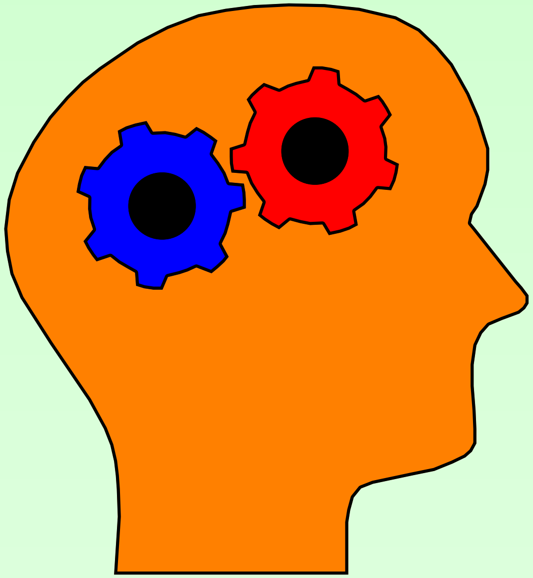
CS2104: Programming Languages Concepts

Lecture 12-13 : **Scala Highlights**



"Boosting Java
With FP and Stronger Types"

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Motivation for Scala Language

- interoperable with Java
- conciseness (2-10 times shorter)
- supports higher-order functions (OOP+FP)
- advance static typing and inference
- developed by Martin Odersky group @ EPFL

Conciseness

```
// in Java
class MyClass {
 private int index;
 private String name;
 public MyClass(int index, String name) {
  this.index = index;
  this.name = name;
 }
}
```

```
// in Scala:
class MyClass(index: Int, name: String)
```

Object-Oriented Style Supported

- Every value is an object

- Types and behavior of objects are described by
  - classes (including abstract classes)
  - *traits*

- Class abstraction are extended by
  - sub-classing
  - *mixin* composition
    (cleaner replacement for multiple inheritance)

Functional Style Supported

- Every function is an object

- Functions are first-class values
  - passed as argument
  - returned as result
  - can be stored in data structures

- Anonymous functions allowed

- Pattern-matching via Case Classes

Highlights of Scala

- Scala Classes
- Types
- Higher-Order Functions
- Lists
- Pattern-Matching
- Traits as Mixins
- Implicits

Scala Classes

Scala Classes

- Factory templates that can be instantiated to objects.
- Class Parameters and Explicit Overriding

```
class Point(xc: Int, yc: Int) {
  var x: Int = xc
  var y: Int = yc
  def move(dx: Int, dy: Int) {
    x = x + dx
    y = y + dy
  }
  override def toString(): String
        = "(" + x + ", " + y + ")";
}
```

Scala Classes

- Parameterised by constructor arguments.
  Objects are instantiated with new command, e.g.

```
new Point(3,4);
```

- Uses dynamically-dispatched methods only:

```
this.move(dx,dy);
this.toString();
```

Scala Classes

- A class with a single object is declared with the "object" keyword.
- This example captures an executable application with a main method that can be directly executed.

```
object Classes {
  def main(args: Array[String]) {
    val pt = new Point(1, 2)
    println(pt)
    pt.move(10,10)
    println(pt)
  }
}
```

Abstract Classes

- Classes are parameterized with values and with types.
- Supports generic classes.
- Abstract class may have
  - (i) deferred/abstract type
  - (ii) deferred value definition

```
abstract class Buffer {
  type T
  val element: T
}
```

Abstract Classes

- Can *reveal* more information on an abstract type by giving *type bounds*.

```
abstract class SeqBuffer extends Buffer {
  type U
  type T <: Seq[U]
  def length = element.length
}
```

- *Refinement* could be added to instantiate abstract type definition:

```
abstract class IntSeqBuffer extends SeqBuffer {
  type U = Int
}
```

Abstract Classes

- Abstract type definition can be turned into type parameters with declaration-site variance annotation:

```
abstract class Buffer[+T] {
  val element: T
}

abstract class SeqBuffer[U,+T<:Seq[U]] extends Buffer[T] {
  def length = element.length
}
```

Types

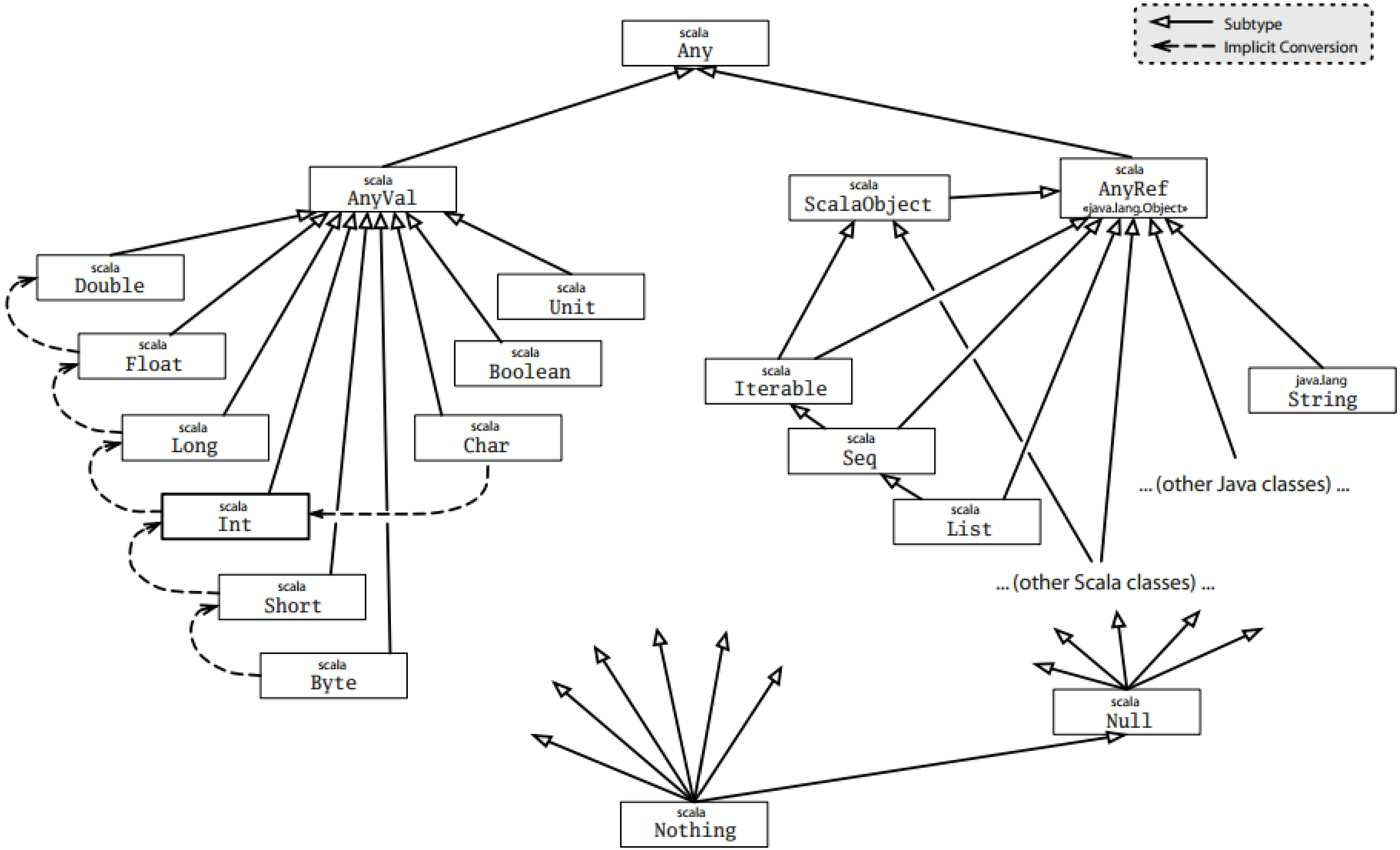

Figure 11.1 · Class hierarchy of Scala.

Unified Types

- all values (including numerics and functions) are objects
  - all values are instances of a class
  - superclass of all classes

    scala.Any

    :> scala.AnyVal

    :> scala.AnyRef

- Every user-defined class
  - are (indirectly) subclass of `scala.AnyRef`
  - implicitly extends trait `scala.ScalaObject`

Unified Types

```
object UnifiedTypes {
  def main(args: Array[String]) {
    val set = new scala.collection.mutable.HashSet[Any]
    set += "This is a string"  // add a string
    set += 732                 // add a number
    set += 'c'                 // add a character
    set += true                // add a boolean value
    set += main _              // add the main function
    val iter: Iterator[Any] = set.iterator
    while (iter.hasNext) {
      println(iter.next.toString())
    }
  }
}
```

```
c
true
<function>
732
This is a string
```

Polymorphic Methods

- Methods can be parameterized by both values and types
- Values are enclosed in parenthesis, while types are declared within a pair of brackets.

```
object PolyTest extends Application {
  def dup[T](x: T, n: Int): List[T] =
    if (n == 0) Nil
    else x :: dup(x, n - 1)
  println(dup[Int](3, 4))
  println(dup("three", 3))
}
```

Lists

Pervasive List

- List is a pervasive data type in programming. Though Array also captures sequence, List has the following properties
  (i) immutable
  (ii) unbounded length
  (iii) dynamically-linked data structure
- Examples:

```
val fruit = List("apples", "oranges", "pears")
val nums = List(1, 2, 3, 4)
val diag3 =
List(
  List(1, 0, 0),
  List(0, 1, 0),
  List(0, 0, 1)
)
val empty = List()
```

Pervasive List

- Two basic constructors (i) `Nil` (ii) `::`

```
val fruit = "apples" :: ("oranges" :: ("pears" :: Nil))
val nums = 1 :: (2 :: (3 :: (4 :: Nil)))
val diag3 = (1 :: (0 :: (0 :: Nil))) ::
(0 :: (1 :: (0 :: Nil))) ::
(0 :: (0 :: (1 :: Nil))) :: Nil
val empty = Nil
```

- Three primitive List operations:
  - `head` returns the first element of a list
  - `tail` returns a list consisting of all elements except the first
  - `isEmpty` returns true if the list is empty

Pervasive List

Extractor is used to provide List patterns/views:

```
scala> val List(a, b, c) = fruit
a: String = apples
b: String = oranges
c: String = pears
```

```
scala> val a :: b :: rest = fruit
a: String = apples
b: String = oranges
rest: List[String] = List(pears)
```

Pervasive List

How would you *join* two Lists together?

```
def append[T](xs: List[T], ys: List[T]): List[T] =
 xs match {
   case List()   =>
   case x :: xs1 =>
 }
```

How would you *reverse* a given List?

```
def rev[T](xs: List[T]): List[T] =
 xs match {
   case List()   =>
   case x :: xs1 =>
 }
```

Folding over List

- Common to combine the elements of a list with some operator. For instance:

```
sum(List(a, b, c)) equals 0 + a + b + c
```

This summation can be implemented by:

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

- Similarly:

```
product(List(a, b, c)) equals 1 * a * b * c
```

This product operation can be implemented by:

```
def product(xs: List[Int]): Int = (1 /: xs) (_ * _)
```

Folding over Lists

- Fold left operation :

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

- Fold right operation:

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

Pattern Matching

Pattern Matching

- Match on any sort of data with a *first-match* policy

- Match keyword allows *pattern-matching function* to be applied to an object, e.g.

```
object MatchTest1 extends Application {
  def matchTest(x: Int): String = x match {
    case 1 => "one"
    case 2 => "two"
    case _ => "many"
  }
  println(matchTest(3))
}
```

Pattern Matching

- Possible to match a value against patterns of different types. e.g.

```
object MatchTest2 extends Application {
  def matchTest(x: Any): Any = x match {
    case 1 => "one"
    case "two" => 2
    case y: Int => "scala.Int"
  }
  println(matchTest("two"))
}
```

Case Classes

- Case classes allow their constructor parameters to be exported via pattern-matching.

- Example to denote untyped lambda calculus:

```
abstract class Term
case class Var(name: String) extends Term
case class Fun(arg: String, body: Term) extends Term
case class App(f: Term, v: Term) extends Term
```

Case Classes

- Advantages : "new" primitive is not required

```
Fun("x", Fun("y", App(Var("x"), Var("y"))))
```

- Constructor parameters are treated as public values that can be directly accessed

```
val x = Var("x")
Console.println(x.name)
```

- Automatic derivation of *equality* and *toString* method.

```
val x1 = Var("x")
val x2 = Var("x")
val y1 = Var("y")
println("" + x1 + " == " + x2 + " => " + (x1 == x2))
println("" + x1 + " == " + y1 + " => " + (x1 == y1))
```

Case Classes

- Supports pattern-matching:

```
// pretty printer
object TermTest extends Application {
  def printTerm(term: Term) {
    term match {
      case Var(n) =>
        print(n)
      case Fun(x, b) =>
        print("^" + x + ".")
        printTerm(b)
      case App(f, v) =>
        Console.print("(")
        printTerm(f)
        print(" ")
        printTerm(v)
        print(")")
    }
  }
```

Higher-Order Functions

Higher-Order Functions

- Scala supports functions as *first-class* values
  - function as parameter
  - function as result
  - function inside data structure.
- An example:

```
def apply(f: Int => String, v: Int) = f(v)
```

Higher-Order Functions

```
class Decorator(left: String, right: String) {
  def layout[A](x: A) = left + x.toString() + right
}

object FunTest extends Application {
  def apply(f: Int => String, v: Int) = f(v)
  val decorator = new Decorator("[", "]")
  println(apply(decorator.layout, 7))
}
```

- Polymorphic layout of type `A => String` is automatically coerced to a value of type `Int => String`

Anonymous Functions

- A shorthand for writing anonymous functions

```
(x: Int) => x + 1
```

- Full longer form :

```
new Function1[Int, Int] {
   def apply(x: Int): Int = x + 1
}
```

- Function with two parameters

```
(x: Int, y: Int) => "(" + x + ", " + y + ")"
```

- Function with no parameter

```
() => { System.getProperty("user.dir") }
```

Placeholder Function

- The symbol _ denotes a placeholder for parameters

```
_ + 1    or    (_:Int)+1
```

denotes :

```
(x: Int) => x + 1
```

- Similarly:

```
(_:Int) + (_:int)
```

denotes :

```
(x:Int,y:Int) => x + y
```

Types for Functions

- Shorthand for Types:

```
Int => Int
(Int, Int) => String
() => String
```

- Longer form for Types

```
Function1[Int, Int]
Function2[Int, Int, String]
Function0[String]
```

Operators

- Infix and postfix form are occasionally more readable
  - Method with one parameter → infix
  - Method with no parameter → postfix.

```
class MyBool(x: Boolean) {
  def and(that: MyBool): MyBool = if (x) that else this
  def or(that: MyBool): MyBool = if (x) this else that
  def negate: MyBool = new MyBool(!x)
}
```

Operators

- Possible to use "negate" in postfix form:

```
def not(x: MyBool) = x negate;
        // semicolon required here
```

- Possible to use "and" and "or" in infix form:

```
def xor(x: MyBool, y: MyBool)
      = (x or y) and not(x and y)
```

- Traditional form:

```
def not(x: MyBool) = x.negate;
        // semicolon required here
def xor(x: MyBool, y: MyBool)
        = x.or(y).and(x.and(y).negate)
```

Currying

- Methods may define multiple parameter lists.

- When a method is called with fewer argument list, it yields a function which expects the remaining parameter lists.

```
object CurryTest extends Application {
  def filter(xs: List[Int], p: Int => Boolean): List[Int] =
    if (xs.isEmpty) xs
    else if (p(xs.head)) xs.head :: filter(xs.tail, p)
    else filter(xs.tail, p)
  def modN(n: Int)(x: Int) = ((x % n) == 0)
  val nums = List(1, 2, 3, 4, 5, 6, 7, 8)
  println(filter(nums, modN(2)))
  println(filter(nums, modN(3)))
}
```

```
filter : (List[Int], Int => Boolean) => List[Int]
modN : Int => (Int => Boolean)
```

Traits as Mixin

Traits

- Similar to interfaces in Java
  - can have fields and methods
  - may have default implementation from some methods
  - do not have constructor parameters

Example:

```
trait Similarity {
   def isSimilar(x: Any): Boolean
   def isNotSimilar(x: Any): Boolean = !isSimilar(x)
  }
```

`isSimilar` is an abstract method,
but `isNotSimilar` has a concrete implementation

Traits

```
class Point(xc: Int, yc: Int) extends Similarity {
  var x: Int = xc
  var y: Int = yc
  def isSimilar(obj: Any) =
    obj.isInstanceOf[Point] &&
    obj.asInstanceOf[Point].x == x
}
object TraitsTest extends Application {
  val p1 = new Point(2, 3)
  val p2 = new Point(2, 4)
  val p3 = new Point(3, 3)
  println(p1.isNotSimilar(p2))
  println(p1.isNotSimilar(p3))
  println(p1.isNotSimilar(2))
}
```

Mixin Class Composition

- Neither single inheritance, nor just multiple inheritance.
- Allows reuse of new member definitions from a class
- An abstract class:

```
abstract class AbsIterator {
  type T
  def hasNext: Boolean
  def next: T
}
```

Mixin Class Composition

- A mixin through keyword trait:

```
trait RichIterator extends AbsIterator {
  def foreach(f: T => Unit)
    { while (hasNext) f(next) }
}
```

- A concrete iterator class (where type T has been instantiated):

```
class StringIterator(s: String) extends AbsIterator {
  type T = Char
  private var i = 0
  def hasNext = i < s.length()
  def next = { val ch = s charAt i; i += 1; ch }
}
```

Mixin Class Composition

- A mixin class composition
  (with both `StringIterator` and `RichIterator`)

```
object StringIteratorTest {
  def main(args: Array[String]) {
    class Iter extends StringIterator(args(0))
       with RichIterator
    val iter = new Iter
    iter foreach println
  }
}
```

Implicits

Implicit Parameters

- Implicit can help with type conversion.
- For example, `Double` cannot be automatically converted to `Int`.

```
scala> val i: Int = 3.5
<console>:4: error: type mismatch;
found : Double(3.5)
required: Int
val i: Int = 3.5
```

Implicit Parameters

However, we can define an *implicit* conversion to automatically perform such casting.

```
scala> implicit def doubleToInt(x: Double)
             = x.toInt
doubleToInt: (x: Double)Int
scala> val i: Int = 3.5
i: Int = 3
```

Implicit Parameters

- Implicit allows our code to inter-operate with new types:

```
class Rational(n: Int, d: Int) {
  ...
  def + (that: Rational): Rational = ...
  def + (that: Int): Rational = ...
}
```

- Add an implicit to convert to Rational type:

```
implicit def intToRational(x:Int) =
      new Rational(x,1)
```

Implicit Parameters

- Default parameter can be customized using implicit.

```
class PreferredPrompt(val preference: String)
  object Greeter {
  def greet(name: String)(implicit prompt: PreferredPrompt) {
    println("Welcome, "+ name +". The system is ready.")
    println(prompt.preference)
}
```

Implicit parameter can be supplied explicitly:

```
scala> val bobsPrompt = new PreferredPrompt("relax> ")
scala> Greeter.greet("Bob")(bobsPrompt)
Welcome, Bob. The system is ready.
relax>
```

Implicit Parameters

- We can also define it implicitly:

```
object JoesPrefs {
implicit val prompt =
      new PreferredPrompt("Yes, master> ")
}
```

- This results in :

```
scala> import JoesPrefs._
import JoesPrefs._
scala> Greeter.greet("Joe")
Welcome, Joe. The system is ready.
Yes, master>
```

Implicit Parameters

- a special feature to support systematic method overloading
- define abstract classes

```
abstract class SemiGroup[A] {
  def add(x: A, y: A): A
}
abstract class Monoid[A] extends SemiGroup[A] {
  def unit: A
}
```

Implicit Parameters

- allow instances of these abstract classes.

e.g. `Int` and `String` are indirectly instances of `Monoid[?]`

```
object ImplicitTest extends Application {
implicit object StringMonoid extends Monoid[String] {
  def add(x: String, y: String): String = x concat y
  def unit: String = ""
}
implicit object IntMonoid extends Monoid[Int] {
  def add(x: Int, y: Int): Int = x + y
  def unit: Int = 0
}
```

Implicit Parameters

- with implicit objects, we can now define generic method, that sum up a list of monoid values:
e.g.

```
def sum[A](xs: List[A])(implicit m: Monoid[A]): A =
  if (xs.isEmpty) m.unit
  else m.add(xs.head, sum(xs.tail))
```

- implicit parameters can be inferred
given:

```
println(sum(List(1, 2, 3)))
println(sum(List("a", "b", "c")))
```

can infer:

```
println(sum(List(1, 2, 3))(IntMonoid))
println(sum(List("a", "b", "c"))(StringMonoid))
```

Miscellaneous

Packages

- A package is a special object which defines a set of member classes, objects and packages.
- A packaging package p { ds } injects all definitions in ds as members into the package whose qualified name is p.
- If a definition in ds is labeled *private*, it is visible only for other members in the package.
- A *protected* modifier allows its members to be accessible from all code inside the package p.

Import

- An import clause determines a set of names of that can be used without qualifications.

```
import p._
  //all members of p
  //(this is analogous to import p.* in Java).
import p.x
  //the member x of p.
import p.{x => a}
  //the member x of p renamed as a.
import p.{x, y}
  //the members x and y of p.
import p1.p2.z
  //the member z of p2, itself member of p1.
```

Import

- Implicitly imported into every compilation unit:
  - the package java.lang,
  - the package scala,
  - and the object scala.Predef.

Type Inference

Local Type Inference

- Types can either be declared or inferred.
- Eases programmers burden by automatically inferring certain type annotations.
- Can infer type of:

  (i) variable (through its initialization)
  (ii) results of non-recursive method
  (iii) type instantiation of polymorphic methods

- May fail occasionally.

Local Type Inference

Example 1: Type Instantiation of Generic Methods

```
case class MyPair[A, B](x: A, y: B);
object InferenceTest3 extends Application {
  def id[T](x: T) = x
  val p = new MyPair(1, "scala")
         // type: MyPair[Int, String]
  val q = id(1)
         // type: Int
}
```

Explicit Instantiation:

```
val x: MyPair[Int, String] =
       new MyPair[Int, String](1, "scala")
val y: Int = id[Int](1)
```

Local Type Inference

Example 2:

```
object InferenceTest2 extends Application {
  val x = 1 + 2 * 3          // the type of x is Int
  val y = x.toString()       // the type of y is String
  def succ(x: Int) = x + 1   // method succ returns
                             //Int values
}
```

Failures of type inference

```
object InferenceTest3 {
  def fac(n: Int) = if (n == 0) 1 else n * fac(n - 1)
}
```

```
object InferenceTest4 {
  var obj = null    // Null inferred
  obj = new Object()
}
```

Runtime Type Representation

- **classOf[T]** returns string representation of a type
- `var.getClass()` returns the representation of runtime type for object

```
object ClassReprTest {
  abstract class Bar {
    type T <: AnyRef
    def bar(x: T) {
      println("5: " + x.getClass() )}
  }
  def main(args: Array[String]) {
    println("1: " + args.getClass())
    println("2: " + classOf[Array[String]])
    new Bar {
      type T = Array[String]
      val x: T = args
      println("3: " + x.getClass() )
      println("4: " + classOf[T])
    }.bar(args) }
}
```