



Chapter 13:

Generics

Yepang LIU (刘烨庞)

liuypl@sustech.edu.cn



Objectives

- ▶ Motivation of generic methods (泛型方法)
- ▶ Declare and use generic methods
- ▶ Declare and use generic classes (泛型类)

Recall Method Overloading

- ▶ A language feature that allows a class to have multiple methods with the same name, but different parameter lists.

```
public static void printArray(Integer[] array) {  
    for (Integer element : array) System.out.printf("%s ", element);  
    System.out.println();  
}
```

```
public static void printArray(Double[] array) {  
    for (Double element : array) System.out.printf("%s ", element);  
    System.out.println();  
}
```

```
public static void printArray(Character[] array) {  
    for (Character element : array) System.out.printf("%s ", element);  
    System.out.println();  
}
```



Using overloaded methods

```
public static void main(String[] args) {  
    Integer[] integerArray = { 1, 2, 3, 4, 5, 6 }; // autoboxing  
    Double[] doubleArray = { 1.1, 2.2, 3.3, 4.4, 5.5 }; // autoboxing  
    Character[] characterArray = { 'H', 'E', 'L', 'L', 'O' }; // autoboxing  
    System.out.print("integerArray contains: ");  
    printArray(integerArray);  
    System.out.print("doubleArray contains: ");  
    printArray(doubleArray);  
    System.out.print("characterArray contains: ");  
    printArray(characterArray);  
}
```

Compiler will find the
appropriate method

```
integerArray contains: 1 2 3 4 5 6  
doubleArray contains: 1.1 2.2 3.3 4.4 5.5  
characterArray contains: H E L L O
```

Looks good, but wait...

```
public static void printArray(Integer[] array) {  
    for (Integer element : array) System.out.printf("%s ", element);  
    System.out.println();  
}
```

```
public static void printArray(Double[] array) {  
    for (Double element : array) System.out.printf("%s ", element);  
    System.out.println();  
}
```

```
public static void printArray(Character[] array) {  
    for (Character element : array) System.out.printf("%s ", element);  
    System.out.println();  
}
```

These methods are identical except the data type part (in red). If the input is `Long[]` or `String[]`, shall we continue the overloading?



A better design with generics

- ▶ If the operations performed by several overloaded methods are identical for each argument type, the overloaded methods can be more compactly coded using a generic method.

```
public static <T> void printArray(T[] array) {  
    for (T element : array) System.out.printf("%s ", element);  
    System.out.println();  
}
```

Type-parameter section: one or more type parameters (类型参数) delimited by <>

Each type parameter parameterizes the data types that can be used in the method (in the above example, T can be used anywhere a data type name is expected)

Declaring generic methods

- ▶ Generic methods can be declared like any other normal methods.
- ▶ **Type parameters can represent only reference types** (not primitive types)

```
public static void printArray(Double[] array) {  
    for (Double element : array) System.out.printf("%s ", element);  
    System.out.println();  
}
```



No difference except the data type is parameterized

```
public static <T> void printArray(T[] array) {  
    for (T element : array) System.out.printf("%s ", element);  
    System.out.println();  
}
```



Using generic methods

```
public static void main(String[] args) {  
    Integer[] integerArray = { 1, 2, 3, 4, 5, 6 };  
    Double[] doubleArray = { 1.1, 2.2, 3.3, 4.4, 5.5 };  
    Character[] characterArray = { 'H', 'E', 'L', 'L', 'O' };  
    System.out.print("integerArray contains: ");  
    printArray(integerArray);  
    System.out.print("doubleArray contains: ");  
    printArray(doubleArray);  
    System.out.print("characterArray contains: ");  
    printArray(characterArray);  
}
```

Results are the same as before.
But we only declare one
printArray method!

```
integerArray contains: 1 2 3 4 5 6  
doubleArray contains: 1.1 2.2 3.3 4.4 5.5  
characterArray contains: H E L L O
```


How does compiler work here?

```
public class GenericMethodExample {  
    public static void main(String[] args) {  
        Integer[] integerArray = ...;  
        Double[] doubleArray = ...;  
        Character[] characterArray = ...;  
        printArray(integerArray);  
        printArray(doubleArray);  
        printArray(characterArray);  
    }  
    public static <T> void printArray(T[] array) {  
        for (T element : array)  
            System.out.printf("%s ", element);  
        System.out.println();  
    }  
}
```

A high-level view

Determine integerArray's type is Integer[]

Locate a method named printArray with a single parameter of Integer[] type. **No such method.**

Determine whether there is a generic method named printArray with a single parameter of array type and uses a type parameter to represent the array element type. **Yes, found the method.**

Check whether the operations in the method can be applied to the type of elements stored in the actual array argument. **Yes, all objects have a toString method (implicit call here). The code compiles!**

Under the hood: Erasure (消除)

- ▶ When the compiler translates generic method `printArray` into Java bytecodes, it **removes the type-parameter section** and **replaces the type parameters with actual types**. This process is known as **erasure**.
- ▶ By default, all generic types are replaced with type **Object**
- ▶ The compiled version of `printArray` is shown below (we show source code instead of bytecodes)

```
public static void printArray(Object[] array) {  
    for (Object element : array) System.out.printf("%s ", element);  
    System.out.println();  
}
```


Benefits of generic methods


In the earlier example, it seems that using generic methods is the same as using `Object` array as parameter of `printArray` (like the code below). Why using generics then?

```
public static void main(String[] args) {
    Integer[] integerArray = { 1, 2, 3, 4, 5, 6 };
    Double[] doubleArray = { 1.1, 2.2, 3.3, 4.4, 5.5 };
    Character[] characterArray = { 'H', 'E', 'L', 'L', 'O' };
    System.out.print("integerArray contains: ");
    printArray(integerArray);
    System.out.print("doubleArray contains: ");
    printArray(doubleArray);
    System.out.print("characterArray contains: ");
    printArray(characterArray);
}

public static void printArray(Object[] array) {
    for (Object element : array) System.out.printf("%s ", element);
    System.out.println();
}
```

Benefits of generic methods

```
public static Object simplyReturn(Object o) {  
    return o;  
}  
  
public static void main(String[] args) {  
     String s = simplyReturn("hello");  
}
```




The compiler sees that the method return type is `Object`, assigning a reference of `Object` to a `String` variable is illegal, so a **compilation error** will occur.

Can we downcast to `String`?

Benefits of generic methods

```
public static Object simplyReturn(Object o) {  
    return o;  
}
```

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

```
 String s = (String) simplyReturn(100);  
}
```

Programmers need to perform **explicit type cast**: `(String) simplyReturn("hello")`,
However, the code may generate **ClassCastException** if the cast fails **at runtime**.

Benefits of generic methods

```
public static <T> T simplyReturn(T o) {  
    return o;  
}  
  
public static void main(String[] args) {  
    ✓ String s = simplyReturn("hello");  
}
```

With the generic method, the compiler will perform **careful type checking** and **infer the return type is String** when the actual argument's type is `String` and **inserts type cast automatically** (such cast will never throw `ClassCastException`, **guaranteed to be safe**).

Therefore, the code can be successfully compiled and is more type safe (类型安全).
The benefits become obvious when the return type is also parameterized.



Bounded Type Parameter

```
public static <T> T simplyReturn(T o) {  
    return o;  
}
```

- ▶ In generic methods like the above, all reference types up to `Object` can be passed to the type parameter (we say `Object` is an **upper bound**).
- ▶ There are times when you want to **restrict the types that are allowed to be passed to a type parameter**, e.g., a method that operates on numbers might only want to accept instances of `Number` or its subclasses
- ▶ **Bounded type parameters (有界类型参数)** are useful in such cases.

Bounded Type Parameter

- ▶ To declare a bounded type parameter, simply list the type parameter's name followed by the `extends` keyword and an upper bound (上边界)
 - Here, `extends` is used in a general sense to mean either “extends” as in classes or “implements” as in interfaces.

```
public static <T extends Number> int sum(T x, T y) {  
    return x.intValue() + y.intValue();  
}
```

T can be any type that extends the
Number class, therefore we can
invoke `intValue()` of such type T

Bounded Type Parameter

- ▶ To declare a bounded type parameter, simply list the type parameter's name followed by the `extends` keyword and an upper bound (上边界)
 - Here, `extends` is used in a general sense to mean either “extends” as in classes or “implements” as in interfaces.

```
public static <T extends Comparable<T>> T maximum(T x, T y, T z) {  
    T max = x;  
    if (y.compareTo(max) > 0) max = y;  
    if (z.compareTo(max) > 0) max = z;  
    return max;  
}
```

T can be any type that implements the Comparable interface, therefore we can invoke `compareTo` on objects of type T

Example

Maximum of 3, 4 and 5 is 5
Maximum of 6.6, 8.8 and 7.7 is 8.8
Maximum of pear, apple and orange is pear

```
public static void main(String[] args) {  
    System.out.printf("Maximum of %d, %d and %d is %d\n", 3, 4, 5,  
        maximum(3, 4, 5));  
  
    System.out.printf("Maximum of %.1f, %.1f and %.1f is %.1f\n", 6.6,  
        8.8, 7.7, maximum(6.6, 8.8, 7.7));  
  
    System.out.printf("Maximum of %s, %s and %s is %s\n", "pear",  
        "apple", "orange", maximum("pear", "apple", "orange"));  
}
```

Integer, Double and String all implement the Comparable interface,
so can be passed to the type parameter

Compiler's view

```
// Erasure: replacing the type parameter T with the upper bound Comparable
public static Comparable maximum(Comparable x, Comparable y, Comparable z) {
    Comparable max = x;
    if (y.compareTo(max) > 0) max = y;
    if (z.compareTo(max) > 0) max = z;
    return max;
}
```

When encountering method calls, **infer the return type** and **insert explicit casts** (the compiler guarantees that the cast will never throw `ClassCastException`):

`maximum(3, 4, 5) → (Integer) maximum(3, 4, 5)`

`maximum(6.6, 8.8, 7.7) → (Double) maximum(6.6, 8.8, 7.7)`

`maximum("pear", "apple", "orange") → (String) maximum("pear", "apple", "orange")`

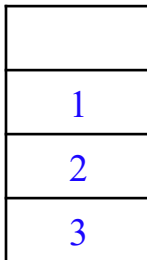


Objectives

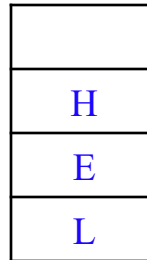
- ▶ Motivation of generic methods (泛型方法)
- ▶ Declare and use generic methods
- ▶ Declare and use generic classes (泛型类)

Generic classes

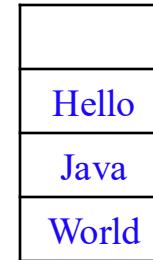
- ▶ The concept of many data structures, such as a stack, can be understood independently of the element type it manipulates.
- ▶ **Generic classes** provide a means for describing the concept of a stack (or any other classes) in a type independent manner.
- ▶ We can then instantiate type-specific objects of the generic classes. This makes software reusable (**program in general, not in specifics**).



A stack of Integer objects



A stack of Character objects



A stack of String objects



We've seen generic classes before

`ArrayList<E>` is a **generic class**, where `E` is a placeholder (占位符) (**type parameter**) for the type of elements that you want the `ArrayList` to hold.

```
ArrayList<String> list;
```

Declares `list` as an `ArrayList` collection to store `String` objects

```
ArrayList<Integer> list;
```

Declares `list` as an `ArrayList` collection to store `Integer` objects

Declaring a generic class

- ▶ A generic class declaration looks like a non-generic class declaration, except that the class name is followed by a **type-parameter section**.
- ▶ The type-parameter section can have **one or more type parameters** separated by commas.
- ▶ Generic classes are also known as **parameterized classes**.
- ▶ In a generic class, type parameters can be used anywhere a type is expected (e.g., when declaring method parameters, return types, defining variables ...)

A generic Stack class

```
public class Stack<T> {  
    private ArrayList<T> elements; // use an ArrayList to implement the stack  
    public Stack() { this(10); }  
    public Stack(int capacity) {  
        int initCapacity = capacity > 0 ? capacity : 10;  
        elements = new ArrayList<T>(initCapacity);  
    }  
    public void push(T value) {  
        elements.add(value);  
    }  
    public T pop() {  
        if(elements.isEmpty())  
            throw new RuntimeException("Empty Stack!!!"); // RuntimeException  
        return elements.remove(elements.size() - 1);  
    }  
}
```




Test the generic Stack class

```
public static void main(String[] args) {  
  
    Stack<Double> doubleStack = new Stack<Double>(5);  
    Stack<Integer> integerStack = new Stack<Integer>();  
  
    doubleStack.push(1.2);  
    Double value = doubleStack.pop();  
    System.out.println(value);  
  
    integerStack.push(1);  
    integerStack.push(2);  
  
    while(true) {  
        Integer i = integerStack.pop();  
        System.out.println(i);  
    }  
}
```

1.2
2
1
Exception!

Compiler's view

Erasure (similar to generic methods): Replacing all type parameters with `Object` or their bounds if the type parameters are bounded

The produced bytecodes contain only ordinary classes, interfaces, and methods, i.e., **no generics at the bytecode level**

```
public class Stack {  
    private ArrayList<Object> elements;  
    public Stack() { this(10); }  
    public Stack(int capacity) {...  
        elements = new ArrayList<Object>(initCapacity);  
    }  
    public void push(Object value) { ... }  
    public Object pop() { ... }  
}
```

Compiler's view

The compiler will insert type casts if necessary to preserve type safety

```
Stack<Double> doubleStack = new Stack<Double>(5);  
doubleStack.push(1.2);  
Double value = doubleStack.pop();
```

```
Stack doubleStack = new Stack(5);  
doubleStack.push(1.2);  
Double value = (Double) doubleStack.pop();
```



Let's test our understanding

- ▶ **Q1:** Will the compiler successfully compile the following code?

```
String s = "hello world";  
Object obj = s;
```



- ▶ It is **safe** to assign `s` (of type `String`) to `obj` (of type `Object`) because an instance of a subclass (subtype) is also an instance of a superclass (supertype).
- ▶ **“Safe”** means any operations that can be done via the reference `obj` are also allowed to be done via the reference `s`

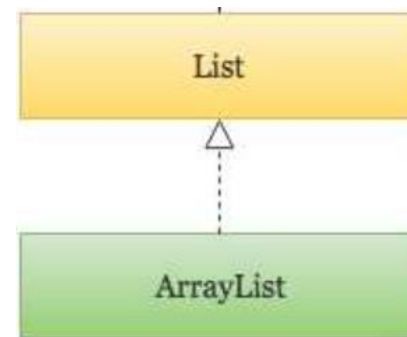
A more difficult question

- ▶ **Q2:** Will the compiler successfully compile the following code?

```
ArrayList<String> ls = new ArrayList<String>();  
List<String> ls2 = ls;
```



- ▶ It is safe to assign `ls` to `ls2` because an `ArrayList` of `String` is also a `List` of `String`.
- ▶ Any operations that can be done via the reference `ls2` can also be done via the reference `ls`



The “hardest” question about generics

- ▶ **Q3:** Will the compiler successfully compile the following code?

```
List<String> ls = new ArrayList<String>();
```

```
List<Object> lo = ls; 
```

- ▶ This boils down to the question: *is a List of String a List of Object?* (Most people will instinctively answer “yes”...)
- ▶ **What if we ask the safety question:** *is it true that any operations that can be done via the reference LO can also be done via LS?*

Let's do some analysis

- ▶ As a reference of type `List<Object>`, `lo` can be used for the following operation:

```
lo.add(new Double());
```

- ▶ However, we cannot perform the same operation via the reference `ls` because it is of type `List<String>`

```
List<String> ls = new ArrayList<String>();
```

```
List<Object> lo = ls; // type mismatch
```



Further analysis from compiler's view

- ▶ If the compiler allows assigning `ls` to `lo`, then the code

```
List<String> ls = new ArrayList<String>();  
List<Object> lo = ls;  
lo.add(new Double(0.0));  
String s = ls.get(0);
```

- ▶ will be compiled into the following form:

```
List ls = new ArrayList();  
List lo = ls;  
lo.add(new Double(0.0));  
String s = (String) ls.get(0);
```



ClassCastException

Generic classes are designed to provide type safety, such exceptions are awkward

General Rule

- ▶ If `Foo` is a subtype (subclass or subinterface) of `Bar`, and `G` is some generic type declaration, it is not the case that `G<Foo>` is a subtype of `G<Bar>`.
- ▶ `G<?>` is a superclass of `G<T>` for any `T` => Self-learning
- ▶ This is probably the hardest thing one needs to learn about generics, because it goes against our intuitions...