Meme Credit: Grayson Schultz

Lab 4: Optionals and Lambdas

CS 2112 Fall 2025

September 22 / 24, 2025

Dynamic Typing

In dynamically typed languages, no type-checking is performed for the programmer.

```
1 function subtract(a, b) {
2     return a - b;
3 }
4
5 subtract("1", 1);
```

While this has its advantages, it can lead to difficult-to-debug errors, and thus has been losing popularity in recent years.

Type System

A statically typed language can enforce correct types. Thus, this entire class of error is impossible to reproduce in a typed language, as the code would never have compiled.

```
1  int subtract(int a, int b) {
2      return a - b;
3  }
4  subtract("1", 1); // TYPE ERROR
5
6  String concat(String a, int b) {
7      return a.concat(b);
8  }
9  concat("1", 1); // ok
```

Null

Except...

```
1 String concat(String a, int b) {
2     return a.concat(b);
3 }
4
5 concat(null, 1);
```

Null is a magic value that overrides all type-checking and can be passed in as any type, despite not being an object of that class. As such, NullPointerExceptions are frequent and difficult to debug.

Regret

"I call it my billion-dollar mistake.
It was the invention of the null reference in 1965."

- Tony Hoare, inventor of null (and QuickSort)

Why null?

It can be useful to have an empty value

```
1 /**
2  * Returns middle initial of the given user.
3  */
4 public char getMiddleInitial()
```

It's convenient to use null to represent an empty value, but it's easy to forget to check

Fundamental Theorem of Software Engineering

All problems in computer science can be solved by another level of indirection (abstraction)

Optional

- Contains a value, or is empty
- Makes you check when you access the value

Optional<T> API

```
1 public boolean isEmpty() { ... }
2 public T get() { ... }
```

Unfortunately, `get()` can throw an unchecked exception, which kind of defeats the point.

Creating Our Own Abstraction

We'll build our own class, called `Maybe<T>`.
TODO list:

- Class Signature
- Instance Variables
- Class Invariant
- Constructors

Basic Setup

Implement the following three methods:

```
1 boolean isPresent()
2
3 T get() throws AbsentInformationException
4
5 T orElse(T other)
```

You may choose another checked exception for `get()` to throw if you wish.

Why "Lambda"?

Anonymous functions are also called lambdas.
Name originates from Alonzo Church's "Lambda Calculus" (1930s)
Wrote functions as $(\lambda x.M)$ with x as the parameter, M as the expression

Portions of this section's slides are adapted from CS 2110 by Prof. David Gries

Motivation

Imagine having two methods that share almost all their code, save for a single value in the middle:

```
1 void method1() {
2     // Lots of code
3     int c = a + 1;
4     // More code
5 }
```

```
1 void method2() {
2     // The same code
3     int c = a + 2;
4     // More code
5 }
```

The solution is to factor this code into a helper function and then each implementation can call that function.

```
1 // method1:
2 helper(1);
3
4 // method2:
5 helper(2);
```

```
1 void helper(int v) {
2     // The same code
3     int c = a + v;
4     // More code
5 }
```

Motivation cont.

But now, imagine the difference is in an operation in the middle:

```
1 void method1() {
2     // Lots of code
3     int c = a + b;
4     // More code
5 }
```

```
1 void method2() {
2     // The same code
3     int c = a * b;
4     // More code
5 }
```

The setup is the same. But here, the difference is in code. How could we pass in the operation we with to perform as a parameter?

Assert Throws

Or consider the `AssertThrows` method from JUnit. How does the method call the code that's supposed to throw an exception?

```
1  try {
2      // ??? What goes here?
3      fail();
4  } catch (Throwable t) {
5      // Test passes if t has correct type
6  }
```

We know how to pass primitives and objects to a method, but how could we go about passing an entire function as a value?

Example

The expression on the right below is equivalent to the method in the class on the left.

```
1  class Test {
2    int sum(int a, int b) {
3      return a + b;
4    }
5  }
```

```
1  (a, b) -> a + b
```

More Examples

```
1  // without parameters
2  () -> System.out.println("Hello, world")
3
4  // with only 1 parameter
5  a -> a
6
7  // with explicit types
8  (int id, String name) -> name + id
9
10 // with a code block
11 (a, b) -> { if (a < b) return a; else return b; }
```

Implementation

Imagine trying to figure out how to pass a function as a value before lambdas existed in Java.
If we want to call a method, we have to call it on an object. If we accept an object as a parameter, we should declare an interface to ensure the object has the method we require.

```
1 interface F1 {
2     Integer m(String s);
3 }
4 void doSomething(F1 v1) {
5     System.out.println(v1.m("34"));
6 }
```

Implementation

To use this method, we'd then need to make a new class that implements the interface, instantiate the class, and pass that object in as the parameter.

```
1  interface F1 { Integer m(String s); }
2  void doSomething(F1 v1) {
3      System.out.println(v1.m("34"));
4  }
5  class C implements F1 {
6      public Integer m(String s) {
7          return Integer.valueOf(s);
8      }
9  }
10 doSomething(new C());
```

Implementation

An anonymous function is actually equivalent to doing all of that. The anonymous function itself will create a new class that implements the interface and its method:

```
1 interface F1 { Integer m(String s); }
2 void doSomething(F1 v1) {
3     System.out.println(v1.m("34"));
4 }
5
6 // equivalent to last slide
7 doSomething(s -> Integer.valueOf(s));
```

Demo

You can actually see this by creating your own interface, and then calling `toString()` on some lambdas, as the default `toString()` is to print the class name and memory location:

```
1 interface F1 { Integer m(String s); }
2 F1 v1 = s -> Integer.valueOf(s);
3 v1.toString(); // $Lambda$13/0x000008@6cc4
4 F1 v2 = s -> Integer.valueOf(s);
5 v2.toString(); // $Lambda$14/0x000004@643b
```

Functional Interface

An interface that has exactly one abstract method in it can be annotated with `@FunctionalInterface`

```
1 @FunctionalInterface
2 interface F1 {
3     Integer m(String s);
4 }
```

Functional Interface Example

An example of a commonly used functional interface.

```
1 int[] a = {1,2,3,4};
2 a = Arrays.stream(a).filter(x -> x%2 == 0).toArray();
3 // a now contains {2,4}
```

Syntactic Sugar

An anonymous function that takes the same parameters as an existing method can be used directly with double colon notation

```
1 s -> Integer.valueOf(s)
2 // equivalent to
3 Integer::valueOf
```

Built-In Interfaces

Java's standard library provides a large number of built-in functional interfaces that you may find useful. They are under the `java.util.function` package.

Practice

Fill in the blank:

```
1 /** Remove empty strings from str.*/
2 public void practice(List<String> str) {
3     str.removeIf(       TODO        );
4 }
```

Practice

Fill in the blank:

```
1 /** Remove empty strings from str.*/
2 public void practice(List<String> str) {
3     str.removeIf(       TODO        );
4 }
```

The answer is `s -> s.isEmpty()`

ifPresent()

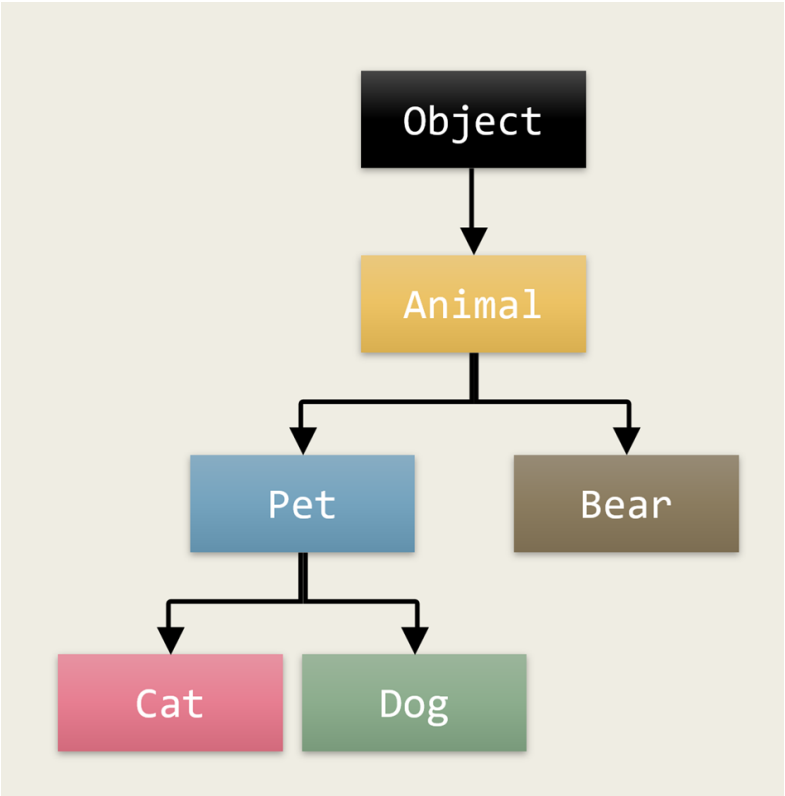
Write the method `ifPresent()` which calls a lambda on the value if it exists.
You may find the interface `Consumer<E>` useful. It represents a function from `E` to `void`.

```
1 void ifPresent(Consumer< ??? > action);
```

What should the action be parameterized on? It is a lambda that must be able to take something the value (of type `T`) can be cast to, meaning `T` or a supertype of `T`. Thus, the answer is `Consumer<? super T>`.

Contravariance

Why does the lambda need to accept supertypes of `T`?
Imagine trying to pass an object of type `Pet` to a function as an argument. Which of these types could the argument be declared as if this is to succeed?
Notice that if the function accepted `Animal` or `Object` as its argument, this would still work.
The input type must be a supertype of the given value.



filter()

Write the method `filter()` which returns a Maybe with the value if the value exists and matches a given condition.
You may find the interface `Predicate <E>` useful. It represents a function from `E` to `boolean`.

```
1 Maybe<T> filter(Predicate< ??? > predicate);
```

What should the predicate be parameterized on? It is a lambda that must be able to take something the value (of type `T`) can be cast to, meaning `T` or a supertype of `T`. Thus, the answer is `Predicate<? super T>`.

map()

Write the method `map()` which calls a lambda on the value if it exists and returns a Maybe with the result.
You may find the interface `Function<E, F>` useful. It represents a function from `E` to `F`.

```
1 <U> Maybe<U> map(Function< ??? , ??? > mapper);
```

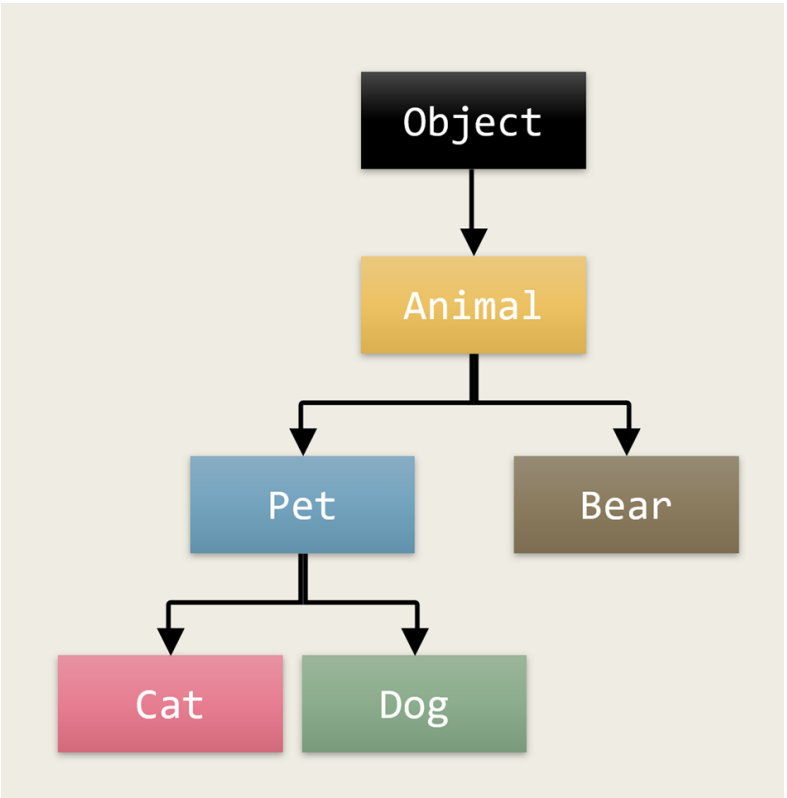
What should the mapper be parameterized on? It is a lambda that must be able to take something the value (of type `T`) can be cast to, meaning `T` or a supertype of `T`. It must return something that can be cast to `U`, either `U` or a subtype of `U`. Thus, the answer is `Function<? super T, ? extends U>`.

Covariance

We saw that the lambda must accept a supertype of `T`. Why does the lambda need to return a subtype of `U`? Imagine calling a function and expecting an object of type `Pet` as the return value. Which of these types could the function return if this is to succeed?

Notice that if the function returned `Dog` or `Cat` as its argument, this would still work. The output type must be a subtype of what's expected.

In essence, the given type must be a subtype of the receiving type. When passing arguments into a function, the function is receiving. When the function returns, the function is giving. Hence the asymmetry.



toString()

Now implement `toString()`, which returns the value of calling `toString()` on the value if it is present, or a special string (you get to pick) if it is not.
This can be done in **just one line** using `map()` and `orElse()`.
Hopefully this shows how powerful lambdas can be, helping you keep your code succinct and legible.

Additional Exercise

Implement any or all of the following methods you may find useful.

- `int hashCode()`
- `Maybe<T> or(Supplier<? extends Maybe<? extends T>>)`
- `T orElseGet(Supplier<? extends T>)`
- `<U> Maybe<U> flatMap(`
  `Function<? super T, ? extends Maybe<? extends U>>)`

Congratulations! You've built your own abstraction that will hopefully make your future code cleaner and simpler.