API Design with Java 8
Lambda and Streams

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Introduction

• Impact of new Java 8 language features on your APIs
  – Lambda
  – Streams
  – Optional
  – Default Methods

• When to use, when *not* to use, how to use effectively

• We’re taking questions on Twitter – tweet with hashtag #JavaAPI
Lambda
Lambda

• Allows passing **behavior** through an API, not just values
  – concise, efficient means of expressing “code as data”
  – parameterizing with behavior (not just values and types)
  – this is a big new tool in the API design toolbox

• APIs previously used anonymous inner classes to pass code as data
  – create a new class, then a new instance
  – overall a roundabout way to express a bit of behavior
  – too clunky to use widely in APIs
Example: ThreadLocal

• Instance of the Template Method pattern to do lazy initialization

• Before Java 8, to provide an initial value
  – Subclass and override initialValue() method
  – initialValue() called at first get() call
  – value cached for subsequent get() calls

• Java 8: use lambda to “plug in” initialization function into the right place
  – no need for subclassing
static ThreadLocal<Integer> threadId = new ThreadLocal<Integer>() {
    protected Integer initialValue() {
        return computeNextId();
    }
};

static ThreadLocal<Integer> threadId = ThreadLocal.withInitial(() -> computeNextId());
Example: Multi-Valued Map

• Task: maintain a map with multiple keys for each value
  Map<Key, List<Value>>

• To add a (key, value) pair
  – first check to see if the key is present in the map
  – if it isn’t
    • create an empty list
    • add the value to the list
    • put the key and list into the map
  – if the key is present
    • get the list
    • add the value to the list
Example: Multi-Valued Map

```java
Map<Key, List<Value>> map = ... ;

// OLD

List<Value> list = map.get(key);
if (list == null) {
    list = new ArrayList<>();
    map.put(key, list);
}
list.add(newValue);

// NEW

map.computeIfAbsent(key, k -> new ArrayList<>()).add(newValue);
```
Conditional Execution in Java 8

• `Map.computeIfAbsent()`
  – if key is absent, computes a value, puts it into map, returns it
  – if key is present, returns the value

• Advantages
  – encapsulates highly stylized code into the library
  – gives it a nice name
  – can be made atomic for concurrent maps
Example: Sorting Collections

• Existing sort methods
  – Collections.sort(List)
  – Collections.sort(List, Comparator)

• Common cases that should be supported by the library
  – sort by a field or property (sort by name, sort by age) using “key extractor” function
  – reversed-order sort
  – special handling for null (nulls-first, nulls-last)
  – multi-level sort (sort by last name, then by first name)

• Answer has historically been: “Provide your own Comparator”
  – but writing your own comparator is tedious and error-prone
How Many Sorting Methods to Provide?

- sort()
- sortReversed()
- sortBy(extractor)
- sortByReversed(extractor)
- sortByInt(intExtractor)
- sortByIntReversed(intExtractor)
- sortByDouble(dblExtractor)
- sortByDoubleReversed(dblExtractor)
- sortNullsFirst()
- sortNullsLast()
- sortNested(extractor1, extractor2)
- sortNestedIntObj(intExt1, ext2)
- sortNestedObjInt(ext1, intExt2)
- sortReversedNested(ext1, ext2)
- sortReversedNestedIntObj(intExt1, ext2)
- sortNestedReversed(ext1, ext2)
- sortNestedReversedIntObj(intExt1, ext2)
- ...
Seems Like the Wrong Direction

• Adding sort method variations isn’t working
  – combinatorial explosion of different methods
  – can try to minimize, but if one is missing, client is out of luck
  – “This is not the abstraction you are looking for”

• Time to step back and reconsider the problem
Think about Comparators Instead of Sorting

• A Comparator is just a function:
  – \((T, T) => \{ < 0, 0, > 0 \} \)

• Most Comparators are highly stylized code
  – complexity comes in when multiple cases are combined
  – this suggests a way to break things down and simplify them
Base Case: Comparator from Field Extractor

// some data class

class Student {
   public String getLastName() { ... }
   public String getFirstName() { ... }
   public int getScore() { ... }
}

Comparator<Student> studentsByLastName =
   (s1, s2) -> s1.getLastName().compareTo(s2.getLastName())

Comparator<Student> studentsByScore =
   (s1, s2) -> Integer.compare(s1.getScore(), s2.getScore())
Base Case: Comparator from Field Extractor

- **Commonality**
  - the same function is run on two objects, resulting in two Comparable values
  - these values are then compared
  - extract this into a static utility method

```java
// NEW
(s1, s2) -> s1.getLastName().compareTo(s2.getLastName())
(s1, s2) -> Integer.compare(s1.getScore(), s2.getScore())

// NEW AND IMPROVED
Comparator.comparing(Student::getLastName)
Comparator.comparingInt(Student::getScore)
```
Creating Comparator Variants: Null Handling

```java
Comparator<Student> studentsByFirstNameNullsFirst = 
  (s1, s2) -> {
    String fn1 = s1.getFirstName();
    String fn2 = s2.getFirstName();
    if (fn1 == null)
      return (fn2 == null) ? 0 : -1;
    else
      return (fn2 == null) ? 1 : fn1.compareTo(fn2);
  };
```
Creating Comparator Variants: Two-Level Sorting

```java
Comparator<Student> studentsByLastNameThenFirstName =
    (s1, s2) -> {
        int r = s1.getLastName().compareTo(s2.getLastName());
        if (r != 0)
            return r;
        else
            return s1.getFirstName().compareTo(s2.getFirstName());
    };
```
Two-Level Sorting and Null Handling

```java
Comparator<Student> studentsByLastNameThenNullableFirstName =
    (s1, s2) -> {
        int r = s1.getLastName().compareTo(s2.getLastName());
        if (r != 0) {
            return r;
        } else {
            String fn1 = s1.getFirstName();
            String fn2 = s2.getFirstName();
            if (fn1 == null)
                return (fn2 == null) ? 0 : -1;
            else
                return (fn2 == null) ? 1 : fn1.compareTo(fn2);
        }
    };
```
Creating a Null-Handling Comparator

// function that null-specializes a comparator and returns a new comparator

static <T> Comparator<T> nullsFirst(Comparator<T> original) {
    return (t1, t2) -> {
        if (t1 == null)
            return (t2 == null) ? 0 : -1;
        else
            return (t2 == null) ? 1 : original.compare(t1, t2);
    };
}

// example

Comparator<Student> studentsByFirstNameNullsFirst =
    Comparator.comparing(Student::getFirstName, nullsFirst(naturalOrder()));
Creating Comparator Variants: Two-Level Sorting

// default method in Comparator interface

default Comparator<T> thenComparing(Comparator<T> other) {
    return (t1, t2) -> {
        int res = this.compare(t1, t2);
        return (res != 0) ? res : other.compare(t1, t2);
    };
}

// example

Comparator<Student> studentsByLastNameThenFirstName = Comparator.comparing(Student::getLastName)
    .thenComparing(Student::getFirstName);
Comparator Example

```java
students.sort((s1, s2) -> { // OLD
    int r = s1.getLastName().compareTo(s2.getLastName());
    if (r != 0)
        return r;
    String f1 = s1.getFirstName();
    String f2 = s2.getFirstName();
    if (f1 == null) {
        return f2 == null ? 0 : -1;
    } else {
        return f2 == null ? 1 : f1.compareTo(f2);
    }
});

students.sort(comparing(Student::getLastName).thenComparing(Student::getFirstName, nullsFirst(naturalOrder()))); // NEW
```
Lessons from Comparator API

• Some APIs have combinatorial explosion of complexity
  – look for proliferation of method variations (e.g., sort methods)
  – look for long parameter lists, with many optional parameters
  – look for lots of overloads with different variations of parameters

• Large number of variations comes from combinations of smaller features

• Break down the problem into smaller features that can be composed
  – write higher order functions to do the composition
  – allow user to plug in logic using lambdas
  – combination of static factories and default methods
Streams
Adding Streams to APIs

• Early Java 8 effort – “lambdafication”
  – many objects are conceptually containers of other objects
  – easy step: add forEach() method on them

• But also want to transform, filter, sort, etc.
  forEach
  forEachFiltered
  forEachMapped
  forEachFilteredMapped
  forEachSorted
  forEachFilteredSorted
  forEachMappedSorted
  forEachFilteredMappedSorted

• Sound familiar?
Adding Streams to APIs

• “Lambdafication” quickly turned to “Streamification”
  – adding a single stream() method opens up full range of stream functionality
  – many conceptually aggregate objects can return collections
  – should they return a stream or a collection or both?

• Mostly, doesn’t matter
  – easy for caller to convert a stream into a collection and vice versa
Stream vs. Collection

• Stream instead of Collection
  – creating the collection is expensive
  – cheaper to produce elements lazily on demand
  – caller needs only a subset of the elements (filter, findFirst), can short-circuit
  – avoids creating defensive copies
  – returned stream can be infinite

• Collection instead of Stream
  – snapshot semantics
  – caller needs to traverse multiple times
  – or in different directions
How to Return a Stream

• If you have zero elements
  – Stream.empty()

• If you have a fixed number of elements
  – Stream.of(e1, e2, e3, ...)

• If you have a collection
  – just call stream()

• If you have an array
  – call Arrays.stream(array)
Create a Stream from an Iterator

```java
// if size unknown
StreamSupport.stream(
    Spliterators.spliteratorUnknownSize(iterator, 0), false)

// if size is known
StreamSupport.stream(
    Spliterators.spliterator(iterator, size, 0), false)
```
Create a Spliterator, then a Stream

• Create subclass of Spliterators.AbstractSpliterator
  – only one method required: tryAdvance()
    
    ```java
    boolean tryAdvance(Consumer<Object> consumer) {
        Object obj = getTheNextObject();
        if (obj == null)
            return false;
        consumer.accept(obj);
        return true;
    }
    ```
  – for improved sequential performance, implement forEachRemaining()
  – for better parallel scaling, implement trySplit()
Create a Spliterator, then a Stream

• Once you have a spliterator, call
  – StreamSupport.stream(spliterator, isParallel)

• Consider also primitive specializations for int, long, double
Spectrum of Stream-Returning Techniques

- Create from Iterator
  - Spliterators.spliteratorUnknownSize
  - Spliterators.spliterator

- Create from Spliterator
  - AbstractSpliterator.tryAdvance
  - AbstractSpliterator.forEachRemaining
  - AbstractSpliterator.trySplit

- Later ones are more effort, but offer improved performance
Why Spliterator?

• Iterator
  – two method calls per element traversed: hasNext() and next()
  – often interact in subtle ways
    • hasNext() must cache value for next() to return
  – need to guard against unusual call order
    • e.g., next() called twice in succession

• Spliterator
  – one method per element: tryAdvance()
  – a better iterator than Iterator, even for sequential execution
  – adds splitting abstraction for parallelism
Optional
#JavaAPI

The Primary Use of Optional

Optional is intended to provide a **limited** mechanism for library method **return types** where there is a clear need to represent “no result,” and where using null for that is overwhelmingly **likely to cause errors.**
When To Use Optional

• Use as method return value, when absence of a value is an *expected* result
  – as opposed to an exceptional result
  – example: findFirst() or similar method
  – allows caller to deal with absence of value without checking for null
  – allows convenient method chaining

• A method returning Optional should **NEVER** return null!

• Terminology note: prefer “empty Optional” over “Optional containing null”
When To Use Optional

• Method chaining
  – returning an Optional allows caller to chain methods safely
  – orElse() – returns value if present, else substitutes a default value
    • NOTE: avoid orElse(null) if possible
  – orElseGet() – returns value if present, else calls a lambda to generate the value
  – orElseThrow() – returns value if present, else throws the given exception
  – get() – returns a value if present, otherwise throws NoSuchElementException
    • WARNING: use get() only if you can prove the value is always present!
Examples

```java
Optional<String> match = words.stream()
    .filter(word -> word.startsWith("A"))
    .findFirst();

System.out.println(match.orElse("not found"));

System.out.println(match.orElseGet(() -> getNotFoundMessage()));
```
When Not To Use Optional

• It’s very tempting to use Optional in other contexts
  – method arguments
  – object fields
  – in a collection

• It *seems* like these techniques ought to work
  – end up cluttering and obscuring code unnecessarily
When Not To Use Optional

- It is **not** a goal of Optional to get rid of nulls everywhere
- Yes! Sometimes it’s ok to use null
  - a private field with null as a sentinel can easily be verified correct
  - as a method argument – you check your arguments, right?
- Returning a collection, array, or stream
  - don’t return Optional<Collection<T>> or Optional<Object[]> or Optional<Stream<T>>
  - don’t return null
  - instead, return an empty collection, array, or stream
Method Chaining is Cool, But...

    // BAD
    String process(String s) {
        return Optional.ofNullable(s).orElseGet(this::getDefault);
    }

    // GOOD
    String process(String s) {
        return (s != null) ? s : getDefault();
    }
Summary of Optional

• Focus on using Optional as a return value
  – where search or computation might not return a result
  – and where returning null is likely to cause errors

• Resist temptation to apply Optional elsewhere
  – it’s not necessarily wrong, but it’s unlikely to be useful
  – misuse of Optional has led to the invention of several new code smells

• Optional works well for specific cases
  – don’t overdo it!
Default Methods
Primary Use Case: Evolving an Existing Interface

- Before Java 8, adding a method to an interface could result in AbstractMethodError
  – so basically it was never done
- Default methods are interface methods plus a fallback implementation
- Default methods are ordinary virtual methods and can be overridden
Example Default Method in Interface

• Iterable.forEach

```java
default void forEach(Consumer<? super T> action) {
    Objects.requireNonNull(action);
    for (T t : this) {
        action.accept(t);
    }
}
```

• Implemented only in terms of statics, **this**, and parameters
Default Methods: Secondary Use Cases

• When the method is optional
  – example: Iterator.remove()
    ```java
    default void remove() {
        throw new UnsupportedOperationException("remove");
    }
    ```

• Convenience method, not necessary to be overridden
  – example: Comparator.reversed()
    ```java
    default Comparator<T> reversed() {
        return (t1, t2) -> this.compare(t2, t1);
    }
    ```
Default Methods vs Abstract Classes

• Abstract classes are obsolete now that we have default methods, right?

• No! Classes still have the following that interfaces do not:
  – state (fields)
  – constructors (allowing control over instance creation)
  – protected methods
    • allow communication with subclasses as distinct from callers

• Before adding a default method, ask whether it’s useful to callers
  – interface methods are all public
  – don’t use default methods for sharing code among implementors
  – if it’s only useful to subclasses, maybe you should use an abstract class instead
Default Method Tradeoffs

• Incompatibility risks
  – possible name collisions, e.g., List.sort()
  – fragile superclass problem
    • same issue that has always existed for classes
    • arguably riskier for interfaces, since they’re more widely subclassed

• Works well for intended use
  – if applied judiciously
  – if applied outside intended use, results are often unsatisfactory
  – misuse of default methods is another generator of new code smells
Summary

• Lambda
• Streams
• Optional
• Default methods
Safe Harbor Statement

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