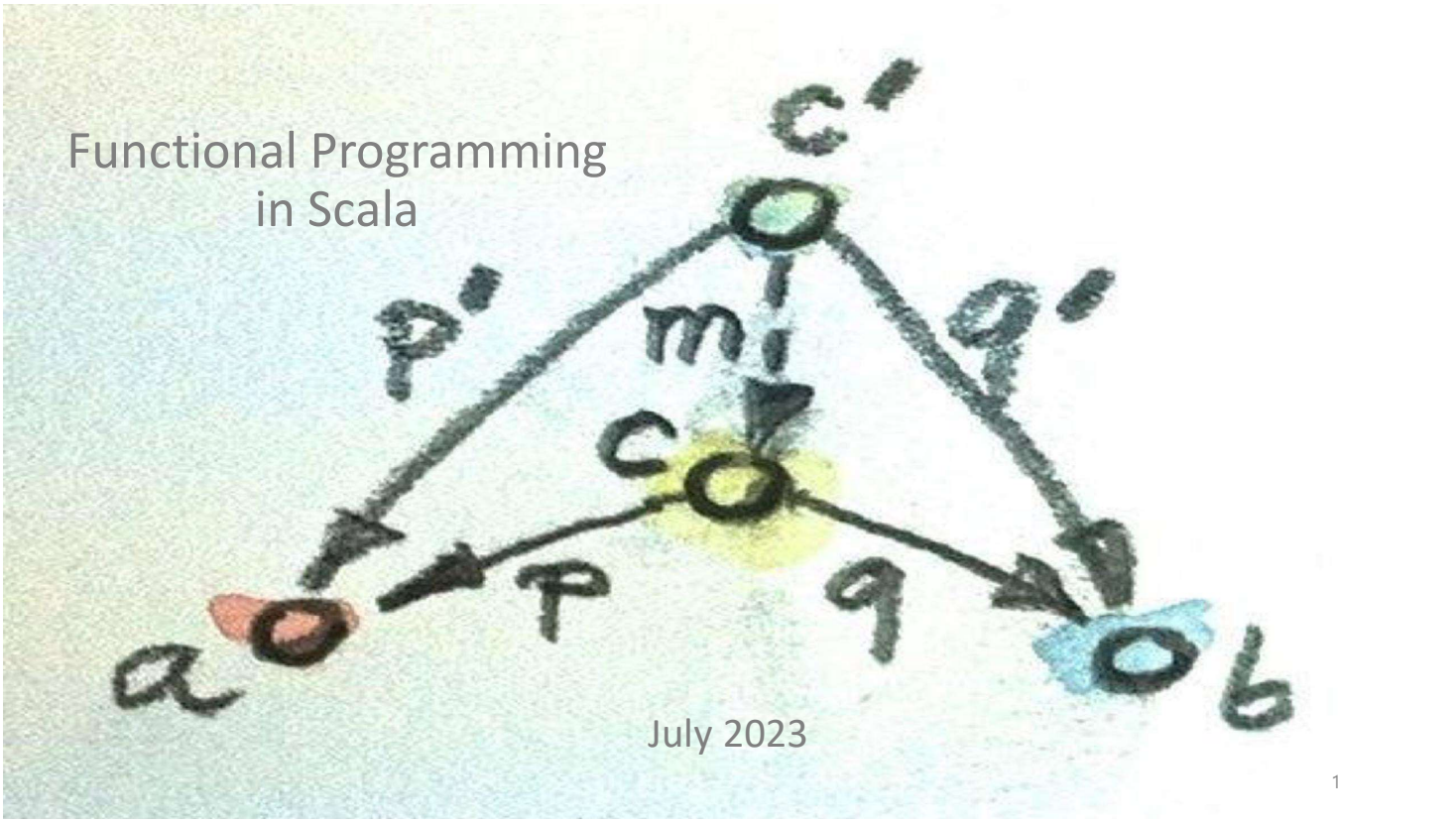
Functional Programming in Scala



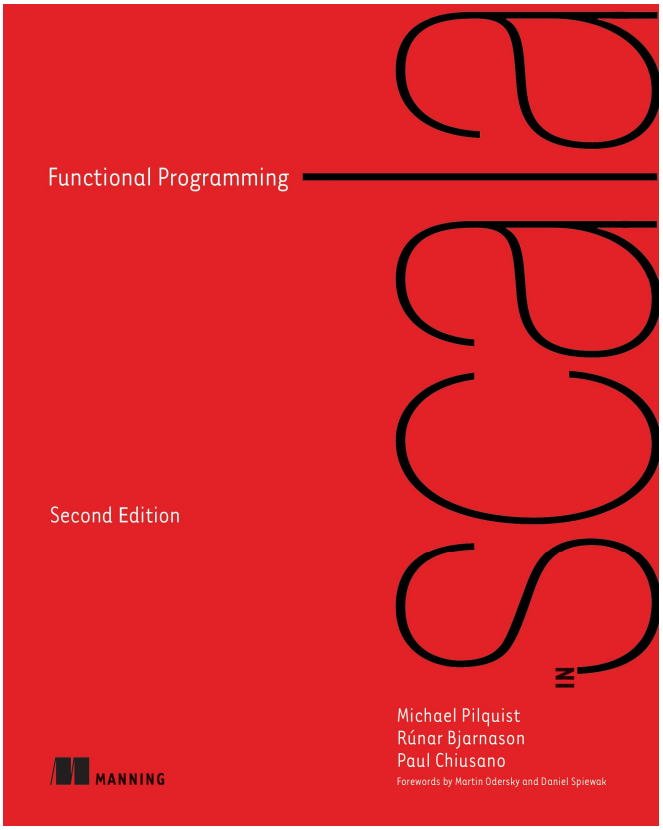
July 2023

Prerequisites – Not Really ☺

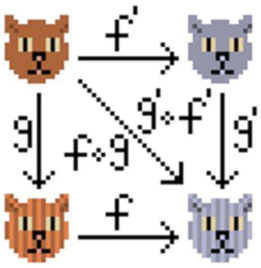
- A reasonable background in functional programming, especially in Scala
- Recommended prerequisite course: "**Principles of Functional Programming in Scala**", Coursera Course by Martin Odersky
- Other experiences in some other functional programming languages, such as Haskell, F#, Clojure, etc. would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

Textbook

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



Course Contents



Tools

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

Functional Programming

Functional programming

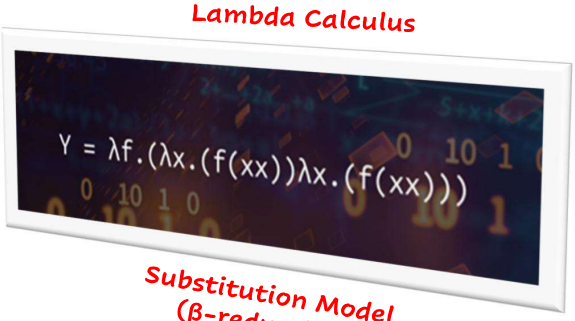
- FP is a *declarative-style* programming.
- Functional programs are composed of nested *pure functions*.
- A pure function is one with *referential transparency* (and therefore *no side effects*).
- Everything is basically *immutable*.
  - Use *recursions* instead of loops
- FP is based on *lambda calculus*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

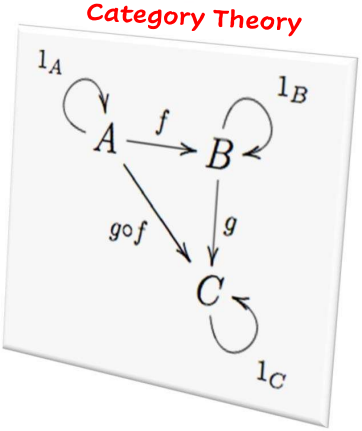


Substitution Model
(β-reduction)

Functional Pattens

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

Category Theory



Imperative Programming

- Tell **how** to do it.

- **Mutability**

  Root of all Evils!

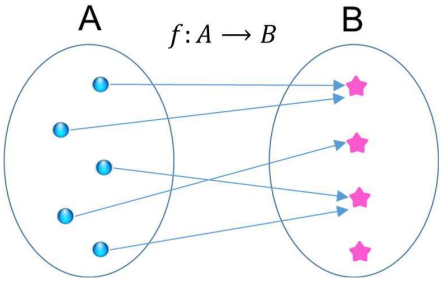
```
def qsort(xs: Array[Int], low: Int, high: Int) {
  def swap(i: Int, j: Int) = {
    val temp = xs(i)
    xs(i) = xs(j)
    xs(j) = temp
  }

  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) xs
  else {
    val pivot = xs(xs.length / 2)
    val (l, e, r) = partition(xs, pivot)
    List.concat(qsort(l), e, qsort(r))
  }
}
```

Pure Functions



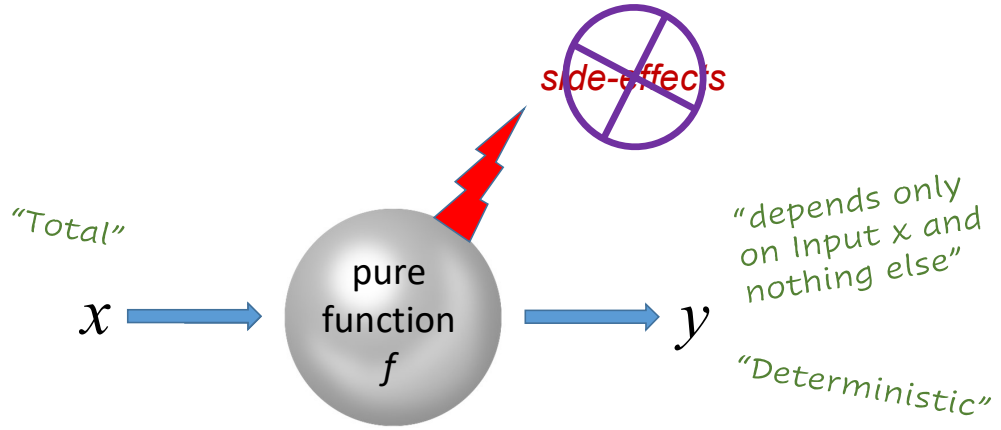
FP means programming with **pure functions**.

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

f : A => B

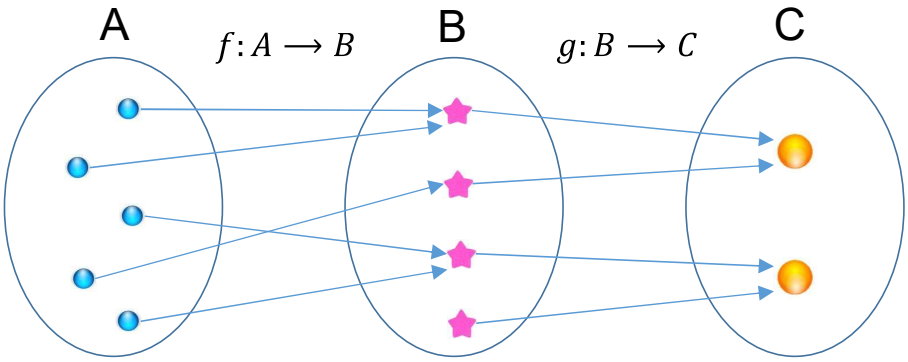
- Relates every value *a* of type **A** to exactly one value *b* of type **B** such that *b* is determined solely by the value of *a*.

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



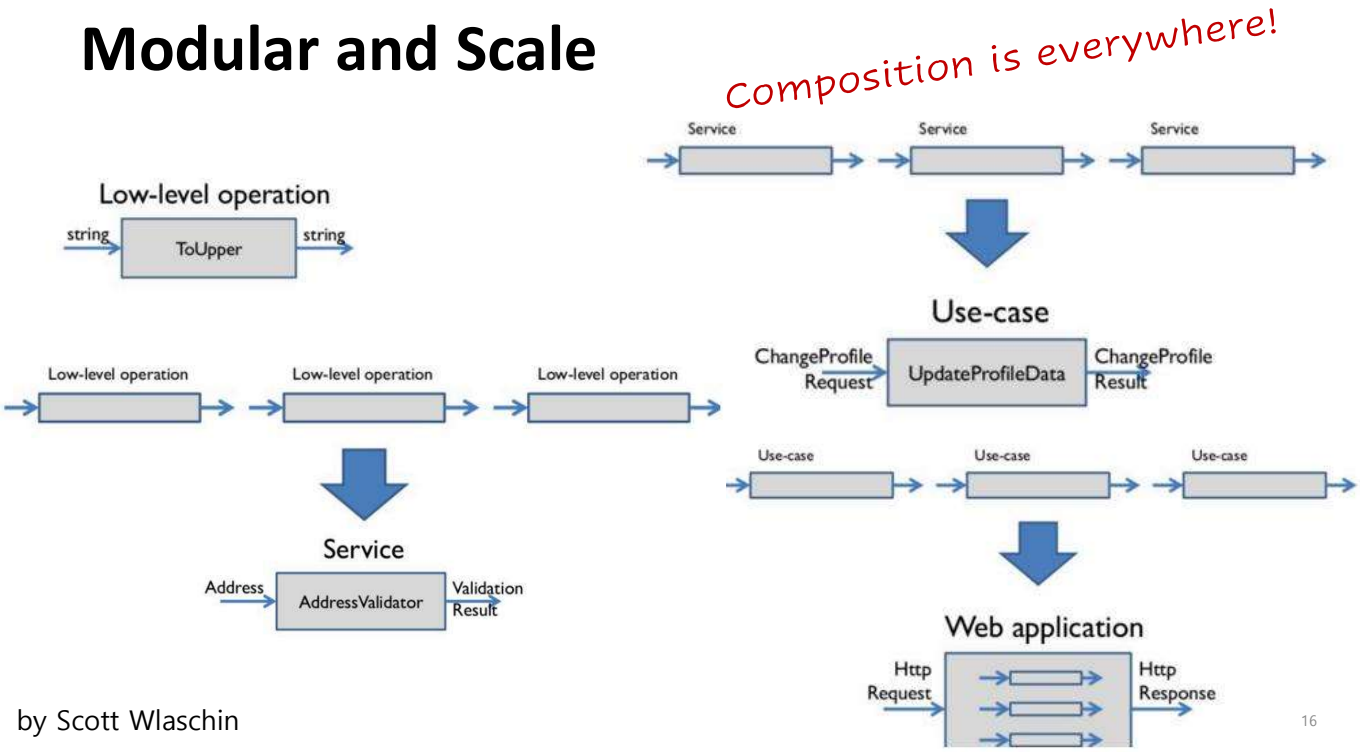
y = sin(x)

Functions and Types (Morphisms and Sets)



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

Modular and Scale



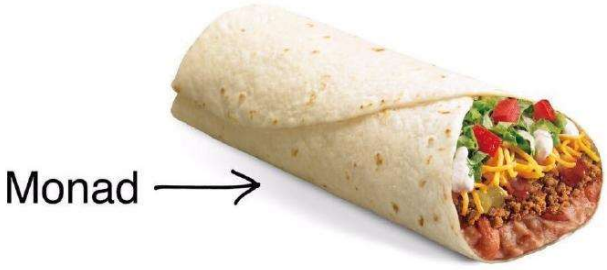
by Scott Wlaschin

Side Effects

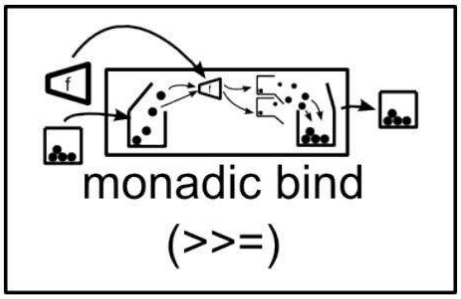
- Modifying a variable
- Modifying a data structure in place
- Setting a field on an object
- Throwing an exception or halting with an error
- Printing to the console or reading user input
- Reading from or writing to a file
- Drawing on the screen

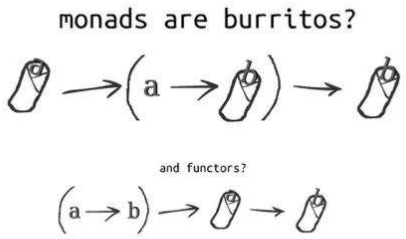
etc.

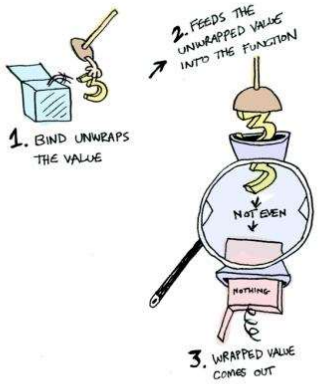
Monads are like Burritos

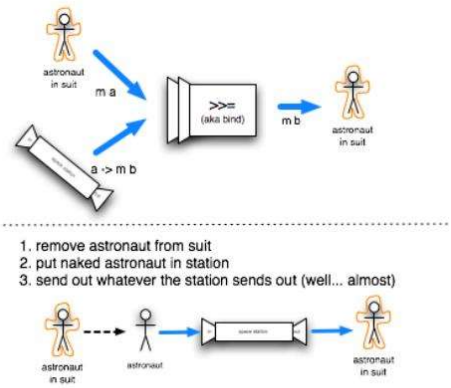


From https://twitter.com/monadburritos/status/915624691829587968



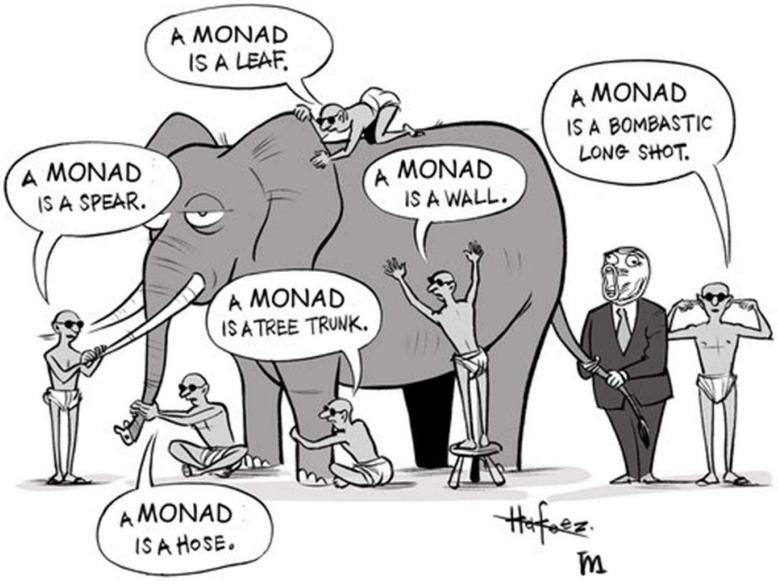






https://homepages.inf.ed.ac.uk/wadler/papers/yow/monads-haskell.pdf

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



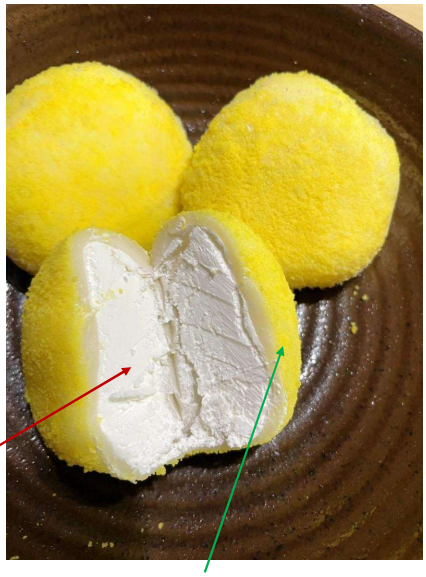
A monad is just a monoid in the category of endofunctors.

What's the problem?

Functional Programming

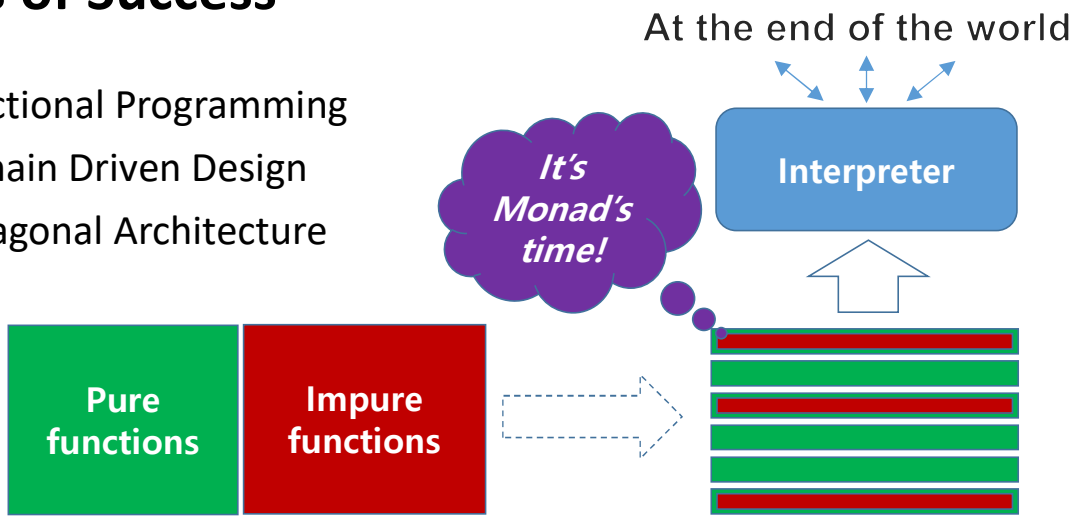
- Functional programming is a restriction on *"how" we write programs*, but not on what programs we can express.
- Over the course of this tutorial, we'll learn how to express all of our programs without side effects, and that includes programs that perform I/O, handle errors, and modify data.
- **General 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



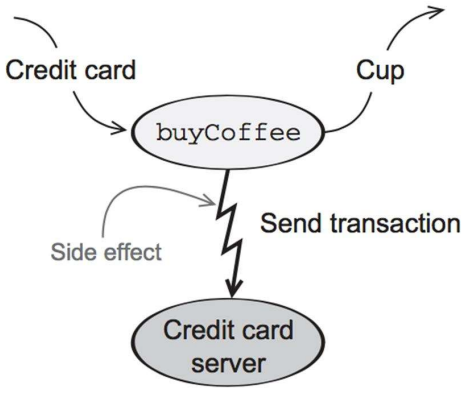
A Scala Program with Side Effects

```
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 …

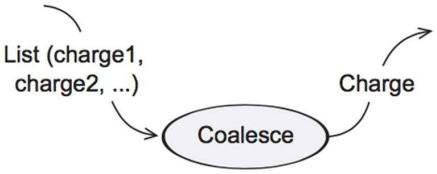
```
class Cafe {
  def buyCoffee(cc: CreditCard, p: Payments): Coffee = {
    val cup = Coffee()
    p.charge(cc, cup.price)
    cup
  }
}
```

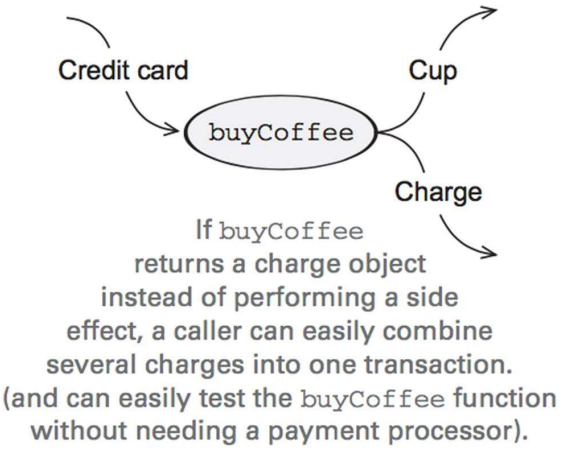
Side effect.

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(buyCoffee(aliceCreditCard))== p(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!***

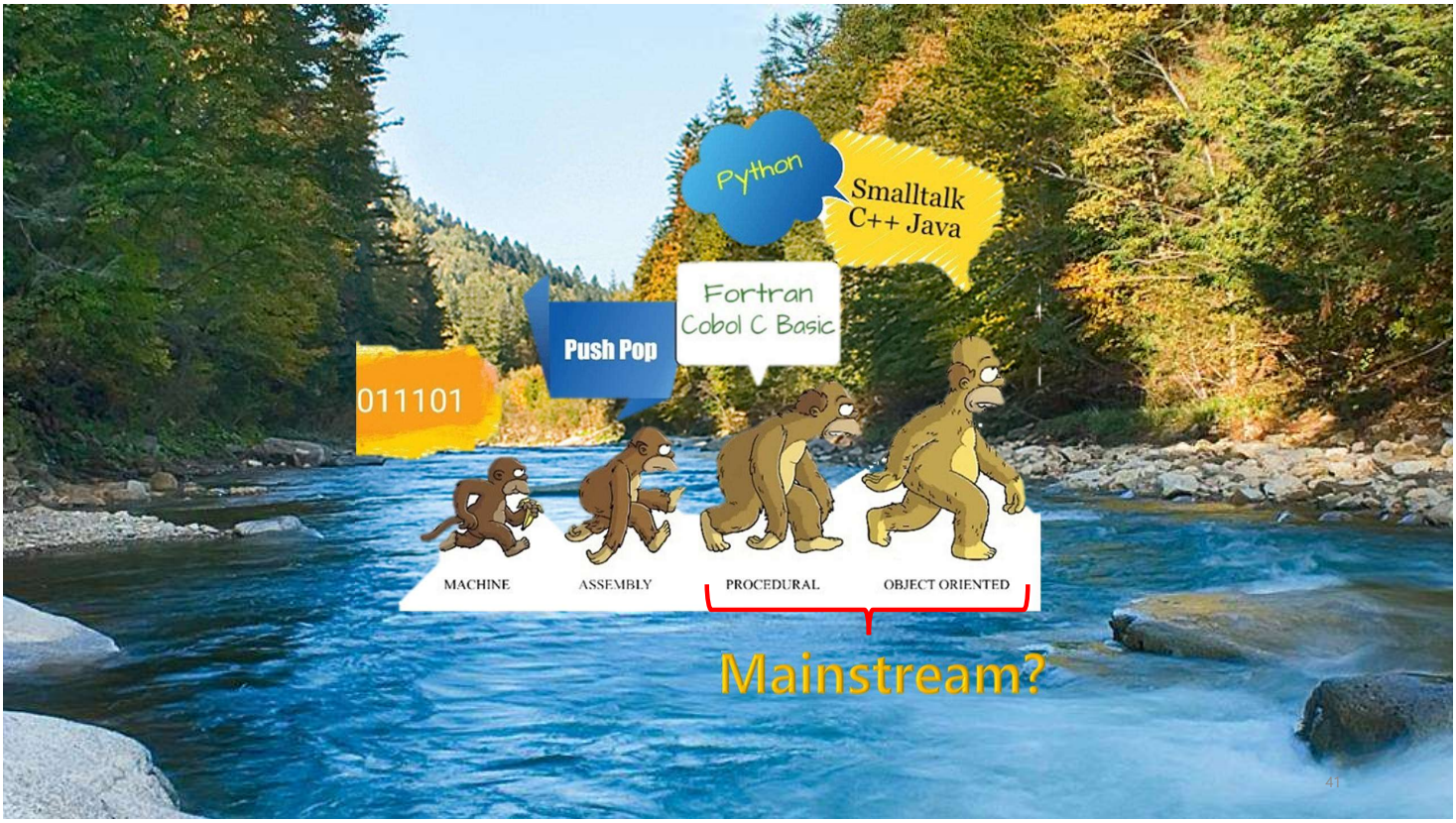
OO patterns/principles	FP equivalents
• Single Responsibility Principle	• Functions
• Open Closed Principle	• Functions
• Interface Segregation Principle	• Functions also
• Dependency Inversion Principle	• Functions
• Factory Pattern	• You will be assimilated!
• Strategy Pattern	• Function again
• Decorator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