Programming in Scala

Lecture Three

Angelo Corsaro

19 November 2018

Chief Technology Officer, ADLINK Technology Inc.

Table of contents i

Table of contents ii

Logistics

Virtual Office Hours

I will be available to answer question through a Zoom webconferencing service. Through Zoom we will be able to share desktops – which is useful to review your code.

`https://zoom.us/j/436949908`
`tel:+33-1-82-88-01-88`
`tel:+33-7-56-78-40-48`

The office hours schedule is as follows:

- 21 November from 15.00 to 16.00
- 23 November from 15.00 to 16.00
- TBD

Project Open House

We need to fix a date, for what concerns the format:

- 10 minutes for presenting your project (slides)
- 20 minutes for showing the some code fragment and a demo
- You'll have to provide me with the code at latest the day before.

Reviewing Fold

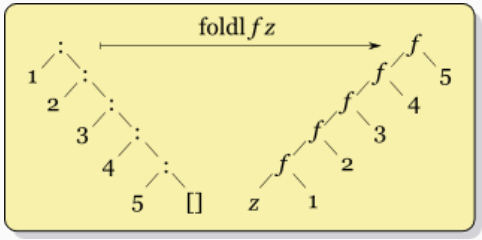
Folding

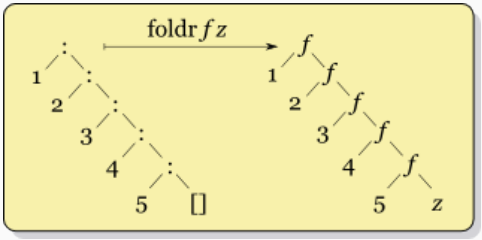
In functional programming, **fold**, refers to a family of *higher-order functions* that analyze a recursive data structure and through use of a given combining operation, recombine the results of recursively processing its constituent parts, building up a return value.

Folds can be regarded as consistently replacing the structural components of a data structure with functions and values.

Two variants of **fold** exist, namely **foldl** and **foldr**.

Visualizing folds





Folding Lists

The functions we just wrote for lists can all be expressed in terms of fold operator.

```
1  def sum(xs: List[Int]): Int = xs.foldRight(0)(_ + _)
2
3  def sum(xs: List[Int]): Int = xs.foldLeft(0)(_ + _)
4
5  def reversel(ys: List[Int])= ys.foldLeft(List[Int]())((xs: List[Int], x: Int) => x :: xs)
6
7  def reverser(ys: List[Int]) = zs.foldRight(List[Int]())((x: Int, xs: List[Int]) => xs ::: List(x) )
```

foldr and foldl

```scala
def reverse(xs: List[Int]): List[Int] = xs match {
        case List() => List()
        case y::ys => reverse(ys) ::: List(y)
}
val xs = List(1,2,3,4,5)
val ys = reverse(xs)

val zs = ys.foldLeft(List[Int]())((xs: List[Int], x: Int) => x :: xs)

val ks = zs.foldRight(List[Int]())((x: Int, xs: List[Int]) => xs ::: List(x) )
```

More on Scala Classes

Scala Classes Refresher

In the first lecture we saw the basic mechanism provided by Scala to declare Classes. Back than we had seen *closures* without realizing it, thus let's take a fresh look at some of the examples:

```
1  class Complex(val re: Double, val im: Double) {
2    override def toString = s"$re+i$im"
3  }
4
5  class Rational(a: Int, b: Int) {
6    assert(b != 0)
7    val num: Int = a / gcd(a, b)
8    val den: Int = b / gcd(a, b)
9
10   def this(n: Int) = this(n, 1)
11 }
```

Abstract Classes

In Scala the **abstract** modifier is used to denote an abstract class. In other terms, a class that cannot be instantiated.

An abstract class *may have* abstract members that don't have an implementation (definition).

```scala
package edu.esiee.scala18.ex1

abstract class Shape {
  def scale(a: Float): Shape

  // Parameter-less methods: Two takes:
  def show(): Unit

  def area: Float
  def perimeter: Float

}
```

Parameter-less Methods

Parameter-less methods can be declared with or without parenthesis.

The convention is that parenthesis are used for methods that cause side-effects – like show above.

Parenthesis are not used to methods that compute properties. This way there **uniform access** between attributes and methods.

Extending a Class

The *Shape* abstract type had defined some of the characteristics shared by some geometrical shapes.

A concrete shape can be defined by extending the abstract Shape class as follows:

```
1  package edu.esiee.scala18.ex1
2
3  class Circle(val radius: Float) extends Shape {
4
5    def scale(a: Float): Shape = new Circle(a * radius)
6
7    def show(): Unit = print(s"Circle($radius)")
8
9    def area: Float = Math.PI.toFloat*radius*radius
10   def perimeter: Float = 2*Math.PI.toFloat*radius
11 }
```

Methods or Vals?

The **area** and **perimeter** have been defined as parenthesis less methods.

As our shape are immutable, a valid question is if we could define them with **vals** and compute them only once, as opposed to every-time the method is called.

The good news is that Scala supports the concept of *abstract val*, let's see how to leverage them.

Abstract val

Along with abstract methods, an abstract class can also have abstract `vals`.

These are values which are declared but not defined.

If we were to leverage abstract values our Shape class could be declared as follows:

```
1  package edu.esiee.scala18.ex2
2
3  abstract class Shape {
4    def scale(a: Float): Shape
5
6    def show(): Unit
7
8    val area: Float
9    val perimeter: Float
10
11 }
```

Implementing abstract val

Implementing an abstract val is as simple ad defining it as show in the code example below:

```
1  package edu.esiee.scala18.ex2
2
3  class Circle(val radius: Float) extends Shape {
4
5    def scale(a: Float): Shape = new Circle(a * radius)
6
7    def show(): Unit = print(s"Circle($radius)")
8
9    val area: Float = Math.PI.toFloat*radius*radius
10   val perimeter: Float = 2*Math.PI.toFloat*radius
11 }
```

Observation

Now, as we are using *val* the shape area is computed only once, at the time of initialization. This is an improvement compared from the previous example. Additionally, the client code cannot tell whether we are implementing the area and the perimeter with a val or with a parenthesis less method which is very good.

Yet... We are still spending the time even if the client code is never calling that operation. In an ideal world we would want to compute it once and only if needed... Can we do that?

lazy val

Scala defines the **lazy** modifier to indicate a value that should be computed lazily only when accessed.

If we want o do so, the only thing we need to change is the definition of the val, as shown below:

```scala
package edu.esiee.scala18.ex3

import edu.esiee.scala18.ex2.Shape

class Circle(val radius: Float) extends Shape {
  def scale(a: Float): Shape = new Circle(a * radius)

  def show(): Unit = print(s"Circle($radius)")

  lazy val area: Float = Math.PI.toFloat*radius*radius
  lazy val perimeter: Float = 2*Math.PI.toFloat*radius
}
```

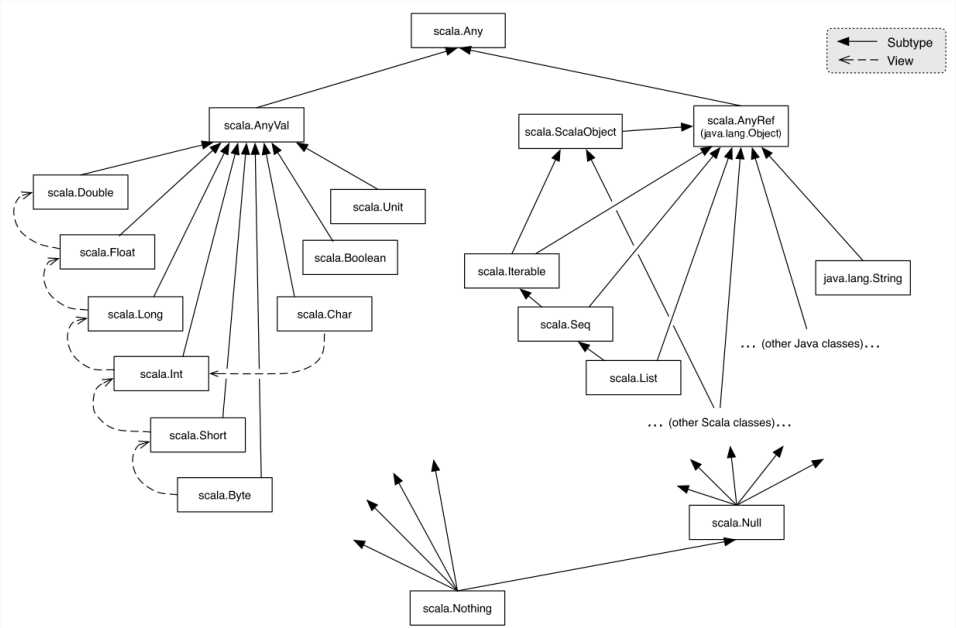
Overriding

A subclass can override both *methods* as well as *val* defined in the parent class.

The super-class constructor can also be explicitly called as part of the extend declaration as shown in the example below:

```
1  package edu.esiee.scala18.ex3
2
3  class FastCircle(r: Float) extends Circle(r) {
4    override lazy val perimeter: Float = Math.PI.toFloat * (radius.toInt << 1)
5
6    override def show(): Unit = print(s"O($radius")
7  }
```

Scala Type Hierarchy



Algebraic Data Types

Algebraic Data Type

In type theory and commonly in functional programming, an **algebraic data type** is a kind of composite type. In other term a type obtained by composing other types.

Depending on the composition operator we can have **product types** and **sum types**

Product Types

Product types are algebraic data types in which the *algebra* is *product*

A **product type** is defined by the conjunction of two or more types, called fields. The set of all possible values of a product type is the set-theoretic product, i.e., the Cartesian product, of the sets of all possible values of its field types.

Example

```
data Point = Point Double Double
```

In the example above the product type Point is defined by the Cartesian product of $Int \times Int$

Sum Types

The values of a sum type are typically grouped into several classes, called variants.

A value of a variant type is usually created with a quasi-functional entity called a constructor.

Each variant has its own constructor, which takes a specified number of arguments with specified types.

Sum Types Cont.

The set of all possible values of a sum type is the set-theoretic sum, *i.e.*, the disjoint union, of the sets of all possible values of its variants.

Enumerated types are a special case of sum types in which the constructors take no arguments, as exactly one value is defined for each constructor.

Values of algebraic types are analyzed with pattern matching, which identifies a value by its constructor or field names and extracts the data it contains.

Example

```
data Tree = Empty
          | Leaf Int
          | Node Tree Tree deriving (Show)

> let t = Node (Leaf 1) (Node (Leaf 2) (Leaf 3))
> :t t
t :: Tree
```

Case Classes and Pattern Matching

Case Classes

Scala **case classes** provide a way to *mimic* algebraic data types as found in functional programming languages.

The Scala version of the *Tree* type we defined in Haskell is:

```
1  abstract class Tree
2  object Empty extends Tree
3  case class Leaf(v: Int) extends Tree
4  case class Node(l: Tree, r: Tree) extends Tree
5
6  val t = Node(Leaf(1), Node(Leaf(2), Leaf(3)))
```

Case Classes / Cont.

If you noticed the *Tree* algebraic data type was declared through case classes that did not have named attributes. In other term, there were no **val** or **var**.

That does not mean that you cannot declare **val** or **var** as part of a case class. It has more to do with the fact that case classes are worked upon using pattern matching.

Pattern Matching

Scala pattern matching has the following structure:

selector `match` *alternatives*

A pattern match includes a series of *alternatives*, each starting with the keyword **case**.

Each alternative includes a *pattern* and one or more expressions, which are evaluated only if the pattern matches.

Let's see what are the kinds of patterns supported by Scala.

Wildcard Pattern

The *wildcard pattern*, denotated by _, matches anything – thus its appelation.

Example

```
1  def isEmpty(xs: List[Int]) = xs match {
2          case List() => return true
3          case _ => return false
4  }
5
6  def isSingleElementList(xs: List[Int]) =  xs match {
7          case List(_) => true
8          case _ => false
9  }
```

Constant Pattern

A constant pattern matches only itself. Any literal, such as `18`, `42`, `"Ciao"`, `true` can be used as a constant.

Any **val** or **singleton object** can also be used as a constant.

Example

```
def toString(d: Int) = d match {
        case 0 => "Zero"
        case 1 => "Uno"
        // ...
        case 9 => "Nove"
}

```

Variable Pattern

A variable pattern matches any object, just like a wildcard. But unlike a wildcard, Scala binds the variable to whatever the object is.

You can then use this variable to act on the object further.

Example

```
1  def checkZero(d: Int) =
2          d match {
3                  0 => "zero"
4                  v =>  v + " is not zero"
5          }
```

Constructor Pattern

A constructor pattern looks like `Node(Leaf(1), Node(Leaf(2), _))` . It consists of a name (`Tree`) and then a number of patterns within parentheses.

Assuming the name designates a case class, such a pattern means to first check that the object is a member of the named case class, and then to check that the constructor parameters of the object match the extra patterns supplied.

Example

```
1  def triangleTree(t: Tree) =
2     t match {
3        case Node(Leaf(_), Leaf(_)) => True
4        case _ => False
5     }
```

Please notice that Sequence and Tuple patters are just a special case of constructor patterns.

Exercise

Define the following functions for our `Tree` type:

1. `height` which computes the tree height.
2. `sum` which is the function that computes the sum of all the elements of the tree.
3. `fold` which is a function that applies a generic binary operator to the tree, where the zero is used when for empty nodes.

Typed Pattern

Typed pattern are used to test and cast types.

Example

```
1  def generalSize(x: Any) = x match {
2    case s: String => s.length
3    case m: Map[_, _] => m.size
4    case _ => -1
5  }
```

Pattern Guards

A pattern guard comes after a pattern and starts with an **if**. The guard can be an arbitrary boolean expression, which typically refers to variables in the pattern.

If a pattern guard is present, the match succeeds only if the guard evaluates to true.

Example

```
1  // match only positive integers
2  case n: Int if 0 < n => ...
3
4  // match only strings starting with the letter `a'
5  case s: String if s(0) == 'a' => ...
```

Other use of Patterns

Patterns can be used also in assignments, such as in:

```
1  val (a, b, c) = tripetFun(something)
```

Patterns can also be used in for expressions:

```
1  for ((key, value) <- store)
2    print("The key = " + key + "has value = " + value)
```

For Expression Revisited

For Expression

The general form of a **for** expression is:

for (*seq*) **yield** *expr*

Here, *seq* is a sequence of *generators*, *definitions*, and *filters*, with semicolons between successive elements.

Generator, Definition and Filter

A **generator** is of the form:

$$pat \leftarrow expr$$

A **definition** is of the form:

$$pat = expr$$

A **filter** is of the form:

$$if \quad expr$$

for expression: Examples

Example

```
1  for (x <- List(1, 2); y <- List("one", "two")) yield (x, y)
2
3  for ( i <- 1 to 10; j <- i to 10) yield (i,j)
4
5  val names = List("Morpheus", "Neo", "Trinity", "Tank", "Dozer")
6
7  for (name <- names; if name.length == 3) yield name
8
9  val xxs = List(List(1,2,3,4), List(6, 8, 10, 12), List(14, 16, 18))
10
11 for (xs <- xxs; e <- xs; if (e % 2 == 0)) yield e
12
13 for (xs <- xxs; if (xs.isEmpty == false); h = xs.head) yield h
```

Type Parameterization

Type Constructors in Scala

Beside first order types, Scala supports Type Constructors, – a kind of higher order types.

In the case of Scala, a parametric class is an n-ary type operator taking as argument one or more types, and returning another type.

Example
The list time we have seen this far, is a type constructor declared as:

$$class \quad List[+T]$$

Thus *List[Int]* and *List[String]* are two instances of the List[+T] type constructor.

Monads: A Gentle Introduction

Monad: Basic Idea

Monads can be thought of as composable computation descriptions.

The essence of monad is the separation of composition timeline from the composed computation's execution timeline, as well as the ability of computation to implicitly carry extra data, as pertaining to the computation itself, in addition to its one (hence the name) output, that it will produce when run (or queried, or called upon).

This lends monads to supplementing pure calculations with features like I/O, common environment, updatable state, etc.

Monad: Basic Idea / Cont.

Each monad, or computation type, provides means, subject to Monad Laws, to:

- create a description of a computation that will produce (a.k.a. "return") a value, and
- combine (a.k.a. "bind") a computation description with a *reaction* to it, – a pure function that is set to receive a computation-produced value (when and if that happens) and return another computation description.

Reactions are thus computation description constructors. A monad might also define additional primitives to provide access to and/or enable manipulation of data it implicitly carries, specific to its nature; cause some specific side-effects; etc..

Monad Class and Monad Laws

Monads can be viewed as a standard programming interface to various data or control structures, which is captured by the Monad class. All common monads are members of it:

```
class Monad m where
  (>>=)  :: m a -> (a -> m b) -> m b
  (>>)   :: m a ->  m b       -> m b
  return ::   a               -> m a
  fail   :: String            -> m a
```

In addition to implementing the class functions, all instances of Monad should obey the following equations, or Monad Laws:

```
return a >>= k                  =  k a
m        >>= return             =  m
m        >>= (\x -> k x >>= h)  =  (m >>= k) >>= h
```

Maybe Monad

The Haskell Maybe type is defined as:

```
data Maybe a = Just a | Nothing
     deriving (Eq, Ord)
```

It is an instance of the Monad and Functor classes.

Maybe Monad Implementation

Let's see how the Monad operations are defined for the Maybe type:

```haskell
return :: a -> Maybe a
return x = Just x

(>>=) :: Maybe a -> (a -> Maybe b) -> Maybe b
(>>=) Nothing _ = Nothing
(>>=) (Just x) f = f x

(>>) :: Maybe a ->  Maybe b -> Maybe b
(>>) x y =  x >>= (\_ -> y)
```

Verifying the First Monad Laws for Maybe

The first law states that:

```
return a >>= k =  k a
```

Let's play the substitution game:

```
return a >>= Just a >>= k  = k a
```

Verifying the Second Monad Laws for Maybe

The second law states that:

```
m >>= return =  m
```

Let's play the substitution game:

```
Just x >>= return = return x = Just x
Nothing >>= return = Nothing
```

Verifying the Third Monad Laws for Maybe

The third law states that:

```
m  >>= (\x -> k x >>= h)  =  (m >>= k) >>= h
```

Let's play the substitution game:

```
Just x  >>= (\y -> k y >>= h)  =  Just k x >>= h = (Just k x) >>= h = (Just x >>= k) >>= h
```

Thus we have proved that the Maybe type satisfies the three key monads rule. There are types you are already familiar with that satisfy the monadic laws, such as lists.

Monads in Scala

Scala does not define a Monad higher-order type, but monadic type (as well as some time that are not strictly monads), provide the key monadic operations.

These operations, however are named differently.

Option Type in Scala

The **Option** type is Scala's equivalent to Haskell's *Maybe* Monad. Looking at it is a good way of learning about monadic computations in Scala.

The *Option* type is defined as follows:

```
sealed abstract class Option[+A] extends Product with Serializable

case object None extends Option[Nothing] {
  // ...
}
final case class Some[+A](value: A) extends Option[A] {
 // ...
}
```

Option Type in Scala

The monad operations provided are the following:

```
// this is  the equivalent of Haskell's bind (>>=)
def flatMap[B](f: A => Option[B]): Option[B]
```

Notice that the equivalent of *return* is the constructor. That said, Scala does not provide the sequencing operator ($>>$). But as we've seen that can be easily defined from bind.

The Option type is technically also a functor (as lists also are), thus it also provides the *map* operation.

```
// this is  the equivalent of Haskell's bind (>>=)
def map[B](f: A => B): B
```

Monadic Computation with the Option Type

```scala
def parseInt(s: String): Option[Int] = {
  try {
    Some(s.toInt)
  } catch {
    case e: java.lang.NumberFormatException => None
  }
}

val x = parseInt("10")
val y = parseInt("10")

val z = x.flatMap(a => y.flatMap(b => Some(a+b)))

// Or using for

for (a <- x; b <- y) yield (a + b)
```

Parallel and Concurrent Computations

Motivation

As the number of cores on processors are constantly increasing while the clock frequencies are essentially stagnating, exploiting the additional computational power requires to leverage parallel and concurrent computations.

Scala provides some elegant mechanism for supporting both parallel as well as concurrent computations.

Parallel Collections

Scala supports the following parallel collections:

- ParArray
- ParVector
- mutable.ParHashMap
- mutable.ParHashSet
- immutable.ParHashMap
- immutable.ParHashSet
- ParRange
- ParTrieMap

Using Parallel Collections

Using parallel collections is rather trivial. A parallel collection can be created from a regular one by using the *.par* property.

Example

```
val parArray = (1 to 10000).toArray.par
parArray.fold(0)(_ + _)

val lastNames = List("Smith","Jones","Frankenstein","Bach","Jackson","Rodin").par
lastNames.map(_.toUpperCase)
```

Given this *out-of-order* semantics, also must be careful to perform only associative operations in order to avoid non-determinism.

Concurrent Computation on the JVM

The traditional approach to concurrent computations on the JVM is to leverage threads and the built-in support for monitors, through the *synchronized* keyword, to avoid race conditions.

This concurrency model is based on the assumption that different threads of execution collaborate by mutating some shared state. This shared state has to be protected to avoid race conditions.

This programming model is quite error-prone and is often source of bugs that are very hard to debug due to the inherent non-determinism of concurrent computations.

Furthermore, lock-based synchronization can lead to deadlocks.

Scala futures

Scala provide a mechanism for concurrent execution that makes it easier to work under the share nothing model and that support more importantly supports composability.

This mechanism is provided by Scala's futures.

Futures are monads, thus, you can operate and compose them as any other monad.

Futures Example

Below is an example of computing and composing futures.

```
import scala.concurrent.ExecutionContext.Implicits.global
import scala.concurrent.Future

val f1 = Future {
  Thread.sleep(2)
  10
}

val f2 = Future {
  Thread.sleep(1)
  20
}

val c = for (a <- f1; b <- f2) yield a + b
c.onComplete(r => r.foreach(a => println(a)))
```

Promises

The most general way of creating a future and is through *promises*.

The completion of *future* create from a promise is controlled by completing the *promise*.

Example

```
def asynchComputation(): Future[Int] = {
  import Converters._
  val promise = Promise[Int]
  new Thread {
    val r = someComputeIntenseFun()
      promise.success(r)
    }.start()
    return promise.future
}
```

Homeworks

Reading

From the **Programming in Scala** book you should read:

- Chapter 10
- Chapter 11
- Chapter 15
- Chapter 19 (Variance concetps already covered in lecture 1 and 2)
- Chapter 23
- Chapter 32