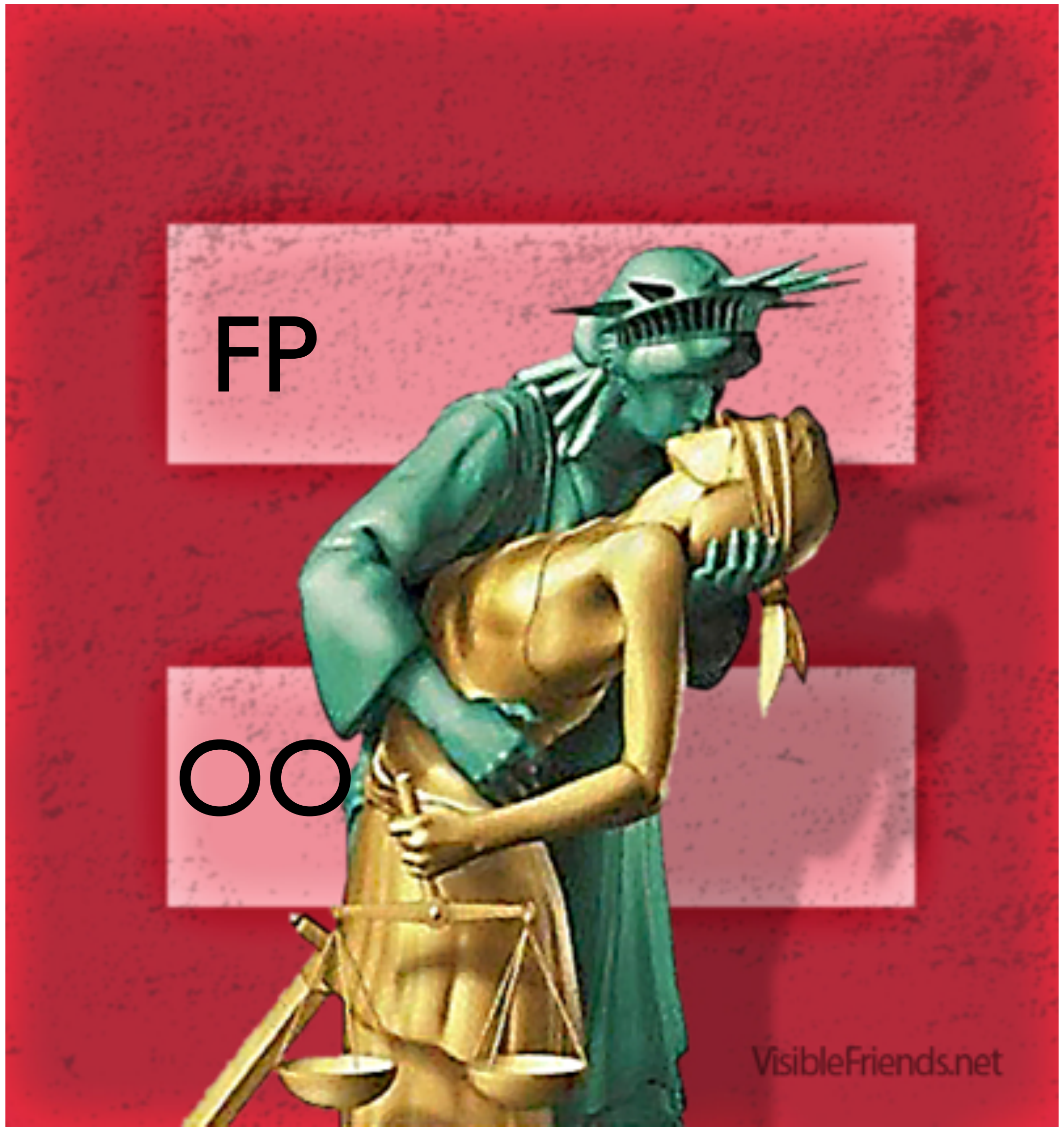
# Scala, an equal marriage
## Part 2




Jacques.Noye@Mines-Nantes.fr

# Methods and functions

# Abstract point of view

## A method is a *function*

```
class C {
   ...
   def m(a1: A1, ..., an: An):B = ...
   ...
}
```

*m* is a *function* (maths)

```
m : C x A1 x ... x An -> B
    (this, a1, ..., an) -> m(this, a1, ..., an)
```

# Concrete point of view

## A method is not a (first-class) function

```
scala> def inc(x: Int) = x + 1
add: (Int)Int

scala> val z = inc(2)
z: Int = 3

scala> inc
<console>:7: error: missing arguments for method inc in object
$iw;
follow this method with `_' if you want to treat it as a
partially applied function
       inc
       ^
```

A method is only available as a name to be used in a method call. It is not available as a value.

Note: toplevel definitions are actually made members of an internal object.
Try `scala -Xprint:parser` (scary).

# First-class functions in Scala

a function literal

```
scala> val inc = (x: Int) => x + 1
add: (Int) => Int = <function1>

scala> val z = inc(2)
z: Int = 3

scala> inc
res1: (Int) => Int = <function1>

scala> println(inc)
<function1>
```

a function value
an object

# Implementation Principle (in Java)

```
public interface Function1<T1, T> {
   T apply(T1 e1);
}
public class Inc implements Function1<Integer, Integer> {
   public Integer apply(Integer e1) {
      return e1 + 1;
   }
   public static void main(String[] args){
      Function1<Integer, Integer> inc = new Inc();
      Integer z = inc.apply(2);
      System.out.println(z);
      System.out.println(inc);
   }
}
```

creating the function

# Implementation Principle (in Java)

```java
public interface Function1<T1, T> {
   T apply(T1 e1);
}
public class Inc implements Function1<Integer, Integer> {
   public Integer apply(Integer e1) {
      return e1 + 1;
   }
   public static void main(String[
      Function1<Integer, Integer> i
      Integer z = inc.apply(2);
      System.out.println(z);
      System.out.println(inc);
   }
}
```

calling the function

Note: this is not as easy in the general case (closure).

# Using an anonymous Java class

```
public interface Function1<T1, T> {
   T apply(T1 e1);
}
public class Test1 {
  public static void main(String[] args){
    Function1<Integer,Integer> inc =
      new Function1<Integer, Integer>(){
        public Integer apply(Integer e1) {
          return e1 + 1;
      }
    };
    Integer z = inc.apply(2);
    System.out.println(z);
    System.out.println(inc);
  }
}
```

instantiation of the anonymous class, which implements `Function1`

# Implementation Principle (in Scala)

```
scala> val inc = new Function1[Int, Int]{
     |              def apply(e1: Int) = e1 + 1
     |            }
inc: Integer => Integer = <function1>

scala> inc.apply(2)
res4: Integer = 3

scala> inc(2)
res5: Integer = 3

scala> inc{2}
res6: Int = 2
```

instantiation of the anonymous class, which inherits the trait `Function1`

when there is a single parameter

Note: the anonymous class is instantiated, not the trait.

# The trait $\texttt{Function}_n$

variance
annotations
(on the definition side)

```
trait Function_n[-T_1, ..., -T_n, +R] {
  def apply(x_1: T_1, ..., x_n: T_n): R
  override def toString = "<function_n>"
}
```

This is the usual rule: function types are covariant (+) in their result type and contravariant (–) in their argument type.

# Variance

if `S <: T` then

- Covariance: `U[..., S, ...] <: U[..., T, ...]`
- Contravariance: `U[..., S, ...] :> U[..., T, ...]`
- Nonvariance: `U[..., S, ...]` and `U[..., T, ...]` cannot be compared

# Turning a method into a function

```
scala> def inc(x: Int) = x + 1
add: (Int)Int

scala> val incF = (x: Int) => inc(x)
incF: Int => Int = <function1>

scala> def add(x: Int, y: Int) = x + y
add: (x: Int, y: Int)Int

scala> val addF = (x: Int, y: Int) => add(x, y)
addF: (Int, Int) => Int = <function2>
```

Note: compare the answers for `def` and `val`.

# Using partial application

## Explicit

```
scala> val incF = inc _
incF: Int => Int = <function1>

scala> val addF = add _
addF: (Int, Int) => Int = <function2>
```

## Implicit

```
scala> val incF: Int => Int = inc
incF: Int => Int = <function1>

scala> val addF: addF: (Int, Int) = add
addF: (Int, Int) => Int = <function2>
```

# Using partial application

```
scala> val incF = (_: Int) + 1
incF: Int => Int = <function1>

scala> val addF = (_: Int) + (_: Int)
addF: (Int, Int) => Int = <function2>
```

```
scala> val incF: Int => Int = _ + 1
incF: Int => Int = <function1>

scala> val addF: addF: (Int, Int) = _ + _
addF: (Int, Int) => Int = <function2>
```

# Curried methods

```
scala> val addF = (x: Int, y: Int) => x + 1
addF: (Int, Int) => Int = <function2>

scala> val inc = addF(_:Int, 1)
inc: Int => Int = <function1>

scala> val inc = addF(1, _:Int)
inc: Int => Int = <function1>
```

partial application applies to any argument

```
scala> def addC(x: Int) (y: Int) = x + y // curried method
addC: (x: Int)(y: Int)Int

scala> val inc = addC(1)_
inc: Int => Int = <function1>

scala> val inc: Int => Int = addC(1)
inc: Int => Int = <function1>
```

applies to last list of arguments

# Closures

The value of more is fixed here

```
scala> val more = 1
more: Int = 1

scala> val addMore = (x: Int) => x + more
addMore: (Int) => Int = <function1>

scala> addMore(10)
res26: Int = 11

scala> val more = 2
more: Int = 2

scala> addMore(10)
res27: Int = 11
```

# Terminology

- Let us consider the expression *e*

```
(x: Int) => x + more
```

- `x` is bound in *e* (it appears as a parameter)
- `more` is free in *e* (it is defined elsewhere)
- The value of *e* is a closure (*e* is closed over its free variables)

# Closures

## with mutable free variables

The "value" of more is fixed here

```
scala> var more = 1
more: Int = 1

scala> val addMore = (x: Int) => x + more
addMore: (Int) => Int = <function1>

scala> addMore(10)
res26: Int = 11

scala> more = 2
more: Int = 2

scala> addMore(10)
res27: Int = 12
```

# Parameter passing

- By value, by default
- By name with by-name parameters: compare:

```
def assert(test: Boolean) =
  if (assertionEnable && !test)
    throw new assertion
def assert(test: () => Boolean) =
  if (assertionEnable && !test())
    throw new assertion
def assert(test: => Boolean) =
  if (assertionEnable && !test)
    throw new assertion
```

test is a by-name parameter

# Lists

## Typing, pattern matching and higher-order programming

# Inductive definition

- A list is
  - either an empty list `Nil`
  - or a list `x :: l` consisting of an element `x`, *head* of the list, and of a list `l`, *tail* of the list (`::` is the *cons* operator).

# Building lists

singleton type {Nil, null}

```
scala> Nil
res0: scala.collection.immutable.Nil.type = List()

scala> 1 :: Nil
res1: List[Int] = List(1)

scala> val l = 1 :: (2 :: Nil)
l: List[Int] = List(1, 2)

scala> val tail = 2 :: Nil
tail: List[Int] = List(2)

scala> val l = 1 :: tail
l: List[Int] = List(1, 2)
```

`::` is right-associative

# Building lists with the constructor `List`

```
scala> val l = List(1, 2, 3)
l: List[Int] = List(1, 2, 3)

scala> val l = List(1) :: Nil
l: List[List[Int]] = List(List(1))

scala> val l = 1 :: List(1) :: Nil
l: List[Any] = List(1, List(1))
```

This uses the "apply trick":

A variable nb of args.
xs is of type Seq[A]

```
object List {
  def apply[A](xs: A*): List[A] = xs.toList
}
```

# Typing

- Lists are homogeneous: all the elements are considered to have the same type `T` The list has type `List[T]`.
- Lists are covariants:

```
abstract class List[+T] {
  ...
}
```

# Covariance and subtyping

- If `S <: T` then `List[S] <: List[T]`
- If an apple is a fruit then a basket of apples is a basket of fruits.
- If `S1 <: T` and `S2 <:T` then a list of `S1` and `S2` is a list of `T`

new

- Mixing cabbages and carrots in a basket results in a basket of vegetables.

# The empty list

```
scala> val l = List()
l: List[Nothing] = List()

scala> val l: List[Int] = empty
l: List[Int] = List()
```

- `Nothing` is the smallest type: for all `T`, `Nothing` <: `T`
- `List[Nothing]` <: `List[T]`
- `T = Int`: the empty list is a list of integers

# Accessors

```
scala> val numbers = List(1, 2, 3)
numbers: List[Int] = List(1, 2, 3)

scala> numbers(1)
res5: Int = 2

scala> numbers.head
res6: Int = 1

scala> numbers.tail
res7: List[Int] = List(2, 3)

scala> numbers.isEmpty
res8: Boolean = false

scala> Nil.head
java.util.NoSuchElementException: head of empty
list
```

# Computing with lists

## basic idiom: follow the inductive definition

```
scala> def length[T](l: List[T]): Int =
     if (l.isEmpty) 0
     else 1 + length(l.tail)
length: [T](l: List[T])Int

scala> length[Int](List(1, 2, 3))
res0: Int = 3
```

# Immutability

```
scala> var e = 1
e: Int = 1

scala> val l = List(e)
l: List[Int] = List(1)

scala> e = 2
e: Int = 2

scala> l
res0: List[Int] = List(1)
```

Note: compare with closures.

# Modifying a list

## Copying the list with the modifications!

```
scala> def append[T](l1: List[T], l2: List[T]): List[T] =
    if (l1.isEmpty) l2
    else l1.head :: append(l1.tail, l2)
append: [T](l1: List[T],l2: List[T])List[T]

scala> append(List(1, 2), List(3, 4))
res0: List[Int] = List(1, 2, 3, 4)

scala> append(List(1, 2), List("3", "4"))
res1: List[Any] = List(1, 2, "3", "4")
```

A thrill

# Patterns

```
scala> val h :: t = List(1, 2)
h: Int = 1
t: List[Int] = List(2)

scala> val e1 :: e2 :: Nil = List(1, 2)
e1: Int = 1
e2: Int = 2

scala> val List(_, x) = List(1, 2)
x: Int = 2

scala> val List(1, x) = List(2, 1)
scala.MatchError: List(2, 1)
```

# The construct `match`

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

def append[T](l1: List[T], l2: List[T]): List[T] =
  l1 match {
    case Nil => l2
    case h1 :: t1 => h1 :: append(t1, l2)
  }
```

Note: the compiler detects non exhaustive patterns.

# A case sequence is a (partial) function literal

```
scala> val isEmpty: List[Int] => Boolean =
{case Nil => true; case _ :: _ => false}
isEmpty: List[Int] => Boolean = <function1>
```

*Partial functions* (instances of `PartialFunction[-A, +B]`) extend functions of one argument with a method:

```
def isDefinedAt(x: A): Boolean
```

# Pattern Matching

The expression `{ case` *p1* `=>` *e1*`; …; case` *pn* `=>` *en* `}`

is a partial function:

- `isDefinedAt` returns `true` if one of the patterns matches, `false` otherwise
- `apply` returns the value of $e$ for the first pattern $p$ which matches, throws `MatchError` otherwise

# Other basic patterns

- Typed Patterns: *varId* `:` *Type* (checks type of *varId*, as *varId*`.isInstanceOf[`*Type*`]`)
- Pattern Binders: *varId*`@`*Pattern* (binds matched value to *varId*)

# The class `List`

```
object List extends SeqFactory {
  def apply[A](xs: A*): List[A] = xs.toList
}
abstract class List[+T] {
  def isEmpty: Boolean
  def head: T
  def tail: List[T]

  def ::[U >: T](x: U): List[U] = new ::(x, this)
}

case object Nil extends List[Nothing] {
  ...
}
case class ::[T](h: T, tl: List[T]) extends List[T] {
  ...
}
```

to get an *extractor*

lower type bound

*case* object and class

There are also upper bounds: `U <: Upper >: Lower`

# Case classes

Syntactic convenience:

- Adds a factory method with the class (`new` not needed)
- Parameters turned into fields
- Creates methods `toString`, `hashCode`, and `equals`
- Supports pattern matching (`::` and `Nil` for lists)

# Typical AST example

```
abstract class Expr
case class BinExpr(op: String, e1: Expr, e2: Expr) extends Expr
case class UnExpr(op: String, e: Expr) extends Expr
case class Number(n: Int) extends Expr

object Eval {
  def eval(e: Expr): Int = e match {
    case Number(n) => n
    case BinExpr("+", e1, e2) => eval(e1) + eval(e2)
    case BinExpr("-", e1, e2) => eval(e1) - eval(e2)
    case UnExpr("-", e) => - eval(e)
  }
  def main(args : Array[String]) =
    println(eval(BinExpr("+", Number(1), UnExpr("-", Number(1)))))
}
```

# The lower bound is not an option

```
scala> :paste
// Entering paste mode (ctrl-D to finish)

abstract class MyList[+T] {
  def ::(x: T): MyList[T] = new ::(x, this)
}
case object Nil extends MyList[Nothing]
case class ::[T](h: T, tl: MyList[T]) extends MyList[T]

// Exiting paste mode, now interpreting.


<console>:12: error: covariant type T occurs in
contravariant position in type T of value x
         def ::(x: T): MyList[T] = new ::(x, this)
                ^
```

detected by the compiler

# Extractors

Un *extractor* is an object which provides a method `apply` (optional) and `unapply` (mandatory) to construct and destruct a pattern, respectively.

```
object Pair {
  def apply[A, B](x: A, y:B) = Tuple2(x, y)
  def unapply[A, B](x: Tuple2[A, B]): Option[Tuple2[A, B]] = Some(x)
}
```

# Capturing recursion patterns
# `map`

```
def mapInc(xs: List[Int]): List[Int] = xs match {
  case Nil => Nil
  case x :: xs => x + 1 :: mapInc(xs)
}
def map2String(xs: List[Int]): List[String] = xs match {
  case Nil => Nil
  case x :: xs => x.toString :: map2String(xs)
}
```

↓ 1st generalization

```
def mapInt[T](xs: List[Int], f: Int=>T): List[T] = xs match {
  case Nil => Nil
  case x :: xs => f(x) :: mapInt(xs, f)
}
```

↓ 2nd generalization

```
def map[S, T](xs:List[S], f: S=>T): List[T] = xs match {
  case Nil => Nil
  case x :: xs => f(x) :: map(xs, f)
}
```

# Example of use

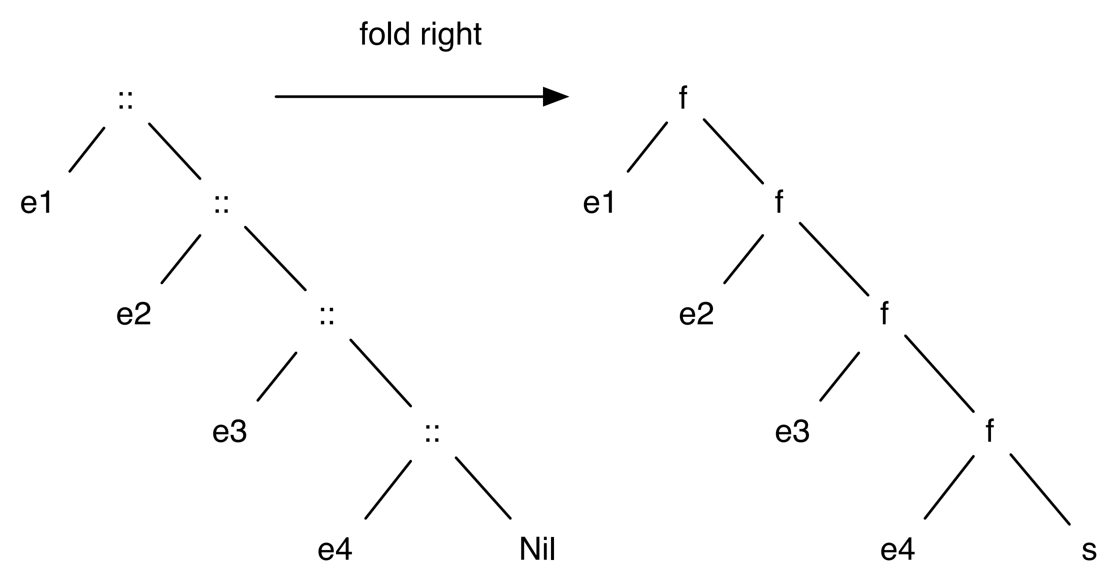
```
def map[S, T](xs:List[S], f: S=>T): List[T] = xs match {
  case Nil => Nil
  case x :: xs => f(x) :: map(xs, f)
}
```

```
scala> map(List(1, 2, 3), (_:Int) + 1)
res18: List[Int] = List(2, 3, 4)

scala> def map2String[S](xs: List[S]) =
  map[S, String](xs, (x: S) => x.toString)
map2String: [S](xs: List[S])List[String]

scala> map2String[Char](List('a', 'b'))
res19: List[String] = List(a, b)
```

# Capturing recursion patterns `foldRight`

```
def sum(xs: List[Int]): Int = xs match {
  case Nil => 0
  case x :: xs => x + sum(xs)
}
```

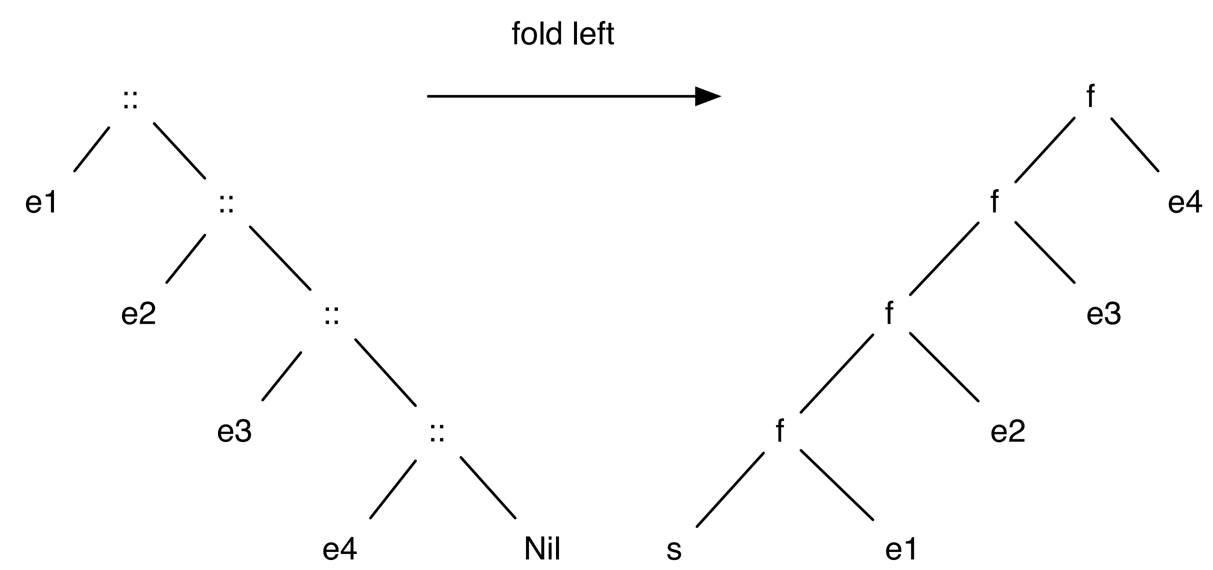
↓ generalization




```
def foldRight[S,T](xs: List[S], s: T, f: (S, T) => T): T = xs match {
  case Nil => s
  case x :: xs => f(x, foldRight(xs, s, f))
}
```

# Capturing recursion patterns
# `foldLeft`

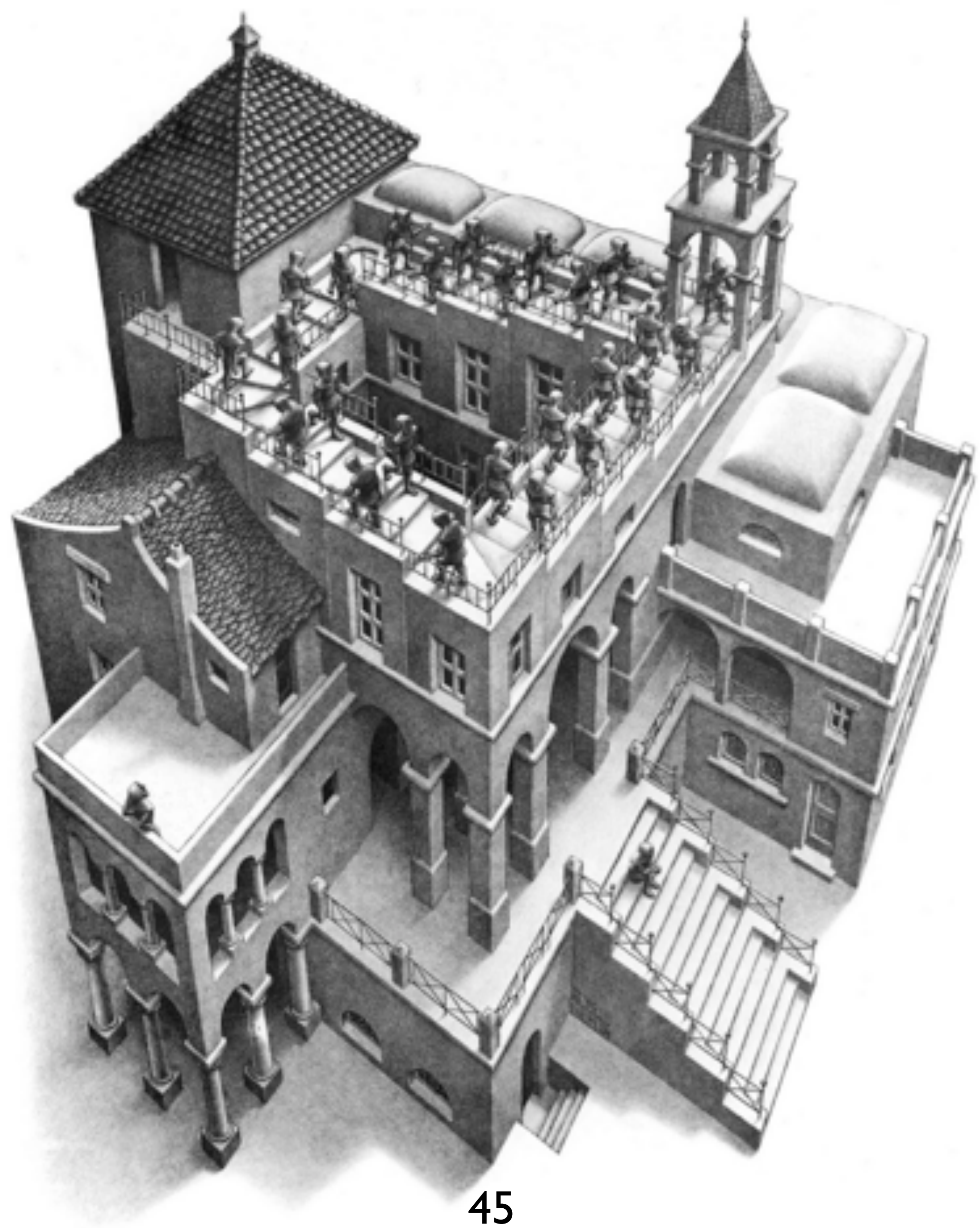
```
def sum(soFar: Int, xs: List[Int]): Int = xs match {
  case Nil => soFar
  case x :: xs => sum(soFar+x, xs)
}
```




↓ generalization

```
def foldLeft[S,T](s: T, xs: List[S], f: (T, S) => T): T = xs match {
  case Nil => s
  case x :: xs => foldLeft(f(s, x), xs, f)
}
```

# for expressions



45

# map & Co as methods

```
def myMap[A, B](f: A => B, xs: List[A]): List[B] = xs match {
  case Nil => Nil
  case x::xs => f(x) :: myMap(f, xs)
}
def myFilter[A](p: A => Boolean, xs: List[A]): List[A] = xs match {
  case Nil => Nil
  case x::xs => if (p(x)) x :: myFilter(p, xs) else myFilter(p, xs)
}
def myFlatMap[A, B](f: A => List[B], xs: List[A]): List[B] = xs match {
  case Nil => Nil
  case x::xs =>  f(x) ::: myFlatMap(f, xs)
}
def myForeach[A](f: A => Unit, xs: List[A]): Unit = xs match {
  case Nil => ()
  case x :: xs => f(x); myForeach(f, xs)
}
```

# map & Co as methods of `List`

```
scala> val words = List("The", "Dark", "Knight", "Rises")
words: List[java.lang.String] = List(The, Dark, Knight, Rises)

scala> words map (_.length)
res9: List[Int] = List(3, 4, 6, 5)

scala> words map (_.toList)
res13: List[List[Char]] = List(List(T, h, e), List(D, a, r, k), List(K, n, i, g, h, t),
List(R, i, s, e, s))

scala> words filter (_.length > 3)
res10: List[java.lang.String] = List(Dark, Knight, Rises)

scala> words flatMap (_.toList)
res11: List[Char] = List(T, h, e, D, a, r, k, K, n, i, g, h, t, R, i, s, e, s)

scala> words foreach (print _)
TheDarkKnightRises
```

# `for` expressions

## loops and comprehensions

```
-- comprehension in Haskell, ZF
mySort :: Ord a => [a] -> [a]
mySort [] = []
mySort (x:xs) = mySort [e | e <- xs, e<x] ++
                [x] ++
                mySort [e | e <- xs, e>=x]
```

```
for (e <- xs if e < x) yield e
```

`e <- xs` is a *generator*

`if e < x` is a *filter*

# map & Co. using `for` expressions

```
// for comprehensions (yield)
def myMap[A, B](f: A => B, xs: List[A]): List[B] =
  for (x <- xs) yield f(x)

def myFilter[A](p: A => Boolean, xs: List[A]): List[A] =
  for (x <- xs if p(x)) yield x

def myFlatMap[A, B](f: A => List[B], xs: List[A]): List[B] =
  for (x <- xs; y <- f(x)) yield y

// for loop (no yield)
def myForeach[A](f: A => Unit, xs: List[A]): Unit =
  for (x <- xs) f(x)
```

# Translating `for` loops

## A single generator

(1) `for (x <- expr) body →  expr foreach (x => body)`

## Several generators: one loop per generator

(2) `for (x <- expr1; y <- expr2 tail) body`
`→ expr1 foreach (for (y <- expr2 tail) body)`

# Translating `for` comprehensions

## A single generator

(3) `for (x <- expr1) yield expr2` → `expr1 map (x => expr2)`

## A sequence of generators

(4) `for (x <- expr1; y <- expr2 tail) yield expr3`
→ `expr1 flatMap (x => for (y <- expr2 tail) yield expr3)`

# Eliminating filters and definitions

## Filter

(5) *x* `<-` *expr1* `if` *expr2*
→ *x* `<-` *expr1* `filter` `(`*x* `=>` *expr2*`)`

## Definition

(6) *x* `<-` *expr1*`;` *y* `=` *expr2*
→ `(`*x*`,` *y*`)` `<-` `for` `(`*x* `<-` *expr1*`)` `yield` `(`*x*`,` *expr2*`)`

Note: *x*, *expr1*... are metavariables.

# Eliminating patterns

## Refutable pattern in a generator

(0) *p* <- *expr1*
→ *expr1* filter { case *p* => true; case _ => false}

## Irrefutable pattern in a generator requires variants of rules (1) to (6)

(3') for (*p* <- *expr1*) yield *expr2*
→ *expr1* map { case *p* => *expr2* }

Note: full scheme is given in *Scala Language Specifications*.

# Generalization

Translation applied by the compiler.

Applies to any class implementing `map`, `flatMap`, `filter` and `foreach` (possibly partially).

For instance:

```
scala> val a = Array(1, 2, 3)
a: Array[Int] = Array(1, 2, 3)
scala> for (i <- 0 to 2) print(a(i))
123
scala> 0 to 2
res1: scala.collection.immutable.Range.Inclusive = Range(0, 1, 2)
scala> for (x <- a) print(x)
123
scala> for (i <- 0 to 2) yield a(i)
res2: scala.collection.immutable.IndexedSeq[Int] = Vector(1, 2, 3)
scala> for (x <- a) yield x
res3: Array[Int] = Array(1, 2, 3)
```

the type of the result depends on the generator

# Some more fun/headaches

# A case for abstract types

```
scala> :paste
// Entering paste mode (ctrl-D to finish)
class Food
class Grass extends Food

abstract class Animal {
  def eat(food: Food)
}
class Cow extends Animal {
  override def eat(food: Grass){}
}
// Exiting paste mode, now interpreting.

<console>:15: error: class Cow needs to be abstract, since method eat
in class Animal of type (food: Food)Unit is not defined
(Note that Food does not match Grass: class Grass is a subclass of
class Food, but method parameter types must match exactly.)
       class Cow extends Animal {
             ^
<console>:16: error: method eat overrides nothing.
Note: the super classes of class Cow contain the following, non final
members named eat:
def eat(food: Food): Unit
         override def eat(food: Grass){}
```

covariant parameters are unsound

# Abstract types to the rescue

```
class Food
class Grass extends Food
class Fish extends Food

abstract class Animal {
  type SuitableFood <: Food // abstract type with upper bound
  def eat(food: SuitableFood)
}
class Cow extends Animal {
  type SuitableFood = Grass // concrete type
  override def eat(food: Grass) {}
}
```

# Abstract types to the rescue

```
scala> val bessy = new Cow
bessy: Cow = Cow@6d643e7b

scala> bessy eat (new Grass)

scala> bessy eat (new Fish)
<console>:14: error: type mismatch;
 found   : Fish
 required: Grass
              bessy eat (new Fish)
                         ^
```

# Path-dependent types

```
scala> val bessy:Animal = new Cow
bessy: Animal = Cow@647a303a

scala> bessy eat (new Grass)
<console>:13: error: type mismatch;
 found   : Grass
 required: bessy.SuitableFood
              bessy eat (new Grass)

scala> val bessy = new Cow
bessy: Cow = Cow@575db0f5

scala> val lili = new Cow
lili: Cow = Cow@1416c1f4

scala> lili eat (new bessy.SuitableFood)
```

path-dependent type

# Path-dependent types and inner classes

```
scala> class Outer {
  class Inner
  }
}
defined class Outer
scala> val o1 = new Outer
o1: Outer = Outer@2029a303
scala> val i1 = new o1.Inner
i1: o1.Inner = Outer$Inner@200069ed
scala> val o2 = new Outer
o2: Outer = Outer@badfba
scala> val i2 = new o2.Inner
i2: o2.Inner = Outer$Inner@6ec4786e
scala> val l = List(i1, i2)
l: List[Outer#Inner] = List(Outer$Inner@200069ed,
Outer$Inner@6ec4786e)
```

creating an inner instance

type projection (an Inner from any Outer)

# (Simple) Types

| Type | Syntax |
|---|---|
| Class or trait | `class C ...`, `trait C ...` |
| Tuple type | ($T_1$, ..., $T_n$) |
| Function type | ($T_1$, ..., $T_n$) => $T$ |
| Annotated type | $T$ @A |
| Parameterized type | A[$T_1$, ..., $T_n$] |
| Singleton type | *value*.type |
| Type projection | *O#I* |
| Compound type | $T_1$ with $T_2$ with ... with $T_n$ { *declarations* } |
| Infix type | $T_1$ A $T_2$ |
| Existential type | $T$ forSome { *type and val declarations* } |

Simple: not qualified.

From *Scala for the Impatient*

# Compound types

## structural subtyping

```
case class Bird(val name: String) {
  def fly(height: Int) = {}
}
case class Plane(val callsign: String) {
  def fly(height: Int) = {}
}
def takeoff(
      runway: Int,
      r: {val callsign: String; def fly(height: Int)}) = {
   r.fly(1000)
}
val bird = new Bird("Polly the parrot"){ val callsign = name }
val a380 = new Plane("TZ-987")
takeoff(42, bird)
takeoff(89, a380)
```

refinement

Note: uses reflection at runtime.

# Existential types

*T* `forSome { ` *decls* ` }`

- Mainly used for interoperability with Java
- Java:
  - `Iterator<?>`
  - `Iterator<? extends Component>`
- Scala:
  - `Iterator<?> **forSome** { **type** T }` or `Iterator[_]`
  - `Iterator[T] **forSome** { **type** T <: Component }`

# Actors

# Concurrency paradigms (asynchronous)

- Shared memory
  - Pessimistic protocols: locking, monitors (Java)
  - Optimistic protocols: transactional memory
- Shared nothing
  - Synchronous message passing (Ada's rendez-vous)
  - Asynchronous message passing (Actor's mailbox)

# Bounded Buffer v1.0
# à la Java

```scala
class Buffer(capacity: Int) {
  protected val data = new Array[AnyRef](capacity)
  protected var in, out, count = 0

  def put(o: AnyRef): Unit = { ... }
  def get(): AnyRef = { ... }

  def await(cond: => Boolean) = // parameter by name
    while (!cond) { wait() }
}
```

# Bounded Buffer v1.0 put and get

```
def put(o: AnyRef) =
  synchronized {
    await(count < capacity)
    data(in) = o
    count += 1; in = (in + 1) % capacity
    if (count == 1) notifyAll()
  }
def get() = {
  synchronized {
    await(count != 0)
    val o = data(out); data(out) = null
    count -= 1; out = (out + 1) % capacity
    if (count == capacity - 1) notifyAll()
    o
  }
    }
```

# Producers and Consumers

```
class Producer(buf: Buffer) extends Runnable {
  new Thread(this).start()

  def run() =
    while(true) buf.put(new Product())
}
class Consumer(buf: Buffer) extends Runnable {
  new Thread(this).start()

  def run() =
    while(true) buf.get()
}
```

# Actors

[Hewitt-Bishop-Steiger:ijcai73, Agha:86]

- Actors are named concurrent autonomous entities with local state that interact which each other through asynchronous message passing (each actor has its own mailbox).
- Fair scheduling: Messages are eventually delivered. No actor can permanently starve. An actor can still misbehave!
- Location transparency and mobility.

R.K. Karmani and A. Shali and G. Agha, Actor frameworks for the JVM platform: a comparative analysis, Proc. of the 7th Intl Conf. on Principles and Practice of Programming in Java, 2009

# Actors in Scala

- Inherited from Erlang [Armstrong:86]
- Impure in many ways (bad and good)
- Thread-based and event-based actors
- Remote actors (no migration)

P. Haller and M. Odersky, Scala Actors: Unifying thread-based and event-based programming, Theoretical Computer Science, 410(2-3), 2009

# Creating Actors

```
import scala.actors.Actor

class Acteur(name: String, surname: String) extends Actor {
  def act(): Unit = {
    while (true)
      println("Bonjour, je suis " + name + " " + surname)
  }
}
object Take1 {
  def main(args: Array[String]) = {
    new Acteur("Laura", "Smet").start()
    new Acteur("Louis", "Garrel").start()
  }
}
```

Think about `Thread` and `run()` (but `Actor` is a *trait*)

# Creating actors - Take 2

```
import scala.actors.Actor.actor

object Take2 {
  def main(args: Array[String]) = {
    private def loop(name: String, surname: String) =
      while (true)
        println("Bonjour, je suis " + name + " " + surname)

    actor { loop("Laura", "Smet") }
    actor { loop("Louis", "Garrel") }
  }
}
```

# Sending and Receiving Messages

```
case object Bonjour
case object Malotru

val louis = actor {
    receive { case Bonjour => sender ! Bonjour }
}
val laura = actor {
    louis ! Bonjour
    receive {
        case Bonjour =>
        case _ => sender ! Malotru
    }
}
```

sending a message

# Syntactic Sugar for Replies

```
val louis = actor {
    receive { case Bonjour => reply(Bonjour) }
}
val laura = actor {
    louis ! Bonjour
    receive {
        case Bonjour =>
        case _ => reply(Malotru)
    }
}
```

sender ! *message* □ reply(*message*)

# Two-way messages

```
val louis = actor {
    receive { case Bonjour => reply(Bonjour) }
}
val laura = actor {
    louis !? Bonjour match {
        case Bonjour =>
        case _ => reply(Malotru)
    }
}
```

sender ! *message* ; receive { case r => r}

□ sender !? *message*

# There is more to it

- Forwarding: the expression *actor* `forward` *message* sends *message* to *actor* on the behalf of `sender`
- Futures: non-blocking version of `!?`
- Receive with timeout: `receiveWithin`

# Actors, Objects and Threads

- this and self: this denotes the current object and self the current actor (they are different when `actor { body }` is used).
- So far, actors are *thread-based* (each actor is associated a thread) and each thread can be seen as an actor.

# Each Thread is an Actor

```
object SelfActor {
  def main(args: Array[String]) = {
    self ! Hello
    receive { case Hello => println("I am an actor!")}
  }
}
```

# Each Actor is a Thread

## (Not quite)

```
import scala.actors.Actor._

object Main4 {
   def main(args: Array[String]) =
      println(currentThread);
      actor { println(currentThread) }
}
```

**Output:**

```
Thread[main,5,main]
Thread[ForkJoinPool-1-worker-1,5,main]
```

# `actor` vs `actor`

## Scala shows off

- `actor`, `!`, `receive` are not specific Scala keywords!
- There is not a single mention of actors in The Scala Language Specification.
- Actors are implemented as a library: `scala.actor`.

# The trait and object Actor

```
trait Actor {
  val mailbox = new Queue[Any]
  def !(msg: Any): Unit = ...
  def receive[R](f: PartialFunction[Any, R]): R = ...
  ...
}
object Actor {
  def self: Actor = ...
  def actor(Body: => Unit): Actor = ...
  ...
}
```

# Message sending

- Enqueues the message in the receiving actor's mailbox
- If the receiving actor is waiting for the message, the actor is resumed

# Message reception

`receive { f }`

- The mailbox is scanned for expected messages (messages `m` such that `f.isDefinedAt(m)` returns `true`).
- If there is such a message, it is removed from the mailbox and `f` is applied to it.
- If not, the actor is suspended.

# Event-based vs Thread-Based Actors

- There are two ways to store continuations:
  - as frames on the (actor's thread) stack: *thread-based actors*
  - as a term on the heap (referenced by an instance variable of the actor) : *event-based actors*
- Event-based threads can be seen as event handlers: each execution of the actor's body is executed by a worker taken from a thread pool.

# Syntax

- Thread-based

```
val louis = actor {
  while (true) {
    receive { case Bonjour => sender ! Bonjour }
  }
}
```

- Event-based

```
val louis = actor {
  loop {
    react { case Bonjour => sender ! Bonjour }
  }
}
```

Huh?

# react vs receive

```
trait Actor {
  def receive[R](f: PartialFunction[Any, R]): R = ...
  def react(f: PartialFunction[Any, Unit]): Nothing = ...
  ...
}
```

Calling react never returns: the rest of the computation (the continuation) is defined in `f`.

# Message handling

- When the actor is suspended, the continuation is stored in the actor and the thread executing the actor is released.
- A message send checks whether the actor is thread-based or event-based.
  - Thread-based: the underlying thread is resumed.
  - Event-based: a new task (handled by a thread pool) is created with the current continuation as a parameter.

# Bounded Buffer v2.0

(Based on example from Scala's distribution)

```scala
class Buffer(size: Int) {
   private case class Put(x: AnyRef)
   private case object Get

  private val buffer = actor { ... }

  def put(o: Object) { buffer !? Put(o) }
  def get: Object = (buffer !? Get).asInstanceOf[AnyRef]
}
```

# Bounded Buffer v2.0

```
private val buffer = actor {
  val data = new Array[AnyRef](capacity)
  var in, out, count = 0
  loop {  react {
            case Put(o) if count < capacity =>
              data(in) = o
              count += 1; in = (in + 1) % capacity
              reply()
            case Get if count > 0 =>
              val o = data(out); data = null
              count -= 1; out = (out + 1) % capacity
              reply(o)
          }
        }
}
```

# Comments

- How is it that we don't need to care any longer about notifications?
- What do we gain?

```java
public class Buffer {
  protected Object[] data;
  protected int in, out, count = 0;
  protected final int capacity;

  public Buffer(int capacity) {
    this.capacity = capacity;
      data = new Object[capacity];
  }
  public synchronized void put(Object o) {
    while (count==capacity)
    try { wait();
      } catch (InterruptedException ex) {}
    data[in] = o;
    ++count;
    in=(in+1) % capacity;
    if (count==1) notify();
  }
  public synchronized Object get() {
    while (count==0)
      try { wait();
      } catch (InterruptedException ex) {}
      Object o = data[out];
      data[out] = null;
      -count;
      out=(out+1) % capacity;
      if (count == capacity - 1) notify();
      return (o);
    }
}
```

```scala
class Buffer(size: Int) {
  private case class Put(x: AnyRef)
  private case object Get
  private case object Stop

  private val buffer = actor {
    val data = new Array[AnyRef](size)
    var in, out, count = 0
    loop {
      react {
        case Put(o) if count < capacity =>
          data(in) = o
          count += 1; in = (in + 1) % capacity
          reply()
        case Get if count > 0 =>
          val o = data(out); data(out) = null
          count -= 1; out = (out + 1) % capacity
          reply(o)
       }
    }
  }

  def put(o: AnyRef) { buffer !? Put(o) }
  def get: Object = (buffer !? Get)
}
```

# Buffer as an actor (v3.0)

```
case class Put(o: Object)
case object Get

class Buffer(size: Int) extends Actor {
   val data = new Array[AnyRef](capacity)
   var in, out, count = 0

   def act() : Unit = {
      loop {  react { // as before
           }
      }
   }
}
```

# Producers and Consumers v3.0

```
class Producer(buf: Buffer) extends Actor {
  def act(): Unit =
    loop { buf !? Put(new Product()) }
}
class Consumer(buf: Buffer) extends Actor {
  def act() : Unit =
    loop { (buf !? Get) }
}
```

# Producers and consumers

## v4.0 (fully asynchronous)

```
case class Put(o: Object)
case object Reply // new
case object Get
case class Reply(o : Object) // new

class Producer(buf: Buffer) extends Actor {
  def act(): Unit = loop {
                      buf ! Put(new Product())
                      react { case Reply => }
                    }
}
class Consumer(buf: Buffer) extends Actor {
  def act() : Unit = loop {
                       buf ! Get
                       react { case Reply(o) => }
                     }
}
```

# Conclusion

- Scala’s extensibility (functions, syntax)
- Scala’s actors are nice but not that easy to use (new programming patterns)
  - Possibility of mixing shared memory with threads (eg to deal with blocking IO) and shared nothing with actors (eg to create a large number of concurrent entities)
  - Quizz: what about sending/receiving mutable objects?

# Conclusion

# Some other stuff to look at

- Scalaz, a library for putting more Haskell in your Scala
- The Typesafe platform: Scala + Akka (distribution) + Play (web programming)

# Scala as

- Food for thought
- Food for action (ie programming)

# It is up to you

- to go farther and higher
- to design and implement even better languages


Mount Everest North Face as seen from the path to the base camp, Tibet. Wikimedia Commons. GNU 1.2.