Java SE: Where We've Been, Where We're Going

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Executive Summary

- Java SE 7 released Summer 2011
- Java SE 8 targeted for Summer 2013
- More transparent JCP and OpenJDK

Audience survey

- Downloaded JDK7 GA or 7u1?
  - JDK7 Mac OS X Port – Developer Preview Release
    http://jdk7.java.net/macportpreview/
- Subscribed to coin-dev @ OpenJDK ?
- Subscribed to lambda-dev @ OpenJDK ?
- OpenJDK contributor?
  - http://openjdk.java.net/contribute/

Java SE 7

Features in Java SE 7

- Small language changes (JSR 334)
- Dynamic language support (JSR 292)
- Fork/Join Framework (JSR 166y)
- ClassLoader, Swing, and Java2D improvements
- Unicode 6.0 and improved regex support
- HotSpot: G1 GC, Tiered Compilation, Compressed OOPs
- Specs: JLS7 and JVMS7 on jcp.org now, books coming soon

Small language changes in Java SE 7

- Consistency and clarity
  - Numeric literals
  - Strings in switch
- Ease of use for generics
  - Varargs warnings
  - Diamond operator
- Concise error handling
  - Multi-catch and precise rethrow
  - try-with-resources

NetBeans 7.0

Eclipse 3.7.1

IntelliJ IDEA 10.5

Consistency and clarity

- Underscores in numeric literals
  - `650_506_7000`
  - `0xCAFE_BABE`
- Binary literals
  - `0b0010_1100`
- Strings in switch
  - ```
    int daysInMonth(String month, int year) {
        switch (month) {
            case "April":
            case "June":
            case "September":
            case "November":
                return 30;
    ```
    ```

@SafeVarargs

- Unchecked warnings indicate possible heap pollution
- Prior to Java SE 7, calling certain varargs methods in the platform resulted in unchecked warnings
  - <T> List<T> Arrays.asList(T… a)
  - <T> boolean Collections.addAll(Collection<? super T> c, T… elements)
  - <E extends Enum<E>> EnumSet<E> EnumSet.of(E first, E… rest)
  - void javax.swing.SwingWorker.publish(V… chunks)
  - Warnings were due to a poor interaction of arrays and generics, but nothing bad actually happens
- In Java SE 7, @SafeVarargs suppresses these warnings

Diamond

- `List<String> ls = new ArrayList<>();`
- `List<List<String>> ls = new ArrayList<>();`
- `List<? extends String> ls = new ArrayList<>();`
- `Map<? extends Number, ? extends String> m = new HashMap<>();`

- Types of constructor arguments are taken into account
- Important to keep static type information on the left-hand side
- <> turns out to be very useful for using lambda-fied libraries

Concise error handling

```
void exampleMethod(Future future) throws
    InterruptedException, ExecutionException, TimeoutException
{
    Object result = future.get(5, SECONDS);

    // Future.get(long, TimeUnit) is declared to throw
    // InterruptedException, ExecutionException, TimeoutException
}
```

- How would we catch, clean up, and rethrow?

Multiple catch clauses in Java SE 6

```
void exampleMethod(Future future) throws
    InterruptedException, ExecutionException, TimeoutException
{
    try {
        Object result = future.get(5, SECONDS);
    } catch (InterruptedException ex) {
        cleanup();
        throw ex;
    } catch (ExecutionException ex) {
        cleanup();
        throw ex;
    } catch (TimeoutException ex) {
        cleanup();
        throw ex;
    }
}
```

Multi-catch in Java SE 7

```
void exampleMethod(Future future) throws
    InterruptedException, ExecutionException, TimeoutException
{
    try {
        Object result = future.get(5, SECONDS);
    } catch (InterruptedException |
             ExecutionException |
             TimeoutException ex) {
        cleanup();
        throw ex;
    }
}
```

Precise rethrow instead of multi-catch

```
void exampleMethod(Future future) throws
    InterruptedException, ExecutionException, TimeoutException
{
    try {
        Object result = future.get(5, SECONDS);
    } catch (Exception ex) {
        cleanup();
        throw ex;
    }
}
```

Type of `ex` *is inferred as:*
`InterruptedException | ExecutionException | TimeoutException`

- An entirely new exception handling idiom!
- The exception variable must be final or effectively final

try-with-resources

- Aims to avoid leaks of external resources

- You type this:

```
try (Resource r = ...) {
    ...
} catch (Exception e) {
    ...
} finally {
    ...
}
```

- Compiler generates this:

```
try {
    Resource r = null;
    try {
        r = ...;
        ...
    } finally {
        if (r != null) r.close();
    }
} catch (Exception e) { ... }
} finally { ... }
```

- Allows initialization of one or more resource variables

- Allows a try block with no catch or finally blocks

Example

Applying Java SE 7 features in the JDK

- 7018392 “update URLJarFile.java to use try-with-resources”
- Example method: URLJarFile.retrieve()
  - Takes a URL
  - Opens it
  - Downloads content into a temporary file
  - Creates and returns a JarFile instance backed by the temp file
  - Removes temp file if there was an error
  - Mustn’t leak anything
  - Must handle all errors without loss of information

Original code (Part 1 of 3)

```
JarFile retrieve(URL url) throws IOException {
    InputStream  in       = url.openStream();
    OutputStream out      = null;
    File         tmpFile = null;
    try {
        tmpFile = File.createTempFile("jar_cache", null);
        out     = new FileOutputStream(tmpFile);
        ...
```

Original code (Part 2 of 3)

```
...
int read = 0;
byte[] buf = new byte[BUF_SIZE];
while ((read = in.read(buf)) != -1) {
    out.write(buf, 0, read);
}
out.close();
out = null;
return new JarFile(tmpFile);
...
```

Original code (Part 3 of 3)

```
        ...
    } catch (IOException e) {
        if (tmpFile != null) {
            tmpFile.delete();
        }
        throw e;
    } finally {
        if (in != null) {
            in.close();
        }
        if (out != null) {
            out.close();
        }
    }
}
```

Original code (Part 3 of 3)

```
        ...
    } catch (IOException e) {
        if (tmpFile != null) {
            tmpFile.delete();
        }
        throw e;
    } finally {
        if (in != null) {
            in.close();
        }
        if (out != null) {
            out.close();
        }
    }
}
```

Bug: If non-IOException is thrown, temp file will not be deleted

Bug: If in.close() fails, out will remain open

Problem: Suppressed exceptions are mishandled

Problem: Uses null references to keep track of what needs cleanup

Pathology: trying to do too much in a single try/catch/finally block

Alternative (nested try-statements) is arguably worse

Improvement #1: NIO2

- Allows us to replace this…

```
out = new FileOutputStream(tmpFile);
int read = 0;
byte[] buf = new byte[BUF_SIZE];
while ((read = in.read(buf)) != -1) {
    out.write(buf, 0, read);
}
out.close();
out = null;
return new JarFile(tmpFile);
```

- With…

```
import java.nio.file.*;
Files.copy(in, tmpFile, REPLACE_EXISTING);
return new JarFile(tmpFile.toFile());
```

Improvement #2: try-with-resources

- Allows us to replace this…

```
InputStream in = url.openStream();
try { … }
catch (…) { … }
finally {
    if (in != null) {
        in.close();
    }
}
```

- With…

```
try (InputStream in = url.openStream()) { … }
catch (…) { … }
```

Improvement #2: try-with-resources

```
JarFile retrieve(URL url) throws IOException {
  InputStream in = url.openStream();
  Path tmpFile = null;
  try {
    tmpFile =
      Files.createTempFile("jar_cache", null);
    Files.copy(in, tmpFile, REPLACE_EXISTING);
    return new JarFile(tmpFile.toFile());
  } catch (IOException e) {
    if (tmpFile != null) {
      Files.delete(tmpFile);
    }
    throw e;
  } finally {
    if (in != null) {
      in.close();
    }
  }
}
```

```
JarFile retrieve(URL url) throws IOException {
  Path tmpFile = null;
  try (InputStream in = url.openStream()) {
    tmpFile =
      Files.createTempFile("jar_cache", null);
    Files.copy(in, tmpFile, REPLACE_EXISTING);
    return new JarFile(tmpFile.toFile());
  } catch (IOException e) {
    if (tmpFile != null) {
      Files.delete(tmpFile);
    }
    throw e;
  }
}
```

Improvement #3: Drop the null sentinels

- The `in` and `out` variables are now handled for us
  - `in` is a resource variable, `out` is “buried” inside Files.copy()
- The only thing to clean up after an IOException is the temp file, so we can create it first and drop its null sentinel

```
JarFile retrieve(URL url) throws IOException {
    Path tmpFile = Files.createTempFile("jar_cache", null);
    try (InputStream in = url.openStream()) {
        Files.copy(in, tmpFile, REPLACE_EXISTING);
        return new JarFile(tmpFile.toFile());
    } catch (IOException e) {
        Files.delete(tmpFile);
        throw e;
    }
}
```

Improvement #4: Precise rethrow

- We want to delete the temp file on any error

- Precise rethrow to the rescue!

```
JarFile retrieve(URL url) throws IOException {
    Path tmpFile = Files.createTempFile("jar_cache", null);
    try (InputStream in = url.openStream()) {
        Files.copy(in, tmpFile, REPLACE_EXISTING);
        return new JarFile(tmpFile.toFile());
    } catch (~~IOException~~Throwable e) {
        Files.delete(tmpFile);
        throw e;
    }
}
```

Improvement #5: Suppressed exceptions

- An exception from Files.delete() in the catch clause would suppress the exception thrown by the try block
- Better to catch an exception from Files.delete() and add it to the *suppressed exception list* of the try block's exception
  - Throwable.addSuppressed()
  - Throwable.getSuppressed()
  - Suppressed exceptions are orthogonal to an exception's *cause*
- More verbose, but closes a big gap in exception handling

Improvement #5: Suppressed exceptions

```
JarFile retrieve(URL url) throws IOException {
    Path tmpFile = Files.createTempFile("jar_cache", null);
    try (InputStream in = url.openStream()) {
        Files.copy(in, tmpFile, REPLACE_EXISTING);
        return new JarFile(tmpFile.toFile());
    } catch (Throwable e) {
        try {
            Files.delete(tmpFile);
        } catch (Throwable e2) {
            e.addSuppressed(e2);
        }
        throw e;
    }
}
```

Before and After

```java
JarFile retrieve(URL url) throws IOException {
    InputStream in = url.openStream();
    OutputStream out = null;
    File tmpFile = null;
    try {
        tmpFile = Files.createTempFile("jar_cache", null);
        out = new FileOutputStream(tmpFile);
        int read = 0;
        byte[] buf = new byte[BUF_SIZE];
        while ((read = in.read(buf)) != -1) {
            out.write(buf, 0, read);
        }
        out.close();
        out = null;
        return new JarFile(tmpFile);
    } catch (IOException e) {
        if (tmpFile != null) {
            tmpFile.delete();
        }
        throw e;
    } finally {
        if (in != null) {
            in.close();
        }
        if (out != null) {
            out.close();
        }
    }
}
```

```java
JarFile retrieve(URL url) throws IOException {
    Path tmpFile = Files.createTempFile("jar_cache", null);
    try (InputStream in = url.openStream()) {
        Files.copy(in, tmpFile, REPLACE_EXISTING);
        return new JarFile(tmpFile.toFile());
    } catch (Throwable e) {
        try {
            Files.delete(tmpFile);
        } catch (Throwable e2) {
            e.addSuppressed(e2);
        }
      throw e;
    }
}
```

Proving language changes on the JDK

- Wrote annotation processors to detect idiomatic *types*
  - Types to be retrofitted as `AutoCloseable`
  - E.g. JDBC's `Connection`, `ResultSet`, `Statement`
  - Methods and constructors to be annotated with @SafeVarargs
- Extended javac to detect idiomatic *statements*
  - Instance creation expressions that could use diamond
  - try/catch/finally blocks that could use try-with-resources
  - Null handling of try-with-resources was changed in part from experiences applying it in JDK code
- Seven-dimensional test case generation for @SafeVarargs

Java SE 8

Platform evolution for multicore

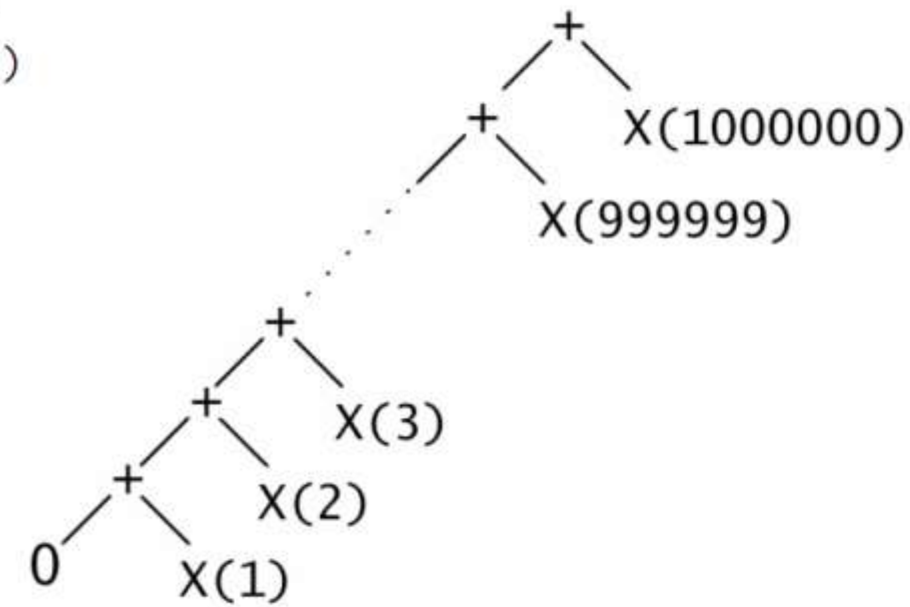
- Multicore hardware is now the default
- Our goal is to exploit it *gracefully*, with a small syntactic and semantic gap between serial and parallel code
- Better libraries are the key to graceful parallelization
  - Libraries can hide domain-specific concerns (e.g. task scheduling)
  - Libraries are easier to evolve than languages
  - Fork/Join in Java SE 7 is a good start, but we need more
- Libraries need some help from the language
  - A concise “code as data” construct
  - In turn, the language may need help from the VM

Inspiration

Inspiration

Sequential Computation Tree

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

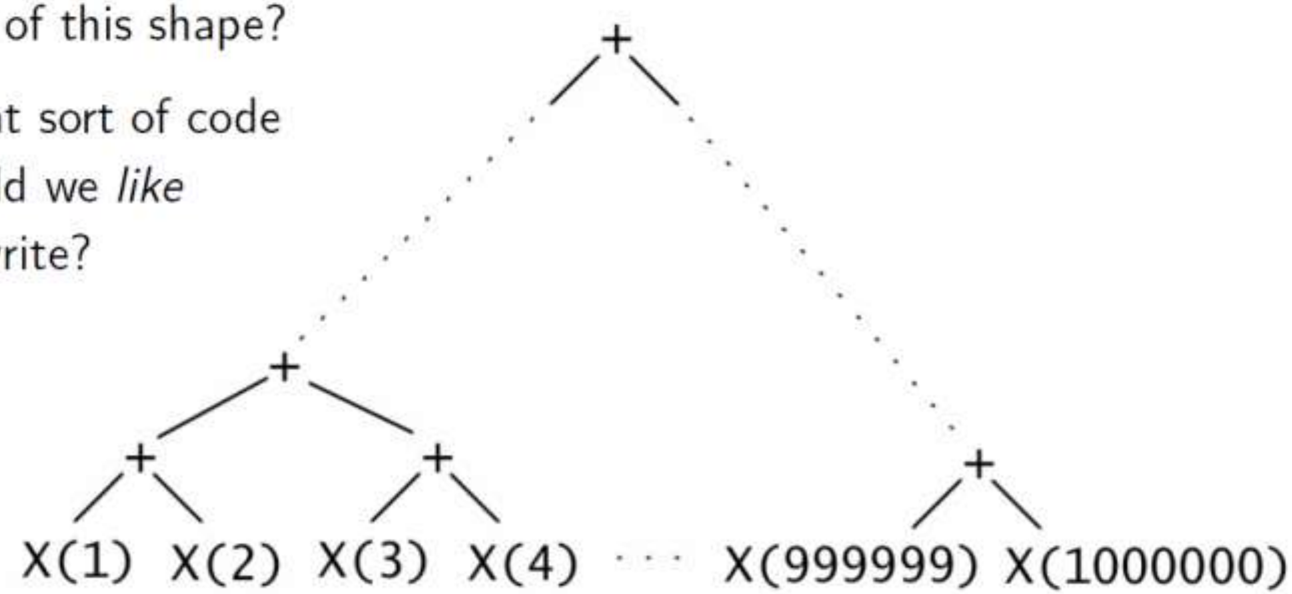


Inspiration

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?



Inspiration

We Need a New Mindset

- DO loops are so 1950s! (Literally: Fortran is now 50 years old.)
- So are linear linked lists! (Literally: Lisp is now 50 years old.)
- Java™-style iterators are **so** last millennium!
- Even arrays are suspect! (Constant-time indexing is an illusion.)
- As soon as you say "first, `SUM = 0`" you are hosed.
- Accumulators are BAD. They encourage sequential dependence and tempt you to use nonassociative updates.
- If you say, "process subproblems in order," you lose.
- The great tricks of the sequential past WON'T WORK.
- The programming idioms that have become second nature to us as everyday tools for the last 50 years WON'T WORK.

Java encourages external iteration

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

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

Internal iteration with inner classes

```
SomeCoolList<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();
```

- Library controls iteration and accumulation
- Not inherently serial: traversal may be done in parallel
- Traversal may be done lazily, so one pass not three
- Thread-safe because business logic is stateless
- But ... ugly, and new libraries

Internal iteration with lambda expressions

```
SomeCoolList<Student> students = ...
double highestScore =
  students.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
- Something Must Be Done About The Libraries

Lambda expressions

- A lambda expression is an anonymous function

```
Comparator<String> c = new Comparator<String>() {
    public boolean compare(String x, String y) {
        return x.length() - y.length();
    }
};
boolean x = c.compare(“hello”, “goodbye”);

Comparator<String> c = (String x, String y) -> x.length() - y.length();
boolean x = c.compare(“hello”, “goodbye”);
```

- Do not assume implementation is with anonymous classes!

Lambda expression typing

- The type of a lambda expression is a *functional interface*
- “An interface with one method”

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

- We’ve used interfaces like this to describe functions forever
  - No need for A=>B function types which would bifurcate the libraries

Target typing

- The functional interface of a lambda expression is inferred from the assignment or method invocation context

```
Collections.sort(lst, new Comparator<String>() {
    public boolean compare(String x, String y) {
        return x.length() - y.length();
    }
});

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

Variable capture

- Can refer to any *effectively final* variables in enclosing scope
  - Effectively final means the variable meets the requirements for a final variable (e.g. assigned to once), even if not declared final
  - A kind of type inference, introduced for precise rethrow in Java SE 7

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

Lexical scoping

- Meaning of a name is the same inside the lambda as outside
- Meaning of `this` is the enclosing object, not the lambda

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

  boolean check(long time, long expiry) { … }

  void expire(File root) {
    … root.listFiles((File p) -> check(p.lastModified(), this.before))
  }
}
```

Improved type inference

- Parameter types in a lambda expression are inferred based on the method signature in the target functional interface
  - Below, the lambda expression will be inferred as `Comparator<String>`
  - The formal parameters must therefore each be `String`

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

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

- Fully statically typed – no dynamic typing here
  - Builds on type inference for generic methods (SE 5.0) and diamond (SE 7)

Method references

- "A way to reuse a method as a lambda expression"

```
FileFilter x = new FileFilter() {
    public boolean accept(File f) {
        return f.canRead();
    }
}

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

FileFilter x = File::canRead;
// canRead is a function from File (receiver) to boolean
```

Putting it all together

- With some library improvements, we can make common tasks more expressive, reliable, and compact

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

Collections.sort(people,
  (Person x, Person y) -> x.getLastName().compareTo(y.getLastName()));
```

Putting it all together

- With some library improvements, we can make common tasks more expressive, reliable, and compact

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

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

Putting it all together

- With some library improvements, we can make common tasks more expressive, reliable, and compact

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

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

Putting it all together

- With some library improvements, we can make common tasks more expressive, reliable, and compact

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

Collections.sort(people, comparing(Person::getLastName));
```

Putting it all together

- With some library improvements, we can make common tasks more expressive, reliable, and compact

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

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

The real challenge: Library evolution

- If Java had lambdas on day 1, all APIs would look different
- Adding lambdas now makes aging APIs show their age more
- The most important APIs (Collections) are based on interfaces
  - Can’t add methods to interfaces without breaking <u>source</u> compatibility
  - But adding lambdas and not upgrading the APIs would be silly
- We need a mechanism for API evolution
  - Burden of API evolution should fall on *implementers*, not users
  - A solution that requires users to permanently cruft up their code to use new methods is unacceptable

Library-based options for API evolution

- Add more static methods to java.util.Collections helper class
  - `Collections.map`
- Add aggregate methods to existing collection implementations
  - `ArrayList.map`
- Add new collection implementations with aggregate methods
  - `ParallelArrayList.map`
- Add new subinterfaces to existing collection interfaces
  - `interface ParallelList<T> extends List<T>`
- Introduce an entirely new set of collection interfaces

Language-based options for API evolution

- Static extension methods
  - What appears to be an instance method call is really a static method call
  - Client says: `import static Collections.sort(List);`
  - Then a call to `ls.sort()` would compile to `Collections.sort(ls)`

  - Simple to implement, and “proven” in C#
  - Programmer must reason about extension in scope for each call
  - Classes don’t know about their extension methods, so cannot provide better implementations
  - Poor interaction with instance methods of the same name
  - Poor interaction with reflection

API evolution is a cross-cutting concern

- Pure library changes don’t help, nor most language proposals
- Let’s revisit “Can’t add a method to an interface”
- This is a problem for implementers, not callers, but an interface has relatively few implementers compared to callers
- A new interface method often has an “obvious” implementation
- Let the interface provide a *default* implementation for a method
- Implementers may override it at their leisure

Virtual extension methods

- “Allow an interface method to have an implementation”

```
interface List<T> … {
    // existing methods, plus
    void sort(Comparator<? super T> cmp)
        default { Collections.sort(this, cmp); }
}
```

- From caller’s perspective, an ordinary interface method
  - Default is only invoked if the receiver class does not override the interface method
  - “If you cannot afford an implementation of `sort`, one will be provided for you at no charge”

Implications of virtual extension methods

- Java always had multiple inheritance of types
- Java now has multiple inheritance of behavior (not state)
- Multiple inheritance can be fairly benign
  - Invocation requires a unique, most-specific, default-providing interface
  - Some situations can be automatically resolved by “pruning”
  - Some situations can be detected at compile-time (under globally consistent compilation) and resolved automatically or manually
  - Only some situations (which imply inconsistent separate compilation) need to be handled at runtime

Implementation of virtual extension methods

- Many possible techniques
  - Inline default body into calling class at compile-time
  - Inject default body into calling class at class load-time
  - Invoke extension method via `invokedynamic`, and let bootstrap method resolve default
- Best technique is to view extension methods as a VM feature
  - Integrate extension methods into vtables at runtime
  - `invokeinterface` prefers declaration in class to declaration in interface
  - `invokeinterface` prefers declaration in a more specific interface than a less specific interface, and must detect ambiguity
- Non-Java languages benefit too

Application: Optional methods

- Virtual extension methods can reduce boilerplate
- Most implementations of `Iterator` don't provide a useful remove() method, so why make the implementer declare it?

```
interface Iterator<T> {
    boolean hasNext();
    T next();
    void remove()
        default { throw new UnsupportedOperationException(); }
}
```

Application: Retrofits

- JDK 1.0 had `Enumeration`, later replaced with `Iterator`
- APIs that returned `Enumeration` became second-class citizens
- Let's retrofit `Enumeration` to implement `Iterator`

```
interface Enumeration<E> extends Iterator<E> {
    boolean hasMoreElements();
    E nextElement();
    boolean hasNext()
        default { return hasMoreElements(); }
    E next()
        default { return nextElement(); }
    void remove()
        default { throw new UnsupportedOperationException(); }
}
```

Application: Simple extensions

```
interface Collection<E> {
    void removeAll(Predicate<? super E> p) default { ... };
}
interface List<E> {
    void sort(Comparator<? super E> c) default { ... };
}
interface Reader {
    void eachLine(Block<String> block) default { ... };
}
```

```
collection.removeAll(s -> s.length() > 20);
collection.removeAll(String::isEmpty);

list.sort(comparing(Person::getLastName).reverse());

reader.eachLine(s -> { System.out.println(s); });
```

Parallel Collections

Remember what we wanted to write?

```
List<Student> students = ...
double highestScore =
  students.filter(s -> s.getGradYear() == 2011)
          .map(s -> s.getScore())
          .reduce(0.0, Math::max);
```

- Need to add extension methods to `Collection` / `List`
- Many design choices
  - Eager v. lazy
  - In-place v. create-new
  - Serial v. parallel
  - Exactly where in the hierarchy to put new methods

Attractive target: Iterable

```
public interface Iterable<T> {
    Iterator<T>     iterator();
    boolean         isEmpty()                                default ...;
    void            forEach(Block<? super T> block)          default ...;
    Iterable<T>     filter(Predicate<? super T> predicate)   default ...;
    <U> Iterable<U> map(Mapper<? super T, ? extends U> mapper) default ...;
    T               reduce(T base, Operator<T> reducer)      default ...;
    Iterable<T>     sorted(Comparator<? super T> comp)       default ...;
    <C extends Collection<? super T>> C into(C collection)   default ...;
    // and more...
}
```

- All collections get these for free
- Defaults easily implemented in terms of iterator()
- Scala `Traversable`, Ruby `Enumerable`, .NET `IReadOnlyList`

Eager v. lazy

- New methods are a mix of lazy and eager
  - `filter`, `map`, `cumulate` – naturally lazy
  - `reduce`, `forEach`, `into` – naturally eager
- Many useful operations can be represented as pipelines of source – lazy … lazy – eager
  - collection – `filter` – `map` – `reduce`
  - array – `map` – `sorted` – `forEach`
- Laziness is mostly invisible
  - No new abstractions for LazyCollection, LazyList, etc

Serial v. parallel

- A collection knows how to operate on elements serially
  - By adding to `Iterable`, all `Collection` types now expose serial bulk data operations without changing implementations ☺
- Can we do the same for parallel operations?
  - i.e. what is the parallel equivalent of `Iterable`?
- Many problems yield to "divide-and-conquer" recursive decomposition
  - Break down problems into subproblems, solve in parallel, combine results
  - Break down subproblems recursively until small enough for serial solution
  - Embodied by the Fork/Join framework in Java SE 7

Parallel high score finder with Fork/Join

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

class ScoreFinder extends RecursiveAction {
  private final ScoreProblem problem;
  double highestScore;

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

```
class ScoreProblem {
  final List<Student> students;
  final int size;

  ScoreProblem(List<Student> ls) {
    this.students = ls;
    this.size = this.students.size();
  }

  public double solveSequentially() {
    double highestScore = 0.0;
    for (Student s : students) {
      if (s.gradYear == 2011) {
        if (s.score > highestScore) {
          highestScore = s.score;
        }
      }
    }
    return highestScore;
  }

  public ScoreProblem subproblem(int start, int end) {
    return new ScoreProblem(students.subList(start, end));
  }
}
```

Going parallel

- Fork/Join relies on the client to decompose the problem
  - Configure thread pool
  - Choose serial v. parallel threshold
  - Determine decomposition approach (2-way, 3-way, n-way…)
  - Fork/Join is really “parallelism assembly language”
- It’s more powerful (and object-oriented) for a collection to decompose itself
- `Iterable` embodies internal iteration, so let’s define a type to embody *parallel* internal iteration

Spliterable: the parallel version of Iterable

- A `Spliterable` can be decomposed into two smaller chunks
  - Most data structures (arrays, trees, maps) admit a natural means of subdividing themselves
  - Eventually, small chunks can be processed sequentially

```
public interface Spliterable<T> {
    Iterator<T>     iterator();
    Spliterable<T>  left();
    Spliterable<T>  right();
    Iterable<T>     sequential();
    // plus extension methods
}
```

```
public interface Iterable<T> {
    Iterator<T>     iterator();
    Spliterable<T>  parallel();
    // plus extension methods
}
```

Methods on Spliterable analogous to Iterable

```
public interface Spliterable<T> {
    Iterator<T>     iterator();
    Spliterable<T>  left();
    Spliterable<T>  right();
    Iterable<T>     sequential();

    boolean            isEmpty()                                    default ...;
    void               forEach(Block<? super T> block)              default ...;
    Spliterable<T>     filter(Predicate<? super T> predicate)       default ...;
    <U> Spliterable<U> map(Mapper<? super T, ? extends U> mapper) default ...;
    T                  reduce(T base, Operator<T> reducer)          default ...;
    Spliterable<T>     sorted(Comparator<? super T> comp)           default ...;
    <C extends Collection<? super T>> C into(C collection)          default ...;
    // and more...
}
```

Explicit but unobtrusive parallelism

```
List<Student> students = ...
double highestScore =
  students.parallel()
          .filter(s -> s.getGradYear() == 2011)
          .map(s -> s.getScore())
          .reduce(0.0, Math::max);
```

- Implementation fuses three operations into one parallel pass
- Big win for data locality
- Works on any data structure that knows how to subdivide itself

Example

Given a music library, get the set of albums for which at least one track is highly rated

```
class Library {
    Set<Album> albums;

    Set<Album> allAlbums() {
        return albums;
    }

    Set<Album> favoriteAlbums() {
        // TODO
    }
}
```

```
class Album {
    String      title;
    List<Track> tracks;
}

class Track {
    String title;
    String artist;
    int    rating;
}
```

Identifying a favorite album

```
// Set hasFavorite to true if some track in album a is rated >= 4

boolean hasFavorite = false;
for (Track t : a.tracks) {
    if (t.rating >= 4) {
        hasFavorite = true;
        break;
    }
}

boolean hasFavorite = a.tracks.anyMatch(t -> t.rating >= 4);
```

Making a set of favorite albums

```
// Initialize favs as a set of favorite albums drawn from albums

Set<Album> favs = new HashSet<>();
for (Album a : albums) {
    if (a.tracks.anyMatch(t -> (t.rating >= 4)))
        favs.add(a);
}

Set<Album> favs =
  albums.filter(a -> a.tracks.anyMatch(t -> t.rating >= 4))
        .into(new HashSet<>());
```

Loops v. Lambdas

```
Set<Album> favs = new HashSet<>();
for (Album a : albums) {
    boolean hasFavorite = false;
    for (Track t : a.tracks) {
        if (t.rating >= 4) {
            hasFavorite = true;
            break;
        }
    }
    if (hasFavorite) favs.add(a);
}
```

```
Set<Album> favs =
  albums.filter(a -> a.tracks.anyMatch(t -> t.rating >= 4))
        .into(new HashSet<>());
```

Loops v. Lambdas – Adding parallelism

```
Set<Album> favs = new HashSet<>();
for (Album a : albums) {
    boolean hasFavorite = false;
    for (Track t : a.tracks) {
        if (t.rating >= 4) {
            hasFavorite = true;
            break;
        }
    }
    if (hasFavorite) favs.add(a);
}
```

```
Set<Album> favs =
  albums.parallel()
        .filter(a -> a.tracks.anyMatch(t -> (t.rating >= 4)))
        .into(new ConcurrentHashSet<>());
```

In summary

- Lambdas are the on-ramp to productive parallel programming
- Adding lambdas to Java without lambda-fying Collections would be poor, and replacing Collections is a non-starter
- Compatibly evolving interface-based APIs is impossible without directly addressing the problem in the language and VM
- The solution – an enhanced inheritance model – enables new idioms in Java and helps other languages too
- JSR 335 in Early Draft Review
- Prototype binaries at OpenJDK Project Lambda

Other features in Java SE 8

- Java Module System (JSR TBD) + JDK modularization
- Annotations on type names (JSR 308)
- Repeating annotations
- Parameter name access at runtime
- Refinements to Project Coin
  - try-with-resources on an effectively final variable?
  - Remove restrictions on diamond operator?
  - @SafeVarargs on more kinds of method?

Transparency

Java Community Process 2.8

- Expert Group transparency
  - EG must do all substantive business on a public mailing list
  - EG must track issues in a public issue tracker
  - EG must respond publicly to all comments
- Executive Committee transparency
  - EC must hold public meetings and teleconferences, and publish minutes
  - EC must provide a public mailing list for JCP member feedback
- TCK and License transparency
  - TCK licensing must permit public discussion of testing process and results
  - Spec Lead cannot withdraw a spec/RI/TCK license once offered

Java Community Process 2.8

- Participation
  - EG nominations and Spec Lead responses must be public
  - EG members are identified by name and company
- Agility
  - JSRs must reach Early Draft Review within nine months
  - JSRs must reach Public Review within 12 months after EDR
  - JSRs must reach Final Release within 12 months after PR
  - Faster and simpler Maintenance Releases
- JCP 2.8 is mandatory for new JSRs, and in-flight JSRs are encouraged to adopt it

JDK Enhancement Proposal (JEP) Process

- “A process for collecting, reviewing, sorting, and recording the results of proposals for enhancements to the JDK”
- Goal: Produce a regularly-updated list of proposals to serve as the long-term Roadmap for JDK Release Projects
- Looks at least three years into the future to allow time for the most complex proposals to be defined and implemented
- Open to every OpenJDK Committer
- Does not in any way supplant the Java Community Process

JEPs as of 11/11/11 (11:11:11)

1	JDK Enhancement-Proposal & Roadmap Process
2	JEP Template
101	**Generalized Target-Type Inference**
102	Process API Updates
103	**Parallel Array Sorting**
104	**Annotations on Java Types**
105	DocTree API
106	Add Javadoc to javax.tools
107	**Bulk Data Operations for Collections**
108	**Collections Enhancements from Third-Party Libraries**
109	**Enhance Core Libraries with Lambda**
110	New HTTP Client
111	Additional Unicode Constructs for Regular Expressions
112	Charset Implementation Improvements
113	MS-SFU Kerberos 5 Extensions
114	TLS Server Name Indication (SNI) Extension
115	AEAD CipherSuites
116	Extended Validation Certificates
117	Remove the Annotation-Processing Tool (apt)
118	**Access to Parameter Names at Runtime**
119	javax.lang.model Implementation Backed by Core Reflection
120	**Repeating Annotations**
121	Stronger Algorithms for Password-Based Encryption
122	Remove the Permanent Generation
123	Configurable Secure Random-Number Generation
124	Enhance the Certificate Revocation-Checking API
125	Network Interface Aliases, Events, and Defaults
126	**Lambda Expressions and Virtual Extension Methods**

In Conclusion

Where We've Been, Where We're Going

- Java SE 7 laid the groundwork
  - Language and library changes for productivity
  - Library and VM plumbing for concurrency and functional idioms
- Java SE 8 evolves the language, libraries, and VM together
  - Lambdas + Virtual extension methods + Parallel collections
  - Modules + Modularized libraries and tools
- Java SE's best days lie ahead
  - Multi-language interoperability through a unified, reified type system
  - A two-year tick for Java SE releases
  - Collaboration in OpenJDK and the JCP

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