Functional programming in Scala

Functions

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Definition

In functional programming languages, functions are the fundamental building blocks of computation. They are treated differently than in imperative languages, more like mathematical functions and first-class citizens.
We will learn here what that means in practice.

Impure functions

```scala
/**
 * Not pure because it have side affect
 */
val greeting: Unit = println("Hello, Scala")
```

Pure functions

```scala

/**
 * Deterministic: The same input always gives the same
     output.
 * Side effect-free: It does not modify any state or
    interact with the outside world (no I/O, * no
    global variable changes).
 */
val add = (x: Int, y: Int) => x + y

// Same Function with another declaration
val add: (Int, Int) => Int = (a, b) => a + b
```

Functions are not Methods

Methods look and behave very similar to functions, but there are a few key differences between them.

```

/**
 * Methods are defined with the def keyword. def is
     followed by a name, parameter list(s), a return
     type, and a body
 */
def add(x: Int, y: Int): Int = x + y
println(add(1, 2)) // 3
```

First-Class Citizens

```scala
/**
 * Be assigned to variables
 * Be passed as arguments
 * Be returned from other functions
 */

val sum = (x:Int , y: Int) => x + y
val double = (x: Int) => x * 2
def application(f: Int => Int, x: Int): Int = f(x)
def apply(f: (Int, Int) => Int, x: Int, y: Int): Int =
    f(x, y)
```

Function Composition

```scala

val f = (x: Int) => x + 1
val g = (x: Int) => x * 2
val h = f.compose(g) // h(x) = f(g(x)) = (x * 2) + 1
```

Lamdba λ functions

A lambda (aka anonymous function) is a function defined without a name

```
(x: Int) => x * 2
```

Immutability and Referential Transparency

```scala
// Referentially transparent
def square(n: Int): Int = n * n
// Can be replaced with 16 + 16 or 32
val result = square(4) + square(4)
// Not referentially transparent (depends on external
   state)
```

Recursion and tail call optimization

Recursion is a function that it calls itself

```scala
val factorial: Int => Int = (n: Int) =>
  if (n <= 1) 1          // Base case
  else n * factorial(n - 1) // Recursive case

// Tail call optimization
import scala.annotation.tailrec
val factorial: Int => Int = {
  @tailrec
  def loop(n: Int, acc: Int): Int = n match {
    case 0 | 1 => acc
    case _ => loop(n - 1, n * acc)
  }
  (n: Int) => loop(n, 1)
}
```

Higher-Order Functions (HOFs)

Functions that take other functions as arguments or return them.

Higher-Order Functions (HOFs)
Why Use HOFs?

- **Abstraction**: Reduce code duplication
- **Expressiveness**: Write more declarative code
- **Composability**: Combine small functions into complex operations
- **Flexibility** : Parameterize behavior

Higher-Order Functions (HOFs)

map function

The map function is a fundamental higher-order function in Scala that applies a given function to each element of a collection and returns a new collection with the transformed elements.

```scala
/**
 * The map function functiona implementation
 */

val map: [A, B] => (List[A], A => B) => List[B] =
  [A, B] => (list, f) => list match
    case Nil => Nil
    case head :: tail => f(head) :: map(tail, f)

val numbers = List(1, 2, 3, 4)
val doubled = map(numbers, x => x * 2)
//The result will be List(2, 4, 6, 8)
```

Higher-Order Functions (HOFs)

flatMap function

flatMap combines mapping and flattening operations. It's more powerful than map because it can handle nested structures and transform each element into a new collection, then flatten the results into a single collection

```
val flatMap:[A, B] => (List[A], A => List[B]) => List[
    B] =
  [A, B] => (list, f) => list.foldRight(List.empty[B])
      ((a, acc) => f(a) ++ acc)

val numbers = List(1, 2, 3)
val result = flatMap(numbers)(n => List(n, n * 10))
// result: List[Int] = List(1, 10, 2, 20, 3, 30)
```

Higher-Order Functions (HOFs)

map vs flatMap

Feature	`map`	`flatMap`
Return type	Single element	Collection/Monadic type
Result structure	Wrapped in same context	Flattened structure
Function signature	`A => B`	`A => F[B]`
Use case	Simple transformations	Transform + flatten
Nested collections	Preserves nesting	Removes one level of nest
For-comprehensions	Used with `yield`	Used with `<-`

- Both preserve the original collection
- Both are higher-order functions
- `flatMap` is monadic bind operation

Higher-Order Functions (HOFs)

HOFs Filter function

```scala

/**
 * The filter function
 */

val filter: List[Int] => (Int => Boolean) => List[Int]
    =
  list => predicate => list match
    case Nil => Nil
    case head :: tail =>
      if (predicate(head)) head :: filter(tail)(
          predicate)
      else filter(tail)(predicate)
```

Higher-Order Functions (HOFs)

Fold function

A **fold** function (also known as **reduce** or **aggregate**) is a powerful higher-order function in functional programming that reduces a collection (like a **List**) to a single value by applying a binary operation repeatedly, starting from an initial value.

HOFs/Fold Function
foldLeft implementation

foldLeft processes elements left-to-right (from the first to the last).

```scala

// foldLeft (Tail-recursive, stack-safe)
def left[A, B](list: List[A])(ini: B)(op: (B, A) => B)
    : B =
  list match
    case Nil => initial
    case head :: tail => left(tail)(op(initial, head))
        (op)

val nums = List(1, 2, 3, 4)
// foldLeft: (((0 - 1) - 2) - 3) - 4 = -10
nums.foldLeft(0)(_ - _)
```

HOFs Fold Function

foldRight implementation

foldRight processes elements right-to-left (from the last to the first).

```scala

// foldRight (Not tail-recursive)
def foldRight[A, B](list: List[A])(initial: B)(op: (A,
    B) => B): B =
  list match
    case Nil => initial
    case head :: tail => op(head, foldRight(tail)(
        initial)(op))

val nums = List(1, 2, 3, 4)
// foldRight: 1 - (2 - (3 - (4 - 0))) = -2
nums.foldRight(0)(_ - _)
```

Folds Performance & Stack Safety Comparison

Both foldLeft and foldRight are higher-order functions that combine elements of a collection into a single result, but they differ in key ways

Feature	`foldLeft`	`foldRight`
Tail-recursive	✓	$\times$
Stack-safe on large collections	✓	$\times$
Time Complexity	$O(n)$ (iterative)	$O(n)$ (but stack risk)
Space Complexity	$O(1)$	$O(n)$ (call stack)
Works with infinite streams	$\times$	✓(if lazy)

- ✓= Supported, $\times$= Not supported
- `foldLeft` uses constant space (tail-recursion optimized)
- `foldRight` may overflow on large lists (non-tail-recursive)

Combining Immutability and Referential Transparency

```scala
def double(x: Int): Int = x * 2
def square(x: Int): Int = x * x
val numbers = List(1, 2, 3, 4, 5)
val processed = numbers.map(double).map(square)

// We can also compose
val composed = numbers.map(x => square(double(x)))
```

Partial functions

A partial function is a function that is valid for only a subset of values of those types you might pass in to it

Do not confuse partial functions with partially applied functions

```
val root: PartialFunction[Double,Double] =
  case d if (d >= 0) => math.sqrt(d)

root(-1) // will result scala.MatchError
root.isDefinedAt(-1) // Will result false
root(3) // Double = 1.7320508075688772

// List of only roots which are defined
List(0.5, -0.2, 4).collect(root)
```

Partially Applied Functions

A partially applied function is when you take a function with multiple parameters and fix some of them, creating a new function with fewer parameters.

```scala
val add:(Int, Int, Int)=> Int = (a, b, c) => a + b + c
// Partially applying it by fixing some parameters
val add2Numbers: (Int, Int) => Int = add(2, _, _)
val fivePlusSeven: Int => Int = add(5, 7, _)
// not partial application - all args applied
val fixedSum: Int = add(1, 2, 3)
// Usage
addTwoToNumbers(3, 4)    // 2 + 3 + 4 = 9
fivePlusSeven(10)      // 5 + 7 + 10 = 22
```

Partial Functions vs Partially applied Functions

- Defined only for even inputs (partial domain)
- Uses pattern matching with guard condition
- Provides isDefinedAt to check applicability
- Can be combined with other partial functions
- Throws MatchError for undefined inputs

- Created from regular functions
- **Fixes** some parameters while leaving others open
- Results in a new function with fewer parameters
- Uses underscore _ as placeholder for unspecified parameters

Currying functions

Currying is a functional programming technique that transforms a function taking multiple arguments into a sequence of functions that each take a single argument.

```scala
// Regular multi-argument function
val add: (Int, Int) => Int = (a, b) => a + b

// Curried version
val addCurried: Int => Int => Int = a => b => a + b

// Usage
val add5: Int => Int = addCurried(5)
println(add5(10))  // 15
```

Closures and Lexical Scope

A closure is a function that ”closes over” (captures) variables from its surrounding lexical scope, even if those variables are no longer in scope when the function is executed.

```scala

val outer: Int => () => Int = x => {
  val captured = x
  () => captured + 10
}

val closure = outer(5)
println(closure())  // Output: 15
```

Pure Functions: Key Papers

[Church, 1936] Church, A. *An Unsolvable Problem of Elementary Number Theory*. 1936.
Lambda calculus as basis for pure functions

[Backus, 1978] Backus, J. *Can Programming Be Liberated from the von Neumann Style?* 1978.
FP manifesto emphasizing purity

[Hughes, 1989] Hughes, J. *Why Functional Programming Matters*. 1989.
Purity enables referential transparency

[Odersky, 2014] Odersky, M. *Scala: Unified OOP-FP*. 2014.
Implementing purity in impure environments

[Peyton Jones, 2003] Peyton Jones, S. *Haskell 98 Language Report*. 2003.
Pure-by-default design

[Cherny, 2020] Cherny, E. *Programming TypeScript*. 2020.
Practical purity in TypeScript/JavaScript

Key Papers on Higher-Order Functions in Scala I

[1] Odersky, M., et al. *An Overview of the Scala Programming Language*, 2004. (Introduces first-class HOFs in Scala's OOP/FP blend)

[2] Oliveira, B. C. d. S., et al. *Type Classes as Objects and Implicits*, OOPSLA 2010. (HOFs + implicits for Haskell-style type classes)

[3] Kossakowski, G., et al. *Miniboxing: Improving Specialization*, SCALA 2012. (Optimizing generic HOFs via `@specialized`)

[4] Burmako, E. *Scala Macros: Let Our Powers Combine*, SCALA 2013. (Macros for HOF inlining, e.g., `map`→`while`)

[5] Brachthäuser, J. I. *Effekt: Capability-Passing*, POPL 2020. (HOFs for effect systems beyond monads)

[6] Twitter Engineering. *Functional Programming at Twitter*, 2011. (Scala's `map`/`flatMap` in distributed systems)