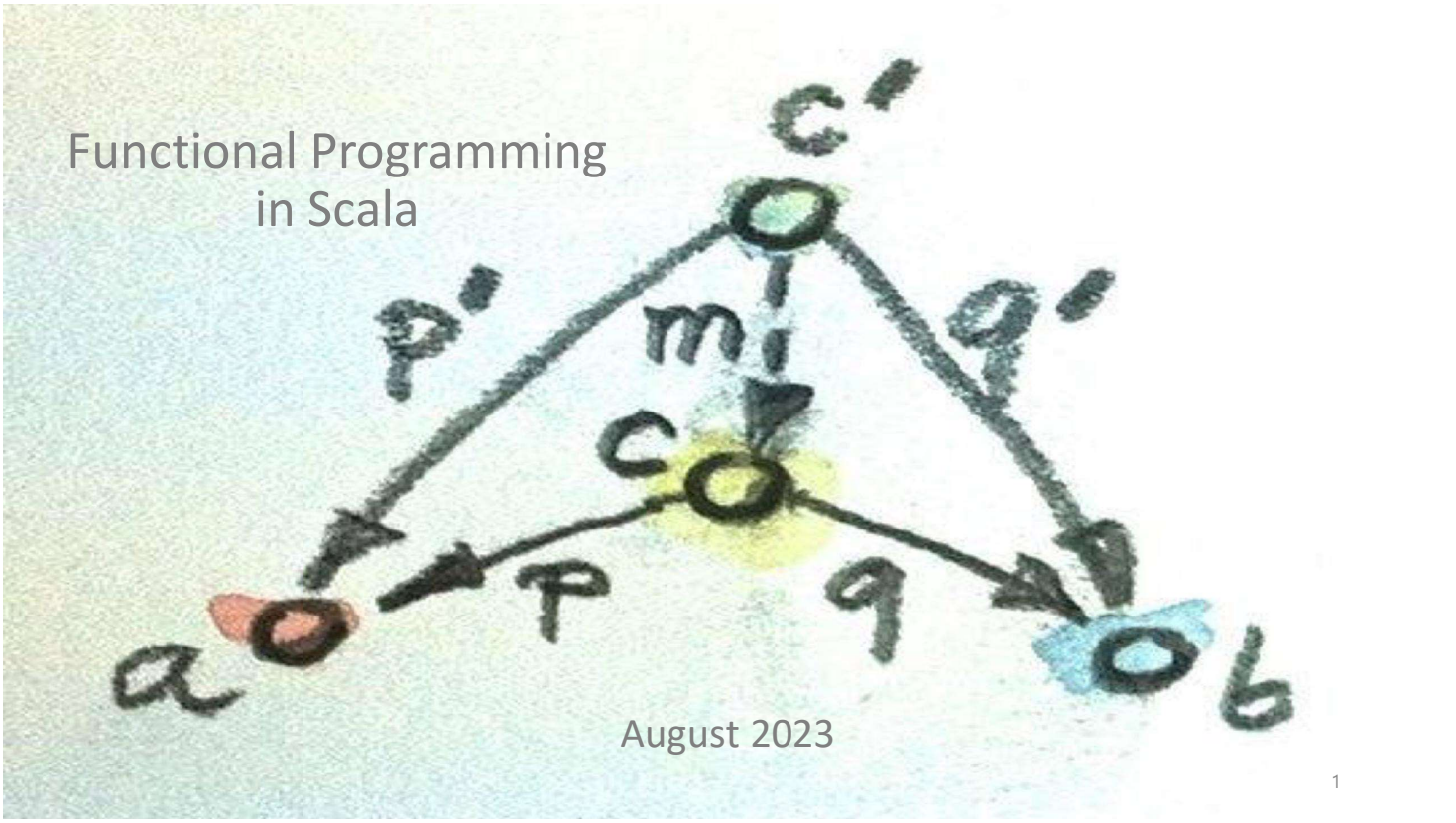
Functional Programming in Scala



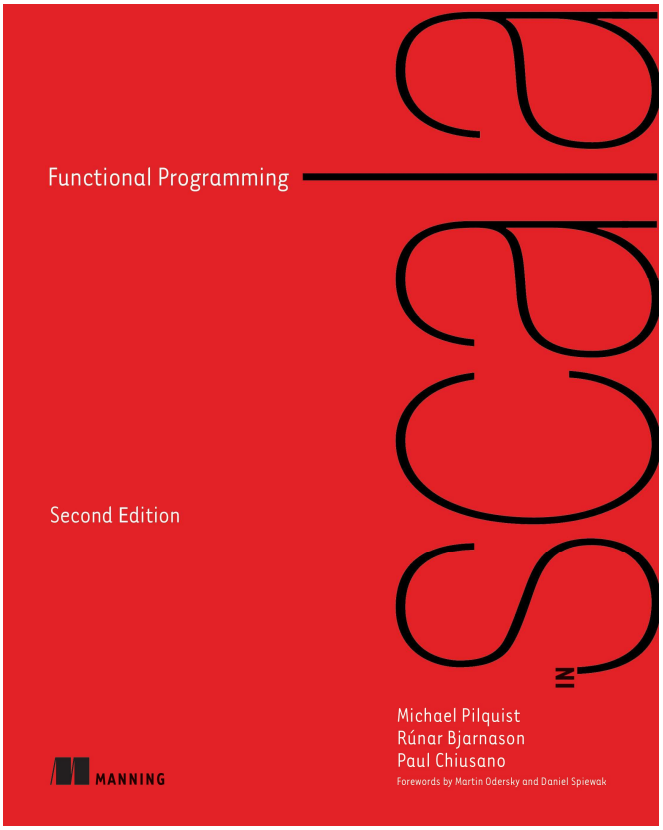
August 2023

Prerequisites – Not Really ☺

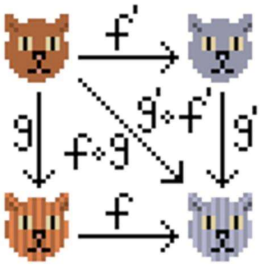
- A reasonable background in functional programming, especially in Scala
- Recommended prerequisite course: "**Principles of Functional Programming in Scala**", Coursera Course by Martin Odersky
- Other experiences in some other functional programming languages, such as Haskell, F#, Clojure, etc. would be fine.

Textbook

Functional Programming in Scala,
2nd Edition,
Michael Pilquist,
Rúnar Bjarnason, and
Paul Chiusano,
Manning, 2023



Course Contents

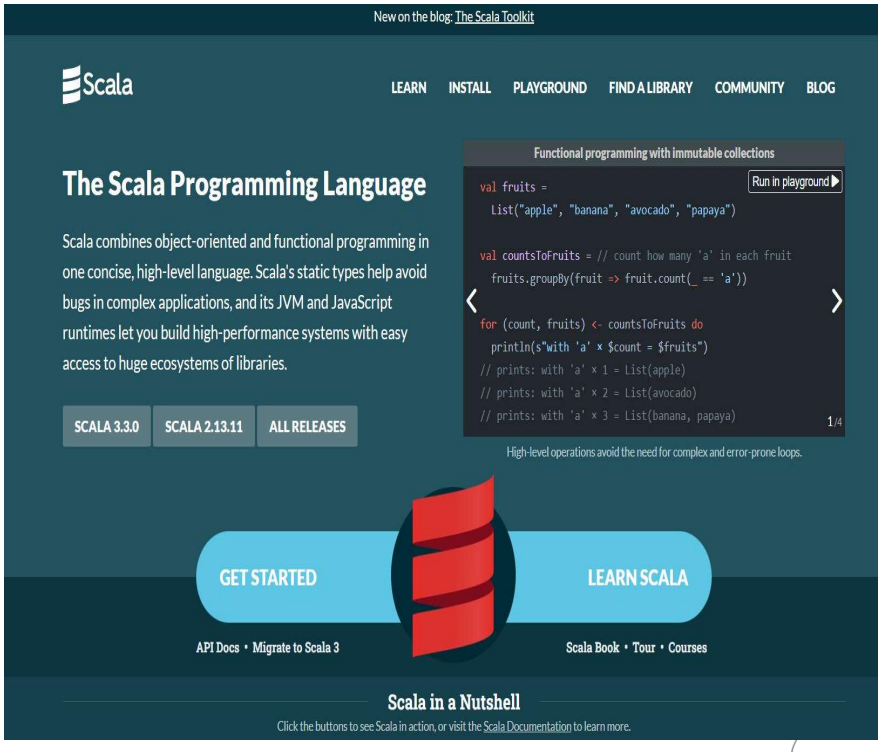


Focus on course

Focus on next course

Tools

- Scala Language 3.3.0
- SBT: Build tool, v.1.9.2
- IDE: VS Code or IntelliJ



Switching from OOP to Functional Programming

Why functional programming is so hard?

Imperative Programming

- Tell **how** to do it.

- **Mutability**

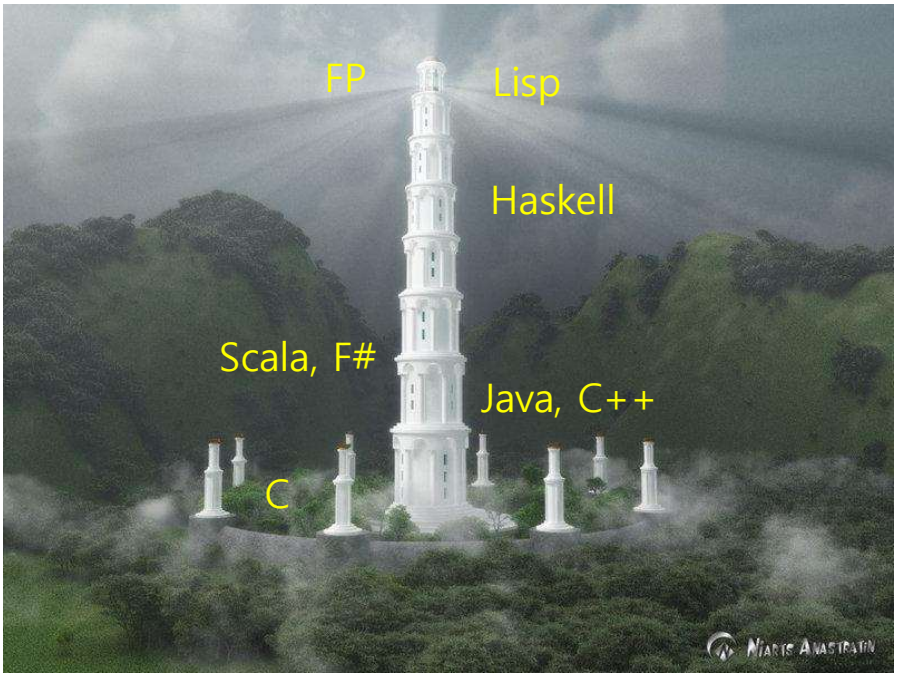
Root of all Evils!

```
def qsort(xs: Array[Int], low: Int, high: Int) {
  def swap(i: Int, j: Int) = {
    val temp = xs(i)
    xs(i) = xs(j)
    xs(j) = temp
  }

  val pivot = xs((low + high) / 2)
  var i = low
  var j = high
  while (i <= j) {
    while (pivot < xs(j)) j -= 1
    while (pivot > xs(i)) i += 1
    if (i <= j) {
      swap(i, j)
      i += 1
      j -= 1
    }
  }
  if (low < j) qsort(xs, low, j)
  if (i < high) qsort(xs, i, high)
}
```

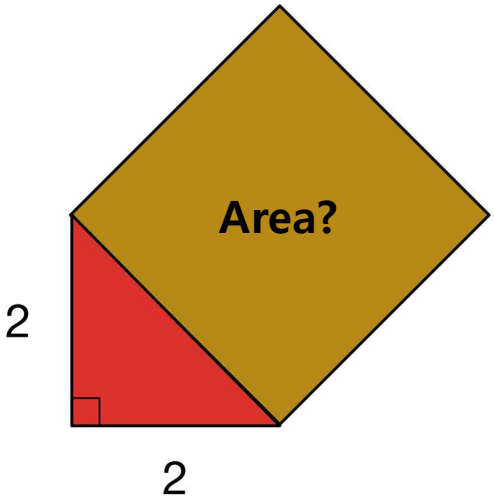

Declarative Programming

- Tell **what** to do.
- **Immutability**

```
def qsort(xs: List[Int]): List[Int] =
  if xs.size <= 1 then xs
  else
    val pivot = xs(xs.length / 2)
    val (l, e, r) = partition(xs, pivot)
    List.concat(qsort(l), e, qsort(r))
```

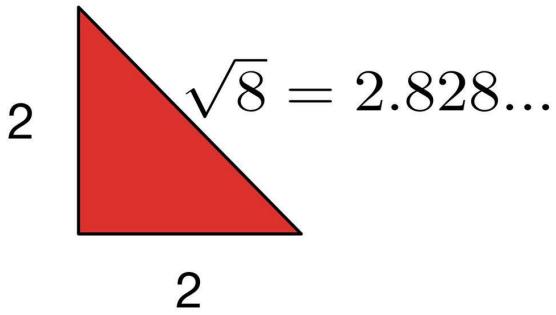


Does abstraction mean less accuracy?

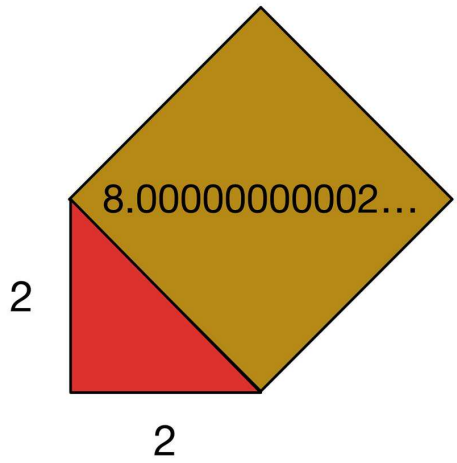


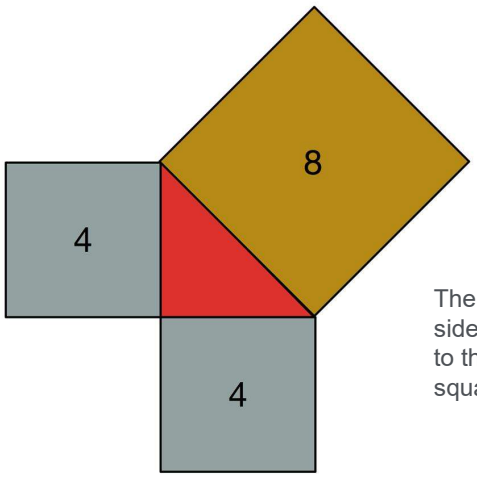
Is this accurate?

$$a^2 + b^2 = c^2$$



$$\sqrt{8} = 2.828\ldots$$





The area of the square whose side is the hypotenuse is equal to the sum of the areas of the squares on the other two sides.

Work with algebraic relationships.
Go to decimals as late as possible.

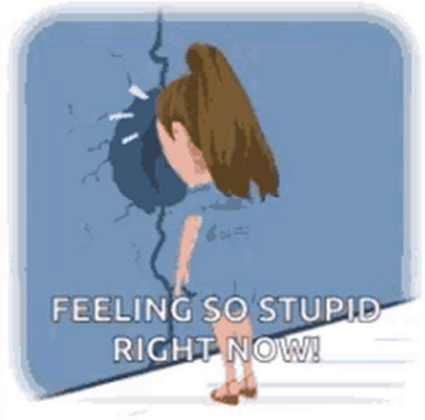
Common Complaints and Question

I've heard a lot of good things about functional programming but I find it very difficult to understand.

I have years of experience in C++/Java/C#/Javascript/etc but it doesn't help, it feels like learning to code from scratch again. Where should I start?

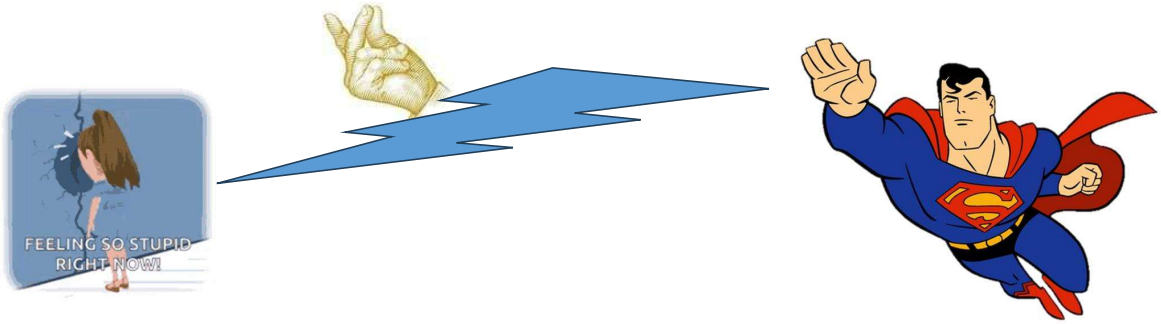
Switching paradigms requires a `mindset` change

- No longer have your usual primitives, like classes, mutable variables, loops, etc.
- You will not be productive for the first couple of months, you will be stuck for hours or days on some simple things that usually took minutes.
- It will be hard and you will feel stupid.



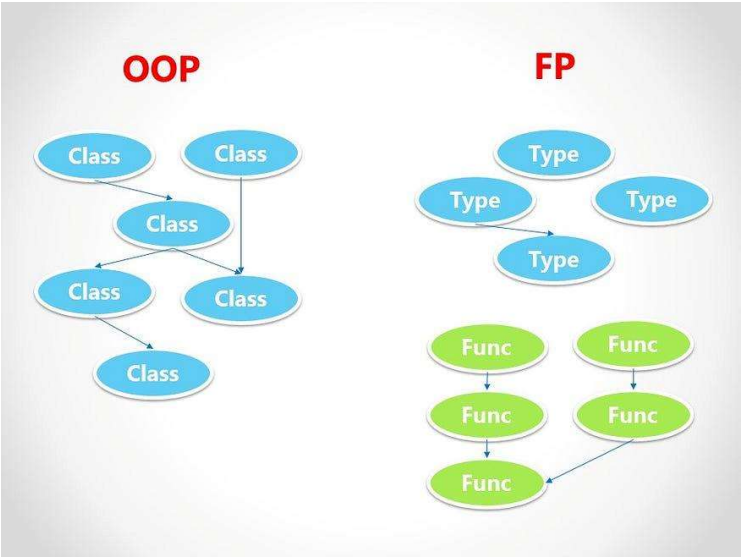
But after it clicks you will gain superpowers

- I don’t know a single person who switched back from FP to OOP after doing FP daily.
- You may switch to a language that doesn’t have FP support but you’ll still be writing using FP concepts, there are that good.



1. There are no classes

Q: No classes? How do I structure my code then?



Slide from https://slidle.com/jivko/functional-programming

Q: What about data? I often have some data and functions that change that data in one class.

- For that we have **Algebraic Data Types (ADT)**, which is just a fancy name for a record that holds data.

```
case class Person(name: String, age: Int)


// Using type constructor
val person = Person("Bob", 42)

// Accessing fields
val personsAge = person.age
```

```
data Person = Person String Int

-- OR

data Person = Person
  { name :: String
  , age :: Int
  , address :: Address
  }
```



```
case class Person(name: String, age: Int)

// Using type constructor
val person = Person("Bob", 42)

// Accessing fields
val personsAge = person.age
```

```
data Person = Person
  { name :: String, age :: Int , address :: Address }

-- Using type constructor
person = Person "Bob" 42

-- Or using records notation
person = Person {name = "Bob", age = 42}

-- Accessing fields
personsName = name person -- "Bob"
```

Q: Ok, but how do I change the person's age?

```
val bob = Person("Bob", 42)

// .copy provided by the 'case class'
val olderBob = bob.copy(age = 43)
```

```
bob = Person "Bob" 42

olderBob = bob { age = 43 }
```

ADTs: product type and sum type

- **Product type**: a collection of fields, all have to be specified to construct a type

```scala
// Person is a product type consisting of 3 fields
case class Person(
 name: String,
 age: Int,
 address: Address)

// Address on its own also is a product type
case class Address(
 country: String, city: String, street: String)

// In order to create a Point
// you have to provide all 3 arguments
case class Point(x: Double, y: Double, z: Double)
```

```haskell
data Person = Person
 { name :: String, age :: Int, address :: Address}

data Address = Address
 { country :: String
 , city :: String
 , street :: String
 }

data Position = Position
 { x :: Integer
 , y :: Integer
 , z :: Integer
 }
```


ADTs: product type and sum type

- **Sum type**: *discriminated union*

```scala
// Scala doesn't have a nice syntax for sum types so
// it looks like a familiar OOP inheritance tree.
sealed trait Shape
case class Circle(radius: Int) extends Shape
case class Square(side: Int) extends Shape

// Scala 3 only
enum Shape:
  case Circle(radius: Int)
  case Square(side: Int)
```

```haskell
-- The | can be read as 'or'
data Shape = Circle Int | Square Int

-- Alternatively
data Shape = Circle { radius :: Int }
           | Square { side :: Int }
```

Q: Why sums and products are so special?

- They are basic building blocks for modeling. Product types can be deconstructed and statically checked while sum types can be used for pattern matching.

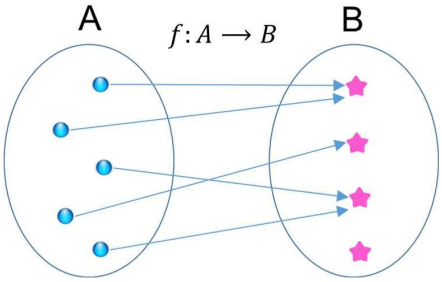
```
enum Shape:
 case Circle(radius: Int)
 case Rectangle(width: Int, height: Int)

// 'match' keyword allows us to pattern match on a
// specific option of the sum type
def area(shape: Shape): Double = shape match {
 case Circle(r) => math.Pi * r * r
 case Rectangle(w, h) => w * h
 // Note how rectangle's width and height
 // are captured in 'w' and 'h'.
}
```

```
data Shape = Circle { radius :: Double }
           | Rectangle { width :: Double
                       , height :: Double }

-- In haskell different options of a sum type can
-- be handled with different 'functions'
area :: Shape -> Double
area (Circle r) = pi * r * r
-- width and height are captured in 'w' and 'h'
area (Rectangle w h) = w * h
```


2. All you need is a function

- Meet your new best friend — a **function**.
- In FP a function is always just a function — it takes values as input and returns values as output.
  - You may know it by different names: getter, setter, constructor, method, builder, static function, etc in OOP.
- There is no need to instantiate anything to use functions, you just import the module where the function is defined and just call it.
- A functional program is just **a collection of ADTs and functions**, as in Shapes example above.

Pure Functions



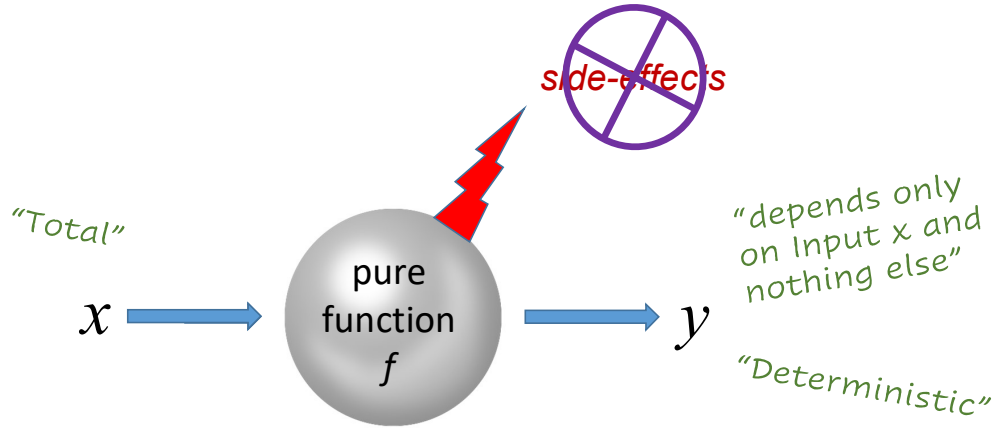
FP means programming with **pure functions**.

A pure function is one with **no side effects**.

f : A => B

- Relates every value *a* of type **A** to exactly one value *b* of type **B** such that *b* is determined solely by the value of *a*.

A **pure** function has **no observable effect** on the execution of the program **other than to compute a result given its inputs**.



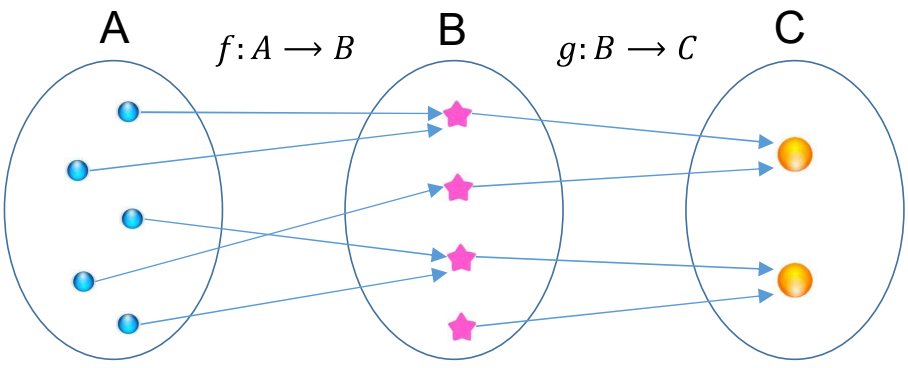
y = sin(x)

3 main properties a function should have

1. **Pure**: *no side effects*. Functions are not allowed to do more than their type definition says.
   - cannot change global variables, access filesystem, do network requests, etc
2. **Total**: *returns values for all inputs*. Functions that crash or throw exceptions on some inputs are not total or partial.
   - e.g., integer divide by zero => partial function
3. **Deterministic**: *always returns the same result for the same input*. For deterministic function it doesn't matter how and when it's called
   - Functions that depend on a current date, clock, timezone or some external state are not deterministic.

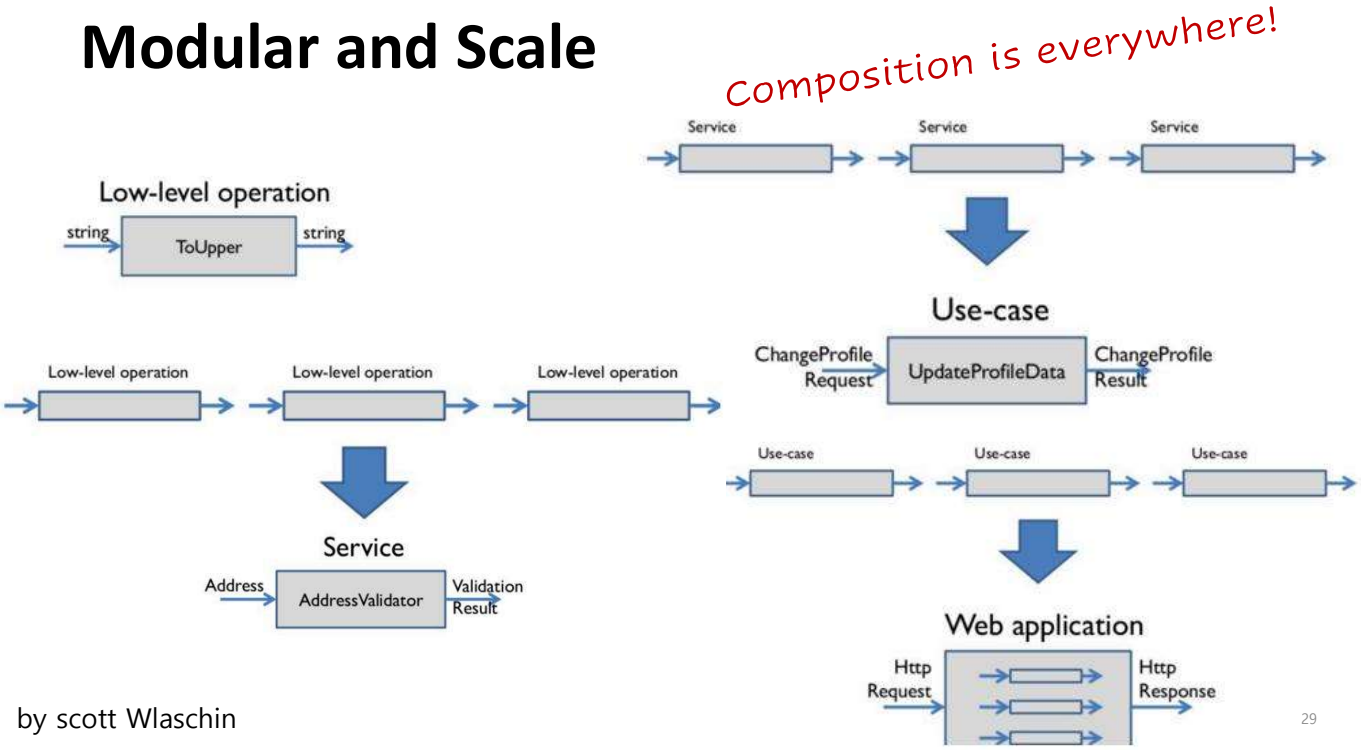
It's programmer responsibility to satisfy those properties.

Functions and Types (Morphisms and Sets)



$$g \circ f : A \longrightarrow C$$

Modular and Scale



by scott Wlaschin

Q: Why do I care if a function has these properties or not?

- If a function satisfy those properties you get "**referential transparency**".
- In short, you'll get the ability to look at the function type definition and know exactly what it can and cannot do.
- You can refactor your code *fearlessly* because RT guarantees you nothing will break.
- RT is basically what allows us to control complexity of our software.

3. No, you can’t change a variable

Q: This is the weirdest part, how do I make anything useful without changing variables?

- **Variables are immutable** and used only to alias or label values, not as a physical reference or a pointer to the actual data.

Q: Why not just change it in place?

- Because it breaks referential transparency and referential transparency is the key to FP.
  - It will make your life so much easier while not having mutable variables is a fair price to pay.
  - Besides, no mutation means you get **thread safe code for free**, no more weekends wasted on ‘happens only on a Tuesday evening’ concurrency bugs.
- Immutability is a simple concept but it’s hard to adopt after years of OOP experience.
  - It’s common to see people reverting to **var**s in Scala just ‘to get this thing working’..
  - Besides, there is no such ‘hack’ in Haskell so you have to be immutable from day 1.

4. No, you can't do 'for' loops

Q: Our bread and butter — the 'for' loop — you say FP doesn't have it as well? How do you iterate over an array?

- We have other means of achieving the same — **recursion** and **higher order functions (HOFs)**.

```
def sum(as: List[Int]): Int = as match
  // Nil is a type constructor for an empty list
  case Nil => 0
  case x :: xs => x + sum(xs)

sum(List(1,2,3,4,5)) // 15
```

```
-- [] is a type constructor for an empty list
mySum :: [Int] -> Int
mySum [] = 0
mySum (x : xs) = x + (mySum xs)
```


Higher Order Functions

- Higher order functions take other functions as an argument.

```
// Pass a function to transform every item in the list
List(1,2,3,4,5).map(n => n + 1) // List(2,3,4,5,6)

// Or shorter syntax
List(1,2,3,4,5).map(_ * 2) // List(2,4,6,8,10)

// Fold example. Sum all the values in a list
List(1,2,3,4,5).fold(0)((l, r) => l + r) // 15

// Multiply each number by 2, convert to string and
// produce a total string appending  results together
List(1,2,3,4,5).foldLeft("")((acc, number) =>
  acc ++ (number * 2).toString) // "246810"
```

```
-- Add 1 to every item in the list
map (+1) [1,2,3,4,5] -- [2,3,4,5,6]

-- Sum all the values
foldl' (+) 0 [1,2,3,4,5] – 15

-- same as left in Scala
foldl' (\acc n -> acc ++ show (n * 2)) "" [1,2,3,4,5]
-- "246810"
```

5. On nulls and exceptions

- **null** is a lower-level details often used to represent *absence* or some sort of internal *failure* that prevents function from returning a proper value.
- In FP, it is possible to represent absence or failures as an ordinary value.
- The same is true with exceptions.
- In your pure program it's possible to represent failures and exceptions with ordinary values, too.
- Throwing exceptions makes function partial which again breaks referential transparency and creates problems.

FP style of null and/or Exceptions

```
// A simple sum type that has two options
sealed trait Option[A]
case class Some[A](value: A) extends Option[A]
case object None extends Option[Nothing]

// Instead of throwing an exception or crashing
// the function will return a value.
def divide(dividend: Int, divisor: Int): Option[Int] =
  if divisor == 0 then None
  else Some(dividend / divisor)
```

```
-- Simple sum type with two options
data Maybe a = Just a | Nothing

-- Safe total function that never throws
divide :: Int -> Int -> Maybe Int
divide dividend divisor =
   if divisor == 0 then Nothing
                   else Just (dividend / divisor)
```

6. Your code is not a sequence of statements anymore

- In imperative language you write a program using **statements**.
- Statements are "***actions*" *to do something*** including *side-effects*.
- Once you call such program — it's done, completed, executed.

```
def main: Unit = {
  println("Good morning, what is your name?")

  val name = scala.io.StdIn.readLine()

  println(s"Nice to meet you, $name!")
}
```


Statements vs. Expressions

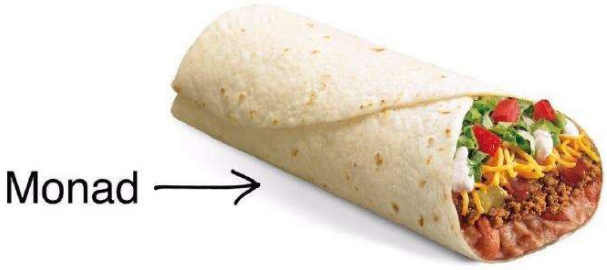
- In functional programs, a program consists of **expressions**.
- Each expression evaluates to a (pure) **value**., no side-effecting allowed.
- Therefore, a program is merely **a** "**description**" **of what should happens**.
- Nothing is executed until the very last moment.

Side Effects

- Modifying a variable
- Modifying a data structure in place
- Setting a field on an object
- Throwing an exception or halting with an error
- Printing to the console or reading user input
- Reading from or writing to a file
- Drawing on the screen

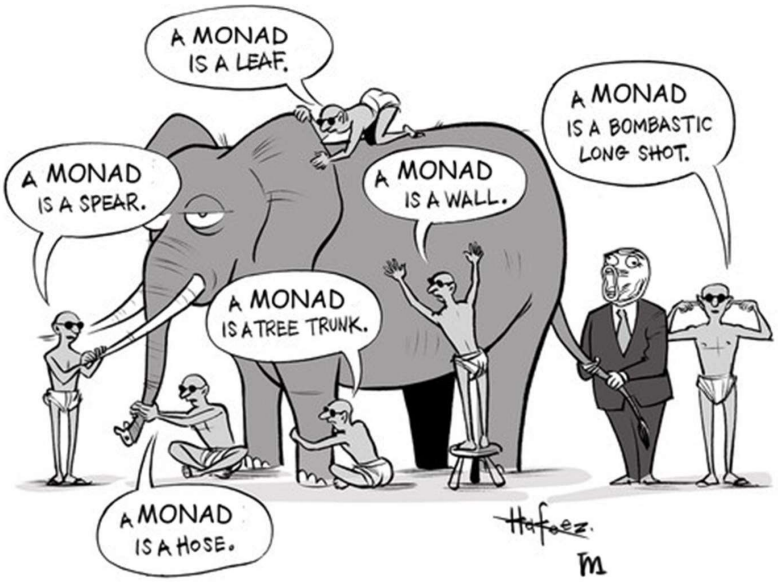
etc.

Monads are like Burritos



From https://twitter.com/monadburritos/status/915624691829587968

Let’s face it: all monad tutorials suck. So here’s another one:



A monad is just a monoid
in the category of endofunctors.

What’s the problem?

Turn Procedural Effect to Functional Effects

IO[A]

A description of an I/O effect that when unsafely interpreted, will succeed with a value of A

- Functional effects are immutable data structures that merely describe sequence of operations.
- At the end of the world, the data structure has to be impurely "interpreted" to real world effects.

In FP, a program is a description of effects

```
def main: IO[Unit] =
  // Nothing happens
  val program = getDescription()

  // When interpreted, effects materialied
  program.unsafeRun()
}

def putStrLn(line: String): IO[Unit] = IO(println(line))

def getStrLn: IO[String] = IO(scala.io.StdIn.readLine())

def getDescription: IO[Unit] =
  for
    _    <- putStrLn("Good morning, what is your name?")
    name <- getStrLn
    _    <- putStrLn(s"Nice to meet you, $name!")
  yield ()
```

```scala
def getDescription: IO[Unit] =
  for
    _    <- putStrLn("Good morning, what is your name?")
    name <- getStrLn
    _    <- putStrLn(s"Nice to meet you, $name!")
  yield ()
```

=

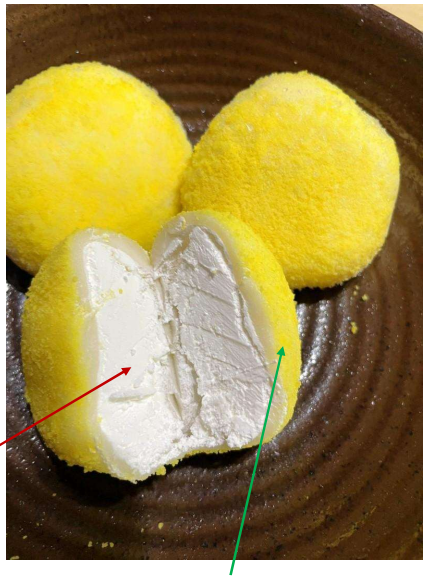
for-comprehension is a syntactic sugar for writing programs in imperative style

```scala
def getDescription: IO[Unit] =
  putStrLn("Good morning, what is your name?").flatMap { _ =>
    getStrLn.flatMap { name =>
      putStrLn(s"Nice to meet you, $name!").map { _ =>
        ()
      }
    }
  }
```


Functional Programming

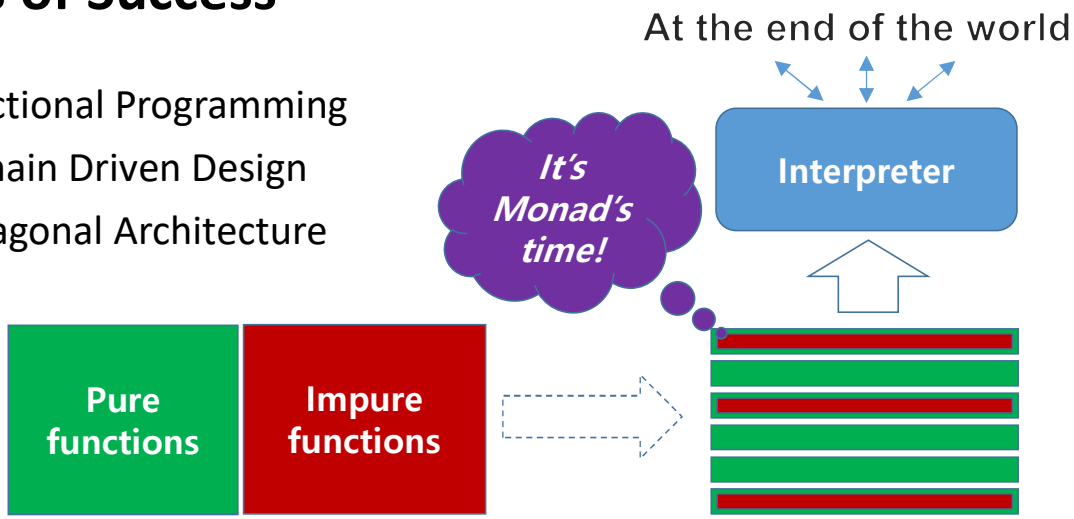
- Over the course of "next" tutorial, we'll *learn how to express all of our programs without side effects*, and that includes programs that perform I/O, handle errors, and modify data.
- **General guideline**: Implement programs with a pure core and a thin layer on the outside that handles effects.

생크림 찹쌀떡 프로그래밍



Pits of Success

- Functional Programming
- Domain Driven Design
- Hexagonal Architecture



7. Functors, Monads, Applicatives?

Q: I hear FP people talk about this things constantly but they don't make any sense to me. Is there an easy explanation?

- **Functors**, **Monads** and **Applicatives** are pretty powerful and **common abstractions** borrowed from *Category Theory*.
- You will see them everywhere.

1. But, get comfortable with function composition, higher order functions and polymorphic functions.
2. Then learn **type classes**.
3. After that **Functors** and **Monads** should come naturally.

Functional programming

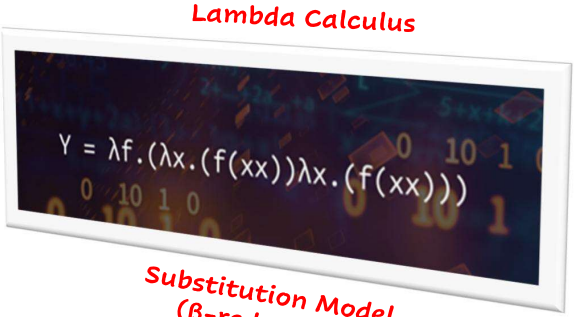
- FP is a *declarative-style* programming.
- Functional programs are composed of nested *pure functions*.
- A pure function is one with *referential transparency* (and therefore *no side effects*).
- Everything is basically *immutable*.
  - Use *recursions* instead of loops
- FP is based on *lambda calculus* and *category theory*.

Alonzo Church
(1903-1995)

Core Concepts of Functional Programming

Pure Functions
Referential Transparency
Composition
High-Order Functions
Immutability
Currying
Recursions
Parametric Polymorphism
Algebraic Data Types
Higher Kind Types
Lazy evaluation

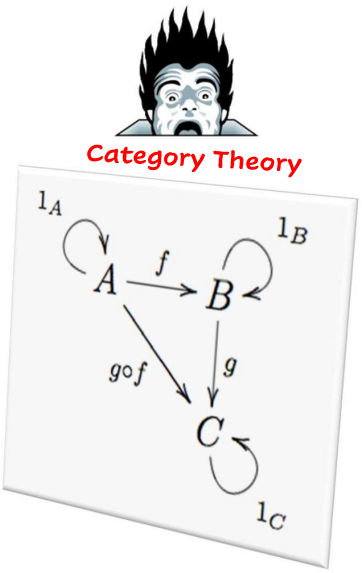
Lambda Calculus



Substitution Model
(β-reduction)

Functional Pattens

Semigroup/Monoid
Functor
Applicative
Monad
Natural Transformation
{Cata, Ana, Hylo} morphisms
Lens
Adjunction
F-Algebra



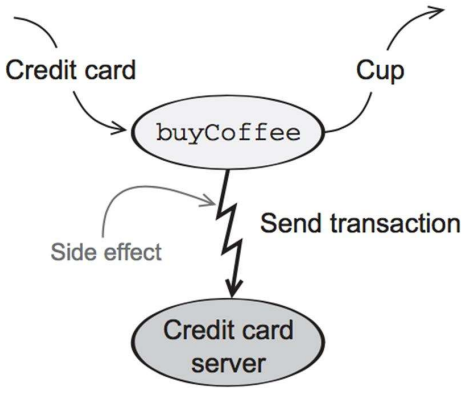
A Scala Program with Side Effects

```
class Cafe {

  def buyCoffee(cc: CreditCard): Coffee = {

    val cup = Coffee()

    cc.charge(cup.price)

    cup
  }
}
```

Side effect. Actually charges the credit card.

Charging a credit card involves some interaction with the outside world.

Problem Due to Side Effects



Can't test `buyCoffee` without credit card server. Can't combine two transactions into one.

The code is difficult to test.

It's difficult to reuse **buyCoffee**.

Adding a Payment Object … but …

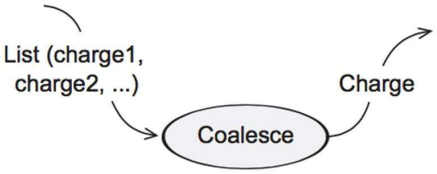
```
class Cafe {
  def buyCoffee(cc: CreditCard, p: Payments): Coffee = {
    val cup = Coffee()
    p.charge(cc, cup.price)
    cup
  }
}
```

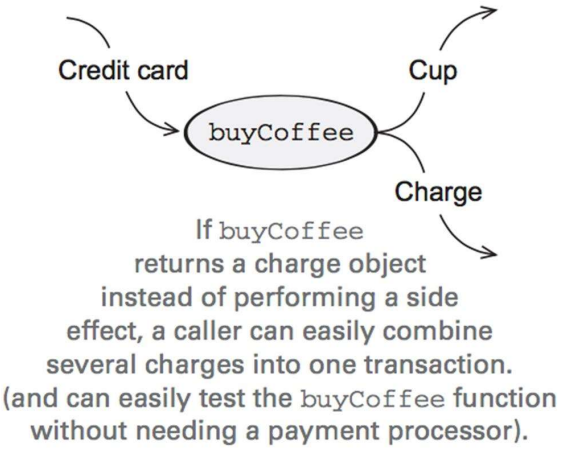
Side effect.

It's still difficult to reuse **buyCoffee**.

Though side effects still occur when we call **p.charge(cc, cup.price)**, at least regained some testability via **Payment** *interface* or mock objects.

Functional Solution





If `buyCoffee` returns a charge object instead of performing a side effect, a caller can easily combine several charges into one transaction. (and can easily test the `buyCoffee` function without needing a payment processor).

The functional solution is to eliminate side effects and have **buyCoffee** *return the charge as a value* in addition to returning the **Coffee**.

Separated the concern of *creating* a charge from the *processing* or *interpretation* of that charge.

Functional Solution

```
class Cafe {
  def buyCoffee(cc: CreditCard): (Coffee, Charge) = {
    val cup = Coffee()
    (cup, Charge(cc, cup.price))
  }
}
```

`buyCoffee` now returns a pair of a `Coffee` and a `Charge`, indicated with the type `(Coffee, Charge)`. Whatever system processes payments is not involved at all here.

Charge as a First-Class Value

```
case class Charge(cc: CreditCard, amount: Double) {
  def combine(other: Charge): Charge =
    if cc == other.cc then
      Charge(cc, amount + other.amount)
    else
      throw new Exception("Can't combine charges to different cards")
}

class Cafe {
  def buyCoffee(cc: CreditCard): (Coffee, Charge) = ???

  def buyCoffees(cc: CreditCard, n: Int): (List[Coffee], Charge) = {
       val purchases: List[(Coffee, Charge)] = List.fill(n)(buyCoffee(cc))
       val (coffees, charges) = purchases.unzip
       (coffees, charges.reduce((c1,c2) => c1.combine(c2)))
  }
}
```


Additional Benefit of First-Class Value

Making **Charge** into a first-class value has other benefits:

➔ more easily assemble business logic for working with these charges

```
def coalesce(charges: List[Charge]): List[Charge] =
  charges.groupBy(_.cc).values.map(_.reduce(_ combine _)).toList
```

Referential Transparency and Purity

An expression ***e*** is referentially transparent
if, for all programs ***p***, all occurrences of ***e*** in ***p***
can be replaced by the result of evaluating ***e***
without affecting the meaning of ***p***.

A function ***f*** is **pure** if the expression ***f(x)*** is referentially transparent
for all referentially transparent ***x***.


```
scala> val x = "Hello, World"
x: java.lang.String = Hello, World

scala> val r1 = x.reverse
r1: String = dlroW ,olleH

scala> val r2 = x.reverse
r2: String = dlroW ,olleH
```

r1 and r2 are the same.

Suppose we replace all occurrences of x with the expression referenced by x.

```
scala> val r1 = "Hello, World".reverse
r1: String = dlroW ,olleH

scala> val r2 = "Hello, World".reverse
r2: String = dlroW ,olleH
```

r1 and r2 are still the same.

What's more, r1 and r2 are referentially transparent as well.

```
scala> val x = new StringBuilder("Hello")
x: java.lang.StringBuilder = Hello

scala> val y = x.append(", World")
y: java.lang.StringBuilder = Hello, World

scala> val r1 = y.toString
r1: java.lang.String = Hello, World

scala> val r2 = y.toString
r2: java.lang.String = Hello, World
```

r1 and r2 are the same.

Replacing all occurrences of y with the expression referenced by y:

```
scala> val x = new StringBuilder("Hello")
x: java.lang.StringBuilder = Hello

scala> val r1 = x.append(", World").toString
r1: java.lang.String = Hello, World

scala> val r2 = x.append(", World").toString
r2: java.lang.String = Hello, World, World
```

We conclude that **StringBuilder.append** is *not* a pure function.

r1 and r2 are no longer the same.

Non RT Example

For **buyCoffee** to be pure, it must be the case that

$$p(\texttt{buyCoffee(aliceCreditCard)}) == p(\texttt{Coffee()})$$

for *any* p.

```
class Cafe {
  def buyCoffee(cc: CreditCard): Coffee = {
    val cup = Coffee()
    cc.charge(cup.price) // return value is ignored here
    cup
  }
}
```

RT and Substitution Model

- Referential transparency forces the invariant that **everything a function *does* is represented by the *value* that it returns**, according to the result type of the function.
- This constraint enables a ***simple and natural mode of reasoning*** about program evaluation called the **substitution model**.

Benefits of Purity, Substitution Model

- **A pure function** is **modular**.
  - because it separates the logic of the computation itself from "*what to do with the result*" and "*how to obtain the input*"; it's a black box.
- Modular programs allows **local reasoning** and **independent reuse**.
  - the meaning of the whole depends only on the meaning of the components and the rules governing their composition
- Hence, pure functions are **composable**.

Hard

Simple made easy (2012)

Complex

- Rich Hickey
- Creator of Clojure

"Simplicity is prerequisite for reliability"

- Edgser W. Dijkstra

Why Functional Programming matters?

Referential transparency *that allows you to* ***modularize*** *your program in new ways, and helps answer these questions by making things* ***as simple as possible!***

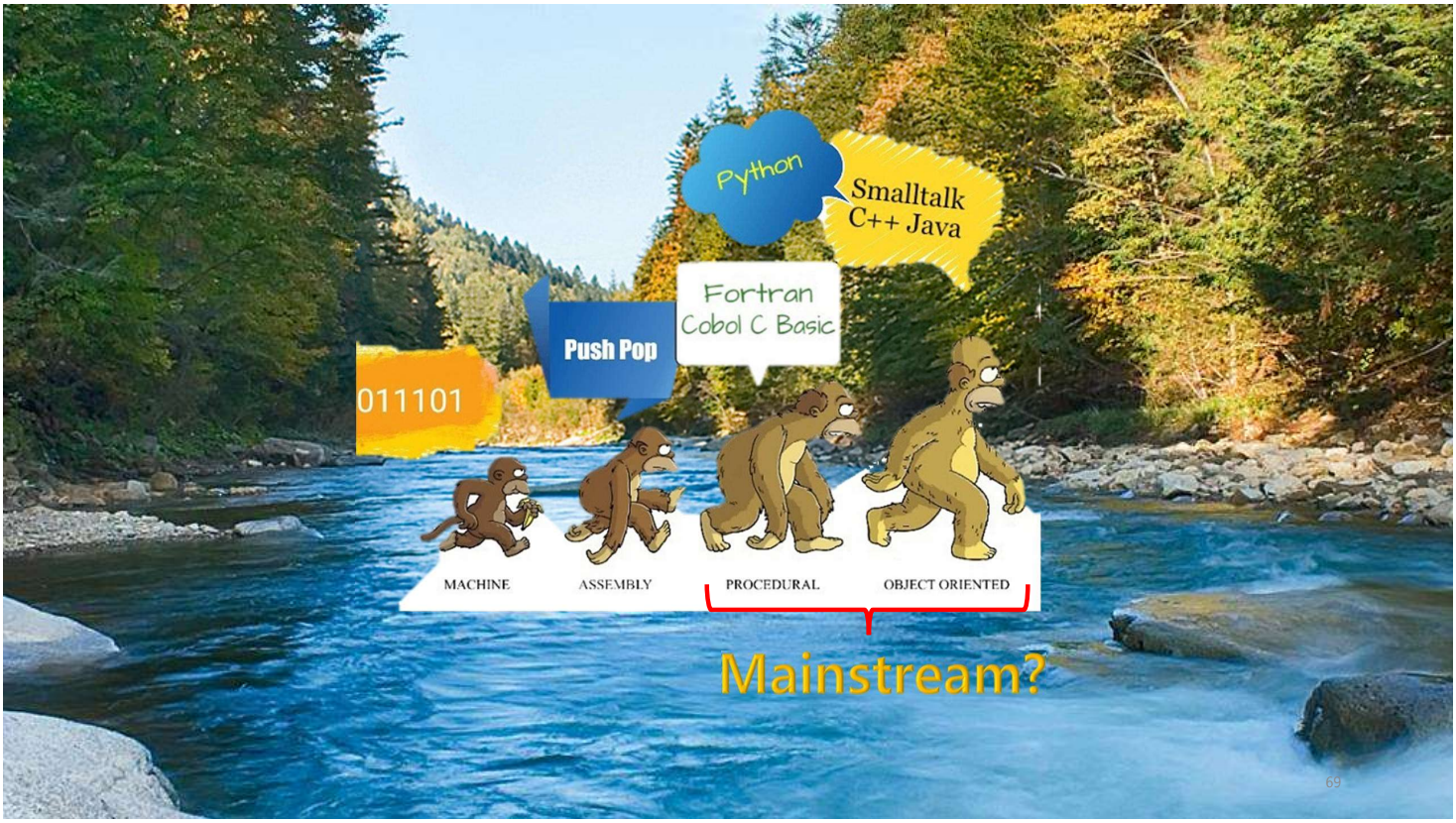
OO patterns/principles	FP equivalents
• Single Responsibility Principle	• Functions
• Open Closed Principle	• Functions
• Interface Segregation Principle	• Functions also
• Dependency Inversion Principle	• Functions
• Factory Pattern	• You will be assimilated!
• Strategy Pattern	• Function again
• Decorator Pattern	• Functions
• Visitor Pattern	• Resistance is futile!
• …	• …

ScottWlaschin's slide

Summary:
Benefits of Functional Programming

Enables **local reasoning** and is more **modular** and **composable**.

- Easier to test
- Easier to reuse
- Easier to **parallelize**
- Easier to optimize
  - Compile-time optimization, Lazy evaluation, Memoization, etc.
- Less prone to bugs
- Easier to generalize



But unfortunately it's often more like this

How many FP
people see OOP

How many OOP
people see FP

And that's where we are ☺

Odersky's slide


FP
OOP