Functional Constructs in Java 8: Lambdas and Streams

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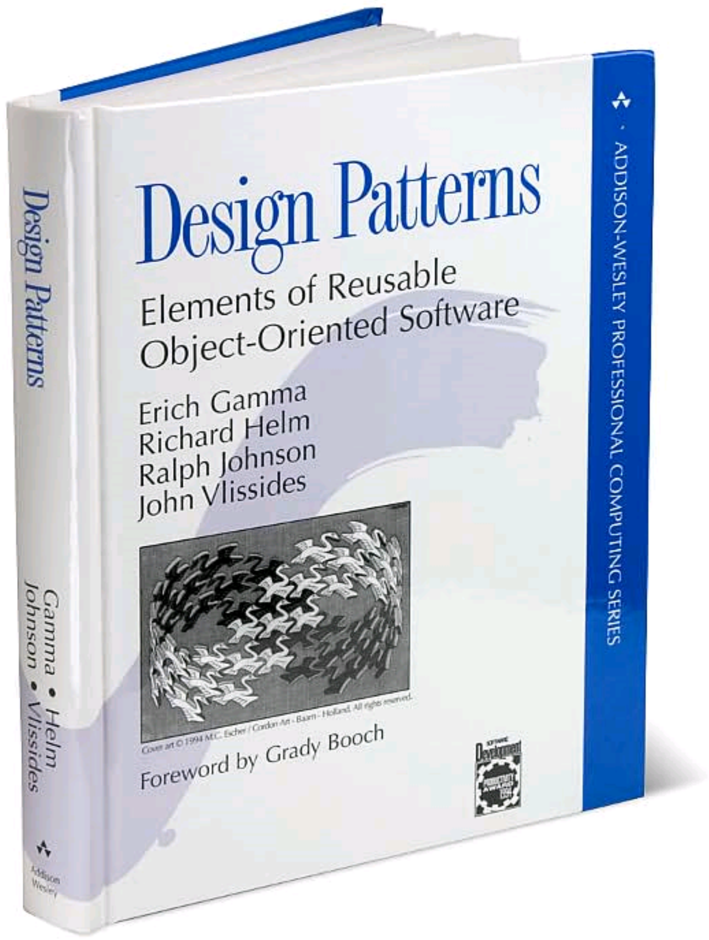
Administrivia

- Homework 6 due Thursday 11:59 pm
- Final exam Friday, Dec 16th 5:30–8:30 pm, GHC 4401
  - Review session Wednesday, Dec 14th 7–9:30 pm, DH 1112

Key concepts from Tuesday

I. Creational Patterns
II. Structural Patterns
III. Behavioral Patterns



I. Creational Patterns

1. Abstract factory
2. Builder
3. Factory method
4. Prototype
5. Singleton

II. Structural Patterns

1. Adapter
2. Bridge
3. Composite
4. Decorator
5. Façade
6. Flyweight
7. Proxy

III. Behavioral Patterns

1. Chain of Responsibility
2. Command
3. Interpreter
4. Iterator
5. Mediator
6. Memento
7. Observer
8. State
9. Strategy
10. Template method
11. Visitor

Today’s topics

- Two features added in Java 8
  - **Lambdas** – language feature
  - **Streams** – library features
- Designed to work together
- Related to Command, Strategy & Visitor patterns

What is a lambda?

- Term comes from λ-Calculus
  - Formal logic introduced by Alonzo Church in the 1930's
  - Everything is a function!
  - Equivalent in power and expressiveness to Turing Machine
  - Church-Turing Thesis, ~1934
- A lambda (λ) is an *anonymous* function
  - A function without a corresponding identifier (name)

Does Java have lambdas?

A. Yes, it’s had them since the beginning
B. Yes, it’s had them since anonymous classes (1.1)
C. Yes, it’s had them since Java 8 — spec says so
D. No, never had ’em, never will

Function objects in Java 1.0

```
class StringLengthComparator implements Comparator {
    private StringLengthComparator() { }
    public static final StringLengthComparator INSTANCE =
            new StringLengthComparator();

    public int compare(Object o1, Object o2) {
        String s1 = (String) o1, s2 = (String) o2;
        return s1.length() - s2.length();
    }
}

Arrays.sort(words, StringLengthComparator.INSTANCE);
```

Function objects in Java 1.1

```
Arrays.sort(words, new Comparator() {
   public int compare(Object o1, Object o2) {
       String s1 = (String) o1, s2 = (String) o2;
       return s1.length() - s2.length();
   }
});
```

Class Instance Creation Expression (CICE)

Function objects in Java 5

```
Arrays.sort(words, new Comparator<String>() {
    public int compare(String s1, String s2) {
        return s1.length() - s2.length();
    }
});
```

CICE with generics

Function objects in Java 8

```
Arrays.sort(words,
    (s1, s2) -> s1.length() - s2.length());
```

- They feel like lambdas, and they're called lambdas
  - But they're no more anonymous than 1.1 CICE's!
  - Method has name, class does not*
  - But method name does not appear in code ☺

No function types in Java, only *functional interfaces*

- Interfaces with only one explicit abstract method
  - AKA *SAM interface* (Single Abstract Method)
- Optionally annotated with `@FunctionalInterface`
  - Do it, for the same reason you use `@Override`
- Some functional interfaces you know
  - `java.lang.Runnable`
  - `java.util.concurrent.Callable`
  - `java.util.Comparator`
  - `java.awt.event.ActionListener`
  - Many, many more in package `java.util.function`

Function interfaces in `java.util.function`

```
BiConsumer<T,U>
BiFunction<T,U,R>
BinaryOperator<T>
BiPredicate<T,U>
BooleanSupplier
Consumer<T>
DoubleBinaryOperator
DoubleConsumer
DoubleFunction<R>
DoublePredicate
DoubleSupplier
DoubleToIntFunction
DoubleToLongFunction
DoubleUnaryOperator
Function<T,R>
IntBinaryOperator
IntConsumer
IntFunction<R>
IntPredicate
IntSupplier
IntToDoubleFunction
IntToLongFunction
IntUnaryOperator
LongBinaryOperator
LongConsumer
LongFunction<R>
LongPredicate
LongSupplier
LongToDoubleFunction
LongToIntFunction
LongUnaryOperator
ObjDoubleConsumer<T>
ObjIntConsumer<T>
ObjLongConsumer<T>
Predicate<T>
Supplier<T>
ToDoubleBiFunction<T,U>
ToDoubleFunction<T>
ToIntBiFunction<T,U>
ToIntFunction<T>
ToLongBiFunction<T,U>
ToLongFunction<T>
UnaryOperator<T>
```

Lambda Syntax

Syntax	Example
parameter -> expression	x -> x * x
parameter -> block	s -> { System.out.println(s); }
(parameters) -> expression	(x, y) -> Math.sqrt(x*x + y*y)
(parameters) -> block	(s1, s2) -> { System.out.println(s1 + "," + s2); }
(parameter decls) -> expression	(double x, double y) -> Math.sqrt(x*x + y*y)
(parameters decls) -> block	(List<?> list) -> { Arrays.shuffle(list); Arrays.sort(list); }

Method references – a more succinct alternative to lambdas

- An instance method of a particular object (*bound*)
  - `objectRef::methodName`
- An instance method whose receiver is unspecified (*unbound*)
  - `ClassName::instanceMethodName`
  - The resulting function has an extra argument for the receiver
- A static method
  - `ClassName::staticMethodName`
- A constructor
  - `ClassName::new`

Method reference examples

Kind	Examples
Bound instance method	`System.out::println`
Unbound instance method	`String::length`
Static method	`Math::cos`
Constructor	`LinkedHashSet<String>::new`
Array constructor	`String[]::new`

Some (not all!) ways to get a `Function<String,Integer>`

Description	Code
Lambda	`s -> Integer.parseInt(s)`
Lambda w/ explicit param type	`(String s) -> Integer.parseInt(s)`
Static method reference	`Interger::parseInt`
Constructor reference	`Integer::new`
Instance method reference	`String::length`

Anonymous class ICE	New Function<String, Integer>(){
	public Integer apply(String s) {
	return s.length();
	}
	}

What is a stream?

- A bunch of data objects, typically from a collection, array, or input device, for bulk data processing
- Processed by a *pipeline*
  - **A single *stream generator* (data source)**
  - **Zero or more *intermediate stream operations***
  - **A single *terminal stream operation***
- Supports mostly-functional data processing
- Enables painless parallelism
  - Simply replace `stream` with `parallelStream`
  - You may or may not see a performance improvement

Stream examples – Iteration

```
// Iteration over a collection
static List<String> stringList = ...;
stringList.stream()
      .forEach(System.out::println);

// Iteration over a range of integers
IntStream.range(0, 10)
      .forEach(System.out::println);

// Puzzler: what does this print?
"Hello world!".chars()
      .forEach(System.out::print);
```

Puzzler solution

```
"Hello world!".chars()
      .forEach(System.out::print);
```

Prints `"721011081081113211911111410810033"`

Why does it do this?

Puzzler Explanation

```
"Hello world!".chars()
      .forEach(System.out::print);
```

Prints `"721011081081113211911111410810033"`

The `chars` method on `String` returns an `IntStream`

How do you fix it?

```
"Hello world!".chars()
      .forEach(x -> System.out.print((char) x));
```

Now prints `"Hello world"`

Moral

- Streams only for object ref types, `int`, `long`, and `double`
  - Minor primitive types are missing
- Type inference can be confusing

Stream examples – mapping, filtering

```
List<String> filteredList = stringList.stream()
      .filter(s -> s.length() > 3)
      .collect(Collectors.toList());

List<String> mappedList = stringList.stream()
      .map(s -> s.substring(0,1))
      .collect(Collectors.toList());

List<String> filteredMappedList =
      stringList.stream()
            .filter(s -> s.length() > 4)
            .map(s -> s.substring(0,1))
            .collect(Collectors.toList());
```

Stream examples – duplicates, sorting

```
List<String> dupsRemoved = stringList.stream()
      .map(s -> s.substring(0,1))
      .distinct()
      .collect(Collectors.toList());

List<String> sortedList = stringList.stream()
      .map(s -> s.substring(0,1))
      .sorted()  // Buffers everything until terminal op
      .collect(Collectors.toList());
```

Stream examples – file input

```
// Prints a file, one line at a time
try (Stream<String> lines = Files.lines(Paths.get(fileName))) {
    lines.forEach(System.out::println);
}

// Prints sorted list of unique non-empty, lines in file (trimmed)
try (Stream<String> lines = Files.lines(Paths.get(fileName))) {
    lines.map(String::trim).filter(s -> !s.isEmpty()).sorted()
         .forEach(System.out::println);
}

// As above, sorted by line length
try (Stream<String> lines = Files.lines(Paths.get(fileName))) {
    lines.map(String::trim).filter(s -> !s.isEmpty())
         .sorted(Comparator.comparingInt(String::length))
         .forEach(System.out::println);
}
```

A subtle difference between lambdas and anonymous class instances

```
class Enclosing {
    Supplier<?> lambda() {
        return () -> this;
    }

    Supplier<?> anon() {
        return new Supplier<Object>() {
            public Object get() { return this; }
        };
    }

    public static void main(String[] args) {
        Enclosing enclosing = new Enclosing();
        Object lambdaThis = enclosing.lambda().get();
        Object anonThis = enclosing.anon().get();
        System.out.println(anonThis == enclosing);   // false
        System.out.println(lambdaThis == enclosing); // true
    }
}
```

Stream examples – bulk predicates

```
boolean allStringHaveLengthThree = stringList.stream()
      .allMatch(s -> s.length() == 3);

boolean anyStringHasLengthThree = stringList.stream()
      .anyMatch(s -> s.length() == 3);
```

Streams are processed *lazily*

- Data is “pulled” by terminal operation, not pushed by source
  - Infinite streams are not a problem
- Intermediate operations can be fused
  - Multiple intermediate operations typically don’t result in multiple traversals
- Intermediate results typically not stored
  - But there are exceptions (e.g., sorted)

A simple parallel stream example

- Consider this for-loop (.96 s runtime; dual-core laptop)

```
long sum = 0;
for (long j = 0; j < Integer.MAX_VALUE; j++) sum += j;
```

- Equivalent stream computation (1.5 s)

```
long sum = LongStream.range(0, Integer.MAX_VALUE).sum();
```

- Equivalent parallel computation (.77 s)

```
long sum = LongStream.range(0,Integer.MAX_VALUE)
        .parallel().sum();
```

- Fastest handcrafted parallel code I could write (.48 s)
  - You don't want to see the code. It took hours.

When to use a parallel stream – loosely speaking

- When operations are independent, and
- Either or both:
  - Operations are computationally expensive
  - Operations are applied to many elements of efficiently splittable data structures
- **Always measure before and after parallelizing!**
  - Jackson's third law of optimization

When to use a parallel stream – in detail

- Consider `s.parallelStream().operation(f)` if
  - `f`, the per-element function, is independent
    - i.e., computation for each element doesn't rely on or impact any other
  - `s`, the source collection, is efficiently splittable
    - Most collections, and `java.util.SplittableRandom`
    - NOT most I/O-based sources
  - Total time to execute sequential version roughly > 100µs
    - "Multiply N (number of elements) by Q (cost per element of `f`), guestimating Q as the number of operations or lines of code, and then checking that N*Q is at least 10,000.
If you're feeling cowardly, add another zero or two."—DL
    - For details: http://gee.cs.oswego.edu/dl/html/StreamParallelGuidance.html

Stream interface is a monster (1/3)

```
public interface Stream<T> extends BaseStream<T, Stream<T>> {
 // Intermediate Operations
 Stream<T> filter(Predicate<T>);
 <R> Stream<R> map(Function<T, R>);
 IntStream mapToInt(ToIntFunction<T>);
 LongStream mapToLong(ToLongFunction<T>);
 DoubleStream mapToDouble(ToDoubleFunction<T>);
 <R> Stream<R> flatMap(Function<T, Stream<R>>);
 IntStream flatMapToInt(Function<T, IntStream>);
 LongStream flatMapToLong(Function<T, LongStream>);
 DoubleStream flatMapToDouble(Function<T, DoubleStream>);
 Stream<T> distinct();
 Stream<T> sorted();
 Stream<T> sorted(Comparator<T>);
 Stream<T> peek(Consumer<T>);
 Stream<T> limit(long);
 Stream<T> skip(long);
```

Stream interface is a monster (2/3)

```
// Terminal Operations
void forEach(Consumer<T>);          // Ordered only for sequential streams
void forEachOrdered(Consumer<T>);  // Ordered if encounter order exists
Object[] toArray();
<A> A[] toArray(IntFunction<A[]> arrayAllocator);
T reduce(T, BinaryOperator<T>);
Optional<T> reduce(BinaryOperator<T>);
<U> U reduce(U, BiFunction<U, T, U>, BinaryOperator<U>);
<R, A> R collect(Collector<T, A, R>); // Mutable Reduction Operation
<R> R collect(Supplier<R>, BiConsumer<R, T>, BiConsumer<R, R>);
Optional<T> min(Comparator<T>);
Optional<T> max(Comparator<T>);
long count();
boolean anyMatch(Predicate<T>);
boolean allMatch(Predicate<T>);
boolean noneMatch(Predicate<T>);
Optional<T> findFirst();
Optional<T> findAny();
```

Stream interface is a monster (2/3)

```
// Static methods: stream sources
public static <T> Stream.Builder<T> builder();
public static <T> Stream<T> empty();
public static <T> Stream<T> of(T);
public static <T> Stream<T> of(T...);
public static <T> Stream<T> iterate(T, UnaryOperator<T>);
public static <T> Stream<T> generate(Supplier<T>);
public static <T> Stream<T> concat(Stream<T>, Stream<T>);
}
```

In case your eyes aren't glazed yet

```
public interface BaseStream<T, S extends BaseStream<T, S>>
    extends AutoCloseable {
  Iterator<T> iterator();
  Spliterator<T> spliterator();
  boolean isParallel();
  S sequential();  // May have little or no effect
  S parallel();    // May have little or no effect
  S unordered();   // Note asymmetry wrt sequential/parallel
  S onClose(Runnable);
  void close();
}
```

Optional<T> – a third (!) way to indicate the absence of a result

It also acts a bit like a degenerate stream

```
public final class Optional<T> {
  boolean isPresent();
  T get();

  void ifPresent(Consumer<T>);
  Optional<T> filter(Predicate<T>);
  <U> Optional<U> map(Function<T, U>);
  <U> Optional<U> flatMap(Function<T, Optional<U>>);
  T orElse(T);
  T orElseGet(Supplier<T>);
  <X extends Throwable> T orElseThrow(Supplier<X>) throws X;
}
```

Summary

- When to use a lambda
  - Always, in preference to CICE
- When to use a method reference
  - Almost always, in preference to a lambda
- When to use a stream
  - When it feels and looks right
- When to use a parallel stream
  - Number of elements * Cost/element >> 10,000
- Keep it classy!
  - Java is not a functional language

For more information

- Read the JavaDoc; it’s good!