Lecture 8

Lambda Expressions

SOEN 6441, Summer 2018

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Outline

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2. Functional interfaces
3. Type Checking and Inference
4. Method References
5. Application
6. Composing lambda expressions
7. Summary
8. Notes and Further Reading

René Witte

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- Function Descriptors
- Execute Around Pattern

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Sorting with a Comparator

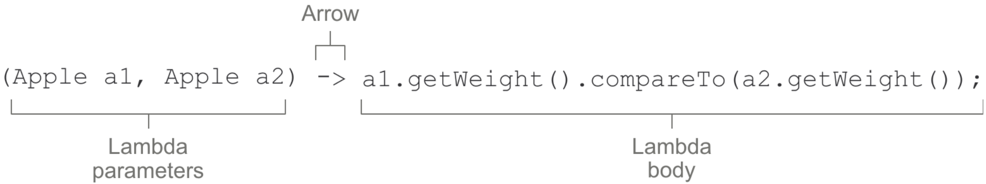
Creating a `Comparator`

```
Comparator<Apple> byWeight = new Comparator<Apple>() {
  public int compare(Apple a1, Apple a2){
    return a1.getWeight().compareTo(a2.getWeight());
  }
};
```

With a lambda expression

```
Comparator<Apple> byWeight =
  (Apple a1, Apple a2) -> a1.getWeight().compareTo(a2.getWeight());
```

Lambda expressions



```
(Apple a1, Apple a2) -> a1.getWeight().compareTo(a2.getWeight());
```

Arrow

Lambda parameters

Lambda body

Lambda expressions (II)

Anonymous Functions

Anonymous: no function name

Function: has parameters, return type, function body, exceptions; but **not** associated with a class

Passed around: can be passed as an argument to a method or stored in a variable

Concise: no need for boilerplate code, like for anonymous classes

Name comes from lambda calculus, see https://en.wikipedia.org/wiki/Lambda_calculus.

Java 8 Syntax

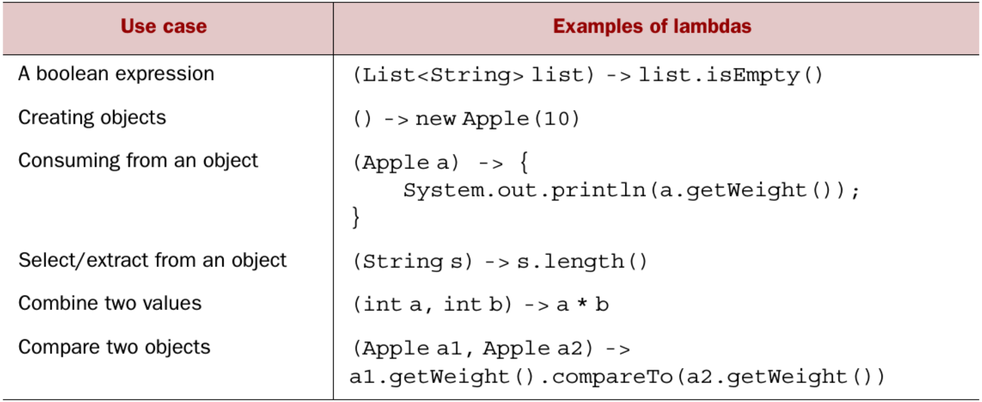
Single expressions:

```
(parameters) -> expression
```

List of statements:

```
(parameters) -> { statements; }
```

Lambda expressions (III)



Use case	Examples of lambdas
A boolean expression	`(List<String> list) -> list.isEmpty()`
Creating objects	`() -> new Apple(10)`

Consuming from an object	`(Apple a) -> {`
	`    System.out.println(a.getWeight());`
	`}`

Select/extract from an object	`(String s) -> s.length()`
Combine two values	`(int a, int b) -> a * b`

Compare two objects	`(Apple a1, Apple a2) ->`
	`a1.getWeight().compareTo(a2.getWeight())`

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Functional Interfaces

Definition

A functional interface is an interface that specifies exactly one abstract method.

Example

```
public interface Predicate<T>{
  boolean test (T t);
}
```

Functional Interface Examples

java.util.Comparator

```
public interface Comparator<T> {
  int compare(T o1, T o2);
}
```

java.lang.Runnable

```
public interface Runnable{
  void run();
}
```

java.awt.event.ActionListener

```
public interface ActionListener extends EventListener{
  void actionPerformed(ActionEvent e);
}
```

Functional Interfaces and Lambdas

```
Runnable r1 = () -> System.out.println("Hello␣World␣1");

Runnable r2 = new Runnable(){
  public void run(){
    System.out.println("Hello␣World␣2");
  }
};

public static void process(Runnable r){
  r.run();
}

process(r1);
process(r2);
process(() -> System.out.println("Hello␣World␣3"));
```

Function Descriptors

Definition

The abstract method in the functional interface is called a function descriptor. The signature of the abstract method describes the signature of the lambda expression.

Example

```
public void process(Runnable r){
  r.run();
}

process(() -> System.out.println("This␣is␣awesome!!"));
```

Note

You can pass lambdas only where a functional interface is expected

The Execute Around Pattern

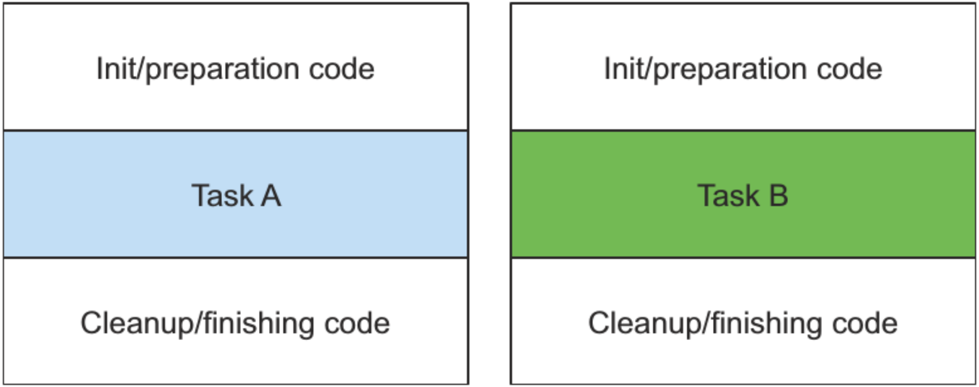
Pattern in resource processing (file, database, . . .)

1. Open a resource
2. Process the resource
3. Close the Resource

Example: File processing in Java 7

```
public static String processFile() throws IOException {
  try (BufferedReader br = new BufferedReader(
                               new FileReader("data.txt"))) {
    return br.readLine();
  }
}
```

Step 1: Behavior parameterization



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Example: Process two lines

```
String result = processFile((BufferedReader br) ->
                              br.readLine() + br.readLine());
```

Step 2: Use a functional interface

Define the Interface

```
@FunctionalInterface
public interface BufferedReaderProcessor {
  String process(BufferedReader b) throws IOException;
}
```

Usage

```
public static String processFile(BufferedReaderProcessor p)
throws IOException {
  ...
}
```

Step 3: Execute a behavior

```java
public static String processFile(BufferedReaderProcessor p)
       throws IOException {
  try (BufferedReader br = new BufferedReader(
                               new FileReader("data.txt"))) {
    return p.process(br);
  }
}
```

Step 4: Pass lambdas

Process one line

```
String oneLine = processFile((BufferedReader br) -> br.readLine());
```

Process two lines

```
String twoLines =
  processFile((BufferedReader br) -> br.readLine() + br.readLine());
```

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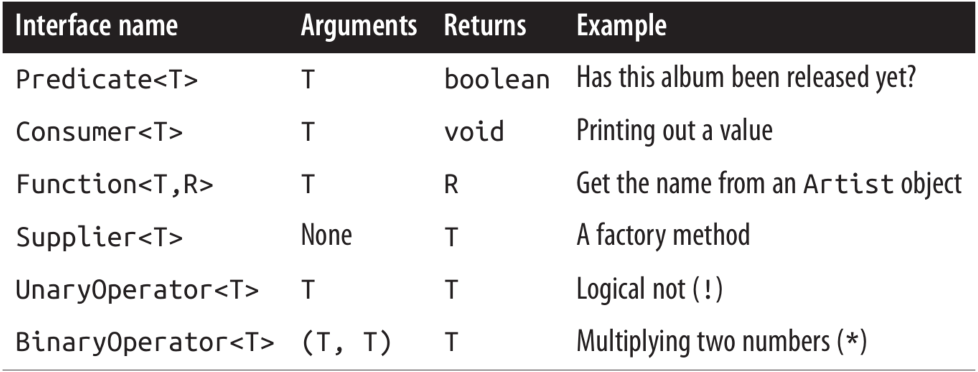
New Functional Interfaces in Java 8: Examples



Interface name	Arguments	Returns	Example
`Predicate<T>`	T	boolean	Has this album been released yet?
`Consumer<T>`	T	void	Printing out a value
`Function<T,R>`	T	R	Get the name from an `Artist` object
`Supplier<T>`	None	T	A factory method
`UnaryOperator<T>`	T	T	Logical not (!)
`BinaryOperator<T>`	(T, T)	T	Multiplying two numbers (*)

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Predicate

```
@FunctionalInterface
public interface Predicate<T>{
  boolean test(T t);
}

public static <T> List<T> filter(List<T> list, Predicate<T> p) {
  List<T> results = new ArrayList<>();
  for(T s: list){
    if(p.test(s)){
      results.add(s);
    }
  }
  return results;
}

Predicate<String> nonEmptyStringPredicate = (String s) -> !s.isEmpty();
List<String> nonEmpty = filter(listOfStrings, nonEmptyStringPredicate);
```

Consumer

```
@FunctionalInterface
public interface Consumer<T>{
  void accept(T t);
}

public static <T> void forEach(List<T> list, Consumer<T> c){
  for(T i: list){
    c.accept(i);
  }
}

forEach(Arrays.asList(1,2,3,4,5), (Integer i) -> System.out.println(i));
```

Function

```java
@FunctionalInterface
public interface Function<T, R> {
  R apply(T t);
}

public static <T, R> List<R> map(List<T> list, Function<T, R> f) {
  List<R> result = new ArrayList<>();
  for(T s: list){
    result.add(f.apply(s));
  }
  return result;
}

List<Integer> l = map(Arrays.asList("lambdas","in","action"),
                      (String s) -> s.length()
                     );
// l = ???
```

Primitive Types

Primitive Types vs. Reference Types

Primitive Types: `int, double, byte, char, ...`

Reference Types: `Byte, Integer, Object, List, ...`

Boxing: converting a primitive type into a reference type

Unboxing: converting a reference type into a primitive type

Autoboxing

```java
List<Integer> list = new ArrayList<>();
for (int i = 300; i < 400; i++){
  list.add(i);
}
```

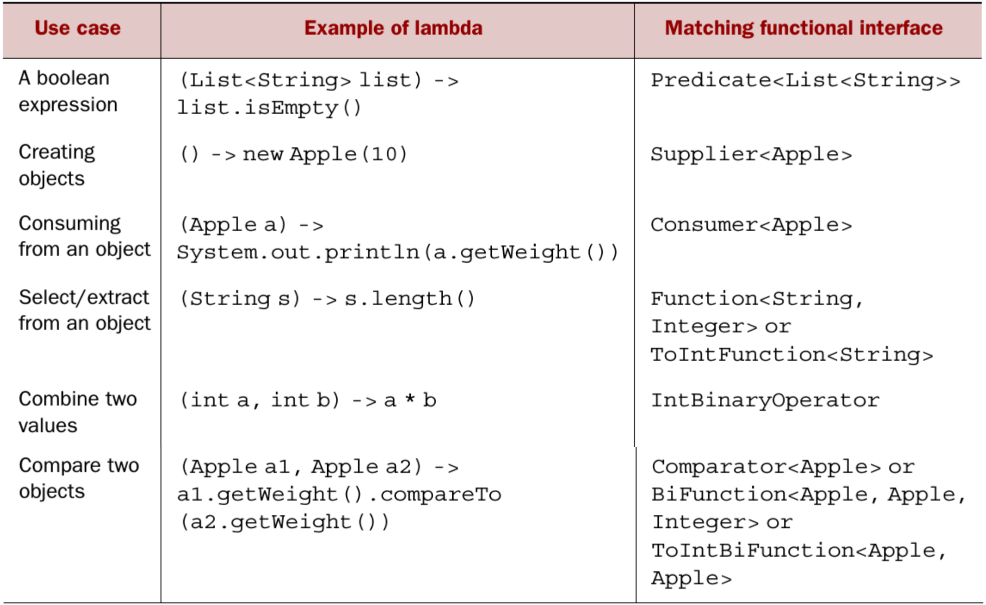
Primitive Specializations

```
public interface IntPredicate{
  boolean test(int t);
}

IntPredicate evenNumbers = (int i) -> i % 2 == 0;
evenNumbers.test(1000);

Predicate<Integer> oddNumbers = (Integer i) -> i % 2 == 1;
oddNumbers.test(1000);
```

Examples



Use case	Example of lambda	Matching functional interface
A boolean expression	`(List<String> list) -> list.isEmpty()`	`Predicate<List<String>>`
Creating objects	`() -> new Apple(10)`	`Supplier<Apple>`
Consuming from an object	`(Apple a) -> System.out.println(a.getWeight())`	`Consumer<Apple>`
Select/extract from an object	`(String s) -> s.length()`	`Function<String, Integer>` or `ToIntFunction<String>`
Combine two values	`(int a, int b) -> a * b`	`IntBinaryOperator`
Compare two objects	`(Apple a1, Apple a2) -> a1.getWeight().compareTo (a2.getWeight())`	`Comparator<Apple>` or `BiFunction<Apple, Apple, Integer>` or `ToIntBiFunction<Apple, Apple>`

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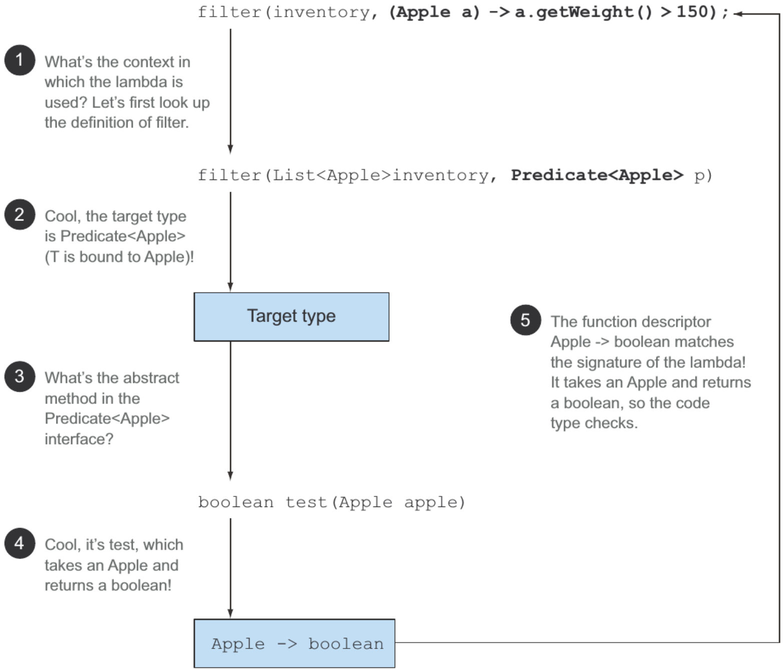
Type checking

```
List<Apple> heavierThan150g =
    filter(inventory, (Apple a) -> a.getWeight() > 150);
```



`filter(inventory, (Apple a) -> a.getWeight() > 150);`

1 What's the context in which the lambda is used? Let's first look up the definition of filter.

`filter(List<Apple>inventory, Predicate<Apple> p)`

2 Cool, the target type is Predicate<Apple> (T is bound to Apple)!

Target type

3 What's the abstract method in the Predicate<Apple> interface?

`boolean test(Apple apple)`

4 Cool, it's test, which takes an Apple and returns a boolean!

`Apple -> boolean`

5 The function descriptor Apple -> boolean matches the signature of the lambda! It takes an Apple and returns a boolean, so the code type checks.

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Target Typing

Same lambda, different functional interfaces

```
Callable<Integer> c = () -> 42;
PrivilegedAction<Integer> p = () -> 42;
```

Compare with Java 7 Diamond Operator

```
List<String> listOfStrings = new ArrayList<>();
List<Integer> listOfIntegers = new ArrayList<>();
```

Special void-compatibility rule

```
// Predicate has a boolean return
Predicate<String> p = s -> list.add(s);
// Consumer has a void return
Consumer<String> b = s -> list.add(s);
```

Type Checking: Example

Does it compile?

```
Object o = () -> {System.out.println("Tricky␣example"); };
```

Error

```
Quiz.java:5: error: incompatible types: Object is not a functional interface
    Object o = () -> {System.out.println("Tricky␣example"); };
               ^
1 error
```

Type Inference

Java compiler can infer lambda parameter types

```
List<Apple> greenApples =
    filter(inventory, a -> "green".equals(a.getColor()));
```

Without type inference

```
Comparator<Apple> c =
    (Apple a1, Apple a2) -> a1.getWeight().compareTo(a2.getWeight());
```

With type inference

```
Comparator<Apple> c =
    (a1, a2) -> a1.getWeight().compareTo(a2.getWeight());
```

Using local variables

Capturing lambdas

```
int portNumber = 1337;
Runnable r = () -> System.out.println(portNumber);
```

Rules

Lambdas can capture:

- instance variables
- static variables
- `final` local variables
- effectively `final` local variables

Error

```
int portNumber = 1337;
Runnable r = () -> System.out.println(portNumber);
portNumber = 31337;
```

```
Error: local variables referenced from a lambda expression must
be final or effectively final.
```

Closures

Definition

A closure is an instance of a function that can reference nonlocal variables of that function with no restrictions.

Closures in Java 8?

- Java 8 does not allow lambdas to modify variables defined outside its scope
- However, they can be passed as method arguments
- and read variables outside their scope

We can say Java 8 lambdas close over values, rather than variables

Method References

Passing an existing method

```
inventory.sort((Apple a1, Apple a2) ->
    a1.getWeight().compareTo(a2.getWeight()));
```

With a method reference

```
inventory.sort(comparing(Apple::getWeight));
```

Improve code readability

Instead of

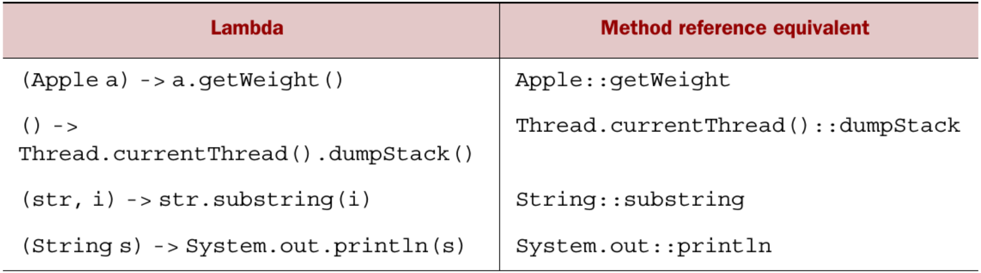
```
(Apple a) -> a.getWeight()
```

you can just say

```
Apple::getWeight
```

Note: no brackets `()` – we are not calling the method!

Method reference examples



Lambda	Method reference equivalent
`(Apple a) -> a.getWeight()`	`Apple::getWeight`
`() -> Thread.currentThread().dumpStack()`	`Thread.currentThread()::dumpStack`
`(str, i) -> str.substring(i)`	`String::substring`
`(String s) -> System.out.println(s)`	`System.out::println`

Constructing method references

1. Reference to a static method, e.g., `Integer::parseInt`
2. Reference to an instance method of an arbitrary type, e.g., `String::length`
3. Reference to an instance method of an existing object, e.g., with a variable `expensiveTransaction` of type `Transaction` that has an instance method `getValue`, write `expensiveTransaction::getValue`

Constructor references

Calling a constructor

```
Supplier<Apple> c1 = () -> new Apple();
Apple a1 = c1.get();
```

Now with constructor reference

```
Supplier<Apple> c1 = Apple::new;
Apple a1 = c1.get();
```

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Constructor references (II)

Calling a non-default constructor

```
Function<Integer, Apple> c2 = (weight) -> new Apple(weight);
Apple a2 = c2.apply(110);
```

Now with constructor reference

```
Function<Integer, Apple> c2 = Apple::new;
Apple a2 = c2.apply(110);
```

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Putting lambdas and method references into practice

```
inventory.sort(comparing(Apple::getWeight));
```

Step 1: Pass code

Java 8 `List.sort`

```
void sort(Comparator<? super E> c)
```

Implement Comparator (behavior parameterization!)

```
public class AppleComparator implements Comparator<Apple> {
  public int compare(Apple a1, Apple a2){
    return a1.getWeight().compareTo(a2.getWeight());
  }
}

inventory.sort(new AppleComparator());
```

Step 2: Use an anonymous class

```java
inventory.sort(new Comparator<Apple>() {
  public int compare(Apple a1, Apple a2){
    return a1.getWeight().compareTo(a2.getWeight());
  }
});
```

Step 3: Use lambda expressions

Goal: Passing Code!

- Can use lambda expression where a functional interface is expected
- `Comparator`: function descriptor `(T, T) -> int`
- here, `(Apple, Apple) -> int`

```
inventory.sort((Apple a1, Apple a2) ->
    a1.getWeight().compareTo(a2.getWeight()));
```

Shorter with type inference

```
inventory.sort((a1, a2) -> a1.getWeight().compareTo(a2.getWeight()));
```

More readable with `comparing` helper method

With

```
import static java.util.Comparator.comparing;
Comparator<Apple> c = Comparator.comparing((Apple a) -> a.getWeight());
```

we can write

```
inventory.sort(comparing((a) -> a.getWeight()));
```

Step 4: Use method references

```
inventory.sort(comparing(Apple::getWeight));
```

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Composing Comparators

Reversed Order

```
inventory.sort(comparing(Apple::getWeight).reversed());
```

Chaining Comparators

```
inventory.sort(comparing(Apple::getWeight)
         .reversed()
         .thenComparing(Apple::getCountry));
```

Composing Predicates

`Predicate` interface

Additional methods: `negate, and, or`

Example: Apples that are *not* red

```java
Predicate<Apple> notRedApple = redApple.negate();
```

Example: Apples that are red *and* heavy

```java
Predicate<Apple> redAndHeavyApple
    = redApple.and(a -> a.getWeight() > 150);
```

Example: Apples that are red *and* heavy *or* green

```java
Predicate<Apple> redAndHeavyAppleOrGreen =
    redApple.and(a -> a.getWeight() > 150)
            .or(a -> "green".equals(a.getColor()));
```

Composing Functions

Math: function composition

Let $f(x) = x + 1$ and $g(x) = x \cdot 2$, then we can compose both functions, written $g(f(x))$ or $(g \circ f)(x)$.

Java 8: `andThen`

To implement $(g \circ f)(x)$, use `andThen`

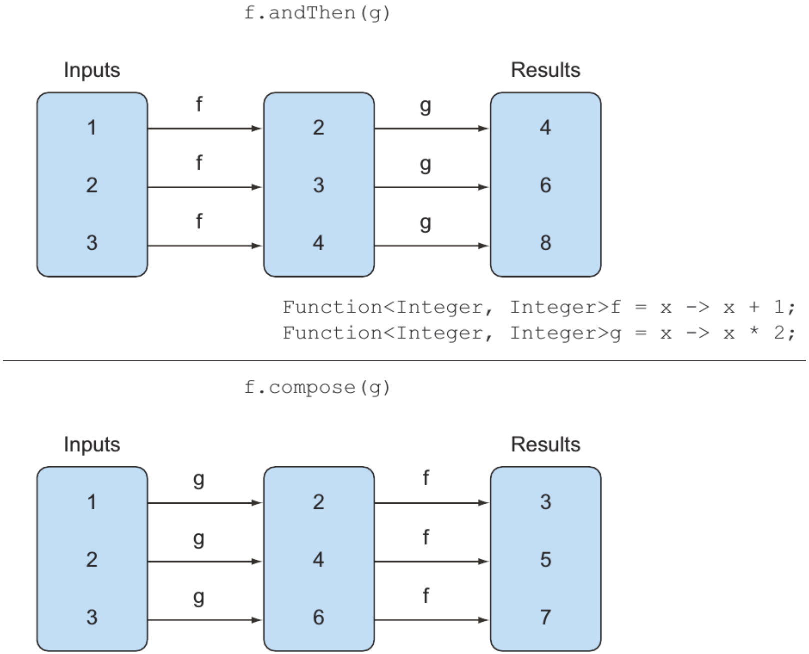
```
Function<Integer, Integer> f = x -> x + 1;
Function<Integer, Integer> g = x -> x * 2;
Function<Integer, Integer> h = f.andThen(g);
int result = h.apply(1);
```

Java 8: `compose`

To implement $(f \circ g)(x)$, use `compose`

```
Function<Integer, Integer> f = x -> x + 1;
Function<Integer, Integer> g = x -> x * 2;
Function<Integer, Integer> h = f.compose(g);
int result = h.apply(1);
```

andThen vs. compose



```
Function<Integer, Integer>f = x -> x + 1;
Function<Integer, Integer>g = x -> x * 2;
```

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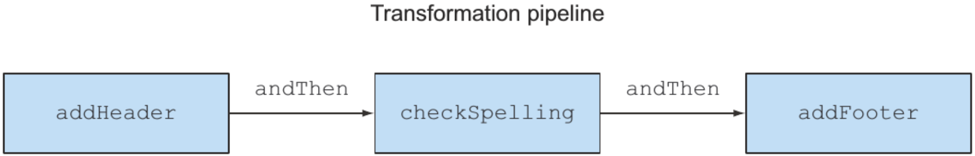
Example: Transformation Pipelines

```
public class Letter{
  public static String addHeader(String text){
    return "From␣Raoul,␣Mario␣and␣Alan:␣" + text;
  }

  public static String addFooter(String text){
    return text + "␣Kind␣regards";
  }

  public static String checkSpelling(String text){
    return text.replaceAll("labda", "lambda");
  }
}
```

Using function composition



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Creating the pipeline

```
Function<String, String> addHeader = Letter::addHeader;
Function<String, String> transformationPipeline
    = addHeader.andThen(Letter::checkSpelling)
               .andThen(Letter::addFooter);
```

Summary

Java 8 Lambdas

- A lambda expression can be understood as a kind of anonymous function: it doesn't have a name, but it has a list of parameters, a body, a return type, and also possibly a list of exceptions that can be thrown.
- Lambda expressions let you pass code concisely
- A functional interface is an interface that declares exactly one abstract method
- Lambda expressions can be used only where a functional interface is expected
- Lambda expressions let you provide the implementation of the abstract method of a functional interface directly inline and treat the whole expression as an instance of a functional interface

Summary (contd.)

Java 8 Lambdas (II)

- Java 8 comes with a list of common functional interfaces in the `java.util.function` package, which includes `Predicate<T>`, `Function<T,R>`, `Supplier<T>`, `Consumer<T>`, and `BinaryOperator<T>`
- There are primitive specializations of common generic functional interfaces such as `Predicate<T>` and `Function<T, R>` that can be used to avoid boxing operations: `IntPredicate`, `IntToLongFunction`, and so on
- The execute around pattern can be used with lambdas to gain additional flexibility and reusability
- The type expected for a lambda expression is called the target type
- Method references let you reuse an existing method implementation and pass it around directly
- Functional interfaces such as `Comparator`, `Predicate`, and `Function` have several default methods that can be used to combine lambda expressions.

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Reading Material

Required

- [UFM14, Chapter 3] (Lambda Expressions)

Supplemental

- [War14, Chapter 2] (Lambda Expressions)

References

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