Lambda Expressions in Java 8: Part 2 – More Details

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Topics in This Section

- The @FunctionalInterface annotation
- Method references
- Lambda scoping rules
- Effectively final local variables

The @FunctionalInterface Annotation

Review: @Override

- **What is benefit of @Override?**

```
public class MyCoolClass {
  @Override
  public String tostring() { ... }
}
```

- **Correct code will work with or without @Override, but @Override still useful**
  - Catches errors at compile time
    - Real method is toString, not tostring
  - Expresses design intent
    - Tells fellow developers this is a method that came from parent class, so API for Object will describe how it is used

New: @FunctionalInterface

- **Catches errors at compile time**
  - If developer later adds a second abstract method, interface will not compile
- **Expresses design intent**
  - Tells fellow developers that this is interface that you expect lambdas to be used for
- **But, like @Override not technically required**
  - You can use lambdas *anywhere* 1-abstract-method interfaces (aka functional interfaces, SAM interfaces) are expected, whether or not that interface used @FunctionalInterface

Interface Used in Numerical Integration Example

- **Last section**

```
public interface Integrable {
  double eval(double x);
}
```

- **Updated**

```
@FunctionalInterface
public interface Integrable {
  double eval(double x);
}
```


Interface Used in Timing Utilities Example

- **Last section**

```
public interface Op {
  void runOp();
}
```

- **Updated**

```
@FunctionalInterface
public interface Op {
  void runOp();
}
```

Method References

Basic Method References

- **Simplest type: static methods**
  - Replace
    ```
    (args) -> ClassName.staticMethodName(args)
    ```
  - with
    ```
    ClassName::staticMethodName
    ```
    - E.g., Math::cos, Arrays::sort, String::valueOf
  - Another way of saying this is that if the function you want to describe already has a name, you don't have to write a lambda for it, but can instead just use the method name
  - The signature of the method you refer to must match signature of the method in functional (SAM) interface to which it is assigned
- **Other method references described later**
  - variable::instanceMethod (e.g., System.out::println)
  - Class::instanceMethod (e.g., String::toUpperCase)
  - ClassOrType::new (e.g., String[]::new)

Example: Numerical Integration

- **In earlier example, replace these**

```
MathUtilities.integrationTest(x -> Math.sin(x), 0, Math.PI);
MathUtilities.integrationTest(x -> Math.exp(x), 2, 20);
```

- **With these**

```
MathUtilities.integrationTest(Math::sin, 0, Math.PI);
MathUtilities.integrationTest(Math::exp, 2, 20);
```


The Type of Method References

- **Question: what is type of Math::sin?**
  - Double? Function? Math?
- **Answer: can determine from context only**
  - The right question to ask would have been "what is the type of Math::sin *in code below*?"
    - MathUtilities.integrationTest(Math::sin, 0, Math.PI);
  - We can answer this the same way we answer any question about the type of an argument to a method: by looking at the API.
  - Conclusion: type here is Integrable
    - But in another context, Math::sin could be something else!
- **This point applies to all lambdas, not just method references**
  - The type can be determined only from context

The Type of Lambdas or Method References

- **Interfaces** (like Java 7)
  - public interface Foo { double method1(double d); }
  - public interface Bar { double method2(double d); }
  - public interface Baz { double method3(double d); }
- **Methods that use the interfaces** (like Java 7)
  - public void blah1(Foo f) { … f.method1(…)… }
  - public void blah2(Bar b) { … b.method2(…)… }
  - public void blah3(Baz b) { … b.method3(…)… }
- **Calling the methods** (use λs or method references)
  - blah1(Math::cos) *or* blah1(d -> Math.cos(d))
  - blah2(Math::cos) *or* blah2(d -> Math.cos(d))
  - blah3(Math::cos) *or* blah3(d -> Math.cos(d))
    - All the above could also use Math::sin, Math::log, Math::sqrt, Math::abs, etc.

Importance of Using Method References

- **Low!**
  - If you do not understand method references, you can always use explicit lambdas
  - Replace foo(Math::cos) with foo(d -> Math.cos(d))
  - Replace bar(System.out::println) with bar(s -> System.out.println(s))
  - Replace baz(Class::twoArgMethod) with (a, b) -> Class.twoArgMethod(a, b)
- **But method references are popular**
  - More succinct
  - Familiar to developers from several other languages, where you can refer directly to existing functions. E.g., in JavaScript

```
function square(x) { return(x*x); }
var f = square;
f(10); → 100
```

The Four Kinds of Method References

Method Ref Type	Example	Equivalent Lambda
SomeClass::staticMethod	Math::cos	x -> Math.cos(x)
someObject::instanceMethod	someString::toUpperCase	() -> someString.toUpperCase()
SomeClass::instanceMethod	String::toUpperCase	s -> s.toUpperCase()
SomeClass::new	Employee::new	() -> new Employee()

var::instanceMethod vs. Class::instanceMethod

- **someObject::instanceMethod**
  - Produces a lambda that takes *exactly as many* arguments as the method expects.

```
String test = "PREFIX:";
String result1 = transform(someString, test::concat);
```

- The concat method takes one arg
- This lambda takes one arg, passing s as argument to test.concat
- Equivalent lambda is s -> test.concat(s)

- **SomeClass::instanceMethod**
  - Produces a lambda that takes *one more* argument than the method expects. The first argument is the object on which the method is called; the rest of the arguments are the parameters to the method.

```
String result2= transform(someString, String::toUpperCase);
```

- The toUpperCase method takes zero args
- This lambda takes one arg, invoking toUpperCase on that argument
- Equivalent lambda is s -> s.toUpperCase()

Method Reference Examples: Helper Interface

```
@FunctionalInterface
public interface StringFunction {
  String applyFunction(String s);
}
```


Method Reference Examples: Helper Class

```
public class Utils {
  public static String transform(String s, StringFunction f) {
    return(f.applyFunction(s));
  }

  public static String makeExciting(String s) {
    return(s + "!!");
  }

  private Utils() {}
}
```

Method Reference Examples: Testing Code

```
public static void main(String[] args) {
  String s = "Test";

  // SomeClass::staticMethod
  String result1 = Utils.transform(s, Utils::makeExciting); Test!!
  System.out.println(result1);

  // someObject::instanceMethod
  String prefix = "Blah";
  String result2 = Utils.transform(s, prefix::concat);      BlahTest
  System.out.println(result2);

  // SomeClass::instanceMethod
  String result3 = Utils.transform(s, String::toUpperCase); TEST
  System.out.println(result3);
}
```


Preview: Constructor References

- **In Java 7, difficult to randomly choose which class to create**
  - Suppose you are populating an array of random shapes, and sometimes you want a Circle, sometimes a Square, and sometimes a Rectangle
  - It requires tedious code to do this, since constructors cannot be bound to variables
- **In Java 8, this is simple**
  - Make array of constructor references and choose one at random
    - `{ Circle::new, Square::new, Rectangle::new }`
  - This will be more clear once we introduce the Supplier type, which can refer to a constructor reference

Preview: Making Random Person

```
private final static Supplier[] peopleGenerators =
  { Person::new, Writer::new, Artist::new, Consultant::new,
    EmployeeSamples::randomEmployee,
    () -> { Writer w = new Writer();
            w.setFirstName("Ernest");
            w.setLastName("Hemingway");
            w.setBookType(Writer.BookType.FICTION);
            return(w); }
  };

public static Person randomPerson() {
  Supplier<Person> generator =
    RandomUtils.randomElement(peopleGenerators);
  return(generator.get());
}
```


Preview: Array Constructor References

- **Will soon see how to turn Stream into array**
  - `Employee[] employees = employeeStream.toArray(Employee[]::new);`
- **This is a special case of a constructor ref**
  - It takes an int as an argument, so you are calling "new Employee[n]" behind the scenes. This builds an empty Employee array, and then toArray fills in the array with the elements of the Stream
- **Most general form**
  - toArray takes a lambda or method reference to anything that takes an int as an argument and produces an array of the right type and right length
    - That array will then be filled in by toArray

Variable Scoping in Lambdas

Main Points

- **Lambdas are lexically scoped**
  - They do not introduce a new level of scoping
- **Implications**
  - The "this" variable refers to the outer class, not to the anonymous inner class that the lambda is turned into
  - There is no "OuterClass.this" variable
    - Unless lambda is inside a normal inner class
  - Lambdas cannot introduce "new" variables with same name as variables in method that creates the lambda
    - However, lambdas can refer to (but not modify) local variables from the surrounding method
  - Lambdas can still refer to (and modify) instance variables from the surrounding class

Examples

- **Illegal: repeated variable name**

```
double x = 1.2;
someMethod(x -> doSomethingWith(x));
```

- **Illegal: repeated variable name**

```
double x = 1.2;
someMethod(y -> { double x = 3.4; … });
```

- **Illegal: lambda modifying local var from the outside**

```
double x = 1.2;
someMethod(y -> x = 3.4);
```

- **Legal: modifying instance variable**

```
private double x = 1.2;
public void foo() {  someMethod(y -> x = 3.4); }
```

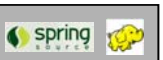
- **Legal: local name matching instance variable name**

```
private double x = 1.2;
public void bar() {  someMethod(x -> x + this.x); }
```









Effectively Final Local Variables

Main Points

- **Lambdas can refer to local variables that are not declared final (but are never modified)**
  - This is known as "effectively final" – variables where it *would have been* legal to declare them final
  - You can still refer to mutable *instance* variables
    - "this" in a lambda refers to main class, not inner class that was created for the lambda
    - There is no OuterClass.this.
- **With explicit declaration (explicitly final)**

```
final String s = "...";
doSomething(someArg -> use(s));
```

- **Effectively final (without explicit declaration)**

```
String s = "...";
doSomething(someArg -> use(s));
```

  - Note the rule where the use of "final" is optional also applies in Java 8 to anonymous inner classes

Example: Button Listeners

```
public class SomeClass ... {
  private Container contentPane;

  private void someMethod() {
    button1.addActionListener(event -> contentPane.setBackground(Color.BLUE));
    Color b2Color = Color.GREEN;
    button2.addActionListener(event -> setBackground(b2Color));
    button3.addActionListener(event -> setBackground(Color.RED));
    ...
  }
  ...
}
```

Instance variable: same rules as with anonymous inner classes in older Java versions; they can be modified.

Local variable: need not be explicitly declared final, but cannot be modified; i.e., must be "effectively final".

Example: Concurrent Image Download

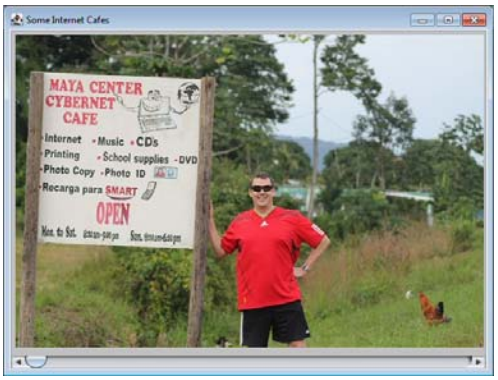
- **Idea**
  - Use standard Java threading to download a series of images of internet cafes and display them in a horizontally scrolling window
- **Java 8 twists**
  - Because ExecutorService.execute expects a Runnable, and because Runnable is a functional (SAM) interface, use lambdas to specify the body of the code that runs in background
  - Have code access local variables (which are effectively final but not explicitly declared final)

Main Code

```
...
ExecutorService taskList = Executors.newFixedThreadPool(poolSize);
for(int i=1; i<=numImages; i++) {
  JLabel label = new JLabel();
  URL location = new URL(String.format(imagePattern, i));
  taskList.execute(() -> {
    ImageIcon icon = new ImageIcon(location);
    label.setIcon(icon);
  });
  imagePanel.add(label);
}
...
```

Full code can be downloaded from
http://www.coreservlets.com/java-8-tutorial/

Results



Multithreaded version takes less than half the time of the single-threaded version.
Speedup could be much larger if the images were taken from different servers.

Wrap-Up

For additional materials, please see http://www.coreservlets.com/. The Java tutorial section contains complete source code for all examples in this tutorial series, plus exercises and exercise solutions for each topic.

Summary

- **@FunctionalInterface**
  - Use for all interfaces that will permanently have only a single abstract method
- **Method references**
  - `arg -> Class.method(arg)` → `Class::method`
- **Variable scoping rules**
  - Lambdas do not introduce a new scoping level
  - "this" always refers to main class
- **Effectively final local variables**
  - Lambdas can refer to, but not modify, local variables from the surrounding method
  - These variables need not be explicitly declared final as in Java 7
  - This rule (cannot modify the local variables but they do not need to be declared final) applies also to anonymous inner classes in Java 8