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Evolving Java
Project Lambda, and Beyond

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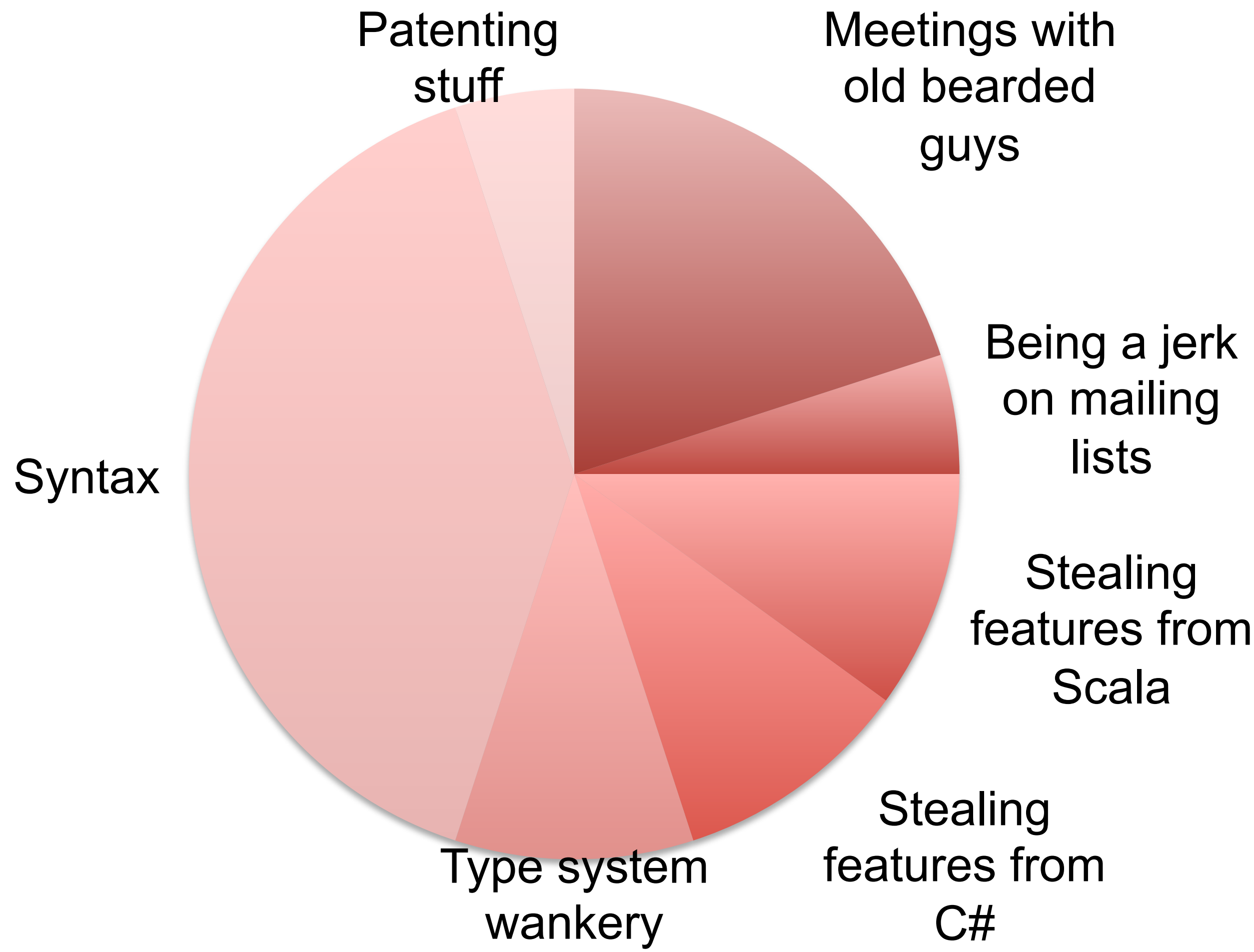
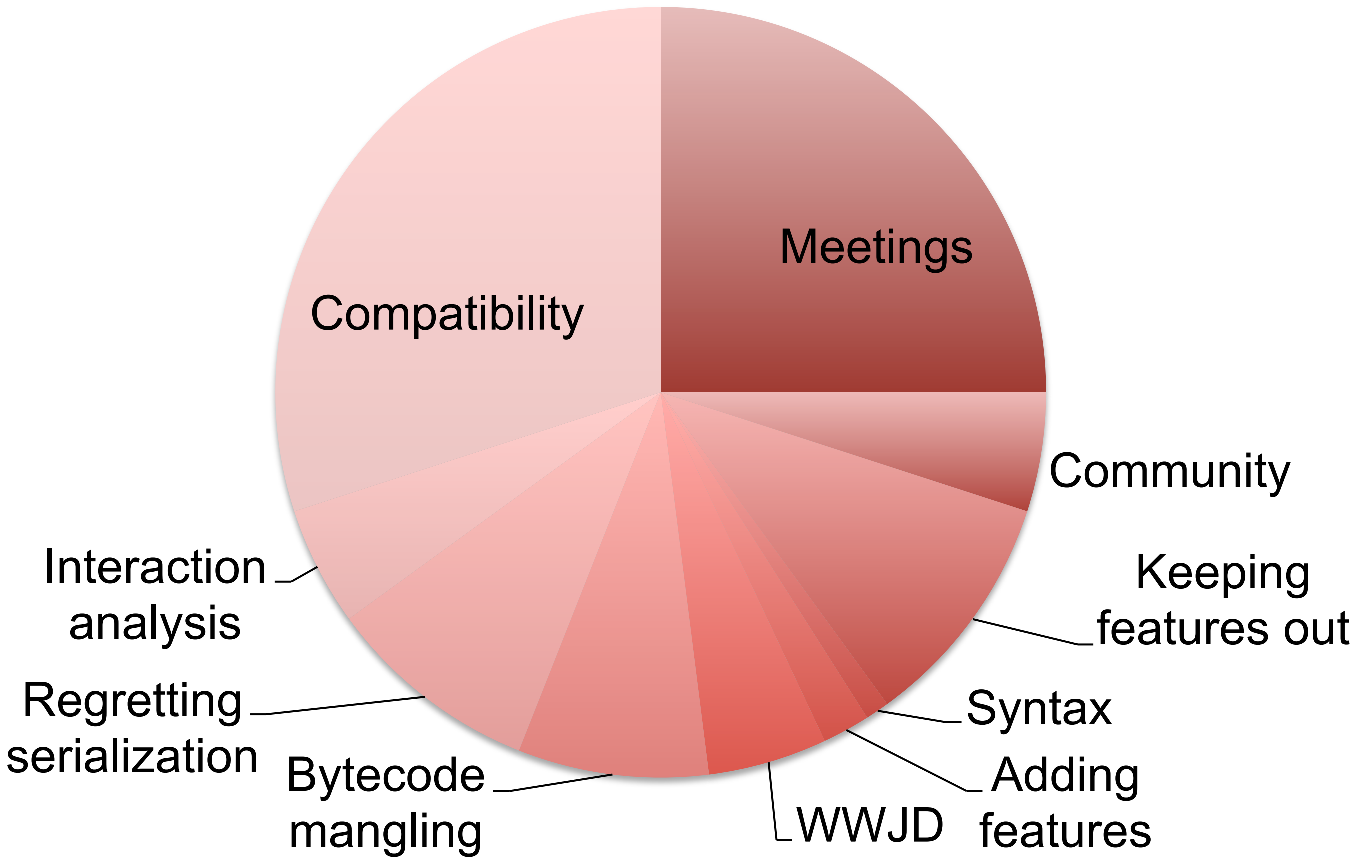
What people think I do

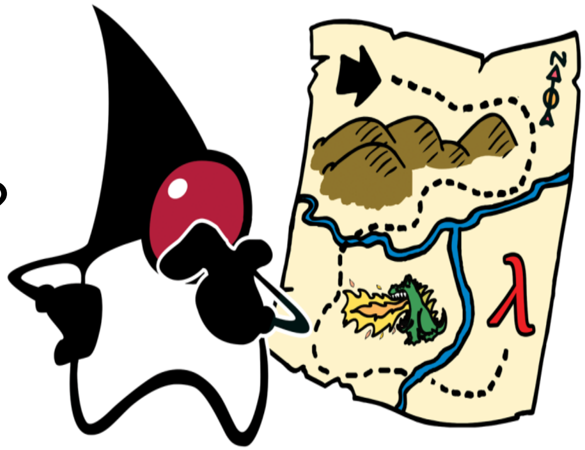


What (it feels like) I actually do



Modernizing Java

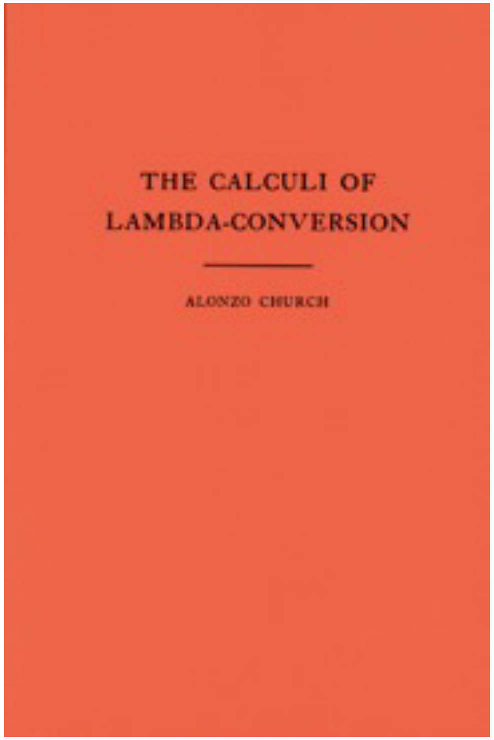
- Java SE 8 is a big step forward in modernizing the Java *Language*
  - Lambda Expressions (closures)
  - Interface Evolution (default methods)
- Java SE 8 is a big step forward in modernizing the Java *Libraries*
  - Bulk data operations on Collections
  - More library support for parallelism
- Why do we choose the features we do?
- How do we evolve a mature language?



Closures for Java – a long and winding road

- 1997 – Odersky/Wadler experimental “Pizza” work
- 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 specification complete
  - Prototype (source and binary) available on OpenJDK
  - Part of Java SE 8 (Summer 2013)
- 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

"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

Adapting to Change

- 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
- Lambda expressions is that gentle push

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

```
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

```
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

```
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

- 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
  - Status quo reduces opportunities for reuse

```
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

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

```
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

```
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)));
```

Example – Sorting

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

```
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);
        }
    }
}
```

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

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

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

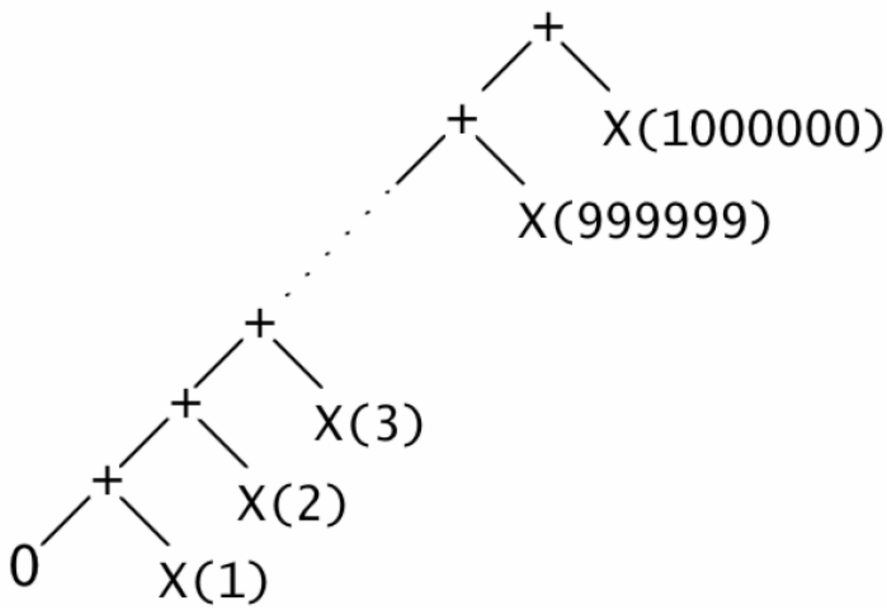
```
int sumOfWeight
    = shapes.stream()
            .filter(s -> s.getColor() == BLUE)
            .map(Shape::getWeight)
            .sum();
```

Brief inspiration diversion

Brief inspiration diversion

Sequential Computation Tree

```
SUM = 0
DO I = 1, 1000000
  SUM = SUM + X(I)
END DO
```



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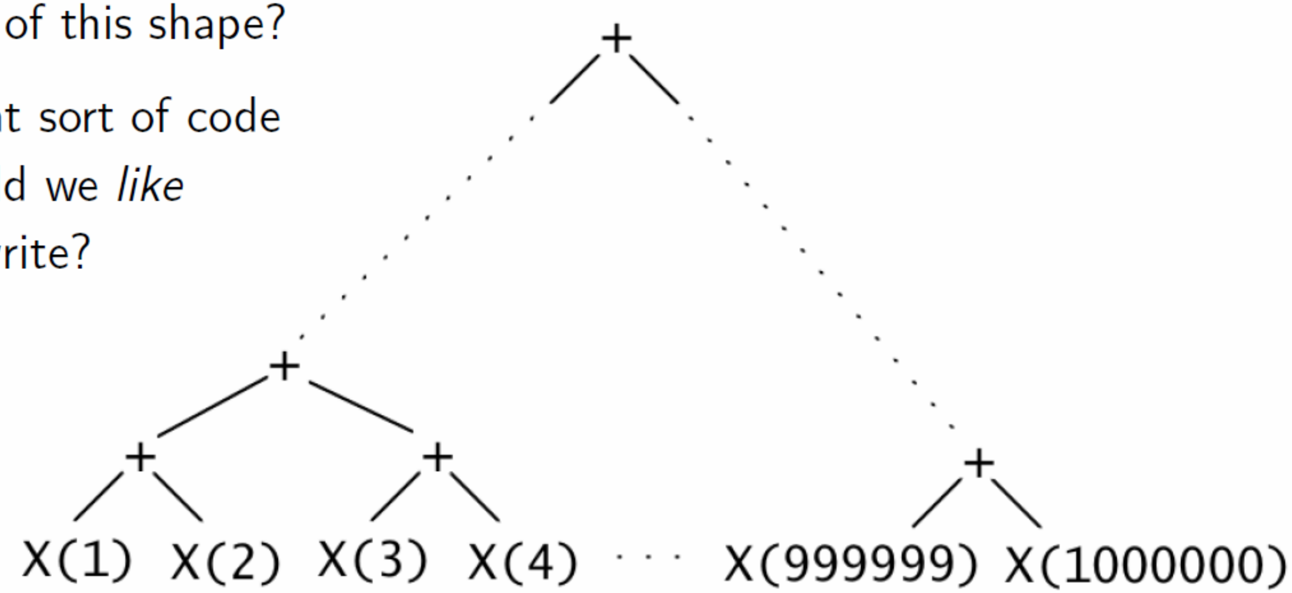
Brief inspiration diversion

Parallel Computation Tree

What sort of code
should we write
to get a computation
tree of this shape?

What sort of code
would we *like*
to write?



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?

```
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

```
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 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

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

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

Aggregation

- The sum() example is a special case of *reduction*
  - Elements $t_1, t_2, \ldots t_n$
  - An associative operator $\times$
  - Computes $t_1 \times t_2 \times \ldots \times t_n$
- We can extend the notion of reduction to mutable aggregations
  - Accumulate elements into a List
  - Concatenate strings into a StringBuffer
  - Classify elements and group into a Map
- Reductions work in parallel as well as sequentially
  - (As long as your operator is associative)

Aggregation

```
// Accumulate elements into a List
List<Person> list = people.stream()
                          .collect(Collectors.toList());

// Accumulate elements into a TreeSet
TreeSet<Person> list =
    people.stream()
          .collect(toCollection(TreeSet::new));

// Convert elements to comma-separated list
String joined =
    stream.map(Object::toString)
          .collect(toStringJoiner(", "))
          .toString();

// Find highest-paid employee
Employee highestPaid =
    employees.stream()
             .collect(maxBy(comparing(Employee::getSalary)));
```

Aggregation

```
// Group employees by department
Map<Department, List<Employee>> byDept =
    emps.stream()
        .collect(groupingBy(Employee::getDepartment));

// Find highest-paid employee by department
Map<Department, Employee> highestPaidByDept =
    emps.stream()
        .collect(groupingBy(Employee::getDepartment,
                            maxBy(comparing(Employee::getSalary))));
```

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

What's Next?

- There's plenty more work to do!
  - Dealing with primitive-reference divide
  - More parallel libraries
  - Value types and tuples
  - Computation on GPUs

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