

Introduction to Scala

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By the end of this lecture, you will have some basic understanding on

- Object Oriented Programming in Scala
- Functional Programming in Scala
 - Algebraic data type and pattern matching
 - Higher order functions
 - Partial functions
 - Implicit functions
 - Type classes
 - Monads
- Data parallelism in Scala
- Concurrent programming in Scala with threads and actors

A general purpose programming language that is

- Object Oriented and Functional
- with distributed programming builtin
- with a rich type system and a huge set of libraries and eco-systems
- Widely used in academic research projects (e.g. Spark was from UC Berkeley) and industries (e.g. Scalding from Twitter, Kakfa from Linkedln, Coursera Walmart, ...)

Hello World in a script

Let's say we have a Scala file `Script.scala`

```
println("Hello world!")
```

To execute it

```
$ scala Script.scala  
Hello world!
```

Hello World in a console application

Compiling Scala program into an application

```
object Main extends App
{
    println("Hello world!")
}
```

object is like a singleton class.

To execute it

```
$ scalac Main.scala
```

```
$ scala Main
```

```
Hello world!
```

Object Oriented Programming in Scala

It is very similar to Java

```
class Person(n:String,i:String) {  
    private val name:String = n  
    private val id:String    = i  
    def getName():String = name  
    def getId():String = id  
}
```

- Person is the name of the class,
 Person(n:String,i:String) is a constructor.
- private sets the accessibility scope of the members
- val introduces a value, (immutable variable)
- def introduces a method definition.

Class Inheritance via the extends keyword

```
class Student(n:String, i:String, g:Double)
    extends Person(n,i) {
  private var gpa = g
  def getGPA() = gpa
  def setGPA(g:Double) = {
    gpa = g
  }
}
```

- var introduces a mutable variable
- Most of the type annotations are optional and will be inferred by the type system.

Object Oriented Programming in Scala

```
class Staff(n:String, i:String, sal:Double)
    extends Person(n,i) {
  private var salary = sal
  def getSalary() = salary
  def setSalary(sal:Double) =
  {
    salary = sal
  }
}
```


Object Oriented Programming in Scala

Traits are like Java interfaces and abstract classes

```
trait NightOwl {  
  def stayUpLate():Unit  
}  
  
class Student(n:String, i:String, g:Double)  
  extends Person(n,i) with NightOwl {  
  private var gpa = g  
  def getGPA() = gpa  
  def setGPA(g:Double) = {  
    gpa = g  
  }  
  override def stayUpLate():Unit = {  
    println("woohoo")  
  }  
}
```

Running our first Scala program

Scala comes with an interpreter (AKA REPL)

```
scala> :load OOP.scala
```

```
Loading OOP.scala...
```

```
defined class Person
```

```
defined trait NightOwl
```

```
defined class Student
```

```
defined class Staff
```

```
scala> val tom = new Student("Tom", "X1235", 4.0)
```

```
tom: Student = Student@601c1dfc
```

```
scala> val jerry = new Staff("Jerry", "T0001", 500000.0)
```

```
jerry: Staff = Staff@650fbe32
```

```
scala> tom.stayUpLate
```

```
woohoo
```

Functional Programming in Scala

OOP is useful, but often less interesting, let's consider the FP features in Scala.



Image taken from <https://www.toptal.com/scala/why-should-i-learn-scala>

Algebraic Data Type

In Scala, this is how we define a data type

```
sealed trait Exp
case class Val(v:Int) extends Exp
case class Plus(e1:Exp, e2:Exp) extends Exp

def simp(e:Exp):Exp = e match {
  case Val(v) => e
  case Plus(Val(0), e2) => e2
  case Plus(e1,e2) => Plus(simp(e1), simp(e2))
}
```

- sealed requires all extensions to the trait Exp must be declared in the same module.
- case makes a class “pattern-matchable”

Algebraic Data Type

In Java, to achieve the above we have to use abstract class and method overriding. (For brevity, setter and getter methods are omitted.)

```
public abstract class Exp { public abstract Exp simp(); }
public class Val extends Exp {
    private int v;
    public Val(int v) { this.v = v; }
    public Exp simp() { return this; }
}
public class Plus extends Exp {
    private Exp e1; private Exp e2;
    public Plus(Exp e1, Exp e2) {
        this.e1 = e1; this.e2 = e2;
    }
    public Exp simp() {
        if (e1 instanceof Val) {
            Val v1 = (Val)e1;
            if (v1.getV() == 0) { return e2; }
        }
        return new Plus(e1.simp(), e2.simp());
    }
}
```

Algebraic data type and pattern matching are useful in case of handling recursive/nested data structures, e.g. a linked list.

```
sealed trait List[A]
case class Nil[A]() extends List[A]
case class Cons[A](x:A, xs:List[A]) extends List[A]

val x = Cons(1,Cons(2,Nil()))

def length[A](l:List[A]):Int = l match {
  case Nil() => 0
  case Cons(_,xs) => 1 + length(xs)
}
```

Observation

- A is a type variable (AKA generics)
- Parametric polymorphism
- Nil() takes no argument, it's always (almost) singleton.

Mixing subtyping with parametric polymorphism

```
sealed trait List[+A]
case object Nil extends List[Nothing]
case class Cons[A](x:A, xs:List[A]) extends List[A]

val x = Cons(1,Cons(2,Nil))

def length[A](l:List[A]):Int = l match {
  case Nil => 0
  case Cons(_,xs) => 1 + length(xs)
}
```

- case object introduces a singleton value constructor.
- + indicates that A is a covariant type parameter, hence `List[Nothing] <: List[A]` for any A .
- Nothing is the bottom type in the sub-typing hierarchy.

List

List is a builtin data type comes with Scala library

```
val x = List(1,2)

def length[A](l:List[A]):Int = l match {
  case Nil => 0
  case (_::xs) => 1 + length(xs)
}
```

which is equivalent to the following Haskell program

```
x = [1,2]
length :: [a] -> Int
length l = case l of
  [] -> 0
  (_:xs) -> 1 + length xs
```



```
val nats:List[Int] = List(1,2,3,4)
val even_plus_1:List[Int] = for (nat <- nats
                                if nat % 2 == 0
                                ) yield (nat+1)
```

- for ... yield denotes a sequence comprehension.
- C.f. set builder notation in math,

$$\{nat + 1 \mid nat \in nats \wedge nat \bmod 2 = 0\}$$

For loop vs comprehension

Note that `for ... yield` denotes a sequence comprehension.

```
val nats:List[Int] = List(1,2,3,4)
val even_plus_1:List[Int] = for (nat <- nats
                                if nat % 2 == 0
                                ) yield (nat+1)
```

While `for` introduces a `for` loop.

```
for (i <- 1 to 10) { println(i) }
```

prints the numbers 1 to 10.

```
for (nat <- nats if nat % 2 == 0) { println(nat) }
```

prints the numbers 2 and 4.

Length

```
val l1 = List(1,2,3)
val len = l1.length // 3
```

Concatenation

```
val l2 = List(-1,-2,-3)
val l3 = l1 ++ l2 // List(1,2,3,-1,-2,-3)
```

Reverse

```
val l4 = l1.reverse // List(3,2,1)
```

min/max

```
// recall l1 = List(1,2,3)
val min = l1.min // 1
val max = l1.max // 3
```

sorting

```
// recall l3 = List(1,2,3,-1,-2,-3)
val sl3 = l3.sortWith(_<_) // List(-3, -2, -1, 1, 2, 3)
// we will look into _<_ in a short while.
```

sub-list

```
val sl3a = sl3.take(3) // List(-3,-2,-1)
val sl3b = sl3.drop(3) // List(1,2,3)
```

Map and Fold

`l.map(f)` returns a new list by applying the unary function `f` to each element in `l`

```
val l = List(1,2,3,4)
val l2 = l.map(x => x * 2) // List(2,4,6,8)
```

Note that `x => x * 2` is a lambda-expression, which can be shortened as `_ * 2`. The `.` is optional.

```
val l2 = l map (_*2)
```

which is equivalent to the following Haskell program

```
l = [1,2,3,4]
l2 = map (\x -> x*2) l
```

Map and Fold

`l.foldLeft(b)(f)` aggregate all the elements in `l` with the binary function `f` and the base value `b`.

```
// recall l = List(1,2,3,4)
val l3 = l.foldLeft(0)((x,y) => x + y)
```

In essence the above is computing

$$(((0 + 1) + 2) + 3) + 4$$

`l.foldRight(b)(f)` aggregate all the elements in `l` with the binary function `f` and the base value `b` with right associativity.

```
val l4 = l.foldRight(0)((x,y) => x + y)
// or val l4 = l.foldRight(0)(_+_)
```

In essence the above is computing

$$1 + (2 + (3 + (4 + 0)))$$

Higher order function

The definition of map.

```
sealed trait List[+A] {  
  def map[B](f:A=>B):List[B] = this match {  
    case Nil => Nil  
    case x::xs => f(x)::xs.map(f)  
  }  
}  
case object Nil extends List[Nothing]  
case class Cons[A](x:A, xs:List[A]) extends List[A]
```

Function $f:A \Rightarrow B$ is used as a formal argument.

Equivalently, in Haskell, we have.

```
map :: (a -> b) -> [a] -> [b]  
map f [] = []  
map f (x:xs) = (f x):(map f xs)
```

Higher order function

Function composition

```
val l1 = List(1,2,3)
val l2 = l1.map ((x:Int) => x*2) compose (y=>y+1))
// List(4, 6, 8)
```

$(f \text{ compose } g)(x)$ is equivalent to $f(g(x))$

```
val l3 = l1.map ((x:Int) => x*2) andThen (y=>y+1))
// List(3, 5, 7)
```

$(f \text{ andThen } g)(x)$ is equivalent to $g(f(x))$

Higher order function

In Scala, functions are instances/objects of trait Function

The definitions of compose and andThen.

```
object Function { // this is like a package
  trait Function1[+A][-B] {
    def apply(x:A):B {...}
    // apply() gives us
    // the syntactic sugar form like f(x)
    def compose[C](that:C=>A):C=>B =
      (c:C) => this(that(c))
    def andThen[C](that:B=>C):A=>C =
      (a:A) => that(this(a))
  }
}
```

Both compose and andThen return functions as results.

Functions vs methods

In Scala there is a clear distinction between functions and methods.

- Methods are introduced by `def` keyword, e.g.

```
scala> def f(x:Int) = x  
f: (x: Int)Int
```

- Functions are implementations of the `FunctionX` traits. e.g. lambda expressions are functions.

```
scala> val g = (x:Int) => x  
g: Int => Int = <function1>
```

- Similarity: both can be used as argument and results

```
scala> List(1,2).map (f) == List(1,2).map (g)  
res2: Boolean = true
```

Functions vs methods

In Scala there is a clear distinction between functions and methods.

- Difference: methods do not possess combinators

```
scala> f compose g
<console>:10: error: missing arguments for method f;
follow this method with '_' if you want to treat it
as a partially applied function
      f compose g
      ^
```

```
scala> g compose f
res1: Int => Int = <function1>
```

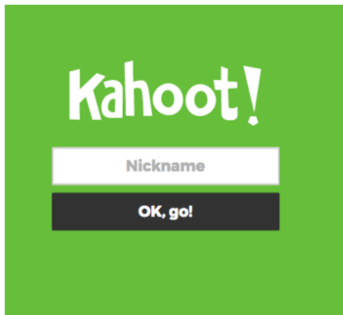
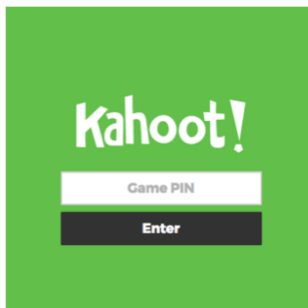
- To convert a method to a function.

```
scala> f _
res1: Int => Int = <function1>
```

Before we take a break...

Let's play some quiz games. Open the web browser in your mobile, tablet or laptop.

- visit `http://kahoot.it`
- key in the game pin, then
- key in your name, please use real name to claim the prize.



Before we take a break...

Q1 Where is the Eiffel Tower located?



Next >

0

Answers



Paris



Rome



Moscow



London

Partial functions

There are situations in which we need to deal with partial functions, naturally, we can use the `Option` type in Scala (similar to the `Maybe` type in Haskell).

```
def div(x:Int)(y:Int):Option[Int] = {  
    if (y == 0) None else Some(x/y)  
}
```

```
val xs = List(0,1,2) map (x => div(2)(x))
```

```
yields List(None, Some(2), Some(1))
```

```
val ys = xs filter (x => x.nonEmpty)
```

```
yields List(Some(2), Some(1))
```

```
val zs = ys map ( x => x match { case Some(y) => y } )
```

```
yields List(2,1)
```

Partial functions

Alternatively, we may use the Scala builtin PartialFunction

```
def div(x:Int): PartialFunction[Int,Int] = {  
  case (y:Int) if y != 0 => x/y  
}  
val xs = List(0,1,2) collect ( div(2) )
```

yields List(2, 1).

Note that we have to use the collect method instead of map

```
val ys = List(0,1,2) map ( div(2) )
```

Will result in a scala.MatchError

Partial functions

`orElse` allows us to compose partial functions which are complementing on their domains.

```
def div(x:Int): PartialFunction[Int,Int] = {  
  case (y:Int) if y != 0 => x/y  
}  
  
val mkZero: PartialFunction[Int,Int] = {  
  case (y:Int) if y == 0 => 0  
}  
  
val ys = List(0,1,2) map ( div(2) orElse mkZero )
```

yields in a `List(0, 2, 1)`

Implicit functions

Implicit function and implicit parameter allow us to define default behaviors.

```
implicit def logger(mesg:String):Unit = {  
    println("[Log] " + mesg)  
}  
  
def fib(x:Int)(implicit log:String=>Unit):Int = {  
    x match {  
        case 0 => 0  
        case 1 => 1  
        case _ => {  
            log("computing fib(" + x +)")")  
            fib(x-1) + fib(x-2)  
        }  
    }  
}
```

```
scala> fib(5)
[Log] computing fib(5)
[Log] computing fib(4)
[Log] computing fib(3)
[Log] computing fib(2)
[Log] computing fib(2)
[Log] computing fib(3)
[Log] computing fib(2)
res7: Int = 5
scala> fib(5)( x => Unit)
res8: Int = 5
```

Scala resolves implicit parameters as follows,

- ➊ Search in current scope
 - ➊ Implicits defined in current scope
 - ➋ Implicits defined in Explicit imports
 - ➌ Implicits defined in wildcard imports
- ➋ Search for associated types in
 - ➊ Companion objects of a type
 - ➋ Implicit scope of an argument's type
 - ➌ Outer objects for nested types
 - ➍ Other dimensions

Type classes

Type classes was introduced in Haskell to allow mixing parametric polymorphism and ad-hoc polymorphism.

Haskell Type Class Example

```
class Eq a where
    (==) :: a -> a -> Bool

instance Eq Int where
    (==) x y = eqInt x y

instance Eq a => Eq [a] where
    (==) [] [] = True
    (==) (x:xs) (y:ys) = (x == y) && (xs == ys)
    (==) _ _ = False

check :: (Eq [a]) => [a] -> [a] -> Bool
check xs ys = xs == ys
```

Type classes

In Scala, type classes are “encoded” using traits and implicit definitions, i.e. `implicit val`, `implicit def` and `implicit object`

```
trait Eq[A] { def eq(x:A,y:A):Boolean }
implicit val eqInt = new Eq[Int] {
  def eq(x:Int,y:Int):Boolean = x == y
}
implicit def eqList[A](implicit ev:Eq[A]) =
  new Eq[List[A]] {
    def eq(xs:List[A],ys:List[A]):Boolean =
      (xs,ys) match {
        case (Nil,Nil) => true
        case (x::xs2, y::ys2) => ev.eq(x,y) && eq(xs2,ys2)
        case (_, _) => false
      }
  }
}
```

By resolving implicit parameter the compiler builds the “evidence” *ev* AKA the dictionary.

```
def check[A](x:List[A], y:List[A])  
  (implicit ev:Eq[List[A]]) = ev.eq(x,y)
```

```
scala> check(List(1,2,3), List(1,2,3))  
res6: Boolean = true
```

The above builds the evidence `ev = eqList(eqInt)`

Type classes

To mimick type classes' effect in OOP languages like Java, we would have to use interface and function overriding with lots of cares. (We omit the getter and setter methods for brevity.)

```
public interface Eq<T> { public boolean eq(T that); }
public class Int implements Eq<Int> {
    private int val;
    public Int(int x) { val = x; }
    public boolean eq(Int that) {
        return (val == that.getVal());
    }
}

public class List<T extends Eq<T>> implements Eq<List<T>> {
    private Node<T> pHead;
    public List() { pHead = null;}
    public void insert(T v) {
        Node<T> n = new Node<T>(v);
        n.setNext(pHead);
        pHead = n;
    }
    public boolean eq(List<T> that) {
        return pHead.eq(that.getPHead());
    }
}
```

Type classes

To mimick type classes' effect in OOP languages like Java, we would have to use interface and function overriding with lots of cares. (We omit the getter and setter methods for brevity.)

```
public class Node<T extends Eq<T>> implements Eq<Node<T>> {  
    private T val;  
    private Node<T> next;  
    public Node(T v) {  
        val = v;  
        next = null;  
    }  
    public boolean eq(Node<T> that) {  
        if (!val.eq(that.getVal())) { return false; }  
        else {  
            if ((next == null) && (that.getNext() == null)) { return true; }  
            else if ((next == null) && (that.getNext() != null)) { return false; }  
            else if ((next != null) && (that.getNext() == null)) { return false; }  
            else { return next.eq(that.getNext()); }  
        }  
    }  
}
```


To mimick type classes' effect in OOP languages like Java, we would have to use interface and function overriding with lots of cares.

Finally we can implement the check function in Java as follows,

```
public static <T extends Eq<T>> boolean check(List<T> l1, List<T> l2) {  
    return l1.eq(l2);  
}
```

For real world applications implemented in Scala, we do not define all the type classes from the scratch. We use a library project called scalaz. <https://github.com/scalaz/scalaz> which provides many useful type classes.

A vague analogy

- Algebraic data types define abstractions of run-time data (or values), i.e. what are the possible values.
- Monads define abstractions of *computations*, i.e. what the possible computations.

So what are monads good for?

- segregating pure computation from computation with side-effect, (i.e. i/o)
- capture program control flow
- generic data traversal
- define user-programmable states and transitions
- compose computations

Monad example: Safe Integer arithmetics

Let's model safe arithmetic computation

```
sealed trait SafeVal[+T]
case class Val[T](x:T) extends SafeVal[T]
case class Err(msg:String) extends SafeVal[Nothing]

type SafeInt = SafeVal[Int]
```

Monad example: Safe Integer arithmetics

```
def add(x:SafeInt, y:SafeInt):SafeInt = x match {  
  case Err(msg) => Err(msg)  
  case Val(i) => y match {  
    case Err(msg) => Err(msg)  
    case Val(j) => Val(i + j)  
  }  
}  
  
def div(x:SafeInt, y:SafeInt):SafeInt = x match {  
  case Err(msg) => Err(msg)  
  case Val(i) => y match {  
    case Err(msg) => Err(msg)  
    case Val(j) => {  
      if (j == 0) {Err("div by 0")} else {Val (i/j)}  
    }  
  }  
}
```

Monad example: Safe Integer arithmetics

We spot many similar code structure, let's rewrite them in terms of some higher order combinators `pnt` and `bnd`.

```
def pnt[A](x: => A): SafeVal[A] = Val(x)
def bnd[A,B](sa: SafeVal[A])
  (f: A => SafeVal[B]): SafeVal[B] = sa match {
  case Err(msg) => Err(msg)
  case Val(a)   => f(a)
}
```

- Note that `x:=> A` defines a *lazy* formal parameter `x` of type `A`.
- `pnt` “lifts” / “injects” a value into the `SafeVal` object.
- `bnd` “composes” the previous `SafeVal` with the subsequent computation.

Monad example: Safe Integer arithmetics

```
def add(x:SafeInt, y:SafeInt):SafeInt = {  
  bnd(x)(x1 => {  
    bnd(y)(y1 => pnt(x1+y1))  
  })  
}  
  
def div(x:SafeInt, y:SafeInt):SafeInt = {  
  bnd(x)( x1 => {  
    bnd(y)( y1 => {  
      if (y1 == 0) { Err("div by 0") }  
      else { pnt(x1 / y1) }  
    })  
  })  
}
```

Monad example: Safe Integer arithmetics

If we use type classes `Monad` and `MonadPlus` provided by `scalaz`, we can make it even more concise.

```
implicit object safeValMonadPlus
  extends MonadPlus[SafeVal] {
  override def point[A](a: => A): SafeVal[A] = Val(a)
  override def bind[A, B](sa: SafeVal[A])
    (f: A => SafeVal[B]): SafeVal[B] = sa match {
    case Err(msg) => Err(msg)
    case Val(a)   => f(a)
  }
  ...
}
```


Monad example: Safe Integer arithmetics

```
def add(x:SafeInt,y:SafeInt):SafeInt = {  
  for ( x1 <- x  
    ; y1 <- y  
    ) yield (x1 + y1)  
}  
  
def div(x:SafeInt,y:SafeInt):SafeInt = {  
  for ( x1 <- x  
    ; y1 <- y  
    ; if y1 != 0  
    ) yield (x1 / y1)  
}
```

Roughly speaking, for (x <- e1 ; e2) is desugared to
bind(e1)(x => e2)

Monad example: Matrix multiplication

Given

```
val l1 = List(1,2,3)
val l2 = List('a','b')
```

We want to define the matrix multiplication `mult`

```
scala> mult(l1,l2)
res0: List[(Int, Char)] = List((1,a), (1,b), (2,a), (2,b),
  (3,a),(3,b))
```

```
def mult[A,B](as:List[A], bs:List[B]):List[(A,B)] = {
  as flatMap ( a =>
    bs map ( b => (a,b) )
  )
}
```

Note `List(List(1),List(2)).flat` yields `List(1,2)`. `flatMap` is defined as the composition of `flat` and `map`.

Monad example: Matrix multiplication

List is a monad,

As defined in the scalaz library

```
implicit object listMonadPlus extends MonadPlus[List] {  
  override def point[A](a: => A):List[A] = List(a)  
  override def bind[A, B](sa: List[A])  
    (f: A => List[B]): List[B] = sa flatMap f  
  ...  
}
```

What a programmer needs to write

```
def mult[A,B](as:List[A], bs:List[B]) : List[(A,B)] = for  
  ( a <- as  
  ; b <- bs  
  ) yield (a,b)
```

There many types of commonly used monads

- List monad - list traversal and aggregate computation.
- State monad - computation with explicit state passing
- Reader monad - input scanning computation
- Monadic parser combinator - LL-style top-down parsing computation

Monads are composable via monad transformer.

So you still want to see how to mimick monads in Java?

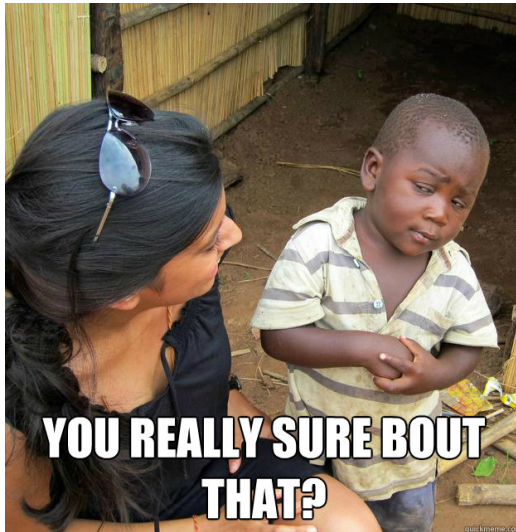


Image taken from <http://quickmeme.com>

Ok, if you are really interested, look here.

`http://github.com/luzhuomi/parsecj/tree/master/
Parsec/src/parsec`

We've covered

- OOP in Scala
- Functional Programming in Scala which includes,
 - Algebraic data type and pattern matching
 - Higher order functions
 - Partial functions
 - Implicit functions
 - Type classes
 - Monads

Latex source and example codes can be found here

<https://github.com/luzhuomi/learning-scala>