Evolving Java

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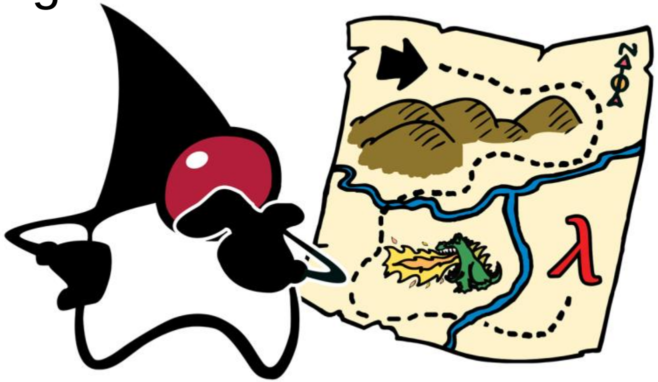
Modernizing Java

- Java SE 8 is a big step forward in modernizing the Java Language
  - Lambda Expressions (closures)
  - Interface Evolution (default methods)
- Java SE 8 is a big step forward in modernizing the Java Libraries
  - Bulk data operations on Collections
  - More library support for parallelism
- Together, perhaps the *biggest upgrade ever* to the Java programming model



What is a Lambda Expression?

- A *lambda expression* (closure) is an anonymous method
  - Has an argument list, a return type, and a body

    ```
    (Object o) -> o.toString()
    ```

  - A *method reference* is a reference to an existing method

    ```
    Object::toString
    ```

  - Lambdas can refer to (capture) values from the enclosing lexical scope

    ```
    (Person p) -> p.getName().equals(name)
    ```

  - Compiler can often *infer* argument types from context

    ```
    p -> p.getName().equals(name)
    ```

- Lambdas and method refs allow you to *treat code as data*
  - Behavior can be stored in variables and passed to methods

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Times Change

- In 1995, most popular languages did *not* support closures
- Today, Java is just about the last holdout that does not
  - C++ added them recently
  - C# added them in 3.0
  - New languages being designed today all do

> "In another thirty years people will laugh at anyone who tries to invent a language without closures, just as they'll laugh now at anyone who tries to invent a language without recursion."
> -Mark Jason Dominus

Problem: External Iteration

- Snippet takes the red blocks and colors them blue
- Uses foreach loop
  - Loop is *inherently sequential*
  - Client has to manage iteration
- This is called *external iteration*
- Foreach loop hides complex interaction between library and client
  - Iterable, iterator(), Iterator.next(), Iterator.hasNext()

```
for (Shape s : shapes) {
    if (s.getColor() == RED)
        s.setColor(BLUE);
}
```


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Internal Iteration

- Re-written to use lambda and Collection.forEach
  - Not just a syntactic change!
  - Now the library is in control
  - This is *internal iteration*
  - More *what*, less *how*

```
shapes.forEach(s -> {
    if (s.getColor() == RED)
        s.setColor(BLUE);
})
```

- Library free to use parallelism, out-of-order execution, laziness
- Client passes behavior (lambda) into the API as data
- Enables API designers to build more powerful, expressive APIs
  - Greater power to abstract over behavior

What is the Type of a Lambda Expression?

- Most languages with lambdas have some notion of a *function type*
  - "Function from long to int"
  - Seemed reasonable (at first) to consider adding them to Java
- But…
  - JVM has no native representation of function type in VM type signatures
  - Obvious tool for representing function types is generics
    - But then function types would be erased (and boxed)
  - Is there a simpler alternative?

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Functional Interfaces

- Historically have used single-method interfaces to represent functions
  - Runnable, Comparator, ActionListener
  - Let's give these a name: *functional interfaces*
  - And add some new ones like Predicate<T>, Consumer<T>, Supplier<T>
- A lambda expression evaluates to an instance of a functional interface

```
Predicate<String> isEmpty = s -> s.isEmpty();
Predicate<String> isEmpty = String::isEmpty;
Runnable r = () -> { System.out.println("Boo!"); };
```

- Compiler recognizes functional interfaces structurally
  - No syntax needed

Functional Interfaces

- “Just add function types” was obvious … and wrong
  - Would have interacted badly with erasure
  - Would have introduced complexity and corner cases
  - Would have bifurcated libraries into “old” and “new” styles
  - Would have created interoperability challenges
- Preserve the Core
  - Stodgy old approach may be better than shiny new one
- Bonus: existing libraries are now *forward-compatible* to lambdas
  - Libraries that never imagined lambdas still work with them!
  - Maintains significant investment in existing libraries
  - Fewer new concepts

Lambdas Enable Better APIs

- Lambda expressions *enable delivery of more powerful APIs*
- The client-library boundary is more permeable
  - Client can provide bits of functionality to be mixed into execution
  - Client determines the *what*
  - Library remains in control of the *how*
- Safer, exposes more opportunities for optimization

Example: Sorting

- If we want to sort a List today, we'd write a Comparator
  - Comparator conflates *extraction of sort key* with *ordering* of that key
- Could replace Comparator with a lambda, but only gets us so far
  - Better to separate the two aspects

```
Collections.sort(people, new Comparator<Person>() {
    public int compare(Person x, Person y) {
        return x.getLastName().compareTo(y.getLastName());
    }
});
```


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Example: Sorting

- Added static method Comparator.comparing(f)
  - Takes a “key extractor” function from T to some Comparable key
  - Returns a Comparator<T>
  - This is a *higher-order function* – functions in, functions out

```
interface Comparator {
    public static<T, U extends Comparable<? super U>>
    Comparator<T> comparing(Function<T, U> f) {
        return (x, y) -> f.apply(x).compareTo(f.apply(y));
    }
}
Comparator<Person> byLastName
      = Comparators.comparing(Person::getLastName);
```

Lambdas Enable Better APIs

- The comparing() method is one built for lambdas
  - Consumes an “extractor” function and produces a “comparator” function
  - Factors key extraction from comparison
  - Eliminates redundancy, boilerplate
- Key effect on APIs is: *more composability*
  - Centralize manipulation of Comparators in one place
  - Leads to better factoring, more regular client code, more reuse
- Lambdas in the languages

  → can write better libraries

  → more readable, less error-prone user code

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Problem: Interface Evolution

- The example used a new Collection method – forEach()
  - I thought you couldn't add new methods to interfaces?
- Interfaces are a double-edged sword
  - Cannot compatibly evolve them unless you control all implementations
  - Reality: APIs age
    - As we add cool new language features, existing APIs look even older!
  - Lots of bad options for dealing with aging APIs
    - Let the API stagnate
    - Replace it in entirety (every few years!)
    - Nail bags on the side (e.g., Collections.sort())

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Default Methods

- Libraries need to evolve, or they stagnate
  - Need a mechanism for compatibly evolving APIs
- New feature: *default methods*
  - Virtual interface method with default implementation
  - “default” is the dual of “abstract”

```
interface Collection<T> {
    default void forEach(Consumer<T> action) {
        for (T t : this)
            action.apply(t);
    }
}
```

- Lets us compatibly evolve libraries over time
  - Default implementation provided in the interface
  - Subclasses can override with better implementations
  - Adding a default method is source- and binary-compatible

Default Methods

- Huh? Is this multiple inheritance in Java?
  - Java always had multiple inheritance of *types*
  - This adds multiple inheritance of *behavior*
    - But not of *state*, where most of the trouble comes from
- Primary goal is interface evolution
- Compared to C# extension methods
  - Java's default methods are *virtual* and *declaration-site,* not *static* and *use-site*
- Compared to Scala's Traits
  - Java interfaces are stateless (more like Fortress' Traits)
- How do we resolve conflicts between declarations in multiple supertypes?
  - Three simple rules

Rule #1: Class Wins

- If a class can inherit a method from a superclass and a superinterface, prefer the superclass method
  - Defaults *only* considered if no method declared in superclass chain
  - True for both concrete and abstract superclass methods
- Ensures compatibility with pre-Java-8 inheritance
  - Any call site that linked under previous rules links to the same target
- Otherwise…

Rule #2: Subtypes Win

- If a class can inherit a method from two interfaces, and one more specific than (a subtype of) the other, prefer the more specific
  - An implementation in List would take precedence over one in Collection
- The shape of the inheritance tree doesn't matter
  - Only consider the set of supertypes, not order in which they are inherited
- Otherwise…

Rule #3: There is No Rule 3

- If rule #1 does not apply, and rule #2 does not yield a *unique, most specific default-providing interface…*
  - Implement the method yourself (or explicitly reabstract it)
  - Implementation can delegate to inherited implementation with new syntax **`A.super.m()`**

```
interface A {
    default void m() { ... }
}
interface B {
    default void m() { ... }
}
class C implements A, B {
    // Must implement/reabstract m()
    void m() { A.super.m(); }
}
```


Diamonds – No Problem

- Diamonds do not pose a problem for behavior inheritance
  - More problematic for state inheritance
- For D, there is a unique, most-specific default-providing interface – A
  - D inherits m() from A, via two paths
  - "Redundant" inheritance does not affect the resolution

```
interface A {
    default void m() { ... }
}
interface B extends A { }
interface C extends A { }
class D implements B, C { }
```


Example – Evolving Interfaces

- Default methods are instance methods
  - Type of 'this' is the declaring interface
  - So default implementation can invoke methods from enclosing interface
    - Such as iterator()
  - Adding a new method with default is source- and binary-compatible

```
interface Collection<E> {
    default boolean removeIf(Predicate<? super E> filter) {
        boolean removed = false;
        Iterator<E> it = iterator();
        while(it.hasNext()) {
            if(filter.test(each.next())) {
                it.remove();
                removed = true;
            }
        }
        return removed;
    }
}
```


Example – “Optional” Methods

- Default methods can reduce implementation burden
- Most implementations of Iterator don’t provide a useful remove()
  - So why make developer write one that just throws?
  - In this way, default methods can be used to declare “optional” methods
  - Adding a default to an existing method is source- and binary- compatible

```
interface Iterator<T> {
    boolean hasNext();

    T next();

    default void remove() {
        throw new UnsupportedOperationException();
    }
}
```


Example – Combinators

- Comparator.reversed() – reverses sort order of a Comparator
  - Instance (default) method on Comparator
    - Invokes compare() with arguments in reverse order
  - Also added Comparator.thenComparing() instance methods

```
interface Comparator {
    default Comparator<T> reversed() {
        return (o1, o2) -> compare(o2, o1);
    }
}
Comparator<Person> byLastNameDescending
      = Comparator.comparing(Person::getLastName)
                  .reversed();
```


Putting it together: Sorting

```
Comparator<Person> byLastName
    = Comparator.comparing(p -> p.getLastName());
Collections.sort(people, byLastName);

Collections.sort(people, comparing(p -> p.getLastName()));

people.sort(comparing(p -> p.getLastName()));

people.sort(comparing(Person::getLastName));

people.sort(comparing(Person::getLastName).reversed());

people.sort(comparing(Person::getLastName)
            .thenComparing(Person::getFirstName));
```

Bulk operations on Collections

- The lambda version of the "shapes" code can be further decomposed
  - Using Streams framework (java.util.stream) for aggregate operations
- "Color the red blocks blue" can be decomposed into filter+forEach

```
shapes.forEach(s -> {
    if (s.getColor() == RED)
        s.setColor(BLUE);
})
```

⬇

```
shapes.stream()
         .filter(s -> s.getColor() == RED)
         .forEach(s -> { s.setColor(BLUE); });
```


Bulk operations on Collections

- Collect the blue Shapes into a List

```
List<Shape> blueBlocks
    = shapes.stream()
            .filter(s -> s.getColor() == BLUE)
            .collect(Collectors.toList());
```

- If each Shape lives in a Box, find Boxes containing a blue shape

```
Set<Box> hasBlueBlock
    = shapes.stream()
            .filter(s -> s.getColor() == BLUE)
            .map(Shape::getContainingBox)
            .collect(Collectors.toSet());
```


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Bulk operations on Collections

- Compute sum of weights of blue shapes

```
int sumOfWeight
    = shapes.stream()
            .filter(s -> s.getColor() == BLUE)
            .mapToInt(Shape::getWeight)
            .sum();
```

Bulk operations on Collections

- The new bulk operations are expressive and composable
  - Compose compound operations from basic building blocks
  - Each stage does one thing
  - Client code reads more like the problem statement
  - Structure of client code is less brittle
  - Less extraneous “noise” from intermediate results
  - Library can use parallelism, out-of-order, laziness for performance

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Streams

- To add bulk operations, we create a new abstraction, Stream
  - Represents a stream of values
    - Not a data structure – doesn’t store the values
  - Source can be a Collection, array, generating function, I/O…
  - Operations that produce new streams are lazy
  - Encourages a “fluent” usage style
  - Efficient – does a single pass on the data

```
collection.stream()
          .filter(f -> f.isBlue())
          .map(f -> f.getBar())
          .forEach(System.out::println);
```

Streams

```
Set<Seller> sellers = new HashSet<>();
for (Txn t : txns) {
    if (t.getBuyer().getAge() >= 65)
        sellers.add(t.getSeller());
}
List<Seller> sorted = new ArrayList<>(sellers);
Collections.sort(sorted, new Comparator<Group>() {
    public int compare(Seller a, Seller b) {
        return a.getName().compareTo(b.getName());
    }
});
for (Seller s : sorted)
    System.out.println(s.getName());
```

- Or…

```
txns.stream()
    .filter(t -> t.getBuyer().getAge() >= 65)
    .map(Txn::getSeller)
    .distinct()
    .sort(comparing(Seller::getName))
    .forEach(s -> System.out.println(s.getName());
```


Comparing Approaches

Imperative	Streams
Code deals with individual data items	Code deals with data set
Focused on *how*	Focused on *what*
Code doesn’t read like the problem statement	Code reads like the problem statement
Steps mashed together	Well-factored
Leaks extraneous details	No “garbage variables”
Inherently sequential	Same code can be sequential or parallel

Parallelism

- Goal: easy-to-use parallel libraries for Java
  - Libraries can hide a host of complex concerns (task scheduling, thread management, load balancing)
- Goal: reduce conceptual and syntactic gap between serial and parallel expressions of the same computation
  - Right now, the serial code and the parallel code for a given computation don't look anything like each other
  - Fork-join (added in Java SE 7) is a good start, but not enough
- Goal: parallelism should be explicit, but unobtrusive

Fork/Join Parallelism

- JDK7 has a general-purpose Fork/Join framework
  - Powerful and efficient, but not so easy to program to
  - Based on recursive decomposition
    - Divide problem into subproblems, solve in parallel, combine results
    - Keep dividing until small enough to solve sequentially
  - Tends to be efficient across a wide range of processor counts
  - Generates reasonable load balancing with no central coordination

Parallel Sum with Fork/Join

```
ForkJoinExecutor pool = new ForkJoinPool(nThreads);
SumProblem finder = new SumProblem(problem);
pool.invoke(finder);

class SumFinder extends RecursiveAction {
  private final SumProblem problem;
  int sum;

  protected void compute() {
    if (problem.size < THRESHOLD)
      sum = problem.solveSequentially();
    else {
      int m = problem.size / 2;
      SumFinder left, right;
      left = new SumFinder(problem.subproblem(0, m))
      right = new SumFinder(problem.subproblem(m, problem.size));
      forkJoin(left, right);
      sum = left.sum + right.sum;
    }
  }
}
```

```
class SumProblem {
  final List<Shape> shapes;
  final int size;

  SumProblem(List<Shape> ls) {
    this.shapes = ls;
    size = ls.size();
  }

  public int solveSequentially() {
    int sum = 0;
    for (Shape s : shapes) {
      if (s.getColor() == BLUE)
        sum += s.getWeight();
    }
    return sum;
  }
  public SumProblem subproblem(int start, int end) {
    return new SumProblem(shapes.subList(start, end));
  }
}
```

Parallel Sum with Collections

- Parallel sum-of-sizes with bulk collection operations

```
int sumOfWeight
    = shapes.parallelStream()
            .filter(s -> s.getColor() == BLUE)
            .mapToInt(Shape::getWeight)
            .sum();
```

  – Explicit but unobtrusive parallelism
  – All three operations fused into a single parallel pass

So … Why Lambda?

- It's about time!
  - Java is the lone holdout among mainstream OO languages at this point to not have closures
  - Adding closures to Java is no longer a radical idea
- Provide libraries a path to multicore
  - Parallel-friendly APIs need internal iteration
  - Internal iteration needs a concise code-as-data mechanism
- Empower library developers
  - More powerful, flexible libraries
  - Higher degree of cooperation between libraries and client code
  - Better libraries means more expressive, less error-prone code for users!

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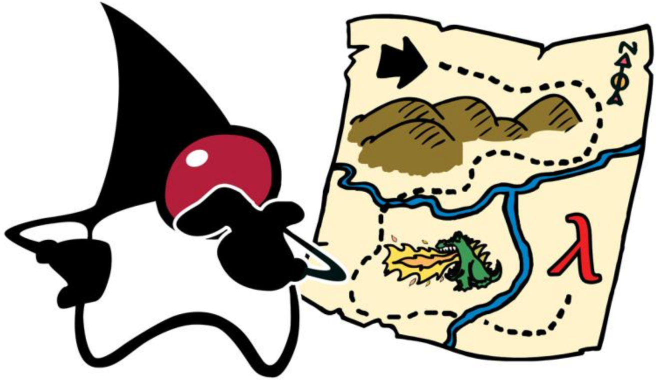
Where are we now?

- Developer Preview available at https://jdk8.java.net/download.html
  - Download and try it out!
- In JCP Public Review
- Shipping with Java SE 8



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