MessageBoxImage.Warning);
```

```

if (result == MessageBoxResult.No)
{
    // If user doesn't want to close, cancel closure.
    e.Cancel = true;
}
}

private void MainWindow_Closed(object sender, EventArgs e)
{
    MessageBox.Show("See ya!");
}

```

Now, run your program and attempt to close the window, either by clicking the X icon in the upper right of the window or by clicking the button control. You should see the confirmation dialog asking if you really want to leave. If you answer Yes, you will then see the farewell message. Clicking the No button will keep the window in memory.

## Intercepting Mouse Events

The WPF API provides a number of events you can capture to interact with the mouse. Specifically, the `UIElement` base class defines a number of mouse-centric events such as `MouseMove`, `MouseUp`, `MouseDown`, `MouseEnter`, `MouseLeave`, and so forth.

Consider, for example, the act of handling the `MouseMove` event. This event works in conjunction with the `System.Windows.Input.MouseEventHandler` delegate, which expects its target to take a `System.Windows.Input.MouseEventArgs` type as the second parameter. Using `MouseEventArgs`, you are able to extract the (x, y) position of the mouse and other relevant details. Consider the following partial definition:

```

public class MouseEventArgs : InputEventArgs
{
    ...
    public Point GetPosition(IInputElement relativeTo);
    public MouseButtonState LeftButton { get; }
    public MouseButtonState MiddleButton { get; }
    public MouseDevice MouseDevice { get; }
    public MouseButtonState RightButton { get; }
    public StylusDevice StylusDevice { get; }
    public MouseButtonState XButton1 { get; }
    public MouseButtonState XButton2 { get; }
}

```

---

■ **Note** The `XButton1` and `XButton2` properties allow you to interact with “extended mouse buttons” (such as the “next” and “previous” buttons found on some mouse controls). These are often used to interact with a browser’s history list to navigate between visited pages.

---

The `GetPosition()` method allows you to get the (x, y) value relative to a UI element on the window. If you are interested in capturing the position relative to the activated window, simply pass in `this`. Handle the `MouseMove` event in the constructor of your `MainWindow` class, like so:

```
public MainWindow(string windowTitle, int height, int width)
{
    ...
    this.MouseMove += MainWindow_MouseMove;
}
```

Here is an event handler for `MouseMove` that will display the location of the mouse in the window's title area (notice you are translating the returned `Point` type into a text value via `ToString()`):

```
private void MainWindow_MouseMove(object sender,
    System.Windows.Input.MouseEventArgs e)
{
    // Set the title of the window to the current (x,y) of the mouse.
    this.Title = e.GetPosition(this).ToString();
}
```

## Intercepting Keyboard Events

Processing keyboard input for the focused window is also straightforward. `UIElement` defines a number of events that you can capture to intercept keypresses from the keyboard on the active element (e.g., `KeyUp`, `KeyDown`). The `KeyUp` and `KeyDown` events both work with the `System.Windows.Input.KeyEventHandler` delegate, which expects the target's second event handler to be of type `KeyEventArgs`, which defines several public properties of interest, shown here:

```
public class KeyEventArgs : KeyboardEventArgs
{
    ...
    public bool IsDown { get; }
    public bool IsRepeat { get; }
    public bool IsToggled { get; }
    public bool IsUp { get; }
    public Key Key { get; }
    public KeyStates KeyStates { get; }
    public Key SystemKey { get; }
}
```

To illustrate handling the `KeyDown` event in the constructor of `MainWindow` (just like you did for the previous events), implement the following event handler that changes the content of the button with the currently pressed key:

```
private void MainWindowOs_KeyDown(object sender, System.Windows.Input.KeyEventArgs e)
{
    // Display key press on the button.
    ClickMe.Content = e.Key.ToString();
}
```



At this point in the chapter, WPF might look like nothing more than yet another GUI framework that is providing (more or less) the same services as Windows Forms, MFC, or VB6. If this were in fact the case, you might question the need for yet another UI toolkit. To truly see what makes WPF so unique, you require an understanding of the XML-based grammar, XAML.

## Summary

Windows Presentation Foundation (WPF) is a user interface toolkit introduced with the release of .NET 3.0. The major goal of WPF is to integrate and unify a number of previously unrelated desktop technologies (2D graphics, 3D graphics, window and control development, etc.) into a single, unified programming model. Beyond this point, WPF programs typically make use of XAML, which allows you to declare the look and feel of your WPF elements via markup.

Recall that XAML allows you to describe trees of .NET objects using a declarative syntax. During this chapter's investigation of XAML, you were exposed to several new bits of syntax, including property-element syntax and attached properties, as well as the role of type converters and XAML markup extensions.

XAML is a key aspect for any production-level WPF application. The final example of this chapter gave you a chance to build a WPF application that showed many of the concepts discussed in this chapter. The next chapters will dive deeper into these concepts as well as introduce many more.



# WPF Controls, Layouts, Events, and Data Binding

Chapter 24 provided a foundation for the WPF programming model, including an examination of the Window and Application classes, the grammar of XAML, and the use of code files. Chapter 24 also introduced you to the process of building WPF applications using the designers of Visual Studio. In this chapter, you will dig into the construction of more sophisticated graphical user interfaces using several new controls and layout managers, learning about additional features of the WPF designers of Visual Studio along the way.

This chapter will also examine some important related WPF control topics such as the data-binding programming model and the use of control commands. You will also learn how to use the Ink and Documents APIs, which allow you to capture stylus (or mouse) input and build rich text documents using the XML Paper Specification, respectively.

## A Survey of the Core WPF Controls

Unless you are new to the concept of building graphical user interfaces (which is fine), the general purpose of the major WPF controls should not raise too many issues. Regardless of which GUI toolkit you might have used in the past (e.g., VB6, MFC, Java AWT/Swing, Windows Forms, macOS, or GTK+/GTK# [among others]), the core WPF controls listed in Table 25-1 are likely to look familiar.

---

■ **Note** Despite what you might be thinking, the intent of this chapter is *not* to walk through each and every member of each and every WPF control. Rather, you will receive an overview of the various controls with an emphasis on the underlying programming model and key services common to most WPF controls.

---

**Table 25-1.** *The Core WPF Controls*

WPF Control Category	Example Members	Meaning in Life
Core user input controls	Button, RadioButton, ComboBox, CheckBox, Calendar, DatePicker, Expander, DataGrid, ListBox, ListView, ToggleButton, TreeView, ContextMenu, ScrollBar, Slider, TabControl, TextBlock, TextBox, RepeatButton, RichTextBox, Label	WPF provides an entire family of controls you can use to build the crux of a user interface.
Window and control adornments	Menu, ToolBar, StatusBar, ToolTip, ProgressBar	You use these UI elements to decorate the frame of a Window object with input devices (such as the Menu) and user informational elements (e.g., StatusBar and ToolTip).
Media controls	Image, MediaElement, SoundPlayerAction	These controls provide support for audio/video playback and image display.
Layout controls	Border, Canvas, DockPanel, Grid, GridView, GridSplitter, GroupBox, Panel, TabControl, StackPanel, Viewbox, WrapPanel	WPF provides numerous controls that allow you to group and organize other controls for the purpose of layout management.

The WPF Ink Controls

In addition to the common WPF controls listed in Table 25-1, WPF defines additional controls for working with the digital Ink API. This aspect of WPF development is useful during Tablet PC development because it lets you capture input from the stylus. However, this is not to say a standard desktop application cannot leverage the Ink API because the same controls can capture input using the mouse.

The `System.Windows.Ink` namespace of `PresentationCore.dll` contains various Ink API support types (e.g., `Stroke` and `StrokeCollection`); however, a majority of the Ink API controls (e.g., `InkCanvas` and `InkPresenter`) are packaged up with the common WPF controls under the `System.Windows.Controls` namespace in the `PresentationFramework.dll` assembly. You'll work with the Ink API later in this chapter.

The WPF Document Controls

WPF also provides controls for advanced document processing, allowing you to build applications that incorporate Adobe PDF-style functionality. Using the types within the `System.Windows.Documents` namespace (also in the `PresentationFramework.dll` assembly), you can create print-ready documents that support zooming, searching, user annotations (sticky notes), and other rich text services.

Under the covers, however, the document controls do not use Adobe PDF APIs; rather, they use the XML Paper Specification (XPS) API. To the end user, there will really appear to be no difference because PDF documents and XPS documents have an almost identical look and feel. In fact, you can find many free utilities that allow you to convert between the two file formats on the fly. Because of space limitation, these controls won't be covered in this edition.

## WPF Common Dialog Boxes

WPF also provides you with a few common dialog boxes such as `OpenFileDialog` and `SaveFileDialog`. These dialog boxes are defined within the `Microsoft.Win32` namespace of the `PresentationFramework.dll` assembly. Working with either of these dialog boxes is a matter of creating an object and invoking the `ShowDialog()` method, like so:

```
using Microsoft.Win32;
//omitted for brevity
private void btnShowDlg_Click(object sender, RoutedEventArgs e)
{
    // Show a file save dialog.
    SaveFileDialog saveDlg = new SaveFileDialog();
    saveDlg.ShowDialog();
}
```

As you would hope, these classes support various members that allow you to establish file filters and directory paths and gain access to user-selected files. You will put these file dialogs to use in later examples; you will also learn how to build custom dialog boxes to gather user input.

## A Brief Review of the Visual Studio WPF Designer

A majority of these standard WPF controls have been packaged up in the `System.Windows.Controls` namespace of the `PresentationFramework.dll` assembly. When you build a WPF application using Visual Studio, you will find most of these common controls contained in the toolbox, provided you have a WPF designer open as the active window.

Similar to other UI frameworks created with Visual Studio, you can drag these controls onto the WPF window designer and configure them using the Properties window (which you learned about in Chapter 24). While Visual Studio will generate a good amount of the XAML on your behalf, it is not uncommon to edit the markup yourself manually. Let's review the basics.

## Working with WPF Controls Using Visual Studio

You might recall from Chapter 24 that when you place a WPF control onto the Visual Studio designer, you want to set the `x:Name` property through the Properties window (or through XAML directly) because this allows you to access the object in your related C# code file. You might also recall that you can use the Events tab of the Properties window to generate event handlers for a selected control. Thus, you could use Visual Studio to generate the following markup for a simple `Button` control:

```
<Button x:Name="btnMyButton" Content="Click Me!" Height="23" Width="140"
Click="btnMyButton_Click" />
```

Here, you set the `Content` property of the `Button` to a simple string with the value "Click Me!". However, thanks to the WPF control content model, you could fashion a `Button` that contains the following complex content:

```
<Button x:Name="btnMyButton" Height="121" Width="156" Click="btnMyButton_Click">
    <Button.Content>
        <StackPanel Height="95" Width="128" Orientation="Vertical">
            <Ellipse Fill="Red" Width="52" Height="45" Margin="5"/>
```

```

        <Label Width="59" FontSize="20" Content="Click!" Height="36" />
    </StackPanel>
</Button.Content>
</Button>

```

You might also recall that the immediate child element of a `ContentControl`-derived class is the implied content; therefore, you do not need to define a `Button.Content` scope explicitly when specifying complex content. You could simply author the following:

```

<Button x:Name="btnMyButton" Height="121" Width="156" Click="btnMyButton_Click">
    <StackPanel Height="95" Width="128" Orientation="Vertical">
        <Ellipse Fill="Red" Width="52" Height="45" Margin="5"/>
        <Label Width="59" FontSize="20" Content="Click!" Height="36" />
    </StackPanel>
</Button>

```

In either case, you set the button's `Content` property to a `StackPanel` of related items. You can also author this sort of complex content using the Visual Studio designer. After you define the layout manager for a content control, you can select it on the designer to serve as a drop target for the internal controls. At this point, you can edit each using the Properties window. If you were to use the Properties window to handle the `Click` event for the `Button` control (as shown in the previous XAML declarations), the IDE would generate an empty event handler, to which you could add your own custom code, like so:

```

private void btnMyButton_Click(object sender, RoutedEventArgs e)
{
    MessageBox.Show("You clicked the button!");
}

```

## Working with the Document Outline Editor

You should recall from the previous chapter that the Document Outline window of Visual Studio (which you can open using the **View ► Other Windows** menu) is useful when designing a WPF control that has complex content. The logical tree of XAML is displayed for the `Window` you are building, and if you click any of these nodes, it is automatically selected in the visual designer and the XAML editor for editing.

With the current edition of Visual Studio, the Document Outline window has a few additional features that you might find useful. To the right of any node you will find an icon that looks similar to an eyeball. When you toggle this button, you can opt to hide or show an item on the designer, which can be helpful when you want to focus in on a particular segment to edit (note that this will *not* hide the item at runtime; this only hides items on the designer surface).

Right next to the “eyeball icon” is a second toggle that allows you to lock an item on the designer. As you might guess, this can be helpful when you want to make sure you (or your coworkers) do not accidentally change the XAML for a given item. In effect, locking an item makes it read-only at design time (however, you can obviously change the object's state at runtime).

## Controlling Content Layout Using Panels

A WPF application invariably contains a good number of UI elements (e.g., user input controls, graphical content, menu systems, and status bars) that need to be well organized within various windows. After you place the UI elements, you need to make sure they behave as intended when the end user resizes the

window or possibly a portion of the window (as in the case of a splitter window). To ensure your WPF controls retain their position within the hosting window, you can take advantage of a good number of *panel types* (also known as *layout managers*).

By default, a new WPF Window created with Visual Studio will use a layout manager of type Grid (more details in just a bit). However, for now, assume a Window with no declared layout manager, like so:

```
<Window x:Class="MyWPFApp.MainWindow"
  xmlns="http://schemas.microsoft.com/winfx/2006/xaml/presentation"
  xmlns:x="http://schemas.microsoft.com/winfx/2006/xaml"
  Title="Fun with Panels!" Height="285" Width="325">

</Window>
```

When you declare a control directly inside a window that doesn't use panels, the control is positioned dead center in the container. Consider the following simple window declaration, which contains a single Button control. Regardless of how you resize the window, the UI widget is always equidistant from all four sides of the client area. The Button's size is determined by the assigned Height and Width properties of the Button.

**<!-- This button is in the center of the window at all times -->**

```
<Window x:Class="MyWPFApp.MainWindow"
  xmlns="http://schemas.microsoft.com/winfx/2006/xaml/presentation"
  xmlns:x="http://schemas.microsoft.com/winfx/2006/xaml"
  Title="Fun with Panels!" Height="285" Width="325">

  <Button x:Name="btnOK" Height = "100" Width="80" Content="OK"/>

</Window>
```

You might also recall that if you attempt to place multiple elements directly within the scope of a Window, you will receive markup and compile-time errors. The reason for these errors is that a window (or any descendant of ContentControl for that matter) can assign only a single object to its Content property. Therefore, the following XAML yields markup and compile-time errors:

**<!-- Error! Content property is implicitly set more than once! -->**

```
<Window x:Class="MyWPFApp.MainWindow"
  xmlns="http://schemas.microsoft.com/winfx/2006/xaml/presentation"
  xmlns:x="http://schemas.microsoft.com/winfx/2006/xaml"
  Title="Fun with Panels!" Height="285" Width="325">

  <!-- Error! Two direct child elements of the <Window>! -->
  <Label x:Name="lblInstructions" Width="328" Height="27" FontSize="15" Content="Enter
Information"/>
  <Button x:Name="btnOK" Height = "100" Width="80" Content="OK"/>

</Window>
```

Obviously, a window that can contain only a single control is of little use. When a window needs to contain multiple elements, those elements must be arranged within any number of panels. The panel will contain all of the UI elements that represent the window, after which the panel itself is used as the single object assigned to the Content property.

The System.Windows.Controls namespace provides numerous panels, each of which controls how subelements are maintained. You can use panels to establish how the controls behave if the end user resizes the window, if the controls remain exactly where they were placed at design time, if the controls reflow horizontally from left to right or vertically from top to bottom, and so forth.

You can also intermix panel controls within other panels (e.g., a `DockPanel` that contains a `StackPanel` of other items) to provide a great deal of flexibility and control. Table 25-2 documents the role of some commonly used WPF panel controls.

**Table 25-2.** *Core WPF Panel Controls*

Panel Control	Meaning in Life
Canvas	Provides a classic mode of content placement. Items stay exactly where you put them at design time.
DockPanel	Locks content to a specified side of the panel (Top, Bottom, Left, or Right).
Grid	Arranges content within a series of cells, maintained within a tabular grid.
StackPanel	Stacks content in a vertical or horizontal manner, as dictated by the <code>Orientation</code> property.
WrapPanel	Positions content from left to right, breaking the content to the next line at the edge of the containing box. Subsequent ordering happens sequentially from top to bottom or from right to left, depending on the value of the <code>Orientation</code> property.

In the next few sections, you will learn how to use these commonly used panel types by copying some predefined XAML data into the `kaxaml.exe` application you installed in Chapter 24. You can find all these loose XAML files contained inside the `PanelMarkup` subfolder of your Chapter 25 code download folder. When working with `Kaxaml`, to simulate resizing a window, change the height or width of the `Page` element in the markup.

## Positioning Content Within Canvas Panels

If you come from a WinForms background, you will probably feel most at home with the `Canvas` panel because it allows for absolute positioning of UI content. If the end user resizes the window to an area that is smaller than the layout maintained by the `Canvas` panel, the internal content will not be visible until the container is stretched to a size equal to or larger than the `Canvas` area.

To add content to a `Canvas`, you begin by defining the required controls within the scope of the opening and closing `Canvas` tags. Next, specify the upper-left corner for each control; this is where the rendering should begin using the `Canvas.Left` and `Canvas.Top` properties. You can specify the bottom-right area indirectly in each control by setting its `Height` and `Width` properties or directly by using the `Canvas.Right` and `Canvas.Bottom` properties.

To see `Canvas` in action, open the provided `SimpleCanvas.xaml` file using `kaxaml.exe`. You should see the following `Canvas` definition (if loading these examples into a WPF application, you will want to change the `Page` tag to a `Window` tag):

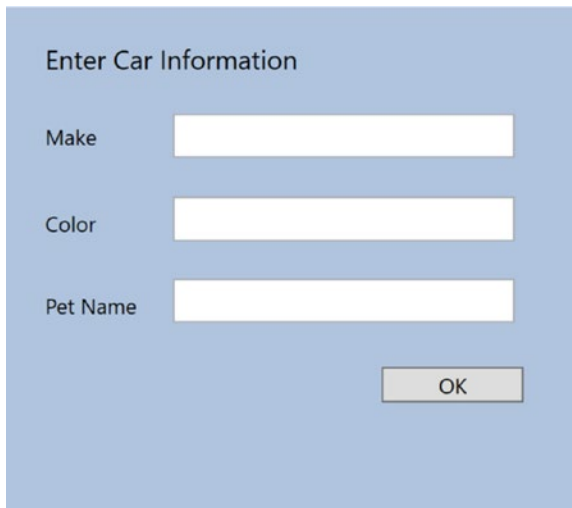
```
<Page
  xmlns="http://schemas.microsoft.com/winfx/2006/xaml/presentation"
  xmlns:x="http://schemas.microsoft.com/winfx/2006/xaml"
  Title="Fun with Panels!" Height="285" Width="325">
  <Canvas Background="LightSteelBlue">
    <Button x:Name="btnOK" Canvas.Left="212" Canvas.Top="203" Width="80" Content="OK"/>
    <Label x:Name="lblInstructions" Canvas.Left="17" Canvas.Top="14" Width="328" Height="27"
      FontSize="15"
      Content="Enter Car Information"/>
  </Canvas>
</Page>
```

```

<Label x:Name="lblMake" Canvas.Left="17" Canvas.Top="60" Content="Make"/>
<TextBox x:Name="txtMake" Canvas.Left="94" Canvas.Top="60" Width="193" Height="25"/>
<Label x:Name="lblColor" Canvas.Left="17" Canvas.Top="109" Content="Color"/>
<TextBox x:Name="txtColor" Canvas.Left="94" Canvas.Top="107" Width="193" Height="25"/>
<Label x:Name="lblPetName" Canvas.Left="17" Canvas.Top="155" Content="Pet Name"/>
<TextBox x:Name="txtPetName" Canvas.Left="94" Canvas.Top="153" Width="193" Height="25"/>
</Canvas>
</Page>

```

You should see the window shown in Figure 25-1 in the top half of the screen.



**Figure 25-1.** The Canvas layout manager allows for absolute positioning of content

Note that the order you declare content within a Canvas is not used to calculate placement; instead, placement is based on the control's size and the Canvas.Top, Canvas.Bottom, Canvas.Left, and Canvas.Right properties.

---

■ **Note** If subelements within a Canvas do not define a specific location using attached property syntax (e.g., Canvas.Left and Canvas.Top), they automatically attach to the extreme upper-left corner of Canvas.

---

Using the Canvas type might seem like the preferred way to arrange content (because it feels so familiar), but this approach does suffer from some limitations. First, items within a Canvas do not dynamically resize themselves when applying styles or templates (e.g., their font sizes are unaffected). Second, the Canvas will not attempt to keep elements visible when the end user resizes the window to a smaller surface.

Perhaps the best use of the Canvas type is for positioning *graphical content*. For example, if you were building a custom image using XAML, you certainly would want the lines, shapes, and text to remain in the same location, rather than see them dynamically repositioned as the user resizes the window! You'll revisit Canvas in Chapter 26 when you examine WPF's graphical rendering services.



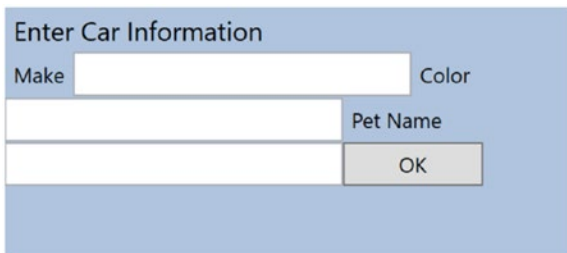
## Positioning Content Within WrapPanel Panels

A `WrapPanel` allows you to define content that will flow across the panel as the window is resized. When positioning elements in a `WrapPanel`, you do not specify top, bottom, left, and right docking values as you typically do with `Canvas`. However, each subelement is free to define a `Height` and `Width` value (among other property values) to control its overall size in the container.

Because content within a `WrapPanel` does not dock to a given side of the panel, the order in which you declare the elements is important (content is rendered from the first element to the last). If you were to load the XAML data found within the `SimpleWrapPanel.xaml` file, you would find it contains the following markup (enclosed within a Page definition):

```
<WrapPanel Background="LightSteelBlue">
  <Label x:Name="lblInstruction" Width="328" Height="27" FontSize="15" Content="Enter Car
  Information"/>
  <Label x:Name="lblMake" Content="Make"/>
  <TextBox x:Name="txtMake" Width="193" Height="25"/>
  <Label x:Name="lblColor" Content="Color"/>
  <TextBox x:Name="txtColor" Width="193" Height="25"/>
  <Label x:Name="lblPetName" Content="Pet Name"/>
  <TextBox x:Name="txtPetName" Width="193" Height="25"/>
  <Button x:Name="btnOK" Width="80" Content="OK"/>
</WrapPanel>
```

When you load this markup, the content looks out of sorts because it flows from left to right across the window (see Figure 25-2).



**Figure 25-2.** Content in a `WrapPanel` behaves much like a traditional HTML page

By default, content within a `WrapPanel` flows from left to right. However, if you change the value of the `Orientation` property to `Vertical`, you can have content wrap in a top-to-bottom manner.

```
<WrapPanel Background="LightSteelBlue" Orientation = "Vertical">
```

You can declare a `WrapPanel` (as well as some other panel types) by specifying `ItemWidth` and `ItemHeight` values, which control the default size of each item. If a subelement does provide its own `Height` and/or `Width` value, it will be positioned relative to the size established by the panel. Consider the following markup:

```

<Page
  xmlns="http://schemas.microsoft.com/winfx/2006/xaml/presentation"
  xmlns:x="http://schemas.microsoft.com/winfx/2006/xaml"
  Title="Fun with Panels!" Height="100" Width="650">
  <WrapPanel Background="LightSteelBlue" Orientation="Horizontal" ItemWidth="200"
    ItemHeight="30">
    <Label x:Name="lblInstruction" FontSize="15" Content="Enter Car Information"/>
    <Label x:Name="lblMake" Content="Make"/>
    <TextBox x:Name="txtMake"/>
    <Label x:Name="lblColor" Content="Color"/>
    <TextBox x:Name="txtColor"/>
    <Label x:Name="lblPetName" Content="Pet Name"/>
    <TextBox x:Name="txtPetName"/>
    <Button x:Name="btnOK" Width="80" Content="OK"/>
  </WrapPanel>
</Page>

```

The rendered code looks like Figure 25-3 (notice the size and position of the Button control, which has a specified unique Width value).



**Figure 25-3** A *WrapPanel* can establish the width and height of a given item

As you might agree after looking at Figure 25-3, a *WrapPanel* is not typically the best choice for arranging content directly in a window because its elements can become scrambled as the user resizes the window. In most cases, a *WrapPanel* will be a subelement to another panel type, allowing a small area of the window to wrap its content when resized (e.g., a *ToolBar* control).

## Positioning Content Within StackPanel Panels

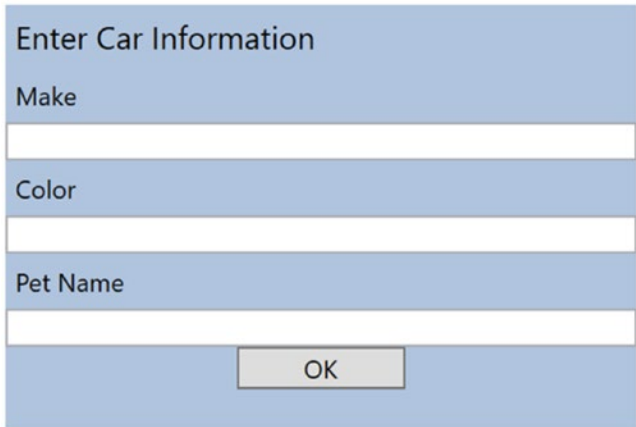
Like a *WrapPanel*, a *StackPanel* control arranges content into a single line that can be oriented horizontally or vertically (the default), based on the value assigned to the *Orientation* property. The difference, however, is that the *StackPanel* will *not* attempt to wrap the content as the user resizes the window. Rather, the items in the *StackPanel* will simply stretch (based on their orientation) to accommodate the size of the *StackPanel* itself. For example, the *SimpleStackPanel.xaml* file contains the following markup, which results in the output shown in Figure 25-4:

```

<Page
  xmlns="http://schemas.microsoft.com/winfx/2006/xaml/presentation"
  xmlns:x="http://schemas.microsoft.com/winfx/2006/xaml"
  Title="Fun with Panels!" Height="200" Width="400">
  <StackPanel Background="LightSteelBlue" Orientation="Vertical">
    <Label Name="lblInstruction"
      FontSize="15" Content="Enter Car Information"/>

```

```
<Label Name="lblMake" Content="Make"/>
<TextBox Name="txtMake"/>
<Label Name="lblColor" Content="Color"/>
<TextBox Name="txtColor"/>
<Label Name="lblPetName" Content="Pet Name"/>
<TextBox Name="txtPetName"/>
<Button Name="btnOK" Width ="80" Content="OK"/>
</StackPanel>
</Page>
```



**Figure 25-4.** Vertical stacking of content

If you assign the `Orientation` property to `Horizontal` as follows, the rendered output will match that shown in Figure 25-5:

```
<StackPanel Background="LightSteelBlue" Orientation="Horizontal">
```



**Figure 25-5.** Horizontal stacking of content

Again, as is the case with the `WrapPanel`, you will seldom want to use a `StackPanel` to arrange content directly within a window. Instead, you should use `StackPanel` as a subpanel to a master panel.

## Positioning Content Within Grid Panels

Of all the panels provided with the WPF APIs, Grid is far and away the most flexible. Like an HTML table, the Grid can be carved up into a set of cells, each one of which provides content. When defining a Grid, you perform three steps:

1. Define and configure each column.
2. Define and configure each row.
3. Assign content to each cell of the grid using attached property syntax.

---

■ **Note** If you do not define any rows or columns, the Grid defaults to a single cell that fills the entire surface of the window. Furthermore, if you do not assign a cell value (column and row) for a subelement within a Grid, it automatically attaches to column 0, row 0.

---

You achieve the first two steps (defining the columns and rows) by using the `Grid.ColumnDefinitions` and `Grid.RowDefinitions` elements, which contain a collection of `ColumnDefinition` and `RowDefinition` elements, respectively. Each cell within a grid is indeed a true .NET object, so you can configure the look and feel and behavior of each cell as you see fit.

Here is a Grid definition (that you can find in the `SimpleGrid.xaml` file) that arranges your UI content as shown in Figure 25-6:

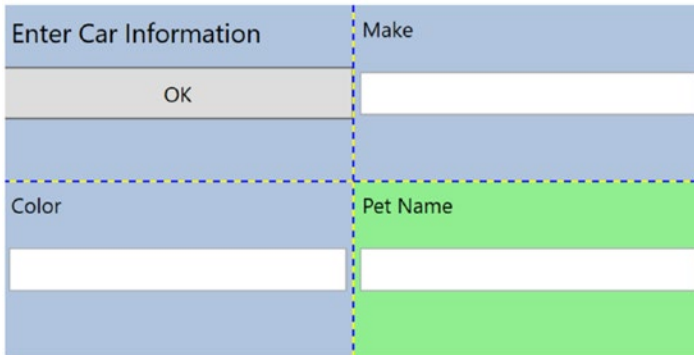
```
<Grid ShowGridLines ="True" Background ="LightSteelBlue">
  <!-- Define the rows/columns -->
  <Grid.ColumnDefinitions>
    <ColumnDefinition/>
    <ColumnDefinition/>
  </Grid.ColumnDefinitions>
  <Grid.RowDefinitions>
    <RowDefinition/>
    <RowDefinition/>
  </Grid.RowDefinitions>

  <!-- Now add the elements to the grid's cells -->
  <Label x:Name="lblInstruction" Grid.Column ="0" Grid.Row ="0"
    FontSize="15" Content="Enter Car Information"/>
  <Button x:Name="btnOK" Height ="30" Grid.Column ="0"
    Grid.Row ="0" Content="OK"/>
  <Label x:Name="lblMake" Grid.Column ="1"
    Grid.Row ="0" Content="Make"/>
  <TextBox x:Name="txtMake" Grid.Column ="1"
    Grid.Row ="0" Width="193" Height="25"/>
  <Label x:Name="lblColor" Grid.Column ="0"
    Grid.Row ="1" Content="Color"/>
  <TextBox x:Name="txtColor" Width="193" Height="25"
    Grid.Column ="0" Grid.Row ="1" />
</Grid>
```

```

<!-- Just to keep things interesting, add some color to the pet name cell -->
<Rectangle Fill="LightGreen" Grid.Column="1" Grid.Row="1" />
<Label x:Name="lblPetName" Grid.Column="1" Grid.Row="1" Content="Pet Name"/>
<TextBox x:Name="txtPetName" Grid.Column="1" Grid.Row="1"
        Width="193" Height="25"/>
</Grid>

```



**Figure 25-6.** The Grid panel in action

Notice that each element (including a light green Rectangle element thrown in for good measure) connects itself to a cell in the grid using the `Grid.Row` and `Grid.Column` attached properties. By default, the ordering of cells in a grid begins at the upper left, which you specify using `Grid.Column="0"` `Grid.Row="0"`. Given that your grid defines a total of four cells, you can identify the bottom-right cell using `Grid.Column="1"` `Grid.Row="1"`.

## Sizing Grid Columns and Rows

Columns and rows in a grid can be sized in one of three ways:

- Absolute sizing (e.g., 100)
- Autosizing
- Relative sizing (e.g., 3x)

Absolute sizing is exactly what you would expect; the column (or row) is sized to a specific number of device-independent units. Autosizing sizes each column or row based on the controls contained within the column or row. Relative sizing is pretty much equivalent to percentage sizing in CSS. The total count of the numbers in relatively sized columns or rows gets divided into the total amount of available space.

In the following example, the first row gets 25 percent of the space, and the second row gets 75 percent of the space:

```

<Grid.ColumnDefinitions>
  <ColumnDefinition Width="1*" />
  <ColumnDefinition Width="3*" />
</Grid.ColumnDefinitions>

```

## Grids with GridSplitter Types

Grid objects can also support *splitters*. As you might know, splitters allow the end user to resize rows or columns of a grid type. As this is done, the content within each resizable cell will reshape itself based on how the items have been contained. Adding splitters to a Grid is easy to do; you simply define the GridSplitter control, using attached property syntax to establish which row or column it affects.

Be aware that you must assign a Width or Height value (depending on vertical or horizontal splitting) for the splitter to be visible on the screen. Consider the following simple Grid type with a splitter on the first column (Grid.Column = "0"). The contents of the provided GridWithSplitter.xaml file look like this:

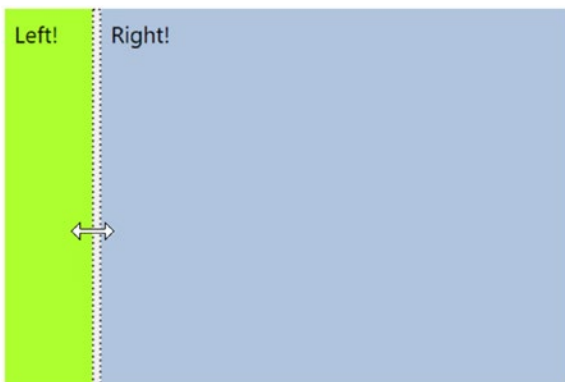
```
<Grid Background ="LightSteelBlue">
  <!-- Define columns -->
  <Grid.ColumnDefinitions>
    <ColumnDefinition Width ="Auto"/>
    <ColumnDefinition/>
  </Grid.ColumnDefinitions>

  <!-- Add this label to cell 0 -->
  <Label x:Name="lblLeft" Background ="GreenYellow"
    Grid.Column="0" Content ="Left!"/>

  <!-- Define the splitter -->
  <GridSplitter Grid.Column ="0" Width ="5"/>

  <!-- Add this label to cell 1 -->
  <Label x:Name="lblRight" Grid.Column ="1" Content ="Right!"/>
</Grid>
```

First, notice that the column that will support the splitter has a Width property of Auto. Next, notice that the GridSplitter uses attached property syntax to establish which column it is working with. If you were to view this output, you would find a five-pixel splitter that allows you to resize each Label. Note that the content fills up the entire cell because you have not specified Height or Width properties for either Label (see Figure 25-7).



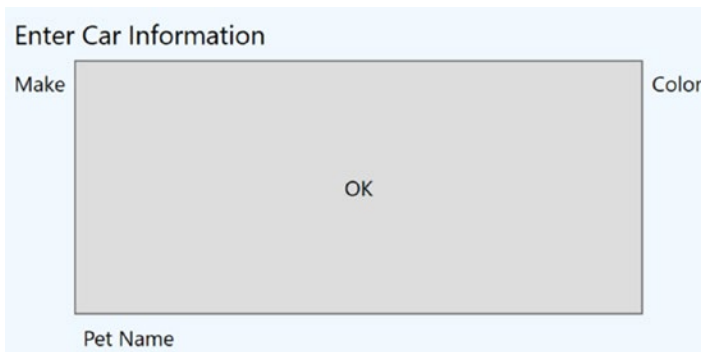
**Figure 25-7.** Grid types containing splitters

## Positioning Content Within DockPanel Panels

DockPanel is typically used as a container that holds any number of additional panels for grouping related content. DockPanels use attached property syntax (as shown with the Canvas or Grid types) to control where each item docks itself within the DockPanel.

The SimpleDockPanel.xaml file defines the following simple DockPanel definition that results in the output shown in Figure 25-8:

```
<DockPanel LastChildFill ="True" Background="AliceBlue">
  <!-- Dock items to the panel -->
  <Label DockPanel.Dock ="Top" Name="lblInstruction" FontSize="15" Content="Enter Car
  Information"/>
  <Label DockPanel.Dock ="Left" Name="lblMake" Content="Make"/>
  <Label DockPanel.Dock ="Right" Name="lblColor" Content="Color"/>
  <Label DockPanel.Dock ="Bottom" Name="lblPetName" Content="Pet Name"/>
  <Button Name="btnOK" Content="OK"/>
</DockPanel>
```



**Figure 25-8.** A simple DockPanel

---

■ **Note** If you add multiple elements to the same side of a DockPanel, they will stack along the specified edge in the order they are declared.

---

The benefit of using DockPanel types is that, as the user resizes the window, each element remains connected to the specified side of the panel (through DockPanel.Dock). Also notice that the opening DockPanel tag in this example sets the LastChildFill attribute to true. Given that the Button control is indeed the “last child” in the container, it will therefore be stretched within the remaining space.

## Enabling Scrolling for Panel Types

It is worth pointing out that WPF supplies a ScrollViewer class, which provides automatic scrolling behaviors for data within panel objects. The SimpleScrollViewer.xaml file defines the following:

```

<ScrollView>
  <StackPanel>
    <Button Content = "First" Background = "Green" Height = "50"/>
    <Button Content = "Second" Background = "Red" Height = "50"/>
    <Button Content = "Third" Background = "Pink" Height = "50"/>
    <Button Content = "Fourth" Background = "Yellow" Height = "50"/>
    <Button Content = "Fifth" Background = "Blue" Height = "50"/>
  </StackPanel>
</ScrollView>

```

You can see the result of the previous XAML definition in Figure 25-9 (notice the scrollbar on the right since the window isn't sized to show all five buttons).



**Figure 25-9.** Working with the *ScrollView* type

As you would expect, each panel provides numerous members that allow you to fine-tune content placement. On a related note, many WPF controls support two properties of interest (*Padding* and *Margin*) that allow the control itself to inform the panel how it wishes to be treated. Specifically, the *Padding* property controls how much extra space should surround the interior control, while *Margin* controls the extra space around the exterior of a control.

This wraps up this chapter's look at the major panel types of WPF, as well as the various ways they position their content. Next, you'll learn how to use the Visual Studio designers to create layouts.

## Configuring Panels Using the Visual Studio Designers

Now that you have been given a walk-through of the XAML used to define some common layout managers, you will be happy to know that Visual Studio has some very good design-time support for constructing your layouts. The key to doing so lies with the Document Outline window described earlier in this chapter. To illustrate some of the basics, create a new WPF application project named *VisualLayoutTester*.

Notice how your initial *Window* makes use of a *Grid* layout by default, as shown here:

```

<Window x:Class="VisualLayoutTester.MainWindow"
  xmlns="http://schemas.microsoft.com/winfx/2006/xaml/presentation"
  xmlns:x="http://schemas.microsoft.com/winfx/2006/xaml"
  xmlns:d="http://schemas.microsoft.com/expression/blend/2008"

```

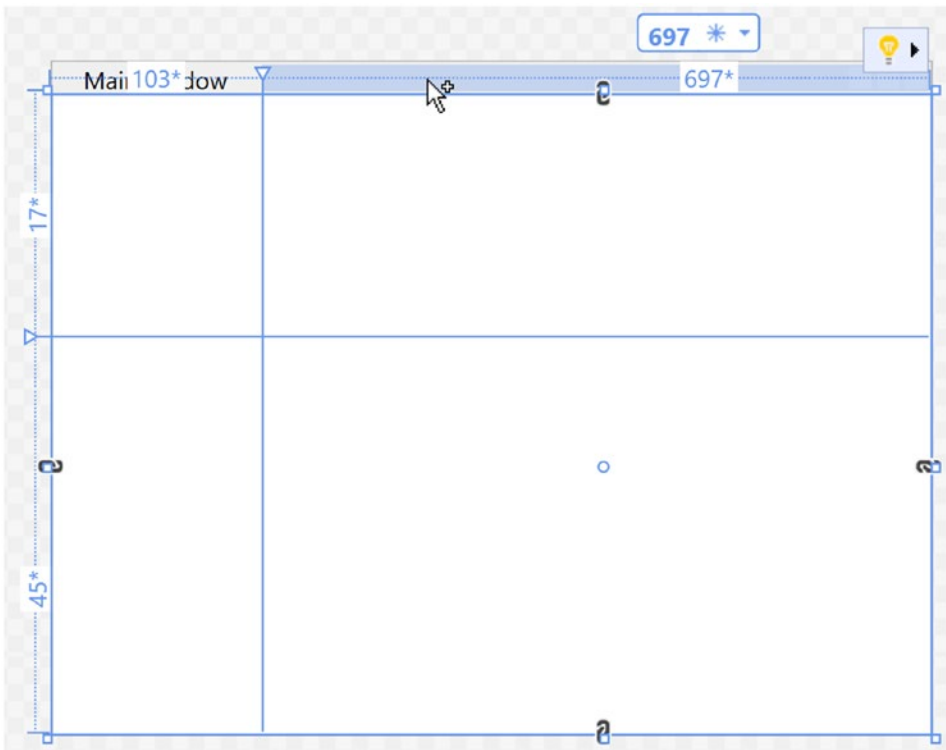


```

xmlns:local="clr-namespace:VisualLayoutTesterApp"
mc:Ignorable="d"
  Title="MainWindow" Height="450" Width="800">
    <Grid>
  </Grid>
</Window>

```

If you are happy using the Grid layout system, notice in Figure 25-10 that you can easily carve out and resize the grid's cells using the visual layout. To do so, first select the Grid component in your Document Outline window and then click the grid's border to create new rows and columns.



**Figure 25-10.** The Grid control can be visually cut into cells using the IDE's designer

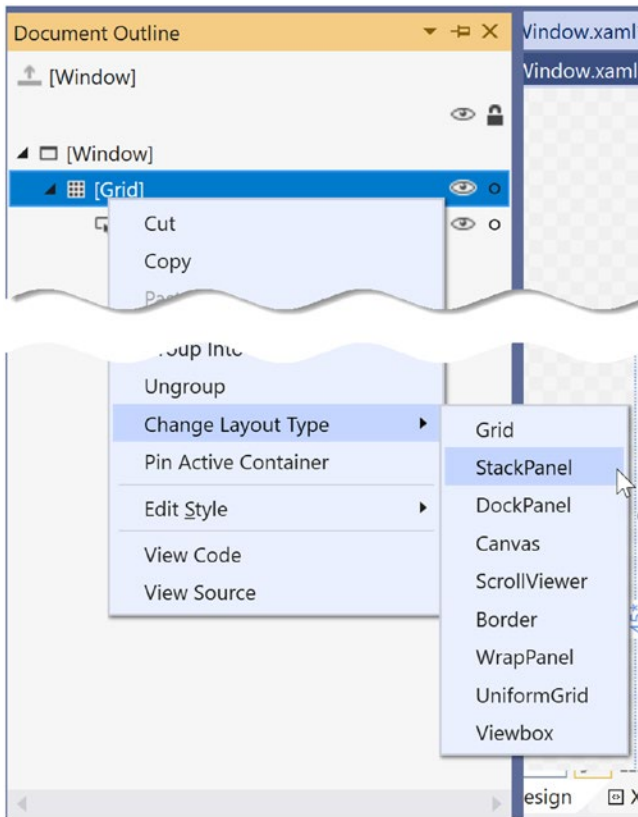
Now, let's say you have defined a grid with some number of cells. You can then drag and drop controls into a given cell of the layout system, and the IDE will automatically set the `Grid.Column` and `Grid.Row` properties of the control in question. Here is some possible markup generated by the IDE after dragging a Button into a predefined cell:

```

<Button x:Name="button" Content="Button" Grid.Column="1" HorizontalAlignment="Left"
Margin="21,21.4,0,0" Grid.Row="1" VerticalAlignment="Top" Width="75"/>

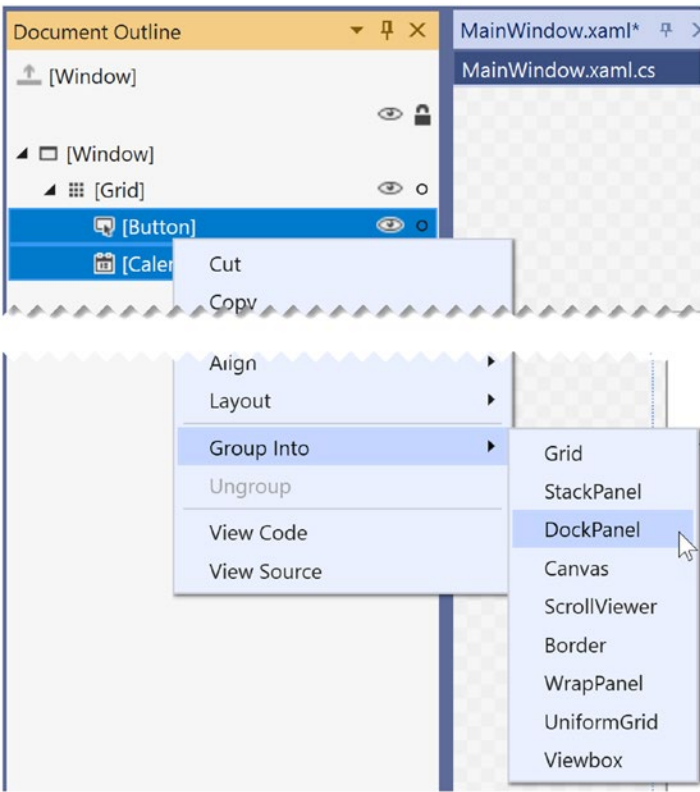
```

Now, let's say you would rather not use a Grid at all. If you right-click any layout node in the Document Outline window, you will find a menu option that allows you to change the current container into another (see Figure 25-11). Be aware that when you do so, you will (most likely) radically change the positioning of the controls because the controls will conform to the rules of the new panel type.



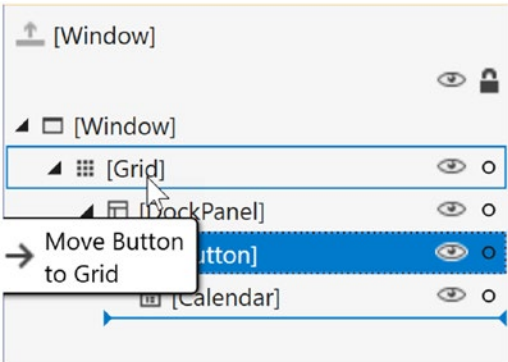
**Figure 25-11.** The Document Outline window allows you to convert to new panel types

Another handy trick is the ability to select a set of controls on the visual designer and group them into a new, nested layout manager. Assume you have a Canvas that defines a set of random objects (if you want to try, convert the initial Grid to a Canvas using the technique shown in Figure 25-11). Now, select a set of items on the designer by holding down the Ctrl key and clicking each item with the left mouse button. If you then right-click the selection, you can group the selected items into a new subpanel (see Figure 25-12).



**Figure 25-12.** Grouping items into a new subpanel

After you have done so, examine the Document Outline window once again to verify the nested layout system. As you build full-featured WPF windows, you will most likely always need to make use of a nested layout system, rather than simply picking a single panel for all of the UI display (in fact, the remaining WPF examples in the text will typically do so). On a final note, the nodes in the Document Outline window are all drag and droppable. For example, if you wanted to move a control currently in the Canvas into the parent panel, you could do so as suggested in Figure 25-13.



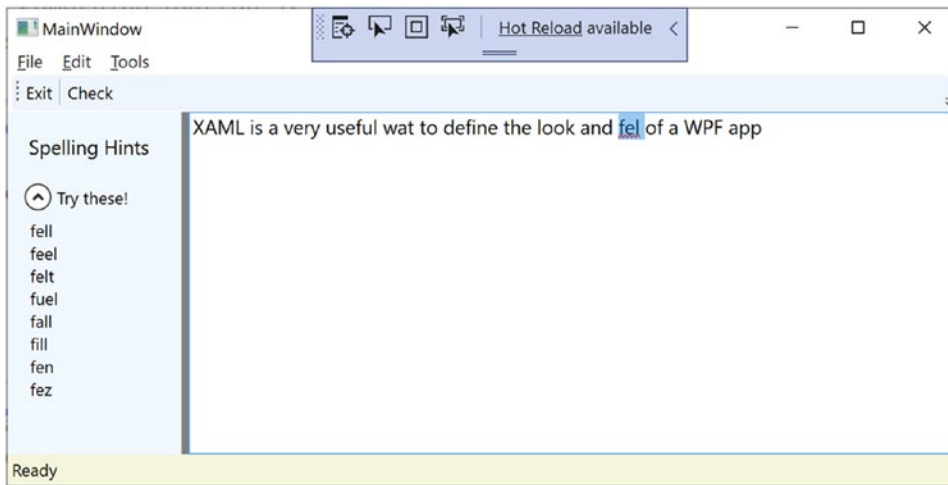
**Figure 25-13.** Relocating items via the Document Outline window

As you work through the remaining WPF chapters, I'll point out additional layout shortcuts where possible. However, it's definitely worth your time to experiment and test various features yourself. To keep you moving in the right direction, the next example in the chapter will illustrate how to build a nested layout manager for a custom text processing application (with spell-checking!).

## Building a Window's Frame Using Nested Panels

As mentioned, a typical WPF window will not use a single panel control but instead will nest panels within other panels to gain the desired layout system. Begin by creating a new WPF application named *MyWordPad*.

Your goal is to construct a layout where the main window has a topmost menu system, a toolbar under the menu system, and a status bar mounted on the bottom of the window. The status bar will contain a pane to hold text prompts that are displayed when the user selects a menu item (or toolbar button), while the menu system and toolbar will offer UI triggers to close the application and display spelling suggestions in an *Expander* widget. Figure 25-14 shows the initial layout you are shooting for; it also shows the spell-checking capabilities within WPF.



**Figure 25-14.** Using nested panels to establish a window's UI

To begin building this UI, update the initial XAML definition for your *Window* type so it uses a *DockPanel* child element, rather than the default *Grid*, as follows:

```
<Window x:Class="MyWordPad.MainWindow"
  xmlns="http://schemas.microsoft.com/winfx/2006/xaml/presentation"
  xmlns:x="http://schemas.microsoft.com/winfx/2006/xaml"
  xmlns:d="http://schemas.microsoft.com/expression/blend/2008"
```

```

xmlns:local="clr-namespace:MyWordPad"
mc:Ignorable="d"
Title="My Spell Checker" Height="450" Width="800">
<!-- This panel establishes the content for the window -->
<DockPanel>
</DockPanel>
</Window>

```

## Building the Menu System

Menu systems in WPF are represented by the `Menu` class, which maintains a collection of `MenuItem` objects. When building a menu system in XAML, you can have each `MenuItem` handle various events. The most notable of these events is `Click`, which occurs when the end user selects a subitem. In this example, you begin by building the two topmost menu items (File and Tools; you will build the Edit menu later in this example), which expose Exit and Spelling Hints subitems, respectively.

In addition to handling the `Click` event for each subitem, you also need to handle the `MouseEnter` and `MouseExit` events, which you will use to set the status bar text in a later step. Add the following markup within your `DockPanel` scope:

```

<!-- Dock menu system on the top -->
<Menu DockPanel.Dock="Top"
    HorizontalAlignment="Left" Background="White" BorderBrush="Black">
  <MenuItem Header="_File">
    <Separator/>
    <MenuItem Header="_Exit" MouseEnter="MouseEnterExitArea"
        MouseLeave="MouseLeaveArea" Click="FileExit_Click"/>
  </MenuItem>
  <MenuItem Header="_Tools">
    <MenuItem Header="_Spelling Hints"
        MouseEnter="MouseEnterToolsHintsArea"
        MouseLeave="MouseLeaveArea" Click="ToolsSpellingHints_Click"/>
  </MenuItem>
</Menu>

```

Notice that you dock the menu system to the top of the `DockPanel`. Also, you use the `Separator` element to insert a thin horizontal line in the menu system, directly before the Exit option. Also notice that the Header values for each `MenuItem` contain an embedded underscore token (e.g., `_Exit`). You use this token to establish which letter will be underlined when the end user presses the Alt key (for keyboard shortcuts). This is a change from the & character used in Windows Forms since XAML is based on XML, and the & character has meaning in XML.

So far you've implemented the complete menu system definition; next, you need to implement the various event handlers. First, you have the File Exit handler, `FileExit_Click()`, which simply closes the window, which in turn terminates the application because this is your topmost window. The `MouseEnter` and `MouseExit` event handlers for each subitem will eventually update your status bar; however, for now, you will simply provide shells. Finally, the `ToolsSpellingHints_Click()` handler for the Tools Spelling Hints menu item will also remain a shell for the time being. Here are the current updates to your code-behind file (including the updated using statements):

```

using System.IO;
using System.Windows;
using System.Windows.Controls;

```

```

using System.Windows.Input;
using Microsoft.Win32;
public partial class MainWindow : Window
{
    public MainWindow()
    {
        InitializeComponent();
    }

    protected void FileExit_Click(object sender, RoutedEventArgs args)
    {
        // Close this window.
        this.Close();
    }

    protected void ToolsSpellingHints_Click(object sender, RoutedEventArgs args)
    {
    }
    protected void MouseEnterExitArea(object sender, RoutedEventArgs args)
    {
    }
    protected void MouseEnterToolsHintsArea(object sender, RoutedEventArgs args)
    {
    }
    protected void MouseLeaveArea(object sender, RoutedEventArgs args)
    {
    }
}

```

## Building Menus Visually

While it is always good to know how to manually define items in XAML, it can be a tad on the tedious side. Visual Studio supports visual design support for menu systems, toolbars, status bars, and many other UI controls. If you right-click the Menu control, you will notice an Add MenuItem option. As the name suggests, this adds a new menu item to the Menu control. After you have added a set of topmost items, you can then add submenu items and separators, expand or collapse the menu itself, and perform other menu-centric operations via a second right-click.

As you see for the remainder of the current MyWordPad example, I'll typically show you the final generated XAML; however, do take the time to experiment with the visual designers to simplify the task at hand.

## Building the Toolbar

Toolbars (represented by the `ToolBar` class in WPF) typically provide an alternative manner for activating a menu option. Add the following markup directly after the closing scope of your Menu definition:

```

<!-- Put Toolbar under the Menu -->
<ToolBar DockPanel.Dock ="Top" >
    <Button Content ="Exit" MouseEnter ="MouseEnterExitArea"
        MouseLeave ="MouseLeaveArea" Click ="FileExit_Click"/>
    <Separator/>

```

```

<Button Content ="Check" MouseEnter ="MouseEnterToolsHintsArea"
        MouseLeave ="MouseLeaveArea" Click ="ToolsSpellingHints_Click"
        Cursor="Help" />
</ToolBar>

```

Your `ToolBar` control consists of two `Button` controls, which just so happen to handle the same events and are handled by the same methods in your code file. Using this technique, you can double up your handlers to serve both menu items and toolbar buttons. Although this toolbar uses the typical push buttons, you should appreciate that the `ToolBar` type “is-a” `ContentControl`; therefore, you are free to embed any types into its surface (e.g., drop-down lists, images, and graphics). The only other point of interest here is that the `Check` button supports a custom mouse cursor through the `Cursor` property.

---

■ **Note** You can optionally wrap the `ToolBar` element within a `ToolBarTray` element, which controls layout, docking, and drag-and-drop operations for a set of `ToolBar` objects.

---

## Building the Status Bar

A `StatusBar` control will be docked to the lower portion of the `DockPanel` and contain a single `TextBlock` control, which you have not used prior to this point in the chapter. You can use a `TextBlock` to hold text that supports numerous textual annotations, such as bold text, underlined text, line breaks, and so forth. Add the following markup directly after the previous `ToolBar` definition:

```

<!-- Put a StatusBar at the bottom -->
<StatusBar DockPanel.Dock ="Bottom" Background="Beige" >
    <StatusBarItem>
        <TextBlock Name="statBarText" Text="Ready"/>
    </StatusBarItem>
</StatusBar>

```

## Finalizing the UI Design

The final aspect of your UI design is to define a splittable `Grid` that defines two columns. On the left, place an `Expander` control that will display a list of spelling suggestions, wrapped within a `StackPanel`. On the right, place a `TextBox` control that supports multiple lines and scrollbars and includes enabled spell-checking. You mount the entire `Grid` to the left of the parent `DockPanel`. Add the following XAML markup directly under the `StatusBar` markup to complete the definition of your window's UI:

```

<Grid DockPanel.Dock ="Left" Background ="AliceBlue">
    <!-- Define the rows and columns -->
    <Grid.ColumnDefinitions>
        <ColumnDefinition />
        <ColumnDefinition />
    </Grid.ColumnDefinitions>

```

```

<GridSplitter Grid.Column="0" Width="5" Background="Gray" />
<StackPanel Grid.Column="0" VerticalAlignment="Stretch" >
    <Label Name="lblSpellingInstructions" FontSize="14" Margin="10,10,0,0">
        Spelling Hints
    </Label>

    <Expander Name="expanderSpelling" Header="Try these!"
        Margin="10,10,10,10">
        <!-- This will be filled programmatically -->
        <Label Name="lblSpellingHints" FontSize="12"/>
    </Expander>
</StackPanel>

<!-- This will be the area to type within -->
<TextBox Grid.Column="1"
    SpellCheck.IsEnabled="True"
    AcceptsReturn="True"
    Name="txtData" FontSize="14"
    BorderBrush="Blue"
    VerticalScrollBarVisibility="Auto"
    HorizontalScrollBarVisibility="Auto">
</TextBox>
</Grid>

```

## Implementing the MouseEnter/MouseLeave Event Handlers

At this point, the UI of your window is complete. The only remaining tasks are to provide an implementation for the remaining event handlers. Begin by updating your C# code file so that each of the `MouseEnter`, `MouseLeave`, and `MouseExit` handlers sets the text pane of the status bar with a fitting message to help the end user, like so:

```

public partial class MainWindow : System.Windows.Window
{
    ...
    protected void MouseEnterExitArea(object sender, RoutedEventArgs args)
    {
        statBarText.Text = "Exit the Application";
    }
    protected void MouseEnterToolsHintsArea(object sender, RoutedEventArgs args)
    {
        statBarText.Text = "Show Spelling Suggestions";
    }
    protected void MouseLeaveArea(object sender, RoutedEventArgs args)
    {
        statBarText.Text = "Ready";
    }
}

```

At this point, you can run your application. You should see your status bar change its text based on which menu item/toolbar button you hover your mouse over.



## Implementing the Spell-Checking Logic

The WPF API ships with built-in spell-checker support, which is independent of Microsoft Office products. This means you don't need to use the COM interop layer to use the spell-checker of Microsoft Word; instead, you can easily add the same type of support with only a few lines of code.

You might recall that when you defined the `TextBox` control, you set the `SpellCheck.IsEnabled` property to `true`. When you do this, misspelled words are underlined with a red squiggle, just as they are in Microsoft Office. Even better, the underlying programming model gives you access to the spell-checker engine, which allows you to get a list of suggestions for misspelled words. Add the following code to your `ToolsSpellingHints_Click()` method:

```
protected void ToolsSpellingHints_Click(object sender, RoutedEventArgs args)
{
    string spellingHints = string.Empty;

    // Try to get a spelling error at the current caret location.
    SpellingError error = txtData.GetSpellingError(txtData.CaretIndex);
    if (error != null)
    {
        // Build a string of spelling suggestions.
        foreach (string s in error.Suggestions)
        {
            spellingHints += $"{s}\n";
        }

        // Show suggestions and expand the expander.
        lblSpellingHints.Content = spellingHints;
        expanderSpelling.IsExpanded = true;
    }
}
```

The preceding code is quite simple. You simply figure out the current location of the caret in the text box by using the `CaretIndex` property to extract a `SpellingError` object. If there is an error at said location (meaning the value is not null), you loop over the list of suggestions using the aptly named `Suggestions` property. After you have all the suggestions for the misspelled word, you connect the data to the `Label` in the `Expander`.

So there you have it! With only a few lines of procedural code (and a healthy dose of XAML), you have the beginnings of a functioning word processor. An understanding of *control commands* can help you add a bit more pizzazz.

## Understanding WPF Commands

WPF provides support for what might be considered *control-agnostic events* via the *command architecture*. A typical .NET Core event is defined within a specific base class and can be used only by that class or a derivative thereof. Therefore, normal .NET Core events are tightly coupled to the class in which they are defined.

In contrast, WPF commands are event-like entities that are independent from a specific control and, in many cases, can be successfully applied to numerous (and seemingly unrelated) control types. By way of a few examples, WPF supports copy, paste, and cut commands, which you can apply to a wide variety of UI elements (e.g., menu items, toolbar buttons, and custom buttons), as well as keyboard shortcuts (e.g., `Ctrl+C` and `Ctrl+V`).

While other UI toolkits (such as Windows Forms) provided standard events for such purposes, using them typically left you with redundant and hard-to-maintain code. Under the WPF model, you can use commands as an alternative. The end result typically yields a smaller and more flexible codebase.

## The Intrinsic Command Objects

WPF ships with numerous built-in control commands, all of which you can configure with associated keyboard shortcuts (or other input gestures). Programmatically speaking, a WPF command is any object that supports a property (often called *Command*) that returns an object implementing the *ICommand* interface, as shown here:

```
public interface ICommand
{
    // Occurs when changes occur that affect whether
    // or not the command should execute.
    event EventHandler CanExecuteChanged;

    // Defines the method that determines whether the command
    // can execute in its current state.
    bool CanExecute(object parameter);

    // Defines the method to be called when the command is invoked.
    void Execute(object parameter);
}
```

WPF provides various command classes, which expose close to 100 command objects, out of the box. These classes define numerous properties that expose specific command objects, each of which implements *ICommand*. Table 25-3 documents some of the standard command objects available.

**Table 25-3.** *The Intrinsic WPF Control Command Objects*

WPF Class	Command Objects	Meaning in Life
ApplicationCommands	Close, Copy, Cut, Delete, Find, Open, Paste, Save, SaveAs, Redo, Undo	Various application-level commands
ComponentCommands	MoveDown, MoveFocusBack, MoveLeft, MoveRight, ScrollToEnd, ScrollToHome	Various commands common to UI components
MediaCommands	BoostBase, ChannelUp, ChannelDown, FastForward, NextTrack, Play, Rewind, Select, Stop	Various media-centric commands
NavigationCommands	BrowseBack, BrowseForward, Favorites, LastPage, NextPage, Zoom	Various commands relating to the WPF navigation model
EditingCommands	AlignCenter, CorrectSpellingError, DecreaseFontSize, EnterLineBreak, EnterParagraphBreak, MoveDownByLine, MoveRightByWord	Various commands relating to the WPF Documents API

## Connecting Commands to the Command Property

If you want to connect any of the WPF command properties to a UI element that supports the `Command` property (such as a `Button` or `MenuItem`), you have very little work to do. You can see how to do this by updating the current menu system so it supports a new topmost menu item named `Edit` and three subitems to account for copying, pasting, and cutting of textual data, like so:

```
<Menu DockPanel.Dock="Top" HorizontalAlignment="Left" Background="White" BorderBrush
="Black">
  <MenuItem Header="_File" Click="FileExit_Click" >
    <MenuItem Header="_Exit" MouseEnter="MouseEnterExitArea" MouseLeave="MouseLeaveArea"
      Click="FileExit_Click"/>
  </MenuItem>

  <!-- New menu item with commands! -->
  <MenuItem Header="_Edit">
    <MenuItem Command="ApplicationCommands.Copy"/>
    <MenuItem Command="ApplicationCommands.Cut"/>
    <MenuItem Command="ApplicationCommands.Paste"/>
  </MenuItem>

  <MenuItem Header="_Tools">
    <MenuItem Header="_Spelling Hints"
      MouseEnter="MouseEnterToolsHintsArea"
      MouseLeave="MouseLeaveArea"
      Click="ToolsSpellingHints_Click"/>
  </MenuItem>
</Menu>
```

Notice that each of the subitems on the `Edit` menu has a value assigned to the `Command` property. Doing this means that the menu items automatically receive the correct name and shortcut key (e.g., `Ctrl+C` for a cut operation) in the menu item UI; it also means that the application is now *copy*, *cut*, and *paste* aware with no procedural code!

If you run the application and select some of text, you can use your new menu items out of the box. As a bonus, your application is also equipped to respond to a standard right-click operation to present the user with the same options.

## Connecting Commands to Arbitrary Actions

If you want to connect a command object to an arbitrary (application-specific) event, you will need to drop down to procedural code. Doing so is not complex, but it does involve a bit more logic than you see in XAML. For example, assume that you want to have the entire window respond to the `F1` key so that when the end user presses this key, he will activate an associated help system. Also, assume your code file for the main window defines a new method named `SetF1CommandBinding()`, which you call within the constructor after the call to `InitializeComponent()`.

```
public MainWindow()
{
    InitializeComponent();
    SetF1CommandBinding();
}
```

This new method will programmatically create a new `CommandBinding` object, which you can use whenever you need to bind a command object to a given event handler in your application. Here, you configure your `CommandBinding` object to operate with the `ApplicationCommands.Help` command, which is automatically F1 aware:

```
private void SetF1CommandBinding()
{
    CommandBinding helpBinding = new CommandBinding(ApplicationCommands.Help);
    helpBinding.CanExecute += CanHelpExecute;
    helpBinding.Executed += HelpExecuted;
    CommandBindings.Add(helpBinding);
}
```

Most `CommandBinding` objects will want to handle the `CanExecute` event (which allows you to specify whether the command occurs based on the operation of your program) and the `Executed` event (which is where you can author the content that should occur once the command occurs). Add the following event handlers to your Window-derived type (note the format of each method, as required by the associated delegates):

```
private void CanHelpExecute(object sender, CanExecuteRoutedEventArgs e)
{
    // Here, you can set CanExecute to false if you want to prevent the command from
executing.
    e.CanExecute = true;
}

private void HelpExecuted(object sender, ExecutedRoutedEventArgs e)
{
    MessageBox.Show("Look, it is not that difficult. Just type something!", "Help!");
}
```

In the preceding snippet, you implemented `CanHelpExecute()` so it always allows F1 help to launch; you do this by simply returning `true`. However, if you have certain situations where the help system should not display, you can account for this and return `false` when necessary. Your “help system” displayed within `HelpExecuted()` is little more than a message box. At this point, you can run your application. When you press the F1 key on your keyboard, you will see your message box appear.

## Working with the Open and Save Commands

To complete the current example, you will add functionality to save your text data to an external file and open up \*.txt files for editing. If you want to take the long road, you can manually add programming logic that enables or disables new menu items based on whether your `TextBox` has data inside it. Once again, however, you can use commands to decrease your burden.

Begin by updating the `MenuItem` element that represents your topmost File menu by adding the following two new submenus that use the `Save` and `Open` `ApplicationCommands` objects:

```
<MenuItem Header="_File">
    <MenuItem Command ="ApplicationCommands.Open"/>
    <MenuItem Command ="ApplicationCommands.Save"/>
    <Separator/>
```

```

<MenuItem Header ="_Exit"
            MouseEnter ="MouseEnterExitArea"
            MouseLeave ="MouseLeaveArea" Click ="FileExit_Click"/>
</MenuItem>

```

Again, remember that all command objects implement the `ICommand` interface, which defines two events (`CanExecute` and `Executed`). Now you need to enable the entire window so it can check whether it is currently okay to fire these commands; if so, you can define an event handler to execute the custom code.

You do this by populating the `CommandBindings` collection maintained by the window. Doing so in XAML requires that you use property-element syntax to define a `Window.CommandBindings` scope in which you place two `CommandBinding` definitions. Update your `Window` like this:

```

<Window x:Class="MyWordPad.MainWindow"
        xmlns="http://schemas.microsoft.com/winfx/2006/xaml/presentation"
        xmlns:x="http://schemas.microsoft.com/winfx/2006/xaml"
        Title="MySpellChecker" Height="331" Width="508"
        WindowStartupLocation ="CenterScreen" >

    <!-- This will inform the Window which handlers to call,
         when testing for the Open and Save commands. -->
    <Window.CommandBindings>
        <CommandBinding Command="ApplicationCommands.Open"
                        Executed="OpenCmdExecuted"
                        CanExecute="OpenCmdCanExecute"/>
        <CommandBinding Command="ApplicationCommands.Save"
                        Executed="SaveCmdExecuted"
                        CanExecute="SaveCmdCanExecute"/>
    </Window.CommandBindings>

    <!-- This panel establishes the content for the window -->
    <DockPanel>
        ...
    </DockPanel>
</Window>

```

Now right-click each of the `Executed` and `CanExecute` attributes in your XAML editor and pick the `Navigate to Event Handler` menu option. As you might recall from Chapter 24, this will automatically generate stub code for the event itself. At this point, you should have four empty handlers in the C# code file for the window.

The implementation of `CanExecute` event handlers will tell the window that it is okay to fire the corresponding `Executed` events at any time by setting the `CanExecute` property of the incoming `CanExecuteRoutedEventArgs` object.

```

private void OpenCmdCanExecute(object sender, CanExecuteRoutedEventArgs e)
{
    e.CanExecute = true;
}

```

```
private void SaveCmdCanExecute(object sender, CanExecuteRoutedEventArgs e)
{
    e.CanExecute = true;
}
```

The corresponding Executed handlers perform the actual work of displaying the open and save dialog boxes; they also send the data in your TextBox to a file. Begin by making sure that you import the `System.IO` and `Microsoft.Win32` namespaces into your code file. The following completed code is straightforward:

```
private void OpenCmdExecuted(object sender, ExecutedRoutedEventArgs e)
{
    // Create an open file dialog box and only show XAML files.
    var openDlg = new OpenFileDialog { Filter = "Text Files (*.txt)";

    // Did they click on the OK button?
    if (true == openDlg.ShowDialog())
    {
        // Load all text of selected file.
        string dataFromFile = File.ReadAllText(openDlg.FileName);

        // Show string in TextBox.
        txtData.Text = dataFromFile;
    }
}

private void SaveCmdExecuted(object sender, ExecutedRoutedEventArgs e)
{
    var saveDlg = new SaveFileDialog { Filter = "Text Files (*.txt)";

    // Did they click on the OK button?
    if (true == saveDlg.ShowDialog())
    {
        // Save data in the TextBox to the named file.
        File.WriteAllText(saveDlg.FileName, txtData.Text);
    }
}
```

---

■ **Note** Chapter 30 will take a much deeper look into the WPF command system. In it, you will create custom commands based on `ICommand` as well as `RelayCommands`.

---

That wraps up this example and your initial look at working with WPF controls. Here, you learned how to work with basic commands, menu systems, status bars, toolbars, nested panels, and a few basic UI controls, such as `TextBox` and `Expander`. The next example will work with some more exotic controls while examining several important WPF services at the same time.

## Understanding Routed Events

You might have noticed the `RoutedEventArgs` parameter instead of `EventArgs` in the previous code example. The routed events model is a refinement of the standard CLR event model designed to ensure that events can be processed in a manner that is fitting for XAML's description of a tree of objects. Assume you have a new WPF application project named `WPF Routed Events`. Now, update the XAML description of the initial window by adding the following `Button` control, which defines some complex content:

```
<Window ...
  <Grid>
    <Button Name="btnClickMe" Height="75" Width = "250"
      Click ="btnClickMe_Clicked">
      <StackPanel Orientation ="Horizontal">
        <Label Height="50" FontSize ="20">
          Fancy Button!</Label>
        <Canvas Height ="50" Width ="100" >
          <Ellipse Name = "outerEllipse" Fill ="Green"
            Height ="25" Width ="50" Cursor="Hand"
            Canvas.Left="25" Canvas.Top="12"/>
          <Ellipse Name = "innerEllipse" Fill ="Yellow"
            Height = "15" Width ="36"
            Canvas.Top="17" Canvas.Left="32"/>
        </Canvas>
      </StackPanel>
    </Button>
  </Grid>
</Window>
```

Notice in the `Button`'s opening definition you have handled the `Click` event by specifying the name of a method to be called when the event is raised. The `Click` event works with the `RoutedEventHandler` delegate, which expects an event handler that takes an object as the first parameter and a `System.Windows.RoutedEventArgs` as the second. Implement this handler as so:

```
public void btnClickMe_Clicked(object sender, RoutedEventArgs e)
{
  // Do something when button is clicked.
  MessageBox.Show("Clicked the button");
}
```

If you run your application, you will see this message box display, regardless of which part of the button's content you click (the green `Ellipse`, the yellow `Ellipse`, the `Label`, or the `Button`'s surface). This is a good thing. Imagine how tedious WPF event handling would be if you were forced to handle a `Click` event for every one of these subelements. Not only would the creation of separate event handlers for each aspect of the `Button` be labor intensive, you would end up with some mighty nasty code to maintain down the road.

Thankfully, WPF *routed events* take care of ensuring that your single `Click` event handler will be called regardless of which part of the button is clicked automatically. Simply put, the routed events model automatically propagates an event up (or down) a tree of objects, looking for an appropriate handler.

Specifically speaking, a routed event can make use of three *routing strategies*. If an event is moving from the point of origin up to other defining scopes within the object tree, the event is said to be a *bubbling event*. Conversely, if an event is moving from the outermost element (e.g., a Window) down to the point of origin, the event is said to be a *tunneling event*. Finally, if an event is raised and handled only by the originating element (which is what could be described as a normal CLR event), it is said to be a *direct event*.

## The Role of Routed Bubbling Events

In the current example, if the user clicks the inner yellow oval, the Click event bubbles out to the next level of scope (the Canvas), then to the StackPanel, and finally to the Button where the Click event handler is handled. In a similar way, if the user clicks the Label, the event is bubbled to the StackPanel and then finally to the Button element.

Given this bubbling routed event pattern, you have no need to worry about registering specific Click event handlers for all members of a composite control. However, if you want to perform custom clicking logic for multiple elements within the same object tree, you can do so.

By way of illustration, assume you need to handle the clicking of the outerEllipse control in a unique manner. First, handle the MouseDown event for this subelement (graphically rendered types such as the Ellipse do not support a Click event; however, they can monitor mouse button activity via MouseDown, MouseUp, etc.).

```
<Button Name="btnClickMe" Height="75" Width = "250"
    Click ="btnClickMe_Clicked">
  <StackPanel Orientation ="Horizontal">
    <Label Height="50" FontSize ="20">Fancy Button!</Label>
    <Canvas Height ="50" Width ="100" >
      <Ellipse Name = "outerEllipse" Fill ="Green"
        Height ="25" MouseDown ="outerEllipse_MouseDown"
        Width ="50" Cursor="Hand" Canvas.Left="25" Canvas.Top="12"/>
      <Ellipse Name = "innerEllipse" Fill ="Yellow" Height = "15" Width ="36"
        Canvas.Top="17" Canvas.Left="32"/>
    </Canvas>
  </StackPanel>
</Button>
```

Then implement an appropriate event handler, which for illustrative purposes will simply change the Title property of the main window, like so:

```
public void outerEllipse_MouseDown(object sender, MouseButtonEventArgs e)
{
    // Change title of window.
    this.Title = "You clicked the outer ellipse!";
}
```

With this, you can now take different courses of action depending on where the end user has clicked (which boils down to the outer ellipse and everywhere else within the button's scope).

---

■ **Note** Routed bubbling events always move from the point of origin to the *next defining scope*. Thus, in this example, if you click the innerEllipse object, the event will be bubbled to the Canvas, *not* to the outerEllipse because they are both Ellipse types within the scope of Canvas.

---



## Continuing or Halting Bubbling

Currently, if the user clicks the `outerEllipse` object, it will trigger the registered `MouseDown` event handler for this `Ellipse` object, at which point the event bubbles to the button's `Click` event. If you want to inform WPF to stop bubbling up the tree of objects, you can set the `Handled` property of the `EventArgs` parameter to `true`, as follows:

```
public void outerEllipse_MouseDown(object sender, MouseButtonEventArgs e)
{
    // Change title of window.
    this.Title = "You clicked the outer ellipse!";
    // Stop bubbling!
    e.Handled = true;
}
```

In this case, you would find that the title of the window is changed, but you will not see the `MessageBox` displayed by the `Click` event handler of the `Button`. In a nutshell, routed bubbling events make it possible to allow a complex group of content to act either as a single logical element (e.g., a `Button`) or as discrete items (e.g., an `Ellipse` within the `Button`).

## The Role of Routed Tunneling Events

Strictly speaking, routed events can be *bubbling* (as just described) or *tunneling* in nature. Tunneling events (which all begin with the `Preview` suffix – e.g., `PreviewMouseDown`) drill down from the topmost element into the inner scopes of the object tree. By and large, each bubbling event in the WPF base class libraries is paired with a related tunneling event that fires *before* the bubbling counterpart. For example, before the bubbling `MouseDown` event fires, the tunneling `PreviewMouseDown` event fires first.

Handling a tunneling event looks just like the processing of handling any other events; simply assign the event handler name in XAML (or, if needed, use the corresponding C# event-handling syntax in your code file) and implement the handler in the code file. Just to illustrate the interplay of tunneling and bubbling events, begin by handling the `PreviewMouseDown` event for the `outerEllipse` object, like so:

```
<Ellipse Name = "outerEllipse" Fill ="Green" Height ="25"
    MouseDown ="outerEllipse_MouseDown"
    PreviewMouseDown ="outerEllipse_PreviewMouseDown"
    Width ="50" Cursor="Hand" Canvas.Left="25" Canvas.Top="12"/>
```

Next, retrofit the current C# class definition by updating each event handler (for all objects) to append data about the current event into a string member variable named `mouseActivity`, using the incoming event args object. This will allow you to observe the flow of events firing in the background.

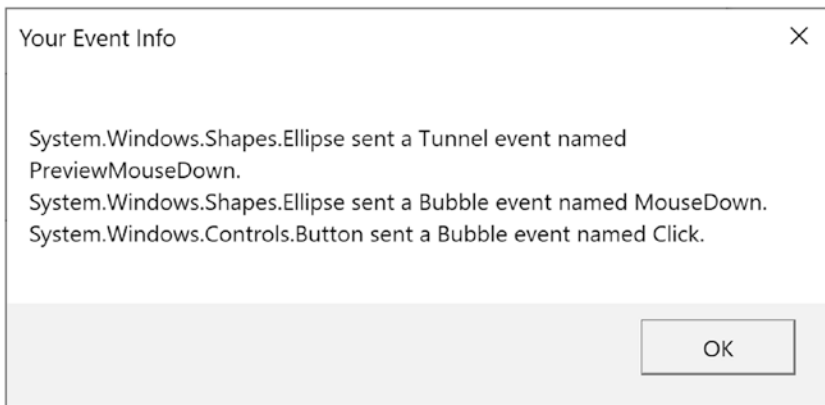
```
public partial class MainWindow : Window
{
    string _mouseActivity = string.Empty;
    public MainWindow()
    {
        InitializeComponent();
    }
}
```

```

public void btnClickMe_Clicked(object sender, RoutedEventArgs e)
{
    AddEventInfo(sender, e);
    MessageBox.Show(_mouseActivity, "Your Event Info");
    // Clear string for next round.
    _mouseActivity = "";
}
private void AddEventInfo(object sender, RoutedEventArgs e)
{
    _mouseActivity += string.Format(
        "{0} sent a {1} event named {2}.\n", sender,
        e.RoutedEvent.RoutingStrategy,
        e.RoutedEvent.Name);
}
private void outerEllipse_MouseDown(object sender, MouseButtonEventArgs e)
{
    AddEventInfo(sender, e);
}
private void outerEllipse_PreviewMouseDown(object sender, MouseButtonEventArgs e)
{
    AddEventInfo(sender, e);
}
}

```

Notice that you are not halting the bubbling of an event for any event handler. If you run this application, you will see a unique message box display based on where you click the button. Figure 25-15 shows the result of clicking the outer Ellipse object.



**Figure 25-15.** Tunneling first, bubbling second

So, why do WPF events typically tend to come in pairs (one tunneling and one bubbling)? The answer is that by previewing events, you have the power to perform any special logic (data validation, disable bubbling action, etc.) before the bubbling counterpart fires. By way of an example, assume you have a `TextBox` that should contain only numerical data. You could handle the `PreviewKeyDown` event, and if you see the user has entered non-numerical data, you could cancel the bubbling event by setting the `Handled` property to `true`.

As you would guess, when you are building a custom control that contains custom events, you could author the event in such a way that it can bubble (or tunnel) through a tree of XAML. For the purpose of this chapter, I will not be examining how to build custom routed events (however, the process is not that different from building a custom dependency property). If you are interested, check out the topic “Routed Events Overview” within the .NET Framework 4.7 SDK documentation. In it you will find a number of tutorials that will help you on your way.

## A Deeper Look at WPF APIs and Controls

The remainder of this chapter will give you a chance to build a new WPF application using Visual Studio. The goal is to create a UI that consists of a `TabControl` widget containing a set of tabs. Each tab will illustrate some new WPF controls and interesting APIs you might want to make use of in your software projects. Along the way, you will also learn additional features of the Visual Studio WPF designers.

### Working with the TabControl

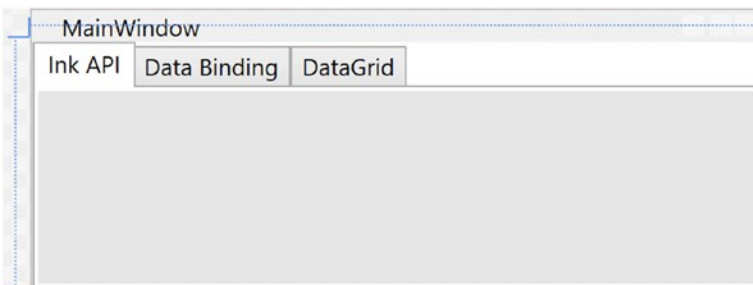
To get started, create a new WPF application named `WpfControlsAndAPIs`. As mentioned, your initial window will contain a `TabControl` with three different tabs, each of which shows off a set of related controls and/or WPF APIs. Update the window’s `Width` to 800 and `Height` to 350.

Locate the `TabControl` control in the Visual Studio toolbox, drop one onto your designer, and update the markup to the following:

```
<TabControl Name="MyTabControl" HorizontalAlignment="Stretch" VerticalAlignment="Stretch">
  <TabItem Header="TabItem">
    <Grid Background="#FFE5E5E5"/>
  </TabItem>
  <TabItem Header="TabItem">
    <Grid Background="#FFE5E5E5"/>
  </TabItem>
</TabControl>
```

You will notice that you are given two tab items automatically. To add additional tabs, you simply need to right-click the `TabControl` node in the Document Outline window and select the `Add TabItem` menu option (you can also right-click the `TabControl` on the designer to activate the same menu option) or just start typing in the XAML editor. Add one additional tab using either approach.

Now, update each `TabItem` control through the XAML editor and change the `Header` property for each tab, naming them `Ink API`, `Data Binding`, and `DataGrid`. At this point, your window designer should look like what you see in Figure 25-16.



**Figure 25-16.** The initial layout of the tab system

Be aware that when you select a tab for editing, that tab becomes the active tab, and you can design that tab by dragging controls from the Toolbox window. Now that you have the core `TabControl` defined, you can work out the details tab by tab and learn more features of the WPF API along the way.

## Building the Ink API Tab

The first tab will be used to show the overall role of WPF's digital Ink API, which allows you to incorporate painting functionality into a program easily. Of course, the application does not literally need to be a painting application; you can use this API for a wide variety of purposes, including capturing handwriting input.

---

■ **Note** For most of the rest of this chapter (and the next WPF chapters as well), I will be editing the XAML directly instead of using the various windows. While the dragging and dropping of controls works, more often than not the layout isn't what you want (Visual Studio adds in margins and padding based on where you drop the control), and you spend a significant amount of time cleaning up the XAML anyway.

---

Begin by changing the `Grid` tag under the `Ink API TabItem` to a `StackPanel` and add a closing tag (make sure to remove `"/"` from the opening tag). Your markup should look like this:

```
<TabItem Header="Ink API">
  <StackPanel Background="#FFE5E5">
    </StackPanel>
</TabItem>
```

## Designing the Toolbar

Add a new `ToolBar` control (using the XAML editor) named `InkToolBar` with a height of 60

```
.<ToolBar Name="InkToolBar" Height="60">
</ToolBar>
```

Add three `RadioButton` controls inside a `WrapPanel`, inside a `Border` control, as follows:

```
<Border Margin="0,2,0,2.4" Width="280" VerticalAlignment="Center">
  <WrapPanel>
    <RadioButton x:Name="inkRadio" Margin="5,10" Content="Ink Mode!" IsChecked="True" />
    <RadioButton x:Name="eraseRadio" Margin="5,10" Content="Erase Mode!" />
    <RadioButton x:Name="selectRadio" Margin="5,10" Content="Select Mode!" />
  </WrapPanel>
</Border>
```

When a `RadioButton` control is not placed inside of a parent panel control, it will take on a UI identical to a `Button` control! That's why I wrapped the `RadioButton` controls in the `WrapPanel`.

Next, add a `Separator` and then a `ComboBox` with a `Width` of 175 and a `Margin` of 10,0,0,0. Add three `ComboBoxItem` tags with content of Red, Green, and Blue, and follow the entire `ComboBox` with another `Separator` control, as follows:

```
<Separator/>
<ComboBox x:Name="comboColors" Width="175" Margin="10,0,0,0">
  <ComboBoxItem Content="Red"/>
  <ComboBoxItem Content="Green"/>
  <ComboBoxItem Content="Blue"/>
</ComboBox>
<Separator/>
```

## The RadioButton Control

In this example, you want these three `RadioButton` controls to be mutually exclusive. In other GUI frameworks, ensuring that a group of related controls (such as radio buttons) were mutually exclusive required that you place them in the same group box. You don't need to do this under WPF. Instead, you can simply assign them all to the same *group name*. This is helpful because the related items do not need to be physically collected in the same area but can be anywhere in the window.

The `RadioButton` class includes an `IsChecked` property, which toggles between `true` and `false` when the end user clicks the UI element. Furthermore, `RadioButton` provides two events (`Checked` and `Unchecked`) that you can use to intercept this state change.

## Add the Save, Load, and Delete Buttons

The final controls in the `ToolBar` control will be a `Grid` holding three `Button` controls. Add the following markup after the last `Separator` control:

```
<Grid>
  <Grid.ColumnDefinitions>
    <ColumnDefinition Width="Auto"/>
    <ColumnDefinition Width="Auto"/>
    <ColumnDefinition Width="Auto"/>
  </Grid.ColumnDefinitions>
  <Button Grid.Column="0" x:Name="btnSave" Margin="10,10" Width="70" Content="Save Data"/>
  <Button Grid.Column="1" x:Name="btnLoad" Margin="10,10" Width="70" Content="Load Data"/>
  <Button Grid.Column="2" x:Name="btnClear" Margin="10,10" Width="70" Content="Clear"/>
</Grid>
```

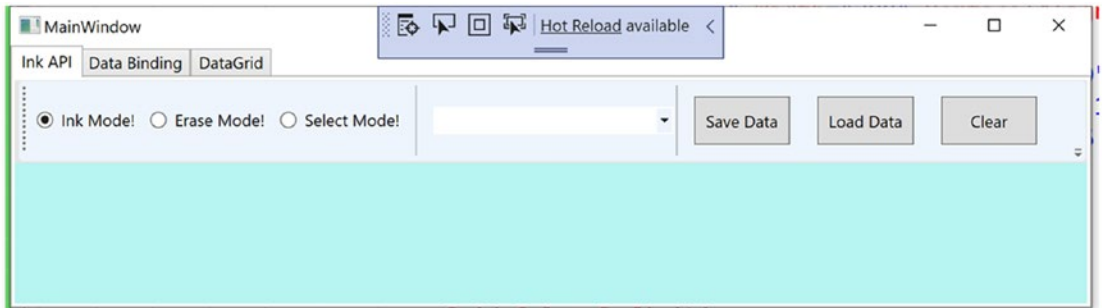
## Add the InkCanvas Control

The final control for the `TabControl` is the `InkCanvas` control. Add the following markup after the closing `ToolBar` tag and before the closing `StackPanel` tag, as follows:

```
<InkCanvas x:Name="MyInkCanvas" Background="#FFB6F4F1" />
```

## Preview the Window

At this point, you're ready to test the program, which you can do by pressing the F5 key. You should now see three mutually exclusive radio buttons, a combo box with three selections, and three buttons (see Figure 25-17).



**Figure 25-17.** The completed layout for the Ink API tab

## Handling Events for the Ink API Tab

The next step for the Ink API tab is to handle the Click event for each RadioButton control. As you have done in other WPF projects in this book, simply click the lightning bolt icon of the Visual Studio Properties editor to enter the names of event handlers. Using this approach, route the Click event for each button to the same handler, named `RadioButtonClicked`. After you handle all three Click events, handle the `SelectionChanged` event of the ComboBox using a handler named `ColorChanged`. When you finish, you should have the following C# code:

```
public partial class MainWindow : Window
{
    public MainWindow()
    {
        this.InitializeComponent();

        // Insert code required on object creation below this point.
    }
    private void RadioButtonClicked(object sender, RoutedEventArgs e)
    {
        // TODO: Add event handler implementation here.
    }

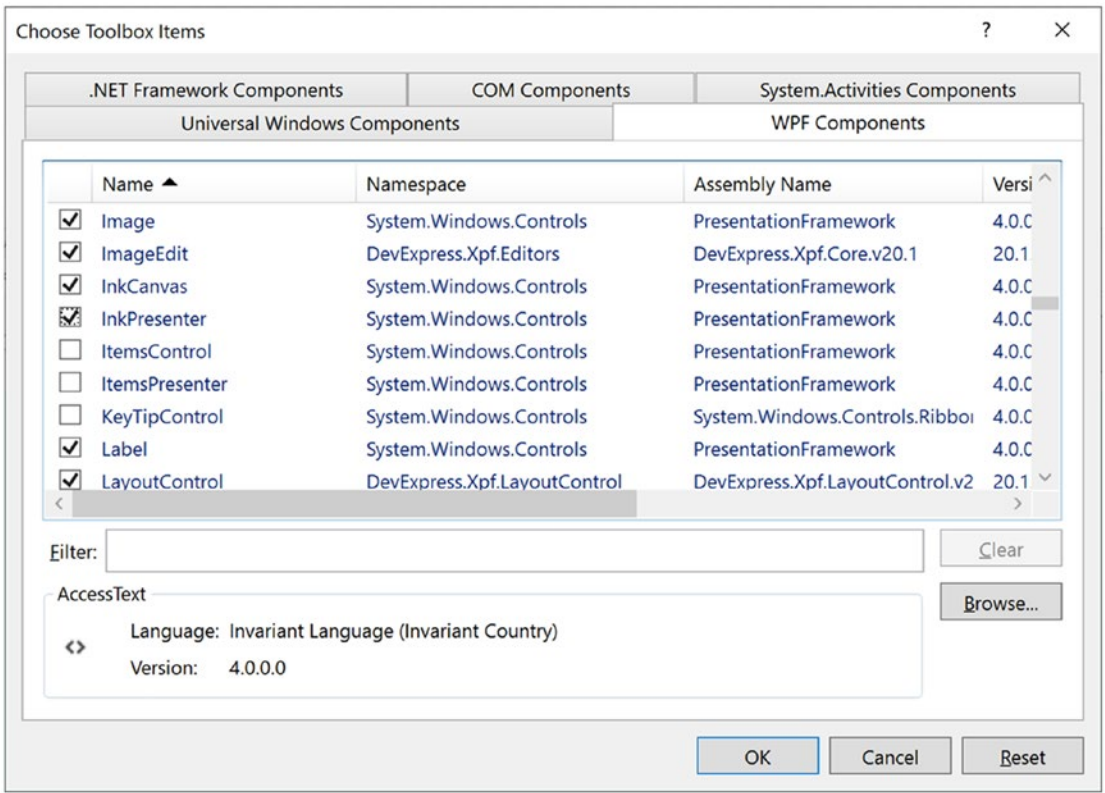
    private void ColorChanged(object sender, SelectionChangedEventArgs e)
    {
        // TODO: Add event handler implementation here.
    }
}
```

You will implement these handlers in a later step, so leave them empty for the time being.

## Add Controls to the Toolbox

You added an InkCanvas control by editing the XAML directly. If you wanted to use the UI to add it, the Visual Studio toolbox does *not* show you every possible WPF component by default. But you can update the items that are displayed in the toolbox.

To do so, right-click anywhere in the Toolbox area and select the Choose Items menu option. After a moment or two, you will see a list of possible components to add to the Toolbox. For your purposes, you are interested in adding the InkCanvas control (see Figure 25-18).



**Figure 25-18.** Adding new components to the Visual Studio Toolbox

## The InkCanvas Control

Just adding the InkCanvas enables drawing in your window. You can use your mouse or, if you have a touch-enabled device, your finger or a digitizer pen. Run the application and draw into the box (see Figure 25-19).



**Figure 25-19.** The *InkCanvas* in action

The *InkCanvas* does more than draw mouse (or stylus) strokes; it also supports a number of unique editing modes, controlled by the *EditingMode* property. You can assign this property any value from the related *InkCanvasEditingMode* enumeration. For this example, you are interested in Ink mode, which is the default option you just witnessed; Select mode, which allows the user to select a region with the mouse to move or resize; and *EraseByStoke*, which will delete the previous mouse stroke.

---

■ **Note** A *stroke* is the rendering that takes place during a single mouse down/mouse up operation. The *InkCanvas* stores all strokes in a *StrokeCollection* object, which you can access using the *Strokes* property.

---

Update your *RadioButtonClicked()* handler with the following logic, which places the *InkCanvas* in the correct mode, based on the selected *RadioButton*:

```
private void RadioButtonClicked(object sender, RoutedEventArgs e)
{
    // Based on which button sent the event, place the InkCanvas in a unique
    // mode of operation.
    this.MyInkCanvas.EditingMode = (sender as RadioButton)?.Content.ToString() switch
    {
        // These strings must be the same as the Content values for each
        // RadioButton.
        "Ink Mode!" => InkCanvasEditingMode.Ink,
        "Erase Mode!" => InkCanvasEditingMode.EraseByStroke,
        "Select Mode!" => InkCanvasEditingMode.Select,
        _ => this.MyInkCanvas.EditingMode
    };
}
```



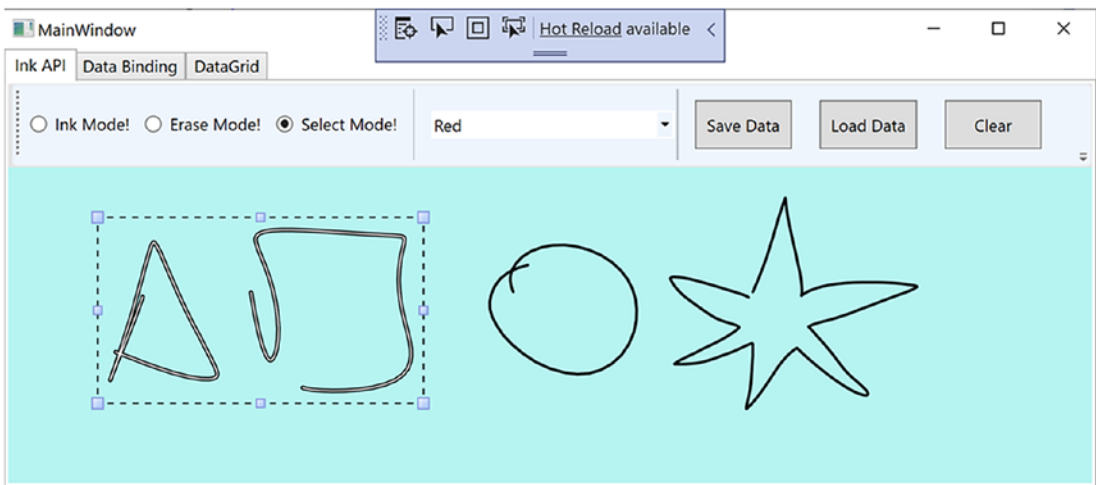
Also, set the mode to Ink by default in the window's constructor. And while you are at it, set a default selection for the ComboBox (more details on this control in the next section), as follows:

```
public MainWindow()
{
    this.InitializeComponent();

    // Be in Ink mode by default.
    this.MyInkCanvas.EditingMode = InkCanvasEditingMode.Ink;
    this.inkRadio.IsChecked = true;
    this.comboColors.SelectedIndex = 0;
}
```

Now run your program again by pressing F5. Enter Ink mode and draw some data. Next, enter Erase mode and remove the previous mouse stroke you entered (you'll notice the mouse icon automatically looks like an eraser). Finally, enter Select mode and select some strokes by using the mouse as a lasso.

After you circle the item, you can move it around the canvas and resize its dimensions. Figure 25-20 shows your edit modes at work.



**Figure 25-20.** The InkCanvas in action, with edit modes!

## The ComboBox Control

After you populate a ComboBox control (or a ListBox), you have three ways to determine the selected item. First, if you want to find the numerical index of the item selected, you can use the `SelectedIndex` property (which is zero based; a value of -1 represents no selection). Second, if you want to obtain the object within the list that has been selected, the `SelectedItem` property fits the bill. Third, the `SelectedValue` allows you to obtain the value of the selected object (typically obtained using a call to `ToString()`).

You need to add the last bit of code for this tab to change the color of the strokes entered on the InkCanvas. The `DefaultDrawingAttributes` property of InkCanvas returns a `DrawingAttributes` object that allows you to configure numerous aspects of the pen nib, including its size and color (among other settings). Update your C# code with this implementation of the `ColorChanged()` method:

```
private void ColorChanged(object sender, SelectionChangedEventArgs e)
{
    // Get the selected value in the combo box.
    string colorToUse =
        (this.comboColors.SelectedItem as ComboBoxItem)?.Content.ToString();

    // Change the color used to render the strokes.
    this.MyInkCanvas.DefaultDrawingAttributes.Color =
        (Color)ColorConverter.ConvertFromString(colorToUse);
}
```

Now recall that the `ComboBox` has a collection of `ComboBoxItems`. If you view the generated XAML, you'll see the following definition:

```
<ComboBox x:Name="comboColors" Width="100" SelectionChanged="ColorChanged">
    <ComboBoxItem Content="Red"/>
    <ComboBoxItem Content="Green"/>
    <ComboBoxItem Content="Blue"/>
</ComboBox>
```

When you call `SelectedItem`, you grab the selected `ComboBoxItem`, which is stored as a general `Object`. After you cast the `Object` as a `ComboBoxItem`, you pluck out the value of the `Content`, which will be the string `Red`, `Green`, or `Blue`. This string is then converted to a `Color` object using the handy `ColorConverter` utility class. Now run your program again. You should be able to change between colors as you render your image.

Note that the `ComboBox` and `ListBox` controls can contain complex content as well, rather than a list of text data. You can get a sense of some of the things that are possible by opening the XAML editor for your window and changing the definition of your `ComboBox` so it contains a set of `StackPanel` elements, each of which contains an `Ellipse` and a `Label` (notice that the `Width` of the `ComboBox` is 175).

```
<ComboBox x:Name="comboColors" Width="175" Margin="10,0,0,0" SelectionChanged="ColorChanged">
    <StackPanel Orientation="Horizontal" Tag="Red">
        <Ellipse Fill="Red" Height="50" Width="50"/>
        <Label FontSize="20" HorizontalAlignment="Center"
            VerticalAlignment="Center" Content="Red"/>
    </StackPanel>

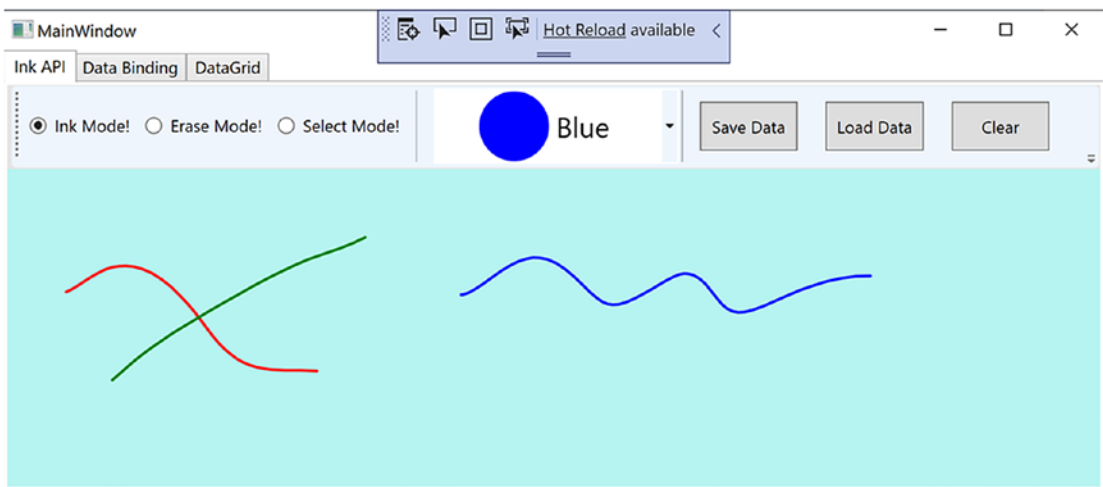
    <StackPanel Orientation="Horizontal" Tag="Green">
        <Ellipse Fill="Green" Height="50" Width="50"/>
        <Label FontSize="20" HorizontalAlignment="Center"
            VerticalAlignment="Center" Content="Green"/>
    </StackPanel>

    <StackPanel Orientation="Horizontal" Tag="Blue">
        <Ellipse Fill="Blue" Height="50" Width="50"/>
        <Label FontSize="20" HorizontalAlignment="Center"
            VerticalAlignment="Center" Content="Blue"/>
    </StackPanel>
</ComboBox>
```

Notice that each `StackPanel` assigns a value to its `Tag` property, which is a simple, fast, and convenient way to discover which stack of items has been selected by the user (there are better ways to do this, but this will do for now). With this adjustment, you need to change the implementation of your `ColorChanged()` method, like this:

```
private void ColorChanged(object sender, SelectionChangedEventArgs e)
{
    // Get the Tag of the selected StackPanel.
    string colorToUse = (this.comboColors.SelectedItem
        as StackPanel).Tag.ToString();
    ...
}
```

Now run your program again and take note of your unique `ComboBox` (see Figure 25-21).



**Figure 25-21.** A custom `ComboBox`, thanks to the WPF content model

## Saving, Loading, and Clearing InkCanvas Data

The last part of this tab will enable you to save and load your canvas data, as well as clear it of all content by adding event handlers for the buttons in the toolbar. Update the XAML for the buttons by adding markup for the click events, as follows:

```
<Button Grid.Column="0" x:Name="btnSave" Margin="10,10" Width="70" Content="Save Data"
Click="SaveData"/>
<Button Grid.Column="1" x:Name="btnLoad" Margin="10,10" Width="70" Content="Load Data"
Click="LoadData"/>
<Button Grid.Column="2" x:Name="btnClear" Margin="10,10" Width="70" Content="Clear"
Click="Clear"/>
```

Next, import the `System.IO` and `System.Windows.Ink` namespaces to your code file. Implement the handlers, like this:

```
private void SaveData(object sender, RoutedEventArgs e)
{
    // Save all data on the InkCanvas to a local file.
    using (FileStream fs = new FileStream("StrokeData.bin", FileMode.Create))
    this.MyInkCanvas.Strokes.Save(fs);
    fs.Close();
}

private void LoadData(object sender, RoutedEventArgs e)
{
    // Fill StrokeCollection from file.
    using (FileStream fs = new FileStream("StrokeData.bin", FileMode.Open, FileAccess.Read))
    StrokeCollection strokes = new StrokeCollection(fs);
    this.MyInkCanvas.Strokes = strokes;
}

private void Clear(object sender, RoutedEventArgs e)
{
    // Clear all strokes.
    this.MyInkCanvas.Strokes.Clear();
}
```

You should now be able to save your data to a file, load it from the file, and clear the `InkCanvas` of all data. That wraps up the first tab of the `TabControl`, as well as your examination of the WPF digital Ink API. To be sure, there is more to say about this technology; however, you should be in a good position to dig into the topic further if that interests you. Next, you will learn how to use WPF data binding.

## Introducing the WPF Data-Binding Model

Controls are often the target of various data-binding operations. Simply put, *data binding* is the act of connecting control properties to data values that might change over the course of your application's lifetime. Doing so lets a user interface element display the state of a variable in your code. For example, you might use data binding to accomplish the following:

- Check a `CheckBox` control based on a Boolean property of a given object.
- Display data in `DataGrid` objects from a relational database table.
- Connect a `Label` to an integer that represents the number of files in a folder.

When you use the intrinsic WPF data-binding engine, you must be aware of the distinction between the *source* and the *destination* of the binding operation. As you might expect, the source of a data-binding operation is the data itself (e.g., a Boolean property or relational data), while the destination (target) is the UI control property that uses the data content (e.g., a property on a `CheckBox` or `TextBox` control).

In addition to binding to traditional data, WPF enables element binding, as stated in the previous examples. This means you can bind (for example) the visibility of a property based on the checked property of a check box. You could certainly do this in WinForms, but it had to be done through code. The WPF framework provides a rich data-binding ecosystem that can be almost entirely handled in markup. This also enables you to ensure that the source and destination stay in sync if either of their values changes.

## Building the Data Binding Tab

Using the Document Outline editor, change the Grid of your second tab to a StackPanel. Now, use the Toolbox and Properties editor of Visual Studio to build the following initial layout:

```
<TabItem x:Name="tabDataBinding" Header="Data Binding">
  <StackPanel Width="250">
    <Label Content="Move the scroll bar to see the current value"/>

    <!-- The scrollbar's value is the source of this data bind. -->
    <ScrollBar x:Name="mySB" Orientation="Horizontal" Height="30"
      Minimum = "1" Maximum = "100" LargeChange="1" SmallChange="1"/>

    <!-- The label's content will be bound to the scroll bar! -->
    <Label x:Name="labelSBThumb" Height="30" BorderBrush="Blue"
      BorderThickness="2" Content = "0"/>
  </StackPanel>
</TabItem>
```

Notice that the ScrollBar object (named mySB here) has been configured with a range between 1 and 100. The goal is to ensure that, as you reposition the thumb of the scrollbar (or click the left or right arrow), the Label will automatically update with the current value. Currently, the Content property of the Label control is set to the value "0"; however, you will change this via a data-binding operation.

## Establishing Data Bindings

The glue that makes it possible to define a binding in XAML is the {Binding} markup extension. While you can define bindings through Visual Studio, it's just as easy to do it directly in the markup. Edit the Content property for the Label named labelSBThumb to the following:

```
<Label x:Name="labelSBThumb" Height="30" BorderBrush="Blue" BorderThickness="2"
  Content = "{Binding Path=Value, ElementName=mySB}"/>
```

Note the value assigned to the Label's Content property. The {Binding} statement denotes a data-binding operation. The ElementName value represents the source of the data-binding operation (the ScrollBar object), while the Path indicates the property being bound to, in this case the Value of the scrollbar.

If you run your program again, you will find that the content of the label updates based on the scrollbar value as you move the thumb!

## The DataContext Property

You can define a data-binding operation in XAML using an alternative format, where it is possible to break out the values specified by the {Binding} markup extension by explicitly setting the DataContext property to the source of the binding operation, as follows:

```
<!-- Breaking object/value apart via DataContext -->
<Label x:Name="labelSBThumb" Height="30" BorderBrush="Blue" BorderThickness="2"
  DataContext = "{Binding ElementName=mySB}" Content = "{Binding Path=Value}" />
```

In the current example, the output would be identical if you were to modify the markup in this way. Given this, you might wonder when you would want to set the `DataContext` property explicitly. Doing so can be helpful because subelements can inherit its value in a tree of markup.

In this way, you can easily set the same data source to a family of controls, rather than having to repeat a bunch of redundant `"{Binding ElementName=X, Path=Y}"` XAML values to multiple controls. For example, assume you have added the following new `Button` to the `StackPanel` of this tab (you'll see why it is so large in just a moment):

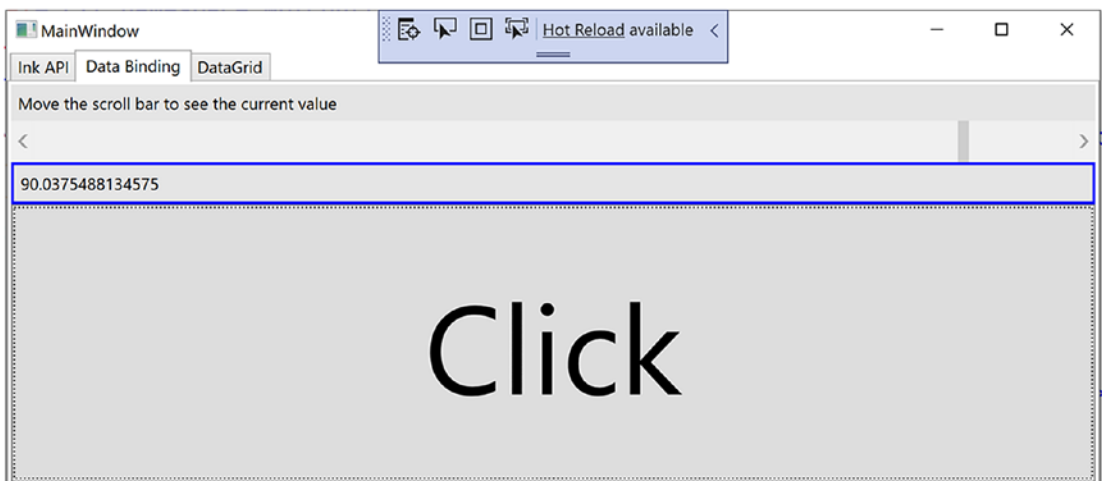
```
<Button Content="Click" Height="200"/>
```

You could use Visual Studio to generate data bindings for multiple controls, but instead try entering the modified markup manually using the XAML editor, like so:

```
<!-- Note the StackPanel sets the DataContext property. -->
<StackPanel Background="#FFE5E5" DataContext = "{Binding ElementName=mySB}">
...
  <!-- Now both UI elements use the scrollbar's value in unique ways. -->
  <Label x:Name="labelSBThumb" Height="30" BorderBrush="Blue" BorderThickness="2"
    Content = "{Binding Path=Value}"/>

  <Button Content="Click" Height="200" FontSize = "{Binding Path=Value}"/>
</StackPanel>
```

Here, you set the `DataContext` property on the `StackPanel` directly. Therefore, as you move the thumb, you see not only the current value on the `Label` but also the font size of the `Button` grow and shrink accordingly, based on the same value (Figure 25-22 shows one possible output).



**Figure 25-22.** Binding the `ScrollBar` value to a `Label` and a `Button`

## Formatting the Bound Data

The `ScrollBar` type uses a double to represent the value of the thumb, rather than an expected whole number (e.g., an integer). Therefore, as you drag the thumb, you will find various floating-point numbers displayed within the `Label` (e.g., 61.0576923076923). The end user would find this rather unintuitive because he is most likely expecting to see whole numbers (e.g., 61, 62, and 63).

If you want to format the data, you can add a `ContentStringFormat` property, passing in a custom string and a .NET Core format specifier, as follows:

```
<Label x:Name="labelSBThumb" Height="30" BorderBrush="Blue"
      BorderThickness="2" Content = "{Binding Path=Value}" ContentStringFormat="The value is:
      {0:F0}"/>
```

If you don't have any text in the format specification, then you need to lead with an empty set of braces, which is the escape sequence for XAML. This lets the processor know that the next characters are literals and not a binding statement, for example. Here is the updated XAML:

```
<Label x:Name="labelSBThumb" Height="30" BorderBrush="Blue"
      BorderThickness="2" Content = "{Binding Path=Value}" ContentStringFormat="{0:F0}"/>
```

---

■ **Note** If you are binding a `Text` property of a control, you can add a `StringFormat` name-value pair right in the binding statement. It only needs to be separate for `Content` properties.

---

## Data Conversion Using `IValueConverter`

If you need to do more than just format the data, you can create a custom class that implements the `IValueConverter` interface of the `System.Windows.Data` namespace. This interface defines two members that allow you to perform the conversion to and from the target and destination (in the case of a two-way data binding). After you define this class, you can use it to qualify further the processing of your data-binding operation.

Instead of using the format property, you can use a value converter to display whole numbers within the `Label` control. To do this, add a new class (named `MyDoubleConverter`) to the project class. Next, add the following:

```
using System;
using System.Windows.Data;
public class MyDoubleConverter : IValueConverter
{
    public object Convert(object value, Type targetType, object parameter, System.
        Globalization.CultureInfo culture)
    {
        // Convert the double to an int.
        double v = (double)value;
        return (int)v;
    }
}
```

```

public object ConvertBack(object value, Type targetType, object parameter, System.
Globalization.CultureInfo culture)
{
    // You won't worry about "two-way" bindings here, so just return the value.
    return value;
}
}

```

The `Convert()` method is called when the value is transferred from the source (the `ScrollBar`) to the destination (the `Text` property of the `TextBox`). You will receive many incoming arguments, but you only need to manipulate the incoming object for this conversion, which is the value of the current double. You can use this type to cast the type into an integer and return the new number.

The `ConvertBack()` method will be called when the value is passed from the destination to the source (if you have enabled a two-way binding mode). Here, you simply return the value straightaway. Doing so lets you type a floating-point value into the `TextBox` (e.g., 99.9) and have it automatically convert to a whole-number value (e.g., 99) when the user tabs off the control. This “free” conversion happens because the `Convert()` method is called again, after a call to `ConvertBack()`. If you were simply to return null from `ConvertBack()`, your binding would appear to be out of sync because the text box would still be displaying a floating-point number.

To use this converter in markup, you first have to create a local resource representing the custom class you just built. Don’t worry about the mechanics of adding resources; the next few chapters will dive deeper into this subject. Add the following just after the opening `Window` tag:

```

<Window.Resources>
    <local:MyDoubleConverter x:Key="DoubleConverter"/>
</Window.Resources>

```

Next, update the binding statement for the `Label` control to the following:

```

<Label x:Name="labelSBThumb" Height="30" BorderBrush="Blue"
    BorderThickness="2" Content = "{Binding Path=Value,Converter={StaticResource
    DoubleConverter}}" />

```

Now when you run the app, you see only whole numbers.

## Establishing Data Bindings in Code

You can also register your data conversion class in code. Begin by cleaning up the current definition of the `Label` control in your data binding tab so that it no longer uses the `{Binding}` markup extension.

```

<Label x:Name="labelSBThumb" Height="30" BorderBrush="Blue" BorderThickness="2" />

```

Make sure there is a `using` for `System.Windows.Data`; then in your window’s constructor, call a new private helper function called `SetBindings()`. In this method, add the following code (and make sure to call it from the constructor):

```

private void SetBindings()
{
    // Create a Binding object.
    Binding b = new Binding

```



```

{
    // Register the converter, source, and path.
    Converter = new MyDoubleConverter(),
    Source = this.mySB,
    Path = new PropertyPath("Value")
};

// Call the SetBinding method on the Label.
this.labelsBThumb.SetBinding(Label.ContentProperty, b);
}

```

The only part of this function that probably looks a bit off is the call to `SetBinding()`. Notice that the first parameter calls a static, read-only field of the `Label` class named `ContentProperty`. As you will learn later in this chapter, you are specifying what is known as a *dependency property*. For the time being, just know that when you set bindings in code, the first argument will nearly always require you to specify the name of the class that wants the binding (the `Label`, in this case), followed by a call to the underlying property with the `Property` suffix. In any case, running the application illustrates that the `Label` prints out only whole numbers.

## Building the DataGrid Tab

The previous data-binding example illustrated how to configure two (or more) controls to participate in a data-binding operation. While this is helpful, it is also possible to bind data from XML files, database data, and in-memory objects. To complete this example, you will design the final tab of your tab control so it displays data obtained from the `Inventory` table of the `AutoLot` database.

As with the other tabs, you begin by changing the current `Grid` to a `StackPanel`. Do this by directly updating the XAML using Visual Studio. Now define a `DataGrid` control in your new `StackPanel` named `gridInventory`, like so:

```

<TabItem x:Name="tabDataGrid" Header="DataGrid">
    <StackPanel>
        <DataGrid x:Name="gridInventory" Height="288"/>
    </StackPanel>
</TabItem>

```

Use the NuGet package manager to add `Microsoft.EntityFrameworkCore.SqlServer` and `Microsoft.Extensions.Configuration.Json` to your project. Next, right-click the solution, select **Add ► Existing Project**, and add the `AutoLot.Dal` and `AutoLot.Dal.Models` projects from Chapter 23. Add project references to the `AutoLot.Dal` and `AutoLot.Dal.Models` projects from the `WpfControlsAndAPIs` project, and confirm that the project reference from `AutoLot.Dal` to `AutoLot.Dal.Models` is still in place. Add the following namespaces to `MainWindow.cs`:

```

using AutoLot.Dal.EfStructures;
using AutoLot.Dal.Repos;
using Microsoft.EntityFrameworkCore;
using Microsoft.Extensions.Configuration;

```

Add two module-level properties in `MainWindow.cs` to hold the instances of `IConfiguration` and `ApplicationDbContext`:

```
private IConfiguration _configuration;
private ApplicationDbContext _context;
```

Add a new method named `GetConfigurationAndContext` to create those instances, and call it from the constructor. The entire method is listed here:

```
private void GetConfigurationAndDbContext()
{
    _configuration = new ConfigurationBuilder()
        .SetBasePath(Directory.GetCurrentDirectory())
        .AddJsonFile("appsettings.json", true, true)
        .Build();
    var optionsBuilder =
        new DbContextOptionsBuilder<ApplicationDbContext>();
    var connectionString =
        _configuration.GetConnectionString("AutoLotFinal");
    optionsBuilder.UseSqlServer(connectionString,
        sqlOptions => sqlOptions.EnableRetryOnFailure());
    _context = new ApplicationDbContext(optionsBuilder.Options);
}
```

Add a new JSON file named `appsettings.json` to the project, and set its build status to copy always. This can be done by right-clicking the file in Solution Explorer, selecting Properties, and then setting the Copy To Output Directory value to “Copy always.” You can also add this to the project file to accomplish the same thing:

```
<ItemGroup>
  <None Update="appsettings.json">
    <CopyToOutputDirectory>Always</CopyToOutputDirectory>
  </None>
</ItemGroup>
```

Update the JSON file to the following (updating your connection string to match your environment):

```
{
  "ConnectionStrings": {
    "AutoLotFinal": "server=.,5433;Database=AutoLotFinal;User Id=sa;Password=P@ssw0rd;"
  }
}
```

Open the code file for your window and add a final helper function called `ConfigureGrid` and call this from your constructor after you have configured the `ApplicationDbContext`. All you need to do is add a few lines of code, like so:

```
private void ConfigureGrid()
{
    using var repo = new CarRepo(_context);
    gridInventory.ItemsSource = repo
        .GetAllIgnoreQueryFilters()
        .ToList()
}
```

```

.Select(x=> new {
    x.Id,
    Make=x.MakeNavigation.Name,
    x.Color,
    x.PetName
});
}

```

Now when you run the project, you see the data populating the grid. If you want to make the grid somewhat fancier, you can use the Visual Studio Properties window to edit grid to make it more appealing.

That wraps up the current example. You'll see some other controls in action during later chapters; at this point, however, you should feel comfortable with the process of building UIs in Visual Studio and manually using XAML and C# code.

## Understanding the Role of Dependency Properties

Like any .NET Core API, WPF makes use of each member of the .NET Core type system (classes, structures, interfaces, delegates, enumerations) and each type member (properties, methods, events, constant data, read-only fields, etc.) within its implementation. However, WPF also supports a unique programming concept termed a *dependency property*.

Like a “normal” .NET Core property (often termed a *CLR property* in the WPF literature), dependency properties can be set declaratively using XAML or programmatically within a code file. Furthermore, dependency properties (like CLR properties) ultimately exist to encapsulate data fields of a class and can be configured as read-only, write-only, or read-write.

To make matters more interesting, in almost every case you will be blissfully unaware that you have actually set (or accessed) a dependency property as opposed to a CLR property! For example, the `Height` and `Width` properties that WPF controls inherit from `FrameworkElement`, as well as the `Content` member inherited from `ControlContent`, are all, in fact, dependency properties.

**<!-- Set three dependency properties! -->**

```
<Button x:Name = "btnMyButton" Height = "50" Width = "100" Content = "OK"/>
```

Given all of these similarities, why does WPF define a new term for such a familiar concept? The answer lies in how a dependency property is implemented within the class. You'll see a coding example in just a little bit; however, from a high level, all dependency properties are created in the following manner:

- First, the class that defined a dependency property must have `DependencyObject` in its inheritance chain.
- A single dependency property is represented as a public, static, read-only field in the class of type `DependencyProperty`. By convention, this field is named by suffixing the word `Property` to the name of the CLR wrapper (see final bullet point).
- The `DependencyProperty` variable is registered via a static call to `DependencyProperty.Register()`, which typically occurs in a static constructor or inline when the variable is declared.
- Finally, the class will define a XAML-friendly CLR property, which makes calls to methods provided by `DependencyObject` to get and set the value.

Once implemented, dependency properties provide a number of powerful features that are used by various WPF technologies including data binding, animation services, styles, templates, and so forth. In a nutshell, the motivation of dependency properties is to provide a way to compute the value of a property based on the value of other inputs. Here is a list of some of these key benefits, which go well beyond those of the simple data encapsulation found with a CLR property:

- Dependency properties can inherit their values from a parent element's XAML definition. For example, if you defined a value for the `FontSize` attribute in the opening tag of a `Window`, all controls in that `Window` would have the same font size by default.
- Dependency properties support the ability to have values set by elements contained within their XAML scope, such as a `Button` setting the `Dock` property of a `DockPanel` parent. (Recall that *attached properties* do this very thing because attached properties are a form of dependency properties.)
- Dependency properties allow WPF to compute a value based on multiple external values, which can be important for animation and data-binding services.
- Dependency properties provide infrastructure support for WPF triggers (also used quite often when working with animation and data binding).

Now remember, in many cases you will interact with an existing dependency property in a manner identical to a normal CLR property (thanks to the XAML wrapper). In the previous section, which covered data binding, you saw that if you need to establish a data binding in code, you must call the `SetBinding()` method on the object that is the destination of the operation and specify the *dependency property* it will operate on, like so:

```
private void SetBindings()
{
    Binding b = new Binding
    {
        // Register the converter, source, and path.
        Converter = new MyDoubleConverter(),
        Source = this.mySB,
        Path = new PropertyPath("Value")
    };
    // Specify the dependency property!
    this.labelsBThumb.SetBinding(Label.ContentProperty, b);
}
```

You will see similar code when you examine how to start an animation in code in Chapter 27.

```
// Specify the dependency property!
rt.BeginAnimation(RotateTransform.AngleProperty, dblAnim);
```

The only time you need to build your own custom dependency property is when you are authoring a custom WPF control. For example, if you are building a `UserControl` that defines four custom properties and you want these properties to integrate well within the WPF API, you should author them using dependency property logic.

Specifically, if your properties need to be the target of a data-binding or animation operation, if the property must broadcast when it has changed, if it must be able to work as a `Setter` in a WPF style, or if it must be able to receive their values from a parent element, a normal CLR property will *not* be enough.

If you were to use a normal CLR property, other programmers may indeed be able to get and set a value; however, if they attempt to use your properties within the context of a WPF service, things will not work as expected. Because you can never know how others might want to interact with the properties of your custom `UserControl` classes, you should get in the habit of *always* defining dependency properties when building custom controls.

## Examining an Existing Dependency Property

Before you learn how to build a custom dependency property, let's take a look at how the `Height` property of the `FrameworkElement` class has been implemented internally. The relevant code is shown here (with my included comments):

```
// FrameworkElement is-a DependencyObject.
public class FrameworkElement : UIElement, IFrameworkInputElement,
    IInputElement, ISupportInitialize, IHaveResources, IQueryAmbient
{
    ...
    // A static read-only field of type DependencyProperty.
    public static readonly DependencyProperty HeightProperty;

    // The DependencyProperty field is often registered
// in the static constructor of the class.
    static FrameworkElement()
    {
        ...
        HeightProperty = DependencyProperty.Register(
            "Height",
            typeof(double),
            typeof(FrameworkElement),
            new FrameworkPropertyMetadata((double) 1.0 / (double) 0.0,
                FrameworkPropertyMetadataOptions.AffectsMeasure,
                new PropertyChangedCallback(FrameworkElement.OnTransformDirty)),
            new ValidateValueCallback(FrameworkElement.IsWidthHeightValid));
    }

    // The CLR wrapper, which is implemented using
    // the inherited GetValue()/SetValue() methods.
    public double Height
    {
        get { return (double) base.GetValue(HeightProperty); }
        set { base.SetValue(HeightProperty, value); }
    }
}
```

As you can see, dependency properties require quite a bit of additional code from a normal CLR property! And in reality, a dependency can be even more complex than what you see here (thankfully, many implementations are simpler than `Height`).

First, remember that if a class wants to define a dependency property, it must have `DependencyObject` in the inheritance chain because this is the class that defines the `GetValue()` and `SetValue()` methods used in the CLR wrapper. Because `FrameworkElement` *is-a* `DependencyObject`, this requirement is satisfied.

Next, recall that the entity that will hold the actual value of the property (a double in the case of `Height`) is represented as a public, static, read-only field of type `DependencyProperty`. The name of this field should, by convention, always be named by suffixing the word `Property` to the name of the related CLR wrapper, like so:

```
public static readonly DependencyProperty HeightProperty;
```

Given that dependency properties are declared as static fields, they are typically created (and registered) within the static constructor of the class. The `DependencyProperty` object is created via a call to the static `DependencyProperty.Register()` method. This method has been overloaded many times; however, in the case of `Height`, `DependencyProperty.Register()` is invoked as follows:

```
HeightProperty = DependencyProperty.Register(
    "Height",
    typeof(double),
    typeof(FrameworkElement),
    new FrameworkPropertyMetadata((double)0.0,
        FrameworkPropertyMetadataOptions.AffectsMeasure,
        new PropertyChangedCallback(FrameworkElement.OnTransformDirty)),
    new ValidateValueCallback(FrameworkElement.IsWidthHeightValid));
```

The first argument to `DependencyProperty.Register()` is the name of the normal CLR property on the class (`Height`, in this case), while the second argument is the type information of the underlying data type it is encapsulating (a double). The third argument specifies the type information of the class that this property belongs to (`FrameworkElement`, in this case). While this might seem redundant (after all, the `HeightProperty` field is already defined within the `FrameworkElement` class), this is a very clever aspect of WPF, in that it allows one class to register properties on another (even if the class definition has been sealed!).

The fourth argument passed to `DependencyProperty.Register()` in this example is what really gives dependency properties their own unique flavor. Here, a `FrameworkPropertyMetadata` object is passed that describes various details regarding how WPF should handle this property with respect to callback notifications (if the property needs to notify others when the value changes) and various options (represented by the `FrameworkPropertyMetadataOptions` enum) that control what is affected by the property in question. (Does it work with data binding? Can it be inherited?) In this case, the constructor arguments of `FrameworkPropertyMetadata` break down as so:

```
new FrameworkPropertyMetadata(
    // Default value of property.
    (double)0.0,

    // Metadata options.
    FrameworkPropertyMetadataOptions.AffectsMeasure,

    // Delegate pointing to method called when property changes.
    new PropertyChangedCallback(FrameworkElement.OnTransformDirty)
)
```

Because the final argument to the `FrameworkPropertyMetadata` constructor is a delegate, note that its constructor parameter is pointing to a static method on the `FrameworkElement` class named `OnTransformDirty()`. I won't bother to show the code behind this method, but be aware that any time you are building a custom dependency property, you can specify a `PropertyChangedCallback` delegate to point to a method that will be called when your property value has been changed.

This brings me to the final parameter passed to the `DependencyProperty.Register()` method, a second delegate of type `ValidateValueCallback`, which points to a method on the `FrameworkElement` class that is called to ensure the value assigned to the property is valid.

```
new ValidateValueCallback(FrameworkElement.IsWidthHeightValid)
```

This method contains logic you might normally expect to find in the set block of a property (more information on this point in the next section).

```
private static bool IsWidthHeightValid(object value)
{
    double num = (double) value;
    return ((!DoubleUtil.IsNaN(num) && (num >= 0.0))
        && !double.IsPositiveInfinity(num));
}
```

After the `DependencyProperty` object has been registered, the final task is to wrap the field within a normal CLR property (`Height`, in this case). Notice, however, that the get and set scopes do not simply return or set a class-level double-member variable but do so indirectly using the `GetValue()` and `SetValue()` methods from the `System.Windows.DependencyObject` base class, as follows:

```
public double Height
{
    get { return (double) base.GetValue(HeightProperty); }
    set { base.SetValue(HeightProperty, value); }
}
```

## Important Notes Regarding CLR Property Wrappers

So, just to recap the story thus far, dependency properties look like normal everyday properties when you get or set their values in XAML or code, but behind the scenes they are implemented with much more elaborate coding techniques. Remember, the whole reason to go through this process is to build a custom control that has custom properties that need to integrate with WPF services that demand communication with a dependency property (e.g., animation, data binding, and styles).

Even though part of the implementation of a dependency property includes defining a CLR wrapper, *you should never put validation logic in the set block*. For that matter, the CLR wrapper of a dependency property *should never do anything other than call `GetValue()` or `SetValue()`*.

The reason is that the WPF runtime has been constructed in such a way that when you write XAML that seems to set a property, such as

```
<Button x:Name="myButton" Height="100" .../>
```

the runtime will completely bypass the set block of the `Height` property and *directly* call `SetValue()`! The reason for this odd behavior has to do with a simple optimization technique. If the WPF runtime were to call the set block of the `Height` property, it would have to perform runtime reflection to figure out where the `DependencyProperty` field (specified by the first argument to `SetValue()`) is located, reference it in memory, and so forth. The same story holds true if you were to write XAML that retrieves the value of the `Height` property – `GetValue()` would be called directly.

Since this is the case, why do you need to build this CLR wrapper at all? Well, WPF XAML does not allow you to call functions in markup, so the following markup would be an error:

```
<!-- Nope! Can't call methods in WPF XAML! -->
<Button x:Name="myButton" this.SetValue("100") .../>
```

In effect, when you set or get a value in markup using the CLR wrapper, think of it as a way to tell the WPF runtime “Hey! Go call `GetValue()`/`SetValue()` for me since I can’t directly do it in markup!” Now, what if you call the CLR wrapper in code like so:

```
Button b = new Button();
b.Height = 10;
```

In this case, if the set block of the `Height` property contained code other than a call to `SetValue()`, it *would* execute because the WPF XAML parser optimization is not involved.

The basic rule to remember is that when registering a dependency property, use a `ValidateValueCallback` delegate to point to a method that performs the data validation. This ensures that the correct behavior will occur, regardless of whether you use XAML or code to get/set a dependency property.

## Building a Custom Dependency Property

If you have a slight headache at this point in the chapter, this is a perfectly normal response. Building dependency properties can take some time to get used to. However, for better or worse, it is part of the process of building many custom WPF controls, so let’s take a look at how to build a dependency property.

Begin by creating a new WPF application named `CustomDependencyProperty`. Now, using the Project menu, activate the Add User Control menu option, and create a control named `ShowNumberControl.xaml`.

---

■ **Note** You will learn more details about the WPF `UserControl` in Chapter 27, so just follow along as shown for now.

---

Just like a window, WPF `UserControl` types have a XAML file and a related code file. Update the XAML of your user control to define a single `Label` control in the `Grid`, like so:

```
<UserControl x:Class="CustomDepProp.ShowNumberControl"
    xmlns="http://schemas.microsoft.com/winfx/2006/xaml/presentation"
    xmlns:x="http://schemas.microsoft.com/winfx/2006/xaml"
    xmlns:d="http://schemas.microsoft.com/expression/blend/2008"
    xmlns:local="clr-namespace: CustomDependencyProperty"
    mc:Ignorable="d"
    d:DesignHeight="300" d:DesignWidth="300">
    <Grid>
        <Label x:Name="numberDisplay" Height="50" Width="200" Background="LightBlue"/>
    </Grid>
</UserControl>
```



In the code file of this custom control, create a normal, everyday .NET Core property that wraps an `int` and sets the `Content` property of the `Label` with the new value, as follows:

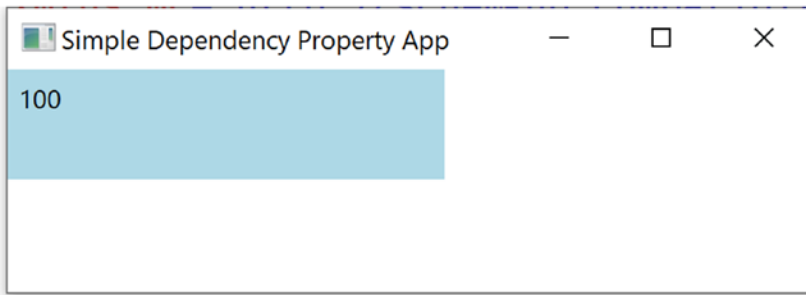
```
public partial class ShowNumberControl : UserControl
{
    public ShowNumberControl()
    {
        InitializeComponent();
    }

    // A normal, everyday .NET property.
    private int _currNumber = 0;
    public int CurrentNumber
    {
        get => _currNumber;
        set
        {
            _currNumber = value;
            numberDisplay.Content = CurrentNumber.ToString();
        }
    }
}
```

Now, update the XAML definition of your window to declare an instance of your custom control within a `StackPanel` layout manger. Because your custom control is not part of the core WPF assembly stack, you will need to define a custom XML namespace that maps to your control. Here is the required markup:

```
<Window x:Class="CustomDepPropApp.MainWindow"
    xmlns="http://schemas.microsoft.com/winfx/2006/xaml/presentation"
    xmlns:x="http://schemas.microsoft.com/winfx/2006/xaml"
    xmlns:d="http://schemas.microsoft.com/expression/blend/2008"
    xmlns:myCtrls="clr-namespace: CustomDependencyProperty"
    xmlns:local="clr-namespace: CustomDependencyProperty"
    mc:Ignorable="d"
    Title="Simple Dependency Property App" Height="150" Width="250"
    WindowStartupLocation="CenterScreen">
    <StackPanel>
        <myCtrls:ShowNumberControl HorizontalAlignment="Left" x:Name="myShowNumberCtrl"
            CurrentNumber="100"/>
    </StackPanel>
</Window>
```

As you can see, the Visual Studio designer appears to correctly display the value that you set in the `CurrentNumber` property (see Figure 25-23).



**Figure 25-23.** *It appears your property works as expected*

However, what if you want to apply an animation object to the `CurrentNumber` property so that the value changes from 100 to 200 over a period of 10 seconds? If you wanted to do so in markup, you might update your `myCtrls:ShowNumberControl` scope as so:

```
<myCtrls:ShowNumberControl x:Name="myShowNumberCtrl" CurrentNumber="100">
  <myCtrls:ShowNumberControl.Triggers>
    <EventTrigger RoutedEvent = "myCtrls:ShowNumberControl.Loaded">
      <EventTrigger.Actions>
        <BeginStoryboard>
          <Storyboard TargetProperty = "CurrentNumber">
            <Int32Animation From = "100" To = "200" Duration = "0:0:10"/>
          </Storyboard>
        </BeginStoryboard>
      </EventTrigger.Actions>
    </EventTrigger>
  </myCtrls:ShowNumberControl.Triggers>
</myCtrls:ShowNumberControl>
```

If you run your application, the animation object cannot find a proper target, and an exception is thrown. The reason is that the `CurrentNumber` property has not been registered as a dependency property! To fix matters, return to the code file of your custom control, and completely comment out the current property logic (including the private backing field).

Now, add the following code to create the `CurrentNumber` as a dependency property:

```
public int CurrentNumber
{
    get => (int)GetValue(CurrentNumberProperty);
    set => SetValue(CurrentNumberProperty, value);
}
public static readonly DependencyProperty CurrentNumberProperty =
    DependencyProperty.Register("CurrentNumber",
        typeof(int),
        typeof>ShowNumberControl),
    new UIPropertyMetadata(0));
```

This is similar to what you saw in the implementation of the `Height` property; however, the code snippet registers the property inline rather than within a static constructor (which is fine). Also notice that a `UIPropertyMetadata` object is used to define the default value of the integer (0) rather than the more complex `FrameworkPropertyMetadata` object. This is the simplest version of `CurrentNumber` as a dependency property.

## Adding a Data Validation Routine

Although you now have a dependency property named `CurrentNumber` (and the exception is no longer being thrown), you still won't see your animation take hold. The next adjustment you might want to make is to specify a function to call to perform some data validation logic. For this example, assume that you need to ensure that the value of `CurrentNumber` is between 0 and 500.

To do so, add a final argument to the `DependencyProperty.Register()` method of type `ValidateValueCallback`, which points to a method named `ValidateCurrentNumber`.

`ValidateValueCallback` is a delegate that can only point to methods returning `bool` and take an object as the only argument. This object represents the new value that is being assigned. Implement `ValidateCurrentNumber` to return `true` or `false`, if the incoming value is within the expected range.

```
public static readonly DependencyProperty CurrentNumberProperty =
    DependencyProperty.Register("CurrentNumber",
        typeof(int),
        typeof(ShowNumberControl),
        new UIPropertyMetadata(100),
        new ValidateValueCallback(ValidateCurrentNumber));

// Just a simple rule. Value must be between 0 and 500.
public static bool ValidateCurrentNumber(object value) =>
    Convert.ToInt32(value) >= 0 && Convert.ToInt32(value) <= 500;
```

## Responding to the Property Change

So, now you have a valid number but still no animation. The final change you need to make is to specify a second argument to the constructor of `UIPropertyMetadata`, which is a `PropertyChangedCallback` object. This delegate can point to any method that takes a `DependencyObject` as the first parameter and a `DependencyPropertyChangedEventArgs` as the second. First, update your code as so:

**// Note the second param of UIPropertyMetadata constructor.**

```
public static readonly DependencyProperty CurrentNumberProperty =
    DependencyProperty.Register("CurrentNumber", typeof(int), typeof(ShowNumberControl),
        new UIPropertyMetadata(100, new PropertyChangedCallback(CurrentNumberChanged)),
        new ValidateValueCallback(ValidateCurrentNumber));
```

Within the `CurrentNumberChanged()` method, your ultimate goal is to change the `Content` of the `Label` to the new value assigned by the `CurrentNumber` property. You have one big problem, however: the `CurrentNumberChanged()` method is static, as it must be to work with the static `DependencyProperty` object. So, how are you supposed to gain access to the `Label` for the current instance of `ShowNumberControl`?

That reference is contained in the first `DependencyObject` parameter. You can find the new value using the incoming event arguments. Here is the necessary code that will change the `Content` property of the `Label`:

```
private static void CurrentNumberChanged(DependencyObject depObj, DependencyPropertyChangedEventArgs args)
{
    // Cast the DependencyObject into ShowNumberControl.
    ShowNumberControl c = (ShowNumberControl)depObj;
    // Get the Label control in the ShowNumberControl.
    Label theLabel = c.numberDisplay;
    // Set the Label with the new value.
    theLabel.Content = args.NewValue.ToString();
}
```

Whew! That was a long way to go just to change the output of a label. The benefit is that your `CurrentNumber` dependency property can now be the target of a WPF style, an animation object, the target of a data-binding operation, and so forth. If you run your application once again, you should now see the value change during execution.

That wraps up your look at WPF dependency properties. While I hope you have a much better idea about what these constructs allow you to do and have a better idea of how to make your own, please be aware that there are many details I have not covered here.

If you find yourself in a position where you are building a number of custom controls that support custom properties, please look up the topic “Properties” under the “WPF Fundamentals” node of the .NET Framework 4.7 SDK documentation. In it you will find many more examples of building dependency properties, attached properties, various ways to configure property metadata, and a slew of other details.

## Summary

This chapter examined several aspects of WPF controls, beginning with an overview of the control toolkit and the role of layout managers (panels). The first example gave you a chance to build a simple word processor application that illustrated the integrated spell-checking functionality of WPF, as well as how to build a main window with menu systems, status bars, and toolbars.

More importantly, you examined how to use WPF commands. Recall that you can attach these control-agnostic events to a UI element or an input gesture to inherit out-of-the-box services automatically (e.g., clipboard operations).

You also learned quite a bit about building complex UI’s in XAML, and you learned about the WPF Ink API at the same time. You also received an introduction to WPF data-binding operations, including how to use the WPF `DataGrid` class to display data from your custom `AutoLot` database.

Finally, you investigated how WPF places a unique spin on traditional .NET Core programming primitives, specifically properties and events. As you have seen, a *dependency property* allows you to build a property that can integrate within the WPF set of services (animations, data bindings, styles, etc.). On a related note, *routed events* provide a way for an event to flow up or down a tree of markup.

## CHAPTER 26



# WPF Graphics Rendering Services

In this chapter, you'll examine the graphical rendering capabilities of WPF. As you'll see, WPF provides three separate ways to render graphical data: shapes, drawings, and visuals. After you understand the pros and cons of each approach, you will start learning about the world of interactive 2D graphics using the classes within `System.Windows.Shapes`. After this, you'll see how drawings and geometries allow you to render 2D data in a more lightweight manner. Last but not least, you'll learn how the visual layer gives you the greatest level of power and performance.

Along the way, you will explore a number of related topics, such as how to create custom brushes and pens, how to apply graphical transformations to your renderings, and how to perform hit-test operations. In particular, you'll see how the integrated tools of Visual Studio and an additional tool named Inkscape can simplify your graphical coding endeavors.

---

**Note** Graphics are a key aspect of WPF development. Even if you are not building a graphics-heavy application (such as a video game or multimedia application), the topics in this chapter are critical when you work with services such as control templates, animations, and data-binding customization.

---

## Understanding WPF's Graphical Rendering Services

WPF uses a particular flavor of graphical rendering that goes by the term *retained-mode graphics*. Simply put, this means that since you are using XAML or procedural code to generate graphical renderings, it is the responsibility of WPF to persist these visual items and ensure that they are correctly redrawn and refreshed in an optimal manner. Thus, when you render graphical data, it is always present, even when the end user hides the image by resizing or minimizing the window, by covering the window with another, and so forth.

In stark contrast, previous Microsoft graphical rendering APIs (including Windows Forms' GDI+) were *immediate-mode* graphical systems. In this model, it was up to the programmer to ensure that rendered visuals were correctly "remembered" and updated during the life of the application. For example, in a Windows Forms application, rendering a shape such as a rectangle involved handling the `Paint` event (or overriding the virtual `OnPaint()` method), obtaining a `Graphics` object to draw the rectangle, and, most important, adding the infrastructure to ensure that the image was persisted when the user resized the window (e.g., creating member variables to represent the position of the rectangle and calling `Invalidate()` throughout your program).

The shift from immediate-mode to retained-mode graphics is indeed a good thing, as programmers have far less grungy graphics code to author and maintain. However, I'm not suggesting that the WPF graphics API is *completely* different from earlier rendering toolkits. For example, like GDI+, WPF supports

various brush types and pen objects, techniques for hit-testing, clipping regions, graphical transformations, and so on. So, if you currently have a background in GDI+ (or C/C++-based GDI), you already know a good deal about how to perform basic renderings under WPF.

## WPF Graphical Rendering Options

As with other aspects of WPF development, you have a number of choices regarding how to perform your graphical rendering, beyond the decision to do so via XAML or procedural C# code (or perhaps a combination of both). Specifically, WPF provides the following three distinct ways to render graphical data:

- *Shapes*: WPF provides the `System.Windows.Shapes` namespace, which defines a small number of classes for rendering 2D geometric objects (rectangles, ellipses, polygons, etc.). While these types are simple to use and powerful, they do come with a fair amount of memory overhead if used with reckless abandon.
- *Drawings and geometries*: The WPF API provides a second way to render graphical data, using descendants from the `System.Windows.Media.Drawing` abstract class. Using classes such as `GeometryDrawing` or `ImageDrawing` (in addition to various *geometry objects*), you can render graphical data in a more lightweight (but less feature-rich) manner.
- *Visuals*: The fastest and most lightweight way to render graphical data under WPF is using the visual layer, which is accessible only through C# code. Using descendants of `System.Windows.Media.Visual`, you can speak directly to the WPF graphical subsystem.

The reason for offering different ways to do the same thing (i.e., render graphical data) has to do with memory use and, ultimately, application performance. Because WPF is such a graphically intensive system, it is not unreasonable for an application to render hundreds or even thousands of different images on a window's surface, and the choice of implementation (shapes, drawings, or visuals) could have a huge impact.

Do understand that when you build a WPF application, chances are good you'll use all three options. As a rule of thumb, if you need a modest amount of *interactive* graphical data that can be manipulated by the user (receive mouse input, display tooltips, etc.), you'll want to use members in the `System.Windows.Shapes` namespace.

In contrast, drawings and geometries are more appropriate when you need to model complex, generally noninteractive, vector-based graphical data using XAML or C#. While drawings and geometries can still respond to mouse events, hit-testing, and drag-and-drop operations, you will typically need to author more code to do so.

Last but not least, if you require the fastest possible way to render massive amounts of graphical data, the visual layer is the way to go. For example, let's say you are using WPF to build a scientific application that can plot out thousands of points of data. Using the visual layer, you can render the plot points in the most optimal way possible. As you will see later in this chapter, the visual layer is accessible only via C# code and is not XAML-friendly.

No matter which approach you take (shapes, drawings and geometries, or visuals), you will make use of common graphical primitives such as brushes (which fill interiors), pens (which draw exteriors), and transformation objects (which, well, transform the data). To begin the journey, you will start working with the classes of `System.Windows.Shapes`.

---

■ **Note** WPF also ships with a full-blown API that can be used to render and manipulate 3D graphics, which is not addressed in this edition of the text.

---

## Rendering Graphical Data Using Shapes

Members of the `System.Windows.Shapes` namespace provide the most straightforward, most interactive, yet most memory-intensive way to render a two-dimensional image. This namespace (defined in the `PresentationFramework.dll` assembly) is quite small and consists of only six sealed classes that extend the abstract `Shape` base class: `Ellipse`, `Rectangle`, `Line`, `Polygon`, `Polyline`, and `Path`.

The abstract `Shape` class inherits from `FrameworkElement`, which inherits from `UIElement`. These classes define members to deal with sizing, tooltips, mouse cursors, and whatnot. Given this inheritance chain, when you render graphical data using `Shape`-derived classes, the objects are just about as functional (as far as user interactivity is concerned) as a WPF control!

For example, determining whether the user has clicked your rendered image is no more complicated than handling the `MouseDown` event. By way of a simple example, if you authored this XAML of a `Rectangle` object in the `Grid` of your initial window:

```
<Rectangle x:Name="myRect" Height="30" Width="30" Fill="Green" MouseDown="myRect_
MouseDown"/>
```

you could implement a C# event handler for the `MouseDown` event that changes the rectangle's background color when clicked, like so:

```
private void myRect_MouseDown(object sender, MouseButtonEventArgs e)
{
    // Change color of Rectangle when clicked.
    myRect.Fill = Brushes.Pink;
}
```

Unlike with other graphical toolkits you may have used, you do *not* need to author a ton of infrastructure code that manually maps mouse coordinates to the geometry, manually calculates hit-testing, renders to an off-screen buffer, and so forth. The members of `System.Windows.Shapes` simply respond to the events you register with, just like a typical WPF control (e.g., `Button`, etc.).

The downside of all this out-of-the-box functionality is that the shapes do take up a fair amount of memory. If you're building a scientific application that plots thousands of points on the screen, using shapes would be a poor choice (essentially, it would be about as memory intensive as rendering thousands of `Button` objects!). However, when you need to generate an interactive 2D vector image, shapes are a wonderful choice.

Beyond the functionality inherited from the `UIElement` and `FrameworkElement` parent classes, `Shape` defines a number of members for each of the children; some of the more useful ones are shown in Table 26-1.

**Table 26-1.** *Key Properties of the Shape Base Class*

Properties	Meaning in Life
DefiningGeometry	Returns a Geometry object that represents the overall dimensions of the current shape. This object contains <i>only</i> the plot points that are used to render the data and has no trace of the functionality from UIElement or FrameworkElement.
Fill	Allows you to specify a brush object to fill the interior portion of a shape.
GeometryTransform	Allows you to apply transformations to a shape <i>before</i> it is rendered on the screen. The inherited RenderTransform property (from UIElement) applies the transformation <i>after</i> it has been rendered on the screen.
Stretch	Describes how to fill a shape within its allocated space, such as its position within a layout manager. This is controlled using the corresponding System.Windows.Media.Stretch enumeration.
Stroke	Defines a brush object or, in some cases, a pen object (which is really a brush in disguise) that is used to paint the border of a shape.
StrokeDashArray, StrokeEndLineCap, StrokeStartLineCap, StrokeThickness	These (and other) stroke-related properties control how lines are configured when drawing the border of a shape. In a majority of cases, these properties will configure the brush used to draw a border or line.

■ **Note** If you forget to set the Fill and Stroke properties, WPF will give you “invisible” brushes and, therefore, the shape will not be visible on the screen!

## Adding Rectangles, Ellipses, and Lines to a Canvas

You will build a WPF application that can render shapes using XAML and C# and, while doing so, learn a bit about the process of hit-testing. Create a new WPF application named `RenderingWithShapes`, and change the title of `MainWindow.xaml` to “Fun with Shapes!” Update the initial XAML of the `<Window>`, replacing the `Grid` with a `<DockPanel>` containing a (now empty) `<ToolBar>` and a `<Canvas>`. Note that each contained item has a fitting name via the `Name` property.

```
<DockPanel LastChildFill="True">
  <ToolBar DockPanel.Dock="Top" Name="mainToolBar" Height="50">
  </ToolBar>
  <Canvas Background="LightBlue" Name="canvasDrawingArea"/>
</DockPanel>
```

Now, populate the `<ToolBar>` with a set of `<RadioButton>` objects, each of which contains a specific Shape-derived class as content. Notice that each `<RadioButton>` is assigned to the same `GroupName` (to ensure mutual exclusivity) and is also given a fitting name.

```
<ToolBar DockPanel.Dock="Top" Name="mainToolBar" Height="50">
  <RadioButton Name="circleOption" GroupName="shapeSelection" Click="circleOption_Click">
    <Ellipse Fill="Green" Height="35" Width="35" />
  </RadioButton>
```



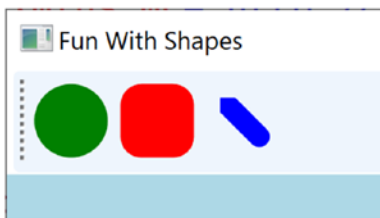
```

<RadioButton Name="rectOption" GroupName="shapeSelection" Click="rectOption_Click">
  <Rectangle Fill="Red" Height="35" Width="35" RadiusY="10" RadiusX="10" />
</RadioButton>
<RadioButton Name="lineOption" GroupName="shapeSelection" Click="lineOption_Click">
  <Line Height="35" Width="35" StrokeThickness="10" Stroke="Blue"
    X1="10" Y1="10" Y2="25" X2="25"
    StrokeStartLineCap="Triangle" StrokeEndLineCap="Round" />
</RadioButton>
</ToolBar>

```

As you can see, declaring `Rectangle`, `Ellipse`, and `Line` objects in XAML is quite straightforward and requires little comment. Recall that the `Fill` property is used to specify a *brush* to paint the interior of a shape. When you require a solid-colored brush, just specify a hard-coded string of known values, and the underlying type converter will generate the correct object. One interesting feature of the `Rectangle` type is that it defines `RadiusX` and `RadiusY` properties to allow you to render curved corners.

`Line` represents its starting and ending points using the `X1`, `X2`, `Y1`, and `Y2` properties (given that *height* and *width* make little sense when describing a line). Here you are setting up a few additional properties that control how to render the starting and ending points of the `Line`, as well as how to configure the stroke settings. Figure 26-1 shows the rendered toolbar, as seen through the Visual Studio WPF designer.



**Figure 26-1.** Using Shapes as content for a set of `RadioButtons`

Now, using the Properties window of Visual Studio, handle the `MouseLeftButtonDown` event for the `Canvas`, and handle the `Click` event for each `RadioButton`. In your C# file, your goal is to render the selected shape (a circle, square, or line) when the user clicks within the `Canvas`. First, define the following nested enum (and corresponding member variable) within your `Window`-derived class:

```

public partial class MainWindow : Window
{
    private enum SelectedShape
    { Circle, Rectangle, Line }
    private SelectedShape _currentShape;
}

```

Within each `Click` event handler, set the `currentShape` member variable to the correct `SelectedShape` value, as follows:

```

private void circleOption_Click(object sender, RoutedEventArgs e)
{
    _currentShape = SelectedShape.Circle;
}

```

```

private void rectOption_Click(object sender, RoutedEventArgs e)
{
    _currentShape = SelectedShape.Rectangle;
}

private void lineOption_Click(object sender, RoutedEventArgs e)
{
    _currentShape = SelectedShape.Line;
}

```

With the `MouseLeftButtonDown` event handler of the `Canvas`, you will render out the correct shape (of a predefined size), using the `X,Y` position of the mouse cursor as a starting point. Here is the complete implementation, with analysis to follow:

```

private void canvasDrawingArea_MouseLeftButtonDown(object sender, MouseButtonEventArgs e)
{
    Shape shapeToRender = null;
    // Configure the correct shape to draw.
    switch (_currentShape)
    {
        case SelectedShape.Circle:
            shapeToRender = new Ellipse() { Fill = Brushes.Green, Height = 35, Width = 35 };
            break;
        case SelectedShape.Rectangle:
            shapeToRender = new Rectangle()
            { Fill = Brushes.Red, Height = 35, Width = 35, RadiusX = 10, RadiusY = 10 };
            break;
        case SelectedShape.Line:
            shapeToRender = new Line()
            {
                Stroke = Brushes.Blue,
                StrokeThickness = 10,
                X1 = 0, X2 = 50, Y1 = 0, Y2 = 50,
                StrokeStartLineCap = PenLineCap.Triangle,
                StrokeEndLineCap = PenLineCap.Round
            };
            break;
        default:
            return;
    }
    // Set top/left position to draw in the canvas.
    Canvas.SetLeft(shapeToRender, e.GetPosition(canvasDrawingArea).X);
    Canvas.SetTop(shapeToRender, e.GetPosition(canvasDrawingArea).Y);
    // Draw shape!
    canvasDrawingArea.Children.Add(shapeToRender);
}

```

---

■ **Note** You might notice that the `Ellipse`, `Rectangle`, and `Line` objects being created in this method have the same property settings as the corresponding XAML definitions! As you might hope, you can streamline this code, but that requires an understanding of the WPF object resources, which you will examine in Chapter 27.

---

As you can see, you are testing the `currentShape` member variable to create the correct Shape-derived object. After this point, you set the top-left value within the Canvas using the incoming `MouseButtonEventArgs`. Last but not least, you add the new Shape-derived type to the collection of `UIElement` objects maintained by the Canvas. If you run your program now, you should be able to click anywhere in the canvas and see the selected shape rendered at the location of the left mouse-click.

## Removing Rectangles, Ellipses, and Lines from a Canvas

With the Canvas maintaining a collection of objects, you might wonder how you can dynamically remove an item, perhaps in response to the user right-clicking a shape. You can certainly do this using a class in the `System.Windows.Media` namespace called the `VisualTreeHelper`. Chapter 27 will explain the roles of “visual trees” and “logical trees” in some detail. Until then, you can handle the `MouseRightButtonDown` event on your Canvas object and implement the corresponding event handler like so:

```
private void canvasDrawingArea_MouseRightButtonDown(object sender, MouseButtonEventArgs e)
{
    // First, get the X,Y location of where the user clicked.
    Point pt = e.GetPosition((Canvas)sender);
    // Use the HitTest() method of VisualTreeHelper to see if the user clicked
    // on an item in the canvas.
    HitTestResult result = VisualTreeHelper.HitTest(canvasDrawingArea, pt);
    // If the result is not null, they DID click on a shape!
    if (result != null)
    {
        // Get the underlying shape clicked on, and remove it from
        // the canvas.
        canvasDrawingArea.Children.Remove(result.VisualHit as Shape);
    }
}
```

This method begins by obtaining the exact X,Y location the user clicked in the Canvas and performs a hit-test operation via the static `VisualTreeHelper.HitTest()` method. The return value, a `HitTestResult` object, will be set to null if the user does not click a `UIElement` within the Canvas. If `HitTestResult` is *not* null, you can obtain the underlying `UIElement` that was clicked via the `VisualHit` property, which you are casting into a Shape-derived object (remember, a Canvas can hold any `UIElement`, not just shapes!). Again, you’ll get more details on exactly what a “visual tree” is in the next chapter.

---

■ **Note** By default, `VisualTreeHelper.HitTest()` returns the topmost `UIElement` clicked and does not provide information on other objects below that item (e.g., objects overlapping by Z-order).

---

With this modification, you should be able to add a shape to the canvas with a left mouse-click and delete an item from the canvas with a right mouse-click!

So far, so good. At this point, you have used Shape-derived objects to render content on `RadioButtons` using XAML and populated a `Canvas` using C#. You will add a bit more functionality to this example when you examine the role of brushes and graphical transformations. On a related note, a different example in this chapter will illustrate drag-and-drop techniques on `UIElement` objects. Until then, let's examine the remaining members of `System.Windows.Shapes`.

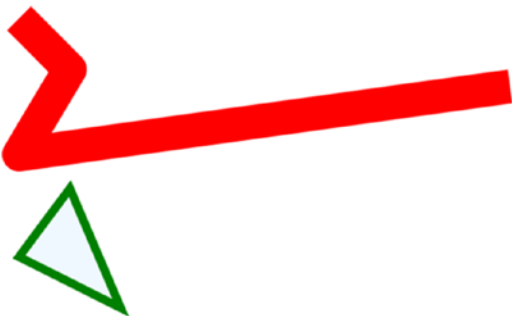
## Working with Polylines and Polygons

The current example used only three of the Shape-derived classes. The remaining child classes (`Polyline`, `Polygon`, and `Path`) are extremely tedious to render correctly without tool support (such as Microsoft Blend, the companion tool for Visual Studio designed for WPF developers, or other tools that can create vector graphics) simply because they require a large number of plot points to represent their output. Here is an overview of the remaining Shapes types.

The `Polyline` type lets you define a collection of (x, y) coordinates (via the `Points` property) to draw a series of line segments that do not require connecting ends. The `Polygon` type is similar; however, it is programmed so that it will always close the starting and ending points and fill the interior with the specified brush. Assume you have authored the following `<StackPanel>` in the Kaxaml editor:

```
<!-- Polylines do not automatically connect the ends. -->
<Polyline Stroke ="Red" StrokeThickness ="20" StrokeLineJoin ="Round" Points ="10,10 40,40
10,90 300,50"/>
<!-- A Polygon always closes the end points. -->
<Polygon Fill ="AliceBlue" StrokeThickness ="5" Stroke ="Green" Points ="40,10 70,80 10,50"
/>
```

Figure 26-2 shows the rendered output in Kaxaml.



**Figure 26-2.** Polygons and polylines

## Working with Paths

Using the `Rectangle`, `Ellipse`, `Polygon`, `Polyline`, and `Line` types alone to draw a detailed 2D vector image would be extremely complex, as these primitives do not allow you to easily capture graphical data such as curves, unions of overlapping data, and so forth. The final Shape-derived class, `Path`, provides the ability to define complex 2D graphical data represented as a collection of independent *geometries*. After you have defined a collection of such geometries, you can assign them to the `Data` property of the `Path` class, where this information will be used to render your complex 2D image.

The Data property takes a `System.Windows.Media.Geometry`-derived class, which contains the key members described in Table 26-2.

**Table 26-2.** *Select Members of the System.Windows.Media.Geometry Type*

Member	Meaning in Life
Bounds	Establishes the current bounding rectangle containing the geometry.
FillContains()	Determines whether a given Point (or other Geometry object) is within the bounds of a particular Geometry-derived class. This is useful for hit-testing calculations.
GetArea()	Returns the entire area that a Geometry-derived type occupies.
GetRenderBounds()	Returns a Rect that contains the smallest possible rectangle that could be used to render the Geometry-derived class.
Transform	Assigns a Transform object to the geometry to alter the rendering.

The classes that extend Geometry (see Table 26-3) look very much like their Shape-derived counterparts. For example, `EllipseGeometry` has similar members to `Ellipse`. The big distinction is that Geometry-derived classes *do not know* how to render themselves directly because they are not `UIElements`. Rather, Geometry-derived classes represent little more than a collection of plot-point data, which say in effect “If a Path uses my data, this is how I would render myself.”

**Table 26-3.** *Geometry-Derived Classes*

Geometry Class	Meaning in Life
<code>LineGeometry</code>	Represents a straight line
<code>RectangleGeometry</code>	Represents a rectangle
<code>EllipseGeometry</code>	Represents an ellipse
<code>GeometryGroup</code>	Allows you to group together several Geometry objects
<code>CombinedGeometry</code>	Allows you to merge two different Geometry objects into a single shape
<code>PathGeometry</code>	Represents a figure composed of lines and curves

■ **Note** Path is not the only class in WPF that can use a collection of geometries. For example, `DoubleAnimationUsingPath`, `DrawingGroup`, `GeometryDrawing`, and even `UIElement` can all use geometries for rendering, using the `PathGeometry`, `ClipGeometry`, `Geometry`, and `Clip` properties, respectively.

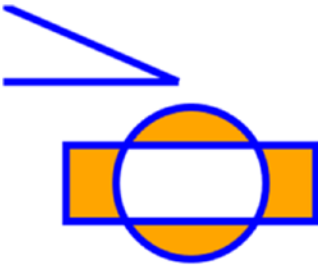
The following is a Path that makes use of a few Geometry-derived types. Notice that you are setting the Data property of Path to a `GeometryGroup` object that contains other Geometry-derived objects such as `EllipseGeometry`, `RectangleGeometry`, and `LineGeometry`. Figure 26-3 shows the output.

```
<!-- A Path contains a set of geometry objects, set with the Data property. -->
<Path Fill = "Orange" Stroke = "Blue" StrokeThickness = "3">
  <Path.Data>
    <GeometryGroup>
      <EllipseGeometry Center = "75,70" RadiusX = "30" RadiusY = "30" />
```

```

<RectangleGeometry Rect = "25,55 100 30" />
<LineGeometry StartPoint="0,0" EndPoint="70,30" />
<LineGeometry StartPoint="70,30" EndPoint="0,30" />
</GeometryGroup>
</Path.Data>
</Path>

```



**Figure 26-3.** A Path containing various Geometry objects

The image in Figure 26-3 could have been rendered using the `Line`, `Ellipse`, and `Rectangle` classes shown earlier. However, this would have put various `UIElement` objects in memory. When you use geometries to model the plot points of what to draw and then place the geometry collection into a container that can render the data (`Path`, in this case), you reduce the memory overhead.

Now recall that `Path` has the same inheritance chain as any other member of `System.Windows.Shapes` and therefore has the ability to send the same event notifications as other `UIElements`. Thus, if you were to define this same `<Path>` element in a Visual Studio project, you could determine whether the user clicked anywhere in the sweeping line simply by handling a mouse event (remember, Xaml does not allow you to handle events for the markup you have authored).

## The Path Modeling “Mini-Language”

Of all the classes listed in Table 26-3, `PathGeometry` is the most complex to configure in terms of XAML or code. This has to do with the fact that each *segment* of the `PathGeometry` is composed of objects that contain various segments and figures (e.g., `ArcSegment`, `BezierSegment`, `LineSegment`, `PolyBezierSegment`, `PolyLineSegment`, `PolyQuadraticBezierSegment`, etc.). Here is an example of a `Path` object whose `Data` property has been set to a `<PathGeometry>` composed of various figures and segments:

```

<Path Stroke="Black" StrokeThickness="1" >
  <Path.Data>
    <PathGeometry>
      <PathGeometry.Figures>
        <PathFigure StartPoint="10,50">
          <PathFigure.Segments>
            <BezierSegment
              Point1="100,0"
              Point2="200,200"
              Point3="300,100"/>
            <LineSegment Point="400,100" />
          </PathFigure.Segments>
        </PathFigure>
      </PathGeometry.Figures>
    </PathGeometry>
  </Path.Data>
</Path>

```

```

        <ArcSegment
            Size="50,50" RotationAngle="45"
            IsLargeArc="True" SweepDirection="Clockwise"
            Point="200,100"/>
    </PathFigure.Segments>
</PathFigure>
</PathGeometry.Figures>
</PathGeometry>
</Path.Data>
</Path>

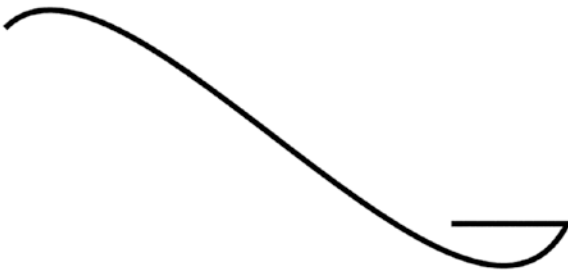
```

Now, to be perfectly honest, few programmers will ever need to manually build complex 2D images by directly describing Geometry- or PathSegment-derived classes. Later in this chapter, you will learn how to convert vector graphics into path statements that can be used in XAML.

Even with the assistance of these tools, the amount of XAML required to define a complex Path object would be ghastly, as the data consists of full descriptions of various Geometry- or PathSegment-derived classes. To produce more concise and compact markup, the Path class has been designed to understand a specialized “mini-language.”

For example, rather than setting the Data property of Path to a collection of Geometry- and PathSegment-derived types, you can set the Data property to a single string literal containing a number of known symbols and various values that define the shape to be rendered. Here is a simple example, and the resulting output is shown in Figure 26-4:

```
<Path Stroke="Black" StrokeThickness="3" Data="M 10,75 C 70,15 250,270 300,175 H 240" />
```



**Figure 26-4.** The path mini-language allows you to compactly describe a Geometry/PathSegment object model

The M command (short for *move*) takes an X,Y position that represents the starting point of the drawing. The C command takes a series of plot points to render a *curve* (a cubic Bézier curve to be exact), while H draws a *horizontal* line.

Now, to be perfectly honest, the chances that you will ever need to manually build or parse a string literal containing path mini-language instructions are slim to none. However, at the least, you will no longer be surprised when you view XAML-generated dedicated tools.

## WPF Brushes and Pens

Each of the WPF graphical rendering options (shape, drawing and geometries, and visuals) makes extensive use of *brushes*, which allow you to control how the interior of a 2D surface is filled. WPF provides six different brush types, all of which extend `System.Windows.Media.Brush`. While `Brush` is abstract, the descendants described in Table 26-4 can be used to fill a region with just about any conceivable option.

**Table 26-4.** *WPF Brush-Derived Types*

Brush Type	Meaning in Life
DrawingBrush	Paints an area with a Drawing-derived object (GeometryDrawing, ImageDrawing, or VideoDrawing)
ImageBrush	Paints an area with an image (represented by an ImageSource object)
LinearGradientBrush	Paints an area with a linear gradient
RadialGradientBrush	Paints an area with a radial gradient
SolidColorBrush	Paints a single color, set with the Color property
VisualBrush	Paints an area with a Visual-derived object (DrawingVisual, Viewport3DVisual, and ContainerVisual)

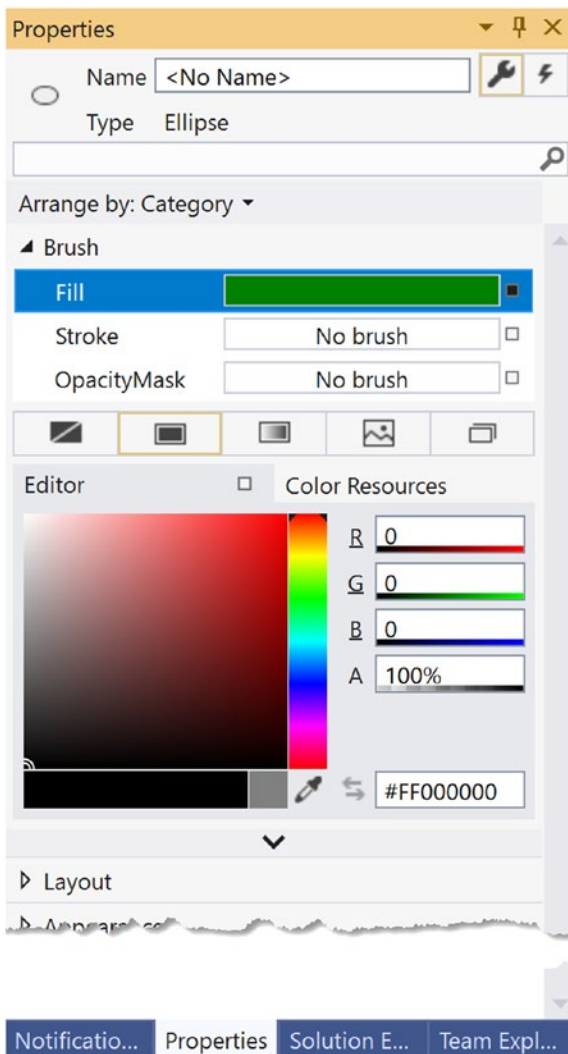
The `DrawingBrush` and `VisualBrush` classes allow you to build a brush based on an existing Drawing- or Visual-derived class. These brush classes are used when you are working with the other two graphical options of WPF (drawings or visuals) and will be examined later in this chapter.

`ImageBrush`, as the name suggests, lets you build a brush that displays image data from an external file or embedded application resource, by setting the `ImageSource` property. The remaining brush types (`LinearGradientBrush` and `RadialGradientBrush`) are quite straightforward to use, though typing in the required XAML can be a tad verbose. Thankfully, Visual Studio supports integrated brush editors that make it simple to generate stylized brushes.

## Configuring Brushes Using Visual Studio

Let's update your WPF drawing program, `RenderingWithShapes`, to use some more interesting brushes. The three shapes you've employed so far to render data on your toolbar use simple, solid colors, so you can capture their values using simple string literals. To spice things up a tad, you will now use the integrated brush editor. Ensure that the XAML editor of your initial window is the open window within the IDE, and select the `Ellipse` element. Now, in the Properties window, locate the Brush category and then click `Fill` property listed on the top (see Figure 26-5).





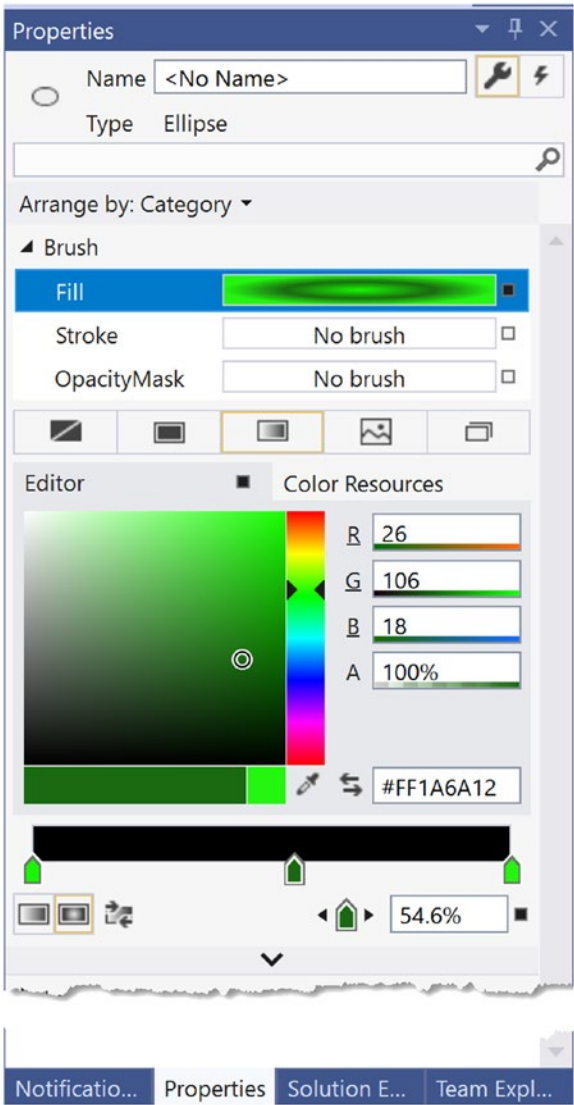
**Figure 26-5.** Any property that requires a brush can be configured with the integrated brush editor

At the top of the Brushes editor, you will see a set of properties that are all “brush compatible” for the selected item (i.e., Fill, Stroke, and OpacityMask). Below this, you will see a series of tabs that allow you to configure different types of brushes, including the current solid color brush. You can use the color selector tool, as well as the ARGB (alpha, red, green, and blue, where “alpha” controls transparency) editors to control the color of the current brush. Using these sliders and the related color selection area, you can create any sort of solid color. Use these tools to change the Fill color of your Ellipse and view the resulting XAML. You’ll notice the color is stored as a hexadecimal value, as follows:

```
<Ellipse Fill="#FF47CE47" Height="35" Width="35" />
```

More interestingly, this same editor allows you to configure gradient brushes, which are used to define a series of colors and transition points. Recall that this Brushes editor provides you with a set of tabs, the first of which lets you set a *null brush* for no rendered output. The other four allow you to set up a solid color brush (what you just examined), gradient brush, tile brush, or image brush.

Click the gradient brush button and the editor will display a few new options (see Figure 26-6). The three buttons on the lower left allow you to pick a linear gradient, pick a radial gradient, or reverse the gradient stops. The bottommost strip will show you the current color of each gradient stop, each of which is marked by a “thumb” on the strip. As you drag these thumbs around the gradient strip, you can control the gradient offset. Furthermore, when you click a given thumb, you can change the color for that particular gradient stop via the color selector. Finally, if you click directly on the gradient strip, you can add additional gradient stops.



**Figure 26-6.** The Visual Studio brush editor allows you to build basic gradient brushes

Take a few minutes to play around with this editor to build a radial gradient brush containing three gradient stops, set to your colors of choice. Figure 26-6 shows the brush you just constructed, using three different shades of green.

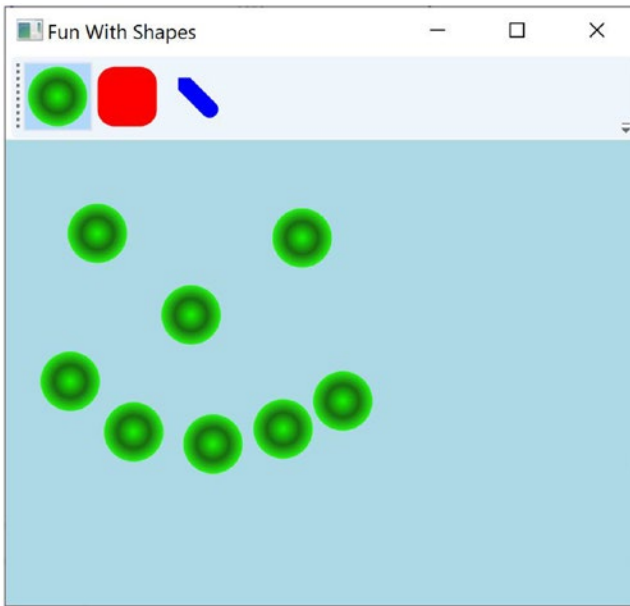
When you are done, the IDE will update your XAML with a custom brush, set to a brush-compatible property (the Fill property of the Ellipse in this example) using property-element syntax, as follows:

```
<Ellipse Height="35" Width="35">
  <Ellipse.Fill>
    <RadialGradientBrush>
      <GradientStop Color="#FF17F800"/>
      <GradientStop Color="#FF24F610" Offset="1"/>
      <GradientStop Color="#FF1A6A12" Offset="0.546"/>
    </RadialGradientBrush>
  </Ellipse.Fill>
</Ellipse>
```

## Configuring Brushes in Code

Now that you have built a custom brush for the XAML definition of your Ellipse, the corresponding C# code is out-of-date, in that it will still render a solid green circle. To sync things back up, update the correct case statement to use the same brush you just created. The following is the necessary update, which looks more complex than you might expect, just because you are converting the hexadecimal value to a proper Color object via the System.Windows.Media.ColorConverter class (see Figure 26-7 for the modified output):

```
case SelectedShape.Circle:
    shapeToRender = new Ellipse() { Height = 35, Width = 35 };
    // Make a RadialGradientBrush in code!
    RadialGradientBrush brush = new RadialGradientBrush();
    brush.GradientStops.Add(new GradientStop(
        (Color)ColorConverter.ConvertFromString("#FF77F177"), 0));
    brush.GradientStops.Add(new GradientStop(
        (Color)ColorConverter.ConvertFromString("#FF11E611"), 1));
    brush.GradientStops.Add(new GradientStop(
        (Color)ColorConverter.ConvertFromString("#FF5A8E5A"), 0.545));
    shapeToRender.Fill = brush;
    break;
```



**Figure 26-7.** *Drawing circles with a bit more pizzazz!*

By the way, you can build `GradientStop` objects by specifying a simple color as the first constructor parameter using the `Colors` enumeration, which returns a configured `Color` object.

```
GradientStop g = new GradientStop(Colors.Aquamarine, 1);
```

Or, if you require even finer control, you can pass in a configured `Color` object, like so:

```
Color myColor = new Color() { R = 200, G = 100, B = 20, A = 40 };
GradientStop g = new GradientStop(myColor, 34);
```

Of course, the `Colors` enum and `Color` class are not limited to gradient brushes. You can use them anytime you need to represent a color value in code.

## Configuring Pens

In comparison with brushes, a *pen* is an object for drawing borders of geometries or, in the case of the `Line` or `PolyLine` class, the line geometry itself. Specifically, the `Pen` class allows you to draw a specified thickness, represented by a double value. In addition, a `Pen` can be configured with the same sort of properties seen in the `Shape` class, such as starting and stopping pen caps, dot-dash patterns, and so forth. For example, you can add the following markup to a shape to define the pen attributes:

```
<Pen Thickness="10" LineJoin="Round" EndLineCap="Triangle" StartLineCap="Round" />
```

In many cases, you won't need to directly create a `Pen` object because this will be done indirectly when you assign a value to properties, such as `StrokeThickness` to a `Shape`-derived type (as well as other `UIElements`). However, building a custom `Pen` object is handy when working with `Drawing`-derived types (described later in the chapter). Visual Studio does not have a pen editor, *per se*, but it does allow you to configure all the stroke-centric properties of a selected item using the Properties window.

# Applying Graphical Transformations

To wrap up the discussion of using shapes, let's address the topic of *transformations*. WPF ships with numerous classes that extend the `System.Windows.Media.Transform` abstract base class. Table 26-5 documents many of the key out-of-the-box Transform-derived classes.

**Table 26-5.** Key Descendants of the `System.Windows.Media.Transform` Type

Type	Meaning in Life
<code>MatrixTransform</code>	Creates an arbitrary matrix transformation that is used to manipulate objects or coordinate systems in a 2D plane
<code>RotateTransform</code>	Rotates an object clockwise about a specified point in a 2D (x, y) coordinate system
<code>ScaleTransform</code>	Scales an object in the 2D (x, y) coordinate system
<code>SkewTransform</code>	Skews an object in the 2D (x, y) coordinate system
<code>TranslateTransform</code>	Translates (moves) an object in the 2D (x, y) coordinate system
<code>TransformGroup</code>	Represents a composite Transform composed of other Transform objects

Transformations can be applied to any `UIElement` (e.g., descendants of `Shape` as well as controls such as `Button` controls, `TextBox` controls, and the like). Using these transformation classes, you can render graphical data at a given angle, skew the image across a surface, and expand, shrink, or flip the target item in a variety of ways.

---

**Note** While transformation objects can be used anywhere, you will find them most useful when working with WPF animations and custom control templates. As you will see later in the chapter, you can use WPF animations to incorporate visual cues to the end user for a custom control.

---

Transformations (or a whole set of them) can be assigned to a target object (e.g., `Button`, `Path`, etc.) using two common properties, `LayoutTransform` and `RenderTransform`.

The `LayoutTransform` property is helpful, in that the transformation occurs *before* elements are rendered into a layout manager, and therefore the transformation will not affect Z-ordering operations (in other words, the transformed image data will not overlap).

The `RenderTransform` property, on the other hand, occurs after the items are in their container, and therefore it is quite possible that elements can be transformed in such a way that they could overlap each other, based on how they were arranged in the container.

## A First Look at Transformations

You will add some transformational logic to your `RenderingWithShapes` project in just a moment. However, to see transformation objects in action, open `Kaxaml` and define a simple `StackPanel` in the root `Page` or `Window`, and set the `Orientation` property to `Horizontal`. Now, add the following `Rectangle`, which will be drawn at a 45-degree angle using a `RotateTransform` object:

```
<!-- A Rectangle with a rotate transformation. -->
<Rectangle Height ="100" Width ="40" Fill ="Red">
  <Rectangle.LayoutTransform>
```

```

    <RotateTransform Angle ="45"/>
  </Rectangle.LayoutTransform>
</Rectangle>

```

Here is a `<Button>` that is skewed across the surface by 20 degrees, using a `<SkewTransform>`:

```

<!-- A Button with a skew transformation. -->
<Button Content ="Click Me!" Width="95" Height="40">
  <Button.LayoutTransform>
    <SkewTransform AngleX ="20" AngleY ="20"/>
  </Button.LayoutTransform>
</Button>

```

And for good measure, here is an `Ellipse` that is scaled by 20 degrees with a `ScaleTransform` (note the values set to the initial Height and Width), as well as a `TextBox` that has a group of transformation objects applied to it:

```

<!-- An Ellipse that has been scaled by 20%. -->
<Ellipse Fill ="Blue" Width="5" Height="5">
  <Ellipse.LayoutTransform>
    <ScaleTransform ScaleX ="20" ScaleY ="20"/>
  </Ellipse.LayoutTransform>
</Ellipse>
<!-- A TextBox that has been rotated and skewed. -->
<TextBox Text ="Me Too!" Width="50" Height="40">
  <TextBox.LayoutTransform>
    <TransformGroup>
      <RotateTransform Angle ="45"/>
      <SkewTransform AngleX ="5" AngleY ="20"/>
    </TransformGroup>
  </TextBox.LayoutTransform>
</TextBox>

```

Note that when a transformation is applied, you are not required to perform any manual calculations to correctly respond to hit-testing, input focus, or whatnot. The WPF graphics engine handles such tasks on your behalf. For example, in Figure 26-8, you can see that the `TextBox` is still responsive to keyboard input.



**Figure 26-8.** The results of graphical transformation objects

## Transforming Your Canvas Data

Now, let's incorporate some transformational logic into your `RenderingWithShapes` example. In addition to applying a transformation object to a single item (e.g., `Rectangle`, `TextBox`, etc.), you can also apply transformation objects to a layout manager in order to transform all of the internal data. You could, for example, render the entire `DockPanel` of the main window at an angle.

```
<DockPanel LastChildFill="True">
  <DockPanel.LayoutTransform>
    <RotateTransform Angle="45"/>
  </DockPanel.LayoutTransform>
  ...
</DockPanel>
```

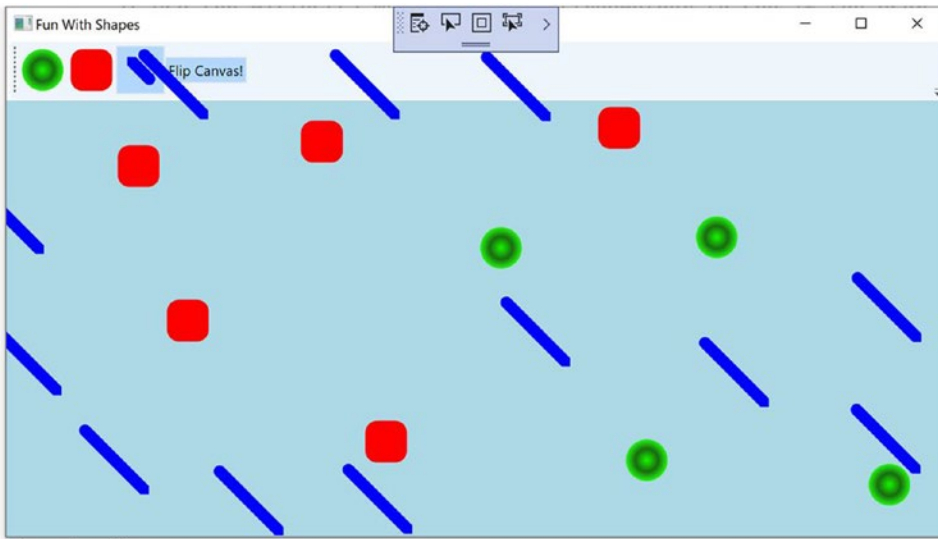
This is a bit extreme for this example, so let's add a final (less aggressive) feature that allows the user to flip the entire Canvas and all contained graphics. Begin by adding a final `ToggleButton` to your `ToolBar`, defined as follows:

```
<ToggleButton Name="flipCanvas" Click="flipCanvas_Click" Content="Flip Canvas!"/>
```

Within the `Click` event handler, create a `RotateTransform` object and connect it to the `Canvas` object via the `LayoutTransform` property if this new `ToggleButton` is clicked. If the `ToggleButton` is not clicked, remove the transformation by setting the same property to `null`.

```
private void flipCanvas_Click(object sender, RoutedEventArgs e)
{
    if (flipCanvas.IsChecked == true)
    {
        RotateTransform rotate = new RotateTransform(-180);
        canvasDrawingArea.LayoutTransform = rotate;
    }
    else
    {
        canvasDrawingArea.LayoutTransform = null;
    }
}
```

Run your application and add a bunch of graphics throughout the canvas area, making sure to go edge to edge with them. If you click your new button, you will find that the shape data flows outside of the boundaries of the canvas! This is because you have not defined a clipping region (see [Figure 26-9](#)).



**Figure 26-9.** Oops! Your data is flowing outside of the canvas after the transformation!

Fixing this is trivial. Rather than manually authoring complex clipping-logic code, simply set the `ClipToBounds` property of the `Canvas` to `true`, which prevents child elements from being rendered outside the parent's boundaries. If you run your program again, you'll find the data will not bleed off the canvas boundary.

```
<Canvas ClipToBounds = "True" ... >
```

The last tiny modification to make has to do with the fact that when you flip the canvas by pressing your toggle button and then click the canvas to draw a new shape, the point at which you click is *not* the point where the graphical data is applied. Rather, the data is rendered above the mouse cursor.

To resolve this issue, apply the same transformation object to the shape being drawn before the rendering occurs (via `RenderTransform`). Here is the crux of the code:

```
private void canvasDrawingArea_MouseLeftButtonDown(object sender, MouseButtonEventArgs e)
{
    //omitted for brevity
    if (flipCanvas.IsChecked == true)
    {
        RotateTransform rotate = new RotateTransform(-180);
        shapeToRender.RenderTransform = rotate;
    }
    // Set top/left to draw in the canvas.
    Canvas.SetLeft(shapeToRender,
        e.GetPosition(canvasDrawingArea).X);
    Canvas.SetTop(shapeToRender,
        e.GetPosition(canvasDrawingArea).Y);

    // Draw shape!
    canvasDrawingArea.Children.Add(shapeToRender);
}
```



This wraps up your examination of `System.Windows.Shapes`, brushes, and transformations. Before looking at the role of rendering graphics using drawings and geometries, let's see how Visual Studio can be used to simplify how you work with primitive graphics.

## Working with the Visual Studio Transform Editor

In the previous example, you applied various transformations by manually entering markup and authoring some C# code. While this is certainly useful, you will be happy to know that the latest version of Visual Studio ships with an integrated transformation editor. Recall that any UI element can be the recipient of transformational services, including a layout system containing various UI elements. To illustrate the use of Visual Studio's transform editor, create a new WPF application named `FunWithTransforms`.

### Building the Initial Layout

First, split your initial `Grid` into two columns using the integrated grid editor (the exact size does not matter). Now, locate the `StackPanel` control within your Toolbox and add it to take up the entire space of the first column of the `Grid`; then add three `Button` controls to the `StackPanel`, like so:

```
<Grid>
  <Grid.ColumnDefinitions>
    <ColumnDefinition Width="*" />
    <ColumnDefinition Width="*" />
  </Grid.ColumnDefinitions>
  <StackPanel Grid.Row="0" Grid.Column="0">
    <Button Name="btnSkew" Content="Skew" Click="Skew" />
    <Button Name="btnRotate" Content="Rotate" Click="Rotate" />
    <Button Name="btnFlip" Content="Flip" Click="Flip" />
  </StackPanel>
</Grid>
```

Add the handlers for the buttons to the code page, like this:

```
private void Skew(object sender, RoutedEventArgs e)
{
}
private void Rotate(object sender, RoutedEventArgs e)
{
}
private void Flip(object sender, RoutedEventArgs e)
{
}
```

To finalize the UI, create a graphic of your choosing (using any of the techniques discussed in this chapter) defined in the second column of the `Grid`. The markup used in the sample is listed here:

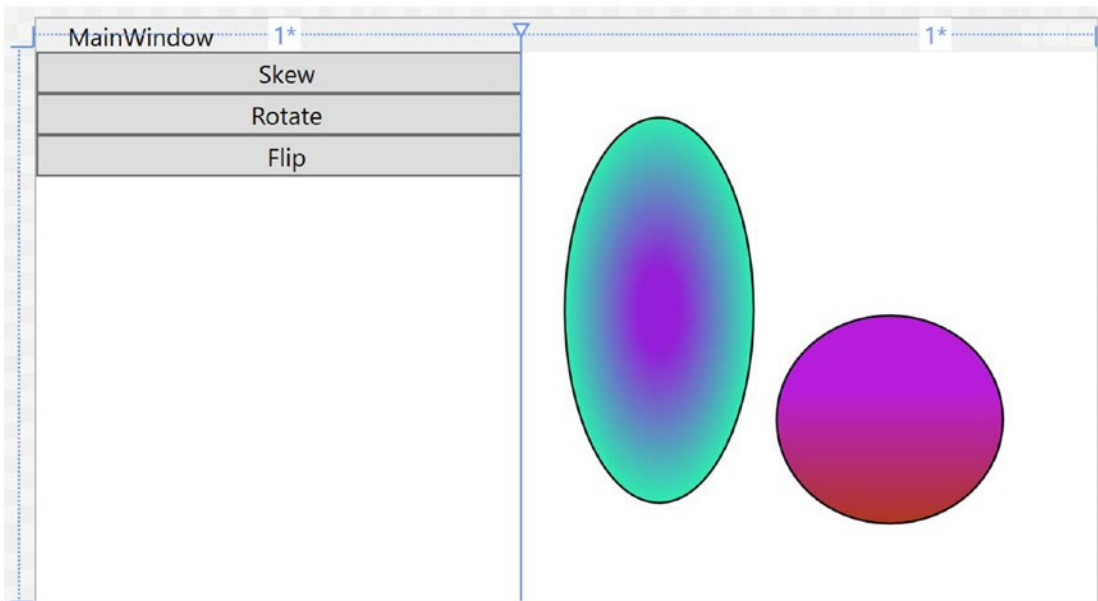
```
<Canvas x:Name="myCanvas" Grid.Column="1" Grid.Row="0">
  <Ellipse HorizontalAlignment="Left" VerticalAlignment="Top"
    Height="186" Width="92" Stroke="Black"
    Canvas.Left="20" Canvas.Top="31">
    <Ellipse.Fill>
```

```

    <RadialGradientBrush>
      <GradientStop Color="#FF951ED8" Offset="0.215"/>
      <GradientStop Color="#FF2FECB0" Offset="1"/>
    </RadialGradientBrush>
  </Ellipse.Fill>
</Ellipse>
<Ellipse HorizontalAlignment="Left" VerticalAlignment="Top"
  Height="101" Width="110" Stroke="Black"
  Canvas.Left="122" Canvas.Top="126">
  <Ellipse.Fill>
    <LinearGradientBrush EndPoint="0.5,1" StartPoint="0.5,0">
      <GradientStop Color="#FFB91DDC" Offset="0.355"/>
      <GradientStop Color="#FFB0381D" Offset="1"/>
    </LinearGradientBrush>
  </Ellipse.Fill>
</Ellipse>
</Canvas>

```

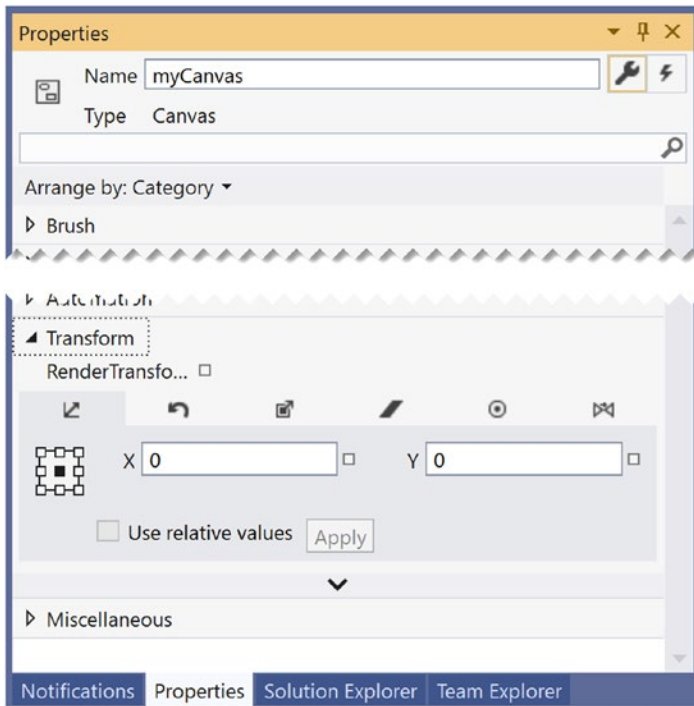
Figure 26-10 shows the final layout for the example.



**Figure 26-10.** The layout of your transformation example

## Applying Transformations at Design Time

As mentioned, Visual Studio provides an integrated Transform editor, which can be found in the Properties panel. Locate this area, and make sure you expand the Transform section to view the RenderTransform and LayoutTransform sections of the editor (see Figure 26-11).



**Figure 26-11.** The Transform editor

Similar to the Brushes section, the Transform section provides a number of tabs to configure various types of graphical transformation to the currently selected item. Table 26-6 describes each transformation option, listed in the order of evaluating each tab left to right.

**Table 26-6.** Blend Transformation Options

Transformation Option	Meaning in Life
Translate	Allows you to offset the location of an item on an X, Y position.
Rotate	Allows you to rotate an item on a 360-degree angle.
Scale	Allows you to grow or shrink an item by a factor in the X and Y directions.
Skew	Allows you to skew the bounding box containing the selected item by a factor in the X and Y directions.
Center Point	When you rotate or flip an object, the item moves relative to a fixed point, called the object's center point. By default, an object's center point is located at the object's center; however, this transformation allows you to change an object's center point in order to rotate or flip the object around a different point.
Flip	Flips a selected item based on an X or Y center point.

I suggest you test each of these transformations using your custom shape as a target (just press Ctrl+Z to undo the previous operation). Like many other aspects of the Transform Properties panel, each transformation section has a unique set of configuration options, which should become fairly understandable as you tinker. For example, the Skew transform editor allows you to set the X and Y skew values, the Flip transform editor allows you to flip on the x or y axis, and so forth.

## Transforming the Canvas in Code

The implementation of each Click event handler will be more or less the same. You will configure a transformation object and assign it to the `myCanvas` object. Then, when you run the application, you can click a button to see the result of the applied transformation. Here is the complete code for each event handler (notice that you are setting the `LayoutTransform` property so the shape data remains positioned relative to the parent container):

```
private void Flip(object sender, System.Windows.RoutedEventArgs e)
{
    myCanvas.LayoutTransform = new ScaleTransform(-1, 1);
}

private void Rotate(object sender, System.Windows.RoutedEventArgs e)
{
    myCanvas.LayoutTransform = new RotateTransform(180);
}

private void Skew(object sender, System.Windows.RoutedEventArgs e)
{
    myCanvas.LayoutTransform = new SkewTransform(40, -20);
}
```

## Rendering Graphical Data Using Drawings and Geometries

While the Shape types allow you to generate any sort of interactive two-dimensional surface, they entail quite a bit of memory overhead due to their rich inheritance chain. And though the Path class can help remove some of this overhead using contained geometries (rather than a large collection of other shapes), WPF provides a sophisticated drawing and geometry programming interface that renders even more lightweight 2D vector images.

The entry point into this API is the abstract `System.Windows.Media.Drawing` class (in `PresentationCore.dll`), which on its own does little more than define a bounding rectangle to hold the rendering. The Drawing class is significantly more lightweight than Shape, given that neither `UIElement` nor `FrameworkElement` is in the inheritance chain.

WPF provides various classes that extend Drawing, each of which represents a particular way of drawing the content, as described in Table 26-7.

**Table 26-7.** *WPF Drawing-Derived Types*

Type	Meaning in Life
DrawingGroup	Used to combine a collection of separate Drawing-derived objects into a single composite rendering.
GeometryDrawing	Used to render 2D shapes in a very lightweight manner.
GlyphRunDrawing	Used to render textual data using WPF graphical rendering services.
ImageDrawing	Used to render an image file, or geometry set, into a bounding rectangle.
VideoDrawing	Used to play an audio file or video file. This type can only be fully exploited using procedural code. If you would like to play videos via XAML, the MediaPlayer type is a better choice.

Because they are more lightweight, Drawing-derived types do not have intrinsic support for handling input events, as they are not UIElements or FrameworkElements (although it is possible to programmatically perform hit-testing logic).

Another key difference between Drawing-derived types and Shape-derived types is that Drawing-derived types have no ability to render themselves, as they do not derive from UIElement! Rather, derived types must be placed within a hosting object (specifically, DrawingImage, DrawingBrush, or DrawingVisual) to display their content.

DrawingImage allows you to place drawing and geometries inside a WPF Image control, which typically is used to display data from an external file. DrawingBrush allows you to build a brush based on a drawing and its geometries in order to set a property that requires a brush. Finally, DrawingVisual is used only in the “visual” layer of graphical rendering, which is driven completely via C# code.

Although using drawings is a bit more complex than using simple shapes, this decoupling of graphical composition from graphical rendering makes the Drawing-derived types much more lightweight than the Shape-derived types while still retaining key services.

## Building a DrawingBrush Using Geometries

Earlier in this chapter, you filled a Path with a group of geometries, like so:

```
<Path Fill = "Orange" Stroke = "Blue" StrokeThickness = "3">
  <Path.Data>
    <GeometryGroup>
      <EllipseGeometry Center = "75,70" RadiusX = "30" RadiusY = "30" />
      <RectangleGeometry Rect = "25,55 100 30" />
      <LineGeometry StartPoint="0,0" EndPoint="70,30" />
      <LineGeometry StartPoint="70,30" EndPoint="0,30" />
    </GeometryGroup>
  </Path.Data>
</Path>
```

By doing this, you gain interactivity from Path but are still fairly lightweight given your geometries. However, if you want to render the same output and have no need for any (out-of-the-box) interactivity, you can place the same <GeometryGroup> inside a DrawingBrush, like this:

```
<DrawingBrush>
  <DrawingBrush.Drawing>
    <GeometryDrawing>
      <GeometryDrawing.Geometry>
        <GeometryGroup>
          <EllipseGeometry Center = "75,70" RadiusX = "30" RadiusY = "30" />
          <RectangleGeometry Rect = "25,55 100 30" />
          <LineGeometry StartPoint="0,0" EndPoint="70,30" />
          <LineGeometry StartPoint="70,30" EndPoint="0,30" />
        </GeometryGroup>
      </GeometryDrawing.Geometry>
      <!-- A custom pen to draw the borders. -->
      <GeometryDrawing.Pen>
        <Pen Brush="Blue" Thickness="3"/>
      </GeometryDrawing.Pen>
      <!-- A custom brush to fill the interior. -->
      <GeometryDrawing.Brush>
        <SolidColorBrush Color="Orange"/>
      </GeometryDrawing.Brush>
    </GeometryDrawing>
  </DrawingBrush.Drawing>
</DrawingBrush>
```

When you place a group of geometries into a DrawingBrush, you also need to establish the Pen object used to draw the boundaries because you no longer inherit a Stroke property from the Shape base class. Here, you created a <Pen> with the same settings used in the Stroke and StrokeThickness values of the previous Path example.

Furthermore, since you no longer inherit a Fill property from Shape, you also need to use property-element syntax to define a brush object to use for the <DrawingGeometry>, which here is a solid-colored orange brush, just like the previous Path settings.

## Painting with the DrawingBrush

Now that you have a DrawingBrush, you can use it to set the value of any property requiring a brush object. For example, if you are authoring this markup in Xaml, you could use property-element syntax to paint your drawing over the entire surface of a Page, like so:

```
<Page
  xmlns="http://schemas.microsoft.com/winfx/2006/xaml/presentation"
  xmlns:x="http://schemas.microsoft.com/winfx/2006/xaml">
  <Page.Background>
    <DrawingBrush>
    <!-- Same DrawingBrush as seen above. -->
    </DrawingBrush>
  </Page.Background>
</Page>
```

Or, you can use this `<DrawingBrush>` to set a different brush-compatible property, such as the `Background` property of a `Button`.

```
<Page
  xmlns="http://schemas.microsoft.com/winfx/2006/xaml/presentation"
  xmlns:x="http://schemas.microsoft.com/winfx/2006/xaml">
  <Button Height="100" Width="100">
    <Button.Background>
      <DrawingBrush>
        <!-- Same DrawingBrush as seen above. -->
      </DrawingBrush>
    </Button.Background>
  </Button>
</Page>
```

No matter which brush-compatible property you set with your custom `<DrawingBrush>`, the bottom line is you are rendering a 2D vector image with much less overhead than the same 2D image rendered with shapes.

## Containing Drawing Types in a `DrawingImage`

The `DrawingImage` type allows you to plug your drawing geometry into a WPF `<Image>` control. Consider the following:

```
<Image>
  <Image.Source>
    <DrawingImage>
      <DrawingImage.Drawing>
        <!--Same GeometryDrawing from above -->
      </DrawingImage.Drawing>
    </DrawingImage>
  </Image.Source>
</Image>
```

In this case, your `<GeometryDrawing>` has been placed into a `<DrawingImage>`, rather than a `<DrawingBrush>`. Using this `<DrawingImage>`, you can set the `Source` property of the `Image` control.

## Working with Vector Images

As you might agree, it would be quite challenging for a graphic artist to create a complex vector-based image using the tools and techniques provided by Visual Studio. Graphic artists have their own set of tools that can produce amazing vector graphics. Neither Visual Studio nor its companion Expression Blend for Visual Studio has that type of design power. Before you can import vector images into WPF application, they must be converted into Path expressions. At that point, you can program against the generated object model using Visual Studio.

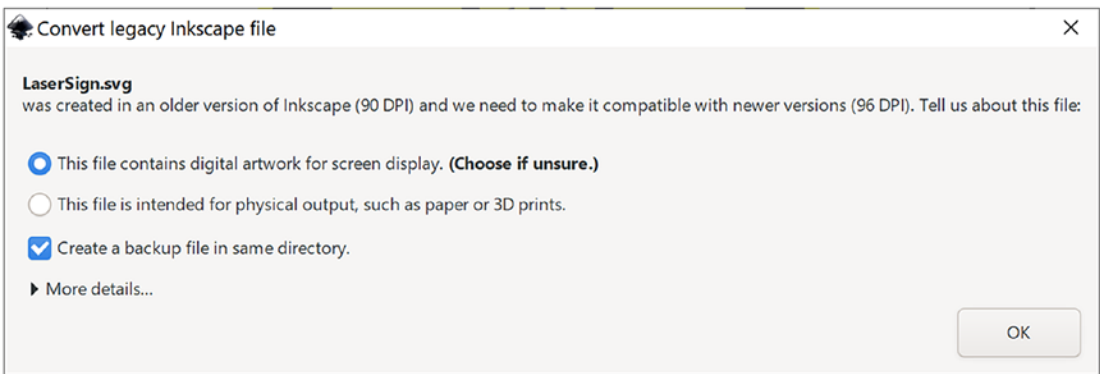
---

■ **Note** You can find the image being used (LaserSign.svg) as well as the exported path (LaserSign.xaml) data in the Chapter 26 folder of the download files. The image is originally from Wikipedia, located in this article: [https://en.wikipedia.org/wiki/Hazard\\_symbol](https://en.wikipedia.org/wiki/Hazard_symbol).

---

## Converting a Sample Vector Graphic File into XAML

Before you can import complex graphical data (such as vector graphics) into a WPF application, you need to convert the graphics into path data. As an example of how to do this, start with a sample .svg image file, such as the laser sign referenced in the preceding note. Then download and install an open source tool called Inkscape (located at [www.inkscape.org](http://www.inkscape.org)). Using Inkscape, open the LaserSign.svg file from the chapter download. You might be prompted to upgrade the format. Fill in the selections as shown in Figure 26-12.



**Figure 26-12.** Upgrading the SVG file to the latest format in Inkscape

The next steps will seem a bit odd at first, but once you get over the oddity, it is a simple way to convert vector images to the correct XAML. When you have the image the way you want it, select the File ► Print menu option. Next, select the Microsoft XPS Document Writer as the printer target and then click Print. On the next screen, enter a file name and select where the file should be saved; then click Save. Now you have a complete \*.xps (or \*.oxps) file.

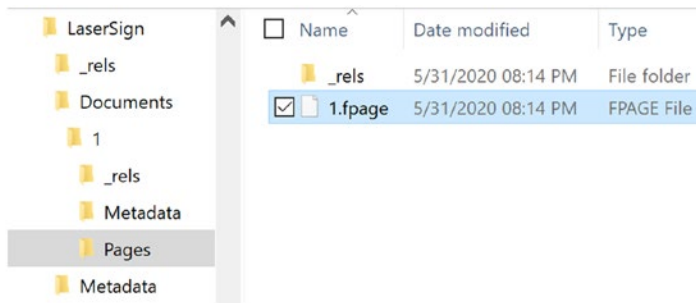
---

■ **Note** Depending on a number of variables with your system configuration, the generated file will have either the .xps or .oxps extension. Either way, the process works the same.

---

The \*.xps and \*.oxps formats are actually .zip files. Rename the extension of the file to .zip and you can open the file in File Explorer (or 7-Zip, or your favorite archive tool). You will see that it contains the hierarchy shown in Figure 26-13.





**Figure 26-13.** The folder hierarchy of the printed XPS file

The file that you need is in the Pages directory (Documents/1/Pages) and is named 1.fpage. Open the file with a text editor and copy everything except the <FixedPage> open and closing tags. The path data can then be copied into the Kaxaml and placed inside a Canvas in the main Window. Your image will show in the XAML window!

---

■ **Note** The latest version of Inkscape has an option to save the file as Microsoft XAML. Unfortunately, at the time of this writing, it is not compatible with WPF.

---

## Importing the Graphical Data into a WPF Project

At this point, create a new WPF application named InteractiveLaserSign. Resize the Window to a Height of 600 and Width of 650, and replace the Grid with a Canvas:

```
<Window x:Class="InteractiveLaserSign.MainWindow"
        xmlns="http://schemas.microsoft.com/winfx/2006/xaml/presentation"
        xmlns:x="http://schemas.microsoft.com/winfx/2006/xaml"
        xmlns:d="http://schemas.microsoft.com/expression/blend/2008"
        xmlns:local="clr-namespace:InteractiveLaserSign"
        mc:Ignorable="d"
        Title="MainWindow" Height="600" Width="650">
    <Canvas>
    </Canvas>
</Window>
```

Copy the entire XAML from the 1.fpage file (excluding the outer FixedPage tag) and paste into the Canvas control. View the Window in design mode, and you will see the sign reproduced in your application.

If you view the Document Outline, you will see that each part of the image is represented as a XAML Path element. If you resize your Window, the image quality stays the same, regardless of how big you make the window. This is because images represented by Path elements are rendered using the drawing engine and math instead of flipping pixels.

## Interacting with the Sign

Recall that routed event tunnel and bubble, so any Path clicked inside the Canvas can be handled by a click event handler on the canvas. Update the Canvas markup to the following:

```
<Canvas MouseLeftButtonDown="Canvas_MouseLeftButtonDown">
```

Add the event handler with the following code:

```
private void Canvas_MouseLeftButtonDown(object sender, MouseButtonEventArgs e)
{
    if (e.OriginalSource is Path p)
    {
        p.Fill = new SolidColorBrush(Colors.Red);
    }
}
```

Now, run your application. Click the lines to see the effects.

You now understand the process of generating Path data for complex graphics and how to interact with the graphical data in code. As you might agree, the ability for professional graphic artists to generate complex graphical data and export the data as XAML is extremely powerful. Once the graphical data has been generated, developers can import the markup and program against the object model.

## Rendering Graphical Data Using the Visual Layer

The final option for rendering graphical data with WPF is termed the *visual layer*. As mentioned, you can gain access to this layer only through code (it is not XAML-friendly). While a vast majority of your WPF applications will work just fine using shapes, drawings, and geometries, the visual layer does provide the fastest possible way to render huge amounts of graphical data. This low-level graphical layer can also be useful when you need to render a single image over a large area. For example, if you need to fill the background of a window with a plain, static image, the visual layer is the fastest way to do so. It can also be useful if you need to change between window backgrounds quickly, based on user input or whatnot.

I won't spend too much time delving into the details of this aspect of WPF programming, but let's build a small sample program to illustrate the basics.

## The Visual Base Class and Derived Child Classes

The abstract `System.Windows.Media.Visual` class type supplies a minimal set of services (rendering, hit-testing, transformations) to render graphics, but it does not provide support for additional nonvisual services, which can lead to code bloat (input events, layout services, styles, and data binding). The `Visual` class is an abstract base class. You need to use one of the derived types to perform actual rendering operations. WPF provides a handful of subclasses, including `DrawingVisual`, `Viewport3DVisual`, and `ContainerVisual`.

In this example, you will focus only on `DrawingVisual`, a lightweight drawing class that is used to render shapes, images, or text.

## A First Look at Using the DrawingVisual Class

To render data onto a surface using `DrawingVisual`, you need to take the following basic steps:

1. Obtain a `DrawingContext` object from the `DrawingVisual` class.
2. Use the `DrawingContext` to render the graphical data.

These two steps represent the bare minimum necessary for rendering some data to a surface. However, if you want the graphical data you've rendered to be responsive to hit-testing calculations (which would be important for adding user interactivity), you will also need to perform these additional steps:

1. Update the logical and visual trees maintained by the container upon which you are rendering.
2. Override two virtual methods from the `FrameworkElement` class, allowing the container to obtain the visual data you have created.

You will examine these final two steps in a bit. First, to illustrate how you can use the `DrawingVisual` class to render 2D data, create a new WPF application named `RenderingWithVisuals`. Your first goal is to use a `DrawingVisual` to dynamically assign data to a WPF `Image` control. Begin by updating the XAML of your window to handle the `Loaded` event, like so:

```
<Window x:Class="RenderingWithVisuals.MainWindow"
    <!--omitted for brevity -->
    Title="Fun With Visual Layer" Height="450" Width="800"
    Loaded="MainWindow_Loaded">
```

Next, replace the `Grid` with a `StackPanel` and add an `Image` in the `StackPanel`, like this:

```
<StackPanel Background="AliceBlue" Name="myStackPanel">
    <Image Name="myImage" Height="80"/>
</StackPanel>
```

Your `<Image>` control does not yet have a `Source` value because that will happen at runtime. The `Loaded` event will do the work of building the in-memory graphical data, using a `DrawingBrush` object. Make sure the following namespaces are at the top of `MainWindow.cs`:

```
using System;
using System.Windows;
using System.Windows.Media;
using System.Windows.Media.Imaging;
```

Here is the implementation of the `Loaded` event handler:

```
private void MainWindow_Loaded(
    object sender, RoutedEventArgs e)
{
    const int TextFontSize = 30;
    // Make a System.Windows.Media.FormattedText object.
    FormattedText text = new FormattedText(
        "Hello Visual Layer!",
        new System.Globalization.CultureInfo("en-us"),
        FlowDirection.LeftToRight,
```

```

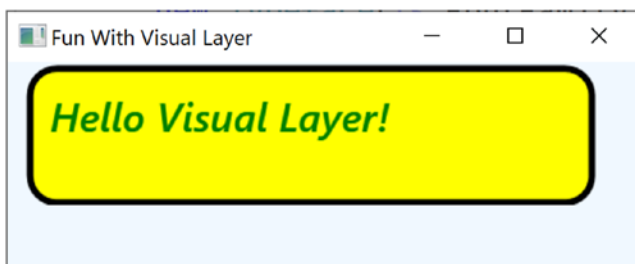
    new Typeface(this.FontFamily, FontStyles.Italic,
        FontWeights.DemiBold, FontStretches.UltraExpanded),
    TextFontSize,
    Brushes.Green,
    null,
    VisualTreeHelper.GetDpi(this).PixelsPerDip);
// Create a DrawingVisual, and obtain the DrawingContext.
DrawingVisual drawingVisual = new DrawingVisual();
using(DrawingContext drawingContext =
    drawingVisual.RenderOpen())
{
    // Now, call any of the methods of DrawingContext to render data.
    drawingContext.DrawRoundedRectangle(
        Brushes.Yellow, new Pen(Brushes.Black, 5),
        new Rect(5, 5, 450, 100), 20, 20);
    drawingContext.DrawText(text, new Point(20, 20));
}
// Dynamically make a bitmap, using the data in the DrawingVisual.
RenderTargetBitmap bmp = new RenderTargetBitmap(
    500, 100, 100, 90, PixelFormats.Pbgra32);
bmp.Render(drawingVisual);
// Set the source of the Image control!
myImage.Source = bmp;
}

```

This code introduces a number of new WPF classes, which I will briefly comment on here. The method begins by creating a new `FormattedText` object that represents the textual portion of the in-memory image you are constructing. As you can see, the constructor allows you to specify numerous attributes such as font size, font family, foreground color, and the text itself.

Next, you obtain the necessary `DrawingContext` object via a call to `RenderOpen()` on the `DrawingVisual` instance. Here, you are rendering a colored, rounded rectangle into the `DrawingVisual`, followed by your formatted text. In both cases, you are placing the graphical data into the `DrawingVisual` using hard-coded values, which is not necessarily a great idea for production but is fine for this simple test.

The last few statements map the `DrawingVisual` into a `RenderTargetBitmap` object, which is a member of the `System.Windows.Media.Imaging` namespace. This class will take a visual object and transform it into an in-memory bitmap image. After this point, you set the `Source` property of the `Image` control, and sure enough, you will see the output in Figure 26-14.



**Figure 26-14.** Using the visual layer to render an in-memory bitmap

---

■ **Note** The `System.Windows.Media.Imaging` namespace contains a number of additional encoding classes that let you save the in-memory `RenderTargetBitmap` object to a physical file in a variety of formats. Check out the `JpegBitmapEncoder` class (and friends) for more information.

---

## Rendering Visual Data to a Custom Layout Manager

While it is interesting to use `DrawingVisual` to paint onto the background of a WPF control, it is perhaps more common to build a custom layout manager (`Grid`, `StackPanel`, `Canvas`, etc.) that uses the visual layer internally to render its content. After you have created such a custom layout manager, you can plug it into a normal `Window` (or `Page` or `UserControl`) and have a part of the UI using a highly optimized rendering agent while the noncritical aspects of the hosting `Window` are using shapes and drawings for the remainder of the graphical data.

If you don't require the extra functionality provided by a dedicated layout manager, you could opt to simply extend `FrameworkElement`, which does have the necessary infrastructure to also contain visual items. To illustrate how this could be done, insert a new class to your project named `CustomVisualFrameworkElement`. Extend this class from `FrameworkElement` and import the `System`, `System.Windows`, `System.Windows.Input`, `System.Windows.Media`, and `System.Windows.Media.Imaging` namespaces.

This class will maintain a member variable of type `VisualCollection`, which contains two fixed `DrawingVisual` objects (of course, you could add new members to this collection via a mouse operation, but this example will keep it simple). Update your class with the following new functionality:

```
public class CustomVisualFrameworkElement : FrameworkElement
{
    // A collection of all the visuals we are building.
    VisualCollection theVisuals;
    public CustomVisualFrameworkElement()
    {
        // Fill the VisualCollection with a few DrawingVisual objects.
        // The ctor arg represents the owner of the visuals.
        theVisuals = new VisualCollection(this)
            {AddRect(), AddCircle()};
    }
    private Visual AddCircle()
    {
        DrawingVisual drawingVisual = new DrawingVisual();
        // Retrieve the DrawingContext in order to create new drawing content.
        using DrawingContext drawingContext =
            drawingVisual.RenderOpen()
        // Create a circle and draw it in the DrawingContext.
        Rect rect =
            new Rect(new Point(160, 100), new Size(320, 80));
        drawingContext.DrawEllipse(Brushes.DarkBlue, null,
            new Point(70, 90), 40, 50);
        return drawingVisual;
    }
}
```

```

private Visual AddRect()
{
    DrawingVisual drawingVisual = new DrawingVisual();
    using DrawingContext drawingContext =
        drawingVisual.RenderOpen()
    Rect rect =
        new Rect(new Point(160, 100), new Size(320, 80));
    drawingContext.DrawRectangle(Brushes.Tomato, null, rect);
    return drawingVisual;
}
}

```

Now, before you can use this custom `FrameworkElement` in your `Window`, you must override two key virtual methods mentioned previously, both of which are called internally by WPF during the rendering process. The `GetVisualChild()` method returns a child at the specified index from the collection of child elements. The read-only `VisualChildrenCount` property returns the number of visual child elements within this visual collection. Both methods are easy to implement because you can delegate the real work to the `VisualCollection` member variable.

```

protected override int VisualChildrenCount
    => theVisuals.Count;

protected override Visual GetVisualChild(int index)
{
    // Value must be greater than zero, so do a sanity check.
    if (index < 0 || index >= theVisuals.Count)
    {
        throw new ArgumentOutOfRangeException();
    }
    return theVisuals[index];
}

```

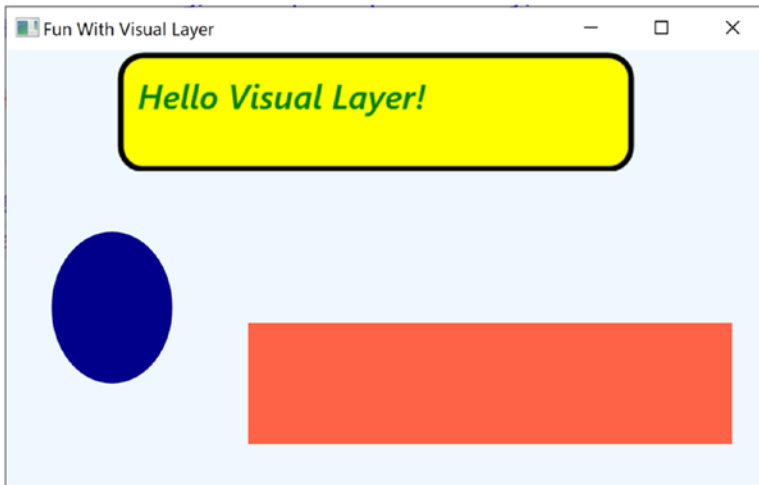
You now have just enough functionality to test your custom class. Update the XAML description of the `Window` to add one of your `CustomVisualFrameworkElement` objects to the existing `StackPanel`. Doing so will require you to add a custom XML namespace that maps to your .NET Core namespace.

```

<Window x:Class="RenderingWithVisuals.MainWindow"
    xmlns="http://schemas.microsoft.com/winfx/2006/xaml/presentation"
    xmlns:x="http://schemas.microsoft.com/winfx/2006/xaml"
    xmlns:local="clr-namespace:RenderingWithVisuals"
    Title="Fun with the Visual Layer" Height="350" Width="525"
    Loaded="Window_Loaded" WindowStartupLocation="CenterScreen">
    <StackPanel Background="AliceBlue" Name="myStackPanel">
        <Image Name="myImage" Height="80"/>
        <local:CustomVisualFrameworkElement/>
    </StackPanel>
</Window>

```

When you run the program, you will see the result shown in Figure 26-15.



**Figure 26-15.** Using the visual layer to render data to a custom *FrameworkElement*

## Responding to Hit-Test Operations

Because *DrawingVisual* does not have any of the infrastructures of *UIElement* or *FrameworkElement*, you will need to programmatically add in the ability to calculate hit-test operations. Thankfully, this is fairly easy to do in the visual layer because of the concept of *logical* and *visual* trees. As it turns out, when you author a blob of XAML, you are essentially building a logical tree of elements. However, behind every logical tree is a much richer description known as the visual tree, which contains lower-level rendering instructions.

Chapter 27 will delve into these trees in more detail, but for now, just understand that until you register your custom visuals with these data structures, you will not be able to perform hit-testing operations. Luckily, the *VisualCollection* container does this on your behalf (which explains why you needed to pass in a reference to the custom *FrameworkElement* as a constructor argument).

First, update the *CustomVisualFrameworkElement* class to handle the *MouseDown* event in the class constructor using standard C# syntax, like so:

```
this.MouseDown += CustomVisualFrameworkElement_MouseDown;
```

The implementation of this handler will call the *VisualTreeHelper.HitTest()* method to see whether the mouse is within the boundaries of one of the rendered visuals. To do this, you specify as a parameter to *HitTest()* a *HitTestResultCallback* delegate that will perform the calculations. If you click a visual, you will toggle between a skewed rendering of the visual and the original rendering. Add the following methods to your *CustomVisualFrameworkElement* class:

```
void CustomVisualFrameworkElement_MouseDown(object sender, MouseButtonEventArgs e)
{
    // Figure out where the user clicked.
    Point pt = e.GetPosition((UIElement)sender);
    // Call helper function via delegate to see if we clicked on a visual.
    VisualTreeHelper.HitTest(this, null,
        new HitTestResultCallback(myCallback), new PointHitTestParameters(pt));
}
```

```

public HitTestResultBehavior myCallback(HitTestResult result)
{
    // Toggle between a skewed rendering and normal rendering,
    // if a visual was clicked.
    if (result.VisualHit.GetType() == typeof(DrawingVisual))
    {
        if (((DrawingVisual)result.VisualHit).Transform == null)
        {
            ((DrawingVisual)result.VisualHit).Transform = new SkewTransform(7, 7);
        }
        else
        {
            ((DrawingVisual)result.VisualHit).Transform = null;
        }
    }
    // Tell HitTest() to stop drilling into the visual tree.
    return HitTestResultBehavior.Stop;
}

```

Now, run your program once again. You should now be able to click either rendered visual and see the transformation in action! While this is just a simple example of working with the visual layer of WPF, remember that you make use of the same brushes, transformations, pens, and layout managers as you would when working with XAML. As a result, you already know quite a bit about working with this Visual-derived classes.

That wraps up your investigation of the graphical rendering services of Windows Presentation Foundation. While you learned a number of interesting topics, the reality is that you have only scratched the surface of WPF's graphical capabilities. I will leave it in your hands to dig deeper into the topics of shapes, drawings, brushes, transformations, and visuals (and, to be sure, you will see some additional details of these topics in the remaining WPF chapters).

## Summary

Because Windows Presentation Foundation is such a graphically intensive GUI API, it comes as no surprise that we are given a number of ways to render graphical output. This chapter began by examining each of three ways a WPF application can do so (shapes, drawings, and visuals) and discussed various rendering primitives such as brushes, pens, and transformations.

Remember that when you need to build interactive 2D renderings, shapes make the process very simple. However, static, noninteractive renderings can be rendered in a more optimal manner by using drawings and geometries, while the visual layer (accessible only in code) gives you maximum control and performance.



## CHAPTER 27



# WPF Resources, Animations, Styles, and Templates

This chapter introduces you to three important (and interrelated) topics that will deepen your understanding of the Windows Presentation Foundation (WPF) API. The first order of business is to learn the role of *logical resources*. As you will see, the logical resource (also known as an *object resource*) system is a way to name and refer to commonly used objects within a WPF application. While logical resources are often authored in XAML, they can also be defined in procedural code.

Next, you will learn how to define, execute, and control an animation sequence. Despite what you might think, WPF animations are not limited to video game or multimedia applications. Under the WPF API, animations can be as subtle as making a button appear to glow when it receives focus or expanding the size of a selected row in a `DataGrid`. Understanding animations is a key aspect of building custom control templates (as you'll see later in this chapter).

You'll then explore the role of WPF styles and templates. Much like a web page that uses CSS or the ASP.NET theme engine, a WPF application can define a common look and feel for a set of controls. You can define these styles in markup and store them as object resources for later use, and you can also apply them dynamically at runtime. The final example will teach you how to build custom control templates.

## Understanding the WPF Resource System

Your first task is to examine the topic of embedding and accessing application resources. WPF supports two flavors of resources. The first is a *binary resource*, and this category typically includes items most programmers consider to be resources in the traditional sense (embedded image files or sound clips, icons used by the application, etc.).

The second flavor, termed *object resources* or *logical resources*, represents a named .NET object that can be packaged and reused throughout the application. While any .NET object can be packaged as an object resource, logical resources are particularly helpful when working with graphical data of any sort, given that you can define commonly used graphic primitives (brushes, pens, animations, etc.) and refer to them when required.

## Working with Binary Resources

Before getting to the topic of object resources, let's quickly examine how to package up *binary resources* such as icons or image files (e.g., company logos or images for an animation) into your applications. If you'd like to follow along, create a new WPF application named `BinaryResourcesApp`. Update the markup for your initial window to handle the `Window Loaded` event and to use a `DockPanel` as the layout root, like so:

```
<Window x:Class="BinaryResourcesApp.MainWindow"
  <!-- Omitted for brevity -->
  Title="Fun with Binary Resources" Height="500" Width="649" Loaded="MainWindow_OnLoaded">
  <DockPanel LastChildFill="True">
  </DockPanel>
</Window>
```

Now, let's say your application needs to display one of three image files inside part of the window, based on user input. The WPF `Image` control can be used to display not only a typical image file (\*.bmp, \*.gif, \*.ico, \*.jpg, \*.png, \*.wdp, or \*.tiff) but also data in a `DrawingImage` (as you saw in Chapter 26). You might build a UI for your window that supports a `DockPanel` containing a simple toolbar with `Next` and `Previous` buttons. Below this toolbar you can place an `Image` control, which currently does not have a value set to the `Source` property, like so:

```
<DockPanel LastChildFill="True">
  <ToolBar Height="60" Name="picturePickerToolBar" DockPanel.Dock="Top">
    <Button x:Name="btnPreviousImage" Height="40" Width="100" BorderBrush="Black"
      Margin="5" Content="Previous" Click="btnPreviousImage_Click"/>
    <Button x:Name="btnNextImage" Height="40" Width="100" BorderBrush="Black"
      Margin="5" Content="Next" Click="btnNextImage_Click"/>
  </ToolBar>
  <!-- We will fill this Image in code. -->
  <Border BorderThickness="2" BorderBrush="Green">
    <Image x:Name="imageHolder" Stretch="Fill" />
  </Border>
</DockPanel>
```

Next, add the following empty event handlers:

```
private void MainWindow_OnLoaded(
  object sender, RoutedEventArgs e)
{
}
private void btnPreviousImage_Click(
  object sender, RoutedEventArgs e)
{
}
private void btnNextImage_Click(
  object sender, RoutedEventArgs e)
{
}
```

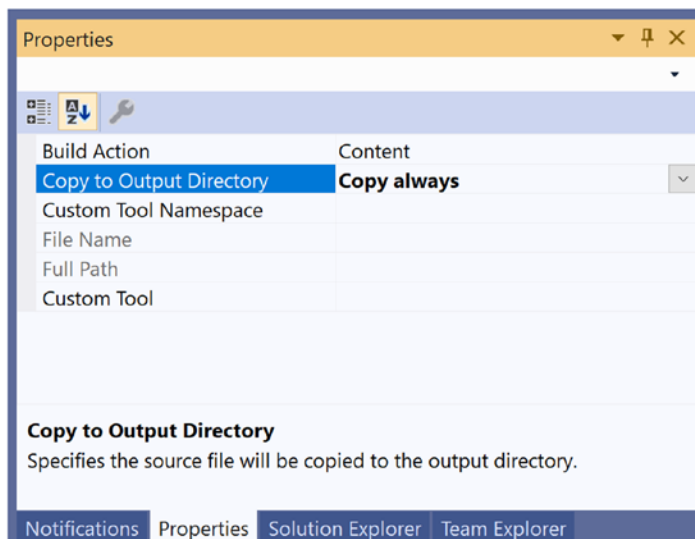
When the window loads, images will be added to a collection that the Next and Previous buttons will cycle through. Now that the application framework is in place, let's examine the different options for implementing this.

## Including Loose Resource Files in a Project

One option is to ship your image files as a set of loose files in a subdirectory of the application install path. Start by adding a new folder (named Images) to your project. Into this folder add some images by right-clicking and selecting Add ► Existing Item. Make sure to change the file filter in the Add Existing Item dialog to \*.\* so the image files show. You can add your own image files or use the three image files named Deer.jpg, Dogs.jpg, and Welcome.jpg from the downloadable code.

## Configuring the Loose Resources

To copy the content of your \Images folder to the \bin\Debug folder when the project builds, begin by selecting all the images in Solution Explorer. Now, with these images still selected, right-click and select Properties to open the Properties window. Set the Build Action property to Content, and set the Copy to Output Directory property to Content, and set the Copy to Output Directory property to Copy always (see Figure 27-1).



**Figure 27-1.** Configuring the image data to be copied to your output directory

---

■ **Note** You could also select Copy if Newer, which will save you time if you're building large projects with a lot of content. For this example, Copy always works just fine.

---

If you build your project, you can now click the Show All Files button of Solution Explorer and view the copied Image folder under your \bin\Debug directory (you might need to click the Refresh button).

## Programmatically Loading an Image

WPF provides a class named `BitmapImage`, which is part of the `System.Windows.Media.Imaging` namespace. This class allows you to load data from an image file whose location is represented by a `System.Uri` object. Add a `List<BitmapImage>` to hold all of the images, as well as an `int` to store the index of the currently displayed image.

```
// A List of BitmapImage files.
List<BitmapImage> _images = new List<BitmapImage>();
// Current position in the list.
private int _currImage = 0;
```

In the `Loaded` event of your window, fill the list of images and then set the `Image` control source to the first image in the list.

```
private void MainWindow_OnLoaded(
    object sender, RoutedEventArgs e)
{
    try
    {
        string path = Environment.CurrentDirectory;
        // Load these images from disk when the window loads.
        _images.Add(new BitmapImage(new Uri($"{path}\Images\Deer.jpg")));
        _images.Add(new BitmapImage(new Uri($"{path}\Images\Dogs.jpg")));
        _images.Add(new BitmapImage(new Uri($"{path}\Images\Welcome.jpg")));
        // Show first image in the list.
        imageHolder.Source = _images[_currImage];
    }
    catch (Exception ex)
    {
        MessageBox.Show(ex.Message);
    }
}
```

Next, implement the previous and next handlers to loop through the images. If the user gets to the end of the list, start them back at the beginning and vice versa.

```
private void btnPreviousImage_Click(
    object sender, RoutedEventArgs e)
{
    if (--_currImage < 0)
    {
        _currImage = _images.Count - 1;
    }
    imageHolder.Source = _images[_currImage];
}
private void btnNextImage_Click(
    object sender, RoutedEventArgs e)
{
    if (++_currImage >= _images.Count)
```

```

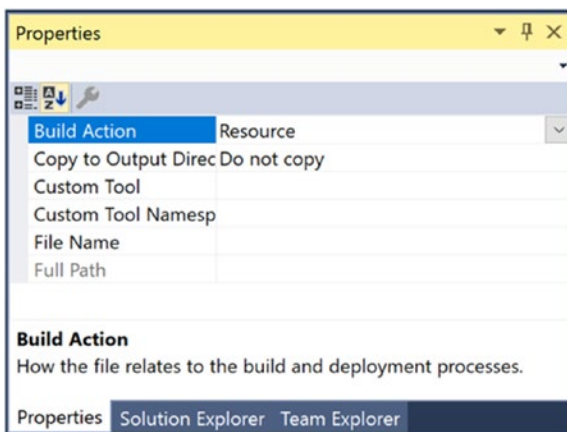
{
    _currImage = 0;
}
imageHolder.Source = _images[_currImage];
}

```

At this point, you can run your program and flip through each picture.

## Embedding Application Resources

If you'd rather configure your image files to be compiled directly into your .NET Core assembly as binary resources, select the image files in Solution Explorer (in the `\Images` folder, not in the `\bin\Debug\Images` folder). Change the **Build Action** property to **Resource**, and set the **Copy to Output Directory** property to **Do not copy** (see Figure 27-2).



**Figure 27-2.** Configuring the images to be embedded resources

Now, using Visual Studio's Build menu, select the **Clean Solution** option to wipe out the current contents of `\bin\Debug\Images` and then rebuild your project. Refresh Solution Explorer, and observe the absence of data in your `\bin\Debug\Images` directory. With the current build options, your graphical data is no longer copied to the output folder and is now embedded within the assembly itself. This ensures that the resources exist but also increases the size of your compiled assembly.

You need to modify your code to load these images into your list by extracting them from the compiled assembly.

```

// Extract from the assembly and then load images
_images.Add(new BitmapImage(new Uri(@"Images/Deer.jpg", UriKind.Relative)));
_images.Add(new BitmapImage(new Uri(@"Images/Dogs.jpg", UriKind.Relative)));
_images.Add(new BitmapImage(new Uri(@"Images/Welcome.jpg", UriKind.Relative)));

```

In this case, you no longer need to determine the installation path and can simply list the resources by name, which takes into account the name of the original subdirectory. Also notice, when you create your `Uri` objects, you specify a `UriKind` value of `Relative`. At this point, your executable is a stand-alone entity that can be run from any location on the machine because all the compiled data is within the binary.

## Working with Object (Logical) Resources

When you are building a WPF application, it is common to define a blurb of XAML to use in multiple locations within a window or perhaps across multiple windows or projects. For example, say you have created the *perfect* linear gradient brush, which consists of ten lines of markup. Now, you want to use that brush as the background color for every `Button` control in the project (which consists of eight windows) for a total of 16 `Button` controls.

The worst thing you could do is to copy and paste the XAML to every control. Clearly, this would be a nightmare to maintain, as you would need to make numerous changes any time you wanted to tweak the look and feel of the brush.

Thankfully, *object resources* allow you to define a blob of XAML, give it a name, and store it in a fitting dictionary for later use. Like a binary resource, object resources are often compiled into the assembly that requires them. However, you don't need to tinker with the `Build Action` property to do so. As long as you place your XAML into the correct location, the compiler will take care of the rest.

Working with object resources is a big part of WPF development. As you will see, object resources can be far more complex than a custom brush. You can define a XAML-based animation, a 3D rendering, a custom control style, data template, control template, and more and package each one as a reusable resource.

## The Role of the Resources Property

As mentioned, object resources must be placed in a fitting dictionary object to be used across an application. As it stands, every descendant of `FrameworkElement` supports a `Resources` property. This property encapsulates a `ResourceDictionary` object that contains the defined object resources. The `ResourceDictionary` can hold any type of item because it operates on `System.Object` types and may be manipulated via XAML or procedural code.

In WPF, all controls, `Windows`, `Pages` (used when building navigation applications), and `UserControls` extend `FrameworkElement`, so just about all widgets provide access to a `ResourceDictionary`. Furthermore, the `Application` class, while not extending `FrameworkElement`, supports an identically named `Resources` property for the same purpose.

## Defining Window-Wide Resources

To begin exploring the role of object resources, create a new WPF application named `ObjectResourcesApp` and change the initial `Grid` to a horizontally aligned `StackPanel` layout manager. Into this `StackPanel`, define two `Button` controls like so (you really don't need much to illustrate the role of object resources, so this will do):

```
<StackPanel Orientation="Horizontal">
  <Button Margin="25" Height="200" Width="200" Content="OK" FontSize="20"/>
  <Button Margin="25" Height="200" Width="200" Content="Cancel" FontSize="20"/>
</StackPanel>
```

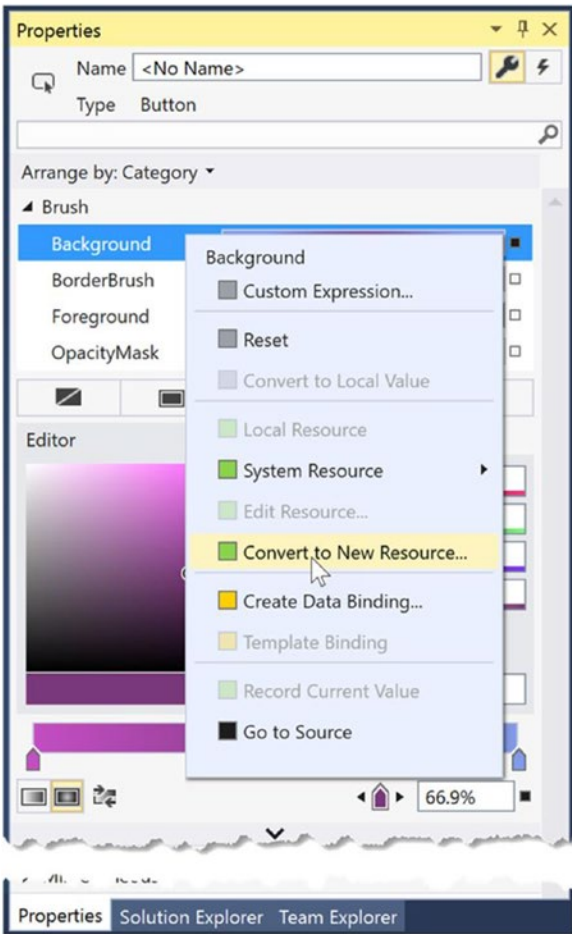
Now, select the OK button and set the Background color property to a custom brush type using the integrated Brushes editor (discussed in Chapter 26). After you've done so, notice how the brush is embedded within the scope of the <Button> and </Button> tags, as shown here:

```
<Button Margin="25" Height="200" Width="200" Content="OK" FontSize="20">
  <Button.Background>
    <RadialGradientBrush>
      <GradientStop Color="#FFC44EC4" Offset="0" />
      <GradientStop Color="#FF829CEB" Offset="1" />
      <GradientStop Color="#FF793879" Offset="0.669" />
    </RadialGradientBrush>
  </Button.Background>
</Button>
```

To allow the Cancel button to use this brush as well, you should promote the scope of your <RadialGradientBrush> to a parent element's resource dictionary. For example, if you move it to the <StackPanel>, both buttons can use the same brush because they are child elements of the layout manager. Even better, you could package the brush into the resource dictionary of the Window itself so all of the window's content can use it.

When you need to define a resource, you use the property-element syntax to set the Resources property of the owner. You also give the resource item an x:Key value, which will be used by other parts of the window when they want to refer to the object resource. Be aware that x:Key and x:Name are not the same! The x:Name attribute allows you to gain access to the object as a member variable in your code file, while the x:Key attribute allows you to refer to an item in a resource dictionary.

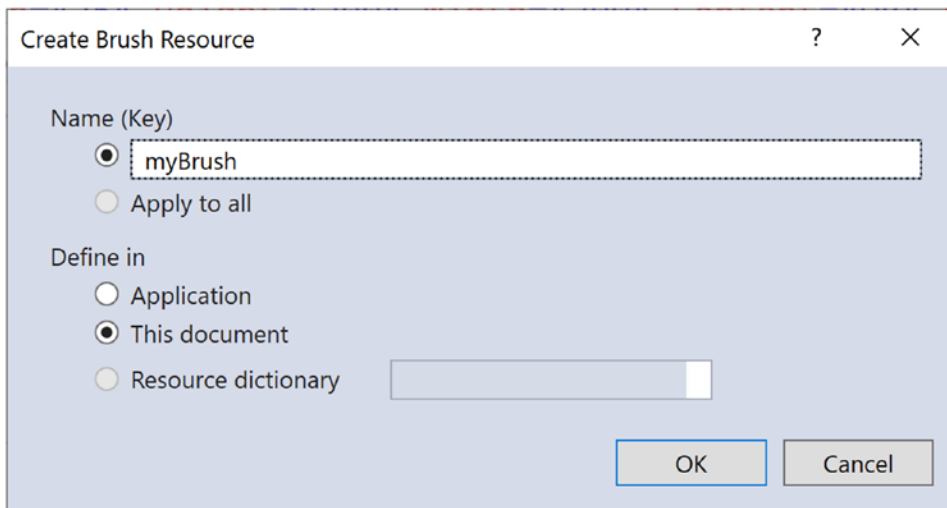
Visual Studio allows you to promote a resource to a higher scope using its respective Properties window. To do so, first identify the property that has the complex object you want to package as a resource (the Background property, in this example). To the right of the property is a small square that, when clicked, will open a pop-up menu. From it, select the Convert to New Resource option (see Figure 27-3).



**Figure 27-3.** Moving a complex object into a resource container

You are asked to name your resource (myBrush) and specify where to place it. For this example, leave the default selection of the current document (see Figure 27-4).





**Figure 27-4.** Naming the object resource

When you're done, you will see the brush has been moved inside the `Window.Resources` tag.

```
<Window.Resources>
  <RadialGradientBrush x:Key="myBrush">
    <GradientStop Color="#FFC44EC4" Offset="0" />
    <GradientStop Color="#FF829CEB" Offset="1" />
    <GradientStop Color="#FF793879" Offset="0.669" />
  </RadialGradientBrush>
</Window.Resources>
```

And the Button control's Background has been updated to use a new resource.

```
<Button Margin="25" Height="200" Width="200" Content="OK"
  FontSize="20" Background="{DynamicResource myBrush}"/>
```

The Create Resource Wizard creates the new resource as a `DynamicResource`. You will learn about `DynamicResources` later in the text, but for now, change it to a `StaticResource`, like this:

```
<Button Margin="25" Height="200" Width="200" Content="OK"
  FontSize="20" Background="{StaticResource myBrush}"/>
```

To see the benefit, update the Cancel Button's Background property to the same `StaticResource`, and you can see the reuse in action.

```
<Button Margin="25" Height="200" Width="200" Content="Cancel"
  FontSize="20" Background="{StaticResource myBrush}"/>
```

## The {StaticResource} Markup Extension

The {StaticResource} markup extension applies the resource only once (on initialization) and stays “connected” to the original object during the life of the application. Some properties (such as gradient stops) will update, but if you create a new Brush, for example, the control will not be updated. To see this in action, add a Name and Click event handler to each Button control, as follows:

```
<Button Name="Ok" Margin="25" Height="200" Width="200" Content="OK"
    FontSize="20" Background="{StaticResource myBrush}" Click="Ok_OnClick"/>
<Button Name="Cancel" Margin="25" Height="200" Width="200" Content="Cancel"
    FontSize="20" Background="{StaticResource myBrush}" Click="Cancel_OnClick"/>
```

Next, add the following code to the Ok\_OnClick() event handler:

```
private void Ok_OnClick(object sender, RoutedEventArgs e)
{
    // Get the brush and make a change.
    var b = (RadialGradientBrush)Resources["myBrush"];
    b.GradientStops[1] = new GradientStop(Colors.Black, 0.0);
}
```

---

■ **Note** You are using the Resources indexer to locate a resource by name here. Be aware, however, that this will throw a runtime exception if the resource can't be found. You could also use the TryFindResource() method, which will not throw a runtime error; it will simply return null if the specified resource can't be located.

---

When you run the program and click the OK Button, you see the gradients change appropriately. Now add the following code to the Cancel\_OnClick() event handler:

```
private void Cancel_OnClick(object sender, RoutedEventArgs e)
{
    // Put a totally new brush into the myBrush slot.
    Resources["myBrush"] = new SolidColorBrush(Colors.Red);
}
```

Run the program again, click the Cancel Button, and nothing happens!

## The {DynamicResource} Markup Extension

It is also possible for a property to use the DynamicResource markup extension. To see the difference, change the markup for the Cancel Button to the following:

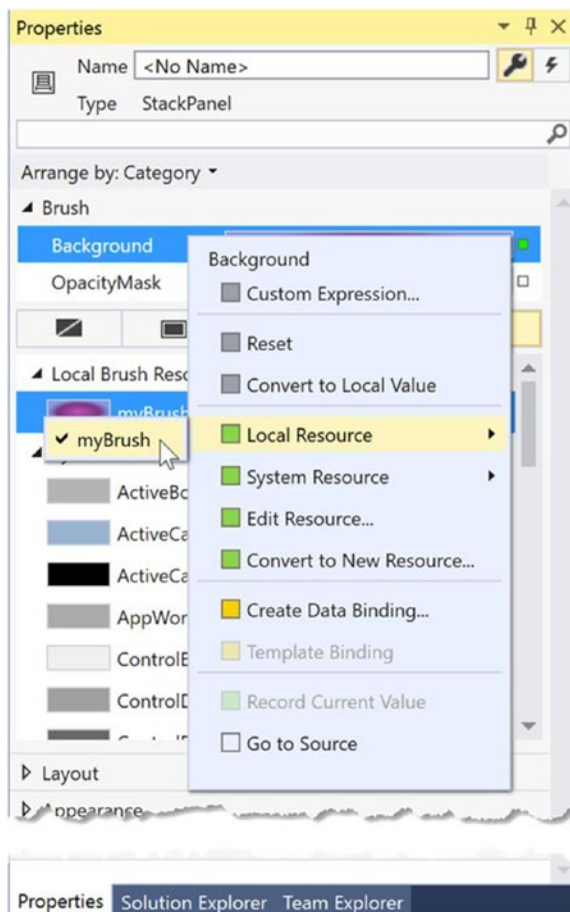
```
<Button Name="Cancel" Margin="25" Height="200" Width="200" Content="Cancel"
    FontSize="20" Background="{DynamicResource myBrush}" Click="Cancel_
    OnClick"/>
```

This time, when you click the Cancel Button, the background for the Cancel Button changes, but the background for the OK Button remains the same. This is because the `{DynamicResource}` markup extension is able to detect whether the underlying keyed object has been replaced with a new object. As you might guess, this requires some extra runtime infrastructure, so you should typically stick to using `{StaticResource}` unless you know you have an object resource that will be swapped with a different object at runtime and you want all items using that resource to be informed.

## Application-Level Resources

When you have object resources in a window's resource dictionary, all items in the window are free to make use of it, but other windows in the application cannot. The solution to share resources across your application is to define the object resource at the application level, rather than at the window level. There is no way to automate this within Visual Studio, so simply cut the current brush object out of the `<Windows.Resources>` scope, and place it in the `<Application.Resources>` scope in your `App.xaml` file.

Now any additional window or control in your application is free to use this same brush. If you want to set the `Background` property for a control, the application-level resources are available for selection, as shown in Figure 27-5.

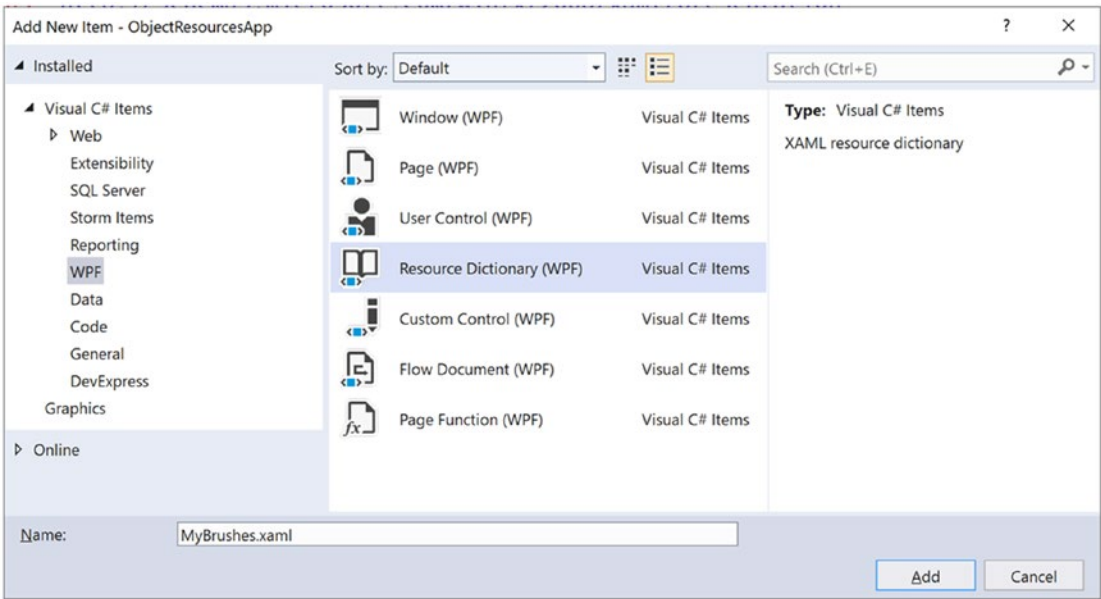


**Figure 27-5.** Applying application-level resources

**Note** Placing the resources at the application level and assigning it to a control's property will freeze the resource, preventing changing values at runtime. The resource can be cloned, and the clone can be updated.

## Defining Merged Resource Dictionaries

Application-level resources are a quite often good enough, but they don't help reuse across projects. In this case, you want to define what is known as a *merged resource dictionary*. Think of it as a class library for WPF resources; it is nothing more than a .xaml file that contains a collection of resources. A single project can have as many of these files as required (one for brushes, one for animations, etc.), each of which can be inserted using the Add New Item dialog box activated via the Project menu (see Figure 27-6).



**Figure 27-6.** Inserting a new merged resource dictionary

In the new `MyBrushes.xaml` file, cut the current resources in the `Application.Resources` scope and move them into your dictionary, like so:

```
<ResourceDictionary xmlns=http://schemas.microsoft.com/winfx/2006/xaml/presentation
xmlns:local=clr-namespace:ObjectResourcesApp
xmlns:x=http://schemas.microsoft.com/winfx/2006/xaml">
  <RadialGradientBrush x:Key="myBrush">
    <GradientStop Color="#FFC44EC4" Offset="0" />
    <GradientStop Color="#FF829CEB" Offset="1" />
    <GradientStop Color="#FF793879" Offset="0.669" />
  </RadialGradientBrush>
</ResourceDictionary>
```

Even though this resource dictionary is part of your project, all resource dictionaries must be merged (typically at the application level) into an existing resource dictionary in order to be used. To do this, use the following format in the `App.xaml` file (note that multiple resource dictionaries can be merged by adding multiple `<ResourceDictionary>` elements within the `<ResourceDictionary.MergedDictionaries>` scope):

```
<Application.Resources>
  <ResourceDictionary>
    <ResourceDictionary.MergedDictionaries>
      <ResourceDictionary Source = "MyBrushes.xaml"/>
    </ResourceDictionary.MergedDictionaries>
  </ResourceDictionary>
</Application.Resources>
```

The problem with this approach is that each resource file must be added to each project that needs the resources. A better approach for sharing resources is to define a .NET Core class library to share between projects, which you will do next.

## Defining a Resource-Only Assembly

The easiest way to build a resource-only assembly is to actually begin with a WPF User Control Library (.NET Core) project. Add such a project (named `MyBrushesLibrary`) to your current solution via the **Add ► New Project** menu option of Visual and add a project reference to it from the `ObjectResourcesApp` project.

Now, delete the `UserControl1.xaml` file from the project. Next, drag and drop the `MyBrushes.xaml` file into your `MyBrushesLibrary` project and delete it from the `ObjectResourcesApp` project. Finally, open `MyBrushes.xaml` in the `MyBrushesLibrary` project and change the `x:local` namespace in the file to `clr-namespace:MyBrushesLibrary`. Your `MyBrushes.xaml` file should look like this:

```
<ResourceDictionary xmlns="http://schemas.microsoft.com/winfx/2006/xaml/presentation"
                    xmlns:x="http://schemas.microsoft.com/winfx/2006/xaml"
                    xmlns:local="clr-namespace:MyBrushesLibrary">
  <RadialGradientBrush x:Key="myBrush">
    <GradientStop Color="#FFC44EC4" Offset="0" />
    <GradientStop Color="#FF829CEB" Offset="1" />
    <GradientStop Color="#FF793879" Offset="0.669" />
  </RadialGradientBrush>
</ResourceDictionary>
```

Compile your User Control Library project. Now, merge these binary resources into the application-level resource dictionary of the `ObjectResourcesApp` project. Doing so, however, requires some rather funky syntax, shown here:

```
<Application.Resources>
  <ResourceDictionary>
    <ResourceDictionary.MergedDictionaries>
      <!-- The syntax is /NameOfAssembly;Component/NameOfXamlFileInAssembly.xaml -->
      <ResourceDictionary Source = "/MyBrushesLibrary;Component/MyBrushes.xaml"/>
    </ResourceDictionary.MergedDictionaries>
  </ResourceDictionary>
</Application.Resources>
```

First, be aware that this string is space sensitive. If you have extra whitespace around your semicolon or forward slashes, you will generate errors. The first part of the string is the friendly name of the external library (no file extension). After the semicolon, type in the word `Component` followed by the name of the compiled binary resource, which will be identical to the original XAML resource dictionary.

That wraps up the examination of WPF's resource management system. You will make good use of these techniques for most (if not all) of your applications. Next up, let's investigate the integrated animation API of Windows Presentation Foundation.

## Understanding WPF's Animation Services

In addition to the graphical rendering services you examined in Chapter 26, WPF supplies a programming interface to support animation services. The term *animation* may bring to mind visions of spinning company logos, a sequence of rotating image resources (to provide the illusion of movement), text bouncing across the screen, or specific types of programs such as video games or multimedia applications.

While WPF's animation APIs could certainly be used for such purposes, animation can be used any time you want to give an application additional flair. For example, you could build an animation for a button on a screen that magnifies slightly when the mouse cursor hovers within its boundaries (and shrinks back once the mouse cursor moves beyond the boundaries). Or you could animate a window so that it closes using a particular visual appearance, such as slowly fading into transparency. A more business application-centric use is to fade in error messages on an application screen to improve the user experience. In fact, WPF's animation support can be used within any sort of application (a business application, multimedia programs, video games, etc.) whenever you want to provide a more engaging user experience.

As with many other aspects of WPF, the notion of building animations is nothing new. What is new is that, unlike other APIs you might have used in the past (including Windows Forms), developers are not required to author the necessary infrastructure by hand. Under WPF, there's no need to create the background threads or timers used to advance the animation sequence, define custom types to represent the animation, erase and redraw images, or bother with tedious mathematical calculations. Like other aspects of WPF, you can build an animation entirely using XAML, entirely using C# code, or using a combination of the two.

---

■ **Note** Visual Studio has no support for authoring animations using GUI animation tools. If you author an animation with Visual Studio, you will do so by typing in the XAML directly. However, Blend for Visual Studio (the companion product that ships with Visual Studio 2019) does indeed have a built-in animation editor that can simplify your life a good deal.

---

## The Role of the Animation Class Types

To understand WPF's animation support, you must begin by examining the animation classes within the `System.Windows.Media.Animation` namespace of `PresentationCore.dll`. Here, you will find more than 100 different class types that are named using the `Animation` token.

All of these classes can be placed into one of three broad categories. First, any class that follows the name convention *DataTypeName* (`ByteAnimation`, `ColorAnimation`, `DoubleAnimation`, `Int32Animation`, etc.) allows you to work with linear interpolation animations. This enables you to change a value smoothly over time from a start value to a final value.

Next, the classes that follow the naming convention *DataTypeAnimationUsingKeyFrames* (*StringAnimationUsingKeyFrames*, *DoubleAnimationUsingKeyFrames*, *PointAnimationUsingKeyFrames*, etc.) represent “key frame animations,” which allow you to cycle through a set of defined values over a period of time. For example, you could use key frames to change the caption of a button by cycling through a series of individual characters.

Finally, classes that follow the *DataTypeAnimationUsingPath* naming convention (*DoubleAnimationUsingPath*, *PointAnimationUsingPath*, among others) are path-based animations that allow you to animate objects to move along a path you define. By way of an example, if you were building a GPS application, you could use a path-based animation to move an item along the quickest travel route to the user’s destination.

Now, obviously, these classes are *not* used to somehow provide an animation sequence directly to a variable of a particular data type (after all, how exactly could you animate the value “9” using an *Int32Animation?*).

For example, consider the *Label* type’s *Height* and *Width* properties, both of which are dependency properties wrapping a *double*. If you wanted to define an animation that would increase the height of a label over a time span, you could connect a *DoubleAnimation* object to the *Height* property and allow WPF to take care of the details of performing the actual animation itself. By way of another example, if you wanted to transition the color of a brush type from green to yellow over a period of five seconds, you could do so using the *ColorAnimation* type.

To be clear, these *Animation* classes can be connected to any *dependency property* of a given object that matches the underlying types. As explained in Chapter 25, dependency properties are a specialized form of property required by many WPF services including animation, data binding, and styles.

By convention, a dependency property is defined as a static, read-only field of the class and is named by suffixing the word *Property* to the normal property name. For example, the dependency property for the *Height* property of a *Button* would be accessed in code using *Button.HeightProperty*.

## The To, From, and By Properties

All *Animation* classes define the following handful of key properties that control the starting and ending values used to perform the animation:

- **To:** This property represents the animation’s ending value.
- **From:** This property represents the animation’s starting value.
- **By:** This property represents the total amount by which the animation changes its starting value.

Despite that all *Animation* classes support the *To*, *From*, and *By* properties, they do not receive them via virtual members of a base class. The reason for this is that the underlying types wrapped by these properties vary greatly (integers, colors, *Thickness* objects, etc.), and representing all possibilities using a single base class would result in complex coding constructs.

On a related note, you might also wonder why .NET generics were not used to define a single generic animation class with a single type parameter (e.g., *Animate<T>*). Again, given that there are so many underlying data types (colors, vectors, ints, strings, etc.) used to animated dependency properties, it would not be as clean a solution as you might expect (not to mention XAML has only limited support for generic types).

## The Role of the Timeline Base Class

Although a single base class was not used to define virtual To, From, and By properties, the Animation classes do share a common base class: `System.Windows.Media.Animation.Timeline`. This type provides a number of additional properties that control the pacing of the animation, as described in Table 27-1.

**Table 27-1.** Key Members of the Timeline Base Class

Properties	Meaning in Life
AccelerationRatio, DecelerationRatio, SpeedRatio	These properties can be used to control the overall pacing of the animation sequence.
AutoReverse	This property gets or sets a value that indicates whether the timeline plays in reverse after it completes a forward iteration (the default value is false).
BeginTime	This property gets or sets the time at which this timeline should begin. The default value is 0, which begins the animation immediately.
Duration	This property allows you to set a duration of time to play the timeline.
FillBehavior, RepeatBehavior	These properties are used to control what should happen once the timeline has completed (repeat the animation, do nothing, etc.).

## Authoring an Animation in C# Code

Specifically, you will build a Window that contains a Button, which has the odd behavior of spinning in a circle (based on the upper-left corner) whenever the mouse enters its surface area. Begin by creating a new WPF application named `SpinningButtonAnimationApp`. Update the initial markup to the following (note you are handling the button's `MouseEnter` event):

```
<Button x:Name="btnSpinner" Height="50" Width="100" Content="I Spin!"
        MouseEnter="btnSpinner_MouseEnter" Click="btnSpinner_OnClick"/>
```

In the code-behind file, import the `System.Windows.Media.Animation` namespace and add the following code in the window's C# code file:

```
private bool _isSpinning = false;

private void btnSpinner_MouseEnter(
    object sender, MouseEventArgs e)
{
    if (!_isSpinning)
    {
        _isSpinning = true;
        // Make a double animation object, and register
        // with the Completed event.
        var dblAnim = new DoubleAnimation();
        dblAnim.Completed += (o, s) => { _isSpinning = false; };
        // Set the start value and end value.
        dblAnim.From = 0;
        dblAnim.To = 360;
    }
}
```



```

// Now, create a RotateTransform object, and set
// it to the RenderTransform property of our
// button.
var rt = new RotateTransform();
btnSpinner.RenderTransform = rt;
// Now, animation the RotateTransform object.
rt.BeginAnimation(RotateTransform.AngleProperty, dblAnim);
    }
}
private void btnSpinner_OnClick(
    object sender, RoutedEventArgs e)
{
}

```

The first major task of this method is to configure a `DoubleAnimation` object, which will start at the value 0 and end at the value 360. Notice that you are handling the `Completed` event on this object as well, to toggle a class-level `bool` variable that is used to ensure that if an animation is currently being performed, you don't "reset" it to start again.

Next, you create a `RotateTransform` object that is connected to the `RenderTransform` property of your `Button` control (`btnSpinner`). Last but not least, you inform the `RenderTransform` object to begin animating its `Angle` property using your `DoubleAnimation` object. When you are authoring animations in code, you typically do so by calling `BeginAnimation()` and then pass in the underlying *dependency property* you would like to animate (remember, by convention, this is a static field on the class), followed by a related animation object.

Let's add another animation to the program, which will cause the button to fade into invisibility when clicked. First, add the following code in the `Click` event handler:

```

private void btnSpinner_OnClick(
    object sender, RoutedEventArgs e)
{
    var dblAnim = new DoubleAnimation
    {
        From = 1.0,
        To = 0.0
    };
    btnSpinner.BeginAnimation(Button.OpacityProperty, dblAnim);
}

```

Here, you are changing the `Opacity` property value to fade the button out of view. Currently, however, this is hard to do, as the button is spinning very fast! How, then, can you control the pace of an animation? Glad you asked.

## Controlling the Pace of an Animation

By default, an animation will take approximately one second to transition between the values assigned to the `From` and `To` properties. Therefore, your button has one second to spin around a full 360-degree angle, while the button will fade away to invisibility (when clicked) over the course of one second.

If you want to define a custom amount of time for an animation's transition, you may do so via the animation object's `Duration` property, which can be set to an instance of a `Duration` object. Typically, the time span is established by passing a `TimeSpan` object to the `Duration`'s constructor. Consider the following update that will give the button a full four seconds to rotate:

```
private void btnSpinner_MouseEnter(
    object sender, MouseEventArgs e)
{
    if (!_isSpinning)
    {
        _isSpinning = true;

        // Make a double animation object, and register
        // with the Completed event.
        var dblAnim = new DoubleAnimation();
        dblAnim.Completed += (o, s) => { _isSpinning = false; };

        // Button has four seconds to finish the spin!
        dblAnim.Duration = new Duration(TimeSpan.FromSeconds(4));

        ...
    }
}
```

With this adjustment, you should have a fighting chance of clicking the button while it is spinning, at which point it will fade away.

---

■ **Note** The `BeginTime` property of an `Animation` class also takes a `TimeSpan` object. Recall that this property can be set to establish a wait time before starting an animation sequence.

---

## Reversing and Looping an Animation

You can also tell `Animation` objects to play an animation in reverse at the completion of the animation sequence by setting the `AutoReverse` property to `true`. For example, if you want to have the button come back into view after it has faded away, you could author the following:

```
private void btnSpinner_OnClick(object sender, RoutedEventArgs e)
{
    DoubleAnimation dblAnim = new DoubleAnimation
    {
        From = 1.0,
        To = 0.0
    };
}
```

```
// Reverse when done.
dblAnim.AutoReverse = true;
btnSpinner.BeginAnimation(Button.OpacityProperty, dblAnim);
}
```

If you'd like to have an animation repeat some number of times (or to never stop once activated), you can do so using the `RepeatBehavior` property, which is common to all `Animation` classes. If you pass in a simple numerical value to the constructor, you can specify a hard-coded number of times to repeat. On the other hand, if you pass in a `TimeSpan` object to the constructor, you can establish an amount of time the animation should repeat. Finally, if you want an animation to loop *ad infinitum*, you can simply specify `RepeatBehavior.Forever`. Consider the following ways you could change the repeat behaviors of either of the `DoubleAnimation` objects used in this example:

```
// Loop forever.
dblAnim.RepeatBehavior = RepeatBehavior.Forever;

// Loop three times.
dblAnim.RepeatBehavior = new RepeatBehavior(3);

// Loop for 30 seconds.
dblAnim.RepeatBehavior = new RepeatBehavior(TimeSpan.FromSeconds(30));
```

That wraps up your investigation about how to animate aspects of an object using C# code and the WPF animation API. Next, you will learn how to do the same using XAML.

## Authoring Animations in XAML

Authoring animations in markup is similar to authoring them in code, at least for simple, straightforward animation sequences. When you need to capture more complex animations, which may involve changing the values of numerous properties at once, the amount of markup can grow considerably. Even if you use a tool to generate XAML-based animations, it is important to know the basics of how an animation is represented in XAML because this will make it easier for you to modify and tweak tool-generated content.

---

■ **Note** You will find a number of XAML files in the `XamlAnimations` folder of the downloadable source code. As you go through the next several pages, copy these markup files into your custom XAML editor or into the Kaxaml editor to see the results.

---

For the most part, creating an animation is similar to what you saw already. You still configure an `Animation` object and associate it to an object's property. One big difference, however, is that WPF is not function call-friendly. As a result, instead of calling `BeginAnimation()`, you use a *storyboard* as a layer of indirection.

Let's walk through a complete example of an animation defined in terms of XAML, followed by a detailed breakdown. The following XAML definition will display a window that contains a single label. As soon as the `Label` object loads into memory, it begins an animation sequence in which the font size increases from 12 points to 100 over a period of four seconds. The animation will repeat for as long as the `Window` object is loaded in memory. You can find this markup in the `GrowLabelFont.xaml` file, so copy it into Kaxaml (make sure to press F5 to show the window) and observe the behavior.

```

<Window
  xmlns="http://schemas.microsoft.com/winfx/2006/xaml/presentation"
  xmlns:x="http://schemas.microsoft.com/winfx/2006/xaml"
  Height="200" Width="600" WindowStartupLocation="CenterScreen" Title="Growing Label Font!">
  <StackPanel>
    <Label Content = "Interesting...">
      <Label.Triggers>
        <EventTrigger RoutedEvent = "Label.Loaded">
          <EventTrigger.Actions>
            <BeginStoryboard>
              <Storyboard TargetProperty = "FontSize">
                <DoubleAnimation From = "12" To = "100" Duration = "0:0:4"
                  RepeatBehavior = "Forever"/>
              </Storyboard>
            </BeginStoryboard>
          </EventTrigger.Actions>
        </EventTrigger>
      </Label.Triggers>
    </Label>
  </StackPanel>
</Window>

```

Now, let's break this example down, bit by bit.

## The Role of Storyboards

Working from the innermost element outward, you first encounter the `<DoubleAnimation>` element, which makes use of the same properties you set in procedural code (`From`, `To`, `Duration`, and `RepeatBehavior`).

```

<DoubleAnimation From = "12" To = "100" Duration = "0:0:4"
  RepeatBehavior = "Forever"/>

```

As mentioned, Animation elements are placed within a `<Storyboard>` element, which is used to map the animation object to a given property on the parent type via the `TargetProperty` property, which in this case is `FontSize`. A `<Storyboard>` is always wrapped in a parent element named `<BeginStoryboard>`.

```

<BeginStoryboard>
  <Storyboard TargetProperty = "FontSize">
    <DoubleAnimation From = "12" To = "100" Duration = "0:0:4"
      RepeatBehavior = "Forever"/>
  </Storyboard>
</BeginStoryboard>

```

## The Role of Event Triggers

After the `<BeginStoryboard>` element has been defined, you need to specify some sort of action that will cause the animation to begin executing. WPF has a few different ways to respond to runtime conditions in markup, one of which is termed a *trigger*. From a high level, you can consider a trigger a way of responding to an event condition in XAML, without the need for procedural code.

Typically, when you respond to an event in C#, you author custom code that will execute when the event occurs. A trigger, however, is just a way to be notified that some event condition has happened (“I’m loaded into memory!” or “The mouse is over me!” or “I have focus!”).

Once you’ve been notified that an event condition has occurred, you can start the storyboard. In this example, you are responding to the Label being loaded into memory. Because it is the Label’s Loaded event you are interested in, the <EventTrigger> is placed in the Label’s trigger collection.

```
<Label Content = "Interesting...">
  <Label.Triggers>
    <EventTrigger RoutedEvent = "Label.Loaded">
      <EventTrigger.Actions>
        <BeginStoryboard>
          <Storyboard TargetProperty = "FontSize">
            <DoubleAnimation From = "12" To = "100" Duration = "0:0:4"
                          RepeatBehavior = "Forever"/>
          </Storyboard>
        </BeginStoryboard>
      </EventTrigger.Actions>
    </EventTrigger>
  </Label.Triggers>
</Label>
```

Let’s see another example of defining an animation in XAML, this time using a *key frame* animation.

## Animation Using Discrete Key Frames

Unlike the linear interpolation animation objects, which can only move between a starting point and an ending point, the *key frame* counterparts allow you to create a collection of specific values for an animation that should take place at specific times.

To illustrate the use of a discrete key frame type, assume you want to build a Button control that animates its content so that over the course of three seconds the value “OK!” appears, one character at a time. You’ll find the following markup in the `AnimateString.xaml` file. Copy this markup into your `MyXamlPad.exe` program (or `Kaxaml`) and view the results:

```
<Window xmlns="http://schemas.microsoft.com/winfx/2006/xaml/presentation"
  xmlns:x="http://schemas.microsoft.com/winfx/2006/xaml"
  Height="100" Width="300"
  WindowStartupLocation="CenterScreen" Title="Animate String Data!">
  <StackPanel>
    <Button Name="myButton" Height="40"
      FontSize="16pt" FontFamily="Verdana" Width = "100">
    <Button.Triggers>
      <EventTrigger RoutedEvent="Button.Loaded">
        <BeginStoryboard>
          <Storyboard>
            <StringAnimationUsingKeyFrames RepeatBehavior = "Forever"
              Storyboard.TargetProperty="Content"
              Duration="0:0:3">
              <DiscreteStringKeyFrame Value="" KeyTime="0:0:0" />
              <DiscreteStringKeyFrame Value="O" KeyTime="0:0:1" />
              <DiscreteStringKeyFrame Value="OK" KeyTime="0:0:1.5" />
            </StringAnimationUsingKeyFrames>
          </Storyboard>
        </BeginStoryboard>
      </EventTrigger>
    </Button.Triggers>
  </Button>
</StackPanel>
</Window>
```

```

        <DiscreteStringKeyFrame Value="OK!" KeyTime="0:0:2" />
    </StringAnimationUsingKeyFrames>
</Storyboard>
</BeginStoryboard>
</EventTrigger>
</Button.Triggers>
</Button>
</StackPanel>
</Window>

```

First, notice that you have defined an event trigger for your button to ensure that your storyboard executes when the button has loaded into memory. The `StringAnimationUsingKeyFrames` class is in charge of changing the content of the button, via the `Storyboard.TargetProperty` value.

Within the scope of the `<StringAnimationUsingKeyFrames>` element, you define four `DiscreteStringKeyFrame` elements, which change the button's `Content` property over the course of two seconds (note that the duration established by `StringAnimationUsingKeyFrames` is a total of three seconds, so you will see a slight pause between the final ! and looping 0).

Now that you have a better feel for how to build animations in C# code and XAML, let's look at the role of WPF styles, which make heavy use of graphics, object resources, and animations.

## Understanding the Role of WPF Styles

When you are building the UI of a WPF application, it is not uncommon for a family of controls to require a shared look and feel. For example, you might want all button types to have the same height, width, background color, and font size for their string content. Although you could handle this by setting each button's individual properties to identical values, such an approach makes it difficult to implement changes down the road because you would need to reset the same set of properties on multiple objects for every change.

Thankfully, WPF offers a simple way to constrain the look and feel of related controls using *styles*. Simply put, a WPF style is an object that maintains a collection of property-value pairs. Programmatically speaking, an individual style is represented using the `System.Windows.Style` class. This class has a property named `Setters`, which exposes a strongly typed collection of `Setter` objects. It is the `Setter` object that allows you to define the property-value pairs.

In addition to the `Setters` collection, the `Style` class also defines a few other important members that allow you to incorporate triggers, restrict where a style can be applied, and even create a new style based on an existing style (think of it as “style inheritance”). In particular, be aware of the following members of the `Style` class:

- **Triggers:** Exposes a collection of trigger objects, which allow you to capture various event conditions within a style
- **BasedOn:** Allows you to build a new style based on an existing style
- **TargetType:** Allows you to constrain where a style can be applied

## Defining and Applying a Style

In almost every case, a `Style` object will be packaged as an object resource. Like any object resource, you can package it at the window or application level, as well as within a dedicated resource dictionary (this is great because it makes the `Style` object easily accessible throughout your application). Now recall that the goal is to define a `Style` object that fills (at minimum) the `Setters` collection with a set of property-value pairs.

Let's build a style that captures the basic font characteristics of a control in your application. Start by creating a new WPF application named `WpfStyles`. Open your `App.xaml` file and define the following named style:

```
<Application.Resources>
  <Style x:Key = "BasicControlStyle">
    <Setter Property = "Control.FontSize" Value = "14"/>
    <Setter Property = "Control.Height" Value = "40"/>
    <Setter Property = "Control.Cursor" Value = "Hand"/>
  </Style>
</Application.Resources>
```

Notice that your `BasicControlStyle` adds three `Setter` objects to the internal collection. Now, let's apply this style to a few controls in your main window. Because this style is an object resource, the controls that want to use it still need to use the `{StaticResource}` or `{DynamicResource}` markup extension to locate the style. When they find the style, they will set the resource item to the identically named `Style` property. Replace the default `Grid` control with the following markup:

```
<StackPanel>
  <Label x:Name="lblInfo" Content="This style is boring..."
        Style="{StaticResource BasicControlStyle}" Width="150"/>
  <Button x:Name="btnTestButton" Content="Yes, but we are reusing settings!"
        Style="{StaticResource BasicControlStyle}" Width="250"/>
</StackPanel>
```

If you view the Window in the Visual Studio designer (or run the application), you'll find that both controls support the same cursor, height, and font size.

## Overriding Style Settings

While both of your controls have opted in to the style, if a control wants to apply a style and then change some of the defined settings, that's fine. For example, the `Button` will now use the `Help` cursor (rather than the `Hand` cursor defined in the style).

```
<Button x:Name="btnTestButton" Content="Yes, but we are reusing settings!"
        Cursor="Help" Style="{StaticResource BasicControlStyle}" Width="250" />
```

Styles are processed before the individual property settings of the control using the style; therefore, controls can “override” settings on a case-by-case basis.

## The Effect of `TargetType` on Styles

Currently, your style is defined in such a way that any control can adopt it (and has to do so explicitly by setting the control's `Style` property), given that each property is qualified by the `Control` class. For a program that defines dozens of settings, this would entail a good amount of repeated code. One way to clean this style up a bit is to use the `TargetType` attribute. When you add this attribute to a `Style`'s opening element, you can mark exactly once where it can be applied (in this example, in `App.xaml`).

```
<Style x:Key="BasicControlStyle" TargetType="Control">
  <Setter Property="FontSize" Value="14"/>
  <Setter Property="Height" Value="40"/>
  <Setter Property="Cursor" Value="Hand"/>
</Style>
```

---

■ **Note** When you build a style that uses a base class type, you needn't be concerned if you assign a value to a dependency property not supported by derived types. If the derived type does not support a given dependency property, it is ignored.

---

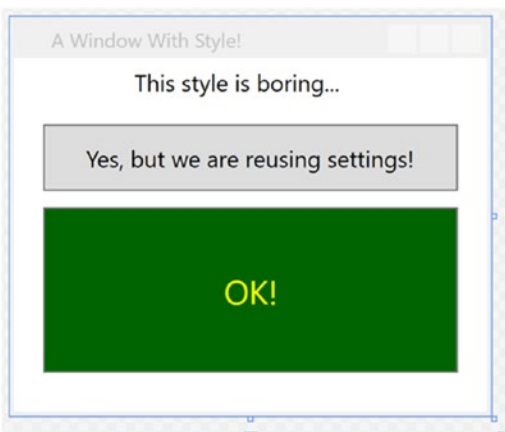
This is somewhat helpful, but you still have a style that can apply to any control. The `TargetType` attribute is more useful when you want to define a style that can be applied to only a particular type of control. Add the following new style to the application's resource dictionary:

```
<Style x:Key="BigGreenButton" TargetType="Button">
  <Setter Property="FontSize" Value="20"/>
  <Setter Property="Height" Value="100"/>
  <Setter Property="Width" Value="100"/>
  <Setter Property="Background" Value="DarkGreen"/>
  <Setter Property="Foreground" Value="Yellow"/>
</Style>
```

This style will work only on `Button` controls (or a subclass of `Button`). If you apply it to an incompatible element, you will get markup and compiler errors. Add a new `Button` that uses this new style, as follows:

```
<Button x:Name="btnAnotherButton" Content="OK!" Margin="0,10,0,0"
  Style="{StaticResource BigGreenButton}" Width="250" Cursor="Help"/>
```

You'll see output like that shown in Figure 27-7.



**Figure 27-7.** Controls with different styles



Another effect of `TargetType` is that the style will get applied to all elements of that type within the scope of the style definition as long as the `x:Key` property *doesn't* exist.

Here is another application-level style that will apply automatically to all `TextBox` controls in the current application:

```
<!-- The default style for all text boxes. -->
<Style TargetType="TextBox">
  <Setter Property = "FontSize" Value = "14"/>
  <Setter Property = "Width" Value = "100"/>
  <Setter Property = "Height" Value = "30"/>
  <Setter Property = "BorderThickness" Value = "5"/>
  <Setter Property = "BorderBrush" Value = "Red"/>
  <Setter Property = "FontStyle" Value = "Italic"/>
</Style>
```

You can now define any number of `TextBox` controls, and they will automatically get the defined look. If a given `TextBox` does not want this default look and feel, it can opt out by setting the `Style` property to `{x:Null}`. For example, `txtTest` will get the default unnamed style, while `txtTest2` is doing things its own way.

```
<TextBox x:Name="txtTest"/>
<TextBox x:Name="txtTest2" Style="{x:Null}" BorderBrush="Black"
  BorderThickness="5" Height="60" Width="100" Text="Ha!"/>
```

## Subclassing Existing Styles

You can also build new styles using an existing style, via the `BasedOn` property. The style you are extending must have been given a proper `x:Key` in the dictionary, as the derived style will reference it by name using the `{StaticResource}` or `{DynamicResource}` markup extension. Here is a new style based on `BigGreenButton`, which rotates the button element by 20 degrees:

```
<!-- This style is based on BigGreenButton. -->
<Style x:Key ="TiltButton" TargetType="Button" BasedOn = "{StaticResource BigGreenButton}">
  <Setter Property = "Foreground" Value = "White"/>
  <Setter Property = "RenderTransform">
    <Setter.Value>
      <RotateTransform Angle = "20"/>
    </Setter.Value>
  </Setter>
</Style>
```

To use this new style, update the markup for the button to this:

```
<Button x:Name="btnAnotherButton" Content="OK!" Margin="0,10,0,0"
  Style="{StaticResource TiltButton}" Width="250" Cursor="Help"/>
```

This changes the appearance to the image shown in Figure 27-8.



**Figure 27-8.** Using a derived style

## Defining Styles with Triggers

WPF styles can also contain triggers by packaging up `Trigger` objects within the `Triggers` collection of the `Style` object. Using triggers in a style allows you to define certain `<Setter>` elements in such a way that they will be applied only if a given trigger condition is true. For example, perhaps you want to increase the size of a font when the mouse is over a button. Or maybe you want to make sure that the text box with the current focus is highlighted with a given color. Triggers are useful for these sorts of situations, in that they allow you to take specific actions when a property changes, without the need to author explicit C# code in a code-behind file.

Here is an update to the `TextBox` style that ensures that when a `TextBox` has the input focus, it will receive a yellow background:

```
<!-- The default style for all text boxes. -->
<Style TargetType="TextBox">
  <Setter Property = "FontSize" Value = "14"/>
  <Setter Property = "Width" Value = "100"/>
  <Setter Property = "Height" Value = "30"/>
  <Setter Property = "BorderThickness" Value = "5"/>
  <Setter Property = "BorderBrush" Value = "Red"/>
  <Setter Property = "FontStyle" Value = "Italic"/>
  <!-- The following setter will be applied only when the text box is in focus. -->
  <Style.Triggers>
    <Trigger Property = "IsFocused" Value = "True">
      <Setter Property = "Background" Value = "Yellow"/>
    </Trigger>
  </Style.Triggers>
</Style>
```

If you test this style, you'll find that as you tab between various `TextBox` objects, the currently selected `TextBox` has a bright yellow background (provided it has not opted out by assigning `{x:Null}` to the `Style` property).

Property triggers are also very smart, in that when the trigger's condition is *not true*, the property automatically receives the default assigned value. Therefore, as soon as a `TextBox` loses focus, it also automatically becomes the default color without any work on your part. In contrast, event triggers (examined when you looked at WPF animations) do not automatically revert to a previous condition.

## Defining Styles with Multiple Triggers

Triggers can also be designed in such a way that the defined <Setter> elements will be applied when *multiple conditions* are true. Let's say you want to set the background of a TextBox to Yellow only if it has the active focus and the mouse is hovering within its boundaries. To do so, you can make use of the <MultiTrigger> element to define each condition, like so:

```
<!-- The default style for all text boxes. -->
<Style TargetType="TextBox">
  <Setter Property = "FontSize" Value = "14"/>
  <Setter Property = "Width" Value = "100"/>
  <Setter Property = "Height" Value = "30"/>
  <Setter Property = "BorderThickness" Value = "5"/>
  <Setter Property = "BorderBrush" Value = "Red"/>
  <Setter Property = "FontStyle" Value = "Italic"/>
<!-- The following setter will be applied only when the text box is
in focus AND the mouse is over the text box. -->
  <Style.Triggers>
    <MultiTrigger>
      <MultiTrigger.Conditions>
        <Condition Property = "IsFocused" Value = "True"/>
        <Condition Property = "IsMouseOver" Value = "True"/>
      </MultiTrigger.Conditions>
      <Setter Property = "Background" Value = "Yellow"/>
    </MultiTrigger>
  </Style.Triggers>
</Style>
```

## Animated Styles

Styles can also incorporate triggers that kick off an animation sequence. Here is one final style that, when applied to Button controls, will cause the controls to grow and shrink in size when the mouse is inside the button's surface area:

```
<!-- The growing button style! -->
<Style x:Key = "GrowingButtonStyle" TargetType="Button">
  <Setter Property = "Height" Value = "40"/>
  <Setter Property = "Width" Value = "100"/>
  <Style.Triggers>
    <Trigger Property = "IsMouseOver" Value = "True">
      <Trigger.EnterActions>
        <BeginStoryboard>
          <Storyboard TargetProperty = "Height">
            <DoubleAnimation From = "40" To = "200"
              Duration = "0:0:2" AutoReverse="True"/>
          </Storyboard>
        </BeginStoryboard>
      </Trigger.EnterActions>
    </Trigger>
  </Style.Triggers>
</Style>
```

Here, the Triggers collection is on the lookout for the `IsMouseOver` property to return true. When this occurs, you define a `<Trigger.EnterActions>` element to execute a simple storyboard that forces the button to grow to a `Height` value of 200 (and then return to a `Height` of 40) over two seconds. If you want to perform other property changes, you could also define a `<Trigger.ExitActions>` scope to define any custom actions to take when `IsMouseOver` changes to false.

## Assigning Styles Programmatically

Recall that a style can be applied at runtime as well. This can be helpful if you want to let end users choose how their UI looks and feels or if you need to enforce a look and feel based on security settings (e.g., the `DisableAllButton` style) or what have you.

During this project, you have defined a number of styles, many of which can apply to `Button` controls. So, let's retool the UI of your main window to allow the user to pick from some of these styles by selecting names in a `ListBox`. Based on the user's selection, you will apply the appropriate style. Here is the new (and final) markup for the `<Window>` element:

```
<DockPanel >
  <StackPanel Orientation="Horizontal" DockPanel.Dock="Top" Margin="0,0,0,50">
    <Label Content="Please Pick a Style for this Button" Height="50"/>
    <ListBox x:Name="lstStyles" Height="80" Width="150" Background="LightBlue"
      SelectionChanged="comboStyles_Changed" />
  </StackPanel>
  <Button x:Name="btnStyle" Height="40" Width="100" Content="OK!"/>
</DockPanel>
```

The `ListBox` control (named `lstStyles`) will be filled dynamically within the window's constructor, like so:

```
public MainWindow()
{
    InitializeComponent();
    // Fill the list box with all the Button styles.
    lstStyles.Items.Add("GrowingButtonStyle");
    lstStyles.Items.Add("TiltButton");
    lstStyles.Items.Add("BigGreenButton");
    lstStyles.Items.Add("BasicControlStyle");
}
```

The final task is to handle the `SelectionChanged` event in the related code file. Notice in the following code how you are able to extract the current resource by name, using the inherited `TryFindResource()` method:

```
private void comboStyles_Changed(object sender, SelectionChangedEventArgs e)
{
    // Get the selected style name from the list box.
    var currStyle = (Style)TryFindResource(lstStyles.SelectedValue);
    if (currStyle == null) return;
    // Set the style of the button type.
    this.btnStyle.Style = currStyle;
}
```

When you run this application, you can pick from one of these four button styles on the fly. Figure 27-9 shows your completed application.



**Figure 27-9.** Controls with different styles

## Logical Trees, Visual Trees, and Default Templates

Now that you understand styles and resources, there are a few more preparatory topics to investigate before you begin learning how to build custom controls. Specifically, you need to learn the distinction between a logical tree, a visual tree, and a default template. When you are typing XAML into Visual Studio or a tool such as `kaxaml.exe`, your markup is the *logical view* of the XAML document. As well, if you author C# code that adds new items to a layout control, you are inserting new items into the logical tree. Essentially, a logical view represents how your content will be positioned within the various layout managers for a main Window (or another root element, such as Page or NavigationWindow).

However, behind every logical tree is a much more verbose representation termed a *visual tree*, which is used internally by WPF to correctly render elements onto the screen. Within any visual tree, there will be full details of the templates and styles used to render each object, including any necessary drawings, shapes, visuals, and animations.

It is useful to understand the distinction between logical and visual trees because when you are building a custom control template, you are essentially replacing all or part of the default visual tree of a control and inserting your own. Therefore, if you want a Button control to be rendered as a star shape, you could define a new star template and plug it into the Button's visual tree. Logically, the Button is still of type Button, and it supports all of the properties, methods, and events as expected. But visually, it has taken on a whole new appearance. This fact alone makes WPF an extremely useful API, given that other toolkits would require you to build a new class to make a star-shaped button. With WPF, you simply need to define new markup.

---

■ **Note** WPF controls are often described as *lookless*. This refers to the fact that the look and feel of a WPF control is completely independent (and customizable) from its behavior.

---

## Programmatically Inspecting a Logical Tree

While analyzing a window's logical tree at runtime is not a tremendously common WPF programming activity, it is worth mentioning that the `System.Windows` namespace defines a class named `LogicalTreeHelper`, which allows you to inspect the structure of a logical tree at runtime. To illustrate the connection between logical trees, visual trees, and control templates, create a new WPF application named `TreesAndTemplatesApp`.

Replace the `Grid` with the following markup that contains two `Button` controls and a large read-only `TextBox` with scrollbars enabled. Make sure you use the IDE to handle the `Click` event of each button. The following XAML will do nicely:

```
<DockPanel LastChildFill="True">
  <Border Height="50" DockPanel.Dock="Top" BorderBrush="Blue">
    <StackPanel Orientation="Horizontal">
      <Button x:Name="btnShowLogicalTree" Content="Logical Tree of Window"
        Margin="4" BorderBrush="Blue" Height="40" Click="btnShowLogicalTree_Click"/>
      <Button x:Name="btnShowVisualTree" Content="Visual Tree of Window"
        BorderBrush="Blue" Height="40" Click="btnShowVisualTree_Click"/>
    </StackPanel>
  </Border>
  <TextBox x:Name="txtDisplayArea" Margin="10" Background="AliceBlue" IsReadOnly="True"
    BorderBrush="Red" VerticalScrollBarVisibility="Auto" HorizontalScrollBarVisibility
    ="Auto" />
</DockPanel>
```

Within your C# code file, define a string member variable named `_dataToShow`. Now, within the `Click` handler for the `btnShowLogicalTree` object, call a helper function that calls itself recursively in order to populate the string variable with the logical tree of the `Window`. To do so, you will call the static `GetChildren()` method of `LogicalTreeHelper`. Here is the code:

```
private string _dataToShow = string.Empty;

private void btnShowLogicalTree_Click(object sender, RoutedEventArgs e)
{
    _dataToShow = "";
    BuildLogicalTree(0, this);
    txtDisplayArea.Text = _dataToShow;
}

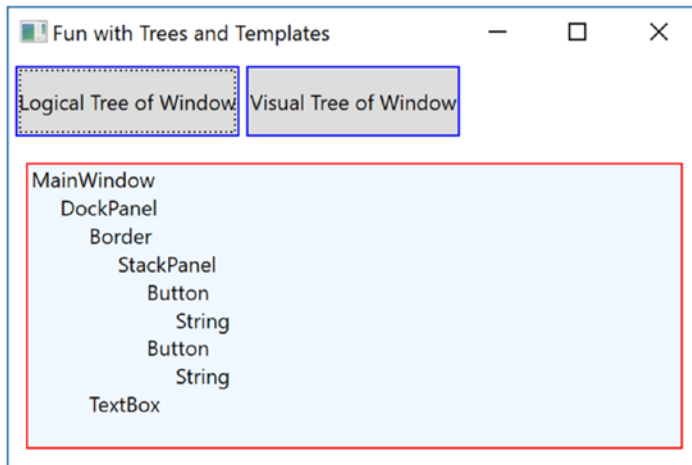
void BuildLogicalTree(int depth, object obj)
{
    // Add the type name to the dataToShow member variable.
    _dataToShow += new string(' ', depth) + obj.GetType().Name + "\n";
    // If an item is not a DependencyObject, skip it.
    if (!(obj is DependencyObject))
        return;
    // Make a recursive call for each logical child.
    foreach (var child in LogicalTreeHelper.GetChildren((DependencyObject)obj))
    {
        BuildLogicalTree(depth + 5, child);
    }
}
```

```

}
private void btnShowVisualTree_Click(
    object sender, RoutedEventArgs e)
{
}

```

If you run your application and click this first button, you will see a tree print in the text area, which is just about an exact replica of the original XAML (see Figure 27-10).



**Figure 27-10.** Viewing a logical tree at runtime

## Programmatically Inspecting a Visual Tree

A Window's visual tree can also be inspected at runtime using the `VisualTreeHelper` class of `System.Windows.Media`. Here is a Click implementation of the second Button control (`btnShowVisualTree`), which performs similar recursive logic to build a textual representation of the visual tree:

```

using System.Windows.Media;

private void btnShowVisualTree_Click(object sender, RoutedEventArgs e)
{
    _dataToShow = "";
    BuildVisualTree(0, this);
    txtDisplayArea.Text = _dataToShow;
}

void BuildVisualTree(int depth, DependencyObject obj)
{
    // Add the type name to the dataToShow member variable.
    _dataToShow += new string(' ', depth) + obj.GetType().Name + "\n";
    // Make a recursive call for each visual child.
}

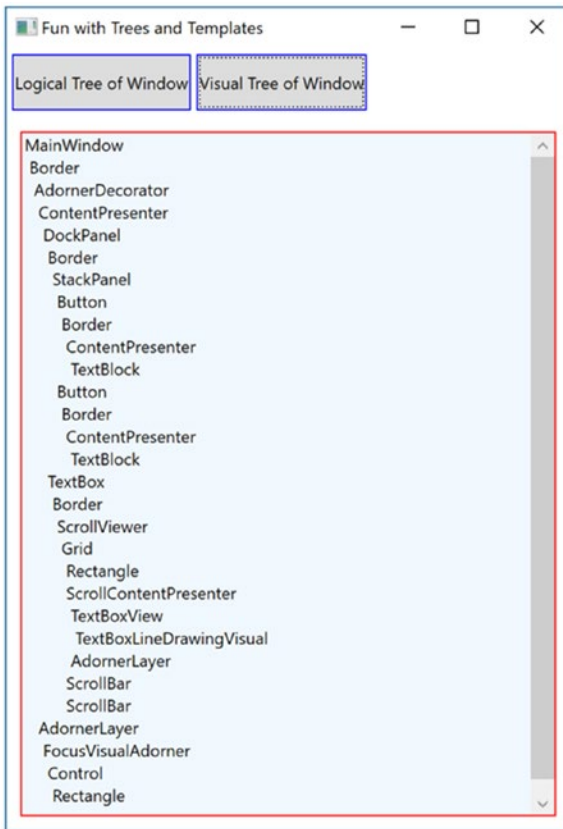
```

```

for (int i = 0; i < VisualTreeHelper.GetChildrenCount(obj); i++)
{
    BuildVisualTree(depth + 1, VisualTreeHelper.GetChild(obj, i));
}
}

```

As you can see in Figure 27-11, the visual tree exposes a number of lower-level rendering agents such as `ContentPresenter`, `AdornerDecorator`, `TextBoxLineDrawingVisual`, and so forth.



**Figure 27-11.** Viewing a visual tree at runtime

## Programmatically Inspecting a Control's Default Template

Recall that a visual tree is used by WPF to understand how to render a window and all contained elements. Every WPF control stores its own set of rendering commands within its default template. Programmatically speaking, any template can be represented as an instance of the `ControlTemplate` class. As well, you can obtain a control's default template by using the aptly named `Template` property, like so:

```

// Get the default template of the Button.
Button myBtn = new Button();
ControlTemplate template = myBtn.Template;

```



Likewise, you could create a new `ControlTemplate` object in code and plug it into a control's `Template` property as follows:

```
// Plug in a new template for the button to use.
Button myBtn = new Button();
ControlTemplate customTemplate = new ControlTemplate();

// Assume this method adds all the code for a star template.
MakeStarTemplate(customTemplate);
myBtn.Template = customTemplate;
```

While you could build a new template in code, it is far more common to do so in XAML. However, before you start building your own templates, let's finish the current example and add the ability to view the default template of a WPF control at runtime. This can be a really useful way to take a look at the overall composition of a template. Update the markup of your window with a new `StackPanel` of controls docked to the left side of the master `DockPanel`, defined as so (placed just before the `<TextBox>` element):

```
<Border DockPanel.Dock="Left" Margin="10" BorderBrush="DarkGreen" BorderThickness="4"
Width="358">
  <StackPanel>
    <Label Content="Enter Full Name of WPF Control" Width="340" FontWeight="DemiBold" />
    <TextBox x:Name="txtFullName" Width="340" BorderBrush="Green"
      Background="BlanchedAlmond" Height="22" Text="System.Windows.Controls.Button" />
    <Button x:Name="btnTemplate" Content="See Template" BorderBrush="Green"
      Height="40" Width="100" Margin="5" Click="btnTemplate_Click"
      HorizontalAlignment="Left" />
    <Border BorderBrush="DarkGreen" BorderThickness="2" Height="260"
      Width="301" Margin="10" Background="LightGreen" >
      <StackPanel x:Name="stackTemplatePanel" />
    </Border>
  </StackPanel>
</Border>
```

Add an empty event handler function for the `btnTemplate_Click` event like this:

```
private void btnTemplate_Click(
    object sender, RoutedEventArgs e)
{
}
}
```

The upper-left text area allows you to enter in the fully qualified name of a WPF control located in the `PresentationFramework.dll` assembly. Once the library is loaded, you will dynamically create an instance of the object and display it in the large square in the bottom left. Last but not least, the control's default template will be displayed in the right-hand text area. First, add a new member variable to your C# class of type `Control`, like so:

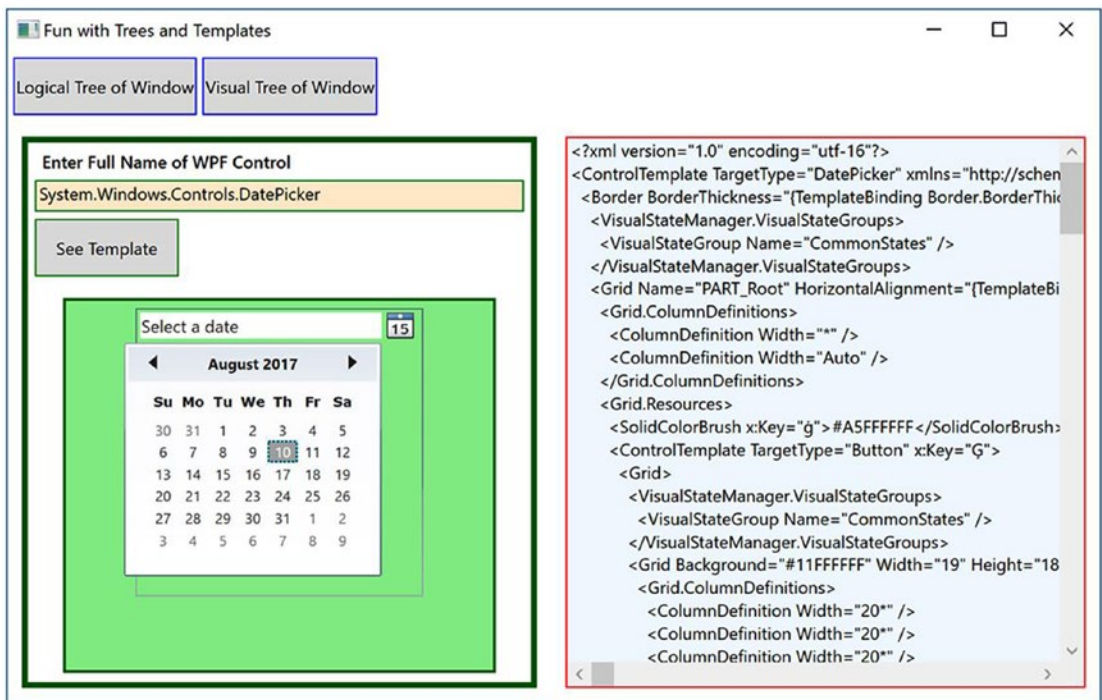
```
private Control _ctrlToExamine = null;
```

Here is the remaining code, which will require you to import the `System.Reflection`, `System.Xml`, and `System.Windows.Markup` namespaces:

```
private void btnTemplate_Click(
    object sender, RoutedEventArgs e)
{
    _dataToShow = "";
    ShowTemplate();
    txtDisplayArea.Text = _dataToShow;
}

private void ShowTemplate()
{
    // Remove the control that is currently in the preview area.
    if (_ctrlToExamine != null)
        stackTemplatePanel.Children.Remove(_ctrlToExamine);
    try
    {
        // Load PresentationFramework, and create an instance of the
        // specified control. Give it a size for display purposes, then add to the
        // empty StackPanel.
        Assembly asm = Assembly.Load("PresentationFramework, Version=4.0.0.0," +
            "Culture=neutral, PublicKeyToken=31bf3856ad364e35");
        _ctrlToExamine = (Control)asm.CreateInstance(txtFullName.Text);
        _ctrlToExamine.Height = 200;
        _ctrlToExamine.Width = 200;
        _ctrlToExamine.Margin = new Thickness(5);
        stackTemplatePanel.Children.Add(_ctrlToExamine);
        // Define some XML settings to preserve indentation.
        var xmlSettings = new XmlWriterSettings{Indent = true};
        // Create a StringBuilder to hold the XAML.
        var strBuilder = new StringBuilder();
        // Create an XmlWriter based on our settings.
        var xWriter = XmlWriter.Create(strBuilder, xmlSettings);
        // Now save the XAML into the XmlWriter object based on the ControlTemplate.
        XmlWriter.Save(_ctrlToExamine.Template, xWriter);
        // Display XAML in the text box.
        _dataToShow = strBuilder.ToString();
    }
    catch (Exception ex)
    {
        _dataToShow = ex.Message;
    }
}
```

The bulk of the work is just tinkering with the compiled BAML resource to map it into a XAML string. Figure 27-12 shows your final application in action, displaying the default template of the `System.Windows.Controls.DatePicker` control. The image shows the Calendar, which is accessed by clicking the button on the right side of the control.



**Figure 27-12.** Investigating a `ControlTemplate` at runtime

Great! You should have a better idea about how logical trees, visual trees, and control default templates work together. Now you can spend the remainder of this chapter learning how to build custom templates and user controls.

## Building a Control Template with the Trigger Framework

When you build a custom template for a control, you could do so with nothing but C# code. Using this approach, you would add data to a `ControlTemplate` object and then assign it to a control's `Template` property. Most of the time, however, you will define the look and feel of a `ControlTemplate` using XAML and add bits of code (or possibly quite a bit of code) to drive the runtime behavior.

In the remainder of this chapter, you will examine how to build custom templates using Visual Studio. Along the way, you will learn about the WPF trigger framework and the Visual State Manager (VSM), and you'll see how to use animations to incorporate visual cues for the end user. Using Visual Studio alone to build complex templates can entail a fair amount of typing and a bit of heavy lifting. To be sure, production-level templates will benefit from the use of Blend for Visual Studio, the (now) free companion application installed with Visual Studio. However, given that this edition of the text does not include coverage of Blend, it's time to roll up your sleeves and pound out some markup.

To begin, create a new WPF application named `ButtonTemplate`. For this project, you are more interested in the mechanics of creating and using templates, so replace the `Grid` with the following markup:

```
<StackPanel Orientation="Horizontal">
  <Button x:Name="myButton" Width="100" Height="100" Click="myButton_Click"/>
</StackPanel>
```

In the Click event handler, simply display a message box (via `MessageBox.Show()`) to show a message confirming the clicking of the control. Remember, when you build custom templates, the *behavior* of the control is constant, but the *look* may vary.

Currently, this Button is rendered using the default template, which, as the previous example illustrated, is a BAML resource within a given WPF assembly. When you want to define your own template, you essentially replace this default visual tree with your own creation. To begin, update the definition of the <Button> element to specify a new template using the property-element syntax. This template will give the control a round appearance.

```
<Button x:Name="myButton" Width="100" Height="100" Click="myButton_Click">
  <Button.Template>
    <ControlTemplate>
      <Grid x:Name="controllayout">
        <Ellipse x:Name="buttonSurface" Fill = "LightBlue"/>
        <Label x:Name="buttonCaption"
          VerticalAlignment = "Center"
          HorizontalAlignment = "Center"
          FontWeight = "Bold" FontSize = "20" Content = "OK!"/>
      </Grid>
    </ControlTemplate>
  </Button.Template>
</Button>
```

Here, you have defined a template that consists of a named Grid control containing a named Ellipse and a Label. Because your Grid has no defined rows or columns, each child stacks on top of the previous control, which centers the content. If you run your application now, you will notice that the Click event will fire *only* when the mouse cursor is within the bounds of the Ellipse! This is a great feature of the WPF template architecture: you do not need to recalculate hit-testing, bounds checking, or any other low-level detail. So, if your template used a Polygon object to render some oddball geometry, you can rest assured that the mouse hit-testing details are relative to the shape of the control, not the larger bounding rectangle.

## Templates As Resources

Currently, your template is embedded to a specific Button control, which limits reuse. Ideally, you would place your template into a resource dictionary so you can reuse your round button template between projects or, at minimum, move it into the application resource container for reuse within this project. Let's move the local Button resource to the application level by cutting the template definition from the Button and pasting it into the Application.Resources tag in the App.xaml file. Add in a Key and a TargetType, as follows:

```
<Application.Resources>
  <ControlTemplate x:Key="RoundButtonTemplate" TargetType="{x:Type Button}">
    <Grid x:Name="controllayout">
      <Ellipse x:Name="buttonSurface" Fill = "LightBlue"/>
      <Label x:Name="buttonCaption" VerticalAlignment = "Center" HorizontalAlignment =
        "Center"
        FontWeight = "Bold" FontSize = "20" Content = "OK!"/>
    </Grid>
  </ControlTemplate>
</Application.Resources>
```

Update the Button markup to the following:

```
<Button x:Name="myButton" Width="100" Height="100"
  Click="myButton_Click"
  Template="{StaticResource RoundButtonTemplate}">
</Button>
```

Now, because this resource is available for the entire application, you can define any number of round buttons just by simply applying the template. Create two additional Button controls that use this template for testing purposes (no need to handle the Click event for these new items).

```
<StackPanel>
  <Button x:Name="myButton" Width="100" Height="100"
    Click="myButton_Click"
    Template="{StaticResource RoundButtonTemplate}"></Button>
  <Button x:Name="myButton2" Width="100" Height="100"
    Template="{StaticResource RoundButtonTemplate}"></Button>
  <Button x:Name="myButton3" Width="100" Height="100"
    Template="{StaticResource RoundButtonTemplate}"></Button>
</StackPanel>
```

## Incorporating Visual Cues Using Triggers

When you define a custom template, all of the visual cues of the default template are removed as well. For example, the default button template contains markup that informs the control how to look when certain UI events occur, such as when it receives focus, when it is clicked with the mouse, when it is enabled (or disabled), and so on. Users are quite accustomed to these sort of visual cues because it gives the control somewhat of a tactile response. However, your RoundButtonTemplate does not define any such markup, so the look of the control is identical regardless of the mouse activity. Ideally, your control should look slightly different when clicked (maybe via a color change or drop shadow) to let the user know the visual state has changed.

This can be done using triggers, as you have already learned. For simple operations, triggers work perfectly well. There are additional ways to do this that are beyond the scope of this book, but there is more information available at <https://docs.microsoft.com/en-us/dotnet/desktop-wpf/themes/how-to-create-apply-template>.

By way of example, update your RoundButtonTemplate with the following markup, which adds two triggers. The first will change the color of the control to blue and the foreground color to yellow when the mouse is over the surface. The second shrinks the size of the Grid (and, therefore, all child elements) when the control is pressed via the mouse.

```
<ControlTemplate x:Key="RoundButtonTemplate" TargetType="Button" >
  <Grid x:Name="controlLayout">
    <Ellipse x:Name="buttonSurface" Fill="LightBlue" />
    <Label x:Name="buttonCaption" Content="OK!"
      FontSize="20" FontWeight="Bold"
      HorizontalAlignment="Center"
      VerticalAlignment="Center" />
  </Grid>
```

```

<ControlTemplate.Triggers>
  <Trigger Property = "IsMouseOver" Value = "True">
    <Setter TargetName = "buttonSurface" Property = "Fill"
      Value = "Blue"/>
    <Setter TargetName = "buttonCaption"
      Property = "Foreground" Value = "Yellow"/>
  </Trigger>
  <Trigger Property = "IsPressed" Value="True">
    <Setter TargetName="controlLayout"
      Property="RenderTransformOrigin" Value="0.5,0.5"/>
    <Setter TargetName="controlLayout"
      Property="RenderTransform">
      <Setter.Value>
        <ScaleTransform ScaleX="0.8" ScaleY="0.8"/>
      </Setter.Value>
    </Setter>
  </Trigger>
</ControlTemplate.Triggers>
</ControlTemplate>

```

## The Role of the {TemplateBinding} Markup Extension

The problem with the control template is that each of the buttons looks and says the same thing. Updating the markup to the following has no effect:

```

<Button x:Name="myButton" Width="100" Height="100"
  Background="Red" Content="Howdy!" Click="myButton_Click"
  Template="{StaticResource RoundButtonTemplate}" />
<Button x:Name="myButton2" Width="100" Height="100"
  Background="LightGreen" Content="Cancel!" Template="{StaticResource RoundButtonTemplate}" />
<Button x:Name="myButton3" Width="100" Height="100"
  Background="Yellow" Content="Format" Template="{StaticResource RoundButtonTemplate}" />

```

This is because the control's default properties (such as Background and Content) are overridden in the template. To enable them, they must be mapped to the related properties in the template. You can solve these issues by using the {TemplateBinding} markup extension when you build your template. This allows you to capture property settings defined by the control using your template and use them to set values in the template itself.

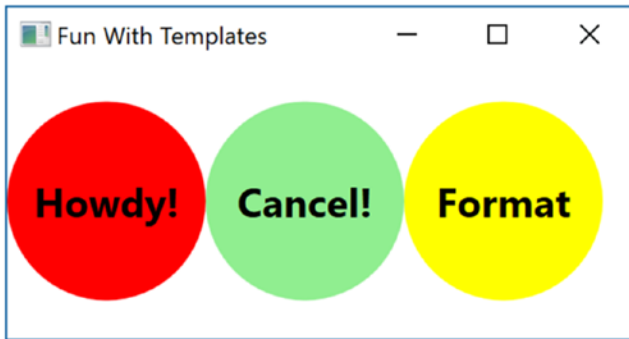
Here is a reworked version of RoundButtonTemplate, which now uses this markup extension to map the Background property of the Button to the Fill property of the Ellipse; it also makes sure the Content of the Button is indeed passed to the Content property of the Label:

```

<Ellipse x:Name="buttonSurface" Fill="{TemplateBinding Background}"/>
<Label x:Name="buttonCaption" Content="{TemplateBinding Content}"
  FontSize="20" FontWeight="Bold" HorizontalAlignment="Center"
  VerticalAlignment="Center" />

```

With this update, you can now create buttons of various colors and textual values (see Figure 27-13). Figure 27-13 shows the result of the updated XAML.



**Figure 27-13.** Template bindings allow values to pass through to the internal controls

## The Role of ContentPresenter

When you designed your template, you used a `Label` to display the textual value of the control. Like the `Button`, the `Label` supports a `Content` property. Therefore, given your use of `{TemplateBinding}`, you could define a `Button` that contains complex content beyond that of a simple string.

However, what if you need to pass in complex content to a template member that does *not* have a `Content` property? When you want to define a generalized *content display area* in a template, you can use the `ContentPresenter` class as opposed to a specific type of control (`Label` or `TextBlock`). There is no need to do so for this example; however, here is some simple markup that illustrates how you could build a custom template that uses `ContentPresenter` to show the value of the `Content` property of the control using the template:

```
<!-- This button template will display whatever is set to the Content of the hosting button. -->
<ControlTemplate x:Key="NewRoundButtonTemplate" TargetType="Button">
  <Grid>
    <Ellipse Fill="{TemplateBinding Background}"/>
    <ContentPresenter HorizontalAlignment="Center" VerticalAlignment="Center"/>
  </Grid>
</ControlTemplate>
```

## Incorporating Templates into Styles

Currently, your template simply defines a basic look and feel of the `Button` control. However, the process of establishing the basic properties of the control (content, font size, font weight, etc.) is the responsibility of the `Button` itself.

```
<!-- Currently the Button must set basic property values, not the template. -->
<Button x:Name="myButton" Foreground="Black" FontSize="20"
  FontWeight="Bold"
  Template="{StaticResource RoundButtonTemplate}"
  Click="myButton_Click"/>
```

If you want, you could establish these values *in the template*. By doing so, you can effectively create a default look and feel. As you might have already realized, this is a job for WPF styles. When you build a style (to account for basic property settings), you can define a template *within the style*! Here is your updated application resource in the application resources in `App.xaml`, which has been rekeyed as `RoundButtonStyle`:

```
<!-- A style containing a template. -->
<Style x:Key = "RoundButtonStyle" TargetType = "Button">
  <Setter Property = "Foreground" Value = "Black"/>
  <Setter Property = "FontSize" Value = "14"/>
  <Setter Property = "FontWeight" Value = "Bold"/>
  <Setter Property = "Width" Value = "100"/>
  <Setter Property = "Height" Value = "100"/>
  <!-- Here is the template! -->
  <Setter Property = "Template">
    <Setter.Value>
      <ControlTemplate TargetType = "Button">
        <!-- Control template from above example -->
        </ControlTemplate>
      </Setter.Value>
    </Setter>
  </Style>
```

With this update, you can now create button controls by setting the `Style` property as so:

```
<Button x:Name="myButton" Background="Red" Content="Howdy!"
  Click="myButton_Click" Style="{StaticResource RoundButtonStyle}"/>
```

While the rendering and behavior of the button are identical, the benefit of nesting templates within styles is that you are able to provide a canned set of values for common properties. That wraps up your look at how to use Visual Studio and the trigger framework to build custom templates for a control. While there is still much more about the Windows Presentation Foundation API than has been examined here, you should be in a solid position for further study.

## Summary

The first part of this chapter examined the resource management system of WPF. You began by looking at how to work with binary resources, and then you examined the role of object resources. As you learned, object resources are named blobs of XAML that can be stored at various locations in order to reuse content.

Next, you learned about WPF's animation framework. Here you had a chance to create some animations using C# code, as well as with XAML. You learned that if you define an animation in markup, you use `<Storyboard>` elements and triggers to control execution. You then looked at the WPF-style mechanism, which makes heavy use of graphics, object resources, and animations.

You examined the relationship between a *logical tree* and a *visual tree*. The logical tree is basically a one-to-one correspondence of the markup you author to describe a WPF root element. Behind this logical tree is a much deeper visual tree that contains detailed rendering instructions.

The role of a *default template* was then examined. Remember, when you are building custom templates, you are essentially ripping out all (or part) of a control's visual tree and replacing it with your own custom implementation.



## CHAPTER 28



# WPF Notifications, Validations, Commands, and MVVM

This chapter will conclude your investigation of the WPF programming model by covering the capabilities that support the Model-View-ViewModel (MVVM) pattern. The first section covers the Model-View-ViewModel pattern. Next, you learn about the WPF notification system and its implementation of the Observable pattern through observable models and observable collections. Having the data in the UI accurately portray the current state of the data automatically improves the user experience significantly and reduces the manual coding required in older technologies (such as WinForms) to achieve the same result.

Building on the Observable pattern, you will examine the mechanisms to add validation into your application. Validation is a vital part of any application – not only letting the user know that something is wrong but also letting them know *what* is wrong. To inform the user what the error is, you will also learn how to incorporate validation into the view markup.

Next, you will take a deeper dive into the WPF command system and create custom commands to encapsulate program logic, much as you did in Chapter 25 with the built-in commands. There are several advantages to creating custom commands, including (but not limited to) enabling code reuse, logic encapsulation, and separation of concerns.

Finally, you will bring all of this together in a sample MVVM application.

## Introducing Model-View-ViewModel

Before you dive into notifications, validations, and commands in WPF, it would be good to understand the end goal of this chapter, which is the Model-View-ViewModel pattern (MVVM). Derived from Martin Fowler's Presentation Model pattern, MVVM leverages XAML-specific capabilities, discussed in this chapter, to make your WPF development faster and cleaner. The name itself describes the main components of the pattern: model, view, view model.

### The Model

The *model* is the object representation of your data. In MVVM, models are conceptually the same as the models from your data access layer (DAL). Sometimes they are the same physical class, but there is no requirement for this. As you read this chapter, you will learn how to decide whether you can use your DAL models or whether you need to create new ones.

Models typically take advantage of the built-in (or custom) validations through data annotations and the `INotifyDataErrorInfo` interface and are configured as observable to tie into the WPF notification system. You will see all of this later in this chapter.

## The View

The *view* is the UI of the application, and it is designed to be very lightweight. Think of the menu board at a drive-thru restaurant. The board displays menu items and prices, and it has a mechanism so the user can communicate with the back-end systems. However, there isn't any intelligence built into the board, unless it is specifically user interface logic, such as turning on the lights if it gets dark.

MVVM Views should be developed with the same goals in mind. Any intelligence should be built into the application elsewhere. The only code in the code-behind file (e.g., `MainWindow.xaml.cs`) should be directly related to manipulating the UI. It should not be based on business rules or anything that needs to be persisted for future use. While not a main goal of MVVM, well-developed MVVM applications typically have very little code in the code-behind.

## The View Model

In WPF and other XAML technologies, the *view model* serves two purposes:

- The view model provides a single stop for all the data needed by the view. This doesn't mean the view model is responsible for getting the actual data; instead, it is merely a transport mechanism to move the data from the data store to the view. Usually, there is a one-to-one correlation between views and view models, but architectural differences exist, and your mileage may vary.
- The second job is to act as the controller for the view. Just like the menu board, the view model takes direction from the user and relays that call to the relevant code to make sure the proper actions are taken. Quite often this code is in the form of custom commands.

## Anemic Models or Anemic View Models

In the early days of WPF, when developers were still working out how best to implement the MVVM pattern, there were significant (and sometimes heated) discussions about *where* to implement items like validation and the Observable pattern. One camp (the anemic model camp) argued that it all should be in the view model since adding those capabilities to the model broke separation of concerns. The other camp (the anemic view model camp) argued it should all be in the models since that reduced duplication of code.

The real answer is, of course, it depends. When `INotifyPropertyChanged`, `IDataErrorInfo`, and `INotifyDataErrorInfo` are implemented on the model classes, this ensures that the relevant code is close to the target of the code (as you will see in this chapter) and is implemented only once for each model. That being said, there are times when your view model classes will need to be developed as observables themselves. At the end of the day, you need to determine what makes the most sense for your application, without over-complicating your code or sacrificing the benefits of MVVM.

---

■ **Note** There are multiple MVVM frameworks available for WPF, such as `MVVMLite`, `Caliburn.Micro`, and `Prism` (although `Prism` is much more than just an MVVM framework). This chapter discusses the MVVM pattern and the features in WPF that support implementing the pattern. I leave it to you, the reader, to examine the different frameworks and select the one that best matches your app's needs.

---

## The WPF Binding Notification System

A significant shortcoming in the binding system for WinForms is a lack of notifications. If the data represented in the view is updated programmatically, the UI must also be refreshed programmatically to keep them in sync. This leads to a lot of calls to `Refresh()` on controls, typically more than are absolutely necessary in order to be safe. While usually not a significant performance issue to include too many calls to `Refresh()`, if you don't include enough, the experience for the user could be affected negatively.

The binding system built into XAML-based applications corrects this problem by enabling you to hook your data objects and collections into a notification system by developing them as observables. Whenever a property's value changes on an observable model or the collection changes (e.g., items are added, removed, or reordered) on an observable collection, an event is raised (either `NotifyPropertyChanged` or `NotifyCollectionChanged`). The binding framework automatically listens for those events to occur and updates the bound controls when they fire. Even better, as a developer, you have control over which properties raise the notifications. Sounds perfect, right? Well, it's not *quite* perfect. There can be a fair amount of code involved in setting this up for observable models if you are doing it all by hand. Fortunately, there is an open source framework that makes it much simpler, as you shall soon see.

## Observable Models and Collections

In this section, you will create an application that uses observable models and collections. To get started, create a new WPF application named `WpfNotifications`. The application will be a master-detail form, allowing the user to select a specific car using a `ComboBox`, and then the details for that car will be displayed in the `TextBox` controls below. Update `MainWindow.xaml` by replacing the default `Grid` with the following markup:

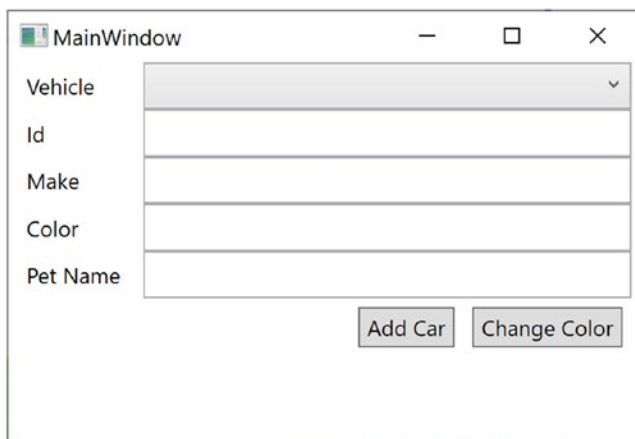
```
<Grid IsSharedSizeScope="True" Margin="5,0,5,5">
  <Grid.RowDefinitions>
    <RowDefinition Height="Auto"/>
    <RowDefinition Height="Auto"/>
  </Grid.RowDefinitions>
  <Grid Grid.Row="0">
    <Grid.ColumnDefinitions>
      <ColumnDefinition Width="Auto"
        SharedSizeGroup="CarLabels"/>
      <ColumnDefinition Width="*/>
    </Grid.ColumnDefinitions>
    <Label Grid.Column="0" Content="Vehicle"/>
    <ComboBox Name="cboCars" Grid.Column="1"
      DisplayMemberPath="PetName" />
  </Grid>
  <Grid Grid.Row="1" Name="DetailsGrid">
    <Grid.ColumnDefinitions>
      <ColumnDefinition Width="Auto"
        SharedSizeGroup="CarLabels"/>
      <ColumnDefinition Width="*/>
    </Grid.ColumnDefinitions>
    <Grid.RowDefinitions>
      <RowDefinition Height="Auto"/>
      <RowDefinition Height="Auto"/>
      <RowDefinition Height="Auto"/>
    </Grid.RowDefinitions>
  </Grid>
</Grid>
```

```

    <RowDefinition Height="Auto"/>
    <RowDefinition Height="Auto"/>
</Grid.RowDefinitions>
<Label Grid.Column="0" Grid.Row="0" Content="Id"/>
<TextBox Grid.Column="1" Grid.Row="0" />
<Label Grid.Column="0" Grid.Row="1" Content="Make"/>
<TextBox Grid.Column="1" Grid.Row="1" />
<Label Grid.Column="0" Grid.Row="2" Content="Color"/>
<TextBox Grid.Column="1" Grid.Row="2" />
<Label Grid.Column="0" Grid.Row="3" Content="Pet Name"/>
<TextBox Grid.Column="1" Grid.Row="3" />
<StackPanel Grid.Column="0" Grid.ColumnSpan="2" Grid.Row="4"
    HorizontalAlignment="Right" Orientation="Horizontal" Margin="0,5,0,5">
    <Button x:Name="btnAddCar" Content="Add Car" Margin="5,0,5,0" Padding="4, 2" />
    <Button x:Name="btnChangeColor" Content="Change Color" Margin="5,0,5,0"
        Padding="4, 2"/>
</StackPanel>
</Grid>
</Grid>

```

Your window will resemble Figure 28-1.



**Figure 28-1.** Master-detail window displaying Car details

The `IsSharedSizeScope` tag on the `Grid` control sets up child grids to share dimensions. The `ColumnDefinitions` marked `SharedSizeGroup` will automatically be sized to the same width without any programming needed. In this example, if the `Pet Name` label was changed to something much longer, the `Vehicle` column (which is in a different `Grid` control) would be sized to match it, keeping the window's appearance nice and tidy.

Next, right-click the project name in Solution Explorer, select Add ► New Folder, and name the folder Models. In this new folder, create a class named Car. The initial class is listed here:

```
public class Car
{
    public int Id { get; set; }
    public string Make { get; set; }
    public string Color { get; set; }
    public string PetName { get; set; }
}
```

## Adding Bindings and Data

The next step is to add the binding statements for the controls. Remember that data-binding statements revolve around a data context, and this can be set on the control itself or on a parent control. Here, you are going to set the context on the DetailsGrid, so each control contained will inherit that data context. Set the DataContext to the SelectedItem property of the ComboBox. Update the Grid that holds the detail controls to the following:

```
<Grid Grid.Row="1" Name="DetailsGrid"
    DataContext="{Binding ElementName=cboCars, Path=SelectedItem}">
```

The text boxes in the DetailsGrid will show the individual properties of the select car. Add the appropriate text attributes and related bindings to the TextBox controls, like so:

```
<TextBox Grid.Column="1" Grid.Row="0" Text="{Binding Path=Id}" />
<TextBox Grid.Column="1" Grid.Row="1" Text="{Binding Path=Make}" />
<TextBox Grid.Column="1" Grid.Row="2" Text="{Binding Path=Color}" />
<TextBox Grid.Column="1" Grid.Row="3" Text="{Binding Path=PetName}" />
```

Finally, add data to the ComboBox. In MainWindow.xaml.cs, create a new list of Car records, and set the ItemsSource for the ComboBox to the list. Also, add the using statement for the Notifications.Models namespace.

```
using WpfNotifications.Models;
//omitted for brevity
public partial class MainWindow : Window
{
    readonly IList<Car> _cars = new List<Car>();
    public MainWindow()
    {
        InitializeComponent();
        _cars.Add(new Car {Id = 1, Color = "Blue", Make = "Chevy", PetName = "Kit"});
        _cars.Add(new Car {Id = 2, Color = "Red", Make = "Ford", PetName = "Red Rider"});
        cboCars.ItemsSource = _cars;
    }
}
```

Run the app. You'll see that the vehicle selector has two cars to choose from. Choose one of them, and the text boxes will be automatically populated with the vehicle detail. Change the color of one of the vehicles, select the other vehicle, and then go back to the vehicle you edited. You will see the new color is indeed still attached to the vehicle. This isn't anything remarkable; you've seen the power of XAML data binding in previous examples.

## Programmatically Changing the Vehicle Data

While the previous example works as expected, if the data is changed programmatically, the UI will *not* reflect the changes unless you program the app to refresh the data. To demonstrate this, add an event handler for the `btnChangeColor` Button, like so:

```
<Button x:Name="btnChangeColor" Content="Change Color" Margin="5,0,5,0"
        Padding="4, 2" Click="BtnChangeColor_OnClick"/>
```

In the `BtnChangeColor_Click()` event handler, use the `SelectedItem` property of the `ComboBox` to locate the selected record from the cars list, and change the color to Pink. The code is listed here:

```
private void BtnChangeColor_OnClick(object sender, RoutedEventArgs e)
{
    _cars.First(x => x.Id == ((Car)cboCars.SelectedItem)?.Id).Color = "Pink";
}
```

Run the app, select a vehicle, and click the Change Color button. Nothing changes visibly. Select the other vehicle and go back to your originally selected vehicle. Now you will see the updated value. This is not a very good experience for the user!

Now add an event handler to the `btnAddCar` button, like this:

```
<Button x:Name="btnAddCar" Content="Add Car" Margin="5,0,5,0" Padding="4, 2"
        Click="BtnAddCar_OnClick" />
```

In the `BtnAddCar_Click` event handler, add a new record to the Car list.

```
private void BtnAddCar_Click(object sender, RoutedEventArgs e)
{
    var maxCount = _cars?.Max(x => x.Id) ?? 0;
    _cars?.Add(new Car { Id=++maxCount,Color="Yellow",Make="VW",PetName="Birdie"});
}
```

Run the app, click the Add Car button, and examine the contents of the `ComboBox`. Even though you know there are three cars in the list, only two are displayed! To correct both of these problems, you will convert the Car class to an observable model and use an observable collection to hold all of the Car instances.

## Observable Models

The problem of data changing on a property of your model and not being displayed in the UI is resolved by implementing the `INotifyPropertyChanged` interface on your `Car` model class. The `INotifyPropertyChanged` interface contains a single event: `PropertyChangedEvent`. The XAML binding engine listens for this event for each bound property on classes that implement the `INotifyPropertyChanged` interface. The interface is shown here:

```
public interface INotifyPropertyChanged
{
    event PropertyChangedEventHandler PropertyChanged;
}
```

Add the following using statements to the `Car.cs` class:

```
using System.ComponentModel;
using System.Runtime.CompilerServices;
```

Next, implement the `INotifyPropertyChanged` interface on the class, as follows:

```
public class Car : INotifyPropertyChanged
{
    //Omitted for brevity
    public event PropertyChangedEventHandler PropertyChanged;
}
```

The `PropertyChanged` event takes an object reference and a new instance of the `PropertyChangedEventArgs` class, like in this example:

```
PropertyChanged?.Invoke(this,
    new PropertyChangedEventArgs("Model"));
```

The first parameter is the object instance that is raising the event. The `PropertyChangedEventArgs` constructor takes a string that indicates the property that was changed and needs to be updated. When the event is raised, the binding engine looks for any controls bound to the named property on that instance. If you pass `String.Empty` into the `PropertyChangedEventArgs`, all of the bound properties of the instance are updated.

You control which properties are enlisted in the automatic updates. Only those properties that raise the `PropertyChanged` event in the setter will be automatically updated. This is usually all of the properties on your model classes, but you have the option of omitting certain properties based on your application's requirements. Instead of raising the event directly in the setter for each of the enlisted properties, a common pattern is to create a helper method (typically named `OnPropertyChanged`) that raises the event on behalf of the properties, usually in a base class for your models. Add the following method and code into the `Car.cs` class:

```
protected void OnPropertyChanged([CallerMemberName] string propertyName = "")
{
    PropertyChanged?.Invoke(this,
        new PropertyChangedEventArgs(propertyName));
}
```

Next, update each of the automatic properties in the `Car` class to have a full getter and setter with a backing field. When the value is changed, call the `OnPropertyChanged` helper method. Here is the `Id` property updated:

```
private int _id;
public int Id
{
    get => _id;
    set
    {
        if (value == _id) return;
        _id = value;
        OnPropertyChanged();
    }
}
```

Make sure you do the same for all of the properties in the class and then run the app again. Select a vehicle and click the Change Color button. You will immediately see the change show up in the UI. First problem solved!

## Using nameof

A feature added in C# 6 is the `nameof` operator, which provides the string name of the item passed into the `nameof` method. You can use this in the calls to `OnPropertyChanged()` in your setters, like this:

```
public string Color
{
    get { return _color; }
    set
    {
        if (value == _color) return;
        _color = value;
        OnPropertyChanged(nameof(Color));
    }
}
```

Note that you don't have to remove the `CallerMemberName` attribute from the `OnPropertyChanged` when you use the `nameof` method (although it becomes unnecessary). In the end, whether you use the `nameof` method or the `CallerMemberName` attribute comes down to a matter of personal choice.

## Observable Collections

The next problem to resolve is updating the UI when the contents of a collection changes. This is done by implementing the `INotifyCollectionChanged` interface. Like the `INotifyPropertyChanged` interface, this interface exposes one event, the `CollectionChanged` event. Unlike the `INotifyPropertyChanged` event, implementing this interface by hand is more than just calling a method in the setter. You need to create a full `List` implementation and raise the `CollectionChanged` event any time your list changes.



## Using the ObservableCollection Class

Fortunately, there is a much easier way than creating your own collection class. The `ObservableCollection<T>` class implements `INotifyCollectionChanged`, `INotifyPropertyChanged`, and `Collection<T>`, and it is part of the .NET Core Framework. No extra work! To see this, add a `using` statement for `System.Collections.ObjectModel` and then update the private field for `_cars` to the following:

```
private readonly IList<Car> _cars =
    new ObservableCollection<Car>();
```

Run the app again, and click the Add Car button. You will see the new records appear appropriately.

## Implementing a Dirty Flag

Another advantage of observable models is the ability to track state changes. Dirty tracking (tracking when one or more of an object's values have changed) with WPF is fairly trivial. Add a `bool` property named `IsChanged` to the `Car` class. Make sure to call `OnPropertyChanged()` just like the other properties in the `Car` class.

```
private bool _isChanged;
public bool IsChanged {
    get => _isChanged;
    set
    {
        if (value == _isChanged) return;
        _isChanged = value;
        OnPropertyChanged();
    }
}
```

You need to set the `IsChanged` property to `true` in the `OnPropertyChanged()` method. You also need to make sure you aren't setting `IsChanged` to `true` when `IsChanged` is updated, or you will hit a stack overflow exception! Update the `OnPropertyChanged` method to the following (which uses the `nameof` method discussed earlier):

```
protected virtual void OnPropertyChanged(
    [CallerMemberName] string propertyName = "")
{
    if (propertyName != nameof(IsChanged))
    {
        IsChanged = true;
    }
    PropertyChanged?.Invoke(this,
        new PropertyChangedEventArgs(propertyName));
}
```

Open `MainWindow.xaml`, and add an additional `RowDefinition` to the `DetailsGrid`. Add the following to the end of the `Grid`, which contains a `Label` and a `CheckBox`, bound to the `IsChanged` property, as follows:

```
<Label Grid.Column="0" Grid.Row="5" Content="Is Changed"/>
<CheckBox Grid.Column="1" Grid.Row="5" VerticalAlignment="Center"
    Margin="10,0,0,0" IsEnabled="False" IsChecked="{Binding Path=IsChanged}" />
```

If you were to run the app now, you would see that every single record shows up as changed, even though you haven't changed anything! This is because object creation sets property values, and setting any values calls `OnPropertyChanged()`. This sets the object's `IsChanged` property. To correct this, set the `IsChanged` property to `false` as the last property in the object initialization code. Open `MainWindow.xaml.cs` and change the code that creates the list to the following:

```
_cars.Add(
    new Car {Id = 1, Color = "Blue", Make = "Chevy", PetName = "Kit", IsChanged = false});
_cars.Add(
    new Car {Id = 2, Color = "Red", Make = "Ford", PetName = "Red Rider", IsChanged = false});
```

Run the app again, select a vehicle, and click the `Change Color` button. You will see the check box get selected along with the updated color.

## Updating the Source Through UI Interaction

You might notice that if you type text into the UI, the `Is Changed` check box doesn't actually get selected until you tab out of the control being edited. This is because of the `UpdateSourceTrigger` property on the `TextBox` bindings. The `UpdateSourceTrigger` determines what event (such as changing the value, tabbing out, etc.) causes the UI to update the underlying data. There are four options, as shown in [Table 28-1](#).

**Table 28-1.** *UpdateSourceTrigger Values*

Member	Meaning in Life
Default	Sets to the default for the control (e.g., <code>LostFocus</code> for <code>TextBox</code> controls).
Explicit	Updates the source object only when the <code>UpdateSource</code> method is called.
LostFocus	Updates when the control loses focus. This is the default for <code>TextBox</code> controls.
PropertyChanged	Updates as soon as the property changes. This is the default for <code>CheckBox</code> controls.

The default source trigger for a `TextBox` is the `LostFocus` event. Change this to `PropertyChanged` by updating the binding for the `Color` `TextBox` to the following XAML:

```
<TextBox Grid.Column="1" Grid.Row="2" Text="{Binding Path=Color, UpdateSourceTrigger=
PropertyChanged}" />
```

Now, when you run the app and start typing into the `Color` text box, the check box is immediately selected. You might ask why the default is set to `LostFocus` for `TextBox` controls. Any validation (covered in a moment) for a model fires in conjunction with the `UpdateSourceTrigger`. For a `TextBox`, this would then potentially cause errors continually flashing until the user entered the correct values. For example, if the validation rules don't allow less than five characters in a `TextBox`, the error would show on each keystroke until the user got five or more entered. In those cases, it's best to wait for the user to tab out of the `TextBox` (after completing the change to the text) to update the source.

## Wrapping Up Notifications and Observables

Using `INotifyPropertyChanged` on your models and `ObservableCollections` classes for your lists improves the user experience by keeping the data and the UI in sync. While neither interface is complicated, they do require updates to your code. Fortunately, Microsoft has included the `ObservableCollection` class to handle all of the plumbing to create observable collections. Just as fortunate is the update to the Fody project to add `INotifyPropertyChanged` functionality automatically. With these two tools in hand, there isn't any reason to not implement observables in your WPF applications.

## WPF Validations

Now that you've implemented `INotifyPropertyChanged` and are using an `ObservableCollection`, it's time to add validations to your application. Applications need to validate user input and provide feedback to the user when the data entered is incorrect. This section covers the most common validation mechanisms for modern WPF applications, but these are still just a portion of the capabilities built into WPF.

Validation occurs when a data binding attempts to update the data source. In addition to built-in validations, such as exceptions in a property's setter, you can create custom validation rules. If *any* validation rule (built-in or custom) fails, the `Validation` class, discussed shortly, comes into play.

---

**Note** For each of the sections in this chapter, you can continue working in the same project from the previous section, or you can create a copy of the project for each new section. In the repo for this chapter, each section is a different project.

---

## Updating the Sample for the Validation Examples

In the repo for this chapter, the new project (copied from the previous example) is called `WpfValidations`. If you are using the same project from the previous section, you just need to make note of the namespace changes when copying code into your project from the examples listed in this section.

## The Validation Class

Before adding validations to your project, it's important to understand the `Validation` class. This class is part of the validation framework, and it provides methods and attached properties that can be used to display validation results. There are three main properties of the `Validation` class commonly used when handling validation errors (shown in Table 28-2). You will use each of these through the rest of this section.

**Table 28-2.** *Key Members of the Validation Class*

Member	Meaning in Life
<code>HasError</code>	Attached property indicating that a validation rule failed somewhere in the process
<code>Errors</code>	Collection of all active <code>ValidationError</code> objects
<code>ErrorTemplate</code>	Control template that becomes visible and adorns the bound element when <code>HasError</code> is set to true

## Validation Options

As mentioned, XAML technologies have several mechanisms for incorporating validation logic into your application. You will examine three of the most commonly used validation choices in the next sections.

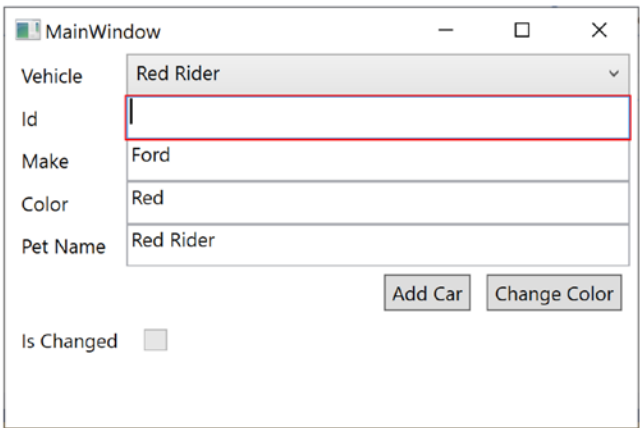
## Notify on Exceptions

While exceptions should not be used to enforce business logic, exceptions can and do happen, and they should be handled appropriately. In case they aren't handled in code, the user should receive visual feedback of the problem. An important change from WinForms is that WPF binding exceptions are not, by default, propagated to the user as exceptions. They are, however, visually indicated, using an adorning (visual layer that resides on top of your controls).

To test this, run the app, select a record from the ComboBox, and clear out the Id value. Since the Id property is defined as an `int` (not a nullable `int`), a numeric value is required. When you tab out of the Id field, an empty string is sent to the Id property by the binding framework, and since an empty string can't be converted to an `int`, an exception is thrown in the setter. Normally, an unhandled exception would generate a message box to the user, but in this case, nothing like that happened. If you look in the Debug portion of the Output window, you will see the following:

```
System.Windows.Data Error: 7 : ConvertBack cannot convert value '' (type 'String').  
BindingExpression:Path=Id; DataItem='Car' (HashCode=52579650); target element is  
'TextBox' (Name=''); target property is 'Text' (type 'String') FormatException:'System.  
FormatException: Input string was not in a correct format.
```

Visual display of the exception is a thin red box around the control, as shown in Figure 28-2.



**Figure 28-2.** The default error template

The red box is the `ErrorTemplate` property of the `Validation` object and acts as an adorning for the bound control. While the default error adorning shows that there is indeed an error, there isn't any indication as to *what* is wrong. The good news is that the `ErrorTemplate` is completely customizable, as you will see later in this chapter.

## IDataErrorInfo

The `IDataErrorInfo` interface provides a mechanism for you to add custom validations to your model classes. This interface is added directly to your model (or view model) classes, and the validation code is placed inside your model classes (preferably in partial classes). This centralizes validation code in your project, in direct contrast to WinForms projects, where validation was typically done in the UI itself.

The `IDataErrorInfo` interface, shown here, contains two properties: an indexer and a string property named `Error`. Note that the WPF binding engine doesn't use the `Error` property.

```
public interface IDataErrorInfo
{
    string this[string columnName] { get; }
    string Error { get; }
}
```

You will be adding the `Car` partial class shortly, but first you need to update the `Car.cs` class and mark it as partial. Next, add another file to the `Models` directory named `CarPartial.cs`. Rename this class `Car`, make sure the class is marked as partial, and add the `IDataErrorInfo` interface. Finally, implement the API for the interface. The initial code is listed here:

```
public partial class Car : IDataErrorInfo
{
    public string this[string columnName] => string.Empty;
    public string Error { get; }
}
```

For a bound control to opt in to the `IDataErrorInfo` interface, it must add `ValidatesOnDataErrors` to the binding expression. Update the binding expression for the `Make` text box to the following (and update the rest of the binding statements in the same way):

```
<TextBox Grid.Column="1" Grid.Row="1" Text="{Binding Path=Make, ValidatesOnDataErrors=True}" />
```

Once this update is made to the binding statements, the indexer on the model gets called each time the `PropertyChanged` event is raised. The property name from the event is used as the `columnName` parameter in the indexer. If the indexer returns `string.Empty`, the framework assumes that all validations passed, and no error condition exists. If the indexer returns anything but `string.Empty`, an error is presumed to exist on the property for that object instance, and each control that is bound to the property being validated on this specific instance of the class is considered to have an error, the `HasError` property of the `Validation` object is set to true, and the `ErrorTemplate` adorner is activated for the controls effected.

Next, you will add some simple validation logic to the indexer in `CarPartial.cs`. The validation rules are simple:

- If `Make` equals `ModelT`, set the error equal to "Too Old".
- If `Make` equals `Chevy` and `Color` equals `Pink`, set the error equal to \$"{Make}'s don't come in {Color}".

Start by adding a `switch` statement for each of the properties. To avoid using magic strings in the case statements, you will again use the `nameof` method. If the code falls through the `switch` statement, return `string.Empty`. Next, add the validation rules. In the proper case statements, add a check of the property value based on the rules listed earlier. In the case statement for the `Make` property, first check to make sure the value isn't `ModelT`. If it is, return the error. If that passes, the next line will call into a helper method that

returns an error if the second rule is violated, or it will return `string.Empty` if it is not. In the case statement for the `Color` property, also call the helper method. The code is as follows:

```
public string this[string columnName]
{
    get
    {
        switch (columnName)
        {
            case nameof(Id):
                break;
            case nameof(Make):
                return Make == "ModelT"
                    ? "Too Old"
                    : CheckMakeAndColor();
            case nameof(Color):
                return CheckMakeAndColor();
            case nameof(PetName):
                break;
        }
        return string.Empty;
    }
}

internal string CheckMakeAndColor()
{
    if (Make == "Chevy" && Color == "Pink")
    {
        return $"{Make}'s don't come in {Color}";
    }
    return string.Empty;
}
```

Run the app, select the Red Rider vehicle (the Ford), and change the Make to ModelT. Once you tab out of the field, the red error decorator appears. Now select Kit (which is a Chevy) from the drop-down, and click the Change Color button to change the color to Pink. Immediately the red error adorning appears on the Color field but doesn't appear on the Make text box. Now, change Make to Ford, tab out of the text box, and note that the red adorning does *not* disappear!

This is because the indexer runs only when the `PropertyChanged` event is fired for a property. As discussed in the “WPF Binding Notification System”, the `PropertyChanged` event fires when the source object's property changes, and this happens either through code (such as clicking the Change Color button) or through user interaction (the timing of this is controlled through the `UpdateSourceTrigger`). When you changed the color, the Make property did not change, so the event did not fire for the Make property. Since the event didn't fire, the indexer did not get called, so the validation for the Make property didn't run.

There are two ways to fix this. The first is to change `PropertyChangedEventArgs` to update every bound property by passing in `string.Empty` instead of a field name. As discussed, this causes the binding engine to update *every* property on that instance. Update the `OnPropertyChanged` method in the `Car.cs` class like this:

```
protected virtual void OnPropertyChanged([CallerMemberName] string propertyName = "")
{
    if (propertyName != nameof(IsChanged))
    {
        IsChanged = true;
    }
    //PropertyChanged?.Invoke(this, new PropertyChangedEventArgs(propertyName));
    PropertyChanged?.Invoke(this,
        new PropertyChangedEventArgs(string.Empty));
}
```

Now, when you run the same test, you see that both the Make and Color text boxes are adorned with the error template when one of them is updated. So, why not always raise the event in this manner? It's largely a matter of performance. It's *possible* that refreshing every property on an object could hamper performance. Of course, there's no way to know without testing, and your mileage may (and probably will) vary.

The other solution is to raise the `PropertyChanged` event for the other dependent field(s) when one changes. The downside to using this mechanism is that you (or other developers who support your app) must know that the Make and Color properties are related through the validation code.

## INotifyDataErrorInfo

The `INotifyDataErrorInfo` interface introduced in .NET 4.5 builds on the `IDataErrorInfo` interface and adds additional capabilities for validation. Of course, with additional power comes additional work! In a drastic shift from prior validation techniques that you had to specifically opt into, the `ValidatesOnNotifyDataErrors` binding property defaults to `true`, so adding the property to your binding statements is optional.

The `INotifyDataErrorInfo` interface is extremely small but does take a fair amount of plumbing code to make it effective, as you will see shortly. The interface is shown here:

```
public interface INotifyDataErrorInfo
{
    bool HasErrors { get; }
    event EventHandler<DataErrorsChangedEventArgs>
        ErrorsChanged;
    IEnumerable GetErrors(string propertyName);
}
```

The `HasErrors` property is used by the binding engine to determine whether there are *any* errors on any of the instance's properties. If the `GetErrors()` method is called with a null or empty string for the `propertyName` parameter, it returns all errors that exist in the instance. If a `propertyName` is passed into the method, only the errors for that particular property are returned. The `ErrorsChanged` event (like the `PropertyChanged` and `CollectionChanged` events) notifies the binding engine to update the UI for the current list of errors.

## Implement the Supporting Code

When implementing `INotifyDataErrorInfo`, most of the code is usually pushed into a base model class so it needs be written only once. Start by replacing `IDataErrorInfo` with `INotifyDataErrorInfo` in the `CarPartial.cs` class and add the interface members (you can leave the code from `IDataErrorInfo` in the class; you will be updating this later):

```
public partial class Car: INotifyDataErrorInfo, IDataErrorInfo
{
    ...
    public IEnumerable GetErrors(string propertyName)
    {
        throw new NotImplementedException();
    }

    public bool HasErrors { get; }
    public event
        EventHandler<DataErrorsChangedEventArgs> ErrorsChanged;
}
```

Next, add a `Dictionary<string, List<string>>` that will hold any errors grouped by property name. You will also need to add a `using` statement for `System.Collections.Generic`. Both are shown here:

```
using System.Collections.Generic;
private readonly Dictionary<string, List<string>> _errors
    = new Dictionary<string, List<string>>();
```

The `HasErrors` property should return `true` if there are *any* errors in the dictionary. This is easily accomplished like this:

```
public bool HasErrors => _errors.Any();
```

Next, create a helper method to raise the `ErrorsChanged` event (just like raising the `PropertyChanged` event) like this:

```
private void OnErrorsChanged(string propertyName)
{
    ErrorsChanged?.Invoke(this,
        new DataErrorsChangedEventArgs(propertyName));
}
```

As mentioned earlier, the `GetErrors()` method should return any and all errors in the dictionary if the parameter is empty or null. If a `propertyName` value is passed in, it will return any errors found for that property. If the parameter doesn't match (or there aren't any errors for a property), then the method will return null.

```
public IEnumerable GetErrors(string propertyName)
{
    if (string.IsNullOrEmpty(propertyName))
    {
        return _errors.Values;
    }
}
```



```

return _errors.ContainsKey(propertyName)
    ? _errors[propertyName]
    : null;
}

```

The final set of helpers will add one or more errors for a property or clear all of the errors for a property (or all properties). Any time the dictionary changes, remember to call the `OnErrorsChanged()` helper method.

```

private void AddError(string propertyName, string error)
{
    AddErrors(propertyName, new List<string> { error });
}
private void AddErrors(
    string propertyName, IList<string> errors)
{
    if (errors == null || !errors.Any())
    {
        return;
    }
    var changed = false;
    if (!_errors.ContainsKey(propertyName))
    {
        _errors.Add(propertyName, new List<string>());
        changed = true;
    }
    foreach (var err in errors)
    {
        if (_errors[propertyName].Contains(err)) continue;
        _errors[propertyName].Add(err);
        changed = true;
    }
    if (changed)
    {
        OnErrorsChanged(propertyName);
    }
}
protected void ClearErrors(string propertyName = "")
{
    if (string.IsNullOrEmpty(propertyName))
    {
        _errors.Clear();
    }
    else
    {
        _errors.Remove(propertyName);
    }
    OnErrorsChanged(propertyName);
}

```

Now the question is “how is this code activated?” The binding engine listens for the `ErrorsChanged` event and will update the UI if there is a change in the errors collection for a binding statement. But the validation code still needs a trigger to execute. There are two mechanisms for this, and they will be discussed next.

## Use `INotifyDataErrorInfo` for Validations

One place to check for errors is in the property setters, like the following example, simplified to just check for the `ModelT` validation:

```
public string Make
{
    get { return _make; }
    set
    {
        if (value == _make) return;
        _make = value;
        if (Make == "ModelT")
        {
            AddError(nameof(Make), "Too Old");
        }
        else
        {
            ClearErrors(nameof(Make));
        }
        OnPropertyChanged(nameof(Make));
        OnPropertyChanged(nameof(Color));
    }
}
```

The main issue with this approach is you have to combine validation logic with property setters, making the code harder to read and support.

## Combine `IDataErrorInfo` with `INotifyDataErrorInfo` for Validations

You saw in the previous section that `IDataErrorInfo` can be added to a partial class, which means you don’t have to update your setters. You also saw that the indexer automatically gets called when `PropertyChanged` is raised on a property. Combining `IDataErrorInfo` and `INotifyDataErrorInfo` provides you with the additional features for validations from `INotifyDataErrorInfo` and with the separation from the setters provided by `IDataErrorInfo`.

The purpose of using `IDataErrorInfo` is not to run validations but to make sure your validation code that leverages `INotifyDataErrorInfo` gets called every time `PropertyChanged` is raised on your object. Since you aren’t using `IDataErrorInfo` for validation, always return `string.Empty` from the indexer. Update the indexer and the `CheckMakeAndColor()` helper method to the following code:

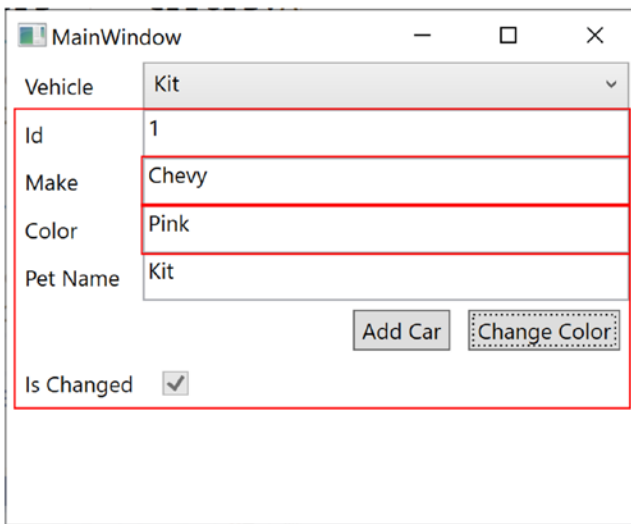
```
public string this[string columnName]
{
    get
    {
        bool hasError = false;
```

```

switch (columnName)
{
    case nameof(Id):
        break;
    case nameof(Make):
        hasError = CheckMakeAndColor();
        if (Make == "ModelT")
        {
            AddError(nameof(Make), "Too Old");
            hasError = true;
        }
        if (!hasError)
        {
            //This is not perfect logic, just illustrative of the pattern
            ClearErrors(nameof(Make));
            ClearErrors(nameof(Color));
        }
        break;
    case nameof(Color):
        hasError = CheckMakeAndColor();
        if (!hasError)
        {
            ClearErrors(nameof(Make));
            ClearErrors(nameof(Color));
        }
        break;
    case nameof(PetName):
        break;
}
return string.Empty;
}
}
internal bool CheckMakeAndColor()
{
    if (Make == "Chevy" && Color == "Pink")
    {
        AddError(nameof(Make), $"{Make}'s don't come in {Color}");
        AddError(nameof(Color),
            $"{Make}'s don't come in {Color}");
        return true;
    }
    return false;
}

```

Run the app, select Chevy, and change the color to Pink. In addition to the red adorners around the Make and Model text boxes, you will also see a red box adorning the entire grid that holds the Car details fields (shown in Figure 28-3).



**Figure 28-3.** The updated error adorner

This is another advantage of using `INotifyDataErrorInfo`. In addition to the controls in error, the control defining the data context also gets adorned with the error template.

## Show All Errors

The `Errors` property on the `Validation` class returns all the validation errors on a particular object in the form of `ValidationError` objects. Each `ValidationError` object has an `ErrorContent` property that contains the list of error messages for the property. This means the error messages you want to display are in this list within a list. To display them properly, you need to create a `ListBox` that holds a `ListBox` to display the data. It sounds a bit recursive, but it will make sense once you see it.

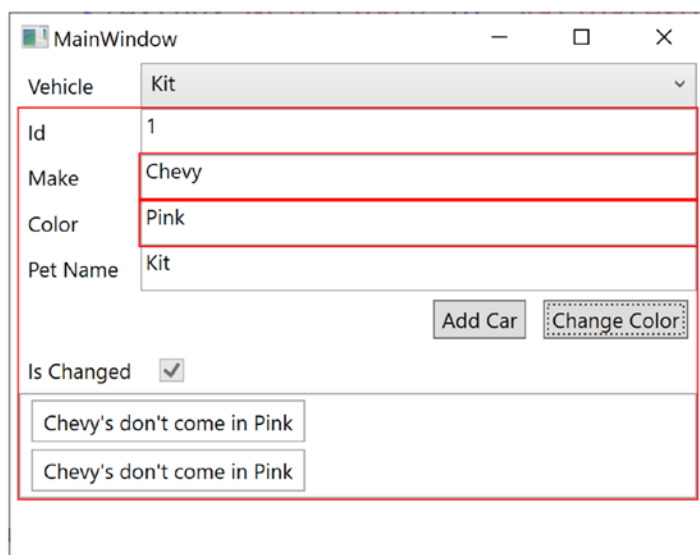
Start by adding another row to the `DetailsGrid` and make sure the `Height` of the Window is at least 300. Add a `ListBox` in the last row, and bind the `ItemsSource` to the `DetailsGrid`, using `Validation.Errors` for the path, as follows:

```
<ListBox Grid.Row="6" Grid.Column="0" Grid.ColumnSpan="2"
  ItemsSource="{Binding ElementName=DetailsGrid, Path=(Validation.Errors)}">
</ListBox>
```

Add a `DataTemplate` to the `ListBox`, and in the `DataTemplate`, add a `ListBox` that is bound to the `ErrorContent` property. The data context for each `ListBoxItem` in this case is a `ValidationError` object, so you don't need to set the data context, just the path. Set the binding path to `ErrorContent`, like this:

```
<ListBox.ItemTemplate>
  <DataTemplate>
    <ListBox ItemsSource="{Binding Path=ErrorContent}" />
  </DataTemplate>
</ListBox.ItemTemplate>
```

Run the app, select `Chevy`, and set the color to `Pink`. You will see the errors displayed in [Figure 28-4](#).



**Figure 28-4.** Showing the errors collection

This just scratches the surface of what you can do with validations and with displaying the errors generated, but it should have you well on your way to developing informative UIs that improve the user experience.

## Move the Support Code to a Base Class

As you probably noticed, there is a lot of code now in the `CarPartial.cs` class. Since this example has only one model class, this isn't terrible. But, as you add models to a real application, you don't want to have to add all of that plumbing into each partial class for your models. The best thing to do is to push all of that supporting code down to a base class. You will do that now.

Add a new class file to the `Models` folder named `BaseEntity.cs`. Add using statements for `System.Collections` and `System.ComponentModel`. Make the class public, and add the `INotifyDataErrorInfo` interface, like this:

```
using System;
using System.Collections;
using System.Collections.Generic;
using System.ComponentModel;
using System.Linq;

namespace Validations.Models
{
    public class BaseEntity : INotifyDataErrorInfo
    }
}
```

Move all of the code from `CarPartial.cs` that relates to `INotifyDataErrorInfo` into the new base class. Any private methods and variables need to be made protected. Next, remove the `INotifyDataErrorInfo` interface from the `CarPartial.cs` class, and add `BaseEntity` as a base class, as follows:

```
public partial class Car : BaseEntity, IDataErrorInfo
{
    //removed for brevity
}
```

Now, any additional model classes you create will inherit all of the `INotifyDataErrorInfo` plumbing code.

## Leverage Data Annotations with WPF

WPF can leverage data annotations as well for UI validation. Let's add some data annotations to the `Car` model.

### Add Data Annotations to the Model

Open up `Car.cs` and add a using statement for `System.ComponentModel.DataAnnotations`. Add the `[Required]` and `[StringLength(50)]` attributes to `Make`, `Color`, and `PetName`. The `Required` attribute adds a validation rule that the property must not be null (admittedly, this is redundant for the `Id` property since it is not a nullable `int`). The `StringLength(50)` attribute adds a validation rule that the value of the property cannot be longer than 50 characters.

### Check for Data Annotation–Based Validation Errors

In WPF you have to programmatically check for data annotation–based validation errors. Two key classes for annotation–based validations are the `ValidationContext` and `Validator` classes. The `ValidationContext` class provides a context for checking a class for validation errors. The `Validator` class allows you to check an object for attribute–based errors within a `ValidationContext`.

Open `BaseEntity.cs`, and add the following using statements:

```
using System.ComponentModel;
using System.ComponentModel.DataAnnotations;
```

Next, create a new method named `GetErrorsFromAnnotations`. This method is generic, takes a string property name and a value of type `T` as the parameters, and returns a string array. Make sure the method is marked as protected. The signature is listed here:

```
protected string[] GetErrorsFromAnnotations<T>(
    string propertyName, T value)
{}
```

In the method, create a `List<ValidationResult>` variable that will hold the results of validation checks and create a `ValidationContext` scoped to the property name passed into the method. When you have those two items in place, call `Validate.TryValidateProperty`, which returns a `bool`. If everything

passes (in regard to data annotation validations), it returns true. If not, it returns false and populates the `List<ValidationResult>` with the errors. The complete code is shown here:

```
protected string[] GetErrorsFromAnnotations<T>(
    string propertyName, T value)
{
    var results = new List<ValidationResult>();
    var vc = new ValidationContext(this, null, null)
        { MemberName = propertyName };
    var isValid = Validator.TryValidateProperty(
        value, vc, results);
    return (isValid)
        ? null
        : Array.ConvertAll(
            results.ToArray(), o => o.ErrorMessage);
}
```

Now you can update the indexer method in `CarPartial.cs` to check for any errors based on data annotations. If any errors are found, add them to the errors collection supporting `INotifyDataErrorInfo`. This enables us to clean up the error handling. In the start of the indexer method, clear the errors for the column. Then process the validations and finally the custom logic for the entity. The updated indexer code is shown here:

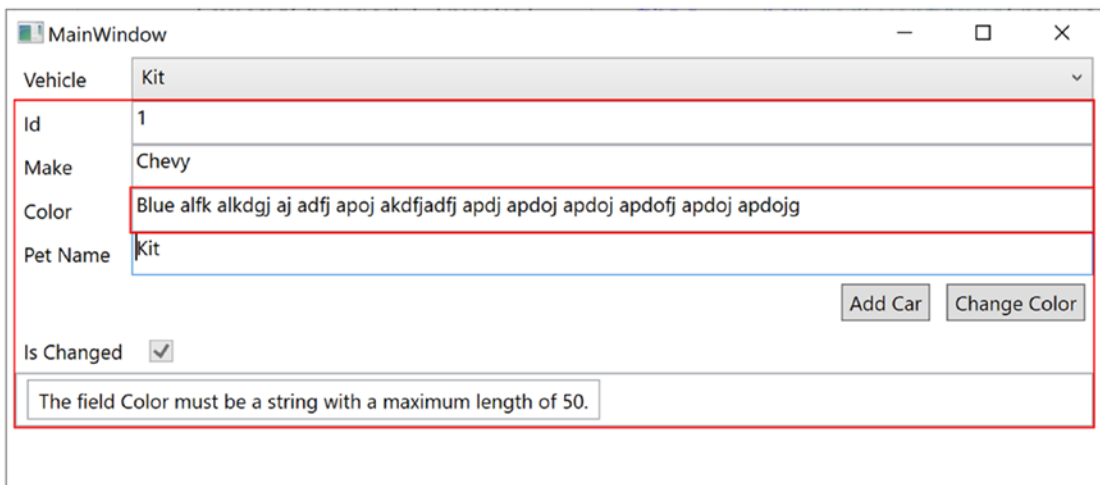
```
public string this[string columnName]
{
    get
    {
        ClearErrors(columnName);
        bool hasError = false;
        var errorsFromAnnotations =
            GetErrorsFromAnnotations(columnName,
                typeof(Car)
                .GetProperty(columnName)?.GetValue(this,null));
        if (errorsFromAnnotations != null)
        {
            AddErrors(columnName, errorsFromAnnotations);
            hasError = true;
        }
        switch (columnName)
        {
            case nameof(Id):
                break;
            case nameof(Make):
                hasError = CheckMakeAndColor();
                if (Make == "ModelT")
                {
                    AddError(nameof(Make), "Too Old");
                    hasError = true;
                }
                break;
        }
    }
}
```

```

        case nameof(Color):
            hasError = CheckMakeAndColor();
            break;
        case nameof(PetName):
            break;
    }
    return string.Empty;
}
}

```

Run the app, select one of the vehicles, and add text for the color that is longer than 50 characters. When you cross the 50-character threshold, the `StringLength` data annotation creates a validation error, and it is reported to the user, as shown in Figure 28-5.



**Figure 28-5.** Validating the required data annotation

## Customizing the ErrorTemplate

The final topic is to create a style that will be applied when a control is in error and also update the `ErrorTemplate` to display more meaningful error information. As you learned in Chapter 27, controls are customizable through styles and control templates.

Start by adding a new style in the `Windows.Resources` section of `MainWindow.xaml` with a target type of `TextBox`. Next, add a trigger on the style that sets properties when the `Validation.HasError` property is set to `true`. The properties and the values to set are `Background` (Pink), `Foreground` (Black), and `ToolTip` to the `ErrorContent`. The `Background` and `Foreground` setters are nothing new, but the syntax for setting the `ToolTip` needs some explanation. The binding points back to the control that this style is applied to, in this case, the `TextBox`. The path is the first `ErrorContent` value of the `Validation.Errors` collection. The markup is as follows:

```

<Window.Resources>
    <Style TargetType="{x:Type TextBox}">
        <Style.Triggers>

```

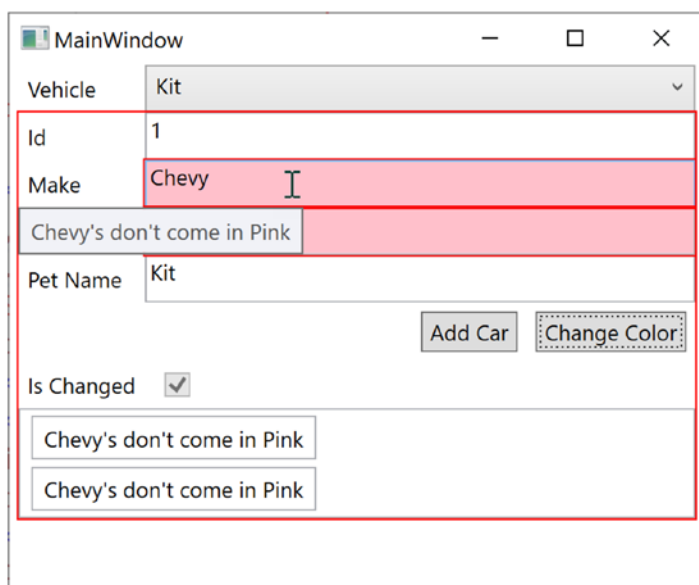


```

<Trigger Property="Validation.HasError" Value="true">
  <Setter Property="Background" Value="Pink" />
  <Setter Property="Foreground" Value="Black" />
  <Setter Property="ToolTip"
    Value="{Binding RelativeSource={RelativeSource Self},
      Path=(Validation.Errors)[0].ErrorContent}"/>
</Trigger>
</Style.Triggers>
</Style>
</Window.Resources>

```

Run the app and create an error condition. The result will be similar to Figure 28-6, complete with tooltip showing the error message.



**Figure 28-6.** Showing a custom *ErrorTemplate*

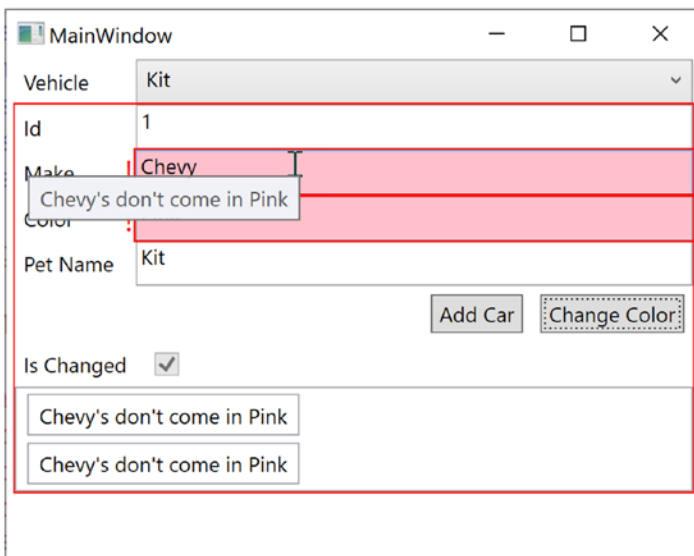
The previous style changed the appearance of any `TextBox` that has an error condition. Next, you will create a custom control template to update the `ErrorTemplate` of the `Validation` class to show a red exclamation mark and set the tooltips for the exclamation mark. The `ErrorTemplate` is an *adornner*, which sits on top of the control. While the style just created updates the control itself, the `ErrorTemplate` will sit on top of the control.

Place a setter immediately after the `Style.Triggers` closing tag within the style you just created. You will be creating a control template that consists of a `TextBlock` (to show the exclamation mark) and a `BorderBrush` to surround the `TextBox` that contains the error(s). There is a special tag in XAML for the control that is being adorned with the `ErrorTemplate` named `AdornedElementPlaceholder`. By adding a name to this control, you can access the errors that are associated with the control. In this example, you want

to access the `Validation.Errors` property so you can get the `ErrorContent` (just like you did in the `Style.Trigger`). Here is the full markup for the setter:

```
<Setter Property="Validation.ErrorTemplate">
  <Setter.Value>
    <ControlTemplate>
      <DockPanel LastChildFill="True">
        <TextBlock Foreground="Red" FontSize="20" Text="!"
          ToolTip="{Binding ElementName=controlWithError,
            Path=AdornedElement.(Validation.Errors)[0].ErrorContent}"/>
        <Border BorderBrush="Red" BorderThickness="1">
          <AdornedElementPlaceholder Name="controlWithError" />
        </Border>
      </DockPanel>
    </ControlTemplate>
  </Setter.Value>
</Setter>
```

Run the app and create an error condition. The result will be similar to Figure 28-7.



**Figure 28-7.** Showing a custom `ErrorTemplate`

## Wrapping Up Validations

This completes your look at validation methods within WPF. Of course, there is much more that you can do. For more information, consult the WPF documentation.

## Creating Custom Commands

As with the validations sections, you can continue working in the same project or create a new one and copy all of the code over to it. I will create a new project named `WpfCommands`. If you are using the same project, be sure to pay attention to the namespaces in the code samples in this section and adjust them as needed.

As you learned in Chapter 25, commands are an integral part of WPF. Commands can be hooked up to WPF controls (such as `Button` and `MenuItem` controls) to handle user events, such as the `Click` event. Instead of creating an event handler directly and adding the code directly into the code-behind file, the `Execute` method of the command is executed when the click event fires. The `CanExecute()` method is used to enable or disable the control based on custom code. In addition to the built-in commands you used in Chapter 25, you can create your own custom commands by implementing the `ICommand` interface. By using commands instead of event handlers, you gain the benefit of encapsulating application code, as well as automatically enabling and disabling controls based on business logic.

## Implementing the ICommand Interface

As a quick review from Chapter 25, the `ICommand` interface is listed here:

```
public interface ICommand
{
    event EventHandler CanExecuteChanged;
    bool CanExecute(object parameter);
    void Execute(object parameter);
}
```

## Adding the ChangeColorCommand

The event handlers for your `Button` controls will be replaced with commands, starting with the `Change Color` button. Start by adding a new folder (named `Cmds`) in your project. Add a new class named `ChangeColorCommand.cs`. Make the class public, and implement the `ICommand` interface. Add the following using statements (the first one might vary depending on whether you created a new project for this sample):

```
using WpfCommands.Models;
using System.Windows.Input;
```

Your class should look like this:

```
public class ChangeColorCommand : ICommand
{
    public bool CanExecute(object parameter)
    {
        throw new NotImplementedException();
    }
    public void Execute(object parameter)
    {
        throw new NotImplementedException();
    }
    public event EventHandler CanExecuteChanged;
}
```

If the `CanExecute()` method returns `true`, any bound controls will be enabled, and if it returns `false`, they will be disabled. If a control is enabled (because `CanExecute()` returns `true`) and clicked, the `Execute()` method will fire. The parameter passed into both of these methods comes from the UI based on the `CommandParameter` property set on binding statements. The `CanExecuteChanged` event ties into the binding and notification system to inform the UI that the result of the `CanExecute()` method has changed (much like the `PropertyChanged` event).

In this example, the Change Color button should work only if the parameter is not null and of type `Car`. Update the `CanExecute()` method to the following:

```
public bool CanExecute(object parameter)
    => (parameter as Car) != null;
```

The value for the `Execute()` method parameter is the same as for the `CanExecute()` method. Since the `Execute()` method can execute only if the object is of type `Car`, the argument must be cast to an `Car` type and have the color updated, as follows:

```
public void Execute(object parameter)
{
    ((Car)parameter).Color="Pink";
}
```

## Attaching the Command to the CommandManager

The final update for the command class is to type the command into the command manager. The `CanExecute()` method fires when the Window first loads and then when the command manager instructs it to reexecute. Each command class has to opt in to the command manager. This is done by updating the code regarding the `CanExecuteChanged` event, as follows:

```
public event EventHandler CanExecuteChanged
{
    add => CommandManager.RequerySuggested += value;
    remove => CommandManager.RequerySuggested -= value;
}
```

## Updating MainWindow.xaml.cs

The next change is to create an instance of this class that the Button can access. For now, you will place this in the code-behind file for the `MainWindow` (later in this chapter, you will move this into a view model). Open `MainWindow.xaml.cs` and delete the Click event handler for the Change Color button. Add the following using statements to the top of the file (again, the namespace may vary based on whether you are still using the same project or started a new one):

```
using WpfCommands.Cmds;
using System.Windows.Input;
```

Next, add a public property named `ChangeColorCmd` of type `ICommand` with a backing field. In the expression body for the property, return the backing property (make sure to instantiate a new instance of the `ChangeColorCommand` if the backing field is null).

```
private ICommand _changeColorCommand = null;
public ICommand ChangeColorCmd
    => _changeColorCommand ??= new ChangeColorCommand();
```

## Updating MainWindow.xaml

As you saw in Chapter 25, clickable controls in WPF (like `Button` controls) have a `Command` property that allows you to assign a command object to the control. Start by connecting your command instantiated in the code-behind to the `btnChangeColor` button. Since the property for the command is on the `MainWindow` class, you use the `RelativeSourceMode` binding syntax to get to the `Window` that contains the `Button`, as follows:

```
Command="{Binding Path=ChangeColorCmd,
    RelativeSource={RelativeSource Mode=FindAncestor, AncestorType={x:Type Window}}}"
```

The `Button` still needs to send in a `Car` object as the parameter for the `CanExecute()` and `Execute()` methods. This is assigned through the `CommandParameter` property. You set this to the `SelectedItem` of the `cboCars` `ComboBox`, as follows:

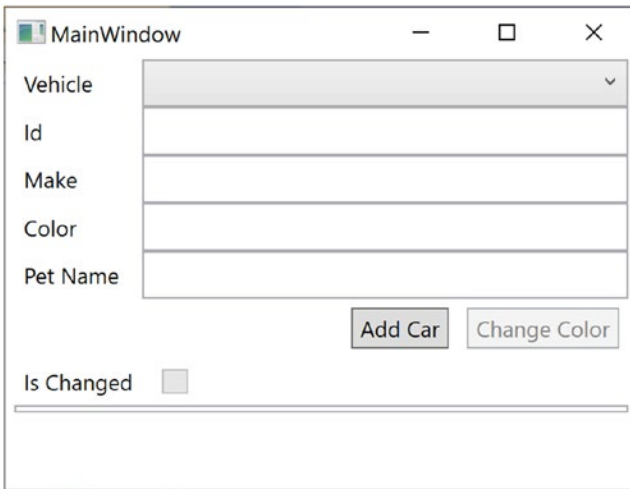
```
CommandParameter="{Binding ElementName=cboCars, Path=SelectedItem}"
```

The complete markup for the button is shown here:

```
<Button x:Name="btnChangeColor" Content="Change Color" Margin="5,0,5,0"
    Padding="4, 2" Command="{Binding Path=ChangeColorCmd,
        RelativeSource={RelativeSource Mode=FindAncestor, AncestorType={x:Type Window}}}"
    CommandParameter="{Binding ElementName=cboCars, Path=SelectedItem}"/>
```

## Testing the Application

Run the application. You will see that the `Change Color` command is *not* enabled, as shown in Figure 28-8, since there isn't a vehicle selected.



**Figure 28-8.** A window with nothing selected

Now, select a vehicle; the button will become enabled, and clicking it will change the color, as expected!

## Creating the CommandBase Class

If you continued with this pattern for `AddCarCommand.cs`, there would be code that would be repeated between the classes. This is a good sign that a base class can help. Create a new class in the `Cmds` folder named `CommandBase.cs` and add a `using` for the `System.Windows.Input` namespace. Set the class to public and implement the `ICommand` interface. Change the class and the `Execute()` and `CanExecute()` methods to abstract. Finally, add in the updated `CanExecuteChanged` event from the `ChangeColorCommand` class. The full implementation is listed here:

```
using System;
using System.Windows.Input;

namespace WpfCommands.Cmds
{
    public abstract class CommandBase : ICommand
    {
        public abstract bool CanExecute(object parameter);
        public abstract void Execute(object parameter);
        public event EventHandler CanExecuteChanged
        {
            add => CommandManager.RequerySuggested += value;
            remove => CommandManager.RequerySuggested -= value;
        }
    }
}
```

## Adding the AddCarCommand Class

Add a new class named `AddCarCommand.cs` to the `Cmds` folder. Make the class public and add `CommandBase` as the base class. Add the following using statements to the top of the file:

```
using System.Collections.ObjectModel;
using System.Linq;
using WpfCommands.Models;
```

The parameter is expected to be an `ObservableCollection<Car>`, so check to make sure of this in the `CanExecute()` method. If it is, then the `Execute()` method should add an additional car, just like the `Click` event handler.

```
public class AddCarCommand :CommandBase
{
    public override bool CanExecute(object parameter)
        => parameter is ObservableCollection<Car>;
    public override void Execute(object parameter)
    {
        if (!(parameter is ObservableCollection<Car> cars))
        {
            return;
        }
        var maxCount = cars.Max(x => x.Id);
        cars.Add(new Car
        {
            Id = ++maxCount,
            Color = "Yellow",
            Make = "VW",
            PetName = "Birdie"
        });
    }
}
```

## Updating MainWindow.xaml.cs

Add a public property named `AddCarCmd` of type `ICommand` with a backing field. In the expression body for the property, return the backing property (make sure to instantiate a new instance of the `AddCarCommand` if the backing field is null).

```
private ICommand _addCarCommand = null;
public ICommand AddCarCmd
    => _addCarCommand ??= new AddCarCommand();
```

## Updating MainWindow.xaml

Update the XAML to remove the Click attribute and add the Command and CommandParameter attributes. The AddCarCommand will receive the list of cars from the cboCars combo box. The entire button's XAML is as follows:

```
<Button x:Name="btnAddCar" Content="Add Car" Margin="5,0,5,0" Padding="4, 2"
  Command="{Binding Path=AddCarCmd,
    RelativeSource={RelativeSource Mode=FindAncestor, AncestorType={x:Type Window}}}"
  CommandParameter="{Binding ElementName=cboCars, Path=ItemsSource}"/>
```

With this in place, you can now add cars and update the color of cars using reusable code contained in stand-alone classes.

## Updating ChangeColorCommand

The final step is to update the ChangeColorCommand to inherit from CommandBase. Change ICommand to CommandBase, add the override keyword to both methods, and delete the CanExecuteChanged code. It's really that simple! The new code is listed here:

```
public class ChangeColorCommand : CommandBase
{
    public override bool CanExecute(object parameter)
        => parameter is Car;
    public override void Execute(object parameter)
    {
        ((Car)parameter).Color = "Pink";
    }
}
```

## RelayCommands

Another implementation of the command pattern in WPF is the RelayCommand. Instead of creating a new class for each command, this pattern uses delegates to implement the ICommand interface. It is a lightweight implementation, in that each command doesn't have its own class. RelayCommand's are usually used when there isn't any reuse needed for the implementation of the command.

## Creating the Base RelayCommand

RelayCommands are typically implemented in two classes. The base RelayCommand class is used when there aren't any parameters needed for the CanExecute() and Execute() methods, and RelayCommand<T> is used when a parameter is required. You will start with the base RelayCommand class, which leverages the CommandBase class. Add a new class named RelayCommand.cs to the Cmds folder. Make the class public and add CommandBase as the base class. Add two class-level variables to hold the Execute() and CanExecute() delegates.

```
private readonly Action _execute;
private readonly Func<bool> _canExecute;
```



Create three constructors. The first is the default constructor (needed by the `RelayCommand<T>`-derived class), the second is a constructor that takes an `Action` parameter, and the third is a constructor that takes an `Action` parameter and a `Func` parameter, as follows:

```
public RelayCommand(){  
public RelayCommand(Action execute) : this(execute, null) { }  
public RelayCommand(Action execute, Func<bool> canExecute)  
{  
    _execute = execute  
    ?? throw new ArgumentNullException(nameof(execute));  
    _canExecute = canExecute;  
}
```

Finally, implement the `CanExecute()` and `Execute()` overrides. `CanExecute()` returns true if the `Func` is null; or if it is not null, it executes and returns true. `Execute()` executes the `Action` parameter.

```
public override bool CanExecute(object parameter)  
=> _canExecute == null || _canExecute();  
public override void Execute(object parameter) { _execute(); }
```

## Creating RelayCommand<T>

Add a new class named `RelayCommandT.cs` to the `Cmds` folder. This class is almost a carbon copy of the base class, except that the delegates all take a parameter. Make the class public and generic, and add `RelayCommand` as the base class, as follows:

```
public class RelayCommand<T> : RelayCommand
```

Add two class-level variables to hold the `Execute()` and `CanExecute()` delegates:

```
private readonly Action<T> _execute;  
private readonly Func<T, bool> _canExecute;
```

Create two constructors. The first takes an `Action<T>` parameter, and the second takes an `Action<T>` parameter and a `Func<T, bool>` parameter, as follows:

```
public RelayCommand(Action<T> execute):this(execute, null) {}  
public RelayCommand(  
    Action<T> execute, Func<T, bool> canExecute)  
{  
    _execute = execute  
    ?? throw new ArgumentNullException(nameof(execute));  
    _canExecute = canExecute;  
}
```

Finally, implement the `CanExecute()` and `Execute()` overrides. `CanExecute()` returns true if the `Func` is null; or, if it is not null, it executes and returns true. `Execute()` executes the `Action` parameter.

```
public override bool CanExecute(object parameter)  
=> _canExecute == null || _canExecute((T)parameter);  
public override void Execute(object parameter)  
{ _execute((T)parameter); }
```

## Updating MainWindow.xaml.cs

When you use RelayCommand, all of the methods for the delegates need to be specified when a new command is constructed. This doesn't mean that the code needs to live in the code-behind (as is shown here); it just has to be accessible from the code-behind. It could live in another class (or even another assembly), providing the code encapsulation benefits of creating a custom command class.

Add a new private variable of type RelayCommand<Car> and a public property named DeleteCarCmd, as shown here:

```
private RelayCommand<Car> _deleteCarCommand = null;
public RelayCommand<Car> DeleteCarCmd
    => _deleteCarCommand ??=
        new RelayCommand<Car>(DeleteCar, CanDeleteCar));
```

The DeleteCar() and CanDeleteCar() methods must be created as well, as follows:

```
private bool CanDeleteCar(Car car) => car != null;
private void DeleteCar(Car car)
{
    _cars.Remove(car);
}
```

Notice the strong typing in the methods – this is one of the benefits of using RelayCommand<T>.

## Adding and Implementing the Delete Car Button

The final step to tie it all together is to add the button and assign the Command and CommandParameter bindings. Add the following markup:

```
<Button x:Name="btnDeleteCar" Content="Delete Car" Margin="5,0,5,0" Padding="4, 2"
    Command="{Binding Path=DeleteCarCmd,
        RelativeSource={RelativeSource Mode=FindAncestor, AncestorType={x:Type Window}}}"
    CommandParameter="{Binding ElementName=cboCars, Path=SelectedItem}"/>
```

Now when you run the application, you can test that the Delete Car button is enabled only if a car is selected in the drop-down and that clicking the button does indeed delete the car from the Car list.

## Wrapping Up Commands

This concludes your brief journey into WPF commands. By moving the event handling out of the code-behind file and into individual command classes, you gain the benefit of code encapsulating, reuse, and improved maintainability. If you don't need that much separation of concerns, you can use the lighter-weight RelayCommand implementation. The goal is to improve maintainability and code quality, so choose the method that works best for you.

## Migrate Code and Data to a View Model

As in the “WPF Validations” section, you can continue working in the same project, or you can create a new one and copy all of the code over. I will create a new project named `WpfViewModel`. If you are using the same project, be sure to pay attention to the namespaces in the code samples in this section and adjust as needed.

Create a new folder named `ViewModels` in your project, and add a new class named `MainWindowViewModel.cs` into that folder. Add the following namespaces and make the class public:

```
using System.Collections.Generic;
using System.Collections.ObjectModel;
using System.Windows.Input;
using WpfViewModel.Cmds;
using WpfViewModel.Models;
```

---

■ **Note** A popular convention is to name the view models after the window they support. I typically follow that convention and will do so in this chapter. However, like any pattern or convention, this isn't a rule, and you will find a wide range of opinions on this.

---

## Moving the MainWindow.xaml.cs Code

Almost all the code from the code-behind file will be moved to the view model. At the end, there will only be a few lines, including the call to `InitializeComponent()` and the code for setting the data context for the window to the view model.

Create a public property of type `ICollection<Car>` named `Cars`, like this:

```
public ICollection<Car> Cars { get; } =
    new ObservableCollection<Car>();
```

Create a default constructor and move all the `Car` creation code from the `MainWindow.xaml.cs` file, updating the list variable name. You can also delete the `_cars` variable from `MainWindow.xaml.cs`. Here is the view model constructor:

```
public MainWindowViewModel()
{
    Cars.Add(
        new Car { Id = 1, Color = "Blue", Make = "Chevy", PetName = "Kit", IsChanged = false });
    Cars.Add(
        new Car { Id = 2, Color = "Red", Make = "Ford", PetName = "Red Rider", IsChanged = false });
}
```

Next, move all of the command-related code from the window code-behind file to the view model, updating the `_cars` variable reference to `Cars`. Here is just the changed code:

```
//rest omitted for brevity
private void DeleteCar(Car car)
{
    Cars.Remove(car);
}
```

## Updating the MainWindow Code and Markup

Most of the code has been removed from the `MainWindow.xaml.cs` file. Remove the line that assigns the `ItemsSource` for the combo box, leaving only the call to `InitializeComponent`. It should now look like this:

```
public MainWindow()
{
    InitializeComponent();
}
```

Add the following using statement to the top of the file:

```
using WpfViewModel.ViewModels;
```

Next, create a strongly typed property to hold the instance of the view model:

```
public MainWindowViewModel ViewModel { get; set; }
= new MainWindowViewModel();
```

Finally, add a `DataContext` property to the window's declaration in XAML:

```
DataContext="{Binding ViewModel, RelativeSource={RelativeSource Self}}"
```

## Updating the Control Markup

Now that the `DataContext` for the window is set to the view model, the XAML bindings for the controls need to be updated. Starting with the combo box, update the markup by adding an `ItemsSource`:

```
<ComboBox Name="cboCars" Grid.Column="1" DisplayMemberPath="PetName" ItemsSource="{Binding Cars}" />
```

This works because the data context for the window is the `MainWindowViewModel`, and `Cars` is a public property on the view model. Recall that binding calls walk up the element tree until a data context is located. Next, you need to update the bindings for the `Button` controls. This is straightforward; since the bindings are already set to the window level, you just need to update the binding statement to start with the `DataContext` property, as follows:

```
<Button x:Name="btnAddCar" Content="Add Car" Margin="5,0,5,0" Padding="4, 2"
    Command="{Binding Path=DataContext.AddCarCmd,
        RelativeSource={RelativeSource Mode=FindAncestor, AncestorType={x:Type Window}}}"
    CommandParameter="{Binding ElementName=cboCars, Path=ItemsSource}" />
<Button x:Name="btnDeleteCar" Content="Delete Car" Margin="5,0,5,0" Padding="4, 2"
    Command="{Binding Path=DataContext.DeleteCarCmd,
        RelativeSource={RelativeSource Mode=FindAncestor, AncestorType={x:Type Window}}}"
    CommandParameter="{Binding ElementName=cboCars, Path=SelectedItem}" />
<Button x:Name="btnChangeColor" Content="Change Color" Margin="5,0,5,0" Padding="4, 2"
    Command="{Binding Path=DataContext.ChangeColorCmd,
        RelativeSource={RelativeSource Mode=FindAncestor, AncestorType={x:Type Window}}}"
    CommandParameter="{Binding ElementName=cboCars, Path=SelectedItem}" />
```

## Wrapping Up View Models

Believe it or not, you have just completed your first MVVM WPF application. You might be thinking – “This isn’t a real application. What about data? The data in this example is hard-coded.” And you would be correct. It’s not a real app; it’s demoware. However, that is the beauty of the MVVM pattern. The view doesn’t know anything about where the data is coming from; it’s just binding to a property on the view model. You can swap out view model implementations, perhaps using a version with hard-coded data for testing and one that hits the database for production.

There are a lot of additional points that could be discussed, including various open source frameworks, the View Model Locator pattern, and a host of differing opinions on how to best implement the pattern. That’s the beauty of software design patterns – there are usually many correct ways to implement it, and then you just need to find the best manner based on your business and technical requirements.

## Updating AutoLot.Dal for MVVM

If you want to update AutoLot.Dal for MVVM, you will have to apply the changes that we did for the Car class to all of the entities in the AutoLot.Dal.Models project, including the BaseEntity.

## Summary

This chapter examined the WPF topics that support the Model-View-ViewModel pattern. You started off learning how to tie model classes and collections into the notification system in the binding manager. You implemented `INotifyPropertyChanged` and used `ObservableCollections` classes to keep the UI in sync with the bound data.

Next, you added validation code to the model using `IDataErrorInfo` and `INotifyDataErrorInfo` and checked for data annotation errors. You then displayed any validation errors in the UI so the user would know what the problem is and how to fix it, and you created a style and custom control template to render errors in a meaningful way.

Finally, you put it all together by adding a view model, and you cleaned up the UI markup and code-behind file to increase separation of concerns.

**PART VIII**



# **ASP.NET Core**

## CHAPTER 29



# Introducing ASP.NET Core

The final section of this book covered ASP.NET Core, the latest version of the web development framework that uses C# and .NET Core. This chapter introduces ASP.NET Core and some of the changes from the previous version of the web development framework, ASP.NET.

After covering the basics of the MVC pattern as implemented in ASP.NET Core, you will start to build two applications that will work together. The first is covered in Chapter 30, and is an ASP.NET Core RESTful service. The second is covered in Chapter 31, and is an ASP.NET Core web application using the Model-View-Controller pattern. The `AutoLot.Dal` and `AutoLot.Models` projects that you finished in Chapter 23 will serve as the data access layer for the applications.

## A Quick Look Back

Microsoft released ASP.NET MVC in 2007 to great success. The framework is based on the Model-View-Controller pattern and provided an answer to developers who were frustrated by WebForms, which was essentially a leaky abstraction over HTTP. WebForms was created to help client-server developers move to the Web, and it was pretty successful in that respect. However, as developers became more accustomed to web development, many wanted more control over the rendered output, elimination of view state, and adherence to a proven web application design pattern. With those goals in mind, ASP.NET MVC was created.

## Introducing the MVC Pattern

The Model-View-Controller (MVC) pattern has been around since the 1970s, originally created as a pattern for use in Smalltalk. The pattern has made a resurgence recently, with implementations in many different and varied languages, including Java (Spring Framework), Ruby (Ruby on Rails), and .NET (ASP.NET MVC).

## The Model

The Model is the data of your application. The data is typically represented by Plain Old CLR Objects (POCOs). View models are composed of one or more models and shaped specifically for the consumer of the data. One way to think about models and view models is to relate them to database tables and database views.

Academically, models should be extremely clean and not contain validation or any other business rules. Pragmatically, whether or not models contain validation logic or other business rules depends entirely on the language and frameworks used, as well as specific application needs. For example, EF Core contains many data annotations that double as a mechanism for shaping the database tables and a means for validation in ASP.NET Core Web Applications. In this book (and in my professional work), the examples focus on reducing duplication of code, which places data annotations and validations where they make the most sense.

## The View

The View is the user interface of the application. Views accept commands and render the results of those commands to the user. The View should be as lightweight as possible and not actually process any of the work, but hand off all work to the controller.

## The Controller

The controller is the brains of the application. Controllers take commands/requests from the user (via the View) or client (through API calls) through action methods and handle them appropriately. The results of the operation are then returned to the user or client. Controllers should be lightweight and leverage other components or services to handle the details of the requests. This promotes separation of concerns and increases testability and maintainability.

## ASP.NET Core and the MVC Pattern

ASP.NET Core is capable of creating many types of web applications and services. Two options are “Web Application (Model-View-Controller)” and “API”. If you have worked with ASP.NET “classic”, these are analogous to ASP.NET MVC and ASP.NET WebAPI, respectively. The Web Application (MVC) and API application types share the “Model” and the “Controller” portion of the pattern, while Web Applications (MVC) also implement the “View” to complete the MVC pattern.

## ASP.NET Core and .NET Core

Just as Entity Framework Core is a complete rewrite of Entity Framework 6, ASP.NET Core is a rewrite of the popular ASP.NET framework. Rewriting ASP.NET was no small task, but necessary in order to remove the dependency on `System.Web`. Removing this dependency enables ASP.NET applications to run on operating systems other than Windows and other web servers besides Internet Information Services (IIS), including self-hosted. This opened the door for ASP.NET Core applications to use a cross-platform, lightweight, fast, and open source web server called Kestrel. Kestrel presents a uniform development experience across all platforms.

---

■ **Note** Kestrel was originally based on libuv, but since ASP.NET Core 2.1, it is now based on managed sockets.

---

Like EF Core, ASP.NET Core is being developed on GitHub as a completely open source project (<https://github.com/aspnet>). It is also designed as a modular system of NuGet packages. Developers only install the features that are needed for a particular application, minimizing the application footprint, reducing the overhead, and decreasing security risks. Additional improvements include a simplified startup, built-in dependency injection, a cleaner configuration system, and pluggable middleware.

## One Framework, Many Uses

There are a lot of changes and improvements in ASP.NET Core, as you will see throughout the rest of the chapters in this section. Besides the cross-platform capabilities, another significant change is that there is now a single framework that unifies ASP.NET MVC, ASP.NET WebAPI, WebPages, and Blazor into a single development framework. Developing web applications and services with the full .NET framework presents several choices: WebForms, MVC, WebAPI, Windows Communication Foundation (WCF), and WebMatrix.



They all had their positives and negatives, some were closely related and some very different. All of the choices meant developers had to know each of them in order to select the proper one for the task at hand or just select one and hope for the best.

With ASP.NET Core, you can build applications that use Razor Pages, the Model-View-Controller pattern, RESTful services, and SPA applications using JavaScript frameworks like Angular and React. While the UI rendering varies with choices between the MVC pattern and JavaScript frameworks, the underlying development framework is the same across all choices. Two prior choices that have not been carried forward into ASP.NET Core are WebForms and WCF.

---

■ **Note** With all of the separate frameworks brought under the same roof, the former names of ASP.NET MVC and ASP.NET Web API have been officially retired. In this book, I still refer to ASP.NET Core Web Applications using the Model-View-Controller pattern as MVC and ASP.NET RESTful services as WebAPI for simplicity.

---

## ASP.NET Core Features from MVC/WebAPI

Many of the design goals and features that brought developers to use ASP.NET MVC and ASP.NET WebAPI are still supported (and improved) in ASP.NET Core. Some of these (but not all) are listed here:

- Convention over Configuration

- Controllers and Actions

- Model Binding

- Model Validation

- Routing

- Filters

- Layouts and Razor Views

These are covered in the next sections, except for Layouts and Razor Views, which are covered in Chapter 31.

### Convention over Configuration

ASP.NET MVC and ASP.NET Web API reduced the amount of configuration necessary by introducing certain conventions. When followed, these conventions reduce the amount of manual (or templated) configuration, but also requires the developers to know the conventions in order to take advantage of them. Two of the main conventions include naming conventions and directory structure.

### Naming Conventions

There are multiple naming conventions in ASP.NET Core, both for MVC and API applications. For example, controllers are typically named with the “Controller” suffix (e.g. HomeController) in addition to deriving from Controller (or ControllerBase). When accessed through routing, the “Controller” suffix is dropped. When looking for a controller’s views, the controller name minus the suffix is the starting search location. This convention of dropping the suffix is repeated through ASP.NET Core. There will be many examples covered in the following chapters.

Another naming convention is for Razor Views. By default, an action method (in an MVC application) will render the view of the same name as the action method. Editor and Display templates are named after the class that they render in the view. These defaults can be changed if your application requires it.

## Directory Structure

There are several folder conventions that you must understand to successfully build ASP.NET Core web applications and services.

### The Controllers Folder

By convention, the Controllers folder is where the ASP.NET Core MVC and API implementations (and the routing engine) expect that the controllers for your application are placed.

### The Views Folder

The Views folder is where the views for the application are stored. Each controller gets its own folder under the main Views folder named after the controller name (minus the Controller suffix). The action methods will render views in their controller's folder by default. For example, the Views/Home folder holds all the views for the HomeController controller class.

### The Shared Folder

A special folder under Views is named Shared. This folder is accessible to all controllers and their action methods. After searching the folder named for the controller, if the view can't be found, then the Shared folder is searched for the view.

### The wwwroot Folder (New in ASP. NET Core)

An improvement over ASP.NET MVC is the creation of a special folder named `wwwroot` for ASP.NET Core Web Applications. In ASP.NET MVC, the JavaScript files, images, CSS, and other client-side content were intermingled with all of the other folders. In ASP.NET Core, client-side is all contained under the `wwwroot` folder. This significantly cleans up the project structure when working with ASP.NET Core.

## Controllers and Actions

Just like ASP.NET MVC and ASP.NET Web API, controllers and action methods are the workhorses of an ASP.NET Core MVC or API application.

### The Controller Class

As mentioned already, ASP.NET Core unified ASP.NET MVC5 and ASP.NET Web API. This unification also combines the `Controller`, `ApiController`, and `AsyncController` base classes from MVC5 and Web API 2.2 into one new class, `Controller`, which has a base class of its own named `ControllerBase`. ASP.NET Core Web Application controllers inherit from the `Controller` class, while ASP.NET Core service controller inherits from the `ControllerBase` class (covered next).

The Controller class provides a host of helper methods for web applications. The most commonly used methods are listed in Table 29-1.

**Table 29-1.** *Some of the Helper Methods Provided by the Controller Class*

Helper Method	Meaning in Life
ViewDataTempDataViewBag	Provide data to the view through the ViewDataDictionary, TempDataDictionary, and dynamic ViewBag transport.
View	Returns a ViewResult (derived from ActionResult) as the HTTP response. Defaults to view of the same name as the action method, with the option of specifying a specific view. All options allow specifying a ViewModel that is strongly typed and sent to the View. Views are covered in Chapter 31.
PartialView	Returns a PartialViewResult to the response pipeline. Partial views are covered in Chapter 31.
ViewComponent	Returns a ViewComponentResult to the response pipeline. ViewComponents are covered in Chapter 31.
Json	Returns a JsonResult containing an object serialized as JSON as the response.
OnActionExecuting	Executes before an action method executes.
OnActionExecutionAsync	Async version of OnActionExecuting.
OnActionExecuted	Executes after an action method executes.

# The ControllerBase Class

The ControllerBase class provides the core functionality for both ASP.NET Core web applications and services, in addition to helper methods for returning HTTP status codes. Table 29-2 lists some of the core functionality in ControllerBase, and Table 29-3 covers the helper methods for return HTTP status codes.

**Table 29-2.** *Some of the Helper Methods Provided by the ControllerBase Class*

Helper Method	Meaning in Life
HttpContext	Returns the HttpContext for the currently executing action.
Request	Returns the HttpRequest for the currently executing action.
Response	Returns the HttpResponse for the currently executing action.
RouteData	Returns the RouteData for the currently executing action (routing is covered later in this chapter).
ModelState	Returns the state of the model in regard to model binding and validation (both covered later in this chapter).
Url	Returns an instance of the IUrlHelper, providing access to building URLs for ASP.NET Core MVC applications and services
User	Returns the ClaimsPrincipal User.

(continued)

**Table 29-2.** (continued)

Helper Method	Meaning in Life
Content	Returns a <code>ContentResult</code> to the response. Overloads allow for adding content type and encoding definition.
File	Returns a <code>FileContentResult</code> to the response.
Redirect	A series of methods that redirect the user to another URL by returning a <code>RedirectResult</code> .
LocalRedirect	A series of methods that redirect the user to another URL only if the URL is local. More secure than the generic <code>Redirect</code> methods.
RedirectToAction RedirectToPage RedirectToRoute	A series of methods that redirect to another action method, Razor Page, or named route. Routing is covered later in this chapter.
TryUpdateModel	Explicit model binding (covered later in this chapter).
TryValidateModel	Explicit model validation (covered later in this chapter).

**Table 29-3.** Some of the HTTP Status Code Helper Methods Provided by the `ControllerBase` Class

Helper Method	HTTP Status Code Action Result	Status Code
NoContent	<code>NoContentResult</code>	204
Ok	<code>OkResult</code>	200
NotFound	<code>NotFoundResult</code>	404
BadRequest	<code>BadRequestResult</code>	400
Created	<code>CreatedResult</code>	201
CreatedAtAction	<code>CreatedAtActionResult</code>	
CreatedAtRoute	<code>CreateAtRouteResult</code>	
Accepted	<code>AcceptedResult</code>	202
AcceptedAtAction	<code>AcceptedAtActionResult</code>	
AcceptedAtRoute	<code>AcceptedAtRouteResult</code>	

Actions

Actions are methods on a controller that return an `IActionResult` (or `Task<IActionResult>` for async operations) or a class that implements `IActionResult`, such as `ActionResult` or the `ViewResult`. Actions will be covered more in the following chapters.

Model Binding

Model binding is the process where ASP.NET Core takes the name/value pairs available and attempts to reconstitute the action parameter types using reflection and recursion. Implicit conversions are executed where applicable, such as setting a string property using an int value in the name/value pairs. If conversion doesn't succeed, that property is flagged in the `ModelState` as an error.

The name/value pairs available to the action method are searched in order, with the first name match being attempted. The order is as follows:

- Form values from an HTTP Post method (including JavaScript ajax posts)
- Route values provided through ASP.NET Core routing
- Query string values

When binding complex types, the type must have a public default constructor and public writable properties to bind. When a parameter is bound, the binding engine looks for a name match in the name/value pairs (in the order listed earlier). If a name isn't found, the property is set to its default value. For example, the following method will attempt to set all of the properties on the `ShoppingCartRecord` type. If there aren't any errors, `ModelState.IsValid` will be set to true.

```
[HttpPost]
public ActionResult Create(ShoppingCartRecord cartRecord)
{
    if (ModelState.IsValid)
    {
        //Save the data;
    }
}
```

## Implicit vs. Explicit Model Binding

There is explicit and implicit model binding. Implicit model binding happens when a request is routed to an action method that has a parameter to be bound. Explicit model binding is executed with a call to `TryUpdateModelAsync`, passing in an instance of the type being bound and the list of properties to bind. If the model binding fails, the method returns false and sets the `ModelState` errors in the manner as implicit model binding.

When using explicit model binding, the type being bound doesn't need to be a parameter of the action method. For example, you could write the `Create` method this way and use implicit model binding:

```
[HttpPost]
public async Task<IActionResult> Create()
{
    var car = new Car();
    if (await TryUpdateModelAsync(vm, "",
        c=>c.Color,c=>c.PetName,c=>c.MakeId))
    {
        //do something important
    }
}
```

## The Bind Attribute

The `Bind` attribute in HTTP Post methods allows you to whitelist properties (to prevent over posting attacks) or specify a prefix for the properties. When fields are *white listed*, they are the only fields that will be assigned through model binding. If the `Bind` attribute is not used, all fields are white listed.

In the following Create action method example, all of the fields on the Car instance are available for model binding since the Bind attribute isn't used:

```
[HttpPost]
[ValidateAntiForgeryToken]
public IActionResult Create(Car car)
{
    if (ModelState.IsValid)
    {
        //Add the record
    }
    //Allow the user to retry
}
```

Suppose your business requirements specified to only allow updating the PetName and Color fields in the Create method. Adding in the Bind attribute (shown in the following example) whitelists the two required properties and instructs the model binder to ignore the rest.

```
[HttpPost]
[ValidateAntiForgeryToken]
public ActionResult Create(
[Bind(nameof(Car.PetName),nameof(Car.Color))]Car car)
{
    if (ModelState.IsValid)
    {
        //Save the data;
    }
    //Allow the user to retry
}
```

The Bind attribute can also be used to specify a prefix for the property names. When displaying a list of properties or using view models, the names of the name/value pairs might have a prefix added when sent to the action method. If the goal is to only bind to one item in the list or not bind the entire view model, the Prefix property of the Bind attribute can be used as follows:

```
[HttpPost]
[ValidateAntiForgeryToken]
public ActionResult Create(
[Bind(nameof(Car.PetName),nameof(Car. Color),Prefix="CartItem")]Car car)
{
    if (ModelState.IsValid)
    {
        //Save the data;
    }
}
```

# The ModelState Dictionary

The ModelState dictionary contains an entry for every item being bound through the model binder and items for the entire model itself. If an error occurs during model binding, the binding engine adds the errors to the dictionary entry for the property and sets the ModelState.IsValid = false. If all matched properties are successfully assigned, the binding engine sets ModelState.IsValid = true.

---

**Note** Model validation, which also sets the ModelState dictionary entries, happens after model binding. Both implicit and explicit model binding automatically call validation for the model. Validation is covered in the next section.

---

## Adding Custom Errors to the ModelState Dictionary

In addition to the properties and errors added by the binding engine, custom errors can be added to the ModelState dictionary. Errors can be added at the property level or the entire model. To add a specific error for a property, use the following code:

```
ModelState.AddModelError("PetName", "Name is required");
```

To add an error for the entire model, use string.Empty for the property name, like this:

```
ModelState.AddModelError(string.Empty, $"Unable to create record: {ex.Message}");
```

## Controlling Model Binding Sources in ASP.NET Core

Binding sources can be controlled through a set of attributes on the action parameters. Custom model binders can also be created; however, that is beyond the scope of this book. Table 29-4 lists the attributes that can be used to control model binding.

**Table 29-4.** Controlling Model Binding Sources

Attribute	Meaning in Life
BindingRequired	A model state error will be added if binding cannot occur instead of just setting the property to its default value.
BindNever	Tells the model binder to never bind to this parameter.
FromHeader	Used to specify the exact binding source to apply (Header, QueryString, Route parameters, or Form values).
FromQuery	
FromRoute	
FromForm	
FromServices	Binds the type using dependency injection (covered later in this chapter).
FromBody	Binds data from the request body. The formatter is selected based on the content of the request (e.g., JSON, XML, etc.). There can be at most one parameter decorated with the FromBody attribute.
ModelBinder	Used to override the default model binder (for custom model binding).

## Model Validation

Model validation occurs immediately after model binding (both explicit and implicit) or explicitly through `TryValidateModel`. While model binding adds errors to the `ModelState` data dictionary due to conversion issues, validation adds errors to the `ModelState` data dictionary based on business rules. Examples of business rules include missing required fields, strings that exceed the maximum allowed length, or dates outside of the allowed range.

Validation rules are set through validation attributes, either built-in or custom. Some of the built-in validation attributes are listed in Table 29-5. Note that several also double as data annotations for shaping the EF Core entities.

**Table 29-5.** *Some of the Built-In Validation Attributes*

Attribute	Meaning in Life
CreditCard	Performs a luhn-10 check on the credit card number
Compare	Validates the two properties in a model match
EmailAddress	Validates the property has a valid email format
Phone	Validates the property has a valid phone number format
Range	Validates the property falls within a specified range
RegularExpression	Validates the property matches a specified regular expression
Required	Validates the property has a value
StringLength	Validates the property doesn't exceed a maximum length
Url	Validates the property has a valid URL format
Remote	Validates input on the client by calling an action method on the server

Custom validation attributes can also be developed, but are not covered in this book.

## Routing

Routing is how ASP.NET Core matches URL requests to controllers and actions (the *endpoints*) in your application, instead of the old Web Forms process of matching URLs to the project file structure. It also provides a mechanism for creating URLs from within the app based on those endpoints. A `RouteEndpoint` is an endpoint in an MVC or WebAPI style app and consists of a controller, action, HTTP Verb, and optional values (called route values).

■ **Note** Routes also apply to Razor Pages, SignalR, gRPC Services, and more. This book will only cover MVC and WebAPI style controllers.

ASP.NET Core uses Routing middleware to match URLs of incoming requests and to generate URLs sent out in responses. The middleware is registered in the `Startup` class and endpoints are added in the `Startup` or through route attributes, both covered later in this chapter.



# URL Patterns and Route Tokens

Routing endpoints are composed of URL patterns that contain variable placeholders (called tokens) and literals placed into an ordered collection known as the *route table*. Each entry defines a different URL pattern to match. Placeholders can be custom variables or from a predefined list. Table 29-6 lists the reserved routing names.

**Table 29-6.** *Reserved Route Tokens*

Token	Meaning in Life
Area	Defines the MVC area for the route
Controller	Defines the controller (minus the controller suffix)
Action	Defines the action name in MVC applications
Page	Defines the Razor Page

In addition to the reserved tokens, routes can contain custom tokens that are mapped (model bound) to action method parameters.

## Routing and ASP.NET Core Services

When defining routes for ASP.NET Services, an action method is not specified. Instead, once the controller is located, the action method to execute is based on the HTTP Verb of the request and HTTP Verb assignments to action methods. More on this shortly.

## Conventional Routing

Conventional routing builds the route table in the `UseEndpoints` method in the `Startup.cs` class. It is called conventional routing because the templates added in the `Startup` class create a convention for URL paths.

The `MapControllerRoute` method adds the endpoint into the route table. The call specifies a name, URL pattern, and any default values for the variables in the URL pattern. In the following code sample, the predefined `{controller}` and `{action}` placeholders refer to a controller and an action method. The placeholder `{id}` is custom and is translated into a parameter (named `id`) for the action method. Adding a question mark to a route token indicates that it is optional.

```
app.UseEndpoints(endpoints =>
{
    endpoints.MapControllerRoute(
        name: "default",
        template: "{controller=Home}/{action=Index}/{id?}");
});
```

When a URL is requested, it is checked against the route table. If there is a match, the proper code is executed. An example URL that would be serviced by this route is `Car/Delete/5`. This invokes the `Delete` action method on the `CarController`, passing `5` to the `id` parameter.

The defaults specify how to fill in the blanks for URLs that don't contain all of the defined components. In the previous code, if nothing was specified in the URL (such as `http://localhost:60466`), then the routing engine would call the `Index` action method of the `HomeController` class, without an `id` parameter. The defaults are progressive, meaning that they can be excluded from right to left. However, route parts can't be skipped. Entering a URL like `http://localhost:60466/Delete/5` will fail the `{controller}/{action}/{id}` pattern.

The routing engine will attempt to find the best route based on the controller, action, custom tokens, and HTTP Verb. If the routing engine can't determine the best route, it will throw an `AmbiguousMatchException`.

Notice that the route doesn't contain a server (or domain) address. IIS automatically prepends the correct information before the defined route parameters. For example, if your site was running on <http://skimedic.com>, a correct URL for the example route could be <http://skimedic.com/Car/Delete/5>.

## Named Routes

Route names can be used as a shorthand to generate URLs from within the application. In the preceding conventional round, the endpoint is assigned the name "default".

## Attribute Routing

In attribute routing, routes are defined using C# attributes on controllers and their action methods. This can lead to more precise routing, but can also increase the amount of configuration, since every controller and action needs to have routing information specified.

For example, take the following code snippet. The four `Route` attributes on the `Index` action method equate to the same route defined earlier. The `Index` view will render when the URL is `mysite.com`, `mysite.com/Home`, `mysite.com/Home/Index`, or `mysite.com/Home/Index/5`.

```
public class HomeController : Controller
{
    [Route("/")]
    [Route("/Home")]
    [Route("/Home/Index")]
    [Route("/Home/Index/{id?}")]
    public IActionResult Index(int? id)
    {
        ...
    }
}
```

The major difference is in the fact that additional controllers will also need routes defined or they will not be able to be accessed. For example, the following code will not be discovered with the route `mysite.com/Car/Delete/5` since the controller doesn't have any routing configured:

```
public class CarController : Controller
{
    public IActionResult Delete(int id)
    {
        ...
    }
}
```

---

■ **Note** Conventional and attribute routing can be used together. If the default controller route was set up on `UseEndpoints` (as in the conventional routing example), the preceding controller would be located by endpoint routing.

---

When routes are added at the controller level, the action methods derive from that base route. For example, the following controller route *would* direct the previous URL to the CarController Delete action method:

```
[Route("[controller]/[action]/{id?}")]
public class CarController : Controller
{
    public IActionResult Delete(int id)
    {
        ...
    }
}
```

---

■ **Note** The built-in tokens are distinguished with square brackets (“[]”) instead of curly braces (“{}”) in attribute routing. Custom tokens still use curly braces.

---

If an action method needs to restart the route pattern, prefix the route with a forward slash (“/”). For example, if the delete method should follow the URL pattern `mysite.com/Delete/Car/5`, configure the action as follows:

```
[Route("[controller]/[action]/{id?}")]
public class CarController : Controller
{
    [Route("/[action]/[controller]/{id?}")]
    public IActionResult Delete(int id)
    {
        ...
    }
}
```

Routes can also hard-code the route values instead of using token replacement. The following code will produce the same result as the previous code sample:

```
[Route("[controller]/[action]/{id?}")]
public class CarController : Controller
{
    [Route("/Delete/Car/{id?}")]
    public IActionResult Delete(int id)
    {
        ...
    }
}
```

## Named Routes

Routes can also be assigned a name. This creates a shorthand method for redirecting to a particular route just by using the name. For example, the following route attribute has the name of `GetOrderDetails`:

```
[HttpGet("{orderId}", Name = "GetOrderDetails")]
```

## Routing and HTTP Methods

The HTTP Verbs participate in routing, although differently for MVC applications and API services.

### Web Application Routing

You might have noticed that neither of the route template definition methods defines an HTTP Verb. This is because the routing engine (in MVC- and API-style applications) uses the endpoint *and* the HTTP Verb in combination to select the proper action method. For example, if there are two action methods named `Edit` defined as in the following code sample, the routing engine will match both of the methods. The differentiator is the verb. When the request is an `HttpGet`, the first action method is executed, and if the request is an `HttpPost`, the second will execute.

```
[Route("[controller]/[action]/{id?}")]
public class CarController : Controller
{
    [HttpGet]
    public IActionResult Delete(int id)
    {
        ...
    }
    [HttpPost]
    public IActionResult Delete(int id, Car recordToDelete)
    {
        ...
    }
}
```

Routes can also be modified using the HTTP Verbs. For example, if the optional `id` route token is removed from the controller-level route definition, it can be added into the `Delete` methods as a required route parameter, as the following code demonstrates:

```
[Route("[controller]/[action] ")]
public class CarController : Controller
{
    [HttpGet("{id?}")]
    public IActionResult Delete(int? id)
    {
        ...
    }
    [HttpPost("{id}")]
    public IActionResult Delete(int id, Car recordToDelete)
    {
        ...
    }
}
```

Routes can also be restarted using the HTTP Verbs, just preface the route with a forward slash ("`/`").

## API Service Routing

As mentioned before, routing for ASP.NET Core API services does not specify action methods in the routes. The action methods are selected based on the HTTP Verb of the request and the HTTP Verb attribute on the action method. For example, the previous sample is modified to reflect an API controller as shown here:

```
[Route("api/[controller]")]
public class CarController : Controller
{
    [HttpGet("{id}")]
    public IActionResult Delete(int id)
    {
        ...
    }
    [HttpPost("{id}")]
    public IActionResult Delete(int id, Car recordToDelete)
    {
        ...
    }
}
```

While both action methods satisfy the same route (localhost:36522/Car/5), the HTTP Verb attribute for each action method is also examined. The action method that matches the route and the HTTP Verb of the request will be executed. If the route request is matched but the verb isn't, then the server will return a 404 (not found).

---

■ **Note** ASP.NET Web API allowed you to not specify the HTTP Verb for a method if the name started with Get, Put, Delete, or Post. This convention is generally considered a bad idea, and has been removed in ASP.NET Core. If an action method does not have an HTTP Verb specified, it will be called using an HTTP Get.

---

## Redirecting Using Routing

Another advantage of routing is that you no longer have to hard-code URLs for other pages in your site. The routing entries are used bidirectionally, not only to match incoming requests but also to build URLs for your site. For example, the following code samples (the first using an HTML helper and the second using the new TagHelpers) each create a link to the /Home/Contact URL. The scheme, host, and port are added based on the current values.

```
@Html.ActionLink("Contact", "Contact", "Home")
<a asp-controller="Home" asp-action="Contact">Contact</a>
```

This feature enables your application code to work regardless of the host, scheme, or port. On the controller side, the `RedirectToAction` works the same way:

```
RedirectToAction("Home", "Contact")
```

## Filters

Filters in ASP.NET Core run code before or after specific stages of the request processing pipeline. There are built-in filters for authorization and caching, as well as options for assign customer filters. Table 29-7 lists the types of filters that can be added into the pipeline, listed in their order of execution.

**Table 29-7.** *Filters Available in ASP.NET Core*

Filter	Meaning in Life
Authorization filters	Run first and determine if the user is authorized for the current request
Resource filters	Run immediately after the authorization filter and can run after the rest of the pipeline has completed. Run before model binding
Action filters	Run immediately before an action is executed and/or immediately after an action is executed. Can alter values passed into an action and the result returned from an action
Exception filters	Used to apply global policies to unhandled exceptions that occur before writing to the response body
Result filters	Run code immediately after the successful execution of action results. Useful for logic that surrounds view or formatter execution

The filter types are covered in the next sections.

### Authorization Filters

Authorization filters work with the ASP.NET Core Identity system to prevent access to controllers or actions that the user doesn't have permission to use. It's not recommended to build custom authorization filters since the built-in `AuthorizeAttribute` and `AllowAnonymousAttribute` usually provide enough coverage when using ASP.NET Core Identity.

### Resource Filters

The before code executes after authorization filters and prior to any other filters, and the after code executes after all other filters. This enables resource filters to short-circuit the entire response pipeline. A common user for resource filters is for caching. If the response is in the cache, the filter can skip the rest of the pipeline.

### Action Filters

The before code executes immediately before the execution of the action method, and the after code executes immediately after the execution of the action method. Action filters can short-circuit the action method and any filters that are wrapped by the action filter (order of execution and wrapping are covered shortly).

## Exception Filters

Exception filters implement cross-cutting error handling in an application. They don't have before or after events, but handle any unhandled exceptions in controller creation, model binding, action filters, or action methods.

## Result Filters

Result filters wrap the execution of the `IActionResult` for an action method. A common scenario is to add header information into the HTTP response message using a result filter.

## Add Filters to the Processing Pipeline

Filters can be applied to action methods, controllers, or globally to the application. The before code of filters executes from the outside in (global, controller, action method), while the after code of filters executes from the inside out (action method, controller, global).

Adding filters at the application level is accomplished in the `ConfigureServices` method of the `Startup` class when adding `Mvc`. For example, to add a customer exception filter, use the following code:

```
services.AddControllers(config =>
    config.Filters.Add(new CustomerExceptionHandler()));
```

To add filters at the controller or action method, create the filter as an attribute and add the attribute to the controller. To create a custom exception filter attribute, the following code demonstrates the starting point:

```
public class MyExceptionHandlerAttribute :
    ExceptionFilterAttribute
{
    public override void OnException(ExceptionContext context)
    {
        //Do something meaningful
    }
}
```

## What's New in ASP.NET Core

The decision to rewrite ASP.NET Core and to have just one framework has provided the opportunity for the team to innovate and improve the feature set and also to focus on performance as a primary concern. In addition to supporting the base functionality of ASP.NET MVC and ASP.NET Web API, the team has been able to add a host of new features and improvements over the previous frameworks. In addition to the unification of frameworks and controllers, here are some additional improvements and innovations:

- Built-in dependency injection.
- Cloud-ready, environment-based configuration system.
- Can run on .NET Core or the full .NET Framework.
- Lightweight, high-performance, and modular HTTP request pipeline.
- The entire framework is based on fine-grained NuGet packages.

- Integration of modern client-side frameworks and development workflows.
- Introduction of Tag Helpers.
- Introduction of View Components.

## Built-In Dependency Injection

Dependency injection (DI) is a mechanism to support loose coupling between objects. Instead of directly creating dependent objects or passing specific implementations into classes and/or methods, parameters are defined as interfaces. That way, any implementation of the interface can be passed into the classes or methods and classes, dramatically increasing the flexibility of the application.

DI support is one of the main tenets in the rewrite ASP.NET Core. Not only does the `Startup` class (covered later in this chapter) accept all of the configuration and middleware services through dependency injection, your custom classes can (and should) be added to the service container to be injected into other parts of the application.

The ASP.NET Core DI container is typically configured in the `ConfigureServices` method of the `Startup` class using the instance of `IServiceCollection` that itself is injected in. When an item is configured into the DI container, there are three lifetime options, as shown in Table 29-8.

**Table 29-8.** *Lifetime Options for Services*

Lifetime Option	Functionality Provided
Transient	Created <i>each</i> time they are needed.
Scoped	Created once for each request. Recommended for Entity Framework <code>DbContext</code> objects.
Singleton	Created once on first request and then reused for the lifetime of the object. This is the recommended approach vs. implementing your class as a <code>Singleton</code> .

For example, to add the `CarRepo` into the DI container, add this line to the `ConfigureServices` method of the `Startup` class:

```
public void ConfigureServices(IServiceCollection services)
{
    ...
    services.AddScoped<ICarRepo, CarRepo>();
    ...
}
```

To make use of the implementation of the interface in the constructor of a class, add the interface definition as a constructor parameter, as the following code demonstrates:

```
public class CategoryController:Controller
{
    public CarController(ICarRepo repo)
    {
        Repo = repo;
    }
    ...
}
```



Dependencies can also be injected into methods by using the [FromServices] attribute, as demonstrated here:

```
public class OrdersController:Controller
{
    public IActionResult DoSomething([FromServices]ICarRepo repo)
    {
        ...
    }
    ...
}
```

The next two chapters will make extensive use of the DI framework for the repositories and services created in the data access layer.

## Cloud-Ready, Environment-Based Configuration System

This actually encompasses two improvements. The first is the capability of ASP.NET Core applications to leverage machine environment settings in the configuration process. The second is a greatly simplified configuration system.

## Determining the Runtime Environment

ASP.NET Core looks for an environment variable named ASPNETCORE\_ENVIRONMENT to determine the current running environment. In development, this variable can be set using a settings file, while downstream environments typically use standard operating system environment variables. There are three built-in environment names (Development, Staging, and Production), but the name can be set to anything the team decides to use. The value of the environment variable is available through IHostEnvironment instance, which is created by the framework and available through the ASP.NET Core DI framework. Table 29-9 lists some of the more commonly used methods of the IHostEnvironment instance, and Table 29-10 lists the properties available.

**Table 29-9.** *The IHostEnvironment Methods*

Method	Functionality Provided
IsProduction	Returns true if the environment variable is set to “Production” (case insensitive)
IsStaging	Returns true if the environment variable is set to “Staging” (case insensitive)
IsDevelopment	Returns true if the environment variable is set to “Development” (case insensitive)
IsEnvironment	Returns true if the environment variable matches the string passed into the method (case insensitive)

**Table 29-10.** *The IHostEnvironment Properties*

Property	Functionality Provided
ApplicationName	Gets or sets the name of the application. Defaults to the name of the entry assembly
ContentRootPath	Gets or sets the absolute path to the directory that contains the application content files
ContentRootFileProvider	Gets or sets an IFileProvider pointing to the ContentRootPath
EnvironmentName	Gets or sets the name of the environment. Sets to the value of the ASPNETCORE_ENVIRONMENT environment variable
WebRootFileProvider	Gets or sets an IFileProvider pointing at the WebRootPath
WebRootPath	Gets or sets the absolute path to the directory that contains the web-servable application content files

Some examples of using the environment setting are

- Determining which configuration files to load
- Setting debugging, error, and logging options
- Loading environment-specific JavaScript and CSS files

You will see each of these in action while building the `AutoLot.Api` and `AutoLot.Mvc` applications in the next two chapters.

## Application Configuration

Previous versions of ASP.NET used the `web.config` file to configure services and applications, and developers accessed the configuration settings through the `System.Configuration` class. Of course, *all* configuration settings for the site, not just application-specific settings, were dumped into the `web.config` file making it a (potentially) complicated mess.

ASP.NET Core introduces a greatly simplified configuration system. By default, it's based on simple JSON files that hold configuration settings as name/value pairs. The default file for configuration is the `appsettings.json` file. The initial version of `appsettings.json` file created by the ASP.NET Core web application and API service templates simply contains configuration information for the logging as well as a setting to limit the hosts and is listed here:

```
{
  "Logging": {
    "LogLevel": {
      "Default": "Information",
      "Microsoft": "Warning",
      "Microsoft.Hosting.Lifetime": "Information"
    }
  },
  "AllowedHosts": "*"
}
```

The template also creates an `appsettings.Development.json` file. The configuration system works in conjunction with the runtime environment awareness to load additional configuration files based on the runtime environment. This is accomplished by instructing the configuration system to load a file named `appsettings.{environmentname}.json` after the `appSettings.json` file. When running under Development, the `appsettings.Development.json` file is loaded after the initial settings file. If the environment is Staging, the `appsettings.Staging.json` file is loaded. It is important to note that when more than one file is loaded, any settings that appear in both files are overwritten by the last file loaded – they are not additive.

## Retrieving Settings

Once the configuration is built, settings can be accessed using the traditional Get family of methods, such as `GetSection`, `GetValue`, and so on.

```
Configuration.GetSection("Logging")
```

There is also a shortcut for getting application connection strings:

```
Configuration.GetConnectionString("AutoLot")
```

Entire classes can also be populated using the ASP.NET Core configuration system. This will be examined in later chapters.

## Deploying ASP.NET Core Applications

Prior versions of ASP.NET applications could only be deployed to Windows servers using IIS. ASP.NET Core can be deployed to multiple operating systems in multiple ways, including outside of a web server. The high-level options are as follows:

- On a Windows server (including Azure) using IIS
- On a Windows server (including Azure app services) outside of IIS
- On a Linux server using Apache or NGINX
- On Windows or Linux in a Docker container

This flexibility allows organizations to decide the deployment platform that makes the most sense for the organization, including popular container-based deployment models (such as using Docker), as opposed to being locked into Windows servers.

## Lightweight and Modular HTTP Request Pipeline

Following along with the principles of .NET Core, you must opt in for everything in ASP.NET Core. By default, nothing is loaded into an application. This enables applications to be as lightweight as possible, improving performance and minimizing their surface area and potential risk.

## Create and Configure the ASP.NET Core Project

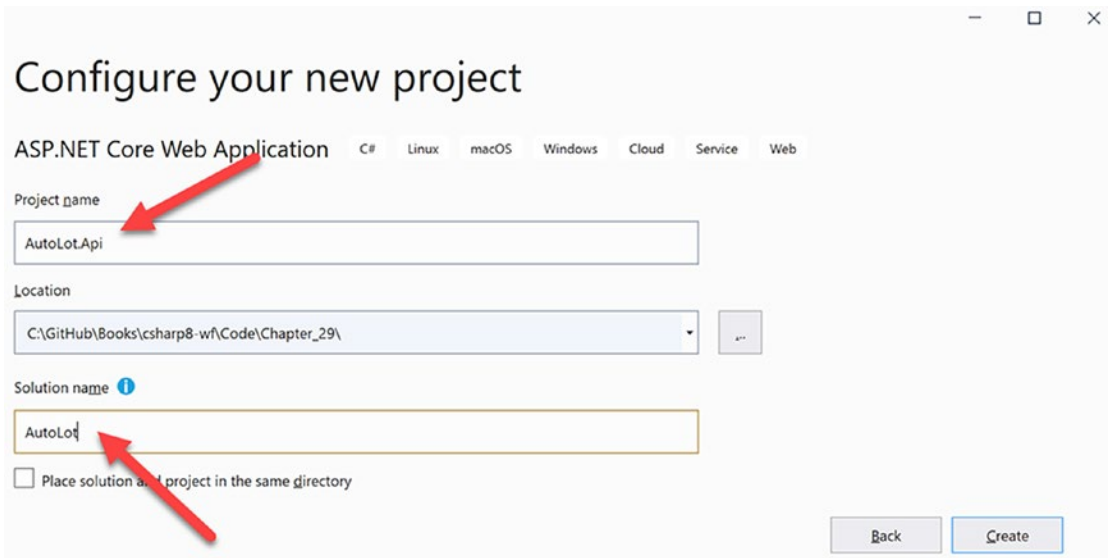
Now that you have a background in some of the major concepts in ASP.NET Core, it's time to build the solution.

## Create the ASP.NET Core Projects

The ASP.NET Core projects can be created using either Visual Studio or the command line. Both options will be covered in the next two sections.

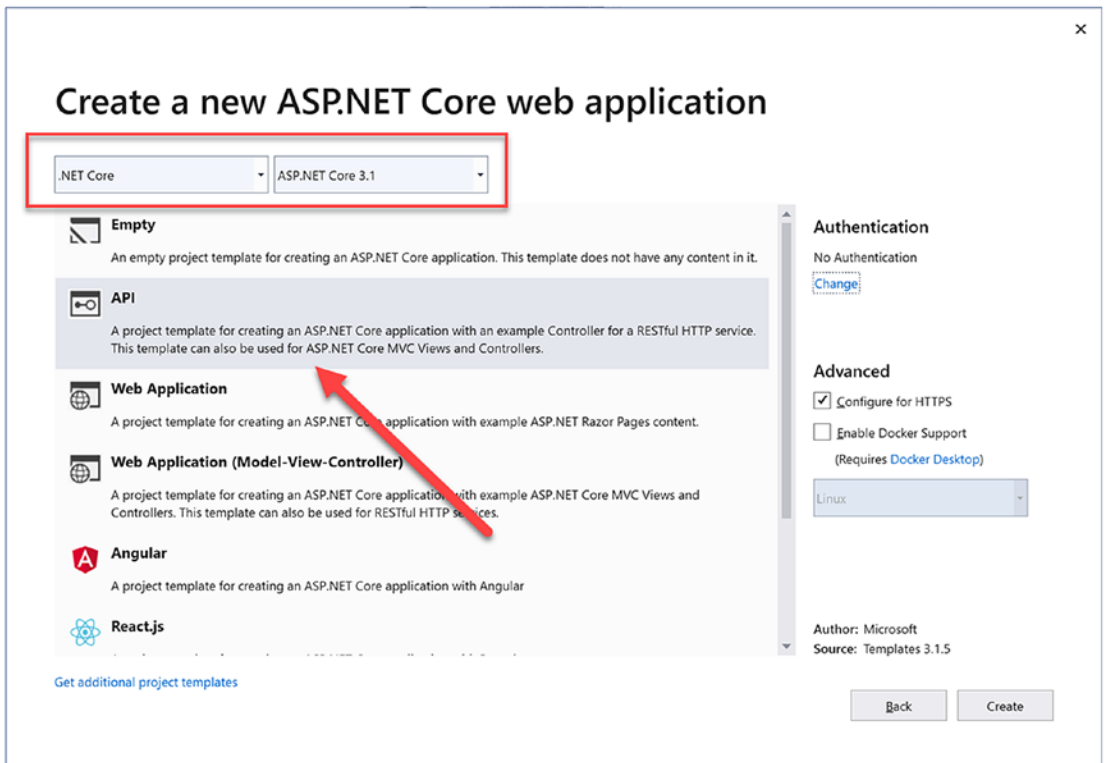
### Using Visual Studio

Start by creating a new project in Visual Studio. Select ASP.NET Core Web Application from the Create a new project dialog. In the Configure your new project dialog, enter `AutoLot.Api` for the project name and `AutoLot` for the solution name, as shown in Figure 29-1.



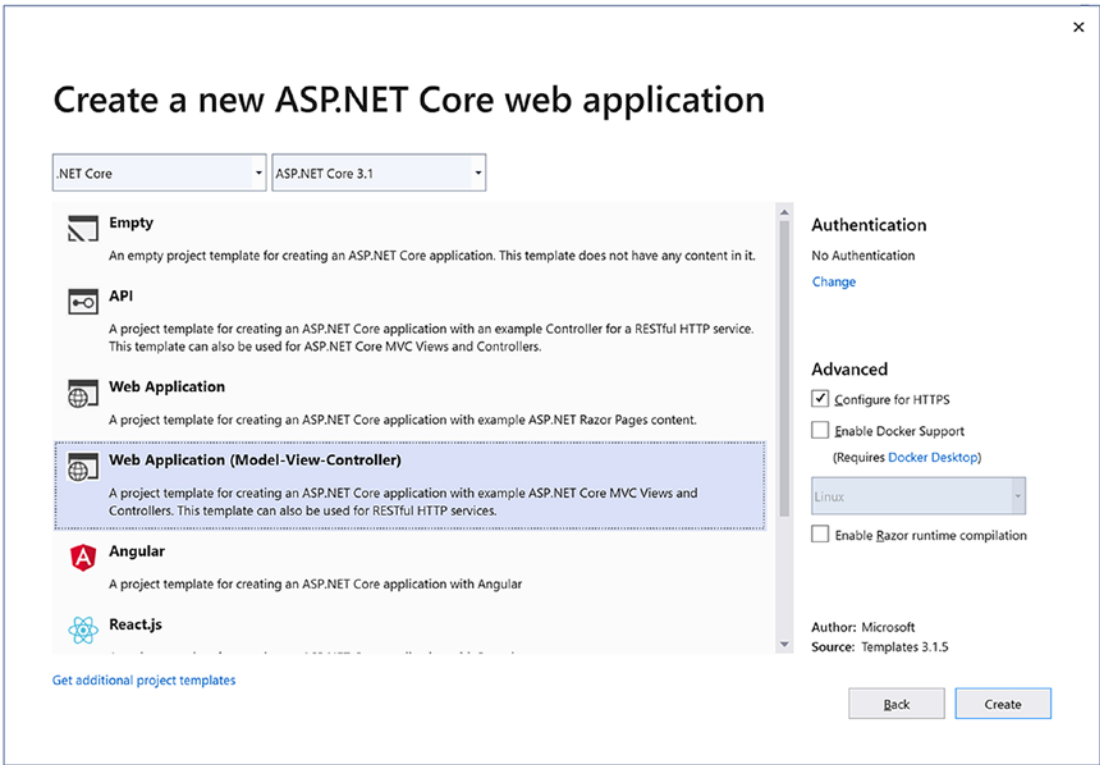
**Figure 29-1.** Creating the `AutoLot.Api` project and `AutoLot` solution

On the next screen, select the API template, making sure .NET Core and ASP.NET Core 3.1 are selected in the select boxes, as shown in Figure 29-2.



**Figure 29-2.** Select the ASP.NET Core API template

Next, add a new project to the solution. Also select the ASP.NET Core Web Application from the Create a new project dialog. On the Configure your new project screen, name it `AutoLot.Mvc`. On the next screen, select Web Application (Model-View-Controller), as shown in Figure 29-3.



**Figure 29-3.** Select the Web Application Template (Model-View-Controller)

## Using the Command Line

As shown earlier in this book, .NET Core projects and solutions can be created using the command line. Open a prompt and navigate to the directory where you want the solution located. Enter the following commands to create a blank solution, and then create the `AutoLot.Api` and `AutoLot.Mvc` projects:

```
dotnet new sln -n AutoLot
dotnet new webapi -n AutoLot.Api -au none -o .\AutoLot.Api
dotnet sln AutoLot.sln add AutoLot.Api
dotnet new mvc -n AutoLot.Mvc -au none -o .\AutoLot.Mvc
dotnet sln AutoLot.sln add AutoLot.Mvc
```

## Add the NuGetPackages

Additional NuGet packages are needed to complete the applications. To `AutoLot.Api`, add the following packages:

- AutoMapper
- System.Text.Json
- Swashbuckle.AspNetCore.Annotations

- Swashbuckle.AspNetCore.Swagger
- Swashbuckle.AspNetCore.SwaggerGen
- Swashbuckle.AspNetCore.SwaggerUI
- Microsoft.VisualStudio.Web.CodeGeneration.Design
- Microsoft.EntityFrameworkCore.SqlServer

You can add them using Visual Studio's NuGet Package Manager or using the command line (from the `AutoLot.Api` directory) as follows (all on one line):

```
dotnet add package AutoMapper
dotnet add package System.Text.Json
dotnet add package Swashbuckle.AspNetCore.Annotations
dotnet add package Swashbuckle.AspNetCore.Swagger
dotnet add package Swashbuckle.AspNetCore.SwaggerGen
dotnet add package Swashbuckle.AspNetCore.SwaggerUI
dotnet add package Microsoft.VisualStudio.Web.CodeGeneration.Design
dotnet add package Microsoft.EntityFrameworkCore.SqlServer
```

To `AutoLot.Mvc`, add the following packages:

- AutoMapper
- System.Text.Json
- LigerShark.WebOptimizer.Core
- Microsoft.Web.LibraryManager.Build

You can add them using Visual Studio's NuGet Package Manager or using the command line (from the `AutoLot.Mvc.Api` directory) as follows (all on one line):

```
dotnet add package AutoMapper
dotnet add package System.Text.Json
dotnet add package LigerShark.WebOptimizer.Core
dotnet add package Microsoft.Web.LibraryManager.Build
```

## Add in AutoLot.Dal

Next, copy the `AutoLot.Dal` and `AutoLot.Dal.Models` projects from Chapter 23 into the solution folder, alongside the two ASP.NET Core projects. Add the project to the solution by right-clicking the solution in Solution Explorer (VS2019) and select **Add ► Existing Project** or use the following command lines (in the solution directory):

```
dotnet sln AutoLot.sln add AutoLot.Dal
dotnet sln AutoLot.sln add AutoLot.Dal.Models
```

Add project references from `AutoLot.Api` to `AutoLot.Models` and `AutoLot.Dal` and a project reference from `AutoLot.Mvc` to `AutoLot.Dal`. The command line to do this is shown here (run from the solution directory):

```
dotnet add AutoLot.Mvc reference AutoLot.Dal.Models
dotnet add AutoLot.Api reference AutoLot.Dal
dotnet add AutoLot.Api reference AutoLot.Dal.Models
```

Now you are ready to start building the applications.

## Running ASP.NET Core Applications

Previous versions of ASP.NET web applications were run from IIS (or IIS Express during development). As mentioned already, the ASP.NET Core team has adopted Kestrel, an open source web server, as the main execution platform. Kestrel presents a uniform development experience across all platforms.

The addition of Kestrel and the .NET Core Command Line Interface (CLI) has opened the door to additional options when running ASP.NET Core applications. They can now be run (during development) in multiple ways:

- From Visual Studio, using IIS Express
- From Visual Studio, using Kestrel
- From a command prompt with the .NET CLI, using Kestrel
- From Visual Studio Code, using Kestrel, from the Run menu
- From Visual Studio Code's Terminal window using the .NET CLI and Kestrel

## Using Visual Studio

The `launchsettings.json` file (located under the Properties node in Solution Explorer) configures how the application will run, both under Kestrel and IIS Express. The `launchsettings.json` file is listed here for reference (your IIS Express ports will be different):

```
{
  "iisSettings": {
    "windowsAuthentication": false,
    "anonymousAuthentication": true,
    "iisExpress": {
      "applicationUrl": "http://localhost:55882",
      "sslPort": 44318
    }
  },
  "profiles": {
    "IIS Express": {
      "commandName": "IISExpress",
      "launchBrowser": true,
      "environmentVariables": {
        "ASPNETCORE_ENVIRONMENT": "Development"
      }
    }
  }
}
```



```

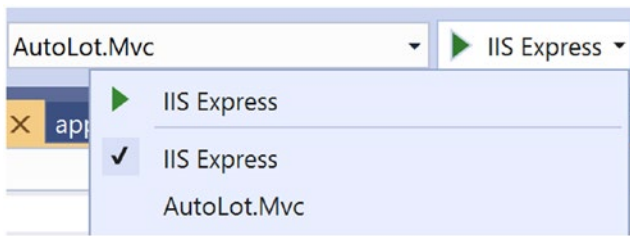
"AutoLot.Mvc ": {
  "commandName": "Project",
  "launchBrowser": true,
  "environmentVariables": {
    "ASPNETCORE_ENVIRONMENT": "Development"
  },
  "applicationUrl": " https://localhost:5001;http://localhost:5000"
},
}
}
}

```

The `iisSettings` section defines the settings of running the application using IIS Express as the web server. The most important settings to note are the `applicationUrl`, which defines the port, and the `environmentVariables` block, which defines the runtime environment. This setting supersedes any machine environment setting when running in debug mode.

The second profile (`AutoLot.Mvc`) defines the settings when running the application using Kestrel as the web server. The profile defines the `applicationUrl` and ports, plus the environment.

The run command in Visual Studio allows for choosing either IIS Express or Kestrel, as shown in Figure 29-4.



**Figure 29-4.** The available Visual Studio debugging profiles

---

■ **Note** When running your application from Visual Studio, edit-and-continue is no longer supported.

---

## Using the Command Line

To run from the command line, navigate to the directory where the `csproj` file for your application is located. Enter the following command to start your application using Kestrel as the web server:

```
dotnet run
```

To end the process, press Ctrl+C.

## Changing Code While Debugging

When running from the command line, code can be changed, but it won't be reflected in the running app. In order to have changes reflected in the running app, enter the following command:

```
dotnet watch run
```

That update to the command runs a file watcher along with launching your application. When changes are detected in the files, the app will automatically stop and then restart. Not exactly edit-and-continue, but a good solution for development.

## Using Visual Studio Code (VSC)

To run the projects from Visual Studio Code, open the folder where the solution is located. When you press F5 (or click Run), VSC will prompt you for which project to run (AutoLot.Api or AutoLot.Mvc), and then create a first create a run configuration and place that in a file named launch.json. VSC also uses the launchsettings.json file for port configuration.

## Changing Code While Debugging

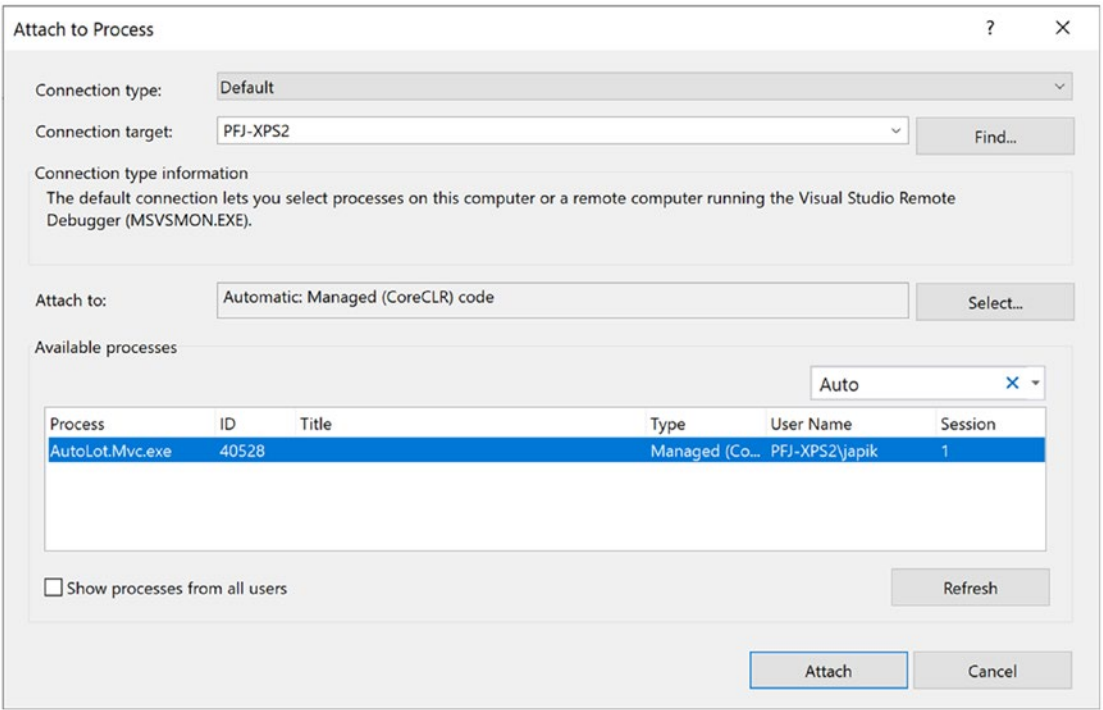
When running from VSC, code can be changed, but it won't be reflected in the running app. In order to have changes reflected in the running app, run the dotnet watch run command from the terminal.

## Debugging ASP.NET Core Applications

When running your application from Visual Studio or Visual Studio Code, debugging works as expected. When running from the command line, you have to attach to the running process before you can debug your application. Doing this in Visual Studio and Visual Studio Code is easy.

## Attaching with Visual Studio

After launching your app (with dotnet run or dotnet watch run), select Debug ► Attach to Process in Visual Studio. When the Attach to Process dialog appears, filter the process by your application name, as shown in Figure 29-5.

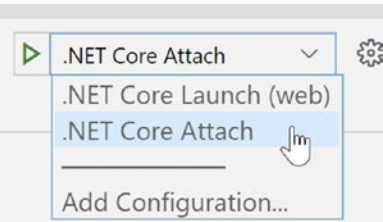


**Figure 29-5.** Attaching to the running applications for debugging in Visual Studio

Once attached to the running process, you can set breakpoints in Visual Studio and debugging works as expected. You can't edit-and-continue; you will have to detach from the process for changes to be reflected in your running app.

## Attaching with Visual Studio Code

After launching your app (with `dotnet run` or `dotnet watch run`), select **.NET Core Attach** instead of **.NET Core Launch (web)** by the green run arrow in VSC, as shown in Figure 29-6.



**Figure 29-6.** Attaching to the running applications for debugging in Visual Studio Code

When you click the run button, you will be prompted for which process to attach. Select your application. And you can now set breakpoints as expected.

The advantage of using Visual Studio Code is that once attached (and using `dotnet watch run`) you can update your code while running (without having to detach) and your changes will be reflected in your app.

## Update the AutoLot.Api Ports

You might have noticed that `AutoLot.Api` and `AutoLot.Mvc` have different ports specified for their IIS Express profiles, but both have their Kestrel ports configured to 5000 (http) and 5001 (https). This will cause problems when you try and run the apps together. Update the `AutoLot.Api` ports to 5011 (https) and 5010 (http), like this:

```
"AutoLot.Api": {
  "commandName": "Project",
  "launchBrowser": true,
  "launchUrl": "api/values",
  "applicationUrl": "https://localhost:5011;http://localhost:5010",
  "environmentVariables": {
    "ASPNETCORE_ENVIRONMENT": "Development"
  }
}
```

## Create and Configure the WebHost

Unlike classic ASP.NET MVC or ASP.NET Web API applications, ASP.NET Core applications are simple .NET Core Console applications that create and configure a `WebHost`. The creation of the `WebHost` and the subsequent configuration is what sets the application up to listen (and respond) to HTTP requests. The `WebHost` is created in the `Main` method of the `Program.cs` file. The `WebHost` is then configured for your application in the `Startup.cs` file.

## The Program.cs File

Open up the `Program.cs` class in the `AutoLot.Api` application, and examine the contents, shown here for reference:

```
public class Program
{
    public static void Main(string[] args)
    {
        CreateHostBuilder(args).Build().Run();
    }

    public static IHostBuilder CreateHostBuilder(string[] args)
    =>
        Host.CreateDefaultBuilder(args)
            .ConfigureWebHostDefaults(webBuilder =>
            {
                webBuilder.UseStartup<Startup>();
            });
}
```

The `CreateDefaultBuilder` method compacts the most typical application setup into one method call. It configures the app (using environment variables and `appsettings.json` files), it configures the default logging provider, and sets up the dependency injection container. This setup is provided by the ASP.NET Core templates for API- and MVC-style applications.

The next method (`ConfigureWebHostDefaults`) is also a meta-method that adds in support for Kestrel, IIS, and additional configuration. The final step is to specify the application-specific configuration class, which in this example (and by convention) is named `Startup`.

The final step is to use the `Run` command to activate the web host.

---

■ **Note** Although not covered in this book, the process for building the `WebHost` can be intercepted to add in additional services, such as the third-party logging framework Serilog. This mechanism makes the process extremely flexible and able to meet the specific needs of your project.

---

## The Startup.cs File

The `Startup` class configures how the application will handle HTTP requests and responses, configures any needed services, and adds services to the dependency injection container. The class name can be anything, as long as it matches the `UseStartup<T>` line in the configuration of the `CreateHostBuilder` method, but the convention is to name the class `Startup`.

Open up the `Startup.cs` file from the `AutoLot.Api` application to follow along with the following sections.

## Available Services for Startup

The startup process needs access to framework and environmental services and values, and these are injected into the class by the framework. There are five services available to the `Startup` class for configuring the application, listed in Table 29-11.

**Table 29-11.** *Available Services in Startup*

Service	Functionality Provided
<code>IApplicationBuilder</code>	Defines a class that provides the mechanisms to configure an application's request pipeline
<code>IWebHostEnvironment</code>	Provides information about the web hosting environment an application is running in
<code>ILoggerFactory</code>	Used to configure the logging system and create instances of loggers from the registered logging providers
<code>IServiceCollection</code>	Specifies the contract for a collection of service descriptors. Part of the dependency injection framework
<code>IConfiguration</code>	An instance of the application configuration, created in the <code>Main</code> method of the <code>Program</code> class

The constructor takes an instance of `IConfiguration` and optional instance of `IHostEnvironment`. The `Configure` method must take an instance of `IApplicationBuilder`, but can also take instances of `IHostEnvironment` and/or `ILoggerFactory`. The `ConfigureServices` method takes an instance of `IServiceCollection`. Each of the components is discussed in the next sections.

## The Constructor

The constructor takes an instance of the `IConfiguration` interface that was created by the `Host.CreateDefaultBuilder` method in the `Program.cs` file and assigns it to the `Configuration` property for use elsewhere in the class. The constructor can also take an instance of the `IWebHostEnvironment` and/or the `ILoggerFactory`, although these are not added in the default template.

Add a parameter for `IWebHostEnvironment` into the constructor and assign it to a local class-level variable. This will be needed in the `ConfigureServices` method.

Do this for both the `AutoLot.Api` and `AutoLot.Mvc` applications:

```
private readonly IWebHostEnvironment _env;
public Startup(
    IConfiguration configuration, IWebHostEnvironment env)
{
    _env = env;
    Configuration = configuration;
}
```

## The ConfigureServices Method

The `ConfigureServices` method is used to configure any services needed by the application and insert them into the dependency injection container. This includes the services needed to support MVC applications and API services.

### AutoLot.Api

The `ConfigureServices` method for `AutoLot API` is configured by default with just one service that adds in support for `Controllers`. Behind this meta-method is a host of additional services getting added in, including routing, authorization, model binding, and all of the non-UI items already discussed in this chapter.

```
public void ConfigureServices(IServiceCollection services)
{
    services.AddControllers();
}
```

The `AddControllers` method can be extended. One example is to configure JSON handling. The default for ASP.NET Core is to camel case JSON (first letter small, each subsequent word character capitalized like “`carRepo`”). This matches most of the non-Microsoft frameworks used for web development. However, prior versions of ASP.NET Pascal cased everything (“`CarRepo`”). The change to camel casing was a breaking

change for many applications that were expecting Pascal casing. To change the application's JSON handling back to Pascal casing (and to format JSON better), add the following to the `AddControllers` method:

```
public void ConfigureServices(IServiceCollection services)
{
    services.AddControllers()
        .AddJsonOptions(options =>
        {
            options.JsonSerializerOptions.PropertyNamingPolicy = null;
            options.JsonSerializerOptions.WriteIndented = true;
        });
}
```

The next updates need the following using statements added to the `Startup.cs` class:

```
using AutoLot.Dal.EfStructures;
using AutoLot.Dal.Initialization;
using AutoLot.Dal.Repos;
using AutoLot.Dal.Repos.Interfaces;
using Microsoft.EntityFrameworkCore;
```

The API services need access to the `ApplicationDbContext` and the repos in the data access layer. There is built-in support for adding EF Core into ASP.NET Core applications. Add the following code into the `ConfigureServices` method of the `Startup` class:

```
var connectionString = Configuration.GetConnectionString("AutoLot");
services.AddDbContextPool<ApplicationDbContext>(
    options => options.UseSqlServer(connectionString,
    sqlOptions => sqlOptions.EnableRetryOnFailure()));
```

The first line gets the connection string from the settings file (more on this later). The next line adds a pool of `ApplicationDbContext` instances into the DI container. Much like a connection pool, the pool of `ApplicationDbContext`s can improve performance by having pre-initialized instances waiting to be used. When a context is needed, it gets loaded from the pool. When it is done being used, it is cleaned up of any remnants of the use and is returned to the pool.

The next update is to add the repos into the DI container. Add the following code to the `ConfigureServices` method after the code to configure the `ApplicationDbContext`:

```
services.AddScoped<ICarRepo, CarRepo>();
services.AddScoped<ICreditRiskRepo, CreditRiskRepo>();
services.AddScoped<ICustomerRepo, CustomerRepo>();
services.AddScoped<IMakeRepo, MakeRepo>();
services.AddScoped<IOrderRepo, OrderRepo>();
```

That configures the services for `AutoLot.Api` for now. More will be added in the next chapter.

## Add the Connection String to the App Settings

Update the `appsettings.development.json` file to the following, which adds in the connection string to the database. Be sure to include the comma separating the sections, and update the connection string to match your environment.

```
{
  "Logging": {
    "LogLevel": {
      "Default": "Information",
      "Microsoft": "Warning",
      "Microsoft.Hosting.Lifetime": "Information"
    }
  },
  "ConnectionStrings": {
    "AutoLot": "Server=.,5433;Database=AutoLotFinal;User ID=sa;Password=P@ssw0rd;"
  }
}
```

As discussed earlier, each configuration file is named after an environment. This permits environment-specific values to be separated into different files. Add a new file named `appsettings.production.json` to the project, and update it to the following:

```
{
  "ConnectionStrings": {
    "AutoLot": "ITSASECRET"
  }
}
```

This keeps the real connection string out of source control and enables replacement of the token (“ITSASECRET”) during the deployment process.

## AutoLot.Mvc

The `ConfigureServices` method for MVC-style web applications adds in the base services for API apps as well as support for rendering view. Instead of calling `AddControllers`, MVC-style applications call `AddControllersWithViews`, as follows:

```
public void ConfigureServices(IServiceCollection services)
{
    services.AddControllersWithViews();
}
```

Much more will be added to this in [Chapter 31](#).

## The Configure Method

The `Configure` method is used to set up the application to respond to HTTP requests. This method executes *after* the `ConfigureServices` method, which means anything added to the DI container can also be injected into the `Configure` method.



There are differences in how API- and MVC-styled apps are configured to handle the HTTP pipeline requests and response.

## AutoLot.Api

The default template checks the environment, and if it's set to development, the `UseDeveloperExceptionPage` middleware is added to the processing pipeline. This provides debugging information, information that you probably don't want exposed in production.

Then `UseHttpsRedirection` is called to redirect all traffic to https (instead of http). Then Routing, Authorization, and Endpoints are added. The entire method is listed here:

```
public void Configure(
    IApplicationBuilder app, IWebHostEnvironment env)
{
    if (env.IsDevelopment())
    {
        //If in development environment, display debug info
        app.UseDeveloperExceptionPage();
    }
    //redirect http traffic to https
    app.UseHttpsRedirection();
    //opt-in to routing
    app.UseRouting();
    //enable authorization checks
    app.UseAuthorization();
    //opt-in to using endpoint routing
    app.UseEndpoints(endpoints =>
    {
        //use attribute routing on controllers
        endpoints.MapControllers();
    });
}
```

The change that we will make to this is to initialize the database when the system runs in development. Add `ApplicationDbContext` as a parameter to the method, and call `InitializeData` from `AutoLot.Dal`. The updated code is listed here:

```
public void Configure(
    IApplicationBuilder app,
    IWebHostEnvironment env,
    ApplicationDbContext context)
{
    if (env.IsDevelopment())
    {
        //If in development environment, display debug info
        app.UseDeveloperExceptionPage();
    }
}
```

```

//Initialize the database
if (Configuration.GetValue<bool>("RebuildDataBase"))
{
    SampleDataInitializer.InitializeData(context);
}
}
...
}

```

Now, update the `appsettings.development.json` with the `RebuildDataBase` property:

```
"RebuildDataBase": true,
```

In the next chapter, you will make additional updates to this method.

## Web Applications

The `Configure` method for web applications is a bit more involved than the API counterpart, as one would expect. The full method is listed here, and discussed afterward:

```

public void Configure(IApplicationBuilder app, IWebHostEnvironment env)
{
    if (env.IsDevelopment())
    {
        app.UseDeveloperExceptionPage();
    }
    else
    {
        app.UseExceptionHandler("/Home/Error");
        app.UseHsts();
    }
    app.UseHttpsRedirection();
    app.UseStaticFiles();
    app.UseRouting();
    app.UseAuthorization();
    app.UseEndpoints(endpoints =>
    {
        endpoints.MapControllerRoute(
            name: "default",
            pattern: "{controller=Home}/{action=Index}/{id?}");
    });
}

```

The method also checks for the environment and, if set to “development”, adds in the `DeveloperExceptionPage` middleware. If the environment is anything but development, the generic `ExceptionHandler` middleware is added to the pipeline as well as HSTS (HTTP Strict Transport Security Protocol).

Back in the main execution path, like its API counterpart, `HttpsRedirection` is added. The next step is adding support for static files. Support for static files is an opt-in as a security measure. If your app doesn’t need them (like APIs), then don’t add support, and they can’t be a security risk. The `Routing` and `Authorization` middleware are added, as well as `Endpoints`.

In the `UseEndpoints` method, the default template sets up conventional routing. We are going to turn that off and use attribute routing throughout the entire application. Comment out (or delete) the call to `MapControllerRoute` and replace that with `MapControllers`, like this:

```
app.UseEndpoints(endpoints =>
{
    endpoints.MapControllers();
});
```

The next change is to add the route attributes to the `HomeController` in the `AutoLot.Mvc` application. First, add the controller/action pattern to the controller itself:

```
[Route("[controller]/[action]")]
public class HomeController : Controller
{
    ...
}
```

Next, add the three routes to the `Index` method so that it is the default action when there isn't an action specified or when there isn't a controller or an action specified. Also put the `HttpGet` attribute on the method to explicitly declare it as a "get" action:

```
[Route("/")]
[Route("/[controller]")]
[Route("/[controller]/[action]")]
[HttpGet]
public IActionResult Index()
{
    return View();
}
```

Much more work will be done with `AutoLot.Mvc` in [Chapter 31](#).

## Logging Support

As part of the startup and configuration process, basic logging is added into the dependency injection container. This can be seen in both the `HomeController` (in `AutoLot.Mvc/Controllers`) and the `WeatherForecastController` (in `AutoLot.Api/Controllers`). Examine the constructors, and you will see the default logger injected into each class:

```
public class HomeController : Controller
{
    private readonly ILogger<HomeController> _logger;
    public HomeController(ILogger<HomeController> logger)
    {
        _logger = logger;
    }
    ...
}
```

```
public class WeatherForecastController : ControllerBase
{
    ...
    private readonly ILogger<WeatherForecastController> _logger;
    public WeatherForecastController(ILogger<WeatherForecastController> logger)
    {
        _logger = logger;
    }
    ...
}
```

Logging can then be done in each of your controllers with a simple call to the logger like this:

```
logger.Log(LogLevel.Information, "This is informational");
```

---

■ **Note** Logging in ASP.NET Core, like everything else, is extensible. A popular logging framework that works very well with ASP.NET Core is Serilog. More information on Serilog can be found here: <https://serilog.net/>.

---

## Summary

This chapter introduced ASP.NET Core, and is the first of a set of chapters covering ASP.NET Core. This chapter began with a brief look back at the history of ASP.NET Core and then looked at the features from classic ASP.NET MVC and ASP.NET WebAPI that also exist in ASP.NET Core.

Next is the list of many of the brand new features in ASP.NET Core and how they work. Then after learning about the different ways to run and debug ASP.NET Core applications, you set up the solution with two ASP.NET Core projects and the AutoLot data access layer (from Chapter 23).

Finally, you closed with making the updates to Startup.cs in both AutoLot.Api and AutoLot.Mvc.

In the next chapter, you will finish AutoLot.Api.

## CHAPTER 30



# RESTful Services with ASP.NET Core

The final section of this book covered ASP.NET Core, the latest version of the web development framework that uses C# and .NET Core. This chapter introduces ASP.NET Core and some of the changes from the previous version of the web development framework, ASP.NET.

After covering the basics of the MVC pattern as implemented in ASP.NET Core, you will start to build two applications that will work together. The first is a RESTful service and the second is a web application. The `AutoLot.Dal` and `AutoLot.Models` projects that you finished in Chapter 23 will serve as the data access layer for the applications.

Now that you have completed the data access layer for the `SpyStore` ecommerce site, it's time to create the RESTful service that exposes the data operations. The service will serve as the back end for all of the UI frameworks used in the rest of this book and is built using ASP.NET Core.

## Introducing ASP.NET Core RESTful Services

The ASP.NET MVC framework started gaining traction almost immediately, and Microsoft released ASP.NET Web API with ASP.NET MVC 4 and Visual Studio 2012. ASP.NET Web API 2 was released with Visual Studio 2013 and then updated the framework to version 2.2 with Visual Studio 2013 Update 1.

ASP.NET Web API from the beginning was designed to be a service-based framework for building RESTful (**RE**presentational **ST**ate **T**ransfer) services. It is based on the MVC framework minus the “V” (view), with optimizations for creating headless services. These services can be called by any technology, not just those under the Microsoft umbrella. Calls to a Web API service are based on the core HTTP Verbs (Get, Put, Post, Delete) through a URI (Uniform Resource Identifier) such as the following:

<http://www.mysite.com:33826/api/cars>

If this looks like a URL (Uniform Resource Locator), that's because it is! A URL is simply a URI that points to physical resource on a network.

Calls to Web API use the HTTP (**H**ypertext **T**ransfer **P**rotocol) scheme on a particular host (in this example, [www.mysite.com](http://www.mysite.com)), on a specific port (33826 in the preceding example), followed by the path (`/api/cars`) and an optional query and fragment (not shown in this example). Web API calls can also include text in the body of the message, as you will see later in this chapter. As discussed in the last chapter, ASP.NET Core unified Web API and MVC into one framework.

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■ **Note** The default ports for calls are 80 for HTTP and 443 for HTTPS.

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It's time to dive into the code and build the service.

## Controller Actions with RESTful Services

As covered in the last chapter, actions return an `IActionResult` (or `Task<IActionResult>` for async operations). In addition to the helper methods in `ControllerBase` that return specific HTTP status codes, Action methods can (and usually do) return content as formatted JSON (JavaScript Object Notation) responses.

### Formatted JSON Response Results

Most RESTful APIs receive data from and send data back to clients using JavaScript Object Notation, or JSON (pronounced jay-sawn) for short. A simple JSON example, consisting of two values, is shown here:

```
[
  "value1",
  "value2"
]
```

APIs also use HTTP status codes to communicate success or failure. Some of these were listed in the previous chapter in Table 29-3. Successful requests return status codes in the 200 range, with 200 (OK) being the most common success code. In fact, it is so common that you don't have to explicitly return an OK. If there isn't an exception thrown and the code does not specify a status code, a 200 will be returned to the client along with any data.

To set up the following examples, we need to add a new controller into the project. In Visual Studio, right-click the Controllers folder in the AutoLot.Api project and select Add ► Controller. Select API Controller – Empty.

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■ **Note** The examples in the ASP.NET Core chapters use Visual Studio 2019, largely due to the rich templating engine. All of the code will work in Visual Studio Code as well; you will just have to add in the templated code. All of the code is shown here, so you will not miss anything from the examples.

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This creates an empty controller with the following code:

```
[Route("api/[controller]")]
[ApiController]
public class ValuesController : ControllerBase
{
}
```

This code sets the route for the controller using a value ("api") and a token ("[controller]"). This sets the base route to be (with an example domain) [www.skimedic.com/api/values](http://www.skimedic.com/api/values). The next attribute (`ApiController`) opts in to several API-specific features (covered in the next section). Finally, the controller inherits from `ControllerBase`. As discussed in Chapter 29, ASP.NET Core rolled all of the different controller types available in classic ASP.NET into one, named `Controller`. `Controller` inherits from `ControllerBase`.

The Controller class provides view specific functionality (the V in MVC), while ControllerBase supplies all of the rest of the core functionality for MVC-style applications.

There are several ways to return content as JSON from an Action method. They all result in the same response, and the differences are largely stylistic. Add the following code into your ValuesController class:

```
[HttpGet]
public IActionResult Get()
{
    return Ok(new string[] { "value1", "value2" });
}
[HttpGet("one")]
public IEnumerable<string> Get1()
{
    return new string[] { "value1", "value2" };
}
[HttpGet("two")]
public ActionResult<IEnumerable<string>> Get2()
{
    return new string[] { "value1", "value2" };
}
[HttpGet("three")]
public string[] Get3()
{
    return new string[] { "value1", "value2" };
}
[HttpGet("four")]
public IActionResult Get4()
{
    return new JsonResult(new string[] { "value1", "value2" });
}
```

Each of the preceding examples return the same JSON (the example shown earlier) along with a 200 status message. To test this, open the launchSettings.json file (under properties in Visual Studio) and update the “launchUrl” property (for both profiles) to api/values, as follows:

```
{
...
  "profiles": {
    "IIS Express": {
      "commandName": "IISExpress",
      "launchBrowser": true,
      "launchUrl": "api/values",
      "environmentVariables": {
        "ASPNETCORE_ENVIRONMENT": "Development"
      }
    },
    "AutoLot.Api": {
      "commandName": "Project",
      "launchBrowser": true,
      "launchUrl": "api/values",
      "applicationUrl": "https://localhost:5011;http://localhost:5010",
    }
  }
}
```

```

        "environmentVariables": {
            "ASPNETCORE_ENVIRONMENT": "Development"
        }
    }
}

```

Also, turn off the database rebuild functionality in `appsettings.development.json`:

```
"RebuildDataBase": false,
```

When you run the app (make sure that the `AutoLot.Api` is set to the startup project), you can navigate to the different methods by adding the additional route parameters (e.g., `http://localhost:5011/api/values/one`).

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■ **Note** The default API template creates a sample controller call `WeatherForecastController`. Examination of the example is left up to the reader.

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## The ApiController Attribute

ASP.NET Core 2.1 added in the `ApiController` attribute, which when combined with the `ControllerBase` class, provides REST-specific conventions and behaviors. These conventions and behaviors are outlined in the following subsections.

## Attribute Routing Requirement

When using the `ApiController` attribute, the controller must use attribute routing. This is just enforcing what many consider to be a best practice.

## Automatic 400 Responses

If there is an issue with model binding, the action will automatically return an HTTP 400 (Bad Request) response code. This replaces the following code:

```

if (!ModelState.IsValid)
{
    return BadRequest(ModelState);
}

```

This behavior can be disabled through configuration in the `ConfigureServices` method of the `Startup.cs` class:

```

services.AddControllers()
    .ConfigureApiBehaviorOptions(options =>
    {
        options.SuppressModelStateInvalidFilter = true;
    });

```



## Binding Source Parameter Inference

The model binding engine will infer where the values are retrieved based on the conventions listed in Table 30-1.

**Table 30-1.** *Binding Source Inference Conventions*

Source	Parameters bound
FromBody	Inferred for complex types. Only one FromBody parameter can exist or an exception will be thrown. Exceptions exist for IFormCollection and CancellationToken.
FromForm	Inferred for action parameters of type IFormFile and IFormFileCollection. When parameter is marked with FromForm, the multipart/form-data content type is inferred.
FromRoute	Inferred for any parameter name that matches a route token name.
FromQuery	Inferred for any other action parameters.

This behavior can be disabled through configuration in the ConfigureServices method of the Startup.cs class:

```
services.AddControllers()
    .ConfigureApiBehaviorOptions(options =>
    {
        options.SuppressInferBindingSourcesForParameters= true;
    });
```

## Problem Details for Error Status Codes

MVC transforms an error result (status of 400 or higher) into a result with ProblemDetails. The ProblemDetails type is listed here:

```
public class ProblemDetails
{
    public string Type { get; set; }
    public string Title { get; set; }
    public int? Status { get; set; }
    public string Detail { get; set; }
    public string Instance { get; set; }
    public IDictionary<string, object> Extensions { get; }
    = new Dictionary<string, object>(StringComparer.Ordinal);
}
```

To test this behavior, add another method to the ValuesController as follows:

```
[HttpGet("error")]
public IActionResult Error()
{
    return NotFound();
}
```

Test this by running the app and navigating to `https://localhost:5011/api/values/error`. You will get the following JSON in your browser (your `traceId` will be different):

```
{
  "type": "https://tools.ietf.org/html/rfc7231#section-6.5.4",
  "title": "Not Found",
  "status": 404,
  "traceId": "|50ad7395-41895b8cb5fa78c9."
}
```

This behavior can be disabled through configuration in the `ConfigureServices` method of the `Startup.cs` class:

```
services.AddControllers()
    .ConfigureApiBehaviorOptions(options =>
    {
        options.SuppressMapClientErrors = true;
    });
```

## Add Swagger/OpenAPI

Swagger (also known as OpenAPI) is an open standard for documenting (and testing) APIs. There are two options for adding Swagger into ASP.NET Core APIs: Swashbuckle.AspNetCore and NSwag. For AutoLot.Api, we will be adding Swashbuckle. In Chapter 29, you added the NuGet packages needed, but as a review, these are the packages used to configure Swashbuckle.AspNetCore:

- Swashbuckle.AspNetCore.Annotations
- Swashbuckle.AspNetCore.Swagger
- Swashbuckle.AspNetCore.SwaggerGen
- Swashbuckle.AspNetCore.SwaggerUI

Next, add the following using statements to the top of the `Startup` class:

```
using System;
using System.IO;
using System.Reflection;
using Microsoft.OpenApi.Models;
using Swashbuckle.AspNetCore.Swagger;
```

## Add the Swagger Middleware

In the `Configure` method of the `Startup.cs` class, opt in to both `Swagger` and `SwaggerUI`:

```
app.UseSwagger();
app.UseSwaggerUI(c =>
{
    c.SwaggerEndpoint("/swagger/v1/swagger.json", "AutoLot Service v1");
});
```

SwaggerUI needs to have the endpoint specified where the UI is to be generated. The UI is generated from the `swagger.json` file and any XML comments (covered later in this section) that you have added to your controllers and actions. The URL for the UI is the endpoint minus the version and json file name. The previous code defined it to be `http://localhost:5011/swagger`.

---

■ **Note** The full URL `https://localhost:5011/swagger/v1/swagger.json` allows you to load the full JSON file into your browser. This can be helpful when troubleshooting Swagger issues, as it will show any SwaggerGen issues in the JSON file.

---

## Add SwaggerGen to the Services Collection

The final block of code adds SwaggerGen into the DI container and configures the options for this application. Add the following to the end of the `ConfigureServices` method:

```
services.AddSwaggerGen(c =>
{
    c.SwaggerDoc("v1",
        new OpenApiInfo
        {
            Title = "AutoLot Service",
            Version = "v1",
            Description = "Service to support the AutoLot dealer site",
            License = new OpenApiLicense
            {
                Name = "Apress Publishing",
                Url = new Uri("https://www.Apress.com")
            }
        });
    var xmlFile = $"{Assembly.GetExecutingAssembly().GetName().Name}.xml";
    var xmlPath = Path.Combine(AppContext.BaseDirectory, xmlFile);
    c.IncludeXmlComments(xmlPath);
});
```

The final block of code uses reflection to find and load the XML documentation file generated by the project, which is covered next.

## Add the XML Documentation File

The last part of the SwaggerGen configuration references an XML document that describes all of the methods. This is not built by default and must be enabled in the project file. Edit the `AutoLot.Api.csproj` file and add the following `PropertyGroup`, as shown here:

```
<PropertyGroup Condition="'$(Configuration)|$(Platform)'=='Debug|AnyCPU'">
  <DocumentationFile>AutoLot.Api.xml</DocumentationFile>
  <NoWarn>1701;1702;1591</NoWarn>
</PropertyGroup>
```

This will generate the `AutoLot.Api.xml` file from any XML comments found in the project. The `NoWarn 1591` turns off compiler warnings for methods that don't have XML comments.

---

■ **Note** The 1701 and 1702 warnings are carryovers from the early days of classic .NET that are exposed by the .NET Core compilers. The default templates (for all .NET Core projects) disable these warnings until a future release will update the compiler to remove the issue.

---

For example, update the `Get` method of the `ValuesController` to this:

```
/// <summary>
/// This is an example Get method returning JSON
/// </summary>
/// <returns>List of strings</returns>
[HttpGet]
public IActionResult Get()
{
    return Ok(new string[] { "value1", "value2" });
}
```

When you build the project, a new file named `AutoLot.Api.xml` will show up in the root of the project. Opening the file will show the comments you just added:

```
<?xml version="1.0"?>
<doc>
  <assembly>
    <name>AutoLot.Api</name>
  </assembly>
  <members>
    <member name="M:AutoLot.Api.Controllers.ValuesController.Get">
      <summary>
        This is an example Get method returning JSON
      </summary>
      <returns>List of strings</returns>
    </member>
  </members>
</doc>
```

Swashbuckle will merge your comments with all of the controllers (and their actions) that are marked with the `ApiController` attribute to provide documentation and a test harness for your API.

---

■ **Note** When using Visual Studio, if you enter three backslashes before a class or method definition, Visual Studio will stub out the initial XML comments for you.

---

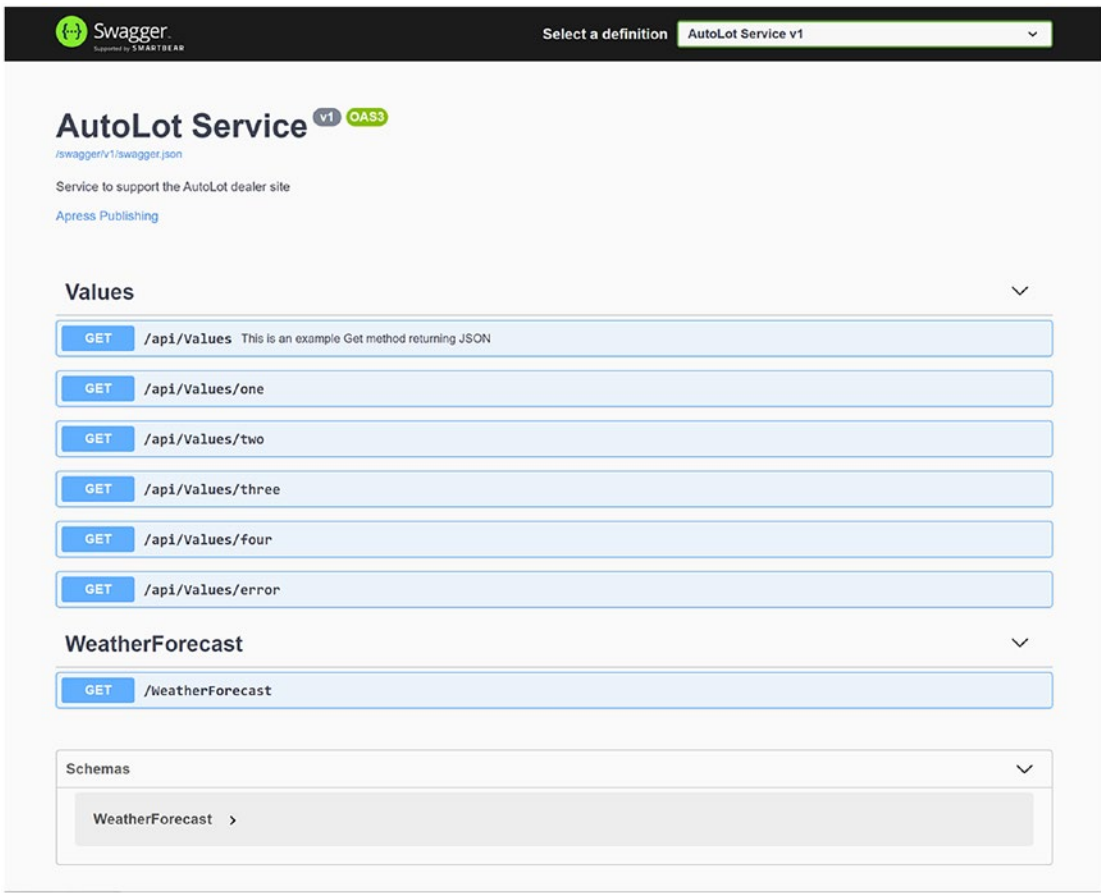
## Update the Launchsettings.json File

Previously, you updated the launchsettings.json file to launch the Values controller. Now you will update both profiles to use SwaggerUI as the start page. Update the launchSetting.json file profiles to match this listing:

```
"profiles": {
  "IIS Express": {
    "commandName": "IISExpress",
    "launchBrowser": true,
    "launchUrl": "swagger",
    "environmentVariables": {
      "ASPNETCORE_ENVIRONMENT": "Development"
    }
  },
  "AutoLot.Api": {
    "commandName": "Project",
    "launchBrowser": true,
    "launchUrl": "swagger",
    "applicationUrl": "https://localhost:5011;http://localhost:5010",
    "environmentVariables": {
      "ASPNETCORE_ENVIRONMENT": "Development"
    }
  }
}
```

## Run and Test the Application

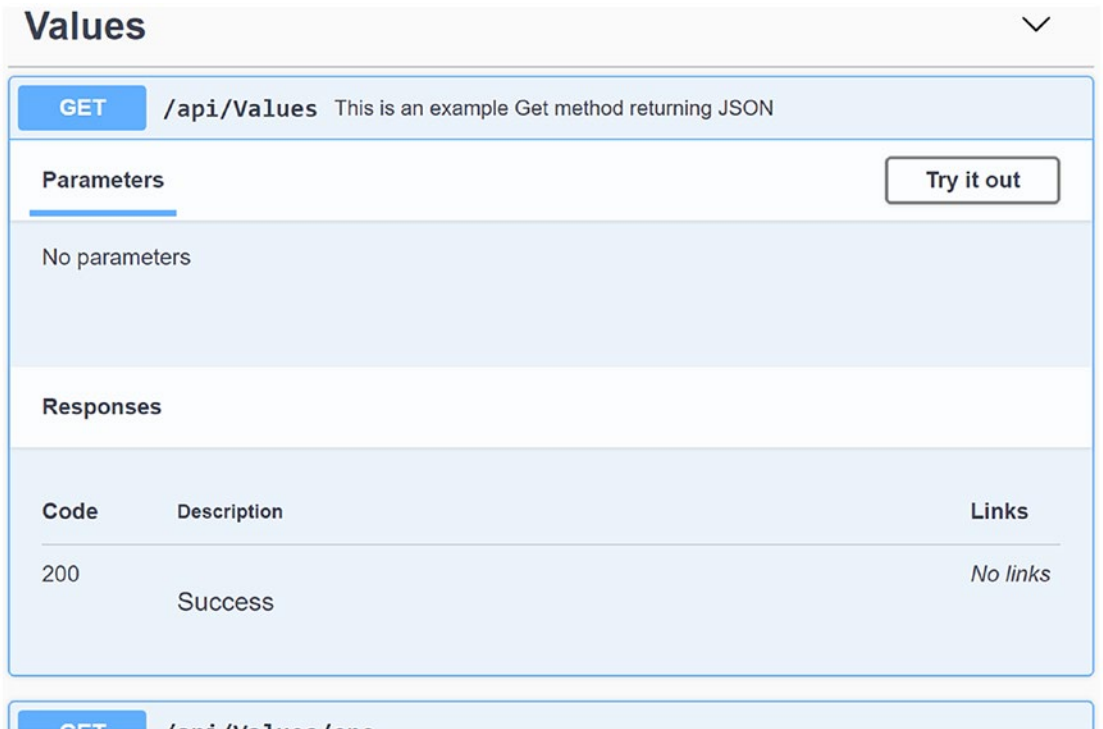
When the browser launches, the Swagger page shows all of the ApiController endpoints in the site (currently only the default WeatherForecast and Values controllers), as shown in Figure 30-1.



**Figure 30-1.** The Swagger Documentation Page

Notice the comment on the first Values controller Get method. This is the comment that was added using the XML documentation, and it has been merged into the page.

Swagger can be used to test the API as well. Click the first Get method, and you will get an expanded UI that lists any input parameters and any potential responses and a button labelled “Try it out”. This is shown in Figure 30-2.



**Figure 30-2.** Endpoint details and the Try it out button

Clicking the button updates the UI to allow for entering input parameters and executing the request. The results of the request are then shown back to the user. The results of executing the request are shown in Figure 30-3.

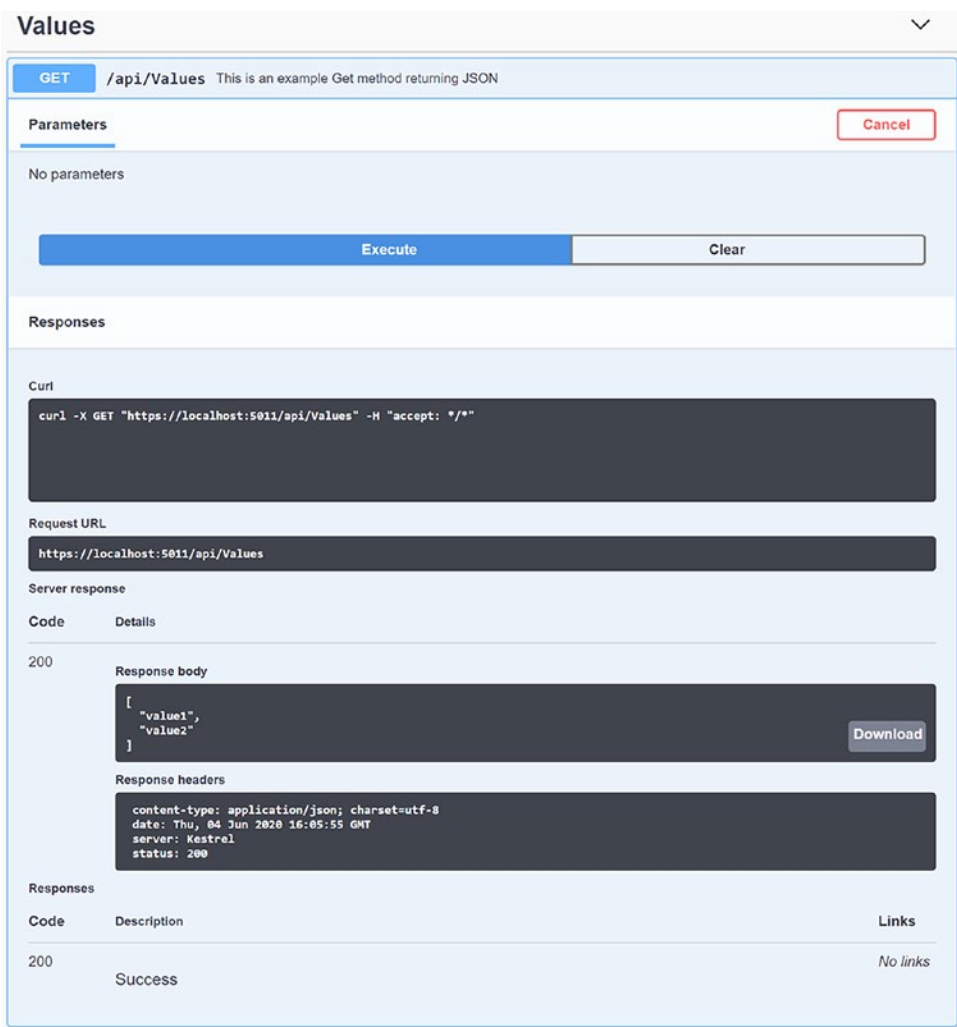


Figure 30-3. Exercising the API

**Note** There is a lot of additional customization that Swashbuckle supports. Consult the docs at <https://github.com/domaindrivendev/Swashbuckle.AspNetCore> for more information.

## Building the Controllers

There will be a controller for each model, as well as a base controller to hold all of the shared Create, Read, Update, and Delete (CRUD) functionality.



## The BaseCrudController

The BaseCrudController will house the standard Get (GetOne, GetAll) methods and the CreateOne, UpdateOne, and DeleteOne methods. Start by creating a new folder named Base in the Controllers directory of the AutoLot.Api project. In this folder, add a new blank API Controller named BaseCrudController.cs. Update the using statements to the following:

```
using System;
using System.Collections.Generic;
using System.IO;
using System.Text;
using System.Text.Json;
using System.Threading.Tasks;
using AutoLot.Dal.Models.Entities.Base;
using AutoLot.Dal.Repos.Base;
using Microsoft.AspNetCore.Mvc;
using Microsoft.EntityFrameworkCore;
using Microsoft.Extensions.Logging;
```

Make the class public and abstract and inherit from ControllerBase. Also, make the class generic that will accept two types. The first derives from BaseEntity and has a default constructor. The second derives from BaseCrudController itself. The reason for this will become clear shortly.

Finally, add the ApiController attribute. When a base class is decorated with the ApiController attribute, and derived controllers get the benefit and functionality provided by the attribute. Your code should look like this:

```
[ApiController]
public abstract class BaseCrudController<T, TController> : ControllerBase
    where T : BaseEntity, new()
    where TController : BaseCrudController<T, TController>
{
}
```

---

■ **Note** There isn't a route defined on this class. It will be set using the derived classes.

---

## The Constructor

The next step is to add two protected class-level variables: one to hold an instance of IRepo<T> and the other to hold an instance of ILogger<T>. The IRepo<T> instance will be based on the entity type that the derived repo is based on. The logger instance needs to be typed to the derived controller so the logs will show the derived controller instance and not the base instance, which helps when using the logs to troubleshoot issues. Both of these should be set using a constructor:

```
protected readonly IRepo<T> MainRepo;
protected readonly ILogger<TController> Logger;
protected BaseCrudController(IRepo<T> repo, ILogger<TController> logger)
{
    MainRepo = repo;
    Logger = logger;
}
```

## The Get Methods

There are two `HttpGet` methods, `GetOne` and `GetAll`. Both use the repo passed into the controller. First, add the `GetAll` method:

```
[HttpGet]
public ActionResult<IEnumerable<T>> GetAll()
{
    return Ok(MainRepo.GetAllIgnoreQueryFilters());
}
```

Recall that in API routing the names of the methods don't affect the route. The Controller name, route parameters, and HTTP Verb define the route. If this method was called using a derived class named `CarsController` with a route of `api/[Controller]`, the route used to reach this method would be

`http://localhost:5011/api/Cars`

The next method gets a single record, based on the `Id`, which is passed in as a route parameter:

```
// GET: api/Cars/5
[HttpGet("{id}")]
public ActionResult<T> GetOne(int id)
{
    var entity = MainRepo.Find(id);
    if (entity == null)
    {
        return NotFound();
    }
    return Ok(entity);
}
```

## The UpdateOne Method

The HTTP Put verb represents an update to a record. The method is listed here, with explanation to follow:

```
[HttpPut("{id}")]
public IActionResult UpdateOne(int id, T entity)
{
    if (id != entity.Id)
    {
        return BadRequest();
    }
    try
    {
        MainRepo.Update(entity);
    }
    catch (DbUpdateConcurrencyException ex)
    {
        //Should handle more gracefully
        return BadRequest(ex);
    }
}
```

```

catch (Exception ex)
{
    //Should handle more gracefully
    return BadRequest(ex);
}
return Ok(entity);
}

```

The method starts by setting the route. It will only accept an `HttpPut` request, and the `Id` of the record is required as part of the route. The route value is automatically assigned to the `id` parameter (implicit `[FromRoute]`), and the entity is assigned from the body of the request (implicit `[FromBody]`). Both of these assignments are benefits of using the `ApiController` attribute.

Also notice that there isn't a check for `ModelState` validity. This is also done automatically by the `ApiController` attribute. If the `ModelState` isn't valid, a 400 (`BadRequest`) will be returned to the client.

The method checks to make sure the route value matches the `id` in the body. If it doesn't, a `BadRequest` is returned. If it does, the repo is used to update the record. If this fails for either a concurrency exception or some other exception, a 400 is returned to the client. Finally, if all succeeds, a 200 (OK) is returned to the client with the updated record passed in as the body of the response.

---

■ **Note** The exception handling in this example (and the rest of the examples as well) is woefully inadequate. Production applications should leverage all you have learned up to this point in the book to gracefully handle problems as the requirements dictate.

---

## The AddOne Method

The HTTP `Post` verb represents an insert to a record. The method is listed here, with explanation to follow:

```

[HttpPost]
public ActionResult<T> AddOne(T entity)
{
    try
    {
        MainRepo.Add(entity);
    }
    catch (Exception ex)
    {
        //Should handle more gracefully
        return BadRequest(ex);
    }
    return CreatedAtAction(nameof(GetOne), new { id = entity.Id }, entity);
}

```

This method starts off by defining the route as an HTTP `Post`. There isn't a route parameter since it's a new record. Once again, the `ApiController` will return a bad request result if the model binding or validation fails.

If the repo successfully adds the record, the response is a `CreatedAtAction`. This returns an HTTP 201 to the client, with the URL for the newly created entity as the `Location` header value. The body of the response is the newly added entity as JSON.

## The DeleteOne Method

The HTTP Delete verb represents a removal of a record and an insert to a record. This method poses a problem when using the ApiController attribute. The reason is that when executing a delete, many systems will only send the minimum data (in our case, the Id and TimeStamp properties). This is how the AutoLot. Mvc delete method will be coded in the next chapter. With the automatic validation and HTTP 400 process, this means that a method signature like this will not work:

```
[HttpDelete("{id}")]
public ActionResult<T> DeleteOne([FromRoute]int id,T entity)
{
    ...
}
```

The body will never get executed. There are a couple of options to fix this. The first is to turn off ModelState checking in the ConfigureServices method in Startup.cs. The code to do that is listed here:

```
services.AddControllers()
    .ConfigureApiBehaviorOptions(options =>
    {
        options.SuppressModelStateInvalidFilter = true;
    })
    .AddJsonOptions(options =>
    {
        options.JsonSerializerOptions.PropertyNamingPolicy = null;
        options.JsonSerializerOptions.WriteIndented = true;
    });
```

The problem with that option is that model state checking is now turned off for your *entire* application. That means adding in a lot more code to your other methods for the benefit of just this one.

Another option is to explicitly build an instance of the entity from the message body content and use that instance for the delete process. Normally, you could call TryUpdateModelAsync, but currently there is a problem with deserializing the TimeStamp byte[] using this method. So, we are going to go old school and roll our own content reading code. The following code will read the JSON from the body content and then use System.Text.Json to deserialize the JSON into an instance of the entity:

```
var bodyStr = "";
using (var reader
    = new StreamReader(HttpContext.Request.Body, Encoding.UTF8, true, 1024, true))
{
    bodyStr = await reader.ReadToEndAsync();
}
var entity = JsonSerializer.Deserialize<T>(bodyStr);
```

Once you have the instance created from the body content, use the repo to process the delete. The entire method is listed here:

```
[HttpDelete("{id}")]
public async Task<ActionResult<T>> DeleteOne(int id)
{
    var bodyStr = "";
```

```

using (var reader
    = new StreamReader(HttpContext.Request.Body, Encoding.UTF8, true, 1024, true))
{
    bodyStr = await reader.ReadToEndAsync();
}
var entity = JsonSerializer.Deserialize<T>(bodyStr);
try
{
    MainRepo.Delete(entity);
}
catch (Exception ex)
{
    //Should handle more gracefully
    return BadRequest();
}
return Ok();
}

```

## The CarsController

The CarsController derives from the BaseCrudController and defines the controller route. Create a new empty API controller named CarsController in the Controllers folder. Update the using statements to the following:

```

using System.Collections.Generic;
using AutoLot.Api.Controllers.Base;
using Microsoft.AspNetCore.Mvc;
using AutoLot.Dal.Models.Entities;
using AutoLot.Dal.Repos.Interfaces;
using Microsoft.Extensions.Logging;

```

The constructor takes in the entity-specific repo and an instance of the logger. Here is the initial controller layout:

```

[Route("api/[controller]")]
public class CarsController : BaseCrudController<Car, CarsController>
{
    public CarsController(ICarRepo carRepo, ILogger<CarsController> logger)
        : base(carRepo, logger) { }
}

```

The CarsController extends the base class with another action method that gets all of the cars for a particular make. Add the following code, and the explanation will follow:

```

[HttpGet("bymake/{id?}")]
public ActionResult<IEnumerable<Car>> GetCarsByMake(int? id)
{
    if (id.HasValue && id.Value>0)
    {
        return Ok(((ICarRepo)MainRepo).GetAllBy(id.Value));
    }
    return Ok(MainRepo.GetAllIgnoreQueryFilters());
}

```

The `HttpGet` attribute extends the route with the “bymake” constant and then the id of the make to filter on, for example:

```
https://localhost:5011/api/cars/bymake/5
```

Next, it checks if a value was passed in for the id. If not, it gets all vehicles. If a value was passed in, it uses the `GetAllBy` method of the `CarRepo` to get the cars by make. Since the `MainRepo` protected property of the base class is defined as `IRepo<T>`, it must be cast back to the `ICarRepo` interface.

## The Remaining Controllers

The remaining entity-specific controllers all derive from the `BaseCrudController`, but don’t add any additional functionality. Add four more empty API controllers named `CreditRisksController`, `CustomersController`, `MakesController`, and `OrdersController` to the `Controllers` folder. Update the using statements for all of the files to the following:

```
using AutoLot.Api.Controllers.Base;
using AutoLot.Dal.Models.Entities;
using AutoLot.Dal.Repos.Interfaces;
using Microsoft.AspNetCore.Mvc;
using Microsoft.Extensions.Logging;
```

The remaining controllers are all shown here:

```
[Route("api/[controller]")]
public class CreditRisksController : BaseCrudController<CreditRisk, CreditRisksController>
{
    public CreditRisksController(
        ICreditRiskRepo creditRiskRepo, ILogger<CreditRisksController> logger)
        : base(creditRiskRepo, logger) { }
}

[Route("api/[controller]")]
public class CustomersController : BaseCrudController<Customer, CustomersController>
{
    public CustomersController(
        ICustomerRepo customerRepo, ILogger<CustomersController> logger)
        : base(customerRepo, logger) { }
}

[Route("api/[controller]")]
public class MakesController : BaseCrudController<Make, MakesController>
{
    public MakesController(IMakeRepo makeRepo, ILogger<MakesController> logger)
        : base(makeRepo, logger) { }
}
```

```
[Route("api/[controller]")]
public class OrdersController : BaseCrudController<Order, OrdersController>
{
    public OrdersController(IOrderRepo orderRepo, ILogger<OrdersController> logger)
        : base(orderRepo, logger) { }
}
```

While this completes all of the controllers, if you were to test the app with Swagger, you will find exceptions due to JSON cycle problems. You will resolve that next.

## Handling Cyclical JSON Serialization

When ASP.NET Core serializes objects into JSON, it recursively walks the properties to serialize the objects connected by navigation properties. Then those objects are serialized as well, including the object that the serialization started with. This causes the JSON equivalent of a stack overflow. You can see this by running the application, selecting the api/Cars method, and trying it out through Swagger. You will receive a message that starts with this:

System.Text.Json.JsonException: A possible object cycle was detected which is not supported. This can either be due to a cycle or if the object depth is larger than the maximum allowed depth of 32.

ASP.NET Core uses System.Text.Json for serialization and deserialization. This file replaces the commonly used project Newtonsoft.Json. System.Text.Json has notable performance improvements over Newtonsoft, but at this time lacks a significant amount of functionality (each release brings it closer to its predecessor). Newtonsoft.Json can be configured to prevent this issue, but at this time, System.Text.Json does not.

One way to resolve this issue is to revert to using Newtonsoft.Json (see <https://docs.microsoft.com> for instructions), but then you lose the performance benefits. Another way to resolve this issue is to create view models that don't have the bidirectional navigation properties and only send/receive the view models.

Yet another way to resolve this is to add the `JsonIgnore` attribute into your models to prevent the cycle. This is what we are going to do to solve this. Open up the Cars.cs, Customer.cs, and Make.cs entities and add the following using statement:

```
using System.Text.Json.Serialization;
```

Next, add the `JsonIgnore` attribute to each of the list properties in those classes, like this:

```
public partial class Car : BaseEntity
{
    ...
    [JsonIgnore]
    [InverseProperty(nameof(Order.CarNavigation))]
    public virtual IEnumerable<Order> Orders { get; set; } = new List<Order>();
}
public partial class Customer : BaseEntity
{
    ...
    [JsonIgnore]
    [InverseProperty(nameof(CreditRisk.CustomerNavigation))]
```

```

public virtual IEnumerable<CreditRisk> CreditRisks { get; set; } = new List<CreditRisk>();
[JsonIgnore]
[InverseProperty(nameof(Order.CustomerNavigation))]
public virtual IEnumerable<Order> Orders { get; set; } = new List<Order>();
}
public class Make : BaseEntity
{
    ...
    [JsonIgnore]
    [InverseProperty(nameof(Car.MakeNavigation))]
    public IEnumerable<Car> Cars { get; set; } = new List<Car>();
}

```

Now when you run the application and test the methods with Swagger, the methods work as expected.

## Exception Filters

When an exception occurs in a Web API application, there isn't an error page that gets displayed to the user. In fact, the user is very seldom a person, but another application. Instead of just returning an HTTP 500 (server error code), it's helpful to send additional information in the JSON that's returned, so the calling application can react appropriately. While it would be fairly trivial to wrap all of the action methods in try-catch blocks, doing so would lead to a lot of repeated code.

Fortunately, there is a better way. As discussed in Chapter 29, ASP.NET Core allows the creation of filters that can run before or after a particular stage of the pipeline or in the event of an unhandled exception. Filters can be applied globally, at the controller level, or at the action level. For this application, you are going to build an exception filter to send formatted JSON back (along with the HTTP 500) and include a stack trace if the site is running in debug mode.

---

■ **Note** Filters are an extremely powerful feature of ASP.NET Core. In this chapter, we are only examining exception filters, but there are many more that can be created that can save significant time when building ASP.NET Core applications. For the full information on filters, refer to the documentation here: <https://docs.microsoft.com/en-us/aspnet/core/mvc/controllers/filters>.

---

## Create the CustomExceptionHandler

Create a new directory named `Filters` in the `AutoLot.Apo` project. Add a new class named `CustomExceptionHandler.cs` in this folder. Update the using statements to the following:

```

using Microsoft.AspNetCore.Hosting;
using Microsoft.AspNetCore.Mvc;
using Microsoft.AspNetCore.Mvc.Filters;
using Microsoft.EntityFrameworkCore;
using Microsoft.Extensions.Hosting;

```



Change the class to public and inherit from `ExceptionHandlerAttribute`. Override the `OnException` method, as shown here:

```
public class CustomExceptionHandler : ExceptionHandlerAttribute
{
    public override void OnException(ExceptionContext context)
    {
        throw new NotImplementedException();
    }
}
```

Unlike most filters in ASP.NET Core that have a before and after event handler, exception filters only have one handler – `OnException` (or `OnExceptionAsync`). This handler has one parameter, `ExceptionContext`. This parameter provides access to the `ActionContext` as well as the exception that was thrown.

Filters also participate in dependency injection, allowing for any item in the container to be accessed in the code. In this example, we need an instance of the `IWebHostEnvironment` injected into the filter. If the environment is `Development`, the response should also include the stack trace. Add a class-level variable to hold the instance of the `IWebHostEnvironment` and add the constructor as shown here:

```
private readonly IWebHostEnvironment _hostEnvironment;
public CustomExceptionHandler(IWebHostEnvironment hostEnvironment)
{
    _hostEnvironment = hostEnvironment;
}
```

The code in the `OnException` event handler checks the type of exception thrown and builds an appropriate response. If the environment is `Development`, the stack trace is included in the response message. A dynamic object that contains the values to be sent to the calling request is built and returned in an `ActionResult`. The updated method is shown here:

```
public override void OnException(ExceptionContext context)
{
    var ex = context.Exception;
    string stackTrace = _hostEnvironment.IsDevelopment()
        ? context.Exception.StackTrace
        : string.Empty;
    string message = ex.Message;
    string error;
    IActionResult actionResult;
    switch (ex)
    {
        case DbUpdateConcurrencyException ce:
            //Returns a 400
            error = "Concurrency Issue.";
            actionResult = new BadRequestObjectResult(
                new { Error = error, Message = message, StackTrace = stackTrace });
            break;
    }
```

```

    default:
        error = "General Error.";
        actionResult = new ObjectResult(
            new { Error = error, Message = message, StackTrace = stackTrace })
        {
            StatusCode = 500
        };
        break;
    }
    //context.ExceptionHandled = true; //If this is uncommented, the exception is swallowed
    context.Result = actionResult;
}

```

If you want the exception filter to swallow the exception and set the response to a 200 (e.g., to log the error but not return it to the client), add the following line before setting the Result (commented out in the preceding example):

```
context.ExceptionHandled = true;
```

## Adding the Exception Filter for All Actions

As stated earlier, filters can be set globally, at the controller level, or on individual actions. Exception filters are usually set globally, and that is what you are going to do next. Open `Startup.cs` and add the following using statement to the top of the file:

```
using AutoLot.Api.Filters;
```

Next, navigate to the `ConfigureServices` method. Change the `AddControllers` line to register the filter, as shown here:

```

services.AddControllers(config => config.Filters.Add(new CustomExceptionFilter(_env)))
    .AddJsonOptions(options =>
    {
        options.JsonSerializerOptions.PropertyNamingPolicy = null;
        options.JsonSerializerOptions.WriteIndented = true;
    });

```

This sets the `CustomExceptionFilter` for all actions in the application.

## Test the Exception Filter

To test the exception filter, open the `ValuesController.cs` file, and update the `Get()` action to the code shown here (you might have to add a using statement for `System`):

```

[HttpGet]
public ActionResult Get()
{
    throw new Exception("Test Exception");
    return Ok(new string[] { "value1", "value2" });
}

```

Run the application and exercise the method using Swagger. The results shown in the Swagger UI should match the following output (stack trace shortened for brevity):

```
{
  "Error": "General Error.",
  "Message": "Test Exception",
  "StackTrace": "    at AutoLot.Api.Controllers.ValuesController.Get() in
    <omitted for brevity>"
}
```

## Add Cross-Origin Requests Support

APIs should have policies in place that allow or prevent clients that originate from another server to communicate with the API. These types of requests are called Cross-Origin Requests (CORS). While this isn't needed when you are running locally on your machine in an all ASP.NET Core world, it is needed by JavaScript frameworks that want to communicate with your API, even when all are running locally.

---

■ **Note** For more information on CORS support, refer to the document article here:  
<https://docs.microsoft.com/en-us/aspnet/core/security/cors>.

---

## Create a CORS Policy

ASP.NET Core has rich support for configuring cores, including methods to allow/disallow headers, methods, origins, credentials, and more. In this example, we are going to leave everything as wide open as possible. Configuration starts by creating a CORS policy and adding the policy into the services collection. The policy is named (this name will be used in the Configure method) followed by the rules. The following example creates a policy named "AllowAll" and then does just that. Add the following code to the ConfigureServices method in the Startup.cs class:

```
services.AddCors(options =>
{
    options.AddPolicy("AllowAll", builder =>
    {
        builder
            .AllowAnyHeader()
            .AllowAnyMethod()
            .AllowAnyOrigin();
    });
});
```

## Add the CORS Policy to the HTTP Pipeline Handling

The final step is to add the CORS policy into the HTTP Pipeline handling. Add the following line into the `Configure` method of `Startup.cs`, making sure it is between the `app.UseRouting` and `app.UseEndpoints` method calls:

```
public void Configure(
    IApplicationBuilder app,
    IWebHostEnvironment env,
    ApplicationDbContext context)
{
    ...
    //opt-in to routing
    app.UseRouting();
    //Add CORS Policy
    app.UseCors("AllowAll");
    //enable authorization checks
    app.UseAuthorization();
    //opt-in to using endpoint routing
    app.UseEndpoints(endpoints =>
    {
        //use attribute routing on controllers
        endpoints.MapControllers();
    });
}
```

## Summary

This chapter continued our study of ASP.NET Core, and finished the `AutoLot.Api` application. It began with a look at how formatted JSON responses are sent back to the client and then looked at the functionality that the `ApiController` attribute adds to controllers that are decorated with it.

Swashbuckle was added into the application to add support for creating Swagger documentation and the Swagger UI. Next, the base controller was built, which holds most of the functionality of the application. After that, the derived, entity-specific controllers were added into the project. The next part was solving the cyclical JSON issue created by the bidirectional navigation properties on our entities.

The final two steps added in an application-wide exception filter and support for cross-origin requests.

In the next chapter, you will build `AutoLot.MVC`.

## CHAPTER 31



# MVC Applications with ASP.NET Core

Chapter 29 laid the foundation for ASP.NET Core, and Chapter 30 built a RESTful service using ASP.NET Core. In this (final) chapter on ASP.NET Core, we build the ASP.NET Core web application using the MVC pattern. We begin by putting the V back into MVC.

## Introducing the “V” in ASP.NET Core

When building ASP.NET Core services, only the “M” (Models) and the “C” (Controllers) of the MVC pattern are used. The user interface is created using the “V”, or the Views of the MVC pattern. Views are built using HTML, JavaScript, CSS, and Razor code, optionally have a base layout page, and are rendered from a controller Action method or a View Component. If you have worked in classic ASP.NET MVC, this should sound familiar.

## ViewResults

As mentioned briefly in Chapter 29, `ViewResults` and `PartialView` results are `ActionResults` that are returned from an action method using the Controller helper methods. A `PartialViewResult` is designed to be rendered inside another view and doesn’t use a layout page, while a `ViewResult` (usually) is rendered in conjunction with a layout page.

The convention in ASP.NET Core (as it was in ASP.NET MVC) is for the View or `PartialView` to render a \*.cshtml file of the same name as the method. The view must either be located in a folder named for the controller (less the controller suffix) or in the Shared folder, both located under the parent Views folder. For example, the following code will render the `MyAction.cshtml` view located in the `Views\My` or `Views\Shared` folder:

```
[Route("[controller]/[action]")]
public class MyController: Controller
{
    public ActionResult MyAction()
    {
        return View();
    }
}
```

---

■ **Note** The view folder named after the controller is searched first. If the view cannot be found, the Shared folder is searched. If it still can't be found, an exception is thrown.

---

To render a view named differently than the action method name, pass in the name of the file (without the cshtml extension). The following code will render the `CustomViewName.cshtml` view.

```
public ActionResult MyAction()
{
    return View("CustomViewName");
}
```

The final two overloads provide for passing in a data object that becomes the model for the view. The first example uses the default view name, and the second example specifies a different view name.

```
public ActionResult MyAction()
{
    var myModel = new MyActionViewModel();
    return View(myModel);
}
public ActionResult MyAction()
{
    var myModel = new MyActionViewModel();
    return View("CustomViewName", myModel);
}
```

## Add the RazorSyntax Action Method

Open the HomeController in the AutoLot.Mvc application Controllers directory. Add the following using statement:

```
using AutoLot.Dal.Models.Entities;
```

Next, add the following Action method to the controller:

```
[HttpGet]
public async Task<IActionResult> RazorSyntax()
{
    var car = new Car { Id = 1, PetName = "Herbie" };
    return View(car);
}
```

This action method will return a ViewResult using the view file named `RazorSyntax.cshtml` located in Views\Home directory. If it isn't found, it will render the `RazorSyntax.cshtml` from the Views\Shared directory. If it isn't found there either, an exception will be returned to the client (browser).

The action method is passing an instance of the Car class into the view as its view model. More on that shortly.

## The Razor View Engine

The Razor View Engine was designed as an improvement over the Web Forms View Engine and uses Razor as the core language. Razor is server-side code that is embedded into a view, is based on C#, and has corrected many annoyances with the Web Forms View Engine. The incorporation of Razor into HTML and CSS results in code that is much cleaner and easier to read, and therefore easier to support and maintain.

To follow along with this section, add a new view by right-clicking the Views\Home folder and selecting Add ► View. Select Razor View from the Add New Scaffolded Item dialog, name the view RazorSyntax, and make sure the box to Use a layout page is checked. After the view generates, update the code to match the following:

```
@model AutoLot.Dal.Models.Entities.Car
@{
    ViewData["Title"] = "RazorSyntax";
}
<h1>Razor Syntax</h1>
```

Don't worry about the syntax just yet. It will all be explained in the following sections.

## Razor Syntax

The first difference between the Web Forms View Engine and the Razor View Engine is that you add Razor code with the @ symbol. There is also intelligence built into Razor that removes a significant number of the Web Form View Engine's "nuggets" (<% %>). For example, Razor is smart enough to handle the @ sign in email addresses correctly.

Statement blocks open with an @ and are either self-contained statements (like foreach) or are enclosed in braces, like the following examples:

```
@for (var i = 0; i < 15; i++)
{
    //do something
}

@{
    //Code Block
    var foo = "Foo";
    var bar = "Bar";
    var htmlString = "<ul><li>one</li><li>two</li></ul>";
}
```

To output the value of a variable to the view, just use the @ sign with the variable name. This is equivalent to Response.Write:

```
@foo
<br />
@htmlString
<br />
@foo.@bar
<br />
```

Notice how the last example (`@foo.@bar`) combined two variables together with a period (.) between them. This is not the usual C# “dot” notation of navigating a property chain. It’s just two variables’ output to the response stream with a physical period between them. If you need to “dot” your way down a variable, use the `@` on the variable, and then write your code as normal:

```
@foo.ToUpper()
```

If you want to output raw HTML, you use what’s referred to as an *HTML Helper*. These are helpers built into the Razor View Engine. Here is the line to output the raw HTML:

```
@Html.Raw(htmlString)

<hr />
```

Code blocks can intermix markup and code. Lines that begin with markup are interpreted as HTML, while all other lines are interpreted as code. If a line starts with text that is *not* code, you must use the content indicator (`@:`) or the `<text></text>` content block indicator. Note that lines can transition back and forth. Here is an example:

```
@{
    @:Straight Text
    <div>Value:@Model.Id</div>
    <text>
        Lines without HTML tag
    </text>
    <br />
}
```

If you want to escape the `@` sign, use a double `@`. Razor is also smart enough to handle email addresses, so they do not need to be escaped. If you need Razor to treat an `@` sign like the Razor token, add parenthesis:

```
foo@foo.com
<br />
@@foo
<br />
test@(foo) = testFoo
<br />
```

The preceding code outputs “foo@foo.com”, “@foo”, and “testFoo”, respectively. Finally, Razor comments are opened with `@*` and closed with `*@`:

```
@*
    Multiline Comments
    Hi.
*@
```

To render this view, start your app and navigate to `https://localhost:5001/Home/RazorSyntax`. You will see more examples of Razor as you work through the rest of this chapter.

## Views

Views are special code files with a `cshtml` extension, written using a combination of HTML markup, CSS, JavaScript, and Razor syntax.



## The Views Directory

The Views folder is where views are stored in ASP.NET Core projects using the MVC pattern. In the root of the Views folder, there are two files, `_ViewStart.cshtml` and `_ViewImports.cshtml`.

The `_ViewStart.cshtml` executes its code before any other view is rendered (excluding partial views and layouts). The file is generally used to set the default layout if one is not specifically assigned for a view. Layouts are discussed in greater detail in the “Layouts” section.

The `_ViewImports.cshtml` file is used for importing shared directives, like using statements. The contents apply to all views at or below the file location.

---

■ **Note** Why the leading underscore for `_ViewStart.html`, `_ViewImports.cshtml`, and `_Layout.cshtml`? The Razor View Engine was originally created for WebMatrix, which would allow any file that did *not* start with an underscore to be rendered directly, so core files (like layout and configuration) all had names that began with an underscore. This is not a convention that MVC cares about, since MVC doesn’t have the same issue as WebMatrix, but the underscore legacy lives on anyway.

---

As mentioned before, each controller gets its own directory under the Views folder where its specific views are stored. The names match the name of the controller (minus the word “Controller”). For example, the Views\Cars directory holds all of the views for the CarsController. The views are named after the action methods by default, although the names can be changed, as shown earlier.

## The Shared Directory

There is special directory under Views named Shared. This directory holds views that are available to all controllers and actions. As mentioned before, if a requested `cshtml` file can’t be found in the controller-specific directory, the shared folder is searched.

## The DisplayTemplates Folder

The DisplayTemplates folder holds custom templates that control how types are rendered. By default, the Razor View Engine looks for a template named after the type being rendered, for example, `Car.cshtml` for a Car class. A custom name can also be specified for the template. The search path starts in the Views\{CurrentControllerName}\DisplayTemplates folder and, if it’s not found, then looks in the Views\Shared\DisplayTemplates folder.

Create a new folder named DisplayTemplates under the Views\Shared folder. Add a new partial view named `DateTime.cshtml` into that folder. Clear out all of the generated code and comments and replace it with the following:

```
@model DateTime?
@if (Model == null)
{
    @:Unknown
}
else
{
    if (ViewData.ModelMetadata.IsNullableValueType)
    {
```

```

        @:@(Model.Value.ToString("d"))
    }
    else
    {
        @:@(((DateTime)Model).ToString("d"))
    }
}

```

If the model (the data passed into the view) is null, the template displays the word “Unknown”. Otherwise, it displays the date in Short Date format, using the Value property of a nullable type or the actual Model itself.

## The EditorTemplates Folder

The EditorTemplates folder works the same as the DisplayTemplates folder, except the templates are used for editing. You will be adding editor templates later in this chapter.

## Layouts

Similar to Web Forms Master Pages, MVC supports layouts. MVC views can be (and typically are) based on a single base layout to give the site a universal look and feel. Navigate to the Views\Shared folder and open the `_Layout.cshtml` file. It is a full-fledged HTML file, complete with `<head>` and `<body>` tags.

This file is the foundation that other views are rendered into. This creates a consistent look and feel to the site. Additionally, since most of the page (such as navigation and any header and/or footer markup) is handled by the layout page, Views Pages are kept small and simple. Scroll down in the file until you see the following line of Razor code:

```
@RenderBody()
```

That line instructs the layout page where to render the view. Now scroll down to the line just before the closing `</body>` tag. The following line creates a new section for the layout and makes it optional:

```
@RenderSection("scripts", required: false)
```

Sections can also be marked as required by passing in true as the second parameter, like this:

```
@RenderSection("Header", true)
```

Any code and/or markup in a `@section` Razor block will not be rendered as part of the body, but rendered in the correct place and order as defined in the layout page. For example, to add `jQuery.Validate` to your page, it must be added after `jQuery` has been added. Since `jQuery` is loaded before the Scripts section in the layout page, the following will load `jQuery.Validate` at the proper time:

```

@section Scripts {
    <script src="~/lib/jquery-validation/dist/jquery.validate.js"></script>
}

```

Two new options in ASP.NET Core are `IgnoreBody` and `IgnoreSection`. These methods, placed in a layout, will respectively not render the body of the view or a specific section. These enable turning features of a view on or off from the layout based on conditional logic, such as security levels.

## Specifying the Default Layout for Views

The default layout page is defined in the `_ViewStart.cshtml` file. Open this file and examine the contents, shown here:

```
@{
    Layout = "_Layout.cshtml";
}
```

This file just has one Razor code block that sets the layout to a specific file. If a view does not specify its own layout file, the file specified here is used. This same code can be added to the top of a View to use a different layout page than the default.

## Partial Views

Partial views are conceptually similar to a user control in Web Forms. Partial views are useful for encapsulating UI, which helps to reduce repeated code and/or markup. A partial view does not use a layout and is injected into another view or is rendered with a View Component (covered later in this chapter).

## Sending Data to Views

MVC views can be strongly typed, based on a model (or view model). The model data is passed into the view from an action method, as was done in the `RazorSyntax` action (although it wasn't used in the view example):

```
[HttpGet]
public async Task<IActionResult> RazorSyntax()
{
    var car = new Car { Id = 1, PetName = "Herbie" };
    return View(car);
}
```

## Strongly Typed Views and View Models

When a model or `ViewModel` is passed into the view method, the value gets assigned to the `@model` property of a strongly typed view, as shown here (note the lowercase “m”):

```
@model IEnumerable<Order>
```

The `@model` sets the type for the view and can then be accessed by using the `@Model` Razor command, like this (note the capital “M”):

```
@foreach (var item in Model)
{
    //Do something interesting here
}
```

## ViewBag, ViewData, and TempData

The ViewBag, ViewData, and TempData objects are mechanisms for sending small amounts of data into a View. Table 31-1 lists the three mechanisms to pass data from a controller to a view (besides the Model property) or from a controller to a controller.

**Table 31-1.** *Additional Ways to Send Data to a View*

Data Transport Object	Description of Use
TempData	This is a short-lived object that works during the current request and next request only. Typically used when redirecting to another action method.
ViewData	A dictionary that allows storing values in name/value pairs (e.g., ViewData["Title"] = "Foo").
ViewBag	Dynamic wrapper for the ViewData dictionary (e.g., ViewBag.Title = "Foo").

Both ViewBag and ViewData point to the same object; they just provide different ways to access the data.

## Tag Helpers

Tag Helpers are a new feature introduced in ASP.NET Core. A *Tag Helper* is markup (a custom tag or an attribute on a standard tag) that represents server-side code. The server-side code then helps shape the HTML emitted. They greatly improve the development experience and readability of MVC views. Unlike HTML Helpers, which are invoked as Razor methods, Tag Helpers are attributes added to standard HTML elements or stand-alone custom tags. If you are developing with Visual Studio, then there is an added benefit of IntelliSense for the built-in Tag Helpers.

For example, the following HTML Helper creates a label for the customer’s FullName:

```
@Html.Label("FullName", "Full Name:", new { @class="customer" })
```

This generates the following HTML:

```
<label class="customer" for="FullName">Full Name:</label>
```

For the C# developer who has been working with ASP.NET MVC and Razor, the HTML helper syntax is probably well understood. But it’s not intuitive, especially for someone who works in HTML/CSS/JavaScript and not C#.

The Tag Helper version looks like this:

```
<label class="customer" asp-for="FullName">Full Name:</label>
```

They produce the same output, but Tag Helpers keep you “in the markup”

There are many built-in Tag Helpers, and they are designed to be used instead of their respective HTML Helpers. However, not all HTML Helpers have an associated Tag Helper. Table 31-2 lists the available Tag Helpers, their corresponding HTML Helper, and the available attributes. Each is explained in the next sections, except for the Label Tag Helper, which was already discussed.

**Table 31-2.** Built-In Tag Helpers

Tag Helper	HTML Helper	Available Attributes
Form	Html.BeginForm Html.BeginRouteForm Html.AntiForgeryToken	<p>asp-route – for named routes (can't be used with controller or action attributes).asp-antiforgery – if the antiforgery should be added.</p> <p>asp-area – the name of the area.</p> <p>asp-controller – defines the controller.</p> <p>asp-action – defines the action.</p> <p>asp-route-<b>&lt;ParameterName&gt;</b> - adds the parameter to the route, e.g., asp-route-id="1".</p> <p>asp-all-route-data - dictionary for additional route values. It also automatically adds the antiforgery token.</p>
Anchor	Html.ActionLink	<p>asp-route – for named routes (can't be used with controller or action attributes).</p> <p>asp-area – the name of the area.</p> <p>asp-controller – defines the controller.</p> <p>asp-action – defines the action.</p> <p>asp-protocol – http or https.</p> <p>asp-fragment – URL fragment.</p> <p>asp-host – the host name.</p> <p>asp-route-<b>&lt;ParameterName&gt;</b> - adds the parameter to the route, e.g., asp-route-id="1".</p> <p>asp-all-route-data - dictionary for additional route values.</p>
Input	Html.TextBox/TextBoxFor Html.Editor/EditorFor	asp-for – a model property. Can navigate the model (Customer.Address.AddressLine1) and use expressions (asp-for="@localVariable"). The id and name attributes are autogenerated. Any HTML5 data-val attributes are autogenerated.
TextArea	Html.TextAreaFor	asp-for – a model property. Can navigate the model (Customer.Address.Description) and use expressions (asp-for="@localVariable"). The id and name attributes are autogenerated. Any HTML5 data-val attributes are autogenerated.
Label	Html.LabelFor	asp-for – a model property. Can navigate the model (Customer.Address.AddressLine1) and use expressions (asp-for="@localVariable").
Partial	Html.Partial(Async) Html.RenderPartial(Async)	<p>name – the path and name of the partial view.</p> <p>for – model expression on current form to be the model in the partial.</p> <p>model – an object to be the model in the partial.</p> <p>view-data – ViewData for the partial.</p>

*(continued)*

**Table 31-2.** (continued)

Tag Helper	HTML Helper	Available Attributes
Select	Html.DropDownListFor Html.ListBoxFor	asp-for – a model property. Can navigate the model (Customer.Address.AddressLine1) and use expressions (asp-for="@localVariable"). asp-items – specifies the options elements. Autogenerates the selected="selected" attribute. The id and name attributes are autogenerated. Any HTML5 data-val attributes are autogenerated.
Validation Message (Span)	Html.ValidationMessageFor	asp-validation-for – a model property. Can navigate the model (Customer.Address.AddressLine1) and use expressions (asp-for="@localVariable"). Adds the data-valmsg-for attribute to the span.
Validation Summary (Div)	Html.ValidationSummaryFor	asp-validation-summary – selects one of All, ModelOnly, or None. Adds the data-valmsg-summary attribute to the div.
Link	N/A	asp-append-version – appends version to filename. asp-fallback-href – fallback file to use if primary is not available; usually used with CDN sources. asp-fallback-href-include – globbed file list of files to include on fallback. asp-fallback-href-exclude – globbed file list of files to exclude on fallback. asp-fallback-test-* – properties to use on fallback test. Included are class, property, and value. asp-href-include – globbed file pattern of files to include. asp-href-exclude – globbed file pattern of files to exclude.
Script	N/A	asp-append-version – appends version to file name. asp-fallback-src – fallback file to use if primary is not available; usually used with CDN sources. asp-fallback-src-include – globbed file list of files to include on fallback. asp-fallback-src-exclude – globbed file list of files to exclude on fallback. asp-fallback-test – the script method to use in fallback test. asp-src-include – globbed file pattern of files to include. asp-src-exclude – globbed file pattern of files to exclude.
Image	N/A	asp-append-version – appends version to filename.
Environment	N/A	name – single host environment name of comma-separated list of names to trigger rendering of the content (ignores case). include – works the same as the name attribute. exclude – works on the opposite of the include attribute.

Two additional tag helpers, Cache and Distributed Cache, are available but not covered here. In addition to the pre-supplied tag helpers, custom tag helpers can be created as well.

## Enabling Tag Helpers

Tag Helpers must be made visible to any code that wants to use them. The `_ViewImports.html` file from the standard template already contains the following line:

```
@addTagHelper *, Microsoft.AspNetCore.Mvc.TagHelpers
```

This makes all Tag Helpers in the `Microsoft.AspNetCore.Mvc.TagHelpers` assembly (which contains all of the built-in Tag Helpers) available to all of the Views at or below the directory level of the `_ViewImports.cshtml` file.

## The Form Tag Helper

The Form Tag Helper replaces the `Html.BeginForm` and `Html.BeginRouteForm` HTML Helpers. For example, to create a form that submits to the HTTP Post version of the `Edit` action on the `CarsController` with one parameter (`Id`), use the following code and markup:

```
<form method="post" asp-controller="Cars" asp-action="Edit"
      asp-route-id="@Model.Id" >
<!-- Omitted for brevity -->
</form>
```

If the Form tag was rendered in a view by the HTTP Get version of the `Edit` action of the `CarsController`, the `asp-controller` and `asp-action` attributes are optional. However, to be an actual Tag Helper, one of the `asp-` tags must be present. As long as one of the `asp-` tags is present, the antiforgery token is added into the form. If none of the tags are present, then it's just a plain old HTML form, and the antiforgery token must be added in manually. The antiforgery token can be disabled by adding `asp-antiforgery="false"` into the form tag. The antiforgery token will be covered later.

## The Anchor Tag Helper

The Anchor Tag Helper replaces the `Html.ActionLink` HTML Helper. For example, to create a link for the site menu, use the following code:

```
<a asp-controller="Cars" asp-action="ByMake" asp-route-makeId="@item.Id"
  asp-route-makeName="@item.Name">
  @item.Name
</a>
```

The Tag Helper creates the URL from the route table. The resulting URL looks like this:

```
<a href="/Cars/ByMake/1/VW">VW</a>
```

## The Input Tag Helper

The Input Tag Helper is one of the most versatile Tag Helpers. In addition to autogenerating the HTML `id` and `name` attributes, as well as any HTML5 `data-val` validation attributes, the Tag Helper builds the appropriate HTML markup based on the datatype of the target property. Table 31-3 lists the HTML type that is created based on the .NET Core type of the property.

**Table 31-3.** *HTML Types Generated from .NET Types Using the Input Tag Helper*

.NET Type	Generated HTML Type
Bool	type="checkbox"
String	type="text"
DateTime	type="datetime"
Byte, Int, Single, Double	type="number"

Additionally, the Input Tag Helper will add HTML5 type attributes based on data annotations. Table 31-4 lists some of the most common annotations and the generated HTML5 type attributes.

**Table 31-4.** *HTML5 Type Attributes Generated from .NET Data Annotations*

.NET Data Annotation	Generated HTML5 Type Attribute
EmailAddress	type="email"
Url	type="url"
HiddenInput	type="hidden"
Phone	type="tel"
DataType(DataType.Password)	type="password"
DataType(DataType.Date)	type="date"
DataType(DataType.Time)	type="time"

For example, to display a text box for editing the Id value on a model, use the following:

```
<input asp-for="Id" />
```

Presuming the value of the Id field is 2, the following HTML gets generated:

```
<input name="Name" id="Name" type="number" value="2" data-val-required="The Id field is required." data-val="true" >
```

The id, name, value, and validation attributes are all added automatically.

## The TextArea Tag Helper

The TextArea Tag Helper adds the id and name attributes automatically and any HTML5 validation tags defined for the property. For example, the following line creates a textarea tag for the Description property:

```
<textarea asp-for="Description"></textarea>
```



## The Select Tag Helper

The Select Tag Helper builds input select tags from a model property and a collection. As with the other input Tag Helpers, the id and name are added to the markup, as well as any HTML5 data-val attributes. If the model property value matches one of the select list item's values, that option gets the selected attribute added to the markup.

For example, take a model that has a property named Country and a SelectList named Countries, with the list defined as follows:

```
public List<SelectListItem> Countries { get; } = new List<SelectListItem>
{
    new SelectListItem { Value = "MX", Text = "Mexico" },
    new SelectListItem { Value = "CA", Text = "Canada" },
    new SelectListItem { Value = "US", Text = "USA" },
};
```

The following markup will render the select tag with the appropriate options:

```
<select asp-for="Country" asp-items="Model.Countries"></select>
```

If the value of the Country property is set to CA, the following full markup will be output to the view:

```
<select id="Country" name="Country">
  <option value="MX">Mexico</option>
  <option selected="selected" value="CA">Canada</option>
  <option value="US">USA</option>
</select>
```

## The Validation Tag Helpers

The Validation Message and Validation Summary Tag Helpers closely mirror the `Html.ValidationMessageFor` and `Html.ValidationSummaryFor` HTML Helpers. The first is applied to an HTML span for a specific property on the model, and the latter is applied to a div tag and represents the entire model. The Validation Summary has the option of All errors, ModelOnly (excluding errors on model properties), or None.

The following code adds a Validation Summary for model-level errors and a Validation Message for the Id property of the model:

```
<div asp-validation-summary="ModelOnly" class="text-danger"></div>
<span asp-validation-for="Id" class="text-danger"></span>
```

These will display ModelState errors from binding and validation.

## The Link and Script Tag Helpers

The most commonly used attributes of the Link and Script Tag Helpers are the `asp-append-version` and `asp-fallback-*` attributes. The `asp-append-version` attribute adds the hash of the file to the name so the cache is invalidated when the file changes and the file is reloaded. The following is an example of the `asp-append-version` attribute:

```
<link rel="stylesheet" href="~/css/site.css" asp-append-version="true"/>
```

The rendered code is as follows (your hash will vary):

```
<link href="/css/site.css?v=v9cmzjNgxPHiYLlrNom5fw3tZj3TNT2QD7a0hBrSa4U" rel="stylesheet">
```

The `asp-fallback-*` attributes are used with CDN file sources. For example, the following code attempts to load jQuery from the CloudFlare CDN. If it fails, it loads the local version:

```
<script src="https://cdnjs.cloudflare.com/ajax/libs/jquery/3.5.1/jquery.min.js"
  asp-fallback-src="~/lib/jquery/jquery.js" asp-fallback-test="window.jQuery"
  crossorigin="anonymous"
  integrity="sha256-FgpCb/KJQlLNfOu91ta32o/NMZxltwRo8QtmkMRdAu8=">
</script>
```

The `asp-fallback-test` for script tags embeds a small piece of JavaScript onto your page to test the property. If the test fails (e.g., the property is undefined), then the fallback file is loaded.

The same test for stylesheet tags is a little more involved. In the following code snippet, the test is looking for a specific value for a property on a CSS class and, if it fails, will load the fallback file:

```
<link rel="stylesheet" href="https://stackpath.bootstrapcdn.com/bootstrap/4.3.1/css/
bootstrap.min.css"
  asp-fallback-href="~/lib/bootstrap/css/bootstrap.css"
  asp-fallback-test-class="sr-only"
  asp-fallback-test-property="position"
  asp-fallback-test-value="absolute"
  crossorigin="anonymous"
  integrity=
  "sha384-ggOyR0iXCbMQv3Xipma34MD+dH/1fQ784/j6cY/iJTQU0hcW7x9JvoRxT2MZw1T" />
```

## The Image Tag Helper

The Image Tag Helper provides the `asp-append-version` attribute, which works the same as described in the Link and Script Tag Helpers.

## The Environment Tag Helper

The Environment Tag Helper is typically used to conditionally load JavaScript and CSS files (or any markup for that matter) based on current environment that the site is running under. The following code will load the un-minified files if the site is running in Development (denoted with the *include* attribute), and the minified versions if the site is anything but Development (denoted with the *exclude* attribute):

```
<environment include="Development" ">
  <link rel="stylesheet" href="~/css/site.css" asp-append-version="true"/>
</environment>
<environment exclude="Development">
  <link rel="stylesheet" href="~/css/site.min.css" />
</environment>
```

## Managing Client-Side Libraries

Client-side libraries (CSS and JavaScript) are an important part of web application development. Just as important is managing those libraries. The mechanism for including and updating the files in the past often involved downloading zip files from the sites page, unzipping into your project, and then checking into source control. This process was tedious at best, and error-prone at worst.

Fortunately, for ASP.NET Core applications, this process is no longer manual. The LibraryManager project (originally built by Mads Kristensen) is now part of Visual Studio (VS2019) and also available as a dotnet global tool. LibraryManager uses a simple JSON file to pull CSS and JavaScript tools from CDNJS.com, UNPKG.com, JSDeliver, or the file system.

### Install Library Manager As a .NET Core Global Tool

Library Manager is now built into Visual Studio. To install it as a .NET Core global tool,

```
dotnet tool install -g Microsoft.Web.LibraryManager.CLI
```

### Add Client-Side Libraries to AutoLot.Mvc

The default template installed a base set of JavaScript and CSS files into the `wwwroot\lib` folder of the project. Delete the lib folder and all of the files contained, as the steps that follow will replace all of them.

### Add the libman.json File

The libman.json file controls what gets installed, from what sources, and the destination of the installed files.

### Visual Studio

If you are using Visual Studio, right-click the `AutoLot.Mvc` project and select `Manage Client-Side Libraries`. This adds the `libman.json` file to the root of the project. There is also an option in Visual Studio to tie Library Manager into the MSBuild process. Right-click the `libman.json` file and select “Enable restore on build”. This prompts you to allow another NuGet package (`Microsoft.Web.LibraryManager.Build`) to be restored into the project. Allow the package to be installed.

### Command Line

Create a new libman.json file with the following command (this sets the default provider to be `cdnjs.com`):

```
libman init --default-provider cdnjs
```

### Update the libman.json File

When searching for libraries to install, CDNJS.com has a nice, human-readable API to use. List all of the available libraries with the following URL:

```
https://api.cdnjs.com/libraries?output=human
```

When you find the library you want to install, update the URL with the library name as it's listed to see all of the versions and files for each version. For example, to see everything available for jQuery, enter

```
https://api.cdnjs.com/libraries/jquery?output=human
```

Once you settle on the version and files to install, add the library name (and version), the destination (typically `wwwroot/lib/<library name>`), and the files to load. For example, to load jQuery, enter the following in the libraries JSON array:

```
{
  "library": "jquery@3.5.1",
  "destination": "wwwroot/lib/jquery",
  "files": [ "jquery.js" ]
},
```

After adding all of the files needed for this app, the entire file is shown here:

```
{
  "version": "1.0",
  "defaultProvider": "cdnjs",
  "defaultDestination": "wwwroot/lib",
  "libraries": [
    {
      "library": "jquery@3.5.1",
      "destination": "wwwroot/lib/jquery",
      "files": [ "jquery.js" ]
    },
    {
      "library": "jquery-validate@1.19.1",
      "destination": "wwwroot/lib/jquery-validation",
      "files": [ "jquery.validate.js", "additional-methods.js" ]
    },
    {
      "library": "jquery-validation-unobtrusive@3.2.11",
      "destination": "wwwroot/lib/jquery-validation-unobtrusive",
      "files": [ "jquery.validate.unobtrusive.js" ]
    },
    {
      "library": "font-awesome@5.13.0",
      "destination": "wwwroot/lib/fontawesome"
    },
    {
      "library": "twitter-bootstrap@4.5.0",
      "destination": "wwwroot/lib/bootstrap",
      "files": [
        "css/bootstrap.css",
        "css/bootstrap.css.map",
        "js/bootstrap.bundle.js",
        "js/bootstrap.bundle.js.map",
        "js/bootstrap.js",

```

```

        "js/bootstrap.js.map",
    ]
}
]
}

```

---

■ **Note** If you are wondering why there aren't any minified files listed, that will be covered next.

---

Once you save the file (in Visual Studio), the files will be loaded into the `wwwroot\lib` folder of the project. If running from the command line, enter the following command to reload all of the files:

```
libman restore
```

Additional command-line options are available. Enter `libman -h` to explore all of the options.

## Bundling and Minification

Two additional considerations for building web applications with client-side libraries are bundling and minification for improved performance.

### Bundling

Web browsers have a set limit of how many files they allow to be downloaded concurrently from the same endpoint. This can be problematic if you use SOLID development techniques with your JavaScript and CSS files, separating out related code and styles into smaller, more maintainable files. This provides a better development experience, but can crush an application's performance while the files are waiting their turn to be downloaded. Bundling is simply concatenating files together to prevent them from being blocked while waiting for the browser download limit.

### Minification

Also, for improved performance, the minification process changes CSS and JavaScript files to make them smaller. Unnecessary whitespace and line endings are removed, and non-keyword names are shortened. While this makes a file almost unreadable to a human, the functionality is not affected, and the size can be significantly reduced. This, in turn, speeds up the download process, thereby improving the performance of the application.

## The WebOptimizer Solution

There are many development tools that can bundle and minify files as part of the build process. These are certainly effective, but can be problematic if the processes become out of sync, since there really isn't a good comparer for the original files and the bundled and minified ones.

WebOptimizer is an open source package that bundles, minifies, and caches as part of the ASP.NET Core pipeline. This ensures that the bundled and minified files accurately represent the raw files. Not only are they accurate, but they are cached, significantly cutting down on the number disk reads for page requests. You have already added the `Libershark.WebOptimizer.Core` package in Chapter 29. Now you will use it.

## Update Startup.cs

The first step is to add WebOptimizer into the pipeline. Open the `Startup.cs` file in the `AutoLot.Mvc` project, navigate to the `Configure` method, and add the following line (just before the `app.UseStaticFiles` call):

```
app.UseWebOptimizer();
```

The next step is to configure what to minimize and bundle. Typically, when developing your application, you want to see the non-bundle/non-minified versions of the files, but for staging and production, the bundling and minification is what is desired. In the `ConfigureServices` method, add the following code block:

```
if (!_env.IsDevelopment())
{
    services.AddWebOptimizer(false, false);
}
else
{
    services.AddWebOptimizer(options =>
    {
        options.MinifyCssFiles(); //Minifies all CSS files
        options.MinifyJsFiles("js/site.js");
        options.MinifyJsFiles("lib/**/*.js");
    });
}
```

If the environment is `Development`, all bundling and minification is disabled. If it isn't, the following code minifies all CSS files, minifies `site.js`, and minifies all JavaScript files (with the extension `.js`) in and under the `lib` directory. Note that all paths start at the `wwwroot` folder in the project.

There are additional options. The following minifies all JavaScript (`*.js`) files:

```
options.MinifyJsFiles();
```

The next two lines create a bundle. The first example creates a bundle using file globbing, and the second creates a bundle listing specific names.

```
options.AddJavaScriptBundle("js/validations/validationCode.js", "js/validations/**/*.js");
options.AddJavaScriptBundle("js/validations/validationCode.js", "js/validations/validators.js",
"js/validations/errorFormatting.js");
```

It's important to note that the minified and bundled files aren't actually on disk, but they are placed in cache. It's also important to note that the minified files keep the same name (`site.js`) and don't have the usual `min` in the name (`site.min.js`).

---

■ **Note** When updating your views to add the links for bundled files, Visual Studio will complain that the bundled file doesn't exist. Don't worry, it will still render from the cache.

---

## Update \_ViewImports.cshtml

The final step is to add the WebOptimizer Tag Helpers into the system, which function the same way as the `asp-append-version` tag helpers covered earlier in this chapter, but do it automatically for all bundled and minified files. Add the following line to the end of the `_ViewImports.cshtml` file:

```
@addTagHelper *, WebOptimizer.Core
```

## Update the Layout and Partial

In this section, we are going to update the views effected by the changes that we have made to the project as well as add in the environment Tag Helpers for our CSS and JavaScript.

### Create the Partial

Create a new folder named `Partials` under the `Shared` folder. Create three empty views named `_Head.cshtml`, `_JavaScriptFiles.cshtml`, and `_Menu.cshtml`.

### The Header Partial

In the current version of the ASP.NET Core Website (using MVC) project template, neither the `_Layout.cshtml` nor `_ValidationScriptsPartial` files use the environment tag helper, even though previous templates did. Add the following markup to the `_Head.cshtml` partial. Changes from the original `_Layout` Head section are shown in bold, but be sure to add all of the following markup:

```
<meta charset="utf-8"/>
<meta name="viewport" content="width=device-width, initial-scale=1.0"/>
<title>@ViewData["Title"] - AutoLot.Web</title>
<environment include="Development ">
  <link rel="stylesheet" href="~/lib/bootstrap/css/bootstrap.css"
    asp-append-version="true"/>
</environment>
<environment exclude="Development ">
  <link rel="stylesheet"
    href="https://stackpath.bootstrapcdn.com/bootstrap/4.3.1/css/bootstrap.min.css"
    asp-fallback-href="~/lib/bootstrap/css/bootstrap.css"
    asp-fallback-test-class="sr-only" asp-fallback-test-property="position"
    asp-fallback-test-value="absolute" crossorigin="anonymous"
    integrity="sha384-ggOyR0iXCbMQV3Xipma34MD+dH/1fQ784/j6cY/iJTQUOhcWr7x9JvoRxT2MZw1T"/>
</environment>
<link rel="stylesheet" href="~/lib/fontawesome/css/all.css" asp-append-version="true"/>
<link rel="stylesheet" href="~/css/site.css" asp-append-version="true"/>
```

Note that the fallback files don't use the `*.min.css` files, since all of the CSS files have been minified by WebOptimizer.

In `_Layout.cshtml`, delete all of the code between the `<head></head>` tags and replace it with the new partial:

```
<head>
  <partial name="Partials/_Head"/>
</head>
```

The format for rendering a partial view is to use the <partial> Tag Helper and pass in the name of the partial. The path starts at the view's current directory, in this case, Views\Shared.

## The Menu Partial

For the menu partial, just cut all of the markup between the <header></header> tags (not the <head></head> tags) and paste it into the \_Menu.cshtml file. This is a standard Bootstrap menu. Update the \_Layout with the partial:

```
<header>
  <partial name="Partials/_Menu"/>
</header>
```

## The JavaScript Files Partial

The original \_Layout.cshtml file doesn't use the environment tag helper for the JavaScript files either. Add in the following code to the \_JavaScriptFiles.cshtml file:

```
<environment include="Development,Local">
  <script src="~/lib/jquery/jquery.js" asp-append-version="true"></script>
  <script src="~/lib/bootstrap/js/bootstrap.bundle.js" asp-append-version="true"></script>
</environment>
<environment exclude="Development,Local">
  <script src="https://cdnjs.cloudflare.com/ajax/libs/jquery/3.5.1/jquery.min.js"
    asp-fallback-src="~/lib/jquery/jquery.js"
    asp-fallback-test="window.jQuery"
    crossorigin="anonymous"
    integrity="sha256-FgpCb/KJQlLNfOu91ta32o/NMZxltwRo8QtmkMRdAu8=">
  </script>
  <script src="https://stackpath.bootstrapcdn.com/bootstrap/4.5.0/js/bootstrap.bundle.min.js"
    asp-fallback-src="~/lib/bootstrap/js/bootstrap.bundle.js"
    asp-fallback-test="window.jQuery && window.jQuery.fn && window.jQuery.fn.modal"
    crossorigin="anonymous"
    integrity="sha384-xrRywqdh3PHs8keKZN+8zzc5TX0GRTLcmivcBNjWm2rs5C8PRhcEn3czEjhA09o">
  </script>
</environment>
<script src="~/js/site.js" asp-append-version="true"></script>
```

The updated code from the original head is shown in bold. Note that the fallback files don't use the \*.min.js files, since all of the .js JavaScript files have been minified by WebOptimizer.

In \_Layout.cshtml, delete all of the script tags at the bottom of the file and replace with this line, just before the RenderSection call:

```
<partial name="Partials/_JavaScriptFiles"/>
@RenderSection("Scripts", required: false)
```



## Update the \_ValidationScripts Partial

A common mechanism to load related JavaScript files is to place them into a view to be loaded as a partial view. The default template uses this technique to load the jQuery files used for validation. However, this partial doesn't use the environment tag helper either. Update the markup to the following:

```
<environment include="Development">
  <script src="~/lib/jquery-validation/jquery.validate.js" asp-append-version="true"></script>
  <script src="~/lib/jquery-validation-unobtrusive/jquery.validate.unobtrusive.js"
    asp-append-version="true"></script>
</environment>
<environment exclude="Development">
  <script src="https://cdnjs.cloudflare.com/ajax/libs/jquery-validate/1.19.1/jquery.
    validate.min.js"
    asp-fallback-src="~/lib/jquery-validation/jquery.validate.js"
    asp-fallback-test="window.jQuery && window.jQuery.validator"
    crossorigin="anonymous"
    integrity="sha256-F6h55Qw6sweK+t7Si0JX+2bpSAa3b/fn1rVCJvmej1A=">
  </script>
  <script src="https://cdnjs.cloudflare.com/ajax/libs/jquery-validation-unobtrusive/
    3.2.11/jquery.validate.unobtrusive.min.js"
    asp-fallback-src="~/lib/jquery-validation-unobtrusive/jquery.validate.unobtrusive.js"
    asp-fallback-test="window.jQuery && window.jQuery.validator && window.jQuery.
    validator.unobtrusive"
    crossorigin="anonymous"
    integrity="sha256-9GycpJnliUjJDVDqPOUEu/bsm9U+3dnQUH8+3W10vkY=">
  </script>
</environment>
```

## Create the Service Wrapper

The AutoLot.Mvc app will use AutoLot.Api as the gateway to the database by using HTTP/HTTPS calls. ASP.NET Core provides a series of features that greatly simplifies creating and maintaining the code to do this. Over the next few sections, you will use the configuration system to add in the environment-specific URIs and then create a strongly typed class that uses the HttpClientFactory for the service wrapper.

## Configure the Application

The AutoLot.Api application endpoints will vary based on the environment. For example, when developing on your workstation, the base URI is `https://localhost:5011`. In your integration environment, the URI might be <https://mytestserver.com>. The environmental awareness in conjunction with the updated configuration system (introduced in Chapter 29) will be used to add these different values.

## Update the AppSettings.Development.JSON File

As covered earlier, each environment can have its own settings file, allowing for environment-specific configuration. The AppSettings.Development.JSON file will add the service information for the local machine. As code moves through different environments, the settings would be updated in each

environment's specific file to match the base URI and endpoints for that environment. In this example, you only update the settings for the development environment. Open the `appsettings.Development.json` file and update it to the following (changes in bold):

```
{
  "Logging": {
    "LogLevel": {
      "Default": "Information",
      "Microsoft": "Warning",
      "Microsoft.Hosting.Lifetime": "Information"
    }
  },
  "ServiceSettings": {
    "BaseUri": "https://localhost:5011",
    "CarBaseUri": "api/Cars",
    "MakeBaseUri": "api/Makes",
    "CreditRiskBaseUri": "api/CreditRisks",
    "CustomerBaseUri": "api/Customers",
    "OrderBaseUri": "api/Orders"
  }
}
```

---

■ **Note** Make sure the port number matches your configuration for `AutoLot.Api`.

---

By utilizing the ASP.NET Core configuration system and updating the environment-specific files (e.g., `appsettings.staging.json` and `appsettings.production.json`), your application will have the appropriate values without having to change any code.

## Create the ServiceSettings Class

Chapter 29 hinted that the configuration system can populate a class based on the values in a configuration file. Now is the time to utilize this capability. Create a new folder named `ServiceInfo` in the `AutoLot.Mvc` project. In this folder, add a class named `ServiceSettings.cs`. The property names of the class need to match the property names in the JSON `ServiceSettings` section. The class is listed here:

```
public class ServiceSettings
{
    public string BaseUri { get; set; }
    public string CarBaseUri { get; set; }
    public string MakeBaseUri { get; set; }
    public string CreditRiskBaseUri { get; set; }
    public string CustomerBaseUri { get; set; }
    public string OrderBaseUri { get; set; }
}
```

---

■ **Note** The class to be configured must have a public parameterless constructor and be nonabstract. Default values can be set on the class properties.

---

## Populate the ServiceSettings Class Using the Services Collection

Earlier you added various custom classes into the services collection. In addition to configuring interface implementations using `services.AddScoped`, the services collection can also use the configuration system to instantiate a class from a settings file. This instance is then available for injection using the Options pattern, covered shortly.

Add the following using statement to `Startup.cs`:

```
using AutoLot.Mvc.ServiceInfo;
```

Next, use the `Configure` method of the `IServiceCollection` instance, typed to the C# `ServiceSettings` class, and take the configuration section as the single parameter. Add the following code to the `ConfigureServices` method of the `Startup` class:

```
services.Configure<ServiceSettings>(Configuration.GetSection("ServiceSettings"));
```

Now with this completed, it's time to examine the Options pattern.

## The Options Pattern in ASP.NET Core

The Options pattern provides access of the configured settings classes to other classes through dependency injection. The configuration classes can be injected into another class using one of the versions of `IOptions<T>`. There are several versions of this interface, as shown in Table 31-5.

**Table 31-5.** *Some of the IOptions Interfaces*

Interface	Description
<code>IOptionsMonitor&lt;T&gt;</code>	Retrieves options and supports: Notification of changes (with <code>OnChange</code> ), Configuration reloading, Named options (with <code>Get</code> and <code>CurrentValue</code> ), and Selective options invalidation
<code>IOptionsMonitorCache&lt;T&gt;</code>	Caches instances of <code>T</code> with support for full/partial invalidation/reload
<code>IOptionsSnapshot&lt;T&gt;</code>	Recomputes options on every request
<code>IOptionsFactory&lt;T&gt;</code>	Creates new instances of <code>T</code>
<code>IOptions&lt;T&gt;</code>	Root interface. Can be used for options, but doesn't support <code>IOptionsMonitor&lt;T&gt;</code> . Left in for backward compatibility.

To see this in action, create a new class named `AutoLotServiceWrapper` in the `ServiceInfo` directory of the `AutoLot.Mvc` project. Update the using statements to the following (the key one for this example is `Microsoft.Extensions.Options`):

```
using System;
using System.Collections.Generic;
using System.Net.Http;
using System.Text;
using System.Text.Json;
using System.Threading.Tasks;
using AutoLot.Dal.Models.Entities;
using AutoLot.Dal.Models.Entities.Base;
using Microsoft.Extensions.Options;
```

Make the class public, and add a constructor that takes an instance of `IOptionsMonitor<ServiceSettings>`. Create a private variable of type `ServiceSettings`, and assign it using the `CurrentValue` property of the `IOptionsMonitor<ServiceSettings>` parameter. The code is shown here:

```
public class AutoLotServiceWrapper
{
    private readonly ServiceSettings _settings;
    public AutoLotServiceWrapper(IOptionsMonitor<ServiceSettings> settings)
    {
        _settings = settings.CurrentValue;
    }
}
```

---

■ **Note** The `CurrentValue` is used to get the default instance. Named instances aren't covered here. More information on the Options pattern at <https://docs.microsoft.com/en-us/aspnet/core/fundamentals/configuration/options?view=aspnetcore-3.1>.

---

## The API Service Wrapper

ASP.NET Core 2.1 introduced the `IHttpClientFactory`, which allows configuring strongly typed classes for calling into RESTful services. Creating a strongly typed class allows for encapsulating all of the API calls in one place. This centralizes communication with the service, configuration of the HTTP Client, error handling, and so on. The class can then be added into the dependency injection container for use later in your application. The DI container and the `IHttpClientFactory` handle creation and disposal of the `HttpClient`.

## The IAutoLotServiceWrapper Interface

The AutoLot Service Wrapper interface contains the methods to call into the AutoLot.Api API. Create a new interface named `IAutoLotServiceWrapper.cs` in the `ServiceInfo` directory, and update the using statements to the following:

```
using System.Collections.Generic;
using System.Threading.Tasks;
using AutoLot.Dal.Models.Entities;
using AutoLot.Dal.Models.Entities.Base;
```

Update the interface to the code shown here (the interface is implemented in the next section):

```
public interface IAutoLotServiceWrapper
{
    Task<List<Car>> GetCarsByMakeAsync(int makeId);
    Task<List<T>> GetAllAsync<T>() where T : BaseEntity, new();
    Task<T> GetOneAsync<T>(int id) where T : BaseEntity, new();
    Task<T> UpdateOneAsync<T>(T entity) where T : BaseEntity, new();
    Task<T> AddOneAsync<T>(T entity) where T : BaseEntity, new();
    Task DeleteOneAsync<T>(T entity) where T : BaseEntity, new();
}
```

## The AutoLotServiceWrapper Class

To leverage the `IHttpClientFactory`, the `AutoLotServiceWrapper` class must have an instance of the `HttpClient` as a constructor parameter. Reopen the `AutoLotServiceWrapper` class and update the class to the following code (updates in bold):

```
public class AutoLotServiceWrapper : IAutoLotServiceWrapper
{
    private readonly HttpClient _client;
    private readonly ServiceSettings _settings;
    public AutoLotServiceWrapper(HttpClient client, IOptionsMonitor<ServiceSettings> settings)
    {
        _settings = settings.CurrentValue;
        _client = client;
    }
}
```

---

■ **Note** The next sections contain a lot of code without any error handling. This is a really bad idea! The error handling was left out to save space in an already lengthy chapter.

---

## The Internal Support Methods

The class contains four support methods that are used by the public methods.

### The GetBaseUri Method

This method uses a switch expression and the injected `ServiceSettings` class to build the base URI for each class-specific endpoint:

```
internal string GetBaseUri<T>(T entity) where T : BaseEntity, new()
=> entity switch
{
    Car c => $"{_settings.BaseUri}/{_settings.CarBaseUri}",
    CreditRisk cr => $"{_settings.BaseUri}/{_settings.CreditRiskBaseUri}",
    Customer cu => $"{_settings.BaseUri}/{_settings.CustomerBaseUri}",
    Make m => $"{_settings.BaseUri}/{_settings.MakeBaseUri}",
    Order o => $"{_settings.BaseUri}/{_settings.OrderBaseUri}",
    _ => null
};
```

## The Post and Put Helper Methods

These methods wrap the related `HttpClient` methods:

```
internal async Task<HttpResponseMessage> PostAsJsonAsync(string uri, string json)
=> await _client.PostAsync(uri, new StringContent(json, Encoding.UTF8, "application/json"));
internal async Task<HttpResponseMessage> PutAsJsonAsync(string uri, string json)
=> await _client.PutAsync(uri, new StringContent(json, Encoding.UTF8, "application/json"));
```

## The HTTP Delete Helper Method Call

The final helper method is used for executing an HTTP Delete. New in the Http 1.1 specification allows for passing a body in a delete statement, but there isn't yet an extension method of the `HttpClient` for doing this – the `HttpRequestMessage` must be built up from scratch.

The first step is to then create a request message using object initialization to set the Content, Method, and `RequestUri`. Once this is complete, the message is sent and the response is returned to the calling code. The method is shown here:

```
internal async Task<HttpResponseMessage> DeleteAsJsonAsync(string uri, string json)
{
    var request = new HttpRequestMessage
    {
        Content = new StringContent(json, Encoding.UTF8, "application/json"),
        Method = HttpMethod.Delete,
        RequestUri = new Uri(uri)
    };
    return await _client.SendAsync(request);
}
```

## The HTTP Get Calls

There are three Get calls: one to get all records on a specific entity, one to get a single entity, and a specific method call to get all of the cars by make. They all follow the same pattern. The specific URI is retrieved (if it's null, a `BadRequest` is returned), and then the `GetAsync` method is called to return an `HttpResponseMessage`. The success or failure of the call is checked with the `EnsureSuccessStatusCode` method, which throws an exception if the call did not return a successful status code. Then the body of the response is serialized back into the property type (either an entity or a list of entities) and returned back to the calling code. Each of these methods is shown here:

```
public async Task<List<T>> GetAllAsync<T>() where T : BaseEntity, new()
{
    string uri = GetBaseUri(new T());
    if (uri == null)
    {
        return null;
    }
    var response = await _client.GetAsync(uri);
    response.EnsureSuccessStatusCode();
    return await JsonSerializer.DeserializeAsync<List<T>>(
        await response.Content.ReadAsStreamAsync());
}

public async Task<T> GetOneAsync<T>(int id) where T : BaseEntity, new()
{
    string uri = GetBaseUri(new T());
    if (uri == null)
    {
        return null;
    }
}
```

```

var response = await _client.GetAsync($"{uri}/{id}");
response.EnsureSuccessStatusCode();
return await JsonSerializer.DeserializeAsync<T>(
    await response.Content.ReadAsStreamAsync());
}

public async Task<List<Car>> GetCarsByMakeAsync(int makeId)
{
    var response = await _client.GetAsync(
        $"{_settings.BaseUri}/{_settings.CarBaseUri}/bymake/{makeId}");
    response.EnsureSuccessStatusCode();
    return await JsonSerializer.DeserializeAsync<List<Car>>(
        await response.Content.ReadAsStreamAsync());
}

```

## The HTTP Post and Put Calls

There are two methods that use HTTP Post (add) and HTTP Put (update). They follow the same pattern as the HTTP Get calls: get the URI, call the appropriate helper method (that then uses the HTTPClient), check the status code with `EnsureSuccessStatusCode`, and then return the appropriate entity deserialized from the body of the response message.

HTTP Post methods also return the URI of the newly created object and add it to the Headers Location property. This example doesn't use this information, but instead gets the entire object from the body of the response message.

```

public async Task<T> AddOneAsync<T>(T entity) where T : BaseEntity, new()
{
    string uri = GetBaseUri(entity);
    if (uri == null)
    {
        return null;
    }
    var response = await PostAsJsonAsync($"{uri}", JsonSerializer.Serialize(entity));
    response.EnsureSuccessStatusCode();
    //OPTIONAL: Get Header Information
    return await JsonSerializer.DeserializeAsync<T>(
        await response.Content.ReadAsStreamAsync());
}

public async Task<T> UpdateOneAsync<T>(T entity) where T : BaseEntity, new()
{
    string uri = GetBaseUri(entity);
    if (uri == null)
    {
        return null;
    }
    var response = await PutAsJsonAsync($"{uri}/{entity.Id}", JsonSerializer.Serialize(entity));
    response.EnsureSuccessStatusCode();
    return await JsonSerializer.DeserializeAsync<T>(
        await response.Content.ReadAsStreamAsync());
}

```

## The HTTP Delete Call

The final method to add is for executing an HTTP Delete. The pattern follows the rest of the methods: get and check the URI, use the helper method, and then check the response for success. There isn't anything to return to the calling code, since the entity was deleted. The method is shown here:

```
public async Task DeleteOneAsync<T>(T entity) where T : BaseEntity, new()
{
    string uri = GetBaseUri(entity);
    if (uri == null)
    {
        return;
    }
    var response = await DeleteAsJsonAsync(
        $"{uri}/{entity.Id}", JsonSerializer.Serialize(entity));
    response.EnsureSuccessStatusCode();
}
```

## Add the AutoLotServiceWrapper to the DI Container

In the `ConfigureServices` method of the `Startup` class, add the following line immediately after the call to `services.Configure<ServiceSettings>`. This will add the `IHttpClientFactory` and its related services into the DI container and add a binding to the `IAutoLotServiceWrapper`:

```
services.AddHttpClient<IAutoLotServiceWrapper, AutoLotServiceWrapper>();
```

Now that the code is in place to access the data, it's time to build the menu `ViewComponent`.

## View Components

View Components are another new feature in ASP.NET Core. They combine the benefits of partial views with child actions to render parts of the UI. Like partial views, they are called from another view, but unlike partial views by themselves, View Components also have a server-side component. This combination makes them a great fit for functions like creating dynamic menus (as shown shortly), login panels, sidebar content, or anything that needs to run server-side code but doesn't qualify to be a stand-alone view.

---

■ **Note** Child actions in classic ASP.NET MVC were action methods on a controller that could not serve as client facing endpoints. They do not exist in ASP.NET Core.

---

For AutoLot, the `ViewComponent` will dynamically create the menu based on the Makes that are in the database. The menu is visible on every page, so the logical place for it is in the `_Layout`. But the `_Layout` doesn't have a server-side component (unlike Views), so every action in the app must supply the data to the `_Layout`. This can be done in the `OnActionExecuting` event handler, where the records are placed in the `ViewBag`, but that can be messy to maintain. The blending of the server-side capabilities and the encapsulation of the UI make this scenario a perfect user case for View Components.



## The Server-Side Code

Create a new folder named `ViewComponents` in the root directory of the `AutoLot.Mvc` project. Add a new class file named `MenuViewComponent.cs` into this folder. The convention is to name the View Component classes with the `ViewComponent` suffix, just like controllers. And just like controllers, the `ViewComponent` suffix is dropped when calling View Components.

Add the following `using` statements to the top of the file:

```
using System.Threading.Tasks;
using AutoLot.Dal.Models.Entities;
using AutoLot.Mvc.ServiceInfo;
using Microsoft.AspNetCore.Mvc;
using Microsoft.AspNetCore.Mvc.ViewComponents;
```

Change the class to public and inherit from `ViewComponent`. View Components don't have to inherit from the `ViewComponent` base class, but like the Controller base class, there are methods in the base class that are very useful. Create a constructor that takes an instance of the `IAutoLotServiceWrapper` interface, and assign that to a class-level variable. The code at this point looks like this:

```
public class MenuViewComponent : ViewComponent
{
    private readonly IAutoLotServiceWrapper _serviceWrapper;
    public MenuViewComponent(IAutoLotServiceWrapper serviceWrapper)
    {
        _serviceWrapper = serviceWrapper;
    }
}
```

There are two methods that are available for View Components, `Invoke` and `InvokeAsync`. One of them must be implemented, and since the `MenuViewComponent` needs to use the async `GetAll` method of the service wrapper, add in the `InvokeAsync` method, like this:

```
public async Task<IViewComponentResult> InvokeAsync()
{
}
```

When a View Component is rendered from a View, the public method `InvokeAsync` is invoked. This method returns an `IViewComponentResult`, which is conceptually similar to a `PartialViewResult`, but much more streamlined. In the `InvokeAsync` methods, get the list of Makes from the service, and if successful, return a `ViewViewComponentResult` (no, that's not a typo; it's actually the name of the type) using the list of Makes as the view model. If the call to get the Makes fails, return a `ContentViewComponentResult` with an error message. Update the method to the following:

```
public async Task<IViewComponentResult> InvokeAsync()
{
    var makes = await _serviceWrapper.GetAllAsync<Make>();
    if (makes == null)
    {
        return new ContentViewComponentResult("Unable to get the makes");
    }
    return View("MenuView", makes);
}
```

The View helper method from the base `ViewComponent` class is similar to the Controller class helper method of the same name, with a couple of key differences. The first difference is that the default view file name is `Default.cshtml` instead of the name of the method. However, like the Controller View helper method, the name of the view can be anything as long as the name is passed into the method call (without the `.cshtml` extension). The second difference is that the location of the view **must** be one of these three directories:

```
Views/< controller>/Components/<view_component_name>/<view_name>
Views/Shared/Components/<view_component_name>/<view_name>
Pages/Shared/Components/<view_component_name>/<view_name>
```

---

■ **Note** ASP.NET Core 2.x introduced Razor Pages as another mechanism for creating web applications. This book doesn't cover Razor Pages.

---

The C# class can live anywhere (even in another assembly), but the `<viewname>.cshtml` must be in one of the directories listed earlier.

## Build the Partial View

The Partial View rendered by the Menu View Component will iterate through the Make records, adding each as a list item to be displayed in the Bootstrap menu. The All menu item is added first as a hard-coded value.

Create a new folder named `Components` under the `Views\Shared` folder. In this new folder, create another new folder named `Menu`. This folder name must match the name of the View Component class created earlier, minus the `ViewComponent` suffix. In this folder, create a partial view named `MenuView.cshtml`.

Clear out the existing code and add the following markup:

```
@model IEnumerable<Make>
<div class="dropdown-menu">
<a class="dropdown-item text-dark" asp-area="" asp-controller="Cars" asp-action="Index">All</a>

@foreach (var item in Model)
{
    <a class="dropdown-item text-dark" asp-controller="Cars" asp-action="ByMake"
    asp-route-makeId="@item.Id" asp-route-makeName="@item.Name">@item.Name</a>
}
</div>
```

Notice how there isn't a `using` statement to fully qualify the `Make` class name. For this code to compile, you need to fully qualify the file or add the following `using` statement to `_ViewImports.cshtml`:

```
@using AutoLot.Dal.Models.Entities
```

Also notice the anchor tag holders. The `asp-controller` and `asp-action` attributes are set to the objects that don't yet exist. This won't cause a compile error, but will prevent the anchor tag helper from building proper route. The `CarsController` will be built soon.

## Invoking View Components

View Components are typically rendered from a view (although they can be rendered from a Controller Action method as well). The syntax is very straightforward: `Component.Invoke(<view component name>)` or `@await Component.InvokeAsync(<view component name>)`. Just like with controllers, the `ViewComponent` suffix must be removed when invoking a View Component.

```
@await Component.InvokeAsync("Menu")
```

## Invoking View Components As Custom Tag Helpers

Introduced in ASP.NET 1.1, View Components can be invoked using Tag Helpers syntax. Instead of using `Component.InvokeAsync`, simply call the View Component like this:

```
<vc:menu></vc:menu>
```

In order to use this method of calling View Components, your application must opt in to using them. This is done by adding the `@addTagHelper` command with the name of the assembly that contains the `ViewComponent`. Add the following line to `_ViewImports.cshtml`:

```
@addTagHelper *, AutoLot.Mvc
```

## Updating the Menu

Open the `_Menu.cshtml` partial and navigate to just after the `<li></li>` block that maps to the Home/Index action method. Copy the following markup to the partial:

```
<li class="nav-item dropdown">
  <a class="nav-link dropdown-toggle text-dark" data-toggle="dropdown">Inventory
  <i class="fa fa-car"></i></a>
  <vc:menu />
</li>
```

The line in bold renders the `MenuViewComponent` into the menu. The surrounding markup is Bootstrap formatting.

To catch the menu up to where the code stands, add in another menu item to render the `RazorSyntax` view that you built earlier in the chapter:

```
<li class="nav-item">
  <a class="nav-link text-dark" asp-area="" asp-controller="Home"
    asp-action=
    "RazorSyntax">Razor Syntax <i class="fas fa-cut"></i></a>
</li>
```

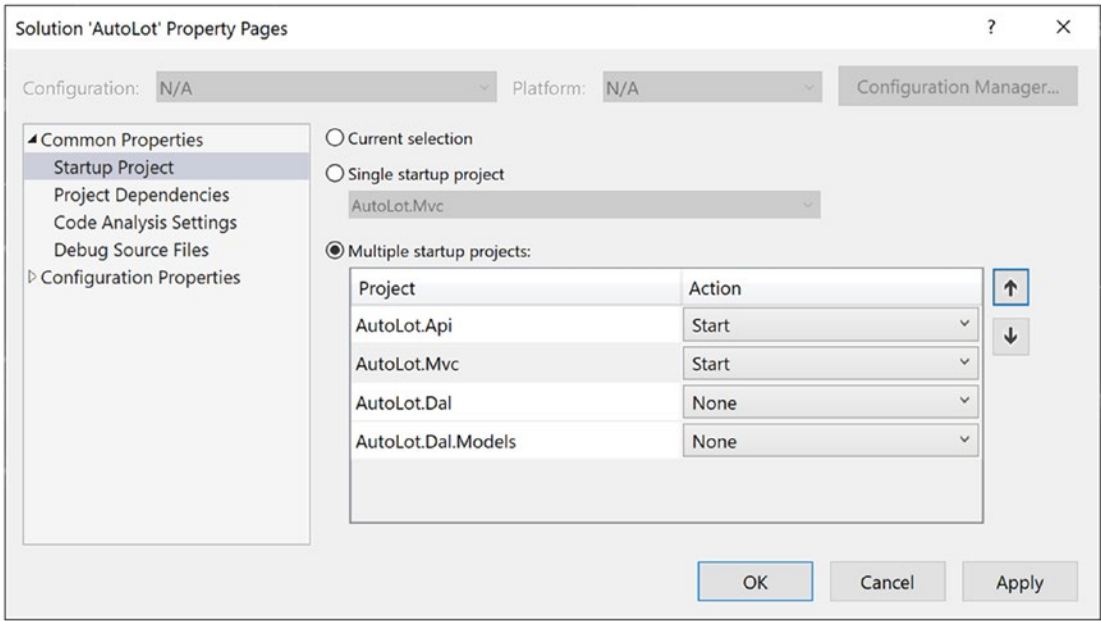
# Run AutoLot.Mvc and AutoLot.Api Together

AutoLot.Mvc depends on AutoLot.Api to be running. This can be done with Visual Studio or the command line, or a combination of the two.

**Note** Remember that AutoLot.Api is configured to rebuild the database every time it runs. To speed up debugging, turn this off when you are testing functionality that doesn't change any data.

## Using Visual Studio

You can configure Visual Studio to run multiple projects at the same time. This is accomplished by right-clicking the solution in Solution Explorer, selecting "Select Startup Projects...", and the turning on, as shown in Figure 31-1.



**Figure 31-1.** Setting multiple startup projects in Visual Studio

When you press F5 (or click the green run arrow), both projects will launch. There are some intricacies when you do this. The first is that Visual Studio remembers the last profile used to run an app. Which means if you used IIS Express to run AutoLot.Api, running both together will run AutoLot.Api using IIS Express, and the port in the service settings will be incorrect. That's easy enough to fix. Either change the ports in the appsettings.development.json file or run the app with Kestrel before configuring the multiple startup options.

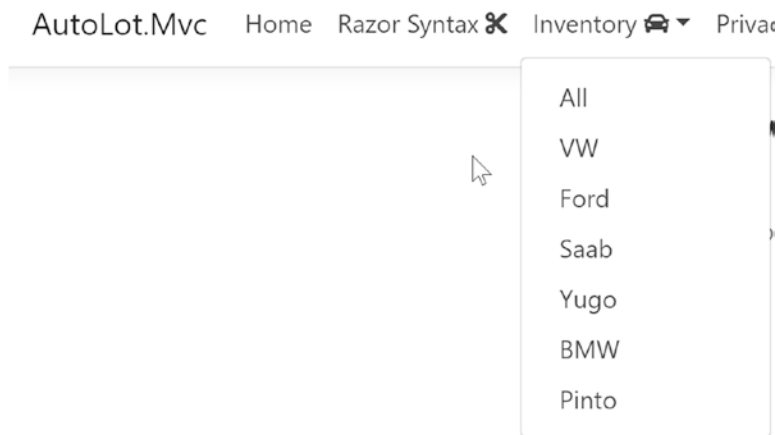
The second comes down to timing. Both projects start at essentially the same time. If you have AutoLot.Api configured to recreate the database each time it runs, it will not be ready for AutoLot.Mvc when the ViewComponent executes to build the menu. A quick refresh of the AutoLot.Mvc browser (once you see the SwaggerUI in AutoLot.Api) will resolve this.

## Using the Command Line

Open a command prompt in each of the project directories and enter “dotnet watch run”. This allows you to control the order and the timing and will also ensure that the apps are executed using Kestrel and not IIS. For information on debugging when running from the command line, please refer to Chapter 29.

## Viewing the Updated Menu

When you run both apps together, the Inventory menu is drop down that shows all of the Makes in the database. This is shown in Figure 31-2. Remember the links don’t actually work yet; that will be corrected next.



**Figure 31-2.** The *MenuViewComponent* in action

Experiment with the data. Add something to the Makes table and watch it appear on the next refresh of your browser.

Now, it’s time to build the CarsController.

## Build the CarsController

It’s now time to build the CarsController. Add a new class named CarsController to the Controllers directory. Update the using statements to the following:

```
using System;
using System.Threading.Tasks;
using AutoLot.Dal.Models.Entities;
using AutoLot.Mvc.ServiceInfo;
using Microsoft.AspNetCore.Mvc;
using Microsoft.AspNetCore.Mvc.Rendering;
```

Next, make the class public, inherit from Controller, and add the Route attribute. Create a constructor that accepts an instance of *IAutoLotServiceWrapper*, and assign the instance to a class-level variable. The starter code is shown here:

```
[Route("[controller]/[action]")]
public class CarsController : Controller
{
    private readonly IAutoLotServiceWrapper _serviceWrapper;
    public CarsController(IAutoLotServiceWrapper serviceWrapper)
    {
        _serviceWrapper = serviceWrapper;
    }
}
```

This section only creates the CarsController and its action methods. All of the views will be created in the next section.

---

■ **Note** Visual Studio has built-in scaffolding support for controllers and views. This section doesn't use the scaffolding to show you how to build the actions and views by hand.

---

## The GetMakes Helper Method

The GetMakes helper method builds a SelectList of all of the Makes in the database. It uses the Id as the value and the Name as the display text:

```
internal async Task<SelectList> GetMakes()
=> new SelectList(
    await _serviceWrapper.GetAllAsync<Make>(),
    nameof(Make.Id),
    nameof(Make.Name));
```

## The Index Action Method

The Index action method gets all of the cars using the service wrapper and sends them to the Index view:

```
[HttpGet]
[Route("/[controller]")]
[Route("[controller]/[action]")]
public async Task<IActionResult> Index()
=> View(await _serviceWrapper.GetAllAsync<Car>());
```

The Route attributes set the default route for the controller as well as the full route. Either of these URLs will invoke the Index action:

```
https://localhost:5011/Cars
https://localhost:5011/Cars/Index
```

## The ByMake Action Method

The ByMake action method gets all of the cars with a certain MakeId using the service wrapper and sends them to the ByMake view:

```
[HttpGet("{makeId}/{makeName}")]
[Route("/{controller}/{action}")]
public async Task<IActionResult> ByMake(int makeId, string makeName)
{
    ViewBag.MakeName = makeName;
    return View(await _serviceWrapper.GetCarsByMakeAsync(makeId));
}
```

The name of the Make is added to the ViewBag for use by the view.

The Route attributes set the route for the controller using two tokens: the MakeId and the Make Name. Here is an example URL that invokes the ByMake action:

`https://localhost:5011/1/VW`

## The Details Action Method

The Details action method gets a single car by Id using the service wrapper and sends it to the Details view:

```
[HttpGet("{id?}")]
public async Task<IActionResult> Details(int? id)
{
    if (id == null)
    {
        return NotFound();
    }
    var car = await _serviceWrapper.GetOneAsync<Car>(id.Value);
    if (car == null)
    {
        return NotFound();
    }
    return View(car);
}
```

The Route takes an optional route parameter and sets it to the id parameter of the method. If the parameter is not supplied or if the service wrapper can't find a vehicle with the supplied route parameter, the method returns a NotFound result. Otherwise, the method sends the located Car record to the Details view.

## The Create Action Methods

The Create process uses two action methods: one (HTTP Get) to return a blank view for input of the new record and one (HTTP Put) to submit the values of the new record.

## The Create Get Method

The Create HTTP Get action method gets a single car, by Id using the service wrapper, and sends it to the Create view:

```
[HttpGet]
public async Task<IActionResult> Create()
{
    ViewData["MakeId"] = await GetMakes();
    return View();
}
```

The SelectList of makes is passed to the view as ViewData.

## The Create Post Method

The Create HTTP Post action method uses implicit model binding to build a Car entity from the form values. The code is listed here, with the explanation to follow:

```
[HttpPost]
[ValidateAntiForgeryToken]
public async Task<IActionResult> Create(Car car)
{
    if (ModelState.IsValid)
    {
        var newCar = await _serviceWrapper.AddOneAsync(car);
        return RedirectToAction(nameof(Details), new {id = newCar.Id});
    }
    ViewData["MakeId"] = await GetMakes();
    return View(car);
}
```

If the ModelState is valid, the entity is added to the database using the service wrapper and then the user is redirected to the Detail action method, using the newly created Car Id as the route parameter. This is the Post-Redirect-Get pattern. The user submitted a Post method (Create), is then redirected to a Get method (Details). This prevents the browser from resubmitting the post if the user refreshes the page.

If the ModelState is not valid, the Makes SelectList is added to ViewData, and the entity that was submitted is sent back to the Create view. ModelState is implicitly sent to the view as well so any errors can be displayed.

## The Edit Action Methods

The Edit process also uses two action methods: one (HTTP Get) to return the entity to be edited and one (HTTP Put) to submit the values of the updated record.



## The Edit Get Method

The Create HTTP Get action method gets a single car by Id using the service wrapper and sends it to the Create view:

```
[HttpGet("{id?}")]
public async Task<IActionResult> Edit(int? id)
{
    if (id == null)
    {
        return NotFound();
    }
    var car = await _serviceWrapper.GetOneAsync<Car>(id.Value);
    if (car == null)
    {
        return NotFound();
    }
    ViewData["MakeId"] = await GetMakes();
    return View(car);
}
```

This method functions the same as the Details action method with the exception of populating the SelectList, adding it to the ViewData, and using the Edit view instead of the Details view.

## The Edit Post Method

The Edit HTTP Post action method is similar to the Create HTTP Post method with the exceptions noted after the code listing:

```
[HttpPost("{id}")]
[ValidateAntiForgeryToken]
public async Task<IActionResult> Edit(int id, Car car)
{
    if (id != car.Id)
    {
        return NotFound();
    }
    if (ModelState.IsValid)
    {
        await _serviceWrapper.UpdateOneAsync(car);
        return RedirectToAction(nameof(Details), new { id = car.Id });
    }
    ViewData["MakeId"] = await GetMakes();
    return View(car);
}
```

The Edit HTTP Post method takes a single route parameter, which is required. If this doesn't match the Id of the reconstituted Car, a NotFound result is sent to the client. If the ModelState is valid, the entity is updated using the service wrapper and then the user is redirected to the Detail action method, using the Car Id as the route parameter. This also used the Post-Redirect-Get pattern.

If the ModelState is not valid, the Makes SelectList is added to ViewData, and the entity that was submitted is sent back to the Edit view. ModelState is implicitly sent to the view as well so any errors can be displayed.

## The Delete Action Methods

The Delete process also uses two action methods: one (HTTP Get) to return the entity to be deleted and one (HTTP Put) to submit the values to be deleted.

### The Delete Get Method

The Delete HTTP Get action method functions the same as the Details action method:

```
[HttpGet("{id?}")]
public async Task<IActionResult> Delete(int? id)
{
    if (id == null)
    {
        return NotFound();
    }
    var car = await _serviceWrapper.GetOneAsync<Car>(id.Value);
    if (car == null)
    {
        return NotFound();
    }
    return View(car);
}
```

### The Delete Post Method

The Delete HTTP Post action method only sends the Id and TimeStamp to the service wrapper:

```
[HttpPost("{id}")]
[ValidateAntiForgeryToken]
public async Task<IActionResult> Delete(int id, byte[] timeStamp)
{
    await _serviceWrapper.DeleteOneAsync(new Car { Id = id, TimeStamp = timeStamp });
    return RedirectToAction(nameof(Index));
}
```

The Delete HTTP Post method is streamlined to only send the values needed by EF Core to delete a record.

## Add the Custom Tag Helpers

Custom Tag Helpers can help eliminate repeated code. For AutoLot, custom Tag Helpers will replace the HTML used to navigate around the Car CRUD screens. The custom tag helpers will use the UrlFactory to generate links using the routing and endpoint information.

## Add the Support Code

Not directly related to Tag Helper creation, but necessary for the following examples, are some updates to `Startup.cs` and the addition of a string extension method.

## Update Startup.cs

In order to create an instance of the `UrlFactory` from a non-Controller-derived class, the `IActionContextAccessor` must be added to the services collection. Start by adding the following namespaces to `Startup.cs`:

```
using Microsoft.AspNetCore.Mvc.Infrastructure;
using Microsoft.Extensions.DependencyInjection.Extensions;
```

Next, add the following lines to the `ConfigureServices` method:

```
services.TryAddSingleton<IActionContextAccessor, ActionContextAccessor>();
services.AddHttpContextAccessor();
```

## Create the String Extension Method

When referring to controller names in code, quite often ASP.NET Core needs to have the raw string value, without the “Controller” suffix. This prevents using the `nameof()` method without then calling `string.Replace`. As this gets tedious over time, add a new folder named `Extensions` to the `AutoLot.Mvc` project, and in that folder, add a new static class named `StringExtensions`. Update the code to the following to add in the `RemoveController` extension method:

```
using System;

namespace AutoLot.Mvc.Extensions
{
    public static class StringExtensions
    {
        public static string RemoveController(this string original)
            => original.Replace("Controller", "", StringComparison.OrdinalIgnoreCase);
    }
}
```

## Create the Base Class

Create a new folder named `TagHelpers` in the root of the `AutoLot.Mvc` project. In this folder, create a new folder named `Base`, and in that folder, create a class named `CarLinkTagHelperBase.cs` and inherit from `TagHelper`. Add the following using statements to the new file:

```
using AutoLot.Mvc.Controllers;
using AutoLot.Mvc.Extensions;
using Microsoft.AspNetCore.Mvc;
using Microsoft.AspNetCore.Mvc.Infrastructure;
using Microsoft.AspNetCore.Mvc.Routing;
using Microsoft.AspNetCore.Razor.TagHelpers;
```

Add a constructor that takes instances of `IActionContextAccessor` and `IUrlHelperFactory`. Use the `UrlHelperFactory` with the `ActionContextAccessor` to create an instance of `IUrlHelper`, and store that in a class-level variable. The code is shown here:

```
public class CarLinkTagHelperBase: TagHelper
{
    protected readonly IUrlHelper UrlHelper;
    protected CarLinkTagHelperBase(IActionContextAccessor contextAccessor,
        IUrlHelperFactory urlHelperFactory)
    {
        UrlHelper = urlHelperFactory.GetUrlHelper(contextAccessor.ActionContext);
    }
}
```

Add a single public property to hold the Id of the Car, as follows:

```
public string CarId { get; set; }
```

Public properties are accessed as attributes of the tag helper, converted to lower-kebab-case. You will see this in action in the next section.

When a Tag Helper is invoked, the `Process` method is called. The `Process` method takes two parameters, a `TagHelperContext` and a `TagHelperOutput`. The `TagHelperContext` is used to get any other attributes on the tag and a dictionary of objects used to communicate with other tag helpers targeting child elements. The `TagHelperOutput` is used to create the rendered output.

Since this is a base class, we will add a method called `BuildContent` that the child classes can call from the `Process` method. Add the following method and code:

```
protected void BuildContent(TagHelperOutput output,
    string actionName, string className,
    string displayText, string fontAwesomeName)
{
    output.TagName = "a"; // Replaces the class specific tag with an <a> tag
    //Use the IUrlHelper to generate the correct Url
    var target = UrlHelper.Action(
        actionName, nameof(CarsController).RemoveController(), new {id = CarId});
    output.Attributes.SetAttribute("href", target);
    output.Attributes.Add("class", className);
    //Set the label
    output.Content.AppendHtml(
        $"{displayText} <i class="{fontAwesomeName}"></i>");
}
```

## The Car Details Tag Helper

Create a new class named `CarDetailsTagHelper.cs` in the `TagHelpers` folder. Make the class public and inherit from `CarLinkTagHelperBase`. Add the following using statements to the new file:

```
using AutoLot.Mvc.Controllers;
using AutoLot.Mvc.TagHelpers.Base;
```

```
using Microsoft.AspNetCore.Mvc.Infrastructure;
using Microsoft.AspNetCore.Mvc.Routing;
using Microsoft.AspNetCore.Razor.TagHelpers;
```

Add a public constructor to take in the required object instances and pass them to the base class:

```
public CarDetailsTagHelper(
    IActionContextAccessor contextAccessor,
    IUrlHelperFactory urlHelperFactory)
    : base(contextAccessor, urlHelperFactory) { }
```

Override the Process method, calling the BuildContent method in the base class:

```
public override void Process(TagHelperContext context, TagHelperOutput output)
{
    BuildContent(output, nameof(CarsController.Details), "text-info", "Details", "info-circle");
}
```

This creates the Detail link with the font-awesome info image.

## The Delete Car Tag Helper

Create a new class named DeleteCarTagHelper.cs in the TagHelpers folder. Make the class public and inherit from CarLinkTagHelperBase. Add the following using statements to the new file:

```
using AutoLot.Mvc.Controllers;
using AutoLot.Mvc.TagHelpers.Base;
using Microsoft.AspNetCore.Mvc.Infrastructure;
using Microsoft.AspNetCore.Mvc.Routing;
using Microsoft.AspNetCore.Razor.TagHelpers;
```

Add a public constructor to take in the required object instances and pass them to the base class:

```
public DeleteCarTagHelper(
    IActionContextAccessor contextAccessor,
    IUrlHelperFactory urlHelperFactory)
    : base(contextAccessor, urlHelperFactory) { }
```

Override the Process method, calling the BuildContent method in the base class:

```
public override void Process(TagHelperContext context, TagHelperOutput output)
{
    BuildContent(output, nameof(CarsController.Delete), "text-danger", "Delete", "trash");
}
```

This creates the Delete link with the font-awesome garbage can image.

## The Edit Car Tag Helper

Create a new class named `EditCarTagHelper.cs` in the `TagHelpers` folder. Make the class public and inherit from `CarLinkTagHelperBase`. Add the following using statements to the new file:

```
using AutoLot.Mvc.Controllers;
using AutoLot.Mvc.TagHelpers.Base;
using Microsoft.AspNetCore.Mvc.Infrastructure;
using Microsoft.AspNetCore.Mvc.Routing;
using Microsoft.AspNetCore.Razor.TagHelpers;
```

Add a public constructor to take in the required object instances and pass them to the base class:

```
public EditCarTagHelper(
    IActionContextAccessor contextAccessor,
    IUrlHelperFactory urlHelperFactory)
    : base(contextAccessor, urlHelperFactory) { }
```

Override the `Process` method, calling the `BuildContent` method in the base class:

```
public override void Process(TagHelperContext context, TagHelperOutput output)
{
    BuildContent(output, nameof(CarsController.Edit), "text-warning", "Edit", "edit");
}
```

This creates the Edit link with the font-awesome pencil image.

## Making Custom Tag Helpers Visible

To make custom Tag Helpers visible, the `@addTagHelper` command must be executed for any views that use the Tag Helpers or added to the `_ViewImports.cshtml` file. Open the `_ViewImports.cshtml` file in the root of the Views folder and add the following line:

```
@addTagHelper *, AutoLot.Mvc
```

---

■ **Note** This `@addTagHelper` line was already added in a previous section.

---

## Build the Cars Views

The main views for the `CarsController` pages will use a combination of Display Templates, Editor Templates, and Partial Views to reduce the replication of markup. Start by creating a folder name `Cars` under the Views folder in the `AutoLot.Mvc` application.

## The Helper Views

Create three new folders, named `DisplayTemplates`, `EditorTemplates`, and `Partials`, under the `Cars` folder. These will hold the helper views.

## The Car List Partial View

The list views (one for the entire inventory of cars and one for the list of cars by make) both share the `_CarListPartial.cshtml` partial view. Create a new view named `_CarListPartial.cshtml` in the `Partials` directory, and clear out the existing code. Set `IEnumerable<Car>` as the type (it doesn't need to be fully qualified because we added the namespace to the `_ViewImports.cshtml` file):

```
@model IEnumerable< Car>
```

Next, add a Razor block with the set of a Boolean variable indicating whether or not the Makes should be displayed. When this partial is used by the entire inventory list, the Makes should be displayed. When it is only showing a single Make, the Make field should be hidden.

```
@{
    var showMake = true;
    if (bool.TryParse(ViewBag.ByMake?.ToString(), out bool byMake))
    {
        showMake = !byMake;
    }
}
```

The next markup uses the anchor tag helper to create a link to the Create HTTP Get method:

```
<p>
    <a asp-action="Create" class="text-success">Create New <i class="fas fa-plus"></i></a>
</p>
```

To set the table and the table headers, a Razor HTML Helper is used to get the `DisplayName` for each of the properties. The `Display Name` will select the value of the `Display` or `DisplayName` attribute, and if that isn't set, it will use the property name. This section uses a Razor block to show the Make information based on the view-level variable set earlier.

```
<table class="table">
    <thead>
    <tr>
        <th>
            @Html.DisplayNameFor(model => model.PetName)
        </th>
        <th>
            @Html.DisplayNameFor(model => model.Color)
        </th>
        @if (showMake)
        {
            <th>
                @Html.DisplayNameFor(model => model.MakeNavigation)
            </th>
        }
        <th></th>
    </tr>
</thead>
```

The final section loops through the records and displays the table records using the DisplayFor Razor HTML Helper. This helper will look for a DisplayTemplate template name that matches the type of the property and, if not found, will out the value in a default manner. If the Car had a DateTime property, the DisplayTemplate shown earlier in the chapter would be invoked for the property.

This block also uses the edit-car, car-details, and delete-car custom Tag Helpers that were added in the previous section.

[illegible]

Custom tag helpers are invoked in a tag named for the class transformed into lower-kebab-casing the class. The public properties are lower-kebab-cased as attributes. Take each capital letter, make it lowercase, and then add a dash (-) before each of them (except the first). This makes them look like the words are on a shish-kebab.

## The Car Editor Template

The Car Editor Template will be shared by the Create and Edit views. Create a new view named Car.cshtml in the EditorTemplates directory, clear out any generated code, and add in the following:

```
@model Car
<div asp-validation-summary="All" class="text-danger"></div>
<div class="form-group">
    <label asp-for="PetName" class="col-form-label"></label>
    <input asp-for="PetName" class="form-control" />
    <span asp-validation-for="PetName" class="text-danger"></span>
</div>
```



```

<div class="form-group">
    <label asp-for="MakeNavigation" class="col-form-label"></label>
    <select asp-for="MakeId" class="form-control" asp-items="ViewBag.MakeId"></select>
    <span asp-validation-for="MakeId" class="text-danger"></span>
</div>
<div class="form-group">
    <label asp-for="Color" class="col-form-label"></label>
    <input asp-for="Color" class="form-control" />
    <span asp-validation-for="Color" class="text-danger"></span>
</div>

```

This template uses the validation Tag Helpers and the Label and Input tag helpers.

## The Car Display Template

The Car Display Template will be shared by the Details and Delete views. Create a new view named Car.cshtml in the DisplayTemplates directory, clear out any generated code, and add in the following:

```

@model Car
<hr />
<div>
    <dl class="row">
        <dt class = "col-sm-2">@Html.DisplayNameFor(model => model.PetName)</dt>
        <dd class = "col-sm-10">@Html.DisplayFor(model => model.PetName)</dd>
        <dt class = "col-sm-2">@Html.DisplayNameFor(model => model.MakeNavigation)</dt>
        <dd class = "col-sm-10">@Html.DisplayFor(model => model.MakeNavigation.Name)</dd>
        <dt class = "col-sm-2">@Html.DisplayNameFor(model => model.Color)</dt>
        <dd class = "col-sm-10">@Html.DisplayFor(model => model.Color)</dd>
    </dl>
</div>

```

## The Index View

With the `_CarListPartial` partial in place, the Index view is very small. Create a new view named Index.cshtml in the Cars directory. Clear out any generated code and add in the following:

```

@model IEnumerable<Car>
@{
    ViewData["Title"] = "Index";
}
<h1>Vehicle Inventory</h1>
<partial name="_CarListPartial" model="@Model"/>

```

Setting the `ViewData["Title"]` sets the title of the tab in the browser, as that `ViewData` item is used in the `_Layout's _HeadPartial`:

```
<title>@ViewData["Title"] - AutoLot.Web</title>
```

Invoking the partial `_CarListPartial` shows another capability, and this is passing data into the partial view. In this example, the model of the partial view is set to the model of the calling view (`@Model`).

Now that you have the Index view in place, run both apps, and select All inventory from the drop-down. You are presented with the screen shown in Figure 31-3.

# Vehicle Inventory

Create New +

PetName	Color	MakeNavigation	
Bimmer	Black	BMW	Edit   Details   Delete
Brownie	Brown	Yugo	Edit   Details   Delete
Clunker	Yellow	Yugo	Edit   Details   Delete
Hank	Green	BMW	Edit   Details   Delete
Mel	Black	Saab	Edit   Details   Delete
Pete	Black	Pinto	Edit   Details   Delete
Pinky	Pink	BMW	Edit   Details   Delete
Rusty	Rust	Ford	Edit   Details   Delete
Zippy	Black	VW	Edit   Details   Delete

Figure 31-3. The Car Inventory Page

The page shows the custom tag helpers as the links on the right side of the table.


## The ByMake View







The ByMake view is similar to the index, but sets up the partial to not display Make information except in the title of the page. Create a new view named ByMake.cshtml in the Cars directory. Clear out any generated code and add in the following:

```
@model IEnumerable<Car>
@{
    ViewData["Title"] = "Index";
}
<h1>Vehicle Inventory for @ViewBag.MakeName</h1>
@{
    var mode = new ViewDataDictionary(ViewData) {"ByMake", true};
}
<partial name="_CarListPartial" model="Model" view-data="@mode"/>
```

There are two distinct differences. The first is create a new ViewDataDictionary containing the ByMake property from the ViewBag. This is then passed into the partial, along with the model, which allows for hiding the Make information.

# Vehicle Inventory for Yugo

Create New 

PetName	Color	
Brownie	Brown	<a href="#">Edit </a>   <a href="#">Details </a>   <a href="#">Delete </a>
Clunker	Yellow	<a href="#">Edit </a>   <a href="#">Details </a>   <a href="#">Delete </a>

**Figure 31-4.** The list filtered by Make

## The Details View

Create a new view named `Details.cshtml` in the `Cars` directory. Clear out any generated code and add in the following:

[illegible]

The `@Html.DisplayForModel` uses the Display Template (`Car.cshtml`) built earlier in this section to display the Car details.



## Create a New Car

PetName

MakeNavigation

VW

Color

Create +

|

Back to List ≡

**Figure 31-6.** *The Details view*

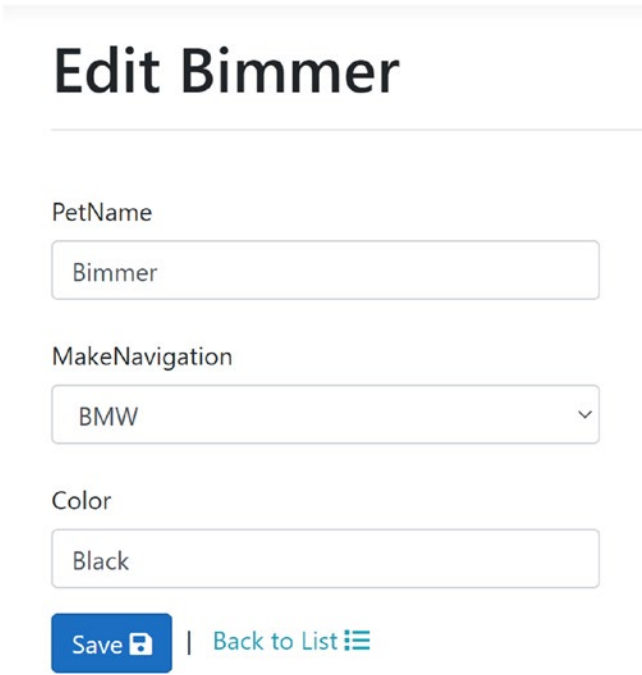
## The Edit View

Create a new view named `Edit.cshtml` in the `Cars` directory. Clear out any generated code and add in the following:

```
@model Car
@{
    ViewData["Title"] = "Edit";
}
<h1>Edit @Model.PetName</h1>
<hr/>
<div class="row">
    <div class="col-md-4">
        <form asp-action="Edit">
            @Html.EditorForModel()
            <input type="hidden" asp-for="Id" />
            <input type="hidden" asp-for="TimeStamp" />
            <div class="form-group">
                <button type="submit" class="btn btn-primary">
                    Save <i class="fas fa-save"></i></button>
                    &nbsp;&nbsp;&nbsp;&nbsp;&nbsp;&nbsp;&nbsp;&nbsp;&nbsp;&nbsp;&nbsp;&nbsp;&nbsp;&nbsp;&nbsp;&nbsp;&nbsp;&nbsp;&nbsp;&nbsp;&nbsp;&nbsp;&nbsp;&nbsp;&nbsp;&nbsp;&nbsp;&nbsp;&nbsp;&nbsp;&nbsp;&nbsp;&nbsp;&nbsp;&nbsp;&nbsp;&nbsp;&nbsp;&nbsp;&nbsp;&nbsp;&nbsp;&nbsp;&nbsp;&nbsp;&nbsp;&nbsp;&nbsp;&nbsp;&~
                    <a asp-action="Index" class="text-info">Back to List <i class="fas fa-list"></i></a>
            </div>
        </form>
    </div>
```

```
        </form>
    </div>
</div>
@section Scripts {
    @{ await Html.RenderPartialAsync("_ValidationScriptsPartial"); }
}
```

This view also uses the `@Html.EditorForModel` and the `_ValidationScriptsPartial`. But it also includes two hidden inputs for the `Id` and `TimeStamp`. These will be posted along with the rest of the form data, but should not be edited by users.



**Figure 31-7.** The *Edit* view

## The Delete View

Create a new view named `Delete.cshtml` in the `Cars` directory. Clear out any generated code and add in the following:

```
@model Car

@{
    ViewData["Title"] = "Delete";
}

<h1>Delete @Model.PetName</h1>
```

```
<h3>Are you sure you want to delete this car?</h3>  
<div>  
    @Html.DisplayForModel()  
    <form asp-action="Delete">  
        <input type="hidden" asp-for="Id" />  
        <input type="hidden" asp-for="TimeStamp" />  
        <button type="submit" class="btn btn-danger">Delete <i class="fas fa-trash"></i>  
    </button>&nbsp;&nbsp;&nbsp;&nbsp;&nbsp;&nbsp;&nbsp;&nbsp;&nbsp;&nbsp;&nbsp;&nbsp;&nbsp;&nbsp;&nbsp;&nbsp;&nbsp;&nbsp;&nbsp;&nbsp;&nbsp;&nbsp;&nbsp;&nbsp;&nbsp;&nbsp;&nbsp;&nbsp;&nbsp;&nbsp;&nbsp;&nbsp;&nbsp;&nbsp;&nbsp;&nbsp;&nbsp;&nbsp;&nbsp;&nbsp;&nbsp;&nbsp;&nbsp;&nbsp;&nbsp;&nbsp;&nbsp;&nbsp;&nbsp;&nbsp;&nbsp;&nbsp;&nbsp;&nbsp;&nbsp;&nbsp;&nbsp;&nbsp;&nbsp;&nbsp;&nbsp;&nbsp;&nbsp;&nbsp;&nbsp;&nbsp;&nbsp;&nbsp;&nbsp;&nbsp;&nbsp;&nbsp;&nbsp;&nbsp;&nbsp;&nbsp;&nbsp;&nbsp;&nbsp;&nbsp;&nbsp;&nbsp;&nbsp;&nbsp;&nbsp;&~  
    <a asp-action="Index" class="text-info">Back to List <i class="fas fa-list"></i></a>  
    </form>  
</div>
```

This view also uses the `@Html.DisplayForModel` and the two hidden inputs for the `Id` and `TimeStamp`. These will be the only fields posted as the form data.

## Delete Bimmer

Are you sure you want to delete this car?

**PetName** Bimmer  
**MakeNavigation** BMW  
**Color** Black

[Delete](#) | [Back to List](#)

**Figure 31-8.** *The Delete view*

## Summary

This chapter completed our study of ASP.NET Core, and finished the AutoLot.Mvc application. It began with a deep dive into Views, Partial Views, Editor and Display Templates, and Layouts. Next was an examination of Tag Helpers, blending client-side markup with server-side code.

The next set of topics covered client-side libraries, including management of what libraries are in the project as well as bundling and minification. Once that was configured, the Layout was updated with the new path to the libraries, the layout was broken up into a set of partials, and the environment Tag Helper was added to further refine client-side library handling.

Next was using the `HttpClientFactory` and the ASP.NET Core configuration system to create the service wrapper that communicates with `AutoLot.Api`, and this was used to create a View Component for the dynamic menu system. After a brief discussion of how to load both applications (`AutoLot.Api` and `AutoLot.Mvc`) at the same time, the core of the application was developed.

This development began with the creation of the `CarsController` and all of the action methods. Then the custom Tag Helpers were added, and finished by creating all of the `Cars` views. Of course, we only built one controller and its views, but the pattern can be followed to provide controllers and views for all of the `AutoLot` entities.

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