

# Learning to Love the Lambda in the Stream

Introduction to Java Lambdas, Functional Interfaces, and Streams

# Speaker Introduction

- ▶ These slides (web): <https://tinyurl.com/lambda-web>
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# What is a Lambda Expression?

- ▶ In Java, it is an unnamed function that is bound to a *functional interface* as an object.
- ▶ A *functional interface* is an interface with exactly one abstract method.
- ▶ Similar to an inner class: class members, *effectively final* arguments and local variables are available to it.
- ▶ 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.
- ▶ Lambdas may only exist when assigned to a functional interface, including being passed in as a parameter or returned as a result.

# Lambda Examples

## ► Example 1a

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

## ► Example 1b

```
// Higher order function that creates predicates.
```

```
Predicate<Integer> makeTestFunction(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
```

```
► var predicateType = mkTestFunc(4); // Compiles
```

# Lambda Syntax

- ▶ *[Argument List]* -> *[Statements]*
- ▶ Argument List may take one of the following forms:
  - ▶ `()` ->
  - ▶ `i` ->
  - ▶ `(i)` -> or Java 11+: `(@Annotations var i)` ->
  - ▶ `(@Annotations Integer i)` ->
  - ▶ `(i,j...)` -> or Java 11+: `(@Annotations var i, @Annotations var j, ...)` ->
  - ▶ `(@Annotations Integer i, @Annotations String j...)` ->
- ▶ Statements may take one of the following forms:
  - ▶ `-> statement`
  - ▶ `-> { statement ... statement; return result; }`
- ▶ *@Annotations* are zero or more parameter annotations.

# Functional Interface (FI) in Java

- ▶ “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); // Not abstract -- in Object
    int hashCode(); // Not abstract -- in Object
    default int myMethod2() {return myMethod();} // Has
implementation
    static int myMethod3() {return 0;} // Static and has
implementation
}
```

# Inner Classes vs Lambda

```
Example2 innerClass = new Example2() {  
    @Override  
    public int myMethod() {  
        return 2;  
    }  
};
```

```
Example2 lambda = () -> 2;
```

- ▶ Equivalent implementations of the Example2 interface.
- ▶ The lambda declaration has two key advantages:
  - ▶ It is a single, concise line of code.
  - ▶ Because it is self-contained, the compiler will automatically fold it into a single (static) implementation.

# Key Functional Interfaces

Used by Streams



# Functional Interface Conventions

- ▶ The abstract method is called the *functional method*
- ▶ The term “Functional Interface” may be abbreviated as “FI”
- ▶ The following conventions apply for type variables used by Java FIs:
  - ▶ T - First argument, R - Return Value, U - Second argument
  - ▶ Any of the above are omitted if not used or the same as T.
- ▶ Many FIs that take one argument have a corresponding two argument version prefixed with “Bi”
- ▶ Many generic FIs have related primitive FIs prefixed with Double, Int, and Long for the respective data types.

# Predicate<T>

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

```
boolean removeIf (Predicate<? super E> filter)
```

# Consumer<T>

- ▶ Accepts an argument. Returns no value (void).
- ▶ Commonly used to perform an operation, such as printing.
- ▶ Functional Method: `void accept (T t)`
- ▶ 2 Argument FI: `BiConsumer<T, U>`
- ▶ Related Primitive FIs: `DoubleConsumer`, `IntConsumer`, and `LongConsumer`
- ▶ Collections and Streams have a `forEach` method to apply an action to each of their elements:

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

- ▶ Has side effects and never a pure function.

# Supplier<T>

- ▶ Accepts no arguments, returns a result
- ▶ Commonly used to provide an initial value to an algorithm, and as a source for multiple values.
- ▶ Functional Method: `T get()`
- ▶ **Related Primitive FIs:** `DoubleSupplier`, `IntSupplier`, `LongSupplier`
- ▶ Does not require that a new object be created.
- ▶ Associated with object creation and constructors.
- ▶ Useful for implementing the Abstract Factory design pattern.

# Function<T,R>

- ▶ Accepts an argument, returns a result.
- ▶ Commonly used to map one value to another value, or compute a result.
- ▶ Represents a mapping from its input to its output.
- ▶ 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> & BinaryOperator<T>

- ▶ A specialization of function: 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 lhs, T rhs)`
  - ▶ When `lhs < rhs`, returns `< 0`
  - ▶ When `lhs = rhs`, returns `0`
  - ▶ When `lhs > rhs`, returns `> 0`
- ▶ 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> - Alternative to Null

- ▶ Represents a value that may or may not exist.
  - ▶ of - Create an optional from a non-null value.
  - ▶ ofNullable - Create an optional from a possible null value. An empty optional is created from a null value.
  - ▶ isPresent - Returns true when a value is present.
  - ▶ ifPresent - Accepts a Consumer on a present value.
  - ▶ get - Return present value or throw NoSuchElementException
  - ▶ orElse - Return present value or a provided value.
  - ▶ orElseGet - Return present value or get a value from Supplier.
  - ▶ orElseThrow - Return present value or throw Exception from Supplier.
  - ▶ map - Apply a Function mapping on a present value.
  - ▶ filter - Tests a Predicate on a present value, returning an empty Optional when the test result is false.



# Pure Commutative Functions

- ▶ Do not use any information outside of their argument(s).
- ▶ No side effects: nothing outside of the return value changes.
- ▶ For any given arguments  $X$  an equivalent value  $Y$  is always returned regardless of the argument ordering.
- ▶ For Functions: `fn.apply(X).equals(fn.apply(X))` is always true.
- ▶ For Suppliers: `s.get().equals(s.get())` is always true.
- ▶ For BiFunctions `fn.apply(X, Y).equals(fn.apply(X, Y))` and `fn.apply(Y, X).equals(fn.apply(X, Y))` are always true.
- ▶ Such functions are inherently safe.
- ▶ “Pure Function” usually means Pure Commutative Function.

# Is It Pure Commutative? (Yes)

- ▶ `IntUnaryOperator addOne = x -> x + 1;`
  - ▶ A function with one or zero arguments is commutative.
- ▶ `ToDoubleFunction<Employee> getSalary =  
employee -> employee.getSalary();`
  - ▶ Property getters without side-effects are pure.
- ▶ `Supplier<Set<Integer>> getSet = () -> new  
HashSet<>();`
  - ▶ This Supplier is pure: it always creates an empty hash set.
- ▶ `IntBinaryOperator plus = (x, y) -> x + y;`
  - ▶ It is pure and commutative:  $3 + 4 = 7 = 4 + 3$ .

# Is it Pure Commutative? (No)

- ▶ `IntBinaryOperator minus = (x, y) -> x - y;`
  - ▶ It is pure but not commutative:  $3 - 4 = -1 \neq 1 = 4 - 3$
- ▶ `IntPredicate testSet = x -> mySet.add(x) ;`
  - ▶ It has side effects and uses information outside of its arguments.
- ▶ `IntConsumer printConsumer = x -> System.out.println(x) ;`
  - ▶ Consumers are not pure functions because they have side effects.

# 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`
  - ▶ Constructor reference, such as `StringBuilder::new`
  - ▶ Method on an instance, such as `System.out::println`
  - ▶ 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:

```
// public static valueOf(char[] data) method on String
Function<char[],String> valueOf = String::valueOf;
// Equivalent lambda expression
// valueOf = s -> String.valueOf(s);
String value = valueOf.apply(new char[] {'H','i'});
System.out.println(value); // Hi
```

## ► Arguments are bound in declaration order.

# Constructor Reference

## ► Example:

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

- Syntax similar to static method reference that creates a new object.
- Creates a new instance of the class, and returns it as the result.
- Must be bound to a functional interface with a compatible return type.
- Arguments are bound in declaration order.
- Supplier FI is canonically used for a constructor method reference.

# Method Reference on an Instance

## ► Example:

```
// public void print(Object x) method on out's  
PrintStream
```

```
Consumer<Object> printer = System.out::print;
```

```
// Equivalent lambda expression
```

```
// printer = i -> System.out.print(i);
```

```
printer.accept("We come in peace."); // We come in peace.
```

- class members, *effectively final* arguments and local variables may be used as a method reference on an instance.
- Arguments are bound in declaration order.



# Instance Method Reference

## ► Example:

```
// public String toUpperCase() method on String
UnaryOperator<String> toUpper = String::toUpperCase;
// Equivalent lambda expression
// 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
  2. Zero or more intermediate operations.
  3. A terminal operation, which starts the processing.
  4. (Optional) A close operation, to release any resources such a files.

# A Data Source

- ▶ Can be anything that supplies data
  - ▶ A Collection
  - ▶ A file
  - ▶ An Iterated Function
  - ▶ Can Be Infinite
- ▶ Is Lazy
  - ▶ Only used when a *terminal operation* is applied to the stream.

# Intermediate Operations

- ▶ Returns a stream with the operation appended.
- ▶ Are Lazy
  - ▶ Only used when a *terminal operation* is applied to the stream.
- ▶ Typical Intermediate operations
  - ▶ Filtering or finding items that match a predicate
  - ▶ Mapping items using a function
  - ▶ Skipping and limiting items processed. Can turn an infinite stream into a finite stream.
  - ▶ Reordering the items

# A Terminal Operation

- ▶ Often returns a result such as a value or collection
  - ▶ A *reduction* produces a result from every stream element
- ▶ Is Eager
  - ▶ Starts the processing of elements from the data source through any Intermediate operations
  - ▶ A stream is a passive description of a data source and intermediate operations until a terminal operation is applied.
- ▶ Executes the stream
  - ▶ Any further operations except `close()` result in an `IllegalStateException`
  - ▶ Does **not** close the stream.
  - ▶ Use a try-with-resources block with Closable data source streams.

# 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. The terminal operation is like the worker who packages the finished product.
- ▶ Like a conveyor belt takes the result of the previous worker's changes to the next worker, a Stream takes the data source output or previous intermediate operation result as the input to the next intermediate 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 it is running, it can't be changed.

# Breaking Down the Stream

```
int addPositive(Collection<Integer> numbers) {  
    return numbers.stream() // Data Source  
        .filter(i->i > 0) // Intermediate Operation  
        .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.
- ▶ `filter` is an intermediate operation.
- ▶ `reduce` is the *reduction* terminal operation 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.



# Primitive Streams

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

```
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>`

# Parallelism and Ordering

- ▶ Parallel streams may process multiple elements at a time.
- ▶ Sequential streams process a single element at a time.
- ▶ Ordered streams have a defined order.
- ▶ Unordered streams lack a defined order.
- ▶ Both sequential and parallel streams may be ordered, but only an ordered sequential stream guarantees actual encounter order.
  - ▶ Certain operations are only well defined for ordered streams, and impose additional overhead on ordered parallel streams.
- ▶ Pure commutative functions and operations work correctly with any parallelism and ordering.

# Data Source Examples

## ▶ Collection

- ▶ `Collection.stream()` creates a sequential stream
- ▶ `Collection.parallelStream()` creates a parallel stream
- ▶ Stream ordering determined by underlying collection ordering
  - ▶ `List`, `Queue`, `SortedSet`, and `LinkedHashSet` are ordered
  - ▶ `HashSet` is unordered
- ▶ Stream from a set has its distinct attribute set until mapped.

## ▶ `Stream.of()` - Array

- ▶ `Stream.of(T... values)` creates a sequential ordered stream.

## ▶ File

- ▶ `Files.lines(Path path)` creates a sequential ordered `String` stream.
- ▶ File streams should be closed and used with `try-with-resources`.

## ▶ Iterated Function (Infinite Stream)

- ▶ `Stream.iterate(T seed, UnaryOperator<T> function)` creates a sequential ordered infinite stream.

# Intermediate Operations

These Create a New Stream with the Operation Appended to It

# Map

- ▶ Not to be confused with `java.util.Map`.
- ▶ Uses a `Function<T,R>` to apply a computation or mapping on stream elements.
- ▶ A pure function should be used if possible.
- ▶ Clears the distinct attribute. Mapped streams are not known to be distinct
- ▶ May change the type of a stream by returning values of a different type.

```
public double totalSalary(Collection<Employee> employees) {  
    return employees.stream()  
        .map(Employee::getSalary).reduce(0.0, (i,sum) -> i+sum);  
}
```

- ▶ Use `flatMap` to process functions that return Streams.

```
int sumListOfLists(List<List<Integer>> listOfLists) {  
    // flatMap replaces an element with the contents of a stream.  
    // mapToInt creates an IntStream from a Stream.  
    return listOfLists.stream()  
        .flatMap(List::stream).mapToInt(i->i).sum();  
}
```

# Distinct

- ▶ Filters out any duplicate items according to the `Object.equals` method.
- ▶ Distinct objects should have a `hashCode` method that is *consistent with equals*. When `a.equals(b)` then `a.hashCode() == b.hashCode()`.
- ▶ For sequential ordered streams, the first of a given value is preserved.
- ▶ For streams known to be distinct, such as an unmapped stream from a set, this method passes the values through. Examples:
  - ▶ `getCollectionStream().distinct().map(i->i+1)` // Better
  - ▶ `getCollectionStream().map(i->i+1).distinct()` // Worse
  - ▶ The first example bypasses distinct processing when the collection is a set.
- ▶ Introduces overhead on a parallel stream.

```
IntStream.of(1,4,2,1,2,5,4,3).distinct()  
    .forEach(i->System.out.print(" " + i));  
/* 1 4 2 5 3 */
```

# Filter

- ▶ The `filter` intermediate operation retains the contents of the stream where the Predicate is **true**.

```
double totalCommissionPayable(Collection<Associate> associates) {  
    return associates.stream()  
        .filter(Associate::isCommissionQualified)  
        .mapToDouble(Associate::getCommissionEarned).sum();  
}
```

- ▶ In this example, the total commission payable is computed by filtering for records that are qualified for commission payment and then summing the commission earned.
- ▶ A pure function should be used if possible

# Limit and Skip - Infinite to Finite Stream

- ▶ Limit intermediate operation limits the values produced by a stream. An infinite stream becomes a finite stream.
- ▶ Skip intermediate operation skips the specified elements
- ▶ Not pure commutative. Undefined on unordered stream.
- ▶ Introduces overhead on a parallel stream.
- ▶ 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`



# Limit Unbounded Streams

- ▶ An unbounded stream is a stream that has no known upper limit on its elements. An infinite stream is a kind of unbounded stream.
- ▶ Unless an unbounded stream is intentionally infinite, it should always be limited to prevent hanging.
- ▶ Even if the stream “should” terminate it is still a good defensive programming practice to include a limit.
- ▶ A limit larger than the upper bound of what should be processed but small enough to stop processing in a reasonable amount of time should be used.
- ▶ A good starting point for a limit value is an order or two of magnitude (ten to a hundred times) more than the longest observed (or known possible) size.

# Dangerous Unbounded Processing

## ► Dangerous

```
► public Optional<Widget> findBlueWidget() {  
    // May never get to the end nor find a blue widget  
    // Will not close any underlying stream resources.  
    return getUnboundedStream().filter(widget ->  
        "blue".equals(widget.getColor())) .findAny();  
}
```

- The stream has no upper limit on what it will process.
- The stream does not close any resources such as files
  - Note: terminal operations do *not* close a stream.

# Safe Unbounded Processing

## ► Safe

```
► public Optional<Widget> findBlueWidget() {  
    // Will exit with Optional.empty() after 10000 widgets.  
    try (Stream<Widget> unbounded = getUnboundedStream()) {  
        return unbounded.limit(10000).filter(widget ->  
            "blue".equals(widget.getColor())) .findAny();  
    }  
}
```

- The limit intermediate operation ensures an exit from the stream.
- The try-with-resources ensures that any underlying resources are closed.
- When building a stream from a closable resource, use the `.onClose()` intermediate operation to register a handler that is called when the stream is closed to close any underlying resources.

# Sorted

- ▶ Sorts stream items. Resulting stream is an ordered stream.
- ▶ Supports parallel streams. Stable for sequential ordered streams.
  - ▶ Stable sort means ties (compare = 0) retain underlying stream ordering.
- ▶ Sorts using the *natural order* only when elements are Comparable

```
Stream.of(8,4,6,3,7,8,2,3,4).sorted()  
    .forEach(i->System.out.print(" " + i));  
/* 2 3 3 4 4 6 7 8 8 */
```

- ▶ Sorts using a comparator

```
Stream.of(8,4,6,3,7,8,2,3,4)  
    .sorted((lhs,rhs)->rhs-lhs)  
    .forEach(i->System.out.print(" " + i));  
/* 8 8 7 6 4 4 3 3 2 */
```

# Unordered

- ▶ Removes the ordered constraint from an ordered stream.
- ▶ Improves the performance of a parallel ordered stream.
- ▶ Use on a parallel stream that does not rely on ordering.
- ▶ Pure commutative functions and operations always work.

```
int total = IntStream.of(4,3,6,7,8,5,6,7,8)
    .parallel().unordered().sum();
```

```
System.out.print(total); // 54
```

- ▶ No benefit to using unordered with a sequential stream.

# Sequential and Parallel

- ▶ The `sequential()` intermediate operation makes a stream sequential.
- ▶ The `parallel()` intermediate operation makes a stream parallel.
- ▶ May be used to maximize performance by parallelizing a stream when it is most beneficial to do so.

```
try (Stream<Widget> unbounded = getUnboundedStream()) {  
    return unbounded.limit(10000).parallel()  
        .unordered().filter(widget ->  
            "blue".equals(widget.getColor())) .findAny();  
}
```

- ▶ Making the stream parallel after the limit operation avoids the additional overhead of the parallel ordered limit operation.

# takeWhile (Java 9+)

- Transforms the stream to include the elements that match the predicate stopping when an element does not match.

```
IntStream.of(0,1,2,3,4,2,1).takeWhile(i->i/4 == 0)
    .forEach(i->System.out.print(" " + i));
```

```
/* 0 1 2 3 */
```

- Unlike filter, processing stops at number 4.
- Stream is empty if first element does not match.
- Not pure commutative. Undefined on unordered stream.
- Introduces overhead on a parallel stream.

# dropWhile (Java 9+)

- Transforms the stream to skip the elements that match the predicate stopping when an element matches.

```
IntStream.of(0,1,2,3,4,2,1).dropWhile(i->i/4 == 0)
    .forEach(i->System.out.print(" " + i));
/* 4 2 1 */
```

- Unlike filter, matching and skipping stops at number 4.
- Stream has all elements if first element does not match.
- Not pure commutative. Undefined on unordered stream.
- Introduces overhead on a parallel stream.



# Intermediate Operations May Be Added Conditionally

- ▶ Consider this code:

```
▶ public int addModulo(int[] data, Integer modulo) {  
return IntStream.of(data)  
    .filter(datum->modulo == null || (datum % modulo) == 0)  
    .sum();  
}
```

- ▶ When a null modulo is passed in, all elements will be processed
- ▶ Is there a way we can take advantage of the fact that all are processed when modulo is null?

# Optimize By Filtering Conditionally

- ▶ The example on the previous slide may be optimized by conditionally adding the filter and unboxing modulo.

```
▶ public int addModulo(int[] data, Integer modulo) {  
    IntStream sumStream = IntStream.of(data);  
    if (modulo != null) {  
        final int mod = modulo; // Factor out unboxing of int.  
        // Must re-assign because .filter returns a stream.  
        sumStream = sumStream.filter(datum->(datum % mod) == 0);  
    }  
    return sumStream.sum();  
}
```

- ▶ The check for null and unboxing of modulo is done only once. The resulting stream operation will be more performant.

# 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`, **true** otherwise. Empty Stream is **true**.
- ▶ `forEach` - A **void** operation that presents each element to a `Consumer` for processing. Avoid use on an infinite stream.
- ▶ A reduction is an operation that computes a single value by processing all the values on the stream. Never reduce an infinite stream.

# Reduction - Add a Collection of Numbers

- ▶ Given `Collection<Integer> numbers` that has integers from 1 to 1000, add the collection.
- ▶ Stream reduction (using a `BinaryOperator<Integer>`)

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

```
// 500500
```

- ▶ The first argument to reduce is the identity value. For addition and counting, it is 0. For a multiplication it is 1, for strings it is "" (empty string). In this case  $X + 0 = X$ .
- ▶ The second argument to reduce is the reduction function. In this case the reduction adds the numbers together.
- ▶ The identity value is returned for empty streams or used as the second argument when the first stream value is processed.
- ▶ This reduction function is both pure and commutative.

## Terminal Operations that return `Optional<T>`

- ▶ These terminal operations return an `Optional<T>` because no value exists in an empty stream.
- ▶ `findFirst` - produces the first element in a stream. Imposes additional overhead on an ordered parallel stream. Equivalent to `findAny` when used on an unordered stream.
- ▶ `findAny` - produces any element on the stream. It does not impose any overhead on parallel stream, but may produce differing values from the same stream.
- ▶ `Min` - produces the minimum element.
- ▶ `Max` - produces the maximum element.
- ▶ Operations `findFirst` and `findAny` are not pure commutative.

# Terminal Operations May Be Invoked Conditionally

- ▶ Consider the add modulo example from earlier.

```
▶ public int addModulo(int[] data, Integer modulo) {  
    IntStream sumStream = IntStream.of(data);  
    if (modulo != null) {  
        final int mod = modulo;  
        sumStream = sumStream.filter(datum -> (datum % mod) == 0);  
    }  
    return sumStream.sum();  
}
```

- ▶ How can this function be changed to support an operation argument that can be “count” if the numbers should be counted, or “sum” if the numbers should be summed?

# Terminal Operations May Be Invoked Conditionally

- ▶ The terminal operation may be called conditionally after the stream has been built with its intermediate conditions.

```
▶ public int addOrCountModulo(int[] data, Integer modulo,
    String operation) {
    IntStream opStream = IntStream.of(data);
    if (modulo != null) {
        final int mod = modulo;
        opStream = opStream.filter(datum -> (datum % mod) == 0);
    }
    // Use count or sum depending on the requested operation.
    return "count".equals(operation) ?
        (int) opStream.count() : opStream.sum();
}
```

- ▶ These techniques provide a more elegant solution for providing multi-purpose processing than an “if-else” statement chain or “case” statements.
- ▶ The Strategy pattern can also be used to build and configure a stream.



# 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.
- ▶ In Java 16+ `toList()` is also a terminal operation for convenience.

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

```
System.out.println(ints); /* [5, 4, 3, 3, 2, 1, 1] */
```

```
▶ Set<Integer> intSet = IntStream.of(5,4,3,3,2,1,1).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(5,4,3,3,2,1,1)  
.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 is typically 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(Collectors.partitioningBy(i -> i%4==0,  
Collectors.summingInt(i -> i)));  
System.out.println(summap); // {false=375000, true=124500}
```

The `summingInt` collector is a *downstream collector*. It processes each classification (key) for the map. 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] */  

```

- ▶ The `Collectors.toCollection` is a *downstream collector*. It processes the elements for each classification (key) in the map.

# 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.

```
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 */
```

# Teeing Collector (Java 12+)

- ▶ A downstream collector that processes every element through two collectors and then uses a merge BiFunction to produce a result.

```
Double[] salaries = {95_000d, 125_000d, 35_000d, 40_000d};
Range salaryRange =
    Stream.of(salaries).collect(Collectors.teeing(
        Collectors.minBy(Double::compare),
        Collectors.maxBy(Double::compare),
        (min, max) -> new Range(min.orElse(0d), max.orElse(0d))));
System.out.println("Salary range is " + salaryRange.getMin() +
    " - " + salaryRange.getMax());
/* Salary range is 35000.0 - 125000.0 */
```

# Execute Around and Loan Patterns

Separate the concerns of manipulating resources from program logic

Source: *Functional Programming in Java* book by Venkat Subramaniam



# The Execute Around Pattern

- ▶ Pattern to eliminate boilerplate code by performing operations before and after an operation.
- ▶ Consider this code for using a lock:

```
Lock lock = getLock();  
try {  
    return doSomething();  
} finally {  
    lock.unlock();  
}
```

- ▶ We would have better separation of concerns if we could separate the lock manipulation from the operation.

# Apply the Execute Around Pattern

- The boilerplate lock and unlock code may be refactored like this:

```
► <T> T useLock(Supplier<T> operation) {  
    Lock lock = getLock();  
    lock.lock();  
    try {  
        return operation.get();  
    } finally {  
        lock.unlock();  
    }  
}
```

- Then using the lock can be accomplished in a single line of code:

```
useLock(() -> doSomething());
```

# Loan Pattern

- ▶ Specialized version of the execute around pattern
  1. Obtains or allocates a resource
  2. Initializes it
  3. Invokes a user specified operation with the resource
  4. Cleans it up
  5. Returns or deallocates a resource

# Apply the Loan Pattern

- ▶ This example applies the loan pattern for JDBC connections

```
▶ @FunctionalInterface interface SqlFunction<T,R> {  
    R apply(T t) throws SQLException;  
}  
  
<T> T useDb(SqlFunction<? super Connection, ? extends T>  
operation) throws SQLException {  
    try (Connection conn = getJdbcConnection()) {  
        return operation.apply(conn);  
    }  
}
```

- ▶ The JDBC connection can be used with a single line of code:

```
useDb(conn -> doDbOperation(conn));
```

# 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 declared Exception will either need to be caught or processed.
- ▶ This may result in the code being littered with unnecessary catch statements.



# Fixing the AutoCloseable 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](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)) {  
        readSomethingFromContext(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 anything 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.
  - ▶ Rethrow - Do something, such as log the exception, then throw it.
  - ▶ Rethrow When - Do something, then conditionally throw it.
  - ▶ Hide - Hide a checked exception from the compiler and throw it.
  - ▶ Wrap - Wrap the exception within another exception of a different type. This is also a form of the Adapter design pattern.  
[https://en.wikipedia.org/wiki/Adapter\\_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:1.7
- ▶ This Project: <https://github.com/RichardRoda/2017-CodePaLOUsa-Lambda>
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