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

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Review: @Override

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

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

- With these
  ```java
  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
    ```javascript
    function square(x) { return(x*x); }
    var f = square;
    f(10); → 100
    ```
The Four Kinds of Method References

<table>
<thead>
<tr>
<th>Method Ref Type</th>
<th>Example</th>
<th>Equivalent Lambda</th>
</tr>
</thead>
<tbody>
<tr>
<td>SomeClass::staticMethod</td>
<td>Math::cos</td>
<td>x -&gt; Math.cos(x)</td>
</tr>
<tr>
<td>someObject::instanceMethod</td>
<td>someString::toUpperCase</td>
<td>() -&gt; someString.toUpperCase()</td>
</tr>
<tr>
<td>SomeClass::instanceMethod</td>
<td>String::toUpperCase</td>
<td>s -&gt; s.toUpperCase()</td>
</tr>
<tr>
<td>SomeClass::new</td>
<td>Employee::new</td>
<td>() -&gt; new Employee()</td>
</tr>
</tbody>
</table>

var::instanceMethod vs. Class::instanceMethod

- **someObject::instanceMethod**
  - Produces a lambda that takes *exactly as many* arguments as the method expects.
    ```java
    String test = "PREFIX:";
    String result1 = transform(someString, test::concat);
    ```

- **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.
    ```java
    String result2= transform(someString, String::toUpperCase);
    ```
Method Reference Examples: Helper Interface

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

Method Reference Examples: Helper Class

```java
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

```java
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
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());
}

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

- Illegal: repeated variable name
  ```java
double x = 1.2;
someMethod(y -> { double x = 3.4; ... });
  ```

- Illegal: lambda modifying local var from the outside
  ```java
double x = 1.2;
someMethod(y -> x = 3.4);
  ```

- Legal: modifying instance variable
  ```java
private double x = 1.2;
public void foo() {  someMethod(y -> x = 3.4); }
  ```

- Legal: local name matching instance variable name
  ```java
private double x = 1.2;
public void bar() {  someMethod(x -> x + this.x); }
  ```
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)**
  
  ```java
  final String s = "...";
  doSomething(someArg -> use(s));
  ```
- **Effectively final (without explicit declaration)**
  
  ```java
  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

```java
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.

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)  \(\rightarrow\)  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