JSR-335 Update
Lambda expressions for the Java Language

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JSR-335

• JSR 335 is a coordinated co-evolution of the Java platform
  • Language – lambda expressions (closures), interface evolution, better type inference
  • Libraries – Bulk parallel operations on collections
  • VM – support for default methods and lambda conversion

• Major step forward for the Java programming model
  • More parallel-friendly
  • Enable delivery of more powerful libraries
  • Enable developers to write more concise, less error-prone code
Closures for Java – a long and winding road

• 1997 – Java 1.1 added inner classes – a weak form of closures
  • Too bulky, complex name resolution rules, many limitations
• In 2006-2008, a vigorous community debate about closures
  • Multiple proposals, including BGGA and CICE
  • Each had a different orientation
    • BGGA – creating control abstraction in libraries
    • CICE – reducing syntactic overhead of inner classes
  • Things ran aground at this point…
• Little evolution from Java SE 5 (2004) until now
  • Project Coin (Small Language Changes) in Java SE 7
Closures for Java – a long and winding road
Closures for Java – a long and winding road

• Dec 2009 – OpenJDK Project Lambda formed
• November 2010 – JSR-335 filed
• Current status
  • EDR #3 filed
  • Prototype RI (source and binary) available on OpenJDK
  • Component of Java SE 8
• JSR-335 = Lambda Expressions
  + Interface Evolution
  + Bulk Collection Operations
Evolving a major language

• Key evolutionary forces
  • Adapting to change
    • Everything changes: hardware, attitudes, fashions, problems, demographics
  • Righting what’s wrong
    • Inconsistencies, holes, poor user experience
  • Maintaining compatibility
    • Low tolerance for change that will break anything
  • Preserving the core
    • Can’t alienate user base in quest for “something better”
    • Easy to focus on cool new stuff, but there’s lots of cool old stuff too
Adapting to Change

• In 1995, most mainstream languages did not support closures
  • Perceived to be “too hard” for ordinary developers
• Today, Java is just about the last holdout that doesn’t
  • C++ added them recently
  • C# added them in 3.0
  • New languages being designed today all do
Adapting to Change

- Language design is influenced by the dominant hardware
  - Which changes over time
- In 1995, pervasive sequentiality infected programming language design
  - For loops are sequential
    - Why wouldn’t they be? Why invite nondeterminism?
    - Determinism is convenient – when free
    - Similarly, Iterator/Iterable is sequential
  - Pervasive mutability
    - Mutability is convenient – when free
    - Object creation was expensive and mutation cheap
- In today’s world, these are just the wrong defaults!
  - Can’t just outlaw for loops and mutability
  - Instead, gently encourage something better
Problem – External Iteration

• “Take the red blocks and colors them blue”
• Typical solution with foreach loop
  • Loop is *inherently sequential*
    • Wasn’t a big problem 20 years ago, but times change
  • Client has to manage iteration
    • Conflates “what” with “how”
  • This is called *external iteration*
  • Hides complex interaction between library and client

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

- Re-written to use lambda and Collection.forEach
  - Not just a syntactic change!
  - Now the library is in control
  - *Internal iteration* – More *what*, less *how*
  - Client passes behavior into the API as data
- Library can use parallelism, out-of-order, laziness
- Also enable more powerful, expressive APIs
  - Greater power to abstract over behavior

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

- A lambda expression is an anonymous method
  - Has an argument list, a return type, and a body
    `(Object o) -> o.toString()`
  - Can refer to values from the enclosing lexical scope
    `(Person p) -> p.getName().equals(name)`
  - Compiler can often infer parameter types from context
    `p -> p.getName().equals(name)`
- A method reference is a reference to an existing method
  `Object::toString`
- All of these forms allow you to treat code as data
  - Behavior can be stored in variables and passed to methods
What is the type of a lambda?

- Most languages with lambdas have some notion of a function type
  - Java language has no concept of function type
  - JVM has no native (unerased) representation of function type in VM type signatures
  - Adding function types would create many questions
    - How do we represent functions in VM type signatures?
    - How do we create instances of function types?
    - Want to avoid significant VM changes
  - Obvious tool for representing function types is generics
    - But then function types would be … erased
Functional Interfaces

• Historically used single-method interfaces to model functions
  • Runnable, Comparator, ActionListener
  • Let’s just give these a name: functional interfaces
  • And add some new ones like Predicate<T>, Block<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!"); }
Functional Interfaces

• “Just add function types” was obvious … and wrong
  • 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
Problem – Interface Evolution

• 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())
Interface Evolution

- 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"

- Three simple rules for resolving inheritance conflicts
  - Superclasses win over superinterfaces
  - More specific interfaces win over less specific
  - After that, concrete classes must override

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

• Similar to, but different from, C# extension methods
  • Java’s default methods are *virtual* and *declaration-site*
  • Core principle: API owners should control their APIs

• Primary goal is *API evolution*
  • Inheritance rules directed at this primary goal
  • But very useful as an inheritance mechanism on its own!

• Wait, 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
It’s All About The Libraries

• Generally, we prefer to evolve the programming model through libraries
  • Time to market – can evolve libraries faster than language
  • Decentralized – more library developers than language developers
  • Risk – easier to change libraries, more practical to experiment
  • Impact – language changes require coordinated changes to multiple compilers, IDEs, and other tools

• Sometimes we reach the limits of what is practical to express in libraries, and need a little help from the language
  • A little help, in the right places, can go a long way!
Lambdas Enable Better APIs

- Lambda expressions enable more powerful APIs
  - Boundary between client and library is more permeable
  - Client provides bits of behavior to be mixed into execution (“what”)
  - Library remains in control of the computation (“how”)
  - Safer, exposes more opportunities for optimization
- Key effect on APIs is: more composability
  - Leads to better factoring, more regular client code, more reuse
- Lambdas in the language
  → can write better libraries
  → more readable, less error-prone user code
Example – Sorting

- Default methods can enhance composability
  - Comparator.reverse(), Comparator.compose()
  - Default methods offer a “right place” to put certain code

```java
interface Comparator<T> {
    int compare(T o1, T o2);

    default Comparator<T> reverse() {
        return (o1, o2) -> -(compare(o1, o2));
    }

    default Comparator<T> compose(Comparator<T> other) {
        return (o1, o2) -> {
            int cmp = compare(o1, o2);
            return (cmp != 0) ? cmp : other.compare(o1, o2);
        }
    }
}
```

```java
Comparator<Person> byFirst = ...
Comparator<Person> byLast = ...

Comparator<Person> byFirstLast = byFirst.compose(byLast);
Comparator<Person> byLastDescending = byLast.reverse();
```
Example – Sorting

- If we want to sort a List today, we write a Comparator
- Many layers of nastiness here!
  - Conflates extraction of sort key with ordering of that key
  - Collections class required for helper methods
  - Syntactically verbose
    - Could replace with a lambda, but only gets us so far
    - Better to untangle the intertwined aspects
  - Fewer opportunities for reuse

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

- Lambdas encourage finer-grained APIs
  - We add a method that takes a “key extractor” and returns Comparator
  - The comparing() method is one built for lambdas
    - Higher-order function
    - Eliminates redundancy, boilerplate

```java
Comparator<Person> byLastName = Comparators.comparing(p -> p.getLastName());
```

```java
class Comparators {
    public static<T, U extends Comparable<? super U>>
        Comparator<T> comparing(Mapper<T, U> m) {
            return (x, y) -> m.map(x).compareTo(m.map(y));
        }
}
```
Example – Sorting

```java
Comparator<Person> byLastName
    = Comparators.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).reverse());
people.sort(comparing(Person::getLastName)
    .compose(comparing(Person::getFirstName)));
```
Bulk operations on Collections

- Compute sum of weights of blue shapes
  - 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
    - No “garbage variables”
  - Library can use parallelism, out-of-order, laziness for performance

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

• To add bulk operations, we create a new abstraction, Stream (in package java.util.stream)
  • Key new library abstraction for JSR-335
  • Represents a stream of values
    • Not a data structure – doesn’t store the values
  • Source can be a Collection, array, generating function, IO
  • Encourages a “fluent” usage style
    • Supports operations like filter(), map(), reduce()
  • Retrofit stream() method on Collection
    • As well as: Reader.lines(), Random.ints(), String.chars(), etc
  • Easy to adapt any aggregate to be a Stream source
Streams

- What does this code do?

```java
Set<Group> groups = new HashSet<>();
for (Person p : people) {
    if (p.getAge() >= 65)
        groups.add(p.getGroup());
}
List<Group> sorted = new ArrayList<>(groups);
Collections.sort(sorted, new Comparator<Group>() {
    public int compare(Group a, Group b) {
        return Integer.compare(a.getSize(), b.getSize());
    }
});
for (Group g : sorted)
    System.out.println(g.getName());

people.stream()
    .filter(p -> p.getAge() > 65)
    .map(p -> p.getGroup())
    .removeDuplicates()
    .sorted(comparing(g -> g.getSize()))
    .forEach(g -> System.out.println(g.getName()));
```
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 added 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

```java
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));
    }
}

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;
        }
    }
}
```
Parallel Sum with Streams

- Explicit but unobtrusive parallelism
  - All three operations fused into a single parallel pass
  - Works with ordinary, non-thread-safe collections
  - Extensible mechanism to work with any bulk container

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

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

• Encourage better idioms
  • Gentle push towards a more functional style of programming