Computer Programming with Scala

Week 3: Functional Programming (FP)

Martin Quinson

November 2015

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 ⇝ 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 `\:`

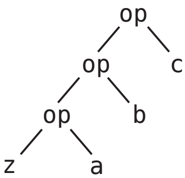
- Reduce all elements into a single value using the provided function

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

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

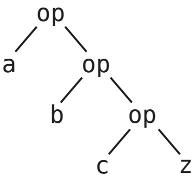
- `(z /:  xs) (op)` z: initial value, xs: list, op: operation to apply

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



Fold Left

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



Fold Right

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

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

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

scala> val b = sum(1, _:Int , 3)            # Here, only one parameter remains
b: Int => Int = <function1>                 # 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 $\rightsquigarrow$ 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

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

```scala
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 wi

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

- This explains the :/ syntax

Function Composition

```scala
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
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
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

```
trait 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)

```
trait 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)

```
trait 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?

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?
- 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

- 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?
- 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

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 sub-typing

```
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`

Variance and sub-typing

```
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`

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 sub-typing

```
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`

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

Don't mix Parameters' and Receiver Variances

```scala
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)	Up		
?.cv(Middle)	Up		
?.cv(Bottom)	Up		
?.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

Don't mix Parameters' and Receiver Variances

```scala
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)	Up		
?.cv(Middle)	Up		
?.cv(Bottom)	Up		
?.inv(Top)	Error		
?.inv(Middle)	Up		
?.inv(Bottom)	Up		
?.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`

Don't mix Parameters' and Receiver Variances

```scala
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)	Up		
?.cv(Middle)	Up		
?.cv(Bottom)	Up		
?.inv(Top)	Error		
?.inv(Middle)	Up		
?.inv(Bottom)	Up		
?.ctv(Top)	Error		
?.ctv(Middle)	Error		
?.ctv(Bottom)	Up		

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"
  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)	Up	Up	
?.cv(Middle)	Up	Down	
?.cv(Bottom)	Up	Down	
?.inv(Top)	Error		
?.inv(Middle)	Up		
?.inv(Bottom)	Up		
?.ctv(Top)	Error		
?.ctv(Middle)	Error		
?.ctv(Bottom)	Up		

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"
  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)	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

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"
  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)	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) ≈ 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"
  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)	Up	Up	Up
?.cv(Middle)	Up	Down	Up
?.cv(Bottom)	Up	Down	Up
?.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) ≈ 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"
  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)	Up	Up	Up
?.cv(Middle)	Up	Down	Up
?.cv(Bottom)	Up	Down	Up
?.inv(Top)	Error	Error	Error
?.inv(Middle)	Up	Down	Down
?.inv(Bottom)	Up	Down	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) ≈ 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"
  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)	Up	Up	Up
?.cv(Middle)	Up	Down	Up
?.cv(Bottom)	Up	Down	Up
?.inv(Top)	Error	Error	Error
?.inv(Middle)	Up	Down	Down
?.inv(Bottom)	Up	Down	Down
?.ctv(Top)	Error	Error	Error
?.ctv(Middle)	Error	Down	Error
?.ctv(Bottom)	Up	Error	Up

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`

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

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

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)
```

Other Polymorphism Bounds

View bounds: Filter things that can be *viewed as*

```
scala> math.max("123", 111)
res1: Int = 123    # Works thanks to the (String -> Int) implicit conversion

scala> class Container[A <% Int] { def addIt(x: A) = 123 + x }
defined class Container   # Accepts everything that can be converted to an Int
```

Other Polymorphism Bounds

View bounds: Filter things that can be *viewed as*

```
scala> math.max("123", 111)
res1: Int = 123    # Works thanks to the (String -> Int) implicit conversion

scala> class Container[A <% Int] { def addIt(x: A) = 123 + x }
defined class Container   # Accepts everything that can be converted to an Int
```

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
```

Other Polymorphism Bounds

View bounds: Filter things that can be *viewed as*

```
scala> math.max("123", 111)
res1: Int = 123    # Works thanks to the (String -> Int) implicit conversion

scala> class Container[A <% Int] { def addIt(x: A) = 123 + x }
defined class Container   # Accepts everything that can be converted to an Int
```

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
```

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   # Abstract until a get() function is defined

scala> foo(new { def get = 10 })    # This creates an ad-hoc anonymous class
res0: Int = 133
```

Type Erasure and Manifest

Erasure

- Unfortunately, the JVM erases every type specialization
- From `List[Int]`, only `List[_]` remains at runtime
- Generics added in Java5 (2004); Erasure avoids major changes on runtime
- Unfortunate: some cast errors may be missed

Manifest and TypeTags

- Scala stores the erased information, You can retrieve it at run time
- But the interface is still changing (Manifest in pre-2.10, TypeTags after)
- And it's still rather cumbersome. It will probably further evolve
- Or the Valhalla Project will success and the JVM will get fixed at least
  `http://openjdk.java.net/projects/valhalla/`

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 debatable: targets Java ecosystem, bound to technology