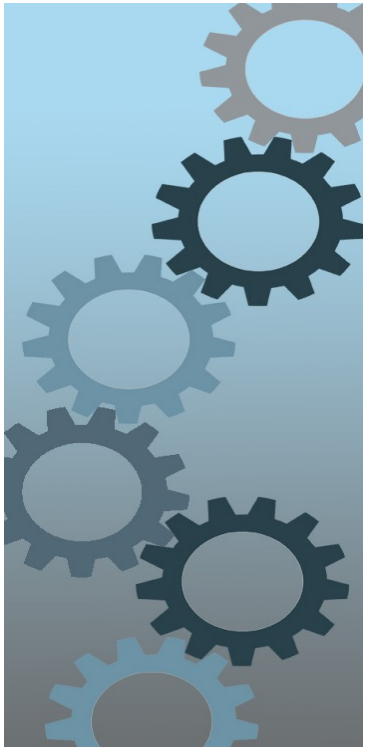
HSLU Hochschule Luzern

Programming Concepts And Paradigms

Functional Programming Lambdas and Streams



Marcel Baumann

Functional vs OOP

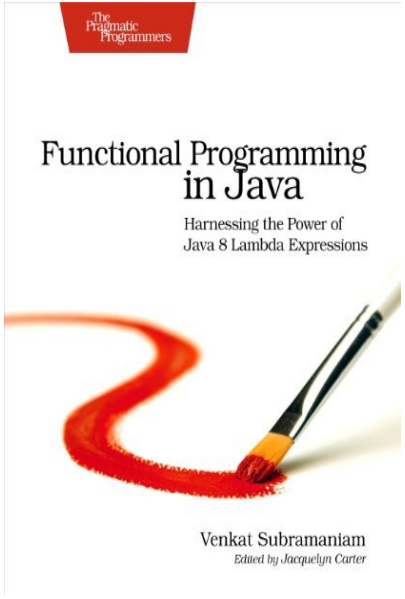
Functional

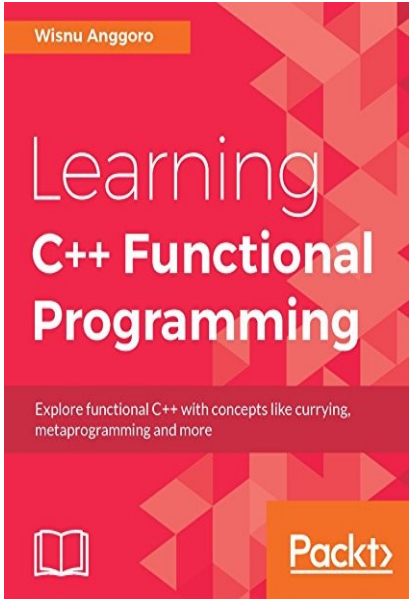
- Order of execution isn't always important, it can be asynchronous
- **Functions** are basic building elements to work with data structures
- Follows the **declarative** paradigm
- Focuses on the **result** desired and its final conditions
- Ensures immutability; programs should be stateless
- Primary activity is writing **new functions and composing existing ones**

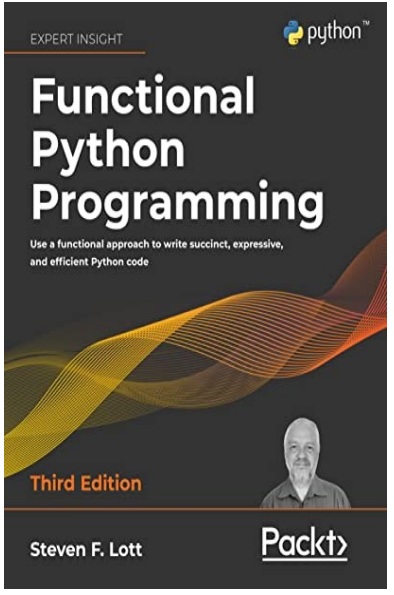
Object-Oriented

- A specific execution sequence of statements is crucial
- **Objects** are the main abstractions for data
- Follows the **imperative** paradigm
- Focuses on **how** the desired result can be achieved
- **State changes** are an important part of the execution
- Primary activity is **building, extending and composing objects**

Functional is Hype







Content

- Functional Approaches
  - Conditional expressions, switch, lambda
- Functional Programming
  - Composition
  - Currying
  - Monad
  - Collections

Build-in Functional Concepts in Java

- Ternary operator instead of *if () then {} else {}*
  - Part of the initial Java language definition 25 years ago
- Switch expression instead of switch statement
  - Construct delivered with Java 12
- Streams instead of loop statements

Conditional Expressions

```
return object != null ? object.getValue() : null;
```

Ternary operator is the expression construct for the if statement

Functional Idioms

```
@Override
public boolean equals(Object obj) {
    return (obj instanceof EntityImp o) &&
                Objects.equals(oid(), o.oid());
}
```

Match operator to access fields

Switch Expressions

```
int numLetters = switch (day) {
    case MONDAY, FRIDAY, SUNDAY -> 6;
    case TUESDAY -> 7;
    case THURSDAY, SATURDAY -> 8;
    case WEDNESDAY -> 9;
};
```

Lambdas

- Conciseness for anonymous classes
- Similar to function pointers in C or C++
- Similar to lambdas in Clojure

Functional Programming

```
static final IntToDoubleFunction squares =
    x -> (x == 0) ? 0 : Math.pow(x, 2) + Lecture5.squares.applyAsDouble(x – 1);

public static double meanOfSquaresRecusive(int n) {
    return squares.applyAsDouble(n-1) / n;
}
```

```
static final BiFunction<Integer, Double, Double> squaresTail =
        (x, r) -> (x == 0) ? r : Lecture5.squaresTail.apply(x - 1, r +Math.pow(x, 2));

public static double meanOfSquaresTailRecursive(int n) {
    return squaresTail.apply(n-1, 0D) / n;
}
```

Control Questions

1. What does *(Integer x, final Integer y) → x * y* mean?
2. What does *(var x, final var y) → x * y* mean?
3. What does *(x, y) → x * y* mean?
4. What is the type of the lambda *(Integer x, final Integer y) → x * y?*
5. What does *<? super T>* mean?
6. What does *<? extends T>* mean?

Functional Concepts

- Referential Transparency (Clojure lectures)
  - A function, or more generally an expression, is called referentially transparent if a call can be replaced by its value without affecting the behavior of the program. Simply spoken, given the same input the output is always the same.
- Higher Order Functions (Clojure lectures)
  - In computer science, a higher-order function is a function that does at least one of the following:
    - takes one or more functions as arguments
    - returns a function as its result

Functional Concepts

- Pure Functions (Clojure Lectures)
  - The function return values are identical for identical arguments (no variation with local static variables, non-local variables, mutable reference arguments or input streams)
  - The function application has no side effects (no mutation of local static variables, non-local variables, mutable reference arguments or input/output streams)

Functional Concepts

- Functional Composition (Clojure lectures)
  - In mathematics, function composition is an operation that takes two functions f and g and produces a function h such that h(x) = g(f(x))
  - Composition requires higher order functions

Advanced Functional Concepts

- Lambda Lifting
  - Lambda lifting is a meta-process that restructures a computer program so that functions are defined independently of each other in a global scope. An individual "lift" transforms a local function into a global function. It is a two step process:
    - Eliminating free variables in the function by adding parameters
    - Moving functions from a restricted scope to broader or global scope
- Currying
  - In computer science, currying is the technique of converting a function that takes multiple arguments into a sequence of functions that each take a single argument

Composition

You can compose functions. In mathematics, function composition is the application of one function to the result of another to produce a third function. For instance, the functions $f : X \rightarrow Y$ and $g : Y \rightarrow Z$ can be composed to yield a function h: g(f(x)) which maps $X \rightarrow Z$

Function Composition

- **default** <V> Function<T, V> andThen (Function<? super R,? extends V> after)
- **default** <V> Function<V, R> compose (Function<? super V,? extends T> before)

Predicate Composition

- **default** Predicate<T> and(Predicate<? super T> other)
- **default** Predicate<T> or(Predicate<? super T> other)
- **default** Predicate<T> negate()

Comparator Composition

- **default** Comparator<T> thenComparing
  (Comparator<? super T> other)
- **default** <U> Comparator<T> thenComparing(
  Function<? super T,? extends U> keyExtractor,
  Comparator<? super U> keyComparator)
- **default** <U extends Comparable<? super U>>
  Comparator<T> thenComparing(
  Function<? super T,? extends U> keyExtractor)

Currying Simple Example

```
// factory creation pattern
static Letter of(String salutation, String body){
    return new Letter(salutation, body);
}

// functional building with a bi-function
BiFunction<String, String, Letter> letterCreator
  = (salutation, body) -> new Letter(salutation, body);

// functional currying building with a sequence of functions
Function<String, Function<String, Letter>> letterCreatorCurried
  = salutation -> body -> new Letter(salutation, body);

// Calling the functions
var letter1 = Letter.of(salutation, body);

var letter2 = letterCreator.apply(salutation, body);

var letter3 = letterCreatorCurried.apply(salutation).apply(body)
```

Currying: More Complex Example

```
// factory creation pattern

static Letter of(String returnAddress, String insideAddress,
    LocalDate date, String salutation, String body, String closing) {
        return new Letter(returnAddress, insideAddress, date, salutation,
            body, closing);
}

// functional currying building with a sequence of functions

Function<String, Function<String, Function<LocalDate, Function<String,
    Function<String, Function<String, Letter>>>>>> letterCreator =
    returnAddress -> returnAddress -> insideAddress -> date -> salutation -> body
    -> closing
    -> new Letter(returnAddress, insideAddress, date, salutation, body, closing);

// Calling the functions

var letter1 = Letter.of(returnAddress, insideAddress, date, salutation, body, closing);
var letter2 = letterCreator.apply(returnAddress).apply(insideAddress).apply(date)
    .apply(salutation).apply(body).apply(closing);
```

Currying Builder Example (1/2)

```
// All interfaces are SAM – Single Abstract Method

public static class Builder {
    public static ReturnAddress builder() {
       return returnAddress -> insideAddress -> dateOfLetter -> salutation -> body -> closing ->
                new Letter(returnAddress, insideAddress, dateOfLetter, salutation, body, closing);
    }

    public interface ReturnAddress {
        InsideAddress withReturnAddress(String returnAddress);
    }

    public interface InsideAddress {
        DateOfLetter withInsideAddress(String insideAddress);
    }

    public interface DateOfLetter {
        Salutation withDateOfLetter(LocalDate dateOfLetter);
    }

    public interface Salutation {
        Body withSalutation(String salutation);
    }

    public interface Body {
        Closing withBody(String body);
    }

    public interface Closing {
        Letter withClosing(String closing);
    }
}
```

Currying Builder Example (2/2)

```
// create a letter with the functional builder

var letter = Letter.Builder.builder().
         .withReturnAddress(returnAddress)
         .withInsideAddress(insideAddress)
         .withDateOfLetter(dateOfLetter)
         .withSalutation(salutation)
         .withBody(body)
         .withClosing(closing);
```

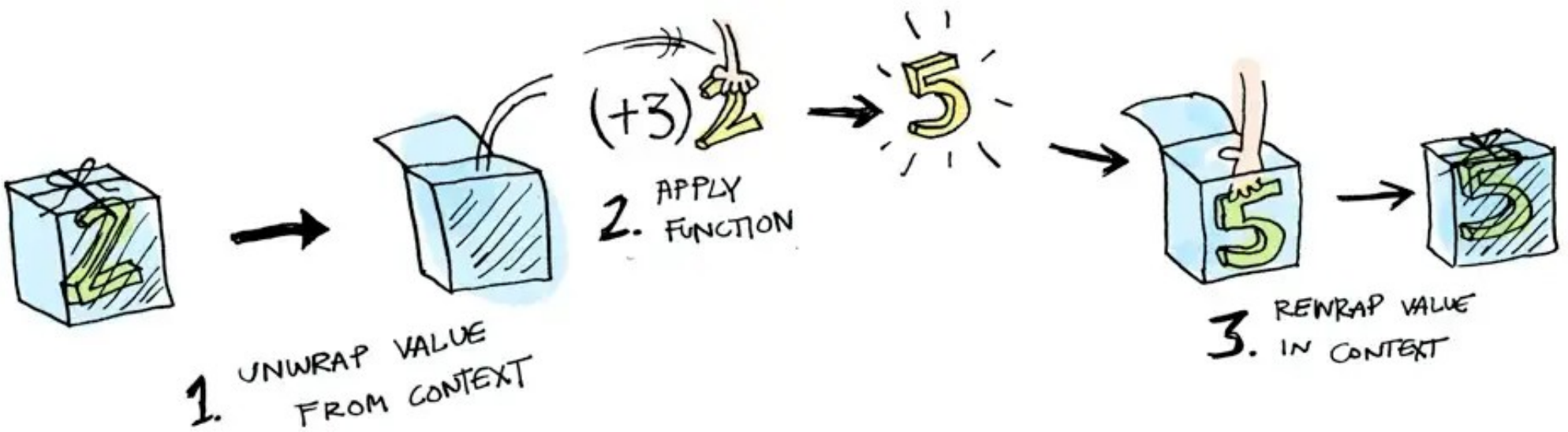
Partial Application and Currying

- Arity is a measure of the number of parameters a function takes.
  - Concept was introduced in Prolog lectures e.g. is_bigger/2
  - Java provides existing functional interfaces for nullary (Supplier), unary (Function), and binary (BiFunction), but that's it.
- Partial application allows you to derive a new function from an existing one by fixing some values
- Fixing one parameter is called currying

Control Questions

1. What does functional composition mean?
2. What are examples of composition defined in the standard API?
3. What does currying mean?

Monad Concept



Monad Components

- To implement Monad, you need
  - a parameterized type M<T> - *Optional<T>*
  - A method unit
    M<T> unit(T t)
    - ***static*** *<T> Optional<T> of(T value)*
  - A method bind
    M<U> bind(M<T> m, Function<T, M<U>> f)
    - *<U> Optional<U> flatMap(*
      *Function<? **super** T, ? **extends** Optional<? **extends** U> mapper)*

Monad Laws

- Given
  - **f** is a function mapping from type T to type Optional<R>
  - **g** is a function mapping from type R to type Optional<U>
- Left Identity
  - ```
    Optional<String> leftIdentity = Optional.of(x).flatMap(f);
    Optional<String> mappedX = f.apply(x);
    assert leftIdentity.equals(mappedX);
    ```
- Right Identity
  - ```
    Optional<Integer> rightIdentity = Optional.of(x).flatMap(Optional::of);
    Optional<Integer> wrappedX = Optional.of(x);
    assert rightIdentity.equals(wrappedX);
    ```
- Associativity
  - ```
    Optional<Long> leftSide = Optional.of(x).flatMap(f).flatMap(g);
    Optional<Long> rightSide = Optional.of(x).flatMap(v -> f.apply(v).flatMap(g));
    assert leftSide.equals(rightSide);
    ```
    ```

Optional<T> Monad

The Optional monad makes the possibility of missing data
explicit
in the type system, while
hiding
the boilerplate of *if non-null* logic

Stream<T> Monad

The Stream monad makes the possibility of multiple data
explicit
in the type system, while
hiding
the boilerplate of *if non-null* logic

CompletableFuture<T> Monad

The CompletableFuture monad makes
asynchronous computation
explicit
in the type system, while
hiding
the boilerplate of thread logic

Why Monads?

- Hide complexity
- Encapsulate implementation details
- Reduce code duplication
- Improve maintainability
- Increase readability
- Remove side effects
- Allow composability

Discussion

Collection Functional Concepts

- Map (Java Lectures)
  - Stream map returns a stream consisting of the results of applying the given function to the elements of this stream. Stream map(Function mapper) is an intermediate operation
- Filter (Java Lectures)
  - Stream filter returns a stream consisting of the elements of the given stream that match the given predicate. The filter() argument should be stateless predicate which is applied to each element in the stream to determine if it should be included or not
- Reduce (Java Lectures)
  - Reducing is the repeated process of combining all elements. reduce operation applies a binary operator to each element in the stream where the first argument to the operator is the return value of the previous application and second argument is the current stream element

Map Operations on streams

- <R> Stream<R> ***map***(Function<? **super** T,? **extends** R> mapper)
- <R> Stream<R> ***flatMap***(Function<? **super** T,? **extends** Stream<? **extends** R>> mapper)
- **default** <R> Stream<R> ***mapMulti*** (BiConsumer<? **super** T,? **super** Consumer<R>> mapper)

Map Operations Examples (1/3)

```
void testMap() {
    var list = List.of(1, 2, 3, 4, 5, 6, 7, 8, 9, 10, 11, 12, 13, 14, 15);

    System.out.println(list.stream().map(o -> o * o).map(String::valueOf)
        .collect(Collectors.joining(", ", "(", ")")));
}
```

```
void testMapToString() {
    var list = List.of(1, 2, 3, 4, 5, 6, 7, 8, 9, 10, 11, 12, 13, 14, 15);

    System.out.println(list.stream().map(o -> String.valueOf(o * o))
        .collect(Collectors.joining(", ", "(", ")")));
}
```

Map Operations Examples (2/3)

```
void testFlatMap() {
    var list = List.of(List.of(1, 2, 3, 4, 5), List.of(6, 7, 8, 9, 10),
                       List.of(11, 12, 13, 14, 15));

    System.out.println(list.stream().flatMap(o -> o.stream())
        .map(o -> o * o).map(String::valueOf)
        .collect(Collectors.joining(", ", "(", ")")));
}
```

```
void testFlatMap() {
    var list = List.of(List.of(1, 2, 3, 4, 5), List.of(6, 7, 8, 9, 10),
                       List.of(11, 12, 13, 14, 15));

    System.out.println(list.stream().flatMap(Collection::stream)
        .map(o -> o * o).map(String::valueOf)
        .collect(Collectors.joining(", ", "(", ")")));
}
```

Map Operations Examples (3/3)

```
void testMapMulti() {
    var list = List.of(List.of(1, 2, 3, 4, 5), List.of(6, 7, 8, 9, 10),
                List.of(11, 12, 13, 14, 15));

    System.out.println(list.stream()
    .mapMulti((o, c) -> o.forEach(o1 -> c.accept(o1 * o1)))
            .map(String::valueOf).collect(Collectors.joining(", ", "(", ")")));
}
```

```
void testMapMultiWithOptional() {
    var list = List.of(Optional.of(1), Optional.of(2), Optional.of(3),
                       Optional.empty(), Optional.of(4), Optional.of(5),
                       Optional.empty());

    System.out.println(list.stream().mapMulti(Optional::ifPresent)
                .map(String::valueOf)
                .collect(Collectors.joining(", ", "(", ")")));
}
```

Gatherers (1/3)

- The optional initializer function provides an object that maintains private state while processing stream elements.
- The integrator function integrates a new element from the input stream, possibly inspecting the private state object and possibly emitting elements to the output stream.

Gatherers (2/3)

- The optional combiner function can be used to evaluate the gatherer in parallel when the input stream is marked as parallel.
- The optional finisher function is invoked when there are no more input elements to consume.

Gatherers (3/3)

```
boolean isSuspicious(Reading previous, Reading next) {
    return next.obtainedAt().isBefore(previous.obtainedAt().plusSeconds(5))
           && (next.kelvins() > previous.kelvins() + 30
               || next.kelvins() < previous.kelvins() - 30);
}

List<List<Reading>> findSuspicious(Stream<Reading> source) {
    return source.gather(Gatherers.windowSliding(2))
                 .filter(window -> (window.size() == 2
                                    && isSuspicious(window.get(0), window.get(1))))
                 .toList();
```

Java Exception Pains (1/2)

```
@FunctionalInterface
public interface ThrowingFunction<T, R, E extends Exception> {
    R apply(T t) throws E;

    static <T, R, E extends Exception> Function<T, R>
      of(ThrowingFunction<T, R, E> f) {
        return t -> {
            try {
                return f.apply(t);
            } catch (Exception e) {
                throw new CompletionException(e);
            }
        };
    }
}
```

Java Exception Pains (2/2)

```
Double function(Integer value) throws TimeoutException {
    if (value != 50) {
        return Double.valueOf(value);
    } else {
        throw new TimeoutException();
    }
}

@Test
void testWrappers() {
    assertThatExceptionOfType(RuntimeException.class)
    .isThrownBy(() -> IntStream.range(1, 101)
    .boxed().map(ThrowingFunction.of(this::function)).forEach(o -> {}));
}
```

Limits of Current Java

- Advanced functional programming concepts are a pain to write in Java
- Ruedi will show you more elegant constructs to implement the same concepts in other programming languages such as Kotlin

Control Questions

1. How does streams handle checked exceptions?
2. What are the implications if you want to use a functional style?
3. *How can you define your own stream?*
4. *How can you define you own intermediate operation?*
5. *How can you define you own terminal operation?*

Solutions and Compromises

- Java is an object-oriented language adding functional features
- Java tries very hard to be backward compatible
- Often the solutions are compromises

Outlook Project Amber

- Concise Method Declaration
  (Draft JEP, open for years)

```
int length(String s) {
    return s.length();
}

int length(String s) -> s.length();

int length(String s) = String::length;
```

Outlook Project Loom

- Tail-call elimination for recursion
  - Finally we could use recursion instead of loop statements
- Delimited continuation
- *Functional programming is fun ;-)*

Links

- Open JDK
- JEP List
- Project Amber
- Project Loom

Exercises

- Lambdas
- Currying and functional builder
- If you are interested in functional programming with Java look at Vavr or FunctionalJava