Special Annotated Edition for C# 4.0

The C# Programming Language

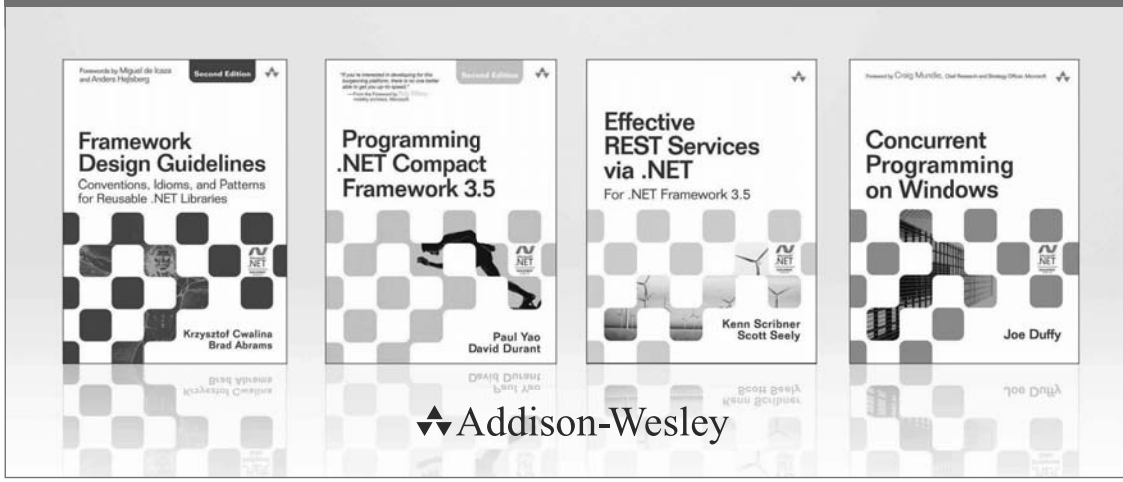
Fourth Edition

Microsoft .NET DEVELOPMENT SERIES

Anders Hejlsberg
Mads Torgersen
Scott Wiltamuth
Peter Golde

The C# Programming Language
Fourth Edition

Microsoft® .NET Development Series

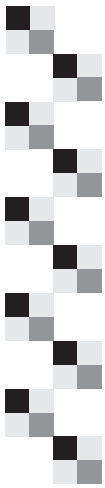


Visit **informit.com/msdotnetseries** for a complete list of available products.

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.

PEARSON

Addison-Wesley Cisco Press EXAM/CRAM IBM Press QUE PRENTICE HALL SAMS | Safari Books Online



The C# Programming Language

Fourth Edition

Anders Hejlsberg
Mads Torgersen
Scott Wiltamuth
Peter Golde

Addison-Wesley

Upper Saddle River, NJ • Boston • Indianapolis • San Francisco
New York • Toronto • Montreal • London • Munich • Paris • Madrid
Capetown • Sydney • Tokyo • Singapore • Mexico City

Library of Congress Cataloging-in-Publication Data

The C# programming language / Anders Hejlsberg ... [et al.]. — 4th ed.
p. cm.
Includes index.
ISBN 978-0-321-74176-9 (hardcover : alk. paper)
1. C# (Computer program language) I. Hejlsberg, Anders.
QA76.73.C154H45 2010
005.13'3—dc22

2010032289

ISBN-13: 978-0-321-74176-9
ISBN-10: 0-321-74176-5
Text printed in the United States on recycled paper at Courier in Westford, Massachusetts.
First printing, October 2010

Contents

Foreword

It's been ten years since the launch of .NET in the summer of 2000. For me, the significance of .NET was the one-two combination of managed code for local execution and XML messaging for program-to-program communication. What wasn't obvious to me at the time was how important C# would become.

From the inception of .NET, C# has provided the primary lens used by developers for understanding and interacting with .NET. Ask the average .NET developer the difference between a value type and a reference type, and he or she will quickly say, "Struct versus class," not "Types that derive from `System.ValueType` versus those that don't." Why? Because people use languages—not APIs—to communicate their ideas and intention to the runtime and, more importantly, to each other.

It's hard to overstate how important having a great language has been to the success of the platform at large. C# was initially important to establish the baseline for how people think about .NET. It's been even more important as .NET has evolved, as features such as iterators and true closures (also known as anonymous methods) were introduced to developers as purely language features implemented by the C# compiler, not as features native to the platform. The fact that C# is a vital center of innovation for .NET became even more apparent with C# 3.0, with the introduction of standardized query operators, compact lambda expressions, extension methods, and runtime access to expression trees—again, all driven by development of the language and compiler. The most significant feature in C# 4.0, dynamic invocation, is also largely a feature of the language and compiler rather than changes to the CLR itself.

It's difficult to talk about C# without also talking about its inventor and constant shepherd, Anders Hejlsberg. I had the distinct pleasure of participating in the recurring C# design meetings for a few months during the C# 3.0 design cycle, and it was enlightening watching Anders at work. His instinct for knowing what developers will and will not like is truly

world-class—yet at the same time, Anders is extremely inclusive of his design team and manages to get the best design possible.

With C# 3.0 in particular, Anders had an uncanny ability to take key ideas from the functional language community and make them accessible to a very broad audience. This is no trivial feat. Guy Steele once said of Java, "We were not out to win over the Lisp programmers; we were after the C++ programmers. We managed to drag a lot of them about halfway to Lisp." When I look at C# 3.0, I think C# has managed to drag at least one C++ developer (me) most of the rest of the way. C# 4.0 takes the next step toward Lisp (and JavaScript, Python, Ruby, et al.) by adding the ability to cleanly write programs that don't rely on static type definitions.

As good as C# is, people still need a document written in both natural language (English, in this case) and some formalism (BNF) to grok the subtleties and to ensure that we're all speaking the same C#. The book you hold in your hands is that document. Based on my own experience, I can safely say that every .NET developer who reads it will have at least one "aha" moment and will be a better developer for it.

Enjoy.

Don Box
Redmond, Washington
May 2010

Preface

The C# project started more than 12 years ago, in December 1998, with the goal to create a simple, modern, object-oriented, and type-safe programming language for the new and yet-to-be-named .NET platform. Since then, C# has come a long way. The language is now in use by more than a million programmers and has been released in four versions, each with several major new features added.

This book, too, is in its fourth edition. It provides a complete technical specification of the C# programming language. This latest edition includes two kinds of new material not found in previous versions. Most notably, of course, it has been updated to cover the new features of C# 4.0, including dynamic binding, named and optional parameters, and covariant and contravariant generic types. The overarching theme for this revision has been to open up C# more to interaction with objects outside of the .NET environment. Just as LINQ in C# 3.0 gave a language-integrated feel to code used to access external data sources, so the dynamic binding of C# 4.0 makes the interaction with objects from, for example, dynamic programming languages such as Python, Ruby, and JavaScript feel native to C#.

The previous edition of this book introduced the notion of annotations by well-known C# experts. We have received consistently enthusiastic feedback about this feature, and we are extremely pleased to be able to offer a new round of deep and entertaining insights, guidelines, background, and perspective from both old and new annotators throughout the book. We are very happy to see the annotations continue to complement the core material and help the C# features spring to life.

Many people have been involved in the creation of the C# language. The language design team for C# 1.0 consisted of Anders Hejlsberg, Scott Wiltamuth, Peter Golde, Peter Sollich, and Eric Gunnerson. For C# 2.0, the language design team consisted of Anders Hejlsberg, Peter Golde, Peter Hallam, Shon Katzenberger, Todd Proebsting, and Anson Horton.

Furthermore, the design and implementation of generics in C# and the .NET Common Language Runtime is based on the "Gyro" prototype built by Don Syme and Andrew Kennedy of Microsoft Research. C# 3.0 was designed by Anders Hejlsberg, Erik Meijer, Matt Warren, Mads Torgersen, Peter Hallam, and Dinesh Kulkarni. On the design team for C# 4.0 were Anders Hejlsberg, Matt Warren, Mads Torgersen, Eric Lippert, Jim Hugunin, Lucian Wischik, and Neal Gafter.

It is impossible to acknowledge the many people who have influenced the design of C#, but we are nonetheless grateful to all of them. Nothing good gets designed in a vacuum, and the constant feedback we receive from our large and enthusiastic community of developers is invaluable.

C# has been and continues to be one of the most challenging and exciting projects on which we've worked. We hope you enjoy using C# as much as we enjoy creating it.

Anders Hejlsberg
Mads Torgersen
Scott Wiltamuth
Peter Golde
Seattle, Washington
September 2010

1. Introduction

C# (pronounced "See Sharp") is a simple, modern, object-oriented, and type-safe programming language. C# has its roots in the C family of languages and will be immediately familiar to C, C++, and Java programmers. C# is standardized by ECMA International as the ***ECMA-334*** standard and by ISO/IEC as the ***ISO/IEC 23270*** standard. Microsoft's C# compiler for the .NET Framework is a conforming implementation of both of these standards.

C# is an object-oriented language, but C# further includes support for ***component-oriented*** programming. Contemporary software design increasingly relies on software components in the form of self-contained and self-describing packages of functionality. Key to such components is that they present a programming model with properties, methods, and events; they have attributes that provide declarative information about the component; and they incorporate their own documentation. C# provides language constructs to directly support these concepts, making C# a very natural language in which to create and use software components.

Several C# features aid in the construction of robust and durable applications: ***Garbage collection*** automatically reclaims memory occupied by unused objects; ***exception handling*** provides a structured and extensible approach to error detection and recovery; and the ***type-safe*** design of the language makes it impossible to read from uninitialized variables, to index arrays beyond their bounds, or to perform unchecked type casts.

C# has a ***unified type system***. All C# types, including primitive types such as `int` and `double`, inherit from a single root `object` type. Thus all types share a set of common operations, and values of any type can be stored, transported, and operated upon in a consistent manner. Furthermore, C# supports both user-defined reference types and value types, allowing dynamic allocation of objects as well as in-line storage of lightweight structures.

To ensure that C# programs and libraries can evolve over time in a compatible manner, much emphasis has been placed on ***versioning*** in C#'s design. Many programming languages pay little attention to this issue. As a result, programs written in those languages break more often than necessary when newer versions of dependent libraries are introduced. Aspects of C#'s design that were directly influenced by versioning considerations include the separate `virtual` and `override` modifiers, the rules for method overload resolution, and support for explicit interface member declarations.

The rest of this chapter describes the essential features of the C# language. Although later chapters describe rules and exceptions in a detail-oriented and sometimes mathematical manner, this chapter strives for clarity and brevity at the expense of completeness. The intent is to provide the reader with an introduction to the language that will facilitate the writing of early programs and the reading of later chapters.

CHRIS SELLS I'm absolutely willing to go with "modern, object-oriented, and type-safe," but C# isn't nearly as simple as it once was. However, given that the language gained functionality such as generics and anonymous delegates in C# 2.0, LINQ-related features in C# 3.0, and dynamic values in C# 4.0, the programs themselves become simpler, more readable, and easier to maintain—which should be the goal of any programming language.

ERIC LIPPERT C# is also increasingly a functional programming language. Features such as type inference, lambda expressions, and monadic query comprehensions allow traditional object-oriented developers to use these ideas from functional languages to increase the expressiveness of the language.

CHRISTIAN NAGEL C# is not a pure object-oriented language but rather a language that is extended over time to get more productivity in the main areas where C# is used. Programs written with C# 3.0 can look completely different than programs written in C# 1.0 with functional programming constructs.

JON SKEET Certain aspects of C# have certainly made this language more functional over time—but at the same time, mutability was encouraged in C# 3.0 by both automatically implemented properties and object initializers. It will be interesting to see whether features encouraging immutability arrive in future versions, along with support for other areas such as tuples, pattern matching, and tail recursion.

BILL WAGNER This section has not changed since the first version of the C# spec. Obviously, the language has grown and added new idioms—and yet C# is still an approachable language. These advanced features are always within reach, but not always required for every program. C# is still approachable for inexperienced developers even as it grows more and more powerful.

1.1 Hello, World

The "Hello, World" program is traditionally used to introduce a programming language. Here it is in C#:

```
using System;

class Hello
{
    static void Main() {
        Console.WriteLine("Hello, World");
    }
}
```

C# source files typically have the file extension `.cs`. Assuming that the "Hello, World" program is stored in the file `hello.cs`, the program can be compiled with the Microsoft C# compiler using the command line

```
csc hello.cs
```

which produces an executable assembly named `hello.exe`. The output produced by this application when it is run is

```
Hello, World
```

The "Hello, World" program starts with a `using` directive that references the `System` namespace. Namespaces provide a hierarchical means of organizing C# programs and libraries. Namespaces contain types and other namespaces—for example, the `System` namespace contains a number of types, such as the `Console` class referenced in the program, and a number of other namespaces, such as `IO` and `Collections`. A `using` directive that references a given namespace enables unqualified use of the types that are members of that namespace. Because of the `using` directive, the program can use `Console.WriteLine` as shorthand for `System.Console.WriteLine`.

The `Hello` class declared by the "Hello, World" program has a single member, the method named `Main`. The `Main` method is declared with the `static` modifier. While instance methods can reference a particular enclosing object instance using the keyword `this`, static methods operate without reference to a particular object. By convention, a static method named `Main` serves as the entry point of a program.

The output of the program is produced by the `WriteLine` method of the `Console` class in the `System` namespace. This class is provided by the .NET Framework class libraries, which, by default, are automatically referenced by the Microsoft C# compiler. Note that C# itself does not have a separate runtime library. Instead, the .NET Framework *is* the runtime library of C#.

BRAD ABRAMS It is interesting to note that `Console.WriteLine()` is simply a shortcut for `Console.Out.WriteLine`. `Console.Out` is a property that returns an implementation of the `System.IO.TextWriter` base class designed to output to the console. The preceding example could be written equally correctly as follows:

```
using System;
class Hello
{
    static void Main() {
        Console.Out.WriteLine("Hello, World");
    }
}
```

Early in the design of the framework, we kept a careful eye on exactly how this section of the C# language specification would have to be written as a bellwether of the complexity of the language. We opted to add the convenience overload on `Console` to make "Hello, World" that much easier to write. By all accounts, it seems to have paid off. In fact, today you find almost no calls to `Console.Out.WriteLine()`.

1.2 Program Structure

The key organizational concepts in C# are ***programs***, ***namespaces***, ***types***, ***members***, and ***assemblies***. C# programs consist of one or more source files. Programs declare types, which contain members and can be organized into namespaces. Classes and interfaces are examples of types. Fields, methods, properties, and events are examples of members. When C# programs are compiled, they are physically packaged into assemblies. Assemblies typically have the file extension `.exe` or `.dll`, depending on whether they implement ***applications*** or ***libraries***.

The example

```
using System;

namespace Acme.Collections
{
    public class Stack
    {
        Entry top;

        public void Push(object data) {
            top = new Entry(top, data);
        }

        public object Pop() {
            if (top == null) throw new InvalidOperationException();
            object result = top.data;
```

```
            top = top.next;
            return result;
        }

        class Entry
        {
            public Entry next;
            public object data;

            public Entry(Entry next, object data) {
                this.next = next;
                this.data = data;
            }
        }
    }
}
```

declares a class named `Stack` in a namespace called `Acme.Collections`. The fully qualified name of this class is `Acme.Collections.Stack`. The class contains several members: a field named `top`, two methods named `Push` and `Pop`, and a nested class named `Entry`. The `Entry` class further contains three members: a field named `next`, a field named `data`, and a constructor. Assuming that the source code of the example is stored in the file `acme.cs`, the command line

```
csc /t:library acme.cs
```

compiles the example as a library (code without a `Main` entry point) and produces an assembly named `acme.dll`.

Assemblies contain executable code in the form of ***Intermediate Language*** (IL) instructions, and symbolic information in the form of ***metadata***. Before it is executed, the IL code in an assembly is automatically converted to processor-specific code by the Just-In-Time (JIT) compiler of .NET Common Language Runtime.

Because an assembly is a self-describing unit of functionality containing both code and metadata, there is no need for `#include` directives and header files in C#. The public types and members contained in a particular assembly are made available in a C# program simply by referencing that assembly when compiling the program. For example, this program uses the `Acme.Collections.Stack` class from the `acme.dll` assembly:

```
using System;
using Acme.Collections;

class Test
{
    static void Main() {
        Stack s = new Stack();
        s.Push(1);
        s.Push(10);
        s.Push(100);
```

```
            Console.WriteLine(s.Pop());
            Console.WriteLine(s.Pop());
            Console.WriteLine(s.Pop());
        }
    }
```

If the program is stored in the file `test.cs`, when `test.cs` is compiled, the `acme.dll` assembly can be referenced using the compiler's `/r` option:

```
csc /r:acme.dll test.cs
```

This creates an executable assembly named `test.exe`, which, when run, produces the following output:

```
100
10
1
```

C# permits the source text of a program to be stored in several source files. When a multi-file C# program is compiled, all of the source files are processed together, and the source files can freely reference one another—conceptually, it is as if all the source files were concatenated into one large file before being processed. Forward declarations are never needed in C# because, with very few exceptions, declaration order is insignificant. C# does not limit a source file to declaring only one public type nor does it require the name of the source file to match a type declared in the source file.

ERIC LIPPERT This is unlike the Java language. Also, the fact that the declaration order is insignificant in C# is unlike the C++ language.

CHRIS SELLS Notice in the previous example the `using Acme.Collections` statement, which looks like a C-style `#include` directive, but isn't. Instead, it's merely a naming convenience so that when the compiler encounters the `Stack`, it has a set of namespaces in which to look for the class. The compiler would take the same action if this example used the fully qualified name:

```
Acme.Collections.Stack s = new Acme.Collections.Stack();
```

1.3 Types and Variables

There are two kinds of types in C#: ***value types*** and ***reference types***. Variables of value types directly contain their data, whereas variables of reference types store references to their data, the latter being known as objects. With reference types, it is possible for two

variables to reference the same object and, therefore, possible for operations on one variable to affect the object referenced by the other variable. With value types, the variables each have their own copy of the data, and it is not possible for operations on one to affect the other (except in the case of `ref` and `out` parameter variables).

JON SKEET The choice of the word "reference" for reference types is perhaps unfortunate. It has led to huge amounts of confusion (or at least miscommunication) when considering the difference between pass-by-reference and pass-by-value semantics for parameter passing.

The difference between value types and reference types is possibly the most important point to teach C# beginners: Until that point is understood, almost nothing else makes sense.

ERIC LIPPERT Probably the most common misconception about value types is that they are "stored on the stack," whereas reference types are "stored on the heap." First, that behavior is an implementation detail of the runtime, not a fact about the language. Second, it explains nothing to the novice. Third, it's false: Yes, the data associated with an instance of a reference type is stored on the heap, but that data can include instances of value types and, therefore, value types are also stored on the heap sometimes. Fourth, if the difference between value and reference types was their storage details, then the CLR team would have called them "stack types" and "heap types." The real difference is that value types are copied by value, and reference types are copied by reference; how the runtime allocates storage to implement the lifetime rules is not important in the vast majority of mainline programming scenarios.

BILL WAGNER C# forces you to make the important decision of value semantics versus reference semantics for your types. Developers using your type do not get to make that decision on each usage (as they do in C++). You need to think about the usage patterns for your types and make a careful decision between these two kinds of types.

VLADIMIR RESHETNIKOV C# also supports unsafe pointer types, which are described at the end of this specification. They are called "unsafe" because their negligent use can break the type safety in a way that cannot be caught by the compiler.

C#'s value types are further divided into ***simple types***, ***enum types***, ***struct types***, and ***nullable types***. C#'s reference types are further divided into ***class types***, ***interface types***, ***array types***, and ***delegate types***.

The following table provides an overview of C#'s type system.

Category		Description
Value types	Simple types	Signed integral: `sbyte`, `short`, `int`, `long`
		Unsigned integral: `byte`, `ushort`, `uint`, `ulong`
		Unicode characters: `char`
		IEEE floating point: `float`, `double`
		High-precision decimal: `decimal`
		Boolean: `bool`
	Enum types	User-defined types of the form `enum E {...}`
	Struct types	User-defined types of the form `struct S {...}`
	Nullable types	Extensions of all other value types with a `null` value
Reference types	Class types	Ultimate base class of all other types: `object`
		Unicode strings: `string`
		User-defined types of the form `class C {...}`
	Interface types	User-defined types of the form `interface I {...}`
	Array types	Single- and multi-dimensional; for example, `int[]` and `int[,]`
	Delegate types	User-defined types of the form e.g. `delegate int D(...)`

The eight integral types provide support for 8-bit, 16-bit, 32-bit, and 64-bit values in signed or unsigned form.

JON SKEET Hooray for `byte` being an unsigned type! The fact that in Java a byte is signed (and with no unsigned equivalent) makes a lot of bit-twiddling pointlessly error-prone.

It's quite possible that we should all be using `uint` a lot more than we do, mind you: I'm sure many developers reach for `int` by default when they want an integer type. The framework designers also fall into this category, of course: Why should `String.Length` be signed?

ERIC LIPPERT The answer to Jon's question is that the framework is designed to work well with the Common Language Specification (CLS). The CLS defines a set of basic language features that all CLS-compliant languages are expected to be able to consume; unsigned integers are not in the CLS subset.

The two floating point types, `float` and `double`, are represented using the 32-bit single-precision and 64-bit double-precision IEEE 754 formats.

The `decimal` type is a 128-bit data type suitable for financial and monetary calculations.

JON SKEET These two paragraphs imply that `decimal` isn't a floating point type. It is—it's just a floating *decimal* point type, whereas `float` and `double` are floating *binary* point types.

C#'s `bool` type is used to represent boolean values—values that are either `true` or `false`.

Character and string processing in C# uses Unicode encoding. The `char` type represents a UTF-16 code unit, and the `string` type represents a sequence of UTF-16 code units.

The following table summarizes C#'s numeric types.

Category	Bits	Type	Range/Precision
Signed integral	8	`sbyte`	–128...127
	16	`short`	–32,768...32,767
	32	`int`	–2,147,483,648...2,147,483,647
	64	`long`	–9,223,372,036,854,775,808...9,223,372,036,854,775,807

Continued

Category	Bits	Type	Range/Precision
Unsigned integral	8	`byte`	0...255
	16	`ushort`	0...65,535
	32	`uint`	0...4,294,967,295
	64	`ulong`	0...18,446,744,073,709,551,615
Floating point	32	`float`	1.5×10^{-45} to 3.4×10^{38}, 7-digit precision
	64	`double`	5.0×10^{-324} to 1.7×10^{308}, 15-digit precision
Decimal	128	`decimal`	1.0×10^{-28} to 7.9×10^{28}, 28-digit precision

CHRISTIAN NAGEL One of the problems we had with C++ on different platforms is that the standard doesn't define the number of bits used with `short`, `int`, and `long`. The standard defines only `short <= int <= long`, which results in different sizes on 16-, 32-, and 64-bit platforms. With C#, the length of numeric types is clearly defined, no matter which platform is used.

C# programs use ***type declarations*** to create new types. A type declaration specifies the name and the members of the new type. Five of C#'s categories of types are user-definable: class types, struct types, interface types, enum types, and delegate types.

A class type defines a data structure that contains data members (fields) and function members (methods, properties, and others). Class types support single inheritance and polymorphism, mechanisms whereby derived classes can extend and specialize base classes.

ERIC LIPPERT Choosing to support single rather than multiple inheritance on classes eliminates in one stroke many of the complicated corner cases found in multiple inheritance languages.

A struct type is similar to a class type in that it represents a structure with data members and function members. However, unlike classes, structs are value types and do not require heap allocation. Struct types do not support user-specified inheritance, and all struct types implicitly inherit from type `object`.

VLADIMIR RESHETNIKOV Structs inherit from `object` indirectly. Their implicit direct base class is `System.ValueType`, which in turn directly inherits from `object`.

An interface type defines a contract as a named set of public function members. A class or struct that implements an interface must provide implementations of the interface's function members. An interface may inherit from multiple base interfaces, and a class or struct may implement multiple interfaces.

A delegate type represents references to methods with a particular parameter list and return type. Delegates make it possible to treat methods as entities that can be assigned to variables and passed as parameters. Delegates are similar to the concept of function pointers found in some other languages, but unlike function pointers, delegates are object-oriented and type-safe.

Class, struct, interface, and delegate types all support generics, whereby they can be parameterized with other types.

An enum type is a distinct type with named constants. Every enum type has an underlying type, which must be one of the eight integral types. The set of values of an enum type is the same as the set of values of the underlying type.

VLADIMIR RESHETNIKOV Enum types cannot have type parameters in their declarations. Even so, they can be generic if nested within a generic class or struct type. Moreover, C# supports pointers to generic enum types in unsafe code.

Sometimes enum types are called "enumeration types" in this specification. These two names are completely interchangeable.

C# supports single- and multi-dimensional arrays of any type. Unlike the types listed above, array types do not have to be declared before they can be used. Instead, array types are constructed by following a type name with square brackets. For example, `int[]` is a single-dimensional array of `int`, `int[,]` is a two-dimensional array of `int`, and `int[][]` is a single-dimensional array of single-dimensional arrays of `int`.

Nullable types also do not have to be declared before they can be used. For each non-nullable value type `T` there is a corresponding nullable type `T?`, which can hold an additional value `null`. For instance, `int?` is a type that can hold any 32 bit integer or the value `null`.

CHRISTIAN NAGEL `T?` is the C# shorthand notation for the `Nullable<T>` structure.

ERIC LIPPERT In C# 1.0, we had nullable reference types and non-nullable value types. In C# 2.0, we added nullable value types. But there are no non-nullable reference types. If we had to do it all over again, we probably would bake nullability and non-nullability into the type system from day one. Unfortunately, non-nullable reference types are difficult to add to an existing type system that wasn't designed for them. We get feature requests for non-nullable reference types all the time; it would be a great feature. However, code contracts go a long way toward solving the problems solved by non-nullable reference types; consider using them if you want to enforce non-nullability in your programs. If this subject interests you, you might also want to check out Spec#, a Microsoft Research version of C# that does support non-nullable reference types.

C#'s type system is unified such that a value of any type can be treated as an object. Every type in C# directly or indirectly derives from the `object` class type, and `object` is the ultimate base class of all types. Values of reference types are treated as objects simply by viewing the values as type `object`. Values of value types are treated as objects by performing ***boxing*** and ***unboxing*** operations. In the following example, an `int` value is converted to `object` and back again to `int`.

```
using System;

class Test
{
    static void Main() {
        int i = 123;
        object o = i;           // Boxing
        int j = (int)o;         // Unboxing
    }
}
```

When a value of a value type is converted to type `object`, an object instance, also called a "box," is allocated to hold the value, and the value is copied into that box. Conversely, when an `object` reference is cast to a value type, a check is made that the referenced object is a box of the correct value type, and, if the check succeeds, the value in the box is copied out.

C#'s unified type system effectively means that value types can become objects "on demand." Because of the unification, general-purpose libraries that use type `object` can be used with both reference types and value types.

There are several kinds of ***variables*** in C#, including fields, array elements, local variables, and parameters. Variables represent storage locations, and every variable has a type that determines what values can be stored in the variable, as shown by the following table.

Type of Variable	Possible Contents
Non-nullable value type	A value of that exact type
Nullable value type	A null value or a value of that exact type
`object`	A null reference, a reference to an object of any reference type, or a reference to a boxed value of any value type
Class type	A null reference, a reference to an instance of that class type, or a reference to an instance of a class derived from that class type
Interface type	A null reference, a reference to an instance of a class type that implements that interface type, or a reference to a boxed value of a value type that implements that interface type
Array type	A null reference, a reference to an instance of that array type, or a reference to an instance of a compatible array type
Delegate type	A null reference or a reference to an instance of that delegate type

1.4 Expressions

Expressions are constructed from ***operands*** and ***operators***. The operators of an expression indicate which operations to apply to the operands. Examples of operators include `+`, `-`, `*`, `/`, and `new`. Examples of operands include literals, fields, local variables, and expressions.

When an expression contains multiple operators, the ***precedence*** of the operators controls the order in which the individual operators are evaluated. For example, the expression `x + y * z` is evaluated as `x + (y * z)` because the `*` operator has higher precedence than the `+` operator.

> **ERIC LIPPERT** Precedence controls the order in which the operators are executed, but not the order in which the operands are evaluated. Operands are evaluated from left to right, period. In the preceding example, `x` would be evaluated, then `y`, then `z`, then the multiplication would be performed, and then the addition. The evaluation of operand `x` happens before that of `y` because `x` is to the left of `y`; the evaluation of the multiplication happens before the addition because the multiplication has higher precedence.

Most operators can be ***overloaded***. Operator overloading permits user-defined operator implementations to be specified for operations where one or both of the operands are of a user-defined class or struct type.

The following table summarizes C#'s operators, listing the operator categories in order of precedence from highest to lowest. Operators in the same category have equal precedence.

Category	Expression	Description
Primary	`x.m`	Member access
	`x(...)`	Method and delegate invocation
	`x[...]`	Array and indexer access
	`x++`	Post-increment
	`x--`	Post-decrement
	`new T(...)`	Object and delegate creation
	`new T(...){...}`	Object creation with initializer
	`new {...}`	Anonymous object initializer
	`new T[...]`	Array creation
	`typeof(T)`	Obtain `System.Type` object for `T`
	`checked(x)`	Evaluate expression in checked context
	`unchecked(x)`	Evaluate expression in unchecked context
	`default(T)`	Obtain default value of type `T`
	`delegate {...}`	Anonymous function (anonymous method)
Unary	`+x`	Identity
	`-x`	Negation
	`!x`	Logical negation
	`~x`	Bitwise negation
	`++x`	Pre-increment
	`--x`	Pre-decrement
	`(T)x`	Explicitly convert `x` to type `T`

Category	Expression	Description
Multiplicative	`x * y`	Multiplication
	`x / y`	Division
	`x % y`	Remainder
Additive	`x + y`	Addition, string concatenation, delegate combination
	`x - y`	Subtraction, delegate removal
Shift	`x << y`	Shift left
	`x >> y`	Shift right
Relational and type testing	`x < y`	Less than
	`x > y`	Greater than
	`x <= y`	Less than or equal
	`x >= y`	Greater than or equal
	`x is T`	Return `true` if `x` is a `T`, `false` otherwise
	`x as T`	Return `x` typed as `T`, or `null` if `x` is not a `T`
Equality	`x == y`	Equal
	`x != y`	Not equal
Logical AND	`x & y`	Integer bitwise AND, boolean logical AND
Logical XOR	`x ^ y`	Integer bitwise XOR, boolean logical XOR
Logical OR	`x | y`	Integer bitwise OR, boolean logical OR
Conditional AND	`x && y`	Evaluates `y` only if `x` is `true`
Conditional OR	`x || y`	Evaluates `y` only if `x` is `false`
Null coalescing	`X ?? y`	Evaluates to `y` if `x` is `null`, to `x` otherwise
Conditional	`x ? y : z`	Evaluates `y` if `x` is `true`, `z` if `x` is `false`

Continued

Category	Expression	Description
Assignment or anonymous function	`x = y`	Assignment
	`x` *op*`= y`	Compound assignment; supported operators are `*= /= %= += -= <<= >>= &= ^= |=`
	`(T x) => y`	Anonymous function (lambda expression)

ERIC LIPPERT It is often surprising to people that the lambda and anonymous method syntaxes are described as operators. They are unusual operators. More typically, you think of an operator as taking expressions as operands, not declarations of formal parameters. Syntactically, however, the lambda and anonymous method syntaxes are operators like any other.

1.5 Statements

The actions of a program are expressed using ***statements***. C# supports several kinds of statements, a number of which are defined in terms of embedded statements.

A ***block*** permits multiple statements to be written in contexts where a single statement is allowed. A block consists of a list of statements written between the delimiters `{` and `}`.

Declaration statements are used to declare local variables and constants.

Expression statements are used to evaluate expressions. Expressions that can be used as statements include method invocations, object allocations using the `new` operator, assignments using `=` and the compound assignment operators, and increment and decrement operations using the `++` and `--` operators.

Selection statements are used to select one of a number of possible statements for execution based on the value of some expression. In this group are the `if` and `switch` statements.

Iteration statements are used to repeatedly execute an embedded statement. In this group are the `while`, `do`, `for`, and `foreach` statements.

Jump statements are used to transfer control. In this group are the `break`, `continue`, `goto`, `throw`, `return`, and `yield` statements.

The `try`...`catch` statement is used to catch exceptions that occur during execution of a block, and the `try`...`finally` statement is used to specify finalization code that is always executed, whether an exception occurred or not.

> **ERIC LIPPERT** This is a bit of a fib; of course, a `finally` block does not *always* execute. The code in the `try` block could go into an infinite loop, the exception could trigger a "fail fast" (which takes the process down without running any `finally` blocks), or someone could pull the power cord out of the wall.

The `checked` and `unchecked` statements are used to control the overflow checking context for integral-type arithmetic operations and conversions.

The `lock` statement is used to obtain the mutual-exclusion lock for a given object, execute a statement, and then release the lock.

The `using` statement is used to obtain a resource, execute a statement, and then dispose of that resource.

The following table lists C#'s statements and provides an example for each one.

Statement	Example

Local variable declaration	`static void Main() {`
	`  int a;`
	`  int b = 2, c = 3;`
	`  a = 1;`
	`  Console.WriteLine(a + b + c);`
	`}`

Local constant declaration	`static void Main() {`
	`  const float pi = 3.1415927f;`
	`  const int r = 25;`
	`  Console.WriteLine(pi * r * r);`
	`}`

Expression statement	`static void Main() {`
	`  int i;`
	`  i = 123;  // Expression statement`
	`  Console.WriteLine(i);  // Expression statement`
	`  i++;  // Expression statement`
	`  Console.WriteLine(i);  // Expression statement`
	`}`

Continued

Statement	Example

`if` statement	`static void Main(string[] args) {`
	`  if (args.Length == 0) {`
	`  Console.WriteLine("No arguments");`
	`  }`
	`  else {`
	`  Console.WriteLine("One or more arguments");`
	`  }`
	`}`

`switch` statement	`static void Main(string[] args) {`
	`  int n = args.Length;`
	`  switch (n) {`
	`  case 0:`
	`  Console.WriteLine("No arguments");`
	`  break;`
	`  case 1:`
	`  Console.WriteLine("One argument");`
	`  break;`
	`  default:`
	`  Console.WriteLine("{0} arguments", n);`
	`  break;`
	`  }`
	`  }`
	`}`

`while` statement	`static void Main(string[] args) {`
	`  int i = 0;`
	`  while (i < args.Length) {`
	`  Console.WriteLine(args[i]);`
	`  i++;`
	`  }`
	`}`

`do` statement	`static void Main() {`
	`  string s;`
	`  do {`
	`  s = Console.ReadLine();`
	`  if (s != null) Console.WriteLine(s);`
	`  } while (s != null);`
	`}`

Statement	Example

for statement	`static void Main(string[] args) {`
	`  for (int i = 0; i < args.Length; i++) {`
	`  Console.WriteLine(args[i]);`
	`  }`
	`}`

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

break statement	`static void Main() {`
	`  while (true) {`
	`  string s = Console.ReadLine();`
	`  if (s == null) break;`
	`  Console.WriteLine(s);`
	`  }`
	`}`

continue statement	`static void Main(string[] args) {`
	`  for (int i = 0; i < args.Length; i++) {`
	`  if (args[i].StartsWith("/")) continue;`
	`  Console.WriteLine(args[i]);`
	`  }`
	`}`

goto statement	`static void Main(string[] args) {`
	`  int i = 0;`
	`  goto check;`
	`  loop:`
	`  Console.WriteLine(args[i++]);`
	`  check:`
	`  if (i < args.Length) goto loop;`
	`}`

return statement	`static int Add(int a, int b) {`
	`  return a + b;`
	`}`
	`static void Main() {`
	`  Console.WriteLine(Add(1, 2));`
	`  return;`
	`}`

Continued

Statement	Example

yield statement	`static IEnumerable<int> Range(int from, int to) {`
	`  for (int i = from; i < to; i++) {`
	`  yield return i;`
	`  }`
	`  yield break;`
	`}`
	`static void Main() {`
	`  foreach (int x in Range(-10,10)) {`
	`  Console.WriteLine(x);`
	`  }`
	`}`

throw and try statements	`static double Divide(double x, double y) {`
	`  if (y == 0) throw new DivideByZeroException();`
	`  return x / y;`
	`}`
	`static void Main(string[] args) {`
	`  try {`
	`  if (args.Length != 2) {`
	`  throw new Exception("Two numbers required");`
	`  }`
	`  double x = double.Parse(args[0]);`
	`  double y = double.Parse(args[1]);`
	`  Console.WriteLine(Divide(x, y));`
	`  }`
	`  catch (Exception e) {`
	`  Console.WriteLine(e.Message);`
	`  }`
	`  finally {`
	`  Console.WriteLine(“Good bye!”);`
	`  }`
	`}`

checked and unchecked statements	`static void Main() {`
	`  int i = int.MaxValue;`
	`  checked {`
	`  Console.WriteLine(i + 1);  // Exception`
	`  }`
	`  unchecked {`
	`  Console.WriteLine(i + 1);  // Overflow`
	`  }`
	`}`

Statement	Example

`lock` statement	`class Account`
	`{`
	`  decimal balance;`
	`  public void Withdraw(decimal amount) {`
	`  lock (this) {`
	`  if (amount > balance) {`
	`  throw new Exception("Insufficient funds");`
	`  }`
	`  balance -= amount;`
	`  }`
	`  }`
	`}`

`using` statement	`static void Main() {`
	`  using (TextWriter w = File.CreateText("test.txt")) {`
	`  w.WriteLine("Line one");`
	`  w.WriteLine("Line two");`
	`  w.WriteLine("Line three");`
	`  }`
	`}`

1.6 Classes and Objects

Classes are the most fundamental of C#'s types. A class is a data structure that combines state (fields) and actions (methods and other function members) in a single unit. A class provides a definition for dynamically created ***instances*** of the class, also known as ***objects***. Classes support ***inheritance*** and ***polymorphism***, mechanisms whereby ***derived classes*** can extend and specialize ***base classes***.

New classes are created using class declarations. A class declaration starts with a header that specifies the attributes and modifiers of the class, the name of the class, the base class (if given), and the interfaces implemented by the class. The header is followed by the class body, which consists of a list of member declarations written between the delimiters { and }.

The following is a declaration of a simple class named `Point`:

```
public class Point
{
    public int x, y;

    public Point(int x, int y)
    {
        this.x = x;
        this.y = y;
    }
}
```

Instances of classes are created using the `new` operator, which allocates memory for a new instance, invokes a constructor to initialize the instance, and returns a reference to the instance. The following statements create two `Point` objects and store references to those objects in two variables:

```
Point p1 = new Point(0, 0);
Point p2 = new Point(10, 20);
```

The memory occupied by an object is automatically reclaimed when the object is no longer in use. It is neither necessary nor possible to explicitly deallocate objects in C#.

1.6.1 Members

The members of a class are either ***static members*** or ***instance members***. Static members belong to classes, and instance members belong to objects (instances of classes).

> **ERIC LIPPERT** The term "static" was chosen because of its familiarity to users of similar languages, rather than because it is a particularly sensible or descriptive term for "shared by all instances of a class."

> **JON SKEET** I'd argue that "shared" (as used in Visual Basic) gives an incorrect impression, too. "Sharing" feels like something that requires one or more participants, whereas a static member doesn't require *any* instances of the type. I have the perfect term for this situation, but it's too late to change "static" to "associated-with-the-type-rather-than-with-any-specific-instance-of-the-type" (hyphens optional).

The following table provides an overview of the kinds of members a class can contain.

Member	Description
Constants	Constant values associated with the class
Fields	Variables of the class
Methods	Computations and actions that can be performed by the class
Properties	Actions associated with reading and writing named properties of the class
Indexers	Actions associated with indexing instances of the class like an array
Events	Notifications that can be generated by the class
Operators	Conversions and expression operators supported by the class
Constructors	Actions required to initialize instances of the class or the class itself
Destructors	Actions to perform before instances of the class are permanently discarded
Types	Nested types declared by the class

1.6.2 Accessibility

Each member of a class has an associated accessibility, which controls the regions of program text that are able to access the member. The five possible forms of accessibility are summarized in the following table.

Accessibility	Meaning
`public`	Access not limited
`protected`	Access limited to this class or classes derived from this class
`internal`	Access limited to this program
`protected internal`	Access limited to this program or classes derived from this class
`private`	Access limited to this class

KRZYSZTOF CWALINA People need to be careful with the `public` keyword. `public` in C# is *not* equivalent to `public` in C++! In C++, it means "internal to my compilation unit." In C#, it means what `extern` meant in C++ (i.e., everybody can call it). This is a huge difference!

CHRISTIAN NAGEL I would describe the internal access modifier as "access limited to this assembly" instead of "access limited to this program." If the internal access modifier is used within a DLL, the EXE referencing the DLL does not have access to it.

ERIC LIPPERT `protected internal` has proven to be a controversial and somewhat unfortunate choice. Many people using this feature incorrectly believe that `protected internal` means "access is limited to derived classes within this program." That is, they believe it means the *more* restrictive combination, when in fact it means the *less* restrictive combination. The way to remember this relationship is to remember that the "natural" state of a member is "private" and every accessibility modifier makes the accessibility domain *larger*.

Were a hypothetical future version of the C# language to provide a syntax for "the more restrictive combination of protected and internal," the question would then be which combination of keywords would have that meaning. I am holding out for either "proternal" or "intected," but I suspect I will have to live with disappointment.

CHRISTIAN NAGEL C# defines `protected internal` to limit access to this assembly *or* classes derived from this class. The CLR also allows limiting access to this assembly *and* classes derived from this class. C++/CLI offers this CLR feature with the `public private` access modifier (or `private public`—the order is not relevant). Realistically, this access modifier is rarely used.

1.6.3 Type Parameters

A class definition may specify a set of type parameters by following the class name with angle brackets enclosing a list of type parameter names. The type parameters can then be used in the body of the class declarations to define the members of the class. In the following example, the type parameters of `Pair` are `TFirst` and `TSecond`:

```
public class Pair<TFirst, TSecond>
{
    public TFirst First;

    public TSecond Second;
}
```

A class type that is declared to take type parameters is called a generic class type. Struct, interface, and delegate types can also be generic.

> **ERIC LIPPERT** If you need a pair, triple, and so on, the generic "tuple" types defined in the CLR 4 version of the framework are handy types.

When the generic class is used, type arguments must be provided for each of the type parameters:

```
Pair<int,string> pair = new Pair<int,string> { First = 1, Second = "two" };
int i = pair.First;     // TFirst is int
string s = pair.Second; // TSecond is string
```

A generic type with type arguments provided, like `Pair<int,string>` above, is called a constructed type.

1.6.4 Base Classes

A class declaration may specify a base class by following the class name and type parameters with a colon and the name of the base class. Omitting a base class specification is the same as deriving from type `object`. In the following example, the base class of `Point3D` is `Point`, and the base class of `Point` is `object`:

```
public class Point
{
    public int x, y;

    public Point(int x, int y)
    {
        this.x = x;
        this.y = y;
    }
}

public class Point3D : Point
{
    public int z;

    public Point3D(int x, int y, int z): base(x, y)
    {
        this.z = z;
    }
}
```

A class inherits the members of its base class. Inheritance means that a class implicitly contains all members of its base class, except for the instance and static constructors, and the destructors of the base class. A derived class can add new members to those it inherits, but it cannot remove the definition of an inherited member. In the previous example, `Point3D`

inherits the `x` and `y` fields from `Point`, and every `Point3D` instance contains three fields, `x`, `y`, and `z`.

> **JESSE LIBERTY** There is nothing more important to understand about C# than inheritance and polymorphism. These concepts are the heart of the language and the soul of object-oriented programming. Read this section until it makes sense, or ask for help or supplement it with additional reading, but do not skip over it—these issues are the sine qua non of C#.

An implicit conversion exists from a class type to any of its base class types. Therefore, a variable of a class type can reference an instance of that class or an instance of any derived class. For example, given the previous class declarations, a variable of type `Point` can reference either a `Point` or a `Point3D`:

```
Point a = new Point(10, 20);
Point b = new Point3D(10, 20, 30);
```

1.6.5 Fields

A field is a variable that is associated with a class or with an instance of a class.

A field declared with the `static` modifier defines a ***static field***. A static field identifies exactly one storage location. No matter how many instances of a class are created, there is only ever one copy of a static field.

> **ERIC LIPPERT** Static fields are per *constructed* type for a generic type. That is, if you have a
>
> ```
> class Stack<T> {
>         public readonly static Stack<T> empty = whatever; ...
> }
> ```
>
> then `Stack<int>.empty` is a different field than `Stack<string>.empty`.

A field declared without the `static` modifier defines an ***instance field***. Every instance of a class contains a separate copy of all the instance fields of that class.

In the following example, each instance of the `Color` class has a separate copy of the `r`, `g`, and `b` instance fields, but there is only one copy of the `Black`, `White`, `Red`, `Green`, and `Blue` static fields:

```
public class Color
{
    public static readonly Color Black = new Color(0, 0, 0);
    public static readonly Color White = new Color(255, 255, 255);
    public static readonly Color Red = new Color(255, 0, 0);
    public static readonly Color Green = new Color(0, 255, 0);
    public static readonly Color Blue = new Color(0, 0, 255);

    private byte r, g, b;

    public Color(byte r, byte g, byte b)
    {
        this.r = r;
        this.g = g;
        this.b = b;
    }
}
```

As shown in the previous example, ***read-only fields*** may be declared with a `readonly` modifier. Assignment to a `readonly` field can occur only as part of the field's declaration or in a constructor in the same class.

BRAD ABRAMS `readonly` protects the location of the field from being changed outside the type's constructor, but does not protect the value at that location. For example, consider the following type:

```
public class Names
{
    public static readonly StringBuilder FirstBorn = new StringBuilder("Joe");
    public static readonly StringBuilder SecondBorn = new StringBuilder("Sue");
}
```

Outside of the constructor, directly changing the `FirstBorn` instance results in a compiler error:

```
Names.FirstBorn = new StringBuilder("Biff");
// Compile error
```

However, I am able to accomplish exactly the same results by modifying the `StringBuilder` instance:

```
Names.FirstBorn.Remove(0,6).Append("Biff");
Console.WriteLine(Names.FirstBorn);       // Outputs "Biff"
```

It is for this reason that we strongly recommend that read-only fields be limited to immutable types. Immutable types do not have any publicly exposed setters, such as `int`, `double`, or `String`.

BILL WAGNER Several well-known design patterns make use of the read-only fields of mutable types. The Adapter, Decorator, Façade, and Proxy patterns are the most obvious examples. When you are creating a larger structure by composing smaller structures, you will often express instances of those smaller structures using read-only fields. A read-only field of a mutable type should indicate that one of these structural patterns is being used.

1.6.6 Methods

A ***method*** is a member that implements a computation or action that can be performed by an object or class. ***Static methods*** are accessed through the class. ***Instance methods*** are accessed through instances of the class.

Methods have a (possibly empty) list of ***parameters***, which represent values or variable references passed to the method, and a ***return type***, which specifies the type of the value computed and returned by the method. A method's return type is `void` if it does not return a value.

Like types, methods may also have a set of type parameters, for which type arguments must be specified when the method is called. Unlike types, the type arguments can often be inferred from the arguments of a method call and need not be explicitly given.

The ***signature*** of a method must be unique in the class in which the method is declared. The signature of a method consists of the name of the method, the number of type parameters, and the number, modifiers, and types of its parameters. The signature of a method does not include the return type.

ERIC LIPPERT An unfortunate consequence of generic types is that a constructed type may potentially have two methods with identical signatures. For example, `class C<T> { void M(T t){} void M(int t){} ...}` is perfectly legal, but `C<int>` has two methods `M` with identical signatures. As we'll see later on, this possibility leads to some interesting scenarios involving overload resolution and explicit interface implementations. A good guideline: Don't create a generic type that can create ambiguities under construction in this way; such types are extremely confusing and can produce unexpected behaviors.

1.6.6.1 *Parameters*

Parameters are used to pass values or variable references to methods. The parameters of a method get their actual values from the ***arguments*** that are specified when the method is invoked. There are four kinds of parameters: value parameters, reference parameters, output parameters, and parameter arrays.

A ***value parameter*** is used for input parameter passing. A value parameter corresponds to a local variable that gets its initial value from the argument that was passed for the parameter. Modifications to a value parameter do not affect the argument that was passed for the parameter.

> **BILL WAGNER** The statement that modifications to value parameters do not affect the argument might be misleading because mutator methods may change the contents of a parameter of reference type. The value parameter does not change, but the contents of the referred-to object do.

Value parameters can be optional, by specifying a default value so that corresponding arguments can be omitted.

A ***reference parameter*** is used for both input and output parameter passing. The argument passed for a reference parameter must be a variable, and during execution of the method, the reference parameter represents the same storage location as the argument variable. A reference parameter is declared with the `ref` modifier. The following example shows the use of `ref` parameters.

```
using System;

class Test
{
    static void Swap(ref int x, ref int y) {
        int temp = x;
        x = y;
        y = temp;
    }

    static void Main() {
        int i = 1, j = 2;
        Swap(ref i, ref j);
        Console.WriteLine("{0} {1}", i, j); // Outputs "2 1"
    }
}
```

ERIC LIPPERT This syntax should help clear up the confusion between the two things both called "passing by reference." Reference types are called this name in C# because they are "passed by reference"; you pass an object instance to a method, and the method gets a reference to that object instance. Some other code might also be holding on to a reference to the same object.

Reference parameters are a slightly different form of "passing by reference." In this case, the reference is to the variable itself, not to some object instance. If that variable happens to contain a value type (as shown in the previous example), that's perfectly legal. The value is not being passed by reference, but rather the variable that holds it is.

A good way to think about reference parameters is that the reference parameter becomes an *alias* for the variable passed as the argument. In the preceding example, `x` and `i` are essentially *the same variable.* They refer to the same storage location.

An ***output parameter*** is used for output parameter passing. An output parameter is similar to a reference parameter except that the initial value of the caller-provided argument is unimportant. An output parameter is declared with the `out` modifier. The following example shows the use of `out` parameters.

```
using System;

class Test
{
    static void Divide(int x, int y, out int result, out int remainder) {
        result = x / y;
        remainder = x % y;
    }

    static void Main() {
        int res, rem;
        Divide(10, 3, out res, out rem);
        Console.WriteLine("{0} {1}", res, rem);     // Outputs "3 1"
    }
}
```

ERIC LIPPERT The CLR directly supports only `ref` parameters. An `out` parameter is represented in metadata as a `ref` parameter with a special attribute on it indicating to the C# compiler that this `ref` parameter ought to be treated as an `out` parameter. This explains why it is not legal to have two methods that differ solely in "out/ref-ness"; from the CLR's perspective, they would be two identical methods.

A ***parameter array*** permits a variable number of arguments to be passed to a method. A parameter array is declared with the `params` modifier. Only the last parameter of a method can be a parameter array, and the type of a parameter array must be a single-dimensional array type. The `Write` and `WriteLine` methods of the `System.Console` class are good examples of parameter array usage. They are declared as follows.

```
public class Console
{
    public static void Write(string fmt, params object[] args) {...}

    public static void WriteLine(string fmt, params object[] args) {...}

    ...
}
```

Within a method that uses a parameter array, the parameter array behaves exactly like a regular parameter of an array type. However, in an invocation of a method with a parameter array, it is possible to pass either a single argument of the parameter array type or any number of arguments of the element type of the parameter array. In the latter case, an array instance is automatically created and initialized with the given arguments. This example

```
Console.WriteLine("x={0} y={1} z={2}", x, y, z);
```

is equivalent to writing the following.

```
string s = "x={0} y={1} z={2}";
object[] args = new object[3];
args[0] = x;
args[1] = y;
args[2] = z;
Console.WriteLine(s, args);
```

BRAD ABRAMS You may recognize the similarity between `params` and the C programming language's `varargs` concept. In keeping with our goal of making C# very simple to understand, the `params` modifier does not require a special calling convention or special library support. As such, it has proven to be much less prone to error than `varargs`.

Note, however, that the C# model does create an extra object allocation (the containing array) implicitly on each call. This is rarely a problem, but in inner-loop type scenarios where it could get inefficient, we suggest providing overloads for the mainstream cases and using the `params` overload for only the edge cases. An example is the `StringBuilder.AppendFormat()` family of overloads:

```
public StringBuilder AppendFormat(string format, object arg0);
public StringBuilder AppendFormat(string format, object arg0, object arg1);
public StringBuilder AppendFormat(string format, object arg0, object arg1, object arg2);
public StringBuilder AppendFormat(string format, params object[] args);
```

CHRIS SELLS One nice side effect of the fact that `params` is really just an optional shortcut is that I don't have to write something crazy like the following:

```
static object[] GetArgs() { ... }

static void Main() {
        object[] args = GetArgs();
        object x = args[0];
        object y = args[1];
        object z = args[2];
        Console.WriteLine("x={0} y={1} z={2}", x, y, z);
}
```

Here I'm calling the method and cracking the parameters out just so the compiler can create an array around them again. Of course, I should really just write this:

```
static object[] GetArgs() { ... }

static void Main() {
        Console.WriteLine("x={0} y={1} z={2}", GetArgs());
}
```

However, you'll find fewer and fewer methods that return arrays in .NET these days, as most folks prefer using `IEnumerable<T>` for its flexibility. This means you'll probably be writing code like so:

```
static IEnumerable<object> GetArgs() { ... }

static void Main() {
        Console.WriteLine("x={0} y={1} z={2}", GetArgs().ToArray());
}
```

It would be handy if `params` "understood" `IEnumerable` directly. Maybe next time.

1.6.6.2 *Method Body and Local Variables*

A method's body specifies the statements to execute when the method is invoked.

A method body can declare variables that are specific to the invocation of the method. Such variables are called ***local variables***. A local variable declaration specifies a type name, a variable name, and possibly an initial value. The following example declares a local variable `i` with an initial value of zero and a local variable `j` with no initial value.

```
using System;

class Squares
{
    static void Main() {
        int i = 0;
        int j;
        while (i < 10) {
            j = i * i;
            Console.WriteLine("{0} x {0} = {1}", i, j);
            i = i + 1;
        }
    }
}
```

C# requires a local variable to be ***definitely assigned*** before its value can be obtained. For example, if the declaration of the previous `i` did not include an initial value, the compiler would report an error for the subsequent usages of `i` because `i` would not be definitely assigned at those points in the program.

A method can use `return` statements to return control to its caller. In a method returning `void`, `return` statements cannot specify an expression. In a method returning non-`void`, `return` statements must include an expression that computes the return value.

1.6.6.3 *Static and Instance Methods*

A method declared with a `static` modifier is a ***static method***. A static method does not operate on a specific instance and can only directly access static members.

> **ERIC LIPPERT** It is, of course, perfectly legal for a static method to access instance members should it happen to have an instance handy.

A method declared without a `static` modifier is an ***instance method***. An instance method operates on a specific instance and can access both static and instance members. The instance on which an instance method was invoked can be explicitly accessed as `this`. It is an error to refer to `this` in a static method.

The following `Entity` class has both static and instance members.

```
class Entity
{
    static int nextSerialNo;

    int serialNo;

    public Entity()
    {
```

```
            serialNo = nextSerialNo++;
        }
        public int GetSerialNo()
        {
            return serialNo;
        }

        public static int GetNextSerialNo()
        {
            return nextSerialNo;
        }

        public static void SetNextSerialNo(int value)
        {
            nextSerialNo = value;
        }
    }
```

Each `Entity` instance contains a serial number (and presumably some other information that is not shown here). The `Entity` constructor (which is like an instance method) initializes the new instance with the next available serial number. Because the constructor is an instance member, it is permitted to access both the `serialNo` instance field and the `nextSerialNo` static field.

The `GetNextSerialNo` and `SetNextSerialNo` static methods can access the `nextSerialNo` static field, but it would be an error for them to directly access the `serialNo` instance field.

The following example shows the use of the `Entity` class.

```
using System;

class Test
{
    static void Main() {
        Entity.SetNextSerialNo(1000);

        Entity e1 = new Entity();
        Entity e2 = new Entity();

        Console.WriteLine(e1.GetSerialNo());            // Outputs "1000"
        Console.WriteLine(e2.GetSerialNo());            // Outputs "1001"
        Console.WriteLine(Entity.GetNextSerialNo());    // Outputs "1002"
    }
}
```

Note that the `SetNextSerialNo` and `GetNextSerialNo` static methods are invoked on the class, whereas the `GetSerialNo` instance method is invoked on instances of the class.

1.6.6.4 *Virtual, Override, and Abstract Methods*

When an instance method declaration includes a `virtual` modifier, the method is said to be a ***virtual method***. When no `virtual` modifier is present, the method is said to be a ***nonvirtual method***.

When a virtual method is invoked, the ***runtime type*** of the instance for which that invocation takes place determines the actual method implementation to invoke. In a nonvirtual method invocation, the ***compile-time type*** of the instance is the determining factor.

A virtual method can be ***overridden*** in a derived class. When an instance method declaration includes an `override` modifier, the method overrides an inherited virtual method with the same signature. Whereas a virtual method declaration *introduces* a new method, an override method declaration *specializes* an existing inherited virtual method by providing a new implementation of that method.

> **ERIC LIPPERT** A subtle point here is that an overridden virtual method is still considered to be a method of the class that introduced it, and not a method of the class that overrides it. The overload resolution rules in some cases prefer members of more derived types to those in base types; overriding a method does not "move" where that method belongs in this hierarchy.
>
> At the very beginning of this section, we noted that C# was designed with versioning in mind. This is one of those features that helps prevent "brittle base-class syndrome" from causing versioning problems.

An ***abstract*** method is a virtual method with no implementation. An abstract method is declared with the `abstract` modifier and is permitted only in a class that is also declared `abstract`. An abstract method must be overridden in every non-abstract derived class.

The following example declares an abstract class, `Expression`, which represents an expression tree node, and three derived classes, `Constant`, `VariableReference`, and `Operation`, which implement expression tree nodes for constants, variable references, and arithmetic operations. (This is similar to, but not to be confused with, the expression tree types introduced in §4.6).

```
using System;
using System.Collections;

public abstract class Expression
{
    public abstract double Evaluate(Hashtable vars);
}
```

```
public class Constant: Expression
{
    double value;

    public Constant(double value) {
        this.value = value;
    }

    public override double Evaluate(Hashtable vars) {
        return value;
    }
}
public class VariableReference: Expression
{
    string name;

    public VariableReference(string name) {
        this.name = name;
    }

    public override double Evaluate(Hashtable vars) {
        object value = vars[name];
        if (value == null) {
            throw new Exception("Unknown variable: " + name);
        }
        return Convert.ToDouble(value);
    }
}

public class Operation: Expression
{
    Expression left;
    char op;
    Expression right;

    public Operation(Expression left, char op, Expression right) {
        this.left = left;
        this.op = op;
        this.right = right;
    }

    public override double Evaluate(Hashtable vars) {
        double x = left.Evaluate(vars);
        double y = right.Evaluate(vars);
        switch (op) {
            case '+': return x + y;
            case '-': return x - y;
            case '*': return x * y;
            case '/': return x / y;
        }
        throw new Exception("Unknown operator");
    }
}
```

The previous four classes can be used to model arithmetic expressions. For example, using instances of these classes, the expression `x + 3` can be represented as follows.

```
Expression e = new Operation(
    new VariableReference("x"),
    '+',
    new Constant(3));
```

The `Evaluate` method of an `Expression` instance is invoked to evaluate the given expression and produce a `double` value. The method takes as an argument a `Hashtable` that contains variable names (as keys of the entries) and values (as values of the entries). The `Evaluate` method is a virtual abstract method, meaning that non-abstract derived classes must override it to provide an actual implementation.

A `Constant`'s implementation of `Evaluate` simply returns the stored constant. A `VariableReference`'s implementation looks up the variable name in the hashtable and returns the resulting value. An `Operation`'s implementation first evaluates the left and right operands (by recursively invoking their `Evaluate` methods) and then performs the given arithmetic operation.

The following program uses the `Expression` classes to evaluate the expression `x * (y + 2)` for different values of `x` and `y`.

```
using System;
using System.Collections;

class Test
{
    static void Main() {

        Expression e = new Operation(
            new VariableReference("x"),
            '*',
            new Operation(
                new VariableReference("y"),
                '+',
                new Constant(2)
            )
        );

        Hashtable vars = new Hashtable();

        vars["x"] = 3;
        vars["y"] = 5;
        Console.WriteLine(e.Evaluate(vars));    // Outputs "21"

        vars["x"] = 1.5;
        vars["y"] = 9;
        Console.WriteLine(e.Evaluate(vars));    // Outputs "16.5"
    }
}
```

CHRIS SELLS Virtual functions are a major feature of object-oriented programming that differentiate it from other kinds of programming. For example, if you find yourself doing something like this:

```
double GetHourlyRate(Person p) {
  if( p is Student ) { return 1.0; }
  else if( p is Employee ) { return 10.0; }
  return 0.0;
}
```

You should almost always use a virtual method instead:

```
class Person {
         public virtual double GetHourlyRate() {
            return 0.0;
         }
}
class Student {
         public override double GetHourlyRate() {
            return 1.0;
         }
}
class Employee {
         public override double GetHourlyRate() {
            return 10.0;
         }
}
```

1.6.6.5 *Method Overloading*

Method ***overloading*** permits multiple methods in the same class to have the same name as long as they have unique signatures. When compiling an invocation of an overloaded method, the compiler uses ***overload resolution*** to determine the specific method to invoke. Overload resolution finds the one method that best matches the arguments or reports an error if no single best match can be found. The following example shows overload resolution in effect. The comment for each invocation in the `Main` method shows which method is actually invoked.

```
class Test
{
    static void F() {
        Console.WriteLine("F()");
    }

    static void F(object x) {
        Console.WriteLine("F(object)");
    }
```

```
    static void F(int x) {
        Console.WriteLine("F(int)");
    }

    static void F(double x) {
        Console.WriteLine("F(double)");
    }

    static void F<T>(T x) {
        Console.WriteLine("F<T>(T)");
    }

    static void F(double x, double y) {
        Console.WriteLine("F(double, double)");
    }

    static void Main() {
        F();                    // Invokes F()
        F(1);                   // Invokes F(int)
        F(1.0);                 // Invokes F(double)
        F("abc");               // Invokes F(object)
        F((double)1);           // Invokes F(double)
        F((object)1);           // Invokes F(object)
        F<int>(1);              // Invokes F<T>(T)
        F(1, 1);                // Invokes F(double, double)
        }
}
```

As shown by the example, a particular method can always be selected by explicitly casting the arguments to the exact parameter types and/or explicitly supplying type arguments.

BRAD ABRAMS The method overloading feature can be abused. Generally speaking, it is better to use method overloading only when all of the methods do semantically the same thing. The way many developers on the consuming end think about method overloading is that a single method takes a variety of arguments. In fact, changing the type of a local variable, parameter, or property could cause a different overload to be called. Developers certainly should not see side effects of the decision to use overloading. For users, however, it can be a surprise when methods with the same name do different things. For example, in the early days of the .NET Framework (before version 1 shipped), we had this set of overloads on the `string` class:

```
public class String {
    public int IndexOf (string value);
         // Returns the index of value with this instance
    public int IndexOf (char value);
         // Returns the index of value with this instance
    public int IndexOf (char [] value);
         // Returns the first index of any of the
         // characters in value within the current instance
}
```

Continued

This last overload caused problems, as it does a different thing. For example,

```
"Joshua, Hannah, Joseph".IndexOf("Hannah");// Returns 7
```

but

```
"Joshua, Hannah, Joseph".IndexOf(new char [] {'H','a','n','n','a,'h;");
// Returns 3
```

In this case, it would be better to give the overload that does something a different name:

```
public class String {
    public int IndexOf (string value);
         // Returns the index of value within this instance
    public int IndexOf (char value);
         // Returns the index of value within this instance
    public int IndexOfAny(char [] value);
         // Returns the first index of any of the
         // characters in value within the current instance
}
```

BILL WAGNER Method overloading and inheritance don't mix very well. Because overload resolution rules sometimes favor methods declared in the most derived class, that can sometimes mean a method declared in the derived class may be chosen instead of a method that appears to be a better match in the base class. For that reason, I recommend not overloading members that are declared in a base class.

1.6.7 Other Function Members

Members that contain executable code are collectively known as the ***function members*** of a class. The preceding section describes methods, which are the primary kind of function members. This section describes the other kinds of function members supported by C#: constructors, properties, indexers, events, operators, and destructors.

The following table shows a generic class called `List<T>`, which implements a growable list of objects. The class contains several examples of the most common kinds of function members.

```
public class List<T>
{
```

`const int defaultCapacity = 4;`	Constant
`T[] items;` `int count;`	Fields

`public List(int capacity = defaultCapacity) {`
`  items = new T[capacity];`
`}`
	Constructors

`public int Count {`
`  get { return count; }`
`}`
`public int Capacity {`
`  get {`
`  return items.Length;`
`  }`
`  set {`
`  if (value < count) value = count;`
`  if (value != items.Length) {`
`  T[] newItems = new T[value];`
`  Array.Copy(items, 0, newItems, 0, count);`
`  items = newItems;`
`  }`
`  }`
`}`
	Properties

`public T this[int index] {`
`  get {`
`  return items[index];`
`  }`
`  set {`
`  items[index] = value;`
`  OnChanged();`
`  }`
`}`
	Indexer

Continued

`public void Add(T item) {`
`  if (count == Capacity) Capacity = count * 2;`
`  items[count] = item;`
`  count++;`
`  OnChanged();`
`}`
`protected virtual void OnChanged() {`
`  if (Changed != null) Changed(this, EventArgs.Empty);`
`}`
`public override bool Equals(object other) {`
`  return Equals(this, other as List<T>);`
`}`
`static bool Equals(List<T> a, List<T> b) {`
`  if (a == null) return b == null;`
`  if (b == null || a.count != b.count) return false;`
`  for (int i = 0; i < a.count; i++) {`
`  if (!object.Equals(a.items[i], b.items[i])) {`
`  return false;`
`  }`
`  }`
`return true;`
`}`
	Methods

`public event EventHandler Changed;`	Event

`public static bool operator ==(List<T> a, List<T> b) {`
`  return Equals(a, b);`
`}`
`public static bool operator !=(List<T> a, List<T> b) {`
`  return !Equals(a, b);`
`}`
	Operators

`}`	

1.6.7.1 *Constructors*

C# supports both instance and static constructors. An ***instance constructor*** is a member that implements the actions required to initialize an instance of a class. A ***static constructor*** is a member that implements the actions required to initialize a class itself when it is first loaded.

A constructor is declared like a method with no return type and the same name as the containing class. If a constructor declaration includes a `static` modifier, it declares a static constructor. Otherwise, it declares an instance constructor.

Instance constructors can be overloaded. For example, the `List<T>` class declares two instance constructors, one with no parameters and one that takes an `int` parameter. Instance constructors are invoked using the `new` operator. The following statements allocate two `List<string>` instances using each of the constructors of the `List` class.

```
List<string> list1 = new List<string>();
List<string> list2 = new List<string>(10);
```

Unlike other members, instance constructors are not inherited, and a class has no instance constructors other than those actually declared in the class. If no instance constructor is supplied for a class, then an empty one with no parameters is automatically provided.

BRAD ABRAMS Constructors should be lazy! The best practice is to do minimal work in the constructor—that is, to simply capture the arguments for later use. For example, you might capture the name of the file or the path to the database, but don't open those external resources until absolutely necessary. This practice helps to ensure that possibly scarce resources are allocated for the smallest amount of time possible.

I was personally bitten by this issue recently with the `DataContext` class in Linq to Entities. It opens the database in the connection string provided, rather than waiting to perform that operation until it is needed. For my test cases, I was providing test suspect data directly and, in fact, never wanted to open the database. Not only does this unnecessary activity lead to a performance loss, but it also makes the scenario more complicated.

1.6.7.2 *Properties*

Properties are a natural extension of fields. Both are named members with associated types, and the syntax for accessing fields and properties is the same. However, unlike fields, properties do not denote storage locations. Instead, properties have ***accessors*** that specify the statements to be executed when their values are read or written.

JESSE LIBERTY A property looks to the creator of the class like a method allowing the developer to add behavior prior to setting or retrieving the underlying value. In contrast, the property appears to the client of the class as if it were a field, providing direct, unencumbered access through the assignment operator.

ERIC LIPPERT A standard "best practice" is to always expose field-like data as properties with getters and setters rather than exposing the field. That way, if you ever want to add functionality to your getter and setter (e.g., logging, data binding, security checking), you can easily do so without "breaking" any consumer of the code that might rely on the field always being there.

Although in some sense this practice is a violation of another bit of good advice ("Avoid premature generalization"), the new "automatically implemented properties" feature makes it very easy and natural to use properties rather than fields as part of the public interface of a type.

CHRIS SELLS Eric makes such a good point that I wanted to show an example. Don't ever make a field `public`:

```
class Cow
{
     public int Milk; // BAD!
}
```

If you don't want to layer in anything besides storage, let the compiler implement the property for you:

```
class Cow
{
    public int Milk { get; set; } // Good
}
```

That way, the client binds to the property getter and setter so that later you can take over the compiler's implementation to do something fancy:

```
class Cow {
  bool gotMilk = false;
  int milk;
  public int Milk {
   get {
      if( !gotMilk ) {
        milk = ApplyMilkingMachine();
        gotMilk = true; }
      return milk;
    }
    set {
```

```
        ApplyReverseMilkingMachine(value); // The cow might not like this..
        milk = value;
      }
    }
    ...
  }
```

Also, I really love the following idiom for cases where you know a calculated value will be used in your program:

```
class Cow {
  public Cow() {
    Milk = ApplyMilkingMachine();
  }


  public int Milk { get; private set; }
  ...
}
```

In this case, we are precalculating the property, which is a waste if we don't know whether we will need it. If we do know, we save ourselves some complication in the code by eliminating a flag, some branching logic, and the storage management.

BILL WAGNER Property accesses look like field accesses to your users—and they will naturally expect them to act like field accesses in every way, including performance. If a `get` accessor needs to do significant work (reading a file or querying a database, for example), it should be exposed as a method, not a property. Callers expect that a method may be doing more work.

For the same reason, repeated calls to property accessors (without intervening code) should return the same value. `DateTime.Now` is one of very few examples in the framework that does not follow this advice.

A property is declared like a field, except that the declaration ends with a `get` accessor and/or a `set` accessor written between the delimiters `{` and `}` instead of ending in a semicolon. A property that has both a `get` accessor and a `set` accessor is a ***read-write property***, a property that has only a `get` accessor is a ***read-only property***, and a property that has only a `set` accessor is a ***write-only property***.

A `get` accessor corresponds to a parameterless method with a return value of the property type. Except as the target of an assignment, when a property is referenced in an expression, the `get` accessor of the property is invoked to compute the value of the property.

A `set` accessor corresponds to a method with a single parameter named `value` and no return type. When a property is referenced as the target of an assignment or as the operand of `++` or `--`, the `set` accessor is invoked with an argument that provides the new value.

The `List<T>` class declares two properties, `Count` and `Capacity`, which are read-only and read-write, respectively. The following is an example of use of these properties.

```
List<string> names = new List<string>();
names.Capacity = 100;               // Invokes set accessor
int i = names.Count;                // Invokes get accessor
int j = names.Capacity;             // Invokes get accessor
```

Similar to fields and methods, C# supports both instance properties and static properties. Static properties are declared with the `static` modifier, and instance properties are declared without it.

The accessor(s) of a property can be virtual. When a property declaration includes a `virtual`, `abstract`, or `override` modifier, it applies to the accessor(s) of the property.

> **VLADIMIR RESHETNIKOV** If a virtual property happens to have a `private` accessor, this accessor is implemented in CLR as a nonvirtual method and cannot be overridden in derived classes.

1.6.7.3 *Indexers*

An ***indexer*** is a member that enables objects to be indexed in the same way as an array. An indexer is declared like a property except that the name of the member is `this` followed by a parameter list written between the delimiters `[` and `]`. The parameters are available in the accessor(s) of the indexer. Similar to properties, indexers can be read-write, read-only, and write-only, and the accessor(s) of an indexer can be virtual.

The `List` class declares a single read-write indexer that takes an `int` parameter. The indexer makes it possible to index `List` instances with `int` values. For example:

```
List<string> names = new List<string>();
names.Add("Liz");
names.Add("Martha");
names.Add("Beth");
for (int i = 0; i < names.Count; i++) {
    string s = names[i];
    names[i] = s.ToUpper();
}
```

Indexers can be overloaded, meaning that a class can declare multiple indexers as long as the number or types of their parameters differ.

1.6.7.4 *Events*

An ***event*** is a member that enables a class or object to provide notifications. An event is declared like a field except that the declaration includes an `event` keyword and the type must be a delegate type.

JESSE LIBERTY In truth, `event` is just a keyword that signals C# to restrict the way a delegate can be used, thereby preventing a client from directly invoking an event or hijacking an event by assigning a handler rather than adding a handler. In short, the keyword `event` makes delegates behave in the way you expect events to behave.

CHRIS SELLS Without the `event` keyword, you are allowed to do this:

```
delegate void WorkCompleted();

class Worker {
  public WorkCompleted Completed;   // Delegate field, not event
  ...
}

class Boss {
  public void WorkCompleted() { ... }
}

class Program {
  static void Main() {
    Worker peter = new Worker();
    Boss boss = new Boss();

   peter.Completed += boss.WorkCompleted;  // This is what you want to happen
    peter.Completed = boss.WorkCompleted;  // This is what the compiler allows
    ...
  }
}
```

Continued

Unfortunately, with the `event` keyword, `Completed` is just a `public` field of type delegate, which can be stepped on by anyone who wants to—and the compiler is okay with that. By adding the `event` keyword, you limit the operations to `+=` and `-=` like so:

```
class Worker {
  public event WorkCompleted Completed;
  ...
}
...
    peter.Completed += boss.WorkCompleted;  // Compiler still okay
    peter.Completed = boss.WorkCompleted;   // Compiler error
```

The use of the `event` keyword is the one time where it's okay to make a field `public`, because the compiler narrows the use to safe operations. Further, if you want to take over the implementation of `+=` and `-+` for an event, you can do so.

Within a class that declares an event member, the event can be accessed like a field of a delegate type (provided the event is not abstract and does not declare accessors). The field stores a reference to a delegate that represents the event handlers that have been added to the event. If no event handlers are present, the field is `null`.

The `List<T>` class declares a single event member called `Changed`, which indicates that a new item has been added to the list. The `Changed` event is raised by the `OnChanged` virtual method, which first checks whether the event is `null` (meaning that no handlers are present). The notion of raising an event is precisely equivalent to invoking the delegate represented by the event—thus there are no special language constructs for raising events.

Clients react to events through ***event handlers***. Event handlers are attached using the `+=` operator and removed using the `-=` operator. The following example attaches an event handler to the `Changed` event of a `List<string>`.

```
using System;

class Test
{
    static int changeCount;

    static void ListChanged(object sender, EventArgs e) {
        changeCount++;
    }
```

```
    static void Main() {
        List<string> names = new List<string>();
        names.Changed += new EventHandler(ListChanged);
        names.Add("Liz");
        names.Add("Martha");
        names.Add("Beth");
        Console.WriteLine(changeCount);     // Outputs "3"
    }
}
```

For advanced scenarios where control of the underlying storage of an event is desired, an event declaration can explicitly provide `add` and `remove` accessors, which are somewhat similar to the `set` accessor of a property.

CHRIS SELLS As of C# 2.0, explicitly creating a delegate instance to wrap a method was no longer necessary. As a consequence, the code

```
names.Changed += new EventHandler(ListChanged);
```

can be more succinctly written as

```
names.Changed += ListChanged;
```

Not only does this shortened form require less typing, but it is also easier to read.

1.6.7.5 *Operators*

An ***operator*** is a member that defines the meaning of applying a particular expression operator to instances of a class. Three kinds of operators can be defined: unary operators, binary operators, and conversion operators. All operators must be declared as `public` and `static`.

The `List<T>` class declares two operators, `operator ==` and `operator !=`, and thus gives new meaning to expressions that apply those operators to `List` instances. Specifically, the operators define equality of two `List<T>` instances as comparing each of the contained objects using their `Equals` methods. The following example uses the `==` operator to compare two `List<int>` instances.

```
using System;

class Test
{
    static void Main() {
        List<int> a = new List<int>();
        a.Add(1);
```

```
            a.Add(2);
            List<int> b = new List<int>();
            b.Add(1);
            b.Add(2);
            Console.WriteLine(a == b);          // Outputs "True"
            b.Add(3);
            Console.WriteLine(a == b);          // Outputs "False"
        }
    }
```

The first `Console.WriteLine` outputs `True` because the two lists contain the same number of objects with the same values in the same order. Had `List<T>` not defined `operator ==`, the first `Console.WriteLine` would have output `False` because `a` and `b` reference different `List<int>` instances.

1.6.7.6 *Destructors*

A ***destructor*** is a member that implements the actions required to destruct an instance of a class. Destructors cannot have parameters, they cannot have accessibility modifiers, and they cannot be invoked explicitly. The destructor for an instance is invoked automatically during garbage collection.

The garbage collector is allowed wide latitude in deciding when to collect objects and run destructors. Specifically, the timing of destructor invocations is not deterministic, and destructors may be executed on any thread. For these and other reasons, classes should implement destructors only when no other solutions are feasible.

> **VLADIMIR RESHETNIKOV** Destructors are sometimes called "finalizers." This name also appears in the garbage collector API—for example, `GC.WaitForPendingFinalizers`.

The `using` statement provides a better approach to object destruction.

1.7 Structs

Like classes, ***structs*** are data structures that can contain data members and function members, but unlike classes, structs are value types and do not require heap allocation. A variable of a struct type directly stores the data of the struct, whereas a variable of a class type stores a reference to a dynamically allocated object. Struct types do not support user-specified inheritance, and all struct types implicitly inherit from type `object`.

ERIC LIPPERT The fact that structs do not *require* heap allocation does *not* mean that they are *never* heap allocated. See the annotations to §1.3 for more details.

Structs are particularly useful for small data structures that have value semantics. Complex numbers, points in a coordinate system, or key–value pairs in a dictionary are all good examples of structs. The use of structs rather than classes for small data structures can make a large difference in the number of memory allocations an application performs. For example, the following program creates and initializes an array of 100 points. With `Point` implemented as a class, 101 separate objects are instantiated—one for the array and one each for the 100 elements.

```
class Point
{
    public int x, y;

    public Point(int x, int y)
    {
        this.x = x;
        this.y = y;
    }
}

class Test
{
    static void Main()
    {
        Point[] points = new Point[100];
        for (int i = 0; i < 100; i++) points[i] = new Point(i, i);
    }
}
```

An alternative is to make `Point` a struct.

```
    struct Point
    {
        public int x, y;
        public Point(int x, int y)

        {
            this.x = x;
            this.y = y;
        }
    }
```

Now, only one object is instantiated—the one for the array—and the `Point` instances are stored in-line in the array.

ERIC LIPPERT The takeaway message here is that certain specific data-intensive applications, which would otherwise be gated on heap allocation performance, benefit greatly from using structs. The takeaway message is emphatically *not* "Always use structs because they make your program faster."

The performance benefit here is a tradeoff: Structs can in some scenarios take less time to allocate and deallocate, but because every assignment of a struct is a value copy, they can take more time to copy than a reference copy would take.

Always remember that it makes little sense to optimize anything other than the *slowest* thing. If your program is not gated on heap allocations, then pondering whether to use structs or classes for performance reasons is not an effective use of your time. Find the slowest thing, and then optimize it.

Struct constructors are invoked with the `new` operator, but that does not imply that memory is being allocated. Instead of dynamically allocating an object and returning a reference to it, a struct constructor simply returns the struct value itself (typically in a temporary location on the stack), and this value is then copied as necessary.

With classes, it is possible for two variables to reference the same object and thus possible for operations on one variable to affect the object referenced by the other variable. With structs, the variables each have their own copy of the data, and it is not possible for operations on one to affect the other. For example, the output produced by the following code fragment depends on whether `Point` is a class or a struct.

```
Point a = new Point(10, 10);
Point b = a;
a.x = 20;
Console.WriteLine(b.x);
```

If `Point` is a class, the output is `20` because `a` and `b` reference the same object. If `Point` is a struct, the output is `10` because the assignment of `a` to `b` creates a copy of the value, and this copy is unaffected by the subsequent assignment to `a.x`.

The previous example highlights two of the limitations of structs. First, copying an entire struct is typically less efficient than copying an object reference, so assignment and value parameter passing can be more expensive with structs than with reference types. Second, except for `ref` and `out` parameters, it is not possible to create references to structs, which rules out their usage in a number of situations.

BILL WAGNER Read those last two paragraphs again. They describe the most important design differences between structs and classes. If you don't want value semantics in all cases, you must use a class. Classes can implement value semantics in some situations (`string` is a good example), but by default they obey reference semantics. That difference is more important for your designs than size or stack versus heap allocations.

1.8 Arrays

An ***array*** is a data structure that contains a number of variables that are accessed through computed indices. The variables contained in an array, also called the ***elements*** of the array, are all of the same type, and this type is called the ***element type*** of the array.

Array types are reference types, and the declaration of an array variable simply sets aside space for a reference to an array instance. Actual array instances are created dynamically at runtime using the `new` operator. The `new` operation specifies the ***length*** of the new array instance, which is then fixed for the lifetime of the instance. The indices of the elements of an array range from `0` to `Length - 1`. The `new` operator automatically initializes the elements of an array to their default value, which, for example, is zero for all numeric types and `null` for all reference types.

ERIC LIPPERT The confusion resulting from some languages indexing arrays starting with `1` and some others starting with `0` has befuddled multiple generations of novice programmers. The idea that array "indexes" start with `0` comes from a subtle misinterpretation of the C language's array syntax.

In C, when you say `myArray[x]`, what this means is "start at the beginning of the array and refer to the thing `x` steps away." Therefore, `myArray[1]` refers to the *second* element, because that is what you get when you start at the first element and *move* one step.

Really, these references should be called array *offsets* rather than *indices*. But because generations of programmers have now internalized that arrays are "indexed" starting at `0`, we're stuck with this terminology.

The following example creates an array of `int` elements, initializes the array, and prints out the contents of the array.

```
using System;

class Test
{
    static void Main() {
        int[] a = new int[10];
        for (int i = 0; i < a.Length; i++) {
            a[i] = i * i;
        }
        for (int i = 0; i < a.Length; i++) {
            Console.WriteLine("a[{0}] = {1}", i, a[i]);
        }
    }
}
```

This example creates and operates on a ***single-dimensional array***. C# also supports ***multi-dimensional arrays***. The number of dimensions of an array type, also known as the ***rank*** of the array type, is one plus the number of commas written between the square brackets of the array type. The following example allocates one-dimensional, two-dimensional, and three-dimensional arrays.

```
int[] a1 = new int[10];
int[,] a2 = new int[10, 5];
int[,,] a3 = new int[10, 5, 2];
```

The `a1` array contains 10 elements, the `a2` array contains 50 (10 × 5) elements, and the `a3` array contains 100 (10 × 5 × 2) elements.

> **BILL WAGNER** An FxCop rule recommends against multi-dimensional arrays; it's primarily guidance against using multi-dimensional arrays as sparse arrays. If you know that you really are filling in all the elements in the array, multi-dimensional arrays are fine.

The element type of an array can be any type, including an array type. An array with elements of an array type is sometimes called a ***jagged array*** because the lengths of the element arrays do not all have to be the same. The following example allocates an array of arrays of `int`:

```
int[][] a = new int[3][];
a[0] = new int[10];
a[1] = new int[5];
a[2] = new int[20];
```

The first line creates an array with three elements, each of type `int[]` and each with an initial value of `null`. The subsequent lines then initialize the three elements with references to individual array instances of varying lengths.

The new operator permits the initial values of the array elements to be specified using an *array initializer*, which is a list of expressions written between the delimiters { and }. The following example allocates and initializes an int[] with three elements.

```
int[] a = new int[] {1, 2, 3};
```

Note that the length of the array is inferred from the number of expressions between { and }. Local variable and field declarations can be shortened further such that the array type does not have to be restated.

```
int[] a = {1, 2, 3};
```

Both of the previous examples are equivalent to the following:

```
int[] t = new int[3];
t[0] = 1;
t[1] = 2;
t[2] = 3;
int[] a = t;
```

ERIC LIPPERT In a number of places thus far, the specification notes that a particular local initialization is equivalent to "assign something to a temporary variable, do something to the temporary variable, declare a local variable, and assign the temporary to the local variable." You may be wondering why the specification calls out this seemingly unnecessary indirection. Why not simply say that this initialization is equivalent to this:

```
int[] a = new int[3];
a[0] = 1; a[1] = 2; a[2] =3;
```

In fact, this practice is necessary because of definite assignment analysis. We would like to ensure that all local variables are definitely assigned before they are used. In particular, we would like an expression such as `object[] arr = {arr};` to be illegal because it appears to use arr before it is definitely assigned. If this were equivalent to

```
object[] arr = new object[1];
arr[0] = arr;
```

then that would be legal. But by saying that this expression is equivalent to

```
object[] temp = new object[1];
temp[0] = arr;
object[] arr = temp;
```

then it becomes clear that arr is being used before it is assigned.

1.9 Interfaces

An ***interface*** defines a contract that can be implemented by classes and structs. An interface can contain methods, properties, events, and indexers. An interface does not provide implementations of the members it defines—it merely specifies the members that must be supplied by classes or structs that implement the interface.

Interfaces may employ ***multiple inheritance***. In the following example, the interface `IComboBox` inherits from both `ITextBox` and `IListBox`.

```
interface IControl
{
    void Paint();
}

interface ITextBox : IControl
{
    void SetText(string text);
}

interface IListBox : IControl
{
    void SetItems(string[] items);
}

interface IComboBox : ITextBox, IListBox { }
```

Classes and structs can implement multiple interfaces. In the following example, the class `EditBox` implements both `IControl` and `IDataBound`.

```
interface IDataBound
{
    void Bind(Binder b);
}

public class EditBox : IControl, IDataBound
{
    public void Paint() {...}

    public void Bind(Binder b) {...}
}
```

KRZYSZTOF CWALINA Perhaps I am stirring up quite a bit of controversy with this statement, but I believe the lack of support for multiple inheritance in our type system is the single biggest contributor to the complexity of the .NET Framework. When we designed the type system, we explicitly decided not to add support for multiple inheritance so as to provide simplicity. In retrospect, this decision had the exact opposite effect. The lack of multiple inheritance forced us to add the concept of interfaces, which in turn are responsible for problems with the evolution of the framework, deeper inheritance hierarchies, and many other problems.

When a class or struct implements a particular interface, instances of that class or struct can be implicitly converted to that interface type. For example:

```
EditBox editBox = new EditBox();
IControl control = editBox;
IDataBound dataBound = editBox;
```

In cases where an instance is not statically known to implement a particular interface, dynamic type casts can be used. For example, the following statements use dynamic type casts to obtain an object's `IControl` and `IDataBound` interface implementations. Because the actual type of the object is `EditBox`, the casts succeed.

```
object obj = new EditBox();
IControl control = (IControl)obj;
IDataBound dataBound = (IDataBound)obj;
```

In the previous `EditBox` class, the `Paint` method from the `IControl` interface and the `Bind` method from the `IDataBound` interface are implemented using `public` members. C# also supports ***explicit interface member implementations***, using which the class or struct can avoid making the members `public`. An explicit interface member implementation is written using the fully qualified interface member name. For example, the `EditBox` class could implement the `IControl.Paint` and `IDataBound.Bind` methods using explicit interface member implementations as follows.

```
public class EditBox : IControl, IDataBound
{
    void IControl.Paint() {...}

    void IDataBound.Bind(Binder b) {...}
}
```

Explicit interface members can only be accessed via the interface type. For example, the implementation of `IControl.Paint` provided by the previous `EditBox` class can only be invoked by first converting the `EditBox` reference to the `IControl` interface type.

```
EditBox editBox = new EditBox();
editBox.Paint();                        // Error; no such method
IControl control = editBox;
control.Paint();                        // Okay
```

VLADIMIR RESHETNIKOV Actually, explicitly implemented interface members can also be accessed via a type parameter, constrained to the interface type.

1.10 Enums

An ***enum type*** is a distinct value type with a set of named constants. The following example declares and uses an enum type named `Color` with three constant values, `Red`, `Green`, and `Blue`.

```
using System;

enum Color
{
   Red,
   Green,
   Blue
}

class Test
{
    static void PrintColor(Color color) {
        switch (color) {
            case Color.Red:
                Console.WriteLine("Red");
                break;
            case Color.Green:
                Console.WriteLine("Green");
                break;
            case Color.Blue:
                Console.WriteLine("Blue");
                break;
            default:
                Console.WriteLine("Unknown color");
                break;
        }
    }

    static void Main() {
        Color c = Color.Red;
        PrintColor(c);
        PrintColor(Color.Blue);
    }
}
```

Each enum type has a corresponding integral type called the ***underlying type*** of the enum type. An enum type that does not explicitly declare an underlying type has an underlying type of `int`. An enum type's storage format and range of possible values are determined by its underlying type. The set of values that an enum type can take on is not limited by its enum members. In particular, any value of the underlying type of an enum can be cast to the enum type and is a distinct valid value of that enum type.

The following example declares an enum type named `Alignment` with an underlying type of `sbyte`.

```
enum Alignment : sbyte
{
    Left = -1,
```

```
        Center = 0,
        Right = 1
    }
```

VLADIMIR RESHETNIKOV Although this syntax resembles base type specification, it has a different meaning. The base type of `Alignment` is not `sbyte`, but `System.Enum`, and there is no implicit conversion from `Alignment` to `sbyte`.

As shown by the previous example, an enum member declaration can include a constant expression that specifies the value of the member. The constant value for each enum member must be in the range of the underlying type of the enum. When an enum member declaration does not explicitly specify a value, the member is given the value zero (if it is the first member in the enum type) or the value of the textually preceding enum member plus one.

Enum values can be converted to integral values and vice versa using type casts. For example:

```
int i = (int)Color.Blue;          // int i = 2;
Color c = (Color)2;               // Color c = Color.Blue;
```

BILL WAGNER The fact that zero is the default value for a variable of an enum type implies that you should always ensure that zero is a valid member of any enum type.

The default value of any enum type is the integral value zero converted to the enum type. In cases where variables are automatically initialized to a default value, this is the value given to variables of enum types. For the default value of an enum type to be easily available, the literal `0` implicitly converts to any enum type. Thus the following is permitted.

```
Color c = 0;
```

BRAD ABRAMS My first programming class in high school was in Turbo Pascal (Thanks, Anders!). On one of my first assignments I got back from my teacher, I saw a big red circle around the number 65 in my source code and the scrawled note, "No Magic Constants!!" My teacher was instilling in me the virtues of using the constant `RetirementAge` for readability and maintenance. Enums make this a super-easy decision to make. Unlike in some programming languages, using an enum does not incur any runtime performance overhead in C#. While I have heard many excuses in API reviews, there are just no good reasons to use a magic constant rather than an enum!

1.11 Delegates

A ***delegate type*** represents references to methods with a particular parameter list and return type. Delegates make it possible to treat methods as entities that can be assigned to variables and passed as parameters. Delegates are similar to the concept of function pointers found in some other languages, but unlike function pointers, delegates are object-oriented and type-safe.

The following example declares and uses a delegate type named `Function`.

```
using System;

delegate double Function(double x);

class Multiplier
{
    double factor;

    public Multiplier(double factor) {
        this.factor = factor;
    }

    public double Multiply(double x) {
        return x * factor;
    }
}

class Test
{
    static double Square(double x) {
        return x * x;
    }

    static double[] Apply(double[] a, Function f) {
        double[] result = new double[a.Length];
        for (int i = 0; i < a.Length; i++) result[i] = f(a[i]);
        return result;
    }

    static void Main() {
        double[] a = {0.0, 0.5, 1.0};

        double[] squares = Apply(a, Square);

        double[] sines = Apply(a, Math.Sin);

        Multiplier m = new Multiplier(2.0);
        double[] doubles =  Apply(a, m.Multiply);
    }
}
```

An instance of the `Function` delegate type can reference any method that takes a `double` argument and returns a `double` value. The `Apply` method applies a given `Function` to the elements of a `double[]`, returning a `double[]` with the results. In the `Main` method, `Apply` is used to apply three different functions to a `double[]`.

A delegate can reference either a static method (such as `Square` or `Math.Sin` in the previous example) or an instance method (such as `m.Multiply` in the previous example). A delegate that references an instance method also references a particular object, and when the instance method is invoked through the delegate, that object becomes `this` in the invocation.

Delegates can also be created using anonymous functions, which are "in-line methods" that are created on the fly. Anonymous functions can see the local variables of the surrounding methods. Thus the multiplier example above can be written more easily without using a `Multiplier` class:

```
double[] doubles =  Apply(a, (double x) => x * 2.0);
```

An interesting and useful property of a delegate is that it does not know or care about the class of the method it references; all that matters is that the referenced method has the same parameters and return type as the delegate.

BILL WAGNER This property of delegates make them an excellent tool for providing interfaces between components with the lowest possible coupling.

1.12 Attributes

Types, members, and other entities in a C# program support modifiers that control certain aspects of their behavior. For example, the accessibility of a method is controlled using the `public`, `protected`, `internal`, and `private` modifiers. C# generalizes this capability such that user-defined types of declarative information can be attached to program entities and retrieved at runtime. Programs specify this additional declarative information by defining and using ***attributes***.

The following example declares a `HelpAttribute` attribute that can be placed on program entities to provide links to their associated documentation.

```
using System;

public class HelpAttribute: Attribute
{
    string url;
    string topic;

    public HelpAttribute(string url) {
        this.url = url;
    }

    public string Url {
        get { return url; }
    }
```

```
    public string Topic {
        get { return topic; }
        set { topic = value; }
    }
}
```

All attribute classes derive from the `System.Attribute` base class provided by the .NET Framework. Attributes can be applied by giving their name, along with any arguments, inside square brackets just before the associated declaration. If an attribute's name ends in `Attribute`, that part of the name can be omitted when the attribute is referenced. For example, the `HelpAttribute` attribute can be used as follows.

```
[Help("http://msdn.microsoft.com/.../MyClass.htm")]
public class Widget
{
   [Help("http://msdn.microsoft.com/.../MyClass.htm", Topic = "Display")]
    public void Display(string text) { }
}
```

This example attaches a `HelpAttribute` to the `Widget` class and another `HelpAttribute` to the `Display` method in the class. The public constructors of an attribute class control the information that must be provided when the attribute is attached to a program entity. Additional information can be provided by referencing public read-write properties of the attribute class (such as the reference to the `Topic` property previously).

The following example shows how attribute information for a given program entity can be retrieved at runtime using reflection.

```
using System;
using System.Reflection;

class Test
{
    static void ShowHelp(MemberInfo member) {
        HelpAttribute a = Attribute.GetCustomAttribute(member,
            typeof(HelpAttribute)) as HelpAttribute;
        if (a == null) {
            Console.WriteLine("No help for {0}", member);
        }
        else {
            Console.WriteLine("Help for {0}:", member);
            Console.WriteLine("  Url={0}, Topic={1}",
                              a.Url, a.Topic);
        }
    }

    static void Main() {
        ShowHelp(typeof(Widget));
        ShowHelp(typeof(Widget).GetMethod("Display"));
    }
}
```

When a particular attribute is requested through reflection, the constructor for the attribute class is invoked with the information provided in the program source, and the resulting attribute instance is returned. If additional information was provided through properties, those properties are set to the given values before the attribute instance is returned.

BILL WAGNER The full potential of attributes will be realized when some future version of the C# compiler enables developers to read attributes and use them to modify the code model before the compiler creates IL. I've wanted to be able to use attributes to change the behavior of code since the first release of C#.

4. Types

The types of the C# language are divided into two main categories: ***value types*** and ***reference types***. Both value types and reference types may be ***generic types***, which take one or more ***type parameters***. Type parameters can designate both value types and reference types.

type:
    value-type
    reference-type
    type-parameter

A third category of types, pointers, is available only in unsafe code. This issue is discussed further in §18.2.

Value types differ from reference types in that variables of the value types directly contain their data, whereas variables of the reference types store ***references*** to their data, the latter being known as ***objects***. With reference types, it is possible for two variables to reference the same object, and thus possible for operations on one variable to affect the object referenced by the other variable. With value types, the variables each have their own copy of the data, so it is not possible for operations on one to affect the other.

C#'s type system is unified such that *a value of any type can be treated as an object*. Every type in C# directly or indirectly derives from the `object` class type, and `object` is the ultimate base class of all types. Values of reference types are treated as objects simply by viewing the values as type `object`. Values of value types are treated as objects by performing boxing and unboxing operations (§4.3).

ERIC LIPPERT We normally do not think of interface types or the types associated with type parameters as having a "base class" per se. What this discussion is getting at is that every concrete object—no matter how you are treating it at compile time—may be treated as an instance of `object` at runtime.

4.1 Value Types

A value type is either a struct type or an enumeration type. C# provides a set of predefined struct types called the ***simple types***. The simple types are identified through reserved words.

value-type:
    struct-type
    enum-type

struct-type:
    type-name
    simple-type
    nullable-type

simple-type:
    numeric-type
    `bool`

numeric-type:
    integral-type
    floating-point-type
    `decimal`

integral-type:
    `sbyte`
    `byte`
    `short`
    `ushort`
    `int`
    `uint`
    `long`
    `ulong`
    `char`

floating-point-type:
    `float`
    `double`

nullable-type:
    non-nullable-value-type `?`

non-nullable-value-type:
    type

enum-type:
    type-name

Unlike a variable of a reference type, a variable of a value type can contain the value `null` only if the value type is a nullable type. For every non-nullable value type, there is a corresponding nullable value type denoting the same set of values plus the value `null`.

Assignment to a variable of a value type creates a *copy* of the value being assigned. This differs from assignment to a variable of a reference type, which copies the reference but not the object identified by the reference.

4.1.1 The System.ValueType Type

All value types implicitly inherit from the class `System.ValueType`, which in turn inherits from class `object`. It is not possible for any type to derive from a value type, and value types are thus implicitly sealed (§10.1.1.2).

Note that `System.ValueType` is not itself a *value-type*. Rather, it is a *class-type* from which all *value-type*s are automatically derived.

> **ERIC LIPPERT** This point is frequently confusing to novices. I am often asked, "But how is it possible that a value type derives from a reference type?" I think the confusion arises as a result of a misunderstanding of what "derives from" means. Derivation does not imply that the layout of the bits in memory of the base type is somewhere found in the layout of bits in the derived type. Rather, it simply implies that some mechanism exists whereby members of the base type may be accessed from the derived type.

4.1.2 Default Constructors

All value types implicitly declare a public parameterless instance constructor called the ***default constructor***. The default constructor returns a zero-initialized instance known as the ***default value*** for the value type:

- For all *simple-types*, the default value is the value produced by a bit pattern of all zeros:
  - For `sbyte`, `byte`, `short`, `ushort`, `int`, `uint`, `long`, and `ulong`, the default value is `0`.
  - For `char`, the default value is `'\x0000'`.
  - For `float`, the default value is `0.0f`.
  - For `double`, the default value is `0.0d`.
  - For `decimal`, the default value is `0.0m`.
  - For `bool`, the default value is `false`.

- For an *enum-type* `E`, the default value is `0`, converted to the type `E`.
- For a *struct-type*, the default value is the value produced by setting all value type fields to their default values and all reference type fields to `null`.

> **VLADIMIR RESHETNIKOV** Obviously, the wording "all fields" here means only instance fields (not static fields). It also includes field-like instance events, if any exist.

- For a *nullable-type*, the default value is an instance for which the `HasValue` property is false and the `Value` property is undefined. The default value is also known as the ***null value*** of the nullable type.

Like any other instance constructor, the default constructor of a value type is invoked using the `new` operator. For efficiency reasons, this requirement is not intended to actually have the implementation generate a constructor call. In the example below, variables `i` and `j` are both initialized to zero.

```
class A
{
    void F() {
        int i = 0;
        int j = new int();
    }
}
```

Because every value type implicitly has a public parameterless instance constructor, it is not possible for a struct type to contain an explicit declaration of a parameterless constructor. A struct type is, however, permitted to declare parameterized instance constructors (§11.3.8).

> **ERIC LIPPERT** Another good way to obtain the default value of a type is to use the `default(type)` expression.

> **JON SKEET** This is one example of where the C# language and the underlying platform may have different ideas. If you ask the .NET platform for the constructors of a value type, you usually won't find a parameterless one. Instead, .NET has a specific instruction for initializing the default value for a value type. Usually these small impedence mismatches have no effect on developers, but it's good to know that they're possible—and that they don't represent a fault in either specification.

4.1.3 Struct Types

A struct type is a value type that can declare constants, fields, methods, properties, indexers, operators, instance constructors, static constructors, and nested types. The declaration of struct types is described in §11.1.

4.1.4 Simple Types

C# provides a set of predefined struct types called the ***simple types***. The simple types are identified through reserved words, but these reserved words are simply aliases for predefined struct types in the `System` namespace, as described in the table below.

Reserved Word	Aliased Type
`sbyte`	`System.SByte`
`byte`	`System.Byte`
`short`	`System.Int16`
`ushort`	`System.UInt16`
`int`	`System.Int32`
`uint`	`System.UInt32`
`long`	`System.Int64`
`ulong`	`System.UInt64`
`char`	`System.Char`
`float`	`System.Single`
`double`	`System.Double`
`bool`	`System.Boolean`
`decimal`	`System.Decimal`

Because a simple type aliases a struct type, every simple type has members. For example, `int` has the members declared in `System.Int32` and the members inherited from `System.Object`, and the following statements are permitted:

```
int i = int.MaxValue;         // System.Int32.MaxValue constant
string s = i.ToString();      // System.Int32.ToString() instance method
string t = 123.ToString();    // System.Int32.ToString() instance method
```

The simple types differ from other struct types in that they permit certain additional operations:

- Most simple types permit values to be created by writing *literals* (§2.4.4). For example, `123` is a literal of type `int` and `'a'` is a literal of type `char`. C# makes no provision for literals of struct types in general, and nondefault values of other struct types are ultimately always created through instance constructors of those struct types.

> **ERIC LIPPERT** The "most" in the phrase "most simple types" refers to the fact that some simple types, such as `short`, have no literal form. In reality, any integer literal small enough to fit into a `short` is implicitly converted to a `short` when used as one, so in that sense there are literal values for all simple types.
>
> There are a handful of possible values for simple types that have no literal forms. The NaN (Not-a-Number) values for floating point types, for example, have no literal form.

- When the operands of an expression are all simple type constants, it is possible for the compiler to evaluate the expression at compile time. Such an expression is known as a *constant-expression* (§7.19). Expressions involving operators defined by other struct types are not considered to be constant expressions.

> **VLADIMIR RESHETNIKOV** It is not just "possible": The compiler always **does** fully evaluate *constant-expressions* at compile time.

- Through `const` declarations, it is possible to declare constants of the simple types (§10.4). It is not possible to have constants of other struct types, but a similar effect is provided by `static readonly` fields.
- Conversions involving simple types can participate in evaluation of conversion operators defined by other struct types, but a user-defined conversion operator can never participate in evaluation of another user-defined operator (§6.4.3).

> **JOSEPH ALBAHARI** The simple types also provide a means by which the compiler can leverage direct support within the IL (and ultimately the processor) for computations on integer and floating point values. This scheme allows arithmetic on simple types that have processor support (typically `float`, `double`, and the integral types) to run at native speed.

4.1.5 Integral Types

C# supports nine integral types: `sbyte`, `byte`, `short`, `ushort`, `int`, `uint`, `long`, `ulong`, and `char`. The integral types have the following sizes and ranges of values:

- The `sbyte` type represents signed 8-bit integers with values between –128 and 127.
- The `byte` type represents unsigned 8-bit integers with values between 0 and 255.
- The `short` type represents signed 16-bit integers with values between –32768 and 32767.
- The `ushort` type represents unsigned 16-bit integers with values between 0 and 65535.
- The `int` type represents signed 32-bit integers with values between –2147483648 and 2147483647.
- The `uint` type represents unsigned 32-bit integers with values between 0 and 4294967295.
- The `long` type represents signed 64-bit integers with values between –9223372036854775808 and 9223372036854775807.
- The `ulong` type represents unsigned 64-bit integers with values between 0 and 18446744073709551615.
- The `char` type represents unsigned 16-bit integers with values between 0 and 65535. The set of possible values for the `char` type corresponds to the Unicode character set. Although `char` has the same representation as `ushort`, not all operations permitted on one type are permitted on the other.

> **JESSE LIBERTY** I have to confess that with the power of modern PCs, and the greater cost of programmer time relative to the cost of memory, I tend to use `int` for just about any integral (nonfractional) value and `double` for any fractional value. All the rest, I pretty much ignore.

The integral-type unary and binary operators always operate with signed 32-bit precision, unsigned 32-bit precision, signed 64-bit precision, or unsigned 64-bit precision:

- For the unary `+` and `~` operators, the operand is converted to type `T`, where `T` is the first of `int`, `uint`, `long`, and `ulong` that can fully represent all possible values of the operand. The operation is then performed using the precision of type `T`, and the type of the result is `T`.
- For the unary `-` operator, the operand is converted to type `T`, where `T` is the first of `int` and `long` that can fully represent all possible values of the operand. The operation is then

performed using the precision of type `T`, and the type of the result is `T`. The unary `-` operator cannot be applied to operands of type `ulong`.

- For the binary `+`, `-`, `*`, `/`, `%`, `&`, `^`, `|`, `==`, `!=`, `>`, `<`, `>=`, and `<=` operators, the operands are converted to type `T`, where `T` is the first of `int`, `uint`, `long`, and `ulong` that can fully represent all possible values of both operands. The operation is then performed using the precision of type `T`, and the type of the result is `T` (or `bool` for the relational operators). It is not permitted for one operand to be of type `long` and the other to be of type `ulong` with the binary operators.
- For the binary `<<` and `>>` operators, the left operand is converted to type `T`, where `T` is the first of `int`, `uint`, `long`, and `ulong` that can fully represent all possible values of the operand. The operation is then performed using the precision of type `T`, and the type of the result is `T`.

The `char` type is classified as an integral type, but it differs from the other integral types in two ways:

- There are no implicit conversions from other types to the `char` type. In particular, even though the `sbyte`, `byte`, and `ushort` types have ranges of values that are fully representable using the `char` type, implicit conversions from `sbyte`, `byte`, or `ushort` to `char` do not exist.
- Constants of the `char` type must be written as *character-literal*s or as *integer-literal*s in combination with a cast to type `char`. For example, `(char)10` is the same as `'\x000A'`.

The `checked` and `unchecked` operators and statements are used to control overflow checking for integral-type arithmetic operations and conversions (§7.6.12). In a `checked` context, an overflow produces a compile-time error or causes a `System.OverflowException` to be thrown. In an `unchecked` context, overflows are ignored and any high-order bits that do not fit in the destination type are discarded.

4.1.6 Floating Point Types

C# supports two floating point types: `float` and `double`. The `float` and `double` types are represented using the 32-bit single-precision and 64-bit double-precision IEEE 754 formats, which provide the following sets of values:

- Positive zero and negative zero. In most situations, positive zero and negative zero behave identically as the simple value zero, but certain operations distinguish between the two (§7.8.2).

VLADIMIR RESHETNIKOV Be aware that the default implementation of the `Equals` method in value types can use bitwise comparison in some cases to speed up performance. If two instances of your value type contain in their fields positive and negative zero, respectively, they can compare as not equal. You can override the `Equals` method to change the default behavior.

```
using System;

struct S
{
    double X;

    static void Main()
    {
        var a = new S {X = 0.0};
        var b = new S {X = -0.0};
        Console.WriteLine(a.X.Equals(b.X)); // True
        Console.WriteLine(a.Equals(b)); // False
    }
}
```

PETER SESTOFT Some of the confusion over negative zero may stem from the fact that the current implementations of C# print positive and negative zero in the same way, as `0.0`, and no combination of formatting parameters seems to affect that display. Although this is probably done with the best of intentions, it is unfortunate. To reveal a negative zero, you must resort to strange-looking code like this, which works because `1/(-0.0) = -Infinity < 0`:

```
public static string DoubleToString(double d) {
  if (d == 0.0 && 1/d < 0)
    return "-0.0";
  else
    return d.ToString();
}
```

- Positive infinity and negative infinity. Infinities are produced by such operations as dividing a non-zero number by zero. For example, `1.0 / 0.0` yields positive infinity, and `-1.0 / 0.0` yields negative infinity.
- The ***Not-a-Number*** value, often abbreviated NaN. NaNs are produced by invalid floating point operations, such as dividing zero by zero.

PETER SESTOFT A large number of distinct NaNs exist, each of which has a different "payload." See the annotations on §7.8.1.

- The finite set of non-zero values of the form $s \times m \times 2^e$, where s is 1 or −1, and m and e are determined by the particular floating point type: For `float`, $0 < m < 2^{24}$ and $-149 \leq e \leq 104$; for `double`, $0 < m < 2^{53}$ and $-1075 \leq e \leq 970$. Denormalized floating point numbers are considered valid non-zero values.

The `float` type can represent values ranging from approximately 1.5×10^{-45} to 3.4×10^{38} with a precision of 7 digits.

The `double` type can represent values ranging from approximately 5.0×10^{-324} to 1.7×10^{308} with a precision of 15 or 16 digits.

If one of the operands of a binary operator is of a floating point type, then the other operand must be of an integral type or a floating point type, and the operation is evaluated as follows:

- If one of the operands is of an integral type, then that operand is converted to the floating point type of the other operand.
- Then, if either of the operands is of type `double`, the other operand is converted to `double`, the operation is performed using at least `double` range and precision, and the type of the result is `double` (or `bool` for the relational operators).
- Otherwise, the operation is performed using at least `float` range and precision, and the type of the result is `float` (or `bool` for the relational operators).

The floating point operators, including the assignment operators, never produce exceptions. Instead, in exceptional situations, floating point operations produce zero, infinity, or NaN, as described below:

- If the result of a floating point operation is too small for the destination format, the result of the operation becomes positive zero or negative zero.
- If the result of a floating point operation is too large for the destination format, the result of the operation becomes positive infinity or negative infinity.
- If a floating point operation is invalid, the result of the operation becomes NaN.
- If one or both operands of a floating point operation is NaN, the result of the operation becomes NaN.

Floating point operations may be performed with higher precision than the result type of the operation. For example, some hardware architectures support an "extended" or "long double" floating point type with greater range and precision than the `double` type, and implicitly perform all floating point operations using this higher precision type. Only at excessive cost in performance can such hardware architectures be made to perform floating point operations with *less* precision. Rather than require an implementation to forfeit

both performance and precision, C# allows a higher precision type to be used for all floating point operations. Other than delivering more precise results, this rarely has any measurable effects. However, in expressions of the form `x * y / z`, where the multiplication produces a result that is outside the `double` range, but the subsequent division brings the temporary result back into the `double` range, the fact that the expression is evaluated in a higher range format may cause a finite result to be produced instead of an infinity.

JOSEPH ALBAHARI NaNs are sometimes used to represent special values. In Microsoft's Windows Presentation Foundation, `double.NaN` represents a measurement whose value is "automatic." Another way to represent such a value is with a nullable type; yet another is with a custom struct that wraps a numeric type and adds another field.

4.1.7 The decimal Type

The `decimal` type is a 128-bit data type suitable for financial and monetary calculations. The `decimal` type can represent values ranging from 1.0×10^{-28} to approximately 7.9×10^{28} with 28 or 29 significant digits.

The finite set of values of type `decimal` are of the form $(-1)^s \times c \times 10^{-e}$, where the sign s is 0 or 1, the coefficient c is given by $0 \le c < 2^{96}$, and the scale e is such that $0 \le e \le 28$.The `decimal` type does not support signed zeros, infinities, or NaNs. A `decimal` is represented as a 96-bit integer scaled by a power of 10. For `decimal`s with an absolute value less than `1.0m`, the value is exact to the 28th decimal place, but no further. For `decimal`s with an absolute value greater than or equal to `1.0m`, the value is exact to 28 or 29 digits. Unlike with the `float` and `double` data types, decimal fractional numbers such as 0.1 can be represented exactly in the `decimal` representation. In the `float` and `double` representations, such numbers are often infinite fractions, making those representations more prone to round-off errors.

PETER SESTOFT The IEEE 754-2008 standard describes a decimal floating point type called `decimal128`. It is similar to the type `decimal` described here, but packs a lot more punch within the same 128 bits. It has 34 significant decimal digits, a range from 10^{-6134} to 10^{6144}, and supports NaNs. It was designed by Mike Cowlishaw at IBM UK. Since it extends the current `decimal` in all respects, it would seem feasible for C# to switch to IEEE `decimal128` in some future version.

If one of the operands of a binary operator is of type `decimal`, then the other operand must be of an integral type or of type `decimal`. If an integral type operand is present, it is converted to `decimal` before the operation is performed.

> **BILL WAGNER** You cannot mix `decimal` and the floating point types (`float`, `double`). This rule exists because you would lose precision mixing computations between those types. You must apply an explicit conversion when mixing `decimal` and floating point types.

The result of an operation on values of type `decimal` is what would result from calculating an exact result (preserving scale, as defined for each operator) and then rounding to fit the representation. Results are rounded to the nearest representable value and, when a result is equally close to two representable values, to the value that has an even number in the least significant digit position (this is known as "banker's rounding"). A zero result always has a sign of 0 and a scale of 0.

> **ERIC LIPPERT** This method has the attractive property that it typically introduces less bias than methods that always round down or up when there is a "tie" between two possibilities.
>
> Oddly enough, despite the nickname, there is little evidence that this method of rounding was ever in widespread use in banking.

If a `decimal` arithmetic operation produces a value less than or equal to 5×10^{-29} in absolute value, the result of the operation becomes zero. If a `decimal` arithmetic operation produces a result that is too large for the `decimal` format, a `System.OverflowException` is thrown.

The `decimal` type has greater precision but smaller range than the floating point types. Thus conversions from the floating point types to `decimal` might produce overflow exceptions, and conversions from `decimal` to the floating point types might cause loss of precision. For these reasons, no implicit conversions exist between the floating point types and `decimal`, and without explicit casts, it is not possible to mix floating point and `decimal` operands in the same expression.

> **ERIC LIPPERT** C# does not support the `Currency` data type familiar to users of Visual Basic 6 and other OLE Automation-based programming languages. Because `decimal` has both more range and precision than `Currency`, anything that you could have done with a `Currency` can be done just as well with a `decimal`.

4.1.8 The bool Type

The `bool` type represents boolean logical quantities. The possible values of type `bool` are `true` and `false`.

No standard conversions exist between `bool` and other types. In particular, the `bool` type is distinct and separate from the integral types; a `bool` value cannot be used in place of an integral value, and vice versa.

In the C and C++ languages, a zero integral or floating point value, or a null pointer, can be converted to the boolean value `false`, and a non-zero integral or floating point value, or a non-null pointer, can be converted to the boolean value `true`. In C#, such conversions are accomplished by explicitly comparing an integral or floating point value to zero, or by explicitly comparing an object reference to `null`.

CHRIS SELLS The inability of a non-`bool` to be converted to a `bool` most often bites me when comparing for `null`. For example:

```
object obj = null;
if( obj ) { ... }            // Okay in C/C++, error in C#
if( obj != null ) { ... }    // Okay in C/C++/C#
```

4.1.9 Enumeration Types

An enumeration type is a distinct type with named constants. Every enumeration type has an underlying type, which must be `byte`, `sbyte`, `short`, `ushort`, `int`, `uint`, `long`, or `ulong`. The set of values of the enumeration type is the same as the set of values of the underlying type. Values of the enumeration type are not restricted to the values of the named constants. Enumeration types are defined through enumeration declarations (§14.1).

ERIC LIPPERT This is an important point: Nothing stops you from putting a value that is not in the enumerated type into a variable of that type. Do not rely on the language or the runtime environment to verify that instances of enumerated types are within the bounds you expect.

VLADIMIR RESHETNIKOV The CLR also supports `char` as an underlying type of an enumeration. If you happen to reference an assembly containing such a type in your application, the C# compiler will not recognize this type as an enumeration and will not allow you, for example, to convert it to or from an integral type.

4.1.10 Nullable Types

A nullable type can represent all values of its ***underlying type*** plus an additional null value. A nullable type is written `T?`, where `T` is the underlying type. This syntax is shorthand for `System.Nullable<T>`, and the two forms can be used interchangeably.

A ***non-nullable value type***, conversely, is any value type other than `System.Nullable<T>` and its shorthand `T?` (for any `T`), plus any type parameter that is constrained to be a non-nullable value type (that is, any type parameter with a `struct` constraint). The `System.Nullable<T>` type specifies the value type constraint for `T` (§10.1.5), which means that the underlying type of a nullable type can be any non-nullable value type. The underlying type of a nullable type cannot be a nullable type or a reference type. For example, `int??` and `string?` are invalid types.

An instance of a nullable type `T?` has two public read-only properties:

- A `HasValue` property of type `bool`
- A `Value` property of type `T`

An instance for which `HasValue` is `true` is said to be non-null. A non-null instance contains a known value and `Value` returns that value.

An instance for which `HasValue` is `false` is said to be null. A null instance has an undefined value. Attempting to read the `Value` of a null instance causes a `System.InvalidOperationException` to be thrown. The process of accessing the `Value` property of a nullable instance is referred to as ***unwrapping***.

In addition to the default constructor, every nullable type `T?` has a public constructor that takes a single argument of type `T`. Given a value `x` of type `T`, a constructor invocation of the form

```
new T?(x)
```

creates a non-null instance of `T?` for which the `Value` property is `x`. The process of creating a non-null instance of a nullable type for a given value is referred to as ***wrapping***.

Implicit conversions are available from the `null` literal to `T?` (§6.1.5) and from `T` to `T?` (§6.1.4).

4.2 Reference Types

A reference type is a class type, an interface type, an array type, or a delegate type.

reference-type:
    class-type
    interface-type
    array-type
    delegate-type

class-type:
    type-name
    `object`
    `dynamic`
    `string`

interface-type:
    type-name

array-type:
    non-array-type rank-specifiers

non-array-type:
    type

rank-specifiers:
    rank-specifier
    rank-specifiers rank-specifier

rank-specifier:
    `[` *dim-separators*$_{opt}$ `]`

dim-separators:
    `,`
    dim-separators `,`

delegate-type:
    type-name

A reference type value is a reference to an ***instance*** of the type, the latter known as an ***object***. The special value `null` is compatible with all reference types and indicates the absence of an instance.

4.2.1 Class Types

A class type defines a data structure that contains data members (constants and fields), function members (methods, properties, events, indexers, operators, instance constructors, destructors, and static constructors), and nested types. Class types support inheritance, a mechanism whereby derived classes can extend and specialize base classes. Instances of class types are created using *object-creation-expressions* (§7.6.10.1).

Class types are described in §10.

Certain predefined class types have special meaning in the C# language, as described in the table below.

Class Type	Description
`System.Object`	The ultimate base class of all other types. (See §4.2.2.)
`System.String`	The string type of the C# language. (See §4.2.3.)
`System.ValueType`	The base class of all value types. (See §4.1.1.)
`System.Enum`	The base class of all enum types. (See §14.)
`System.Array`	The base class of all array types. (See §12.)
`System.Delegate`	The base class of all delegate types. (See §15.)
`System.Exception`	The base class of all exception types. (See §16.)

4.2.2 The object Type

The `object` class type is the ultimate base class of all other types. Every type in C# directly or indirectly derives from the `object` class type.

The keyword `object` is simply an alias for the predefined class `System.Object`.

4.2.3 The dynamic Type

The `dynamic` type, like `object`, can reference any object. When operators are applied to expressions of type `dynamic`, their resolution is deferred until the program is run. Thus, if the operator cannot legally be applied to the referenced object, no error is given during compilation. Instead, an exception will be thrown when resolution of the operator fails at runtime.

The dynamic type is further described in §4.7, and dynamic binding in §7.2.2.

4.2.4 The string Type

The `string` type is a sealed class type that inherits directly from `object`. Instances of the `string` class represent Unicode character strings.

Values of the `string` type can be written as string literals (§2.4.4.5).

The keyword `string` is simply an alias for the predefined class `System.String`.

4.2.5 Interface Types

An interface defines a contract. A class or struct that implements an interface must adhere to its contract. An interface may inherit from multiple base interfaces, and a class or struct may implement multiple interfaces.

Interface types are described in §13.

4.2.6 Array Types

An array is a data structure that contains zero or more variables that are accessed through computed indices. The variables contained in an array, also called the elements of the array, are all of the same type, and this type is called the element type of the array.

Array types are described in §12.

4.2.7 Delegate Types

A delegate is a data structure that refers to one or more methods. For instance methods, it also refers to their corresponding object instances.

The closest equivalent of a delegate in C or C++ is a function pointer, but whereas a function pointer can reference only static functions, a delegate can reference both static and instance methods. In the latter case, the delegate stores not only a reference to the method's entry point, but also a reference to the object instance on which to invoke the method.

Delegate types are described in §15.

CHRIS SELLS Although C++ can reference instance member functions via a member function pointer, it's such a difficult thing to get right that the feature might as well be illegal!

4.3 Boxing and Unboxing

The concept of boxing and unboxing is central to C#'s type system. It provides a bridge between *value-type*s and *reference-type*s by permitting any value of a *value-type* to be converted to and from type `object`. Boxing and unboxing enables a unified view of the type system wherein a value of any type can ultimately be treated as an object.

JOSEPH ALBAHARI Prior to C# 2.0, boxing and unboxing were the primary means by which you could write a general-purpose collection, such as a list, stack, or queue. Since the introduction of C# 2.0, generics have provided an alternative solution in these cases, which leads to better static type safety and performance. Boxing/unboxing necessarily demands a small performance overhead, because it means copying values, dealing with indirection, and allocating memory on the heap.

JESSE LIBERTY I would go further and say that the introduction of generics has, for all practical purposes, dislodged boxing and unboxing from a central concern to a peripheral one, of interest only when passing value types as `out` or `ref` parameters.

CHRISTIAN NAGEL The normally small performance overhead associated with boxing and unboxing can become huge if you are iterating over large collections. Generic collection classes help with this problem.

4.3.1 Boxing Conversions

A boxing conversion permits a *value-type* to be implicitly converted to a *reference-type*. The following boxing conversions exist:

- From any *value-type* to the type `object`.
- From any *value-type* to the type `System.ValueType`.
- From any *non-nullable-value-type* to any *interface-type* implemented by the *value-type*.
- From any *nullable-type* to any *interface-type* implemented by the underlying type of the *nullable-type*.

VLADIMIR RESHETNIKOV The *nullable-type* does not **implement** the interfaces from its underlying type; it is simply **convertible** to them. This distinction is important in some contexts—for example, in checking generic constraints.

- From any *enum-type* to the type `System.Enum`.
- From any *nullable-type* with an underlying *enum-type* to the type `System.Enum`.

BILL WAGNER The choice of the word "conversion" here is illustrative of the behavior seen in these circumstances. You are not reinterpreting the same storage as a different type; you are converting it. That is, you are examining different storage, not looking at the same storage through two different variable types.

Note that an implicit conversion from a type parameter will be executed as a boxing conversion if at runtime it ends up converting from a value type to a reference type (§6.1.10).

Boxing a value of a *non-nullable-value-type* consists of allocating an object instance and copying the *non-nullable-value-type* value into that instance.

Boxing a value of a *nullable-type* produces a null reference if it is the `null` value (`HasValue` is `false`), or the result of unwrapping and boxing the underlying value otherwise.

The actual process of boxing a value of a *non-nullable-value-type* is best explained by imagining the existence of a generic ***boxing class***, which behaves as if it were declared as follows:

```
sealed class Box<T>: System.ValueType
{
    T value;

    public Box(T t) {
        value = t;
    }
}
```

Boxing of a value `v` of type `T` now consists of executing the expression `new Box<T>(v)` and returning the resulting instance as a value of type `object`. Thus the statements

```
int i = 123;
object box = i;
```

conceptually correspond to

```
int i = 123;
object box = new Box<int>(i);
```

A boxing class like `Box<T>` above doesn't actually exist, and the dynamic type of a boxed value isn't actually a class type. Instead, a boxed value of type `T` has the dynamic type `T`, and a dynamic type check using the `is` operator can simply reference type `T`. For example,

```
int i = 123;
object box = i;
if (box is int) {
    Console.Write("Box contains an int");
}
```

will output the string "`Box contains an int`" on the console.

A boxing conversion implies *making a copy* of the value being boxed. This is different from a conversion of a *reference-type* to type `object`, in which the value continues to reference the same instance and simply is regarded as the less derived type `object`. For example, given the declaration

```
struct Point
{
    public int x, y;
    public Point(int x, int y) {

        this.x = x;
        this.y = y;
    }
}
```

the following statements

```
Point p = new Point(10, 10);
object box = p;
p.x = 20;
Console.Write(((Point)box).x);
```

will output the value 10 on the console because the implicit boxing operation that occurs in the assignment of `p` to `box` causes the value of `p` to be copied. Had `Point` been declared a `class` instead, the value 20 would be output because `p` and `box` would reference the same instance.

ERIC LIPPERT This possibility is just one reason why it is a good practice to make structs immutable. If the struct cannot mutate, then the fact that boxing makes a copy is irrelevant: Both copies will be identical forever.

4.3.2 Unboxing Conversions

An unboxing conversion permits a *reference-type* to be explicitly converted to a *value-type*. The following unboxing conversions exist:

- From the type `object` to any *value-type*.
- From the type `System.ValueType` to any *value-type*.
- From any *interface-type* to any *non-nullable-value-type* that implements the *interface-type*.
- From any *interface-type* to any *nullable-type* whose underlying type implements the *interface-type*.
- From the type `System.Enum` to any *enum-type*.
- From the type `System.Enum` to any *nullable-type* with an underlying *enum-type*.

BILL WAGNER As with boxing, unboxing involves a conversion. If you box a struct and then unbox it, three different storage locations may result. You most certainly do not have three variables examining the same storage.

Note that an explicit conversion to a type parameter will be executed as an unboxing conversion if at runtime it ends up converting from a reference type to a value type (§6.2.6).

An unboxing operation to a *non-nullable-value-type* consists of first checking that the object instance is a boxed value of the given *non-nullable-value-type*, and then copying the value out of the instance.

ERIC LIPPERT Although it is legal to convert an unboxed `int` to an unboxed `double`, it is not legal to convert a boxed `int` to an unboxed `double`—only to an unboxed `int`. This constraint exists because the unboxing instruction would then have to know all the rules for type conversions that are normally done by the compiler. If you need to do these kinds of conversions at runtime, use the `Convert` class instead of an unboxing cast.

Unboxing to a *nullable-type* produces the null value of the *nullable-type* if the source operand is `null`, or the wrapped result of unboxing the object instance to the underlying type of the *nullable-type* otherwise.

Referring to the imaginary boxing class described in the previous section, an unboxing conversion of an object `box` to a *value-type* `T` consists of executing the expression `((Box<T>) box).value`. Thus the statements

```
object box = 123;
int i = (int)box;
```

conceptually correspond to

```
object box = new Box<int>(123);
int i = ((Box<int>)box).value;
```

For an unboxing conversion to a given *non-nullable-value-type* to succeed at runtime, the value of the source operand must be a reference to a boxed value of that *non-nullable-value-type*. If the source operand is `null`, a `System.NullReferenceException` is thrown. If the source operand is a reference to an incompatible object, a `System.InvalidCastException` is thrown.

JON SKEET Some unboxing conversions aren't guaranteed to work by the C# specification, yet are legal under the CLI specification. For example, the previously given description precludes unboxing from an enum value to its underlying type, and vice versa:

```
object o = System.DayOfWeek.Sunday;
int i = (int) o;
```

This conversion will succeed in .NET, but would not be guaranteed to succeed on a different C# implementation.

For an unboxing conversion to a given *nullable-type* to succeed at runtime, the value of the source operand must be either `null` or a reference to a boxed value of the underlying *non-nullable-value-type* of the *nullable-type*. If the source operand is a reference to an incompatible object, a `System.InvalidCastException` is thrown.

CHRIS SELLS Boxing and unboxing are designed such that you almost never have to think about them unless you're trying to reduce your memory usage (in which case, profiling is your friend!). However, if you see `out` or `ref` values whose values don't seem to be set properly at the caller's site, suspect boxing.

4.4 Constructed Types

A generic type declaration, by itself, denotes an ***unbound generic type*** that is used as a "blueprint" to form many different types, by way of applying ***type arguments***. The type arguments are written within angle brackets (< and >) immediately following the name of the generic type. A type that includes at least one type argument is called a ***constructed type***. A constructed type can be used in most places in the language in which a type name can appear. An unbound generic type can be used only within a *typeof-expression* (§7.6.11).

Constructed types can also be used in expressions as simple names (§7.6.2) or when accessing a member (§7.6.4).

When a *namespace-or-type-name* is evaluated, only generic types with the correct number of type parameters are considered. Thus it is possible to use the same identifier to identify different types, as long as the types have different numbers of type parameters. This is useful when mixing generic and nongeneric classes in the same program:

```
namespace Widgets
{
    class Queue {...}
    class Queue<TElement> {...}
}

namespace MyApplication
{
    using Widgets;

    class X
    {
        Queue q1;               // Nongeneric Widgets.Queue
        Queue<int> q2;          // Generic Widgets.Queue
    }
}
```

A *type-name* might identify a constructed type even though it doesn't specify type parameters directly. This can occur where a type is nested within a generic class declaration, and the instance type of the containing declaration is implicitly used for name lookup (§10.3.8.6):

```
class Outer<T>
{
    public class Inner {...}

    public Inner i;                     // Type of i is Outer<T>.Inner
}
```

In unsafe code, a constructed type cannot be used as an *unmanaged-type* (§18.2).

4.4.1 Type Arguments

Each argument in a type argument list is simply a *type*.

type-argument-list:
    < *type-arguments* >

type-arguments:
    type-argument
    type-arguments , *type-argument*

type-argument:
    type

In unsafe code (§18), a *type-argument* may not be a pointer type. Each type argument must satisfy any constraints on the corresponding type parameter (§10.1.5).

4.4.2 Open and Closed Types

All types can be classified as either ***open types*** or ***closed types***. An open type is a type that involves type parameters. More specifically:

- A type parameter defines an open type.
- An array type is an open type if and only if its element type is an open type.
- A constructed type is an open type if and only if one or more of its type arguments is an open type. A constructed nested type is an open type if and only if one or more of its type arguments or the type arguments of its containing type(s) is an open type.

A closed type is a type that is not an open type.

At runtime, all of the code within a generic type declaration is executed in the context of a closed constructed type that was created by applying type arguments to the generic declaration. Each type parameter within the generic type is bound to a particular runtime type. The runtime processing of all statements and expressions always occurs with closed types, and open types occur only during compile-time processing.

Each closed constructed type has its own set of static variables, which are not shared with any other closed constructed types. Since an open type does not exist at runtime, there are no static variables associated with an open type. Two closed constructed types are the same type if they are constructed from the same unbound generic type, and their corresponding type arguments are the same type.

4.4.3 Bound and Unbound Types

The term ***unbound type*** refers to a nongeneric type or an unbound generic type. The term ***bound type*** refers to a nongeneric type or a constructed type.

> **ERIC LIPPERT** Yes, nongeneric types are considered to be *both* bound *and* unbound.

An unbound type refers to the entity declared by a type declaration. An unbound generic type is not itself a type, and it cannot be used as the type of a variable, argument, or return value, or as a base type. The only construct in which an unbound generic type can be referenced is the `typeof` expression (§7.6.11).

4.4.4 Satisfying Constraints

Whenever a constructed type or generic method is referenced, the supplied type arguments are checked against the type parameter constraints declared on the generic type or

method (§10.1.5). For each `where` clause, the type argument `A` that corresponds to the named type parameter is checked against each constraint as follows:

- If the constraint is a class type, an interface type, or a type parameter, let `C` represent that constraint with the supplied type arguments substituted for any type parameters that appear in the constraint. To satisfy the constraint, it must be the case that type `A` is convertible to type `C` by one of the following:
  - An identity conversion (§6.1.1).
  - An implicit reference conversion (§6.1.6).
  - A boxing conversion (§6.1.7), provided that type A is a non-nullable value type.
  - An implicit reference, boxing, or type parameter conversion from a type parameter `A` to `C`.
- If the constraint is the reference type constraint (`class`), the type `A` must satisfy one of the following:
  - `A` is an interface type, class type, delegate type, or array type. Both `System.ValueType` and `System.Enum` are reference types that satisfy this constraint.
  - `A` is a type parameter that is known to be a reference type (§10.1.5).
- If the constraint is the value type constraint (`struct`), the type `A` must satisfy one of the following:
  - `A` is a struct type or enum type, but not a nullable type. Both `System.ValueType` and `System.Enum` are reference types that do not satisfy this constraint.
  - `A` is a type parameter having the value type constraint (§10.1.5).
- If the constraint is the constructor constraint `new()`, the type `A` must not be `abstract` and must have a public parameterless constructor. This is satisfied if one of the following is true:
  - `A` is a value type, since all value types have a public default constructor (§4.1.2).
  - `A` is a type parameter having the constructor constraint (§10.1.5).
  - `A` is a type parameter having the value type constraint (§10.1.5).
  - `A` is a class that is not `abstract` and contains an explicitly declared `public` constructor with no parameters.
  - `A` is not `abstract` and has a default constructor (§10.11.4).

A compile-time error occurs if one or more of a type parameter's constraints are not satisfied by the given type arguments.

Since type parameters are not inherited, constraints are never inherited either. In the example below, `D` needs to specify the constraint on its type parameter `T` so that `T` satisfies the constraint imposed by the base class `B<T>`. In contrast, class `E` need not specify a constraint, because `List<T>` implements `IEnumerable` for any `T`.

```
class B<T> where T: IEnumerable {...}

class D<T>: B<T> where T: IEnumerable {...}

class E<T>: B<List<T>> {...}
```

4.5 Type Parameters

A type parameter is an identifier designating a value type or reference type that the parameter is bound to at runtime.

type-parameter:
identifier

Since a type parameter can be instantiated with many different actual type arguments, type parameters have slightly different operations and restrictions than other types:

- A type parameter cannot be used directly to declare a base class (§10.2.4) or interface (§13.1.3).
- The rules for member lookup on type parameters depend on the constraints, if any, applied to the type parameter. They are detailed in §7.4.
- The available conversions for a type parameter depend on the constraints, if any, applied to the type parameter. They are detailed in §6.1.10 and §6.2.6.
- The literal `null` cannot be converted to a type given by a type parameter, except if the type parameter is known to be a reference type (§6.1.10). However, a `default` expression (§7.6.13) can be used instead. In addition, a value with a type given by a type parameter *can* be compared with `null` using `==` and `!=` (§7.10.6) unless the type parameter has the value type constraint.
- A `new` expression (§7.6.10.1) can be used with a type parameter only if the type parameter is constrained by a *constructor-constraint* or the value type constraint (§10.1.5).
- A type parameter cannot be used anywhere within an attribute.
- A type parameter cannot be used in a member access (§7.6.4) or type name (§3.8) to identify a static member or a nested type.
- In unsafe code, a type parameter cannot be used as an *unmanaged-type* (§18.2).

As a type, type parameters are purely a compile-time construct. At runtime, each type parameter is bound to a runtime type that was specified by supplying a type argument to the generic type declaration. Thus the type of a variable declared with a type parameter will, at runtime, be a closed constructed type (§4.4.2). The runtime execution of all statements and expressions involving type parameters uses the actual type that was supplied as the type argument for that parameter.

4.6 Expression Tree Types

Expression trees permit anonymous functions to be represented as data structures instead of executable code. Expression trees are values of ***expression tree types*** of the form `System.Linq.Expressions.Expression<D>`, where `D` is any delegate type. For the remainder of this specification, we will refer to these types using the shorthand `Expression<D>`.

If a conversion exists from an anonymous function to a delegate type `D`, a conversion also exists to the expression tree type `Expression<D>`. Whereas the conversion of an anonymous function to a delegate type generates a delegate that references executable code for the anonymous function, conversion to an expression tree type creates an expression tree representation of the anonymous function.

Expression trees are efficient in-memory data representations of anonymous functions and make the structure of the anonymous function transparent and explicit.

Just like a delegate type `D`, `Expression<D>` is said to have parameter and return types, which are the same as those of `D`.

The following example represents an anonymous function both as executable code and as an expression tree. Because a conversion exists to `Func<int,int>`, a conversion also exists to `Expression<Func<int,int>>`:

```
Func<int,int> del = x => x + 1;                // Code
Expression<Func<int,int>> exp = x => x + 1;    // Data
```

Following these assignments, the delegate `del` references a method that returns `x + 1`, and the expression tree `exp` references a data structure that describes the expression `x => x + 1`.

The exact definition of the generic type `Expression<D>` as well as the precise rules for constructing an expression tree when an anonymous function is converted to an expression tree type are implementation defined.

Two things are important to make explicit:

- Not all anonymous functions can be represented as expression trees. For instance, anonymous functions with statement bodies and anonymous functions containing assignment expressions cannot be represented. In these cases, a conversion still exists, but will fail at compile time.
- `Expression<D>` offers an instance method `Compile` that produces a delegate of type `D`:

```
Func<int,int> del2 = exp.Compile();
```

Invoking this delegate causes the code represented by the expression tree to be executed. Thus, given the definitions above, `del` and `del2` are equivalent, and the following two statements will have the same effect:

```
int i1 = del(1);
int i2 = del2(1);
```

After executing this code, `i1` and `i2` will both have the value `2`.

4.7 The dynamic Type

The type `dynamic` has special meaning in C#. Its purpose is to allow dynamic binding, which is described in detail in §7.2.2.

The `dynamic` type is considered identical to the `object` type except in the following respects:

- Operations on expressions of type `dynamic` can be dynamically bound (§7.2.2).
- Type inference (§7.5.2) will prefer `dynamic` over `object` if both are candidates.

Because of this equivalence, the following statements hold:

- There is an implicit identity conversion between `object` and `dynamic`, and between constructed types that are the same when replacing `dynamic` with `object`.
- Implicit and explicit conversions to and from `object` also apply to and from `dynamic`.
- Method signatures that are the same when replacing `dynamic` with `object` are considered the same signature.

The type `dynamic` is indistinguishable from `object` at runtime.

An expression of the type `dynamic` is referred to as a ***dynamic expression***.

ERIC LIPPERT The type `dynamic` is a bizarre type, but it is important to note that, from the compiler's perspective, it *is* a type. Unlike with `var`, you can use it in most of the situations that call for a type: return types, parameter types, type arguments, and so on.

PETER SESTOFT Actually, `var` is a reserved word, not a compile-time type, whereas `dynamic` is a compile-time type. The `var` keyword tells the compiler, "Please infer the compile-time type of this variable from its initializer expression." The `dynamic` type essentially tells the compiler, "Do not worry about compile-time type checking of expressions in which this variable appears; the runtime system will do the right thing based on the runtime type of the *value* of the variable (or throw an exception, where the compiler would have reported a type error)." The type `dynamic` cannot be used as receiver (`this` type) of an extension method, as base type of a class, or as type bound for a generic type parameter, but otherwise it can be used pretty much like any other type.

MAREK SAFAR Method signatures are considered to be same when using the `dynamic` and `object` types. This allows use of a nice trick: The interface method declared using type `object` can be directly implemented using a method with type `dynamic`.

CHRIS SELLS I begin to wonder about any language where the following string of characters is both valid and meaningful:

```
class Foo {
  public static dynamic DoFoo() {...}
}
```

Of course, this means that the `DoFoo` method is a type method (as opposed to an instance method) and that the type of the return value is unknown until runtime, but it's hard not to read `DoFoo` as both `static` and `dynamic` at the same time and worry about an occurrence of a singularity.

Index

B

C

D

E

F

I

J

K

L

M

N

O

P

Q

R

S

T

U

V

W

X

Y

Z