

Learning to Love the Lambda in the Stream

Introduction to Java 8 Lambda and Functional Interfaces

Speaker Introduction

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What is a Lambda Expression?

- ▶ In Java, it is an unnamed function that is bound to an interface as an object.
- ▶ Similar to a closure: class members, *effectively final* arguments and local variables are available to it.
- ▶ Lambdas may only exist when assigned to a Functional Interface, including being passed in as a parameter or returned as a result.
- ▶ An *effectively final* local variable or argument is either declared final, or is not changed such that if the final declaration were added, the code remains valid.

Lambda Examples

► Example 1a

```
Predicate<Integer> isFive = n -> n == 5;  
System.out.println(isFive.test(4)); // false
```

► Example 1b

```
Predicate<Integer> mkTestFunc(int value)  
    { return n -> n == value; }
```

```
Predicate<Integer> isFour = mkTestFunc(4);  
System.out.println(isFour.test(4)); // true
```

► Lambda expressions must be assigned to a functional interface

► `(n -> n == 5).test(4);` // Does not compile

► `var unknownType = n -> n == 5;` // Does not compile

Lambda Syntax

- ▶ A lambda expression may take one of the following forms:
 - ▶ *[Argument List]* -> *statement*
 - ▶ *[Argument List]* -> { *statements*; **return**; }
- ▶ Argument List may take one of the following forms:
 - ▶ () -> ...
 - ▶ i -> ...
 - ▶ (i) -> ...
 - ▶ (Integer i) -> ...
 - ▶ (i,j...) -> ...
 - ▶ (Integer i, String j...) -> ...
- ▶ When using the { *statements*; **return**; } form, the return is optional for a void return value. When using a single *statement*, the result of the statement is implicitly returned.

Functional Interface (FI) in Java 8

- ▶ “A functional interface is any interface that contains only one abstract method.” — [Oracle Java Tutorial](#)
- ▶ The sole abstract method is referred to as the *functional method*
- ▶ Example 2- Valid Functional Interface

```
@FunctionalInterface // Optional
public interface Example2 {

    int myMethod(); // Functional Method

    boolean equals(Object other); // In Object
    int hashCode(); // In Object
    default int myMethod2() {return myMethod();}
    static int myMethod3() {return 0;}
}
```

Binding Lambda to Example2 FI vs Anonymous Inner class

- ▶ Both of these implement myMethod defined in Example2.
- ▶ Since there is exactly one abstract functional method, method types and return values are inferred from the FI.

```
public class Example3 {  
    static public void main(String[] args) {  
        Example2 lambda = () -> 3; // 8 chars  
        Example2 innerClass = new Example2() {  
            @Override public int myMethod() {  
                return 3;  
            }  
        }; // 5 lines of code, 65 chars  
        System.out.println(lambda.myMethod()); // 3  
        System.out.println(innerClass.myMethod()); // 3  
    }  
}
```

Key Functional Interfaces

Used by Streams

Functional Interface Conventions

- ▶ The abstract method is called the *functional method*
- ▶ The following conventions apply for type variables used by Java 8 FIs:
- ▶ T - First argument
- ▶ U - Second argument
- ▶ R - Return Value
- ▶ Any of the above are omitted if not used.
- ▶ If an FI lacks an argument, T is used for the return value instead of R.
- ▶ Many FIs that take one argument have a corresponding two argument version prefixed with “Bi”.

Predicate<T>

- ▶ Accepts an argument, returns a `boolean`.
- ▶ Commonly used to select matching elements, or filter for matching elements.
- ▶ Functional method: `boolean test(T t)`
- ▶ 2 argument FI: `BiPredicate<T, U>`
- ▶ **Related Primitive FIs:** `DoublePredicate`, `IntPredicate`, `LongPredicate`

Consumer<T>

- ▶ Accepts an argument. Returns no value (void).
- ▶ Commonly used to perform an operation, such as printing.
- ▶ Collections and Streams have this method to apply an action to each of their elements:

```
void forEach (Consumer<? super T> action)
```

- ▶ Functional Method: `void accept (T t)`
- ▶ 2 Argument FI: `BiConsumer<T, U>`
- ▶ Related Primitive FIs: `DoubleConsumer`, `IntConsumer`, and `LongConsumer`

Supplier<T>

- ▶ Accepts no arguments, returns a result
- ▶ Commonly used to provide an initial value to an algorithm.
- ▶ Useful for implementing the Factory pattern.
- ▶ Functional Method: `T get()`
- ▶ **Related Primitive Fis:** `DoubleSupplier`, `IntSupplier`, `LongSupplier`

Function<T,R>

- ▶ Accepts an argument, returns a result.
- ▶ Commonly used to compute a result, or to map one value to another value.
- ▶ Functional Method: `R apply(T t)`
- ▶ 2 Argument FI: `BiFunction<T,U,R>`
- ▶ Related Primitive FIs: `[Double,Int,Long]Function`,
`[Double,Int,Long]To[Double,Int,Long]Function`, `To`
`[Double,Int,Long]Function`,
`To[Double,Int,Long]BiFunction`

UnaryOperator<T>

- ▶ Accepts an argument, returns the same type of result as its argument.
- ▶ Used to compute a result or map a value to the same type as the input.
- ▶ Functional Method: `T apply(T t)`
- ▶ 2 Argument FI: `BinaryOperator<T>`
- ▶ Related Primitive FIs:
`[Double,Int,Long]UnaryOperator,`
`[Double,Int,Long]BinaryOperator`
- ▶ `UnaryOperator<T>` extends `Function<T, T>`
- ▶ `BinaryOperator<T>` extends `BiFunction<T, T, T>`

Comparator<T>

- ▶ Accepts two arguments, and returns an integer.
- ▶ Used to compare objects, and to impose a *total ordering* on a collection of objects.
- ▶ Functional Method: `int compare(T o1, T o2)`
 - ▶ When $o1 < o2$, returns ≤ -1
 - ▶ When $o1 = o2$, returns 0
 - ▶ When $o1 > o2$, returns ≥ 1
- ▶ Even though Comparator has been around since the early days, it is a functional interface that is used by the stream framework for sorting data.

Optional<T> Class

- ▶ Container class returned by various stream methods.
- ▶ Represents a value that may or may not exist. Used instead of returning a **null** value.
- ▶ `isPresent` returns **true** when a value exists, `ifPresent` executes a `Consumer<T>` when a value exists, and `get()` obtains the value, throwing `NoSuchElementException` if it does not exist.
- ▶

```
Optional<Integer> found = Stream.of(1,2).max((a,b) -> a - b);  
System.out.print("Found: " + found.isPresent() + ", value = ");  
found.ifPresent(System.out::println); // Found: true, value = 2
```
- ▶

```
Optional<Object> notFound = Stream.of().max((a,b) -> 0);  
System.out.print("Found: " + notFound.isPresent());  
notFound.ifPresent(System.out::println); // Found: false
```


Method Reference

Shorthand for lambdas that invoke a single method

Method Reference

- ▶ Shorthand for a Lambda that only calls a method
- ▶ Types of References
 - ▶ Static method, such as `String::valueOf`
 - ▶ Method on an instance, such as `System.out::println`
 - ▶ Constructor reference, such as `StringBuilder::new`
 - ▶ Instance method, such as `String::toUpperCase`
- ▶ Once familiar with syntax, these can often be read and understood faster.
- ▶ A method reference may always be transformed into a lambda, but a lambda may not always be transformed into a method reference.

Static Method Reference

► Example:

```
Function<char[],String> valueOf = String::valueOf;  
// valueOf = s -> String.valueOf(s);  
String value = valueOf.apply(new char[]  
{ 'H', 'e', 'l', 'l', 'o' });  
System.out.println(value); // Hello
```

► Arguments are bound in declaration order.

Method Reference on an Instance

► Example:

```
Consumer<Object> printer = System.out::print;  
// printer = i -> System.out.print(i);  
Arrays.asList(1,2,3,4).forEach(printer); // 1234
```

- The same rules that apply for binding lambda variables also apply when binding to a method on an instance:
- class members, *effectively final* arguments and local variables may be used as a method reference on an instance.
- Arguments are bound in declaration order.

Constructor Method Reference

► Example:

```
Supplier<StringBuilder> supplier = StringBuilder::new;  
// supplier = () -> new StringBuilder();  
StringBuilder sb = supplier.get().append("Hi!");  
System.out.println(sb); // Hi!
```

- Creates a new instance of the class, and returns it as the result.
- Must be bound to a functional interface with a non-void return type.
- Supplier is canonically used for a constructor method reference.
- Function and BiFunction may be used for constructors with arguments.

Instance Method Reference

► Example:

```
UnaryOperator<String> toUpper = String::toUpperCase;  
// toUpper = s -> s.toUpperCase();  
System.out.println(toUpper.apply("abc")); // ABC
```

- The first argument of the lambda becomes the instance the method reference operates on.
- The remaining arguments are bound in the order they occur.
- The first argument rule has significance when choosing the order of arguments for the “Bi” family of Functional Interfaces.

Streams

Not to be confused with IO Streams

What is a Java Stream?

- ▶ Abstraction for computation of elements.
- ▶ A computation structure, not a data structure.
- ▶ A stream consists of
 1. A data source, such as a collection, file, stream builder, or computation. May be infinite, such as the set of numbers starting at 0. A data source is *lazy*.
 2. Zero or more intermediate operations.
 - ▶ Accepts a stream and returns a another stream with the operation appended to it.
 - ▶ *Lazy*: Only executed when a terminal operation processed the stream.
 3. A terminal operation
 - ▶ Returns a result, such as a number or a collection.
 - ▶ *Eager*: It requests the elements from the final stream, which has the effect of pulling elements from the data source and applying the intermediate operations to them. A stream is a passive description of a computation until a terminal operation is applied.
 - ▶ Closes the stream. Any further operations are invalid and result in an `IllegalStateException`.

Streams are Like Factory Conveyor Belts

- ▶ The data source is the raw material to be processed.
- ▶ Adding the intermediate operations is like getting the workers into place.
- ▶ Like a conveyor belt takes the result of the previous worker's changes to the next worker, a Stream takes the result of the previous intermediate operation as the input to the next intermediate operation or terminal operation.
- ▶ A conveyor belt doesn't start until all the workers are in place and ready. Likewise a stream doesn't start until all the intermediate operations and the terminal operation have been defined.
- ▶ Defining the terminal operation starts the processing. Once the conveyor belt is running, it can't be changed.

Reduction - Add a Collection of Numbers

- ▶ Given `Collection<Integer> numbers` that has integers from 1 to 1000, add the collection.
- ▶ For Loop

```
int total = 0;  
for(Integer number : numbers) {total += number;}  
return total; // 500500
```

- ▶ Stream reduction (using a `BinaryOperator<Integer>`)

```
return numbers.stream().reduce(0, (i,sum) -> i+sum); // 500500
```

Breaking Down the Stream

```
stream(Collection<Integer> numbers) {  
    return numbers.stream() // Data Source  
        .reduce(0, (i,sum) -> i+sum); // Terminal Operation  
}
```

- ▶ All streams have a data source, zero or more intermediate operations, and a terminal operation.
- ▶ `numbers` collection is the data source.
- ▶ `reduce` is a terminal *reduction* on the stream.
- ▶ A reduction processes all of the values in a given stream to a single value.
- ▶ Integer reduction examples: sum, average, median, min, and max.
- ▶ The first argument to `reduce` is the identity property. For addition and counting, it is 0. For a multiplication it is 1, for strings it is "" (empty string).
- ▶ The lambda is a `BinaryOperator<Integer>` that is given a running total and the current element. They are processed by adding them together.

Primitive Streams

- ▶ `IntStream`, `LongStream`, and `DoubleStream`
- ▶ Offers a performance benefit over the generic stream by avoiding boxing of primitive computations.
- ▶ Offers additional methods, such as `sum()`, `min()`, `max()`, `average()`, and `summaryStatistics()`.
- ▶ Can replace a traditional for loop

```
IntStream.range(0, 10).forEach(System.out::println); // Print 0-9
```

- ▶ Use `mapToInt`, `mapToLong`, `mapToDouble`, and `mapToObj` to convert an existing stream to an `IntStream`, `LongStream`, `DoubleStream`, and `Stream<T>` respectively.
- ▶ Use the `boxed()` method to convert a primitive stream to its equivalent object stream by boxing the primitive values as follows:
 - ▶ `IntStream` to `Stream<Integer>`
 - ▶ `LongStream` to `Stream<Long>`
 - ▶ `DoubleStream` to `Stream<Double>`

Intermediate Operations

These Create a New Stream with the Operation Appended to It

Map

- ▶ Not to be confused with `java.util.Map`.
- ▶ Apply a computation on stream elements.
- ▶ May be used to change the element type of a stream by returning values of a different type.

```
Stream<Character> s = IntStream.range(65, 75)
    .mapToObj(i -> (char) i); // Stream<Character>
s.forEach(System.out::print); // ABCDEFGHIJ
```

- ▶ Change values, but keep data type (int).

```
IntStream.range(0, 10).map(i -> i*10)
    .forEach(System.out::println); // 0, 10 ... 90
```

Filter

The `filter` intermediate operation creates a new stream with the contents of the previous stream where the `Predicate<T>` or primitive predicate is **true**.

```
IntSummaryStatistics summaryStatistics =  
IntStream.range(0, 1000) // Data Source  
.filter(i -> i %4 == 0) // Intermediate Operation  
.summaryStatistics(); // Terminal Operation  
System.out.println(summaryStatistics);  
/* count=250, sum=124500, min=0,  
average=498.000000, max=996 */
```

Limit and Skip - Infinite Streams

- ▶ Limit intermediate operation limits the values produced by a stream. An infinite stream becomes a finite stream.
- ▶ Skip intermediate operation skips the specified elements
- ▶ Order of these operations matters
 - ▶ Skip before limit - Skipped items not counted against limit
 - ▶ Skip after limit - Skipped items counted against limit
- ▶ `IntStream.iterate(0, i -> i+1).skip(4).limit(6).forEach(System.out::print); // 456789`
- ▶ `IntStream.iterate(0, i -> i+1).limit(6).skip(4).forEach(System.out::print); // 45`
- ▶ `IntStream.iterate` uses an initial value with an `IntUnaryOperator` to create an infinite stream.

Terminal Operations

Let's Get This Party Started. Let's Get This Stream Processing

Terminal Operations

- ▶ `count` - A *reduction* that returns the number of elements in the stream. Never use on an infinite stream.
- ▶ `reduce` - Perform a *reduction* of the stream using a `BinaryOperator` to accumulate the elements. Never use on an infinite stream.
- ▶ `anyMatch` - Returns **true** and stops processing if any element matches the supplied `Predicate`, **false** otherwise. Empty Stream is **false**.
- ▶ `allMatch` - Returns **false** and stops processing if any element does not match the supplied `Predicate`, **true** otherwise. Empty Stream is **true**.
- ▶ `noneMatch` - Returns **false** and stops processing if any element matches the supplied `Predicate`. Empty Stream is **true**.
- ▶ `forEach` - A **void** operation that presents each element to a `Consumer` for processing.

Terminal Operations that return Optional<T>

- ▶ These terminal operations return an `Optional<T>` because the value does not exist in an empty stream.
- ▶ `findFirst` - produces the first element in a stream. Because this implies ordering of the elements, any parallel stream is transformed into a sequential stream to guarantee element encounter order
- ▶ `findAny` - produces any element on the stream. It does not impose any overhead on parallel stream, but may produce differing values on invocation of the same stream.
- ▶ `min` - produces the minimum element
- ▶ `max` - produces the maximum element.

Collector (Terminal Operation)

A Mutable Reduction That Creates an Object to Process All Stream Elements

Never Use on an Infinite Stream

Collections Collectors

- ▶ These collectors take the elements and add them to a collection.
- ▶ There are `toList()`, `toSet()`, and `toCollection()` collectors.

```
▶ List<Integer> ints = IntStream.of(1,2,2,3,4,5).boxed()  
.collect(Collectors.toList()); System.out.println(ints);  
// [1, 2, 2, 3, 4, 5]
```

```
▶ Set<Integer> intSet = IntStream.of(1,2,2,3,4,5).boxed()  
.collect(Collectors.toSet()); System.out.println(intSet);  
// [1, 2, 3, 4, 5]
```

```
▶ // Custom collection type with a sort applied to it.
```

```
LinkedHashSet<Integer> sortedSet = IntStream.of(1,2,2,3,4,5)  
.boxed().sorted(Comparator.reverseOrder())  
.collect(Collectors.toCollection(LinkedHashSet::new));  
System.out.println(sortedSet);  
// [5, 4, 3, 2, 1]
```

Partition Collector

- ▶ The Partition collector uses a `Predicate<T>` to create a map with the keys `false` and `true`.
- ▶ Both the `false` and `true` key and value always exist in the map even if the corresponding value is not present. In such a case, the value will be an empty collection, an empty optional, or a sum or count of 0.
- ▶ Use the predicate in the previous example to create a map with elements divisible by 4 and not divisible by 4.

```
Map<Boolean,Integer> summap =  
IntStream.range(0, 1000).boxed()  
.collect(partitioningBy(i -> i%4==0, summingInt(i -> i)));  
System.out.println(summap); // {false=375000, true=124500}
```

The `summingInt` collector is an example of a *downstream collector*. In this case, it accepts the values of the partitioning by collector and produces a sum reduction of the values.

Grouping By Collector

- ▶ For the next example, consider the following stream producing function

```
▶ static Stream<String> aboutJack() {  
return Stream.of("All", "work", "and", "no", "play", "makes",  
"jack", "a", "dull", "boy", "but", "all", "play", "and", "no",  
"work", "makes", "jack", "a", "fool"); }
```

- ▶ Group each word by starting letter, in alphabetical order

```
aboutJack().sorted().collect(  
    Collectors.groupingBy(s -> s.charAt(0),  
        TreeMap::new, Collectors.toCollection(TreeSet::new)));  
/* A=[All], a=[a, all, and], b=[boy, but], d=[dull],  
f=[fool], j=[jack], m=[makes], n=[no], p=[play], w=[work] */
```

Grouping By Concurrent

- ▶ Streams may be processed in parallel by using the `parallel` method using concurrent collectors and data structures.

```
aboutJack().parallel().collect( Collectors.groupingByConcurrent (
s -> s.charAt(0), ConcurrentSkipListMap::new,
Collectors.toCollection(ConcurrentSkipListSet::new))) ;

/* A=[All], a=[a, all, and], b=[boy, but], d=[dull], f=[fool],
j=[jack], m=[makes], n=[no], p=[play], w=[work] */
```

- ▶ Count the words

```
▶ aboutJack().parallel().collect(Collectors.groupingByConcurrent (
s -> s, ConcurrentSkipListMap::new, Collectors.counting())) ;

/* All=1, a=2, all=1, and=2, boy=1, but=1, dull=1, fool=1, jack=2,
makes=2, no=2, play=2, work=2 */
```


Joining Collector

- ▶ A process where a stream of CharSequence is concatenated together to form a string. Recall the aboutJack stream:

```
static Stream<String> aboutJack() { return Stream.of(
    "All", "work", "and", "no", "play", "makes", "jack", "a", "dull",
    "boy", "but", "all", "play", "and", "no", "work", "makes",
    "jack", "a", "fool"); }
```

- ▶ Join this into words separated with a space:

```
aboutJack().collect(Collectors.joining(" "));

/* All work and no play makes jack a dull boy but all play
and no work makes jack a fool */
```

AutoClosable Lambdas

Use try-with-resources with any class, and catch the close exception

AutoCloseable is a Functional Interface

- ▶ `public interface AutoCloseable {`
- ▶ `void close() throws Exception;`
- ▶ `}`
- ▶ This interface is a functional interface (FI) because it has exactly one abstract method.
- ▶ The Functional Method is: `void close()`.
- ▶ The missing `@FunctionalInterface` annotation is unnecessary.

Use try-with-resources with any class

Example: Close a Context

- ▶ In Java 7, try-with-resources was added to the language.
- ▶ Unfortunately, not every class that could benefit from it implemented it.
- ▶ Using Lambdas, anything can leverage try-with-resources.
- ▶ `public void useContext(Context ctx) throws Exception {`
- ▶ `try (AutoCloseable it = ctx::close) {`
- ▶ `doSomethingWithContext(ctx);`
- ▶ `}`
- ▶ `}`

Issues with the AutoClosable Functional Interface (FI)

- ▶ The close method throws Exception.
- ▶ The thrown Exception will either need to be caught or processed.
- ▶ This may result in the code being littered with catch statements.

Fixing the AutoClosable FI

► If we wrote our own Closable interface:

```
► public interface NamingClosable extends AutoCloseable {  
►     @Override public void close() throws NamingException;  
► }
```

► Then we can write

```
► public void useContext(Context ctx) throws NamingException  
{  
►     try (NamingClosable it = ctx::close) {  
►         doSomethingWithContext(ctx);  
►     }  
► }
```

Parameterizing AutoClosable Exceptions

- ▶ Using generics, it is possible to parameterize the checked exceptions that a sub-interface of AutoClosable may throw.
- ▶ This example demonstrates how to parameterize a single checked exception.
- ▶

```
public interface CloseIt1<E extends Exception>  
    extends AutoCloseable {  
  
        default void close() throws E { closeIt(); }  
  
        void closeIt() throws E;  
  
    }
```
- ▶ The default `close()` method is necessary because applying the generic to an abstract `close()` method results in a compiler error when used in a try-with-resources statement.

Using the Parameterized FI

- ▶ Using `CloseIt1` from the previous slide:
- ▶

```
public void useContext (Context ctx) throws NamingException  
{  
    try (CloseIt1<NamingException> it = ctx::close) {  
        doSomethingWithContext (ctx);  
    }  
}
```
- ▶ The `close` method of the `Context` is bound to the `CloseIt1` resource. The try-with-resources feature of Java does the heavy lifting of the resource exception processing.

Decorator Pattern

- ▶ One of the core patterns introduced in the *Design Patterns, Elements of Reusable Object Oriented Software* by Gamma, Helm, Johnson, and Vlissides.
- ▶ Pattern allows behavior to be added to an object dynamically, by decorating it, or wrapping it with another object of the same abstract type (such as an interface).
- ▶ This pattern may be leveraged to add capabilities to AutoClosables, such as exception handling.
- ▶ Since AutoClosable is a Functional Interface, the decorator may be expressed as a lambda.
- ▶ https://en.wikipedia.org/wiki/Decorator_pattern

Decorating the Close Lambda

- ▶ Consider the following code

- ▶ Assume `NotClosedException` is an unchecked exception with an accessible constructor that takes a `Throwable`.

```
public interface CloseIt0 extends AutoCloseable {  
    public void close() throws NotClosedException;  
    public static CloseIt0 wrapAllException(AutoCloseable  
        autoCloseable) {  
        // Decorating with a lambda that wraps all Exceptions  
        return () -> { try { autoCloseable.close(); }  
            catch (Exception ex) { throw new NotClosedException(ex); }  
        };  
    }  
}
```

Catching the Decorated Close Exception

- ▶ This close lambda is decorated to wrap any exceptions that occur within a `NotClosedException`. If no exception occurs within the body, this wrapped exception will be caught and processed by the catch clause. Otherwise, it will be a suppressed exception.

```
public void useContext(Context ctx) throws NamingException {  
    try(CloseIt0 it = CloseIt0.wrapAllException(ctx::close)) {  
        doSomethingWithContext(ctx);  
    } catch (NotClosedException ex) {  
        logger.log(Level.WARNING, ex.getCause().getMessage()  
            , ex.getCause());  
    }  
}
```

The CloseIt Project

- ▶ Provides generic functional interfaces extending `AutoCloseable` to use as the target of try-with-resources lambdas. Supports 0-5 checked exceptions.
- ▶ Makes it easy to use try-with-resources for any object that needs cleanup. May replace the try-finally construct.
- ▶ Provides these decorators for handling close exceptions
 - ▶ Ignore - Pretend the exception never happened. Discard it.
 - ▶ Consume - Do something, such as log the exception, then discard.
 - ▶ Hide - Hide a checked exception from the compiler and throw it.
 - ▶ Wrap - Wrap the exception within another exception of a different type. This is a form of the Adapter design pattern.
https://en.wikipedia.org/wiki/Adapter_pattern.

Questions

- ▶ Oracle's Lambda Quick Start Tutorial: <http://www.oracle.com/webfolder/technetwork/tutorials/obe/java/Lambda-QuickStart/index.html>
- ▶ These slides (pdf): <https://tinyurl.com/love-lambda>
- ▶ CloseIt: <https://github.com/RichardRoda/closeit> - com.github.richardroda.util:closeit:1.4
- ▶ This Project: <https://github.com/RichardRoda/2017-CodePaLOUsa-Lambda>
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