Module 3

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Lecture 3 – Generics

Learning Objectives

After successfully completing the module, students will be able to do the following:

1. Use and develop generic methods and generic classes.
2. Use bounded generic types.
3. Examine the benefits of generics.
4. Determine when wildcard generic types are necessary.
5. Analyze generic type erasure.
6. Analyze the limitations of generics.
7. Find out the relationship among interfaces and classes in Java Collections Framework.
8. Differentiate between Collection and Collections.
9. Use the common methods in the Collection interface.
10. Use the common methods in the Collections class.
11. Use the common methods in the Arrays class.
12. Develop applications using ArrayList, LinkedList, Stack, Queue, Set, Map.

Module 3 Study Guide and Deliverables

May 23 – May 29

Topics: Lecture 3 Generics

Readings:

- Generic collections: Deitel & Deitel, Chapter 16
- Generic classes and methods: Deitel & Deitel, Chapter 20
- Module 3 online content

Assignments:

- **Draft Assignment 3** due Sunday, May 28 at 6:00 AM ET (submit at “Assignments” on the left-hand course menu)
- **Assignment 3** due Wednesday, May 31 at 6:00 AM ET (submit at “Assignments” on the left-hand course menu)

Live Classrooms:	• Wednesday, May 24, from 8:00 PM to 9:00 PM ET • Thursday, May 25, from 8:00 PM to 9:00 PM ET • Live Office: Wednesday and Thursday and after Live Classroom, for as long as there are questions • Join the live sessions from "Live Classroom/Offices" on the left-hand course menu

Module Welcome and Introduction

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Generics

Generics make code reuse easier and enable detection of errors at compile time rather than at run time. As we will see shortly, generics eliminate or minimize the use of casts and make code easier to read and modify. This module discusses generic methods, generic classes, and generic collections.

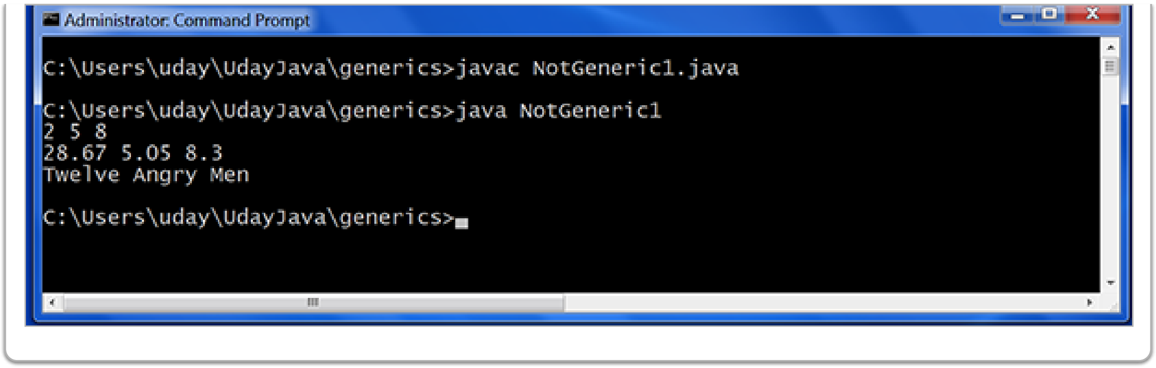
Need for Generic Methods

Consider the following example where the task is to print the elements of each of three different arrays. The arrays are different because they hold items of different types—Integer, Double, and String. Three different methods—showIntarray(), showDoubleArray(), and showStringArray()—are needed to print the arrays, since one method prints elements of only one type.

```
// Not generic

public class NotGeneric1
{
    public static void main(String[] args)
    {
       Integer[] iarr = {2, 5, 8};           // autobox
       Double[] darr = {28.67, 5.05, 8.3};  // autobox
       String[] sarr = {"Twelve", "Angry", "Men"};

       showIntArray(iarr);
       showDoubleArray(darr);
       showStringArray(sarr);
    }

    public static void showIntArray(Integer[] a)
    {
         for (Integer elem: a)
            System.out.print(elem + " ");
         System.out.println();
    }

    public static void showDoubleArray(Double[] a)
    {
         for (Double elem: a)
            System.out.print(elem + " ");
         System.out.println();
    }

    public static void showStringArray(String[] a)
    {
         for (String elem: a)
            System.out.print(elem + " ");
         System.out.println();
    }
}
```

The output of the program is shown below.

Output of the program – non-generic example



Now, it is not difficult to see that the three methods showIntarray(), showDoubleArray(), and showStringArray() are almost identical except for the type of the elements they handle. If the same method could handle different types, the code would be much cleaner (and shorter). This is possible if the method is generic. A generic method can handle arbitrary non-primitive or reference types; it is not confined to a single type.

The following example illustrates the use of a generic method showGeneric() that is capable of printing arrays of arbitrary (reference) types. A generic method is specified by providing the generic type name in angle brackets before the return type in the method's header. Note that the argument to showGeneric is of type T[], or an array of type T, where T stands for type (T is used by convention; we could have used, say, A or X as well).

```
// Generic method

public class Generics1
{
    public static void main(String[] args)
    {
       Integer[] iarr = {2, 5, 8};          // autobox
       Double[] darr = {28.67, 5.05, 8.3}; // autobox
       String[] sarr = {"Twelve", "Angry", "Men"};

       showGeneric(iarr);
       showGeneric(darr);
       showGeneric(sarr);
    }

    public static <T> void showGeneric(T[] a) // generic method
    {
         for (T elem: a)
           System.out.print(elem + " ");
         System.out.println();
    }
}
```

The output of the above program is the same as that of its non-generic counterpart.

Let us repeat that primitive types (e.g., int, double, char) cannot be used as the actual type for a generic type name T. For example, it would be wrong to expect showGeneric(myarr) to work when myarr is an array of int's (or double's or char's). (Note the autoboxing in the above code.)

As another example of a situation where a generic method is useful, consider the problem of finding the maximum of three given elements. The non-generic version (class NotGeneric2 below) has three different methods—intFindMax, doubleFindMax, and stringFindMax—for the three types of elements, whereas a single generic method genericFindMax (in class Generics2) handles all the different types.

```
// Not generic

public class NotGeneric2
{
    public static void main(String[] args)
    {
       int imax = intFindMax(2, 5, 8);
       double dmax = doubleFindMax(28.67, 5.05, 8.3);
       String smax = stringFindMax("good", "bad", "ugly");

       System.out.printf("imax = %d, dmax = %f, smax = %s%n", imax, dmax, smax);
    }

    public static int intFindMax(int a, int b, int c)
    {
       int largest = a > b ? a : b;
       largest = c > largest ? c : largest;
       return largest;
    }

    public static double doubleFindMax(double a, double b, double c)
    {
       double largest = a > b ? a : b;
       largest = c > largest ? c : largest;
       return largest;
    }

    public static String stringFindMax(String a, String b, String c)
    {
       String largest = a.compareTo(b) > 0 ? a : b;
       largest = c.compareTo(largest) > 0 ? c : largest;
       return largest;
    }
}


// Generic method

public class Generics2
{
    public static void main(String[] args)
    {
       int imax = genericFindMax(2, 5, 8);  // autobox, autounbox
       double dmax = genericFindMax(28.67, 5.05, 8.3); // autobox, autounbox
```

```java
        String smax = genericFindMax("good", "bad", "ugly");

        System.out.printf("imax = %d, dmax = %f, smax = %s%n", imax, dmax, smax);
    }


    public static <T extends Comparable<T>> T genericFindMax(T a, T b, T c)
    {
        T largest = a.compareTo(b) > 0 ? a : b;
        largest = c.compareTo(largest) > 0 ? c : largest;
        return largest;
    }
}
```

The generic version of the Comparable interface, Comparable<T>, is used in the above program. Note that the return type of method genericFindMax() is T. Note also the autoboxing and autounboxing that take place at the invocation of genericFindMax() and in storing the method's return object.

Why not use "Object" all through? Let us see what the problem is with the following:

```java
public static void showObject(Object[] a)
{
     for (Object elem: a)
         System.out.println(elem);
}
```

We object to "Object" because Object is too wide (general), and offers no guarantee that type compatibility will be maintained. For instance, a part of a program could put an Integer element in the array while another part could expect a String as an element. The use of generics catches such errors at compile time.

Generic Class

A generic type can be defined for a class. A generic class is a parameterized class. When using the generic class to create objects, we must supply a concrete type.

Consider (non-generic) class Item:

```java
class Item       // non-generic class
{
    private Object object;
    public void set(Object object) { this.object = object; }
    public Object get() { return object; }
}

A better alternative is a generic class:

class GenericItem<T>         // T stands for "Type"
{
    private T t;
```

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

Study the definition and use of the generic class GenericItem<T> in the following example.

```
// Generic class

public class GenericClass1
{
    public static void main(String[] args)
    {
       GenericItem<Integer> myint = new GenericItem<Integer>();
       System.out.printf("myint: %s%n", myint);

       GenericItem<Double> mydouble = new GenericItem<Double>(3.1416);
       System.out.printf("mydouble: %s%n", mydouble);

       GenericItem<String> mystring = new GenericItem<String>("Hello");
       System.out.printf("mystring: %s%n", mystring);

       GenericItem<Alpha> myalpha = new GenericItem<Alpha>(new Alpha(91));
       System.out.printf("myalpha: %s%n", myalpha);
   }
}

class GenericItem<T>
{
    private T t;

    public GenericItem()
    {
      t = null;
    }

    public GenericItem(T t)
    {
      this.t = t;
    }

    public String toString()
    {
      return t == null ?
             "GenericItem<T> has no object" :
             "GenericItem<T> object: " + t.toString();
    }
}

class Alpha
{
   private int id;
```

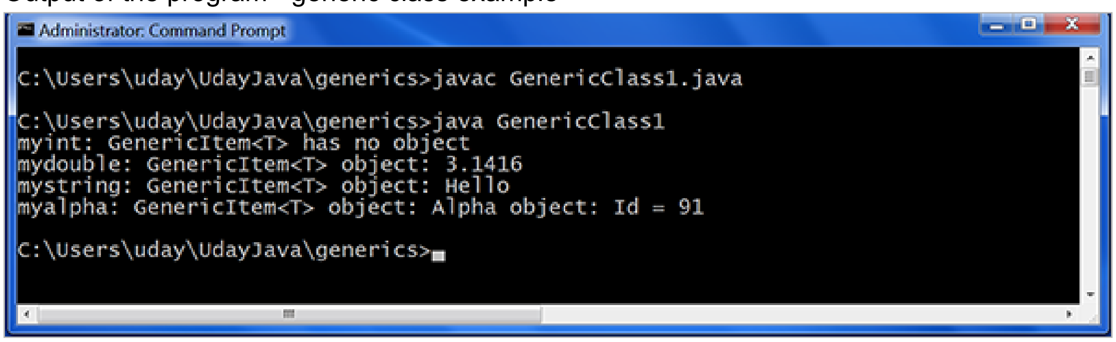
```
        public Alpha(int number)
        {
            id = number;
        }

        public String toString()
        {
            return "Alpha object: Id = " + id;
        }
    }
```

The above example demonstrated that by instantiating the same generic class with the types Integer, Double, String, and Alpha, we obtained four different classes:

- GenericItem<Integer>,
- GenericItem<Double>,
- GenericItem<String>,
- GenericItem<Alpha>.

Note that the constructor of class GenericItem<T> has method name GenericItem, not GenericItem<T>. The output of the program is shown below.

Output of the program - generic class example



To instantiate a parameterized class, the T must be replaced with a reference type, that is:

- a non-primitive type (e.g., Integer)
- a class type (e.g., Alpha where Alpha is a user-defined class)
- an interface (e.g., Comparable or Comparable<String> or a user-defined interface)
- an array type (e.g., double[] or Double[])

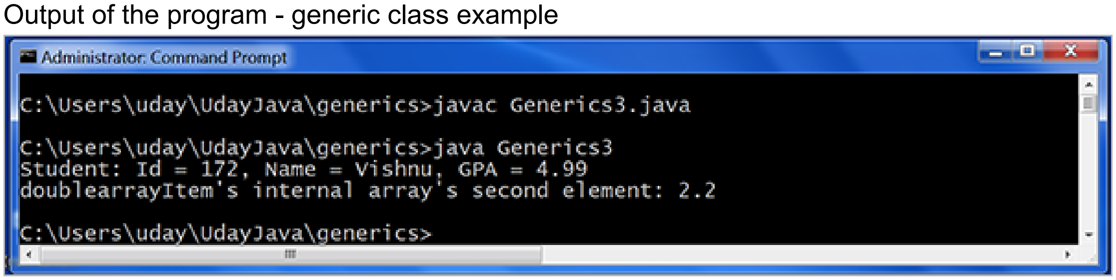
A further example of generic class instantiation is given below. Note how Double[] is used as the type, defining GenericItem<Double[]>.

```
    // Generic class

    public class Generics3
    {
        public static void main(String[] args)
```

```
    {
       GenericItem<Student> stu = new GenericItem<Student>();
       stu.set(new Student(172, "Vishnu", 4.99));
       System.out.printf("Student: %s%n", stu.get());

       GenericItem<Double[]> doublearrayItem = new GenericItem<Double[]>();
       Double Darr[] = {1.1, 2.2, 3.3};
       doublearrayItem.set(Darr);
       System.out.println("doublearrayItem's internal array's second element: " +
                    (doublearrayItem.get())[1]);
    }
}

class GenericItem<T>          // T stands for "Type"
{
    private T t;
    public void set(T t) { this.t = t; }
    public T get() { return t; }
}

class Student
{
   private int id;
   private String name;
   private double gpa;

   public Student(int serialno, String nm, double grade)
   {
      id = serialno;
      name = nm;
      gpa = grade;
   }

   public String toString()
   {
      return "Id = " + id + ", Name = " + name + ", GPA = " + gpa;
   }
}
```

The program’s output is shown below.

Output of the program - generic class example



Generics eliminate or minimize the use of casts. Consider the following piece of code:

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

When re-written to use generics, the code does not require casting:

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

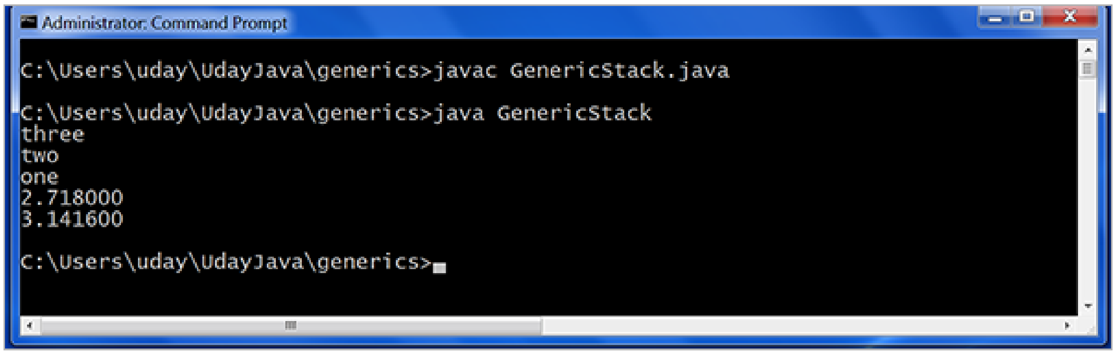
An extremely useful generic class is a generic stack. The following example demonstrates how a generic stack can be defined and used. (Java already provides a generic Stack<T> class; we show the following example only for pedagogical purposes.) In particular, note the use of GenStack<GenericItem<Double>>.

```
// Generic stack

import java.util.*;

public class GenericStack
{
    public static void main(String[] args)
    {
          GenStack<String> s2 = new GenStack<String>();
          s2.push("one");
          s2.push("two");
          s2.push("three");
          while (!s2.isEmpty()) System.out.printf("%s%n", s2.pop());

          GenericItem<Double> g1 = new GenericItem<Double>();
          g1.set(3.1416);

          GenericItem<Double> g2 = new GenericItem<Double>();
          g2.set(2.718);

          GenStack<GenericItem<Double>> s3 = new GenStack<GenericItem<Double>>();
          s3.push(g1);
          s3.push(g2);
          while (!s3.isEmpty()) System.out.printf("%f%n", s3.pop().get());
    }
}

class GenStack<T>
{
   private ArrayList<T> a;

   public GenStack() {  a = new ArrayList<T>();   }
   public void push(T t) {  a.add(t);   }
   public T pop() { return isEmpty() ? null : a.remove(a.size() - 1);   }
```

```
    public boolean isEmpty() { return a.size() == 0; }
}

class GenericItem<T>
{
    private T t;
    public void set(T t) { this.t = t; }
    public T get() { return t; }
}
```

The output is shown below:

Output of the program – generic stack example



Bounded Generic Type

Consider the following program, which is reduced to the bare outlines in order to focus on an important idea.

```
// Bounded type - wrong - doesn't compile

public class BoundedTypeWrong
{
    public static void main(String[] args)
    {
        GenericItem<Student> stu = new GenericItem<Student>();

        GenericItem<GradStudent> grad = new GenericItem<GradStudent>();

        processItem(stu);
        processItem(grad);
    }

    public static void processItem(GenericItem<Student> item)
    {

    }
}
```

```
class GenericItem<T>
{
}

class Student
{
}

class GradStudent extends Student
{
}
```

The above program is wrong; it doesn’t compile, let alone run. The problem with this program is that the statement

```
processItem(grad);
```

is erroneous. Even though GradStudent is a subtype of Student, GenericItem<GradStudent> is *not* a subtype of GenericItem<Student>. That is, the object grad is not an instance of GenericItem<Student>.

The solution to the above problem is to use what is known as a "bounded generic type," or a generic type that can be specified as a subtype of another type. We illustrate this concept of bounded type in the following (correct) program which is a modification to the wrong program.

```
// Bounded type

public class BoundedTypeCorrect
{
    public static void main(String[] args)
    {
       GenericItem<Student> stu = new GenericItem<Student>();

       GenericItem<GradStudent> grad = new GenericItem<GradStudent>();

       processItem(stu);
       processItem(grad);
    }

    public static <E extends Student> void processItem(GenericItem<E> item)
    {

    }
}


class GenericItem<T>
{
}

class Student
{
```

```
}

class GradStudent extends Student
{
}
```

In the above code, <E extends Student> represents any subtype of Student (including, of course, the Student type itself). This makes GenericItem<GradStudent> a valid type for use as the argument in method processItem, and therefore the statement

```
processItem(grad);
```

is now okay. <E extends Student> is an example of a bounded generic type. Note that the generic type <E> is equivalent to <E extends Object>.

Wildcard Generic Types

Wildcard generic types, indicated with a question mark (?), are often useful. Three types of wildcard generic types exist:

1. Upper-bounded wild card: **Class<? extends T>**

   <? extends T> is a wildcard type that represents T or its subtypes.

2. Lower-bounded wild card: **Class<? super T>**

   <? super T> is a wildcard type that represents T or its supertypes.

3. Unbounded wild card: **Class<?>**

   <?> is the same as <? extends Object>, a wildcard type that represents any type.

Study the following example. You should be able to realize that this program will not work because of the type-subtype issue discussed earlier.

```
// Wrong program
// Upper-bounded wildcard

import java.util.*;

public class WildcardWrong
{
    public static void main(String[] args)
    {
          GenStack<Integer> s = new GenStack<Integer>();
          s.push(2);
          s.push(7);
          System.out.println(maxInStack(s)); // wrong

    }

    public static double maxInStack(GenStack<Number> inputStack)
```

```
    {
        double max = inputStack.pop().doubleValue();
        while (!inputStack.isEmpty())
        {
            double value = inputStack.pop().doubleValue();
            max = value > max ? value : max;
        }
        return max;
    }
}

class GenStack<T>
{
   private ArrayList<T> a;

   public GenStack() {  a = new ArrayList<T>();   }
   public void push(T t) {  a.add(t);   }
   public T pop() { return isEmpty() ? null : a.remove(a.size() - 1);   }
   public boolean isEmpty() { return a.size() == 0; }
}
```

Note the following issues with types in generics in the above program:

- Integer is a subtype of Number, but Stack<Integer> is not a subtype of Stack<Number>
- Stack<Integer> can be used where Stack<? extends Number> is expected

A correct version of the same task follows.

```
// Upper-bounded wildcard: correct version

import java.util.*;

public class WildcardCorrect
{
    public static void main(String[] args)
    {
          GenStack<Integer> s = new GenStack<Integer>();
          s.push(2);
          s.push(7);
          s.push(5);
          System.out.println(maxInStack(s));

    }

    public static double maxInStack(GenStack<? extends Number> inputStack)
    {
        double max = inputStack.pop().doubleValue();
        while (!inputStack.isEmpty())
        {      double value = inputStack.pop().doubleValue();
               max = value > max ? value : max;
        }
```

```
        return max;
    }
}


class GenStack<T>
{
   private ArrayList<T> a;

   public GenStack() {  a = new ArrayList<T>();   }
   public void push(T t) {  a.add(t);  }
   public T pop() { return isEmpty() ? null : a.remove(a.size() - 1);  }
   public boolean isEmpty() { return a.size() == 0; }
}
```

An alternative version of the above program is given below.

```
// Upper-bounded wildcard: alternative version

import java.util.*;

public class WildcardCorrect2
{
    public static void main(String[] args)
    {
          GenStack<Integer> s = new GenStack<Integer>();
          s.push(2);
          s.push(7);
          s.push(5);
          System.out.println(maxInStack(s));

    }

    public static <E extends Number> double maxInStack(GenStack<E> inputStack)
    {
         double max = inputStack.pop().doubleValue();
         while (!inputStack.isEmpty())
         {      double value = inputStack.pop().doubleValue();
                max = value > max ? value : max;
         }
         return max;
    }
}

class GenStack<T>
{
   private ArrayList<T> a;

   public GenStack() {  a = new ArrayList<T>();   }
   public void push(T t) {  a.add(t);  }
   public T pop() { return isEmpty() ? null : a.remove(a.size() - 1);  }
```

```java
    public boolean isEmpty() { return a.size() == 0; }
}
```

To see the advantage of the style

```java
public static <E extends  Number> double maxInStack(GenStack<E> inputStack)
```

over the one with a ? in the header,

```java
public static double maxInStack(GenStack<? extends Number> inputStack)
```

consider the following example where instead of a stack an arraylist is used.

```java
// Upper-bounded wildcard
import java.util.*;

public class WildcardCorrect3
{
    public static void main(String[] args)
    {
         ArrayList<Integer> arr = new ArrayList<Integer>();
         arr.add(2);
         arr.add(7);
         arr.add(5);
         System.out.println(maxInArrayList(arr));

    }

    public static <E extends Number> double maxInArrayList(ArrayList<E> inputlist)
    {
         double max = inputlist.get(0).doubleValue();
         for (E elem: inputlist)
         {       double val = elem.doubleValue();
                 max = val > max ? val : max;
         }
         return max;
    }
}
```

The advantage of the above style is that the generic type E can be used in the body of the method, as in the statement

```java
for (E elem: inputlist)
```

Note that "? elem: inputlist" is invalid.

Unbounded Wildcard

The following program demonstrates the effect of misusing an unbounded wildcard.

```java
// Unbounded wildcard

import java.util.*;
```

```
public class UnboundedWildcard
{
    public static void printListObject(ArrayList<Object> list)
    {
        for (Object elem : list)
             System.out.println(elem);
    }

    public static void printListWild(ArrayList<?> list)
    {
        for (Object elem: list)
             System.out.println(elem);
    }

    public static void main(String[] args)
    {
        ArrayList<Integer> intlist = new ArrayList<Integer>();
        intlist.add(1); intlist.add(2); intlist.add(3);

        printListWild(intlist); // ok
        printListObject(intlist); // error
    }
}
```

This program doesn’t compile because ArrayList<Integer> is not a subtype of ArrayList<Object>. However, ArrayList<Integer> can be used where ArrayList<?> is expected.

Let us reiterate the salient points:

- <?> is a wildcard that represents any object type.
- ArrayList<?> is equivalent to ArrayList<? extends Object>
- ArrayList<?> is NOT the same as ArrayList<Object>
- printListObject(ArrayList<Object>) cannot print ArrayList<Integer>, ArrayList<String>, ArrayList<Double>, because they are not subtypes of ArrayList<Object>.

Lowerbounded Wildcard

Study the following example. The code works fine, because <? super Integer> means Integer or its supertype.

```
// Lower-bounded wildcard

import java.util.*;

public class LowerboundedWildcard
{
    public static void addNumbers(ArrayList<? super Integer> list)
                              // Integer or its supertype
    {
         for (int i = 1; i <= 10; i++)
```

```
            list.add(i);
    }

    public static void main(String[] args)
    {
        ArrayList<Integer> ai = new ArrayList<Integer>();
        ArrayList<Number> an = new ArrayList<Number>();

        addNumbers(ai);
        addNumbers(an);
    }
}
```

Type Erasure

While the use of generics is good for compile-time detection of errors, it is important to understand that generic information is not available after compilation. This ensures backward compatibility with legacy code that uses raw types.

Example #1

Code with generics:

```
ArrayList<String> list = new ArrayList<String>();
list.add("Boston");
String city = list.get(0);
```

Equivalent raw code after compilation:

```
ArrayList list = new ArrayList();
list.add("Boston");
String city = (String) list.get(0);
```

Example #2

```
public static <E> void print(E[] list)
{
   for (E elem: list)
       System.out.println(elem);
}
```

Equivalent raw code after compilation:

```
public static void print(Object[] list)
{
    for (Object elem: list)
```

```
        System.out.println(elem);
}
```

Example #3

```
public static <E extends Stu> boolean  checkStudents(E s1, E s2)
{
     return s1.getScore() == s2.getScore();
}
```

Equivalent code after type erasure:

```
public static boolean checkStudents(Stu s1, Stu s2)
{
     return  s1.getScore() == s2.getScore();
}
```

Limitations of Generics

Some important limitations:

- No instanceof generic-type
- No new E()
- No new E[]
- No static field of generic type of the same class
- No static method of generic type of the same class

Example #1

A generic class is shared by all its instances regardless of their actual concrete types.

Given

```
ArrayList<String> list1 = new ArrayList<String>();
ArrayList<String> list2 = new ArrayList<String>();
list1 instanceof  ArrayList      is true,
list2 instanceof  ArrayList      is true,  but

list1 instanceof  ArrayList<String>
```

does not compile. At run-time, there is no ArrayList<String> class.

Example #2

- E object = new E(); is wrong because new E() is executed at run-time

- E[] myarray = new E[10]; is wrong

Example #3

A generic type not allowed in a static field of a generic class because there is only one memory location of static field for class Alpha:

```
class Alpha<E>
{
    private E field;
    private static E staticField;   // wrong

    private static int count = 0;  //ok
}
```

In the above class, the (non-generic) static field count is OK, but Alpha<String>, Alpha<Double>, etc. all use the same count.

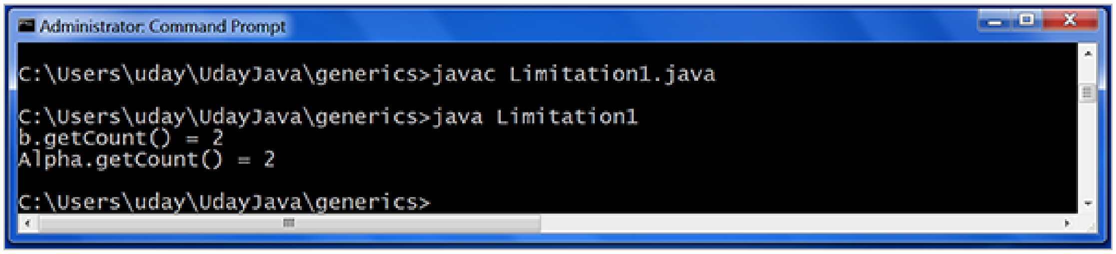
Example #4

Observe what happens to the (non-generic) static field count of class Alpha<E> in the program below:

```
// Limitations of generics

public class Limitation1
{
  public static void main(String[] args)
  {
     String s = "hi";
     Alpha<String> a = new Alpha<String>(s);
     Alpha<Number> b = new Alpha<Number>(172);
     System.out.println("b.getCount() = " + b.getCount());            // count is 2
     System.out.println("Alpha.getCount() = " + Alpha.getCount());    // count is 2
   }
}


class Alpha<E>
{
   private E field;
   private static int count = 0; // Only one memory location of static field
                                 // for class Alpha

   public Alpha(E e)
   {
      field = e;
      count++;
   }
```

```
    public static int getCount() {return count;}
}
```

Output of the program - limitations of generics example



Example #5

For further illustration of the issue of static fields and methods in a generic context, study the following example carefully; the comments in the code explain the issue.

```
// Limitations of generics

public class Limitation2
{
   public static void main(String[] args)
   {
       Alpha<String> a = new Alpha<String>();
   }
}

class Alpha<E>
{
     public static void illegalStaticMethod (E e)
     // Illegal; static method cannot involve generic type E
     {
         E obj = null; // Illegal; no generic type in a static context
     }

     public static <T> void  okStaticMethod1(T t)
     // OK;   this method is generic on type T but NOT generic on type E
     {
         T obj = t;
         System.out.printf("%s\n", obj.toString());
     }

     public static <E> void  okStaticMethod2 (E t)
     // OK; this method is NOT generic on the same type on which class Alpha is generic;
     // The E here and the E in Alpha<E> are different
     {
          E obj = t;
```

```
            System.out.printf("%s\n", obj.toString());
        }
    }
```

Generic Collections

The "Java Collections Framework" includes two types of containers:

- Collection objects (e.g., lists, stacks, queues, sets), created from the **Collection** interface,
- Map objects (for storing key-value pairs), created from the **Map** interface

This module discusses the following types of objects from the Java Collections Framework:

- ArrayList
- LinkedList
- Vector
- Stack
- Queue
- Set
- Map

The Collection interface is the root (main) interface for operations on a collection of objects.

The **Collections** class (note the plural; this is not to be confused with the Collection – singular - interface) and the **Arrays** class (note the plural again) provide useful static methods for working with collection objects.

The collections discussed in this module are all generic.

ArrayList

Two classes, ArrayList and LinkedList, are used for creating lists or sequential collections of elements of the same (reference) type. The List interface extends the Collection interface, and both ArrayList and LinkedList implement the List interface. We repeat that ArrayList<E> and LinkedList<E> are classes, while List<E> is an interface.

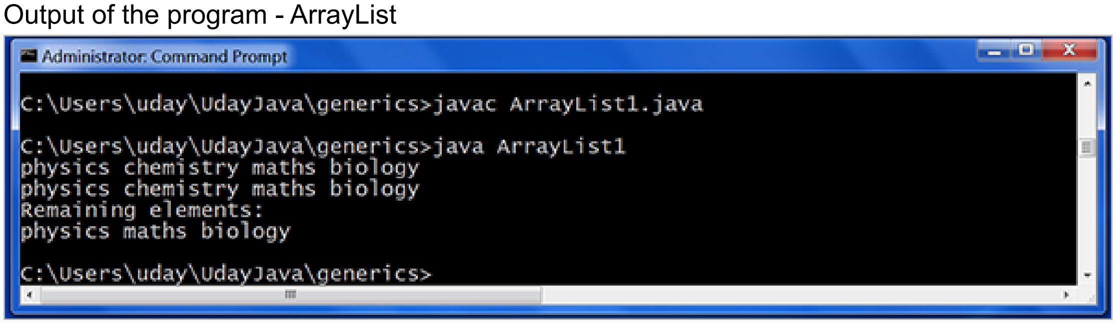
An ArrayList stores elements in an array; the array grows in size dynamically. A LinkedList stores elements in a linked list of a dynamically changing size.

The following example demonstrates several important methods: add() for inserting an element, get() to retrieve the element at the given index, size() for retrieving the current size of the ArrayList.

```
// ArrayList

import java.util.*;

public class ArrayList1
```

```
{
    public static void main(String[] args)
    {
          String[] subjects = {"physics", "chemistry", "maths", "biology"};

          List<String> a = new ArrayList<String>();
          for (String sub: subjects)
               a.add(sub);

          for (String elem: a)
               System.out.print(elem + " ");
          System.out.println();

          for (int i = 0; i < a.size(); i++)
               System.out.print(a.get(i) + " ");
          System.out.println();

          Iterator<String> iter = a.iterator();
          while (iter.hasNext())
              if (iter.next().length() > 7)
                  iter.remove();

          System.out.println("Remaining elements: ");
          for (String elem: a)
               System.out.print(elem + " ");
          System.out.println();
    }
}
```

Output of the program - ArrayList



The above code illustrates two different ways of printing the elements of the ArrayList: using a traditional for loop with explicit indexing of the elements, and using the enhanced-for (for-each) loop (with no explicit indexing).

The above example also demonstrates the use of an Iterator. An Iterator object is used to traverse the elements of a collection. Iterable is an interface that defines a method called iterator() that returns an Iterator object. Each collection is Iterable. For instance, in the above code, a.iterator() returns an Iterator object of type Iterator<String>.

Iterator's boolean method hasNext() returns true if there's at least one more element to be examined, false otherwise. The next() method returns the next element in the iteration; if no elements remain, the method throws NoSuchElementException. The remove() method deletes from the collection the last element that was returned by next().

Corresponding to a given call to next(), there can be exactly one remove() call; a second remove() corresponding to the same next() is an error.

Removing Elements from an ArrayList

The following program is an attempt to selectively remove some elements from an ArrayList. It does not work. Why?

```
// Remove elements from ArrayList - program doesn't work

import java.util.*;

public class ArrayList2
{
    public static void main(String[] args)
    {

       List<Integer> a = new ArrayList<Integer>();

       a.add(-2); //autobox
       a.add(-5);
       a.add(-7);
       a.add(-3);
       a.add(2);

       for (int i = 0; i < a.size(); i++)
           if (a.get(i) < 0) // auto-unbox
               a.remove(i);

       for (Integer elem: a)
             System.out.print(elem + " ");
       System.out.println();
    }
}
```

The output of this program is:

```
-5, -3, 2
```

even though the negative numbers were supposed to be removed from the ArralyList.

The reason is that the index i varies from 0 to 4 (note that the call to a.size() returns 5), but after each removal takes place, the array size goes down by 1. A fix is provided by the following version, where the looping starts from the end of the list:

```
// Remove elements from ArrayList - correct version

import java.util.*;

public class ArrayList3
{
    public static void main(String[] args)
```

```
    {
        List<Integer> a = new ArrayList<Integer>();

        a.add(-2); //autobox
        a.add(-5);
        a.add(-7);
        a.add(-3);
        a.add(2);

        for (int i = a.size() - 1; i >= 0; i--)
            if (a.get(i) < 0) // auto-unbox
                a.remove(i);

        for (Integer elem: a)
            System.out.print(elem + " ");
        System.out.println();
    }
}
```

The output of the above program is 2, as expected. In this context, keep in mind that a for-each (enhanced-for) loop cannot be used to remove elements from a list; for that purpose, we have to use an iterator.

LinkedList

While ArrayList is a resizable-array implementation of the List interface, LinkedList provides a linked list implementation. An ArrayList or LinkedList can have a no-argument constructor and can also be constructed from an existing collection object. For the constructors and other methods, see the documentation: Class ArrayList<E> and Class LinkedList<E>.

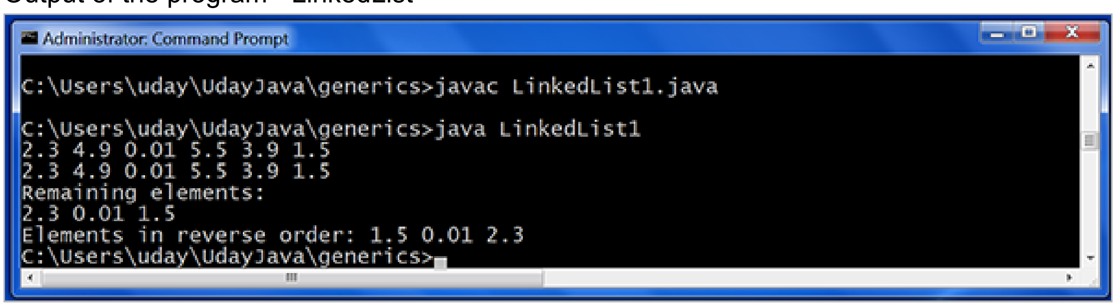
The following example illustrates a LinkedList<Double> object and also a ListIterator. The listIterator() or listIterator(startIndex) method returns an instance of ListIterator. The ListIterator interface extends the Iterator interface and adds bidirectional traversal of the list.

```
// LinkedList: ListIterator

import java.util.*;

public class LinkedList1
{
    public static void main(String[] args)
    {
        Double[] numbers = {2.3, 4.9, 0.01, 5.5, 3.9, 1.5};

        List<Double> a = new LinkedList<Double>();
        for (Double num: numbers)
             a.add(num);

        for (Double elem: a)
             System.out.print(elem + " ");
```

```
            System.out.println();

            for (int i = 0; i < a.size(); i++)
                 System.out.print(a.get(i) + " ");
            System.out.println();

            Iterator<Double> iter = a.iterator(); // forward only
            while (iter.hasNext())
                if (iter.next() > 3.0)
                    iter.remove();

            System.out.println("Remaining elements: ");
            for (Double elem: a)
                 System.out.print(elem + " ");
            System.out.println();

            System.out.print("Elements in reverse order: ");
            ListIterator<Double> it = a.listIterator(a.size()); // bi-directional
            while (it.hasPrevious())
                  System.out.print(it.previous() + " ");
      }
  }
```

In the above example, the ListIterator<Double> object named "it" is made to start at the end of the list; the hasPrevious() and previous() methods are counterparts to the hasNext() and next() methods discussed earlier. The output of the program is shown below.

Output of the program - LinkedList



Collections Class and Arrays Class

Two classes—Collections and Arrays—are full of extremely useful static methods that take collection objects as arguments, performing common operations on the arguments. We illustrate the following methods in the example below:

- sort
- binary search
- (random) shuffle
- reverse
- max3

- min

The default order of sorting is ascending. Binary search returns the index of the matching entry, if one exists; when the search fails, a negative integer, corresponding to the negative of (1 + insertion place) is returned.

The toArray() method (non-static) of the List interface works on a list and delivers an array of Objects containing all the elements. The asList() method of class Arrays takes an array (of non-primitive elements) and delivers a list made up of the elements of the array. See the screenshot of the output. Read the documentation of Class Collections and Class Arrays for further details.

```
// Static methods of Collections class

import java.util.*;

public class CollectionsStaticMethods
{
    public static void main(String[] args)
    {
          Double[] numbers = {2.3, 4.9, 0.01, 5.5, 3.9, 1.5};

          List<Double> a = new LinkedList<Double>();
          for (Double num: numbers)
                  a.add(num);

          Collections.sort(a);
          System.out.println(a);

          List<Double> b = new ArrayList<Double>(a); // constructor taking a list
          Collections.sort(b, Collections.reverseOrder());
          System.out.println(b);

          Integer[] arr = {2, 8, 4, 9, 1, 3, 5, 7, 6};
          List<Integer> c = Arrays.asList(arr);
          Collections.sort(c);
          System.out.println(c);

          System.out.printf("Binary search index: %d%n", Collections.binarySearch(c, 5));
          System.out.printf("Binary search index: %d%n", Collections.binarySearch(c, 12));

          Collections.shuffle(c);
          System.out.println(c);

          System.out.printf("Max: %d%n", Collections.max(c));
          System.out.printf("Max: %d%n", Collections.min(c));

          List<String> d = Arrays.asList("For", "Whom", "The", "Bell", "Tolls");
          Collections.reverse(d);
          System.out.println(d);

          String[] strarray = (String[]) (d.toArray());
```

```
            for (String elem: strarray)
                System.out.print(elem + " ");
        }
    }
```

Output of the program - static methods of Collections class

```
Administrator: Command Prompt
C:\Users\uday\UdayJava\generics>javac CollectionsStaticMethods.java

C:\Users\uday\UdayJava\generics>java CollectionsStaticMethods
[0.01, 1.5, 2.3, 3.9, 4.9, 5.5]
[5.5, 4.9, 3.9, 2.3, 1.5, 0.01]
[1, 2, 3, 4, 5, 6, 7, 8, 9]
Binary search index: 4
Binary search index: -10
[1, 6, 8, 7, 3, 5, 9, 4, 2]
Max: 9
Max: 1
[Tolls, Bell, The, Whom, For]
Tolls Bell The Whom For
C:\Users\uday\UdayJava\generics>
```

Vector and Stack

In the Java API, Vector is a subclass of AbstractList, and Stack is a subclass of Vector. Vector<E> is almost the same as ArrayList<E> but contains synchronized methods for thread-safe concurrent tasks. (Multithreading is discussed in Module 6.) Read the documentation of Vector for more details.

Java's Stack class is almost identical to the GenStack<T> class we developed earlier in this module. The Stack<E> class supports the following methods:

- Constructor Stack()
- Boolean empty(): tests if the stack is empty
- E peek(): looks at the top-of-the-stack element (but doesn't remove it)
- E pop((): removes and returns the top-of-the-stack element
- E push(E): pushes an item on the top of the stack
- int search(Object): returns the position of the given object in the stack

For more details, read the documentation of Stack.

Queue

A queue is a first-in-first-out data structure. Java provides the Queue<E> interface; LinkedList<E> is one of the implementing classes. The offer() method is used to add an item to the queue; the remove() method removes an item. See the following example; the code is self-explanatory. The LinkedList class is a good choice for implementing a queue because a linked list is an efficient data structure for inserting and removing elements from both ends of the list.

```
// Queue
```

```
import java.util.*;
public class Queue1
{
    public static void main(String[] args)
    {
       Queue<String> q = new LinkedList<String>();

       q.offer("All");
       q.offer("art");
       q.offer("is");
       q.offer("quite");
       q.offer("useless.");

       while (q.size() > 0)
       System.out.print(q.remove() + " ");
    }
}
```

The output of the program is the following line:

```
All art is quite useless.
```

For further details, see the documentation of Queue.

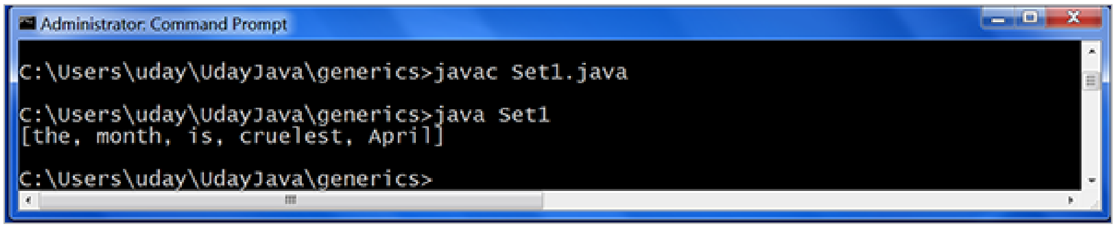
Set

A set is an unordered collection of unique (non-duplicate) elements. Java provides the Set interface and three concrete classes: HashSet, LinkedHashSet, and TreeSet. The following program illustrates the HashSet class.

```
// Set

import java.util.*;
public class Set1
{
    public static void main(String[] args)
    {
       Set<String> myset = new HashSet<String>();

       myset.add("April");
       myset.add("is");
       myset.add("the");
       myset.add("cruelest");
       myset.add("month");
       myset.add("the");

       System.out.println(myset);
    }
}
```

The output of the program is shown below.

Output of the program - Set



Note that the string "the" was added twice, but the set does not contain duplicate items. As shown in the output, the strings are not stored in the order in which they are inserted into the set. No particular order exists for items in a HashSet. If we want to impose an order, we have to use the LinkedHashSet class. For further details, see the documentation of Set.

Map

A map is a container that holds key-value pairs. The keys serve as indexes and must be distinct (a map cannot have duplicate keys). Java provides the Map<K, V> interface and three concrete classes to create a map:

- HashMap
- LinkedHashMap
- TreeMap

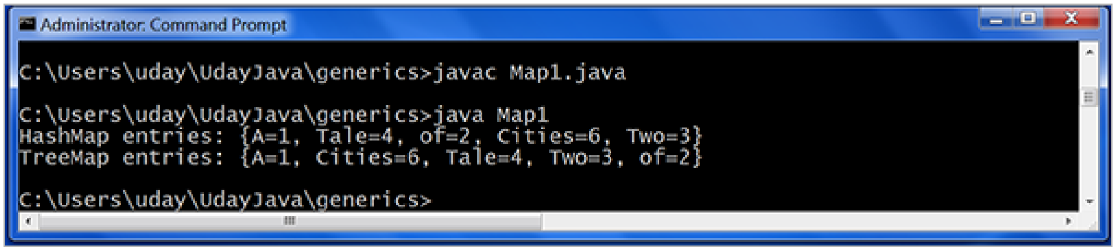
Note that the Map<K, V> interface is **not** a sub-interface of Collection<E>; the Map hierarchy is independent of the Collection hierarchy. (Note, however, that Set is included in Collection.) The Java Collections Framework includes both Collection and Map. See https://docs.oracle.com/javase/8/docs/api/java/util/Map.html.

The following program demonstrates the creation of a HashMap and the subsequent creation of a TreeMap from the existing HasMap. Observe in the accompanying screenshot that TreeMap holds the keys in sorted order but HasMap stores the entries in random order.

```
// Map

import java.util.*;

public class Map1
{
    public static void main(String[] args)
    {
       Map<String, Integer> hmap = new HashMap<>();
       hmap.put("A", 1);
       hmap.put("Tale", 4);
       hmap.put("of", 2);
       hmap.put("Two", 3);
       hmap.put("Cities", 6);

       System.out.println("HashMap entries: " + hmap);

       Map<String, Integer> tmap = new TreeMap<>(hmap);
```

```
        System.out.println("TreeMap entries: " + tmap);
    }
}
```

Output of the program - Map method example 1

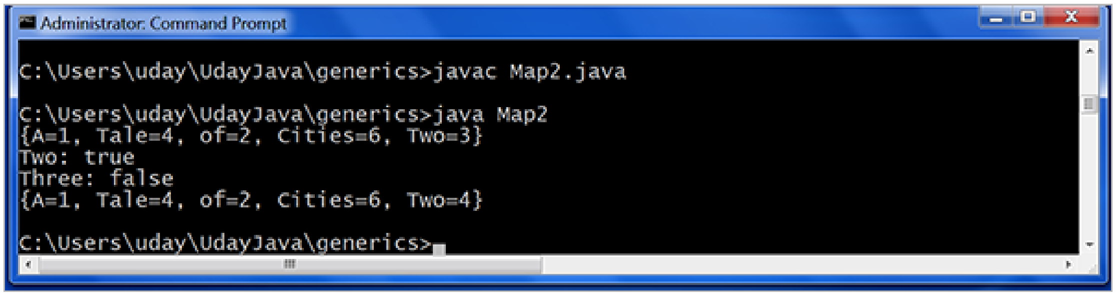


The next program illustrates the following Map methods:

- get
- put
- containsKey

```
import java.util.*;

public class Map2
{
    public static void main(String[] args)
    {
        Map<String, Integer> hmap = new HashMap<>();
        hmap.put("A", 1);
        hmap.put("Tale", 4);
        hmap.put("of", 2);
        hmap.put("Two", 3);
        hmap.put("Cities", 6);

        System.out.println(hmap);
        System.out.println("Two: " + hmap.containsKey("Two"));
        System.out.println("Three: " + hmap.containsKey("Three"));

        int val = hmap.get("Two");
        val++;
        hmap.put("Two", val);
        System.out.println(hmap);

    }
}
```

Output of the program - Map method example 2



Module 3 Practice Questions

The following are some review questions for you to practice. Please read each question, think carefully, figure out your own answer first, and then click "Show Answer" to compare yours to the suggested answer.

Test Yourself 3.1

What, if any, is wrong in the following?

```
// Assume Book is a user-defined class,
// and mylist is an ArrayList<Book> object.
Iterator<Book> myiter = mylist.iterator();
Book thisBook = myiter.next();
myiter.remove();
myiter.remove();
```

Suggested answer: Every remove() must be preceded by a next(). The above code will throw an exception. (Can you find out the type of the exception?)

Test Yourself 3.2

True or false? A collection object cannot store elements of primitive types.

True.

This is true.

False.

This is false.

Test Yourself 3.3

True or false? A LinkedList cannot contain duplicates.

True.

This option is not correct. A LinkedList can contain duplicates.

False.

This option is right. A LinkedList can contain duplicates.

Test Yourself 3.4

True or false? A Map<Key, Value> object can contain duplicate values as long as the keys are distinct.

True.

This is true.

False.

This is false.

Test Yourself 3.5

What is the output of this program?

```
import java.util.*;
public class ArraysClass
{
    public static void main(String[] args)
    {
        Arrays myarr = new Arrays();
        System.out.println(myarr);
    }
}
```

Suggested answer: It will not compile; a user program cannot construct an Arrays object.

Test Yourself 3.6

If a method expects an argument of type NewStack<? super Number>, then is it correct to invoke the method with an object of type Newstack<Double> ?

Suggested answer: No. Number is not a subtype of Double.

References

- Oracle. *The Java™ Tutorials: Generics (Updated)*. Retrieved from https://docs.oracle.com/javase/tutorial/java/generics/index.html.