Imperative to Functional Programming with Java 8

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Agenda

- Basic Vocabulary and Concepts
- Changing Your Thinking
- Going Deeper

Topics

- Immutability
- First-class functions
- Higher-order functions
- Currying
- Partial application
- Function pipelines
- Function composition
- Recursion
- Map, filter, and reduce
- Continuations
- Memoization
- Monads (computation expressions)

BASIC VOCABULARY & CONCEPTS

Basic Vocabulary and Concepts

- Lambda calculus was introduced by mathematician **Alonzo Church** in the 1930s
- it makes functions first-class objects
- first-class functions were introduced in C# 3.0 in 2007 while in Java in 2014!

What is a λ-expression

- A λ (lambda) expression is an anonymous function that can be passed as argument or returned as the value of function calls.
- In the Java context they are similar to anonymous methods. Like a method it provides a list of formal parameters and a body—an expression or block—expressed in terms of those parameters
- They make it easier to distribute processing of collections over multiple threads
- Collection methods take a function and apply it to every element

λ-expressions

Parameter list

- `f(x) = y`, maps x -> y, e.g. `f(x) = 2*x`, maps x -> 2*x
- `double dbl(double x) { return 2*x; }`

  ➔ `(double x) -> 2*x`

param type

body

```
FileFilter directoryFilter = new FileFilter() {
  public boolean accept(File file) {
    return file.isDirectory();
  }
};
```

@FunctionalInterface

```
FileFilter directoryFilter =
    (File f) -> f.isDirectory();
// f -> f.isDirectory();
```

- Lambdas are lexically scoped, meaning that a lambda recognizes the immediate environment around its definition as the next outermost scope.

λ-expressions

Syntax:

```
 (parameters) -> expression
or
 (parameters) -> { statements; }
```

E.g.

```
(int x, int y) -> x + y
(x, y) -> x % y
() -> Math.pi
(String s) -> s.toUpperCase()  or
String::toUpperCase              ← Method Reference
x -> 2 * x
c -> { int n = c.size(); c.clear(); return n ; }
```

No return

Functional interfaces

```
@FunctionalInterface
public interface MyInterface<T> {
   MyInterface<T> apply();
   default boolean isComplete() {
      return false;
   }
   //...
}
```

A *functional interface* is an interface that has just one abstract method (and zero or more default or implemented methods), and thus represents a functional contract.

Functional interfaces

```
@FunctionalInterface
public interface UnaryOperator<T> {
    T apply(T t);
}
```

- describes the function: `f: T -> T`

java.util.function

- Consumer<T> T -> void
- Supplier<T> () -> T
- Predicate<T> T -> boolean
- Function<T,R> T -> R
- BiFunction<T,U,R> (T,U) -> R
- UnaryOperator<T> T -> T
- BinaryOperator<T> (T,T) -> T

java.util.function.Consumer<T>

```
interface Consumer<T> {
    void accept(T t);   // T -> void
}
```

java.util.function.Supplier<T>

```
interface Supplier<T> {
    T get();// () -> T
}
```

java.util.function.Predicate<T>

```
interface Predicate<T> {
    boolean test(T t);// T -> boolean
    default Predicate<T> and(Predicate<? super T> other);
    default Predicate<T> or(Predicate<? super T> other);
    default Predicate<T> negate();
    static <T> Predicate<T> isEqual(Object other);
}
```

java.util.function.Function<T, R>

```
interface Function<T, R> {
   R apply(T t);        // T -> R
   default <V> Function<V,R> compose(Function<? super V, ? extends T> before);
   default <V> Function<T,V> andThen(Function<? super R, ? extends V> after);
   static <T> Function<T, T> identity();
}
```

First-class functions

First-class function

- Can be used wherever we use values, e.g.

```
Function<Person,String> byName
  = person -> person.getName();
List<Person> people;
people.stream().map(byName)
.collect(toList());
```

First-class functions

- Can be used wherever we use values, BUT

```
List<Function<Integer,
  Integer>> functionList = new
  ArrayList<>() {
  (Integer x) -> doubl(x),
  (Integer x) -> square(x)};
```

Function closures

Function closure

- Functions that use variables defined outside of them, e.g.

```
public static Predicate<String>
  startsWith(final String letter)
  {
    return name ->
  name.startsWith(letter);
}
```

`letter` is defined in the method that contains the `startsWith()` function

and `letter` needs to be "effectively final"

Higher-order Functions

- Functions that take or return other functions
  - pass functions to functions
  - create functions within functions
  - return functions from functions

Higher-order function

```
public static int sum
(Function<Integer, Integer> function,
int a, int b) {
   if (a > b) return 0;
   else return function.apply(a) +
sum(function, a + 1, b);
}
```

Return functions

- Higher-order functions can also return functions:

```
Function<Integer, Integer>
evenOrOdd(int n) {
  return (n % 2 == 0) ?
     x -> 2*x : x -> 3*x;
}
```

Return function

Method References

- When a λ-expression simply calls a single method e.g.
  `s -> s.toUpperCase()`

the following syntax is preferred:

`String::toUpperCase`

- This syntax is called method reference

Method References

Category	Syntax	λ-expression	Example
Static	`ClassName::staticMethod`	`(args) -> ClassName.staticMethod(args)`	`String::valueOf`
Bound Instance	`ObjectName::instMethod`	`(args) -> ObjectName.instMethod(args)`	`str::replace`
Unbound Instance	`ClassName::instMethod`	`(arg0,rest) -> arg0.instMethod(rest)`	`String::concat`
Constructor	`ClassName::new`	`(args) -> new ClassName(args)`	`File::new`

Bound Method References

```
Map<String, String> map = new
TreeMap<>();
map.put("alpha", "A");
map.put("bravo", "B");
map.put("charlie", "C");
String s = "alpha-bravo-charlie";
map.replaceAll(s::replace);
```

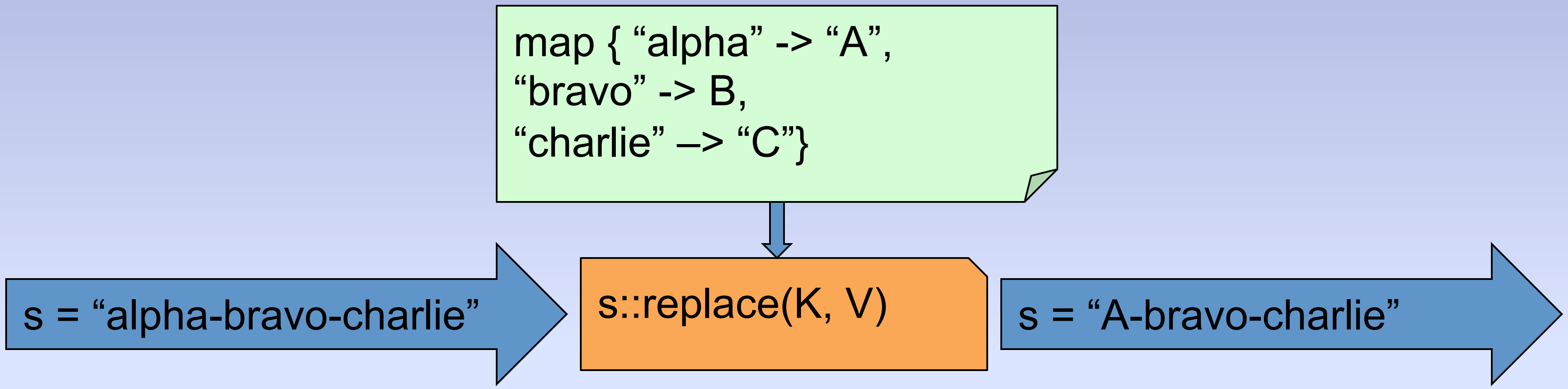
Bound Method References (cont.)

```
// <T> the type of the first argument to the function
// <U> the type of the second argument to the function
// <R> the type of the result of the function
BiFunction<T, U, R> { R apply(T t, U u); }

void replaceAll(BiFunction<? super K, ? super V, ? extends V> function) // (K,V)->V

String replace(CharSequence target, CharSequence replacement)
```

Bound Method References (cont.)



Bound Method References (cont.)

```
s.replace("alpha", "A");  // s ==
"A-bravo-charlie"
s.replace("bravo", "B");  // s ==
"alpha-B-charlie"
s.replace("charlie", "C"); // s ==
"alpha-bravo-C"
==================================
{alpha=A-bravo-charlie, bravo=alpha-
B-charlie, charlie=alpha-bravo-C}
```

Unbound Method References

```
Map<String, String> map = new
TreeMap<>();
map.put("alpha", "A");
map.put("bravo", "B");
map.put("charlie", "C");
map.replaceAll(String::concat);
```

No recipient aka closure

Unbound Method References (cont.)

```
String concat(String str); =>
key.concat(value);
"alpha".concat("A"); // "alphaA"
"bravo".concat("B"); // "bravoB"
"charlie".concat("C"); //
"charlieC"
=================================
{alpha=alphaA, bravo=bravoB,
charlie=charlieC}
```

Immutability

- Imperative programming is based on mutability – state change => side effects
- Functional programming is based on immutability – no state change; a new object is created each time
- = sign indicates equation *not* assignment

```
var = 1
var = var + 1    // Error!!!
```

Currying

- "…the technique of transforming a function that takes multiple arguments (or a tuple of arguments) in such a way that it can be called as a chain of functions, each with a single argument (partial application)".
- `def f(args`$_1$`)…(args`$_{n-1}$`)(args`$_n$`) = E` ⬄ `def f = (args`$_1$` => (args`$_2$` => … (args`$_n$` => E)…))`

```
def  sum(f: Int  => Int)(a: Int , b: Int ):
Int  = if  (a > b) 0 else  f(a) + sum(f)(a +
1, b)
```

Partial Application

- "…partial application (or partial function application) refers to the process of fixing a number of arguments to a function, producing another function of smaller arity."

  "Arity" means the number of arguments that a function accepts.
- it is a process of binding values to parameters resulting in a function with fewer parameters; it depends on currying
- currying is a process that replaces a single multi-parameter function with a nested set or chain of single-parameter functions

Currying in Java

- Java provides:
  - `Function<T,R>` `T -> R`
  - `BiFunction<T,U,R>` `(T,U) -> R`
- But how can we calculate a function that takes >2 arguments?
  - `f(x, y, z) = x * y + z`
  - There is no `TriFunction<T,U,W,R>` `(T,U,W) -> R`
  - `(A, B, C) -> D` ➔ `A -> B -> C -> D`
  - `f(2, y, z) = g(y, z) = 2 * y + z =>`
  - `g(3, z) = 2 * 3 + z`

Currying in Java

```
List<Integer> list =
                Arrays.asList(1, 2, 3, 4, 5);
private Stream<Integer>
       calculate(Stream<Integer> stream,
Integer a, Integer b) {
  return stream.map(
((Function<Integer,
     Function<Integer,
        Function<Integer, Integer>>>)
   x -> y -> z -> x + y * z).
                      apply(a).apply(b));
} // a => x, b => y, stream arg => z
 // [5, 8, 11, 14, 17]
```

Currying in Java

```
interface TriIntegerFunction extends
Function<Integer, Function<Integer,
Function<Integer, Integer>>> {}

private Stream<Integer>
  calculate(Stream<Integer> stream,
Integer a, Integer b) {
  TriIntegerFunction sline =
                x -> y -> z -> x + y * z;
  return
     stream.map(sline.apply(a).apply(b));
}
```

Automatic currying in Java

```
public class Functions {
  public static <A, B, C> Function<A, Function<B,
C>> curry(final BiFunction<A, B, C> f) {
    return (A a) -> (B b) -> f.apply(a, b);
  }

  public static <A, B, C> BiFunction<A, B, C>
   uncurry(Function<A, Function<B, C>> f) {
   return (A a, B b) -> f.apply(a).apply(b);
  }
}
Function<Integer, Function<Integer, Integer>> c1 =
   curry((y, z) -> y * z);
Function<Integer, Function<Integer, Integer>> c2 =
   curry((t, x) -> t + x);
return stream.map(c1.apply(b)).map(c2.apply(a));
// a => x, b => y, stream arg => z, t
```

CHANGE YOUR THINKING

Expression-based programming

- stop thinking in terms of statement-based programming (imperative)
- start thinking in terms of expression-based programming (functional)
- A statement mutates the current value; does not return anything
- An expression always returns a result or a new value

statement

```
point.moveTo(x1, y1);
```

expression

```
newpoint = point.move(x1, y1);
```

Eager vs lazy evaluation

- In ***eager evaluation***, an expression is evaluated as soon as it is bound to a variable.
- The alternative to eager evaluation is ***lazy evaluation***, where expressions are only evaluated when evaluating a dependent expression, i.e. until its value is needed
- Java is an "eager" language
- `List<Integer> list = Arrays.asList(1, 2, 3, 4, 5);` is eagerly (strictly) evaluated
- Java 8 streams allow for lazy evaluation

Lazy constructions in Java

- `&&` and `||`
- the ternary operator `?:`
- `if... then...else`
- the `for` loop
- the `while` loop
- the Java 8 `Stream`
- the Java 8 `Optional`

Lazy evaluated methods in Java

- Java methods evaluate their arguments eagerly, i.e. before the method is called

```
public static boolean andMethod (boolean arg1, boolean arg2) {
   return arg1 && arg2;
}
```

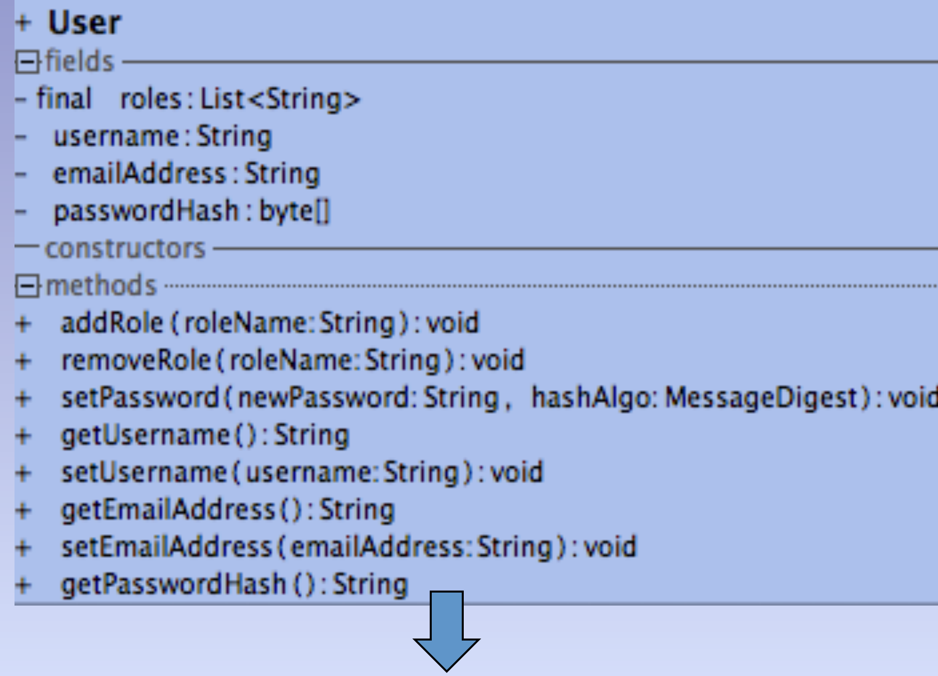
- To lazily evaluate its arguments:

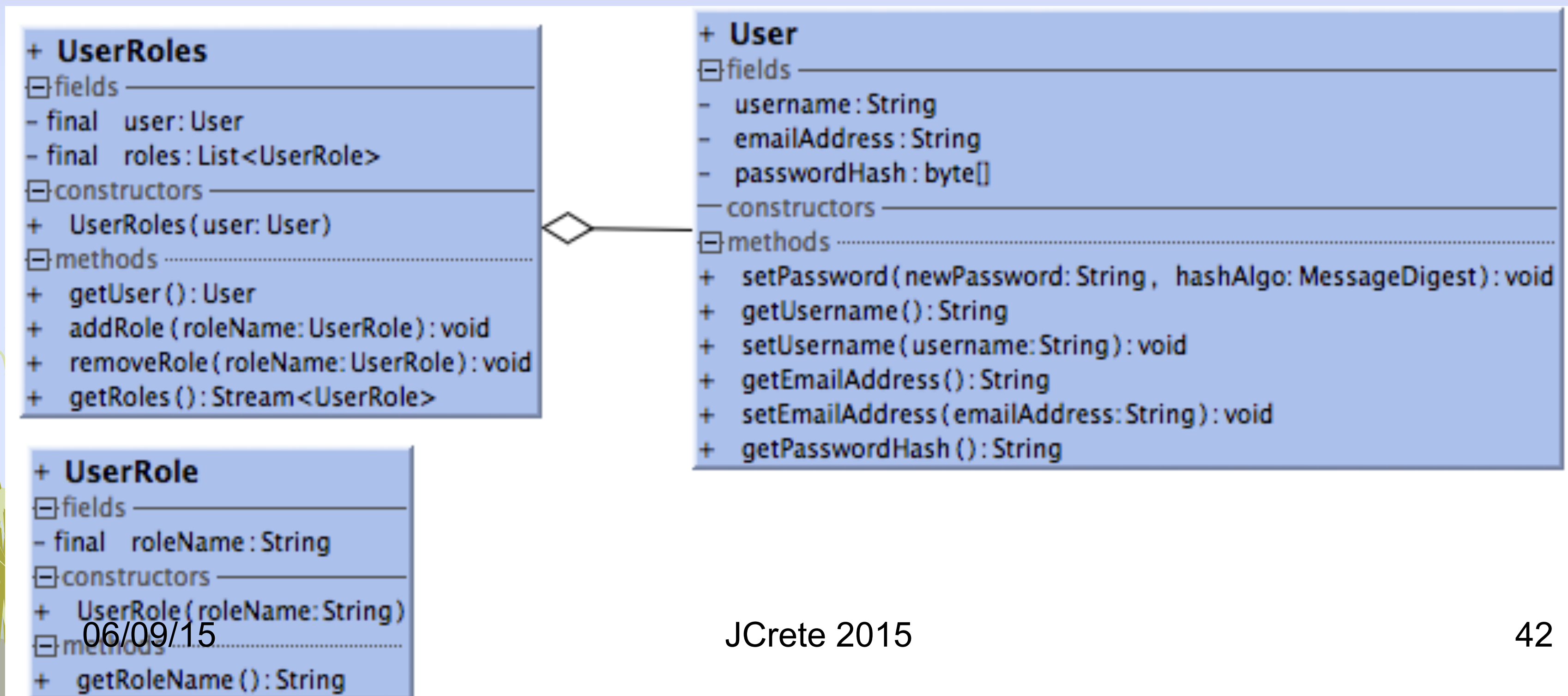
```
public static boolean andMethod (Supplier<Boolean> arg1, Supplier<Boolean> arg2) {
   return arg1.get() && arg2.get();
}
```

Start thinking immutable

- Reduce encapsulation by creating associations explicitly as maps
  - Think like relational database architecture, i.e. in terms of tables and relations
  - Identify core types i.e. fields
  - Associate with other types via foreign keys
  - normalize
- Create smaller functions that do just one thing; then combine them together using partial application or function pipelining or composition

Example


+ User
fields
- final roles : List<String>
- username : String
- emailAddress : String
- passwordHash : byte[]
constructors
methods
+ addRole (roleName: String) : void
+ removeRole (roleName: String) : void
+ setPassword (newPassword: String , hashAlgo: MessageDigest) : void
+ getUsername ( ) : String
+ setUsername (username: String) : void
+ getEmailAddress ( ) : String
+ setEmailAddress (emailAddress: String) : void
+ getPasswordHash ( ) : String


+ UserRoles
fields
- final user : User
- final roles : List<UserRole>
constructors
+ UserRoles (user: User)
methods
+ getUser ( ) : User
+ addRole (roleName: UserRole) : void
+ removeRole (roleName: UserRole) : void
+ getRoles ( ) : Stream<UserRole>
+ UserRole
fields
- final roleName : String
constructors
+ UserRole (roleName: String)
methods
+ getRoleName ( ) : String
+ User
fields
- username : String
- emailAddress : String
- passwordHash : byte[]
constructors
methods
+ setPassword (newPassword: String , hashAlgo: MessageDigest) : void
+ getUsername ( ) : String
+ setUsername (username: String) : void
+ getEmailAddress ( ) : String
+ setEmailAddress (emailAddress: String) : void
+ getPasswordHash ( ) : String

Streams

- Find sum of odd numbers:

```
int[] numbers = {1, 2, 3, 4, 5};
int sumOfOddNumbers =
  IntStream.of(numbers).
    filter(x -> x % 2 == 1).sum();
```

Streams

```
/* Create an output list that contains
 * only the odd-length words, converted
 * to upper case.
*/
List<String> result = input.stream()
   .filter(s -> s.length() % 2 != 0)
   .map(String::toUpperCase)
   .collect(Collectors.toList());
```

Filter-map-reduce

Input: **`Stream<T>`**

method	λ	function	output	eager/lazy
`map`	`T -> R`	`Function<T,R>`	`Stream<R>`	lazy
`flatMap`	`T -> Stream<R>`	`Function<T,Stream<R>>`	`Stream<R>`	lazy
`filter`	`T -> boolean`	`Predicate<T>`	`Stream<T>`	lazy
`reduce`	`(T,T) -> T`	`BinaryOperator<T>`	`Optional<T>`	eager
`collect`	`R -> R`	`Supplier<R>`	`R`	eager
`forEach`	`T -> void`	`Consumer<T>`	`void`	eager

- Streams are evaluated when we apply to them some specific operations called ***terminal (eager)***. This may be done only once. Once a terminal operation is applied to a stream, the stream is no longer usable.

Infinite streams - Lazyness

```
Streams.iterate(seed, UnaryOperator)
.limit(count)
.collect(Collectors.toList());
```

E.g.

```
Function<Integer, Stream<Integer>>
f = x -> Stream.iterate(1,
          y -> y + 1).limit(x);
```

Infinite stream example

```
public class Primes {
  public static boolean isPrime(final int number) {
    return number > 1 && IntStream.rangeClosed(2,
(int) Math.sqrt(number)).noneMatch(divisor -> number
% divisor == 0);
  }

  private static int nextPrime(final int number) {
    return isPrime(number + 1) ? number + 1 :
nextPrime(number + 1);
  }

  public static List<Integer> primes(final int count)
{
    return Stream.iterate(2, Primes::nextPrime)
          .limit(count)
          .collect(Collectors.<Integer>toList());
 }
}
```

Terminal Operations

- `forEach`
- `forEachOrdered`
- `toArray`
- `reduce`
- `collect`
- `min, max`
- `count`
- `anyMatch`
- `allMatch`
- `noneMatch`
- `findFirst`
- `findAny`
- `iterator`
- `spliterator`

Intermediate Operations

- filter
- map
- mapTo...*
- flatMap
- flatMapTo...*
- Distinct
- sorted
- peek
- limit
- skip
- sequential
- parallel
- unordered
- onClose

*(Int, Long or Double)

Parallel streams

- Things to consider:
  - size of data
  - do we really want to run the lambda expressions concurrently?
  - the code should be able to run independently without causing any side effects or race conditions
  - the correctness of the solution should not depend on the order of execution of the lambda expressions that are scheduled to run concurrently

Function pipelining

```
List<String> result =
input.stream()
.filter(s -> s.length() % 2 != 0)
.map(String::toUpperCase)
.collect(Collectors.toList());
```

- stream | filter | map | collect

Function composition

- The ability to compose functions into a chain of operations
- The lack of mutability reduces the chance of errors and makes it easier to parallelize the code
- We can alter a few links in the chain and easily alter the behavior along the way

Recap

- Favor immutability
- Reduce side-effects
- Prefer expressions over statements
- Expressions can be composed
- Design with higher-order functions

GOING DEEPER

Continuations

- "[A] continuation represents the remainder of a computation given a point in the computation."
- the idea is that a function is provided with another function that is invoked with the result of the first function's computation
- Java 8 provides `CompletableFuture<T>` and `CompletableStage<T>` (a stage of a possibly asynchronous computation, that performs an action or computes a value when another CompletionStage completes)
- `CompletableFuture<T>` is functional, monadic, asynchronous and event-driven

Continuations in Java 8

```
public void processOrder(String custId) {
    return CompletableFuture
        .supplyAsync(() -> getFromDB(custId))
        .thenApplyAsync(c -> getOrder(c.getCustId()))
        .thenAccept(System.out::println);
}

private Customer getFromDB(String custID){
    // TODO get customer from database
}
private Order getOrder(String custID){
    // TODO get order ...
}
```

Continuation Frameworks

- Javaflow (Play framework uses Javaflow)
- RIFE
- JauVM implements tail call / continuation
- Scala 2.8
- Cocoon
- Rhino
- Jetty retry request.
- Coroutines
- Jconts
- jyield
- Kilim
- ATCT

Start thinking immutable - recursion

- Use recursion to avoid mutability
- Example of ***recursion****:*

```
public int fact(int n) {
    return n == 0 ? 1 : n * fact(n-1);
}
```

- Biggest problem with recursion is *stack overflow*.
- If a function calls itself as its last action, the function's stack frame can be reused. This is called ***tail recursion***. This resolves stack overflow.
- If the last action of a function consists of calling a function (which may be the same), one stack frame would be sufficient for both functions. Such calls are called ***tail-calls***.

Start thinking immutable - recursion

- Convert loops to tail recursion
- Tail recursion example:

```
public static int foo(int a, int b) {
     int x = …; int y = …;
    return foo(x, y);
}
```

Start thinking immutable - recursion

- Example: calculate the sum of:

```
public static int sum(IntUnaryOperator
func, int a, int b) {
   if (a > b) return 0;
   else return function.apply(a) +
              sum(function, a + 1, b);
}
```

This is not tail recursive; why!!!

Fibonacci numbers

- Standard fibonacci function is ***not*** tail-recursive:

```
f(n) = f(n - 1) + f(n - 2)
```

- Why?

Tail recursive fibonacci function

```
public static BigInteger fibTailRec(int x) {
    return fibTailRecHelper(BigInteger.ONE,
BigInteger.ZERO, BigInteger.valueOf(x));
}

public static BigInteger
fibTailRecHelper(BigInteger acc1, BigInteger acc2,
BigInteger x) {
    if (x.equals(BigInteger.ZERO)) {
        return BigInteger.ONE;
    } else if (x.equals(BigInteger.ONE)) {
        return acc1.add(acc2);
    } else {
        return fibTailRecHelper(acc2,
acc1.add(acc2), x.subtract(BigInteger.ONE));
    }
}
-----------------------------------------------
fibTailRec(9813);    // 9814 => stack overflow
```

Tail recursive

Tail recursive factorial function

```
public static BigInteger factTailRec(int number) {
    return factTailRecHelper(BigInteger.ONE,
BigInteger.valueOf(number));
}
public static BigInteger factTailRecHelper(BigInteger
factorial, BigInteger number) {
    if (number.equals(BigInteger.ZERO)) {
        return BigInteger.ONE;
    } else if (number.equals(BigInteger.ONE)) {
        return factorial.multiply(number);
    } else {
        return factTailRecHelper(
factorial.multiply(number), number.subtract(BigInteger.ONE));
    }
}
-----------------------------------------------
factTailRec(11799);   // 11800 => stack overflow
```

Tail recursive

Tail Recursion Optimisation (TCO)

- We need a way for the last operation to be a (delayed/lazy) call to itself, and no further computation to carry out on the result upon return.

```
@FunctionalInterface
public interface RecCall<T> {

    RecCall<T> next();

    default boolean isDone() { return false; }

    default T getValue() { throw new
IllegalStateException(); }

    default T apply() {
        return Stream.iterate(this, RecCall::next)
                .filter(RecCall::isDone)
                .findFirst()
                .get()
                .getValue();
    }
// ...
```

Tail Recursion Optimisation (TCO)

```
static <T> RecCall<T> call(final RecCall<T> nextCall) {
    return nextCall;
}
static <T> RecCall<T> done(final T value) {
    return new RecCall<T>() {
        @Override
        public boolean isDone() {
            return true;
        }
        @Override
        public T getValue() {
            return value;
        }
        @Override
        public RecCall<T> next() {
            throw new IllegalStateException();
        }
    };
}
}
```

TCO fibonacci function

```
public static BigInteger fibTailRec(int x) {
    return fibTailRecHelper(BigInteger.ONE,
BigInteger.ZERO, BigInteger.valueOf(x).apply());
}

public static BigInteger fibTailRecHelper(BigInteger acc1,
BigInteger acc2, BigInteger x) {
    if (x.equals(BigInteger.ZERO)) {
        return Recall.done(BigInteger.ONE);
    } else if (x.equals(BigInteger.ONE)) {
        return Recall.done(acc1.add(acc2));
    } else {
        return Recall.call(() -> fibTailRecHelper(acc2,
acc1.add(acc2), x.subtract(BigInteger.ONE));
    }
}
----------------------------------------------
fibTailRec(800_000);
```

Tail recursive lazily executed

TCO factorial function

```
public static BigInteger factTailRec(int number) {
    return factTailRecHelper(BigInteger.ONE,
BigInteger.valueOf(number).apply());
}
public static RecCall<BigInteger>
factTailRecHelper(BigInteger factorial, BigInteger number) {
    if (number.equals(BigInteger.ZERO)) {
        return Recall.done(factTailRec);
    } else if (number.equals(BigInteger.ONE)) {
        return Recall.done(factorial.multiply(number));
    } else {
        return Recall.call(() -> factTailRecHelper(
factorial.multiply(number),
number.subtract(BigInteger.ONE)));
    }
}
-----------------------------------------------
factTailRec(500_000);
```

Tail recursive lazily executed

Tuples

- ordered collections of values of different types of fixed size, e.g.
  `(person, "John", 42, 1.78)`
- Java supports tuples:
  - Implicitly, e.g.:

```
int sum2(int a, int b) {
   return a+b; }
```

Single argument function!!!!

```
(int a, int b) -> a + b;
```

but we cannot use them for a function’s return values

Tuples

- Explicitly, e.g.

```
/** A Tuple: double -> (int, double) for integer and
decimal parts */
public class Tuple {
  public final int integerPart;
  public final double decimalPart;

  public Tuple(int integerPart, double decimalPart) {
     super();
     this.integerPart = integerPart;
     this.decimalPart = decimalPart;
  }

  @Override
  public String toString() {
    return String.format("(%s, %s)", integerPart,
decimalPart);
  }
}
```

Tuples

```
private static Tuple
split(double x) {
  int integerPart = (int) x;
  return new Tuple(integerPart,
x - integerPart);
};
System.out.println(split(3.14));
```

➔ (3, 0.14000000000000012)

Fibonacci function with tuples

- 1, 1, 2, 3, 5, 8, 13, 21, ...
- (1, 1), (1, 2), (2, 3), (3, 5), (5, 8), (8, 13), (13, 21), ...

```
Tuple2<BigInteger, BigInteger> seed = new
Tuple2<>(BigInteger.ONE, BigInteger.ONE);
UnaryOperator<Tuple2<BigInteger,
BigInteger>> fbc = x -> new
Tuple2<>(x.elem2, x.elem1.add(x.elem2));
```

```
BigInteger fiboCoRecursive=
Stream.iterate(seed, fbc)
  .map(x -> x.elem1)
  .limit(1_000_000).reduce(
              (a, b) -> b).get();
```

Memoization

- Memoization means caching the results of functions in order to speed them up when they are called several times with the same argument.
- The first call implies computing and storing the result in memory before returning it.
- Subsequent calls with the same parameter imply only fetching (lookup) the previously stored value and returning it.
- Memoizing is about maintaining state between function calls.
- A memoized function is a function which behavior is dependent upon the current state.

Memoization Example

```
public class Cache {
  private static final Map<Integer,
Integer> cache = new
ConcurrentHashMap<>();

  public static Integer
square(Integer x) { return
cache.computeIfAbsent(x, y -> y * y);
  }
}
-----------------------------------
int sq3 = Cache.square(3);
```

Memoization Example (cont.)

```
public class Cache {
  private static final Map<Integer,
Integer> cache = new
ConcurrentHashMap<>();

  public static Function<Integer,
Integer> square = x ->
cache.computeIfAbsent(x, y -> y * y);
  }
}
-------------------------------------
int sq3 = Cache.square.apply(3);
```

We have to repeat this modification for all functions.

Memoizer

```
Function<Integer, Integer> f = x -> x
* x;
Function<Integer, Integer> g =
Memoizer.memoize(f);  // reference to
the function to be memoized
--------------------------------
int sq3 = g.apply(3);
```

- All values returned by function `g` will be calculated through the original function `f` the first time, and returned from the cache for all subsequent accesses.

Memoizer (cont.)

```
public class Memoizer {
    private Memoizer() {}

    public static <T, U> Function<T, U>
memoize(final Function<T, U> function) {
        final Map<T, U> cache = new
ConcurrentHashMap<>();
        return input ->
cache.computeIfAbsent(input,
function::apply);
    }
}
```

What about functions with >1 arguments?

- i.e. functions of *tuples* that may also return *tuples*
- More difficult to store multiple values to a Map
- For 2 arguments, `f` can be a `BiFunction<T,U,R>`:

```
BiFunction<Integer, Integer,
Integer> h = (x, y) -> x*x + y*y;
```

- Or use *currying* for ≥ 2 arguments:

```
Function<Integer, Function<Integer,
Integer>> hc = x -> y -> x*x + y*y;
```

Memoizer with a parameter

```
public class Memoizer2 {
 private Memoizer2() {}

 public static <T, R> R  memoize(final
BiFunction<Function<T, R>, T, R> function, final T
input) {
   final Map<T, R> cache = new
ConcurrentHashMap<>();
   Function<T, R> memoized = new Function<T, R>() {
     @Override
     public R apply(final T input) {
       return cache.computeIfAbsent(input, key ->
function.apply(this, key));
    }
};
     return memoized.apply(input);
  }
}
```

Memoizer with currying

```
Function<Integer, Function<Integer, Integer>> f2m =
    Memoizer.memoize(x ->
      Memoizer.memoize(y -> x*x + y*y));
----------------------------------------
f2m.apply(2).apply(3);
----------------------------------------
Function<Integer, Function<Integer,
Function<Integer, Integer>>> f3 =
         x -> y -> z -> x*x + y*y + z*z;
Function<Integer, Function<Integer,
Function<Integer, Integer>>> f3m =
   Memoizer.memoize(x -> Memoizer.memoize(y ->
Memoizer.memoize(z -> x*x + y*y + z*z)));
-----------------------------------------
f3m.apply(2).apply(3).apply(-1);
```

Memoizer with tuples (cont.)

```
private static final
Function<Tuple3<Integer, Integer,
Integer>, Integer> ft = t ->
t.elem1*t.elem1 + t.elem2*t.elem2 +
t.elem3*t.elem3;

private static final
Function<Tuple3<Integer, Integer,
Integer>, Integer> ftm =
Memoizer.memoize(ft);
-----------------------------------------
ftm.apply(new Tuple3<>(2, 3, 4));
```

Memoizer with tuples (cont.)

```
public class Tuple3<T, U, V> {
    public final T elem1;
    public final U elem2;
    public final V elem3;
    public Tuple3(T t, U u, V v) {
        elem1 = Objects.requireNonNull(t);
        elem2 = Objects.requireNonNull(u);
        elem3 = Objects.requireNonNull(v);
    }
    @Override
    public boolean equals(Object o) {
        if (!(o instanceof Tuple3)) return false;
        else {
            Tuple3 that = (Tuple3) o;
            return elem1.equals(that.elem1) &&
elem2.equals(that.elem2) && elem3.equals(that.elem3);
        }
    }
    @Override
    public int hashCode() {
        return elem1.hashCode() + elem2.hashCode() + elem3.hashCode();
    }
}
```

Monads (Computation expressions)

- A ***monad*** is a structure that represents computations defined as sequences of steps
- Monads can be chained together in order to build pipelines that process data in steps
- One of the uses for a monad is retain state without resorting to mutable variables
- Monads are a great way to create *workflows* where you have to manage data, control logic, and state (side effects)
- Continuations are a key aspect of computational expressions

Simple Monad example

```
int a = 5, b = 6;
int c = a + b;
==========================
int pipeFunc(int x, IntUnaryOperator
f) {
    return f.applyAsInt(x);
}
int result = pipeFunc(5,
    a -> pipeFunc(6,
        b -> pipeFunc(a+b, c -> c)));
```

Monads

- Formally, a monad consists of a *type constructor M* and two operations, *bind* and *return* (where return is often also called *unit*):
- The *return* operation takes a value from a plain type and puts it into a monadic container using the constructor, creating a monadic value.
- The *bind* operation takes as its arguments a monadic value and a function from a plain type to a monadic value, and returns a new monadic value.

Monads

- A monad is a set of three things:
  - A parameterized type `M<T>`
  - A *unit* or *return* function `T -> M<T>`
  - A *bind* operation

    `M<T> bind T -> M<U> = M<U>`
- Java supports monads, e.g.: `Optional<T>`
  - Parameterized type: `Optional<T>`
  - unit: `Optional.of()`
  - bind: `Optional.flatMap()`

java.util.Optional<T>

E.g.

```
// unit
Optional<Integer> maybeInteger =
Optional.of(1);
// bind
Optional<Integer> maybePlusOne =
maybeInteger.flatMap(
            n -> Optional.of(n + 1));
```

Other monads in Java 8

- `Streams`
- `CompletableFuture<T>`
- Better-Java-Monads by Jason Goodwin
  - Try
  - Futures
    - List<CompletableFuture<T>> → CompletableFuture<List<T>>

Monads

- Maybe or Try
- I/O
- Identity
- State
- Continuation
- …

State Monad in Java 8

- a state monad allows to attach state information of any type to a calculation
- a state monad maintains state within a specific *workflow.*
- a state monad is basically a function from a state to a pair (state,content).
- Parameterized type: `<T,S>:`
  - unit: `t -> (t,s)`
  - bind: `x -> (y,s)`
- See ref[9].

Conclusion

OO style

- Abstraction
- Encapsulation
- Polymorsphism
- Inheritance
- Statements
- imperative

Functional style

- Higher order functions
- Function composition
- Immutability
- Expressions
- declarative

Conclusion

- Java 8 is not a fully functional programming language
- Allows you to combine imperative with functional style
- Thinking functionally can help you become a better coder
- Think of immutability
- Think of (small) functions (lambdas)
- Think of Streams

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