

INDEX

Symbols

! (null-forgiving; dammit) operator, 66–67

!= operator, 150, 167–168, 215–217

- arithmetic and nonarithmetic types, 208
- comparing generic variables, 162
- equality behavior in derived classes, 219
- implementing custom vs. generated behavior, 201
- method overloading, 240
- nonstandard operator behavior, 209
- optimizing equality, 266–267
- value-based equality for classes, 215–217

& (binary combination) operator, 122

&& (logical AND) operator, 216

* operator, 14–17

?? (null-coalescing) operator, 51, 151–152

| (binary combination) operator, 122

|| (logical OR) operator, 216

- operator, 17

+ (concatenation) operator, 241

+ operator, 122

+= operator, 76

< operator, 122, 206, 208, 229

== (equals-equals) operator, 122, 139–140, 150

- boxing values and identity comparison, 158–161
- class equality, 151–152, 156
- compiler-generated equality, 167–172
- custom vs. generated behavior, 201
- equality behavior in derived classes, 219–220

- floating-point values, 141–142, 145
- generic variable comparison, 162–163
- interface boxes, 161
- method overloading, 240
- nonstandard behavior, 209
- optimizing equality, 266–270
- reference equality, 146–148
- struct equality, 157–158
- value-based equality for classes, 215–217
- value semantics vs. reference semantics, 177
- whole numbers, 140

=> (expression body) syntax, 7, 24, 32, 92, 151

> operator, 208, 229

A

abstraction

- abstract types, 29, 36
- composing, 199
- encapsulation and cohesion, 192–193
- missing abstractions, 15, 28
- new expression, 50
- performance, 279
- vocabulary and, 191–192

accessors, read-only, 134–135

Action type, 93–94

actual parameters, 38. *See also* arguments

address

- of an object, 74–75
- of a variable, 128

ad hoc polymorphism (method overloading), 238–242

- generic delegates for polymorphism, 241–242

- ad hoc polymorphism (*continued*)
 - symbolic polymorphism with
 - overloaded operators, 240–241
 - anemic domain model, 184, 192–193
 - AngleExtensions class, 26
 - angle parameter, 3–5, 11
 - Angle type
 - automatic vs. nonautomatic
 - properties, 129–133, 135
 - boxing, 161
 - composition, 199
 - encapsulation, 5–7, 10
 - floating-point fields, 155
 - unit conversions, 24–28
 - anonymous methods, 85, 242
 - anonymous types, 60, 91
 - ApproximatelyEqual method, 143, 155
 - Area type, implementation inheritance
 - and, 228–230
 - arguments, 69–103. *See also* methods;
 - actual parameters
 - by-reference parameters, 76–82, 102–103
 - checking for invalid, 8
 - copying, 118–123
 - custom types, 5–6
 - double type and, 4–5
 - method arguments, 70–75, 118–123
 - method calls, 38
 - named, 4–5, 7–8, 33
 - null-forgiving operator, 66–67
 - object initialization, 6
 - ordering, 5
 - ArgumentException and
 - ArgumentOutOfRangeException
 - Exception type, 8
 - overloading constructors, 54
 - parameterless constructors, 54–55
 - passing null as, 52, 61, 65–66
 - passing variables as, 37–38, 44, 47
 - private constructors, 57
 - properties as, for read-only
 - parameters, 127–128
 - read-only references, 92–102
 - arithmetic operators, 14–15, 208–209
 - array elements
 - accessibility, 38
 - default initialization, 56
 - identifiers, 38
 - instance storage, 41–42
 - variables, 38, 42, 147–148
 - asynchronous methods, 86–87
 - AutoAppend method, by-reference
 - parameters and, 76–77
 - automatic properties, 43, 58, 130–134, 213, 265–266
 - await keyword and statements, 86–87
- ## B
- BallisticRange method
 - address of a variable, 127–130
 - defensive copying, 132–133
 - benchmarking, 251–252, 271
 - binary combination (| and &)
 - operators, 122
 - bitwise comparison, 49, 141, 256–257, 259
 - bne instruction, 171
 - boxed values, 44–45
 - generic code and Equals method, 163
 - identifying unnecessary boxing, 115–118
 - identity comparisons, 158–162
 - lock statements, 47
 - optimizing equality, 263–265
 - passing values by reference, 79
 - performance and, 172–173
 - Brush type
 - returning by-reference, 101
 - value type member layout, 40–42
 - value type reassignment, 113
 - by-reference fields, 84–87
 - asynchronous methods, 86–87
 - closures, 84–85
 - iterator blocks, 85–86
 - by-reference parameters, 76–92, 99, 102–103
 - defined, 70
 - kinds of, 70
 - limitations of, 82–88
 - output parameters, 79–82
 - passing arguments by reference, 70–71
 - passing references by reference, 77–78

- passing values by reference, 78–79
 - reference types vs., 70–71
 - reference type variables vs., 76–77
 - side effects and direct effects, 88–92
- by-reference returns, 97, 99
- by-reference variables (ref locals), 84, 94, 97–102, 104, 123, 133, 270
 - defined, 95
 - keeping within scope, 97–101
 - performance vs. simplicity, 101–102

C

- callback delegate, mutating arguments
 - for read-only parameters and, 93–94
- cancellation
 - defined, 142
 - mitigating limitations of, 142–144
- ceq instruction, 141, 145–147, 151
 - bne instruction vs., 171–172
 - efficiency of, 216
- Character class, default object hash
 - codes and, 153–154
- CI (continuous integration) services, 251
- classes, xx, xxiii
 - abstract, 36
 - records vs., 33, 200–201
 - default constructors, 52
 - defining, 33
 - embedded references, 42
 - embedded values, 40
 - equality behavior in derived classes, 218–219
 - equality comparisons, 149–156
 - field assignment, 53
 - field initializers, 58
 - generics and null, 61, 63
 - immutability, 33, 35
 - inheritance, 34–35
 - iterator blocks, 85–86
 - memory allocation, 50
 - object initializers, 58–59
 - parameterless constructors, 54, 57, 59
 - protected members, 35

- sealed, 35
 - value equality, 48, 214–218
- class factory methods, 22–25, 57
 - custom vs. generated behavior, 201–202
 - returning types implied by units, 27
 - symmetry, 23–24, 196
- class invariants
 - defined, 9
 - discarded, 13–14
 - establishing, 194–195
 - testing, 9
- class keyword, 33, 45
- Clone method
 - boxing, 115
 - of record types, 114, 165
- clones (deep copies), 200
- Close method, reference semantics
 - and, 75
- closures
 - by-reference parameters and, 84–85
 - defined, 84–85
 - looping and iteration, 280–281
- code craft, 3
- coercion polymorphism, 242–247
 - conversions for purpose, 245–247
 - conversions for representation, 244–245
 - widening vs. narrowing conversions, 244
- cohesion, 192–196, 198
 - clarifying with symmetry, 196
 - eliminating duplication, 193–194
 - establishing class invariants, 194–195
- collisions of hash table elements, 153
- ColorBuilder type, as mutable
 - companion type, 246–247
- ColorParser type, generic type
 - constraints and, 235–238
- Color type
 - ad hoc polymorphism, 239–242
 - array elements, 41–42
 - boxed values, 44
 - classes, 33
 - coercion polymorphism, 243–247

- Color type (*continued*)
 - compiler-generated equality, 165–169
 - constructing value types, 112–113
 - constructor accessibility, 57
 - conversion to interfaces, 116–117
 - copying records like value type, 114
 - default and generated
 - constructors, 53
 - embedded values, 40–42
 - generic code and Equals method, 163
 - IEquatable interface, 164
 - inclusion polymorphism and subtyping, 222–229, 231–232
 - init-only properties, 59
 - instance fields of value types, 98
 - measuring performance with Equals, 253–259
 - non-destructive mutation, 60
 - ordering, 206
 - overloaded constructors, 54
 - overriding Equals for structs, 157–159
 - overriding generated methods, 203
 - parametric polymorphism with generics, 233, 235–238
 - records, 33
 - record structs, 34
 - references to references, 100
 - sealed value types, 213–221
 - structs, 32–33
 - uniformity and consistency, 207
 - value-based comparisons, 181
 - value type initialization, 56–57
- Combine method, of hashCode, 259–261
- Command type
 - controller object role, 190
 - inheritance, 34–35
 - reference semantics, 74–75
- Common Type System, 45–46
- CompareTo method
 - boxing, 116–117
 - inheriting, 228–230
 - sorting, 204–208
- comparison operators, 122, 205, 208
- composition, 199
- concatenation (+) operator, 241
- concrete types, 36
- conjunctive pattern, 195
- constant pattern, 61, 145, 151–152, 195, 216
- constants
 - enums, 19
 - hidden copies, 128
 - replacing magic numbers with named constants, 10–11
- constructors, 49–57
 - accessibility, 57
 - default and generated, 52–53
 - expression body syntax, 7, 32
 - field and property initializers, 58
 - new object creation, 110–111
 - object initializers, 58–59
 - overloaded, 53–54
 - parameterless, 54–55, 62–63
 - private, 57
 - replacing public constructors with static methods, 22–23
 - structs and default values, 55–56
 - value type construction and initialization, 56–57, 112–113
 - value validation, 8–9
- continuous integration (CI) services, 251
- contract for comparisons, 205–206
 - antisymmetric, 205
 - irreflexive, 205
 - safe, 206
 - stable, 206
 - transitive, 205
- contract for equality, 217–218
 - breach of, 221
 - reflexive, 217
 - safe, 217
 - stable, 217
 - symmetric, 217
 - transitive, 217
 - upholding, 224–225
- controllers
 - avoiding implementation inheritance, 230–231
 - characteristics of, 190–191
 - defined, 185
- conversion operators, 7, 12, 122–123, 243–246

- Coordinate type
 - boxing, 115–116
 - value type memory layout, 71–72
 - value tuples, 102–103
- copying, 46–48, 105–137
 - copy-by-value semantics, 73–74
 - defensive copies, 128–133
 - identifying unnecessary boxing, 115–118
 - large instances, 272
 - locks and reference semantics, 46–47
 - measuring cost of, 270–271
 - method parameters and arguments, 118–123
 - modifying return type instances, 123–128
 - new object creation, 110–115
 - references vs. instances, 105–106
 - simple assignment, 106–110
 - value equality, 47–48
 - value semantics vs. reference semantics, 177–181
- CPU sampling, 254, 271
- CreateColor method, returning by reference and, 100
- CrossGen utility, 250
- D**
- dammit (!; null-forgiving) operator, 66–67
- dangling references, 84, 99
- DataAdapter type, generic type
 - constraints and, 234–238
- DataStore type, reference semantics and, 74–75
- DateTime type
 - boxing, 118
 - IComparable interface, 206
 - TryXXX idiom, 79–80
- decimal type, 143
- declaration patterns, 150, 157
- declarative code
 - defined, 89
 - immutability, 89
 - performance and, 91–92
 - vs. procedural code, 89, 284
- Deconstruct method, 102–103
- deep copies (clones), 200
- default constructor, 52–54, 58
- default keyword, 62–63
- default values
 - avoiding pitfalls of default variables, 200–201
 - default initialization, 50, 56
 - generics and, 62–63
 - null, 64
 - object initializers, 59
 - valid, 63
- defensive copies, 128–133
 - automatic vs. nonautomatic properties, 130–131
 - avoiding, 133–136
 - causes of, 133
 - defending against mutation, 133–134, 136
 - mutable value types and in parameters, 129–130
 - read-only fields, 132–133
 - read-only reference variables, 131–132
- definite assignment, 39
 - generics, 62
 - ref and out parameters, 79
 - static fields, 58
 - struct variables, 56–57
- deferred execution (lazy enumeration), 85
- delegates
 - callback delegate, 93–94
 - defined, 93, 241
 - generic, for polymorphism, 241–242
- derived type, 34
- Difference method, memory layout of
 - method parameters and, 72
- digit separators, 262
- Direction property, nondestructive mutation and, 90–91, 127–128
- discard pattern, 20–21, 195, 284–285
- Disconnect method, reference semantics and, 178–179, 181
- disjunctive pattern, 195
- Displacement method, 2–29
 - custom types, 5–6
 - encoding units, 18–28

- Displacement method (*continued*)
 - importance and value of good names, 2–3
 - named arguments, 4–5
 - refactoring implementation, 9–18
 - value validation, 8–9
 - DistanceInKm method
 - read-only reference parameters, 92–93
 - user-defined conversions, 122–123
 - Distance type, refactoring and, 16–18
 - domain-specific types, 9
 - double argument, 12, 25
 - double values
 - custom types vs., 4–5
 - equality comparisons, 141–142, 145, 155, 229
- E**
- embedded values, 40–43
 - array elements, 41–42
 - embedded references, 42–43
 - field and property layout, 43
 - encapsulation, 6–7, 25–26, 28, 192–196
 - abstracting types, 29
 - clarifying with symmetry, 196
 - cohesion and, 192
 - eliminating duplication, 193–194
 - establishing class invariants, 194–195
 - public interface and, 196–199
 - testing, 9
 - entities
 - characteristics of, 188–189
 - defined, 184–185
 - Enumerable class, 262, 282
 - enum (enumerated types)
 - Common Type System, 45
 - defined, 19
 - itemizing units with, 19–22
 - EqualityComparer class, 263
 - IEquatable interface and, 164–166
 - performance of, 277–278
 - equality comparisons, 139–172
 - boxing, 158–161, 163
 - built-in, 140–149
 - classes, 149–156
 - compiler-generated, 165–172
 - contract, 217
 - equality behavior in derived classes, 218–219
 - equivalence vs., 203–205
 - floating-point numbers, 141–142, 144–145
 - generics, 162–165
 - records, 165–168
 - reference-based, 47–48, 146–152, 177–178
 - strings, 148–149
 - structs, 156–162
 - transitivity, 155
 - type safe, 152
 - type substitution, 220–221
 - value-based equality for classes, 214–218
 - value semantics vs. reference semantics, 177–181
 - EqualityContract property, 226–228, 247
 - equals-equals operator. *See* == operator
 - Equals method, 33, 44, 46, 64, 139–140, 150–151
 - boxing values and identity comparison, 158–159, 161
 - canonical form of, 215–217
 - class equality, 151–152, 155–156
 - compiler-generated equality, 165–166, 172, 277–279
 - copying large instances, 272
 - custom vs. generated behavior, 201
 - equality behavior in derived classes, 219, 221
 - floating-point values, 145
 - generic variable comparison, 163–164
 - GetHashCode method and, 152–156, 259–261
 - IEquatable interface, 164–165
 - inheriting classes, 218–221
 - inheriting record types, 225–228
 - input and output types of virtual methods, 223, 225
 - measuring basic performance with, 253–261
 - measuring cost of copying, 271
 - method overloading, 238–239

- object base class, 47–48, 158–161, 163–164
 - optimizing equality, 261–265, 268–269
 - overloading, 152, 164–165
 - overriding base class
 - implementation, 199
 - overriding for structs, 156–158
 - records and structs, 48–49
 - reference equality, 146, 148, 276–277
 - struct equality, 156–158
 - value-based equality for classes, 215–217
 - value equality, 48
 - value semantics vs. reference semantics, 177
 - ValueType base class, 156, 256–258
 - EqualsOperatorComparer class, 268
 - EqualViaBase method, 221, 226, 228
 - EqualViaDerived method, 221, 226
 - equivalence vs. equality, 203–205
 - explicit conversions, 106, 243, 245
 - explicit interface conversion, 116–117
 - expressions, using with operators, 121–123
 - expression-bodied properties (nonautomatic properties), 130
 - expression body (=>) syntax, 7, 24, 32, 92, 151
 - extension methods
 - ad hoc polymorphism, 239
 - of built-in types, 26
 - by-reference parameters and, 87–88
 - composing abstractions, 199
 - extending interfaces, 197–198
 - iterators, 281
 - passing and returning by value, 119–120
 - returning types implied by units, 27
 - external interface, 198
 - extensionality, 204
- F**
- fakes (test doubles), 230
 - field initializers, 58, 113
 - fields
 - array elements, 41–42
 - by-reference, 84–87
 - copy semantics, 46
 - default initialization, 50, 53
 - embedded fields, 40–41
 - embedded references, 42
 - embedded values, 43
 - field and property layout, 43
 - generics, 62
 - identity equality vs. value equality, 47–48
 - initializers, 58
 - instance, 37, 98
 - parameterless constructors, 54–55
 - properties vs., 265–266
 - protected, 35
 - read-only, 132–134
 - return by reference, 131–132
 - static, 38, 58
 - value semantics, 49
 - value type initialization, 56–57
 - floating-point values equality
 - comparisons, 141–145
 - rounding and cancellation errors, 141–144
 - using as keys with hash codes, 154–156
 - fluent syntax form of LINQ (Language-Integrated Query), 279–280
 - foreach loop, 36, 66, 281–284
 - for loop, 283–284
 - formal parameters *See* parameters
 - FormatConnection method, output parameters of extension methods and, 87
 - Format method, method group overloading and, 242
 - FORTRAN, 182
- G**
- garbage collection, xxiii, 37, 41, 74, boxing, 115
 - managed pointers, 99
 - performance, 263, 275
 - read-only references, 131
 - generics, xx–xxii
 - arithmetic, 162

- generics (*continued*)
 - base-class constraint, 162–163
 - deduced type parameters, 236–238
 - default values, 62–63
 - equality comparisons, 162–165
 - generic delegates for
 - polymorphism, 241–242
 - interface constraint, 116–117
 - null values, 61–62
 - parametric polymorphism, 233–238
 - partial deduction of generic parameters, 237
- get accessor, 32–34, 128
 - automatic vs. nonautomatic, 130–131
 - methods for, 120–121
 - read-only, 134–135
 - symmetry with set accessor, 209
- GetAddress method, 99
 - returning by reference, 99
- get_Current method, 282
- GetEnumerator method, 281
- GetHashCode method
 - collision, 152–153
 - defining, 154, 157
 - performance, 259–261
 - ValueType definition, 156, 259
 - where used, 152
- get_Speed method, 120–121
- GetType method, 118, 166, 216, 227
- GetValueOrDefault method, 169
- Gravity.Earth constant, replacing magic numbers with, 11

H

- HashCode class, 154, 259–261
- hash codes, 152–156
 - collision, 152–153
 - creating suitable keys, 154
 - distribution, 152–153, 259
 - Equals and ValueType.GetHashCode methods, 259
 - using floating-point numbers as keys, 154–15
- heap, xxiii–xxiv, 37, 40, 50, 73–74, 107–108
 - boxing, 158–161
 - identity, 180

- hidden copies, 130, 137
 - boxes, 118
 - parameter passing, 128
 - return values, 124–126
 - value type construction, 118

I

- IComparable interface, 116–117, 204–208, 228–229, 231
- IComparer interface, 206–207
- IEEE-754, 141
- identifiers for variables, 37
- identity comparison, 145, 148, 276
 - boxed values, 158–162
 - identity equality vs. value equality, 47–48, 158–159
- identity conversions, 150
- IEnumerable interface, 85, 241, 281–282
- IEnumerator interface, 281–282
- IEqualityComparer interface, 165, 206–207, 267–268, 271
- IEquatable interface
 - avoiding boxing, 164
 - contract for, 217
 - IComparable interface vs., 203–205
 - implementing, 164, 215–216
 - performance effects, 263–265
- if...else statements, 81, 285
- IFormattable interface, 161
- if statements, 284–285
- immutability. *See* mutation and immutability
- imperative code, 89
- implementation inheritance, 213–214
 - avoiding, 230–232
 - containing instead of inheriting types, 231–232
 - interface inheritance vs., 213
 - upholding a type's contract, 224
- implicit conversions, 47, 97, 117, 150
 - boxing, 117–118
 - by-reference variables, 95–97
 - coercion polymorphism, 242–247
 - defining, 12–13
 - discarded invariants, 13–14
 - implicit reference conversion, 150, 220–221
 - primitive obsession, 5

- to and from null, 147
- unexpected interactions, 13
- user defined, 122–123
- Inch Calculator (online unit conversions), 120
- inclusion polymorphism, 222–232
 - avoiding implementation inheritance, 230–232
 - inheriting record types, 225–230
- input and output types of virtual methods, 223–224
- upholding contract, 224–225
- Incremented method
 - naming conventions, 89–90
 - passing by value, 119
- Increment method
 - overloading by-reference parameters, 83
 - passing by reference, 78
- indexers, 82, 106, 118, 125
 - defined, 121
 - mutating values from, 126–127
- infinity, 145
- inheritance, 34–36. *See also* inclusion polymorphism
- init accessor, 59, 91, 112
- init-only properties, 59, 112, 114, 274
- In method, using for unit conversion, 21–22
- in modifier and parameter definition, 70–71
 - as optimization, 268–270
 - property values as arguments for, 127–133
 - using, 92–93
- InMph extension method, 120
- input parameters, 70, 93
- InRadians property
 - automatic vs. nonautomatic properties, 129–130
 - defensive copying, 132–133
 - unit conversions, 24–26
- instrumentation profiling (tracing), 258
- intentionality, 204
- interface constraints, 233–235
- interface keyword, 224

- interfaces
 - abstractness, 36
 - boxed values, 44, 116–117, 161–162
 - extension methods, 27
 - generic constraints and protocol, 233–236
 - implementing and inheritance, 35
 - interface inheritance, 213, 222
 - parametric polymorphism, 233–236
 - types, defined, 161
- internal interface, 198–199
- InternetTime class, as service object, 188
- intern pools, 149
- InvalidCastException error, 45, 107
- IParser interface, generic type constraints and, 234–238
- IsNaN static method, 145
- IsReadOnlyAttribute indicator, 131–132, 134–136
- iterator approach to creating sequences, 281–283
- iterator blocks, 85–86
- iterators, 281–282

J

- JIT (just-in-time) compiler, 137, 141, 250–253, 265, 270–271, 273, 277–279, 281
- Journey type indexer values, 126–127

K

- keys, 152–156
 - creating suitable, 154
 - using floating-point numbers as, 154–156

L

- lambdas, 66, 85, 94, 241–242, 273, 280–281
- lazy enumeration (deferred execution), 85
- ldnull instruction, 147
- level of indirection, 70, 75, 79, 212
- lexicographical ordering, 206
- lifting operators, 169
- local functions, 85

- local variables
 - associated type, 38
 - constructing value types, 112
 - defined, 37
 - definite assignment, 39
 - instance storage, 43
 - keeping by-reference variables
 - within scope, 97–100
 - lifetime of, 36
 - local read-only reference variables
 - (`ref readonly locals`), 132–134
 - passing and returning by value, 119
 - lock statements, 47, 180
 - LogEntry type, equality vs. equivalence
 - and, 203–209
 - logical AND (`&&`) operator, 216
 - logical OR (`||`) operator, 216
 - LogIn type, reference semantics and, 178–181
 - loop approach to creating sequences, 283–284
- M**
- magic numbers, 4, 10–11
 - magnitudinal ordering, 206
 - Mail type, returning by reference and, 95–97, 99
 - managed pointers, 99
 - Math class, 10, 12–13, 17–19, 24–26, 143–144
 - memory profilers, 252
 - memory tearing, 114
 - method groups, 240, 242, 273, 280–281
 - method overloading (ad hoc polymorphism), 238–242
 - methods. *See also* arguments; actual parameters
 - abstract, 36
 - adjectives as names, 90
 - anonymous, 85, 242
 - asynchronous, 86–87
 - class factory, 22–25, 27, 57, 196, 201–202
 - encapsulation, 9
 - encoding units, 22–27
 - extension, 26, 197–199
 - ad hoc polymorphism, 239
 - of built-in types, 27
 - by-reference parameters and, 87–88
 - passing and returning by value, 119–120
 - generics, 61–63
 - identifying unnecessary boxing in
 - method calls, 117–118
 - implementing from interfaces, 35
 - inheritance, 34–36
 - naming identifiers, 2–5
 - overloading, 16, 83–84
 - overriding generated, 202–203
 - protected, 35
 - read-only, 134–135
 - return type instance modification
 - and mutability, 126–127
 - static creation, 22–23
 - value equality, 48
 - mock objects (test doubles), 230
 - ModifyByCallback method, mutating
 - read-only reference parameter arguments and, 93–94
 - Monitor class, 47, 180
 - MoveNext method, 282
 - multiple inheritance, 34, 36
 - MusicTrack type
 - customizing equality, 154, 156–157
 - reference type field initialization, 50–52, 55–56
 - Mutable Companion pattern, 246
 - mutation and immutability, 7–8
 - classes, 33, 35
 - declarative code, 89
 - defending against mutation with
 - defensive copies, 133–134, 136
 - immutable types vs. read-only properties, 109–110
 - init-only properties, 59
 - instance methods and mutability, 126–127
 - mutable immutable properties, 101
 - mutable value types and in
 - parameters, 129–130
 - mutating values from indexers, 126–127
 - mutation vs. creation, 89–91
 - non-destructive mutation, 60
 - in parameter, 92

- read-only properties vs. immutable types, 109–110
- record structs, 34
- return type instance modification and mutability, 126–127
- structs, 32–33
- value semantics vs. reference semantics, 181–182

N

- NaN (not a number), 8, 144–145, 195, 256, 285
- narrowing conversions, 244
- NegativeInfinity method, 145
- new keyword and expression, 14, 50–51, 56–57, 110
- newobj instruction, 146
- NextAppointment method, capturing
 - by-reference parameters and, 85
- nonautomatic properties (expression-bodied properties), 130
- non-destructive mutation, 60
- not a number (NaN), 8, 144–145, 195, 256, 285
- not constant pattern, 216
- nullable reference types, 52, 64–67, 151, 224
- Nullable type, 64, 168–172
- nullable value types, 60, 63–64, 168–170
- null-coalescing (??) operator, 51, 151–152
- null-conditional (?) operator, 52, 151
- null-forgiving (!; dammit) operator, 66–67
- Nullify method, by-reference
 - parameters for extension methods and, 87
- NullReferenceException error, 56
- null references, 51–52, 56, 65–67, 146–147, 151, 206, 233–234
 - comparing reference types with null, 61
 - comparing value types with null, 61
 - equality comparisons with classes, 151–152

- generics and, 61–62
- nullable reference types, 52, 64–67, 151, 224
- nullable value types, 60, 63–64, 168–170
- null-forgiving operator, 66–67
- parameterless constructors, 54

O

- object address, 180
- object base class
 - Common Type System, 33, 44–46
 - default equality, 48, 139, 163, 215–216, 253
 - generic type parameters, 233
- object construction and initialization, 49–60
 - constructors, 51–57
 - copying value type instances, 110–115
 - default initialization, 50–51
 - field and property initializers, 58
 - measuring cost of, 273–277
 - memory allocation, 49–50
 - object initializers, 7, 58–60
 - init-only properties, 59
 - non-destructive mutation, 60
- object deconstruction, 102–103
- object identity, 180, 185–191
 - and boxing, 158, 161
 - hash codes, 153
- object-oriented programming (OOP), 183–184, 211
- object relationships, 183–191
 - characteristics of, 185–191
 - design refinement to model object roles, 191
 - kinds of objects, 184–185
- object roots, 99
- OOP. *See* object-oriented programming
- op_Equality method, 167, 171–172, 268
- operators
 - arithmetic, 14–15, 121–122, 208–209
 - lifting, 168–170
 - nonstandard behavior, 209

- operators (*continued*)
 - symbolic polymorphism with
 - overloaded operators, 240–241
 - using expressions with, 121–123
 - optimization, 101, 142, 250
 - boxing, 118
 - mutable by-reference parameters, 91–92
 - ordering, comparison for, 203–207
 - contract for comparisons, 205–206
 - equivalence vs. equality, 204–205
 - lexicographical ordering, 206
 - ordinal comparisons, 206
 - output parameters, 79–82, 93, 102
 - deconstruction, 102–103
 - defined, 70
 - definite assignment, 80–81
 - object deconstruction, 102
 - reference parameters vs., 79
 - returning by reference, 100
 - selecting operations, 81–82
 - TryXXX idiom, 79–82
 - overloading, 16, 152, 238–241
 - by-reference parameters, 83–84
 - constructors, 53–55
 - operators, 14–15, 208–209
 - overriding vs., 221
 - override keyword, 149
- P**
- parameterized types, 237–238
 - parameterless constructors, 54–59, 62–63
 - parameters, 69–103
 - aliasing, 74–75
 - arguments, 38, 118–120
 - boxed, 160–161
 - by-reference, 70–71, 76–92, 99, 102–103
 - custom types as, 6
 - defining interfaces, 223–224
 - formal vs. actual, 38
 - generic, 61–62, 162–163, 233–238
 - input, 70, 92–93, 127–128, 268–270
 - kinds of, 70
 - modifiers, 70
 - naming, 2–5
 - non-nullable, 52, 66–67
 - output, 70, 79–82, 93, 102
 - overloading constructors, 53
 - overloading methods, 16
 - passing, defined, 69–70
 - read-only, 92–102, 127–128, 268–270
 - reference, 70–71, 73–74
 - ref returns, 92–102
 - value, 70–73
 - parametric polymorphism, 233–238
 - generic constraints and protocol interfaces, 233–236
 - generic method parameters and type deduction, 236–237
 - parameterized types, 237–238
 - Parse method, TryParse vs., 80
 - passing arguments
 - defined, 69–70
 - by reference, 70–71, 77–79
 - by value, 70–71, 119–120
 - pattern matching and selection
 - conjunctive pattern, 195
 - disjunctive pattern, 195
 - is constant pattern, 61, 145, 194–195
 - performance of, 284–286
 - relational pattern, 195
 - switch expression, 20–21, 284–286
 - performance, 249–286
 - effect of common idioms and practices on, 279–286
 - effect of types on, 270–279
 - measuring and optimizing, 250–253
 - measuring with Equals, 253–261
 - optimizing equality, 261–270
 - profilers, 252–253
 - pessimization, 250
 - Playlist class
 - field initializers, 58
 - generic type parameter comparisons, 162
 - parameterless constructors, 54–55
 - pointers
 - managed, 99
 - reference types vs., 74

- polymorphism, 211–247
 - ad hoc, with overloading, 238–242
 - coercion, using conversions, 242–247
 - inclusion and subtyping, 222–232
 - inheritance vs., 211–212
 - parametric, with generics, 233–238
 - sealed value types, 212–221
 - positional records and record structs, 33, 53, 55, 131, 201–203, 273
 - copying, 114
 - equality, 165–168, 277–279
 - inheritance, 225–227
 - PositiveInfinity method, 145, 285
 - precision, 142–144
 - Primitive Obsession code smell, 5
 - private constructors, 23, 57
 - procedural code
 - declarative code vs., 89, 284
 - defined, 89
 - Product type
 - copying large value types, 273–279
 - optimizing equality comparisons, 261–268
 - read-only vs. immutable, 107–110
 - value object role, 186–187
 - profilers, 252–253
 - Projectile type, returning by reference, 131–133
 - properties
 - abstract, 36
 - accessing, 120–121, 265–266
 - as arguments for read-only parameters, 127–128
 - automatic
 - initializers, 58
 - memory layout, 43
 - nonautomatic vs., 130–134
 - performance of fields vs., 265–266
 - by-reference parameters and property values, 82–83
 - circular dependency, 43
 - expression-bodied, 130–131
 - init-only, 59, 112, 114, 274
 - mutable immutable, 101
 - property forwarding, 24
 - property initializers, 58
 - read-only. *See* read-only properties
 - returned reference type instance
 - modification, 125–126
 - simplifying, 11–14
 - value of, 82
 - protocol interfaces, 231, 233–238
 - pseudorandom number generator, 254
 - public interface, encapsulation and, 196–199
 - composing abstractions, 199
 - extending interface, 197–198
 - reducing internal interface, 198–199
 - Purchase type
 - copying large value types, 273–280, 282–283
 - optimizing equality comparisons, 261–269
 - read-only vs. immutable, 107–112
 - value object role, 186–187
- ## Q
- query syntax form of LINQ (Language-Integrated Query), 280–281
- ## R
- race conditions, 96
 - Random class, 254
 - ranges (slices), 235
 - reachable objects, 99
 - readonly keyword, 32–34
 - ref locals, 96
 - structs, 135–136
 - read-only properties, 7
 - as arguments for read-only parameters, 130
 - avoiding defensive copies, 135
 - immutability vs., 109–110
 - and ref returns, 104
 - read-only reference parameters, 88, 92–95, 129, 131–132
 - mutable immutable properties, 101
 - performance vs. simplicity, 101–102
 - preventing modifications to data, 95–97
 - read-only type, 135–136
 - real number, 144
 - record keyword, 33, 45

- records
 - abstract, 36
 - copying like value types, 114–115
 - defining, 33–34
 - equality comparisons, 165–168
 - inheritance, 34
 - inheriting record types, 225–230
 - protected, 35
 - sealed, 35
 - value semantics, 48
- record struct keywords, 34
- record structs
 - defining, 34
 - equality comparisons, 165–168
 - immutability, 34
 - inheritance, 34
 - value semantics, 49
- refactoring, 9–10, 191
- reference equality, 145–148, 178–180, 275–277
- ReferenceEquals method, 148–149, 160–161, 216
- reference parameters, 65, 70–71, 73–74, 79, 239
- reference return values. *See* ref returns
- reference semantics, 45–48, 176–183, 199–203
 - avoiding pitfalls of default variables, 200–201
 - Common Type System, 45–46
 - copying and equality comparison behavior, 177–181
 - copying variables, 46–48
 - implementing custom vs. generated behavior, 201–202
 - mechanics vs. semantics, 182–183
 - mutability, 181–182
 - overriding generated methods, 202–203
- reference types
 - array elements, 42
 - by-reference parameters vs., 70–71
 - classes, 33
 - default initialization, 52–53
 - identity comparison, 47
 - inheritance, 34, 36
 - instance lifetime, 37
 - instance storage, 40
 - locks and semantics, 46–47, 180
 - nullable, 64–66
 - performance, 274–275
 - pointers vs., 74
 - records, 33
 - return type instance modification, 123, 125–126
 - value of, 73–74
 - value-like performance, 274–277
 - value types vs., xx, 31, 70–71, 123–126, 176–181, 212–213, 273–277
- reference variables
 - aliasing and, 74–75, 88, 96, 107–110, 125, 178–180
 - boxing and unboxing, 44
 - by-reference parameters vs., 76–77
 - defensive copies, 131–132
 - equality comparisons, 145–148, 177
 - fields of value types, 107–110
 - instance storage, 42
 - non-nullable reference variables, 64–65
 - passing by reference, 77–78
 - reference storage, 37
 - scope, 37
 - value of, 39
- referential transparency, 180
- reflection, 49, 156, 257–258
- ref locals, 95–96, 132–134. *See also* by-reference variables
- ref parameter modifier, 76–78, 80, 82–88
 - defined, 70–71
 - passing by reference, 77
 - property value arguments for, 127–128
 - returning by reference, 94–97
- ref readonly locals (local read-only reference variables), 96, 132–134
- ref returns (reference return values), 92
 - keeping by-reference variables within scope, 97–101
 - performance vs. simplicity, 101–102
 - preventing modifications to data, 95–97
 - returning values by reference, 94–95

- relational operators, 195
- relational pattern, 195
- RelativeLuminance method, user-
 - defined conversions and, 246
- Reminder class, by-reference fields
 - and, 84
- RemoveRed method, returning
 - by-reference parameters by reference and, 100
- Reset method, variables vs. values
 - and, 126
- return type instance modification,
 - 123–128
 - instance methods and mutability, 126–127
 - properties as arguments for read-only parameters, 127–128
 - reference type properties, 125–126
- rich domain model, 184
- rounding, mitigating limitations of,
 - 142–144
- run-time type, 166, 220–221
- rvalue, 124

S

- sealed, 34, 212–213, 224–225, 231
- seam, 230–231
- Select method, 241–242, 273, 280–281, 283–284
- self-documenting code, 6
- semantics
 - copying, 46–47, 75, 177
 - equality, 166–167, 177
 - reference, 46–47, 176–177
- separation of concerns, 9, 117
- SequenceEqual method
 - comparing array elements, 148
 - effect of IEquatable interface, 262–267
- services
 - characteristics of, 187–188
 - defined, 184
- set accessor, 7, 32–34
 - mutable value types, 78, 89, 107–110
 - object initialization, 58–59, 91, 100–112
 - value type properties, 123–124
- side effects and direct effects, 88–92
 - declarative code and performance, 91–92
 - mutation vs. creation, 89–91
 - reference semantics and, 178–180
- simple assignment, 106–110
 - value copy behavior, 107–109
- single responsibility, 28–29
- slices (ranges), 235
- sorting collections of values, 203–204
- SpeedExtensions type, internal vs.
 - external interface and, 197
- Speed type
 - anemic type, 192
 - automatic vs. nonautomatic properties, 133
 - encapsulation, 192–199
 - passing and returning by value, 119–120
 - replacing built-in types, 5–10, 12–24, 27–28
 - variable vs. value, 129–130
- stack, value types and, 39
- static abstract interface members, 162
- static creation methods, 22–23
- Stopwatch class, 251–252
- StringBuilder type, 125, 246
 - Capacity property, mutating property values and, 125
- string class
 - concatenation, 209, 241
 - equality, 148–149, 177
 - interpolation, 52, 148
 - StringBuilder vs., 246
 - value of, 177
- string interning, 149
- structs
 - cyclic dependencies, 43
 - defining, 32–33
 - equality comparisons, 156–162
 - immutability, 32–33
 - inheritance, 34
 - tightly packed, 256
 - value semantics, 49
- stubs (test doubles), 230
- Subtract method, 223–224
 - derived method behavior, 223–224

- subtyping, 222–232
 - avoiding implementation
 - inheritance, 230–232
 - defined, 222
 - inheriting record types, 225–230
 - input and output types of virtual
 - methods, 223–224
 - substitutability, 222–223
 - upholding contract, 224–225
- switch expressions, 21, 194–195, 284–285
 - switch statement vs., 285
- symbolic polymorphism, 240–241
- symmetry
 - class factory methods, 23–24, 196
 - contract for equality, 217
 - encapsulation and cohesion, 196
- SynchronizationLockException error, 47
- System.Diagnostics namespace, 251
- System types, 45

T

- target-typed default feature, 63
- target-typed new feature, 14, 55
- Temperature type
 - pattern matching, 285
 - positional records, 200–202
- ternary condition (?:) operator, 81, 151
- test doubles (stubs; fakes; mock objects), 230
- testing, 9, 15, 22, 218–221, 229, 245, 262
- theta, 3
- this parameter, 87–88, 120
- TimeSpan type
 - arithmetic operations, 14–18
 - replacing built-in types, 6, 10, 12
 - unit conversions, 24, 27
- Tolerance constant, setting for floating-point comparisons, 143
- ToString method
 - boxing, 118
 - default reference field values, 56
 - implicit conversion vs., 246
- TotalSeconds property of TimeSpan type
 - arithmetic operations, 14–15
 - Seconds property vs., 10
 - unit conversions, 27

- ToTitleCase method, nullable reference
 - types and, 65–66
- TParser parameter, generic type
 - constraints and, 234–237
- tracing (instrumentation profiling), 258
- transitivity
 - equality comparisons, 155, 217
 - ordering comparisons, 206
- TranslucentColorParser class,
 - overloading method groups
 - with, 238
- TranslucentColor type
 - composition, 231–232
 - generic type constraints, 236, 238
 - implementation inheritance,
 - 213–214, 216, 218–229
 - user-defined conversions, 241–244
- triangular number, 258–259
- truth operators, 122
- try...catch blocks, 80
- TryXXX idiom, 79–82
 - selecting operations, 81–82
 - side effects and direct effects,
 - 88–89
- tuples
 - equality comparisons, 170–172
 - named, 102
 - tuple assignment, 32
 - tuple deconstruction, 29, 102–103
- two-stage initialization, 110–113
- typeof method
 - EqualityContract property,
 - 226–227
 - GetType vs., 118
- types, 1–30. *See also* reference types; value types
 - abstracting, 29, 36
 - adding clarity through, 4–9
 - benefits of understanding, xix, xxiii
 - clarity, adding through, 4–9
 - class vs., 222–223
 - deduction, of generic type
 - parameters, 236–237
 - deduction, of var declarations, 106
 - determining need for new types,
 - 15–18
 - effect on performance, 270–279

- encoding units, 18–28
- generic constraint, 117, 162–163, 233–234
- implied by units, returning, 27–28
- inference, 106
- instances and storage, 39–45
- naming, 2–4
- new features in C3, xxiii
- null values and default values, 60–67
- object construction and initialization, 49–60
- purpose and focus of book, xx–xxi
- refactoring implementation, 9–18
- semantics, 45–49
- user defined, 32–37
- type substitution, 220–221
 - breach of contract, 221
 - effects of, 220–221

U

- ubiquitous language, 191–192, 288
- unboxing, 44–45, 116, 163, 263
- unconstrained generic type, 61–62, 162–163
- uninitialized variables, 39
- units, 18–28
 - choosing most natural usage, 25–26
 - itemizing with enumeration types, 19–22
 - making explicit, 24–25
 - returning types implied by, 27–28
 - static creation methods, 22–23
 - symmetry in design, 23–24
- Units enumeration type, 19–21
- unit testing, 251. *See also* testing
- user-defined types. *See* classes; records; record structs; structs

V

- validation, 8–9, 184, 193–194
- value-based comparisons, 48, 177, 180–181, 215–216
 - records, 166–168
 - reference equality vs., 156, 158, 162–163
 - strings, 148–149, 177

- value-like behavior and characteristics
 - classes and records, 35
 - records, 48
- value object role, 184, 186–187
- value parameters, 71–73
 - by-reference parameters vs., 76
 - defined, 70, 118
 - passing and returning by value, 119–120
 - passing arguments, 70
 - replacing with `in` parameters, 269
- values, 175–210
 - abstraction and vocabulary, 191–192
 - boxed, 44–45, 47, 79, 115–118, 158–163
 - by-reference vs., 79
 - optimizing equality, 263–265
 - characteristics of, 186–187
 - comparison for ordering, 203–207
 - default, 50, 56, 59, 62–64, 200–201
 - defined, 184
 - definite assignment, 39
 - embedded, 40–43
 - encapsulation and cohesion, 192–196
 - encapsulation and public interface, 196–199
 - equality, 47–48
 - extensionality vs. intentionality, 204
 - identity comparison, 47–48
 - object relationships, 183–191
 - passing and returning by, 119–120
 - perils of uniformity and consistency, 207–209
 - simplifying, 11–14
 - unit conversions and value comparisons, 20–21
 - validation of, 8–9
 - variables vs., 38–39
- value semantics
 - benefits of understanding, xxiv
 - reference semantics vs., 176–183, 199–203
- value tuples
 - equality comparisons, 170–172
 - tuple deconstruction, 102–103

- ValueTuple type, 170, 172
 - ValueType class
 - Common Type System, 45–46, 211
 - copying and identity, 48–49, 177–8
 - default equality, 156–159, 163, 165, 253–260
 - value types
 - advantages of, xxiii–xxiv
 - arithmetic, 14–15
 - avoiding defensive copies, 135–136
 - construction, 52–53, 112–113
 - copying, 110–115
 - defensive copies, 129–130
 - embedded fields, 43
 - identity comparison, 47
 - inheritance, 36
 - initialization, 56–57
 - instance fields of, 98
 - instance lifetime, 36–37
 - instance storage, 39
 - nullable, 63–64
 - parameters and, 71–73
 - passing variables by reference, 78–79
 - polymorphism, 211–247
 - record structs, 34
 - reference types vs., xx, 31, 70–71, 123–126, 176–181, 212–213, 273–277
 - return type instance modification, 123–124
 - sealed, 35, 212–221
 - semantics, 45–48
 - size of instances, 91–92, 136, 270–274
 - structs, 33
 - variables, 37–39. *See also* array variables; by-reference variables; local variables; parameters; reference variables
 - associated types, 38
 - avoiding pitfalls of default variables, 200–201
 - capturing, 84–85
 - copy-by-value semantics, 73–74
 - copying, 46–48
 - defined, 37
 - definite assignment, 39
 - embedded, 40–43
 - identifiers, 37
 - kinds of, 37–38
 - lifetime of, 36–37, 131–132
 - read-only, 134–136
 - values vs., 38–39, 82, 123–127
 - Velocity type
 - abstraction, 17, 28–29, 199
 - by-reference parameter
 - limitations, 82
 - non-destructive mutation, 90–91
 - perils of mutable value types, 126–127
 - property methods, 120–123
 - virtual dispatch, 212, 228
 - virtual methods, 34, 36, 118
 - vocabulary, 191–192, 199
 - Volume type, implementation
 - inheritance and, 228–230
- ## W
- Where method, 85, 281
 - whole numbers, 140–141
 - widening conversions, 244
 - with keyword, 60, 90–91, 114–115
 - WithPercentAdded method, 197–198
 - WriteLine method, 118
- ## Y
- yield statement, 85–86
- ## Z
- ZeroKelvin constant, using for validation, 285