Principles of Software Construction: Objects, Design, and Concurrency (Part 7: Extra Topics)

Lambdas and Streams in Java 8

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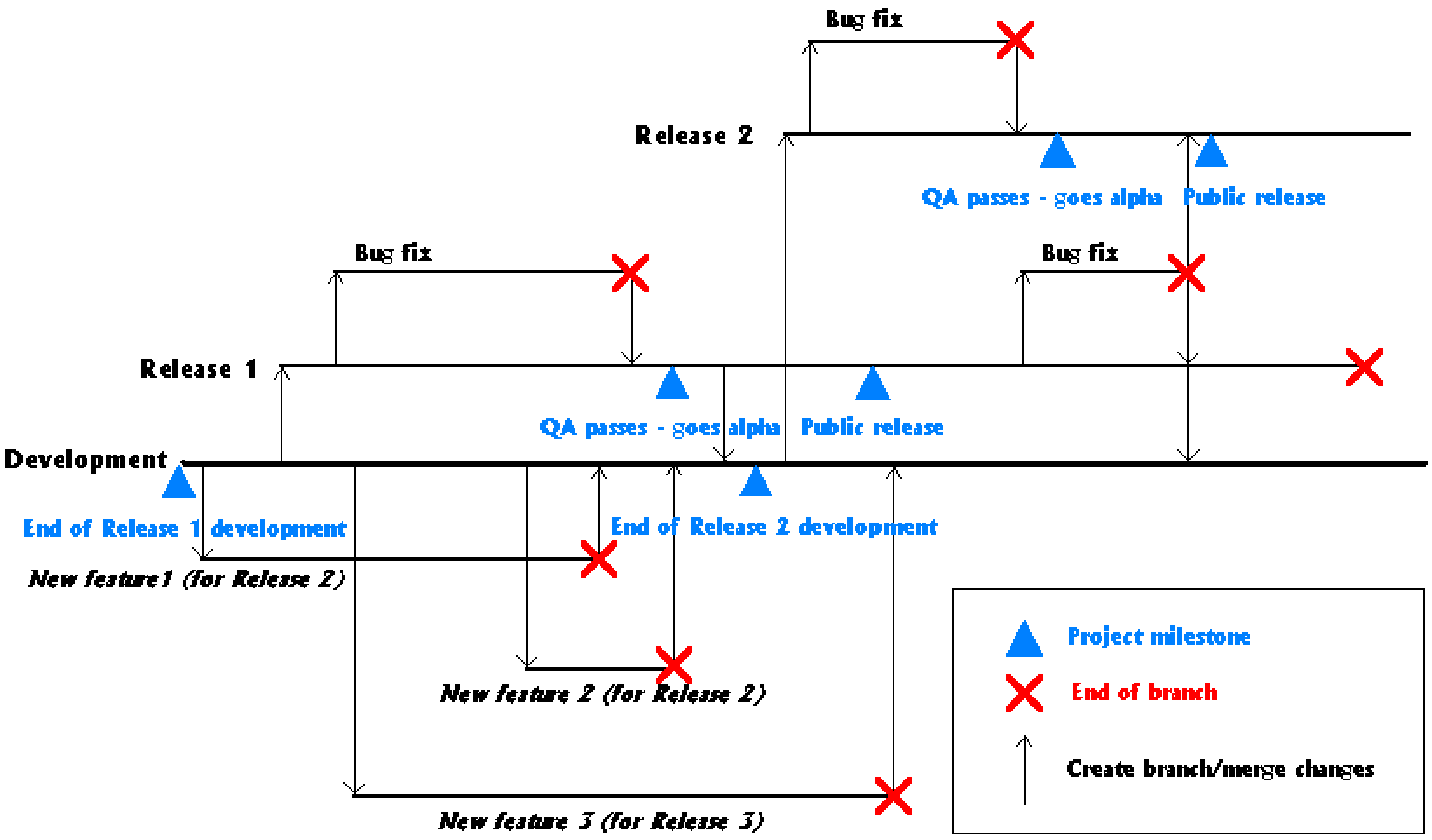
Administrivia

- Homework 6 due tonight
  - Extra office hours for HW6 and exam: see online schedule
- Review session Wednesday 12/16
  - 2-4pm in DH 1112
- Final exam Thursday 12/17
  - 8:30-11:30 in MM 103 & MM A14

Key concepts from Tuesday

Release management with branches


Bug fix
Release 2
QA passes - goes alpha
Public release
Bug fix
Bug fix
Release 1
QA passes - goes alpha
Public release
Development
End of Release 1 development
End of Release 2 development
New feature1 (for Release 2)
New feature 2 (for Release 2)
New feature 3 (for Release 3)
Project milestone
End of branch
Create branch/merge changes

Today:
First, can we have your feedback?

https://cmu.smartevals.com/

https://www.ugrad.cs.cmu.edu/ta/F15/feedback

Today's Lecture: Learning Goals

- Understand the syntax, semantics, and typechecking of lambdas in Java
- Write code effectively with lambdas in Java
- Use the Java stream library both sequentially and in parallel
- Use default methods to put reusable code in Java interfaces

Recall Anonymous Inner Classes

```
final String name = "Charlie";
Runnable greeter = new Runnable() {
    public void run() {
        System.out.println("Hi " + name);
    }
};
```

```
// add functionality to the step button.
step.addActionListener(new ActionListener(){
    @Override
    public void actionPerformed(ActionEvent arg0) {
        worldPanel.step();
    }
});
```

- A lot of boilerplate for 1 line of code in each example!

Lambdas: Convenient Syntax for Single-Function Objects

```
final String name = "Charlie";
Runnable greeter = new Runnable() {
    public void run() {
        System.out.println("Hi " + name);
    }
};

// with Lambdas, can rewrite the code above like this
String name = "Charlie";
Runnable greeter = () -> System.out.println("Hi " + name);
```

The name variable is used in the function; need not be final, but must be *effectively final*

The function can be assigned to a Runnable, because it has the same signature as run()

We us a lambda expression to define a function that takes no arguments

The function body just prints to standard out

Effectively Final Variables

```
final String name = "Charlie";
Runnable greeter = new Runnable() {
    public void run() {
        System.out.println("Hi " + name);
    }
};

// with Lambdas, can rewrite the code above like this
String name = "Charlie";
Runnable greeter = () -> System.out.println("Hi " + name);
```

The name variable is used in the function; need not be final, but must be *effectively final*

Lambdas can use local variables in outer scopes only if they are effectively final. A variable is ***effectively final*** if it can be made final without introducing a compilation error. This facilitates using lambdas for concurrency, and avoids problems with lambdas outliving their surrounding scope.

Replacing For Loops with Lambdas

```
// Java 7 code to print an array
List<Integer> intList = Arrays.asList(1,2,3);
for (Integer i in intList)
    System.out.println(i)

// Java 8 provides a forEach method to do the same thing...
intList.forEach(new Consumer<Integer>() {
    public void accept(Integer i) {
        System.out.println(i);
    }
});

// Java 8's Lambda's make forEach beautiful
intList.forEach((Integer i) -> System.out.println(i));
intList.forEach(i -> System.out.println(i));
```

This lambda expression takes one argument, i, of type Integer

Even cleaner...since intList.forEach() takes a Consumer<Integer>, Java infers that i's type is Integer

Example adapted from Alfred V. Aho

Lambda Syntax Options

Examples from lambdafaq.org

- Lambda Syntax

(*parameters*) -> *expression*

or (*parameters*) -> { *statements;* }

- Details
  - Parameter types may be inferred (all or none)
  - Parentheses may be omitted for a single inferred-type parameter
- Examples

```
(int x, int y) -> x + y                    // takes two integers and returns their sum
(x, y) -> x - y                  // takes two numbers and returns their difference
() -> 42                                                 // takes no values and returns 42
(String s) -> System.out.println(s)               // takes a string, prints its value
x -> 2 * x                 // takes a number and returns the result of doubling it
c -> { int s = c.size(); c.clear(); return s; }                  // takes a collection,
                                             // clears it, and returns its previous size
```

Functional Interfaces

- There are no function types in Java
- Instead, Java has *Functional Interfaces*
  - interfaces with only one explicitly declared abstract method
    - methods inherited from `Object`, like `equals()`, don't count
  - Optionally annotated with `@FunctionalInterface`
    - Helps catch errors if you intend to write a functional interface but don't
- Some Functional Interfaces

```
java.lang.Runnable:               void run()
java.util.function.Consumer<T>:   void accept(T t)
java.util.concurrent.Callable<V>: V call()
java.util.function.Function<T,R>: R apply(T t)
java.util.Comparator<T>:          int compare(T o1, T o2)
java.awt.event.ActionListener:  void actionPerformed(ActionEvent e)
```

- There are many more, especially in package `java.util.function`

Typechecking and Type Inference Using Expected Types

- A lambda expression must match its ***expected type***
  - The type of the variable to which it is assigned or passed

```
intList.forEach(i -> System.out.println(i));
```

- Example: `forEach`
  - `intList.forEach` accepts a parameter of type `Consumer<Integer>`, so this is the expected type for the lambda
  - `Consumer<Integer>` has a function **`void`** `accept(Integer t)`, so the lambda's argument is inferred to be of type `Integer`

```
Runnable greeter = () -> System.out.println("Hi " + name);
```

- Example: `Runnable`
  - We are assigning a lambda to a variable of type `Runnable`, so that is the expected type for the lambda
  - `Runnable` has a function **`void`** `run()`, so the lambda expression must not take any arguments

Comparison to Lambdas in a Functional Language

- Discuss: How do lambdas in Java compare to ML?
  - (or your other favorite functional programming language)

Tradeoffs vs. Lambdas in ML

- Succinctness
  - ML's functions shorter to invoke: `aRunnable()` vs. `aRunnable.run()`
  - ML's non-local inference means fewer type annotations
  - Java's expected types promote local reasoning, understandability
- Type structure
  - ML's structural types need not be declared ahead of time
  - Java's nominal types can have associated semantics described in Javadoc

```
package java.util;
/** A comparison function, which imposes a total ordering on
 *  some collection of objects. */
class Comparator<T> {
   /** The implementor must ensure that
    *    sgn(compare(x, y)) == -sgn(compare(y, x)) for all x and y
    *  The implementor must also ensure that the relation is
    *  transitive... */
   int compare(T o1, T o2);
}
```

Method References

```
// Recall Java 8 code to print integers in an array
List<Integer> intList = Arrays.asList(1,2,3);
intList.forEach(i -> System.out.println(i));

// We can make the last line even shorter!
intList.forEach(System.out::println);
```

- `System.out::println` is a *method reference*
  - Captures the `println` method of `System.out` as a function
  - The type is `Consumer<Integer>`, as required by `intList.forEach`
  - The signature of `println` must match (and it does)

Method Reference Syntactic Forms

- Capturing an instance method of a particular object

  Syntax: `objectReference::methodName`

  Example: `intList.forEach(System.out::println)`

- Capturing a static method

  Syntax: `ClassName::methodName`

  Example: `Arrays.sort(myIntegerArray, Integer::compare)`

- Capturing an instance method, without capturing the object
  - The resulting function has an extra argument for the receiver

  Syntax: `ClassName::methodName`

  Example: `Function<Object,String> printer = Object::toString;`

- Capturing a constructor

  Syntax: `ClassName::methodName`

  Example:

  ```
  Supplier<List<String>> listFactory =
                              ArrayList::<String>new;
  ```

Collections Usage in Java

- Bulk operations: common usage pattern for Java collections
  - Read from a source collection
  - Select certain elements
  - Compute collections holding intermediate data
  - Summarize the results into a single answer
- Example: how much taxes do student employees pay?

```
List<PayStub> studentStubs = new ArrayList<PayStub>();
for (Employee e in employees)
    if (e.getStatus() == Employee.STUDENT)
        studentStubs.addAll(e.payStubs());
double totalTax=0.0;
for (PayStub s in studentStubs)
        totalTax += s.getTax();
```

- Issues
  - Inefficient to create temporary collections
  - Verbose code
  - Hard to do work in parallel

Streams: A Better Way

```
double totalTax =
    employees.parallelStream()
             .filter(e -> e.getStatus() == Employee.STUDENT)
             .flatMap(e -> e.payStubs().stream())
             .map(s -> s.getTax())
             .sum()
```

- Benefits
  - Shorter
  - More abstract – describes what is desired
  - More efficient – avoids intermediate data structure
  - Runs in parallel

Streams

- Definition: a possibly-infinite sequence of elements supporting sequential or parallel aggregate operations
  - *possibly-infinite*: elements are processed lazily
  - *sequential or parallel*: two kinds of streams
  - *aggregate*: operations act on the entire stream
    - contrast: iterators
- Some stream sources
  - Invoking `.stream()` or `.parallelStream()` on any `Collection`
  - Invoking `.lines()` on a `BufferedReader`
  - Generating from a function: `Stream.generate(Supplier<T> s)`
- Intermediate operations
  - Produce one stream from another
  - Examples: `map`, `filter`, `sorted`, …
- Terminal operations
  - Extract a value or a collection from a stream
  - Examples: `reduce`, `collect`, `count`, `findAny`

Each stream is used only once, with an intermediate or terminal operation

Demonstrations

- GetWords
- ComputeANumber
- ComputeABigNumber

Employees and Taxes

```
double totalTax =
    employees.parallelStream()
             .filter(e -> e.getStatus() == Employee.STUDENT)
             .flatMap(e -> e.payStubs().stream())
             .map(s -> s.getTax())
             .sum()
```

- Benefits
  - Shorter
  - More abstract – describes what is desired
  - More efficient – avoids intermediate data structure
  - Runs in parallel

Exercise: minimum age of seniors

- What is the minimum age of seniors in this course?
    - Assume the code opposite
    - You may use functions such as `map`, `filter`, `reduce`, etc.

```
enum ClassStanding {
    FRESHMAN, SOPHOMORE,
    JUNIOR, SENIOR
}
class Student {
    String name;
    int age;
    ClassStanding year;
}

List<Student> roster = ...
```

Default Methods

- Java 8 just added several methods to Collection interfaces

```
Stream<E>      stream()
Stream<E>      parallelStream()
void           forEach(Consumer<E> action)
Spliterator<E> spliterator()
boolean        removeIf(Predicate<E> filter)
```

- If you defined a Collection subclass, did it just break?
- No! These were added as default methods
  - Declared in an interface with the `default` keyword
  - Given a body

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

Default Methods: Semantics and Uses

- Semantics
  - A method defined in a class always overrides a default method
  - Default methods in sub-interfaces override those in super-interfaces
  - Remaining conflicts must be resolved by overriding
  - New syntax for invoking a default method from implementing class

    ```
    A.super.m(...)
    ```

    - Important because m may be defined in two implemented interfaces, so can't use simply `super.m(...)`

- Benefits of default methods
  - Extending an interface without breaking implementers
  - Putting reusable code in an interface
    - can reuse default methods from several interfaces
    - known as ***traits*** in other languages (e.g. Scala)

Take-Home Messages

Java 8 has new features useful in program expression

- Lambdas are a lightweight syntax for defining functions
  - Support shorter and more abstract code
- Succinct manipulation of data through streams
  - Support for pipelining and parallelism
- Default methods provide code reuse in interfaces

Sources and Resources

- Maurice Naftalin's Lambda FAQ
  - http://www.lambdafaq.org/
- The Java Tutorials:
  - Lambda Expressions
    - https://docs.oracle.com/javase/tutorial/java/javaOO/lambdaexpressions.html
  - Aggregate Operations
    - https://docs.oracle.com/javase/tutorial/collections/streams/index.html
- Integer list example is adapted from Alfred Aho
  - http://www1.cs.columbia.edu/~aho/cs6998/