CS2030 Lecture 5

Java Generics

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Lecture Outline and Learning Outcomes

- Familiarity with the usage of a mutable `ArrayList` and how the delegation pattern is used to define an immutable list
- Understand **autoboxing and unboxing** of primitives and its wrapper classes
- Be able to define generic classes and generic methods
- Appreciate how **parametric polymorphism** supports the abstraction principle
- Be able to apply constructs involving Java **generics** to define generic classes
- Understand the implications of substitutability in generics
- Be able to apply upper- and lower- **bounded wildcards**

Mutable `ArrayList<E>`

- `ArrayList<E>`: Java's mutable implementation of `List<E>`
  - type parameter `E` replaced with type argument to indicate the type of *elements* stored, e.g. `ArrayList<String>`
  - `ArrayList<String>` is a **parameterized type**

```
jshell> ArrayList<String> list = new ArrayList<String>()
list ==> []

jshell> list.add("one")
$.. ==> true

jshell> list.add("two")
$.. ==> true

jshell> list.set(0, "three")
$.. ==> "one"

jshell> list // ArrayList is mutable! :(
list ==> [three, two]
```


Type Arguments: Auto-boxing / Unboxing

- Only reference types allowed as type arguments; primitives need to be auto-boxed/unboxed, e.g. `ArrayList<Integer>`

```
jshell> ArrayList<Integer> list = new ArrayList<Integer>()
list ==> []

jshell> list.add(1) // auto-boxing
$.. ==> true

jshell> list.add(new Integer(2)) // explicit boxing
$.. ==> true

jshell> int x = list.get(0) // auto-unboxing
x ==> 1
```

- Placing a value of type `int` into `ArrayList<Integer>` causes it to be **auto-boxed**
- Getting a value out of `ArrayList<Integer>` results in a value of type `Integer`; assigning it to `int` variable causes it to be **auto-unboxed**

Delegation Pattern: `ImList`

- Start by creating an immutable list `ImList` *of integers* by encapsulating a mutable `ArrayList` within the class — immutable delegation pattern
  - create an empty `ImList`, or with elements from a `List`
  - method implementations *delegated* to the `ArrayList`

```
import java.util.List;
import java.util.ArrayList;

class ImList {
    private final ArrayList<Integer> elems;

    ImList() { // creates an empty list
        this.elems = new ArrayList<Integer>();
    }

    ImList(List<Integer> elems) {
        this.elems = new ArrayList<Integer>(elems);
    }

    @Override
    public String toString() {
        return this.elems.toString();
    }
}
```

```
jshell> new ImList()
$.. ==> []

jshell> new ImList(List.of(1, 2))
$.. ==> [1, 2]
```


`ImList`: `get`, `size` and `isEmpty`

- Define the `get`, `size` and `isEmpty` methods in `ImList`

```
Integer get(int index) {
    return this.elems.get(index);
}

int size() {
    return this.elems.size();
}

boolean isEmpty() {
    return this.elems.isEmpty(); // or this.size() == 0
}
```

```
jshell> new ImList().size()
$.. ==> 0

jshell> new ImList().isEmpty()
$.. ==> true

jshell> new ImList(List.of(1, 2, 3)).get(0)
$.. ==> 1

jshell> new ImList(List.of(1, 2, 3)).size()
$.. ==> 3

jshell> new ImList(List.of(1, 2, 3)).isEmpty()
$.. ==> false
```


`ImList`: `add` Method

- Define the `add` method which returns a new `ImList`
  - creates a copy of the original list before adding the element
  - uses the constructor that takes a `List`
    - an `ArrayList` is a `List`

```
ImList add(Integer elem) { // add elem to the back of a new elems
    ImList newList = new ImList(this.elems);
    newList.elems.add(elem);
    return newList;
}
```

```
jshell> ImList list12 = new ImList(List.of(1, 2))
list12 ==> [1, 2]

jshell> list12.add(3).add(4)
$.. ==> [1, 2, 3, 4]

jshell> list12.size()
$.. ==> 2

jshell> list12.add(3).size()
$.. ==> 3

jshell> list12
list12 ==> [1, 2] // ImList is immutable! :)
```


Generic Class: `ImList<E>`

- **Generic** `ImList<E>` class to store elements of generic type `E`

```
import java.util.List;
import java.util.ArrayList;

class ImList<E> { // declare type parameter E
    private final ArrayList<E> elems;

    ImList() {
        this.elems = new ArrayList<E>();
    }

    ImList(List<E> elems) {
        this.elems = new ArrayList<E>(elems);
    }

    ImList<E> add(E elem) { // note return type of ImList<E>
        ImList<E> newList = new ImList<E>(this.elems);
        newList.elems.add(elem); // delegates add to ArrayList
        return newList;
    }

    E get(int index) {
        return this.elems.get(index);
    }
    ...
```

Generic Method

- Defining a generic method without associating to any object

```
jshell> <T> ImList<T> of(T t) { // return ImList<T> of one element
   ...>     return new ImList<T>().add(t);
   ...> }
|  created method of(T)

jshell> of(1)
$.. ==> [1]

jshell> of("one")
$.. ==> [one]
```

- Generic methods are useful as static factory methods in a class

```
class ImList<E> {
    private final ArrayList<E> elems;

    private ImList() { // private
        this.elems = new ArrayList<E>();
    }

    private ImList(List<E> elems) { // private
        this.elems = new ArrayList<E>(elems);
    }

    static <E> ImList<E> of() { // note declaration of <E> for the method
        return new ImList<E>();
    }

    static <E> ImList<E> of(List<E> elems) { // note declaration of <E> for the method
        return new ImList<E>(elems);
    }
    ...
```

```
jshell> ImList.of() // type-inferred
$.. ==> []

jshell> ImList.<Integer>of() // type-witnessed
$.. ==> []

jshell> ImList.<Integer>of(List.of(1,2,3))
$.. ==> [1, 2, 3]
```


Parametric Polymorphism

- Generic typing is also known as **parametric polymorphism**
- Like `add` method, `set` and `remove` can be similarly defined

```
    ImList<E> set(int index, E elem) {
        ImList<E> newList = new ImList<E>(this.elems);
        newList.elems.set(index, elem);
        return newList;
    }

    ImList<E> remove(int index) {
        ImList<E> newList = new ImList<E>(this.elems);
        if (index < this.size()) newList.elems.remove(index); // guard
        return newList;
    }
```

```
jshell> ImList<Integer> list12 = ImList.<Integer>of(List.of(1, 2))
list12 ==> [1, 2]

jshell> list12.add(3).add(4).remove(2)
$.. ==> [1, 2, 4]

jshell> list12.add(3).add(4).remove(2).set(1, 5)
$.. ==> [1, 5, 4]

jshell> list12
list12 ==> [1, 2]
```

- Exercise: define the `iterator` method

Generics and Substitutability

- `ImList<E>` can contain elements of type `T` or it's subclass `S`

```
jshell> ImList<Shape> shapes = ImList.<Shape>of().
   ...> add(new Circle(1)).
   ...> add(new Rectangle(2, 3))
shapes ==> [Circle with radius 1, Rectangle 2 x 3]
```

- Are the following substitutable?
  - `ImList<Shape> shapes = ImList.<Circle>of(...)`
  - `ImList<Circle> circles = ImList.<Shape>of(...)`
- Generics is invariant*; type parameters must match!

```
jshell> ImList<Shape> shapes = ImList.<Circle>of()
|  Error:
|  incompatible types: ImList<Circle> cannot be converted to ImList<Shape>
|  ImList<Shape> shapes = ImList.<Circle>of();
|                         ^------------------^

jshell> ImList<Circle> circles = ImList.<Shape>of()
|  Error:
|  incompatible types: ImList<Shape> cannot be converted to ImList<Circle>
|  ImList<Circle> circles = ImList.<Shape>of();
|                           ^-----------------^
```

* Given `S <: T`, neither `C<S> <: C<T>` (co-variance) nor `C<T> <: C<S>` (contra-variance) holds

Upper Bounded Wildcard

- Define the `addAll` method that takes in elements of another `ImList` and adds to the end of the current `ImList`
  - Suppose we have a `ImList<Shape>` object, what other types of `ImList` can `addAll` method take in?
    - another `ImList<Shape>`? Yes
    - `ImList<Circle>` or `ImList<Rectangle>`? Yes
    - `ImList<Object>`? No
- Use the upper bounded wildcard: `? extends E`

```
    ImList<E> addAll(List<? extends E> list) {
        ImList<E> newList = new ImList<E>(this.elems);
        newList.elems.addAll(list);
        return newList;
    }

    ImList<E> addAll(ImList<? extends E> list) {
        return this.addAll(list.elems);
    }
```

`? extends` is *covariant*: if `S <: T`, then `C<S> <: C<? extends T>`

ImList<E>: addAll Method

```
jshell> ImList<Shape> shapes = ImList.<Shape>of().
   ...> add(new Circle(1)).
   ...> add(new Rectangle(2, 3))
shapes ==> [Circle with radius 1, Rectangle 2 x 3]

jshell> ImList<Rectangle> rects = ImList.<Rectangle>of().
   ...> add(new Rectangle(4, 5))
rects ==> [Rectangle 4 x 5]

jshell> shapes.addAll(rects)
$.. ==> [Circle with radius 1, Rectangle 2 x 3, Rectangle 4 x 5]

jshell> shapes.addAll(shapes)
$.. ==> [Circle with radius 1, Rectangle 2 x 3, Circle with radius 1,
Rectangle 2 x 3]

jshell> ImList<Object> objs = ImList.<Object>of().
   ...> add(new Circle(1)).
   ...> add("circle")
objs ==> [Circle with radius 1, circle]

jshell> shapes.addAll(objs)
|  Error:
|  incompatible types: ImList<java.lang.Object> cannot be converted to
|  ImList<? extends Shape> shapes.addAll(objs)
|                                        ^--^
```

- Likewise, use upper bounded wildcards in `ImList` constructor and `of` method that takes in a list, `List<? extends E> elems`

Lower-Bounded Wildcard

- What are the possible ways to sort `ImList<Shape>`?
  - Sort by area of shape? Yes
  - Sort by radius of circles? No
  - Sort by length of `Object`'s `toString` method? Yes
- Use a lower bounded wildcard: `? super T`

```
import java.util.Comparator;
    ...
    ImList<E> sort(Comparator<? super E> cmp) {
        ImList<E> newList = new ImList<E>(this.elems);
        newList.elems.sort(cmp);
        return newList;
    }
```

- Notice that the actual sorting routine is delegated to the `ArrayList` where a similar `sort` method is defined

`? super` is *contravariant*: if `S <: T`, then `C<T> <: C<? super S>`

ImList<E>: sort Method

- Given `shapes` as an immutable list of type `ImList<Shape>`

```
jshell> ImList<Shape> shapes = ImList.<Shape>of().
   ...> add(new Rectangle(2, 3)).
   ...> add(new Circle(1))
shapes ==> [Rectangle 2 x 3, Circle with radius 1]
```

- Sorting by area of shape, i.e. via `Comparator<Shape>`

```
jshell> class ShapeAreaComp implements Comparator<Shape> {
   ...>     public int compare(Shape s1, Shape s2) {
   ...>         double diff = s1.getArea() - s2.getArea();
   ...>         if (diff < 0) {
   ...>             return -1;
   ...>         } else if (diff > 0) {
   ...>             return 1;
   ...>         } else {
   ...>             return 0;
   ...>         }
   ...>     }
   ...> }
|  created class ShapeAreaComp

jshell> shapes.sort(new ShapeAreaComp())
$.. ==> [Circle with radius 1, Rectangle 2 x 3]
```

- Notice that `ImList::sort` returns a new sorted list

ImList<E>: sort Method

- Sorting by length of `toString`, i.e. via `Comparator<Object>`

```
jshell> class ObjectStringLengthComp implements Comparator<Object> {
   ...>     public int compare(Object o1, Object o2) {
   ...>         return o1.toString().length() - o2.toString().length();
   ...>     }
   ...> }
|  created class ObjectStringLengthComp

jshell> shapes.sort(new ShapeAreaComp()).sort(new ObjectStringLengthComp())
$.. ==> [Rectangle 2 x 3, Circle with radius 1]
```

- Sorting by radius of circle, i.e. via `Comparator<Circle>`

```
jshell> class CircleRadiusComp implements Comparator<Circle> {
   ...>     public int compare(Circle c1, Circle c2) {
   ...>         return c1.getRadius() - c2.getRadius(); // assuming Circle::getRadius() implemented
   ...>     }
   ...> }
|  created class CircleRadiusComp

jshell> shapes.sort(new CircleRadiusComp())
|  Error:
|  incompatible types: CircleRadiusComp cannot be converted to java.util.Comparator<? super Shape>
|  shapes.sort(new CircleRadiusComp())
|              ^--------------------^
```