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Visual C#® 2010

John Sharp
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eBook + exercises

Step by Step

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John Sharp

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Contents at a Glance

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Acknowledgments

An oft-repeated fable is that the workmen who paint the Forth Railway Bridge, a large Victorian cantilever structure that spans the Firth of Forth just north of Edinburgh, have a job for life. According to the myth, it takes them several years to paint it from one end to the other, and when they have finished they have to start over again. I am not sure whether this is due to the ferocity of the Scottish weather, or the sensitivity of the paint that is used, although my daughter insists it is simply that the members of Edinburgh City Council have yet to decide on a color scheme that they really like for the bridge. I sometimes feel that this book has similar attributes. No sooner have I completed an edition and seen it published, then Microsoft announces another cool update for Visual Studio and C#, and my friends at Microsoft Press contact me and say, "What are your plans for the next edition?" However, unlike painting the Forth Railway Bridge, working on a new edition of this text is always an enjoyable task with a lot more scope for inventiveness than trying to work out new ways to hold a paint brush. There is always something novel to learn and innovative technology to play with. In this edition, I cover the new features of C# 4.0 and the .NET Framework 4.0, which developers will find invaluable for building applications that can take advantage of the increasingly powerful hardware now becoming available. Hence, although this work appears to be a never-ending task, it is always fruitful and pleasurable.

A large part of the enjoyment when working on a project such as this is the opportunity to collaborate with a highly motivated group of talented people within Microsoft Press, the developers at Microsoft working on Visual Studio 2010, and the people who review each chapter and make suggestions for various improvements. I would especially like to single out Rosemary Caperton and Stephen Sagman who have worked tirelessly to keep the project on track, to Per Blomqvist who reviewed (and corrected) each chapter, and to Roger LeBlanc who had the thankless task of copy-editing the manuscript and converting my prose into English. I must also make special mention of Michael Blome who provided me with early access to software and answered the many questions that I had concerning the Task Parallal Library. Several members of Content Master were kept gainfully employed reviewing and testing the code for the exercises—thanks Mike Sumsion, Chris Cully, James Millar, and Louisa Perry. Of course, I must additionally thank Jon Jagger who co-authored the first edition of this book with me back in 2001.

Last but by no means least, I must thank my family. My wife Diana is a wonderful source of inspiration. When writing Chapter 28 on the Task Parallel Library I had a mental block and had to ask her how she would explain Barrier methods. She looked at me quizzically, and gave a reply that although anatomically correct if I was in a doctor's surgery, indicated that either I had not phrased the question very carefully or that she had completely misunderstood what I was asking! James has now grown up and will soon have to learn what real work entails if he is to keep Diana and myself in the manner to which we would like to become accustomed in our dotage. Francesca has also grown up, and seems to have refined a strategy for getting all she wants without doing anything other than looking at me with wide, bright eyes, and smiling.

Finally, "Up the Gills!"

—John Sharp

Introduction

Microsoft Visual C# is a powerful but simple language aimed primarily at developers creating applications by using the Microsoft .NET Framework. It inherits many of the best features of C++ and Microsoft Visual Basic, but few of the inconsistencies and anachronisms, resulting in a cleaner and more logical language. C# 1.0 made its public debut in 2001. The advent of C# 2.0 with Visual Studio 2005 saw several important new features added to the language, including Generics, Iterators, and anonymous methods. C# 3.0 which was released with Visual Studio 2008, added extension methods, lambda expressions, and most famously of all, the Language Integrated Query facility, or LINQ. The latest incarnation of the language, C# 4.0, provides further enhancements that improve its interoperability with other languages and technologies. These features include support for named and optional arguments, the *dynamic* type which indicates that the language runtime should implement late binding for an object, and variance which resolves some issues in the way in which generic interfaces are defined. C# 4.0 takes advantage of the latest version of the .NET Framework, also version 4.0. There are many additions to the .NET Framework in this release, but arguably the most significant are the classes and types that constitute the Task Parallel Library (TPL). Using the TPL, you can now build highly scalable applications that can take full advantage of multi-core processors quickly and easily. The support for Web services and Windows Communication Foundation (WCF) has also been extended; you can now build services that follow the REST model as well as the more traditional SOAP scheme.

The development environment provided by Microsoft Visual Studio 2010 makes all these powerful features easy to use, and the many new wizards and enhancements included in Visual Studio 2010 can greatly improve your productivity as a developer.

Who This Book Is For

This book assumes that you are a developer who wants to learn the fundamentals of programming with C# by using Visual Studio 2010 and the .NET Framework version 4.0. In this book, you will learn the features of the C# language, and then use them to build applications running on the Microsoft Windows operating system. By the time you complete this book, you will have a thorough understanding of C# and will have used it to build Windows Presentation Foundation applications, access Microsoft SQL Server databases by using ADO.NET and LINQ, build responsive and scalable applications by using the TPL, and create REST and SOAP Web services by using WCF.

Finding Your Best Starting Point in This Book

This book is designed to help you build skills in a number of essential areas. You can use this book if you are new to programming or if you are switching from another programming language such as C, C++, Java, or Visual Basic. Use the following table to find your best starting point.

If you are	Follow these steps
New to object-oriented programming	**1.** Install the practice files as described in the next section, "Installing and Using the Practice Files." **2.** Work through the chapters in Parts I, II, and III sequentially. **3.** Complete Parts IV, V, and VI as your level of experience and interest dictates.
Familiar with procedural programming languages such as C, but new to C#	**1.** Install the practice files as described in the next section, "Installing and Using the Practice Files." Skim the first five chapters to get an overview of C# and Visual Studio 2010, and then concentrate on Chapters 6 through 21. **2.** Complete Parts IV, and V, and VI as your level of experience and interest dictates.
Migrating from an object-oriented language such as C++, or Java	**1.** Install the practice files as described in the next section, "Installing and Using the Practice Files." **2.** Skim the first seven chapters to get an overview of C# and Visual Studio 2010, and then concentrate on Chapters 8 through 21. **3.** For information about building Windows applications and using a database, read Parts IV and V. **4.** For information about building scalable applications and Web services, read Part VI.

If you are	Follow these steps
Switching from Visual Basic 6	**1.** Install the practice files as described in the next section, "Installing and Using the Practice Files." **2.** Work through the chapters in Parts I, II, and III sequentially. **3.** For information about building Windows applications, read Part IV. **4.** For information about accessing a database, read Part V. **5.** For information about building scalable applications and Web services, read Part VI. **6.** Read the Quick Reference sections at the end of the chapters for information about specific C# and Visual Studio 2010 constructs.
Referencing the book after working through the exercises	**1.** Use the index or the Table of Contents to find information about particular subjects. **2.** Read the Quick Reference sections at the end of each chapter to find a brief review of the syntax and techniques presented in the chapter.

Conventions and Features in This Book

This book presents information using conventions designed to make the information readable and easy to follow. Before you start, read the following list, which explains conventions you'll see throughout the book and points out helpful features that you might want to use.

Conventions

- Each exercise is a series of tasks. Each task is presented as a series of numbered steps (1, 2, and so on). A round bullet (•) indicates an exercise that has only one step.
- Notes labeled "tip" provide additional information or alternative methods for completing a step successfully.
- Notes labeled "important" alert you to information you need to check before continuing.
- Text that you type appears in bold.

- A plus sign (+) between two key names means that you must press those keys at the same time. For example, "Press Alt+Tab" means that you hold down the Alt key while you press the Tab key.

Other Features

- Sidebars throughout the book provide more in-depth information about the exercise. The sidebars might contain background information, design tips, or features related to the information being discussed.
- Each chapter ends with a Quick Reference section. The Quick Reference section contains quick reminders of how to perform the tasks you learned in the chapter.

Prerelease Software

This book was written and tested against Visual Studio 2010 Beta 2. We did review and test our examples against the final release of the software. However, you might find minor differences between the production release and the examples, text, and screenshots in this book.

Hardware and Software Requirements

You'll need the following hardware and software to complete the practice exercises in this book:

- Microsoft Windows 7 Home Premium, Windows 7 Professional, Windows 7 Enterprise, or Windows 7 Ultimate. The exercises will also run using Microsoft Windows Vista with Service Pack 2 or later.
- Microsoft Visual Studio 2010 Standard, Visual Studio 2010 Professional, or Microsoft Visual C# 2010 Express and Microsoft Visual Web Developer 2010 Express.
- Microsoft SQL Server 2008 Express (this is provided with all editions of Visual Studio 2010, Visual C# 2010 Express, and Visual Web Developer 2010 Express).
- 1.6 GHz processor, or faster. Chapters 27 and 28 require a dual-core or better processor.
- 1 GB for x32 processor, 2 GB for an x64 processor, of available, physical RAM.
- Video (1024 ×768 or higher resolution) monitor with at least 256 colors.
- CD-ROM or DVD-ROM drive.
- Microsoft mouse or compatible pointing device

You will also need to have Administrator access to your computer to configure SQL Server 2008 Express Edition.

Code Samples

The companion CD inside this book contains the code samples that you'll use as you perform the exercises. By using the code samples, you won't waste time creating files that aren't relevant to the exercise. The files and the step-by-step instructions in the lessons also let you learn by doing, which is an easy and effective way to acquire and remember new skills.

Installing the Code Samples

Follow these steps to install the code samples and required software on your computer so that you can use them with the exercises.

1. Remove the companion CD from the package inside this book and insert it into your CD-ROM drive.

> **Note** An end user license agreement should open automatically. If this agreement does not appear, open My Computer on the desktop or Start menu, double-click the icon for your CD-ROM drive, and then double-click StartCD.exe.

2. Review the end user license agreement. If you accept the terms, select the accept option and then click **Next**.

   A menu will appear with options related to the book.

3. Click **Install Code Samples**.
4. Follow the instructions that appear.

   The code samples are installed to the following location on your computer:

   Documents\Microsoft Press\Visual CSharp Step By Step

Using the Code Samples

Each chapter in this book explains when and how to use any code samples for that chapter. When it's time to use a code sample, the book will list the instructions for how to open the files.

For those of you who like to know all the details, here's a list of the code sample Visual Studio 2010 projects and solutions, grouped by the folders where you can find them. In many cases, the exercises provide starter files and completed versions of the same projects which you can use as a reference. The completed projects are stored in folders with the suffix "- Complete".

Project	Description
Chapter 1	
TextHello	This project gets you started. It steps through the creation of a simple program that displays a text-based greeting.
WPFHello	This project displays the greeting in a window by using Windows Presentation Foundation.
Chapter 2	
PrimitiveDataTypes	This project demonstrates how to declare variables by using each of the primitive types, how to assign values to these variables, and how to display their values in a window.
MathsOperators	This program introduces the arithmetic operators (+ – * / %).
Chapter 3	
Methods	In this project, you'll re-examine the code in the previous project and investigate how it uses methods to structure the code.
DailyRate	This project walks you through writing your own methods, running the methods, and stepping through the method calls by using the Visual Studio 2010 debugger.
DailyRate Using Optional Parameters	This project shows you how to define a method that takes optional parameters, and call the method by using named arguments.
Chapter 4	
Selection	This project shows how to use a cascading *if* statement to implement complex logic, such as comparing the equivalence of two dates.
SwitchStatement	This simple program uses a *switch* statement to convert characters into their XML representations.
Chapter 5	
WhileStatement	This project demonstrates a *while* statement that reads the contents of a source file one line at a time and displays each line in a text box on a form.
DoStatement	This project uses a *do* statement to convert a decimal number to its octal representation.

Project	Description
Chapter 6	
MathsOperators	This project revisits the MathsOperators project from Chapter 2, "Working with Variables, Operators, and Expressions," and shows how various unhandled exceptions can make the program fail. The *try* and *catch* keywords then make the application more robust so that it no longer fails.
Chapter 7	
Classes	This project covers the basics of defining your own classes, complete with public constructors, methods, and private fields. It also shows how to create class instances by using the *new* keyword and how to define static methods and fields.
Chapter 8	
Parameters	This program investigates the difference between value parameters and reference parameters. It demonstrates how to use the *ref* and *out* keywords.
Chapter 9	
StructsAndEnums	This project defines a *struct* type to represent a calendar date.
Chapter 10	
Cards Using Arrays	This project shows how to use arrays to model hands of cards in a card game.
Cards Using Collections	This project shows how to restructure the card game program to use collections rather than arrays.
Chapter 11	
ParamsArrays	This project demonstrates how to use the *params* keyword to create a single method that can accept any number of *int* arguments.
Chapter 12	
Vehicles	This project creates a simple hierarchy of vehicle classes by using inheritance. It also demonstrates how to define a virtual method.
ExtensionMethod	This project shows how to create an extension method for the *int* type, providing a method that converts an integer value from base 10 to a different number base.

Project	Description
Chapter 13	
Drawing Using Interfaces	This project implements part of a graphical drawing package. The project uses interfaces to define the methods that drawing shapes expose and implement.
Drawing	This project extends the Drawing Using Interfaces project to factor common functionality for shape objects into abstract classes.
Chapter 14	
UsingStatement	This project revisits a small piece of code from Chapter 5, "Using Compound Assignment and Iteration Statements" and reveals that it is not exception-safe. It shows you how to make the code exception-safe with a *using* statement.
Chapter 15	
WindowProperties	This project presents a simple Windows application that uses several properties to display the size of its main window. The display updates automatically as the user resizes the window.
AutomaticProperties	This project shows how to create automatic properties for a class, and use them to initialize instances of the class.
Chapter 16	
Indexers	This project uses two indexers: one to look up a person's phone number when given a name, and the other to look up a person's name when given a phone number.
Chapter 17	
Clock Using Delegates	This project displays a World clock showing the local time as well as the times in London, New York, and Tokyo. The application uses delegates to start and stop the clock displays.
Clock Using Events	This version of the World clock application uses events to start and stop the clock display.
Chapter 18	
BinaryTree	This solution shows you how to use Generics to build a *typesafe* structure that can contain elements of any type.
BuildTree	This project demonstrates how to use Generics to implement a *typesafe* method that can take parameters of any type.
BinaryTreeTest	This project is a test harness that creates instances of the *Tree* type defined in the BinaryTree project.

Project	Description
Chapter 19	
BinaryTree	This project shows you how to implement the generic *IEnumerator*<*T*> interface to create an enumerator for the generic *Tree* class.
IteratorBinaryTree	This solution uses an Iterator to generate an enumerator for the generic *Tree* class.
EnumeratorTest	This project is a test harness that tests the enumerator and iterator for the *Tree* class.
Chapter 20	
QueryBinaryTree	This project shows how to use LINQ queries to retrieve data from a binary tree object.
Chapter 21	
ComplexNumbers	This project defines a new type that models complex numbers, and implements common operators for this type.
Chapter 22	
BellRingers	This project is a Windows Presentation Foundation application demonstrating how to define styles and use basic WPF controls.
Chapter 23	
BellRingers	This project is an extension of the application created in Chapter 22, "Introducing Windows Presentation Foundation," but with drop-down and pop-up menus added to the user interface.
Chapter 24	
OrderTickets	This project demonstrates how to implement business rules for validating user input in a WPF application, using customer order information as an example.
Chapter 25	
ReportOrders	This project shows how to access a database by using ADO.NET code. The application retrieves information from the Orders table in the Northwind database.
LINQOrders	This project shows how to use LINQ to SQL to access a database and retrieve information from the Orders table in the Northwind database.

Project	Description
Chapter 26	
Suppliers	This project demonstrates how to use data binding with a WPF application to display and format data retrieved from a database in controls on a WPF form. The application also enables the user to modify information in the Products table in the Northwind database.
Chapter 27	
GraphDemo	This project generates and displays a complex graph on a WPF form. It uses a single thread to perform the calculations.
GraphDemo Using Tasks	This version of the GraphDemo project creates multiple tasks to perform the calculations for the graph in parallel.
GraphDemo Using Tasks that Return Results	This is an extended version of the GraphDemo Using Tasks project that shows how to return data from a task.
GraphDemo Using the Parallel Class	This version of the GraphDemo project uses the *Parallel* class to abstract out the process of creating and managing tasks.
GraphDemo Canceling Tasks	This project shows how to implement cancelation to halt tasks in a controlled manner before they have completed
ParallelLoop	This application provides an example showing when you should not use the *Parallel* class to create and run tasks.
Chapter 28	
CalculatePI	This project uses a statistical sampling algorithm to calculate an approximation for PI. It uses parallel tasks.
PLINQ	This project shows some examples of using PLINQ to query data by using parallel tasks.

Project	Description
Chapter 29	
ProductInformationService	This project implements a SOAP Web service built by using WCF. The Web service exposes a method that returns pricing information for products from the Northwind database.
ProductDetailsService	This projects implements a REST Web service built by using WCF. The Web service provides a method that returns the details of a specified product from the Northwind database.
ProductDetailsContracts	This project contains the service and data contracts implemented by the ProductDetailsService Web service.
ProductClient	This project shows how to create a WPF application that consumes a Web service. It shows how to invoke the Web methods in the ProductInformationService and ProductDetailsService Web services.

Uninstalling the Code Samples

Follow these steps to remove the code samples from your computer.

1. In **Control Panel**, under **Programs**, click **Uninstall a program**.
2. From the list of currently installed programs, select Microsoft Visual C# 2010 Step By Step.
3. Click **Uninstall**.
4. Follow the instructions that appear to remove the code samples.

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Part I
Introducing Microsoft Visual C# and Microsoft Visual Studio 2010

In this part:

Chapter 1

Welcome to C#

After completing this chapter, you will be able to:

- Use the Microsoft Visual Studio 2010 programming environment.
- Create a C# console application.
- Explain the purpose of namespaces.
- Create a simple graphical C# application.

Microsoft Visual C# is Microsoft's powerful component-oriented language. C# plays an important role in the architecture of the Microsoft .NET Framework, and some people have compared it to the role that C played in the development of UNIX. If you already know a language such as C, C++, or Java, you'll find the syntax of C# reassuringly familiar. If you are used to programming in other languages, you should soon be able to pick up the syntax and feel of C#; you just need to learn to put the braces and semicolons in the right place. I hope this is just the book to help you!

In Part I, you'll learn the fundamentals of C#. You'll discover how to declare variables and how to use arithmetic operators such as the plus sign (+) and minus sign (–) to manipulate the values in variables. You'll see how to write methods and pass arguments to methods. You'll also learn how to use selection statements such as *if* and iteration statements such as *while*. Finally, you'll understand how C# uses exceptions to handle errors in a graceful, easy-to-use manner. These topics form the core of C#, and from this solid foundation, you'll progress to more advanced features in Part II through Part VI.

Beginning Programming with the Visual Studio 2010 Environment

Visual Studio 2010 is a tool-rich programming environment containing the functionality that you need to create large or small C# projects. You can even construct projects that seamlessly combine modules written by using different programming languages such as C++, Visual Basic, and F#. In the first exercise, you will open the Visual Studio 2010 programming environment and learn how to create a console application.

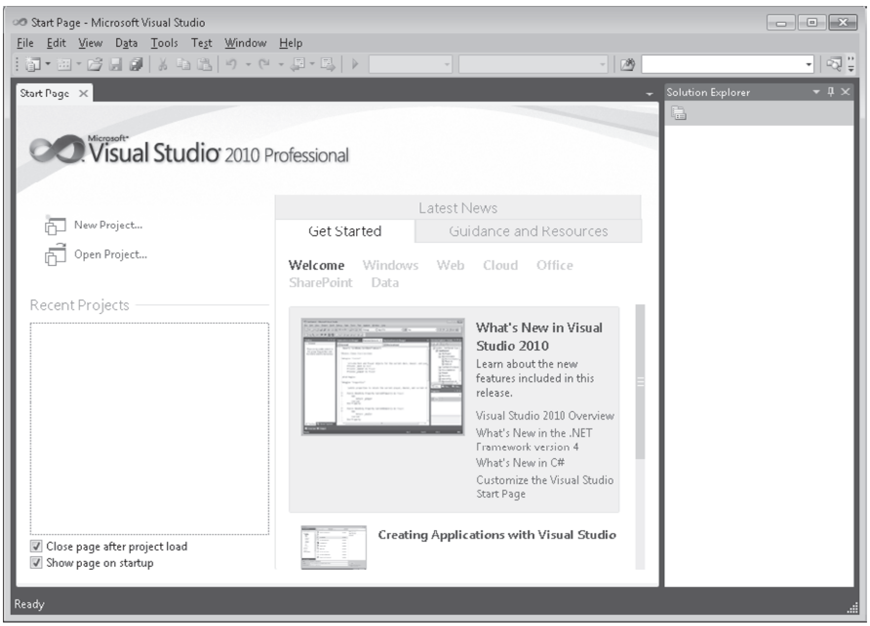
> **Note** A console application is an application that runs in a command prompt window rather than providing a graphical user interface.

Create a console application in Visual Studio 2010

- If you are using Visual Studio 2010 Standard or Visual Studio 2010 Professional, perform the following operations to start Visual Studio 2010:

    1. On the Microsoft Windows task bar, click the *Start* button, point to *All Programs*, and then point to the *Microsoft Visual Studio 2010* program group.
    2. In the Microsoft Visual Studio 2010 program group, click *Microsoft Visual Studio 2010*.

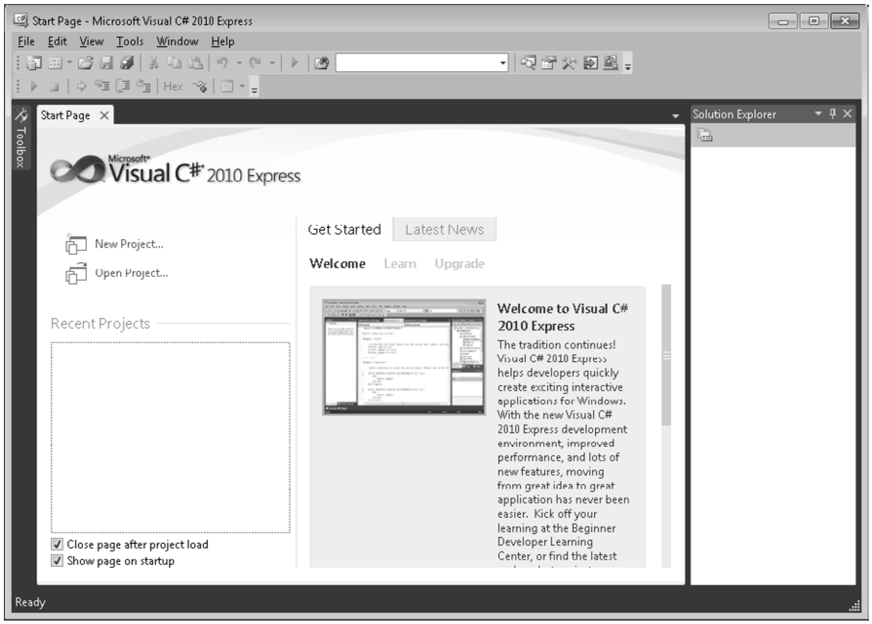
    Visual Studio 2010 starts, like this:



> **Note** If this is the first time you have run Visual Studio 2010, you might see a dialog box prompting you to choose your default development environment settings. Visual Studio 2010 can tailor itself according to your preferred development language. The various dialog boxes and tools in the integrated development environment (IDE) will have their default selections set for the language you choose. Select *Visual C# Development Settings* from the list, and then click the *Start Visual Studio* button. After a short delay, the Visual Studio 2010 IDE appears.

- If you are using Visual C# 2010 Express, on the Microsoft Windows task bar, click the *Start* button, point to *All Programs*, and then click *Microsoft Visual C# 2010 Express*.

  Visual C# 2010 Express starts, like this:



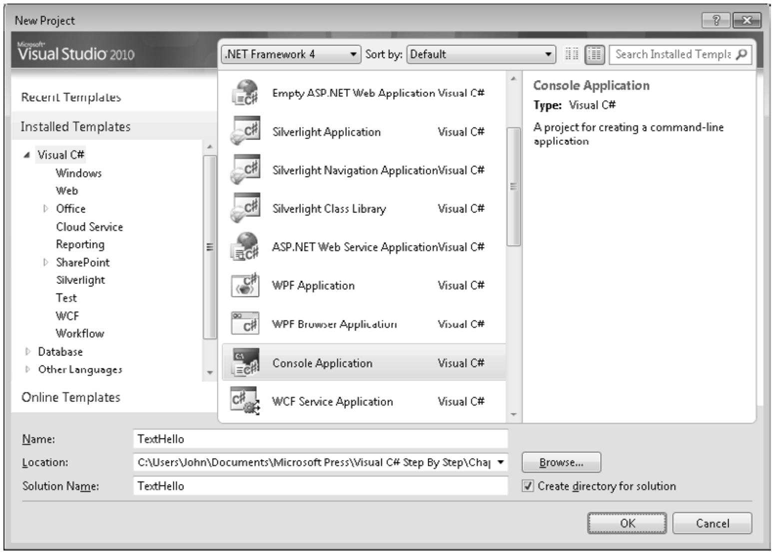
> **Note** To avoid repetition, throughout this book I simply state, "Start Visual Studio" when you need to open Visual Studio 2010 Standard, Visual Studio 2010 Professional, or Visual C# 2010 Express. Additionally, unless explicitly stated, all references to Visual Studio 2010 apply to Visual Studio 2010 Standard, Visual Studio 2010 Professional, and Visual C# 2010 Express.

- If you are using Visual Studio 2010 Standard or Visual Studio 2010 Professional, perform the following tasks to create a new console application:

  1. On the *File* menu, point to *New*, and then click *Project*.

     The *New Project* dialog box opens. This dialog box lists the templates that you can use as a starting point for building an application. The dialog box categorizes templates according to the programming language you are using and the type of application.

  2. In the left pane, under *Installed Templates*, click *Visual C#*. In the middle pane, verify that the combo box at the top of the pane displays the text *.NET Framework 4.0*, and then click the *Console Application* icon. You might need to scroll the middle pane to see the *Console Application* icon.



3. In the *Location* field, type **C:\Users*YourName*\Documents\Microsoft Press\Visual CSharp Step By Step\Chapter 1**. Replace the text *YourName* in this path with your Windows user name.

> **Note** To save space throughout the rest of this book, I will simply refer to the path "C:\Users*YourName*\Documents" as your Documents folder.

> **Tip** If the folder you specify does not exist, Visual Studio 2010 creates it for you.

4. In the *Name* field, type **TextHello**.
5. Ensure that the *Create directory for solution* check box is selected, and then click *OK*.

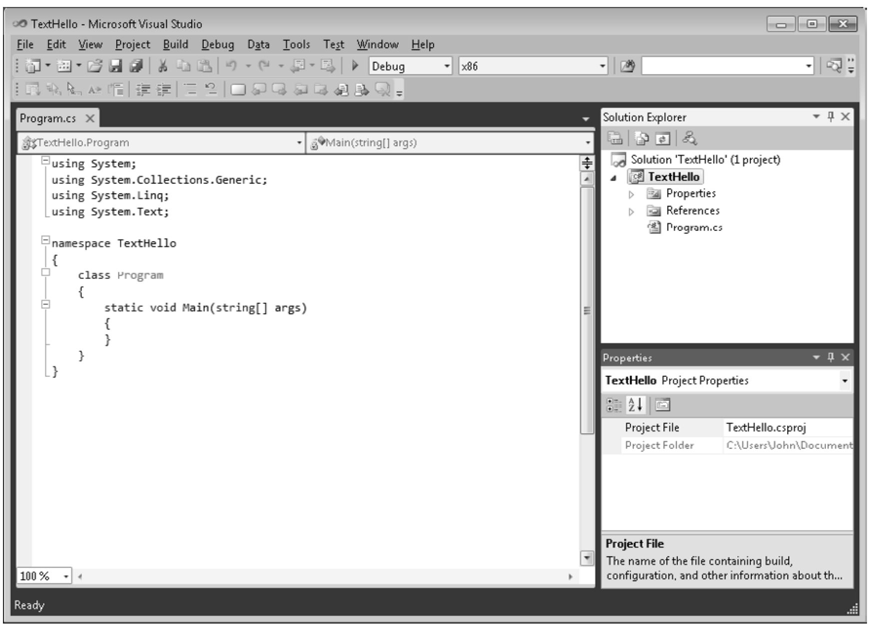
- If you are using Visual C# 2010 Express, perform the following tasks to create a new console application:
  1. On the *File* menu, click *New Project*.
  2. In the *New Project* dialog box, in the middle pane click the *Console Application* icon.
  3. In the *Name* field, type **TextHello**.

4. Click *OK*.

   Visual C# 2010 Express saves solutions to the C:\Users*YourName*\Documents \Visual Studio\Projects folder by default. You can specify an alternative location when you save the solution.

5. On the *File* menu, click *Save TextHello As*.
6. In the *Save Project* dialog box, in the *Location* field specify the **Microsoft Press\Visual CSharp Step By Step\Chapter 1** folder under your Documents folder.
7. Click *Save*.

Visual Studio creates the project using the Console Application template and displays the starter code for the project, like this:



The *menu bar* at the top of the screen provides access to the features you'll use in the programming environment. You can use the keyboard or the mouse to access the menus and commands exactly as you can in all Windows-based programs. The *toolbar* is located beneath the menu bar and provides button shortcuts to run the most frequently used commands.

The *Code and Text Editor* pane occupying the main part of the IDE displays the contents of source files. In a multifile project, when you edit more than one file, each source file has its own tab labeled with the name of the source file. You can click the tab to bring the named source file to the foreground in the *Code and Text Editor* window. The *Solution Explorer* pane (on the right side of the dialog box) displays the names of the files associated with the project, among other items. You can also double-click a file name in the *Solution Explorer* pane to bring that source file to the foreground in the *Code and Text Editor* window.

Before writing the code, examine the files listed in *Solution Explorer*, which Visual Studio 2010 has created as part of your project:

- **Solution 'TextHello'** This is the top-level solution file, of which there is one per application. If you use Windows Explorer to look at your Documents\Microsoft Press\Visual CSharp Step By Step\Chapter 1\TextHello folder, you'll see that the actual name of this file is TextHello.sln. Each solution file contains references to one or more project files.
- **TextHello** This is the C# project file. Each project file references one or more files containing the source code and other items for the project. All the source code in a single project must be written in the same programming language. In Windows Explorer, this file is actually called TextHello.csproj, and it is stored in the \Microsoft Press\Visual CSharp Step By Step\Chapter 1\TextHello\TextHello folder under your Documents folder.
- **Properties** This is a folder in the TextHello project. If you expand it, you will see that it contains a file called AssemblyInfo.cs. AssemblyInfo.cs is a special file that you can use to add attributes to a program, such as the name of the author, the date the program was written, and so on. You can specify additional attributes to modify the way in which the program runs. Learning how to use these attributes is outside the scope of this book.
- **References** This is a folder that contains references to compiled code that your application can use. When code is compiled, it is converted into an assembly and given a unique name. Developers use assemblies to package useful bits of code they have written so that they can distribute it to other developers who might want to use the code in their applications. Many of the features that you will be using when writing applications using this book make use of assemblies provided by Microsoft with Visual Studio 2010.
- **Program.cs** This is a C# source file and is the one currently displayed in the Code and Text Editor window when the project is first created. You will write your code for the console application in this file. It also contains some code that Visual Studio 2010 provides automatically, which you will examine shortly.

Writing Your First Program

The Program.cs file defines a class called *Program* that contains a method called *Main*. All methods must be defined inside a class. You will learn more about classes in Chapter 7, "Creating and Managing Classes and Objects." The *Main* method is special—it designates the program's entry point. It must be a static method. (You will look at methods in detail in Chapter 3, "Writing Methods and Applying Scope," and Chapter 7 describes static methods.)

Important C# is a case-sensitive language. You must spell *Main* with a capital *M*.

In the following exercises, you write the code to display the message "Hello World" in the console; you build and run your Hello World console application; and you learn how namespaces are used to partition code elements.

Write the code by using Microsoft IntelliSense

1. In the *Code and Text Editor* window displaying the Program.cs file, place the cursor in the *Main* method immediately after the opening brace, {, and then press Enter to create a new line. On the new line, type the word **Console**, which is the name of a built-in class. As you type the letter *C* at the start of the word *Console*, an IntelliSense list appears. This list contains all of the C# keywords and data types that are valid in this context. You can either continue typing or scroll through the list and double-click the *Console* item with the mouse. Alternatively, after you have typed *Con*, the IntelliSense list automatically homes in on the *Console* item and you can press the Tab or Enter key to select it.

   Main should look like this:

   ```
   static void Main(string[] args)
   {
       Console
   }
   ```

   Note *Console* is a built-in class that contains the methods for displaying messages on the screen and getting input from the keyboard.

2. Type a period immediately after *Console*. Another IntelliSense list appears, displaying the methods, properties, and fields of the *Console* class.
3. Scroll down through the list, select *WriteLine*, and then press Enter. Alternatively, you can continue typing the characters *W*, *r*, *i*, *t*, *e*, *L* until *WriteLine* is selected, and then press Enter.

   The IntelliSense list closes, and the word *WriteLine* is added to the source file. *Main* should now look like this:

   ```
   static void Main(string[] args)
   {
       Console.WriteLine
   }
   ```

4. Type an opening parenthesis, **(**. Another IntelliSense tip appears.

   This tip displays the parameters that the *WriteLine* method can take. In fact, *WriteLine* is an *overloaded method*, meaning that the *Console* class contains more than one method named *WriteLine*—it actually provides 19 different versions of this method. Each version of the *WriteLine* method can be used to output different types of data. (Chapter 3 describes overloaded methods in more detail.) *Main* should now look like this:

```
static void Main(string[] args)
{
    Console.WriteLine(
}
```

> **Tip** You can click the up and down arrows in the tip to scroll through the different overloads of *WriteLine*.

5. Type a closing parenthesis,) followed by a semicolon, ;.

   Main should now look like this:

```
static void Main(string[] args)
{
    Console.WriteLine();
}
```

6. Move the cursor, and type the string **"Hello World"**, including the quotation marks, between the left and right parentheses following the *WriteLine* method.

   Main should now look like this:

```
static void Main(string[] args)
{
    Console.WriteLine("Hello World");
}
```

> **Tip** Get into the habit of typing matched character pairs, such as (and) and { and }, before filling in their contents. It's easy to forget the closing character if you wait until after you've entered the contents.

IntelliSense Icons

When you type a period after the name of a class, IntelliSense displays the name of every member of that class. To the left of each member name is an icon that depicts the type of member. Common icons and their types include the following:

Icon	Meaning
	method (discussed in Chapter 3)
	property (discussed in Chapter 15, "Implementing Properties to Access Fields")

Icon	Meaning
	class (discussed in Chapter 7)
	struct (discussed in Chapter 9, "Creating Value Types with Enumerations and Structures")
	enum (discussed in Chapter 9)
	interface (discussed in Chapter 13, "Creating Interfaces and Defining Abstract Classes")
	delegate (discussed in Chapter 17, "Interrupting Program Flow and Handling Events")
	extension method (discussed in Chapter 12, "Working with Inheritance")

You will also see other IntelliSense icons appear as you type code in different contexts.

Note You will frequently see lines of code containing two forward slashes followed by ordinary text. These are comments. They are ignored by the compiler but are very useful for developers because they help document what a program is actually doing. For example:

```
Console.ReadLine(); // Wait for the user to press the Enter key
```

The compiler skips all text from the two slashes to the end of the line. You can also add multiline comments that start with a forward slash followed by an asterisk (/*). The compiler skips everything until it finds an asterisk followed by a forward slash sequence (*/), which could be many lines lower down. You are actively encouraged to document your code with as many meaningful comments as necessary.

Build and run the console application

1. On the *Build* menu, click *Build Solution*.

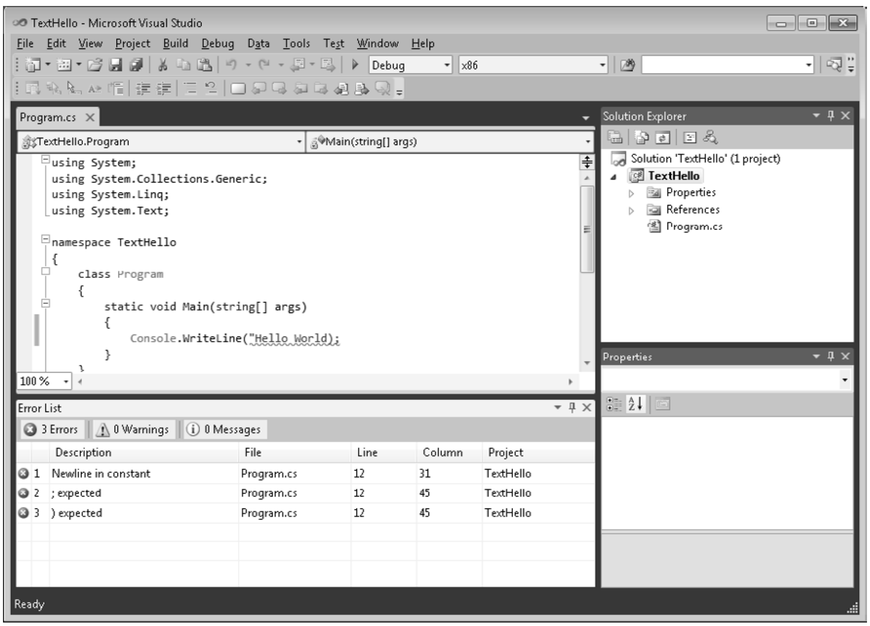
   This action compiles the C# code, resulting in a program that you can run. The *Output* window appears below the *Code and Text Editor* window.

Tip If the *Output* window does not appear, on the *View* menu, click *Output* to display it.

In the *Output* window, you should see messages similar to the following indicating how the program is being compiled:

```
------ Build started: Project: TextHello, Configuration: Debug x86 ----
CopyFilesToOutputDirectory:
  TextHello -> C:\Users\John\My Documents\Microsoft Press\Visual CSharp Step By Step\
Chapter 1\TextHello\TextHello\bin\Debug\TextHello.exe
========== Build: 1 succeeded or up-to-date, 0 failed, 0 skipped ========
```

If you have made some mistakes, they will appear in the *Error List* window. The following image shows what happens if you forget to type the closing quotation marks after the text Hello World in the *WriteLine* statement. Notice that a single mistake can sometimes cause multiple compiler errors.



> **Tip** You can double-click an item in the *Error List* window, and the cursor will be placed on the line that caused the error. You should also notice that Visual Studio displays a wavy red line under any lines of code that will not compile when you enter them.

If you have followed the previous instructions carefully, there should be no errors or warnings, and the program should build successfully.

> **Tip** There is no need to save the file explicitly before building because the *Build Solution* command automatically saves the file.
>
> An asterisk after the file name in the tab above the *Code and Text Editor* window indicates that the file has been changed since it was last saved.

2. If you are using Visual C# 2010 Express, on the *Tools* menu, point to *Settings*, and then click *Expert Settings*. This setting enables some options in Visual C# 2010 Express that do not appear by default.

3. On the *Debug* menu, click *Start Without Debugging*. (If you are using Visual C# 2010 Express and this command is not available, make sure that you selected *Expert Settings* in step 2.)

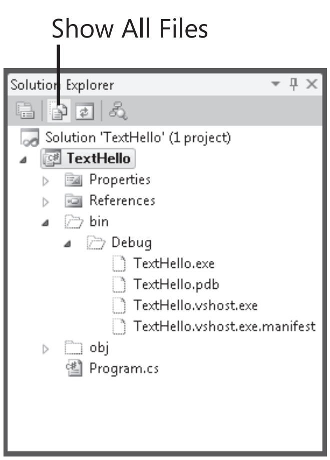
   A command window opens, and the program runs. The message "Hello World" appears, and then the program waits for you to press any key, as shown in the following graphic:

> **Note** The prompt "Press any key to continue . . ." is generated by Visual Studio; you did not write any code to do this. If you run the program by using the *Start Debugging* command on the *Debug* menu, the application runs, but the command window closes immediately without waiting for you to press a key.

4. Ensure that the command window displaying the program's output has the focus, and then press Enter.

   The command window closes, and you return to the Visual Studio 2010 programming environment.

5. In *Solution Explorer*, click the TextHello project (not the solution), and then click the *Show All Files* toolbar button on the *Solution Explorer* toolbar—this is the second leftmost button on the toolbar in the Solution Explorer window.



Entries named *bin* and *obj* appear above the Program.cs file. These entries correspond directly to folders named *bin* and *obj* in the project folder (Microsoft Press\Visual CSharp Step By Step\Chapter 1\TextHello\TextHello). Visual Studio creates these folders when you build your application, and they contain the executable version of the program together with some other files used to build and debug the application.

6. In *Solution Explorer*, expand the *bin* entry.

   Another folder named *Debug* appears. (Note: You might also see a folder called *Release*.)

7. In *Solution Explorer*, expand the *Debug* folder.

   Four more items appear, named TextHello.exe, TextHello.pdb, TextHello.vshost.exe, and TextHello.vshost.exe.manifest.

   The file TextHello.exe is the compiled program, and it is this file that runs when you click *Start Without Debugging* on the *Debug* menu. The other files contain information that is used by Visual Studio 2010 if you run your program in *Debug* mode (when you click *Start Debugging* on the *Debug* menu).

Using Namespaces

The example you have seen so far is a very small program. However, small programs can soon grow into much bigger programs. As a program grows, two issues arise. First, it is harder to understand and maintain big programs than it is to understand and maintain smaller programs. Second, more code usually means more names, more methods, and more classes. As the number of names increases, so does the likelihood of the project build failing because two or more names clash (especially when a program also uses third-party libraries written by developers who have also used a variety of names).

In the past, programmers tried to solve the name-clashing problem by prefixing names with some sort of qualifier (or set of qualifiers). This solution is not a good one because it's not scalable; names become longer, and you spend less time writing software and more time typing (there is a difference) and reading and rereading incomprehensibly long names.

Namespaces help solve this problem by creating a named container for other identifiers, such as classes. Two classes with the same name will not be confused with each other if they live in different namespaces. You can create a class named *Greeting* inside the namespace named *TextHello*, like this:

```
namespace TextHello
{
    class Greeting
    {
        ...
    }
}
```

You can then refer to the *Greeting* class as *TextHello.Greeting* in your programs. If another developer also creates a *Greeting* class in a different namespace, such as *NewNamespace*, and installs it on your computer, your programs will still work as expected because they are using the *TextHello.Greeting* class. If you want to refer to the other developer's *Greeting* class, you must specify it as *NewNamespace.Greeting*.

It is good practice to define all your classes in namespaces, and the Visual Studio 2010 environment follows this recommendation by using the name of your project as the top-level namespace. The .NET Framework class library also adheres to this recommendation; every class in the .NET Framework lives inside a namespace. For example, the *Console* class lives inside the *System* namespace. This means that its full name is actually *System.Console*.

Of course, if you had to write the full name of a class every time you used it, the situation would be no better than prefixing qualifiers or even just naming the class with some globally unique name such *SystemConsole* and not bothering with a namespace. Fortunately, you can solve this problem with a *using* directive in your programs. If you return to the TextHello program in Visual Studio 2010 and look at the file Program.cs in the *Code and Text Editor* window, you will notice the following statements at the top of the file:

```
using System;
using System.Collections.Generic;
using System.Linq;
using System.Text;
```

A *using* statement brings a namespace into scope. In subsequent code in the same file, you no longer have to explicitly qualify objects with the namespace to which they belong. The four namespaces shown contain classes that are used so often that Visual Studio 2010 automatically adds these *using* statements every time you create a new project. You can add further *using* directives to the top of a source file.

The following exercise demonstrates the concept of namespaces in more depth.

Try longhand names

1. In the *Code and Text Editor* window displaying the Program.cs file, comment out the first *using* directive at the top of the file, like this:

   ```
   //using System;
   ```

2. On the *Build* menu, click *Build Solution*.

   The build fails, and the *Error List* window displays the following error message:

   ```
   The name 'Console' does not exist in the current context.
   ```

3. In the *Error List* window, double-click the error message.

   The identifier that caused the error is highlighted in the Program.cs source file.

4. In the *Code and Text Editor* window, edit the *Main* method to use the fully qualified name *System.Console*. When you type *System*, the names of all the items in the *System* namespace are displayed by IntelliSense.

   Main should look like this:

```
static void Main(string[] args)
{
    System.Console.WriteLine("Hello World");
}
```

5. On the *Build* menu, click *Build Solution*.

   The build should succeed this time. If it doesn't, make sure that *Main* is exactly as it appears in the preceding code, and then try building again.

6. Run the application to make sure it still works by clicking *Start Without Debugging* on the *Debug* menu.

Namespaces and Assemblies

A *using* statement simply brings the items in a namespace into scope and frees you from having to fully qualify the names of classes in your code. Classes are compiled into *assemblies*. An assembly is a file that usually has the *.dll* file name extension, although strictly speaking, executable programs with the *.exe* file name extension are also assemblies.

An assembly can contain many classes. The classes that the .NET Framework class library comprises, such as *System.Console,* are provided in assemblies that are installed on your computer together with Visual Studio. You will find that the .NET Framework class library contains many thousands of classes. If they were all held in the same assembly, the assembly would be huge and difficult to maintain. (If Microsoft updated a single method in a single class, it would have to distribute the entire class library to all developers!)

For this reason, the .NET Framework class library is split into a number of assemblies, partitioned by the functional area to which the classes they contain relate. For example, there is a "core" assembly that contains all the common classes, such as *System.Console*, and there are further assemblies that contain classes for manipulating databases, accessing Web services, building graphical user interfaces, and so on. If you want to make use of a class in an assembly, you must add to your project a reference to that assembly. You can then add *using* statements to your code that bring the items in namespaces in that assembly into scope.

You should note that there is not necessarily a 1:1 equivalence between an assembly and a namespace; a single assembly can contain classes for multiple namespaces, and a single namespace can span multiple assemblies. This all sounds very confusing at first, but you will soon get used to it.

When you use Visual Studio to create an application, the template you select automatically includes references to the appropriate assemblies. For example, in *Solution Explorer* for the TextHello project, expand the *References* folder. You will see that a Console application automatically includes references to assemblies called *Microsoft.CSharp*, *System*, *System.Core*, *System.Data*, *System.Data.DataExtensions*, *System.Xml*, and *System.Xml.Linq*. You can add references for additional assemblies to a project by right-clicking the *References* folder and clicking *Add Reference*—you will perform this task in later exercises.

Creating a Graphical Application

So far, you have used Visual Studio 2010 to create and run a basic Console application. The Visual Studio 2010 programming environment also contains everything you need to create graphical Windows-based applications. You can design the forms-based user interface of a Windows application interactively. Visual Studio 2010 then generates the program statements to implement the user interface you've designed.

Visual Studio 2010 provides you with two views of a graphical application: the *design view* and the *code view*. You use the *Code and Text Editor* window to modify and maintain the code and logic for a graphical application, and you use the *Design View* window to lay out your user interface. You can switch between the two views whenever you want.

In the following set of exercises, you'll learn how to create a graphical application by using Visual Studio 2010. This program will display a simple form containing a text box where you can enter your name and a button that displays a personalized greeting in a message box when you click the button.

Note Visual Studio 2010 provides two templates for building graphical applications—the Windows Forms Application template and the WPF Application template. Windows Forms is a technology that first appeared with the .NET Framework version 1.0. WPF, or Windows Presentation Foundation, is an enhanced technology that first appeared with the .NET Framework version 3.0. It provides many additional features and capabilities over Windows Forms, and you should consider using it in preference to Windows Forms for all new development.

Create a graphical application in Visual Studio 2010

- If you are using Visual Studio 2010 Standard or Visual Studio 2010 Professional, perform the following operations to create a new graphical application:

  1. On the *File* menu, point to *New*, and then click *Project*.

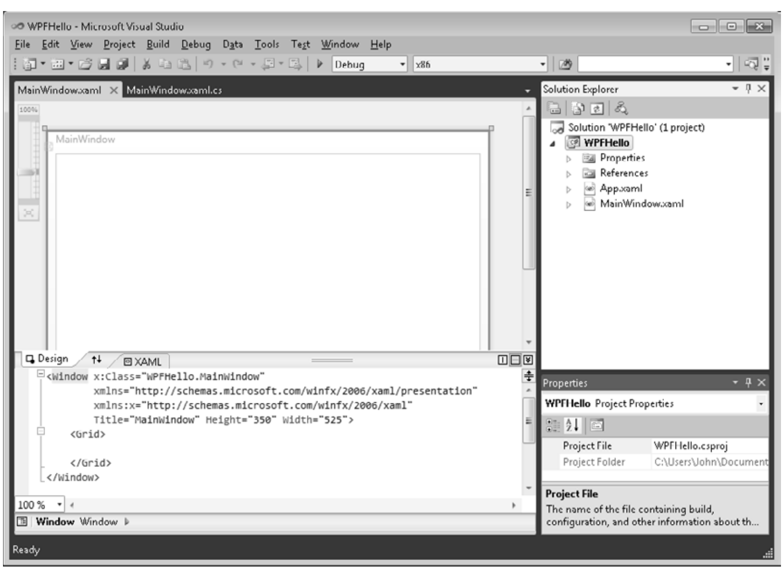
     The *New Project* dialog box opens.

2. In the left pane, under *Installed Templates*, click *Visual C#*.
3. In the middle pane, click the *WPF Application* icon.
4. Ensure that the *Location* field refers to the *\Microsoft Press\Visual CSharp Step By Step\Chapter 1* folder under your *Documents* folder.
5. In the *Name* field, type **WPFHello**.
6. In the *Solution* field, ensure that *Create new solution* is selected.

   This action creates a new solution for holding the project. The alternative, *Add to Solution*, adds the project to the TextHello solution.
7. Click *OK*.

- If you are using Visual C# 2010 Express, perform the following tasks to create a new graphical application:
  1. On the *File* menu, click *New Project*.
  2. If the *New Project* message box appears, click *Save* to save your changes to the TextHello project. In the *Save Project* dialog box, verify that the *Location* field is set to *Microsoft Press\Visual CSharp Step By Step\Chapter 1* under your Documents folder, and then click *Save*.
  3. In the *New Project* dialog box, click the *WPF Application* icon.
  4. In the *Name* field, type **WPFHello**.
  5. Click *OK*.

Visual Studio 2010 closes your current application and creates the new WPF application. It displays an empty WPF form in the *Design View* window, together with another window containing an XAML description of the form, as shown in the following graphic:



> **Tip** Close the *Output* and *Error List* windows to provide more space for displaying the *Design View* window.

XAML stands for Extensible Application Markup Language and is an XML-like language used by WPF applications to define the layout of a form and its contents. If you have knowledge of XML, XAML should look familiar. You can actually define a WPF form completely by writing an XAML description if you don't like using the Design View window of Visual Studio or if you don't have access to Visual Studio; Microsoft provides a XAML editor called XAMLPad that is installed with the Windows Software Development Kit (SDK).

In the following exercise, you use the Design View window to add three controls to the Windows form and examine some of the C# code automatically generated by Visual Studio 2010 to implement these controls.

Create the user interface

1. Click the *Toolbox* tab that appears to the left of the form in the Design View window.

   The *Toolbox* appears, partially obscuring the form, and displays the various components and controls that you can place on a Windows form. (If the Toolbox tab is not visible, on the *View* menu, click *Toolbox*.) Expand the *Common WPF Controls* section. This section displays a list of controls that are used by most WPF applications. The *All Controls* section displays a more extensive list of controls.

2. In the *Common WPF Controls* section, click *Label*, and then drag the label control onto the visible part of the form.

   A label control is added to the form (you will move it to its correct location in a moment), and the *Toolbox* disappears from view.

> **Tip** If you want the *Toolbox* to remain visible but not to hide any part of the form, click the *Auto Hide* button to the right in the *Toolbox* title bar. (It looks like a pin.) The *Toolbox* appears permanently on the left side of the Visual Studio 2010 window, and the *Design View* window shrinks to accommodate it. (You might lose a lot of space if you have a low-resolution screen.) Clicking the *Auto Hide* button once more causes the *Toolbox* to disappear again.

3. The label control on the form is probably not exactly where you want it. You can click and drag the controls you have added to a form to reposition them. Using this technique, move the label control so that it is positioned toward the upper left corner of the form. (The exact placement is not critical for this application.)

> **Note** The XAML description of the form in the lower pane now includes the label control, together with properties such as its location on the form, governed by the *Margin* property. The *Margin* property consists of four numbers indicating the distance of each edge of the label from the edges of the form. If you move the control around the form, the value of the *Margin* property changes. If the form is resized, the controls anchored to the form's edges that move are resized to preserve their margin values. You can prevent this by setting the *Margin* values to zero. You learn more about the *Margin* and also the *Height* and *Width* properties of WPF controls in Chapter 22, "Introducing Windows Presentation Foundation."

4. On the *View* menu, click *Properties Window*.

   If it was not already displayed, the *Properties* window appears on the lower right side of the screen, under *Solution Explorer*. You can specify the properties of controls by using the XAML pane under the *Design View* window. However, the *Properties* window provides a more convenient way for you to modify the properties for items on a form, as well as other items in a project. It is context sensitive in that it displays the properties for the currently selected item. If you click the title bar of the form displayed in the *Design View* window, you can see that the *Properties* window displays the properties for the form itself. If you click the label control, the window displays the properties for the label instead. If you click anywhere else on the form, the *Properties* window displays the properties for a mysterious item called a *grid*. A grid acts as a container for items on a WPF form, and you can use the grid, among other things, to indicate how items on the form should be aligned and grouped together.

5. Click the label control on the form. In the *Properties* window, locate the *FontSize* property. Change the *FontSize* property to **20**, and then in the *Design View* window click the title bar of the form.

   The size of the text in the label changes.

6. In the XAML pane below the *Design View* window, examine the text that defines the label control. If you scroll to the end of the line, you should see the text *FontSize="20"*. Any changes that you make by using the *Properties* window are automatically reflected in the XAML definitions and vice versa.

   Overtype the value of the *FontSize* property in the XAML pane, and change it back to **12**. The size of the text in the label in the *Design View* window changes back.

7. In the XAML pane, examine the other properties of the label control.

   The properties that are listed in the XAML pane are only the ones that do not have default values. If you modify any property values by using the *Properties Window*, they appear as part of the label definition in the XAML pane.

8. Change the value of the *Content* property from **Label** to **Please enter your name**.

   Notice that the text displayed in the label on the form changes, although the label is too small to display it correctly.

9. In the *Design View* window, click the label control. Place the mouse over the right edge of the label control. It should change into a double-headed arrow to indicate that you can use the mouse to resize the control. Click the mouse and drag the right edge of the label control further to the right, until you can see the complete text for the label.
10. Click the form in the *Design View* window, and then display the *Toolbox* again.
11. In the *Toolbox*, click and drag the *TextBox* control onto the form. Move the text box control so that it is directly underneath the label control.

> **Tip** When you drag a control on a form, alignment indicators appear automatically when the control becomes aligned vertically or horizontally with other controls. This gives you a quick visual cue for making sure that controls are lined up neatly.

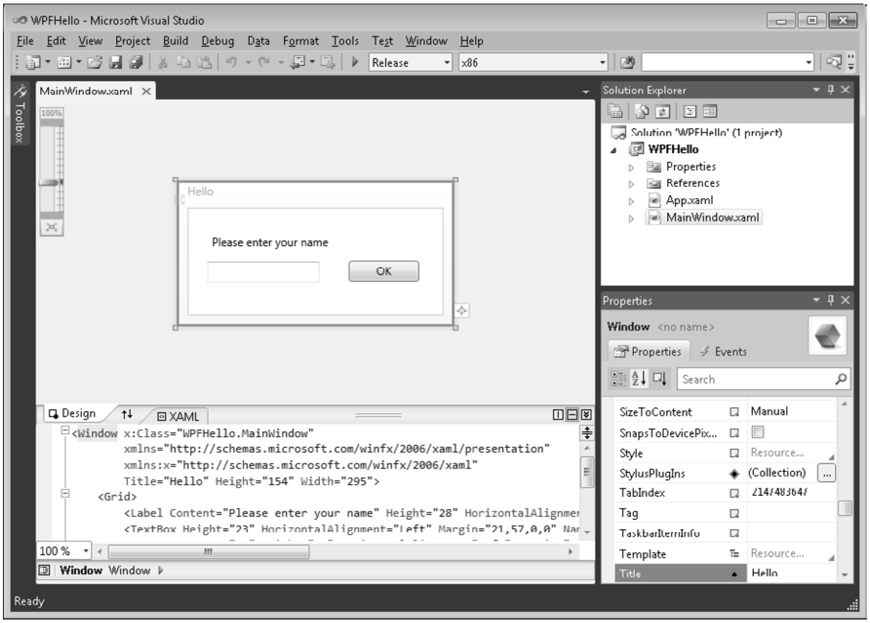
12. While the text box control is selected, in the *Properties* window, change the value of the *Name* property displayed at the top of the window to **userName**.

> **Note** You will learn more about naming conventions for controls and variables in Chapter 2, "Working with Variables, Operators, and Expressions."

13. Display the *Toolbox* again, and then click and drag a *Button* control onto the form. Place the button control to the right of the text box control on the form so that the bottom of the button is aligned horizontally with the bottom of the text box.
14. Using the *Properties* window, change the *Name* property of the button control to **ok**. And change the *Content* property from Button to **OK**. Verify that the caption of the button control on the form changes.
15. Click the title bar of the MainWindow.xaml form in the *Design View* window. In the *Properties* window, change the *Title* property to **Hello**.
16. In the *Design View* window, notice that a resize handle (a small square) appears on the lower right corner of the form when it is selected. Move the mouse pointer over the resize handle. When the pointer changes to a diagonal double-headed arrow, click and drag the pointer to resize the form. Stop dragging and release the mouse button when the spacing around the controls is roughly equal.

> **Important** Click the title bar of the form and not the outline of the grid inside the form before resizing it. If you select the grid, you will modify the layout of the controls on the form but not the size of the form itself.

The form should now look similar to the following figure.



17. On the *Build* menu, click *Build Solution*, and verify that the project builds successfully.

18. On the *Debug* menu, click *Start Without Debugging*.

    The application should run and display your form. You can type your name in the text box and click *OK*, but nothing happens yet. You need to add some code to process the *Click* event for the *OK* button, which is what you will do next.

19. Click the *Close* button (the *X* in the upper-right corner of the form) to close the form and return to Visual Studio.

You have managed to create a graphical application without writing a single line of C# code. It does not do much yet (you will have to write some code soon), but Visual Studio actually generates a lot of code for you that handles routine tasks that all graphical applications must perform, such as starting up and displaying a form. Before adding your own code to the application, it helps to have an understanding of what Visual Studio has generated for you.

In *Solution Explorer*, expand the MainWindow.xaml node. The file MainWindow.xaml.cs appears. Double-click the file MainWindow.xaml.cs. The code for the form is displayed in the *Code and Text Editor* window. It looks like this:

```
using System;
using System.Collections.Generic;
using System.Linq;
using System.Text;
using System.Windows;
using System.Windows.Controls;
using System.Windows.Data;
```

```
using System.Windows.Documents;
using System.Windows.Input;
using System.Windows.Media;
using System.Windows.Media.Imaging;
using System.Windows.Navigation;
using System.Windows.Shapes;

namespace WPFHello
{
    /// <summary>
    /// Interaction logic for MainWindow.xaml
    /// </summary>

    public partial class MainWindow : Window
    {

        public MainWindow()
        {
            InitializeComponent();
        }

    }
}
```

In addition to a good number of *using* statements bringing into scope some namespaces that most WPF applications use, the file contains the definition of a class called *MainWindow* but not much else. There is a little bit of code for the *MainWindow* class known as a constructor that calls a method called *InitializeComponent*, but that is all. (A *constructor* is a special method with the same name as the class. It is executed when an instance of the class is created and can contain code to initialize the instance. You will learn about constructors in Chapter 7.) In fact, the application contains a lot more code, but most of it is generated automatically based on the XAML description of the form, and it is hidden from you. This hidden code performs operations such as creating and displaying the form, and creating and positioning the various controls on the form.

The purpose of the code that you *can* see in this class is so that you can add your own methods to handle the logic for your application, such as determining what happens when the user clicks the *OK* button.

> **Tip** You can also display the C# code file for a WPF form by right-clicking anywhere in the *Design View* window and then clicking *View Code*.

At this point, you might be wondering where the *Main* method is and how the form gets displayed when the application runs; remember that *Main* defines the point at which the program starts. In *Solution Explorer*, you should notice another source file called App.xaml. If you double-click this file, the XAML description of this item appears. One property in the XAML code is called *StartupUri*, and it refers to the MainWindow.xaml file as shown in bold in the following code example:

```
<Application x:Class="WPFHello.App"
             xmlns="http://schemas.microsoft.com/winfx/2006/xaml/presentation"
             xmlns:x="http://schemas.microsoft.com.winfx/2006/xaml"
             StartupUri="MainWindow.xaml">
    <Application.Resources>

    </Application.Resources>
</Application>
```

If you click the *Design* tab at the bottom of the XAML pane, the *Design View* window for App.xaml appears and displays the text "Intentionally left blank. The document root element is not supported by the visual designer". This occurs because you cannot use the *Design View* window to modify the App.xaml file. Click the *XAML* tab to return to the XAML pane.

If you expand the App.xaml node in *Solution Explorer*, you will see that there is also an App.xaml.cs file. If you double-click this file, you will find it contains the following code:

```
using System;
using System.Collections.Generic;
using System.Configuration;
using System.Data;
using System.Linq;
using System.Windows;

namespace WPFHello
{
    /// <summary>
    /// Interaction logic for App.xaml
    /// </summary>

    public partial class App : Application
    {
    }
}
```

Once again, there are a number of *using* statements but not a lot else, not even a *Main* method. In fact, *Main* is there, but it is also hidden. The code for *Main* is generated based on the settings in the App.xaml file; in particular, *Main* will create and display the form specified by the *StartupUri* property. If you want to display a different form, you edit the App.xaml file.

The time has come to write some code for yourself!

Write the code for the OK button

1. Click the *MainWindow.xaml* tab above the *Code and Text Editor* window to display MainWindow in the *Design View* window.

2. Double-click the *OK* button on the form.

   The MainWindow.xaml.cs file appears in the *Code and Text Editor* window, but a new method has been added called *ok_Click*. Visual Studio automatically generates code to call this method whenever the user clicks the *OK* button. This is an example of an event. You will learn much more about how events work as you progress through this book.

3. Add the following code shown in bold to the *ok_Click* method:

```
void ok_Click(object sender, RoutedEventArgs e)
{
    MessageBox.Show("Hello " + userName.Text);
}
```

   This is the code that will run when the user clicks the *OK* button. Do not worry too much about the syntax of this code just yet (just make sure you copy it exactly as shown) because you will learn all about methods in Chapter 3. The interesting part is the *MessageBox.Show* statement. This statement displays a message box containing the text "Hello" with whatever name the user typed into the username text box on the appended form.

4. Click the *MainWindow.xaml* tab above the *Code and Text Editor* window to display MainWindow in the *Design View* window again.

5. In the lower pane displaying the XAML description of the form, examine the *Button* element, but be careful not to change anything. Notice that it contains an element called *Click* that refers to the *ok_Click* method:

```
<Button Height="23" … Click="ok_Click" />
```

6. On the *Debug* menu, click *Start Without Debugging*.

7. When the form appears, type your name in the text box and then click *OK*. A message box appears, welcoming you by name:

8. Click *OK* in the message box.

   The message box closes.

9. Close the form.

In this chapter, you have seen how to use Visual Studio 2010 to create, build, and run applications. You have created a console application that displays its output in a console window, and you have created a WPF application with a simple graphical user interface.

- If you want to continue to the next chapter

  Keep Visual Studio 2010 running, and turn to Chapter 2.

- If you want to exit Visual Studio 2010 now

  On the *File* menu, click *Exit*. If you see a *Save* dialog box, click *Yes* and save the project.

Chapter 1 Quick Reference

To	Do this
Create a new console application using Visual Studio 2010 Standard or Professional	On the *File* menu, point to *New*, and then click *Project* to open the *New Project* dialog box. In the left pane, under Installed Templates, click *Visual C#*. In the middle pane, click *Console Application*. Specify a directory for the project files in the *Location* box. Type a name for the project. Click *OK*.
Create a new console application using Visual C# 2010 Express	On the *File* menu, click *New Project* to open the *New Project* dialog box. For the template, select *Console Application*. Choose a name for the project. Click *OK*.
Create a new graphical application using Visual Studio 2010 Standard or Professional	On the *File* menu, point to *New*, and then click *Project* to open the *New Project* dialog box. In the left pane, under Installed Templates, click *Visual C#*. In the middle pane, click *WPF Application*. Specify a directory for the project files in the *Location* box. Type a name for the project. Click *OK*.
Create a new graphical application using Visual C# 2010 Express	On the *File* menu, click *New Project* to open the *New Project* dialog box. For the template, select *WPF Application*. Choose a name for the project. Click *OK*.
Build the application	On the *Build* menu, click *Build Solution*.
Run the application	On the *Debug* menu, click *Start Without Debugging*.

Chapter 27
Introducing the Task Parallel Library

After completing the chapter, you will be able to

- Describe the benefits that implementing parallel operations in an application can bring.
- Explain how the Task Parallel Library provides an optimal platform for implementing applications that can take advantage of multiple processor cores.
- Use the *Task* class to create and run parallel operations in an application.
- Use the *Parallel* class to parallelize some common programming constructs.
- Use tasks with threads to improve responsiveness and throughput in graphical user interface (GUI) applications.
- Cancel long-running tasks, and handle exceptions raised by parallel operations.

You have now seen how to use Microsoft Visual C# to build applications that provide a graphical user interface and that can manage data held in a database. These are common features of most modern systems. However, as technology has advanced so have the requirements of users, and the applications that enable them to perform their day-to-day operations need to provide ever-more sophisticated solutions. In the final part of this book, you will look at some of the advanced features introduced with the .NET Framework 4.0. In particular, in this chapter you will see how to improve concurrency in an application by using the Task Parallel Library. In the next chapter, you will see how the parallel extensions provided with the .NET Framework can be used in conjunction with Language Integrated Query (LINQ) to improve the throughput of data access operations. And in the final chapter, you will meet Windows Communication Foundation for building distributed solutions that can incorporate services running on multiple computers. As a bonus, the appendix (provided on the CD) describes how to use the Dynamic Language Runtime to build C# applications and components that can interoperate with services built by using other languages that operate outside of the structure provided by the .NET Framework, such as Python and Ruby.

In the bulk of the preceding chapters in this book, you learned how to use C# to write programs that run in a single-threaded manner. By "single-threaded," I mean that at any one point in time, a program has been executing a single instruction. This might not always be the most efficient approach for an application to take. For example, you saw in Chapter 23, "Gathering User Input," that if your program is waiting for the user to click a button on a Windows Presentation Foundation (WPF) form, there might be other work that it can perform while it is waiting. However, if a single-threaded program has to perform a lengthy, processor-intensive calculation, it cannot respond to the user typing in data on a form or clicking a menu item. To the user, the application appears to have frozen. Only when the calculation has completed does the user interface start responding again. Applications that can perform multiple tasks at the same time can make far better use of the resources available on a computer, can run more quickly, and can be more responsive. Additionally, some individual tasks might run more quickly if you can divide them into parallel paths of execution that can run concurrently. In Chapter 23, you saw how WPF can take advantage of threads to improve responsiveness in a graphical user interface. In this chapter, you will learn how to use the Task Parallel Library to implement a more generic form of multitasking in your programs that can apply to computationally intensive applications and not just those concerned with managing user interfaces.

Why Perform Multitasking by Using Parallel Processing?

As mentioned in the introduction, there are two principle reasons why you might want to perform multitasking in an application:

- **To improve responsiveness** You can give the user of an application the impression that the program is performing more than one task at a time by dividing the program up into concurrent threads of execution and allowing each thread to run in turn for a short period of time. This is the conventional co-operative model that many experienced Windows developers are familiar with. However, it is not true multitasking because the processor is shared between threads, and the co-operative nature of this approach requires that the code executed by each thread behaves in an appropriate manner. If one thread dominates the CPU and resources available at the expense of other threads, the advantages of this approach are lost. It is sometimes difficult to write well-behaved applications that follow this model consistently.
- **To improve scalability** You can improve scalability by making efficient use of the processing resources available and using these resources to reduce the time required to execute parts of an application. A developer can determine which parts of an application can be performed in parallel and arrange for them to be run concurrently. As more computing resources are added, more tasks can be run in parallel. Until recently, this model was suitable only for systems that either had multiple CPUs or were able to spread the processing across different computers networked together. In both cases, you had to use a model that arranged for coordination between parallel tasks. Microsoft provides a specialized version of Windows called High Performance Compute (HPC) Server 2008, which enables an organization to build clusters of servers that can distribute and execute tasks in parallel. Developers can use the Microsoft implementation of the Message Passing Interface (MPI), a well-known language-independent communications protocol, to build applications based on parallel tasks that coordinate and cooperate with each other by sending messages. Solutions based on Windows HPC Server 2008 and MPI are ideal for large-scale, compute-bound engineering and scientific applications, but they are expensive for smaller scale, desktop systems.

From these descriptions, you might be tempted to conclude that the most cost-effective way to build multitasking solutions for desktop applications is to use the cooperative multithreaded approach. However, the multithreaded approach was simply intended as a mechanism to provide responsiveness—to enable computers with a single processor to ensure that each task got a fair share of the processor. It is not well-suited for multiprocessor machines because it is not designed to distribute the load across processors and, consequently, does not scale well. While desktop machines with multiple processors were expensive (and consequently relatively rare), this was not an issue. However, this situation is changing, as I will briefly explain.

The Rise of the Multicore Processor

Ten years ago, the cost of a decent personal computer was in the range of $500 to $1000. Today, a decent personal computer still costs about the same, even after ten years of price inflation. The specification of a typical PC these days is likely to include a processor running at a speed of between 2 GHz and 3 GHz, 500 GB of hard disk storage, 4 GB of RAM, high-speed and high-resolution graphics, and a rewritable DVD drive. Ten years ago, the processor speed for a typical machine was between 500 MHz and 1 GHz, 80 GB was a big hard drive, Windows ran quite happily with 256 MB or less of RAM, and rewritable CD drives cost well over $100. (Rewritable DVD drives were rare and extremely expensive.) This is the joy of technological progress: ever faster and more powerful hardware at cheaper and cheaper prices.

This is not a new trend. In 1965, Gordon E. Moore, co-founder of Intel, wrote a paper titled "Cramming more components onto integrated circuits," which discussed how the increasing miniaturization of components enabled more transistors to be embedded on a silicon chip, and how the falling costs of production as the technology became more accessible would lead economics to dictate squeezing as many as 65,000 components onto a single chip by 1975. Moore's observations lead to the dictum frequently referred to as "Moore's Law," which basically states that the number of transistors that can be placed inexpensively on an integrated circuit will increase exponentially, doubling approximately every two years. (Actually, Gordon Moore was more optimistic than this initially, postulating that the volume of transistors was likely to double every year, but he later modified his calculations.) The ability to pack transistors together led to the ability to pass data between them more quickly. This meant we could expect to see chip manufacturers produce faster and more powerful microprocessors at an almost unrelenting pace, enabling software developers to write ever more complicated software that would run more quickly.

Moore's Law concerning the miniaturization of electronic components still holds, even after more than 40 years. However, physics has started to intervene. There comes a limit when it is not possible transmit signals between transistors on a single chip any more quickly, no matter how small or densely packed they are. To a software developer, the most noticeable result of this limitation is that processors have stopped getting faster. Six years ago, a fast processor ran at 3 GHz. Today, a fast processor still runs at 3 GHz.

The limit to the speed at which processors can transmit data between components has caused chip companies to look at alternative mechanisms for increasing the amount of work a processor can do. The result is that most modern processors now have two or more *processor cores*. Effectively, chip manufacturers have put multiple processors on the same chip and added the necessary logic to enable them to communicate and coordinate with each other. Dual-core processors (two cores) and quad-core processors (four cores) are now common. Chips with 8, 16, 32, and 64 cores are available, and the price of these is expected to fall sharply in the near future. So, although processors have stopped speeding up, you can now expect to get more of them on a single chip.

What does this mean to a developer writing C# applications?

In the days before multicore processors, a single-threaded application could be sped up simply by running it on a faster processor. With multicore processors, this is no longer the case. A single-threaded application will run at the same speed on a single-core, dual-core, or quad-core processor that all have the same clock frequency. The difference is that on a dual-core processor, one of the processor cores will be sitting around idle, and on a quad-core processor, three of the cores will be simply ticking over waiting for work. To make the best use of multicore processors, you need to write your applications to take advantage of multitasking.

Implementing Multitasking in a Desktop Application

Multitasking is the ability to do more than one thing at the same time. It is one of those concepts that is easy to describe but that, until recently, has been difficult to implement.

In the optimal scenario, an application running on a multicore processor performs as many concurrent tasks as there are processor cores available, keeping each of the cores busy. However, there are many issues you have to consider to implement concurrency, including the following:

- How can you divide an application into a set of concurrent operations?
- How can you arrange for a set of operations to execute concurrently, on multiple processors?
- How can you ensure that you attempt to perform only as many concurrent operations as there are processors available?
- If an operation is blocked (such as while it is waiting for I/O to complete), how can you detect this and arrange for the processor to run a different operation rather than sit idle?

- How can you determine when one or more concurrent operations have completed?
- How can you synchronize access to shared data to ensure that two or more concurrent operations do not inadvertently corrupt each other's data?

To an application developer, the first question is a matter of application design. The remaining questions depend on the programmatic infrastructure—Microsoft provides the Task Parallel Library (TPL) to help address these issues.

In Chapter 28, "Performing Parallel Data Access," you will see how some query-oriented problems have naturally parallel solutions, and how you can use the *ParallelEnumerable* type of PLINQ to parallelize query operations. However, sometimes you need a more imperative approach for more generalized situations. The TPL contains a series of types and operations that enable you to more explicitly specify how you want to divide an application into a set of parallel tasks.

Tasks, Threads, and the *ThreadPool*

The most important type in the TPL is the *Task* class. The *Task* class is an abstraction of a concurrent operation. You create a *Task* object to run a block of code. You can instantiate multiple *Task* objects and start them running in parallel if sufficient processors or processor cores are available.

> **Note** From now on, I will use the term "processor" to refer to either a single-core processor or a single processor core on a multicore processor.

Internally, the TPL implements tasks and schedules them for execution by using *Thread* objects and the *ThreadPool* class. Multithreading and thread pools have been available with the .NET Framework since version 1.0, and you can use the *Thread* class in the *System.Threading* namespace directly in your code. However, the TPL provides an additional degree of abstraction that enables you to easily distinguish between the degree of parallelization in an application (the tasks) and the units of parallelization (the threads). On a single-processor computer, these items are usually the same. However, on a computer with multiple processors or with a multicore processor, they are different. If you design a program based directly on threads, you will find that your application might not scale very well; the program will use the number of threads you explicitly create, and the operating system will schedule only that number of threads. This can lead to overloading and poor response time if the number of threads greatly exceeds the number of available processors, or to inefficiency and poor throughput if the number of threads is less than the number of processors.

The TPL optimizes the number of threads required to implement a set of concurrent tasks and schedules them efficiently according to the number of available processors. The TPL uses a set of threads provided by the .NET Framework, called the *ThreadPool*, and implements a queuing mechanism to distribute the workload across these threads. When a program creates a *Task* object, the task is added to a global queue. When a thread becomes available, the task is removed from the global queue and is executed by that thread. The *ThreadPool* implements a number of optimizations and uses a work-stealing algorithm to ensure that threads are scheduled efficiently.

> **Note** The *ThreadPool* was available in previous editions of the .NET Framework, but it has been enhanced significantly in the .NET Framework 4.0 to support *Tasks*.

You should note that the number of threads created by the .NET Framework to handle your tasks is not necessarily the same as the number of processors. Depending on the nature of the workload, one or more processors might be busy performing high-priority work for other applications and services. Consequently, the optimal number of threads for your application might be less than the number of processors in the machine. Alternatively, one or more threads in an application might be waiting for long-running memory access, I/O, or a network operation to complete, leaving the corresponding processors free. In this case, the optimal number of threads might be more than the number of available processors. The .NET Framework follows an iterative strategy, known as a *hill-climbing* algorithm, to dynamically determine the ideal number of threads for the current workload.

The important point is that all you have to do in your code is divide your application into tasks that can be run in parallel. The .NET Framework takes responsibility for creating the appropriate number of threads based on the processor architecture and workload of your computer, associating your tasks with these threads and arranging for them to be run efficiently. It does not matter if you divide your work into too many tasks because the .NET Framework will attempt to run only as many concurrent threads as is practical; in fact, you are encouraged to *overpartition* your work because this will help to ensure that your application scales if you move it onto a computer that has more processors available.

Creating, Running, and Controlling Tasks

The *Task* object and the other types in the TPL reside in the *System.Threading.Tasks* namespace. You can create *Task* objects by using the *Task* constructor. The *Task* constructor is overloaded, but all versions expect you to provide an *Action* delegate as a parameter. Remember from Chapter 23 that an *Action* delegate references a method that does not return a value. A *task* object uses this delegate to run the method when it is scheduled. The following example creates a *Task* object that uses a delegate to run the method called *doWork* (you can also use an anonymous method or a lambda expression, as shown by the code in the comments):

```
Task task = new Task(new Action(doWork));
// Task task = new Task(delegate { this.doWork(); });
// Task task = new Task(() => { this.doWork(); });
...
private void doWork()
{
    // The task runs this code when it is started
    ...
}
```

> **Note** In many cases, you can let the compiler infer the *Action* delegate type itself and simply specify the method to run. For example, you can rephrase the first example just shown as follows:
>
> ```
> Task task = new Task(doWork);
> ```
>
> The delegate inference rules implemented by the compiler apply not just to the *Action* type, but anywhere you can use a delegate. You will see many more examples throughout the remainder of this book.

The default *Action* type references a method that takes no parameters. Other overloads of the *Task* constructor take an *Action<object>* parameter representing a delegate that refers to a method that takes a single *object* parameter. These overloads enable you to pass data into the method run by the task. The following code shows an example:

```
Action<object> action;
action = doWorkWithObject;
object parameterData = ...;
Task task = new Task(action, parameterData);
...
private void doWorkWithObject(object o)
{
    ...
}
```

After you create a *Task* object, you can set it running by using the *Start* method, like this:

```
Task task = new Task(...);
task.Start();
```

The *Start* method is also overloaded, and you can optionally specify a *TaskScheduler* object to control the degree of concurrency and other scheduling options. It is recommended that you use the default *TaskScheduler* object built into the .NET Framework, or you can define your own custom *TaskScheduler* class if you want to take more control over the way in which tasks are queued and scheduled. The details of how to do this are beyond the scope of this book, but if you require more information look at the description of the *TaskScheduler* abstract class in the .NET Framework Class Library documentation provided with Visual Studio.

You can obtain a reference to the default *TaskScheduler* object by using the static *Default* property of the *TaskScheduler* class. The *TaskScheduler* class also provides the static *Current* property, which returns a reference to the *TaskScheduler* object currently used. (This *TaskScheduler* object is used if you do not explicitly specify a scheduler.) A task can provide hints to the default *TaskScheduler* about how to schedule and run the task if you specify a value from the *TaskCreationOptions* enumeration in the *Task* constructor. For more information about the *TaskCreationOptions* enumeration, consult the documentation describing the .NET Framework Class Library provided with Visual Studio.

When the method run by the task completes, the task finishes, and the thread used to run the task can be recycled to execute another task.

Normally, the scheduler arranges to perform tasks in parallel wherever possible, but you can also arrange for tasks to be scheduled serially by creating a *continuation*. You create a continuation by calling the *ContinueWith* method of a *Task* object. When the action performed by the *Task* object completes, the scheduler automatically creates a new *Task* object to run the action specified by the *ContinueWith* method. The method specified by the continuation expects a *Task* parameter, and the scheduler passes in a reference to the task that completed to the method. The value returned by *ContinueWith* is a reference to the new *Task* object. The following code example creates a *Task* object that runs the *doWork* method and specifies a continuation that runs the *doMoreWork* method in a new task when the first task completes:

```
Task task = new Task(doWork);
task.Start();
Task newTask = task.ContinueWith(doMoreWork);
...
private void doWork()
{
    // The task runs this code when it is started
    ...
}
...
private void doMoreWork(Task task)
{
    // The continuation runs this code when doWork completes
    ...
}
```

The *ContinueWith* method is heavily overloaded, and you can provide a number of parameters that specify additional items, such as the *TaskScheduler* to use and a *TaskContinuationOptions* value. The *TaskContinuationOptions* type is an enumeration that contains a superset of the values in the *TaskCreationOptions* enumeration. The additional values available include

- **NotOnCanceled and OnlyOnCanceled** The *NotOnCanceled* option specifies that the continuation should run only if the previous action completes and is not canceled, and the *OnlyOnCanceled* option specifies that the continuation should run only if the previous action is canceled. The section "Canceling Tasks and Handling Exceptions" later in this chapter describes how to cancel a task.
- **NotOnFaulted and OnlyOnFaulted** The *NotOnFaulted* option indicates that the continuation should run only if the previous action completes and does not throw an unhandled exception. The *OnlyOnFaulted* option causes the continuation to run only if the previous action throws an unhandled exception. The section "Canceling Tasks and Handling Exceptions" provides more information on how to manage exceptions in a task.
- **NotOnRanToCompletion and OnlyOnRanToCompletion** The *NotOnRanToCompletion* option specifies that the continuation should run only if the previous action does not complete successfully; it must either be canceled or throw an exception. *OnlyOnRanToCompletion* causes the continuation to run only if the previous action completes successfully.

The following code example shows how to add a continuation to a task that runs only if the initial action does not throw an unhandled exception:

```
Task task = new Task(doWork);
task.ContinueWith(doMoreWork, TaskContinuationOptions.NotOnFaulted);
task.Start();
```

If you commonly use the same set of *TaskCreationOptions* values and the same *TaskScheduler* object, you can use a *TaskFactory* object to create and run a task in a single step. The constructor for the *TaskFactory* class enables you to specify the task scheduler, task creation options, and task continuation options that tasks constructed by this factory should use. The *TaskFactory* class provides the *StartNew* method to create and run a *Task* object. Like the *Start* method of the *Task* class, the *StartNew* method is overloaded, but all of them expect a reference to a method that the task should run.

The following code shows an example that creates and runs two tasks using the same task factory:

```
TaskScheduler scheduler = TaskScheduler.Current;
TaskFactory taskFactory = new TaskFactory(scheduler, TaskCreationOptions.None,
    TaskContinuationOptions.NotOnFaulted);
Task task = taskFactory.StartNew(doWork);
Task task2 = taskFactory.StartNew(doMoreWork);
```

Even if you do not currently specify any particular task creation options and you use the default task scheduler, you should still consider using a *TaskFactory* object; it ensures consistency, and you will have less code to modify to ensure that all tasks run in the same manner if you need to customize this process in the future. The *Task* class exposes the default *TaskFactory* used by the TPL through the static *Factory* property. You can use it like this:

```
Task task = Task.Factory.StartNew(doWork);
```

A common requirement of applications that invoke operations in parallel is to synchronize tasks. The *Task* class provides the *Wait* method, which implements a simple task coordination method. It enables you to suspend execution of the current thread until the specified task completes, like this:

```
task2.Wait(); // Wait at this point until task2 completes
```

You can wait for a set of tasks by using the static *WaitAll*, and *WaitAny* methods of the *Task* class. Both methods take a *params* array containing a set of *Task* objects. The *WaitAll* method waits until all specified tasks have completed, and *WaitAny* stops until at least one of the specified tasks has finished. You use them like this:

```
Task.WaitAll(task, task2); // Wait for both task and task2 to complete
Task.WaitAny(task, task2); // Wait for either of task or task2 to complete
```

Using the Task Class to Implement Parallelism

In the next exercise, you will use the *Task* class to parallelize processor-intensive code in an application, and you will see how this parallelization reduces the time taken for the application to run by spreading the computations across multiple processor cores.

The application, called GraphDemo, comprises a WPF form that uses an *Image* control to display a graph. The application plots the points for the graph by performing a complex calculation.

> **Note** The exercises in this chapter are intended to run on a computer with a multicore processor. If you have only a single-core CPU, you will not observe the same effects. Also, you should not start any additional programs or services between exercises because these might affect the results that you see.

Examine and run the GraphDemo single-threaded application

1. Start Microsoft Visual Studio 2010 if it is not already running.
2. Open the GraphDemo solution, located in the \Microsoft Press\Visual CSharp Step By Step\Chapter 27\GraphDemo folder in your Documents folder.
3. In Solution Explorer, in the GraphDemo project, double-click the file GraphWindow.xaml to display the form in the *Design View* window.

   The form contains the following controls:

   - An *Image* control called *graphImage*. This image control displays the graph rendered by the application.
   - A *Button* control called *plotButton*. The user clicks this button to generate the data for the graph and display it in the *graphImage* control.
   - A *Label* control called *duration*. The application displays the time taken to generate and render the data for the graph in this label.
4. In Solution Explorer, expand GraphWindow.xaml, and then double-click GraphWindow.xaml.cs to display the code for the form in the *Code and Text Editor* window.

   The form uses a *System.Windows.Media.Imaging.WriteableBitmap* object called *graphBitmap* to render the graph. The variables *pixelWidth* and *pixelHeight* specify the horizontal and vertical resolution, respectively, for the *WriteableBitmap* object; the variables *dpiX* and *dpiY* specify the horizontal and vertical density, respectively, of the image in dots per inch:

```
public partial class GraphWindow : Window
{
    private static long availableMemorySize = 0;
    private int pixelWidth = 0;
    private int pixelHeight = 0;
    private double dpiX = 96.0;
    private double dpiY = 96.0;
    private WriteableBitmap graphBitmap = null;
    …
}
```

5. Examine the *GraphWindow* constructor. It looks like this:

```
public GraphWindow()
{
    InitializeComponent();

    PerformanceCounter memCounter = new PerformanceCounter("Memory", "Available
Bytes");
    availableMemorySize = Convert.ToUInt64(memCounter.NextValue());

    this.pixelWidth = (int)availablePhysicalMemory / 20000;
    if (this.pixelWidth < 0 || this.pixelWidth > 15000)
        this.pixelWidth = 15000;
```

```
    this.pixelHeight = (int)availablePhysicalMemory / 40000;
    if (this.pixelHeight < 0 || this.pixelHeight > 7500)
        this.pixelHeight = 7500;
}
```

To avoid presenting you with code that exhausts the memory available on your computer and generates *OutOfMemory* exceptions, this application creates a *PerformanceCounter* object to query the amount of available physical memory on the computer. It then uses this information to determine appropriate values for the *pixelWidth* and *pixelHeight* variables. The more available memory you have on your computer, the bigger the values generated for *pixelWidth* and *pixelHeight* (subject to the limits of 15,000 and 7500 for each of these variables, respectively) and the more you will see the benefits of using the TPL as the exercises in this chapter proceed. However, if you find that the application still generates *OutOfMemory* exceptions, increase the divisors (20,000 and 40,000) used for generating the values of *pixelWidth* and *pixelHeight*.

If you have a lot of memory, the values calculated for *pixelWidth* and *pixelHeight* might overflow. In this case, they will contain negative values and the application will fail with an exception later on. The code in the constructor checks this case and sets the *pixelWidth* and *pixelHeight* fields to a pair of useful values that enable the application to run correctly in this situation.

6. Examine the code for the *plotButton_Click* method:

```
private void plotButton_Click(object sender, RoutedEventArgs e)
{
    if (graphBitmap == null)
    {
        graphBitmap = new WriteableBitmap(pixelWidth, pixelHeight, dpiX, dpiY,
PixelFormats.Gray8, null);
    }
    int bytesPerPixel = (graphBitmap.Format.BitsPerPixel + 7) / 8;
    int stride = bytesPerPixel * graphBitmap.PixelWidth;
    int dataSize = stride * graphBitmap.PixelHeight;
    byte [] data = new byte[dataSize];

    Stopwatch watch = Stopwatch.StartNew();
    generateGraphData(data);

    duration.Content = string.Format("Duration (ms): {0}", watch.ElapsedMilliseconds);
    graphBitmap.WritePixels(
        new Int32Rect(0, 0, graphBitmap.PixelWidth, graphBitmap.PixelHeight),
        data, stride, 0);
    graphImage.Source = graphBitmap;
}
```

This method runs when the user clicks the *plotButton* button. The code instantiates the *graphBitmap* object if it has not already been created by the user clicking the *plotButton* button previously, and it specifies that each pixel represents a shade of gray, with 8 bits per pixel. This method uses the following variables and methods:

- The *bytesPerPixel* variable calculates the number of bytes required to hold each pixel. (The *WriteableBitmap* type supports a range of pixel formats, with up to 128 bits per pixel for full-color images.)
- The *stride* variable contains the vertical distance, in bytes, between adjacent pixels in the *WriteableBitmap* object.
- The *dataSize* variable calculates the number of bytes required to hold the data for the *WriteableBitmap* object. This variable is used to initialize the *data* array with the appropriate size.
- The *data* byte array holds the data for the graph.
- The *watch* variable is a *System.Diagnostics.Stopwatch* object. The *StopWatch* type is useful for timing operations. The static *StartNew* method of the *StopWatch* type creates a new instance of a *StopWatch* object and starts it running. You can query the running time of a *StopWatch* object by examining the *ElapsedMilliseconds* property.
- The *generateGraphData* method populates the *data* array with the data for the graph to be displayed by the *WriteableBitmap* object. You will examine this method in the next step.
- The *WritePixels* method of the *WriteableBitmap* class copies the data from a byte array to a bitmap for rendering. This method takes an *Int32Rect* parameter that specifies the area in the *WriteableBitmap* object to populate, the data to be used to copy to the *WriteableBitmap* object, the vertical distance between adjacent pixels in the *WriteableBitmap* object, and an offset into the *WriteableBitmap* object to start writing the data to.

> **Note** You can use the *WritePixels* method to selectively overwrite information in a *WriteableBitmap* object. In this example, the code overwrites the entire contents. For more information about the *WriteableBitmap* class, consult the .NET Framework Class Library documentation installed with Visual Studio 2010.

- The *Source* property of an *Image* control specifies the data that the *Image* control should render. This example sets the *Source* property to the *WriteableBitmap* object.

7. Examine the code for the *generateGraphData* method:

```
private void generateGraphData(byte[] data)
{
    int a = pixelWidth / 2;
    int b = a * a;
    int c = pixelHeight / 2;

    for (int x = 0; x < a; x ++)
    {
        int s = x * x;
        double p = Math.Sqrt(b - s);
        for (double i = -p; i < p; i += 3)
        {
            double r = Math.Sqrt(s + i * i) / a;
            double q = (r - 1) * Math.Sin(24 * r);
            double y = i / 3 + (q * c);
            plotXY(data, (int)(-x + (pixelWidth / 2)), (int)(y + (pixelHeight / 2)));
            plotXY(data, (int)(x + (pixelWidth / 2)), (int)(y + (pixelHeight / 2)));
        }
    }
}
```

This method performs a series of calculations to plot the points for a rather complex graph. (The actual calculation is unimportant—it just generates a graph that looks attractive!) As it calculates each point, it calls the *plotXY* method to set the appropriate bytes in the *data* array that correspond to these points. The points for the graph are reflected around the X axis, so the *plotXY* method is called twice for each calculation: once for the positive value of the X coordinate, and once for the negative value.

8. Examine the *plotXY* method:

```
private void plotXY(byte[] data, int x, int y)
{
    data[x + y * pixelWidth] = 0xFF;
}
```

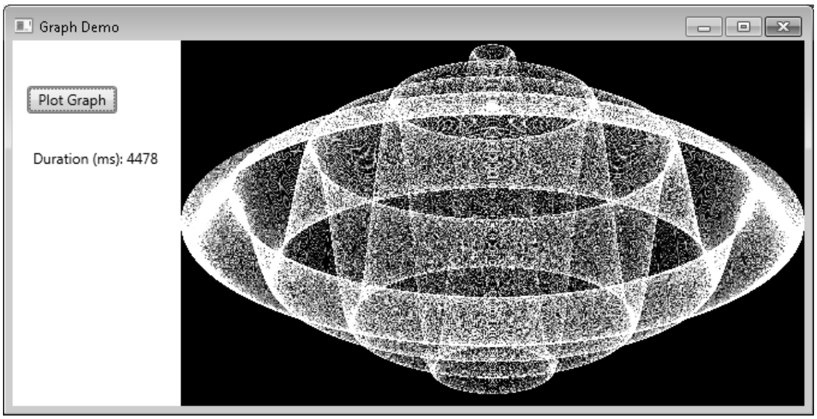
This is a simple method that sets the appropriate byte in the *data* array that corresponds to X and Y coordinates passed in as parameters. The value 0xFF indicates that the corresponding pixel should be set to white when the graph is rendered. Any pixels left unset are displayed as black.

9. On the *Debug* menu, click *Start Without Debugging* to build and run the application.

10. When the *Graph Demo* window appears, click *Plot Graph*, and wait.

    Please be patient. The application takes several seconds to generate and display the graph. The following image shows the graph. Note the value in the *Duration (ms)* label in the following figure. In this case, the application took 4478 milliseconds (ms) to plot the graph.

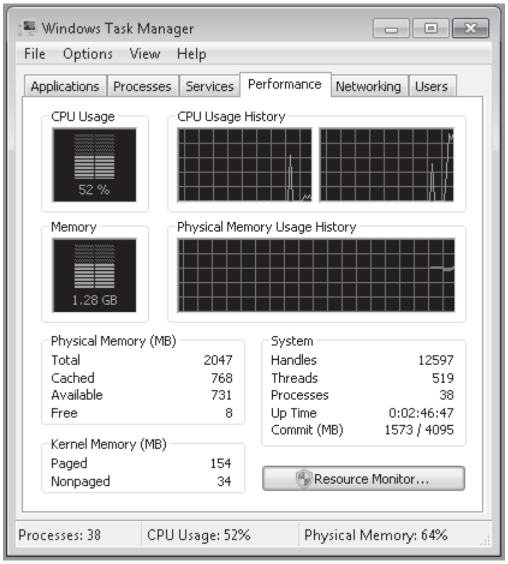
Note The application was run on a computer with 2 GB of memory and an Intel® Core 2 Duo Desktop Processor E6600 running at 2.40 GHz. Your times might vary if you are using a different processor or a different amount of memory. Additionally, you might notice that it seems to take longer initially to display the graph than the reported time. This is because of the time taken to initialize the data structures required to actually display the graph as part of the *WritePixels* method of the *graphBitmap* control rather than the time taken to calculate the data for the graph. Subsequent runs do not have this overhead.



11. Click *Plot Graph* again, and take note of the time taken. Repeat this action several times to get an average value.
12. On the desktop, right-click an empty area of the taskbar, and then in the pop-up menu click *Start Task Manager*.

Note Under Windows Vista, the command in the pop-up menu is called *Task Manager*.

13. In the Windows Task Manager, click the *Performance* tab.
14. Return to the *Graph Demo* window and then click *Plot Graph*.
15. In the Windows Task Manager, note the maximum value for the CPU usage while the graph is being generated. Your results will vary, but on a dual-core processor the CPU utilization will probably be somewhere around 50–55 percent, as shown in the following image. On a quad-core machine, the CPU utilization will likely be below 30 percent.



16. Return to the *Graph Demo* window, and click *Plot Graph* again. Note the value for the CPU usage in the Windows Task Manager. Repeat this action several times to get an average value.
17. Close the *Graph Demo* window, and minimize the Windows Task Manager.

You now have a baseline for the time the application takes to perform its calculations. However, it is clear from the CPU usage displayed by the Windows Task Manager that the application is not making full use of the processing resources available. On a dual-core machine, it is using just over half of the CPU power, and on a quad-core machine it is employing a little over a quarter of the CPU. This phenomenon occurs because the application is single-threaded, and in a Windows application, a single thread can occupy only a single core on a multicore processor. To spread the load over all the available cores, you need to divide the application into tasks and arrange for each task to be executed by a separate thread running on a different core.

Modify the GraphDemo application to use parallel threads

1. Return to the Visual Studio 2010, and display the GraphWindow.xaml.cs file in the *Code and Text Editor* window if it is not already open.
2. Examine the *generateGraphData* method.

If you think about it carefully, the purpose of this method is to populate the items in the *data* array. It iterates through the array by using the outer *for* loop based on the *x* loop control variable, highlighted in bold here:

```
private void generateGraphData(byte[] data)
{
    int a = pixelWidth / 2;
    int b = a * a;
    int c = pixelHeight / 2;


    for (int x = 0; x < a; x ++)
    {
        int s = x * x;
        double p = Math.Sqrt(b - s);
        for (double i = -p; i < p; i += 3)
        {
            double r = Math.Sqrt(s + i * i) / a;
            double q = (r - 1) * Math.Sin(24 * r);
            double y = i / 3 + (q * c);
            plotXY(data, (int)(-x + (pixelWidth / 2)), (int)(y + (pixelHeight / 2)));
            plotXY(data, (int)(x + (pixelWidth / 2)), (int)(y + (pixelHeight / 2)));
        }
    }
}
```

The calculation performed by one iteration of this loop is independent of the calculations performed by the other iterations. Therefore, it makes sense to partition the work performed by this loop and run different iterations on a separate processor.

3. Modify the definition of the *generateGraphData* method to take two additional *int* parameters called *partitionStart* and *partitionEnd*, as shown in bold here:

```
private void generateGraphData(byte[] data, int partitionStart, int partitionEnd)
{
    ...
}
```

4. In the *generateGraphData* method, change the outer *for* loop to iterate between the values of *partitionStart* and *partitionEnd*, as shown in bold here:

```
private void generateGraphData(byte[] data, int partitionStart, int partitionEnd)
{
    ...

    for (int x = partitionStart; x < partitionEnd; x ++)
    {
       ...
    }
}
```

5. In the *Code and Text Editor* window, add the following *using* statement to the list at the top of the GraphWindow.xaml.cs file:

```
using System.Threading.Tasks;
```

6. In the *plotButton_Click* method, comment out the statement that calls the *generateGraphData* method and add the statement shown next in bold that creates a *Task* object by using the default *TaskFactory* object and starts it running:

```
...
Stopwatch watch = Stopwatch.StartNew();
// generateGraphData(data);
Task first = Task.Factory.StartNew(() => generateGraphData(data, 0, pixelWidth / 4));
...
```

   The task runs the code specified by the lambda expression. The values for the *partitionStart* and *partitionEnd* parameters indicate that the *Task* object calculates the data for the first half of the graph. (The data for the complete graph consists of points plotted for the values between 0 and *pixelWidth / 2*.)

7. Add another statement that creates and runs a second *Task* object on another thread, as shown in bold here:

```
...

Task first = Task.Factory.StartNew(() => generateGraphData(data, 0, pixelWidth / 4));
Task second = Task.Factory.StartNew(() => generateGraphData(data, pixelWidth / 4,
pixelWidth / 2));
...
```

   This *Task* object invokes the *generateGraph* method and calculates the data for the values between *pixelWidth / 4* and *pixelWidth / 2*.

8. Add the following statement that waits for both *Task* objects to complete their work before continuing:

```
Task.WaitAll(first, second);
```

9. On the *Debug* menu, click *Start Without Debugging* to build and run the application.

10. Display the Windows Task Manager, and click the Performance tab if it is not currently displayed.

11. Return to the *Graph Demo* window, and click *Plot Graph*. In the Windows Task Manager, note the maximum value for the CPU usage while the graph is being generated. When the graph appears in the *Graph Demo* window, record the time taken to generate the graph. Repeat this action several times to get an average value.

12. Close the *Graph Demo* window, and minimize the Windows Task Manager.

    This time you should see that the application runs significantly quicker than previously. On my computer, the time dropped to 2682 milliseconds—a reduction in time of about 40 percent. Additionally, you should see that the application uses more cores of the CPU. On a dual-core machine, the CPU usage peaked at 100 percent. If you have a quad-core computer, the CPU utilization will not be as high. This is because two of the cores will not be occupied. To rectify this and reduce the time further, add two further *Task* objects and divide the work into four chunks in the *plotButton_Click* method, as shown in bold here:

```
...
Task first = Task.Factory.StartNew(() => generateGraphData(data, 0, pixelWidth / 8));
Task second = Task.Factory.StartNew(() => generateGraphData(data, pixelWidth / 8,
pixelWidth / 4));
Task third = Task.Factory.StartNew(() => generateGraphData(data, pixelWidth / 4,
pixelWidth * 3 / 8));
Task fourth = Task.Factory.StartNew(() => generateGraphData(data, pixelWidth * 3 / 8,
pixelWidth / 2));
Task.WaitAll(first, second, third, fourth);
...
```

If you have only a dual-core processor, you can still try this modification, and you should still notice a beneficial effect on the time. This is primarily because of efficiencies in the TPL and the algorithms in the .NET Framework optimizing the way in which the threads for each task are scheduled.

Abstracting Tasks by Using the Parallel Class

By using the *Task* class, you have complete control over the number of tasks your application creates. However, you had to modify the design of the application to accommodate the use of *Task* objects. You also had to add code to synchronize operations; the application can render the graph only when all the tasks have completed. In a complex application, synchronization of tasks can become a nontrivial process and it is easy to make mistakes.

The *Parallel* class in the TPL enables you to parallelize some common programming constructs without requiring that you redesign an application. Internally, the *Parallel* class creates its own set of *Task* objects, and it synchronizes these tasks automatically when they have completed. The *Parallel* class is located in the *System.Threading.Tasks* namespace and provides a small set of static methods you can use to indicate that code should be run in parallel if possible. These methods are as follows:

- ***Parallel.For*** You can use this method in place of a C# *for* statement. It defines a loop in which iterations can run in parallel by using tasks. This method is heavily overloaded (there are nine variations), but the general principle is the same for each; you specify a start value, an end value, and a reference to a method that takes an integer parameter. The method is executed for every value between the start value and one below the end value specified, and the parameter is populated with an integer that specifies the current value. For example, consider the following simple *for* loop that performs each iteration in sequence:

```
for (int x = 0; x < 100; x++)
{
    // Perform loop processing
}
```

Depending on the processing performed by the body of the loop, you might be able to replace this loop with a *Parallel.For* construct that can perform iterations in parallel, like this:

```
Parallel.For(0, 100, performLoopProcessing);
...
private void performLoopProcessing(int x)
{
    // Perform loop processing
}
```

The overloads of the *Parallel.For* method enable you to provide local data that is private to each thread, specify various options for creating the tasks run by the *For* method, and create a *ParallelLoopState* object that can be used to pass state information to other concurrent iterations of the loop. (Using a *ParallelLoopState* object is described later in this chapter.)

- ***Parallel.ForEach<T>*** You can use this method in place of a C# *foreach* statement. Like the *For* method, *ForEach* defines a loop in which iterations can run in parallel. You specify a collection that implements the *IEnumerable<T>* generic interface and a reference to a method that takes a single parameter of type *T*. The method is executed for each item in the collection, and the item is passed as the parameter to the method. Overloads are available that enable you to provide private local thread data and specify options for creating the tasks run by the *ForEach* method.
- ***Parallel.Invoke*** You can use this method to execute a set of parameterless method calls as parallel tasks. You specify a list of delegated method calls (or lambda expressions) that take no parameters and do not return values. Each method call can be run on a separate thread, in any order. For example, the following code makes a series of method calls:

```
doWork();
doMoreWork();
doYetMoreWork();
```

You can replace these statements with the following code, which invokes these methods by using a series of tasks:

```
Parallel.Invoke(
    doWork,
    doMoreWork,
    doYetMoreWork
);
```

You should bear in mind that the .NET Framework determines the actual degree of parallelism appropriate for the environment and workload of the computer. For example, if you use *Parallel.For* to implement a loop that performs 1000 iterations, the .NET Framework does not necessarily create 1000 concurrent tasks (unless you have an exceptionally powerful processor with 1000 cores). Instead, the .NET Framework creates what it considers to be the optimal number of tasks that balances the available resources against the requirement to keep the processors occupied. A single task might perform multiple iterations, and the tasks coordinate with each other to determine which iterations each task will perform. An important consequence of this is that you cannot guarantee the order in which the iterations are executed, so you must ensure there are no dependencies between iterations; otherwise, you might get unexpected results, as you will see later in this chapter.

In the next exercise, you will return to the original version of the GraphData application and use the *Parallel* class to perform operations concurrently.

Use the *Parallel* class to parallelize operations in the GraphData application

1. Using Visual Studio 2010, open the *GraphDemo* solution, located in the \Microsoft Press\Visual CSharp Step By Step\Chapter 27\GraphDemo Using the Parallel Class folder in your Documents folder.

   This is a copy of the original GraphDemo application. It does not use tasks yet.

2. In Solution Explorer, in the GraphDemo project, expand the GraphWindow.xaml node, and then double-click GraphWindow.xaml.cs to display the code for the form in the *Code and Text Editor* window.

3. Add the following *using* statement to the list at the top of the file:

   ```
   using System.Threading.Tasks;
   ```

4. Locate the *generateGraphData* method. It looks like this:

   ```
   private void generateGraphData(byte[] data)
   {
       int a = pixelWidth / 2;
       int b = a * a;
       int c = pixelHeight / 2;

       for (int x = 0; x < a; x++)
       {
           int s = x * x;
           double p = Math.Sqrt(b - s);
           for (double i = -p; i < p; i += 3)
           {
               double r = Math.Sqrt(s + i * i) / a;
               double q = (r - 1) * Math.Sin(24 * r);
               double y = i / 3 + (q * c);
               plotXY(data, (int)(-x + (pixelWidth / 2)), (int)(y + (pixelHeight / 2)));
               plotXY(data, (int)(x + (pixelWidth / 2)), (int)(y + (pixelHeight / 2)));
           }
       }
   }
   ```

The outer *for* loop that iterates through values of the integer variable *x* is a prime candidate for parallelization. You might also consider the inner loop based on the variable *i*, but this loop takes more effort to parallelize because of the type of *i*. (The methods in the *Parallel* class expect the control variable to be an integer.) Additionally, if you have nested loops such as occur in this code, it is good practice to parallelize the outer loops first and then test to see whether the performance of the application is sufficient. If it is not, work your way through nested loops and parallelize them working from outer to inner loops, testing the performance after modifying each one. You will find that in many cases parallelizing outer loops has the most effect on performance, while the effects of modifying inner loops becomes more marginal.

5. Move the code in the body of the *for* loop, and create a new private *void* method called *calculateData* with this code. The *calculateData* method should take an integer parameter called *x* and a byte array called *data*. Also, move the statements that declare the local variables *a*, *b*, and *c* from the *generateGraphData* method to the start of the *calculateData* method. The following code shows the *generateGraphData* method with this code removed and the *calculateData* method (do not try and compile this code yet):

```
private void generateGraphData(byte[] data)
{
    for (int x = 0; x < a; x++)
    {
    }
}

private void calculateData(int x, byte[] data)
{
    int a = pixelWidth / 2;
    int b = a * a;
    int c = pixelHeight / 2;

    int s = x * x;
    double p = Math.Sqrt(b - s);
    for (double i = -p; i < p; i += 3)
    {
        double r = Math.Sqrt(s + i * i) / a;
        double q = (r - 1) * Math.Sin(24 * r);
        double y = i / 3 + (q * c);
        plotXY(data, (int)(-x + (pixelWidth / 2)), (int)(y + (pixelHeight / 2)));
        plotXY(data, (int)(x + (pixelWidth / 2)), (int)(y + (pixelHeight / 2)));
    }
}
```

6. In the *generateGraphData* method, change the *for* loop to a statement that calls the static *Parallel.For* method, as shown in bold here:

```
private void generateGraphData(byte[] data)
{
    Parallel.For (0, pixelWidth / 2, (int x) => { calculateData(x, data); });
}
```

This code is the parallel equivalent of the original *for* loop. It iterates through the values from 0 to pixelWidth / 2 – 1 inclusive. Each invocation runs by using a task. (Each task might run more than one iteration.) The *Parallel.For* method finishes only when all the tasks it has created complete their work. Remember that the *Parallel.For* method expects the final parameter to be a method that takes a single integer parameter. It calls this method passing the current loop index as the parameter. In this example, the *calculateData* method does not match the required signature because it takes two parameters: an integer and a byte array. For this reason, the code uses a lambda expression to define an anonymous method that has the appropriate signature and that acts as an adapter that calls the *calculateData* method with the correct parameters.

7. On the *Debug* menu, click *Start Without Debugging* to build and run the application.
8. Display the Windows Task Manager, and click the *Performance* tab if it is not currently displayed.
9. Return to the *Graph Demo* window, and click *Plot Graph*. In the Windows Task Manager, note the maximum value for the CPU usage while the graph is being generated. When the graph appears in the *Graph Demo* window, record the time taken to generate the graph. Repeat this action several times to get an average value.
10. Close the *Graph Demo* window, and minimize the Windows Task Manager.

    You should notice that the application runs at a comparable speed to the previous version that used *Task* objects (and possibly slightly faster, depending on the number of CPUs you have available), and that the CPU usage peaks at 100 percent.

When Not to Use the Parallel Class

You should be aware that despite appearances and the best efforts of the Visual Studio development team at Microsoft, the *Parallel* class is not magic; you cannot use it without due consideration and just expect your applications to suddenly run significantly faster and produce the same results. The purpose of the *Parallel* class is to parallelize compute-bound, independent areas of your code.

The key phrases in the previous paragraph are *compute-bound* and *independent*. If your code is not compute-bound, parallelizing it might not improve performance. The next exercise shows you that you should be careful in how you determine when to use the *Parallel.Invoke* construct to perform method calls in parallel.

Determine when to use *Parallel.Invoke*

1. Return to Visual Studio 2010, and display the GraphWindow.xaml.cs file in the *Code and Text Editor* window if it is not already open.
2. Examine the *calculateData* method.

The inner *for* loop contains the following statements:

```
plotXY(data, (int)(-x + (pixelWidth / 2)), (int)(y + (pixelHeight / 2)));
plotXY(data, (int)(x + (pixelWidth / 2)), (int)(y + (pixelHeight / 2)));
```

These two statements set the bytes in the *data* array that correspond to the points specified by the two parameters passed in. Remember that the points for the graph are reflected around the X axis, so the *plotXY* method is called for the positive value of the X coordinate and also for the negative value. These two statements look like good candidates for parallelization because it does not matter which one runs first, and they set different bytes in the *data* array.

3. Modify these two statements, and wrap them in a *Parallel.Invoke* method call, as shown next. Notice that both calls are now wrapped in lambda expressions, and that the semi-colon at the end of the first call to *plotXY* is replaced with a comma and the semi-colon at the end of the second call to *plotXY* has been removed because these statements are now a list of parameters:

```
Parallel.Invoke(
    () => plotXY(data, (int)(-x + (pixelWidth / 2)), (int)(y + (pixelHeight / 2))),
    () => plotXY(data, (int)(x + (pixelWidth / 2)), (int)(y + (pixelHeight / 2)))
);
```

4. On the *Debug* menu, click *Start Without Debugging* to build and run the application.
5. In the *Graph Demo* window, click *Plot Graph*. Record the time taken to generate the graph. Repeat this action several times to get an average value.

   You should find, possibly unexpectedly, that the application takes significantly longer to run. It might be up to 20 times slower than it was previously.
6. Close the *Graph Demo* window.

The questions you are probably asking at this point are, "What went wrong? Why did the application slow down so much?" The answer lies in the *plotXY* method. If you take another look at this method, you will see that it is very simple:

```
private void plotXY(byte[] data, int x, int y)
{
    data[x + y * pixelWidth] = 0xFF;
}
```

There is very little in this method that takes any time to run, and it is definitely not a compute-bound piece of code. In fact, it is so simple that the overhead of creating a task, running this task on a separate thread, and waiting for the task to complete is much greater than the cost of running this method directly. The additional overhead might account for only a few milliseconds each time the method is called, but you should bear in mind the number of times that this method runs; the method call is located in a nested loop and is executed thousands of times, so all of these small overhead costs add up. The general rule is to use

Parallel.Invoke only when it is worthwhile. Reserve *Parallel.Invoke* for operations that are computationally intensive.

As mentioned earlier in this chapter, the other key consideration for using the *Parallel* class is that operations should be independent. For example, if you attempt to use *Parallel.For* to parallelize a loop in which iterations are not independent, the results will be unpredictable. To see what I mean, look at the following program:

```
using System;
using System.Threading;
using System.Threading.Tasks;

namespace ParallelLoop
{
    class Program
    {
        private static int accumulator = 0;

        static void Main(string[] args)
        {
            for (int i = 0; i < 100; i++)
            {
                AddToAccumulator(i);
            }
            Console.WriteLine("Accumulator is {0}", accumulator);
        }

        private static void AddToAccumulator(int data)
        {
            if ((accumulator % 2) == 0)
            {
                accumulator += data;
            }
            else
            {
                accumulator -= data;
            }
        }
    }
}
```

This program iterates through the values from 0 to 99 and calls the *AddToAccumulator* method with each value in turn. The *AddToAccumulator* method examines the current value of the *accumulator* variable, and if it is even it adds the value of the parameter to the *accumulator* variable; otherwise, it subtracts the value of the parameter. At the end of the program, the result is displayed. You can find this application in the ParallelLoop solution, located in the \Microsoft Press\Visual CSharp Step By Step\Chapter 27\ParallelLoop folder in your Documents folder. If you run this program, the value output should be –100.

To increase the degree of parallelism in this simple application, you might be tempted to replace the *for* loop in the *Main* method with *Parallel.For*, like this:

```
static void Main(string[] args)
{
    Parallel.For (0, 100, AddToAccumulator);
    Console.WriteLine("Accumulator is {0}", accumulator);
}
```

However, there is no guarantee that the tasks created to run the various invocations of the *AddToAccumulator* method will execute in any specific sequence. (The code is also not thread-safe because multiple threads running the tasks might attempt to modify the *accumulator* variable concurrently.) The value calculated by the *AddToAccumulator* method depends on the sequence being maintained, so the result of this modification is that the application might now generate different values each time it runs. In this simple case, you might not actually see any difference in the value calculated because the *AddToAccumulator* method runs very quickly and the .NET Framework might elect to run each invocation sequentially by using the same thread. However, if you make the following change shown in bold to the *AddToAccumulator* method, you will get different results:

```
private static void AddToAccumulator(int data)
{
    if ((accumulator % 2) == 0)
    {
        accumulator += data;
        Thread.Sleep(10); // wait for 10 milliseconds
    }
    else
    {
        accumulator -= data;
    }
}
```

The *Thread.Sleep* method simply causes the current thread to wait for the specified period of time. This modification simulates the thread, performing additional processing and affects the way in which the .NET Framework schedules the tasks, which now run on different threads resulting in a different sequence.

The general rule is to use *Parallel.For* and *Parallel.ForEach* only if you can guarantee that each iteration of the loop is independent, and test your code thoroughly. A similar consideration applies to *Parallel.Invoke*; use this construct to make method calls only if they are independent and the application does not depend on them being run in a particular sequence.

Returning a Value from a Task

So far, all the examples you have seen use a *Task* object to run code that performs a piece of work but does not return a value. However, you might also want to run a method that calculates a result. The TPL includes a generic variant of the *Task* class, *Task<TResult>*, that you can use for this purpose.

You create and run a *Task<TResult>* object in a similar way as a *Task* object. The main difference is that the method run by the *Task<TResult>* object returns a value, and you specify the type of this return value as the type parameter, *T*, of the *Task* object. For example, the method *calculateValue* shown in the following code example returns an integer value. To invoke this method by using a task, you create a *Task<int>* object and then call the *Start* method. You obtain the value returned by the method by querying the *Result* property of the *Task<int>* object. If the task has not finished running the method and the result is not yet available, the *Result* property blocks the caller. What this means is that you don't have to perform any synchronization yourself, and you know that when the *Result* property returns a value the task has completed its work.

```
Task<int> calculateValueTask = new Task<int>(() => calculateValue(...));
calculateValueTask.Start(); // Invoke the calculateValue method
...
int calculatedData = calculateValueTask.Result; // Block until calculateValueTask completes
...
private int calculateValue(...)
{
    int someValue;
    // Perform calculation and populate someValue
    ...
    return someValue;
}
```

Of course, you can also use the *StartNew* method of a *TaskFactory* object to create a *Task<TResult>* object and start it running. The next code example shows how to use the default *TaskFactory* for a *Task<int>* object to create and run a task that invokes the *calculateValue* method:

```
Task<int> calculateValueTask = Task<int>.Factory.StartNew(() => calculateValue(...));
...
```

To simplify your code a little (and to support tasks that return anonymous types), the *TaskFactory* class provides generic overloads of the *StartNew* method and can infer the type returned by the method run by a task. Additionally, the *Task<TResult>* class inherits from the *Task* class. This means that you can rewrite the previous example like this:

```
Task calculateValueTask = Task.Factory.StartNew(() => calculateValue(...));
...
```

The next exercise gives a more detailed example. In this exercise, you will restructure the GraphDemo application to use a *Task<TResult>* object. Although this exercise seems a little academic, you might find the technique that it demonstrates useful in many real-world situations.

Modify the GraphDemo application to use a *Task<TResult>* object

1. Using Visual Studio 2010, open the *GraphDemo* solution, located in the \Microsoft Press\Visual CSharp Step By Step\Chapter 27\GraphDemo Using Tasks that Return Results folder in your Documents folder.

   This is a copy of the GraphDemo application that creates a set of four tasks that you saw in an earlier exercise.

2. In Solution Explorer, in the GraphDemo project, expand the GraphWindow.xaml node, and then double-click GraphWindow.xaml.cs to display the code for the form in the *Code and Text Editor* window.

3. Locate the *plotButton_Click* method. This is the method that runs when the user clicks the *Plot Graph* button on the form. Currently, it creates a set of *Task* objects to perform the various calculations required and generate the data for the graph, and it waits for these *Task* objects to complete before displaying the results in the *Image* control on the form.

4. Underneath the *plotButton_Click* method, add a new method called *getDataForGraph*. This method should take an integer parameter called *dataSize* and return a *byte* array, as shown in the following code:

   ```
   private byte[] getDataForGraph(int dataSize)
   {
   }
   ```

   You will add code to this method to generate the data for the graph in a *byte* array and return this array to the caller. The *dataSize* parameter specifies the size of the array.

5. Move the statement that creates the data array from the *plotButton_Click* method to the *getDataForGraph* method as shown here in bold:

   ```
   private byte[] getDataForGraph(int dataSize)
   {
       byte[] data = new byte[dataSize];
   }
   ```

6. Move the code that creates, runs, and waits for the *Task* objects that populate the *data* array from the *plotButton_Click* method to the *getDataForGraph* method, and add a return statement to the end of the method that passes the *data* array back to the caller. The completed code for the *getDataForGraph* method should look like this:

   ```
   private byte[] getDataForGraph(int dataSize)
   {
       byte[] data = new byte[dataSize];
       Task first = Task.Factory.StartNew(() => generateGraphData(data, 0, pixelWidth /
   8));
       Task second = Task.Factory.StartNew(() => generateGraphData(data, pixelWidth / 8,
   pixelWidth / 4));
       Task third = Task.Factory.StartNew(() => generateGraphData(data, pixelWidth / 4,
   ```

```
pixelWidth * 3 / 8));
    Task fourth = Task.Factory.StartNew(() => generateGraphData(data, pixelWidth * 3 /
8, pixelWidth / 2));
    Task.WaitAll(first, second, third, fourth);
    return data;
}
```

> **Tip** You can replace the code that creates the tasks and waits for them to complete with the following *Parallel.Invoke* construct:
>
> ```
> Parallel.Invoke(
>     () => generateGraphData(data, 0, pixelWidth / 8),
>     () => generateGraphData(data, pixelWidth / 8, pixelWidth / 4),
>     () => generateGraphData(data, pixelWidth / 4, pixelWidth * 3 / 8),
>     () => generateGraphData(data, pixelWidth * 3 / 8, pixelWidth / 2)
> );
> ```

7. In the *plotButton_Click* method, after the statement that creates the *Stopwatch* variable used to time the tasks, add the statement shown next in bold that creates a *Task<byte[]>* object called *getDataTask* and uses this object to run the *getDataForGraph* method. This method returns a *byte* array, so the type of the task is *Task<byte []>*. The *StartNew* method call references a lambda expression that invokes the *getDataForGraph* method and passes the *dataSize* variable as the parameter to this method.

```
private void plotButton_Click(object sender, RoutedEventArgs e)
{
    ...
    Stopwatch watch = Stopwatch.StartNew();
    Task<byte[]> getDataTask = Task<byte[]>.Factory.StartNew(() =>
getDataForGraph(dataSize));
    ...
}
```

8. After creating and starting the *Task<byte []>* object, add the following statements shown in bold that examine the *Result* property to retrieve the data array returned by the *getDataForGraph* method into a local byte array variable called *data*. Remember that the *Result* property blocks the caller until the task has completed, so you do not need to explicitly wait for the task to finish.

```
private void plotButton_Click(object sender, RoutedEventArgs e)
{
    ...
    Task<byte[]> getDataTask = Task<byte[]>.Factory.StartNew(() =>
getDataForGraph(dataSize));
    byte[] data = getDataTask.Result;
    ...
}
```

> **Note** It might seem a little strange to create a task and then immediately wait for it to complete before doing anything else because it only adds overhead to the application. However, in the next section, you will see why this approach has been adopted.

9. Verify that the completed code for the *plotButton_Click* method looks like this:

```
private void plotButton_Click(object sender, RoutedEventArgs e)
{
    if (graphBitmap == null)
    {
        graphBitmap = new WriteableBitmap(pixelWidth, pixelHeight, dpiX, dpiY,
PixelFormats.Gray8, null);
    }
    int bytesPerPixel = (graphBitmap.Format.BitsPerPixel + 7) / 8;
    int stride = bytesPerPixel * pixelWidth;
    int dataSize = stride * pixelHeight;

    Stopwatch watch = Stopwatch.StartNew();
    Task<byte[]> getDataTask = Task<byte[]>.Factory.StartNew(() =>
getDataForGraph(dataSize));
    byte[] data = getDataTask.Result;

    duration.Content = string.Format("Duration (ms): {0}", watch.ElapsedMilliseconds);
    graphBitmap.WritePixels(new Int32Rect(0, 0, pixelWidth, pixelHeight), data,
stride, 0);
    graphImage.Source = graphBitmap;
}
```

10. On the *Debug* menu, click *Start Without Debugging* to build and run the application.
11. In the *Graph Demo* window, click *Plot Graph*. Verify that the graph is generated as before and that the time taken is similar to that seen previously. (The time reported might be marginally slower because the data array is now created by the task, whereas previously it was created before the task started running.)
12. Close the *Graph Demo* window.

Using Tasks and User Interface Threads Together

The section "Why Perform Multitasking by Using Parallel Processing?" at the start of this chapter highlighted the two principal reasons for using multitasking in an application—to improve throughput and increase responsiveness. The TPL can certainly assist in improving throughput, but you need to be aware that using the TPL alone is not the complete solution to improving responsiveness, especially in an application that provides a graphical user interface. In the GraphDemo application used as the basis for the exercises in this chapter, although the time taken to generate the data for the graph is reduced by the effective use of tasks, the application itself exhibits the classic symptoms of many GUIs that perform processor-intensive computations—it is not responsive to user input while these computations are being performed. For example, if you run the *GraphDemo* application from the previous exercise, click *Plot Graph*, and then try and move the Graph Demo window by clicking and dragging the title bar, you will find that it does not move until after the various tasks used to generate the graph have completed and the graph is displayed.

In a professional application, you should ensure that users can still use your application even if parts of it are busy performing other tasks. This is where you need to use threads as well as tasks.

In Chapter 23, you saw how the items that constitute the graphical user interface in a WPF application all run on the same user interface (UI) thread. This is to ensure consistency and safety, and it prevents two or more threads from potentially corrupting the internal data structures used by WPF to render the user interface. Remember also that you can use the WPF *Dispatcher* object to queue requests for the UI thread, and these requests can update the user interface. The next exercise revisits the *Dispatcher* object and shows how you can use it to implement a responsive solution in conjunction with tasks that ensure the best available throughput.

Improve responsiveness in the GraphDemo application

1. Return to Visual Studio 2010, and display the GraphWindow.xaml.cs file in the *Code and Text Editor* window if it is not already open.
2. Add a new method called *doPlotButtonWork* below the *plotButton_Click* method. This method should take no parameters and not return a result. In the next few steps, you will move the code that creates and runs the tasks that generate the data for the graph to this method, and you will run this method on a separate thread, leaving the UI thread free to manage user input.

```
private void doPlotButtonWork()
{
}
```

3. Move all the code except for the *if* statement that creates the *graphBitmap* object from the *plotButton_Click* method to the *doPlotButtonWork* method. Note that some of these statements attempt to access user interface items; you will modify these statements to use the *Dispatcher* object later in this exercise. The *plotButton_Click* and *doPlotButtonWork* methods should look like this:

```
private void plotButton_Click(object sender, RoutedEventArgs e)
{
    if (graphBitmap == null)
    {
        graphBitmap = new WriteableBitmap(pixelWidth, pixelHeight, dpiX, dpiY,
PixelFormats.Gray8, null);
    }
}
```

```
private void doPlotButtonWork()
{
    int bytesPerPixel = (graphBitmap.Format.BitsPerPixel + 7) / 8;
    int stride = bytesPerPixel * pixelWidth;
    int dataSize = stride * pixelHeight;

    Stopwatch watch = Stopwatch.StartNew();
    Task<byte[]> getDataTask = Task<byte[]>.Factory.StartNew(() =>
getDataForGraph(dataSize));
    byte[] data = getDataTask.Result;

    duration.Content = string.Format("Duration (ms): {0}", watch.ElapsedMilliseconds);
    graphBitmap.WritePixels(new Int32Rect(0, 0, pixelWidth, pixelHeight), data,
stride, 0);
    graphImage.Source = graphBitmap;
}
```

4. In the *plotButton_Click* method, after the *if* block, create an *Action* delegate called *doPlotButtonWorkAction* that references the *doPlotButtonWork* method, as shown here in bold:

```
private void plotButton_Click(object sender, RoutedEventArgs e)
{
    ...
    Action doPlotButtonWorkAction = new Action(doPlotButtonWork);
}
```

5. Call the *BeginInvoke* method on the *doPlotButtonWorkAction* delegate. The *BeginInvoke* method of the *Action* type executes the method associated with the delegate (in this case, the *doPlotButtonWork* method) on a new thread.

> **Note** The *Action* type also provides the *Invoke* method, which runs the delegated method on the current thread. This behavior is not what we want in this case because it blocks the user interface and prevents it from being able to respond while the method is running.

The *BeginInvoke* method takes parameters you can use to arrange notification when the method finishes, as well as any data to pass to the delegated method. In this example, you do not need to be notified when the method completes and the method does not take any parameters, so specify a *null* value for these parameters as shown in bold here:

```
private void plotButton_Click(object sender, RoutedEventArgs e)
{
    ...
    Action doPlotButtonWorkAction = new Action(doPlotButtonWork);
    doPlotButtonWorkAction.BeginInvoke(null, null);
}
```

The code will compile at this point, but if you try and run it, it will not work correctly when you click *Plot Graph*. This is because several statements in the *doPlotButtonWork* method attempt to access user interface items, and this method is not running on the UI thread. You met this issue in Chapter 23, and you also saw the solution at that time—use the *Dispatcher* object for the UI thread to access UI elements. The following steps amend these statements to use the *Dispatcher* object to access the user interface items from the correct thread.

6. Add the following *using* statement to the list at the top of the file:

```
using System.Windows.Threading;
```

The *DispatcherPriority* enumeration is held in this namespace. You will use this enumeration when you schedule code to run on the UI thread by using the *Dispatcher* object.

7. At the start of the *doPlotButtonWork* method, examine the statement that initializes the *bytesPerPixel* variable:

```
private void doPlotButtonWork()
{
    int bytesPerPixel = (graphBitmap.Format.BitsPerPixel + 7) / 8;
    ...
}
```

This statement references the *graphBitmap* object, which belongs to the UI thread. You can access this object only from code running on the UI thread. Change this statement to initialize the *bytesPerPixel* variable to zero, and add a statement to call the *Invoke* method of the *Dispatcher* object, as shown in bold here:

```
private void doPlotButtonWork()
{
    int bytesPerPixel = 0;
    plotButton.Dispatcher.Invoke(new Action(() =>
        { bytesPerPixel = (graphBitmap.Format.BitsPerPixel + 7) / 8; }),
        DispatcherPriority.ApplicationIdle);
    ...
}
```

Recall from Chapter 23 that you can access the *Dispatcher* object through the *Dispatcher* property of any UI element. This code uses the *plotButton* button. The *Invoke* method expects a delegate and an optional dispatcher priority. In this case, the delegate references a lambda expression. The code in this expression runs on the UI thread. The *DispatcherPriority* parameter indicates that this statement should run only when the application is idle and there is nothing else more important going on in the user interface (such as the user clicking a button, typing some text, or moving the window).

8. Examine the final three statements in the *doPlotButtonWork* method. They look like this:

```
private void doPlotButtonWork()
{
    ...
    duration.Content = string.Format("Duration (ms): {0}", watch.ElapsedMilliseconds);
    graphBitmap.WritePixels(new Int32Rect(0, 0, pixelWidth, pixelHeight), data,
stride, 0);
    graphImage.Source = graphBitmap;
}
```

   These statements reference the *duration*, *graphBitmap*, and *graphImage* objects, which are all part of the user interface. Consequently, you must change these statements to run on the UI thread.

9. Modify these statements, and run them by using the *Dispatcher.Invoke* method, as shown in bold here:

```
private void doPlotButtonWork()
{
    ...
    plotButton.Dispatcher.Invoke(new Action(() =>
    {
        duration.Content = string.Format("Duration (ms): {0}", watch.
ElapsedMilliseconds);
        graphBitmap.WritePixels(new Int32Rect(0, 0, pixelWidth, pixelHeight), data,
stride, 0);
        graphImage.Source = graphBitmap;
    }), DispatcherPriority.ApplicationIdle);
}
```

   This code converts the statements into a lambda expression wrapped in an *Action* delegate, and then invokes this delegate by using the *Dispatcher* object.

10. On the *Debug* menu, click *Start Without Debugging* to build and run the application.

11. In the Graph Demo window, click *Plot Graph* and before the graph appears quickly drag the window to another location on the screen. You should find that the window responds immediately and does not wait for the graph to appear first.

12. Close the Graph Demo window.

Canceling Tasks and Handling Exceptions

Another common requirement of applications that perform long-running operations is the ability to stop those operations if necessary. However, you should not simply abort a task because this could leave the data in your application in an indeterminate state. Instead, the TPL implements a cooperative cancellation strategy. Cooperative cancellation enables a task to select a convenient point at which to stop processing and also enables it to undo any work it has performed prior to cancellation if necessary.

The Mechanics of Cooperative Cancellation

Cooperative cancellation is based on the notion of a *cancellation token*. A cancellation token is a structure that represents a request to cancel one or more tasks. The method that a task runs should include a *System.Threading.CancellationToken* parameter. An application that wants to cancel the task sets the Boolean *IsCancellationRequested* property of this parameter to *true*. The method running in the task can query this property at various points during its processing. If this property is set to *true* at any point, it knows that the application has requested that the task be canceled. Also, the method knows what work it has done so far, so it can undo any changes if necessary and then finish. Alternatively, the method can simply ignore the request and continue running if it does not want to cancel the task.

> **Tip** You should examine the cancellation token in a task frequently, but not so frequently that you adversely impact the performance of the task. If possible, you should aim to check for cancellation at least every 10 milliseconds, but no more frequently than every millisecond.

An application obtains a *CancellationToken* by creating a *System.Threading.CancellationTokenSource* object and querying the *Token* property of this object. The application can then pass this *CancellationToken* object as a parameter to any methods started by tasks that the application creates and runs. If the application needs to cancel the tasks, it calls the *Cancel* method of the *CancellationTokenSource* object. This method sets the *IsCancellationRequested* property of the *CancellationToken* passed to all the tasks.

The following code example shows how to create a cancellation token and use it to cancel a task. The *initiateTasks* method instantiates the *cancellationTokenSource* variable and obtains a reference to the *CancellationToken* object available through this variable. The code then creates and runs a task that executes the *doWork* method. Later on, the code calls the *Cancel* method of the cancellation token source, which sets the cancellation token. The *doWork* method queries the *IsCancellationRequested* property of the cancellation token. If the property is set the method terminates; otherwise, it continues running.

```
public class MyApplication
{
    ...
    // Method that creates and manages a task
    private void initiateTasks()
    {
        // Create the cancellation token source and obtain a cancellation token
        CancellationTokenSource cancellationTokenSource = new CancellationTokenSource();
        CancellationToken cancellationToken = cancellationToken.Token;
```

```
        // Create a task and start it running the doWork method
        Task myTask = Task.Factory.StartNew(() => doWork(cancellationToken));
        ...
        if (...)
        {
            // Cancel the task
            cancellationTokenSource.Cancel();
        }
        ...
    }

    // Method run by the task
    private void doWork(CancellationToken token)
    {
        ...
        // If the application has set the cancellation token, finish processing
        if (token.IsCancellationRequested)
        {
             // Tidy up and finish
            ...
            return;
        }
        // If the task has not been canceled, continue running as normal
        ...
    }
}
```

As well as providing a high degree of control over the cancellation processing, this approach is scalable across any number of tasks. You can start multiple tasks and pass the same *CancellationToken* object to each of them. If you call *Cancel* on the *CancellationTokenSource* object, each task will see that the *IsCancellationRequested* property has been set and can react accordingly.

You can also register a callback method with the cancellation token by using the *Register* method. When an application invokes the *Cancel* method of the corresponding *CancellationTokenSource* object, this callback runs. However, you cannot guarantee when this method executes; it might be before or after the tasks have performed their own cancellation processing, or even during that process.

```
...
cancellationToken,Register(doAdditionalWork);
...
private void doAdditionalWork()
{
    // Perform additional cancellation processing
}
```

In the next exercise, you will add cancellation functionality to the GraphDemo application.

Add cancellation functionality to the GraphDemo application

1. Using Visual Studio 2010, open the *GraphDemo* solution, located in the \Microsoft Press\Visual CSharp Step By Step\Chapter 27\GraphDemo Canceling Tasks folder in your Documents folder.

   This is a completed copy of the GraphDemo application from the previous exercise that uses tasks and threads to improve responsiveness.

2. In Solution Explorer, in the GraphDemo project, double-click GraphWindow.xaml to display the form in the *Design View* window.

3. From the *Toolbox*, add a *Button* control to the form under the *duration* label. Align the button horizontally with the *plotButton* button. In the *Properties* window, change the *Name* property of the new button to *cancelButton*, and change the *Content* property to *Cancel*.

   The amended form should look like the following image.

4. Double-click the *Cancel* button to create a *Click* event handling method called *cancelButton_Click*.

5. In the GraphWindow.xaml.cs file, locate the *getDataForGraph* method. This method creates the tasks used by the application and waits for them to complete. Move the declaration of the *Task* variables to the class level for the *GraphWindow* class as shown in bold in the following code, and then modify the *getDataForGraph* method to instantiate these variables:

```
public partial class GraphWindow : Window
{
    ...
    private Task first, second, third, fourth;
    ...
    private byte[] getDataForGraph(int dataSize)
```

```
    {
        byte[] data = new byte[dataSize];
        first = Task.Factory.StartNew(() => generateGraphData(data, 0, pixelWidth /
8));
        second = Task.Factory.StartNew(() => generateGraphData(data, pixelWidth / 8,
pixelWidth / 4));
        third = Task.Factory.StartNew(() => generateGraphData(data, pixelWidth / 4,
pixelWidth * 3 / 8));
        fourth = Task.Factory.StartNew(() => generateGraphData(data, pixelWidth * 3 /
8, pixelWidth / 2));
        Task.WaitAll(first, second, third, fourth);
        return data;
    }
}
```

6. Add the following *using* statement to the list at the top of the file:

```
using System.Threading;
```

The types used by cooperative cancellation live in this namespace.

7. Add a *CancellationTokenSource* member called *tokenSource* to the *GraphWindow* class, and initialize it to null, as shown here in bold:

```
public class GraphWindow : Window
{
    ...
    private Task first, second, third, fourth;
    private CancellationTokenSource tokenSource = null;
    ...
}
```

8. Find the *generateGraphData* method, and add a *CancellationToken* parameter called *token* to the method definition:

```
private void generateGraphData(byte[] data, int partitionStart, int partitionEnd,
CancellationToken token)
{
    ...
}
```

9. In the *generateGraphData* method, at the start of the inner *for* loop, add the code shown next in bold to check whether cancellation has been requested. If so, return from the method; otherwise, continue calculating values and plotting the graph.

```
private void generateGraphData(byte[] data, int partitionStart, int partitionEnd,
CancellationToken token)
{
    int a = pixelWidth / 2;
    int b = a * a;
    int c = pixelHeight / 2;

    for (int x = partitionStart; x < partitionEnd; x ++)
    {
        int s = x * x;
```

```
        double p = Math.Sqrt(b - s);
        for (double i = -p; i < p; i += 3)
        {
            if (token.IsCancellationRequested)
            {
                return;
            }

            double r = Math.Sqrt(s + i * i) / a;
            double q = (r - 1) * Math.Sin(24 * r);
            double y = i / 3 + (q * c);
            plotXY(data, (int)(-x + (pixelWidth / 2)), (int)(y + (pixelHeight / 2)));
            plotXY(data, (int)(x + (pixelWidth / 2)), (int)(y + (pixelHeight / 2)));
        }
    }
}
```

10. In the *getDataForGraph* method, add the following statements shown in bold that instantiate the *tokenSource* variable and retrieve the *CancellationToken* object into a variable called *token*:

```
private byte[] getDataForGraph(int dataSize)
{
    byte[] data = new byte[dataSize];
    tokenSource = new CancellationTokenSource();
    CancellationToken token = tokenSource.Token;
    ...
}
```

11. Modify the statements that create and run the four tasks, and pass the *token* variable as the final parameter to the *generateGraphData* method:

```
first = Task.Factory.StartNew(() => generateGraphData(data, 0, pixelWidth / 8,
token));
second = Task.Factory.StartNew(() => generateGraphData(data, pixelWidth / 8,
pixelWidth / 4, token));
third = Task.Factory.StartNew(() => generateGraphData(data, pixelWidth / 4, pixelWidth
* 3 / 8, token));
fourth = Task.Factory.StartNew(() => generateGraphData(data, pixelWidth * 3 / 8,
pixelWidth / 2, token));
```

12. In the *cancelButton_Click* method, add the code shown here in bold:

```
private  void cancelButton_Click(object sender, RoutedEventArgs e)
{
    if (tokenSource != null)
    {
       tokenSource.Cancel();
    }
}
```

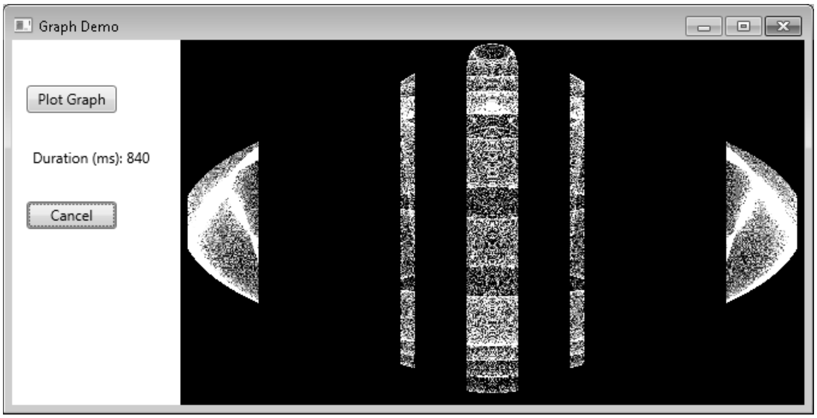
This code checks that the *tokenSource* variable has been instantiated; if it has been, the code invokes the *Cancel* method on this variable.

13. On the *Debug* menu, click *Start Without Debugging* to build and run the application.

14. In the GraphDemo window, click *Plot Graph*, and verify that the graph appears as it did before.

15. Click *Plot Graph* again, and then quickly click *Cancel*.

    If you are quick and click *Cancel* before the data for the graph is generated, this action causes the methods being run by the tasks to return. The data is not complete, so the graph appears with holes, as shown in the following figure. (The size of the holes depends on how quickly you clicked *Cancel*.)



16. Close the GraphDemo window, and return to Visual Studio.

You can determine whether a task completed or was canceled by examining the *Status* property of the *Task* object. The *Status* property contains a value from the *System.Threading.Tasks.TaskStatus* enumeration. The following list describes some of the status values that you might commonly encounter (there are others):

- ***Created*** This is the initial state of a task. It has been created but has not yet been scheduled to run.
- ***WaitingToRun*** The task has been scheduled but has not yet started to run.
- ***Running*** The task is currently being executed by a thread.
- ***RanToCompletion*** The task completed successfully without any unhandled exceptions.
- ***Canceled*** The task was canceled before it could start running, or it acknowledged cancellation and completed without throwing an exception.
- ***Faulted*** The task terminated because of an exception.

In the next exercise, you will attempt to report the status of each task so that you can see when they have completed or have been canceled.

Canceling a Parallel *For* or *ForEach* Loop

The *Parallel.For* and *Parallel.ForEach* methods don't provide you with direct access to the *Task* objects that have been created. Indeed, you don't even know how many tasks are running—the .NET Framework uses its own heuristics to work out the optimal number to use based on the resources available and the current workload of the computer.

If you want to stop the *Parallel.For* or *Parallel.ForEach* method early, you must use a *ParallelLoopState* object. The method you specify as the body of the loop must include an additional *ParallelLoopState* parameter. The TPL creates a *ParallelLoopState* object and passes it as this parameter into the method. The TPL uses this object to hold information about each method invocation. The method can call the *Stop* method of this object to indicate that the TPL should not attempt to perform any iterations beyond those that have already started and finished. The following example shows the *Parallel.For* method calling the *doLoopWork* method for each iteration. The *doLoopWork* method examines the iteration variable; if it is greater than 600, the method calls the *Stop* method of the *ParallelLoopState* parameter. This causes the *Parallel.For* method to stop running further iterations of the loop. (Iterations currently running might continue to completion.)

> **Note** Remember that the iterations in a *Parallel.For* loop are not run in a specific sequence. Consequently, canceling the loop when the iteration variable has the value 600 does not guarantee that the previous 599 iterations have already run. Equally, some iterations with values greater than 600 might already have completed.

```
Parallel.For(0, 1000, doLoopWork);
...
private void doLoopWork(int i, ParallelLoopState p)
{
    ...
    if (i > 600)
    {
        p.Stop();
    }
}
```

Display the status of each task

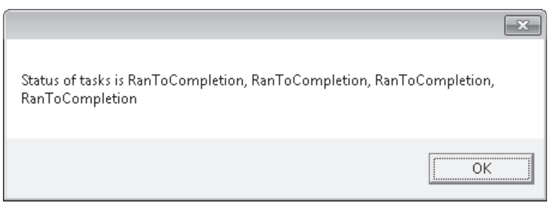
1. In Visual Studio, in the *Code and Text Editor* window, find the *getDataForGraph* method.
2. Add the following code shown in bold to this method. These statements generate a string that contains the status of each task after they have finished running, and they display a message box containing this string.

```
private byte[] getDataForGraph(int dataSize)
{
    ...
    Task.WaitAll(first, second, third, fourth);

    String message = String.Format("Status of tasks is {0}, {1}, {2}, {3}",
        first.Status, second.Status, third.Status, fourth.Status);
    MessageBox.Show(message);

    return data;
}
```

3. On the *Debug* menu, click *Start Without Debugging*.
4. In the GraphDemo window, click *Plot Graph* but do not click *Cancel*. Verify that the following message box appears, which reports that the status of the tasks is *RanToCompletion* (four times), and then click *OK*. Note that the graph appears only after you have clicked *OK*.



5. In the GraphDemo window, click *Plot Graph* again and then quickly click *Cancel*.

   Surprisingly, the message box that appears still reports the status of each task as *RanToCompletion*, even though the graph appears with holes. This is because although you sent a cancellation request to each task by using the cancellation token, the methods they were running simply returned. The .NET Framework runtime does not know whether the tasks were actually canceled or whether they were allowed to run to completion and simply ignored the cancellation requests.
6. Close the GraphDemo window, and return to Visual Studio.

So how do you indicate that a task has been canceled rather than allowed to run to completion? The answer lies in the *CancellationToken* object passed as a parameter to the method that the task is running. The *CancellationToken* class provides a method called *ThrowIfCancellationRequested*. This method tests the *IsCancellationRequested* property of a cancellation token; if it is true, the method throws an *OperationCanceledException* exception and aborts the method that the task is running.

The application that started the thread should be prepared to catch and handle this exception, but this leads to another question. If a task terminates by throwing an exception, it actually reverts to the *Faulted* state. This is true, even if the exception is an *OperationCanceledException* exception. A task enters the *Canceled* state only if it is canceled without throwing an exception. So how does a task throw an *OperationCanceledException* without it being treated as an exception?

The answer lies in the task itself. For a task to recognize that an *OperationCanceledException* is the result of canceling the task in a controlled manner and not just an exception caused by other circumstances, it has to know that the operation has actually been canceled. It can do this only if it can examine the cancellation token. You passed this token as a parameter to the method run by the task, but the task does not actually look at any of these parameters. (It considers them to be the business of the method and is not concerned with them.) Instead, you specify the cancellation token when you create the task, either as a parameter to the *Task* constructor or as a parameter to the *StartNew* method of the *TaskFactory* object you are using to create and run tasks. The following code shows an example based on the GraphDemo application. Notice how the *token* parameter is passed to the *generateGraphData* method (as before), but also as a separate parameter to the *StartNew* method:

```
Task first = null;
tokenSource = new CancellationTokenSource();
CancellationToken token = tokenSource.Token;
...
first = Task.Factory.StartNew(() => generateGraphData(data, 0, pixelWidth / 8, token),
token);
```

Now when the method being run by the task throws an *OperationCanceledException* exception, the infrastructure behind the task examines the *CancellationToken*. If it indicates that the task has been canceled, the infrastructure handles the *OperationCanceledException* exception, acknowledges the cancelation, and sets the status of the task to *Canceled*. The infrastructure then throws a *TaskCanceledException*, which your application should be prepared to catch. This is what you will do in the next exercise, but before you do that you need to learn a little more about how tasks raise exceptions and how you should handle them.

Handling Task Exceptions by Using the *AggregateException* Class

You have seen throughout this book that exception handling is an important element in any commercial application. The exception handling constructs you have met so far are straightforward to use, and if you use them carefully it is a simple matter to trap an exception and determine which piece of code raised it. However, when you start dividing work into multiple concurrent tasks, tracking and handling exceptions becomes a more complex problem. The issue is that different tasks might each generate their own exceptions, and you need a way to catch and handle multiple exceptions that might be thrown concurrently. This is where the *AggregateException* class comes in.

An *AggregateException* acts as a wrapper for a collection of exceptions. Each of the exceptions in the collection might be thrown by different tasks. In your application, you can catch the *AggregateException* exception and then iterate through this collection and perform any necessary processing. To help you, the *AggregateException* class provides the *Handle* method. The *Handle* method takes a *Func<Exception, bool>* delegate that references a method. The referenced method takes an *Exception* object as its parameter and returns a *Boolean* value. When you call *Handle*, the referenced method runs for each exception in the collection in the *AggregateException* object. The referenced method can examine the exception and take the appropriate action. If the referenced method handles the exception, it should return *true*. If not, it should return *false*. When the *Handle* method completes, any unhandled exceptions are bundled together into a new *AggregateException* and this exception is thrown; a subsequent outer exception handler can then catch this exception and process it.

In the next exercise, you will see how to catch an *AggregateException* and use it to handle the *TaskCanceledException* exception thrown when a task is canceled.

Acknowledge cancellation, and handle the *AggregateException* exception

1. In Visual Studio, display the GraphWindow.xaml file in the *Design View* window.
2. From the Toolbox, add a *Label* control to the form underneath the *cancelButton* button. Align the left edge of the *Label* control with the left edge of the *cancelButton* button.
3. Using the Properties window, change the *Name* property of the *Label* control to *status*, and remove the value in the *Content* property.
4. Return to the *Code and Text Editor* window displaying the GraphWindow.xaml.cs file, and add the following method below the *getDataForGraph* method:

```
private bool handleException(Exception e)
{
    if (e is TaskCanceledException)
    {
        plotButton.Dispatcher.Invoke(new Action(() =>
        {
            status.Content = "Tasks Canceled";
        }), DispatcherPriority.ApplicationIdle);
        return true;
    }
    else
    {
        return false;
    }
}
```

This method examines the *Exception* object passed in as a parameter; if it is a *TaskCanceledException* object, the method displays the text "Tasks Canceled" in the *status* label on the form and returns *true* to indicate that it has handled the exception; otherwise, it returns false.

5. In the *getDataForGraph* method, modify the statements that create and run the tasks and specify the *CancellationToken* object as the second parameter to the *StartNew* method, as shown in bold in the following code:

```
private byte[] getDataForGraph(int dataSize)
{
    byte[] data = new byte[dataSize];
    tokenSource = new CancellationTokenSource();
    CancellationToken token = tokenSource.Token;

    ...
    first = Task.Factory.StartNew(() => generateGraphData(data, 0, pixelWidth / 8,
token), token);
    second = Task.Factory.StartNew(() => generateGraphData(data, pixelWidth / 8,
pixelWidth / 4, token), token);
    third = Task.Factory.StartNew(() => generateGraphData(data, pixelWidth / 4,
pixelWidth * 3 / 8, token), token);
    fourth = Task.Factory.StartNew(() => generateGraphData(data, pixelWidth * 3 / 8,
pixelWidth / 2, token), token);
    Task.WaitAll(first, second, third, fourth);
    ...
}
```

6. Add a *try* block around the statements that create and run the tasks, and wait for them to complete. If the wait is successful, display the text "Tasks Completed" in the *status* label on the form by using the *Dispatcher.Invoke* method. Add a *catch* block that handles the *AggregateException* exception. In this exception handler, call the *Handle* method of the *AggregateException* object and pass a reference to the *handleException* method. The code shown next in bold highlights the changes you should make:

```
private byte[] getDataForGraph(int dataSize)
{
    byte[] data = new byte[dataSize];
    tokenSource = new CancellationTokenSource();
    CancellationToken token = tokenSource.Token;

    try
    {
        first = Task.Factory.StartNew(() => generateGraphData(data, 0, pixelWidth / 8,
token), token);
        second = Task.Factory.StartNew(() => generateGraphData(data, pixelWidth / 8,
pixelWidth / 4, token), token);
        third = Task.Factory.StartNew(() => generateGraphData(data, pixelWidth / 4,
pixelWidth * 3 / 8, token), token);
        fourth = Task.Factory.StartNew(() => generateGraphData(data, pixelWidth * 3 /
8, pixelWidth / 2, token), token);
        Task.WaitAll(first, second, third, fourth);
```

```
            plotButton.Dispatcher.Invoke(new Action(() =>
            {
                status.Content = "Tasks Completed";
            }), DispatcherPriority.ApplicationIdle);
        }
        catch (AggregateException ae)
        {
            ae.Handle(handleException);
        }

        String message = String.Format("Status of tasks is {0}, {1}, {2}, {3}",
            first.Status, second.Status, third.Status, fourth.Status);
        MessageBox.Show(message);

        return data;
    }
```

7. In the *generateDataForGraph* method, replace the *if* statement that examines the *IsCancellationProperty* of the *CancellationToken* object with code that calls the *ThrowIfCancellationRequested* method, as shown here in bold:

```
private void generateDataForGraph(byte[] data, int partitionStart, int partitionEnd,
CancellationToken token)
{
   ...
    for (int x = partitionStart; x < partitionEnd; x++);
    {
        ...
        for (double i = -p; I < p; i += 3)
        {
            token.ThrowIfCancellationRequested();
            ...
        }
    }
    ...
}
```

8. On the *Debug* menu, click *Start Without Debugging*.

9. In the Graph Demo window, click *Plot Graph* and verify that the status of every task is reported as *RanToCompletion*, the graph is generated, and the *status* label displays the message “Tasks Completed”.

10. Click *Plot Graph* again, and then quickly click *Cancel*. If you are quick, the status of one or more tasks should be reported as *Canceled*, the *status* label should display the text “Tasks Canceled”, and the graph should be displayed with holes. If you are not quick enough, repeat this step to try again!

11. Close the Graph Demo window, and return to Visual Studio.

Using Continuations with Canceled and Faulted Tasks

If you need to perform additional work when a task is canceled or raises an unhandled exception, remember that you can use the *ContinueWith* method with the appropriate *TaskContinuationOptions* value. For example, the following code creates a task that runs the method *doWork*. If the task is canceled, the *ContinueWith* method specifies that another task should be created and run the method *doCancellationWork*. This method can perform some simple logging or tidying up. If the task is not canceled, the continuation does not run.

```
Task task = new Task(doWork);
task.ContinueWith(doCancellationWork, TaskContinuationOptions.OnlyOnCanceled);
task.Start();
...
private void doWork()
{
    // The task runs this code when it is started
    ...
}
...
private void doCancellationWork(Task task)
{
    // The task runs this code when doWork completes
    ...
}
```

Similarly, you can specify the value *TaskContinuationOptions.OnlyOnFaulted* to specify a continuation that runs if the original method run by the task raises an unhandled exception.

In this chapter, you learned why it is important to write applications that can scale across multiple processors and processor cores. You saw how to use the Task Parallel Library to run operations in parallel, and how to synchronize concurrent operations and wait for them to complete. You learned how to use the *Parallel* class to parallelize some common programming constructs, and you also saw when it is inappropriate to parallelize code. You used tasks and threads together in a graphical user interface to improve responsiveness and throughput, and you saw how to cancel tasks in a clean and controlled manner.

- If you want to continue to the next chapter

  Keep Visual Studio 2010 running, and turn to Chapter 28.

- If you want to exit Visual Studio 2010 now

  On the *File* menu, click *Exit*. If you see a *Save* dialog box, click *Yes* and save the project.

Chapter 27 Quick Reference

To	Do this

Create a task and run it	Either use the *StartNew* method of a *TaskFactory* object to create and run the task in a single step:
	`Task task = taskFactory.StartNew(doWork());`
	`...`
	`private void doWork()`
	`{`
	`    // The task runs this code when it is started`
	`    ...`
	`}`
	Or create a new *Task* object that references a method to run and call the *Start* method:
	`Task task = new Task(doWork);`
	`task.Start();`

Wait for a task to finish	Call the *Wait* method of the *Task* object:
	`Task task = ...;`
	`...`
	`task.Wait();`

Wait for several tasks to finish	Call the static *WaitAll* method of the *Task* class, and specify the tasks to wait for:
	`Task task1 = ...;`
	`Task task2 = ...;`
	`Task task3 = ...;`
	`Task task4 = ...;`
	`...`
	`Task.WaitAll(task1, task2, task3, task4);`

Specify a method to run in a new task when a task has completed	Call the *ContinueWith* method of the task, and specify the method as a continuation:
	`Task task = new Task(doWork);`
	`task.ContinueWith(doMoreWork,`
	`    TaskContinuationOptions.NotOnFaulted);`

Return a value from a task	Use a *Task<TResult>* object to run a method, where the type parameter *T* specifies the type of the return value of the method. Use the *Result* property of the task to wait for the task to complete and return the value:
	`Task<int> calculateValueTask = new Task<int>(() =>`
	`calculateValue(...));`
	`calculateValueTask.Start(); // Invoke the calculateValue method`
	`...`
	`int calculatedData = calculateValueTask.Result; // Block until`
	`calculateValueTask completes`

<table>
<tr><th>To</th><th>Do this</th></tr>
<tr><td>Perform loop iterations and statement sequences by using parallel tasks</td><td>

Use the *Parallel.For* and *Parallel.ForEach* methods to perform loop iterations by using tasks:

```
Parallel.For(0, 100, performLoopProcessing);
...
private void performLoopProcessing(int x)
{
    // Perform loop processing
}
```

Use the *Parallel.Invoke* method to perform concurrent method calls by using separate tasks:

```
Parallel.Invoke(
    doWork,
    doMoreWork,
    doYetMoreWork
);
```

</td></tr>
<tr><td>Handle exceptions raised by one or more tasks</td><td>

Catch the *AggregateException* exception. Use the *Handle* method to specify a method that can handle each exception in the *AggregateException* object. If the exception-handling method handles the exception, return *true*; otherwise, return *false*:

```
try
{
    Task task = Task.Factory.StartNew(...);
    ...
}
catch (AggregateException ae)
{
    ae.Handle(new Func<Exception, bool> (handleException));
}
...
private bool handleException(Exception e)
{
    if (e is TaskCanceledException)
    {
        ...
        return true;
    }
    else
    {
        return false;
    }
}
```

</td></tr>
</table>

To	Do this

Support cancellation in a task	Implement cooperative cancellation by creating a *CancellationTokenSource* object and using a *CancellationToken* parameter in the method run by the task. In the task method, call the *ThrowIfCancellationRequested* method of the *CancellationToken* parameter to throw an *OperationCanceledException* exception and terminate the task:
	`private void generateGraphData(..., CancellationToken token)`
	`{`
	`    ...`
	`    token.ThrowIfCancellationRequested();`
	`    ...`
	`}`

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John Sharp is a principal technologist at Content Master, part of CM Group Ltd, a technical authoring and consulting company. An expert on developing applications by using the Microsoft .NET Framework and other technologies, John has produced numerous tutorials, white papers, and presentations on distributed systems, SOA and Web services, the C# language, and interoperability issues. John has helped to develop a large number of courses for Microsoft Training (he co-wrote the first C# programming course for them) and he is also the author of several popular books, including *Microsoft Windows Communication Foundation Step by Step*.