Object Oriented Programming in Java

11: Collections and custom classes

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Using custom classes in collections

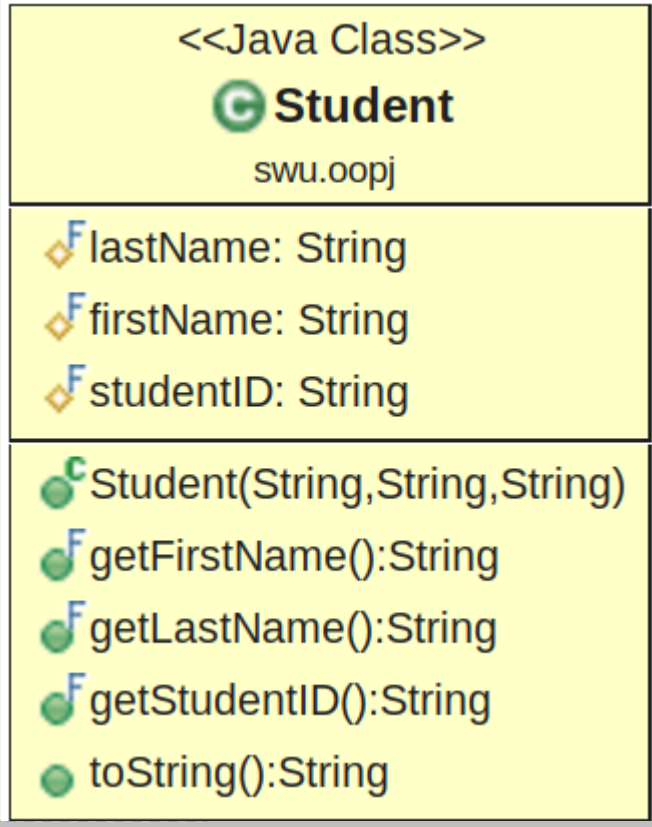
- In previous examples we had used built-in classes (String, Integer, …) as keys in maps or elements of lists and sets
- This presentation describe what is needed to use custom classes in built-in collections
- We shall start with the simple implementation of class Student and extend it through the examples by overriding or implementing
  - equals, hashCode, Comparable, …

Initial version of the custom class

11_.../swu/oopj/Student.java

- Initial implementation of Student contains constructor with parameters for last name, first name, and id
  - Values are stored as *protected final* variables having only *public final* (not overridable) getters and overridden method *toString*

```
public class Student {
...
   public Student(String lastName, String
        firstName, String studentID) {
               this.lastName = lastName;
               this.firstName = firstName;
               this.studentID = studentID;
        }
   @Override
   public String toString() {
        return String.format("(%s) %s %s",
              studentID, firstName, lastName);
   } ...
```



Common methods – printing collection

- One of the common tasks is to print the content of the collection
  - The code iterates through the collection and prints each element
    - *toString* method is called for each element
  - This code could be applied for anything that is Iterable
    - Does not have any restrictions about parameter type T
      - It would be class *Student* or some of its subclasses but does not use anything specific for *Student*

11_.../swu/oopj/Common.java

```
public class Common {
	public static <T> void printCollection(Iterable<T> col){
		for(T element : col) {
			System.out.println(element);
		}
		System.out.println();
	}
	...
```

Common methods – fill collection (1)

- All examples (i.e. collections in examples) should contain same sample data. The initial idea would be to write something like

```
public static void fillStudentsCollection(Collection<Student> col) {
   Student s1 = new Student("Black", "Joe", "1234567890");
   Student s2 = new Student("Poe", "Edgar Allan", "2345678901");
   ...
   col.add(s1);
   col.add(s2);
...
```

- The problem with this approach is that we would use different versions of class Student, not by changing the initial one, but by extending it
  - e.g *class Student2 extends Student*
  - Thus constructor *new Student* is not good for example 2, and must be replaced with *new Student2*

Common methods – fill collection (2)

- We would like to achieve something like

```
public static <S extends Student> void
                        fillStudentsCollection(Collection<S> col) {
   Student s1 = new S("Black", "Joe", "1234567890");
   Student s2 = new S("Poe", "Edgar Allan", "2345678901");
   ...
   col.add(s1);
   col.add(s2);
...
```

  where each subclass of Student would have constructor with 3 parameters

- A nice idea, but unfortunately not possible in Java
  - Java generics does not allow creating new objects of generic type using *new*

Common methods – fill collection (3)

- Instead we can define a function interface

```
@FunctionalInterface
public interface StudentFactory <S extends Student> {
   S create(String lastName, String firstName, String studentID);
}
```

11_.../swu/oopj/StudentFactory.java

with method create implemented in such way that it creates a new (subclass of) *Student*

  - Methods that create new objects (as an alternative to using new) are called factory methods

- How to implement this interface using lambda expression

```
StudentFactory<Student> factory =
       (last, first, id) -> new Student(last, first, id);
```

11_.../swu/oopj/example1/ArrayListMain.java

Common methods – fill collection (4)

- For this functional interface

```
@FunctionalInterface
public interface StudentFactory <S extends Student> {
   S create(String lastName, String firstName, String studentID);
}
```

11_.../swu/oopj/StudentFactory.java

we can use lambda expression

11_.../swu/oopj/example/ArrayListMain.java

```
StudentFactory<Student> factory =
       (last, first, id) -> new Student(last, first, id);
```

or reference to a method that have the required signature

- It must have 3 String parameters and return Student
- At first it looks like we do not have such method, but there is exactly such method – Student's constructor

```
StudentFactory<Student> factory = Student::new;
```

11_.../swu/oopj/example1/ArrayListMain.java

Common methods – fill collection (5)

- Now we can complete out fill collection method

```
public static <S extends Student> void fillStudentsCollection(
                Collection<S> col, StudentFactory<S> factory){
   S s1 = factory.create("Black", "Joe", "1234567890");
   S s2 = factory.create("Poe", "Edgar Allan", "2345678901");
   ...
   col.add(s1);
   col.add(s2);
...
```

11_.../swu/oopj/Common.java

Example #1 – Find element in a list

- We are searching for student that we "think" is a member of list, but the results is *false*
  - We have another student with the same last name, first name, and id, but these are not the same objects (references) in memory
  - *ArrayList's contains* uses *equals* to compare objects

```
I have following students:
(1234567890) Joe Black
(2345678901) Edgar Allan Poe
(3456789012) Immanuel Kant
(0123456789) Joe Rock
(5687461359) Joe Black

Poe present: false
```

```
List<Student> students = new ArrayList<>();
StudentFactory<Student> factory = Student::new;
Common.fillStudentsCollection(students, factory);

System.out.println("I have following students:");
Common.printCollection(students);

Student s = new Student("Poe", "Edgar Allan", "2345678901");
System.out.println("Poe present: " + students.contains(s));
```

11_.../swu/oopj/example1/ArrayListMain.java

Rule #1 – override *equals* method

- We should define when two objects should be considered equal
  - otherwise the reference equality is used
  - Custom rule: Two students should be equal if they have same id

```
public class Student2 extends Student {
   public Student2(String lastName, String firstName, String id) {
       super(lastName, firstName, id);
   }
   @Override
   public boolean equals(Object obj) {
       if(!(obj instanceof Student2)) return false;
       Student2 other = (Student2)obj;
       return this.studentID.equals(other.studentID);
   }
}
```

11_.../swu/oopj/example2/Student2.java

Example #2 – Find element in a list (“fixed”)

- ArrayList’s is still using equals but class *Student2* has overridden equals method and compare id’s

```
I have following students:
(1234567890) Joe Black
(2345678901) Edgar Allan Poe
(3456789012) Immanuel Kant
(0123456789) Joe Rock
(5687461359) Joe Black

Poe present: true
```

11_.../swu/oopj/example2/ArrayListMain.java

```
List<Student2> students = new ArrayList<>();
Common.fillStudentsCollection(students, Student2::new);

System.out.println("I have following students:");
Common.printCollection(students);

Student2 s = new Student2("Poe", "Edgar Allan", "2345678901");
System.out.println("Poe present: " + students.contains(s));
```

Example #2 – Find element in a hashset

- Student2 has equals, but it does not help in case of HashSet
  - *HashSet* puts elements in buckets and uses hasCode to calculate in which bucket an element should be put and searched for

```
I have following students:
(1234567890) Joe Black
(2345678901) Edgar Allan Poe
(3456789012) Immanuel Kant
(0123456789) Joe Rock
(5687461359) Joe Black

Poe present: false
```

11_.../swu/oopj/example2/HashSetMain.java

```
Set<Student2> students = new HashSet<>();
Common.fillStudentsCollection(students, Student2::new);

System.out.println("I have following students:");
Common.printCollection(students);

Student2 s = new Student2("Poe", "Edgar Allan", "2345678901");
System.out.println("Poe present: " + students.contains(s));
```

Rule #2 – override *hashCode* method

- *hashCode* must be implemented in such way that
  - two same objects (in terms of equals) must have same hash
  - Note: Two objects having same hash does not have to be equal
    - Different hash means that objects are different
- *hashCode* should be implemented in a ways that evenly distributes elements into buckets

```
public class Student3 extends Student {
    public Student3(String lastName, String firstName, String id) {
        super(lastName, firstName, id);
    }
    @Override
    public int hashCode() {
        return this.studentID.hashCode();
    }
}
```

11_.../swu/oopj/example3/Student3.java

Example #3 – Find element in a hashset

- Student3 has hashcode but it still does not work properly
  - Bucket is calculated correctly, but as bucket can contain multiple elements, search in the bucket is done using equals

```
I have following students:
(1234567890) Joe Black
(2345678901) Edgar Allan Poe
(3456789012) Immanuel Kant
(0123456789) Joe Rock
(5687461359) Joe Black

Poe present: false
```

11_.../swu/oopj/example3/HashSetMain.java

```
Set<Student3> students = new HashSet<>();
Common.fillStudentsCollection(students, Student3::new);

System.out.println("I have following students:");
Common.printCollection(students);

Student3 s = new Student3("Poe", "Edgar Allan", "2345678901");
System.out.println("Poe present: " + students.contains(s));
```

Rule #3 – override both *equals* and *hashCode*

- Both *hashCode* and *equals* must be implemented
  - Must be mutually consistent

```
public class Student4 extends Student {
    public Student4(String lastName, String firstName, String id) {
        super(lastName, firstName, id);
    }
    @Override
    public boolean equals(Object obj) {
        if(!(obj instanceof Student4)) return false;
        Student4 other = (Student4)obj;
        return this.studentID.equals(other.studentID);
    }
    @Override
    public int hashCode() {
        return this.studentID.hashCode();
    }
}
```

11_.../swu/oopj/example4/Student4.java

Example #4 – Add elements to TreeSet (1)

- An attempt to add student to a TreeSet causes an exception

```
Exception in thread "main" java.lang.ClassCastException: class
swu.oopj.example4.Student4 cannot be cast to class java.lang.Comparable
        at java.base/java.util.TreeMap.compare(TreeMap.java:1291)
        at java.base/java.util.TreeMap.put(TreeMap.java:536)
        at java.base/java.util.TreeSet.add(TreeSet.java:255)
        at swu.oopj.Common.fillStudentsCollection(Common.java:20)
        at swu.oopj.example4.TreeSetMain.main(TreeSetMain.java:13)
```

```
Set<Student4> students = new TreeSet<>();
Common.fillStudentsCollection(students, Student4::new);

System.out.println("I have following students:");
Common.printCollection(students);
```

11_…/swu/oopj/example4/TreeSetMain.java

```
Student4 s = new Student4("Poe", "Edgar Allan", "2345678901");
System.out.println("Poe present: " + students.contains(s));
```

Example #4 – Add elements to TreeSet (2)

- TreeSet must compare objects in order to build the tree
  - Assumes that used type implements *Comparable* (in order to invoke *compare* method), and produces *ClassCastException* if does not
- Two possible solutions
  1. Implement *Comparable* interface in class Student
     - *Comparable* imposes a total ordering on the objects of each class that implements it. It is referred as **natural ordering**, and the class's *compareTo* method is **natural comparison method**.
     - The natural ordering for a class C is consistent with equals if and only if e1.compareTo(e2) == 0 has the same boolean value as e1.equals(e2) for every e1 and e2 of class C.
  2. Specify another comparator in a TreeSet constructor
     - Functional interface *Comparator* with *compare* method used as comparison function, imposing a total ordering on some collection of objects.

Comparable and *Comparator*

- Comparable

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

- Comparator

```
public interface Comparator<T> {
    int compare(T o1, T o2);
    … and several default methods …
}
```

- Comparison should return 0 if objects should be treated as same, less than zero if the first one is before the second one, or greater than zero otherwise
- Note the difference in number of arguments!

Example #5 – implementing natural order

- Should be consistent with equals
  - In this example derived from the version that has equals and hashcode and compares students by their ids

11_.../swu/oopj/example5/Student5.java

```
public class Student5 extends Student4 {
   public Student5(String lastName, String firstName, String id) {
       super(lastName, firstName, id);
   }
   @Override
   public int compareTo(Student5 other) {
     return this.studentID.compareTo(other.studentID);
   }
}
```

Example #6 – writing a comparator

- Could be written as a separate class, anonymous class or using lambda expression
  - Does not require existence of natural comparator
  - An example with a separate class

```
public class StudentComparator implements Comparator<Student4> {
   @Override
   public int compare(Student4 s1, Student4 s2) {
       return s1.getStudentID().compareTo(s2.getStudentID());
   }
}
```

11_.../swu/oopj/example6/StudentComparator.java

```
Set<Student4> students = new TreeSet<>(new StudentComparator());
```

  - An example with a lambda expression

11_...example6/TreeSetMain.java

```
Set<Student> students = new TreeSet<>(
  (s1, s2) -> s1.getStudentID().compareTo(s2.getStudentID())
);
```

Example #7 – complex comparisons

- A comparator that compares first by last name, then (if same) by first name, and then by id

11_.../swu/oopj/example7/StudentComparator.java

  - It is not consistent with equals…
    - … and it is not expected as we can have many comparators

```
public class StudentComparator implements Comparator<Student4> {
   @Override
   public int compare(Student4 s1, Student4 s2) {
       int r = s1.getLastName().compareTo(s2.getLastName());
       if (r != 0)
              return r;
       r = s1.getFirstName().compareTo(s2.getFirstName());
       if (r != 0)
              return r;
       return s1.getStudentID().compareTo(s2.getStudentID());
   }
}
```

Reverse comparator as a decorator example

- Suppose that we would like to implement comparison as in previous example but in descending order
  - We could write a new class (or new lambda expression)
- Better solution: write a new universal comparator that uses an existing comparator (receive it as an argument in the constructor and wraps it) to return an opposite result as result of own compare method
  - The concept is also known as ***decorator*** pattern

Example #7 – Reverse comparator

- Applicable for any comparator, not only for comparator of students
  - "Does not how to compare objects by itself, but wraps an existing comparator that knows"

```
public class ReverseComparator<T> implements Comparator<T> {
    private Comparator<T> original;
    public ReverseComparator(Comparator<T> original) {
        this.original = original;
    }

    @Override
    public int compare(T o1, T o2) {
        int r = original.compare(o1, o2);
        return -r;
    }
}
```

11_.../swu/oopj/example7/ReverseComparator.java

Example #7 – Reverse comparator (usage)

- First, we need some concrete comparator, and then we create new comparator based on it that do reverse comparison

```
I have following students:
(0123456789) Joe Rock
(2345678901) Edgar Allan Poe
(3456789012) Immanuel Kant
(5687461359) Joe Black
(1234567890) Joe Black
```

11_.../swu/oopj/example7/Main.java

```
StudentComparator comparator = new StudentComparator();
Comparator<Student4> reverse = new ReverseComparator<>(comparator);

Set<Student4> students = new TreeSet<>(reverse);
Common.fillStudentsCollection(students, Student4::new);

System.out.println("I have following students:");
Common.printCollection(students);
```

Example #7 – Built in reverse comparators

- Instead of writing custom reverse comparator we can use built in methods:
  - Default method in interface Comparator

    Comparator<Student> reverse = comparator.reversed();
  - *Collections static method reverseOrder with a comparator as argument*

    Comparator<Student> reverse = Collections.reverseOrder(comparator);
  - *Collections* static method *reverseOrder* without arguments
    - Only if class (Student) has natural order defined (it creates reverse comparator of natural order)

    Comparator<Student> reverse = Collections.~~<Student>~~reverseOrder();

```
StudentComparator comparator = new StudentComparator();
Comparator<Student4> reverse = comparator.reversed();
Set<Student4> students = new TreeSet<>(reverse);
...
```

11_.../swu/oopj/example7/Main.java

Combining multiple sorting criteria

- In the previous examples we saw an example of complex comparisons (by last name, then by first name, and then by id)
- What if we want to cover all combinations?
  - Three attributes + ascending and descending yields $3!*2^3 = 48$ combinations
  - E.g. 4 attributes + ascending and descending yields $4!*2^4 = 384$
  - It does make sense to write all combinations!
- Solution:
  - Write comparator for each attribute
  - Use reverse comparator
  - Create composite comparator that contains list of desired comparators
  - With this, we enable a user to create any possible combinations

Example #8 – Composite comparator (1)

- Uses a list of existing comparators for comparison

```
public class CompositeComparator<T> implements Comparator<T> {
   private List<Comparator<T>> comparators;
   public CompositeComparator(List<Comparator<T>> comparators) {
       this.comparators = new ArrayList<>(comparators.size());
       this.comparators.addAll(comparators);
   }
   @Override
   public int compare(T o1, T o2) {
       for (Comparator<T> c : comparators) {
              int r = c.compare(o1, o2);
              if (r != 0)
                     return r;
       }
       return 0;
   }
...
```

11_.../swu/oopj/example8/CompositeComparator.java

Example #8 – Composite comparator (2)

- Instead of list it can have variable number of comparators
  - Eases usage
- Note: Instead of *Comparator<T>, Comparator<? super T>* may be used
  - e.g. if we would like to compare two *Student4* objects, a Comparator<Student> also it could be used

```
public class CompositeComparator<T> implements Comparator<T> {
   private List<Comparator<T>> comparators;
   @SafeVarargs
   public CompositeComparator(Comparator<T>... comparators) {
       this.comparators = new ArrayList<>(comparators.length);
       Collections.addAll(this.comparators, comparators);
   }
...
```

11_.../swu/oopj/example8/CompositeComparator.java

Example #8 – comparator for each attribute

- Besides natural order defined in Student5, let's define comparator for each attribute
  - Could be part of the class or defined somewhere else

11_.../swu/oopj/example8/Student8.java

```
public class Student8 extends Student5 {
   ...
   public static final Comparator<Student8> BY_LAST_NAME =
              (s1,s2) -> s1.lastName.compareTo(s2.lastName);
   public static final Comparator<Student8> BY_FIRST_NAME =
               Comparator.comparing(Student8::getFirstName);
   public static final Comparator<Student8> BY_STUDENT_ID =
              (s1,s2) -> s1.studentID.compareTo(s2.studentID);

}
```

Example #8 – using composite comparator

- We can create new comparator by combining any combination of existing comparators
  - To get natural order use *Comparator.<T>naturalOrder()*

11_.../swu/oopj/example8/Main.java

```
Comparator<Student8> comparator = new CompositeComparator<>(
        Student8.BY_FIRST_NAME.reversed(),
        Student8.BY_LAST_NAME,
        Comparator.naturalOrder()
                        //same as Comparator.<Student>naturalOrder()
);
Set<Student8> students = new TreeSet<>(comparator);
...
```

Example #8 – built in composite comparator

- The same comparator as in the previous example can be created with built-in composite comparator using *thenComparing*
  - default method in interface *Comparator*

11_.../swu/oopj/example8/Main.java

```
Comparator<Student> comparator =
                        Student.BY_FIRST_NAME
                       .reversed()
                       .thenComparing(Student.BY_LAST_NAME)
                       .thenComparing(Comparator.naturalOrder());
Set<Student8> students = new TreeSet<>(comparator);
...
```