Topic 27
Functional Programming

Functional Programming with Java 8

“**It's a long-standing principle of programming style that the functional elements of a program should not be too large.** If some component of a program grows beyond the stage where it's readily comprehensible, it becomes a mass of complexity which conceals errors as easily as a big city conceals fugitives. **Such software will be hard to read, hard to test, and hard to debug**.” – Paul Graham

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.
  - Popular contemporary languages tend to be
    Multi Paradigm Languages

Java 8 FP features

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

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

```
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);
    }
}
```

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 function as a value from another function
  - can create a collection of functions
  - ...

Lambda expressions

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

  (***parameters***) -> ***expression***

- Example:

```
(x) -> x * x          // squares a number
```

  - The above is roughly equivalent to:

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

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?
  - Can functional programming help remove the repetitive code?

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);
}
```

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

Clicker 1

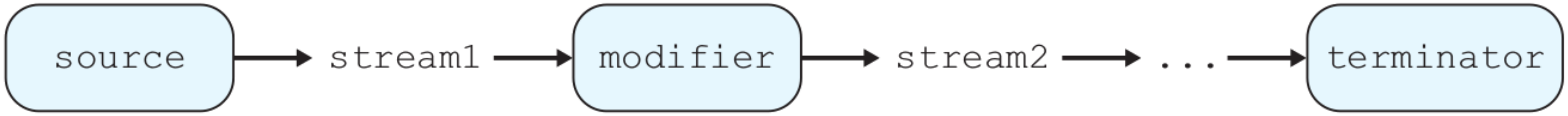
- Which of the following is a lambda that checks if x divides evenly into y?

```
A. (x, y) -> y / x == 0
B. (x, y) -> x / y == 0
C. (x, y) -> y % x == 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:

```
// compute the sum of the squares of integers 1-5
int sum = 0;
for (int i = 1; i <= 5; i++) {
    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.
- Abstracting away loops (and data structures)

```
// 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:

```
// 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, 1, 5, 9, 5, 3]
       -> map -> [9, 1, 1, 25, 81, 25, 9]
       -> sum -> 151
```

Streams and methods

- using streams as part of a regular method:

```
// Returns true if the given integer is prime.
// Assumes n >= 2.
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 (method) 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 subsequent 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

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

Stream operators

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

Static method	**Description**
`concat(`**s1**`, `**s2**`)`	glues two streams together
`empty()`	returns a zero-element stream
`iterate(`**seed**`, `**f**`)`	returns an infinite stream with given start element
`of(`**values**`)`	converts the given values into a stream
`range(`**start**`, `**end**`)`	returns a range of integer values as a stream

Clicker 2

- What is output by the following code?

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

A. (-2, 5, 5, 10, -6)

B. 6

C. (-1, 2.5, 2.5, 5, -3)

D. 9

E. 20

Optional results

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

```
// 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);
```

Optional results fix

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

```
// 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);
```

Method references

ClassName::methodName

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

```
// 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();
```

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.

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.

```
// 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);
```

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

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

```
// 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();
```

Method references

ClassName::methodName

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

```
// 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:

```
// 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 strings

```
// 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]
```

Streams and files

```
// find longest line in the file
int longest = Files.lines(Paths.get("haiku.txt"))
     .mapToInt(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
```

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.)