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Lambdas & Streams: Taking the Hard Work Out of Bulk Operations in Java SE 8

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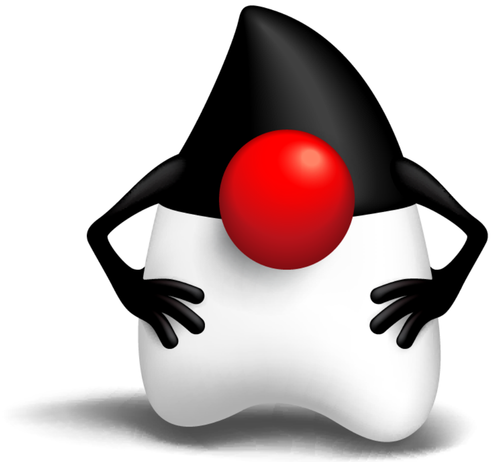
Lambdas In Java



The Problem: External Iteration

```
List<Student> students = ...
double highestScore = 0.0;
for (Student s : students) {
  if (s.gradYear == 2011) {
    if (s.score > highestScore) {
      highestScore = s.score;
    }
  }
}
```

- Client controls iteration
- *Inherently serial:* iterate from beginning to end
- Not thread-safe because business logic is stateful (mutable accumulator variable)

Internal Iteration With Inner Classes

More Functional, Fluent

```
List<Student> students = ...
double highestScore =
  students.filter(new Predicate<Student>() {
    public boolean op(Student s) {
      return s.getGradYear() == 2011;
    }
  }).map(new Mapper<Student,Double>() {
    public Double extract(Student s) {
      return s.getScore();
    }
  }).max();
```

- Iteration, filtering and accumulation are handled by the library
- Not inherently serial – traversal *may* be done in parallel
- Traversal *may* be done lazily – so one pass, rather than three
- Thread safe – client logic is stateless
- High barrier to use
  – Syntactically ugly

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Internal Iteration With Lambdas

```
SomeList<Student> students = ...
double highestScore =
  students.stream()
          .filter(Student s -> s.getGradYear() == 2011)
          .map(Student s -> s.getScore())
          .max();
```

- More readable
- More abstract
- Less error-prone
- No reliance on mutable state
- Easier to make parallel

Lambda Expressions

Some Details

- Lambda expressions represent anonymous functions
  - Like a method, has a typed argument list, a return type, a set of thrown exceptions, and a body
  - Not associated with a class
- We now have parameterised behaviour, not just values

```
double highestScore =
  students.stream()
          .filter(Student s -> s.getGradYear() == 2011)
          .map(Student s -> s.getScore())
          .max();
```

What

How

Lambda Expression Types

- Single-method interfaces are used extensively in Java
  - Functions and callbacks
  - Definition: a *functional interface* is an interface with one abstract method
  - *Functional interfaces* are identified structurally
  - The type of a lambda expression will be a *functional interface*

```
interface Comparator<T>     { boolean compare(T x, T y); }
interface FileFilter        { boolean accept(File x); }
interface Runnable          { void run(); }
interface ActionListener    { void actionPerformed(…); }
interface Callable<T>       { T call(); }
```


Target Typing

- A lambda expression is a way to create an instance of a functional interface
  - Which functional interface is inferred from the context
  - Works both in assignment and method invocation contexts

```
sort(myList, (String x, String y) -> x.length() – y.length());
```

```
Comparator<String> c = (String x, String y) -> x.length() - y.length();
```

  - Be careful, remember signature of functional interface

```
addActionListener((ae) -> System.out.println("Got it!"));
```

Local Variable Capture

- Lambda expressions can refer to *effectively final* local variables from the enclosing scope
  - Effectively final means that the variable meets the requirements for final variables (i.e., assigned once), even if not explicitly declared final
  - This is a form of type inference

```
void expire(File root, long before) {
    root.listFiles(File p -> p.lastModified() <= before);
}
```

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Lexical Scoping

- The meaning of names are the same inside the lambda as outside
  - A ‘this’ reference – refers to the enclosing object, not the lambda itself
  - Think of ‘this’ as a final predefined local
  - Remember the type of a Lambda is a *functional interface*

```
class SessionManager {
  long before = ...;

  void expire(File root) {
     // refers to 'this.before', just like outside the lambda
     root.listFiles(File p -> checkExpiry(p.lastModified(), this.before));
  }

  boolean checkExpiry(long time, long expiry) { ... }
}
```


Type Inferrence

- The compiler can often infer parameter types in a lambda expression
- Inferrence based on the target functional interface's method signature
- Fully statically typed (no dynamic typing sneaking in)
  - More typing with less typing

```
static T void sort(List<T> l, Comparator<? super T> c);
```

```
List<String> ls = getList();
Collections.sort(ls, (String x, String y) -> x.length() - y.length());
```

↓

```
Collections.sort(ls, (x, y) -> x.length() - y.length());
```


Method References

- Method references let us reuse a method as a lambda expression

```
FileFilter x = f -> f.canRead();
```

```
FileFilter x = File::canRead;
```


Constructor References

```
interface Factory<T> {
  T make();
}
```

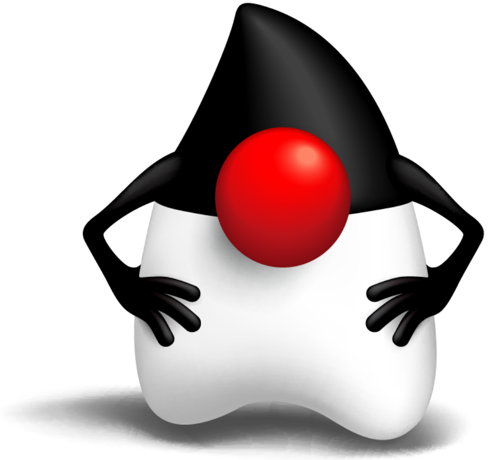
```
Factory<List<String>> f = ArrayList<String>::new;
```

Equivalent to

```
Factory<List<String>> f = () -> return new ArrayList<String>();
```

- When `f.make()` is invoked it will return a `new ArrayList<String>`

Library Evolution



Library Evolution

The Real Challenge

- Adding lambda expressions is a big language change
  - If Java had them from day one, the APIs would definitely look different
- Most important APIs (Collections) are based on interfaces
  - How to extend an interface without breaking backwards compatability?
- Adding lambda expressions to Java, but not upgrading the APIs to use them, would be silly
- Therefore we also need better mechanisms for *library evolution*

Library Evolution Goal

- Requirement: aggregate operations on collections
  - New methods required on Collections to facilitate this

```
int heaviestBlueBlock =
    blocks.stream()
          .filter(b -> b.getColor() == BLUE)
          .map(Block::getWeight)
          .reduce(0, Integer::max);
```

- This is problematic
  - Can’t add new methods to interfaces without modifying all implementations
  - Can’t necessarily find or control all implementations

Solution: Extension Methods

AKA Defender Methods

- Specified in the interface
- From the caller's perspective, just an ordinary interface method
- Provides a default implementation
  - Default is only used when implementation classes do not provide a body for the extension method
  - Implementation classes can provide a better version, or not

```
interface Collection<E> {
  default Stream<E> stream() {
    return StreamSupport.stream(spliterator());
  }
}
```

Virtual Extension Methods

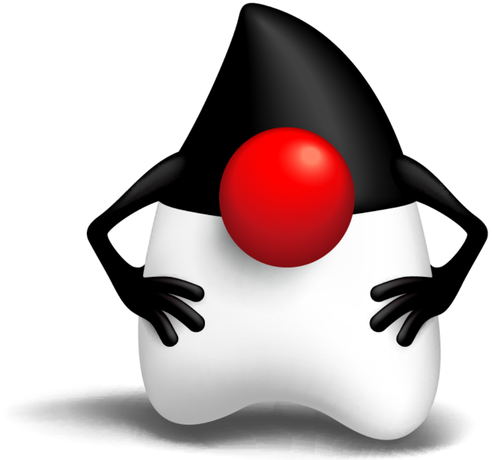
Stop right there!

- Err, isn't this implementing multiple inheritance for Java?
  - Yes, but Java already has multiple inheritance of *types*
  - This adds multiple inheritance of *behavior* too
  - But not *state*, which is where most of the trouble is
  - Can still be a source of complexity due to separate compilation and dynamic linking
    - Class implements two interfaces, both of which have default methods
    - Same signature
    - How does the compiler differentiate?

Functional Interface Definition

- Single Abstract Method (SAM) type
- A functional interface is an interface that has one abstract method
  - Represents a single function contract
  - Doesn't mean it only has one method
- Abstract classes may be considered later
- `@FunctionalInterface` annotation
  - Helps ensure the functional interface contract is honoured
  - Compiler error if not a SAM

Lambdas In Full Flow: Streams



Aggregate Operations

- Most business logic is about aggregate operations
  - Most profitable product by region
  - Group transactions by currency
- As we have seen, up to now, Java uses external iteration
  - Inherently serial
  - Frustratingly imperative
- Java SE 8's answer: **`Streams`**
  - With help from Lambdas

Stream Overview

At The High Level

- Abstraction for specifying aggregate computations
  - Not a data structure
  - Can be infinite
- Simplifies the description of aggregate computations
  - Exposes opportunitires for optimisation
  - Fusing, laziness and parrallelism

Stream Overview

Pipeline

- A stream pipeline consists of three types of things
  - A source
  - Zero or more intermediate operations
  - A terminal operation
    - Producing a result or a side-effect

```
int sum = transactions.stream().
  filter(t -> t.getBuyer().getCity().equals(“London”)).
  mapToInt(Transaction::getPrice).
  sum();
```

Source

Intermediate operation

Terminal operation

Stream Overview

Execution

- The **`filter`** and **`map`** methods don't really do any work
  - Set up a pipeline of operations and return a new **`Stream`**
- All work happens when we get to the **`sum()`** operation
  - **`filter()/map()/sum()`** fused into one pass on the data
    - For both sequential and parallel pipelines

```
int sum = transactions.stream().
  filter(t -> t.getBuyer().getCity().equals("London")).  // Lazy
  mapToInt(Transaction::getPrice).                        // Lazy
  sum();                                   // Execute the pipeline
```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Stream Sources

Many Ways To Create

- From collections and arrays
  - `Collection.stream()`
  - `Collection.parallelStream()`
  - `Arrays.stream(T array)` or `Stream.of()`
- Static factories
  - `IntStream.range()`
  - `Files.walk()`
- Roll your own
  - `java.util.Spliterator()`

Stream Sources Provide

- Access to stream elements
- Decomposition (for parallel operations)
  - Fork-join framework
- Stream characteristics
  - `ORDERED`
  - `DISTINCT`
  - `SORTED`
  - `SIZED`
  - `SUBSIZED`
  - `NONNULL`
  - `IMMUTABLE`
  - `CONCURRENT`

Stream Intermediate Operations

- Can affect pipeline characteristics
  - `map()` preserves `SIZED` but not necessarily `DISTINCT` or `SORTED`
- Some operations fuse/convert to parallel better than others
  - Stateless operations (`map`, `filter`) fuse/convert perfectly
  - Stateful operations (`sorted`, `distint`, `limit`) fuse/convert to varying degrees

Stream Terminal Operations

- Invoking a terminal operation executes the pipeline
  - All operations can execute sequentially or in parallel
- Terminal operations can take advantage of pipeline characteristics
  - `toArray()` can avoid copying for `SIZED` pipelines by allocating in advance

java.util.function Package

- **`Predicate<T>`**
  - Determine if the input of type T matches some criteria
- **`Consumer<T>`**
  - Accept a single input argumentof type T, and return no result
- **`Function<T, R>`**
  - Apply a function to the input type T, generating a result of type R
- Plus several more

The iterable Interface

Used by most collections

- One method, **`forEach()`**
  - Parameter is a **`Consumer`**
- Replace with **`reduce`** or **`collect`** where possible
  - **`forEach`** is not thread safe, and cannot be made parallel

```
wordList.forEach(System.out::println);  // OK

List<T> l = ...
s.map(λ).forEach(e -> l.add(e));
```

Replace with

```
List<T> l = s.map(λ).collect(Collectors.toList());
```

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Maps and FlatMaps

Map Values in a Stream

- One-to-one mapping
  - `<R> Stream<R> map(Function<? super T, ? extends R> mapper)`
  - `mapToDouble`, `mapToInt`, `mapToLong`
- One-to-many mapping
  - `<R> Stream<R> flatMap(`
    `Function<? super T, ? extends Stream<? extends R> mapper)`
  - `flatMapToDouble`, `flatMapToInt`, `flatMapToLong`

Example 1

Convert words in list to upper case

```
List<String> output = wordList.
  stream().
  map(String::toUpperCase).
  collect(Collectors.toList());
```


Example 2

Find words in list with even length

```
List<String> output = wordList.
  stream().
  filter(w -> (w.length() & 1 == 0).
  collect(Collectors.toList());
```


Example 3

Count lines in a file

- BufferedReader has new method
  - `Stream<String> lines()`

```
long count = bufferedReader.
  lines().
  count();
```

Example 4

Join lines 3-4 into a single string

```
String output = bufferedReader.
  lines().
  skip(2).
  limit(2).
  collect(Collectors.joining());
```


Example 5

Find the length of the longest line in a file

```
int longest = reader.
  lines().
  mapToInt(String::length).
  max().
  getAsInt();
```

Example 6

Collect all words in a file into a list

```
List<String> output = reader.
  lines().
  flatMap(line -> Stream.of(line.split(REGEXP))).
  filter(word -> word.length() > 0).
  collect(Collectors.toList());
```


Example 7

List of words lowercased, in aphabetical order

```
List<String> output = reader.
  lines().
  flatMap(line -> Stream.of(line.split(REGEXP))).
  filter(word -> word.length() > 0).
  map(String::toLowerCase).
  sorted().
  collect(Collectors.toList());
```


Conclusions

- Java needs lambda statements
  - Significant improvements in existing libraries are required
- Require a mechanism for interface evolution
  - Solution: virtual extension methods
- Bulk operations on Collections
  - Much simpler with Lambdas
- Java SE 8 evolves the language, libraries, and VM together

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