This book is dedicated to my father,
William A. Newkirk

Practical wisdom is only to be learned in the school of experience. Precepts and instruction are useful so far as they go, but, without the discipline of real life, they remain of the nature of theory only — Samuel Smiles

JWN

This book is dedicated to my mother,
Larisa L. Vorontsova

A thousand-mile journey begins with the first step and can only be taken one step at a time. — An old saying

AAV
# Contents at a Glance

## Part I  Test-Driven Development Primer

1. Test-Driven Development Practices  
2. Test-Driven Development in .NET—By Example  
3. Refactoring—By Example  

## Part II  Test-Driven Development Example

4. The Media Library Example  
5. Programmer Tests: Using TDD with ADO.NET  
6. Programmer Tests: Using TDD with ASP.NET Web Services  
7. Customer Tests: Completing the First Feature  
8. Driving Development with Customer Tests  
9. Driving Development with Customer Tests: Exposing a Failure Condition  
11. Service Layer Refactoring  
12. Implementing a Web Client  

## Part III  Appendixes

A. NUnit Primer  
B. Transactions in ADO.NET  
C. Bibliography  

---

v
## Contents

<table>
<thead>
<tr>
<th>Section</th>
<th>Page</th>
</tr>
</thead>
<tbody>
<tr>
<td>Foreword</td>
<td>xiii</td>
</tr>
<tr>
<td>Acknowledgments</td>
<td>xv</td>
</tr>
<tr>
<td>Introduction</td>
<td>xvii</td>
</tr>
<tr>
<td><strong>Part I</strong> Test-Driven Development Primer</td>
<td></td>
</tr>
<tr>
<td>1 Test-Driven Development Practices</td>
<td>3</td>
</tr>
<tr>
<td>What Is Test-Driven Development?</td>
<td>3</td>
</tr>
<tr>
<td>Test Types</td>
<td>4</td>
</tr>
<tr>
<td>Simple Design</td>
<td>5</td>
</tr>
<tr>
<td>Refactoring</td>
<td>6</td>
</tr>
<tr>
<td>Process</td>
<td>6</td>
</tr>
<tr>
<td>Test List</td>
<td>6</td>
</tr>
<tr>
<td>Red/Green/Refactor</td>
<td>7</td>
</tr>
<tr>
<td>Summary</td>
<td>8</td>
</tr>
<tr>
<td>2 Test-Driven Development in .NET—By Example</td>
<td>9</td>
</tr>
<tr>
<td>The Task</td>
<td>9</td>
</tr>
<tr>
<td>Test List</td>
<td>10</td>
</tr>
<tr>
<td>Choosing the First Test</td>
<td>11</td>
</tr>
<tr>
<td>Red/Green/Refactor</td>
<td>12</td>
</tr>
<tr>
<td>Test 1: Create a Stack and verify that <code>IsEmpty</code> is true.</td>
<td>12</td>
</tr>
<tr>
<td>Test 2: Push a single object on the Stack and verify that <code>IsEmpty</code> is false.</td>
<td>14</td>
</tr>
<tr>
<td>Test 3: Push a single object, Pop the object, and verify that <code>IsEmpty</code> is true.</td>
<td>16</td>
</tr>
<tr>
<td>Test 4: Push a single object, remembering what it is; Pop the object, and verify that the two objects are equal.</td>
<td>17</td>
</tr>
<tr>
<td>Test 5: Push three objects, remembering what they are; Pop each one, and verify that they are correct.</td>
<td>20</td>
</tr>
<tr>
<td>Test 6: Pop a Stack that has no elements.</td>
<td>22</td>
</tr>
<tr>
<td>Test 7: Push a single object and then call Top. Verify that <code>IsEmpty</code> returns false.</td>
<td>24</td>
</tr>
</tbody>
</table>
Test 8: *Push* a single object, remembering what it is; and then call *Top*. Verify that the object that is returned is equal to the one that was pushed.

Test 9: *Push* multiple objects, remembering what they are; call *Top*, and verify that the last item pushed is equal to the one returned by *Top*.

Test 10: *Push* one object and call *Top* repeatedly, comparing what is returned to what was pushed.

Test 11: Call *Top* on a *Stack* that has no elements.

Test 12: *Push null* onto the *Stack* and verify that *IsEmpty* is false.

Test 13: *Push null* onto the *Stack*, *Pop* the *Stack*, and verify that the value returned is *null*.

Test 14: Push *null* onto the *Stack*, call *Top*, and verify that the value returned is *null*.

Summary

3 Refactoring—By Example

The Sieve

Before Refactoring the Code: Make Sure It All Works
Refactoring 0: Remove Unneeded Code
Refactoring 1: Rename Method
Refactoring 2: Add a Test
Refactoring 3: Hide Method
Refactoring 4: Replace Nested Conditional with Guard Clauses
Refactoring 5: Inline Method
Refactoring 6: Rename Variable
Refactoring 7: Collapse Loops
Refactoring 8: Remove Dead Code
Refactoring 9: Collapse Loops (Again)
Refactoring 10: Reduce Local Variable Scope
Refactoring 11: Replace Temp with Query
Refactoring 12: Remove Dead Code
Refactoring 13: Extract Method
Refactoring 14: Extract Method (Again)
Refactoring 15: Reduce Local Variable Scope
Refactoring 16: Convert Procedural Design to Objects
Refactoring 17: Keep the Data Close to Where It Is Used

Summary
## Part II  
**Test-Driven Development Example**

### 4 The Media Library Example  
63
- The Skinny  
  63
- Existing Database  
  64
- The First Feature  
  66
- Additional Features  
  67

### 5 Programmer Tests: Using TDD with ADO.NET  
69
- Testing the Database Access Layer  
  69
- The Task  
  71
  - Connecting to the Database  
    72
  - Individual Entities in Isolation  
    75
- Testing Relationships Between Entities  
  92
  - Track-Recording Relationship  
    94
- Retrieve a Recording  
  97
- Test Organization  
  101
- Summary  
  102

### 6 Programmer Tests: Using TDD with ASP.NET Web Services  
105
- The Task  
  105
  - Test List  
    106
- Data Transformation  
  107
  - Data Transfer Object  
    108
- Database Catalog Service  
  117
- Web Service Tests  
  120
  - Web Service Producer and Consumer Infrastructure  
    121
- Almost Done  
  124
- Summary  
  126
  - Emerging Architecture  
    126

### 7 Customer Tests: Completing the First Feature  
127
- Are We Done?  
  127
- Customer Tests  
  128
- Customer Tests for Recording Retrieval  
  129
  - Script 1. Retrieve an existing recording and verify its content  
    129
  - Script 2. Retrieve a nonexistent recording  
    130
## Table of Contents

- Automating Customer Tests 131
  - FIT Overview 131
  - Connecting FIT to the Implementation 132
  - Automation with FIT 133
- Reconciling Viewpoints 143
  - Track Duration 144
  - Recording Duration 145
- Summary 146

### 8 Driving Development with Customer Tests 147

- The FIT Script 147
  - Add a review to an existing recording 148
  - Implementing Add/Delete Review 151
- Summary 162

### 9 Driving Development with Customer Tests: Exposing a Failure Condition 163

- Programmer Tests 164
  - Implementing a SOAP Fault 168
- Summary 179

### 10 Programmer Tests: Using Transactions 181

- Programmer Tests 182
  - Transaction Manager 183
- Programmer Tests: Catalog Class 193
- Summary 203

### 11 Service Layer Refactoring 205

- The Problem 205
  - What’s Wrong? 207
  - The Solution 208
- Summary 211

### 12 Implementing a Web Client 213

- Testing User Interfaces 213
- The Task 214
Implementing Search 215
  Implementing the Search Service 215
  Implementing the Search Page 216
  Binding the Results to a Repeater Web Control 218
  Enough of This Stub 226
  Summary 230

Part III Appendixes

A NUnit Primer 233
  NUnit Quick Start 233
    Step 1. Create Visual Studio Project for your test code. 233
    Step 2. Add a reference to the NUnit Framework. 234
    Step 3. Add a class to the project. 235
    Step 4. Set up your Visual Studio Project to use the NUnit-Gui test runner. 236
    Step 5. Compile and run your test. 237
    Step 6. Become familiar with the NUnit-Gui layout. 237
  NUnit Core Concepts 240
    Test Case 240
  Other NUnit Capabilities 244
    Using SetUp/TearDown Attributes 244
    Using ExpectedException 246
    Using the Ignore Attribute 246
    UsingTestFixtureSetUp/TestFixtureTearDown 247
  Test Life-Cycle Contract 248
  Using the Visual Studio .NET Debugger with NUnit-Gui 250

B Transactions in ADO.NET 253
  Transaction Management 253
    Manual Transaction Management 254
    Automatic Transaction Management 255
  Transaction Participation 256

C Bibliography

Index 261
I enjoyed reading this book because it stretches the boundaries of Test-Driven Development (TDD). My original TDD book demonstrated TDD in an ideal situation, in which the programmer is just typing in code and doesn’t have to worry about external systems or user interfaces. After you get into the messy realities of widgets and databases, you need new techniques to continue practicing TDD and reaping its benefits, among which is confidence in cleaner code written faster.

With this book, the pieces missing from my book are included. If you want to test drive code that includes a Web interface and a database, you will learn how to do that in these pages. Even if you aren’t using the Microsoft technology, you will find ideas you can carry to your application server or database.

The strength of this book is its concreteness. The extensive examples show you exactly how expert programmers use test-driven development with realistic tasks. Following the examples will show you the techniques used and, more important, the flow between the techniques. Technique can be learned from a book, but to understand the rhythm of development, you usually need to sit down with a programmer who understands it. As you read, paying careful attention to the way the techniques fit together in this book will teach you lessons about the rhythm of programming.

I think TDD is a really valuable tool. It’s inexpensive, it’s easy to adopt, and it brings immediate improvement. TDD has led to fewer defects, less debugging, more confidence, better design, and higher productivity in my programming practice. More important, I sleep better at night knowing that my code works in every circumstance I can think of, and I can prove it at the push of a button. This book gives you the practical advice you need to gain the benefits of TDD.

Kent Beck
Acknowledgments

We would like to thank our technical reviewers, Martin Fowler, Lee Holmes, and Eric Gunnerson. The feedback and guidance that they provided during the writing process was invaluable. In addition to the technical reviews, we also received much needed feedback and criticism from the following individuals: Charlie Poole, Paul Karsten, Peter Provost, Gregor Hohpe, Dragos Manolescu, Michael Two, Kent Beck, Ron Jeffries, Jonathan Wanagel, Scott Densmore, Naveen Yajaman, David Astels, Ward Cunningham, Benjamin Mitchell, Chris Colleran, David Trowbridge, Srinath Vasireddy, and Andrew Slocum. Their input has greatly influenced the content of the book. It is a pleasure for us to acknowledge their contributions and express our appreciation for their efforts.

We would also like to thank the following people at Microsoft Press: Linda Engelman for her help getting us started and everything she did to get the book completed as soon as possible; Robin Van Steenburgh for taking over Linda’s big job; Devon Musgrave for his advice on the first draft; Kathleen Atkins for her help in getting the book completed; and Nancy Sixsmith for converting what we wrote into English.

Every book is an activity that always takes more time than you think. I (James) need to thank my wife, Beth, and my children, Erin and Grant, for allowing me the time that I needed to work on the book. In fact, I owe them for all the nights and weekends that they have given up while I worked on my latest “scheme.” Thank you. In addition, I would like to thank my coauthor Alexei. I thoroughly enjoyed the many hours we worked together trying to cobble together the thoughts and ideas first into a sample program and then into the text that became this book.

Writing this book took a great deal more time than can be explained, justified, or even be considered reasonable, but, without a doubt, it has been the most rewarding experience for me. I (Alexei) owe James a great deal of gratitude for giving me this opportunity. I have learned much in the process of working on the book. I would also like to thank my mentor and manager, Regan Stern, for recognizing the importance of my working on this book and supporting me in this effort.
Introduction

Many people think that Test-Driven Development (TDD) is all about testing software. In fact, test-driven development’s main goal is not testing software, but aiding the programmer and customer during the development process with unambiguous requirements. The requirements are expressed in the form of tests, which are a support mechanism (scaffolding, you might say) that stands firmly under the participants as they undertake the hazards of software development. However, that is not the only purpose of testing. As you will see, the tests, once written, are valuable resources in their own right.

What Are the Benefits of Using Tests?

It is important during development that problems are discovered early and corrected when they are found. Often, the biggest problems occur when there is a misunderstanding of a requirement between the consumers of the software (customers) and the producers (programmers). These types of problems could be avoided if there were a way to specify these requirements unambiguously before development begins. Enter tests. The tests specify requirements in a way that does not require human interpretation to indicate success or failure. If there is a sufficient number of tests and they are present prior to development, simply running the tests and indicating success or failure helps solve the old problem of software development, “Are We Done?” The answer is no longer an interpretation; the code either passes all the tests or it does not. After it passes, it’s done.

Solving this problem alone may be justification enough, but is there more? The tests that are written during development can be run and enhanced by Quality Assurance (QA) with tests of their own. Due to the code being written with testing as a primary motivation, the resulting code should be easier to test. Having a base of existing tests and code that is easier to test should allow QA to shift from a reactive mode into a more proactive mode.

The tests themselves are useful not only in the initial development of the software; if they are maintained along with the production code, they can be used in the ongoing development of the software. For example, if a problem is discovered in the production code, the first step should be to write a test to clearly identify the problem and then, after you have a failing test, correct the
problem. This new test specifies a scenario that was not identified during the prior development. If you do this consistently, the tests will evolve into how the program is used in real life, which increases their value exponentially. When adding new features, you could run this suite of tests to ensure that the new code does not break any of the existing tests. If the test coverage is sufficient; running the tests and getting a successful result should reduce your fear of moving forward. Fear of breaking existing functionality can cause you to become overly cautious, which slows you down. Think of the tests as a way of covering your back.

**An Example**

Let’s look at an example to demonstrate how tests can describe a requirement more clearly than words can. Consider the following description of a Stack. “A Stack is a data structure in which you can access only the item at the top. With a computer, Stack just like a stack of dishes—you add items to the top and remove them from the top” ([http://www.developersdomain.com/vb/articles/stack.htm](http://www.developersdomain.com/vb/articles/stack.htm)). This is not a bad description, but it does not specify method names and it uses an analogy that might not resonate with people. In short, it leaves a great deal open to interpretation, and you would get many implementations that could satisfy this definition.

Now look at a test that specifies the same thing:

```csharp
[Test]
public void PushPop()
{
    string name = "Name";
    Stack stack = new Stack();
    stack.Push(name);
    Assert.AreEqual(name, stack.Pop());
}
```

This code specifies the names of methods, how they are called, and what they should return. It also specifies a sequence that yields a successful result. Finally, the test is executable, meaning that you can run it on the production code, and it will inform you if your implementation passes the test. The only thing that is open to interpretation is how you should implement the Stack, which is exactly what you want if you are a programmer. If your job was to implement a Stack, would you rather have your specification described as a series of tests or as a written specification?
Organization

This book is organized into two sections, followed by three appendixes.

- **Part I: Test-Driven Development Overview**  This section describes the concepts of test-driven development. It begins with Kent Beck’s rules, provides some additional detail about how to use and apply these rules, defines terminology that we use throughout the book, and defines a process for doing test-driven development. In addition to the definitions, we also demonstrate how to apply them by example. The focus in these early chapters is on completeness and following the principles and practices as written.

- **Part II: The Test-Driven Development Example**  This section demonstrates how to do Test-Driven Development on a realistic n-tier application. The application, a media library, is specified in Chapter 4, “The Media Library Example.” As well as implementing the expected functionality, we also investigate important real-world application areas that are typically avoided in sample applications. For example, we demonstrate the use of TDD with concepts such as exception handling and database connectivity. By the end of the sample, you’ll have a good grounding in the techniques needed to use TDD in your own enterprise projects.

- **Appendix A: NUnit Primer**  This appendix contains an introduction to the tool, NUnit.

- **Appendix B: Transactions in ADO.NET**  This appendix provides an overview of transaction support in the .NET Framework.

- **Appendix C: Bibliography**  The bibliography lists the works by other people that we have used ourselves and referred readers to throughout this book.

How to Use This Book

This book is written primarily for experienced programmers. You will get more value from this book if you are familiar with C# syntax and understand object-oriented programming. However, even if your primary development language is not C#, you should be able to port the example to other .NET languages, such as Microsoft Visual Basic .NET. The more complicated concepts do have overview material and pointers to additional sources of information.
If You Have Never Used NUnit Before

Read Chapter 1, “Test-Driven Development Practices.” Then read Appendix A, “NUnit Primer,” which describes the tool that is used for technology facing or programmer tests in the text. Then you can proceed with the rest of the content.

If You Are a Manager or Business Analyst

Read Chapter 1, which introduces the concepts and the process. Then read Chapter 7, “Customer Tests: Completing the First Feature,” in which we discuss ways to use tests without having to write them in C#. We use a tool named FIT ([http://fit.c2.com](http://fit.c2.com)) to implement the business-facing or customer tests.

Small Steps—A Personal Story

Sometimes, people ask me (James) how I got started doing test-driven development. I want to relate this story because as a result of this experience, I finally believed that a series of small steps, verified each time by tests, could actually lead to a better solution. Up until this point, I knew the rules but not how to apply them.

It was December of 1999. I was at Object Mentor, and we were in the midst of the first XP immersion class. Kent Beck, Ron Jeffries, Martin Fowler, Robert C. Martin, Michael Hill, Fred George, Alan Francis, and others were my companions. Needless to say, it was an incredible week, not so much from the perspective of a class, but from being around such an awesome array of talent all focused on this thing called Extreme Programming. Besides participating in the class, I was working on a new Java class that I would be presenting the following January. I was trying to incorporate aspects of refactoring and test-first programming using JUnit ([http://www.junit.org](http://www.junit.org)) into the class. My thought was to write an awful program and then use it to teach the concepts of refactoring. (That same awful program, implemented in C#, is the basis for Chapter 3, “Refactoring—By Example.”)

I was working alone, and the staging of the example was not working well because it turns out that my refactoring steps were much too large. Kent came over and asked what I was doing after noticing me working on code by myself; I told him that I was trying to work out an example of refactoring for my upcoming class. After looking at what I did, he told me he thought I should start over. Instead of walking away, he offered to sit down and help me. During the next hour or so, the whole idea of the small incremental changes leading to a better solution became a reality. This awful code was transformed into something that was very clear and easily understandable.
It is only after I spent that time working with Kent directly that I began to understand just how small the steps were that Kent, Ron, and Martin were talking about. In fact, we thought that this in itself would be a useful activity for the whole class to see the following day. So, Robert Martin went home that night and constructed some UML diagrams around the code and came up with a slightly different implementation of the same algorithm that Kent and I refactored in front of the class the next day. For a couple of hours, we walked step-by-step through the code—making the smallest of changes and then running the tests to make sure that we did not break anything. When we were finished, someone said that we had made 40 separate changes to the code. The code was so much clearer that it was remarkable. Alexei and I have used the same problem that taught me so much during the class as the sample in Chapter 3 so that you can also benefit from that experience.

**Companion Web Site**

Many of the code samples in this book were too long to print without interruption by explanatory text. If you prefer to see the complete code samples from the early chapters and the sample application in its entirety, you can go to http://workspaces.gotdotnet.com/tdd.
In Chapters 1 and 2, we briefly touched on the subject of refactoring. This chapter gives a detailed treatment of this topic because refactoring is one of the fundamental aspects of test-driven development and a very useful practice in its own right.

Refactoring is an activity aimed at improving the internal structure of existing code without making externally visible changes to the functionality. Why would such changes be useful? (After all, there is an age-old engineering adage: “If it ain’t broke, don’t fix it.”) Are we suggesting fixing a problem that does not exist? Is refactoring just another way to waste your time and money? The simple answer is no.

**Note** Refactoring is a long-term, cost-efficient, and responsible approach to software ownership.

We argue that refactoring is the way to make your long-term software ownership less painful. Through refactoring, design intent becomes clearer as the code evolves. Without refactoring, the code’s clarity will degrade over time, eventually becoming unintelligible.

Let’s look at some code to clarify the point. We will demonstrate the basic ideas behind refactoring on a simple piece of code that is in need of some maintenance.
More Info  For additional reading on this topic, read Martin Fowler's book: Refactoring: Improving the Design of Existing Code (Addison-Wesley, 1999). This book is the source of the refactoring names that are used in this chapter. As a side note, the examples in Martin's book are in Java but are straightforward enough to follow if you know C#.

The Sieve

The code we will refactor implements an algorithm to generate small prime numbers (say up to 10,000,000). The algorithm is called the Sieve of Eratosthenes. Make a list of all the integers less than or equal to \( n \) (and greater than one). Strike out the multiples of all primes less than or equal to the square root of \( n \); the numbers that are left are the primes (http://primes.utm.edu/glossary/page.php?sort=SieveOfEratosthenes).

The existing implementation is shown here:

```csharp
using System;
using System.Collections;

public class Primes
{
    public static ArrayList Generate(int maxValue)
    {
        ArrayList result = new ArrayList();

        int[] primes = GenerateArray(maxValue);
        for(int i = 0; i < primes.Length; ++i)
            result.Add(primes[i]);

        return result;
    }

    [Obsolete("This method is obsolete, use Generate instead")]}

public static int[] GenerateArray(int maxValue)
{
    if(maxValue >= 2)
    {
        // declarations
        int s = maxValue + 1; // size of array
        bool[] f = new bool[s];
        int i;
```
As you can see from the code, there are two methods defined to generate prime numbers. The first method, `Generate`, returns the prime numbers in an `ArrayList`. The second method, `GenerateArray`, was written to return an array of integers. The `GenerateArray` method is also marked with the `Obsolete` attribute, which is usually an indicator that the code will be removed when possible. It turns out that today is the day we will remove this function because the `GenerateArray` method is no longer called by the application code but it is still called by the `Generate` method. It looks like we won’t be able to just delete it. Luckily, the code has a set of tests written using NUnit for it:
using System;
using System.Collections;
using NUnit.Framework;

[TestFixture]
public class PrimesFixture
{
    private int[] knownPrimes = new int[]
    { 2, 3, 5, 7, 11, 13, 17, 19, 23, 29 };

    [Test]
    public void Zero()
    {
        int[] primes = Primes.GenerateArray(0);
        Assert.AreEqual(0, primes.Length);
    }

    [Test]
    public void ListZero()
    {
        ArrayList primes = Primes.Generate(0);
        Assert.AreEqual(0, primes.Count);
    }

    [Test]
    public void Single()
    {
        int[] primes = Primes.GenerateArray(2);
        Assert.AreEqual(1, primes.Length);
        Assert.AreEqual(2, primes[0]);
    }

    [Test]
    public void ListSingle()
    {
        ArrayList primes = Primes.Generate(2);
        Assert.AreEqual(1, primes.Count);
        Assert.IsTrue(primes.Contains(2));
    }

    [Test]
    public void Prime()
    {
        int[] centArray = Primes.GenerateArray(100);
        Assert.AreEqual(25, centArray.Length);
        Assert.AreEqual(97, centArray[24]);
    }
}
[Test]
public void ListPrime()
{
    ArrayList centList = Primes.Generate(100);
    Assert.AreEqual(25, centList.Count);
    Assert.AreEqual(97, centList[24]);
}

[Test]
public void Basic()
{
    int[] primes =
        Primes.GenerateArray(knownPrimes[knownPrimes.Length-1]);
    Assert.AreEqual(knownPrimes.Length, primes.Length);

    int i = 0;
    foreach(int prime in primes)
    {
        Assert.AreEqual(knownPrimes[i++], prime);
    }
}

[Test]
public void ListBasic()
{
    ArrayList primes =
        Primes.Generate(knownPrimes[knownPrimes.Length-1]);
    Assert.AreEqual(knownPrimes.Length, primes.Count);

    int i = 0;
    foreach(int prime in primes)
    {
        Assert.AreEqual(knownPrimes[i++], prime);
    }
}

[Test]
public void Lots()
{
    int bound = 10101;
    int[] primes = Primes.GenerateArray(bound);

    foreach(int prime in primes)
    {
        Assert.IsTrue(IsPrime(prime), "is prime");

    }

    foreach(int prime in primes)
    {
        if(IsPrime(prime))
            Assert.IsTrue(Contains(prime, primes), "contains primes");
        else
Assert.IsFalse(Contains(prime, primes),
    "doesn't contain composites");
}
]
[Test]
public void ListLots()
{
    int bound = 10101;
    ArrayList primes = Primes.Generate(bound);
    foreach(int prime in primes)
        Assert.IsTrue(IsPrime(prime), "is prime");

    foreach(int prime in primes)
    {
        if(IsPrime(prime))
            Assert.IsTrue(primes.Contains(prime),
                "contains primes");
        else
            Assert.IsFalse(primes.Contains(prime),
                "doesn't contain composites");
    }
}
]

private static bool IsPrime(int n)
{
    if(n < 2) return false;

    bool result = true;
    double x = Math.Sqrt(n);
    int i = 2;
    while(result && i <= x)
    {
        result = (0 != n % i);
        i += 1;
    }

    return result;
}
]

private static bool Contains(int value, int[] primes)
{
    return (Array.IndexOf(primes, value) != -1);
}
Before Refactoring the Code: Make Sure It All Works

It is important to remember that refactoring has to be done in conjunction with running tests for the code being refactored. After all, refactoring is not supposed to change the externally observable functionality of the code being refactored. The tests are the tools needed to verify such functionality. So the first step of the refactoring process is to run the tests before you make any code changes.

Let’s run the tests. All of them pass, so we can begin from a known good state.

Refactoring Cycle

The cycle we will follow is straightforward: Identify a problem, select a refactoring to address the problem, apply the refactoring by making the appropriate code change; compile and run the tests; repeat. The emphasis is on the code changes being very small—and running the tests. Why small changes? We transition the system from a known good state to the next desirable state.

Think of it as climbing a wall. If the wall is high, you might break your neck attempting to climb it, but you could use a ladder to assist you. With a ladder in place if you feel tired, you can just stop and rest. The tests are your ladder—they are both your safety net and a climbing tool. So, before you start climbing, what should you do? Do yourself a favor: Make sure that your ladder is not broken. This brings us to the following rule for refactoring:

Important As you refactor your code, make sure that the tests are up-to-date. If you need to change them to reflect the changing requirements, do it first.

In short, maintain your ladder. Let’s take a look at the tests.

Refactoring 0: Remove Unneeded Code

There are five test methods for the array-based version and five test methods for the ArrayList version. Because the GenerateArray method is being removed, it appears that we can remove the tests for that method. We can do this safely because we are not losing any test coverage by removing the array-based tests. The ArrayList-based tests are exact duplicates in terms of what is being tested.

After the array-based tests are removed, the following tests remain:
We can also get rid of the utility method Contains because it was used only by the array-based tests. After we finish removing the code, we compile and run the tests. The test method count drops to five and we have a green bar, so it is time to move on.

**Refactoring 1: Rename Method**

The next refactoring is still in the test code. After we remove the array-based tests, there is no need to preface each method with the word List. We need to implement the “Rename method” of refactoring. The reasoning is that you should call an apple an apple; no need to call it a “green apple” unless the greenness of the apple is of the essence. Meaningful method names are important for code readability and in turn its overall maintainability. In short, method names should convey their intentions.

Here is the test code after each method has been renamed; the contents of the methods have not changed, so they are not shown here:

```csharp
using System;
using System.Collections;
using NUnit.Framework;

[TestFixture]
public class PrimesFixture
{
    private int[] knownPrimes = new int[]
    { 2, 3, 5, 7, 11, 13, 17, 19, 23, 29 };

    [Test]
    public void Zero()
    {
        // ...
    }

    [Test]
    public void Single()
    {
        // ...
    }
}
[Test]
public void Prime()
{
    // ...
}

[Test]
public void Basic()
{
    // ...
}

[Test]
public void Lots()
{
    // ...
}

private static bool IsPrime(int n)
{
    // ...
}

In this case, the renaming of the methods is straightforward. There should be no code calling the test methods. The more general case is a bit more complicated because you might have to change the callers of the method being renamed. Modern development environments make it easier to accomplish this task and pretty much take care of the process of finding and replacing the method names. If you are using a simple text editor, you might let your compiler tell you which classes you need to fix (which is crude, but it works). As always, after we make the changes, we compile and run the tests. The tests passed, so it’s time to continue.

**Refactoring 2: Add a Test**

The *Single* test method verifies that 2 is a prime number; the *Zero* test method verifies that 0 is not a prime number. What about the number 1? We should also have a test that ensures that 1 is not a prime number.

We add a new test named *ZeroOne* and rename the *Single* method to be *ZeroTwo* to reflect the range of values being tested:
[Test]
public void ZeroOne()
{
    ArrayList primes = Primes.Generate(1);
    Assert.AreEqual(0, primes.Count);
}

[Test]
public void ZeroTwo()
{
    ArrayList primes = Primes.Generate(2);
    Assert.AreEqual(1, primes.Count);
    Assert.IsTrue(primes.Contains(2));
}

Now we have three methods that test the special cases of 0, 1, and 2. They look very similar, but it is not apparent how to factor out any commonality. When we compile and run all the tests, they succeed. We now have six tests.

When Are We Finished?
At every step of the way, an important question to ask is “Am I finished?” By the very nature of moving from a known good state to the next state, it is possible to stop at any time. What is there left to do? Why didn’t we stop after removing the array-based tests? Because we immediately saw what we could not possibly see before: the method names could be improved. Each simple refactoring we implement opens up opportunities for further refactorings to make the code communicate its intentions more clearly.

What makes the process interesting is that it is a process of discovery. We probably don’t know what refactoring we’ll implement next. We also don’t create a grand plan of 1001 refactorings that are needed to make this code better. We let the code itself drive the process. The code tells us which refactoring is needed at the appropriate time, and it evolves gradually into the shape it wants to take over time. The answer for now is that we are not done. We have not removed the array-based implementation. However, we are done with refactoring the test code.

Refactoring 3: Hide Method
Let’s look at the code that generates the prime numbers. The GenerateArray method is used internally by the Generate method. There is no need to keep it public any more. We’ll implement the “Hide method” refactoring, which is quite simple. In C#, it is accomplished by changing the visibility of the method from public to private. The following code
public static int[] GenerateArray(int maxValue)
now becomes
private static int[] GenerateArray(int maxValue)

Why did we do this refactoring? The less the code promises, the easier it
is to deliver. The GenerateArray method now becomes an implementation
detail. The code compiles and the tests pass, so let’s move on to the next step.

Refactoring 4: Replace Nested Conditional with Guard Clauses

Large monitors with high resolutions allow you to see many more lines of code
onscreen than you could a few years ago. But you won’t make many friends if
you continue to write (or tolerate) code like the GenerateArray method.

What is the biggest problem with the GenerateArray method? Let’s distill it
down to the essence:

```java
if(maxValue >= 2) {
    pages and pages of code that won't fit on your screen
    return primes;
} // maxValue >= 2
else
    return new int[0]; // return null array
```

The problem is that when you finally get to the else statement, the if state-
ment has probably scrolled off the screen, so you do not have the context in
which the statement is being executed. One way to correct this problem is to
use the “Replace nested conditional with a guard clause” refactoring. Employ-
ing a guard clause at the beginning of the method dispenses with the bad input
and focuses the method on processing the good input. Changing the method to
use a guard clause looks like this:

```java
if(maxValue < 2) return new int[0];
```

the rest of the code here.

Those of you who subscribe to one of the major tenets of structured pro-
gramming (single entry point/single exit point) are probably jumping out of
your chair. The reason this other approach is all right in this situation is because
the guard clause identifies a rare situation that can be handled immediately.
This frees up the rest of the code to handle the typical calling scenario without
having to worry about the rare or invalid situations. In short, with the guard
clause in place, the code is easier to read. After we insert the guard clause, the
code compiles and the tests pass.
Refactoring 5: Inline Method

Now that the only code that calls GenerateArray is the Generate method, we can use the “Inline method” refactoring to put the method’s body into the body of its caller and completely remove the method. This is not a license to create huge methods. If we intended to stop refactoring after inlining this method, we would argue to not inline the method.

The point that needs to be stressed is communication. If it makes sense to inline a method because it communicates the intent better than it did previously, you should do it. It also decreases the surface area of the code, which should improve its testability if you don’t have huge methods. Because the Generate method returns an ArrayList and the GenerateArray method returns an array, we will need to slightly alter the guard clause introduced in the previous step to return an empty ArrayList instead of an empty array. Here is the Generate method after inlining the GenerateArray method (the modified guard clause is in boldface):

```java
public static ArrayList Generate(int maxValue)
{
    ArrayList result = new ArrayList();
    if(maxValue < 2) return result;

    // declarations
    int s = maxValue + 1; // size of array
    bool[] f = new bool[s];
    int i;

    // initialize the array to true
    for(i=0; i<s; i++)
        f[i] = true;

    // get rid of known nonprimes
    f[0] = f[1] = false;

    // sieve
    int j;
    for(i=2; i<Math.Sqrt(s)+1; i++)
    {
        for(j=2*i; j<s; j+=i)
            f[j] = false; // multiple is not prime
    }

    // how many primes are there?
    int count = 0;
    for(i=0; i<s; i++)
        if(f[i]) // if prime
```

count++; // bump count

int[] primes = new int[count];

// move the primes into the result
for (i=0, j=0; i<s; i++)
    {
        if (f[i]) // if prime
            primes[j++] = i;
    }

for (i = 0; i < primes.Length; ++i)
    result.Add(primes[i]);

return result;

This refactoring often requires more effort due to local variable name clashes. When performing this refactoring, you will find it useful to comment out the method that is being inlined instead of deleting it. After the code compiles and the tests pass, you can safely delete the commented-out code, which is useful to go back to in case your tests do not pass. You could also use your source-code control system to achieve the same benefit.

The code compiles, and the tests pass. The GenerateArray function has now been removed (or to be more exact, consumed, by the Generate method). Remember, this was the objective of the task. We could stop right now and be finished. However, we are still left with the legacy of the array-based implementation, which is filled with bad variable names and loops that iterate over the list of numbers many times. We need to do some more work to get this code in better shape.

**Refactoring 6: Rename Variable**

Looking at the code in the Generate method, we see several variables whose names do not communicate much about their intended uses, so we should give them more descriptive names. For example, what does the variable \( f \) mean? Does \( f \) indicate that the number is prime or not prime? Let’s take a look at the following code snippet to demonstrate the point:

\[
\text{if(} f[i] \text{)} // \text{if prime}
\]

Instead of having comments in the code describing what the variable \( f \) means, it is better to give the variable a more descriptive name. In almost all cases in the existing program, every time the variable \( f \) is used there is an associated comment. Let’s remove the need for the comment by providing a more
descriptive variable name. The name *isPrime* describes what the variable means in the code more clearly. After the name is changed, we can remove the comment because the variable name is descriptive enough:

```csharp
public static ArrayList Generate(int maxValue)
{
    ArrayList result = new ArrayList();
    if(maxValue < 2) return result;
    // declarations
    int s = maxValue + 1; // size of array
    bool[] isPrime = new bool[s];
    int i;
    for(i=0; i<s; i++)
    {   //multiple is not prime
        isPrime[i] = true;
    }
    isPrime[0] = isPrime[1] = false;
    // sieve
    int j;
    for(i=2; i<Math.Sqrt(s)+1; i++)
    {
        for(j=2*i; j<s; j+=i)
        {   // multiple is not prime
            isPrime[j] = false;
        }
    }
    // how many primes are there?
    int count = 0;
    for(i=0; i<s; i++)
    {
        if(isPrime[i])
        {   // bump count
            count++;
        }
    }
    int[] primes = new int[count];
    // move the primes into the result
    for(i=0, j=0; i<s; i++)
    {
        if(isPrime[i])
        {   // move the primes into the result
            primes[j++] = i;
        }
    }
    for(i = 0; i < primes.Length; ++i)
    {
        result.Add(primes[i]);
    }
    return result;
}
```
The changes are made, the code compiles, and the tests pass. It does not look as if we are finished, however. The code still has a lot of the remnants of the array-based implementation and it still has many loops that seem as if they all iterate over the same elements.

**Refactoring 7: Collapse Loops**

Looking at the last few lines of the Generate method, you can see two loops doing almost entirely the same thing. Here is the existing code:

```csharp
int[] primes = new int[count];

// move the primes into the result
for(i=0, j=0; i<s; i++)
{
    if(isPrime[i])
        primes[j++] = i;
}

for(i=0; i < primes.Length; ++i)
    result.Add(primes[i]);
```

The first loop cycles through the isPrime array to create a new array named primes. The second loop cycles through the primes array to build the list. This is a remnant of the array-based implementation returning an array and the ArrayList function converting it into an ArrayList. Because we no longer return an array, we can do this without creating the primes array, as follows:

```csharp
for(i = 0; i < s; ++i)
{
    if(isPrime[i])
        result.Add(i);
}
```

After this change is made, the code compiles and the test passes.

**Refactoring 8: Remove Dead Code**

The array-based legacy is almost gone. Because we no longer create the primes array, we no longer need the count variable because it was just used to size the primes array. Therefore, we can get rid of the count variable and the loop that calculates it. Let’s move on.
Refactoring 9: Collapse Loops (Again)

Are we done? We could be, but it appears as if a few more changes could make
the code a lot clearer, so let’s continue for awhile longer.

Look at this loop:

```java
for(i=2; i<Math.Sqrt(s)+1; i++)
{
    for(j=2*i; j<s; j+=i)
        isPrime[j] = false; // multiple is not prime
}
```

Can we make it better? The algorithm states that you have to remove mul-
tiples only if the number is a prime number, so the code is not as efficient as it
could be. Try this:

```java
for(i=2; i<Math.Sqrt(s)+1; i++)
{
    if(isPrime[i])
    {
        for(j=2*i; j<s; j+=i)
            isPrime[j] = false; // multiple is not prime
    }
}
```

We make the change, compile, and run the tests. They pass, so adding this
did not have an impact on the functionality, and the code is closer to the intent
of the algorithm.

**We Can Do Some More…**

Is the code faster? Probably, but because we do not have a performance test,
we do not know the answer to that. However, after we make this change, the
two loops at the bottom of the program look very similar; they have the same
*if* statement in them. Perhaps we can collapse the two loops together.

Here’s the existing code:

```java
int j;
for(i = 2; i < Math.Sqrt(s)+1; i++)
{
    if(isPrime[i])
    {
        for(j=2*i; j<s; j+=i)
            isPrime[j] = false; // multiple is not prime
    }
}
```

```java
for(i = 0; i < s; ++i)
{
```
if(isPrime[i])
    result.Add(i);
}

The boundaries of the loops are different. The first loop iterates over the isPrime array, beginning at 2 and continuing to Math.Sqrt(s) + 1. The second loop iterates over the isPrime array, starting at 0 and continuing all the way to s.

Enough about symbols. Let’s look at real numbers. If s were equal to 100, the first loop would execute 10 times, and the second loop would execute 100 times. It looks as if it would be simple to have the second loop start at 2 instead of 0. Let’s make that change. All the tests pass, so it works and the lower boundary conditions are now the same.

Now what about the upper boundary? It looks as if we could change the first loop to continue all the way to s. This is clearly less efficient, but (as stated previously) it is hard to say whether that is a problem because the code does not have a performance test. Let’s change the code to the following and see whether it works:

```csharp
int j;
for (i = 2; i < s; i++)
{
    if(isPrime[i])
    {
        for(j=2*i; j<s; j+=i)
            isPrime[j] = false; // multiple is not prime
    }
}
for(i = 2; i < s; i++)
{
    if(isPrime[i])
    {
        result.Add(i);
    }
}
```

All the tests pass, and the loops have identical boundary conditions. It is clearer now, after looking at the code and knowing that the tests run successfully, that we can safely collapse the loops into a single loop.

```csharp
int j;
for (i = 2; i < s; i++)
{
    if(isPrime[i])
    {
        result.Add(i);
        for(j=2*i; j<s; j+=i)
            isPrime[j] = false; // multiple is not prime
    }
}
```
That works—the tests passed. It is difficult to say that the code is less efficient because we did get rid of the second loop. And we removed a couple of other loops that were used in the *array*-based implementation, so it is possible that what we have now is more efficient than it used to be. We leave it up to you to verify whether the code performs worse now than it did before we started.

**Refactoring 10: Reduce Local Variable Scope**

Because of all the previous refactorings, the variable *j* is now used in only one loop. We can now change its scope by moving its declaration into the loop where it is used:

```csharp
for (i = 2; i < s; i++)
{
    if(isPrime[i])
    {
        result.Add(i);
        for (int j = 2 * i; j < s; j += i)
            isPrime[j] = false; // multiple is not prime
    }
}
```

That works just fine, and the local variable *j*’s scope is diminished.

**Refactoring 11: Replace Temp with Query**

The next step is to replace the temporary variable *s* because it does not communicate what it actually means:

```csharp
int s = maxValue + 1; // size of array
```

Instead of a temporary variable, we can replace the variable entirely by using the expression *isPrime.Length*, which communicates what we really mean and is already provided by the array implementation. The changes are in boldface as follows:

```csharp
public static ArrayList Generate(int maxValue)
{
    ArrayList result = new ArrayList();
    if(maxValue < 2) return result;
    bool[] isPrime = new bool[maxValue+1];
    int i;
    for(i = 0; i < isPrime.Length; i++)
```
isPrime[i] = true;

isPrime[0] = isPrime[1] = false;

// sieve
for(i = 2; i < isPrime.Length; i++)
{
    if(isPrime[i])
    {
        result.Add(i);
        for(int j = 2 * i; j < isPrime.Length; j += i)
            isPrime[j] = false; // multiple is not prime
    }
}

return result;

Refactoring 12: Remove Dead Code

There still is some code that is not used any more due to the collapse of loops done a few refactorings ago. Because the loop that does the sieve process starts at 2 and we load the list from within that loop, we no longer need to initialize 0 and 1 to false because they are never accessed. We can safely remove the following line:

isPrime[0] = isPrime[1] = false;

The tests pass when we compile and run them, so it was probably safe to assume that we could remove the line.

Refactoring 13: Extract Method

Even though the code has come a long way, there is still room for improvement, especially for making the code much more explicit about what it is doing. For example, look at the boldface code in the following snippet:

for(i = 2; i < isPrime.Length; i++)
{
    if(isPrime[i])
    {
        result.Add(i);
        for(int j = 2 * i; j < isPrime.Length; j += i)
            isPrime[j] = false; // multiple is not prime
    }
}
What does the highlighted loop do? It is clear what the loop does; there is a code comment explaining what it does. The comment is a good indicator that the code does not communicate its intent directly. It needs the comment to say what it does.

**Note** When you see a block of code with a comment attached to it, it is often a good idea to extract that code into a method and make sure that the method’s name conveys the meaning specified by the comment.

Let’s extract the boldface code into its own method named `RemoveMultiples`:

```csharp
private static void RemoveMultiples(int prime, bool[] isPrime)
{
    for(int j = 2 * prime; j < isPrime.Length; j += prime)
        isPrime[j] = false;
}
```

After the method is extracted, we need to modify the code to use it. Here is the modified code:

```csharp
for(i = 2; i < isPrime.Length; i++)
{
    if(isPrime[i])
    {
        result.Add(i);
        RemoveMultiples(i, isPrime);
    }
}
```

Instead of needing the comment, the method name communicates exactly what it is doing.

**Refactoring 14: Extract Method (Again)**

The code is getting smaller and smaller with more explicitly named methods and variables; in fact, we can now see that there are two stages in the algorithm: initialization and elimination. Let’s extract the elimination portion into a method called `Sieve` using the “Extract method” refactoring (the changes are boldface):

```csharp
public static ArrayList Generate(int maxValue)
{
    ArrayList result = new ArrayList();
```
if (maxValue < 2) return result;

bool[] isPrime = new bool[maxValue+1];
int i;

for (i = 0; i < isPrime.Length; i++)
    isPrime[i] = true;

Sieve(isPrime, result);

return result;

private static void Sieve(bool[] isPrime, ArrayList result)
{
    for (int i = 2; i < isPrime.Length; i++)
    {
        if (isPrime[i])
        {
            result.Add(i);
            RemoveMultiples(i, isPrime);
        }
    }
}

private static void RemoveMultiples(int prime, bool[] isPrime)
{
    for (int j = 2 * prime; j < isPrime.Length; j += prime)
        isPrime[j] = false;
}

The code is much more explicit. Before we go on, however, let’s make one more change. The Sieve function can return the ArrayList instead of getting it passed to it; as you see here:

public static ArrayList Generate(int maxValue)
{
    if (maxValue < 2) return new ArrayList();

    bool[] isPrime = new bool[maxValue+1];
    int i;

    for (i = 0; i < isPrime.Length; i++)
        isPrime[i] = true;

    return Sieve(isPrime);
}
private static ArrayList Sieve(bool[] isPrime)
{
    ArrayList result = new ArrayList();

    for(int i = 2; i < isPrime.Length; i++)
    {
        if(isPrime[i])
        {
            result.Add(i);
            RemoveMultiples(i, isPrime);
        }
    }

    return result;
}

private static void RemoveMultiples(int prime, bool[] isPrime)
{
    for(int j = 2 * prime; j < isPrime.Length; j += prime)
        isPrime[j] = false;
}

Refactoring 15: Reduce Local Variable Scope

Because we extracted a method that used the variable i, we can reduce the scope of the variable in the Generate method. The following code

```csharp
int i;
for(i=0; i < isPrime.Length; i++)
    isPrime[i] = true;
```

now becomes

```csharp
for(int i=0; i < isPrime.Length; i++)
    isPrime[i] = true;
```

Even though the step is small, it is still important to compile the code and run the tests. If you don’t, you could have a failure a couple of steps ahead and not know exactly what was changed.

Refactoring 16: Convert Procedural Design to Objects

We previously discussed the two steps in the algorithm: initialization and elimination. There is also a variable, isPrime, that is shared between the two stages. So we have the following:
■ State (isPrime)
■ Logic to initialize the state
■ Logic to operate on the state

This set of conditions sounds as if we need an object to hold this state, a constructor to initialize the state, and a method to manipulate this state. Meet the next refactoring: “Convert procedural design to objects.” This step is a little bit larger, so it probably makes sense to comment out the existing code first so that we have something to fall back on if we fail. Another alternative is to check the file into your source code control system and then make the change. If you fail, you can easily roll back to the previous version. The code after the refactoring looks like this:

```csharp
public static ArrayList Generate(int maxValue)
{
    if(maxValue < 2) return new ArrayList();

    Primes primes = new Primes(maxValue);
    return primes.Sieve();
}

private bool[] isPrime;

private Primes(int maxValue)
{
    isPrime = new bool[maxValue+1];

    for(int i = 0; i < isPrime.Length; i++)
        isPrime[i] = true;
}

private ArrayList Sieve()
{
    ArrayList result = new ArrayList();

    for(int i = 2; i < isPrime.Length; i++)
    {
        if(isPrime[i])
        {
            result.Add(i);
            RemoveMultiples(i, isPrime);
        }
    }

    return result;
}
```
private void RemoveMultiples(int prime, bool[] isPrime)
{
    for (int j = 2 * prime; j < isPrime.Length; j += prime)
        isPrime[j] = false;
}

We really did not write a lot of new code; we just moved what we had around a bit. After we compiled and ran the tests, they did pass the first time. We then went back and removed the commented-out code. We are definitely getting close to a point of diminishing returns, but let’s move on.

Refactoring 17: Keep the Data Close to Where It Is Used

For the first time, the code actually looks like object-oriented code. What a departure from what we had! Now that we have an object, we can see that the Sieve method could do a bit more, and the Generate method might do a bit less. The guard clause from the Generate method can be tucked away into the Sieve method to fully encapsulate the algorithm. Here is the code after applying this refactoring:

    public static ArrayList Generate(int maxValue)
    {
        Primes primes = new Primes(maxValue);
        return primes.Sieve();
    }

    private bool[] isPrime;

    private Primes(int maxValue)
    {
        isPrime = new bool[maxValue + 1];

        for (int i = 0; i < isPrime.Length; i++)
            isPrime[i] = true;
    }

    private ArrayList Sieve()
    {
        if (isPrime.Length < 2) return new ArrayList();

        ArrayList result = new ArrayList();
        for (int i = 2; i < isPrime.Length; i++)
        {
            if (isPrime[i])
            {
                result.Add(i);
RemoveMultiples(i, isPrime);
}
}

return result;
}

private void RemoveMultiples(int prime, bool[] isPrime)
{
    for(int j = 2 * prime; j < isPrime.Length; j += prime)
        isPrime[j] = false;
}

After scanning the code, there really isn't much left to do, so we are finished.

---

**Summary**

In this chapter, we demonstrated the following points:

- Refactoring allows the design of the code to improve by following a series of simple steps. For example, in this chapter we went from bad procedural code to a cleaner object-oriented implementation—while staying close to the green bar and without a large-scale rewrite. When you write your code, we expect you will refactor as you discover the need for it (not when it's too late and the code is so messed-up that it is more appealing just to throw it away and write it anew). The more “paranoid” you are about all the little problems in the code, the more proactive you will be in correcting them when you notice them rather than waiting until you have a big job on your hands.

- There was no mention of a debugger. Due to the small steps and the ability to verify them with the tests, you will not have to spend as much time debugging the software because changes can easily be rolled back to the previous state.

- The ability to do refactoring is a benefit that you receive from your investment in tests. The tests provide the safety net that enables the routine maintenance of the program. These tests allow you to alter the code without worrying about whether or not you have broken it.
Without the tests, you would not be able to move as quickly or as incrementally through this problem. In fact, you probably would have scrapped the whole thing and rewritten it.

- You should not turn your “pragmatic paranoia” into a “morbid obsession.” Your goal, after all, is to write software efficiently and not get stuck tweaking existing code into unattainable “perfection.” When do you stop refactoring? There is no simple and fast rule here that we can offer. The general rule of thumb is that you need to refactor whatever code duplication you discover and move toward code that clearly communicates your intentions. And if you have some amount of code duplication that serves the goal of clearly communicating your intentions, it is all right to keep it.

- Last, the order in which we did the refactorings is only an example. There are many other ways this code could be refactored and many other possible implementations. The main point driven home by the series of steps is that the code is the primary feedback mechanism for possible future refactorings.
Index

A
ActionFixture class, automating customer tests with FIT, 133–143
  check action command, 134
  enter action command, 133
  start command, 133
Add Web Reference Wizard, 122
AddReview method
  Catalog class, 155–156
  modifications, 172–173
AddReviewAdapter, add/delete review functionality, 162
AddReviewToRecording method (CatalogService class), 158
AddSecondReview test, 169–171
AddTwoNumbers method, 250
ADO.NET transactions, 253–257
  automatic management, 253–256
  manual management, 253–255
  participation, 256–257
algorithms, Sieve of Eratosthenes, 36–41
  adding tests, 43–44
  applying refactoring, 58–59
  collapse loops, 49–52
  converting procedural design to objects, 56–58
  Extract method, 53–55
  Hide method, 44–45
  inlining methods, 46–47
  reducing variable scope, 52, 56
  removing dead code, 49, 53
  Rename method, 42–43
  rename variables, 47–49
  replacing nested conditionals with guarded clauses, 45
  replacing temporary variables, 52–53
application packages, 206–208
  Data Access, 206
  Data Model, 206–207
  Service Interface, 207–208
appSettings section (configuration file), 74
ArgumentOutOfRangeException, 23
arrays, isPrime, 48–51
Artist entity (media library application), 65
Artist Gateway, defining DataSet for Recording database, 77–86, 189
ArtistFixture.cs, 79–86
  primary key management, 78–86
ArtistFixture class
  ArtistFixture.cs, 79–86
  modification to work with DatabaseFixture class, 187–189
ArtistName method (CatalogAdapter class), 136
ASP.NET
  programmer tests, user interfaces, 213
  Web service programmer tests, 105–126
    data transformation, 107–117
    database catalog service, 117–120
    tasks, 105–106
assemblers, RecordingDto, mapping relationships, 113–117
assertions, 243–244
attributes
  codegen:typedName="Id", 77
  codegen:typedName="Review", 76
genreId, 66
  minOccurs="0", 77
NUnit
  ExpectedException, 246
  Ignore, 246–247
  SetUp, 244–246
  TearDown, 244–246
  TextFixtureSetUp, 247–250
  TextFixtureTearDown, 247–250
Obsolete, 37
setUp, 74
trackId, 66
TransactionOption.Required, 256
automatic transaction management, 253–256
  automation, customer tests (FIT)
  ActionFixture class, 133–143
  bridging FIT and software, 132–133
  CatalogAdapter class, 134–138
  FileRunner class, 135–136
  invalid ID script, 143
  verifying review information, 142–143
  verifying track information, 138–141
averageRating field (RecordingDto), 109
Beck, Kent, 3, 217
binding search results with repeater Web controls, 218–226
bridging FIT and software, 132–133

Catalog class, 97
implementing add/delete review functionality, 152–156
AddReview method, 155–156
DeleteReview method, 155–156
programmer tests, 193–203
CatalogFixture class, 193
FindByRecordingId method, 193–195, 201–203
refactoring Catalog class, 195–203
CatalogAdapter class
ArtistName method, 136
automating customer tests with FIT, 134–138
Duration method, 136
FindByRecordingId method, 133
Found method, 134
LabelName method, 136
ReleaseDate method, 136
Catalog.AddReview function, modifying to throw an exception, 166–167
CatalogFixture class, 193
CatalogGateway class
proxy class, 122
SOAP faults, 168–169
CatalogService base class, 118
CatalogService class, 207–209, 215
AddReviewToRecording method, 158
DeleteReviewFromRecording method, 158
implementing add/delete review functionality, 156–159
Search method, 215
CatalogServiceGateway class, 221, 226–230
CatalogServiceImplementation, 229
CatalogServiceInterface class, 121–122, 207
CatalogServiceStub, 216–218, 226–230
CommandExecutor, refactoring Catalog class, 196–203
ConfigurationSettings, reading connection string from configuration file, 73
DatabaseCatalogService, 207–208
DatabaseFixture
modified ArtistFixture class, 187–189
transaction test pattern, 187
ExistingReviewException, 165–166, 210
ExistingReviewMapper, 176–179, 210
FileRunner, automating customer tests with FIT, 135–136
GenreFixture, 189
GenreGateway, 189
IdGenerator, 189
InMemoryRecordingBuilder, 113, 157
LabelFixture, 189
LabelGateway, 189
NumbersFixture, adding to projects (NUnit), 235
RecordingAssembler, 113, 144, 207
RecordingBuilder, 94
RecordingDisplayAdapter, 218–220
RecordingDto, 207
RecordingFixture, 95
RecordingGateway, 190–192
RecordingGatewayFixture, 190–192
ReviewAdapter
adding and deleting reviews, 149–150
ExistingReviewId method, 174–176
modifying to throw an exception, 167
ReviewerFixture, 189
ReviewerGateway, 189
ReviewFixture, 189
ReviewGateway, 189
SearchPage.aspx.cs, 229
SearchPageHelper, 224–226
ServicedComponent, 256
SqlTransaction, 186
StackFixture, 15
StubCatalogService, 208
StubCatalogServiceFixture, 208
TrackDisplay, 139–141
TrackDisplayAdapter, 144
TrackFixture, 189
TrackGateway, 189
TransactionCheckCommand, 197
TransactionManager, 183–192
clients, Web clients
Search page, 214
binding search results with repeater Web controls, 218–226
CatalogServiceGateway class, 226–230
creating, 221–226
implementing, 215–230
testing user interfaces, 213–214
Close option (NUnit-Gui File menu), 238
code refactoring, 6, 35–60
applications, 58–59
Catalog class, 195–203
CommandExecutor class, 196–203
writing proxy classes, 196
code, Web services, 124–125
collapse loops, 49–52
converting procedural design to objects, 56–58
cycle, 41
defined, 35
Extract method, 53–55
Hide method, 44–45
inlining methods, 46–47
Red/Green/Refactor, 7, 12–22
creating empty Stacks, 12–14
pushing multiple objects on Stacks, 20–22
pushing single objects on Stacks, 14–20
reducing variable scope, 52, 56
removing dead code, 49, 53
removing unneeded code, 41–42
Rename method, 42–43
rename variables, 47–49
replacing nested conditionals with guarded clauses, 45
replacing temporary variables, 52–53
ServiceLayer, 205–211
SetUp, 84
Sieve of Eratosthenes, 36–59
adding tests, 43–44
applying refactoring, 58–59
collapse loops, 49–52
converting procedural design to objects, 56–58
Extract method, 53–55
Hide method, 44–45
inlining methods, 46–47
reducing variable scope, 52, 56
removing dead code, 49, 53
Rename method, 42–43
rename variables, 47–49
replacing nested conditionals with guard clauses, 45
replacing temporary variables, 52–53
testing known good state, 41
tests, 43–44
codegen:typedName="Id" attribute, 77
codegen:typedName="Review" attribute, 76
Collapse All option (NUnit-Gui View menu), 239
Collapse Fixtures option (NUnit-Gui View menu), 239
collapse loops, refactoring, 49–52
Collapse option (NUnit-Gui View menu), 239
Command interface (CommandExecutor class), 197
CommandExecutor class, refactoring Catalog class, 196–203
Command interface, 197
Execute method, 199–200
commands (ActionFixture class)
check action, 134
enter action, 133
start, 133
completion, customer tests, 127–129
conditionals, nested, replacing with guarded clauses, 45
collection files
appSettings section, 74
reading connection strings from
ConfigurationSettings class, 73
separating tests, 74–75
ConfigurationSettings class, reading connection string from configuration file, 73
ConnectionFixture.cs, 90–91
ConnectionString enumerations, 72
consistency, testing database access layer, 70
consumer infrastructure, Web service tests, 122
customer tests, 4, 127–167
adding reviews to recordings, FIT script, 147–162
customer tests (continued)
automation, FIT, 131–143
determining completion, 127–129
exposing failure conditions, 163–164, 167
reconciling viewpoints, 143–145
recording duration, 145
track duration, 144–145
recording retrieval, test scripts, 129–131

Data Access package, 206
Data Model package, 206–207
data models, media library application, 65
data structures, stacks, 9–12, 22–29
calling Top on, 26–27
creating, 9–10
popping, 22–23
pushing multiple objects, 25–26
pushing null on, 27–29
pushing single objects, 24–26
test list, 10–12
unbounded, 9
data transfer object. See DTO (data transfer object), data transformation
data transformation, ASP.NET Web service programmer tests, 105–120
database catalog service, 117–120
tasks, 105–106
database access layer, testing, 69–102
connecting to databases, 72–75
isolating individual entities, 75–92
listing tests needed for completion, 71–72
relationships between entities, 92–97
retrieving recordings, 97–101
test organization, 101–102
database catalog service, CheckId test, 118–120
DatabaseCatalogService class, 207–208
DatabaseCatalogService subclass (CatalogService class), 157–161
DatabaseCatalogServiceTestFixture, 118
DatabaseFixture class
modified ArtistFixture class, 187–189
transactions test pattern, 187
databases, media library application, 64–66
DataSets, defining typed DataSets for Recording databases, 75–90
Artist Gateway, 77–86
Genre Gateway, 86–90
debuggers (Visual Studio .NET), NUnit-Gui, 250–251
declarative transaction management. See automatic transaction management
Delete method (ArtistFixture.cs), 83
DeleteReview method (Catalog class), 155–156
DeleteReviewFromRecording method (CatalogService class), 158
design, simple, 5–6
Detail property, SoapException, 171
direct security context propagation, Web services security, 123
division, NUnit, 246–247
DTO (data transfer object), data transformation, 105–117
RecordingDto, 108–117
Duration method (CatalogAdapter class), 136

e
enter action command (ActionFixture class), 133
entities
Label entity (media library application), 65
media library application, 65–66
testing database access layer
isolated entities, 75–92
relationships between entities, 92–97
test organization, 101
enumerations, ConnectionState, 72
Eratosthenes, Sieve of, 36–59
adding tests, 43–44
applying refactoring, 58–59
collapse loops, 49–52
converting procedural design to objects, 56–58
Extract method, 53–55
Hide method, 44–45
inlining methods, 46–47
reducing variable scope, 52, 56
removing dead code, 49, 53
Rename method, 42–43
rename variables, 47–49
replacing nested conditionals with guard clauses, 45
replacing temporary variables, 52–53
Errors and Failures window (NUnit-Gui), 239
exceptions
ArgumentOutOfRangeException, 23
propagating, 168
Execute method (CommandExecutor class), 199–200
ExistingReviewException class, 165–166, 210
ExistingReviewId method (ReviewAdapter class), 164, 174–176
ExistingReviewMapper class, 176–179, 210
Exit option (NUnit-Gui File menu), 239
Expand All option (NUnit-Gui View menu), 239
Expand Fixtures option (NUnit-Gui View menu), 239
Expand option (NUnit-Gui View menu), 239
ExpectedException attribute (NUnit), 246
explicit transaction management. See manual
transaction management
eXtensible Schema Definition schema file. See XSD
(eXtensible Schema Definition) schema file
Extract method, refactoring, 53–55
Extreme Programming Explored, 7
Extreme Programming Installed, 5

F
failures
adding and deleting reviews, 150–151
exposing with customer tests, 163–164
exposing with programmer tests, 164–179
defining ExistingReviewException class, 165–166
modifying Catalog.AddReview function, 166
propagating exceptions, 168
searching for an exception after second review,
164–165
SOAP faults, 168–179
Failures panel (NUnit-Gui), 238
fields
  RecordingDto, 109
  recordingId, 222
  totalRunTime, 116
File menu (NUnit-Gui)
  Close option, 238
  Exit option, 239
  New Project option, 238
  Open option, 238
  Recent Files option, 239
  Reload option, 238
  Save As option, 238
  Save option, 238
FileRunner class, automating customer tests with FIT,
135–136
FindById method, 82, 119
FindByRecordingId method
  CatalogAdapter class, 133
  RecordingDto, 112
  retrieving recordings, 97
FindByRecordingId method (Catalog class), 193–195,
201–203
FindByRecordingId WebMethod, 121–122
FIT (Framework for Integrated Test), 4
adding reviews to recordings, 147–162
failures, 150–151
implementing with programmer tests, 151–162
removing reviews, 149
ReviewAdapter, 149–150
verifying contents of review, 149
automating customer tests, 131–134
  ActionFixture class, 133–134
  bridging FIT and software, 132–133
  CatalogAdapter class, 134–138
  FileRunner class, 135–136
  invalid ID script, 143
  verifying review information, 142–143
  verifying track information, 138–141
FKx (foreign key), 66
Found method (CatalogAdapter class), 134
Fowler, Martin, 6, 36
Framework for Integrated Test (FIT)
adding reviews to recordings, 147–162
failures, 150–151
implementing with programmer tests, 151–162
removing reviews, 149
ReviewAdapter, 149–150
verifying contents of review, 149
automating customer tests, 131–134
  ActionFixture class, 133–134
  bridging FIT and software, 132–133
  CatalogAdapter class, 134–138
  FileRunner class, 135–136
  invalid ID script, 143
  verifying review information, 142–143
  verifying track information, 138–141
functional tests, user interfaces, 213
functions. See also methods
AddReview
  Catalog class, 155–156
  modifications, 172–173
AddReviewToRecording (CatalogService class), 158
AddTwoNumbers, 250
ArtistName (CatalogAdapter class), 136
Delete (ArtistFixture.cs), 83
DeleteReview (Catalog class), 155–156
DeleteReviewFromRecording (CatalogService class),
158
Duration (CatalogAdapter class), 136
Execute (CommandExecutor class), 199–200
ExistingReviewId (ReviewAdapter class), 164
ExistingReviewId (ReviewAdapter class), 174–176
Extract, refactoring, 53–55
FindById, 119
  ArtistFixture.cs, 82
FindByRecordingId
  CatalogAdapter class, 133
  RecordingDto, 112
  retrieving recordings, 97
FindByRecordingId (Catalog class), 193–195,
201–203
Generate (Sieve of Eratosthenes), 37
functions (continued)
GenerateArray (Sieve of Eratosthenes), 37, 45
GetDt os, 227
GetNextId
    ArtistFixture.cs, 82
    GenreFixture.cs, 88
Hide, refactoring, 44–45
inlining, 46–47
Insert (ArtistFixture.cs), 82
InvalidOperationException, 26
IsEmpty, 9–11
    verifying false value, 14–16, 24–29
    verifying true value, 12–17
LabelName (CatalogAdapter class), 136
PushOne, 14
PushPopContentCheck, 17, 20
PushPopMultipleElements, 20
ReleaseDate (CatalogAdapter class), 136
Rename, refactoring, 42–43
RetrieveConnectionString, 74
RunATransaction, 255
Search (CatalogService class), 215
SearchButtonClick, 222, 226
SetUp, 183, 187
    ArtistFixture.cs, 84
TearDown, 183, 187
    ArtistFixture.cs, 84
Update (ArtistFixture.cs), 86
WriteDto, 114
WriteTotalRunTime, 116
WriteTrack, 114, 144

G
Generate method (Sieve of Eratosthenes), 37
GenerateArray method (Sieve of Eratosthenes), 37, 45
Genre entity (media library application), 65
Genre Gateway, defining DataSet for Recording
database, 86–90
GenreFixture class, 189
GenreFixture.cs, 86–90
GenreGateway class, 189
genreId attribute, 66
GetDt os method, 227
GetNextId method
    ArtistFixture.cs, 82
    GenreFixture.cs, 88
Green (NUnit-Gui progress bar), 237

H–I
Hide method, refactoring, 44–45
IDbConnection interface, 254–255
IDbTransaction interface, 254–255
IdGenerator class, 189
IdGeneratorFixture.cs, 91–92
Ignore attribute (NUnit), 246–247
inlining methods, 46–47
InMemoryRecordingBuilder class, 113, 157
Insert method (ArtistFixture.cs), 82
interfaces
    IDbConnection, 254–255
    IDbTransaction, 254–255
user interfaces, testing, 213–214
invalid ID script, automating customer tests, 143
InvalidId test, 108
InvalidOperationException method, 26
IsEmpty function, 9–11
    verifying false value, 14–16, 24–29
    verifying true value, 12–17
isolated entities, testing database access layer, 75–101
isolated entities, 75–92
relationships between entities, 92–97
test organization, 101
isPrime array, 48–51

J–L
Jeffries, Ron, 5
Label entity (media library application), 65
LabelFixture class, 189
LabelGateway class, 189
LabelName method (CatalogAdapter class), 136
Layout, NUnit-Gui, 237–240
loops, collapse, 49–52

M
management, transactions (ADO.NET)
    automatic, 253–256
    manual, 253–255
manual refactoring of code, Web services, 124–125
manual transaction management, 253–255
mapped security contexts, Web services security, 123
mapping relationships (assemblers), RecordingDto,
    114–117
media library application, 63–67
    ASP.NET Web services, 66
existing databases, 64–66
recordings data model, 65
menus
File (NUnit-Gui)
    Close option, 238
    Exit option, 239
    New Project option, 238
    Open option, 238
    Recent Files option, 239
    Reload option, 238
    Save As option, 238
    Save option, 238
Tools (NUnit-Gui)
  Options option, 239
  Save Results as XML option, 239
View (NUnit-Gui)
  Collapse All option, 239
  Collapse Fixtures option, 239
  Collapse option, 239
  Expand All option, 239
  Expand Fixtures option, 239
  Expand option, 239
  Properties option, 239
methods. See also functions
AddReview
  Catalog class, 155–156
  modifications, 172–173
AddReviewToRecording (CatalogService class), 158
AddTwoNumbers, 250
ArtistName (CatalogAdapter class), 136
Delete (ArtistFixture.cs), 83
DeleteReview (Catalog class), 155–156
DeleteReviewFromRecording (CatalogService class), 158
Duration (CatalogAdapter class), 136
Execute (CommandExecutor class), 199–200
ExistingReviewId (ReviewAdapter), 164
ExistingReviewId (ReviewAdapter class), 174–176
Extract, refactoring, 53–55
FindByld, 119
  ArtistFixture.cs, 82
FindByRecordingld
  CatalogAdapter class, 133
  RecordingDto, 112
  retrieving recordings, 97
FindByRecordingld (Catalog class), 193–195, 201–203
Found (CatalogAdapter class), 134
Generate (Sieve of Eratosthenes), 37
GenerateArray (Sieve of Eratosthenes), 37, 45
GetDtos, 227
GetNextld
  ArtistFixture.cs, 82
  GenreFixture.cs, 88
Hide, refactoring, 44–45
inlining, 46–47
Insert (ArtistFixture.cs), 82
InvalidOperationException, 26
LabelName (CatalogAdapter class), 136
PushOne, 14
PushPopContentCheck, 17, 20
PushPopMultipleElements, 20
ReleaseDate (CatalogAdapter class), 136
Rename, refactoring, 42–43
RetrieveConnectionString, 74
RunATransaction, 255
Search (CatalogService class), 215
SearchButtonClick, 222, 226
SetUp, 183, 187
  ArtistFixture.cs, 84
TearDown, 183, 187
  ArtistFixture.cs, 84
Update (ArtistFixture.cs), 86
WriteDto, 114
WriteTotalRunTime, 116
WriteTrack, 114, 144
minOccurs="0" attribute, 77
multiplication, NUnit, 244–246
N
nested conditionals, replacing with guarded clauses, 45
New Project option (NUnit-Gui File menu), 238
^Nunit (NUnit-Gui), Visual Studio .NET debugger, 250–251
null, pushing on Stacks, 27–29
NumbersFixture class, adding to projects (NUnit), 235
NUnit, 37, 233–251
attributes
  ExpectedException, 246
  Ignore, 246–247
  SetUp, 244–246
  TearDown, 244–246
  TextFixtureSetUp, 247–250
  TextFixtureTearDown, 247–250
NumbersFixture class, adding to projects, 235
nunit.framework.dll, adding references to, 234
NUnit-Gui test runner
  layout, 237–240
  running tests, 237
  setup, 236
projects, 233–234
Test case, 240–244
  assertions, 243–244
  test fixtures, 241–242
  test runners, 242
  test suites, 241
Web site, 233
NUnit-Gui
  layout, 237–240
  running tests, 237
  setup, 236
Visual Studio .NET debugger, 250–251
objects
  converting procedural design to (refactoring), 56–58
  RecordingDto (CatalogService class), 217–218
  SqlConnection, 72
  Obsolete attribute, 37
Open option (NUnit-Gui File menu), 238
Options option (NUnit-Gui Tools menu), 239
organization, testing database access layer, 101–102
  entities, 101
  relationships, 101
  utilities, 102
packages (application), 206–207
  Data Access, 206
  Data Model, 206–207
  Service Interface, 207–208
  structure, Web services, 124–125
panels, NUnit-Gui
  Failures, 238
  Status, 238
  Test Cases, 238
  Tests Run, 238
  Time, 238
PK (primary key), 66
Pop operation, 10
  objects, 16–22
  Stacks, 22–23
primary key (PK), 66, 78–86
producer infrastructure, Web service tests, 121–122
production database, testing database access layer, 70
programmer tests, 4
  add review functionality, 151–162
    AddReviewAdapter modification, 162
    changing Catalog class, 152–156
    changing CatalogService class, 156–159
    test list, 152
    updating CatalogServiceInterface, 161–162
    updating DatabaseCatalogService subclass, 159–161
ASP.NET Web services, 105–126
  data transformation, 107–117
  database catalog service, 117–120
  tasks, 105–106
  Web service tests, 120–125
exposing failure conditions, 164–179
  defining ExistingReviewException class, 165–166
  modifying Catalog.AddReview function, 166–167
  propagating exceptions, 168
  searching for an exception after second review, 164–165
  SOAP faults, 168–179
  synchronizing with customer tests, 143–145
  recording duration, 145
  track duration, 144–145
  Test case (NUnit), 240–244
    assertions, 243–244
    test fixtures, 241–242
    test runners, 242
    test suites, 241
    transactions, 182–203
      Catalog class, 193–203
      TransactionManager class, 183–192
user interfaces, 213
progress bar (NUnit-Gui), 237
projects
  adding NumbersFixture class to, 235
  creating in NUnit, 233–234
  NUnit-Gui
    layout, 237–240
    running tests, 237
    setup, 236
Properties option (NUnit-Gui View menu), 239
publications
  Extreme Programming Explored, 7
  Extreme Programming Installed, 5
  Refactoring: Improving the Design of Existing Code, 6, 36
  Test-Driven Development, 217
  Test-Driven Development: By Example, 3
Push operation, 10
  multiple objects on Stacks, 20–22, 25–26
  single objects on Stacks, 14–20, 24–26
  PushOne method, 14
  PushPopContentCheck method, 17, 20
  PushPopMultipleElements method, 20

R
Recent Files option (NUnit-Gui File menu), 239
recording duration, synchronizing customer and
  programmer tests, 145
Recording entity, testing database access layer, 71–92
  connecting to databases, 72–75
  defining typed DataSets, 75–77
recording retrieval, customer tests, test scripts, 129–131
RecordingAssembler class, 113, 207
  WriteTrack method, 144
RecordingAssemblerFixture, 114
RecordingBuilder class, 94
RecordingDisplayAdapter class, 218–220
RecordingDto, 108–117, 207
building assemblers, 113–117
fields, 109
objects, CatalogService class, 217–218
verifying title field, 112
XML Schema, 109–112
RecordingFixture class, 95
RecordingGateway class, 190–192
RecordingGatewayFixture class, 190–192
recordingId field, 222
recordings
adding reviews to, FIT script, 147–162
retrieving, testing database access layer, 97–101
recordings data model (media library application), 65
recursive descent, 5
Red (NUnit-Gui progress bar), 237
Red/Green/Refactor, 7, 12–22
creating empty Stacks, 12–14
pushing multiple objects on Stacks, 20–22
pushing single objects on Stacks, 14–20
refactoring, 6, 35–60
applications, 58–59
Catalog class, 195–203
CommandExecutor class, 196–203
writing proxy classes, 196
code, Web services, 124–125
collapse loops, 49–52
converting procedural design to objects, 56–58
cycle, 41
defined, 35
Extract method, 53–55
Hide method, 44–45
inlining methods, 46–47
reducing variable scope, 52, 56
removing dead code, 49, 53
Rename method, 42–43
rename variables, 47–49
replacing nested conditionals with guarded clauses, 45
replacing temporary variables, 52–53
testing known good state, 41
tests, 43–44
Refactoring: Improving the Design of Existing Code, 6, 36
references, adding to NUnit nunit.framework.dll, 234
relationships
entities, 66, 92–97
Review and Reviewer entities, 92–94
Track-Recording relationship, 94–97
testing database access layer, test organization, 101
RetrieveConnectionString method (CatalogAdapter class), 136
Reload option (NUnit-Gui File menu), 238
removing
code, refactoring, 41–42
dead code, 49, 53
Rename method, refactoring, 42–43
rename variables, refactoring, 47–49
repeater Web controls, binding search results, 218–226
responsibility (tests), testing database access layer, 70
RetrieveConnectionString method, 74
retrieving recordings
customer tests, test scripts, 129–131
testing database access layer, 97–101
Review entity
media library application, 65
testing relationship to Reviewer entity, 92–94
ReviewAdapter
adding and deleting reviews, 149–150
ExistingReviewId method, 164, 174–176
modifying to throw an exception, 167
Reviewer entity, testing relationship to Review entity, 92–94
ReviewerFixture class, 189
ReviewerGateway class, 189
ReviewFixture class, 189
ReviewGateway class, 189
ReviewReviewerFixture.cs, 92–93
reviews, adding to recordings (FIT script), 147–162
RowFixture (FIT)
verifying review information, 142–143
verifying track information, 138–141
RunATransaction method, 255
Save As option (NUnit-Gui File menu), 238
Save option (NUnit-Gui File menu), 238
Save Results as XML option (NUnit-Gui Tools menu), 239
scope, variables, reducing, 52, 56
Search method, CatalogService class, 215
Search page, Web clients, 214–230
    binding search results with repeater Web controls, 218–226
    CatalogServiceGateway class implementation, 226–230
    creating, 221–226
    implementing search, 215–230
SearchButtonClick method, 222, 226
SearchPage.aspx.cs class, 229
SearchPageHelper class, 224–226
security, Web services, 122–124
    direct security context propagation, 123
    mapped security contexts, 123
self-validating tests, Test case (NUnit), 240–241
    assertions, 243–244
    test fixtures, 241–242
    test runners, 242
    test suites, 241
Service Interface package, 207–208
ServicedComponent class, 256
ServiceLayer namespace, 209
ServiceLayer refactoring, 205–211
SetUp attribute, 74, 244–246
SetUp method, 183, 187
    ArtistFixture.cs, 84
SetUp refactoring, 84
Sieve of Eratosthenes, 36–59
    adding tests, 43–44
    applying refactoring, 58–59
    collapse loops, 49–52
    converting procedural design to objects, 56–58
    Extract method, 53–55
    Hide method, 44–45
    inlining methods, 46–47
    reducing variable scope, 52, 56
    removing dead code, 49, 53
    Rename method, 42–43
    rename variables, 47–49
    replacing nested conditionals with guard clauses, 45
    replacing temporary variables, 52–53
    simple design, 5–6
SOAP (Simple Object Access Protocol), faults, 168–179
    ExistingReviewMapper class, 176–179
    passing id of existing review to client, 173–174
SoapException, Detail property, 171
SqlConnection objects, 72
SqlTransaction class, 186
Stack.cs, 32
StackFixture class, 15
StackFixture.cs, 12, 29–32
stacks
    calling Top on, 26–27
    creating, 9–14
    empty Stacks, 12–14
    test list, 10–12
    popping, 22–23
    pushing multiple objects on, 20–22, 25–26
    pushing null on, 27–29
    pushing single objects on, 14–20, 24–26
    unbounded, 9
Standard Error window (NUnit-Gui), 240
Standard Output window (NUnit-Gui), 240
start command (ActionFixture class), 133
Status panel (NUnit-Gui), 238
StubCatalogService class, 208
StubCatalogService subclass (CatalogService class), 157
StubCatalogServiceFixture class, 208
subclasses, CatalogService
    DatabaseCatalogService, 157–161
    StubCatalogService, 157
synthetic primary keys, 78–86

T
Table Data Gateway, 78
tasks, ASP.NET Web service programmer tests, 105–106
TDD (Test-Driven Development), 3–6, 63
design, 5–6
    process
        Red/Green/Refactor, 7
        test list, 6–7
        refactoring, 6
tests, 4
TearDown attribute (NUnit), 244–246
TearDown method, 84, 183, 187
technology facing tests, 4
    add review functionality, 151–162
        AddReviewAdapter modification, 162
        changing Catalog class, 152–156
        changing CatalogService class, 156–159
        test list, 152
        updating CatalogServiceInterface, 161–162
        updating DatabaseCatalogService subclass, 159–161
ASP.NET Web services, 105–126
data transformation, 107–117
database catalog service, 117–120
tasks, 105–106
Web service tests, 120–125
exposing failure conditions, 164–179
defining ExistingReviewException class, 165–166
modifying Catalog.AddReview function, 166–167
propagating exceptions, 168
searching for an exception after second review, 164–165
SOAP faults, 168–179
synchronizing with customer tests, 143–145
recording duration, 145
track duration, 144–145
Test case (NUnit), 240–244
assertions, 243–244
test fixtures, 241–242
test runners, 242
test suites, 241
transactions, 182–203
Catalog class, 193–203
TransactionManager class, 183–192
user interfaces, 213
Test case, 240–244
assertions, 243–244
test fixtures, 241–242
test runners, 242
test suites, 241
Test Cases panel (NUnit-Gui), 238
Test Not Run window (NUnit-Gui), 239
Test-Driven Development (TDD), 3–6, 63
design, 5–6
process
Red/Green/Refactor, 7
test list, 6–7
refactoring, 6
tests, 4
Test-Driven Development: By Example, 3
Test-Driven Development publication
tests, 4
AddSecondReview, 169–171
ASP.NET Web service programmer tests, 105–126
CheckId test, 122
consumer infrastructure, 122
data transformation, 107–117
database catalog service, 117–120
package structure, 124–125
producer infrastructure, 121–122
security, 122–124
tasks, 105–106
Web service tests, 120–125
CheckId, 118–120, 122
CheckTitle, verifying title field, 112
customer tests, 4, 127–164
adding review to recordings, 147–162
automation, 131–143
determining completion, 127–129
exposing failure conditions, 163–164
reconciling viewpoints, 143–145
recording retrieval, 129–131
database access layer, 69–102
connecting to databases, 72–75
isolating individual entities, 75–92
listing tests needed for completion, 71–72
relationships between entities, 92–97
retrieving recordings, 97–101
test organization, 101–102
fixtures, 241–242
functional, user interfaces, 213
list, 6–7
NUnit-Gui, 237
programmer, 4
add and delete review functionality, 151–162
exposing failure conditions, 164–179
synchronizing with customer tests, 143–145
transactions, 182–203
user interfaces, 213
refactoring, 41–44
applications, 58–59
Catalog class, 195–203
code, Web services, 124–125
collapse loops, 49–52
converting procedural design to objects, 56–58
cycle, 41
defined, 35
Extract method, 53–55
Hide method, 44–45
inlining methods, 46–47
Red/Green/Refactor, 7, 12–22
reducing variable scope, 52, 56
removing dead code, 49, 53
removing unneeded code, 41–42
Rename method, 42–43
rename variables, 47–49
replacing nested conditionals with guarded clauses,
45
replacing temporary variables, 52–53
ServiceLayer, 205–211
SetUp, 84
Sieve of Eratosthenes, 36–59
testing known good state, 41
runners (NUnit-Gui)
layout, 237–240
running tests, 237
setup, 236
suites, 241
Tests Run panel ( NUnit-Gui)

Test case ( NUnit), 240–244
  assertions, 243–244
  test fixtures, 241–242
  test runners, 242
  test suites, 241
  time, testing database access layer, 69
  user interfaces, 213–214
Tests Run panel ( NUnit-Gui), 238
TextFixtureSetUp attribute ( NUnit), 247–250
TextFixtureTearDown attribute ( NUnit), 247–250
Time panel ( NUnit-Gui), 238
title field, verification, CheckTitle test, 112
Tools menu ( NUnit-Gui)
  Options option, 239
    Save Results as XML option, 239
Top operation, 10, 24–27
totalRunTime field, RecordingDto, 109, 116
track duration, synchronizing customer and
  programmer tests, 144–145
TrackAssemblerFixture, 114
TrackDisplay class, 139–141
TrackDisplayAdapter class, 144
TrackFixture class, 189
TrackGateway class, 189
trackId attribute, 66
Track-Recording relationship, testing relationship
  between entities, 94–97
Transaction property, 256
TransactionCheckCommand class, 197
TransactionManager class, 183–192
  integration with tests, 187–192
TransactionOption.Required attribute, 256
transactions
  ADO.NET, 253–257
    automatic management, 253–256
    manual management, 255–255
    participation, 256
    programmer tests, 182–192
    Catalog class, 193–203
    TransactionManager class, 183–192
typed DataSets, defining for Recording database, 75–77
  Artist Gateway, 77–86
  Genre Gateway, 86–90

unbounded Stacks, 9
unit tests
  add review functionality, 151–162
    AddReviewAdapter modification, 162
    changing Catalog class, 152–156
    changing CatalogService class, 156–159
test list, 152
  updating CatalogServiceInterface, 161–162
  updating DatabaseCatalogService subclass, 159–161
ASP.NET Web services, 105–126
  data transformation, 107–117
  database catalog service, 117–120
  tasks, 105–106
  Web service tests, 120–125
  exposing failure conditions, 164–179
    defining ExistingReviewException class, 165–166
    modifying Catalog.AddReview function, 166–167
    propagating exceptions, 168
    searching for an exception after second review,
      164–165
  SOAP faults, 168–179
  synchronizing with customer tests, 143–145
    recording duration, 145
    track duration, 144–145
Test case ( NUnit), 240–244
  assertions, 243–244
  test fixtures, 241–242
  test runners, 242
  test suites, 241
  transactions, 182–203
    Catalog class, 193–203
    TransactionManager class, 183–192
  user interfaces, 213
Update method ( ArtistFixture.cs), 86
  urn:schemas-microsoft-com:xml-msdata namespace, 77
  urn:schemas-microsoft-com:xml-msprop namespace, 76
  user interfaces, testing, 213–214
utilities, testing database access layer, test organization, 102

V
Validating (self) tests, Test case ( NUnit), 240–241
  assertions, 243–244
  test fixtures, 241–242
  test runners, 242
  test suites, 241
variables
  rename, 47–49
  replacing temporary variables, 52–53
  scope, reducing, 52, 56
View menu ( NUnit-Gui)
  Collapse All option, 239
  Collapse Fixtures option, 239
  Collapse option, 239
  Expand All option, 239
  Expand Fixtures option, 239
  Expand option, 239
  Properties option, 239
Visual Studio
creating Search page, 221–226
Nunit, 233–240, 250–251
   adding NumbersFixture class to projects, 235
   adding references to nunit.framework.dll, 234
creating projects, 233–234
debugger, 250–251
layout, 237–240
NUnit-Gui setup, 236
running tests, 237

W
Wake, William, 7
Web clients
   Search page, 214
      binding search results with repeater Web controls, 218–226
      CatalogServiceGateway class, 226–230
      creating, 221–226
      implementing, 215–230
   testing user interfaces, 213–214
Web controls, repeater, binding search results, 218–226
Web Reference Wizard (CatalogGateway proxy class), 122

Web services, ASP.NET
   media library application, 66
   programmer tests, 105–126
      data transformation, 107–117
      database catalog service, 117–120
      tasks, 105–106
   Web service tests, 120–125
Web Services Description Language (WSDL), 109
windows (NUnit-Gui)
   Errors and Failures, 239
   Standard Error, 240
   Standard Output, 240
   Test Not Run, 239
   wizards, 122
WriteDto method, 114
WriteTotalRunTime method, 116
WriteTrack method, 114, 144
WSDL (Web Services Description Language), 109

X-Z
XML Schema, RecordingDto, 109–112
XSD (eXtensible Schema Definition) schema file, 76
Yellow (NUnit-Gui progress bar), 237
ZeroOne test, refactoring, 43–44
What is test-driven development? TDD is not a specific framework or technology - it is an approach. It's a thought process where we think of testing our code from a different perspective by writing the test code first before a single line of related functional code exists! In a typical scenario, you first write some code, then write some tests - rinse and repeat. In TDD, you write the test case before you write a single line of code. Naturally, the test fails. Next, you write just enough code to satisfy the test so it passes. Test-Driven Development in Microsoft.NET rises head and shoulders above the other books on the subject. While I know that is a very strong statement to make, the authors have made the focus of the book a very practical one. Don't get me wrong, there are several other great books on this subject, but they all seem to fall down when it comes to real-world situations. Learn how to apply the concepts and techniques of Test-Driven Development (TDD) to writing software for Microsoft .NET. Two experts in agile software development teach-using a wealth of pragmatic examples in C# and other .NET development tools-how to use automated tests to drive lean, efficient coding and better design. You'll focus on .NET-specific issues for TDD, including the best time to employ the inherent features of .NET class libraries and how to use NUnit, a leading unit-testing framework for .NET. And you'll see real-world examples of TDD-for .NET projects, including a Micr...