Topic 26
Functional Programming

Functional Programming with Java 8

Java 8 FP features

1. Effect-free programming
2. Processing structured data via functions
3. First-class functions
4. Function closures
5. Higher-order operations on collections

What is FP?

- **Functional programming**: A style of programming that emphasizes the use of functions (methods) to decompose a complex task into subtasks.
  - Examples of functional languages:
    - LISP, Scheme, ML, Haskell, Erlang, F#, Clojure, ...

- Java is considered an object-oriented language, not a functional language.

- But Java 8 added several language features to facilitate a partial functional programming style.

Effect-free code (19.1)

- **Side effect**: A change to the state of an object or program variable produced by a call on a function (i.e., a method).
  - Example: modifying the value of a variable
  - Example: printing output to System.out
  - Example: reading/writing data to a file, collection, or network

```java
int result = f(x) + f(x);
int result = 2 * f(x);
```

- Are the two above statements equivalent?
  - Yes, if the function f() has no side effects.
  - One goal of functional programming is to minimize side effects.
**Code w/ side effects**

public class SideEffect {
    public static int x;

    public static int f(int n) {
        x = x * 2;
        return x + n;
    }

    // what if it were 2 * f(x)?
    public static void main(String[] args) {
        x = 5;
        int result = f(x) + f(x);
        System.out.println(result);
    }
}

**Lambda expressions**

- **lambda expression** ("lambda"): Expression that describes a function by specifying its parameters and return value.
  - Java 8 adds support for lambda expressions.

- Syntax:
  
  \[
  (\text{parameters}) \rightarrow \text{expression}
  \]

- Example:

  \[
  (x) \rightarrow x \times x \quad // \text{squares a number}
  \]

  - The above is roughly equivalent to:

  public static int squared(int x) {
      return x * x;
  }

**First-class functions (19.2)**

- **first-class citizen**: An element of a programming language that is tightly integrated with the language and supports the full range of operations generally available to other entities in the language.

- In functional programming, functions (methods) are treated as first-class citizens of the languages.
  - can store a function in a variable
  - can pass a function as a parameter to another function
  - can return a value from a function
  - can create a collection of functions
  - ...

**MathMatrix add / subtract**

- Recall the MathMatrix class:

  public MathMatrix add(MathMatrix rhs) {
      int[][] res = new int[cells.length][cells[0].length];
      for (int r = 0; r < res.length; r++)
          for (int c = 0; c <= res[0].length; c++)
              res[r][c] = cells[r][c] + rhs.cells[r][c];
      return new MathMatrix(res);
  }

  public MathMatrix subtract(MathMatrix rhs) {
      int[][] res = new int[cells.length][cells[0].length];
      for (int r = 0; r < res.length; r++)
          for (int c = 0; c <= res[0].length; c++)
              res[r][c] = cells[r][c] - rhs.cells[r][c];
      return new MathMatrix(res);
  }
MathMatrix add / subtract

• GACK!!

• How do we generalize the idea of "add or subtract"?
  – How much work would it be to add other operators?
  – Would functional programming help?

getMat method

private MathMatrix getMat(MathMatrix rhs, 
IntBinaryOperator operator) {
    int[][] res = new int[cells.length][cells[0].length];
    for (int r = 0; r < cells.length; r++) {
        for (int c = 0; c < cells[0].length; c++) {
            int temp1 = cells[r][c];
            int temp2 = rhs.cells[r][c];
            res[r][c] = operator.applyAsInt(temp1, temp2);
        }
    }
    return new MathMatrix(res);
}

// IntBinaryOperator Documentation

Code w/ lambdas

• We can represent the math operation as a lambda:

public MathMatrix add(MathMatrix rhs) {
    return getMat(rhs, (x, y) -> x + y);
}

public MathMatrix subtract(MathMatrix rhs) {
    return getMat(rhs, (x, y) -> x - y);
}

Clicker Question

• Which of the following is a lambda that checks if x divides evenly into y?

A. (x, y) -> y / x == 0
B. (x, y) -> x / y == 0
C. (x, y) -> x * y == 0
D. (x, y) -> x % y == 0
E. (x, y) -> y % x == 0
**Streams (19.3)**

- **stream:** A sequence of elements from a data source that supports aggregate operations.

- Streams operate on a data source and modify it:

  - example: print each element of a collection
  - example: sum each integer in a file
  - example: concatenate strings together into one large string
  - example: find the largest value in a collection
  - ...

**Code w/o streams**

- Non-functional programming sum code:

  ```java
  // compute the sum of the squares of integers 1-5
  int sum = 0;
  for (int i = 1; i <= 5; i++) {
    sum = sum + i * i;
  }
  ```

**The map modifier**

- The **map** modifier applies a lambda to each stream element:
  - **higher-order function:** Takes a function as an argument.

  ```java
  // compute the sum of the squares of integers 1-5
  int sum = IntStream.range(1, 6)
    .map(n -> n * n)
    .sum();
  ```

  // the stream operations are as follows:

  ```
  IntStream.range(1, 6) -> [1, 2, 3, 4, 5]
    -> map -> [1, 4, 9, 16, 25]
    -> sum -> 55
  ```

**The filter modifier**

- The **filter** stream modifier removes/keeps elements of the stream using a boolean lambda:

  ```java
  // compute the sum of squares of odd integers
  int sum =
    IntStream.of(3, 1, 4, 1, 5, 9, 2, 6, 5, 3)
    .filter(n -> n % 2 != 0)
    .map(n -> n * n)
    .sum();
  ```

  // the stream operations are as follows:

  ```
  IntStream.of -> [3, 1, 4, 1, 5, 9, 2, 6, 5, 3]
    -> filter -> [3, 1, 5, 9, 3]
    -> map -> [9, 1, 25, 81, 9]
    -> sum -> 151
  ```
Streams and methods

• using streams as part of a regular method:

    // Returns true if the given integer is prime. // Assumes n >= 0.
    public static boolean isPrime(int n) {
        return IntStream.range(1, n + 1)
            .filter(x -> n % x == 0)
            .count() == 2;
    }

• How to make this method faster?

The reduce modifier

• The reduce modifier combines elements of a stream using a lambda combination function.
  - Accepts two parameters: an initial value and a lambda to combine that initial value with each next value in the stream.

    // Returns n!, or 1 * 2 * 3 * ... * (n-1) * n. // Assumes n is non-negative.
    public static int factorial(int n) {
        return IntStream.range(2, n + 1)
            .reduce(1, (a, b) -> a * b);
    }

Stream operators

<table>
<thead>
<tr>
<th>Method name</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>anyMatch(f)</td>
<td>returns true if any elements of stream match given predicate</td>
</tr>
<tr>
<td>allMatch(f)</td>
<td>returns true if all elements of stream match given predicate</td>
</tr>
<tr>
<td>average()</td>
<td>returns arithmetic mean of numbers in stream</td>
</tr>
<tr>
<td>collect(f)</td>
<td>convert stream into a collection and return it</td>
</tr>
<tr>
<td>count()</td>
<td>returns number of elements in stream</td>
</tr>
<tr>
<td>distinct()</td>
<td>returns unique elements from stream</td>
</tr>
<tr>
<td>filter(f)</td>
<td>returns the elements that match the given predicate</td>
</tr>
<tr>
<td>forEach(f)</td>
<td>performs an action on each element of stream</td>
</tr>
<tr>
<td>limit(size)</td>
<td>returns only the next size elements of stream</td>
</tr>
<tr>
<td>map(f)</td>
<td>applies the given function to every element of stream</td>
</tr>
<tr>
<td>noneMatch(f)</td>
<td>returns true if zero elements of stream match given predicate</td>
</tr>
</tbody>
</table>

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<thead>
<tr>
<th>Method name</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>parallel()</td>
<td>returns a multithreaded version of this stream</td>
</tr>
<tr>
<td>peek(f)</td>
<td>examines the first element of stream only</td>
</tr>
<tr>
<td>reduce(f)</td>
<td>applies the given binary reduction function to stream elements</td>
</tr>
<tr>
<td>sequential()</td>
<td>single-threaded, opposite of parallel()</td>
</tr>
<tr>
<td>skip(n)</td>
<td>omits the next n elements from the stream</td>
</tr>
<tr>
<td>sorted()</td>
<td>returns stream's elements in sorted order</td>
</tr>
<tr>
<td>sum()</td>
<td>returns sum of elements in stream</td>
</tr>
<tr>
<td>toArray()</td>
<td>converts stream into array</td>
</tr>
</tbody>
</table>

<table>
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<tr>
<th>Static method</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>concat(s1, s2)</td>
<td>glues two streams together</td>
</tr>
<tr>
<td>empty()</td>
<td>returns a zero-element stream</td>
</tr>
<tr>
<td>iterate(seed, f)</td>
<td>returns an infinite stream with given start element</td>
</tr>
<tr>
<td>of(values)</td>
<td>converts the given values into a stream</td>
</tr>
<tr>
<td>range(start, end)</td>
<td>returns a range of integer values as a stream</td>
</tr>
</tbody>
</table>
Clicker Question

- What is output by the following code?

```java
int x1 = IntStream.of(-2, 5, 5, 10, -6)
    .map(x -> x / 2)
    .filter(y -> y > 0)
    .sum();
System.out.println(x1);
```

A. (-2, 5, 5, 10, -6)
B. 6
C. (-1, 2.5, 2.5, 5, -3)
D. 20
E. 9

Optional results fix

- To extract the optional result, use a "get as" terminator.
  - Converts type OptionalInt to Integer

```java
// print largest multiple of 10 in list
// (this version compiles and works.)
int largest =
    IntStream.of(55, 20, 19, 31, 40, -2, 62, 30)
    .filter(n -> n % 10 == 0)
    .max()
    .getAsInt();
System.out.println(largest);
```

Optional results

- Some stream terminators like max return an "optional" result
  because the stream might be empty or not contain the result:

```java
// print largest multiple of 10 in list
// (does not compile!)
int largest =
    IntStream.of(55, 20, 19, 31, 40, -2, 62, 30)
    .filter(n -> n % 10 == 0)
    .max();
System.out.println(largest);
```

Ramya, Spring 2018

- “Okay, but why?”
- Programming with Streams is an alternative to writing out the loops ourselves
- Streams “abstract away” the loop structures we have spent so much time writing
- Why didn’t we just start with these?
Stream exercises

- Write a method `sumAbsVals` that uses stream operations to compute the sum of the absolute values of an array of integers. For example, the sum of \{-1, 2, -4, 6, -9\} is 22.

- Write a method `largestEven` that uses stream operations to find and return the largest even number from an array of integers. For example, if the array is \{5, -1, 12, 10, 2, 8\}, your method should return 12. You may assume that the array contains at least one even integer.

(19.4) Higher Order Operations on Collections (Streams and Arrays)

- An array can be converted into a stream with `Arrays.stream`:

```java
// compute sum of absolute values of even ints
int[] numbers = {3, -4, 8, 4, -2, 17, 9, -10, 14, 6, -12};
int sum = Arrays.stream(numbers)
    .map(n -> Math.abs(n))
    .filter(n -> n % 2 == 0)
    .distinct()
    .sum();
```

Closures (19.4)

- **bound/free variable**: In a lambda expression, parameters are bound variables while variables in the outer containing scope are free variables.

- **function closure**: A block of code defining a function along with the definitions of any free variables that are defined in the containing scope.

```java
// free variables: min, max, multiplier
// bound variables: x, y
int min = 10;
int max = 50;
int multiplier = 3;
compute((x, y) -> Math.max(x, min) *
    Math.max(y, max) * multiplier);
```

Method references

- A method reference lets you pass a method where a lambda would otherwise be expected:

```java
// compute sum of absolute values of even ints
int[] numbers = {3, -4, 8, 4, -2, 17, 9, -10, 14, 6, -12};
int sum = Arrays.stream(numbers)
    .map(Math::abs)
    .filter(n -> n % 2 == 0)
    .distinct()
    .sum();
```
Streams and lists

• A collection can be converted into a stream by calling its stream method:

```java
// compute sum of absolute values of even ints
ArrayList<Integer> list =
    new ArrayList<Integer>();
list.add(42);
list.add(-17);
list.add(68);
list.stream()
    .map(Math::abs)
    .forEach(System.out::println);
```

Streams and files

```java
// find longest line in the file
int longest = Files.lines(Paths.get("haiku.txt"))
    .mapToObj(String::length)
    .max()
    .getAsInt();

stream operations:
Files.lines -> ["haiku are funny",
    "but sometimes they don't make sense",
    "refrigerator"]
    -> mapToInt -> [15, 35, 12]
    -> max -> 35
```

Streams and strings

```java
// convert into set of lowercase words
List<String> words = Arrays.asList(
    "To", "be", "or", "Not", "to", "be");
Set<String> words2 = words.stream()
    .map(String::toLowerCase)
    .collect(Collectors.toSet());
System.out.println("word set = " + words2);
```

output:
word set = [not, be, or, to]

Stream exercises

• Write a method `fiveLetterWords` that accepts a file name as a parameter and returns a count of the number of unique lines in the file that are exactly five letters long. Assume that each line in the file contains at least one word.

• Write a method using streams that finds and prints the first 5 perfect numbers. (Recall a perfect number is equal to the sum of its unique integer divisors, excluding itself.)