CS2030 Lecture 7

The *Maybe* Context

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Outline and Learning Outcome

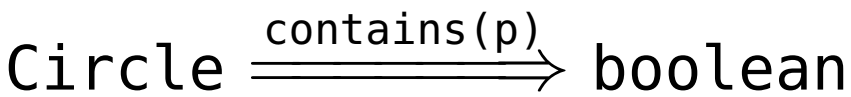
- Understand that `null` values are meaningless and may lead to `NullPointerExceptions` and why they should be avoided
- Know how to use Java's `Optional` class to handle `null` values
- Understand how *higher order functions* can be used to support **cross-barrier manipulation**
- Be able to define anonymous inner classes and lambda expressions
  - Appreciate that functions are first-class citizens
- Understand the concept of a *computation context*
- Able to define implementations of Java functional interfaces
- Appreciate `map` versus `flatMap`

`null` and `NullPointerException`

```
Circle createUnitCircle(Point p, Point q) {
    double d = p.distanceTo(q);
    if (d < EPSILON || d > 2.0 + EPSILON) {
        return null; // null is a Circle?
    } else {
        Point m = p.midPoint(q);
        double mp = Math.sqrt(1.0 - Math.pow(p.distanceTo(m), 2.0));
        double theta = p.angleTo(q);
        m = m.moveTo(theta + Math.PI / 2.0, mp);
        return new Circle(m, 1.0);
    }
}
```

```
jshell> Point p = new Point(0.5, 0.5)
p ==> (0.500, 0.500)
```

```
jshell> createUnitCircle(new Point(0, 0), new Point(0, 0)).contains(p)
|  Exception java.lang.NullPointerException: Cannot invoke
|  "REPL.$JShell$13$Circle.contains(REPL.$JShell$11$Point)"
|  because the return value of
|  "REPL.$JShell$14.createUnitCircle(REPL.$JShell$11$Point, REPL$JShell$11$Point)" is null
|        at (#5:1)
```



My Billion Dollar Mistake...

"I call it my billion-dollar mistake. It was the invention of the null reference in 1965. I couldn't resist the temptation to put in a null reference, simply because it was so easy to implement."

– Sir Charles Antony Richard Hoare
aka Tony Hoare

His friend, Edsger Dijkstra's response:
"If you have a null reference, then every bachelor who you represent in your object structure will seem to be married polyamorously to the same person Null"

A *Maybe* Context: Java `Optional`

- A *context* with connotations of *maybe* that "wraps" around another object of type `T`, i.e. maybe a `T` or maybe empty
- `Optional` static methods: `of` and `empty`

```
jshell> Optional.of("cs2030") // type-inference to Optional<String>
$.. ==> Optional[cs2030]

jshell> Optional.<String>of("cs2030") // type-witness to Optional<String>
$.. ==> Optional[cs2030]

jshell> Optional.<Object>of("cs2030") // type-witness to Optional<Object>
$.. ==> Optional[cs2030]

jshell> Optional.<String>empty() // Optional<String>
$.. ==> Optional.empty

jshell> Optional.empty() // type-inference to Optional<Object>
$.. ==> Optional.empty

jshell> Optional.<String>ofNullable(null) // how about of(null)?
$.. ==> Optional.empty
```

Returning a Context

- Redefine `createUnitCircle` to return `Optional<Circle>`

```
Optional<Circle> createUnitCircle(Point p, Point q) {
    double d = p.distanceTo(q);
    if (d < EPSILON || d > 2.0 + EPSILON) {
        return Optional.<Circle>empty();
    } else {
        Point m = p.midPoint(q);
        double mp = Math.sqrt(1.0 - Math.pow(p.distanceTo(m), 2.0));
        double theta = p.angleTo(q);
        m = m.moveTo(theta + Math.PI / 2.0, mp);
        return Optional.<Circle>of(new Circle(m, 1.0));
    }
}
```

```
jshell> createUnitCircle(new Point(0, 0), new Point(1, 1))
$.. ==> Optional[Circle at (0.000, 1.000) with radius 1.0]

jshell> createUnitCircle(new Point(0, 0), new Point(10, 10))
$.. ==> Optional.empty

jshell> createUnitCircle(new Point(0, 0), new Point(0, 0))
$.. ==> Optional.empty
```

Chaining Methods to a Context

- Chaining with a `contains` method gives a compilation error:

```
jshell> createUnitCircle(new Point(0, 0), new Point(1, 1)).contains(new Point(0, 1))
|  Error:
|  cannot find symbol
|    symbol:   method contains(Point)
|  createUnitCircle(new Point(0, 0), new Point(1, 1)).contains(new Point(0, 1))
|  ^-----------------------------------------------------------^
```

  - Need to pass the `contains` method into `Optional` via a **higher-order function**
    - a function that takes in another function

- A function is a *first-class citizen*, i.e. just like any value/object
  - assign a function to a variable
  - pass a function as an argument to another method
  - return a function from another method

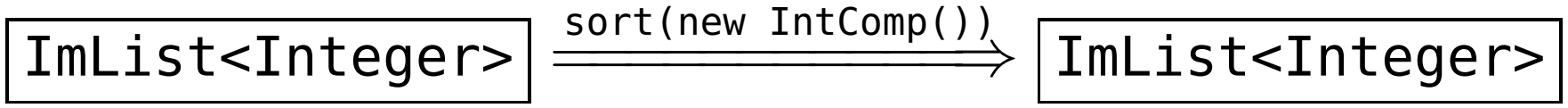
Cross-Barrier Manipulation

- **Cross-barrier manipulation** — where the client defines a function that is passed to the context for execution
- Recap: the `sort` method in `ImList<E>` that takes in a `Comparator<? super E>`

```
jshell> ImList<Integer> list123 = ImList.<Integer>of().add(1).add(2).add(3)
list123 ==> [1, 2, 3]

jshell> class IntComp implements Comparator<Integer> {
   ...>     @Override
   ...>     public int compare(Integer x, Integer y) {
   ...>         return y - x;
   ...>     }
   ...> }
|  created class IntComp

jshell> list123.sort(new IntComp())
$.. ==> [3, 2, 1]
```



Anonymous Inner Class

- Define an *anonymous inner class* instead of a concrete class

```
jshell> Comparator<Integer> comp = new Comparator<Integer>() {
   ...>    @Override
   ...>    public int compare(Integer x, Integer y) {
   ...>       return y - x;
   ...>    }
   ...> }
comp ==> 1@20e2cbe0

jshell> list123.sort(comp)
$.. ==> [3, 2, 1]
```

- Which part of the anonymous inner class is *really* useful?
  - Interface name (`Comparator`) does not add value
  - `Comparator` is a SAM (*single abstract method*) interface
    - there is only one abstract method in `Comparator`
    - method name `compare` does not add value

Lambda Expression

- Lambda syntax: `(`*parameterList*`) -> {`*statements*`}`
  - inferred parameter type with body: `(x, y) -> { return x * y; }`
  - body contains a single return expression: `(x, y) -> x * y`
  - only one parameter: `x -> 2 * x`
  - no parameter: `() -> 1`
- A lambda is a implementation of some *functional interface* — interface with single abstract method (SAM)
  - `Comparator` is a functional interface with SAM `compare`

```
jshell> Comparator<Integer> comp = (x, y) -> y - x
comp ==> $Lambda$15/0x0000001000a9440@68be2bc2

jshell> list123.sort(comp)
$.. ==> [3, 2, 1]
```

  - Other useful functional interfaces: `Supplier`, `Consumer`, `Predicate`, `Function`, `BiFunction`, etc.

Computation Context

- A *computation context* wraps around a value, and abstracts away computations associated with the context
  - a "safe box" in which functions can be safely executed
  - e.g. `Optional` is a computation context that handles invalid or missing values
- A computation context comprises:
  - a way to wrap the parameter within the box, e.g. using `of`

    ```
    Optional<Integer> oi = Optional.<Integer>of(1)
    ```
  - a way to pass a behaviour into the box via a *higher order method* (method that takes in another method) so that it can be applied to the parameter value

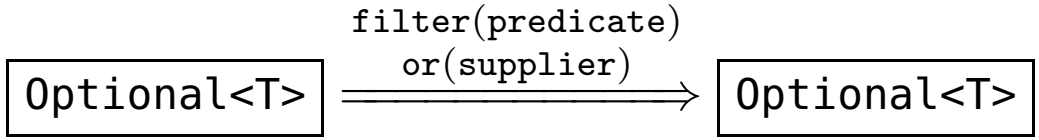
Some Higher Order Methods in `Optional`

`Optional<T> filter(Predicate<? super T> predicate)`

- `Predicate<T>` with a single abstract method: `public boolean test(T t)`

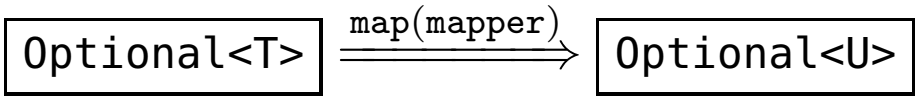
`Optional<T> or(Supplier<? extends Optional<? extends T>> supplier)`

- `Supplier<T>` with a single abstract method: `public T get()`



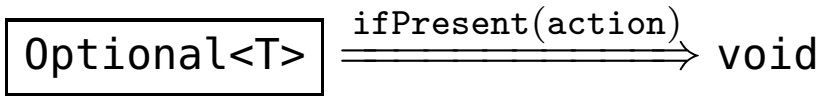
`<U> Optional<U> map(Function<? super T,? extends U> mapper)`

- `Function<T,R>` with a single abstract method: `public R apply(T t)`



`void ifPresent(Consumer<? super T> action)`

- `Consumer<T>` with single abstract method: `public void accept(T t)`



`filter` Higher Order Method

- Defining a `Predicate<Circle> pred` as a function to be applied on a `Circle c` and returning `true` or `false`

```
jshell> Predicate<Circle> pred = c -> c.contains(new Point(0.5, 0.5))
pred ==> $Lambda$20/0x0000000800c0d000@7cd84586
```

- Passing `pred` to the `filter` method of `Optional<Circle>`

```
jshell> createUnitCircle(new Point(0, 0), new Point(1, 1))
$.. ==> Optional[Circle at (0.000, 1.000) with radius 1.0]

jshell> createUnitCircle(new Point(0, 0), new Point(0, 0))
$.. ==> Optional.empty

jshell> createUnitCircle(new Point(0, 0), new Point(1, 1)).
   ...> filter(pred)
$.. ==> Optional[Circle at (0.000, 1.000) with radius 1.0]

jshell> createUnitCircle(new Point(0, 0), new Point(0, 0)).
   ...> filter(pred)
$.. ==> Optional.empty

jshell> createUnitCircle(new Point(0, 0), new Point(1, 1)).
   ...> filter(x -> x.contains(new Point(5.0, 5.0)))
$.. ==> Optional.empty
```

- `Optional<T>::filter` takes in `Predicate<? super T>`

`or` and `ifPresent` Higher Order Methods

- `Optional<T>::ifPresent` takes in `Consumer<? super T>`

```
jshell> Consumer<Circle> action = c -> System.out.println(c)
action ==> $Lambda$24/0x0000000800c13890@41975e01

jshell> createUnitCircle(new Point(0, 0), new Point(1, 0)).ifPresent(action)
Circle at (0.500, 0.866) with radius 1.0

jshell> createUnitCircle(new Point(0, 0), new Point(0, 0)).ifPresent(action) // skips the action

jshell> createUnitCircle(new Point(0, 0), new Point(0, 0)).
   ...> ifPresentOrElse(action, () -> { System.out.println("nil");}) // takes in Runnable too!
nil
```

- `Optional<T>::or` takes in `Supplier<? extends Optional<? extends T>>`

```
jshell> Supplier<Optional<Circle>> supp = () -> {
   ...>     System.out.println("beep!");
   ...>     return Optional.<Circle>of(new Circle(new Point(0, 0), 1.0));}
supp ==> $Lambda$23/0x0000000800c13058@15615099

jshell> createUnitCircle(new Point(0, 0), new Point(1, 0))
$.. ==> Optional[Circle at (0.500, 0.866) with radius 1.0]

jshell> createUnitCircle(new Point(0, 0), new Point(1, 0)).or(supp)
$.. ==> Optional[Circle at (0.500, 0.866) with radius 1.0]

jshell> createUnitCircle(new Point(0, 0), new Point(0, 0)).or(supp)
beep!
$.. ==> Optional[Circle at (0.000, 0.000) with radius 1.0] // supp is invoked on demand
```

`map` as a Higher Order Method

- E.g. mapping `Circle` to a `Boolean` while maintaining the `Optional` context

```
jshell> Function<Circle, Boolean> f = x -> x.contains(new Point(0.5, 0.5))
f ==> $Lambda$20/0x0000000800c0a420@27973e9b

jshell> createUnitCircle(new Point(0, 0), new Point(1, 1)).map(f)
$.. ==> Optional[true]

jshell> createUnitCircle(new Point(0, 0), new Point(0, 0)).map(f)
$.. ==> Optional.empty
```

- `Optional::map` takes in `Function<? super T, ? extends U>`
  - `T thing` in `Optional` can be *read* as `T` or it's supertype
  - result of function can be anything `U` or it's subtype

```
jshell> Function<Object,Integer> g = x -> x.toString().length()
g ==> $Lambda$26/0x0000000800c14838@6f2b958e

jshell> Optional<Number> on = createUnitCircle(new Point(0, 0), new Point(1, 0)).map(g)
on ==> Optional[40]

jshell> Optional<Number> on = createUnitCircle(new Point(0, 0), new Point(0, 0)).map(g)
on ==> Optional.empty
```

map versus flatMap

- Suppose `Circle::contains` returns `Optional<Boolean>`

```
Optional<Boolean> contains(Point p) {
    return Optional.<Boolean>of(this.centre.distanceTo(p) < this.radius);
}
```

- Now consider the following mapping operation:

```
jshell> Function<Circle,Optional<Boolean>> f =
   ...> x -> x.contains(new Point(0.5, 0.5))
f ==> $Lambda$20/0x0000000800c0ae68@3941a79c

jshell> createUnitCircle(new Point(0,0), new Point(1,1)).map(f)
$.. ==> Optional[Optional[true]] // value of type Optional<Optional<Boolean>>
```

- Use `flatMap` instead of `map`

```
jshell> createUnitCircle(new Point(0,0), new Point(1,1)).flatMap(f)
$.. ==> Optional[true]
```

- Higher order method `flatMap` in `Optional`:

```
<U> Optional<U> flatMap(
    Function<? super T, ? extends Optional<? extends U>> mapper)
```