# Advanced Models and Programs

# The Scala language

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## Agenda

- Object-oriented programming in Scala
  - Classes
  - Singletons (object)
  - Traits
- Compiling and running Scala programs
- Functional programming in Scala
  - Type List[T], higher-order and anonymous functions
  - Case classes and pattern matching
  - The Option[T] type
  - For-expressions (comprehensions à la Linq)
- Type system
  - Generic types
  - Co- and contra-variance
  - Type members

## Scala object-oriented programming

- Scala is designed to
  - work with the Java platform
  - be somewhat easy to pick up if you know Java
  - be much more powerful and concise
- Scala has classes like Java and C#
- And abstract classes
- But no interfaces
- Instead, traits = partial classes

- Get Scala from http://www.scala-lang.org/
- You will also need a Java implementation



## Java and Scala

```
class PrintOptions {
  public static void main(String[] args) {
    for (String arg : args)
      if (arg.startsWith("-"))
        System.out.println(" " + arg.substring(1));
  }
}
```

Singleton class, no statics

Declaration syntax

Array[T] is generic type

```
object PrintOptions {
  def main(args : Array[String]) = {
    for (arg <- args)
      if (arg.startsWith("-"))
        System.out.println(" " + arg.substring(1));
  }
}
```

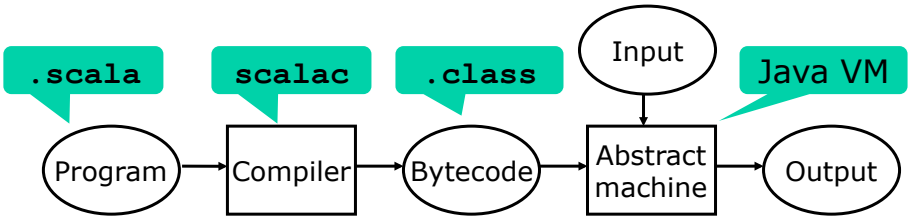
**for** expression

Use Java class libraries

## Compiling and running Scala

- Use **`scalac`** to compile *.scala files
- Use **`scala`** to run the object class file
  - uses **`java`** runtime with Scala's libraries

```
sestoft@mac$ scalac Example.scala
sestoft@mac$ scala PrintOptions -help -verbose do it
 help
 verbose
```






## Interactive Scala

- Scala also has an interactive top-level
  - Like Scheme, F#, most functional languages

```
sestoft@mac $ scala
Welcome to Scala version 2.8.1.final (Java HotSpot(TM))

scala> def fac(n:Int):Int = if (n==0) 1 else n*fac(n-1)
fac: (n: Int)Int

scala> fac(10)
res0: Int = 3628800
```

java.util.BigInteger

```
scala> def fac(n : Int):BigInt = if (n==0) 1 else fac(n-1)*n
fac: (n: Int)BigInt

scala> fac(100)
res1: BigInt = 93326215443944152681699238856266700490715968264381621468592963895217599993229915608941463976156518286253697920827223758251185210916864000000000000000000000000
```

## Much lighter syntax

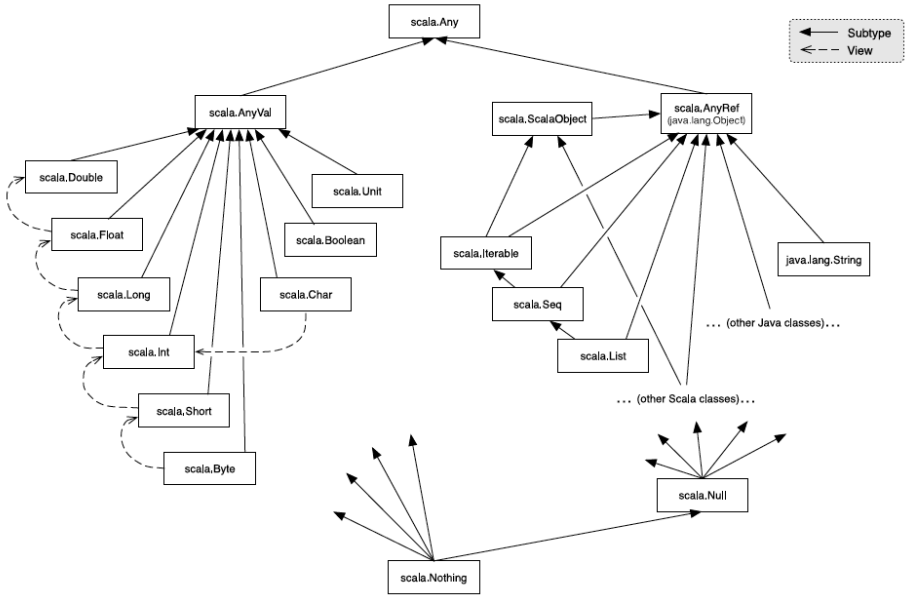
- All declarations start with keyword (no `int x`)
- `void` and `()` and `{}` can often be left out
- All values are objects and have methods
  - So `2.to(10)` is a legal expression
- All operators are methods
  - So `x+y` same as `x.+(y)`
- Method calls can be written infix
  - So `2.to(10)` can be written `2 to 10`

```
for (x <- 2 to 10)
  println(x)
```

Method as infix "operator"



## Uniform type system (like C#)



## Singletons (object declaration)

- Scala has no static fields and methods
- An **object** is a singleton (instance of a) class

```
object PrintOptions {
  def main(args : Array[String]) = {
    ...
  }
}
```

- Can create an Application as a singleton

```
object ListForSum extends Application {
  val xs = List(2,3,5,7,11,13)
  var sum = 0
  for (x <- xs)
    sum += x
  println(sum)
}
```

Immutable, final, readonly

Mutable



## Classes

```
abstract class Person(name : String) {
  def Print
  val Name = name
}
class Student(name : String, programme : String)
  extends Person(name)
{
  def Print {
    println(name + " studies " + programme)
  }
}
```

Field and constructor

Abstract method

Get property

```
object ClassHierarchy extends Application {
  val p : Person = new Student("Ole", "SDT");
  p.Print
  println(p.Name)
}
```

Method call

Property access

## Anonymous subclass and instance

```
val p = new Student("Kasper", "SDT") {
  override def Print {
    super.Print
    println("and does much else")
  }
}
```

Define anonymous subclass of Student, create an instance p

```
scala> p.Print
Kasper studies SDT
and does much else
```

- Same as Java's anonymous inner classes:

Interface

```
pause.addActionListener(new ActionListener() {
  public void actionPerformed(ActionEvent e) {
    canvas.run(false);
  }
});
```

Define anonymous class implementing the interface, & make instance



## Traits: fragments of classes

- Can have fields and methods, no instances

```
trait Counter {
  private var count = 0
  def Increment { count += 1 }
  def Count = count
}
```

- Allows mixin: multiple "base classes"

```
class NumberedPerson(name : String)
  extends Person(name) with Counter {
  def Print {
    Increment
    println(name + " has been printed " + Count + " times")
  }
}
```

Any number of traits can be added

```
val q1 : Person = new NumberedPerson("Hans")
val q2 : Person = new NumberedPerson("Laila")
q1.Print; q1.Print;
q2.Print; q2.Print; q2.Print
```

## Generic class List[T]

- A list
  - has form **`Nil`**, the empty list, or
  - has form **`x::xr`**, first element is **`x`**, rest is **`xr`**

Pronounced "cons"

- A list of integers, type List[Int]:

```
List(1,2,3)
```

```
1 :: 2 :: 3 :: Nil
```

Requires `import scala.collection.immutable._`

- A list of Strings, type List[String]:

```
List("foo", "bar")
```

- A list of pairs, type List[(String, Int)]

```
List(("Peter", 1962), ("Lone", 1960))
```



## Functional programming

- Supported just as well as object-oriented
  - Three ways to print the elements of a list

```
for (x <- xs)
  println(x)
```

```
xs.foreach(println)
```

```
xs foreach println
```

- Anonymous functions; two ways to sum

```
var sum = 0
for (x <- xs)
  sum += x
```

```
var sum = 0
xs foreach (x => sum += x)
```

Like C#

## List functions, pattern matching

- Compute the sum of a list of integers

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

When **xs** has form **Nil**

When **xs** has form **x::xr**

Like F#

- A generic list function

Type parameter

```
def repeat[T](x : T, n : Int) : List[T] = {
  if (n==0)
    Nil
  else
    x :: repeat(x, n-1)
}
```



## Fold and foreach on lists

- Computing a list sum using a fold function

```
def sum(xs : List[Int]) =
    xs.foldLeft(0)((res,x)=>res+x)
```

Value at **Nil**

Value at **x::xr**

- Same, expressed more compactly:

```
def sum(xs : List[Int]) =
    xs.foldLeft(0)(_+_)
```

- Actually, **foreach** is also a function:

```
def foreach[T](xs : List[T], act : T=>Unit) : Unit =
  xs match {
    case Nil    => { }
    case x::xr => { act(x); foreach(xr, act) }
  }
```

## Enumeration types

- A type to represent binary operators

  `+  -  *  /  == !=  <  <=  >  >=`

```
object Operator extends Enumeration {
  val Add, Sub, Mul, Div,
      Eq, Ne, Lt, Le, Gt, Ge = Value
}
```



## Case classes and pattern matching

- Case class objects allow pattern matching
- Good for representing tree data structures
- Example: An Expression is
  - a variable with a name, or
  - a constant integer
  - or a binary operator applied to two expressions

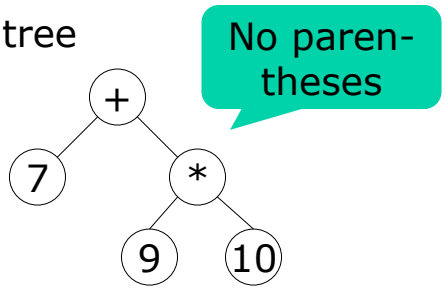
```
abstract class Expression
case class Variable(name : String) extends Expression
case class Constant(value : Int) extends Expression
case class BinOp(op : Operator.Value,
                 e1 : Expression, e2 : Expression)
                 extends Expression
```

## Representation of expressions

- An expression is a tree

```
7 + 9 * 10
```

```
7 + (9 * 10)
```




- Representing it with case class objects:

```
BinOp(Operator.Add,
      Constant(7),
      BinOp(Operator.Mul,
            Constant(9),
            Constant(10)))
```



## Evaluation of expressions

```
def eval(expr : Expression) : Int =
  expr match {
    case Variable(name)  => throw new Exception("ak")
    case Constant(value) => value
    case BinOp(op, e1, e2) => {
      val i1 = eval(e1)
      val i2 = eval(e2)
      op match {
      case Operator.Add => i1+i2
      case Operator.Sub => i1-i2
      case Operator.Mul => i1*i2
      case Operator.Div => i1/i2
      ...
    }
  }
```

```
eval(BinOp(Operator.Add, Constant(42), Constant(27)))
```

## The built-in Option[T] case class

- Values `None` and `Some(x)`
- Same purpose as C# nullable value types

```
def sqrt(x : Double) : Option[Double] =
  if (x<0) None else Some(Math.sqrt(x))
```

- Use pattern matching to distinguish them

```
def mul3(x : Option[Double]) =
  x match {
    case None     => None
    case Some(v)  => Some(3*v)
  }
```



## Scala for-expressions

```
for (x <- primes; if x*x < 100) yield 3*x
```

generator filter transformer

- Just like C#/Linq:

```
from x in primes where x*x < 100 select 3*x
```

- No groupby, orderby
- No built-in aggregates (sum, min, max, ...)

## More for-expression examples

- Example sum

```
sum(for (x <- 1 to 200; if x%5!=0 && x%7!=0)
      yield 1.0/x)
```

```
(from x in Enumerable.Range(1, 200)
 where x%5!=0 && x%7!=0
 select 1.0/x).Sum()
```

C# Linq

- All pairs (i,j) where i>j and i=1..10

```
for (i <- 1 to 10; j <- 1 to i) yield (i,j)
```



## Co-variance and contra-variance

- If generic class C[T] only outputs T's it may be co-variant in T:

```
class C[+T](x : T) {
  def outputT : T = x
}
```

- If generic class C[T] only inputs T's it may be contra-variant in T:

```
class C[-T](x : T) {
  def inputT(y : T) { }
}
```

- Much like C#, with "+" for **out** and "–" for **in**

## Scala co/contra-variance examples

```
trait Iterable[+A] extends ... {
  def iterator : Iterator[A]
}
trait Iterator[+A] extends ... {
  def hasNext : Boolean
  def next() : A
}
```

As for C# IEnumerable, IEnumerator

```
trait MyComparer[-T] {
  def compare(x : T, y : T) : Boolean = ...
}
```

Scala's actual Comparator is from Java and is not contravariant



## Type members in classes

- May be abstract; may be further-bound

```
class Food
abstract class Animal {
  type SuitableFood <: Food
  def eat(food: SuitableFood)
}
```

Abstract type member

```
class Grass extends Food
class Cow extends Animal {
  type SuitableFood = Grass
  override def eat(food : SuitableFood) { }
}
```

Final-binding

```
class DogFood extends Food
class Dog extends Animal {
  type SuitableFood = DogFood
  override def eat(food : SuitableFood) { }
}
```

## Simple Scala Swing example

- Scala interface to Java Swing

```
import scala.swing._

object FirstSwingApp extends SimpleSwingApplication {
  def top = new MainFrame {
    title = "First Swing App"
    contents = new Button {
      text = "Click me"
    }
  }
}
```

```
reactions += {
  case scala.swing.event.ButtonClicked(_) =>
    System.out.println("Button clicked")
}
```



## Concurrency, Scala actors

- Using threads and locks is difficult
  - Too little locking: conflicting updates and reads
  - Too much locking: deadlock
- Scala actors = mostly-sequential programs that communicate via messages
- Similar to the Erlang language; similar to Communicating Sequential Processes (1980) but with asynchronous communication

## Higher-kinded types

- A *type* represents many similar values
  - Eg: Int represents 0, 1, 2, ..., -1, -2, ...
  - Eg: List[Int] represents List(2,3), List(13,21), ...
- A *kind* represents many similar types
  - Eg: * represents Int, String, Double, ...
  - Eg: * -> * represents List[_], Tree[_], ...

- Sounds cool, but why bother?
- Because even generic types lead to some code duplication (and maintenance trouble)



## Motivation: filter and remove

Examples due to David Christiansen

```
trait Iterable[T] {
  def filter(p: T => Boolean): Iterable[T]
  def remove(p: T => Boolean): Iterable[T]
      = this.filter(x = >!p(x))
}

trait List[T] extends Iterable[T] {
  def filter(p: T => Boolean): List[T] = ...
  override def remove(p: T => Boolean): List[T]
      = this.filter(x => !p(x))
}
```

Neat enough

Not neat: silly to have to redefine

- If remove were just inherited, it would have type Iterable[T] not List[T]
- But the result of removing from a list should be a list, not an iterable

## Type constructors to the rescue

- A *type constructor* is a function from types to type. A generic class is a type constructor.
- Idea: Allow type constructors as arguments to types.

Takes a type and returns a type

```
trait Iterable[T, Result[_]] {
  def filter(p: T => Boolean): Result[T]
  def remove(p: T => Boolean): Result[T]
      = this.filter(x => !p(x))
}
trait List[T] extends Iterable[T, List] {
  def filter(p: T => Boolean): List[T] = ...
}
```

The List type constructor

- In List[T] the inherited **`remove`** has return type Result[T] = List[T] as desired
- No need to redefine **`remove`**



## The need for kinds

- Some uses of Iterable are meaningless: Iterable[Int, Double]
- Double is a type (*), not type function (*->*)
- We can use *kinds* to describe legal uses of List, Iterable and so on:
  - Int : *
  - List : * -> *
  - List[Int] : *
  - Result : * -> *
  - Iterable : * -> (* -> *) -> *
- See Moors, Piessens, Odersky: *Generics of a higher kind*, OOPSLA2008

## Other Scala features

- Implicit arguments
- Pattern matching on user-defined types
- Scala Lift (web programming) framework
- Simple build tool **`sbt`**
- Developer and language design community

- Limited tail call optimization (Java platform)



## Commercial use of Scala

- Twitter is written in Scala
- Eclipse plugins can be written in Scala (eg. Hannes does this)
- Several companies use Scala
- Also in Copenhagen ...
  - Because it works with Java libraries
  - And Scala code is shorter and often much clearer

## References

- *A Scala tutorial for Java programmers*, 2010
- *An overview of the Scala programming language*, 2006
- Odersky: *Scala by Example*, 2010.
- Find the above at: http://www.scala-lang.org
- Odersky, Spoon, Venners: *Programming in Scala,* artima 2008 (book)
- http://www.infoq.com/interviews/functional-langs: A discussion between the inventors of Scala, F# and Erlang



## What's next

- Mon 14 Feb: Abstract syntax, interpretation, lexing, parsing
- Wed 16 Feb: Grammar transformations, compilation, stack machines

- You should:
  - Do Exercise sheet 2
  - Hand in solutions no later than Friday 18 Feb by mail to sestoft@itu.dk