

# Computer Programming with Scala

## Week 3: Functional Programming (FP)

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# Named and Default Parameters

## Referring parameters by name

```
scala> def speed ( distance: Double , time: Double ): Double =  
    distance / time  
speed: ( distance: Double , time: Double ) Double  
  
scala> speed (100 , 20)  
res0: Double = 5.0  
scala> speed ( time = 20 , distance = 100)  
res1: Double = 5.0
```

## Default Parameter values

```
scala> def speed ( distance: Double=0.1 , time: Double ): Double =  
    distance / time  
speed: ( distance: Double , time: Double ) Double  
  
scala> val Bolt = speed (time=0.00266111)      # 9.58s = 0.00266111h  
Bolt: Double = 37.578303790523506
```

# Local Functions

- ▶ Functions can be defined within other functions
- ▶ Functions are only visible in surrounding scope
- ▶ Inner function can access namespace of surrounding function

```
def filterEven(name: String, li: List[Int]): List[Int] = {  
  def isEven(i: Int) = {  
    println(name + " contains " + i)  
    (i % 2 == 0)  
  }  
  li match {  
    case Nil => Nil  
    case x::xs if (isEven(x)) => x::filterEven(name, xs)  
    case x::xs                =>      filterEven(name, xs)  
  }  
}  
  
scala> filterEven("my list", List(1,2,3,4,5) )  
my list contains 1  
my list contains 2  
my list contains 3  
my list contains 4  
res0: List[Int] = List(2, 4)
```

# Higher Order Functions

First Class Functions  $\leadsto$  Functions are regular values

- ▶ Can be assigned to a variable
- ▶ Can be passed as arguments to functions
- ▶ Can be returned by other functions

Higher Order Functions = Functions taking function as parameter

- ▶ Powerful abstraction mechanism

```
def my_map (lst: List[Int] , fun: Int => Int) :List[Int] =  
  for (l <- lst) yield fun (l)  
  
val numbers = List (2 ,3 ,4 ,5)  
def addone ( n : Int ) = n + 1  
  
scala> my_map ( numbers , addone )  
res0: List[Int] = List (3 , 4 , 5 , 6)
```

# Higher Order Functions on class List

## Filtering and Partitioning

- Functions as (named) values

```
val li = List(1, 2, 3, 4, 5)
def isEven (n: Int) = n%2 == 0
scala> li filter isEven
res0: List[Int] = List(2, 4)
```

- With an anonymous functions

```
scala> li filter (i => i%2 == 0)
res1: List[Int] = List(2, 4)
scala> li filter (_%2 == 0)
res2: List[Int] = List(2, 4)
```

```
scala> li partition (_%2 == 0)
res3: (List[Int], List[Int]) = (List(2, 4), List(1, 3, 5))
```

- Also defined: find, takeWhile, dropWhile and span. Check the doc

## Mapping over elements

```
scala> li map (_ + 1)
res4: List[Int] = List(2, 3, 4, 5, 6)
scala> li foreach (x => print(x + ", "))
1, 2, 3, 4, 5,
```

## Folding List /: and \:

- Reduce all elements into a single value using the provided function

```
scala> def sum(xs: List[Int]): Int = (0 /: xs) (_ + _)
scala> sum( List(1,2,3,4) )
res0: Int = 10      # = 0 + 1 + 2 + 3 + 4
```

## Folding List /: and \:

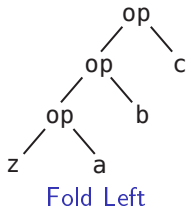
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scala> sum( List(1,2,3,4) )
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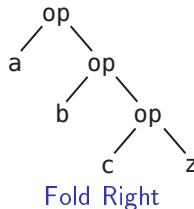
scala> def sumRight(xs: List[Int]): Int = (0 \: xs) (_ + _)
scala> sum( List(1,2,3,4) )
res0: Int = 10      # = 0 + 4 + 3 + 2 + 1
```

- (z /: xs) (op) z: initial value, xs: list, op: operation to apply

(z /: List(a,b,c)) (op)



(z \: List(a,b,c)) (op)



- Same result if op is associative; performance may vary

# Partially Applied Functions: Functions as Objects

- ▶ Passing `_` in place of parameter list creates a partially applied function
- ▶ **Function Object** automatically built by the compiler

```
scala> def sum(a: Int, b: Int, c: Int) = a + b + c
sum: (a: Int, b: Int, c: Int)Int
```

```
scala> sum(1, 2, 3)
res0: Int = 6
```

```
scala> val a = sum _
a: (Int, Int, Int) => Int = <function3>
# This creates an object of type
# <function3> (because sum takes
# 3 parameters)
```

```
scala> a(1,2,3)
res1: Int = 6
# Apply parameters to partially
# applied function => function call
```

```
scala> a.apply(1,2,3)
res2: Int = 6
# Exactly as before
```

```
scala> val b = sum(1, _:Int, 3)
b: Int => Int = <function1>
# Here, only one parameter remains
# free. Thus the type <function1>
```

```
# Manual and bothersome definition (much simpler if it takes only one parameter)
scala> val f = {case(a,b,c) => a + b + c}: (Int,Int,Int)=>Int
f: (Int, Int, Int) => Int = <function3>
```



# Function Objects and Implicits

- Underscore optional in contexts that require a function (and only there)

```
scala> someNumbers.foreach(print)  # no need to write (print _) here
1234
```

```
scala> val c = sum
```

```
<console>:5: error: missing arguments for method sum...
```

```
follow this method with '_' if you want to treat it as a partially applied function
```

- Haskell doesn't require the `_` for the partially applied function (implicit)
- But Scala targets Java developers  $\leadsto$  needs to detect missing parameters
- Thus the need for `_` in general context
- `_` is still optional where it can be no mistake

# Closures

- **Free variable**: variable without a value; **Bound variable**: variable with a value

Closure = when a function refers to an external free variable

```
scala> var more = 1
scala> val addMore = (x: Int) => x + more
addMore: (Int) => Int = <function1>
scala> addMore(10)
res0: Int = 11
```

- This function object is a **closure**, because it **encloses** (packs) the free variables
- In scala, **captures the variables**, not the values (Java captures constants)

```
scala> more = 3 ; addMore(10)
res1: Int = 13
```

## Building Closures

```
scala> def makeIncreaser(more: Int) = (x: Int) => x + more
makeIncreaser: (more: Int)Int => Int

scala> val inc9999 = makeIncreaser(9999)
inc9999: (Int) => Int = <function1>
```

- Each closure gets its own copy of the captured elements

# Other Considerations

## Code Factorization with Higher Order Functions

```
def withOdd(nums: List[Int]): Boolean={  
  var exists = false  
  for (num <- nums)  
    if (num % 2 == 1)  
      exists = true  
  exists  
}
```

```
def withOdd(nums: List[Int]): Boolean=  
  nums.exists(_%2 == 1)
```

- ▶ Q1: Implement List.length with :/
- ▶ Q2: List.reverse() with :/
- ▶ Q3: Type of `((x:Double) => x+1)`
- ▶ Q4: Write a function that adds 1 to every elements of a List[Int]
- ▶ Q5: Define  $S = \{a \times 2 \mid a \in [1, 100] \wedge a^2 < 99 \wedge a^3 > 9\}$
- ▶ Q6: Explain `((_:Double)+2)` and `(_:String).size`

## Tail Recursion Optimization

- ▶ Scala can optimize every tail recursive functions into a while loop
- ▶ Works only for basic forms (not mutually recursive, not partially applied)

## Lazy variables `lazy val ui = ...`

- ▶ Only evaluated on need (usually, scala values are evaluated when defined)

# Currying

- Defining functions with multiple parameter lists

```
scala> def curriedSum(x: Int)(y: Int) = x + y
curriedSum: (x: Int)(y: Int)Int

scala> curriedSum(1)(2)
res5: Int = 3
```

- You are actually defining two functions back to back

```
scala> def first(x: Int) = (y: Int) => x + y
first: (x: Int)(Int) => Int

scala> val second = first(1)
second: (Int) => Int = <function1>
```

- Currying and Partially applied function

```
scala> curriedSum(1)
<console>:14: error: missing arguments for method curriedSum; follow this method with
curriedSum(1)(_)

scala> curriedSum(1)_
res6: Int => Int = <function1>
```

- This explains the `:/` syntax

# Function Composition

```
def f(s: String) = "f(" + s + ")"
def g(s: String) = "g(" + s + ")"
```

compose makes a new function that composes its parameters:  $f(g(x))$

```
scala> val FoG = f _ compose g _
FoG: String => String = <function1>

scala> FoG("yah")
res0: String = f(g(yah))
```

andThen does the same in the reverse order:  $g(f(x))$

```
scala> val FthenG = f _ andThen g _
FthenG: String => String = <function1>

scala> FthenG("yah")
res1: String = g(f(yah))
```

# PartialFunction

- ▶ It's a function that is not defined for every parameter value
- ▶ It is not a Partially Applied Function

```
scala> val one: PartialFunction[Int, String] = { case 1 => "one" }  
one: PartialFunction[Int,String] = <function1>
```

```
scala> one.isDefinedAt(1)  
res0: Boolean = true
```

```
scala> one.isDefinedAt(2)  
res1: Boolean = false
```

- ▶ You can chain PartialFunctions with orElse

```
scala> val two: PartialFunction[Int, String] = { case 2 => "two" }  
two: PartialFunction[Int,String] = <function1>  
scala> val three: PartialFunction[Int, String] = { case 3 => "three" }  
scala> val wildcard: PartialFunction[Int, String] = { case _ => "something else" }  
scala> val partial = one orElse two orElse three orElse wildcard  
partial: PartialFunction[Int,String] = <function1>
```

```
scala> partial(5)  
res1: String = something else
```

```
scala> partial(3)  
res2: String = three
```

```
scala> partial(2)  
res3: String = two
```

```
scala> partial(1)  
res4: String = two
```

# case class and Pattern Matching

## Defining a case class

```
abstract class Tree
case class Branch(left: Tree, right: Tree) extends Tree
case class Leaf(x: Int) extends Tree
```

## Declaring a value

```
val t = Branch(Branch(Leaf(1), Leaf(2)), Branch(Leaf(3), Leaf(4)))
```

## Pattern Matching

```
def sumLeaves(t: Tree): Int = t match {
  case Branch(l, r) => sumLeaves(l) + sumLeaves(r)
  case Leaf(x) => x
}
```

## Matching on Variable Declaration

```
scala> val b = Branch(Leaf(1), Leaf(2))
b: Branch

scala> val Branch(_, l) = b
l: Tree = Leaf(2)
```

# Parametrized types

## Defining a Tree[String] (without duplication)

```
abstract class Tree[A]  
case class Branch[A](left: Tree[A], right: Tree[A]) extends Tree[A]  
case class Leaf[A](x: A) extends Tree[A]  
  
scala> val t = Branch(Branch(Leaf("a"), Leaf("b")), Branch(Leaf("c"), Leaf("d")))  
t: Branch[String] = Branch(Branch(Leaf(a),Leaf(b)),Branch(Leaf(c),Leaf(d)))
```

- Tree is a trait while Tree[Int] is a type



# Parametrized types

## Defining a Tree[String] (without duplication)

```
abstract class Tree[A]  
case class Branch[A](left: Tree[A], right: Tree[A]) extends Tree[A]  
case class Leaf[A](x: A) extends Tree[A]  
  
scala> val t = Branch(Branch(Leaf("a"), Leaf("b")), Branch(Leaf("c"), Leaf("d")))  
t: Branch[String] = Branch(Branch(Leaf(a),Leaf(b)),Branch(Leaf(c),Leaf(d)))
```

- ▶ Tree is a trait while Tree[Int] is a type

## The Option type

- ▶ When you search for a value in a list, you don't know whether you'll find it
- ▶ An Option[A] can either be a Some (containing a value) or a None

```
val capitals = Map("France" -> "Paris", "Japan" -> "Tokyo")
```

```
scala> capitals get "France"  
res0: Option[java.lang.String] = Some(Paris)
```

```
scala> capitals get "North Pole"  
res1: Option[java.lang.String] = None
```

- ▶ Q: Define the following methods over Tree[A]: find, map, foreach, filter

# Variance

- ▶ Would you say that a `Tree[Int]` **is-a** `Tree[Any]`?
- ▶ Is it ok to provide a `Tree[Int]` where a `Tree[Any]` was expected?

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- ▶ Is it ok to provide a `Tree[Int]` where a `Tree[Any]` was expected?
- ▶ Intuitively, yes, but by default, Scala generic types are **nonvariant**
- ▶ If your type `Tree` is **covariant** (flexible), just say so:

```
trait Tree[+T] { ... }    # a Tree[Int] is indeed a Tree[Any]
```

- ▶ In some cases, you can tell that your type is **contravariant**

```
trait Tree[-T] { ... }    # WRONG! a Tree[Any] cannot be a Tree[Int]!
```

- ▶ Purely functional types are often covariant

# Variance

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- ▶ Purely functional types are often covariant

## Mutable Data is often not Covariant

```
class Cell[+T](init: T) { # WRONG
  private[this] var current = init
  def get = current
  def set(x: T) { current = x }
}

val c1 = new Cell[String]("abc")
val c2: Cell[Any] = c1
c2.set(1)
val s: String = c1.get    # WOOOOPS
```

- ▶ This would sets the string to 1!
- ▶ Type system actually prevents this

```
Cell.scala:7: error: covariant type T
occurs in contravariant position in
type T of value x
def set(x: T) = current = x
    ^
```

# Variance and subtyping

```
class Animal { val sound = "rustle" }  
class Bird extends Animal { override val sound = "call" }  
class Chicken extends Bird { override val sound = "cluck" }
```

Specialization: You need a Bird and have a Chicken. That's OK.

- This is the **Liskov Substitution Principle**

```
scala> val a: Bird = new Chicken  
a: Bird = Chicken@1fcaea93  
  
scala> a.sound  
res8: String = cluck
```

- But you cannot use an Animal in place of a Bird

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scala> a.sound  
res8: String = cluck
```

- ▶ But you cannot use an Animal in place of a Bird

## Function parameters are contravariants

- ▶ Can't use a function that takes a Chicken for a function that takes a Bird
  - ▶ It would choke on a Duck; But a function that takes an Animal is OK

```
scala> val getTweet: (Bird => String) = ((a: Animal) => a.sound )  
getTweet: Bird => String = <function1>
```

# Variance and subtyping

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- ▶ But you cannot use an Animal in place of a Bird

## Function parameters are contravariants

- ▶ Can't use a function that takes a Chicken for a function that takes a Bird
  - ▶ It would choke on a Duck; But a function that takes an Animal is OK

```
scala> val getTweet: (Bird => String) = ((a: Animal) => a.sound )  
getTweet: Bird => String = <function1>
```

## Function return value are covariant

- ▶ Need a function that returns a Bird? A function returning a Chicken is OK

```
scala> val hatch: (() => Bird) = (() => new Chicken )  
hatch: () => Bird = <function0>
```

# Don't mix Parameters' and Receiver Variances

```
class Top
class Middle extends Top
class Bottom extends Middle
class Up {
  def cv(t:Top) = "Up"
  def inv(m:Middle) = "Up"
  def ctv(b:Bottom) = "Up"
}
class Down extends Up {
  def cv(m:Middle) = "Down"
  def inv(m:Middle) = "Down"
  def ctv(m:Middle) = "Down"
}
val u: Up = new Up
val d: Down = new Down
val ud: Up = new Down
```

	u.??()	d.??()	ud.??()
?..cv(Top)			
?..cv(Middle)			
?..cv(Bottom)			
?..inv(Top)			
?..inv(Middle)			
?..inv(Bottom)			
?..ctv(Top)			
?..ctv(Middle)			
?..ctv(Bottom)			

## Scala 2.x algorithm to select the Right Call

- ▶ Get signature from static types; Linearize receiver dynamic type to find it
- ▶ Other languages (and Scala 1.x) use other algorithms
- ▶ **Don't do it in Real Projects**

*Courtesy of Antoine Beugnard (Telecom Bretagne)*

<http://public.enst-bretagne.fr/~beugnard/papiers/lb-sem.shtml>



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  def ctv(m:Middle) = "Down"
}
val u: Up = new Up
val d: Down = new Down
val ud: Up = new Down
```

	u.??()	d.??()	ud.??()
?..cv(Top)	Up		
?..cv(Middle)	Up		
?..cv(Bottom)	Up		
?..inv(Top)			
?..inv(Middle)			
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  def ctv(m:Middle) = "Down"
}
val u: Up = new Up
val d: Down = new Down
val ud: Up = new Down
```

	u.??()	d.??()	ud.??()
?..cv(Top)	Up		
?..cv(Middle)	Up		
?..cv(Bottom)	Up		
?..inv(Top)	Error		
?..inv(Middle)	Up		
?..inv(Bottom)	Up		
?..ctv(Top)			
?..ctv(Middle)			
?..ctv(Bottom)			

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?..ctv(Middle)	Error		
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```

	u.??()	d.??()	ud.??()
?..cv(Top)	Up	Up	
?..cv(Middle)	Up	Down	
?..cv(Bottom)	Up	Down	
?..inv(Top)	Error	Error	
?..inv(Middle)	Up	Down	
?..inv(Bottom)	Up	Down	
?..ctv(Top)	Error		
?..ctv(Middle)	Error		
?..ctv(Bottom)	Up		

d.cv(Top)=Up because parameters are contravariant

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  def ctv(m:Middle) = "Down"
}
val u: Up = new Up
val d: Down = new Down
val ud: Up = new Down
```

	u.??()	d.??()	ud.??()
?..cv(Top)	Up	Up	
?..cv(Middle)	Up	Down	
?..cv(Bottom)	Up	Down	
?..inv(Top)	Error	Error	
?..inv(Middle)	Up	Down	
?..inv(Bottom)	Up	Down	
?..ctv(Top)	Error	Error	
?..ctv(Middle)	Error	Down	
?..ctv(Bottom)	Up	Error	

d.cv(Top)=Up because parameters are contravariant  
d.ctv(Bot) ambiguous: Up.ctv(Bot)  $\approx$  Down.ctv(Mid)

## Scala 2.x algorithm to select the Right Call

- Get signature from static types; Linearize receiver dynamic type to find it
- Other languages (and Scala 1.x) use other algorithms
- Don't do it in Real Projects

*Courtesy of Antoine Beugnard (Telecom Bretagne)*

<http://public.enst-bretagne.fr/~beugnard/papiers/lb-sem.shtml>

# Don't mix Parameters' and Receiver Variances

```
class Top
class Middle extends Top
class Bottom extends Middle
class Up {
  def cv(t:Top) = "Up"
  def inv(m:Middle) = "Up"
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class Down extends Up {
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# Polymorphism Bounds

## Refine your polymorphism

```
scala> def cacophony[T](things: Seq[T]) = things map (_.sound)
<console>:7: error: value sound is not a member of type parameter T
    def cacophony[T](things: Seq[T]) = things map (_.sound)
```

```
scala> def biophony[T <: Animal](things: Seq[T]) = things map (_.sound)
biophony: [T <: Animal](things: Seq[T])Seq[java.lang.String]
```

```
scala> biophony(Seq(new Chicken, new Bird))
res5: Seq[java.lang.String] = List(cluck, call)
```

- biophony takes any T that *is-a* Animal

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```

► biophony takes any T that *is-a* Animal

Lower bound: List[T] defines ::(elem T) but also ::(U >: T)

```
scala> val flock = List(new Bird, new Bird)
flock: List[Bird] = List(Bird@7e1ec70e, Bird@169ea8d2)
```

```
scala> new Chicken :: flock
res6: List[Bird] = List(Chicken@56fbda05, Bird@7e1ec70e, Bird@169ea8d2)
```

```
scala> new Animal :: flock
res7: List[Animal] = List(Animal@56fbda05, Bird@7e1ec70e, Bird@169ea8d2)
```

# More on Polymorphism

Quantification: When one you don't care about one type

```
scala> def count[A](l: List[A]) = l.size
count: [A](List[A])Int           # A is useless

scala> def count(l: List[_]) = l.size
count: (List[_])Int              # It's thus omitted
```

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**Structural Types:** specify type requirements by interface structure

```
scala> def foo(x: { def get: Int }) = 123 + x.get
foo: (x: AnyRef{def get: Int})Int

scala> foo(new { def get = 10 })
res0: Int = 133
```

- ▶ x parameter must be provided with a get function to be concrete
- ▶ The second class makes an ad-hoc anonymous class

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- ▶ x parameter must be provided with a get function to be concrete
- ▶ The second class makes an ad-hoc anonymous class

## Erasure

- ▶ Unfortunately, the JVM erases every type specialization
- ▶ From List[Int], only List[\_] remains at runtime

# Take Home Messages

## Functional Programming

- ▶ Avoid mutable values, prefer expressions over statements
- ▶ **Higher Order**: pass functions as parameters (to factorize behavior)
- ▶ **Partially Applied Functions**: Function objects as first-class citizens
- ▶ **Closures**: functions that encapsulate some external state
- ▶ **Currying**: functions with multiple parameter lists
- ▶ **Parametrized types**: containers such as `Tree[A]`
- ▶ **Variance** permits to refine what we expect (the type system to our rescue)  
But don't mess with Receiver and Parameters' variances at the same time

## FP in Scala

- ▶ Having both OOP and FP is nice and funny, but that's a lot of tools
- ▶ Getting used to them requires a lot of practice
- ▶ Some Scala choices are very debatable (it targets the Java ecosystem)