# Lecture 1 – Basic Introduction to Scala

## AAA551: Programming Language Theory

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2026 Spring

# Recall

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

# What is Scala?

PLRG


Scala stands for **Sca**lable **La**nguage.

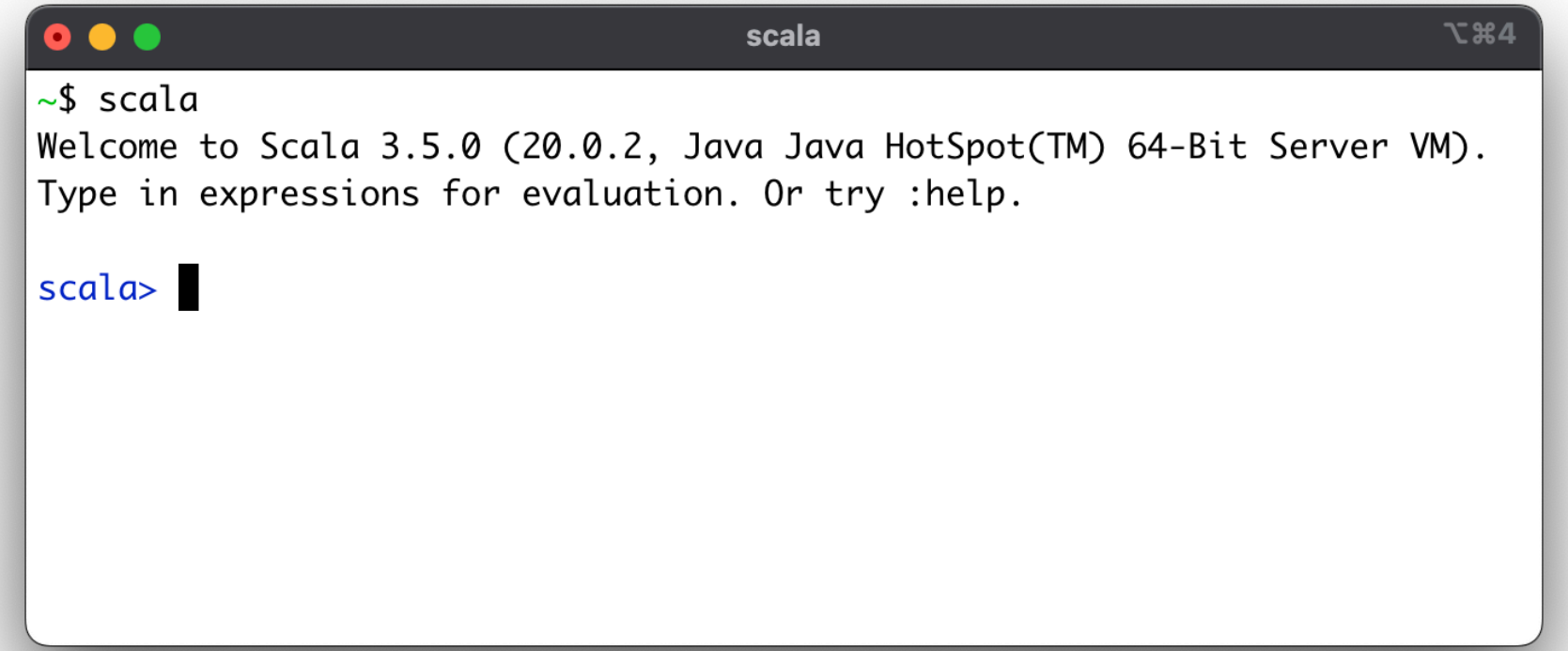
- A general-purpose programming language
- **Java Virtual Machine (JVM)**-based language
- A **statically typed** language
- An **object-oriented programming (OOP)** language
- A **functional programming (FP)** language

# Read-Eval-Print-Loop (REPL)

PLRG

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/



# Functional Programming

PLRG

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

# Contents

1. Basic Features
    - Basic Data Types
    - Variables
    - Methods
    - Conditionals
    - Recursions
2. User-Defined Data Types
    - Product Types – `case class`
    - Algebraic Data Types (ADTs) – `enum`
    - Pattern Matching
    - Methods
3. First-Class Functions
4. Immutable Collections
    - Lists
    - Options and Pairs
    - Maps and Sets
    - For Comprehensions

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# Basic Data Types

```
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`)
```

# Basic Data Types

PLRG

```
42              // 42   : Int     (32-bit signed integer)
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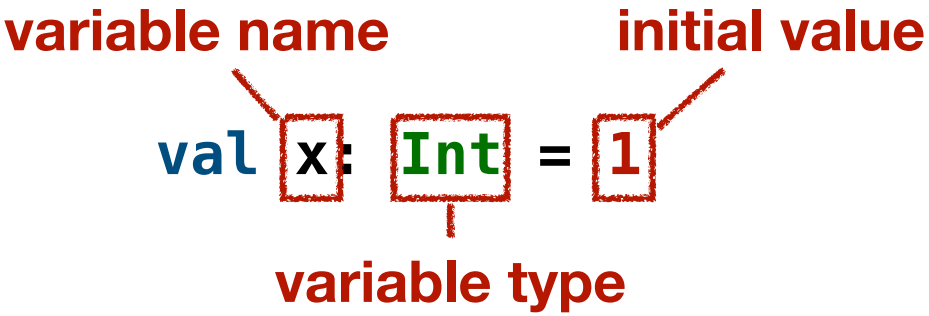
'c'             // 'c'  : Char    (16-bit Unicode character)
"abc"           // "abc": String  (a sequence of characters)
()              // ()   : Unit    (meaningless value - similar to `void`)
```

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")
```

# Immutable Variables




```
// 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
```

# Mutable Variables

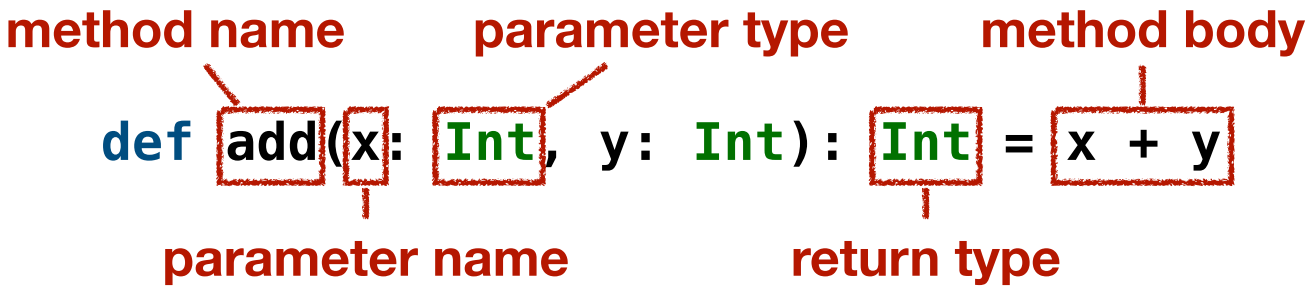
While Scala supports mutable variables (`var`), **DO NOT USE MUTABLE VARIABLES IN THIS COURSE** because it is against the **functional programming** paradigm.

```
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
```

# Methods

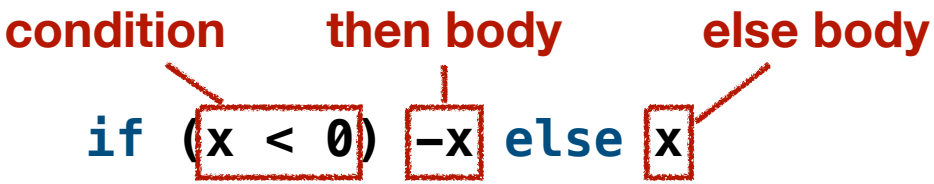



```
// A method `add` of type `(Int, Int) => Int`
// It means that `add` takes two `Int` arguments and returns an `Int`
def add(x: Int, y: Int): Int = x + y
add(1, 2)          // 1 + 2 == 3  : Int
add(5, 6)          // 5 + 6 == 11 : Int

// 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")
```

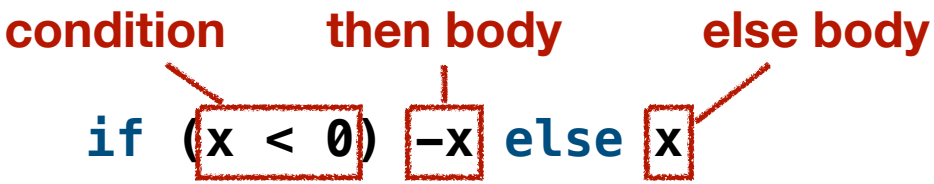
# Conditionals




```
// 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
```

# Conditionals




```
// 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
```

# Recursions

PLRG

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
```

# Recursions

PLRG

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 =
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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
}
```

# Recursions

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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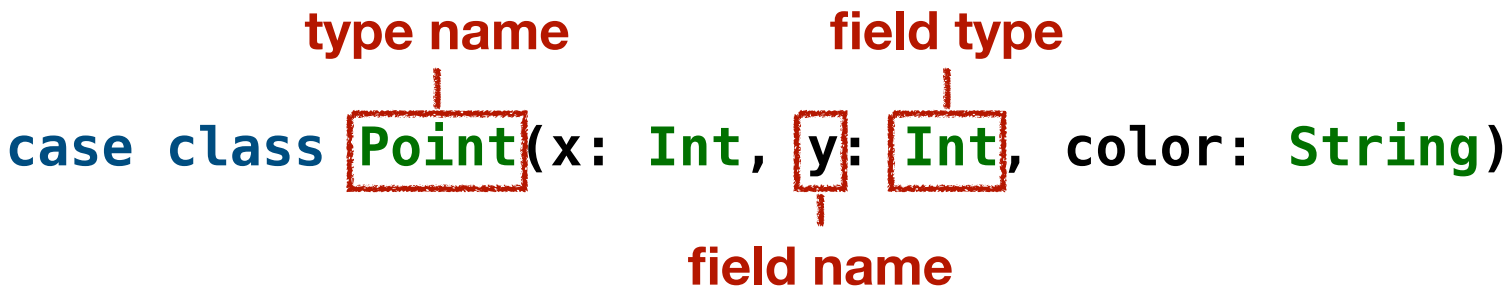
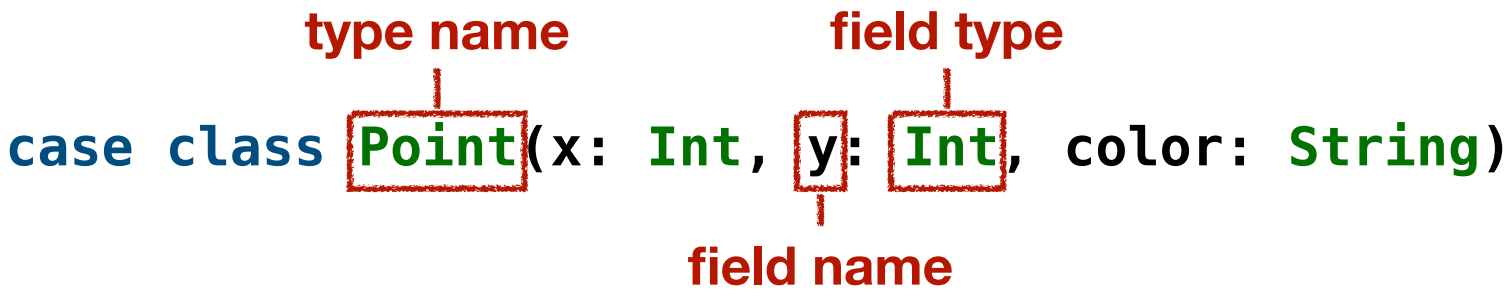
# Product Types – `case class`




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

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

# Product Types – `case class`




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

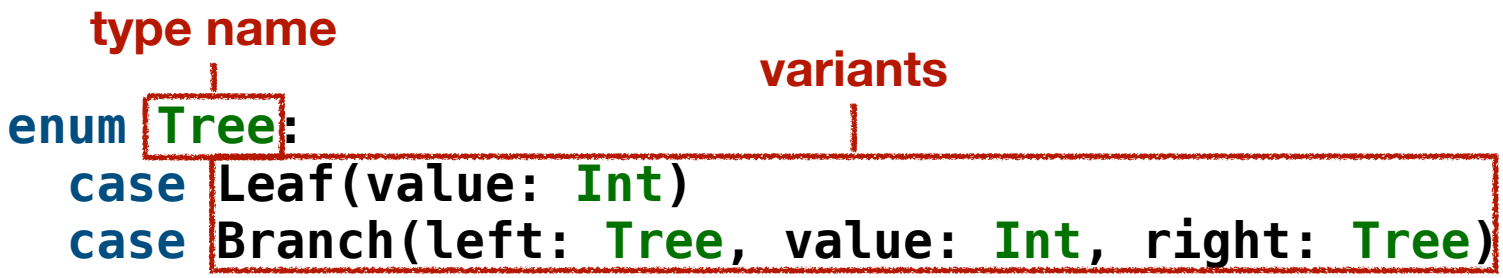
- its **type name** (e.g., `Point`)
- its **constructor** (e.g., `Point`)

```
// 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`
```

# Algebraic Data Types (ADTs) – `enum`




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

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

# Algebraic Data Types (ADTs) – `enum`

PLRG

type name

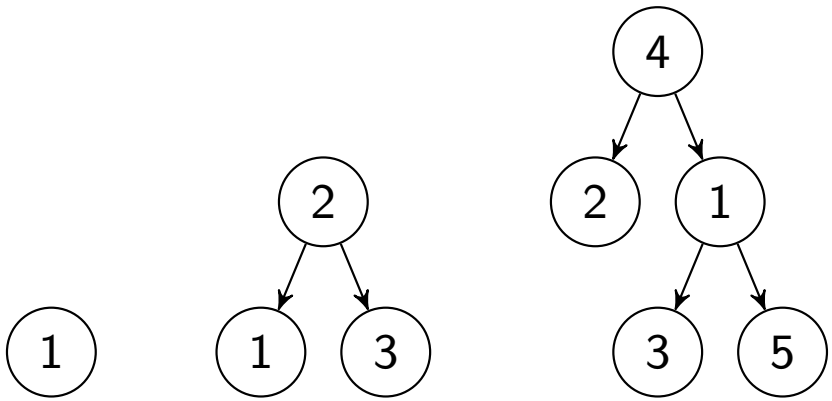
variants

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

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)))
```



# Pattern Matching

PLRG

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
```

# Pattern Matching

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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
```

# Pattern Matching

PLRG

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`
```

# Pattern Matching

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
```

# Methods

PLRG

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
```

# Methods

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case class Point(x: Int, y: Int, color: String):
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  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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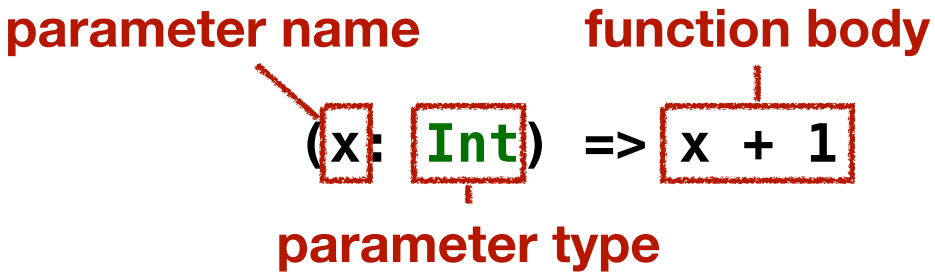
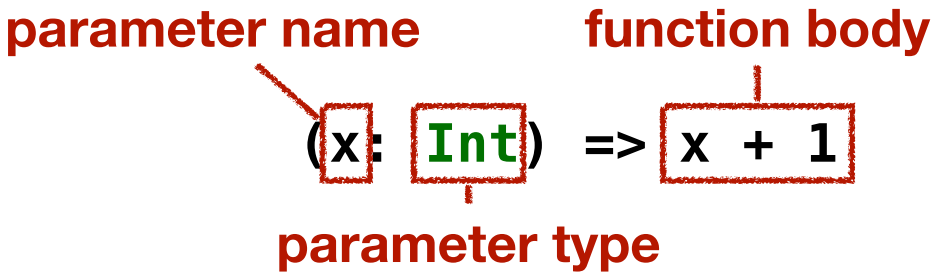
# First-Class Functions




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
```

# First-Class Functions




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

# First-Class Functions

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
```

# First-Class Functions

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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# Lists

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

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

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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

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

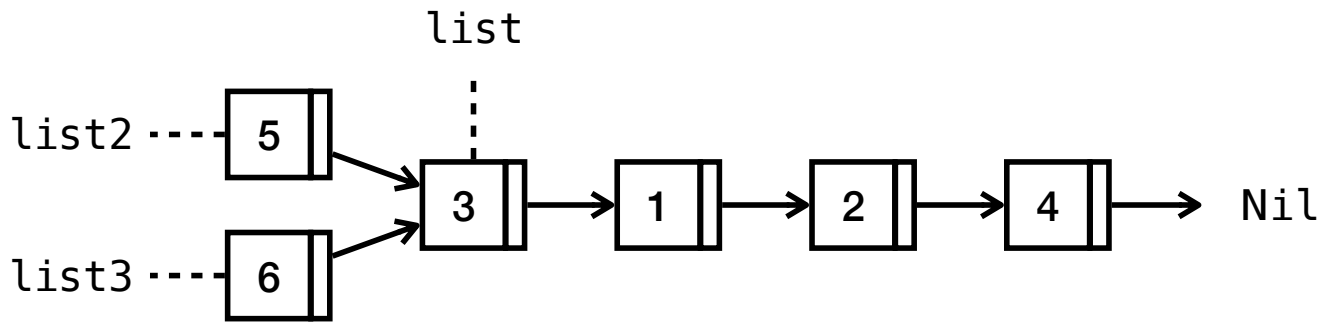
```
val list: List[Int] = List(3, 1, 2, 4)
```

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]
```



# Lists

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]
```

# Lists – Operations

```scala
// 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]
```

# Lists – Operations

```
// 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]
```

# Options

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

# Options

PLRG

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
```

# Pairs

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"
```

# Maps and Sets

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]
```

# For Comprehensions

PLRG

```
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]
```

[1] https://docs.scala-lang.org/tour/for-comprehensions.html

# For Comprehensions

```scala
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:

```scala
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

# Summary

PLRG

1. Basic Features
    - Basic Data Types
    - Variables
    - Methods
    - Conditionals
    - Recursions
2. User-Defined Data Types
    - Product Types – `case class`
    - Algebraic Data Types (ADTs) – `enum`
    - Pattern Matching
    - Methods
3. First-Class Functions
4. Immutable Collections
    - Lists
    - Options and Pairs
    - Maps and Sets
    - For Comprehensions

# Exercise #1

PLRG

- 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.

# Summary

PLRG

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# Next Lecture

- Big-Step Operational Semantics

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