THE ADDISON-WESLEY MICROSOFT TECHNOLOGY SERIES

THIRD EDITION

CONVENTIONS, IDIOMS, AND PATTERNS FOR REUSABLE .NET LIBRARIES

FRAMEWORK DESIGN GUIDELINES

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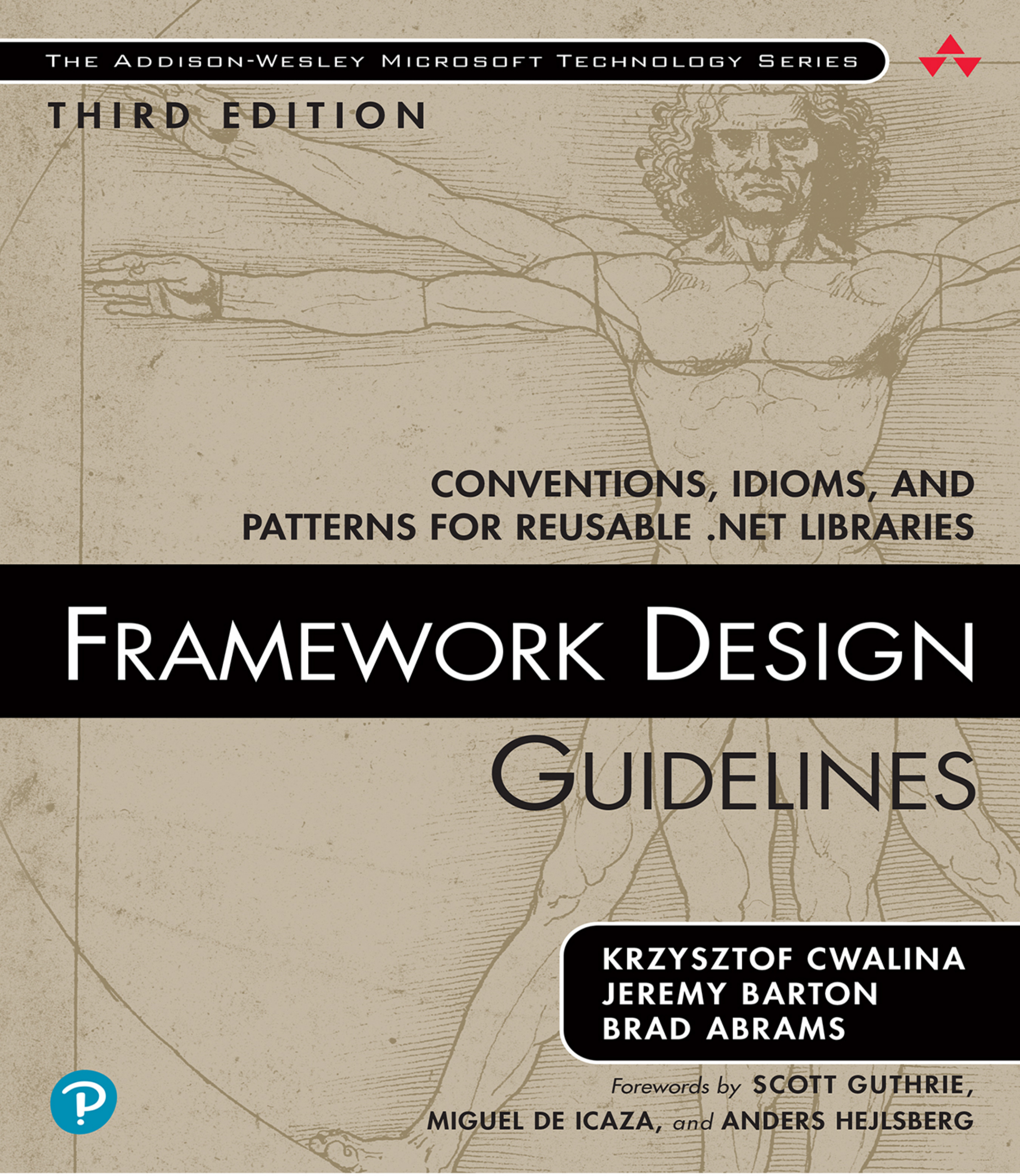

Framework Design Guidelines
Third Edition

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Conventions, Idioms, and Patterns for Reusable .NET Libraries

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Krzysztof Cwalina
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Addison-Wesley

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Dubai • London • Madrid • Milan • Munich • Paris • Montreal • Toronto • Delhi • Mexico City
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Library of Congress Control Number: 2020935344

ISBN-13: 978-0-13-589646-4
ISBN-10: 0-13-589646-0

ScoutAutomatedPrintCode

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 lovely wife, Janine.
I didn't fully appreciate before why authors always dedicate
books to their spouse, and now I do.
So, thank you. I'm sorry. I probably have time now for whatever those
things were that you wanted me to do while I was writing.
—Jeremy Barton

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

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Foreword

When we designed the .NET platform, we wanted it to be the most productive platform for enterprise application development of the time. Twenty years ago, that meant client-server applications hosted on dedicated hardware.

Today, we find ourselves in the midst of one of the biggest paradigm shifts in the industry: the move to cloud computing. Such transformations bring new opportunities for businesses but can be tricky for existing platforms, as they need to adapt to often different requirements imposed by the new kinds of applications that developers want to write.

The .NET platform has transitioned quite successfully, and I think one of the main reasons is that we designed it carefully and deliberately, focusing not only on productivity, consistency, and simplicity, but also on making sure that it can evolve over time. .NET Core represents such evolution with advances important to cloud application developers: performance, resource utilization, container support, and others.

This third edition of *Framework Design Guidelines* adds guidelines related to changes that the .NET team adopted during transition from the world of client-server application to the world of the Cloud.

—Scott Guthrie
Redmond, WA
January 2020

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Foreword to the Second Edition

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 also 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
October 2008

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 core libraries in .NET, 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 Azure SDKs or a game engine.
- 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

1. This includes public types, and the public, protected, and explicitly implemented members of these types.

book about programming. The book assumes the reader has basic familiarity with programming in .NET already.

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 two decades of .NET. 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 a `monospace` font.

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 always[2] be followed (all examples are from this book):

✓ **DO** name custom attribute classes with the suffix "Attribute."

```
public class ObsoleteAttribute : Attribute { ... }
```

2. *Always* might be a bit too strong a word. There are guidelines that should literally be always followed, but they are extremely rare. In contrast, 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.

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** provide set-only properties or properties with the setter having broader accessibility than the getter.

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#, IronPython, and PowerShell, 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 8, "Usage Guidelines," contains guidelines for extending and using types that commonly appear in frameworks.

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

Appendix A, "C# Coding Style Conventions," describes coding conventions used by the team that produces and maintains the core libraries in .NET.

Appendix B, "Obsolete Guidance," contains guidance from previous editions of this book that applies to features or concepts that are no longer recommended.

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

Appendix D, "Breaking Changes," explores various kinds of changes that can negatively impact your users from one version to the next.

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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.

We'd also like to thank the annotators: Mark Alcazar, Chris Anderson, Christopher Brumme, Pablo Castro, Jason Clark, Steven Clarke, Joe Duffy, Patrick Dussud, Kit George, Jan Gray, Brian Grunkemeyer, Eric Gunnerson, Phil Haack, Anders Hejlsberg, Jan Kotas, Immo Landwerth, Rico Mariani, Anthony Moore, Vance Morrison, Christophe Nasarre, Dare Obasanjo, Brian Pepin, Jon Pincus, Jeff Prosise, Brent Rector, Jeffrey Richter, Greg Schechter, Chris Sells, Steve Starck, Herb Sutter, Clemens Szyperski, Stephen Toub, Mircea Trofin, and Paul Vick. Their insights provide much needed commentary, color, humor, and history that add tremendous value to this book.

For all of the help, reviews, and support, both technical and moral, we thank Martin Heller and Stephen Toub. 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

Krzysztof Cwalina is a software architect at Microsoft. He was a founding member of the .NET Framework team and throughout his career has designed many .NET APIs. He is currently working on helping various teams across Microsoft design reusable APIs for many different programming languages. Krzysztof graduated with a B.S. and an M.S. in computer science from the University of Iowa.

Jeremy Barton is an engineer on the .NET Core Libraries team. After a decade of designing and developing small frameworks in C#, he joined the .NET team in 2015 to help get the cryptography types working across all platforms in the then-new .NET Core project. Jeremy graduated with a B.S. in computer science and mathematics from Rose-Hulman Institute of Technology.

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. 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. Brad is currently Group Product Manager at Google where he is incubating new projects for the Google Assistant.

About the Annotators

Mark Alcazar has been at Microsoft for the last 23 years, where he's spent most of his career on UI frameworks and angle-brackets. Mark has worked on Internet Explorer, WPF, Silverlight, and the last several releases of the Windows developer platform. Mark loves snowboarding, sailing, and cooking. He has a B.S. from the University of the West Indies and an M.S. from the University of Pennsylvania, and lives in Seattle with his wife and two kids.

Chris Anderson worked at Microsoft for 22 years, on a variety of projects, but specialized in the design and architecture of .NET technologies used to implement the next generation of applications and services. Chris has written numerous articles and white papers, and he has presented and been a keynote speaker at numerous conferences (e.g., Microsoft Professional Developers Conference, Microsoft TechEd, WinDev, DevCon) 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 distinguished engineer at Microsoft. He's currently part of the Azure Data group, where he's the director of engineering for Azure Synapse/SQL and Azure Cognitive Search. Prior to his current role

Pablo was the director of engineering and data science for the Applied AI group in Azure, and before that he worked on multiple products within the database systems group, including SQL Server, .NET, Entity Framework/LINQ, and OData.

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 he 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 so as to help design APIs that provide an optimal experience to their users.

Joe Duffy is the founder and CEO of Pulumi, a Seattle start-up giving developers and infrastructure teams cloud superpowers. Prior to founding Pulumi in 2017, Joe held leadership roles at Microsoft in the Developer Division, Operating Systems Group, and Microsoft Research. Most recently Joe was director for engineering and technical strategy for Microsoft's developer tools, leading key technical architecture initiatives, in addition to managing the groups building the C#, C++, Visual Basic, and F# languages, as well as IoT and Visual Studio IDE, compiler, and static analysis services. Joe was instrumental in Microsoft's overall open source transformation and assembled the initial team who took .NET open source and to new platforms. Joe has more than 20 years of professional software experience, has written two books, and still loves to code.

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.

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 .NET 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.

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Anders Hejlsberg is a technical fellow in the Developer Division at Microsoft. He is the chief designer of the C# programming language and a key participant in the development of the .NET Framework. Before joining Microsoft in 1996, Anders was a principal engineer at Borland International. As one of the first employees of Borland, he was the original author of Turbo Pascal and later worked as the chief architect of the Delphi product line. Anders studied engineering at the Technical University of Denmark.

Jan Kotas has worked on the .NET Runtime at Microsoft since 2001. He has an eye on striking the right balance between productivity, performance, security and reliability for the .NET platform. Over the years, he has touched nearly all areas of the .NET runtime, including ports to new architectures, ahead-of-time compilers, and many optimizations. He graduated in 1998 with a master's degree in computer science from Charles University in Prague (Czech Republic).

Immo Landwerth is a program manager on the .NET Framework team at Microsoft. He specializes in API design, the Base Class Libraries (BCL), and open source in .NET. He tweets in GIFs.

Rico Mariani has been coding professionally since 1980 with experience in everything from real-time controllers to flagship development systems. Rico was at Microsoft from 1988 to 2017 working on language products, online properties, operating systems, web browsers, and more. In 2017, Rico joined Facebook to work on Facebook Messenger, bringing his passion for high quality and performance with him. Rico's interests include compilers and language theory, databases, 3D art, and good fiction.

Anthony Moore is a development lead for the Connected Systems Division. He was the development lead for the Base Class Libraries of the CLR from 2001 to 2007, spanning FX V1.0 to FX 3.5. Anthony joined Microsoft in 1999 and initially worked on Visual Basic and ASP.NET. Before that, he worked as a corporate developer for eight years in his native Australia, including a three-year period working in the snack food industry.

Vance Morrison is a performance architect for the .NET Runtime at Microsoft. He involves himself with most aspects of runtime performance, with current attention devoted to improving start-up time. He has been involved in designs of components of the .NET runtime since its inception. He previously drove the design of the .NET Intermediate Language (IL) and has been the development lead for the JIT compiler for the runtime.

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Brian Pepin is a software developer at Microsoft and is currently working on the Xbox system software. He's been involved in developer tools and frameworks for 16 years and has provided input on the design of Visual Basic 5, Visual J++, the .NET Framework, WPF, Silverlight, and more than one unfortunate experiment that luckily never made it to market.

Jonathan Pincus was a senior researcher in the Systems and Networking Group at Microsoft Research, where he focused on the security, privacy, and reliability of software and software-based systems. He was previously founder and CTO of Intrinsa and worked in design automation (placement and routing for ICs and CAD frameworks) at GE Calma and EDA Systems.

Jeff Prosise is a co-founder of Wintellect who makes his living writing software and helping others do the same. He has written nine books and hundreds of magazine articles, trained thousands of developers at Microsoft, and spoken at some of the world's largest software conferences. Jeff's passion is teaching software developers how to build cloud-based apps with Microsoft Azure and introducing them to the wonders of AI and machine learning. In his spare time, Jeff builds and flies large radio-controlled jets and travels to development shops, universities, and research institutions around the world educating them about Azure and AI.

Brent Rector is a program manager at Microsoft on a technical strategy incubation effort. He has more than 30 years of experience in the software development industry in the production of programming language compilers, operating systems, ISV applications, and other products. Brent is the author and coauthor of numerous Windows software development books, including *ATL Internals*, *Win32 Programming* (both Addison-Wesley), and *Introducing WinFX* (Microsoft Press). Prior to joining Microsoft, Brent was the president and founder of Wise Owl Consulting, Inc., and chief architect of its premier .NET obfuscator, Demeanor for .NET.

Jeffrey Richter is a Microsoft Azure software architect who is best known as having authored the best-selling *Windows via C/C++* and *CLR via C#* books. Most recently, he's produced the free Architecting Distributed Cloud Applications video series available at http://aka.ms/RichterCloudApps and other videos available at http://WintellectNOW.com. Jeffrey was a consultant and co-founder of Wintellect, a software consulting and training company.

Greg Schechter is a Big Tech industry veteran, having worked at Sun Microsystems from 1988 to 1994 and at Microsoft from 1994 to 2010, primarily on API implementation and API design for more than 20 years. His experience is mostly in the 2D and 3D graphics realm, but also in media, imaging, general user interface systems, and asynchronous programming. In 2011, Greg joined Facebook as one of the first dozen or so Seattle employees, and is currently at Facebook London working as a software engineer in the Ads Infrastructure organization. Beyond all of that, Greg also loves to write about himself in the third person.

Chris Sells, in his past life, was deeply involved in .NET since the beta and has done much writing and speaking on the subject. Currently he is a Google Product Manager on the Flutter development experience. He still enjoys long walks on the beach and various technologies.

Steve Starck is a technical lead on the ADO.NET team at Microsoft, where he has been developing and designing data access technologies, including ODBC, OLE DB, and ADO.NET, for the past ten years.

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.

Stephen Toub is a partner software engineer at Microsoft. He has computer science degrees from Harvard University and New York University, and has spent many years developing .NET, with a focus on its libraries, and in particular with an eye toward performance, parallelism, and asynchrony. He was instrumental in taking .NET open source and cross-platform, and is thrilled by all the possibilities that .NET will enable in the future.

Mircea Trofin is a software engineer at Google, working on compiler optimization problems. He has previously worked at Microsoft as part of the .NET team.

Paul Vick was the language architect for Visual Basic during the transition to .NET and led the language design team for the first several releases of the language. 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.

6 Designing for Extensibility

One important aspect of designing a framework is making sure the extensibility of the framework has been carefully considered. This requires that you understand the costs and benefits associated with various extensibility mechanisms. This chapter helps you decide which of the extensibility mechanisms—subclassing, events, virtual members, callbacks, and so on—can best meet the requirements of your framework. This chapter does not cover the design details of these mechanisms. Such details are discussed in other parts of the book, and this chapter simply provides cross-references to sections that describe those details.

A good understanding of OOP is a necessary prerequisite to designing an effective framework and, in particular, to understanding the concepts discussed in this chapter. However, we do not cover the basics of object-orientation in this book, because there are already excellent books entirely devoted to the topic.

6.1 Extensibility Mechanisms

There are many ways to allow extensibility in frameworks. They range from less powerful but less costly to very powerful but expensive. For any given extensibility requirement, you should choose the least costly extensibility mechanism that meets the requirements. Keep in mind that it's usually possible to add more extensibility later, but you can never take it away without introducing breaking changes.

This section discusses some of the framework extensibility mechanisms in detail.

6.1.1 Unsealed Classes

Sealed classes cannot be inherited from, and they prevent extensibility. In contrast, classes that can be inherited from are called unsealed classes.

```
// string cannot be inherited from
public sealed class String { ... }

// TraceSource can be inherited from
public class TraceSource { ... }
```

Subclasses can add new members, apply attributes, and implement additional interfaces. Although subclasses can access protected members and override virtual members, these extensibility mechanisms result in significantly different costs and benefits. Subclasses are described in sections 6.1.2 and 6.1.4. Adding protected and virtual members to a class can have expensive ramifications if not done with care, so if you are looking for simple, inexpensive extensibility, an unsealed class that does not declare any virtual or protected members is a good way to do it.

✓ **CONSIDER** using unsealed classes with no added virtual or protected members as a great way to provide inexpensive yet much appreciated extensibility to a framework.

Developers often want to inherit from unsealed classes so as to add convenience members such as custom constructors, new methods, or method overloads.[1] For example, `System.Messaging.MessageQueue` is unsealed and thus allows users to create custom queues that default to a particular queue path or to add custom methods that simplify the API for specific scenarios. In the following example, the scenario is for a method sending `Order` objects to the queue.

1. Some convenience methods can be added to sealed types as extension methods.

```
public class OrdersQueue : MessageQueue {
   public OrdersQueue() : base(OrdersQueue.Path){
      this.Formatter = new BinaryMessageFormatter();
   }

   public void SendOrder(Order order){
     Send(order,order.Id);
   }
}
```

PHIL HAACK Because test-driven development has caught fire in the .NET developer community, many developers want to inherit from unsealed classes (often dynamically using a mock framework) in order to substitute a test double in the place of the real implementation.

At the very least, if you've gone to the trouble of making your class unsealed, consider making key members virtual, perhaps via the Template Method Pattern, to provide more control.

Classes are unsealed by default in most programming languages, and this is also the recommended default for most classes in frameworks. The extensibility afforded by unsealed types is much appreciated by framework users and quite inexpensive to provide because of the relatively low test costs associated with unsealed types.

VANCE MORRISON The key word in this advice is "CONSIDER." Keep in mind that you always have the option of unsealing a class in the future (it is not a breaking change); however, once unsealed, a class must remain unsealed. Also, unsealing does inhibit some optimizations [e.g., converting virtual calls to more efficient nonvirtual calls (and then inlining)]. Finally, unsealing helps your users only if they control the creation of the class (sometimes true, sometimes not). In short, designs are only rarely usefully extensible "by accident." Being unsealed is part of the contract of a class and its users, and like everything about the contract, it deserves to be a conscious, deliberate choice on the part of the designer.

6.1.2 Protected Members

Protected members by themselves do not provide any extensibility, but they can make extensibility through subclassing more powerful. They can be used to expose advanced customization options without unnecessarily complicating the main public interface. For example, the `SourceSwitch.Value` property is protected because it is intended for use only in advanced customization scenarios.

```
public class FlowSwitch : SourceSwitch {
   protected override void OnValueChanged() {
      switch (this.Value) {
        case "None" : Level = FlowSwitchSetting.None; break;
        case "Both" : Level = FlowSwitchSetting.Both; break;
        case "Entering": Level = FlowSwitchSetting.Entering; break;
        case "Exiting" : Level = FlowSwitchSetting.Exiting; break;
      }
   }
}
```

Framework designers need to be careful with protected members because the name “protected” can give a false sense of security. Anyone is able to subclass an unsealed class and access protected members, so all the same defensive coding practices used for public members apply to protected members.

✓ **CONSIDER** using protected members for advanced customization.

Protected members are a great way to provide advanced customization without complicating the public interface.

✓ **DO** treat protected members in unsealed classes as public for the purpose of security, documentation, and compatibility analysis.

Anyone can inherit from a class and access the protected members.

BRAD ABRAMS Protected members are just as much a part of your publicly callable interface as public members. In designing the framework, we considered protected and public to be roughly equivalent. We generally did the same level of review and error checking in protected APIs as we did in public APIs because they can be called from any code that just happens to subclass.

6.1.3 Events and Callbacks

Callbacks are extensibility points that allow a framework to call back into user code through a delegate. These delegates are usually passed to the framework through a parameter of a method.

```
List<string> cityNames = ...
cityNames.RemoveAll(delegate(string name) {
  return name.StartsWith("Seattle");
});
```

Events are a special case of callbacks that supports convenient and consistent syntax for supplying the delegate (an event handler). In addition, Visual Studio's statement completion and designers provide help in using event-based APIs.

```
var timer = new Timer(1000);
timer.Elapsed += delegate {
  Console.WriteLine("Time is up!");
};
timerStart();
```

General event design is discussed in section 5.4.

Callbacks and events can be used to provide quite powerful extensibility, comparable to virtual members. At the same time, callbacks—and even more so, events—are more approachable to a broader range of developers because they don't require a thorough understanding of object-oriented design. Also, callbacks can provide extensibility at runtime, whereas virtual members can be customized only at compile-time.

The main disadvantage of callbacks is that they are more heavyweight than virtual members. The performance when calling through a delegate is worse than it is when calling a virtual member. In addition, delegates are objects, so their use affects memory consumption.

You should also be aware that by accepting and calling a delegate, you are executing arbitrary code in the context of your framework. Therefore, a careful analysis of all such callback extensibility points from the security, correctness, and compatibility points of view is required.

✓ **CONSIDER** using callbacks to allow users to provide custom code to be executed by the framework.

✓ **CONSIDER** using events, instead of virtual members, to allow users to customize the behavior of a framework without the need for understanding object-oriented design.

✓ **CONSIDER** using events instead of plain callbacks, because events are more familiar to a broader range of developers and are integrated with Visual Studio statement completion.

✗ **AVOID** using callbacks in performance-sensitive APIs.

KRZYSZTOF CWALINA Delegate calls were made much faster in CLR 2.0, but they are still about two times slower than direct calls to virtual members. In addition, delegate-based APIs are generally less efficient in terms of memory usage. Having said that, the differences are relatively small and should only matter if the API is called very frequently.

STEPHEN TOUB In a performance-critical method, you want to think about all forms of extensibility and what kind of impact they may have on throughput. This goes beyond delegates. In fact, in some situations it may actually be better for your common case to use delegates instead of virtual methods. For example, consider a design where you want a default behavior that can then be potentially replaced if a delegate is provided. If you made the functionality virtual, you'd be paying for the virtual dispatch (unless the JIT could devirtualize the call) regardless of whether a replacement was provided. But with a delegate, you could have a nonvirtual, inlineable implementation that just does a null check on the delegate instance and only pays the delegate invocation costs if there is something else to do instead of the default behavior.

✓ **DO** use the `Func<...>`, `Action<...>`, or `Expression<...>` types instead of custom delegates when possible, when defining APIs with callbacks.

`Func<...>` and `Action<...>` represent generic delegates. The following is how .NET defines them:

```
public delegate void Action()
public delegate void Action<T1, T2>(T1 arg1, T2 arg2)
public delegate void Action<T1, T2, T3>(T1 arg1, T2 arg2, T3 arg3)
public delegate void Action<T1, T2, T3, T4>(T1 arg1, T2 arg2,
  T3 arg3, T4 arg4)
public delegate TResult Func<TResult>()
public delegate TResult Func<T, TResult>(T arg)
public delegate TResult Func<T1, T2, TResult>(T1 arg1, T2 arg2)
public delegate TResult Func<T1, T2, T3, TResult>(T1 arg1, T2 arg2,
  T3 arg3)
public delegate TResult Func<T1, T2, T3, T4, TResult>(T1 arg1, T2 arg2,
  T3 arg3, T4 arg4)
```

They can be used as follows:

```
Func<int,int,double> divide = (x,y)=>(double)x/(double)y;
Action<double> write = (d)=>Console.WriteLine(d);
write(divide(2,3));
```

`Expression<...>` represents function definitions that can be compiled and subsequently invoked at runtime but can also be serialized and passed to remote processes. Continuing with our example:

```
Expression<Func<int,int,double>> expression =
  (x,y)=>(double)x/(double)y;
Func<int,int,double> divide2 = expression.Compile();
write(divide2(2,3));
```

Notice how the syntax for constructing an `Expression<>` object is very similar to that used to construct a `Func<>` object. In fact, the only difference is the static type declaration of the variable (`Expression<>` instead of `Func<...>`).

STEPHEN TOUB In general, if these generic delegate types *can* be used, they *should* be used. However, there are some relatively rare situations where these generic delegates can't be used. One such category is when the types being passed as arguments or return values can't be used as generic type parameters, such as pointer types or `ref struct` types. Another category is when arguments or return values need to be passed as something other than by value—for example, when you want an argument to be `ref`. In such situations, you will need to find an existing delegate (generic or otherwise) that's been declared with an appropriate signature, or else define a new one.

JAN KOTAS The `Action` and `Func` delegates do not allow naming arguments. That makes it impractical to use these delegates for callbacks with more complex signatures where the meaning of the arguments is not obvious and it is important to name the arguments for clarity. For example, the `System.Runtime.InteropServices.DllImportResolver` delegate violates this rule for this reason.

RICO MARIANI Most times you're going to want `Func` or `Action` if all that needs to happen is to run some code. You need `Expression` when the code needs to be analyzed, serialized, or optimized before it is run. `Expression` is for thinking about code; `Func/Action` is for running it.

✓ **DO** measure and understand the performance implications of using `Expression<...>`, instead of using `Func<...>` and `Action<...>` delegates.

`Expression<...>` types are, in most cases, logically equivalent to `Func<...>` and `Action<...>` delegates. The main difference between them is that the delegates are intended to be used in local process scenarios; expressions are intended for cases where it's beneficial and possible to evaluate the expression in a remote process or machine.

RICO MARIANI The remoteness of the evaluation is sort of incidental. The main thing about `Expressions` is that you use them when you are going to need to reason over the code to be executed, often over a composition of expressions such as in a LINQ query, and then, having considered the whole and the execution options, you create some kind of optimized plan for doing the work. This is how LINQ to SQL is able to create a single SQL fragment from a composition of loose-looking expressions.

This plan could easily go wrong. You could do too much analysis of expressions or too little. You could use up too much space holding expression trees, or you could avoid all the trees but then find you have bad performance because you have so many small anonymous delegates.

If you look at the patterns used in the LINQ implementations in .NET, you'll see several good ways to make use of these constructs:

- Use expressions only if you need to "think" about the code and not just run it.
- Don't blindly compose and run code that could be meaningfully optimized if you "thought" about it before running it.
- Don't create systems that optimize the code so much before running it that it would have been faster to just run it directly without optimizing.
- Optimization isn't the only use for expression trees, but it is an important one.

✓ **DO** understand that by calling a delegate, you are executing arbitrary code, and that could have security, correctness, and compatibility repercussions.

BRIAN PEPIN The Windows Forms team bumped up against this issue when writing some of the low-level code in `SystemEvents`. `SystemEvents` defines a static API and therefore needs to be threadsafe. Internally, it uses locks to ensure thread safety. Early code in `SystemEvents` would grab a lock and then raise an event. Here's an example:

```
lock(someInternalLock) {
  if(eventHandler!=null) eventHandler(sender, EventArgs.Empty);
}
```

This is bad because you have no idea what the user code in the event handler is going to do. If the user code signals a thread and waits on its own lock, you might have just introduced a deadlock. This would be better code:

```
EventHandler localHandler = eventHandler;
if(localHandler != null) localHandler(sender, EventArgs.Empty);
```

This way, the user's code will never deadlock due to your own internal implementation. Note that because assignments in managed code are atomic, I didn't need a lock at all in this case. That won't always be true. For example, if your code needed to check more than one variable, you'd still need a lock:

```
EventHandler localHandler = null;
lock(someInternalLock) {
   if (eventHandler != null && shouldRaiseEvents) {
      localHandler = eventHandler;
    }
}
if(localHandler!=null) localHandler(sender,EventArgs.Empty);
```

JEREMY BARTON The null-conditional operator introduced in C# 6 can simplify the event invocation.

```
eventHandler?.Invoke(sender, EventArgs.Empty);
```

This has the same effect as Brian's second example (invoking outside the lock), including only ever reading from the "eventHandler" value once:

```
EventHandler localHandler = eventHandler;
if(localHandler != null) localHandler(sender, EventArgs.Empty);
```

JOE DUFFY In addition to deadlock, invoking a callback under a lock like this can cause reentrancy. Locks on the CLR support recursive acquires, so if the callback somehow manages to call back into the same object that initiated the callback, the results are often not good. Locks are typically used to isolate invariants that are temporarily broken, yet this practice can expose them at the reentrant boundary. Needless to say, this is apt to cause weird exceptions and unexpected behavior.

That said, sometimes this practice is necessary. If the callback is being used to make a decision—as would be the case with a predicate—and that decision needs to be made under a lock, you will have no choice. When invoking a callback under a lock is unavoidable, be sure to carefully document the restrictions (no inter-thread communication, no reentrancy). You must also ensure that, should a developer violate these restrictions, the result will not lead to security vulnerabilities. The risk here is usually greater than the reward.

STEPHEN TOUB From an API design perspective, this whole discussion is really interesting as it applies to compatibility. You may find yourself in a situation where you've invoked a user-supplied callback while holding a lock, and you decide to "fix" it by employing approaches like that outlined. In doing so, however, you're impacting potentially visible behaviors. The invocation will no longer be synchronized with whatever else might be using the same lock. It's possible the user's callback was actually relying on that synchronization for safety, whether they knew it or not.

Extensibility is hard.

6.1.4 Virtual Members

Virtual members can be overridden, thereby changing the behavior of the subclass. They are quite similar to callbacks in terms of the extensibility they provide, but they are better in terms of execution performance and memory consumption. Also, virtual members feel more natural in scenarios that require creating a special kind of an existing type (specialization).

The main disadvantage of virtual members is that the behavior of a virtual member can be modified only at the time of compilation. The behavior of a callback can be modified at runtime.

Virtual members, like callbacks (and maybe more than callbacks), are costly to design, test, and maintain because any call to a virtual member can be overridden in unpredictable ways and can execute arbitrary code. Also, much more effort is usually required to clearly define the contract of virtual members, so the cost of designing and documenting them is higher.

KRZYSZTOF CWALINA A common question I get is whether documentation for virtual members should say that the overrides must call the base implementation. The answer is that overrides should preserve the contract of the base class. They can do that by calling the base implementation or by some other means. It is rare that a member can claim that the only way to preserve its contract (in the override) is to call it. In a lot of cases, calling the base might be the easiest way to preserve the contract (and documentation should point that out), but it's rarely absolutely required.

Because of the risks and costs, limiting extensibility of virtual members should be considered. Extensibility through virtual members today should be limited to those areas that have a clear scenario requiring extensibility. This section presents guidelines for when to allow it and when and how to limit it.

✗ **DO NOT** make members virtual unless you have a good reason to do so and you are aware of all the costs related to designing, testing, and maintaining virtual members.

Virtual members are less forgiving in terms of changes that can be made to them without breaking compatibility. Also, they are slower than nonvirtual members, mostly because calls to virtual members are not inlined.

RICO MARIANI Be sure you understand your extensibility requirements completely before you make decisions in the name of extensibility. A common mistake is sprinkling classes with virtual methods and properties, only to find that the needed extensibility still can't be realized and everything is now (and forever) slower.

JAN GRAY The peril: If you ship types with virtual members, you are promising to forever abide by subtle and complex observable behaviors and subclass interactions. I think framework designers underestimate their peril. For example, we found that `ArrayList` item enumeration calls several virtual methods for each `MoveNext` and `Current`. Fixing those performance problems could (but probably doesn't) break user-defined implementations of virtual members on the `ArrayList` class that are dependent on virtual method call order and frequency.

✓ **CONSIDER** limiting extensibility to only what is absolutely necessary through the use of the Template Method Pattern, described in section 9.9.

✓ **DO** prefer protected accessibility over public accessibility for virtual members. Public members should provide extensibility (if required) by calling into a protected virtual member.

The public members of a class should provide the right set of functionality for direct consumers of that class. Virtual members are designed to be overridden in subclasses, and protected accessibility is a great way to scope all virtual extensibility points to where they can be used.

```
public Control{
   public void SetBounds(...){
     ...
     SetBoundsCore (...);
   }

   protected virtual void SetBoundsCore(...){
     // Do the real work here.
   }
}
```

Section 9.9 provides more insight into this subject.

JEFFREY RICHTER It is common for a type to define multiple overloaded methods for caller convenience. These methods typically allow the caller to pass fewer arguments to the method and then, internally, the method calls a more complex method, passing additional arguments with good default values. If your type offers convenience methods, these methods should not be virtual, but internally they should call the one virtual method that contains the actual implementation of the method (which can be overridden).

6.1.5 Abstractions (Abstract Types and Interfaces)

An abstraction is a type that describes a contract but does not provide a full implementation of that contract. Abstractions are usually implemented as abstract classes or interfaces, and they come with a well-defined set of reference documentation describing the required semantics of the types implementing the contract. Some of the most important abstractions in .NET include `Stream`, `IEnumerable<T>`, and `Object`. Section 4.3 discusses how to choose between an interface and a class when designing an abstraction.

You can extend frameworks by implementing a concrete type that supports the contract of an abstraction and then using this concrete type with framework APIs consuming (operating on) the abstraction.

A meaningful and useful abstraction that is able to withstand the test of time is very difficult to design. The main difficulty is getting the right set of members—no more and no fewer. If an abstraction has too many members, it becomes difficult or even impossible to implement. If it has too few members for the promised functionality, it becomes useless in many interesting scenarios. Also, abstractions without first-class documentation that clearly spells out all the pre- and post-conditions often end up being failures in the long term. Because of this, abstractions have a very high design cost.

JEFFREY RICHTER The `ICloneable` interface is an example of very simple abstraction with a contract that was never explicitly documented. Some types that implement this interface's `Clone` method implement it so that it performs a shallow copy of the object, whereas some implementations perform a deep-copy. Because what this interface's `Clone` method should do was never fully documented, when using an object with a type that implements `ICloneable`, you never know what you're going to get. This makes the interface useless.

Too many abstractions in a framework also negatively affect usability of the framework. It is often quite difficult to understand an abstraction without understanding how it fits into the larger picture of the concrete implementations and the APIs operating on the abstraction. Also, names of abstractions and their members are necessarily abstract, which often makes them cryptic and unapproachable without first understanding the broader context of their usage.

However, abstractions provide extremely powerful extensibility that the other extensibility mechanisms cannot often match. They are at the core of many architectural patterns, such as plug-ins, inversion of control (IoC), pipelines, and so on. They are also extremely important for testability of frameworks. Good abstractions make it possible to stub out heavy dependencies for the purpose of unit testing. In summary, abstractions are responsible for the sought-after richness of the modern object-oriented frameworks.

✗ **DO NOT** provide abstractions unless they are tested by developing several concrete implementations and APIs consuming the abstractions.

✓ **DO** choose carefully between an abstract class and an interface when designing an abstraction. See section 4.3 for more details on this subject.

✓ **CONSIDER** providing reference tests for concrete implementations of abstractions. Such tests should allow users to test whether their implementations correctly implement the contract.

JEFFREY RICHTER I like what the Windows Forms team did: They defined an interface called `System.ComponentModel.IComponent`. Of course, any type can implement this interface. But the Windows Forms team also provided a `System.ComponentModel.Component` class that implements the `IComponent` interface. So a type could choose to derive from `Component` and get the implementation for free, or the type could derive from a different base class and then manually implement the `IComponent` interface. By having available an interface and a base class, developers get to choose whichever works best for them.

STEPHEN TOUB Before shipping an abstraction, you should plan to validate it by building at least two or three distinct implementations and by using the abstraction in at least two or three distinct consumers. Those tests will provide you with a lot more confidence that you've built something that will actually be usable, and in my experience, will most likely help you to find issues that need to be addressed before you ship.

6.2 Base Classes

Strictly speaking, a class becomes a base class when another class is derived from it. For the purpose of this section, however, a base class is defined as a class designed mainly to provide a common abstraction or for other classes to reuse some default implementation though inheritance. Base classes usually sit in the middle of inheritance hierarchies, between an abstraction at the root of a hierarchy and several custom implementations at the bottom.

Base classes serve as implementation helpers for implementing abstractions. For example, one of the abstractions for ordered collections of items in .NET is the `IList<T>` interface. Implementing `IList<T>` is not trivial, so the framework provides several base classes, such as `Collection<T>` and `KeyedCollection<TKey,TItem>`, that serve as helpers for implementing custom collections.

```
public class OrderCollection : Collection<Order> {
   protected override void SetItem(int index, Order item) {
     if(item==null) throw new ArgumentNullException(...);
     base.SetItem(index,item);
   }
}
```

Base classes are usually not suited to serve as abstractions by themselves because they tend to contain too much implementation. For example, the `Collection<T>` base class contains lots of implementation related to the fact that it implements the non-generic `IList` interface (to integrate better with non-generic collections) and to the fact that it is a collection of items stored in memory in one of its fields.

KRZYSZTOF CWALINA `Collection<T>` can also be used directly, without the need to create subclasses, but its main purpose is to provide an easy way to implement custom collections.

As previously discussed, base classes can provide invaluable help for users who need to implement abstractions, but at the same time they can be a significant liability. They add surface area and increase the depth of inheritance hierarchies, thereby conceptually complicating the framework. For this reason, base classes should be used only if they provide significant value to the users of the framework. They should be avoided if they provide value only to the implementers of the framework, in which case delegation to an internal implementation instead of inheritance from a base class should be strongly considered.

✓ **CONSIDER** making base classes abstract even if they don't contain any abstract members. This clearly communicates to the users that the class is designed solely to be inherited from.

> **JEREMY BARTON** My interpretation of this guideline is that it's OK to declare the class abstract even if there are no abstract members, but you still need a reason why. If the class works fine on its own, it should probably be instantiable.

✓ **CONSIDER** placing base classes in a separate namespace from the mainline scenario types. By definition, base classes are intended for advanced extensibility scenarios and are not interesting to the majority of users. See section 2.2.4 for details.

✗ **AVOID** naming base classes with a "Base" suffix if the class is intended for use in public APIs.

For example, despite the fact that `Collection<T>` is designed to be inherited from, many frameworks expose APIs typed as the base class, not as its subclasses, mainly because of the cost associated with a new public type.

```
public Directory {
  public Collection<string> GetFilenames(){
     return new FilenameCollection(this);
     }

  private class FilenameCollection : Collection<string> {
    ...
  }
}
```

The fact that Collection<T> is a base class is irrelevant for the user of the GetFilename method, so the "Base" suffix would simply create an unnecessary distraction for the user of the method.

6.3 Sealing

One of the features of object-oriented frameworks is that developers can extend and customize them in ways unanticipated by the framework designers. This is both the power and the danger of extensible design. When you design your framework, it is very important to carefully design for extensibility when it is desired, and to limit extensibility when it is dangerous.

KRZYSZTOF CWALINA Sometimes framework designers want to limit the extensibility of a type hierarchy to a fixed set of classes. For example, let's say you want to create a hierarchy of living organisms that is split into two and only two subgroups: animals and plants. One way to do so is to make the constructor of LivingOrganism internal, and then provide two subclasses (Plant and Animal) in the same assembly and give them protected constructors. Because the constructor of LivingOrganism is internal, third parties can extend Animal and Plant, but not LivingOrganism.

```
public class LivingOrganism {
  internal LivingOrganism(){}
  ...
}
public class Animal : LivingOrganism {
  protected Animal() {}
  ...
}
public class Plant : LivingOrganism {
  protected Plant() {}
  ...
}
```

Sealing is a powerful mechanism that prevents extensibility. You can seal either the class or individual members. Sealing a class prevents users from inheriting from the class. Sealing a member prevents users from overriding a particular member.

```
public class NonNullCollection<T> : Collection<T> {
    protected sealed override void SetItem(int index, T item) {
      if(item==null) throw new ArgumentNullException();
       base.SetItem(index,item);
   }
}
```

Because one of the key differentiating points of frameworks is that they offer some degree of extensibility, sealing classes and members will likely feel very abrasive to developers using your framework. Therefore, you should seal only when you have good reasons to do so.

✗ **DO NOT** seal classes without having a good reason to do so.

Sealing a class because you cannot think of an extensibility scenario is not a good reason. Framework users like to inherit from classes for various nonobvious reasons, such as adding convenience members. See section 6.1.1 for examples of nonobvious reasons users want to inherit from a type.

Good reasons for sealing a class include the following:

- The class is a static class. For more information on static classes, see section 4.5.
- The class inherits many virtual members, and the cost of sealing them individually would outweigh the benefits of leaving the class unsealed.
- The class is an attribute that requires very fast runtime look-up. Sealed attributes have slightly higher performance levels than unsealed ones. For more information on attribute design, see section 8.2.

BRAD ABRAMS Having classes that are open to some level of customization is one of the core differences between a framework and a library. With an API library (such as the Win32 API), you basically get what you get. It is very difficult to extend the data structures and APIs. With a framework such as MFC or AWT, clients can extend and customize the classes. The productivity boost from this flexibility is obvious.

KRZYSZTOF CWALINA People often ask about the cost of sealing individual members. This cost is relatively small, but it is nonzero and should be taken into account. There is development cost (typing in the overrides), testing cost (have you called the base class from the override?), assembly size cost (new overrides), and working set cost (if both the overrides and the base implementation are ever called).

✗ **DO NOT** declare protected or virtual members on sealed types.

By definition, sealed types cannot be inherited from. This means that protected members on sealed types cannot be called, and virtual methods on sealed types cannot be overridden.

✓ **CONSIDER** sealing members that you override.

```
public class FlowSwitch : SourceSwitch {
   protected sealed override void OnValueChanged() {
      ...
   }
}
```

Problems that can result from introducing virtual members (discussed in section 6.1.4) apply to overrides as well, although to a slightly lesser degree. Sealing an override shields you from these problems starting from that point in the inheritance hierarchy.

In short, part of designing for extensibility is knowing when to limit it, and sealed types are one of the mechanisms by which you do that.

SUMMARY

Designing for extensibility is a critical aspect of designing frameworks. Understanding the costs and benefits provided by various extensibility mechanisms permits the design of frameworks that are flexible while avoiding many of the pitfalls that could lead to trouble later.

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