Java

The Java® Tutorial

A Short Course on the Basics

Fifth Edition

Sharon Biocca Zakhour, Sowmya Kannan, Raymond Gallardo

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Addison-Wesley

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Preface

Since the acquisition of Sun Microsystems by Oracle Corporation in early 2010, it has been an exciting time for the Java language. As evidenced by the activities of the Java Community Process program, the Java language continues to evolve. The publication of this fifth edition of *The Java® Tutorial* reflects release 7 of the Java Platform Standard Edition (Java SE) and references the Application Programming Interface (API) of that release.

This edition introduces new features added to the platform since the publication of the fourth edition (under release 6), such as a section on NIO.2, the new file I/O API, and information on migrating legacy code to the new API. The deployment coverage has been expanded with new chapters on "Doing More with Java Rich Internet Applications" (Chapter 18) and "Deployment in Depth" (Chapter 19). A section on the Fork/Join feature has been added to the "Concurrency" chapter (Chapter 12). Information reflecting Project Coin developments has been added where appropriate, including the new `try`-with-resources statement, the ability to catch more than one type of exception with a single exception handler, support for binary literals, and diamond syntax, which results in cleaner generics code.

In addition to coverage of new features, previous chapters have been rewritten to include new information. For example, "Generics" (Chapter 6), "Java Web Start" (Chapter 16), and "Applets" (Chapter 17) have been updated. The appendix for the Java Certification exam has also been completely replaced.

If you plan to take one of the Java SE 7 certification exams, this book can help. The appendix, "Preparing for Java Programming Language Certification," lists the three exams that are available, detailing the items covered on each exam, cross-referenced to places in the book where you can find more information about each topic. Note that this is one source, among others, that you will want to use to prepare for your exam.

All the material has been thoroughly reviewed by members of Oracle Java engineering to ensure that the information is accurate and up to date. This book is based on the online tutorial hosted on Oracle's web site at the following URL:

```
http://docs.oracle.com/javase/tutorial
```

The information in this book, often referred to as "the core tutorial," is essential for most beginning to intermediate programmers. Once you have mastered this material, you can explore the rest of the Java platform documentation on the web site. If you are interested in developing sophisticated Rich Internet Applications (RIAs), check out JavaFX, the new cutting-edge Java graphical user interface (GUI) toolkit. As of the release of Java SE 7 update 5, you automatically get the JavaFX Software Development Kit (SDK) when you download the JDK. To learn more, see the JavaFX documentation at the following URL:

```
http://docs.oracle.com/javafx
```

As always, our goal is to create an easy-to-read, practical programmers' guide to help you learn how to use the rich environment provided by Java to build applications, applets, and components. Go forth and program!

Who Should Read This Book?

This book is geared toward both novice and experienced programmers.

- *New programmers* can benefit most from reading the book from beginning to end, including the step-by-step instructions for compiling and running your first program in Chapter 1, "Getting Started."
- *Programmers experienced with procedural languages* such as C may want to start with the material on object-oriented concepts and features of the Java programming language.
- *Experienced programmers* may want to jump feet first into the more advanced topics, such as generics, concurrency, or deployment.

This book contains information to address the learning needs of programmers with various levels of experience.

How to Use This Book

This book is designed so you can read it straight through or skip around from topic to topic. The information is presented in a logical order, and forward references are avoided wherever possible.

The examples in this tutorial are compiled against the JDK 7 release. *You need to download this release (or later) in order to compile and run most examples.*

Some material referenced in this book is available online (e.g., the downloadable examples, the solutions to the questions and exercises, the JDK 7 guides, and the API specification). You will see footnotes like the following:

```
7/docs/api/java/lang/Class.html
```

and

```
tutorial/java/generics/examples/BoxDemo.java
```

The Java Tutorials are also available in two e-book formats:

- mobi e-book files for Kindle
- ePub e-book files for iPad, Nook, and other devices that support the ePub format

Each e-book contains a single trail, which is equivalent to several related chapters in this book. You can download the e-books via the link "In Book Form" on the home page for the Java Tutorials:

```
http://docs.oracle.com/javase/tutorial/index.html
```

We welcome feedback on this edition. To contact us, please see the tutorial feedback page:

```
http://docs.oracle.com/javase/feedback.html
```

This book would not be what it is without the Oracle Java engineering team who tirelessly reviews the technical content of our writing. For this edition of the book, we especially want to thank Alan Bateman, Alex Buckley, Calvin Cheung, Maurizio Cimadamore, Joe Darcy, Andy Herrick, Stuart Marks, Igor Nekrestyanov, Thomas Ng, Nam Nguyen, and Daniel Smith.

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Last but not least, thanks for the support of our management: Alan Sommerer, who saw us through the acquisition and beyond; Barbara Ramsey; Sophia Mikulinsky; and Sowmya Kannan, recently elevated as manager of our team.

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6

Generics

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In any nontrivial software project, bugs are simply a fact of life. Careful planning, programming, and testing can help reduce their pervasiveness, but somehow, somewhere, they'll always find a way to creep into your code. This becomes especially apparent as new features are introduced and your code base grows in size and complexity.

Fortunately, some bugs are easier to detect than others. Compile-time bugs, for example, can be detected early on; you can use the compiler's error messages to figure out what the problem is and fix it right then and there. Runtime bugs, however, can be much more problematic; they don't always surface immediately, and when they do, it may be at a point in the program that is far removed from the actual cause of the problem. Generics, introduced in Java SE 5.0, add stability to your code by making more of your bugs detectable at compile time.

Why Use Generics?

In a nutshell, generics enable *types* (classes and interfaces) to be parameters when defining classes, interfaces, and methods. Much like the more familiar *formal parameters* used in method declarations, type parameters provide a way for you to reuse the same code with different inputs. The difference is that the inputs to formal parameters are values, while the inputs to type parameters are types.

Code that uses generics has many benefits over nongeneric code:

- *Stronger type checks at compile time.* A Java compiler applies strong type checking to generic code and issues errors if the code violates type safety. Fixing compile-time errors is easier than fixing runtime errors, which can be difficult to find.
- *Elimination of casts.* The following nongeneric code snippet requires casting:

  ```
  List list = new ArrayList();
  list.add("hello");
  String s = (String) list.get(0);
  ```

  When rewritten using generics, the code does not require casting:

  ```
  List<String> list = new ArrayList<String>();
  list.add("hello");
  String s = list.get(0);   // no cast
  ```

- *The ability to implement generic algorithms.* By using generics, programmers can implement generic algorithms that work on collections of different types, can be customized, and are type safe and easier to read.

Generic Types

A *generic type* is a generic class or interface that is parameterized over types. The following `Box` class will be modified to demonstrate the concept.

A Simple Box Class

Begin by examining a nongeneric `Box` class that operates on objects of any type. It only needs to provide two methods: `set`, which adds an object to the box, and `get`, which retrieves it:

```
public class Box {
    private Object object;

    public void set(Object object) { this.object = object; }
    public Object get() { return object; }
}
```

Since its methods accept or return an Object, you are free to pass in whatever you want, provided that it is not one of the primitive types. At compile time, there is no way to verify how the class is used. One part of the code may place an Integer in the box and expect to get Integers out of it, while another part of the code may mistakenly pass in a String, resulting in a runtime error.

A Generic Version of the Box Class

A *generic class* is defined with the following format:

```
class name<T1, T2, . . . , Tn> { /* . . . */ }
```


The type parameter section, delimited by angle brackets (<>), follows the class name. It specifies the *type parameters* (also called *type variables*) T1, T2, . . . , and Tn.

To update the Box class to use generics, you create a *generic type declaration* by changing the code public class Box to public class Box<T>. This introduces the type variable T, which can be used anywhere inside the class.

With this change, the Box class becomes the following:

```
/**
 * Generic version of the Box class.
 * @param <T> the type of the value being boxed
 */
public class Box<T> {
    // T stands for "Type"
    private T t;

    public void set(T t) { this.t = t; }
    public T get() { return t; }
}
```

As you can see, all occurrences of Object are replaced by T. A type variable can be any nonprimitive type you specify: any class type, interface type, array type, or even another type variable. This same technique can be applied to create generic interfaces.

Type Parameter Naming Conventions

By convention, type parameter names are single, uppercase letters. This stands in sharp contrast to the variable naming conventions that you already know about, with good reason: without this convention, it would be difficult to tell the difference between a type variable and an ordinary class or interface name.

The most commonly used type parameter names are as follows:

- E—Element (used extensively by the Java Collections Framework)
- K—Key
- N—Number
- T—Type
- V—Value
- S, U, V, and so on—Second, third, and fourth types

You'll see these names used throughout the Java SE Application Programming Interface (API) and the rest of this chapter.

Invoking and Instantiating a Generic Type

To reference the generic Box class from within your code, you must perform a *generic type invocation*, which replaces T with some concrete value, such as Integer:

```
Box<Integer> integerBox;
```

You can think of a generic type invocation as being similar to an ordinary method invocation, but instead of passing an argument to a method, you are passing a *type argument* (Integer in this case) to the Box class itself.

> **Note**
> Many developers use the terms *type parameter* and *type argument* interchangeably, but these terms are not the same. In code, one provides type arguments in order to create a parameterized type. Therefore, the T in Foo<T> is a type parameter and the String in Foo<String> f is a type argument. This chapter observes this definition when using these terms.

Like any other variable declaration, this code does not actually create a new Box object. It simply declares that integerBox will hold a reference to a "Box of Integer," which is how Box<Integer> is read.

An invocation of a generic type is generally known as a *parameterized type*. To instantiate this class, use the new keyword, as usual, but place <Integer> between the class name and the parentheses:

```
Box<Integer> integerBox = new Box<Integer>();
```

The Diamond

In Java SE 7 and later, you can replace the type arguments required to invoke the constructor of a generic class with an empty set of type arguments (<>) as long as the compiler can determine, or infer, the type arguments from the context. This pair of angle brackets (<>) is informally called *the diamond*. For example, you can create an instance of Box<Integer> with the following statement:

```
Box<Integer> integerBox = new Box<>();
```

For more information on diamond notation and type inference, see the "Type Inference" section later on in this chapter.

Multiple Type Parameters

As mentioned previously, a generic class can have multiple type parameters. One example is the generic OrderedPair class, which implements the generic Pair interface:

```
public interface Pair<K, V> {
    public K getKey();
    public V getValue();
}

public class OrderedPair<K, V> implements Pair<K, V> {

    private K key;
    private V value;

    public OrderedPair(K key, V value) {
        this.key = key;
        this.value = value;
    }

    public K getKey()   { return key; }
    public V getValue() { return value; }
}
```

The following statements create two instantiations of the OrderedPair class:

```
Pair<String, Integer> p1 = new OrderedPair<String, Integer>("Even", 8);
Pair<String, String>  p2 = new OrderedPair<String, String>("hello", "world");
```

The code, new OrderedPair<String, Integer>, instantiates K as a String and V as an Integer. Therefore, the parameter types of OrderedPair's constructor are String and Integer, respectively. Due to autoboxing, it is valid to pass a String and an int to the class.

As mentioned previously, because a Java compiler can infer the K and V types from the declaration OrderedPair<String, Integer>, these statements can be shortened using diamond notation:

```
OrderedPair<String, Integer> p1 = new OrderedPair<>("Even", 8);
OrderedPair<String, String>  p2 = new OrderedPair<>("hello", "world");
```

To create a generic interface, follow the same conventions as you would to create a generic class.

Parameterized Types

You can also substitute a type parameter (e.g., K or V) with a parameterized type (e.g., List<String>). Here is an example, using OrderedPair<V, K>:

```
OrderedPair<String, Box<Integer>> p = new OrderedPair<>("primes", new
   Box<Integer>( . . . ));
```


Raw Types

A *raw type* is the name of a generic class or interface without any type arguments. Here is an example, given the generic Box class:

```
public class Box<T> {
    public void set(T t) { /* . . . */ }
    // . . .
}
```

To create a parameterized type of Box<T>, you supply an actual type argument for the formal type parameter T:

```
Box<Integer> intBox = new Box<>();
```

If the actual type argument is omitted, you create a raw type of Box<T>:

```
Box rawBox = new Box();
```

Therefore, Box is the raw type of the generic type Box<T>. However, a nongeneric class or interface type is *not* a raw type.

Raw types show up in legacy code because lots of API classes (such as the Collections classes) were not generic prior to the Java SE Development Kit (JDK) 5.0. When using raw types, you essentially get pregenerics behavior: a Box gives you Objects. For backward compatibility, assigning a parameterized type to its raw type is allowed:

```
Box<String> stringBox = new Box<>();
Box rawBox = stringBox;               // OK
```

However, if you assign a raw type to a parameterized type, you get a warning:

```
Box rawBox = new Box();           // rawBox is a raw type of Box<T>
Box<Integer> intBox = rawBox;     // warning: unchecked conversion
```

You also get a warning if you use a raw type to invoke generic methods defined in the corresponding generic type:

```
Box<String> stringBox = new Box<>();
Box rawBox = stringBox;
rawBox.set(8);  // warning: unchecked invocation to set(T)
```

The warning shows that raw types bypass generic type checks, deferring the catch of unsafe code to runtime. Therefore, you should avoid using raw types.

The "Type Erasure" section later on in this chapter has more information on how the Java compiler uses raw types.

Unchecked Error Messages

As mentioned previously, when mixing legacy code with generic code, you may encounter warning messages similar to the following:

```
Note: Example.java uses unchecked or unsafe operations.
Note: Recompile with -Xlint:unchecked for details.
```

This can happen when using an older API that operates on raw types, as shown in the following example:

```
public class WarningDemo {
    public static void main(String[] args){
        Box<Integer> bi;
        bi = createBox();
    }

    static Box createBox(){
        return new Box();
    }
}
```

The term *unchecked* means that the compiler does not have enough type information to perform all type checks necessary to ensure type safety. The unchecked warning is disabled, by default, though the compiler gives a hint. To see all unchecked warnings, recompile with `-Xlint:unchecked`.

Recompiling the previous example with `-Xlint:unchecked` reveals the following additional information:

```
WarningDemo.java:4: warning: [unchecked] unchecked conversion
found   : Box
required: Box<java.lang.Integer>
        bi = createBox();
                      ^
1 warning
```

To completely disable unchecked warnings, use the `-Xlint:-unchecked` flag. The `@SuppressWarnings("unchecked")` annotation suppresses unchecked warnings. If you are unfamiliar with the `@SuppressWarnings` syntax, see Chapter 4, “Annotations.”

Generic Methods

Generic methods are methods that introduce their own type parameters. This is similar to declaring a generic type, but the type parameter’s scope is limited to the method where it is declared. Static and nonstatic generic methods are allowed, as are generic class constructors.

6

The syntax for a generic method includes a type parameter, inside angle brackets, that appears before the method’s return type. For static generic methods, the type parameter section must appear before the method’s return type.

The `Util` class includes a generic method, `compare`, which compares two `Pair` objects:

```
public class Util {
    // Generic static method
    public static <K, V> boolean compare(Pair<K, V> p1, Pair<K, V> p2) {
        return p1.getKey().equals(p2.getKey()) &&
               p1.getValue().equals(p2.getValue());
    }
}

public class Pair<K, V> {

    private K key;
    private V value;

    // Generic constructor
    public Pair(K key, V value) {
        this.key = key;
        this.value = value;
    }

    // Generic methods
    public void setKey(K key) { this.key = key; }
    public void setValue(V value) { this.value = value; }
    public K getKey()   { return key; }
    public V getValue() { return value; }
}
```

The complete syntax for invoking this method is as follows:

```
Pair<Integer, String> p1 = new Pair<>(1, "apple");
Pair<Integer, String> p2 = new Pair<>(2, "pear");
boolean same = Util.<Integer, String>compare(p1, p2);
```

The type has been explicitly provided, as shown in bold. Generally, this can be left out and the compiler will infer the type that is needed:

```
Pair<Integer, String> p1 = new Pair<>(1, "apple");
Pair<Integer, String> p2 = new Pair<>(2, "pear");
boolean same = Util.compare(p1, p2);
```

This feature, known as *type inference*, allows you to invoke a generic method as an ordinary method, without specifying a type between angle brackets. This topic is further discussed later on, in "Type Inference."

Bounded Type Parameters

There may be times when you want to restrict the types that can be used as type arguments in a parameterized type. For example, a method that operates on numbers might only want to accept instances of `Number` or its subclasses. This is what *bounded type parameters* are for.

To declare a bounded type parameter, list the type parameter's name, followed by the `extends` keyword, followed by its *upper bound*, which in this example is `Number`. Note that, in this context, `extends` is used in a general sense to mean either *extends* (as in classes) or *implements* (as in interfaces):

```
public class Box<T> {

    private T t;

    public void set(T t) {
        this.t = t;
    }

    public T get() {
        return t;
    }

    public <U extends Number> void inspect(U u){
        System.out.println("T: " + t.getClass().getName());
        System.out.println("U: " + u.getClass().getName());
    }

    public static void main(String[] args) {
        Box<Integer> integerBox = new Box<Integer>();
        integerBox.set(new Integer(10));
        integerBox.inspect("some text"); // error: this is still String!
    }
}
```

If we modify our generic method to include this bounded type parameter, compilation will now fail, since our invocation of `inspect` still includes a `String`:

```
Box.java:21: <U>inspect(U) in Box<java.lang.Integer> cannot
  be applied to (java.lang.String)
                        integerBox.inspect("10");
                                  ^
1 error
```

In addition to limiting the types you can use to instantiate a generic type, bounded type parameters allow you to invoke methods defined in the bounds:


```
public class NaturalNumber<T extends Integer> {

    private T n;

    public NaturalNumber(T n)  { this.n = n; }

    public boolean isEven() {
        return n.intValue() % 2 == 0;
    }

    // . . .
}
```

The `isEven` method invokes the `intValue` method defined in the `Integer` class through n.

Multiple Bounds

The previous example illustrates the use of a type parameter with a single bound, but a type parameter can have *multiple bounds*:

```
<T extends B1 & B2 & B3>
```

A type variable with multiple bounds is a subtype of all the types listed in the bound. If one of the bounds is a class, it must be specified first, as follows:

```
Class A { /* . . . */ }
interface B { /* . . . */ }
interface C { /* . . . */ }

class D <T extends A & B & C> { /* . . . */ }
```

If bound `A` is not specified first, you get a compile-time error:

```
class D <T extends B & A & C> { /* . . . */ }  // compile-time error
```

Generic Methods and Bounded Type Parameters

Bounded type parameters are key to the implementation of generic algorithms. Consider the following method, which counts the number of elements in an array `T[]` that are greater than a specified element `elem`:

```
public static <T> int countGreaterThan(T[] anArray, T elem) {
    int count = 0;
    for (T e : anArray)
        if (e > elem)  // compiler error
            ++count;
    return count;
}
```


The implementation of the method is straightforward, but it does not compile because the greater than operator (>) applies only to primitive types such as `short`, `int`, `double`, `long`, `float`, `byte`, and `char`. You cannot use the greater than operator to compare objects. To fix the problem, use a type parameter bounded by the `Comparable<T>` interface:

```
public interface Comparable<T> {
    public int compareTo(T o);
}
```

The resulting code is as follows:

```
public static <T extends Comparable<T>> int countGreaterThan(T[] anArray, T elem) {
    int count = 0;
    for (T e : anArray)
        if (e.compareTo(elem) > 0)
            ++count;
    return count;
}
```

Generics, Inheritance, and Subtypes

As you already know, it is possible to assign an object of one type to an object of another type, provided that the types are compatible. For example, you can assign an `Integer` to an `Object`, since `Object` is one of `Integer`'s supertypes:

```
Object someObject = new Object();
Integer someInteger = new Integer(10);
someObject = someInteger;   // OK
```

In object-oriented terminology, this is called an *is a* relationship. Since an `Integer` *is a* kind of `Object`, the assignment is allowed. But `Integer` is also a kind of `Number`, so the following code is valid as well:

```
public void someMethod(Number n) { /* . . . */ }

someMethod(new Integer(10));   // OK
someMethod(new Double(10.1);   // OK
```

The same is also true with generics. You can perform a generic type invocation, passing `Number` as its type argument, and any subsequent invocation of `add` will be allowed if the argument is compatible with `Number`:

```
Box<Number> box = new Box<Number>();
box.add(new Integer(10));   // OK
box.add(new Double(10.1));  // OK
```

Now consider the following method:

```
public void boxTest(Box<Number> n) { /* . . . */ }
```

What type of argument does it accept? By looking at its signature, you can see that it accepts a single argument whose type is `Box<Number>`. But what does that mean? Are you allowed to pass in `Box<Integer>` or `Box<Double>`, as you might expect? The answer is *no* because, as shown in Figure 6.1, `Box<Integer>` and `Box<Double>` are not subtypes of `Box<Number>`. This is a common misunderstanding when it comes to programming with generics and is an important concept to learn.

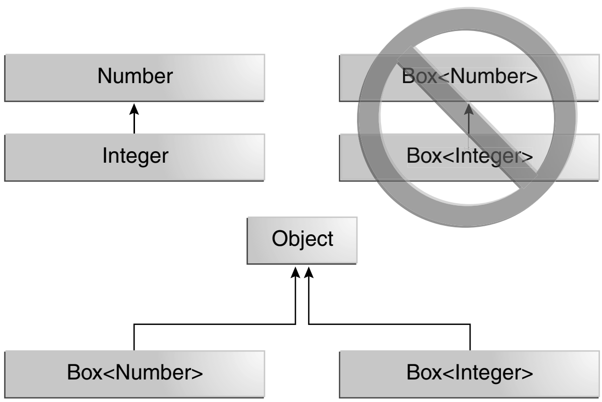

Figure 6.1 Box<Integer> Is Not a Subtype of Box<Number> Even Though Integer Is a Subtype of Number

> **Note**
>
> Given two concrete types `A` and `B` (e.g., `Number` and `Integer`), `MyClass` has no relationship to `MyClass<B>`, regardless of whether or not `A` and `B` are related. The common parent of `MyClass` and `MyClass<B>` is `Object`.
>
> For information on how to create a subtype-like relationship between two generic classes when the type parameters are related, see the section on "Wildcards and Subtyping" later on in this chapter.

Generic Classes and Subtyping

You can subtype a generic class or interface by extending or implementing it. The relationship between the type parameters of one class or interface and the type parameters of another are determined by the `extends` and `implements` clauses.

Using the `Collections` classes as an example, as shown in Figure 6.2, `ArrayList<E> implements List<E>`, and `List<E> extends Collection<E>`. So `ArrayList<String>` is a subtype of `List<String>`, which is a subtype of `Collection<String>`. So long as you do not vary the type argument, the subtyping relationship is preserved between the types.

Now imagine we want to define our own list interface, `PayloadList` (Figure 6.3), which associates an optional value of generic type `P` with each element. Its declaration might resemble the following:

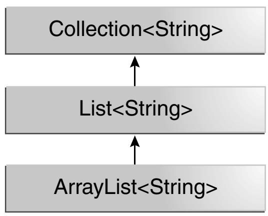

Figure 6.2 A Sample Collections Hierarchy

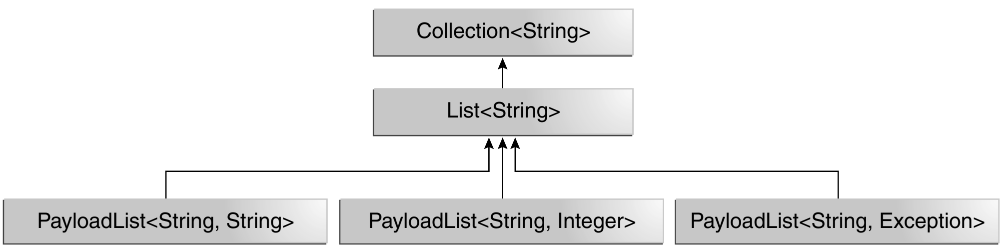

Figure 6.3 A Sample PayloadList Hierarchy

```
interface PayloadList<E,P> extends List<E> {
  void setPayload(int index, P val);
   . . .
}
```

The following parameterizations of `PayloadList` are subtypes of `List<String>`:

- `PayloadList<String,String>`
- `PayloadList<String,Integer>`
- `PayloadList<String,Exception>`

Type Inference

Type inference is a Java compiler's ability to look at each method invocation and corresponding declaration to determine the type argument (or arguments) that makes the invocation applicable. The inference algorithm determines the types of the arguments and, if available, the type that the result is being assigned or returned. Finally, the inference algorithm tries to find the *most specific* type that works with all the arguments.

To illustrate this last point, in the following example, inference determines that the second argument being passed to the `pick` method is of type `Serializable`:

```
static <T> T pick(T a1, T a2) { return a2; }
Serializable s = pick("d", new ArrayList<String>());
```

Type Inference and Generic Methods

The previous discussion of generic methods introduced you to type inference, which enables you to invoke a generic method as you would an ordinary method, without specifying a type between angle brackets. Consider the following example, `BoxDemo`, which requires the `Box` class:

```
public class BoxDemo {

  public static <U> void addBox(U u,
      java.util.List<Box<U>> boxes) {
    Box<U> box = new Box<>();
    box.set(u);
    boxes.add(box);
  }

  public static <U> void outputBoxes(java.util.List<Box<U>> boxes) {
    int counter = 0;
    for (Box<U> box: boxes) {
      U boxContents = box.get();
      System.out.println("Box #" + counter + " contains [" +
```

```
                boxContents.toString() + "]");
            counter++;
        }
    }

    public static void main(String[] args) {
        java.util.ArrayList<Box<Integer>> listOfIntegerBoxes =
            new java.util.ArrayList<>();
        BoxDemo.<Integer>addBox(Integer.valueOf(10), listOfIntegerBoxes);
        BoxDemo.addBox(Integer.valueOf(20), listOfIntegerBoxes);
        BoxDemo.addBox(Integer.valueOf(30), listOfIntegerBoxes);
        BoxDemo.outputBoxes(listOfIntegerBoxes);
    }
}
```


The following is the output from this example:

```
Box #0 contains [10]
Box #1 contains [20]
Box #2 contains [30]
```

The generic method `addBox` defines one type parameter, named `U`. Generally, a Java compiler can infer the type parameters of a generic method call. Consequently, in most cases, you do not need to specify them. For example, to invoke the generic method `addBox`, you can specify the type parameter as follows:

```
BoxDemo.<Integer>addBox(Integer.valueOf(10), listOfIntegerBoxes);
```

Alternatively, if you omit the type parameters, a Java compiler automatically infers (from the method's arguments) that the type parameter is `Integer`:

```
BoxDemo.addBox(Integer.valueOf(20), listOfIntegerBoxes);
```

Type Inference and Instantiation of Generic Classes

You can replace the type arguments required to invoke the constructor of a generic class with an empty set of type parameters (<>; informally known as *the diamond*) as long as the compiler can infer the type arguments from the context.

For example, consider the following variable declaration:

```
Map<String, List<String>> myMap = new HashMap<String, List<String>>();
```

You can substitute the parameterized type of the constructor with an empty set of type parameters (<>):

```
Map<String, List<String>> my Map = new HashMap<>();
```

In order to take advantage of type inference during generic class instantiation, you must place notation inside the diamond. In the following example, the compiler generates an unchecked conversion warning because the HashMap() constructor refers to the HashMap raw type, not the Map<String, List<String>> type:

```
Map<String, List<String>> myMap = new HashMap(); // unchecked conversion warning
```

Java supports limited type inference for generic instance creation; you can only use type inference if the parameterized type of the constructor is obvious from the context. For example, the following code does not compile:

```
List<String> list = new ArrayList<>();
list.add("A");

// The following statement should fail since addAll expects
// Collection<? extends String>
list.addAll(new ArrayList<>());
```

Note that the diamond often works in method calls; however, for greater clarity, it is suggested that you use the diamond primarily to initialize a variable where it is declared. Note that the following example can successfully compile:

```
List<? extends String> list2 = new ArrayList<>();
list.addAll(list2);
```

Type Inference and Generic Constructors of Generic and Nongeneric Classes

Note that constructors can be generic (i.e., declare their own formal type parameters) in both generic and nongeneric classes. Consider the following example:

```
class MyClass<X> {
  <T> MyClass(T t) {
    // . . .
  }
}
```

Now consider the following instantiation of the class MyClass:

```
new MyClass<Integer>("")
```

This statement creates an instance of the parameterized type MyClass<Integer>; the statement explicitly specifies the type Integer for the formal type parameter, X, of the generic class MyClass<X>. Note that the constructor for this generic class contains a formal type parameter, `T`. The compiler infers the type `String` for the formal type parameter, `T`, of the constructor of this generic class (because the actual parameter of this constructor is a `String` object).

Compilers from releases prior to Java SE 7 are able to infer the actual type parameters of generic constructors, similar to generic methods. However, compilers in Java SE 7 and later can infer the actual type parameters of the generic class being instantiated if you use the diamond (<>). Consider the following example:

```
MyClass<Integer> myObject = new MyClass<>("");
```

In this example, the compiler infers the type `Integer` for the formal type parameter, `X`, of the generic class `MyClass<X>`. It infers the type `String` for the formal type parameter, `T`, of the constructor of this generic class.

> **Note**
> It is important to note that the inference algorithm uses only invocation arguments and, possibly, an obvious expected return type to infer types. The inference algorithm does not use results from later in the program.

Wildcards

In generic code, the question mark (`?`), called the *wildcard*, represents an unknown type. The wildcard can be used in a variety of situations: as the type of a parameter, field, or local variable, or sometimes as a return type (though it is better programming practice to be more specific). The wildcard is never used as a type argument for a generic method invocation, a generic class instance creation, or a supertype.

The following sections discuss wildcards in more detail, including upper-bounded wildcards, lower-bounded wildcards, and wildcard capture.

Upper-Bounded Wildcards

You can use an upper-bounded wildcard to relax the restrictions on a variable. For example, say you want to write a method that works on `List<Integer>`, `List<Double>`, *and* `List<Number>`; you can achieve this by using an upper-bounded wildcard.

To declare an upper-bounded wildcard, use the wildcard character (`?`), followed by the `extends` keyword, followed by its *upper bound*. Note that, in this context, `extends` is used in a general sense to mean either *extends* (as in classes) or *implements* (as in interfaces).

To write the method that works on lists of `Number` and the subtypes of `Number`, such as `Integer`, `Double`, and `Float`, you would specify `List<? extends Number>`. The term `List<Number>` is more restrictive than `List<? extends Number>` because the former matches a list of type `Number` only, whereas the latter matches a list of type `Number` or any of its subclasses.

Consider the following `process` method:

```
public static void process(List<? extends Foo> list) { /* . . . */ }
```

The upper-bounded wildcard, `<? extends Foo>`, where `Foo` is any type, matches `Foo` and any subtype of `Foo`. The `process` method can access the list elements as type `Foo`:

```
public static void process(List<? extends Foo> list) {
    for (Foo elem : list) {
        // . . .
    }
}
```

In the `foreach` clause, the `elem` variable iterates over each element in the list. Any method defined in the `Foo` class can now be used on `elem`.

The `sumOfList` method returns the sum of the numbers in a list:

```
public static double sumOfList(List<? extends Number> list) {
    double s = 0.0;
    for (Number n : list)
        s += n.doubleValue();
    return s;
}
```

The following code, using a list of `Integer` objects, prints `sum = 6.0`:

```
List<Integer> li = Arrays.asList(1, 2, 3);
System.out.println("sum = " + sumOfList(li));
```

A list of `Double` values can use the same `sumOfList` method. The following code prints `sum = 7.0`:

```
List<Double> ld = Arrays.asList(1.2, 2.3, 3.5);
System.out.println("sum = " + sumOfList(ld));
```

Unbounded Wildcards

The unbounded wildcard type is specified using the wildcard character (`?`)—for example, `List<?>`. This is called a *list of unknown type*. There are two scenarios where an unbounded wildcard is a useful approach:

- It is useful if you are writing a method that can be implemented using functionality provided in the `Object` class.
- It is useful when the code is using methods in the generic class that don't depend on the type parameter (e.g., `List.size` or `List.clear`). In fact, `Class<?>` is often used because most of the methods in `Class<T>` do not depend on `T`.

Consider the following method, `printList`:

```
public static void printList(List<Object> list) {
    for (Object elem : list)
        System.out.println(elem + " ");
    System.out.println();
}
```

The goal of `printList` is to print a list of any type, but it fails to achieve that goal: It prints only a list of `Object` instances. It cannot print `List<Integer>`, `List<String>`, `List<Double>`, and so on. This is because they are not subtypes of `List<Object>`. To write a generic `printList` method, use `List<?>`:

```
public static void printList(List<?> list) {
    for (Object elem: list)
        System.out.print(elem + " ");
    System.out.println();
}
```

For any concrete type `A`, `List` is a subtype of `List<?>`. Thus you can use `printList` to print a list of any type:

```
List<Integer> li = Arrays.asList(1, 2, 3);
List<String>  ls = Arrays.asList("one", "two", "three");
printList(li);
printList(ls);
```

It's important to note that `List<Object>` and `List<?>` are not the same. You can insert an `Object`, or any subtype of `Object`, into a `List<Object>`. But you can only insert `null` into a `List<?>`. The "Guidelines for Wildcard Use" section has more information on how to determine what kind of wildcard, if any, should be used in a given situation.

> **Note**
>
> The `Arrays.asList`[1] method is used in examples throughout this chapter. This static factory method converts the specified array and returns a fixed-size list.

1. `7/docs/api/java/util/Arrays.html#asList(T...)`

Lower-Bounded Wildcards

The "Upper-Bounded Wildcards" section shows that an upper-bounded wildcard restricts the unknown type to be a specific type or a subtype of that type and is represented using the extends keyword. In a similar way, a lower-bounded wildcard restricts the unknown type to be a specific type or a supertype of that type. A lower-bounded wildcard is expressed using the wildcard character (?), followed by the super keyword, followed by its *lower bound*: <? super A>.

> **Note**
> You can specify either an upper bound or a lower bound for a wildcard; you cannot specify both.

Say you want to write a method that puts Integer objects into a list. To maximize flexibility, you would like the method to work on List<Integer>, List<Number>, and List<Object>—anything that can hold Integer values.

To write the method that works on lists of Integer and the supertypes of Integer, such as Integer, Number, and Object, you would specify List<? super Integer>. The term List<Integer> is more restrictive than List<? super Integer> because the former matches a list of type Integer only, whereas the latter matches a list of any type that is a supertype of Integer.

The following code adds the numbers 1 through 10 to the end of a list:

```
public static void addNumbers(List<? super Integer> list) {
    for (int i = 1; i <= 10; i++) {
        list.add(i);
    }
}
```

The "Guidelines for Wildcard Use" section in this chapter provides guidance on when to use upper-bounded wildcards and when to use lower-bounded wildcards.

Wildcards and Subtyping

As described previously in "Generics, Inheritance, and Subtypes," generic classes or interfaces are not related merely because there is a relationship between their types. However, you can use wildcards to create a relationship between generic classes or interfaces.

Consider the following two regular (nongeneric) classes:

```
class A { /* . . . */ }
```

```
class B extends A { /* . . . */ }
```

For these classes, it would be reasonable to write the following code:

```
B b = new B();
A a = b;
```

This example shows that inheritance of regular classes follows the rule of subtyping: class B is a subtype of class A if B extends A. This rule does not apply to generic types:


```
List<B> lb = new ArrayList<>();
List la = lb;   // compile-time error
```

Given that Integer is a subtype of Number, what is the relationship between List<Integer> and List<Number>? Although Integer is a subtype of Number, List<Integer> is not a subtype of List<Number> and, in fact, these two types are not related. The common parent of List<Number> and List<Integer> is List<?> (Figure 6.4).

In order to create a relationship between these classes so that the code can access Number's methods through List<Integer>'s elements, use an upper-bounded wildcard:

```
List<? extends Integer> intList = new ArrayList<>();
// OK. List<? extends Integer> is a subtype of List<? extends Number>
List<? extends Number>  numList = intList;
```

Because Integer is a subtype of Number, and numList is a list of Number objects, a relationship now exists between intList (a list of Integer objects) and numList. Figure 6.5 shows the relationships between several List classes declared with both upper- and lower-bounded wildcards.

The "Guidelines for Wildcard Use" section later on in this chapter has more information about the ramifications of using upper- and lower-bounded wildcards.

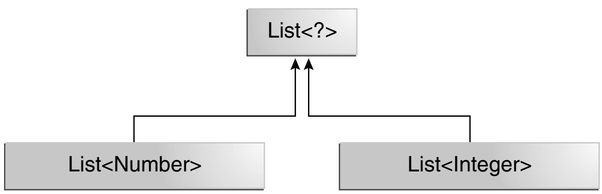

Figure 6.4 The Common Parent Is List<?>

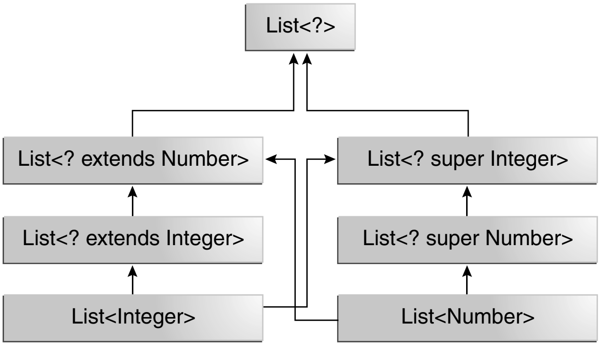

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Figure 6.5 A Hierarchy of Several Generic List Class Declarations

Wildcard Capture and Helper Methods

In some cases, the compiler infers the type of a wildcard. For example, a list may be defined as `List<?>`, but when evaluating an expression, the compiler infers a particular type from the code. This scenario is known as *wildcard capture*. For the most part, you don't need to worry about wildcard capture, except when you see an error message that contains the phrase `capture of`.

The `WildcardError` example produces a capture error when compiled:

```
import java.util.List;

public class WildcardError {

    void foo(List<?> i) {
        i.set(0, i.get(0));
    }
}
```

In this example, the compiler processes the `i` input parameter as being of type `Object`. When the `foo` method invokes `List.set(int, E)`[2], the compiler is not able to confirm the type of object that is being inserted into the list and an error is produced. When this type of error occurs, it typically means that the compiler believes that you are assigning the wrong type to a variable. Generics were added to the Java language for this reason—to enforce type safety at compile time.

The `WildcardError` example generates the following error when compiled by Oracle's JDK 7 `javac` implementation:

```
WildcardError.java:6: error: method set in interface List<E> cannot
   be applied to given types;
```

2. `7/docs/api/java/util/List.html#set(int,E)`

```
    i.set(0, i.get(0));
     ^
  required: int,CAP#1
  found: int,Object
  reason: actual argument Object cannot be converted to CAP#1 by method
     invocation conversion
  where E is a type-variable:
    E extends Object declared in interface List
  where CAP#1 is a fresh type-variable:
    CAP#1 extends Object from capture of ?
1 error
```


In this example, the code is attempting to perform a safe operation, so how can you work around the compiler error? You can fix it by writing a *private helper method*, which captures the wildcard. In this case, you can work around the problem by creating the private helper method, `fooHelper`, as shown in `WildcardFixed`:

```
public class WildcardFixed {

    void foo(List<?> i) {
        fooHelper(i);
    }

    // Helper method created so that the wildcard can be captured
    // through type inference.
    private <T> void fooHelper(List<T> l) {
        l.set(0, l.get(0));
    }
}
```

Thanks to the helper method, the compiler uses inference to determine that `T` is `CAP#1`, the capture variable, in the invocation. The example now compiles successfully.

By convention, helper methods are generally named *`originalMethodNameHelper`*. Now consider a more complex example, `WildcardErrorBad`:

```
import java.util.List;

public class WildcardErrorBad {

    void swapFirst(List<? extends Number> l1, List<? extends Number> l2) {
      Number temp = l1.get(0);
      l1.set(0, l2.get(0)); // expected a CAP#1 extends Number,
                            // got a CAP#2 extends Number;
                            // same bound, but different types
      l2.set(0, temp);      // expected a CAP#1 extends Number,
                            // got a Number
    }
}
```

In this example, the code is attempting an unsafe operation. For example, consider the following invocation of the `swapFirst` method:

```
List<Integer> li = Arrays.asList(1, 2, 3);
List<Double>  ld = Arrays.asList(10.10, 20.20, 30.30);
swapFirst(li, ld);
```

While `List<Integer>` and `List<Double>` both fulfill the criteria of `List<? extends Number>`, it is clearly incorrect to take an item from a list of `Integer` values and attempt to place it into a list of `Double` values.

Compiling the code with Oracle's JDK `javac` compiler produces the following error:


```
WildcardErrorBad.java:7: error: method set in interface List<E> cannot be
   applied to given types;
      l1.set(0, l2.get(0)); // expected a CAP#1 extends Number,
        ^
  required: int,CAP#1
  found: int,Number
  reason: actual argument Number cannot be converted to CAP#1 by method
     invocation conversion
  where E is a type-variable:
    E extends Object declared in interface List
  where CAP#1 is a fresh type-variable:
    CAP#1 extends Number from capture of ? extends Number
WildcardErrorBad.java:10: error: method set in interface List<E> cannot
   be applied to given types;
      l2.set(0, temp);      // expected a CAP#1 extends Number,
        ^
  required: int,CAP#1
  found: int,Number
  reason: actual argument Number cannot be converted to CAP#1 by method
     invocation conversion
  where E is a type-variable:
    E extends Object declared in interface List
  where CAP#1 is a fresh type-variable:
    CAP#1 extends Number from capture of ? extends Number
WildcardErrorBad.java:15: error: method set in interface List<E> cannot
   be applied to given types;
        i.set(0, i.get(0));
         ^
  required: int,CAP#1
  found: int,Object
  reason: actual argument Object cannot be converted to CAP#1 by method
     invocation conversion
  where E is a type-variable:
    E extends Object declared in interface List
  where CAP#1 is a fresh type-variable:
    CAP#1 extends Object from capture of ?
3 errors
```

There is no helper method to work around the problem because the code is fundamentally wrong.

Guidelines for Wildcard Use

One of the more confusing aspects when learning to program with generics is determining when to use an upper-bounded wildcard and when to use a lower-bounded wildcard. This section provides some guidelines to follow when designing your code.

For purposes of this discussion, it is helpful to think of variables as serving one of two functions:

- An *in* variable serves up data to the code. Imagine a copy method with two arguments: `copy(src, dest)`. The `src` argument provides the data to be copied, so it is the *in* parameter.
- An *out* variable holds data for use elsewhere. In the copy example, `copy(src, dest)`, the `dest` argument accepts data, so it is the *out* parameter.

Of course, some variables are used for both in and out purposes, as discussed later. You can use the in and out principles when deciding whether to use a wildcard and what type of wildcard is appropriate. The following list provides the guidelines that you should follow:

- An invariable is defined with an upper-bounded wildcard, using the `extends` keyword.
- An out variable is defined with a lower-bounded wildcard, using the `super` keyword.
- In the case where the in variable can be accessed using methods defined in the `Object` class, use an unbounded wildcard.
- In the case where the code needs to access the variable as both an in and an out variable, do not use a wildcard.

These guidelines do not apply to a method's return type. Using a wildcard as a return type should be avoided because it forces programmers using the code to deal with wildcards.

A list defined by `List<? extends . . . >` can be informally thought of as read only, but that is not a strict guarantee. Suppose you have the following two classes:

```
class NaturalNumber {

    private int i;

    public NaturalNumber(int i) { this.i = i; }
    // . . .
}

class EvenNumber extends NaturalNumber {
```

```
        public EvenNumber(int i) { super(i); }
        // . . .
    }
```

Consider the following code:

```
List<EvenNumber> le = new ArrayList<>();
List<? extends NaturalNumber> ln = le;
ln.add(new NaturalNumber(35));  // compile-time error
```

Because `List<EvenNumber>` is a subtype of `List<? extends NaturalNumber>`, you can assign `le` to `ln`. But you cannot use `ln` to add a natural number to a list of even numbers. The following operations on the list are possible:

- You can add `null`.
- You can invoke `clear`.
- You can get the iterator and invoke `remove`.
- You can capture the wildcard and write elements that you've read from the list.

You can see that the list defined by `List<? extends NaturalNumber>` is not read only in the strictest sense of the word, but you might think of it that way because you cannot store a new element or change an existing element in the list.

Type Erasure

Generics were introduced to the Java language to provide tighter type checks at compile time and to support generic programming. To implement generics, the Java compiler applies type erasure to achieve the following:

- Replace all type parameters in generic types with their bounds or `Object` if the type parameters are unbounded. The produced bytecode, therefore, contains only ordinary classes, interfaces, and methods.
- Insert type casts if necessary to preserve type safety.
- Generate bridge methods to preserve polymorphism in extended generic types.

Type erasure ensures that no new classes are created for parameterized types; consequently, generics incur no runtime overhead.

Erasure of Generic Types

During the type erasure process, the Java compiler erases all type parameters and replaces each with its first bound if the type parameter is bounded or `Object` if the type parameter is unbounded.

Consider the following generic class that represents a node in a singly linked list:

```
public class Node<T> {

    private T data;
    private Node<T> next;

    public Node(T data, Node<T> next) }
        this.data = data;
        this.next = next;
    }

    public T getData() { return data; }
    // . . .
}
```


Because the type parameter `T` is unbounded, the Java compiler replaces it with `Object`:

```
public class Node {

    private Object data;
    private Node next;

    public Node(Object data, Node next) {
        this.data = data;
        this.next = next;
    }

    public Object getData() { return data; }
    // . . .
}
```

In the following example, the generic `Node` class uses a bounded type parameter:

```
public class Node<T extends Comparable<T>> {

    private T data;
    private Node<T> next;

    public Node(T data, Node<T> next) {
        this.data = data;
        this.next = next;
    }

    public T getData() { return data; }
    // . . .
}
```

The Java compiler replaces the bounded type parameter `T` with the first bound class, `Comparable`:

```
public class Node {
```

```
    private Comparable data;
    private Node next;

    public Node(Comparable data, Node next) {
        this.data = data;
        this.next = next;
    }

    public Comparable getData() { return data; }
    // . . .
}
```

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Erasure of Generic Methods

The Java compiler also erases type parameters in generic method arguments. Consider the following generic method:

```
// Counts the number of occurrences of elem in anArray.

public static <T> int count(T[] anArray, T elem) {
    int cnt = 0;
    for (T e : anArray)
        if (e.equals(elem))
            ++cnt
        return cnt;
}
```

Because `T` is unbounded, the Java compiler replaces it with `Object`:

```
public static int count(Object[] anArray, Object elem) {
    int cnt = 0;
    for (Object e : anArray)
        if (e.equals(elem))
            ++cnt;
        return cnt;
}
```

Suppose the following classes are defined:

```
class Shape { /* . . . */ }
class Circle extends Shape { /* . . . */ }
class Rectangle extends Shape { /* . . . */ }
```

You can write a generic method to draw different shapes:

```
public static <T extends Shape> void draw(T shape) { /* . . . */ }
```

The Java compiler replaces `T` with `Shape`:

```
public static void draw(Shape shape) { /* . . . */ }
```

Effects of Type Erasure and Bridge Methods

Sometimes type erasure causes a situation that you may not have anticipated. The following example shows how this can occur. The example shows how a compiler sometimes creates a synthetic method, called a bridge method, as part of the type erasure process.

Consider the following two classes:

```
public class Node<T> {

    private T data;

    public Node(T data) { this.data = data; }

    public void setData(T data) {
        System.out.println("Node.setData");
        this.data = data;
    }
}

public class MyNode extends Node<Integer> {
    public MyNode(Integer data) { super(data); }

    public void setData(Integer data) {
        System.out.println("MyNode.setData");
        super.setData(data);
    }
}
```


Now, consider the following code:

```
MyNode mn = new MyNode(5);
Node n = mn;            // A raw type - compiler throws an unchecked warning
n.setData("Hello");     // Causes a ClassCastException to be thrown.
Integer x = mn.data;
```

After type erasure, this code changes as follows:

```
MyNode mn = new MyNode(5);
Node n = (MyNode)mn;         // A raw type - compiler throws an unchecked warning
n.setData("Hello");
Integer x = (String)mn.data; // Causes a ClassCastException to be thrown.
```

Here is what happens as the code is executed:

- `n.setData("Hello");` causes the method `setData(Object)` to be executed on the object of class `MyNode`. (The `MyNode` class inherited `setData(Object)` from `Node`.)
- In the body of `setData(Object)`, the data field of the object referenced by `n` is assigned to a `String`.

- The data field of that same object, referenced via mn, can be accessed and is expected to be an integer (since mn is a MyNode, which is a Node<Integer>).
- Trying to assign a String to an Integer causes a ClassCastException from a cast inserted at the assignment by a Java compiler.

Bridge Methods

When compiling a class or interface that extends a parameterized class or implements a parameterized interface, the compiler may need to create a synthetic method, called a *bridge method*, as part of the type erasure process. You normally don't need to worry about bridge methods, but you might be puzzled if one appears in a stack trace.

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After type erasure, the Node and MyNode classes are as follows:

```
public class Node {

    private Object data;

    public Node(Object data) { this.data = data; }

    public void setData(Object data) {
        System.out.println("Node.setData");
        this.data = data;
    }
}

public class MyNode extends Node {

    public MyNode(Integer data) { super(data); }

    public void setData(Integer data) {
        System.out.println(Integer data);
        super.setData(data);
    }
}
```

After type erasure, the method signatures do not match. The Node method becomes setData(Object) and the MyNode method becomes setData(Integer). Therefore, the MyNodesetData method does not override the NodesetData method.

To solve this problem and preserve the polymorphism of generic types after type erasure, a Java compiler generates a bridge method to ensure that subtyping works as expected. For the MyNode class, the compiler generates the following bridge method for setData:

```
class MyNode extends Node {
    // Bridge method generated by the compiler

    public void setData(Object data) {
        setData((Integer) data);
    }
```

```
    public void setData(Integer data) {
        System.out.println("MyNode.setData");
        super.setData(data);
    }

    // . . .
}
```

As you can see, the bridge method, which has the same method signature as the `Node` class's `setData` method after type erasure, delegates to the original `setData` method.

Nonreifiable Types

The "Type Erasure" section discusses the process where the compiler removes information related to type parameters and type arguments. Type erasure has consequences related to variable arguments (also known as *varargs*), methods where a vararg formal parameters contains nonreifiable type. See Chapter 4, "Passing Information to a Method or a Constructor," for more information about varargs methods.

Nonreifiable Types Defined

A *reifiable type* is a type whose type information is fully available at runtime. This includes primitives, nongeneric types, raw types, and invocations of unbound wildcards.

Nonreifiable types are types whose information has been removed at compile time by type erasure—invocations of generic types that are not defined as unbounded wildcards. A nonreifiable type does not have all its information available at runtime. Examples of nonreifiable types are `List<String>` and `List<Number>`; the Java Virtual Machine (Java VM) cannot tell the difference between these types at runtime. As shown in the section "Restrictions on Generics" later in this chapter, there are certain situations where nonreifiable types cannot be used (e.g., in an `instanceof` expression or as an element in an array).

Heap Pollution

Heap pollution occurs when a variable of a parameterized type refers to an object that is not of that parameterized type. This situation occurs if the program performed some operation that gives rise to an unchecked warning at compile time. An *unchecked warning* is generated if, either at compile time (within the limits of the compile-time type checking rules) or at runtime, the correctness of an operation involving a parameterized type (e.g., a cast or method call) cannot be verified. For example, heap pollution occurs when mixing raw types and parameterized types or when performing unchecked casts.

In normal situations, when all code is compiled at the same time, the compiler issues an unchecked warning to draw your attention to potential heap pollution. If you compile sections of your code separately, it is difficult to detect the potential risk of heap pollution. If you ensure that your code compiles without warnings, then no heap pollution can occur.

Potential Vulnerabilities of Varargs Methods with Nonreifiable Formal Parameters

Generic methods that include vararg input parameters can cause heap pollution. Consider the following `ArrayBuilder` class:

```
public class ArrayBuilder {

  public static <T> void addToList (List<T> listArg, T . . . elements)
{
    for (T x : elements) {
      listArg.add(x);
    }
  }

  public static void faultyMethod(List<String> . . . l) {
    Object[] objectArray = l;     // Valid
    objectArray[0] = Arrays.asList(42);
    String s = l[0].get(0);       // ClassCastException thrown here
  }

}
```

The following example, `HeapPollutionExample`, uses the `ArrayBuiler` class:

```
public class HeapPollutionExample {

  public static void main(String[] args) {

    List<String> stringListA = new ArrayList<String>();
    List<String> stringListB = new ArrayList<String>();

    ArrayBuilder.addToList(stringListA, "Seven", "Eight", "Nine");
    ArrayBuilder.addToList(stringListA, "Ten", "Eleven", "Twelve");
    List<List<String>> listOfStringLists =
      new ArrayList<List<String>>();
    ArrayBuilder.addToList(listOfStringLists,
      stringListA, stringListB);

    ArrayBuilder.faultyMethod(Arrays.asList("Hello!"),
                Arrays.asList("World!"));
  }
}
```

When this is compiled, the following warning is produced by the definition of the `ArrayBuilder.addToList` method:

```
warning: [varargs] Possible heap pollution from parameterized vararg type T
```

When the compiler encounters a varargs method, it translates the varargs formal parameter into an array. However, the Java programming language does not permit the creation of arrays of parameterized types. In the method `ArrayBuilder.addToList`, the compiler translates the varargs formal parameter `T ... elements` to the formal parameter `T[] elements`, an array. However, because of type erasure, the compiler converts the varargs formal parameter to `Object[] elements`. Consequently, there is a possibility of heap pollution.

The following statement assigns the varargs formal parameter `l` to the `Object` array `objectArgs`:

```
Object[] objectArray = l;
```


This statement can potentially introduce heap pollution. A value that does match the parameterized type of the varargs formal parameter `l` can be assigned to the variable `objectArray` and thus can be assigned to `l`. However, the compiler does not generate an unchecked warning at this statement. The compiler has already generated a warning when it translated the varargs formal parameter `List<String> ... l` to the formal parameter `List[] l`. This statement is valid; the variable `l` has the type `List[]`, which is a subtype of `Object[]`.

Consequently, the compiler does not issue a warning or error if you assign a `List` object of any type to any array component of the `objectArray` array as shown by this statement:

```
objectArray[0] = Arrays.asList(42);
```

The first array component of the `objectArray` array is assigned with a `List` object that contains one object of type `Integer`.

Suppose you invoke `ArrayBuilder.faultyArray` with the following statement:

```
ArrayBuilder.faultyMethod(Arrays.asList("Hello!"), Arrays.asList("World!"));
```

At runtime, the Java VM throws a `ClassCastException` at the following statement:

```
// ClassCastException thrown here
String s = l[0].get(0);
```

The object stored in the first array component of the variable `l` has the type `List<Integer>`, but this statement is expecting an object of type `List<String>`.

Prevent Warnings from Varargs Methods with Nonreifiable Formal Parameters

If you declare a varargs method that has parameters of a parameterized type and you ensure that the body of the method does not throw a `ClassCastException` or other similar exception due to improper handling of the varargs formal parameter, you can prevent the warning that the compiler generates for these kinds of varargs methods by adding the following annotation to static and nonconstructor method declarations:

```
@SafeVarargs
```

The `@SafeVarargs` annotation is a documented part of the method's contract; this annotation asserts that the implementation of the method will not improperly handle the varargs formal parameter.

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It is also possible, though less desirable, to suppress such warnings by adding the following to the method declaration:

```
@SuppressWarnings({"unchecked", "varargs"})
```

However, this approach does not suppress warnings generated from the method's call site. If you are unfamiliar with the `@SuppressWarnings` syntax, see Chapter 4, "Annotations."

Restrictions on Generics

To use Java generics effectively, you must consider the following restrictions.

Cannot Instantiate Generic Types with Primitive Types

Consider the following parameterized type:

```
class Pair<K, V> {

    private K key;
    private V value;

    public Pair(K key, V value) {
        this.key = key;
        this.value = value;
    }

    // . . .
}
```

When creating a `Pair` object, you cannot substitute a primitive type for the type parameter `K` or `V`:

```
Pair<int, char> p = new Pair<>(8, 'a');  // compile-time error
```

You can only substitute nonprimitive types for the type parameters `K` and `V`:

```
Pair<Integer, Character> p = new Pair<>(8, 'a');
```

Note that the Java compiler autoboxes `8` to `Integer.valueOf(8)` and 'a' to `Character('a')`:

```
Pair<Integer, Character> p = new Pair<>(Integer.valueOf(8), new Character('a'));
```

For more information on autoboxing, see Chapter 8.

Cannot Create Instances of Type Parameters

You cannot create an instance of a type parameter. For example, the following code causes a compile-time error:

```
public static <E> void append(List<E> list) {
    E elem = new E();  // compile-time error
    list.add(elem);
}
```

As a workaround, you can create an object of a type parameter through reflection:

```
public static <E> void append(List<E> list, Class<E> cls) throws Exception
{
    E elem = cls.newInstance();   // OK
    list.add(elem);
}
```

You can invoke the `append` method as follows:

```
List<String> ls = new ArrayList<>();
append(ls, String.class);
```

Cannot Declare Static Fields Whose Types Are Type Parameters

A class's static field is a class-level variable shared by all nonstatic objects of the class. Hence, static fields of type parameters are not allowed. Consider the following class:

```
public class MobileDevice<T> {
    private static T os;

    // . . .
}
```

If static fields of type parameters were allowed, then the following code would be confused:

```
MobileDevice<Smartphone> phone = new MobileDevice<>();
MobileDevice<Pager> pager = new MobileDevice<>();
MobileDevice<TabletPC> pc = new MobileDevice<>();
```

Because the static field `os` is shared by `phone`, `pager`, and `pc`, what is the actual type of `os`? It cannot be `Smartphone`, `Pager`, and `TabletPC` at the same time. You cannot, therefore, create static fields of type parameters.

Cannot Use Casts or instanceof with Parameterized Types

Because the Java compiler erases all type parameters in generic code, you cannot verify which parameterized type for a generic type is being used at runtime:

```
public static <E> void rtti(List<E> list) {
    if (list instanceof ArrayList<Integer>) {  // compile-time error
        // . . .
    }
}
```

The set of parameterized types passed to the `rtti` method is as follows:

```
S = { ArrayList<Integer>, ArrayList<String> LinkedList<Character>, . . . }
```

The runtime does not keep track of type parameters, so it cannot tell the difference between an `ArrayList<Integer>` and an `ArrayList<String>`. The most you can do is to use an unbounded wildcard to verify that the list is an `ArrayList`:

```
public static void rtti(List<?> list) {
    if (list instanceof ArrayList<?>) {  // OK; instanceof requires a
                                         // reifiable type
        // . . .
    }
}
```

Typically, you cannot cast to a parameterized type unless it is parameterized by unbounded wildcards. Here is an example:

```
List<Integer> li = new ArrayList<>();
List<Number>  ln = (List<Number>) li;  // compile-time error
```

However, in some cases, the compiler knows that a type parameter is always valid and allows the cast. Here's an example:

```
List<String> l1 = . . . ;
ArrayList<String> l2 = (ArrayList<String>)l1;  // OK
```

Cannot Create Arrays of Parameterized Types

You cannot create arrays of parameterized types. For example, the following code does not compile:

```
List<Integer>[] arrayOfLists = new List<Integer>[2];  // compile-time error
```

The following code illustrates what happens when different types are inserted into an array:


```
Object[] strings = new String[2];
strings[0] = "hi";   // OK
strings[1] = 100;    // An ArrayStoreException is thrown.
```

If you try the same thing with a generic list, there would be a problem:

```
Object[] stringLists = new List<String>[];  // compiler error, but pretend
                                            // it's allowed
stringLists[0] = new ArrayList<String>();   // OK
stringLists[1] = new ArrayList<Integer>();  // An ArrayStoreException
                                            // should be thrown,
                                            // but the runtime can't detect it.
```

If arrays of parameterized lists were allowed, the previous code would fail to throw the desired `ArrayStoreException`.

Cannot Create, Catch, or Throw Objects of Parameterized Types

A generic class cannot extend the `Throwable` class directly or indirectly. For example, the following classes will not compile:

```
// Extends Throwable indirectly
class MathException<T> extends Exception { /* . . . */ }    // compile-time error

// Extends Throwable directly
class QueueFullException<T> extends Throwable { /* . . . */ // compile-time error
```

A method cannot catch an instance of a type parameter:

```
public static <T extends Exception, J> void execute(List<J> jobs) {
    try {
        for (J job : jobs)
            // . . .
    } catch (T e) {   // compile-time error
        // . . .
```

```
    }
}
```

You can, however, use a type parameter in a `throws` clause:

```
class Parser<T extends Exception> {
    public void parse(File file) throws T {     // OK
        // . . .
    }
}
```

6

Cannot Overload a Method Where the Formal Parameter Types of Each Overload Erase to the Same Raw Type

A class cannot have two overloaded methods that will have the same signature after type erasure:

```
public class Example {
    public void print(Set<String> strSet) { }
    public void print(Set<Integer> intSet) { }
}
```

The overloads would all share the same `classfile` representation, which will generate a compile-time error.

Questions and Exercises: Generics

Questions

1. Will the following class compile? If not, why?

```
public final class Algorithm {
    public static T max(T x, T y) {
        return x > y ? x : y;
    }
}
```

2. If the compiler erases all type parameters at compile time, why should you use generics?
3. What is the following class converted to after type erasure?

```
public class Pair<K, V> {


    public Pair(K key, V value) {
        this.key = key;
        this.value = value;
    }

    public K getKey(); { return key; }
```

```
        public V getValue(); { return value; }

        public void setKey(K key)     { this.key = key; }
        public void setValue(V value) { this.value = value; }

        private K key;
        private V value;
    }
```

4. What is the following method converted to after type erasure?

```
    public static <T extends Comparable<T>>
        int findFirstGreaterThan(T[] at, T elem) {
        // . . .
    }
```


5. Will the following method compile? If not, why?

```
    public static void print(List<? extends Number> list) {
        for (Number n : list)
            System.out.print(n + " ");
        System.out.println();
    }
```

6. Will the following class compile? If not, why?

```
    public class Singleton<T> {


        public static T getInstance() {
            if (instance == null)
                instance = new Singleton<T>();

            return instance;
        }

        private static T instance = null;
    }
```

7. Review the following classes:

```
    class Shape { /* . . . */ }
    class Circle extends Shape { /* . . . */ }
    class Rectangle extends Shape { /* . . . */ }

    class Node<T> { /* . . . */ }
```

Will the following code compile? If not, why?

```
    Node<Circle> nc = new Node<>();
    Node<Shape>  ns = nc;
```

8. Consider this class:

```
    class Node<T> implements Comparable<T> {
        public int compareTo(T obj) { /* . . . */ }
        // . . .
    }
```

Will the following code compile? If not, why?

```
Node<String> node = new Node<>();
Comparable<String> comp = node;
```

Exercises

1. Write a generic method to count the number of elements in a collection that have a specific property (e.g., odd integers, prime numbers, palindromes).
2. Write a generic method to exchange the positions of two different elements in an array.
3. Write a generic method to find the maximal element in the range `[begin, end]` of a list.

Answers

You can find answers to these questions and exercises at `http://docs.oracle.com/javase/tutorial/java/generics/QandE/generics-answers.html`.

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