

Lecture 1 – Basic Introduction to Scala

AAA551: Programming Language Theory

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We view Programming Languages through two complementary lenses:

- **Semantics (The Meaning)**
 - **Operational:** *How* is a program executed?
 - **Denotational:** *What* is the mathematical object for a program?
 - **Axiomatic:** *Which properties* does a program satisfy?
- **Type Systems (The Guardrails)**
 - **Modern Types:** Univeral, Substructural, Effects
 - **Type Analysis:** Abstract Interpretation
 - **Propositions as Types:** Curry-Howard Correspondence



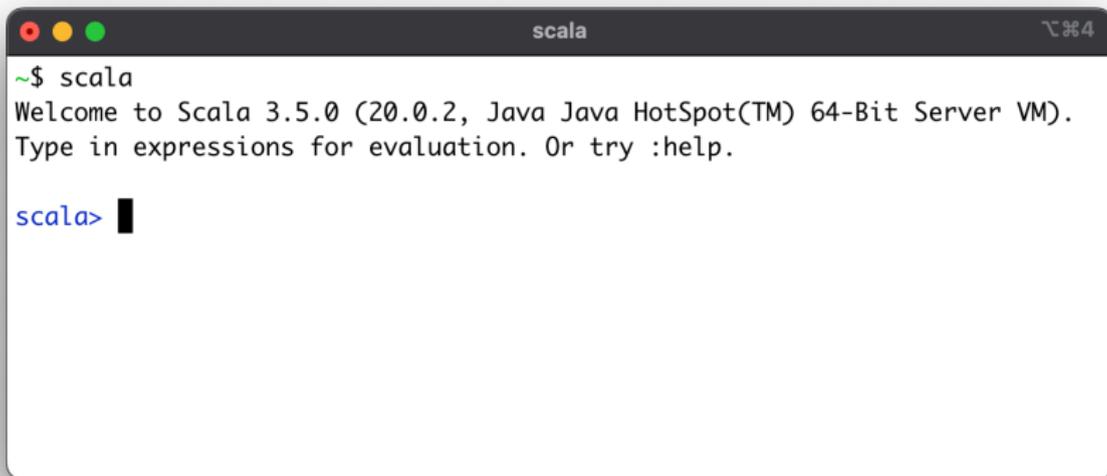
Scala stands for **Scalable Language**.

- A general-purpose programming language
- **Java Virtual Machine (JVM)**-based language
- A **statically typed** language
- An **object-oriented programming (OOP)** language
- A **functional programming (FP)** language

Read-Eval-Print-Loop (REPL)

Please download and install them using the following links.

- **JDK \geq 17**
- **sbt** for Homework – <https://www.scala-sbt.org/download.html>
- **Scala Playground on Web** – <https://scastie.scala-lang.org/>
- **Scala REPL** – <https://www.scala-lang.org/download/>



```
scala
~$ scala
Welcome to Scala 3.5.0 (20.0.2, Java Java HotSpot(TM) 64-Bit Server VM).
Type in expressions for evaluation. Or try :help.

scala> █
```

We will use **functional programming** (FP) by **reducing unexpected side effects** and **increasing code readability**.

- **Immutable Variables**
 - Variables are immutable by default
- **Pure Functions**
 - Functions do not have side effects
- **First-class Functions**
 - Functions are first-class citizens (i.e., functions are values)
- **Functional Error Handling**
 - Using `Option` for error handling

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```
42           // 42   : Int      (32-bit signed integer)
3.7          // 3.7  : Double   (64-bit double-precision floating-point)
true         // true  : Boolean
false        // false : Boolean
'c'          // 'c'   : Char    (16-bit Unicode character)
"abc"        // "abc" : String  (a sequence of characters)
()           // ()    : Unit    (meaningless value - similar to `void`)
```

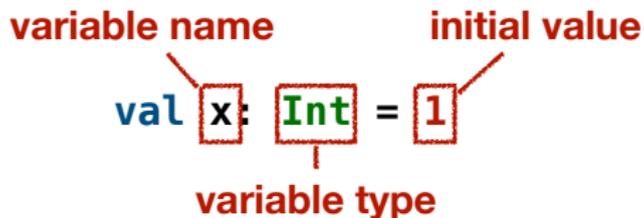
You can perform following operations on these data types.

```
1 + 2 * 3    // 7     : Int      (addition and multiplication)
11 / 3       // 3     : Int      (quotient of division)
11 % 3       // 2     : Int      (remainder of division)
1 < 2        // true   : Boolean  (comparison)
1 == 3       // false  : Boolean  (equality)
true && false // false  : Boolean  (logical AND)
true || false // true   : Boolean  (logical OR)
!true        // false  : Boolean  (logical NOT)
"abc".length // 3     : Int      (length of a string)
"he" + "llo" // "hello": String  (string concatenation)
println("Hi") // ()    : Unit    (side effect: printing "Hi")
```

variable name **initial value**

`val` `x` : `Int` = `1`

variable type



```
// An immutable variable `x` of type `Int` with 1
val x: Int = 1
x + 2           // 1 + 2 == 3 : Int
x = 2           // Type Error: Reassignment to val `x`

// Type Inference: `Int` is inferred from `1`
val y = 1       // y: Int

// Type Mismatch Error: `Boolean` required but `Int` found: 42
val c: Boolean = 42
```

While Scala supports mutable variables (`var`), **DO NOT USE MUTABLE VARIABLES IN THIS COURSE** because it is against the **functional programming** paradigm.

```
var x: Int = 1
```

```
// A mutable variable `x` of type `Int` with 1
var x: Int = 1
x + 2           // 1 + 2 == 3 : Int

// You can reassign a mutable variable `x`
x = 2           // x == 2
x + 2           // 2 + 2 == 4 : Int
```

method name parameter type method body
def **add**(**x**: **Int**, **y**: **Int**): **Int** = **x + y**
parameter name return type

```

// A method `add` of type `(Int, Int) => Int`
// It means that `add` takes two `Int` arguments and returns an `Int`
def add(x: Int, y: Int): Int = x + y
add(1, 2)           // 1 + 2 == 3   : Int
add(5, 6)           // 5 + 6 == 11  : Int

// Type Error: wrong number of arguments
add(1)              // Too few arguments
add(1, 2, 3)        // Too many arguments

// Type Mismatch Error: `Int` required but `String` found: "abc"
add(1, "abc")

```

condition then body else body

if (x < 0) -x else x

```
// A method `abs` which takes an `Int` and returns its absolute value
def abs(x: Int): Int = if (x < 0) -x else x

abs(42)           // 42 : Int
abs(-42)          // 42 : Int
```

Note that it is a conditional **expression** not a **statement** similar to the ternary operator ($x ? y : z$) in other languages.

```
2 * (if (true) 3 else 5) // 2 * 3 == 6 : Int
```

You can **recursively** invoke a method with a conditional expression.

```
// A recursive method `sum` that adds all the integers from 1 to n
def sum(n: Int): Int =
  if (n < 1) 0
  else sum(n - 1) + n

sum(10)           // 55           : Int
sum(100)          // 5050          : Int
```

You can use either **indentation** (above) or **curly braces** (below) for a block of expressions as follows.

```
def sum(n: Int): Int = {
  if (n < 1) 0
  else sum(n - 1) + n
}
```

While Scala supports `while` loops, **DO NOT USE WHILE LOOPS IN THIS COURSE** because it is against the **functional programming** paradigm.

```
// Sum of all the numbers from 1 to n
def sum(n: Int): Int = {
  var s: Int = 0
  var k: Int = 1
  while (k <= n) {
    s = s + k
    k = k + 1
  }
  s
}

sum(10) // 55   : Int
sum(100) // 5050 : Int
```

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type name
field type

```
case class Point(x: Int, y: Int, color: String)
```

field name

A **case class** defines a **product type** with:

- its **type name** (e.g., Point)
- its **constructor** (e.g., Point)

```
// A `Point` instance whose fields: x = 3, y = 4, and color = "RED"  
val p: Point = Point(3, 4, "RED")  
  
// You can access fields using the dot operator  
p.x           // 3           : Int  
p.color       // "RED"      : String  
  
// Fields are immutable by default  
p.x = 5       // Type Error: Reassignment to val `x`
```

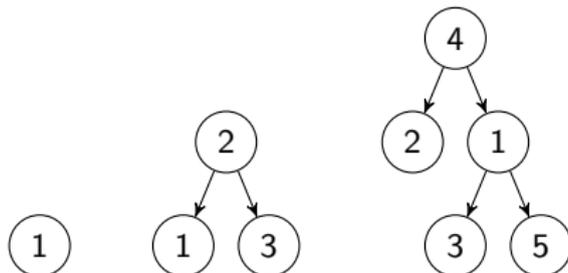
```
enum Tree:  
  case Leaf(value: Int)  
  case Branch(left: Tree, value: Int, right: Tree)
```

Labels: **type name** (Tree), **variants** (Leaf, Branch)

An `enum` defines an **algebraic data type (ADT)** with:

- its **type name** (e.g., `Tree`)
- its **constructors** of variants (e.g., `Leaf`, `Branch`)

```
import Tree.* // Import all constructors for variants of `Tree`  
val tree1: Tree = Leaf(1)  
val tree2: Tree = Branch(Leaf(1), 2, Leaf(3))  
val tree3: Tree = Branch(Leaf(2), 4, Branch(Leaf(3), 1, Leaf(5)))
```



You can **pattern match** on algebraic data types (ADTs).

```
// A recursive method computes the sum of all the values in a tree
def sum(t: Tree): Int = t match
  case Leaf(n)           => n
  case Branch(l, n, r) => sum(l) + n + sum(r)

sum(Branch(Leaf(1), 2, Leaf(3)))           // 6 : Int
sum(Branch(Branch(Leaf(1), 2, Leaf(3)), 4, Leaf(5))) // 15 : Int
```

You can **ignore** some components using an underscore (`_`) and use **if guards** to add conditions to patterns.

```
// A method checks whether a tree is a branch whose value is even
def isEvenBranch(t: Tree): Boolean = t match
  case Branch(_, n, _) if n % 2 == 0 => true
  case _                               => false

isEvenBranch(Leaf(1))           // false : Boolean
isEvenBranch(Branch(Leaf(1), 2, Leaf(3))) // true : Boolean
```

Here is another example of pattern matching on ADTs.

```
// An ADT for natural numbers
enum Nat:
  case Z          // Zero
  case S(n: Nat) // Successor of a natural number

import Nat.* // Import constructors `Z` and `S` for variants of `Nat`
```

We can also use **nested pattern matching**.

```
// A recursive method adds two natural numbers
def isEven(x: Nat): Boolean = x match
  case Z          => true
  case S(S(y)) => isEven(y) // nested pattern matching
  case _         => false

isEven(Z)           // true  : Boolean
isEven(S(Z))       // false : Boolean
isEven(S(S(Z)))    // true  : Boolean
```

You can define methods inside `case class` or enumerations (`enum`).

```
case class Point(x: Int, y: Int, color: String):  
  // A method that returns a new point moved by (dx, dy)  
  def move(dx: Int, dy: Int): Point = Point(x + dx, y + dy, color)  
  
Point(3, 4, "RED").move(1, -2)    // Point(4, 2, "RED"): Point
```

The keyword `this` refers to the current instance.

```
enum Tree:  
  ...  
  // A recursive method counts the number of the given integer in a tree  
  def count(x: Int): Int = this match  
    case Leaf(n)           if n == x => 1  
    case Leaf(_)           => 0  
    case Branch(l, n, r) if n == x => l.count(x) + 1 + r.count(x)  
    case Branch(l, _, r)   => l.count(x) + r.count(x)  
  
import Tree.* // Import all constructors for variants of `Nat`  
Branch(Leaf(7), 3, Branch(Leaf(7), 7, Leaf(42))).count(7) // 3 : Int
```

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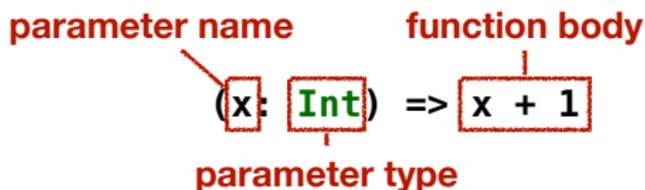
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A **function** is a **first-class citizen** (i.e., a function is a value) in Scala.

```
// A function that increments its input
(x: Int) => x + 1           // a function `Int => Int`
((x: Int) => x + 1)(3)    // 3 + 1 = 4 : Int
```

We can **store** a function in a variable.

```
val inc: Int => Int = (x: Int) => x + 1
inc(3)           // 3 + 1 = 4 : Int
val inc: Int => Int = x => x + 1
inc(3)           // Type Inference: `x` is `Int`
                // 3 + 1 = 4 : Int
val inc: Int => Int = _ + 1
inc(3)           // Placeholder Syntax
                // 3 + 1 = 4 : Int
```

We can **pass** a function to a method (or function) as an **argument**.

```
// A method `twice` that applies the function `f` twice to `x`
def twice(f: Int => Int, x: Int): Int = f(f(x))
twice(inc, 5)                // inc(inc(5)) = 5 + 1 + 1 = 7 : Int

// You can pass a function to `twice`
twice((x: Int) => x + 1, 5)   // 7 : Int
twice(x => x + 1, 5)         // 7 : Int - Type Inference: `x` is `Int`
twice(_ + 1, 5)             // 7 : Int - Placeholder Syntax
```

We can **return** a function from a method (or function).

```
// A function `addN` returns a function that adds `n`
val addN = (n: Int) => (x: Int) => x + n
val add2 = addN(2)           // add2:           Int => Int
add2(3)                     // 3 + 2 = 5       : Int
addN(7)(5)                  // 5 + 7 = 12    : Int
twice(add2, 5)              // 5 + 2 + 2 = 9 : Int
twice(addN(7), 5)          // 5 + 7 + 7 = 19: Int
```

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List[T] type is an **immutable** sequence of elements of type T.

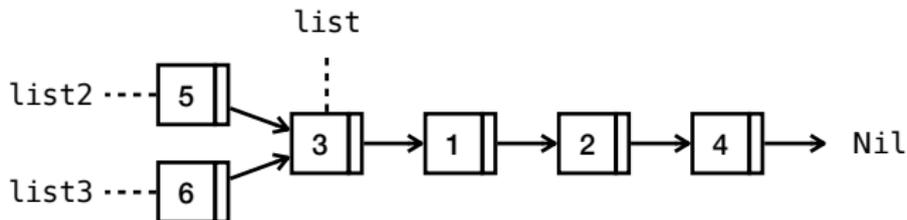
```
val list: List[Int] = List(3, 1, 2, 4)
```

We can define a list using :: (cons) and Nil (empty list).

```
val list = 3 :: 1 :: 2 :: 4 :: Nil
```

Lists are immutable.

```
val list2 = 5 :: list // List(5, 3, 1, 2, 4): List[Int]
val list3 = 6 :: list // List(6, 3, 1, 2, 4): List[Int]
```



We can **pattern match** on lists.

```
val list: List[Int] = 3 :: 1 :: 2 :: 4 :: Nil

// Get the second element of the list or 0
def getSnd(list: List[Int]): Int = list match
  case _ :: x :: _ => x
  case _           => 0

getSnd(list)           // 1 : Int

// Filter odd integers and double them in the list
def filterOddAndDouble(list: List[Int]): List[Int] = list match
  case Nil              => Nil
  case x :: xs if x % 2 == 1 => x * 2 :: filterOddAndDouble(xs)
  case _ :: xs          => filterOddAndDouble(xs)

filterOddAndDouble(list) // List(6, 2) : List[Int]
```

```
// A list of integers: 3, 1, 2, 4
val list: List[Int] = List(3, 1, 2, 4)

// Operations/functions on lists
list.length           // 4                : Int
list.map(_ * 2)       // List(6, 2, 4, 8)   : List[Int]
list.filter(_ % 2 == 1) // List(3, 1)       : List[Int]
list.foldLeft(0)(_ + _) // 0 + 3 + 1 + 2 + 4 = 10 : Int
list.flatMap(x => List(x, -x)) // List(3, -3, ..., 4, -4): List[Int]
list.map(x => List(x, -x)).flatten // List(3, -3, ..., 4, -4): List[Int]
```

We can redefine `filterOddAndDouble` using `filter` and `map`.

```
def filterOddAndDouble(list: List[Int]): List[Int] =
  list
    .filter(_ % 2 == 1)
    .map(_ * 2)

filterOddAndDouble(list) // List(6, 2)      : List[Int]
```

While Scala supports `null` to represent the absence of a value, **DO NOT USE NULL IN THIS COURSE.**

Instead, an **option** (`Option[T]`) is a container that may or may not contain a value of type `T`:

- 1 Some(`x`) represents a value `x` and
- 2 None represents the absence of a value

```
val some: Option[Int] = Some(42)
val none: Option[Int] = None

// Operations/functions on options
some.map(_ + 1)      // Some(43)      : Option[Int]
none.map(_ + 1)     // None           : Option[Int]
some.getOrElse(7)   // 42             : Int
none.getOrElse(7)   // 7            : Int
some.fold(7)(_ * 2) // 42 * 2 = 84 : Int
none.fold(7)(_ * 2) // 7            : Int
```

A **pair** (T, U) is a container that contains two values of types T and U:

```
val pair: (Int, String) = (42, "foo")

// You can construct pairs using `->`
42 -> "foo" == pair // true      : Boolean
true -> 42          // (true, 42) : (Boolean, Int)

// Operations/functions on options
pair(0)           // 42          : Int      - NOT RECOMMENDED
pair(1)           // "foo"       : String  - NOT RECOMMENDED

// Pattern matching on pairs
val (x, y) = pair // x == 42 and y == "foo"
```

A **map** (`Map[K, V]`) is a mapping from keys of type `K` to values of type `V`:

```
val map: Map[String, Int] = Map("a" -> 1, "b" -> 2)

map + ("c" -> 3) // Map("a" -> 1, "b" -> 2, "c" -> 3) : Map[String, Int]
map - "a"       // Map("b" -> 2)                   : Map[String, Int]
map.get("a")    // Some(1)                          : Option[Int]
map.get("c")    // None                             : Option[Int]
```

A **set** (`Set[T]`) is a collection of distinct elements of type `T`:

```
val set1: Set[Int] = Set(1, 2, 3)
val set2: Set[Int] = Set(2, 3, 5)

set1 + 4 // Set(1, 2, 3, 4) : Set[Int]
set1 + 2 // Set(1, 2, 3)   : Set[Int]
set1 - 2 // Set(1, 3)      : Set[Int]
set1.contains(2) // true   : Boolean
set1 ++ set2 // Set(1, 2, 3, 5) : Set[Int]
set1.intersect(set2) // Set(2, 3) : Set[Int]
```

```
val xlist = List(1, 2, 3)
val ylist = List(4, 5, 6)

// Filter pairs of elements whose sum is even and multiply them
xlist.flatMap(x =>
  ylist
    .filter(y => (x + y) % 2 == 0)
    .map(y => x * y)
) // List(5, 8, 12, 15) : List[Int]
```

A **for comprehension**¹ is a syntactic sugar for nested `map`, `flatMap`, and `filter` operations:

```
for {
  x <- xlist
  y <- ylist
  if (x + y) % 2 == 0
} yield x * y // List(5, 8, 12, 15) : List[Int]
```

¹<https://docs.scala-lang.org/tour/for-comprehensions.html>

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Exercise #1

- Please see this document on GitHub:

<https://github.com/ku-plrg-classroom/docs/tree/main/scala/scala-tutorial>

- It is just an exercise, and you **don't need to submit** anything.

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- Big-Step Operational Semantics

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