

Lecture 1 – Basic Introduction of Scala

COSE212: Programming Languages

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2023 Fall

The goal of this course:

Learn **Essential Concepts** of **Programming Languages**

¹<https://docs.scala-lang.org/scala3/book/introduction.html>

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Learn **Essential Concepts** of **Programming Languages**

- How?

By Implementing **Interpreters** using **Scala**

¹<https://docs.scala-lang.org/scala3/book/introduction.html>

The goal of this course:

Learn **Essential Concepts** of **Programming Languages**

- How?

By Implementing **Interpreters** using **Scala**

- Before entering the world of PL,

Let's learn **Scala**

(If you interested in more details, please see Scala 3 Book.¹)

¹<https://docs.scala-lang.org/scala3/book/introduction.html>



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- **Java Virtual Machine (JVM)**-based language
- A **statically typed** language
- A **object-oriented programming (OOP)** language



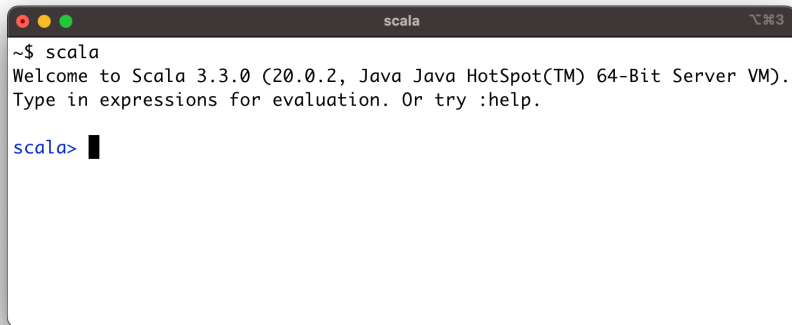
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- A **more concise** version of Java with **advanced features**
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- **Java Virtual Machine (JVM)**-based language
- A **statically typed** language
- A **object-oriented programming (OOP)** language
- A **functional programming (FP)** language

Read-Eval-Print-Loop (REPL)

- Please download Scala REPL:

<https://www.scala-lang.org/download/>

A screenshot of a terminal window titled "scala". The window shows the command prompt "~\$ scala" followed by the Scala REPL welcome message: "Welcome to Scala 3.3.0 (20.0.2, Java Java HotSpot(TM) 64-Bit Server VM). Type in expressions for evaluation. Or try :help." The prompt "scala>" is shown with a black cursor bar.

```
scala
~$ scala
Welcome to Scala 3.3.0 (20.0.2, Java Java HotSpot(TM) 64-Bit Server VM).
Type in expressions for evaluation. Or try :help.

scala> █
```

1. Basic Features

- Built-in Data Types

- Variables

- Functions

- Conditionals

2. Object-Oriented Programming (OOP)

- Case Classes

3. Algebraic Data Types (ADTs)

- Pattern Matching

4. Functional Programming (FP)

- First-Class Functions

- Recursion

5. Immutable Collections (Data Structures)

- Lists

- Options and Pairs

- Maps and Sets

- For Comprehensions

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```
// You can write comments using `// ...` or `/* ... */`  
// Integers  
1 + 2           // 3: Int  
3 - 2           // 1: Int  
2 * 3           // 6: Int  
  
// Booleans  
true && false    // false: Boolean  
true || false    // true : Boolean  
! true           // false: Boolean  
1 == 2           // false: Boolean  
1 < 2            // true : Boolean  
  
// Strings  
"abc"            // "abc"      : String  
"hello" + " world" // "hello world": String  
"hello".length    // 5         : Int
```

Immutable Variables (Identifiers)

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`

// An immutable variables of other types
val b: Boolean = true
val s: String = "abc"

// 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.**

`var x: Int = 1`

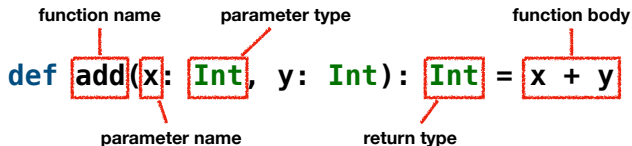
```
// A mutable variable `x` of type `Int` with 1
var x: Int = 1
x + 2           // 1 + 2 == 3 : Int

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

function name parameter type function body

def **add**(**x**: **Int**, **y**: **Int**): **Int** = **x + y**

parameter name return type



```
// A function `add` of type `(Int, Int) => 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
```

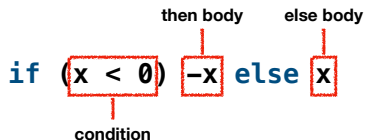
```
// Type Mismatch Error: `Int` required but `String` found: "abc"
```

```
add(1, "abc")
```

then body else body

if (x < 0) -x else x

condition



```
// a function `abs` of type `Int => Int`  
def abs(x: Int): Int = if (x < 0) -x else x  
abs(-3)           // 3 : Int  
abs(42)           // 42 : Int
```

Note that the conditional is an **expression**, not a **statement**.

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Object-oriented programming (OOP) is a programming paradigm based on the concept of **object**, which can contain data and code. The data is in the form of **fields** (often known as attributes or properties), and the code is in the form of **procedures** (often known as methods).²

²https://en.wikipedia.org/wiki/Object-oriented_programming

class name field type

case class **A**(**k**: **Int**)

field name



```
// A case class `A` having a field `k` of type `Int`  
case class A(k: Int)  
  
// An instance object `a` of type `A` whose field `k` has 10  
val a: A = A(10)  
  
// You can access fields using the dot operator  
a.k           // 10 : Int  
  
// Fields are immutable by default  
a.k = 20      // Type Error: Reassignment to val `k`
```

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An **algebraic data type (ADT)** is a kind of composite type, i.e., a type formed by combining other types.

type name

enum **Tree**:

variants

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


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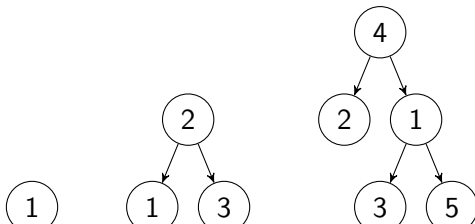
type name

enum **Tree**:

variants

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

```
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 use **pattern matching** to match a value against a pattern.

```
def getValue(t: Tree): Int = t match
  case Leaf(v)           => v
  case Branch(_, v, _)   => v

getValue(tree1) // 1 : Int
getValue(tree2) // 2 : Int
getValue(tree3) // 4 : Int
```

You can use **pattern matching** to match a value against a pattern.

```
def getValue(t: Tree): Int = t match
  case Leaf(v)           => v
  case Branch(_, v, _) => v
```

```
getValue(tree1) // 1 : Int
getValue(tree2) // 2 : Int
getValue(tree3) // 4 : Int
```

```
enum Number:
  case Zero
  case Succ(n: Number)

def toInt(n: Number): Int = n match
  case Zero      => 0
  case Succ(n) => 1 + toInt(n)
```

```
toInt(Zero) // 0 : Int
toInt(Succ(Succ(Zero))) // 2 : Int
```

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In computer science, **functional programming** is a programming paradigm where programs are constructed by applying and composing **functions**. It is a **declarative programming paradigm** in which function definitions are trees of expressions that map values to other values, rather than a sequence of **imperative statements** which update the running state of the program.³

³https://en.wikipedia.org/wiki/Functional_programming

⁴<https://docs.scala-lang.org/scala3/book/fp-pure-functions.html>

In computer science, **functional programming** is a programming paradigm where programs are constructed by applying and composing **functions**. It is a **declarative programming paradigm** in which function definitions are trees of expressions that map values to other values, rather than a sequence of **imperative statements** which update the running state of the program.³

- A **pure function**⁴ is a function that 1) returns the **same result** for the same input and 2) has **no side effects**.

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In computer science, **functional programming** is a programming paradigm where programs are constructed by applying and composing **functions**. It is a **declarative programming paradigm** in which function definitions are trees of expressions that map values to other values, rather than a sequence of **imperative statements** which update the running state of the program.³

- A **pure function**⁴ is a function that 1) returns the **same result** for the same input and 2) has **no side effects**.
- **Immutability** is a cornerstone of pure functions:

```
var y: Int = 1
def f(x) = x + y
f(1)  // 1 + 1 = 2
y = 2
f(1)  // 1 + 2 = 3
```

³https://en.wikipedia.org/wiki/Functional_programming

⁴<https://docs.scala-lang.org/scala3/book/fp-pure-functions.html>

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

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



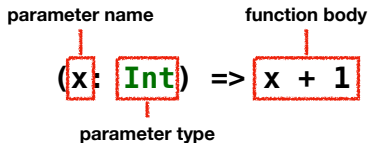
```
// A function `inc` that increments its input
def inc(x: Int): Int = x + 1
inc(3)                      // 3 + 1 = 4 : Int

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

parameter name function body

(x: Int) => x + 1

parameter type



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

You can **recursively** invoke a function.

```
// Sum of all the numbers from 1 to n
def sum(n: Int): Int = if (n < 1) 0 else sum(n - 1) + n

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

You can **recursively** invoke a function.

```
// Sum of all the numbers from 1 to n
def sum(n: Int): Int = if (n < 1) 0 else sum(n - 1) + n

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

```
// An ADT for trees
enum Tree:
  case Leaf(value: Int)
  case Branch(left: Tree, value: Int, right: Tree)
// Import all constructors for variants of `Tree`
import Tree.*
// A function recursively 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
```

While Scala supports `while` loops, **DO NOT USE WHILE LOOPS IN THIS COURSE.**

```
// 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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A **list** (`List[t, fragile]`) is a sequence of elements of the same type `T`:

- 1 `Nil` represents the empty list
- 2 `::` adds an element to the front of a list

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

// You can construct lists using `::` and `Nil`
3 :: 1 :: 2 :: 4 :: Nil == list // true : Boolean

// Pattern matching on lists - filter odd integers and double them
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 ++ List(5, 6, 7) // List(3, 1, 2, 4, 5, 6, 7) : List[Int]
list.reverse          // List(4, 2, 1, 3)         : List[Int]
list.count(_ % 2 == 1) // 2                      : Int
list.foldLeft(0)(_ + _) // 0 + 3 + 1 + 2 + 4 = 10 : Int
list.sorted           // List(1, 2, 3, 4)         : List[Int]
list.map(_ * 2)        // List(6, 2, 4, 8)        : List[Int]
list.flatMap(x => List(x, -x)) // List(3, -3, ..., 4, -4) : List[Int]
list.filter(_ % 2 == 1) // List(3, 1)            : List[Int]

// 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.**

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

Instead, an **option** (`Option[t, fragile]`) 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.keySet       // Set("a", "b")                  : Set[String]
```

A **set** (`Set[t, fragile]`) 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]
set1.diff(set2)    // Set(1)        : Set[Int]
set1.subsetOf(set2) // false        : Boolean
```

A **for comprehension**⁵ is a syntactic sugar for nested `map`, `flatMap`, and `filter` operations:

```
val list = List(1, 2, 3)

// Using `map`, `flatMap`, and `filter`
list.flatMap(x => List(x, -x)) // List(1, -1, 2, -2, 3, -3) : List[Int]
    .map(y => y * 3 + 1)       // List(4, -2, 7, -5, 10, -8) : List[Int]
    .filter(z => z % 5 == 0)   // List(-5, 10) : List[Int]

// Using a for comprehension
for {
  x <- list
  y <- List(x, -x)
  z = y * 3 + 1
  if z % 5 == 0
} yield z // List(-5, 10) : List[Int]
```

⁵<https://docs.scala-lang.org/tour/for-comprehensions.html>

- Please see this document⁶ on GitHub.
- The due date is Sep. 20 (Wed.).
- Please only submit `Implementation.scala` file to **Blackboard**.

⁶<https://github.com/ku-plrg-classroom/docs/tree/main/scala-tutorial>.

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- Syntax and Semantics (1)

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