

Objects Analysis

Threads



Design

15-214

*toad*

Fall 2014



# Principles of Software Construction: Objects, Design, and Concurrency

## Lambdas and Streams in Java 8

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## Administrivia

- Homework 6 checkpoint due tonight
- Homework 6 due Thursday
- Review session Sunday noon-3pm in DH 1212
- Final exam Monday at 8:30am in Porter Hall 100 & 125C

## 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);  
    }  
};
```

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

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

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

We use 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);  
    }  
};
```

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

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

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);  
    }  
});
```

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

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

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
     *  $\text{sgn}(\text{compare}(x, y)) == -\text{sgn}(\text{compare}(y, x))$  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())  
        .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())  
        .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 implementor

`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 implementors
- Putting reusable code in an interface
  - can reuse default methods from several interfaces
  - known as **traits** in other languages (e.g. Scala)

## Toad's 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/>