

Berner Fachhochschule - Technik und Informatik

Object-Oriented Programming 2

Topic 10: Generic Programming

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Outline

Generic Types

Generic Classes and Interfaces

Bounded Type Parameters

Raw Types and Wildcards

Generic Methods

Limitations of Generics

Outline

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Limitations of Generics

Motivation

- ▶ The goal of **generic programming** is to help implementing ...
 - algorithms (e.g. sort)
 - data types (e.g. ArrayList)
 - libraries (e.g. Collection)

independently of concrete data types

- ▶ Advantages of generic programming:
 - Increased code reusability, reduced code redundancy
 - Stronger type checks at compile time
 - Less runtime errors
 - Elimination of casts
 - Improved code readability

Non-Generic Array Lists

- ▶ Java support **generic types** since Java 5 (2004)
- ▶ Before Java 5, using an array list looked as follows:

```
ArrayList list = new ArrayList();  
list.add("HelloWorld");  
  
String s = (String) list.get(0);  
  
Integer i = (Integer) list.get(0); // Runtime error
```

- ▶ The main problem was a lack of **type safety**: a non-generic array list stores elements of type Object

Generic Array Lists

- ▶ Since Java 5, using an array list looked as follows:

```
ArrayList<String> list = new ArrayList<String>();  
list.add("HelloWorld");  
  
String s = list.get(0);  
  
Integer i = list.get(0); // Compilation error
```

- ▶ Java 7 introduced the **diamond operator** to simplify object creation

```
ArrayList<String> list = new ArrayList<>();
```

Type Parameters

- ▶ Generic classes and generic interfaces have one or multiple type parameters

```
public class ArrayList<E> implements List<E> {  
    public ArrayList() { ... }  
    public E get(int index) { ... }  
    public void add(E element) { ... }  
    :  
}  
  
public interface List<E> extends Collection<E> {  
    public E get(int index);  
    public void add(E element);  
    :  
}
```

Naming Conventions

- ▶ The convention for type parameters is to use single capital letters
 - T general generic type
 - N for numbers
 - E for elements in a collection
 - K for keys in a map
 - V for values in a map
 - S, U, W for additional generic types

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Non-Generic Example 1: StringBox I

```
public class StringBox {  
  
    private String content;  
  
    public StringBox(String content) {  
        this.content = content;  
    }  
  
    public void setContent(String content) {  
        this.content = content;  
    }  
  
    public String getContent() {  
        return this.content;  
    }  
}
```

Non-Generic Example 1: StringBox II

```
public static void main(String[] args) {  
  
    StringBox stringBox = new StringBox("HelloWorld");  
    String str = stringBox.getContent();  
  
}  
}
```

Example 1: StringBox.java

Non-Generic Example: IntegerBox I

```
public class IntegerBox {  
  
    private Integer content;  
  
    public IntegerBox(Integer content) {  
        this.content = content;  
    }  
  
    public void setContent(Integer content) {  
        this.content = content;  
    }  
  
    public Integer getContent() {  
        return this.content;  
    }  
}
```

Non-Generic Example: IntegerBox II

```
public static void main(String[] args) {  
  
    IntegerBox integerBox = new IntegerBox(100);  
    int i = integerBox.getContent();  
  
}  
}
```

Example 2: IntegerBox.java

Example: One Generic Type Parameter I

```
public class Box<T> {  
  
    private T content;  
  
    public Box(T content) {  
        this.content = content;  
    }  
  
    public void setContent(T content) {  
        this.content = content;  
    }  
  
    public T getContent() {  
        return this.content;  
    }  
}
```

Example: One Generic Type Parameter II

```
public static void main(String[] args) {  
  
    Box<String> stringBox = new Box<>("HelloWorld");  
    String s = stringBox.getContent();  
  
    Box<Integer> integerBox = new Box<>(100);  
    int i = integerBox.getContent();  
  
    Box<Box<Integer>> doubleIntegerBox = new Box<>(  
        integerBox);  
    int j = doubleIntegerBox.getContent().getContent();  
}  
}
```

Example 3: Box.java

Example: Two Generic Type Parameters I

```
public class Pair<S, T> {  
  
    private S first;  
    private T second;  
  
    public Pair(S first, T second) {  
        this.first = first;  
        this.second = second;  
    }  
  
    public S getFirst() {  
        return this.first;  
    }  
  
    public T getSecond() {
```


Example: Two Generic Type Parameters II

```
        return this.second;
    }

    public void setFirst(S first) {
        this.first = first;
    }

    public void setSecond(T second) {
        this.second = second;
    }

    public static void main(String[] args) {

        Pair<String, Integer> pair1 = new Pair<>("HelloWorld", 100);
        String s1 = pair1.getFirst();
        int i1 = pair1.getSecond();
    }
}
```

Example: Two Generic Type Parameters III

```
Pair<Integer, String> pair2 = new Pair<>(100, "
    HelloWorld");
int i2 = pair2.getFirst();
String s2 = pair2.getSecond();
}
```

Example 4: Pair.java

Example: Inheritance of Type Parameters I

```
public class Couple<T> extends Pair<T, T> {  
  
    public Couple(T first, T second) {  
        super(first, second);  
    }  
  
    public void swap() {  
        T tmp = this.getFirst();  
        this.setFirst(this.getSecond());  
        this.setSecond(tmp);  
    }  
  
    public List<T> toList() {  
        List<T> list = new ArrayList<>();  
        list.add(this.getFirst());  
    }  
}
```

Example: Inheritance of Type Parameters II

```
list.add(this.getSecond());  
return list;  
}  
  
public static void main(String[] args) {  
  
    Couple<Integer> couple = new Couple<>(100, 200);  
    int i1 = couple.getFirst();  
    int i2 = couple.getSecond();  
    List<Integer> list = couple.toList();  
}  
}
```

Example 5: Couple.java

Example: Nested Type Parameters I

```
public class PairOfBoxes<S, T> extends Pair<Box<S>, Box<T>> {  
  
    public PairOfBoxes(Box<S> first, Box<T> second) {  
        super(first, second);  
    }  
  
    public PairOfBoxes(S firstContent, T secondContent) {  
        super(new Box<S>(firstContent), new Box<T>(secondContent));  
    }  
  
    public S getFirstContent() {  
        return this.getFirst().getContent();  
    }  
}
```

Example: Nested Type Parameters II

```
public T getSecondContent() {  
    return this.getSecond().getContent();  
}  
  
public void setFirstContent(S content) {  
    this.getFirst().setContent(content);  
}  
  
public void setSecondContent(T content) {  
    this.getSecond().setContent(content);  
}  
  
public static void main(String[] args) {  
  
    PairOfBoxes<String, Integer> pairOfBoxes = new  
        PairOfBoxes<>("HelloWorld", 200);  
}
```

Example: Nested Type Parameters III

```
Box<String> box1 = pairOfBoxes.getFirst();  
Box<Integer> box2 = pairOfBoxes.getSecond();  
  
String s = pairOfBoxes.getFirstContent();  
Integer i = pairOfBoxes.getSecondContent();  
}  
}
```

Example 6: PairOfBoxes.java

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Raw Types and Wildcards

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Limitations of Generics

Bounded Type Parameters

- ▶ In the examples before, the type parameters were **unbounded**
 - No restrictions on the types used in instantiations
 - No access to specific methods
- ▶ Note that the class declaration **class** Box<T> is a shortcut for **class** Box<T **extends** Object>
- ▶ Example of **bounded type parameters**:

```
public interface Country {  
    public String getLanguage();  
}  
public class Germany implements Country { ... }  
public class France implements Country { ... }
```

Example: Bounded Type Parameters I

```
public class Passport<T extends Country> {  
  
    private T country;  
  
    public Passport(T country) {  
        this.country = country;  
    }  
  
    public T getCountry() {  
        return this.country;  
    }  
  
    public String getLanguage() {  
        return this.country.getLanguage();  
    }  
}
```

Example: Bounded Type Parameters II

```
public static void main(String[] args) {  
    France france = new France();  
    Passport<France> passport = new Passport<>(france);  
    France country = passport.getCountry();  
  
    // the following line produces a compilation error  
    Passport<String> pp = new Passport<>("France");  
}  
}
```

Example 7: Passport.java

Bounded Type Parameters: Remarks

- ▶ When applied to type parameters, the keyword `extends` actually means “`extends` or `implements`”, i.e., the bounds can be either classes or interfaces
- ▶ Occasionally, two or more type bounds are necessary, for example `<T extends Comparable & Cloneable>`
- ▶ If multiple type bounds are specified, and one of them is a class, then the class must be specified first

```
public class A { ... }  
public interface B { ... }  
public interface C { ... }  
  
public class D <T extends A & B & C> { ... } // OK  
public class E <T extends B & A & C> { ... } // Not OK
```

Subtype Rules

- ▶ When type parameters are instantiated, the following **subtype rules** apply:
 - `List<String>` is a subtype of `Object`
 - `List<String>` is a subtype of `List`
 - `ArrayList<String>` is a subtype of `List<String>`
 - `Couple<String>` is a subtype of `Pair<String, String>`
- ▶ Counter-examples:
 - `List` is not a subtype of `List<String>`
 - `List<Integer>` is not a subtype of `List<String>`
 - `List<Number>` is not a subtype of `List<Integer>`
 - `List<Integer>` is not a subtype of `List<Number>`
 - `Passport<France>` is not a subtype of `Passport<Country>`
- ▶ The last two examples are surprising and often lead to misunderstanding

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Raw Types

- ▶ A **raw type** is the name of a generic class or interface with an unspecified type parameter, for example `Box`
- ▶ Raw types are supported for compatibility reasons with Java 1.4 or less (using raw types is not recommended)
- ▶ Note that `Box` is not exactly the same as `Box<Object>`

```
Box rawBox;  
rawBox = new Box("HelloWorld"); // OK  
rawBox = new Box<String>("HelloWorld"); // OK  
rawBox.setContent(10); // OK  
  
Box<Object> objectBox;  
objectBox = new Box<>("HelloWorld"); // OK  
objectBox = new Box<String>("HelloWorld"); // Not OK  
objectBox.setContent(10); // OK
```

Wildcard Types

- ▶ In generic programs, the **wildcard** `?` represents an unknown type, for example `Box<?>`
- ▶ Note that `Box<?>` (unknown type) and `Box` (unspecified type) are not the same, because `Box<?>` guarantees type safety

```
Box rawBox;  
rawBox = new Box("HelloWorld"); // OK  
rawBox = new Box<String>("HelloWorld"); // OK  
rawBox.setContent(10); // OK  
  
Box<?> wildcardBox;  
wildcardBox = new Box<>("HelloWorld"); // OK  
wildcardBox = new Box<String>("HelloWorld"); // OK  
wildcardBox.setContent(10); // Not OK
```


Wildcard Types

- ▶ Wildcards can be used in declaration of ...
 - local variables
 - instance variables
 - static variables
 - method parameters
 - return values
- ▶ Using wildcards in return types is not recommended
- ▶ Wildcards are often used to bypass the restrictions of the strict subtype rules (while avoiding raw types)
- ▶ Note that wildcards cannot be used in the definition of generic classes or when invoking their constructors

Bounded Wildcard Types

- ▶ Note that `Box<?>` is a shortcut for `Box<? extends Object>`
- ▶ Wildcards can be **bounded** in two different ways:
 - Upper-bounded: `Box<? extends Number>`
 $\Leftrightarrow \{\text{Number, Byte, Double, Integer, Long, BigInteger, ...}\}$
 - Lower-bound: `Box<? super Integer>`
 $\Leftrightarrow \{\text{Integer, Number, Object}\}$
- ▶ The following subtype rules apply:
 - `List<Integer>` is a subtype of `List<?>`
 - `ArrayList<Integer>` is a subtype of `List<?>`
 - `List<Integer>` is a subtype of `List<? extends Integer>`
 - `List<Integer>` is a subtype of `List<? extends Number>`
 - `List<Number>` is a subtype of `List<? super Integer>`
 - `List<Number>` is a subtype of `List<? super Number>`

Using Unbounded Wildcards

- Unbounded wildcards are used when some code does not depend on the concrete type

```
public static void printList1(List<Object> list) {  
    for (Object e : list)  
        System.out.println(e + " ");  
}  
  
public static void printList2(List<?> list) {  
    for (Object e : list)  
        System.out.println(e + " ");  
}  
  
List<Integer> list = Arrays.asList(1, 2, 3);  
printList1(list); // Not OK  
printList2(list); // OK
```

Using Upper-Bounded Wildcards

- ▶ Upper-bounded wildcards are used when some code depends on the methods available for a certain type

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

```
List<Integer> list1 = Arrays.asList(1, 2, 3);  
System.out.println("sum = " + sum(list1)); // OK
```

```
List<Double> list2 = Arrays.asList(1.2, 2.3, 3.5);  
System.out.println("sum = " + sum(list2)); // OK
```

Using Lower-Bounded Wildcards

- ▶ Lower-bounded wildcards are occasionally used when a variable holds data for use elsewhere

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

```
List<Integer> list1 = new ArrayList<>();  
addInts(list1); // OK
```

```
List<Object> list2 = new ArrayList<>();  
addInts(list2); // OK
```

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Generic Methods

- ▶ Generic methods are methods that specify their own type parameters (independently of any generic types of the class)
 - They can be defined in generic or non-generic classes and interfaces
 - Static and non-static generic methods are allowed, as well as generic constructors
- ▶ In a generic method, the type parameter's scope is limited to the method
- ▶ The type parameter of a generic method must appear before the method's return type
- ▶ The main purpose of generic methods is to ensure type safety between arguments and return values

Example: BoxUtil I

```
public class BoxUtil {  
  
    // non-generic method using wildcards  
    public static boolean compare1(Box<?> b1, Box<?> b2) {  
        return b1.getContent().equals(b2.getContent());  
    }  
  
    // generic method  
    public static <T> boolean compare2(Box<T> b1, Box<T> b2) {  
        return b1.getContent().equals(b2.getContent());  
    }  
  
    // generic method  
    public static <T> Couple<T> couple(Box<T> b1, Box<T> b2) {  
        return new Couple<T>(b1.getContent(), b2.getContent());  
    }  
}
```


Example: BoxUtil II

```
public static void main(String[] args) {  
    Box<String> box1 = new Box<>("Hello");  
    Box<String> box2 = new Box<>("World");  
    Box<Integer> box3 = new Box<>(10);  
  
    BoxUtil.compare1(box1, box2); // OK  
    BoxUtil.compare1(box1, box3); // OK  
  
    BoxUtil.compare2(box1, box2); // OK  
    BoxUtil.compare2(box1, box3); // Not OK  
  
    Couple<String> c1 = BoxUtil.couple(box1, box2); // OK  
    Couple<String> c2 = BoxUtil.couple(box1, box3); // Not OK  
}  
}
```

Example 8: BoxUtil.java

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Type Erasure

- ▶ The Java compiler fully **erases** generic type parameters:
 - Generic types are replaced with their type bounds
 - Unbounded types are replaced by `Object`
 - Type casts are inserted if necessary
 - Bridge methods are generated to preserve polymorphism (they may appear in a stack trace)
- ▶ The produced bytecode, therefore, contains only ordinary classes, interfaces, and methods
- ▶ As a consequence, generics does not create new classes and implies no computational overhead at runtime
- ▶ Knowing about type erasure types helps understanding the limitations of Java generics

Creating Instances of Type Parameters

- ▶ It is impossible to create instances of type parameters
- ▶ The problem in the following example is that `new T()` is replaced by `new Object()`

```
public static <T> void fill(T[] array) {  
    for (int i = 0; i < array.length; i++)  
        array[i] = new T(); // Not OK  
}  
  
public static <T> void fillWithDefaults(T[] array, T  
    defaultValue) {  
    for (int i = 0; i < array.length; i++)  
        array[i] = defaultValue; // OK  
}
```

Creating Arrays of Type Parameters

- ▶ It is impossible to create arrays of type parameters
- ▶ The problem is that, for compatibility reasons, creating arrays in Java requires knowledge about its type
- ▶ Read detailed explanation [here](#)

```
public class ArrayList<E> implements List<E> {  
  
    private E[] elements; // OK  
  
    public ArrayList() {  
        this.elements = new E[10]; // Not OK  
        this.elements = (E[]) new Object[10]; // OK  
    }  
}
```

Declaring Static Variables of a Generic Type

- ▶ Static variables of type parameters are not allowed, because they are shared by all instances of that class
- ▶ What would be the type of the variable `defaultContent` in the following example?

```
public class Box<T> {  
  
    private static T defaultContent; // Not OK  
    private T content;  
  
    public Box() {  
        this.content = defaultContent;  
    }  
}
```

Method Overloading

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

```
public interface ListPrinter {  
    public void print(List<String> strList);  
    public void print(List<Integer> intList); // Not OK  
    public void print(List<Double> intList); // Not OK  
}
```