Framework Design Guidelines
Conventions, Idioms, and Patterns for Reusable .NET Libraries

Krzysztof Cwalina
Brad Abrams

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Praise for *Framework Design Guidelines*

“*Framework Design Guidelines* is one of those rare books that can be read at different reading levels and can be useful to different kinds of developers. Regardless of whether you want to design an effective object model, improve your understanding of the .NET Framework, borrow from the experience of software gurus, stay clear of the most common programming mistakes, or just get an idea of the huge effort that led to the .NET initiative, this book is a must-read.”

—Francesco Balena, The VB Migration Partner Team (www.vbmigration.com), Code Architect, Author, and Microsoft Regional Director, Italy

“Frameworks are valuable but notoriously difficult to construct: your every decision must be geared toward making them easy to be used correctly and difficult to be used incorrectly. This book takes you through a progression of recommendations that will eliminate many of those downstream ‘I wish I’d known that earlier’ moments. I wish I’d read it earlier.”

—Paul Besly, Principal Technologist, QA

“Not since Brooks’ *The Mythical Man Month* has the major software maker of its time produced a book so full of relevant advice for the modern software developer. This book has a permanent place on my bookshelf and I consult it frequently.”

—George Byrkit, Senior Software Engineer, Genomic Solutions

“Updated for the new language features of the .NET Framework 3.0 and 3.5, this book continues to be the definitive resource for .NET developers and architects who are designing class library frameworks. Some of the existing guidelines have been expanded with new annotations and more detail, and new guidance covering such features as extension methods and nullable types has also been included. The guidance will help any developer write clearer and more understandable code, while the annotations provide invaluable insight into some of the design decisions that made the .NET Framework what it is today.”

—Scott Dorman, Microsoft MVP and President, Tampa Bay International Association of Software Architects
“Filled with information useful to developers and architects of all levels, this book provides practical guidelines and expert background information to get behind the rules. *Framework Design Guidelines* takes the already published guidelines to a higher level, and it is needed to write applications that integrate well in the .NET area.”

—Cristof Falk, Software Engineer

“This book is an absolute must read for all .NET developers. It gives clear ‘do’ and ‘don’t’ guidance on how to design class libraries for .NET. It also offers insight into the design and creation of .NET that really helps developers understand the reasons why things are the way they are. This information will aid developers designing their own class libraries and will also allow them to take advantage of the .NET class library more effectively.”

—Jeffrey Richter, Author/Trainer/Consultant, Wintellect

“The second edition of *Framework Design Guidelines* gives you new, important insight into designing your own class libraries: Abrams and Cwalina frankly discuss the challenges of adding new features to shipping versions of their products with minimal impact on existing code. You’ll find great examples of how to create version N+1 of your software by learning how the .NET class library team created versions 2.0, 3.0, and 3.5 of the .NET library. They were able to add generics, WCF, WPF, WF, and LINQ with minimal impact on the existing APIs, even providing capabilities for customers wanting to use only some of the new features, while still maintaining compatibility with the original library.”

—Bill Wagner, Founder and Consultant, SRT Solutions, author of *Effective C#* and *More Effective C#*

“This book is a must read for all architects and software developers thinking about frameworks. The book offers insight into some driving factors behind the design of the .NET Framework. It should be considered mandatory reading for anybody tasked with creating application frameworks.”

—Peter Winkler, Sr. Software Engineer, Balance Technology Inc.
The award-winning Microsoft .NET Development Series was established in 2002 to provide professional developers with the most comprehensive, practical coverage of the latest .NET technologies. Authors in this series include Microsoft architects, MVPs, and other experts and leaders in the field of Microsoft development technologies. Each book provides developers with the vital information and critical insight they need to write highly effective applications.

Visit informit.com/msdotnetseries for a complete list of available products.
To my wife, Ela,
for her support throughout the long process of writing this book,
and to my parents,
Jadwiga and Janusz, for their encouragement.
—Krzysztof Cwalina

To my wife, Tamara:
Your love and patience strengthen me.
—Brad Abrams
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Contents

Figures xvii
Tables xix
Foreword xxi
Foreword to the First Edition xxiii
Preface xxv
Acknowledgments xxxi
About the Authors xxxiii
About the Annotators xxxv

1 Introduction 1
1.1 Qualities of a Well-Designed Framework 3
1.1.1 Well-Designed Frameworks Are Simple 3
1.1.2 Well-Designed Frameworks Are Expensive to Design 4
1.1.3 Well-Designed Frameworks Are Full of Trade-Offs 5
1.1.4 Well-Designed Frameworks Borrow from the Past 5
1.1.5 Well-Designed Frameworks Are Designed to Evolve 5
1.1.6 Well-Designed Frameworks Are Integrated 6
1.1.7 Well-Designed Frameworks Are Consistent 6

2 Framework Design Fundamentals 9
2.1 Progressive Frameworks 11
2.2 Fundamental Principles of Framework Design 14
   2.2.1 The Principle of Scenario-Driven Design 15
   2.2.2 The Principle of Low Barrier to Entry 21
4.3 Choosing Between Class and Interface 88
4.4 Abstract Class Design 95
4.5 Static Class Design 97
4.6 Interface Design 98
4.7 Struct Design 101
4.8 Enum Design 103
  4.8.1 Designing Flag Enums 110
  4.8.2 Adding Values to Enums 114
4.9 Nested Types 115
4.10 Types and Assembly Metadata 118

5 Member Design 121
5.1 General Member Design Guidelines 121
  5.1.1 Member Overloading 121
  5.1.2 Implementing Interface Members Explicitly 128
  5.1.3 Choosing Between Properties and Methods 132
5.2 Property Design 138
  5.2.1 Indexed Property Design 140
  5.2.2 Property Change Notification Events 142
5.3 Constructor Design 144
  5.3.1 Type Constructor Guidelines 151
5.4 Event Design 153
  5.4.1 Custom Event Handler Design 159
5.5 Field Design 159
5.6 Extension Methods 162
5.7 Operator Overloads 168
  5.7.1 Overloading Operator == 173
  5.7.2 Conversion Operators 173
5.8 Parameter Design 175
  5.8.1 Choosing Between Enum and Boolean Parameters 177
  5.8.2 Validating Arguments 179
  5.8.3 Parameter Passing 183
  5.8.4 Members with Variable Number of Parameters 186
  5.8.5 Pointer Parameters 190
6 Designing for Extensibility 193
   6.1 Extensibility Mechanisms 193
      6.1.1 Unsealed Classes 194
      6.1.2 Protected Members 196
      6.1.3 Events and Callbacks 197
      6.1.4 Virtual Members 201
      6.1.5 Abstractions (Abstract Types and Interfaces) 203
   6.2 Base Classes 206
   6.3 Sealing 207

7 Exceptions 211
   7.1 Exception Throwing 216
   7.2 Choosing the Right Type of Exception to Throw 221
      7.2.1 Error Message Design 225
      7.2.2 Exception Handling 227
      7.2.3 Wrapping Exceptions 232
   7.3 Using Standard Exception Types 234
      7.3.1 Exception and SystemException 234
      7.3.2 ApplicationException 234
      7.3.3 InvalidOperationException 235
      7.3.4 ArgumentException, ArgumentNullException, and ArgumentOutOfRangeException 235
      7.3.5 NullReferenceException, IndexOutOfRangeException, and AccessViolationException 237
      7.3.6 StackOverflowException 237
      7.3.7 OutOfMemoryException 238
      7.3.8 ComException, SEHException, and ExecutionEngine­Exception 239
   7.4 Designing Custom Exceptions 239
   7.5 Exceptions and Performance 240
      7.5.1 Tester-Doer Pattern 241
      7.5.2 Try-Parse Pattern 242
8 Usage Guidelines 245
8.1 Arrays 245
8.2 Attributes 247
8.3 Collections 250
  8.3.1 Collection Parameters 252
  8.3.2 Collection Properties and Return Values 253
  8.3.3 Choosing Between Arrays and Collections 258
  8.3.4 Implementing Custom Collections 259
8.4 DateTime and DateTimeOffset 261
8.5 ICloneable 263
8.6 IComparable<T> and IEquatable<T> 264
8.7 IDisposable 266
8.8 Nullable<T> 266
8.9 Object 268
  8.9.1 Object.Equals 268
  8.9.2 Object.GetHashCode 270
  8.9.3 Object.ToString 271
8.10 Serialization 274
  8.10.1 Choosing the Right Serialization Technology to Support 275
  8.10.2 Supporting Data Contract Serialization 276
  8.10.3 Supporting XML Serialization 280
  8.10.4 Supporting Runtime Serialization 281
8.11 Uri 283
  8.11.1 System.Uri Implementation Guidelines 284
8.12 System.Xml Usage 284
8.13 Equality Operators 286
  8.13.1 Equality Operators on Value Types 287
  8.13.2 Equality Operators on Reference Types 287

9 Common Design Patterns 289
9.1 Aggregate Components 289
  9.1.1 Component-Oriented Design 291
  9.1.2 Factored Types 294
  9.1.3 Aggregate Component Guidelines 295
9.2 The Async Patterns 298
   9.2.1 Choosing Between the Async Patterns 298
   9.2.2 Classic Async Pattern 300
   9.2.3 Classic Async Pattern Basic Implementation Example 304
   9.2.4 Event-Based Async Pattern 305
   9.2.5 Supporting Out and Ref Parameters 307
   9.2.6 Supporting Cancellation 308
   9.2.7 Supporting Progress Reporting 309
   9.2.8 Supporting Incremental Results 311
9.3 Dependency Properties 312
   9.3.1 Dependency Property Design 313
   9.3.2 Attached Dependency Property Design 315
   9.3.3 Dependency Property Validation 316
   9.3.4 Dependency Property Change Notifications 317
   9.3.5 Dependency Property Value Coercion 318
9.4 Dispose Pattern 319
   9.4.1 Basic Dispose Pattern 322
   9.4.2 Finalizable Types 328
9.5 Factories 332
9.6 LINQ Support 337
   9.6.1 Overview of LINQ 337
   9.6.2 Ways of Implementing LINQ Support 339
   9.6.3 Supporting LINQ through IEnumerable<T> 339
   9.6.4 Supporting LINQ through IQueryable<T> 340
   9.6.5 Supporting LINQ through the Query Pattern 341
9.7 Optional Feature Pattern 344
9.8 Simulating Covariance 348
9.9 Template Method 354
9.10 Timeouts 356
9.11 XAML Readable Types 358
9.12 And in the End... 361

A C# Coding Style Conventions 363
   A.1 General Style Conventions 364
      A.1.1 Brace Usage 364
      A.1.2 Space Usage 365
Contents

A.1.3  Indent Usage  367  
A.1.4  Other  367  
A.2  Naming Conventions  367  
A.3  Comments  368  
A.4  File Organization  369

B  Using FxCop to Enforce the Framework Design Guidelines  371
B.1  What Is FxCop?  371  
B.2  The Evolution of FxCop  372  
B.3  How Does It Work?  373  
B.4  FxCop Guideline Coverage  374
   B.4.1  FxCop Rules for the Naming Guidelines  374  
   B.4.2  FxCop Rules for the Type Design Guidelines  384  
   B.4.3  FxCop Rules for Member Design  387  
   B.4.4  FxCop Rules for Designing for Extensibility  394  
   B.4.5  FxCop Rules for Exceptions  395  
   B.4.6  FxCop Rules for Usage Guidelines  397  
   B.4.7  FxCop Rules for Design Patterns  402

C  Sample API Specification  405

Glossary  413
Suggested Reading List  419
Index  423
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Figures

**Figure 2-1:** Learning curve of a multiframework platform  12  
**Figure 2-2:** Learning curve of a progressive framework platform  13  
**Figure 4-1:** The logical grouping of types  77  
**Figure 9-1:** Query Pattern Method Signatures  341
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Tables

Table 3-1: Capitalization Rules for Different Types of Identifiers  40
Table 3-2: Capitalization and Spelling for Common Compound Words and Common Terms  43
Table 3-3: CLR Type Names for Language-Specific Type Names  50
Table 3-4: Name Rules for Types Derived from or Implementing Certain Core Types  65
Table 5-1: Operators and Corresponding Method Names  172
Table 8-1: .NET Framework Serialization Technologies  274
Table B-1: Suffixes for Common Base Types and Interfaces  379
Table B-2: Symmetric Operators  392
Table B-3: Exceptions to Avoid Throwing  396
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When the .NET Framework was first published, I was fascinated by the technology. The benefits of the CLR (Common Language Runtime), its extensive APIs, and the C# language were immediately obvious. But underneath all the technology were a common design for the APIs and a set of conventions that were used everywhere. This was the .NET culture. Once you had learned a part of it, it was easy to translate this knowledge into other areas of the Framework.

For the past 16 years, I have been working on open source software. Since contributors span not only multiple backgrounds but multiple years, adhering to the same style and coding conventions has always been very important. Maintainers routinely rewrite or adapt contributions to software to ensure that code adheres to project coding standards and style. It is always better when contributors and people who join a software project follow conventions used in an existing project. The more information that can be conveyed through practices and standards, the simpler it becomes for future contributors to get up-to-speed on a project. This helps the project converge code, both old and new.

As both the .NET Framework and its developer community have grown, new practices, patterns, and conventions have been identified. Brad and Krzysztof have become the curators who turned all of this new knowledge into the present-day guidelines. They typically blog about a new convention, solicit feedback from the community, and keep track of
these guidelines. In my opinion, their blogs are must-read documents for everyone who is interested in getting the most out of the .NET Framework.

The first edition of *Framework Design Guidelines* became an instant classic in the Mono community for two valuable reasons. First, it provided us a means of understanding why and how the various .NET APIs had been implemented. Second, we appreciated it for its invaluable guidelines that we too strived to follow in our own programs and libraries. This new edition not only builds on the success of the first but has been updated with new lessons that have since been learned. The annotations to the guidelines are provided by some of the lead .NET architects and great programmers who have helped shape these conventions.

In conclusion, this text goes beyond guidelines. It is a book that you will cherish as the “classic” that helped you become a better programmer, and there are only a select few of those in our industry.

Miguel de Icaza
Boston, MA
Foreword to the First Edition

In the early days of development of the .NET Framework, before it was even called that, I spent countless hours with members of the development teams reviewing designs to ensure that the final result would be a coherent platform. I have always felt that a key characteristic of a framework must be consistency. Once you understand one piece of the framework, the other pieces should be immediately familiar.

As you might expect from a large team of smart people, we had many differences of opinion—there is nothing like coding conventions to spark lively and heated debates. However, in the name of consistency, we gradually worked out our differences and codified the result into a common set of guidelines that allow programmers to understand and use the Framework easily.

Brad Abrams, and later Krzysztof Cwalina, helped capture these guidelines in a living document that has been continuously updated and refined during the past six years. The book you are holding is the result of their work.

The guidelines have served us well through three versions of the .NET Framework and numerous smaller projects, and they are guiding the development of the next generation of APIs for the Microsoft Windows operating system.
With this book, I hope and expect that you will also be successful in making your frameworks, class libraries, and components easy to understand and use.

Good luck and happy designing.

Anders Hejlsberg
Redmond, WA
June 2005
Preface

This book, *Framework Design Guidelines*, presents best practices for designing frameworks, which are reusable object-oriented libraries. The guidelines are applicable to frameworks in various sizes and scales of reuse, including the following:

- Large system frameworks, such as the .NET Framework, usually consisting of thousands of types and used by millions of developers.
- Medium-size reusable layers of large distributed applications or extensions to system frameworks, such as the Web Services Enhancements.
- Small components shared among several applications, such as a grid control library.

It is worth noting that this book focuses on design issues that directly affect the programmability of a framework (publicly accessible APIs\(^1\)). As a result, we generally do not cover much in terms of implementation details. Just as a user interface design book doesn’t cover the details of how to implement hit testing, this book does not describe how to implement a binary sort, for example. This scope allows us to provide a definitive guide for framework designers instead of being yet another book about programming.

---

1. This includes public types, and their public, protected, and explicitly implemented members of these types.
These guidelines were created in the early days of .NET Framework development. They started as a small set of naming and design conventions but have been enhanced, scrutinized, and refined to a point where they are generally considered the canonical way to design frameworks at Microsoft. They carry the experience and cumulative wisdom of thousands of developer hours over three versions of the .NET Framework. We tried to avoid basing the text purely on some idealistic design philosophies, and we think its day-to-day use by development teams at Microsoft has made it an intensely pragmatic book.

The book contains many annotations that explain trade-offs, explain history, amplify, or provide critiquing views on the guidelines. These annotations are written by experienced framework designers, industry experts, and users. They are the stories from the trenches that add color and setting for many of the guidelines presented.

To make them more easily distinguished in text, namespace names, classes, interfaces, methods, properties, and types are set in monospace font.

The book assumes basic familiarity with .NET Framework programming. A few guidelines assume familiarity with features introduced in version 3.5 of the Framework. If you are looking for a good introduction to Framework programming, there are some excellent suggestions in the Suggested Reading List at the end of the book.

Guideline Presentation

The guidelines are organized as simple recommendations using Do, Consider, Avoid, and Do not. Each guideline describes either a good or bad practice, and all have a consistent presentation. Good practices have a ✓ in front of them, and bad practices have an ✗ in front of them. The wording of each guideline also indicates how strong the recommendation is. For example, a Do guideline is one that should always2 be followed (all examples are from this book):

---

2. Always might be a bit too strong a word. There are guidelines that should literally be always followed, but they are extremely rare. On the other hand, you probably need to have a really unusual case for breaking a Do guideline and still have it be beneficial to the users of the framework.
DO name custom attribute classes with the suffix “Attribute.”

public class ObsoleteAttribute : Attribute { ... }

On the other hand, Consider guidelines should generally be followed, but if you fully understand the reasoning behind a guideline and have a good reason to not follow it anyway, you should not feel bad about breaking the rules:

CONSIDER defining a struct instead of a class if instances of the type are small and commonly short-lived or are commonly embedded in other objects.

Similarly, Do not guidelines indicate something you should almost never do:

DO NOT assign instances of mutable types to read-only fields.

Less strong, Avoid guidelines indicate that something is generally not a good idea, but there are known cases where breaking the rule makes sense:

AVOID using ICollection<T> or ICollection as a parameter just to access the Count property.

Some more complex guidelines are followed by additional background information, illustrative code samples, and rationale:

DO implement IEquatable<T> on value types.

The Object.Equals method on value types causes boxing and its default implementation is not very efficient because it uses reflection. IEquatable<T>.Equals can offer much better performance and can be implemented so it does not cause boxing.

public struct Int32 : IEquatable<Int32> {
    public bool Equals(Int32 other){ ... }
}
Language Choice and Code Examples

One of the goals of the Common Language Runtime (CLR) is to support a variety of programming languages: those with implementations provided by Microsoft, such as C++, VB, C#, F#, Python, and Ruby, as well as third-party languages such as Eiffel, COBOL, Fortran, and others. Therefore, this book was written to be applicable to a broad set of languages that can be used to develop and consume modern frameworks.

To reinforce the message of multilanguage framework design, we considered writing code examples using several different programming languages. However, we decided against this. We felt that using different languages would help to carry the philosophical message, but it could force readers to learn several new languages, which is not the objective of this book.

We decided to choose a single language that is most likely to be readable to the broadest range of developers. We picked C#, because it is a simple language from the C family of languages (C, C++, Java, and C#), a family with a rich history in framework development.

Choice of language is close to the hearts of many developers, and we offer apologies to those who are uncomfortable with our choice.

About This Book

This book offers guidelines for framework design from the top down.

Chapter 1, “Introduction,” is a brief orientation to the book, describing the general philosophy of framework design. This is the only chapter without guidelines.

Chapter 2, “Framework Design Fundamentals,” offers principles and guidelines that are fundamental to overall framework design.

Chapter 3, “Naming Guidelines,” contains common design idioms and naming guidelines for various parts of a framework, such as namespaces, types, and members.

Chapter 4, “Type Design Guidelines,” provides guidelines for the general design of types.
Chapter 5, “Member Design,” takes a further step and presents guidelines for the design of members of types.

Chapter 6, “Designing for Extensibility,” presents issues and guidelines that are important to ensure appropriate extensibility in your framework.

Chapter 7, “Exceptions,” presents guidelines for working with exceptions, the preferred error reporting mechanisms.


Chapter 9, “Common Design Patterns,” offers guidelines and examples of common framework design patterns.


Appendix B, “Using FxCop to Enforce the Framework Design Guidelines,” describes a tool called FxCop. The tool can be used to analyze framework binaries for compliance with the guidelines described in this book. A link to the tool is included on the DVD that accompanies this book.

Appendix C, “Sample API Specification,” is a sample of an API specification that framework designers within Microsoft create when designing APIs.

Included with the book is a DVD that contains several hours of video presentations covering topics presented in this book by the authors, a sample API specification, and other useful resources.
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Acknowledgments

This book, by its nature, is the collected wisdom of many hundreds of people, and we are deeply grateful to all of them.

Many people within Microsoft have worked long and hard, over a period of years, proposing, debating, and finally, writing many of these guidelines. Although it is impossible to name everyone who has been involved, a few deserve special mention: Chris Anderson, Erik Christensen, Jason Clark, Joe Duffy, Patrick Dussud, Anders Hejlsberg, Jim Miller, Michael Murray, Lance Olson, Eric Gunnerson, Dare Obasanjo, Steve Starck, Kit George, Mike Hillberg, Greg Schecter, Mark Boulter, Asad Jawahar, Justin Van Patten, and Mircea Trofin.

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Their insights provide much needed commentary, color, humor, and history that add tremendous value to this book.

Sheridan Harrison and David Kean actually wrote and edited Appendix B on FxCop, which would not have been done without their skill and passion for this tool.
For all of the help, reviews, and support, both technical and moral, we thank Martin Heller. And for their insightful and helpful comments, we appreciate Pierre Nallet, George Byrkit, Khristof Falk, Paul Besley, Bill Wagner, and Peter Winkler.

We would also like to give special thanks to Susann Ragsdale, who turned this book from a semi-random collection of disconnected thoughts into seamlessly flowing prose. Her flawless writing, patience, and fabulous sense of humor made the process of writing this book so much easier.
About the Authors

Brad Abrams was a founding member of the Common Language Runtime and .NET Framework teams at Microsoft Corporation. He has been designing parts of the .NET Framework since 1998 and is currently Group Program Manager of the .NET Framework team. Brad started his framework design career building the Base Class Library (BCL) that ships as a core part of the .NET Framework. Brad was also the lead editor on the Common Language Specification (CLS), the .NET Framework Design Guidelines, and the libraries in the ECMA\ISO CLI Standard. Brad has authored and coauthored multiple publications, including Programming in the .NET Environment and .NET Framework Standard Library Annotated Reference, Volumes 1 and 2. Brad graduated from North Carolina State University with a B.S. in computer science. You can find his most recent musings on his blog at http://blogs.msdn.com/BradA.

Krzysztof Cwalina is a program manager on the .NET Framework team at Microsoft. He was a founding member of the .NET Framework team and throughout his career has designed many .NET Framework APIs and framework development tools, such as FxCop. He is currently leading a companywide effort to develop, promote, and apply framework design and architectural guidelines to the .NET Framework. He is also leading the team responsible for delivering core .NET Framework APIs. Krzysztof graduated with a B.S. and an M.S. in computer science from the University of Iowa. You can find his blog at http://blogs.msdn.com/kcwalina.
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About the Annotators

Mark Alcazar wanted to be a famous sportsman. After discovering he had no hand-eye coordination or athletic ability, however, he decided a better career might be computers. Mark has been at Microsoft for the last nine years, where he’s worked on the HTML rendering engine in Internet Explorer and has been a member of the Windows Presentation Foundation team since its inception. Mark is a big fan of consistent white space, peach-nectarine Talking Rain, and spicy food. He has a B.Sc. from the University of the West Indies and an M.Sc. from the University of Pennsylvania.

Chris Anderson is an architect at Microsoft in the Connected Systems Division. Chris’s primary focus is on the design and architecture of .NET technologies used to implement the next generation of applications and services. From 2002 until recently he was the lead architect of the WPF team. Chris has written numerous articles and white papers, and he has presented and been a keynote speaker at numerous conferences (Microsoft Professional Developers Conference, Microsoft TechEd, WinDev, DevCon, etc.) worldwide. He has a very popular blog at www.simplegeek.com.

Christopher Brumme joined Microsoft in 1997, when the Common Language Runtime (CLR) team was being formed. Since then, he has contributed to the execution engine portions of the codebase and more broadly to the design. He is currently focused on concurrency issues in managed code. Prior to joining the CLR team, Chris was an architect at Borland and Oracle.
Pablo Castro is a technical lead in the SQL Server team. He has contributed extensively to several areas of SQL Server and the .NET Framework, including SQL-CLR integration, type-system extensibility, the TDS client-server protocol, and the ADO.NET API. Pablo is currently involved with the development of the ADO.NET Entity Framework and also leads the ADO.NET Data Services project, which is looking at how to bring data and Web technologies together. Before joining Microsoft, Pablo worked in various companies on a broad set of topics that range from distributed inference systems for credit scoring/risk analysis to collaboration and groupware applications.

Jason Clark works as a software architect for Microsoft. His Microsoft software engineering credits include three versions of Windows, three releases of the .NET Framework, and WCF. In 2000 he published his first book on software development and continues to contribute to magazines and other publications. He is currently responsible for the Visual Studio Team System Database Edition. Jason’s only other passions are his wife and kids, with whom he happily lives in the Seattle area.

Steven Clarke has been a user experience researcher in the Developer Division at Microsoft since 1999. His main interests are observing, understanding, and modeling the experiences that developers have with APIs in order to help design APIs that provide an optimal experience to their users.

Joe Duffy is the development lead for parallel extensions to .NET at Microsoft. He codes heavily, manages a team of developers, and defines the team’s long-term vision and strategy. Joe previously worked on concurrency in the CLR team and was a software engineer at EMC. While not geeking out, Joe spends his time playing guitar, studying music theory, and blogging at www.bluebytesoftware.com.

Patrick Dussud is a Technical Fellow at Microsoft, where he serves as the chief architect of both the CLR and the .NET Framework architecture groups. He works on .NET Framework issues across the company, helping development teams best utilize the CLR. He specifically focuses on taking advantage of the abstractions the CLR provides to optimize program execution.

Michael Fanning is the current development lead for Expression Web at Microsoft. He was an early member of the team that produced FxCop
for internal use and ultimately added it to Visual Studio 2005 for release to the general public.

**Kit George** is a program manager on the .NET Framework team at Microsoft. He graduated in 1995 with a B.A. in psychology, philosophy, and mathematics from Victoria University of Wellington (New Zealand). Prior to joining Microsoft, he worked as a technical trainer, primarily in Visual Basic. He participated in the design and implementation of the first two releases of the Framework for the last two years.

**Jan Gray** is a software architect at Microsoft who now works on concurrency programming models and infrastructure. He was previously a CLR performance architect, and in the 1990s he helped write the early MS C++ compilers (e.g., semantics, runtime object model, precompiled headers, PDBs, incremental compilation, and linking) and Microsoft Transaction Server. Jan’s interests include building custom multiprocessors in FPGAs.

**Brian Grunkemeyer** has been a software design engineer on the .NET Framework team at Microsoft since 1998. He implemented a large portion of the Framework Class Libraries and contributed to the details of the classes in the ECMA/ISO CLI standard. Brian is currently working on future versions of the .NET Framework, including areas such as generics, managed code reliability, versioning, contracts in code, and improving the developer experience. He has a B.S. in computer science with a double major in cognitive science from Carnegie Mellon University.

**Eric Gunnerson** found himself at Microsoft in 1994 after working in the aerospace and going-out-of-business industries. He has worked on the C++ compiler team, as a member of the C# language design team, and as an early thought follower on the DevDiv community effort. He worked on the Windows DVD Maker UI during Vista and joined the Microsoft HealthVault team in early 2007. He spends his free time cycling, skiing, cracking ribs, building decks, blogging, and writing about himself in the third person.

**Phil Haack** is a program manager with the ASP.NET team working on the ASP.NET MVC Framework, which is being developed in a community-driven transparent manner. The Framework driving goal is to embody and encourage certain principles of good software design: separation of
concerns, testability, and the single responsibility principle, among others. Phil is also a code junkie and loves to both write software as well as write about software development on his blog.

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Jeff Prosise is a cofounder of Wintellect (www.wintellect.com). His most recent book, *Programming Microsoft .NET*, was published by Microsoft Press in 2002, and his writings appear regularly in *MSDN Magazine* and other developer magazines. Jeff’s professional life revolves around ASP.NET, ASP.NET AJAX, and Silverlight. A reformed engineer who discovered after college that there’s more to life than computing loads on
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Herb Sutter is a leading authority on software development. During his career, Herb has been the creator and principal designer of several major commercial technologies, including the PeerDirect peer replication system for heterogeneous distributed databases, the C++/CLI language extensions to C++ for .NET programming, and most recently the Concur concurrent programming model. Currently a software architect at Microsoft, he also serves as chair of the ISO C++ standards committee and is the author of four acclaimed books and hundreds of technical papers and articles on software development topics.

Clemens Szyperski joined Microsoft Research as a software architect in 1999. He focuses on leveraging component software to effectively build new kinds of software. Clemens is cofounder of Oberon Microsystems and its spin-off, Esmertec, and he was an associate professor at the School of Computer Science, Queensland University of Technology, Australia, where he retains an adjunct professorship. He is the author of the Jolt award-winning Component Software (Addison-Wesley) and the coauthor of Software Ecosystem (MIT Press). He has a Ph.D. in computer science from the Swiss Federal Institute of Technology in Zurich and an M.S. in electrical engineering/computer engineering from the Aachen University of Technology.

Mircea Trofin is a program manager with the .NET Application Framework Core group at Microsoft. He is primarily responsible for driving the effort for ensuring and improving the architecture of the .NET Framework. He is also responsible for a number of upcoming features in .NET in the area of component-based programming. He received his B.A.Sc. in computer engineering from University of Waterloo, and his Ph.D. in computer science from University College Dublin.

Paul Vick is the language architect for Visual Basic, leading the language design team. Paul originally began his career working at Microsoft in 1992 on the Microsoft Access team, shipping versions 1.0 through 97 of Access. In 1998, he moved to the Visual Basic team, participating in the design and implementation of the Visual Basic compiler and driving the redesign of the language for the .NET Framework. He is the author of the Visual Basic .NET Language Specification and the Addison-Wesley book The Visual Basic .NET Language. His weblog can be found at www.panopticoncentral.net.
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\textbf{CONSIDER} naming factory types by concatenating the name of the type being created and \texttt{Factory}. For example, consider naming a factory type that creates \texttt{Control} objects \texttt{ControlFactory}.

The next section discusses when and how to design abstractions that might or might not support some features.

\section*{9.6 LINQ Support}

Writing applications that interact with data sources, such as databases, XML documents, or Web Services, was made easier in the .NET Framework 3.5 with the addition of a set of features collectively referred to as LINQ (Language-Integrated Query). The following sections provide a very brief overview of LINQ and list guidelines for designing APIs related to LINQ support, including the so-called Query Pattern.

\subsection*{9.6.1 Overview of LINQ}

Quite often, programming requires processing over sets of values. Examples include extracting the list of the most recently added books from a database of products, finding the e-mail address of a person in a directory service such as Active Directory, transforming parts of an XML document to HTML to allow for Web publishing, or something as frequent as looking up a value in a hashtable. LINQ allows for a uniform language-integrated programming model for querying datasets, independent of the technology used to store that data.

\begin{quote}
\textbf{RICO MARIANI} Like everything else, there are good and bad ways to use these patterns. The Entity Framework and LINQ to SQL offer good examples of how you can provide rich query semantics and still get very good performance using strong typing and by offering query compilation.

The Pit of Success notion is very important in LINQ implementations. I’ve seen some cases where the code that runs as a result of using a LINQ pattern is simply terrible in comparison to what you would write the conventional way. That’s really not good enough—EF and LINQ to SQL let you write it nicely, and you get high-quality database interactions. That’s what to aim for.
\end{quote}
In terms of concrete language features and libraries, LINQ is embodied as:

- A specification of the notion of extension methods. These are described in detail in section 5.6.
- Lambda expressions, a language feature for defining anonymous delegates.
- New types representing generic delegates to functions and procedures: `Func<...>` and `Action<...>`.
- Representation of a delay-compiled delegate, the `Expression<...>` family of types.
- A definition of a new interface, `System.Linq.IQueryable<T>`.
- The Query Pattern, a specification of a set of methods a type must provide in order to be considered as a LINQ provider. A reference implementation of the pattern can be found in `System.Linq.Enumerable` class. Details of the pattern will be discussed later in this chapter.
- Query Expressions, an extension to language syntax allowing for queries to be expressed in an alternative, SQL-like format.

```csharp
// using extension methods:
var names = set.Where(x => x.Age>20).Select(x=>x.Name);

// using SQL-like syntax:
var names = from x in set where x.Age>20 select x.Name;
```

**MIRCEA TROFIN** The interplay between these features is the following: Any `IEnumerable` can be queried upon using the LINQ extension methods, most of which require one or more lambda expressions as parameters; this leads to an in-memory generic evaluation of the queries. For cases where the set of data is not in memory (e.g., in a database) and/or queries may be optimized, the set of data is presented as an `IQueryable`. If lambda expressions are given as parameters, they are transformed by the compiler to `Expression<...>` objects. The implementation of `IQueryable` is responsible for processing said expressions. For example, the implementation of an `IQueryable` representing a database table would translate `Expression` objects to SQL queries.
9.6.2 Ways of Implementing LINQ Support
There are three ways by which a type can support LINQ queries:

- The type can implement IEnumerable<T> (or an interface derived from it).
- The type can implement IQueryable<T>.
- The type can implement the Query Pattern.

The following sections will help you choose the right method of supporting LINQ.

9.6.3 Supporting LINQ through IEnumerable<T>

✓ **DO** implement IEnumerable<T> to enable basic LINQ support.

Such basic support should be sufficient for most in-memory data-sets. The basic LINQ support will use the extension methods on IEnumerable<T> provided in the .NET Framework. For example, simply define as follows:

```csharp
public class RangeOfInt32s : IEnumerable<int> {
    public IEnumerator<int> GetEnumerator() {...}
    IEnumerator IEnumerable.GetEnumerator() {...}
}
```

Doing so allows for the following code, despite the fact that RangeOfInt32s did not implement a Where method:

```csharp
var a = new RangeOfInt32s();
var b = a.Where(x => x > 10);
```

**RICO MARIANI** Keeping in mind that you’ll get your same enumeration semantics, and putting a LINQ façade on them does not make them execute any faster or use less memory.

✓ **CONSIDER** implementing ICollection<T> to improve performance of query operators.
For example, the `System.Linq.Enumerable.Count` method's default implementation simply iterates over the collection. Specific collection types can optimize their implementation of this method, since they often offer an \(O(1)\) - complexity mechanism for finding the size of the collection.

**CONSIDER** supporting selected methods of `System.Linq.Enumerable` or the Query Pattern (see section 9.6.5) directly on new types implementing `IEnumerable<T>` if it is desirable to override the default `System.Linq.Enumerable` implementation (e.g., for performance optimization reasons).

### 9.6.4 Supporting LINQ through `IQueryable<T>`

**CONSIDER** implementing `IQueryable<T>` when access to the query expression, passed to members of `IQueryable`, is necessary.

When querying potentially large datasets generated by remote processes or machines, it might be beneficial to execute the query remotely. An example of such a dataset is a database, a directory service, or Web service.

**DO NOT** implement `IQueryable<T>` without understanding the performance implications of doing so.

Building and interpreting expression trees is expensive, and many queries can actually get slower when `IQueryable<T>` is implemented. The trade-off is acceptable in the LINQ to SQL case, since the alternative overhead of performing queries in memory would have been far greater than the transformation of the expression to an SQL statement and the delegation of the query processing to the database server.

**DO** throw `NotSupportedException` from `IQueryable<T>` methods that cannot be logically supported by your data source.

For example, imagine representing a media stream (e.g., an Internet radio stream) as an `IQueryable<byte>`. The Count method is not logically supported—the stream can be considered as infinite, and so the Count method should throw `NotSupportedException`. 
### 9.6.5 Supporting LINQ through the Query Pattern

The Query Pattern refers to defining the methods in Figure 9-1 without implementing the `IQueryable<T>` (or any other LINQ interface).

Please note that the notation is not meant to be valid code in any particular language but to simply present the type signature pattern.

The notation uses `S` to indicate a collection type (e.g., `IEnumerable<T>`, `ICollection<T>`), and `T` to indicate the type of elements in that collection. Additionally, we use `O<T>` to represent subtypes of `S<T>` that are ordered. For example, `S<T>` is a notation that could be substituted with `IEnumerable<int>`, `ICollection<Foo>`, or even `MyCollection` (as long as the type is an enumerable type).

The first parameter of all the methods in the pattern (marked with this) is the type of the object the method is applied to. The notation uses extension-method-like syntax, but the methods can be implemented as extension methods or as member methods; in the latter case the first parameter should be omitted, of course, and the `this` pointer should be used.

Also, anywhere `Func<...>` is being used, pattern implementations may substitute `Expression<Func<...>>` for it. You can find guidelines later that describe when that is preferable.

### Figure 9-1: Query Pattern Method Signatures

<table>
<thead>
<tr>
<th>Method</th>
<th>Signature</th>
</tr>
</thead>
<tbody>
<tr>
<td><code>S&lt;T&gt; Where(this S&lt;T&gt;, Func&lt;T,bool&gt;)</code></td>
<td></td>
</tr>
<tr>
<td><code>S&lt;T2&gt; Select(this S&lt;T1&gt;, Func&lt;T1,T2&gt;)</code></td>
<td></td>
</tr>
<tr>
<td><code>S&lt;T3&gt; SelectMany(this S&lt;T1&gt;, Func&lt;T1,S&lt;T2&gt;&gt;, Func&lt;T1,T2,T3&gt;)</code></td>
<td></td>
</tr>
<tr>
<td><code>S&lt;T2&gt; SelectMany(this S&lt;T1&gt;, Func&lt;T1,S&lt;T2&gt;&gt;)</code></td>
<td></td>
</tr>
<tr>
<td><code>O&lt;T&gt; OrderBy(this S&lt;T&gt;, Func&lt;T,K&gt;), where K is IComparable</code></td>
<td></td>
</tr>
<tr>
<td><code>O&lt;T&gt; ThenBy(this O&lt;T&gt;, Func&lt;T,K&gt;), where K is IComparable</code></td>
<td></td>
</tr>
<tr>
<td><code>S&lt;T&gt; Union(this S&lt;T&gt;, S&lt;T&gt;)</code></td>
<td></td>
</tr>
<tr>
<td><code>S&lt;T&gt; Take(this S&lt;T&gt;, int)</code></td>
<td></td>
</tr>
<tr>
<td><code>S&lt;T&gt; Skip(this S&lt;T&gt;, int)</code></td>
<td></td>
</tr>
<tr>
<td><code>S&lt;T&gt; SkipWhile(this S&lt;T&gt;, Func&lt;T,bool&gt;)</code></td>
<td></td>
</tr>
<tr>
<td><code>S&lt;T3&gt; Join(this S&lt;T1&gt;, S&lt;T2&gt;, Func&lt;T1,K1&gt;, Func&lt;T2,K2&gt;, Func&lt;T1,T2,T3&gt;)</code></td>
<td></td>
</tr>
<tr>
<td><code>T ElementAt(this S&lt;T&gt;, int)</code></td>
<td></td>
</tr>
</tbody>
</table>
DO implement the Query Pattern as instance members on the new type, if the members make sense on the type even outside of the context of LINQ. Otherwise, implement them as extension methods.

For example, instead of the following:

```csharp
public class MyDataSet<T>:IEnumerable<T>{...}
...
public static class MyDataSetExtensions{
    public static MyDataSet<T> Where(this MyDataSet<T> data, Func<T,bool> query){...}
}
```

Prefer the following, because it’s completely natural for datasets to support Where methods:

```csharp
public class MyDataSet<T>:IEnumerable<T>{
    public MyDataSet<T> Where(Func<T,bool> query){...}
    ...
}
```

DO implement IEnumerable<T> on types implementing the Query Pattern.

CONSIDER designing the LINQ operators to return domain-specific enumerable types. Essentially, one is free to return anything from a Select query method; however, the expectation is that the query result type should be at least enumerable.

This allows the implementation to control which query methods get executed when they are chained. Otherwise, consider a user-defined type MyType, which implements IEnumerable<T>. MyType has an optimized Count method defined, but the return type of the Where method is IEnumerable<T>. In the example here, the optimization is lost after the Where method is called; the method returns IEnumerable<T>, and so the built-in Enumerable.Count method is called, instead of the optimized one defined on MyType.

```csharp
var result = myInstance.Where(query).Count();
```
AVOID implementing just a part of the Query Pattern if fallback to the basic IEnumerable<T> implementations is undesirable.

For example, consider a user-defined type MyType, which implements IEnumerable<T>. MyType has an optimized Count method defined but does not have Where. In the example here, the optimization is lost after the Where method is called; the method returns IEnumerable<T>, and so the built-in Enumerable.Count method is called, instead of the optimized one defined on MyType.

```csharp
var result = myInstance.Where(query).Count();
```

DO represent ordered sequences as a separate type, from its unordered counterpart. Such types should define ThenBy method.

This follows the current pattern in the LINQ to Objects implementation and allows for early (compile-time) detection of errors such as applying ThenBy to an unordered sequence.

For example, the Framework provides the IOrderedEnumerable<T> type, which is returned by OrderBy. The ThenBy extension method is defined for this type, and not for IEnumerable<T>.

DO defer execution of query operator implementations. The expected behavior of most of the Query Pattern members is that they simply construct a new object which, upon enumeration, produces the elements of the set that match the query.

The following methods are exceptions to this rule: All, Any, Average, Contains, Count, ElementAt, Empty, First, FirstOrDefault, Last, LastOrDefault, Max, Min, Single, Sum.

In the example here, the expectation is that the time necessary for evaluating the second line will be independent from the size or nature (e.g., in-memory or remote server) of set1. The general expectation is that this line simply prepares set2, delaying the determination of its composition to the time of its enumeration.

```csharp
var set1 = ...
var set2 = set1.Select(x => x.SomeInt32Property);
foreach(int number in set2){...} // this is when actual work happens
```

DO use Expression<Func<...>> as a parameter instead of Func<...> when it is necessary to inspect the query.

As discussed earlier, interacting with an SQL database is already done through IQueryable<T> (and therefore expressions) rather than IEnumerable<T>, since this gives an opportunity to translate lambda expressions to SQL expressions.

An alternative reason for using expressions is performing optimizations. For example, a sorted list can implement look-up (where clauses) with binary search, which can be much more efficient than the standard IEnumerable<T> or IQueryable<T> implementations.

9.7 Optional Feature Pattern

When designing an abstraction, you might want to allow cases in which some implementations of the abstraction support a feature or a behavior, whereas other implementations do not. For example, stream implementations can support reading, writing, seeking, or any combination thereof.

One way to model these requirements is to provide a base class with APIs for all nonoptional features and a set of interfaces for the optional features. The interfaces are implemented only if the feature is actually supported by a concrete implementation. The following example shows one of many ways to model the stream abstraction using such an approach.

```csharp
// framework APIs
public abstract class Stream {
    public abstract void Close();
    public abstract int Position { get; }
}
public interface IInputStream {
    byte[] Read(int numberOfBytes);
}
```
public interface IOutputStream {
    void Write(byte[] bytes);
}
public interface ISeekableStream {
    void Seek(int position);
}
public interface IFiniteStream {
    int Length { get; }
    bool EndOfStream { get; }
}

// concrete stream
public class FileStream : Stream, IOutputStream, IInputStream, ISeekableStream, IFiniteStream {
    ...
}

// usage
void OverwriteAt(IOutputStream stream, int position, byte[] bytes) {
    // do dynamic cast to see if the stream is seekable
    ISeekableStream seekable = stream as ISeekableStream;
    if (seekable == null) {
        throw new NotSupportedException(...);
    }
    seekable.Seek(position);
    stream.Write(bytes);
}

You will notice the .NET Framework’s System.IO namespace does not follow this model, and with good reason. Such factored design requires adding many types to the framework, which increases general complexity. Also, using optional features exposed through interfaces often requires dynamic casts, and that in turn results in usability problems.

**KRYSZTOF CWALINA** Sometimes framework designers provide interfaces for common combinations of optional interfaces. For example, the OverwriteAt method would not have to use the dynamic cast if the framework design provided ISeekableOutputStream. The problem with this approach is that it results in an explosion of the number of different interfaces for all combinations.

Sometimes the benefits of factored design are worth the drawbacks, but often they are not. It is easy to overestimate the benefits and underestimate
the drawbacks. For example, the factorization did not help the developer who wrote the `OverwriteAt` method avoid runtime exceptions (the main reason for factorization). It is our experience that many designs incorrectly err on the side of too much factorization.

The Optional Feature Pattern provides an alternative to excessive factorization. It has drawbacks of its own but should be considered as an alternative to the factored design described previously. The pattern provides a mechanism for discovering whether the particular instance supports a feature through a query API and uses the features by accessing optionally supported members directly through the base abstraction.

```csharp
// framework APIs
public abstract class Stream {
    public abstract void Close();
    public abstract int Position { get; }

    public virtual bool CanWrite { get { return false; } }
    public virtual void Write(byte[] bytes){
        throw new NotSupportedException(...);
    }

    public virtual bool CanSeek { get { return false; } }
    public virtual void Seek(int position){
        throw new NotSupportedException(...);
    }
    ...
    // other options
}

// concrete stream
public class FileStream : Stream {
    public override bool CanSeek { get { return true; } }
    public override void Seek(int position) { ... }
    }

// usage
void OverwriteAt(Stream stream, int position, byte[] bytes){
    if(!stream.CanSeek || !stream.CanWrite){
        throw new NotSupportedException(...);
    }
    stream.Seek(position);
    stream.Write(bytes);
}
In fact, the System.IO.Stream class uses this design approach. Some abstractions might choose to use a combination of factoring and the Optional Feature Pattern. For example, the Framework collection interfaces are factored into indexable and non-indexable collections (IList<T> and ICollection<T>), but they use the Optional Feature Pattern to differentiate between read-only and read-write collections (ICollection<T>.IsReadOnly property).

**CONSIDER** using the Optional Feature Pattern for optional features in abstractions.

The pattern minimizes the complexity of the framework and improves usability by making dynamic casts unnecessary.

**STEVE STARCK** If your expectation is that only a very small percentage of classes deriving from the base class or interface would actually implement the optional feature or behavior, using interface-based design might be better. There is no real need to add additional members to all derived classes when only one of them provides the feature or behavior. Also, factored design is preferred in cases when the number of combinations of the optional features is small and the compile-time safety afforded by factorization is important.

**DO** provide a simple Boolean property that clients can use to determine whether an optional feature is supported.

```csharp
public abstract class Stream {
    public virtual bool CanSeek { get { return false; } } 
    public virtual void Seek(int position) { ... } 
}
```

Code that consumes the abstract base class can query this property at runtime to determine whether it can use the optional feature.

```csharp
if(stream.CanSeek){
    stream.Seek(position);
}
```
**DO** use virtual methods on the base class that throw NotSupportedException to define optional features.

```csharp
public abstract class Stream {
    public virtual bool CanSeek { get { return false; } }
    public virtual void Seek(int position)
    {
        throw new NotSupportedException(...);
    }
}
```

The method can be overridden by subclasses to provide support for the optional feature. The exception should clearly communicate to the user that the feature is optional and which property the user should query to determine if the feature is supported.

### 9.8 Simulating Covariance

Different constructed types don’t have a common root type. For example, there would not be a common representation of `IEnumerable<string>` and `IEnumerable<object>` if not for a pattern implemented by `IEnumerable<T>` called Simulated Covariance. This section describes the details of the pattern.

Generics is a very powerful type system feature added to the .NET Framework 2.0. It allows creation of so-called parameterized types. For example, `List<T>` is such a type and it represents a list of objects of type `T`. The `T` is specified at the time when the instance of the list is created.

```csharp
var names = new List<string>();
names.Add("John Smith");
names.Add("Mary Johnson");
```

Such generic data structures have many benefits over their nongeneric counterparts. But they also have some—sometimes surprising—limitations. For example, some users expect that a `List<string>` can be cast to `List<object>`, just as a `String` can be cast to `Object`. But unfortunately, the following code won’t even compile.
List<string> names = new List<string>();
List<object> objects = names; // this won’t compile

There is a very good reason for this limitation, and that is to allow for full strong typing. For example, if you could cast List<string> to a List<object> the following incorrect code would compile, but the program would fail at runtime.

static void Main(){
    var names = new List<string>();

    // this of course does not compile, but if it did
    // the whole program would compile, but would be incorrect as it
    // attempts to add arbitrary objects to a list of strings.
    AddObjects((List<object>)names);

    string name = names[0]; // how could this work?
}

// this would (and does) compile just fine.
static void AddObjects(List<object> list){
    list.Add(new object()); // it’s a list of strings, really. Should we throw?
    list.Add(new Button());
}

Unfortunately, this limitation can also be undesired in some scenarios. For example, let’s consider the following type:

public class CountedReference<T> {
    public CountedReference(T value);
    public T Value { get; }
    public int Count { get; }
    public void AddReference();
    public void ReleaseReference();
}

There is nothing wrong with casting a CountedReference<string> to CountedReference<object>, as in the following example.

var reference = new CountedReference<string>(...);
CountedReference<object> obj = reference; // this won’t compile
In general, having a way to represent any instance of this generic type is very useful.

```csharp
// what type should ??? be?
// CountedReference<object> would be nice but it won't work
static void PrintValue(??? anyCountedReference){
    Console.WriteLine(anyCountedReference.Value);
}
```

Of course, `PrintValue` could be a generic method taking `CountedReference<T>` as the parameter.

```csharp
static void PrintValue<T>(CountedReference<T> any){
    Console.WriteLine(any.Value);
}
```

This would be a fine solution in many cases. But it does not work as a general solution and might have negative performance implications. For example, the trick does not work for properties. If a property needed to be typed as “any reference,” you could not use `CountedReference<T>` as the type of the property. In addition, generic methods might have undesirable performance implications. If such generic methods are called with many differently sized type arguments, the runtime will generate a new method for every argument size. This might introduce unacceptable memory consumption overhead.

Unfortunately, unless `CountedReference<T>` implemented the Simulated Covariance Pattern described next, the only common representation of all `CountedReference<T>` instances would be `System.Object`. But `System.Object` is too limiting and would not allow the `PrintValue` method to access the `Value` property.

The reason that casting to `CountedReference<object>` is just fine, but casting to `List<object>` can cause all sorts of problems, is that in case of `CountedReference<object>`, the object appears only in the output position (the return type of `Value` property). In the case of `List<object>`, the object represents both output and input types. For example, `object` is the type of the input to the Add method.
// T does not appear as input to any members except the constructor
public class CountedReference<T> {
    public CountedReference(T value);
    public T Value { get; }
    public int Count { get; }
    public void AddReference();
    public void ReleaseReference();
}

// T does appear as input to members of List<T>
public class List<T> {
    public void Add(T item); // T is an input here
    public T this[int index]{
        get;
        set; // T is actually an input here
    }
}

In other words, we say that in CountedReference<T>, the T is at covariant positions (outputs). In List<T>, the T is at covariant and contravariant (inputs) positions.

To solve the problem of not having a common type representing the root of all constructions of a generic type, you can implement what’s called the Simulated Covariance Pattern.

Consider a generic type (class or interface) and its dependencies described in the code fragment that follows.

public class Foo<T> {
    public T Property1 { get; }
    public T Property2 { set; }
    public T Property3 { get; set; }
    public void Method1(T arg1);
    public T Method2();
    public T Method3(T arg);
    public Type1<T> GetMethod1();
    public Type2<T> GetMethod2();
}

public class Type1<T> {
    public T Property { get; }
}

public class Type2<T> {
    public T Property { get; set; }
}

Create a new interface (root type) with all members containing a T at contravariant positions removed. In addition, feel free to remove all members that might not make sense in the context of the trimmed-down type.

```csharp
public interface IFoo<out T> {
    T Property1 { get; }
    T Property3 { get; } // setter removed
    T Method2();
    Type1<T> GetMethod1();
    IType2<T> GetMethod2(); // note that the return type changed
}
public interface IType2<T> {
    T Property { get; } // setter removed
}
```

The generic type should then implement the interface explicitly and “add back” the strongly typed members (using T instead of object) to its public API surface.

```csharp
public class Foo<T> : IFoo<object> {
    public T Property1 { get; }
    public T Property2 { set; }
    public T Property3 { get; set; }
    public void Method1(T arg1);
    public T Method2();
    public T Method3(T arg);
    public Type1<T> GetMethod1();
    public Type2<T> GetMethod2();

    object IFoo<object>.Property1 { get; }
    object IFoo<object>.Property3 { get; }
    object IFoo<object>.Method2() { return null; }
    Type1<object> IFoo<object>.GetMethod1();
    IType2<object> IFoo<object>.GetMethod2();
}

public class Type2<T> : IType2<object> {
    public T Property { get; set; }
    object IType2<object>.Property { get; }
}
```

Now, all constructed instantiations of Foo<T> have a common root type IFoo<object>.

```csharp
var foos = new List<IFoo<object>>();
foos.Add(new Foo<int>());
foos.Add(new Foo<string>());
```
... 
foreach(IFoo<object> foo in foos){
    Console.WriteLine(foo.Property1);
    Console.WriteLine(foo.GetMethod2().Property);
}

In the case of the simple CountedReference<T>, the code would look like the following:

public interface ICountedReference<out T> {
    T Value { get; }
    int Count { get; }
    void AddReference();
    void ReleaseReference();
}

public class CountedReference<T> : ICountedReference<object> {
    public CountedReference(T value) {...}
    public T Value { get { ... } }
    public int Count { get { ... } }
    public void AddReference(){...}
    public void ReleaseReference(){...}

    object ICountedReference<object>.Value { get { return Value; } }
}

✓ CONSIDER using the Simulated Covariance Pattern if there is a need to have a representation for all instantiations of a generic type.

The pattern should not be used frivolously, because it results in additional types in the framework and can makes the existing types more complex.

✓ DO ensure that the implementation of the root’s members is equivalent to the implementation of the corresponding generic type members.

There should not be an observable difference between calling a member on the root type and calling the corresponding member on the generic type. In many cases, the members of the root are implemented by calling members on the generic type.

public class Foo<T> : IFoo<object> {
    
    public T Property3 { get { ... } set { ... } }
    object IFoo<object>.Property3 { get { return Property3; } }
    ...
}
Common Design Patterns

✓ **CONSIDER** using an abstract class instead of an interface to represent the root.

This might sometimes be a better option, because interfaces are more difficult to evolve (see section 4.3). On the other hand, there are some problems with using abstract classes for the root. Abstract class members cannot be implemented explicitly and the subtypes need to use the new modifier. This makes it tricky to implement the root’s members by delegating to the generic type members.

✓ **CONSIDER** using a nongeneric root type if such type is already available.

For example, `List<T>` implements `IEnumerable` for the purpose of simulating covariance.

### 9.9 Template Method

The Template Method Pattern is a very well-known pattern described in much greater detail in many sources, such as the classic book *Design Patterns* by Gamma et al. Its intent is to outline an algorithm in an operation. The Template Method Pattern allows subclasses to retain the algorithm’s structure while permitting redefinition of certain steps of the algorithm. We are including a simple description of this pattern here, because it is one of the most commonly used patterns in API frameworks.

The most common variation of the pattern consists of one or more non-virtual (usually public) members that are implemented by calling one or more protected virtual members.

```csharp
public Control{
    public void SetBounds(int x, int y, int width, int height){
        ...
        SetBoundsCore (...);
    }

    public void SetBounds(int x, int y, int width, int height, BoundsSpecified specified){
        ...
        SetBoundsCore (...);
    }
}
protected virtual void SetBoundsCore(int x, int y, int width, int height, BoundsSpecified specified)
    {
        // Do the real work here.
    }
}

The goal of the pattern is to control extensibility. In the preceding example, the extensibility is centralized to a single method (a common mistake is to make more than one overload virtual). This helps to ensure that the semantics of the overloads stay consistent, because the overloads cannot be overridden independently.

Also, public virtual members basically give up all control over what happens when the member is called. This pattern is a way for the base class designer to enforce some structure of the calls that happen in the member. The nonvirtual public methods can ensure that certain code executes before or after the calls to virtual members and that the virtual members execute in a fixed order.

As a framework convention, the protected virtual methods participating in the Template Method Pattern should use the suffix “Core.”

**AVOID** making public members virtual.

If a design requires virtual members, follow the template pattern and create a protected virtual member that the public member calls. This practice provides more controlled extensibility.

**CONSIDER** using the Template Method Pattern to provide more controlled extensibility.

In this pattern, all extensibility points are provided through protected virtual members that are called from nonvirtual members.

**CONSIDER** naming protected virtual members that provide extensibility points for nonvirtual members by suffixing the nonvirtual member name with “Core.”

```csharp
public void SetBounds(...)
{
    ...
    SetBoundsCore (...);
}
protected virtual void SetBoundsCore(...){ ... }
```
I like to take the template pattern one step further and implement all argument checking in the nonvirtual public method. This way I can stop garbage entering methods that were possibly overridden by another developer, and it helps to enforce a little more of the API contract across implementations.

9.10 Timeouts

Timeouts occur when an operation returns before its completion because the maximum time allocated for the operation (timeout time) has elapsed. The user often specifies the timeout time. For example, it might take a form of a parameter to a method call.

    server.PerformOperation(timeout);

An alternative approach is to use a property.

    server.Timeout = timeout;
    server.PerformOperation();

The following short list of guidelines describes best practices for the design of APIs that need to support timeouts.

✔ **DO** prefer method parameters as the mechanism for users to provide timeout time.

Method parameters are favored over properties because they make the association between the operation and the timeout much more apparent. The property-based approach might be better if the type is designed to be a component used with visual designers.

✔ **DO** prefer using **TimeSpan** to represent timeout time.
Historically, timeouts have been represented by integers. Integer timeouts can be hard to use for the following reasons:

- It is not obvious what the unit of the timeout is.
- It is difficult to translate units of time into the commonly used millisecond. (How many milliseconds are in 15 minutes?)

Often, a better approach is to use TimeSpan as the timeout type. TimeSpan solves the preceding problems.

```csharp
class Server {
    void PerformOperation(TimeSpan timeout){
        ...
    }
}

var server = new Server();
server.PerformOperation(TimeSpan.FromMinutes(15));
```

Integer timeouts are acceptable if:

- The parameter or property name can describe the unit of time used by the operation, for example, if a parameter can be called milliseconds without making an otherwise self-describing API cryptic.
- The most commonly used value is small enough that users won’t have to use calculators to determine the value, for example, if the unit is milliseconds and the commonly used timeout is less than 1 second.

√ **DO** throw System.TimeoutException when a timeout elapses.

Timeout equal to TimeSpan.Zero means that the operation should throw if it cannot complete immediately. If the timeout equals TimeSpan.MaxValue, the operation should wait forever without timing out. Operations are not required to support either of these values, but they should throw an ArgumentException if an unsupported timeout value is specified.

If a timeout expires and the System.TimeoutException is thrown, the server class should cancel the underlying operation.
In the case of an asynchronous operation with a timeout, the callback should be called and an exception thrown when the results of the operation are first accessed.

```csharp
void OnReceiveCompleted(Object source, ReceiveCompletedEventArgs asyncResult)
{
    MessageQueue queue = (MessageQueue)source;
    // the following line will throw if BeginReceive has timed out
    Message message = queue.EndReceive(asyncResult.AsyncResult);
    Console.WriteLine("Message: "+(string)message.Body);
    queue.BeginReceive(new TimeSpan(1,0,0));
}
```

For more information on timeouts and asynchronous operation, see section 9.2.

✗ **DO NOT** return error codes to indicate timeout expiration.

Expiration of a timeout means the operation could not complete successfully and thus should be treated and handled as any other runtime error (see Chapter 7).

### 9.11 XAML Readable Types

XAML is an XML format used by WPF (and other technologies) to represent object graphs. The following guidelines describe design considerations for ensuring that your types can be created using XAML readers.

✔ **CONSIDER** providing the default constructor if you want a type to work with XAML.

For example, consider the following XAML markup:

```xml
<Person Name="John" Age="22" />
```

It is equivalent to the following C# code:

```csharp
new Person() { Name = "John", Age = 22 };```

Consequently, for this code to work, the `Person` class needs to have a default constructor. Markup extensions, discussed in the next guideline in this section, are an alternative way of enabling XAML.
In my opinion, this one should really be a DO, not a CONSIDER. If you’re designing a new type to support XAML, it’s far preferable to do it with a default constructor than with markup extensions or type converters.

**DO** provide markup extension if you want an immutable type to work with XAML readers.

Consider the following immutable type:

```csharp
public class Person {
    public Person(string name, int age){
        this.name = name;
        this.age = age;
    }
    public string Name { get { return name; } }
    public int Age { get { return age; } }

    string name;
    int age;
}
```

Properties of such type cannot be set using XAML markup, because the reader does not know how to initialize the properties using the parameterized constructor. Markup extensions address the problem.

```csharp
[MarkupExtensionReturnType(typeof(Person))]
public class PersonExtension : MarkupExtension {
    public string Name { get; set; }
    public int Age { get; set; }

    public override object ProvideValue(IServiceProvider serviceProvider){
        return new Person(this.Name,this.Age);
    }
}
```

Keep in mind that immutable types cannot be written using XAML writers.

**AVOID** defining new type converters unless the conversion is natural and intuitive. In general, limit type converter usage to the ones already provided by the .NET Framework.
Type converters are used to convert a value from a string to the appropriate type. They’re used by XAML infrastructure and in other places, such as graphical designers. For example, the string “#FFFF0000” in the following markup gets converted to an instance of a red Brush thanks to the type converter associated with the Rectangle.Fill property.

```xml
<Rectangle Fill="#FFFF0000"/>
```

But type converters can be defined too liberally. For example, the Brush type converter should not support specifying gradient brushes, as shown in the following hypothetical example.

```xml
<Rectangle Fill="HorizontalGradient White Red"/>
```

Such converters define new “minilanguages,” which add complexity to the system.

✓ **CONSIDER** applying the ContentPropertyAttribute to enable convenient XAML syntax for the most commonly used property.

```csharp
[ContentProperty("Image")]
public class Button {
    public object Image { get; set; }
}
```

The following XAML syntax would work without the attribute:

```xml
<Button>
    <Button.Image>
        <Image Source="foo.jpg"/>
    </Button.Image>
</Button>
```

The attribute makes the following much more readable syntax possible.

```xml
<Button>
    <Image Source="foo.jpg"/>
</Button>
```
9.12 And in the End...

The process of creating a great framework is demanding. It requires dedication, knowledge, practice, and a lot of hard work. But in the end, it can be one of the most fulfilling jobs software engineers ever get to do. Large system frameworks can enable millions to build software that was not possible before. Application extensibility frameworks can turn simple applications into powerful platforms and make them shine. Finally, reusable component frameworks can inspire and enable developers to take their applications beyond the ordinary. When you create a framework like that, please let us know. We would like to congratulate you.
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Index

A
Abbreviations, 48, 377
Abstract classes
  choosing between interfaces and, 88–94
  constructor design for, 148
designing, 95–97
extensibility using, 78
FxCop rules for, 384
implementing abstractions as, 203–205
Optional Feature Pattern and,
  344–348
Abstract types
  abstract class design, 95
  choosing between interfaces and, 93, 203–205, 384
defined, 417
Abstractions
  implementing with base classes,
    206–207
  in low vs. high-level APIs, 33–36
  providing extensibility with, 203–205
  in scenario-driven design, 17
  in self-documenting APIs, 31–32
  using classes vs. interfaces, 86–95
AccessViolationException, 237
Acronyms
  avoiding in framework identifiers, 49
capitalization rules for, 40–42, 375
correct spelling of, 377
naming conventions for, 48
Action<> delegates, 198–200
Addition through subtraction, 24
Adjective phrases, naming interfaces,
  60–61
Aggregate Components, 289–298
  component-oriented design, 291–294
design guidelines, 295–298
  factored types, 294–295
  overview of, 289–291
Alias names, avoiding, 50
API specification, sample, 405–412
  API specification, 407–408
  functional specification, 409–412
  overview of, 406
  requirements, 406
APIs, naming new versions of, 51–54,
  378
_AppDomain, 63
Application model
  defined, 417
  namespaces, 58–59
Argument exceptions
  ArgumentException, 235–236
  ArgumentNullException, 180, 235–236
  ArgumentOutOfRangeException, 235–236
  FxCop rules for, 396
Arguments
  avoiding space between, 366
  validating, 179–183
ArrayList, 251
Arrays
  choosing between collections and, 245, 258–259
  FxCop rules for, 387
  of reference vs. value types, 84–85
  usage guidelines, 245–247, 397–398
  using params, 186–189
  working with properties that return, 136–138
ASP.NET, layered architecture, 35–36
Assemblies
  defined, 417
  FxCop rules for naming, 378
  naming conventions, 54–55
  type design guidelines, 118–119
AssemblyCopyrightAttribute, 119
AssemblyFileVersionAttribute, 119
AssemblyVersionAttribute, 119
Assignments, 85
Async Patterns, 298–312
  choosing between, 298–300
  Classic Async Pattern, 300–304
  Classic Async Pattern example, 304–305
  Event-Based Async Pattern, 305–312
  overview of, 298
Asynchronous methods, Event-Based
  Async Pattern, 305–307
Attached dependency property, 315–316, 417
Attribute class, 247
Attributes
  assembly, 119
  defined, 417
  usage guidelines, 247–250, 398
  using properties vs. methods, 134–135
AttributeUsageAttribute, 248, 398

B
Base classes
  designing for extensibility, 206–207, 394
  naming conventions, 62–63
Basic Dispose Pattern
  finalizable types and, 328–332
  overview of, 322–328
  when to implement, 321–322
beforefieldinit metadata, 389
Begin method, Classic Async Pattern, 301–303, 305
Binary operators, 366
Blogs, suggested, 415
Blue screens, Windows, 214
Books, suggested reading list, 413–415
Boolean properties
  choosing for parameters, 177–179
  implementing Optional Feature Pattern, 347
  selecting names for, 69–70
Boxing, 417
Brace usage, 364–367

C
C# coding style conventions, 363–370
  brace usage, 364–365
  comments, 368–369
  file organization, 369–370
  indent usage, 367
  naming conventions, 367–368
  space usage, 365–366
  var keyword usage, 367
Callbacks
  Data Contract Serialization, 277
  defined, 417
  mechanisms of, 153
  providing extensibility with, 197–201
camelCasing convention
  C# coding style, 368
  capitalizing acronyms, 41
  FxCop rules for, 375
  parameter names using, 39–40, 73–74
Cancellation, Event-Based Async Pattern, 308–309
Capitalization conventions, 38–46
  acronyms, 40–42
  case sensitivity, 45–46
  common terms, 43–46
  compound words, 43–46
  defined, 38
  FxCop rules for, 374–375, 383
  identifiers, 38–40
Case sensitivity, 45–46, 376
Case statements, omitting braces in, 365
Change notifications, 142–144, 317–318
Class constructors. See Type constructors

Classes
- base. See Base classes
- choosing interfaces vs., 88–95
- choosing structs vs., 84–88
- FxCop rules for, 384–385
- naming conventions, 60–67, 379–381
- as reference types, 78
- sealing, 207–210
- unsealed, 194–195

Classic Async Pattern
- choosing between async patterns, 298–300
- example, 304–305
- overview of, 300–304

CLI (Common Language Infrastructure), 414

Client-first programming test, 3

Clone method, ICloneable interface, 204, 264

Close( ) method, Basic Dispose Pattern, 327

CLR
- allowing overloading, 122–123
- avoiding language-specific type names, 50–51
- case sensitivity of, 45
- releasing managed memory, 319
- releasing unmanaged resources with finalizers, 319–320

CLS (Common Language Specification), 414

CLSCompliant (true) attribute, 421

Coercion logic, dependency properties, 318–319

Collection parameters, 252–253

Collections, usage guidelines, 250–261
- choosing between arrays and, 245, 258–259
- collection parameters, 252
- FxCop rules, 398–399
- implementing custom collections, 259–260
- naming custom collections, 260–261
- overview of, 250–251
- properties and return values, 253–257
- property names, 69
- snapshots vs. live collections, 257–258

Collection<T> base class
- designing extensibility, 206–207
- implementing custom collections, 259–260
- properties and return values, 253–254, 256

ComException, 239

Comments, C# conventions, 368–369

Common Language Infrastructure (CLI), 414

Common Language Specification (CLS), 414

Common names
- capitalization, 43–45
- naming classes, structs and interfaces, 60–61

Common types, names of, 64–66

CompletedSynchronously property, IAsyncResult, 302

Component class, 205

Component-oriented design, 291–294

Compound words
- capitalization rules, 43–45, 375–376
- FCC rules for naming resources, 383
- ComVisible(false), assembly attribute, 119

Consistency
- designing frameworks for, 6–7
- exceptions promoting, 212
- in self-documenting APIs, 31

Constant fields, 161

Constraints, 64

Constructed type, 414

Constructor design, 144–153

Constructors
- abstract class design and, 95
- attribute usage guidelines, 249
- design guidelines, 144–150, 389
- designing custom exceptions, 240
- factories vs., 333–335
- type constructor guidelines, 151–152

ContentPropertyAttribute, 360

Conversion operators, 173–175, 336

Core namespaces, 59

Create-Call-Get-Pattern, 293

Create-Set-Call-Pattern, 291–293

CriticalFinalizerObject, 332

Custom attributes, interfaces vs., 99–100
Data class, 25
Data Contract Serialization
  choosing, 275
  defined, 274
  supporting, 276–280
  XML Serialization vs., 280
DataContractAttribute, 276
DataMemberAttribute, 276
dateTime, 261–263
dateTimeKind, 263
dateTimeOffset, 261–263
Deadlock, 201
Debugging, 134, 213
Default arguments, member overloading
  vs., 127–128
Default constructors
  aggregate components using, 294, 297
  avoiding defining on structs, 101, 149
  constructor design using, 145,
  147–149
  defined, 144, 414
  XAML readable types using, 358–359
Delegates, 153, 414
Dependency, designing extension
  methods, 164
Dependency properties. See DPs
  (dependency properties)
Descriptive names
  designing extension methods, 167
  designing generic type parameters, 64
  designing resources, 74–75
  designing self-documenting APIs
    using, 28
Design patterns, 289–361
  Aggregate Components. See Aggregate
  Components
  Async Patterns. See Async Patterns
  dependency properties, 312–319
  Dispose Pattern. See Dispose Pattern
  factories, 332–337
  FxCop rules for, 402–404
  LINQ support, 337–344
  Optional Feature Pattern, 344–348
  Simulated Covariance Pattern,
    348–354
  Template Method Pattern, 354–356
  timeouts, 356–358
  XAML readable types, 358–360
Design Patterns (Gamma et al), 354
  .Design subnamespace, 83
Directories, file organization, 369
Dispose method, 320–328, 402–403
Dispose Pattern, 319–332
  Basic Dispose Pattern, 322–328
  finalizable types, 328–332
  FxCop rules for, 402–403
  IDisposable interface, 266
  overview of, 319–322
Distributed computing, 6
DLLs
  naming conventions, 54–55, 378
  type design guidelines, 118–119
Documentation
  naming conventions for new APIs, 52
  purpose of providing, 27
  self-documenting object models vs.
    See Self-documenting object
    models
DPs (dependency properties), 312–319
  attached, 315–316
  change notifications, 317–318
  defined, 414
  designing, 313–315
  overview of, 312–313
  validation, 316–317
  value coercion, 318–319
DWORD, 110

E
e parameter, 71
Edit & Continue feature, 22
EditorBrowsable attribute, 81
EF (Entity Framework), 337
  80/20 rule, 10
Encapsulation, principle of, 159–160
End method, Classic Async Pattern,
  301–303, 305
EnumIsDefined, 181–182
Enums (enumerations), designing,
  103–115
  adding values to, 114–115
  choosing between Boolean param-
    eters and, 177–179
  defined, 105
  flag enums, 109–114
  FxCop rules for, 385–386
naming guidelines, 66–67, 380–381
simple enums, 103–109
validating arguments, 180–181
as value types, 78
Environment class, 98, 218
Equality operators, 286–287
Equals
  overriding equality operators, 286
  usage guidelines, 268–270, 400
Error conditions. See Exceptions
Error message design, 225–226, 232
Event-Based Async Pattern, 305–312
  choosing between async patterns, 298–300
  defining asynchronous methods, 305–307
  supporting cancellation, 308–309
  supporting incremental results, 311–312
  supporting out and ref parameters, 307–308
  supporting progress reporting, 309–311
Event design
  custom event handler design, 159
  overview of, 153–158
Event handlers
  custom design for, 159
  defined, 153, 414
  event design guidelines, 153–158, 389–390
  naming, 71–72
Event handling method, 156, 414
EventArgs suffix, 71–72, 156
EventHandler<T>, 155
Events
  defined, 414
  FxCop rules for design, 389–390
  naming conventions, 70–72, 381
  property change notification, 142–144
  providing extensibility with, 197–201
“Ex” suffix, 45, 53
Exception, 234–235
Exception filters, 221
Exception handling, 227–232
Exceptions, 211–243
  constructor design using, 146–147, 151
  customizing, 239–240
framework design using, 22, 30
FxCop rules for, 395–397
overview of, 211–215
performance and, 240–243
standard types of, 234–239
throwing, 216–221
throwing from equality operators, 286
throwing from finalizers, 332
Exceptions, choosing type to throw, 221–234
  error message design, 225–226, 232
  exception handling, 227–232
  overview of, 221–225
  wrapping exceptions, 232–234
Execution failures, 218, 222
ExecutionEngineException, 239
EXEs (executables), 421
Expense, of framework design, 4
Explicit interface member implementation, 128–132
Expression<T> types, 198–200
Expression<Func<...>>, 343
Extensibility, designing for, 193–210
  with abstractions, 203–205
  base classes, 206–207
  with events and callbacks, 197–201
  FxCop rules for, 394
  with protected members, 196
  sealing, 207–210
  with unsealed classes, 194–195
  with virtual members, 201–203
Extension methods, 162–168, 414

F
Façades. See Aggregate Components
Factored types, aggregate components, 294–295
Factories
  Optional Feature Pattern vs., 346
  overview of, 332–337
Factory methods, 145, 332–336
Fail fasts, 218
Fields
  designing, 159–162
  FxCop rules for design, 390–391
  naming conventions, 72–73, 383
Index

File organization, C#, 369–370
Finalizable types, Dispose Pattern and, 328–332
Finalize method, 146–147
Finalizers
  defined, 414
  finalizable types, 328–332
  FxCop rules for, 403–404
  limitations of, 320
  overview of, 319
Flag enums
  defined, 104
  designing, 109–114
  naming, 67, 110
FlagsAttribute, 110–111, 386
Flow control statements, 366
Framework design
  characteristics of, 3–6
  history of, 1–3
  overview of, 9–11
  principle of layered architecture, 32–36
  principle of low barrier to entry, 21–26
  principle of scenario-driven, 15–21
  principle of self-documenting object models, 26–32
  principles of, overview, 14–15
  progressive frameworks, 11–14
Func<...> delegates, 198–200
FxCop, 371–404
  defined, 371
  design patterns, 402–404
  designing for extensibility, 394
  evolution of, 372–373
  exceptions, 395–397
  how it works, 373–374
  member design. See Member design naming conventions. See Naming conventions, FxCop rules
  overview of, 371–372
  parameter design, 392–394
  spelling rules, 377
  type design guidelines, 384–386
  usage guidelines. See Usage guidelines, FxCop rules
FxCopcmd.exe, 373
FxCop.exe, 373

G
  GC (Garbage Collector), 319, 320
  GC.SuppressFinalize method
    constructor design, 147
    FxCop rules for design patterns, 403
    overview of, 320
  Generic methods, 350, 414
  Generic type parameters, names of, 64
  Generics, 348–354, 419
  “Get” methods, 69
  GetHashCode, usage guidelines, 270–271, 400
  GetObjectData, ISerializable, 282–283
  Getter method, 419
  Glossary, 417–421
  Grid.Column, 316

H
  Hashtable, 251
  Hierarchy
    designing custom exceptions, 239
    namespace, 57–58
    organizing directory, 369
    organizing types into namespace, 79–80
  High-level APIs, 33–36
  High-level components, 419
  Hungarian notation
    C# coding style conventions, 368
    positive and negative effects of, 46–47

I
  “I” prefix, 62–63
  IAsyncResult object, 301–303
  ICloneable interface, 204, 263–264
  ICollection interface, 252–253, 398–399
  ICollection<T> interface
    implementing custom collections, 259–260
    supporting LINQ through
      IEnumerable<T>, 339
    usage guidelines, 252–254
  IComparable<T> interface, 264–266
  IComponent interface, 205
  ID vs. id (identity or identifier), 44, 375
  Identifiers, naming conventions
    abbreviations or contractions, 48–49
    acronyms, 49
avoiding naming conflicts, 48
capitalization rules, 38–40
choosing names, 28–30
IDictionary<TKey, TValue>, 251, 260
IDisposable interface
as Dispose Pattern, 266
FxCop rules for design patterns, 402–403
implementing Basic Dispose Pattern, 322–324
releasing unmanaged resources with, 320–321
rules for finalizers, 403–404
usage guidelines, 266
IEnumerable interface, 252–255, 259–260
IEnumerable<T> interface
Query Pattern and, 342
supporting LINQ through, 339–340
usage guidelines for collections, 252–254
IEnumerator interface, 251–252
IEnumerable<T> interface, 251–252
IEnumerable<T> interface, 103, 264–266
IEnumerable<DataObject> interface, 279
IList<T> interface, 259–260
Immutable types
defined, 86, 419
enabling XAML readers with, 359
“Impl” suffix, 404
Implementation, framework, 4
Incremental results, Event-Based Async Pattern, 311–312
Indent usage, C#, 367
Indexed property design, 140–142, 388
IndexOutOfRangeException, 237
Infrastructure namespaces, 59
Inheritance hierarchy
base classes in, 206
naming classes, structs and interfaces, 61
Inlining, 419
Instance constructors, 144, 146
Instance method, 419
Instrumentation, exceptions promoting, 215
Int32 enum, 109
Integer timeouts, 357
Integration, framework, 6
Intellisense
naming conventions for new APIs, 52
naming conventions in self-documenting APIs, 29
operator overloads not showing in, 169
overview of, 27
strong typing for, 31
support for enums, 105
type design guidelines, 81
Interfaces
choosing between classes and, 88–95, 384–385
defining nested types as members of, 117
designing, 98–101, 385
designing abstractions with, 88–95, 205
designing extension methods for, 163–164
implementing members explicitly, 128–132, 387
naming conventions, 60–67, 379–381
reference and value types implementing, 78
.IInterop subnamespaces, 84
InvalidOperationException, 235
InvalidCastException, 175
InvalidOperationException, 235
IQueryable interface, 338
IQueryable<T> interface, 340–341
ISerializable interface, 281–283
Issue messages, FxCop, 373
It-Just-Works concept, 290
IXmlSerializable interface, 280–281
IXPathNavigable interface, 285
J
Jagged arrays, 246–247
JIT (Just-In-Time) compiler, 160, 419
K
Keyed collections, 256, 259–260
Keywords
avoiding naming identifiers that conflict with common, 48
FxCop rules for naming, 377
KnownTypeAttribute, 278–279
L

Lambda Expressions, 338, 419
Language Integrated Query. See LINQ
(Language Integrated Query)
Language-specific names
avoiding, 49–51
FxCop rules for avoiding, 378
resource names avoiding, 75
Layered architecture principle, frameworks, 32–36
Libraries, reusable, 5, 122–123
LINQ (Language Integrated Query), 337–344
defined, 419
overview of, 337–338
supporting through IEnumerable<T>, 339–340
supporting through IQueryable<T>, 340
supporting through Query Pattern, 341–344
ways of implementing, 339
LINQ to SQL, 337
List<T>, 251
Live collections, snapshots vs., 257–258
Local variables, avoiding prefixing, 368
Low barrier to entry principle, frameworks, 21–26
Low-level APIs, 33–36
Low-level component, 419

M

Managed code, 420
Marker interfaces, avoiding, 99
Markup Extensions, enabling XAML
with, 358–359
MarshalByRefObject, 93
Member design, 121–191
creator design. See Constructor
design
event design, 153–158
extension methods, 162–168
field design, 159–162
member overloading. See Member
overloading
operator overloads, 168–175
parameter design. See Parameter
design
property design, 138–144
Member design, FxCop rules for,
387–394
creator design, 389
event design, 389–390
field design, 390–391
general guidelines, 387–388
operator overloads, 391–392
parameter design, 392–394
property design, 388
Member overloading, 121–138
avoiding inconsistent ordering, 124
avoiding ref or out modifiers,
125–126
choosing between properties and
methods, 132–138
default arguments vs., 127–128
implementing interface members
explicitly, 128–132
overview of, 121–123
passing optional arguments, 126–127
semantics for same parameters, 126
using descriptive parameter names
for, 123–124
Members
defined, 420
PascalCasing for naming, 39–40
providing extensibility with virtual,
201–203
renaming, 130–131
sealing, 207–210
with variable number of parameters,
186–189
Memory, reference vs. value types, 85
Metadata
capitalization guidelines, 44
defined, 420
PropertyMetadata, 318
types and assembly, 118–119
Methods
choosing between properties and,
132–138, 386–387
designing extension, 162–168
eception builder, 220–221
aming conventions for, 28–30, 68
aming for operator overloads,
171–173
supporting timeouts with parameters,
356
Microsoft Office, for FxCop spelling
rules, 377
Microsoft Office Proofing Tools, for  
FxCop spelling rules, 377
Microsoft Windows, blue screens, 214
Microsoft Word development, 10
Multidimensional arrays, jagged arrays  
v.s., 246–247
Multiline syntax (/*...*/), 369
Multiple inheritance, 98–101
Mutable types, 101–102, 162

N
Namespaces
 defining extension methods in,  
164–167
 for experimentation, 22–24
 exposing layers in same, 35–36
 exposing layers in separate, 35
 placing base classes in separate, 207
 standard subnamespace names, 83–84
 type design guidelines, 79–83
Namespaces, naming
 FxCop rules, 378–379, 384
 overview of, 56–59
 PascalCasing for, 39–40
 type name conflicts and, 58–60
Naming conventions, 37–75
 abbreviations, 48
 acronyms, 48
 assemblies, 54–55
 avoiding language-specific names,  
49–51
 C# coding style, 367–368
 capitalization. See Capitalization  
conventions
classes, 60–67
 common types, 64–66
 custom collections, 260–261
 DLLs, 54–55
 enumerations, 66–67
 events, 70–72
 fields, 72–73
 generic type parameters, 64
 interfaces, 60–67
 methods, 68
 namespaces, 56–60
 new versions of APIs, 51–54
 overview of, 37–38
 parameters, 73–74
 properties, 68–70
resources, 74–75
self-documenting APIs, 28–30
structs, 60–67
word choice, 46–48
Naming conventions, FxCop rules,  
374–383
assemblies and DLLs, 378
classes, structs, and interfaces,  
379–381
general, 376–378
namespaces, 378–379
overview of, 374–376
parameters, 383
resources, 383
type members, 381–383
NativeOverlapped*, 305
Nested types
 defined, 420
designing, 115–117
FxCop rules for, 386
FxCop type design guidelines, 386
.NET Framework
 designing self-documenting APIs,  
31–32
 main goals of, 14
 as progressive framework, 13
.NET Remoting, 281
NotSupportedException, 340, 348
Nouns/noun phrases
 naming classes, structs and interfaces  
with, 60–61
 property names, 68–69
 Nullable<T> interface, 266–268
NullReferenceException, 237

O
Object models, 17. See also Self-docu-
menting object models
Object-oriented (OO) design, 2, 211–212
Object-oriented programming (OOP), 2,
79
Object, usage guidelines, 268–273
 defining extension methods on, 165
 object.Equals, 268–270
 object.GetHashCode, 270–271
 object.ToString method, 271–273
object.Equals
 overriding equality operators, 286
 usage guidelines, 268–270, 400
Object.GetHashCode, 270–271, 400
Object.ToString method, 271–273
Ok, capitalizing, 44
OnDeserializedAttribute, 277–278
OO (object-oriented) design, 2, 211–212
OOP (object-oriented programming), 2, 79
Open sets, and enums, 105
Operator overloads
  conversion operators, 173–175
descriptive parameter names for, 74, 123–124
extension methods similar to, 167
FxCop rules, 391–392
overloading operator ==, 173
overview of, 168–173
Operators, FxCop usage guidelines, 401–402
Optional Feature Pattern, 344–348
Organizational hierarchies, 57
out parameters
  avoiding use of, 184–185
Classic Async Pattern, 302
Event-Based Async Pattern, 307–308
FxCop rules for parameter passing, 393
member overloading and, 125–126
parameter design, 176–177
passing arguments through, 184
OutOfMemoryException, 238
Overlapped class, 305
Overloading
  avoiding for custom attribute constructors, 249
defined, 420
designing APIs for experimentation using, 24
equality operators, 286–287
member. See Member overloading
Overloading operator ==, 173, 175

P
Parameter design, 175–191
enum vs. boolean parameters, 177–179
FxCop rules for, 392–394
indexed properties, 141
members with variable number of parameters, 186–189
overview of, 175–177
parameter passing, 183–185
pointer parameters, 190–191
providing good defaults, 25–26
space usage, 366
validating arguments, 179–183
Parameter names
camelCasing for, 39–40
conventions, 73–74
conventions for overloads, 123–124
event handlers and, 71
FxCop rules for, 383
operator overload and, 74
Parameter passing, 183–185
params keyword, 186–188
Parentheses, space usage and, 366
PascalCasing convention
  C# coding style conventions, 368
  field names, 72
  FxCop rules for, 375
  identifier names, 38–40
  namespace names, 57
  property names, 68–69
  resource names, 74–75
Patterns, common design. See Design patterns
Performance
  exceptions and, 240–243
  implications of throwing exceptions, 219
  supporting LINQ through
    IEnumerable<T>, 340
  .Permission subnamespace, 83
  Pit of Success notion, LINQ, 337
Plural namespace names, 57
Pointer parameters, 190–191
Post-events, 153–154, 420
PowerCollections project, 205
Pre-events
  allowing end user to cancel events, 158
defined, 420
examples of, 153
Prefixes
  Boolean properties, 69
class names, 61
Index

enum names, 67
field names avoiding, 72
interface names, 62–63
namespace names, 56
Program errors, 222–224
Programming languages
  case sensitivity guideline for, 45–46
  choice of programming model and, 12
  designing framework to work well with variety of, 11
  exception handling syntax, 217
  writing scenario code samples in different, 16, 18
Progress reporting, 309–311
ProgressChanged event, 309–312
Progressive frameworks, 13–14, 420
Properties
  accessing fields with, 160
  choosing between methods and, 132–138, 386–387
  collection, 399
  defined, 420
  designing, 388
  naming, 68–70, 381
  providing good defaults for, 25–26
  setting with constructor parameters, 145–146
  usage guidelines for collections, 253–254
  using attribute, 247–248
Property change notification events, 142–144
Property design
  indexed, 140–142
  overview of, 138–140
  property change notification events, 142–144
PropertyChangedMetadata, 318–319
Protected members, 194, 196
Prototyping, implementation vs., 4
Public nested type guidelines, 117
Python, 18

R
Raising events, usage guidelines, 154–155
readonly fields, 161–162
“ReadOnly” prefix, custom collections, 261
ReadOnlyCollection<T>, 252–256, 259–260
Recursive acquires, 201
Reentrancy, 201
ref parameters
  Classic Async Pattern and, 302
  Event-Based Async Pattern and, 307–308
  member overloading and, 125–126
  parameter design and, 176
  passing arguments through, 183–185
Reference types
  defined, 420
  equality operators and, 269–270, 287
  overview of, 77
  parameter passing guidelines, 185, 393
  value types vs., 84–88
References, reading list for this book, 413–415
#region blocks, 370
Reserved parameters, 176
Resources, naming, 74–75, 383
Return-code error handling model, 212–213, 217
Return values
  error reporting based on, 212–213
  usage guidelines for collections, 253–254
Ruby, 18
Runtime, layered APIs at, 36
Runtime Serialization
  choosing, 275
  defined, 274
  supporting, 281–283

S
SafeHandle resource wrapper, 329–330
Scenario-driven principle
  example of. See API specification, sample
  overview of, 15–19
  usability studies, 19–21

Q
Query Expressions, 338
Query Pattern, 338, 341–344
Sealing of custom attribute classes, 250
  defined, 420
  FxCop rules for, 394
  preventing extensibility with, 207–210
Security
  avoiding explicit members, 131
  designing custom exceptions, 240
  SEHException, 239
Self-documenting object models, 26–32
  consistency, 31–32
  limiting abstractions, 32
  overview of, 26–30
  strong typing, 30–31
sender parameter, event handlers, 71
Sentinel values, and enums, 107–108
SerializableAttribute interface, 281
Serialization, usage guidelines, 274–283
  choosing right technology, 275
  overview of, 274–275
  supporting Data Contract Serialization, 276–280
  supporting Runtime Serialization, 281–283
  supporting XML Serialization, 280–281
Setter method, 420
Simplicity, well-designed frameworks, 3–4
Simulated Covariance Pattern, 348–354
Single-statement blocks, brace usage, 364–365
Singleline syntax (//...), comments, 369
  “64” suffix, 53–54
Snapshots, live collections vs., 257–258
SomeClass.GetReader, 334
Source files, organizing, 369
Space usage, C#, 365–366
Spelling rules, FxCop, 377
Sponsor class, 163
StackOverflowException, 237–238
State object, 301
Static methods
  defined, 421
  extension methods invoking, 162, 166, 414
Stream class, 322, 347
Strong typing, 30–31, 105
Structs
  defining default constructors in, 149
  defining operator overloads in, 170
  designing, 101–103, 385
  naming conventions, 60–67, 379–381
  type design guidelines, 84–88, 384–385
  as value types, 78
Subnamespace names, 83–84
Suffixes
  naming common types, 64–66
  naming enums, 67
  naming new APIs, 52–54
SuppressFinalize, Basic Dispose Pattern, 324–325
Synchronization, event design, 157
System failure, 222, 225
System namespaces, 59
System._AppDomain, 63
System.Attribute class, 247
System.ComponentModel.ComponentModel
  class, 205
System.ComponentModel.IComponent, 205
System.Data, 25
System.Enum, 110
System.Environment class, 98
System.Environment.FailFast, 218
System.EventHandler<T>, 155
SystemEvents, 200
SystemException, 234–235
System.FlagsAttribute, 110–111
System.InvalidCastException, 175
System.IO namespace, 20
System.IO.Stream class, 322, 347
System.Object, usage guidelines, 268–273
  defining extension methods on, 165
  Object.Equals, 268–270
  Object.GetHashCode, 270–271
  Object.ToString method, 271–273
System.ServiceProcess namespace, 291
System.TimeoutException, 357
System.Uri. See Uri, usage guidelines
System.ValueType, 103
System.Xml, usage guidelines, 284–286, 401

T
TDD (test-driven development)
defined, 15
framework design and, 6–7
scenario-driven design, 19
unsealed classes, 195
Technology namespace groups, 59–60
Template method, 404
Template Method Pattern, 203, 354–356
Tense, for event names, 70–71
Test-driven development. See TDD
(test-driven development)
Tester-Doer Pattern, 219, 241–242
ThenBy method, Query Pattern, 343
This, defined, 421
Throwing exceptions, 216–221. See also
Exceptions, choosing type to throw
TimeoutException, 357
Timeouts, in API design, 356–358
TimeSpan, 356
ToString method, 240, 271–273
Trade-offs, design, 5–6
Transparency, Aggregate Components,
290
Try-Parse Pattern, 219, 242–243
Type arguments
calling generic methods with, 350
in constructed types, 414
defined, 421
Type constructors
defined, 144
designing, 151–152, 389
Type converters, and XAML readers,
359–360
Type design guidelines
abstract classes, 95–97
adding values to enums, 114–115
assembly metadata and, 118–119
choosing class vs. struct, 84–88
choosing classes vs. interfaces, 88–95
flag enums, 109–114
FxCop rules for, 384–386
interfaces, 98–101
namespaces and, 79–84
nested types, 115–117
overview of, 77–79
simple enums, 103–109
static classes, 97–98
structs, 101–103
Type members, naming, 68–73
conflicts with namespace names,
58–60
designing self-documenting APIs,
28–30
events, 70–72, 382
fields, 72–73, 383
methods, 68
PascalCasing for, 39–40
properties, 68–70, 381
Type parameters, 64, 421

U
UEFs (unhandled exception filters), 215
Unary operators, 366
Un boxing, 421
Underscores (_), 73, 75
Un handled exception handlers, 214–215
Unmanaged code, 421
Unmanaged resources, 319
Unsealed classes, 194–195
Uri, usage guidelines, 283–284, 400–401
UrtCop (Universal Runtime Cop), 373
Usability, consistency for, 31–32
Usability studies, API, 19–21, 25
Usage errors, 222–223
Usage guidelines, 245–287
arrays, 245–247
attributes, 247–250
collections. See Collections, usage
guidelines
DateTime and DateTimeOffset,
261–263
equality operators, 286–287
ICloneable, 263–264
IComparable<T> and IEquatable<T>,
264–266
IDisposable, 266
Nullable<T>, 266–268
Object, 268–273
serialization. See Serialization, usage
guidelines
System.Xml usage, 284–286
Uri, 283–284
Usage guidelines, FxCop rules, 397–402
arrays, 397–398
attributes, 398
collections, 398–399
common operators, 401–402
Object, 400
Object.GetHashCode, 400
System.Xml, 401
System.Xml usage, 401
Uri, 400–401
User education experts, 29
using directives, file organization, 370

Virtual members, 149–150, 201–203
Visual Basic developers
case insensitivity of VB, 45
designing frameworks for, 10
experimental approach of, 22
moving to .NET platform, 34
problems with VB.NET, 15
Visual Studio, 299
VisualOperations class, WPF, 22
<V>.<S>.<B>.<R> format, assemblies, 119

Wait handles, Classic Async Pattern, 300
Word choice
FxCop rules for, 376–377
naming conventions, 46–48
WPF (Windows Presentation Foundation) project, 22–23, 168
Wrapping exceptions, 232–234

XAML, 358–360, 421
XML Serialization
choosing, 275
defined, 274
supporting, 280–281
XmlDataDocument, usage guidelines, 285–286
XmlNode, usage guidelines, 285
XmlReader, usage guidelines, 285
XNode, usage guidelines, 285
XPathDocument, usage guidelines, 285
XPathNavigator, usage guidelines, 286

Zero values
enum design, 108–109
flag enums, 113