Lecture 4 – Functional Programming

SWS121: Secure Programming

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2024 Spring

Recall

- Recall: Product Types and Algebraic Data Types
- **Basic Object-Oriented Programming**
  - Constructors
  - Traits
  - Overloading and Overriding
  - Access Modifiers
- **Advanced Object-Oriented Programming**
  - Objects
  - Companion Objects
  - Operators

Contents

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Methods vs Functions

PLRG

In general, a **method** is a member of a class or object, and a **function** is a value that can be assigned to a variable.

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val isEvenFunction = (n: Int) => n % 2 == 0    // a function
```

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Methods should be used by calling them with parentheses.

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The **function** truly is an **object**, so we can use it just like any other variable, including passing it as an argument to a method.

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List(1, 2, 3, 4, 5).filter(isEvenFunction)     // List(2, 4)
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List(1, 2, 3, 4, 5).filter(isEvenFunction)     // List(2, 4)
```

However, we can also pass a **method** as a function in Scala. Why?

```
List(1, 2, 3, 4, 5).filter(isEvenMethod)       // List(2, 4)
```

Eta expansion!

Eta Expansion

To utilize a method as a function, we need to create a **function** as a wrapper around the method.

```
List(1, 2, 3, 4, 5).filter(x => isEvenMethod(x))  // List(2, 4)
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List(1, 2, 3, 4, 5).filter(x => isEvenMethod(x))  // List(2, 4)
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Or, we can simplify it using the **placeholder syntax** (_).

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It is called **eta expansion**, which converts a method into a function.

Scala compiler **automatically performs** the **eta expansion** for us.

```
List(1, 2, 3, 4, 5).filter(isEvenMethod)          // List(2, 4)
```

It means that we can utilize a method as a function without explicitly converting it into a function in Scala.

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In **imperative programming**, we use **loops** to iterate to recursively do something. For example, we can use a **while loop** to calculate the sum of the first n numbers.

```
def sum(n: Int): Int = {
  var k = n
  var sum = 0
  while (k > 0) {
    sum += k
    k -= 1
  }
  sum
}

sum(1000)
```

Recursion

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```

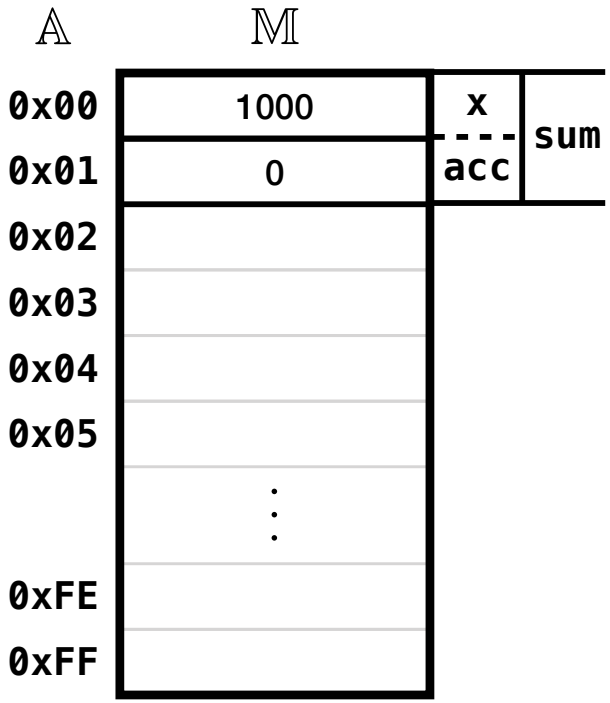
However, in **functional programming**, we use **recursive functions** (or methods) to recursively do something.

Recursive Functions

Here is a Scala code example with a **recursive method**:

```
def sum(n: Int, acc: Int): Int =
  if (n < 1) acc
  else sum(n - 1, n + acc)

sum(1000, 0)
```



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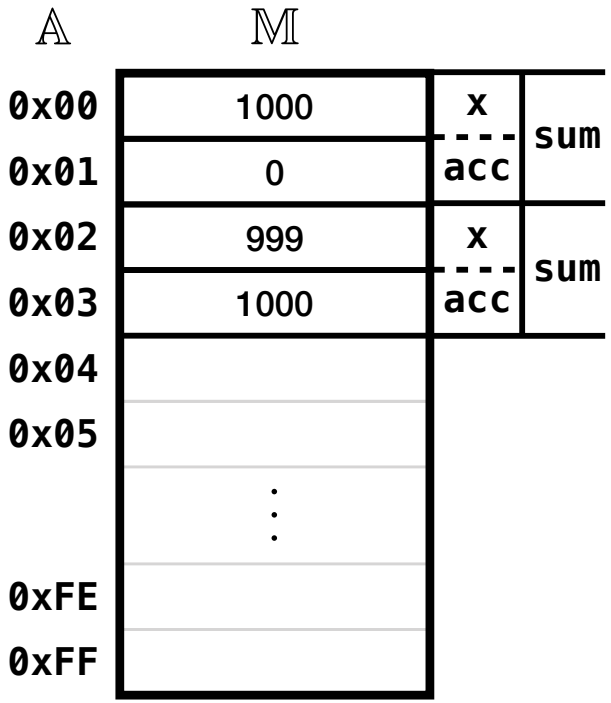

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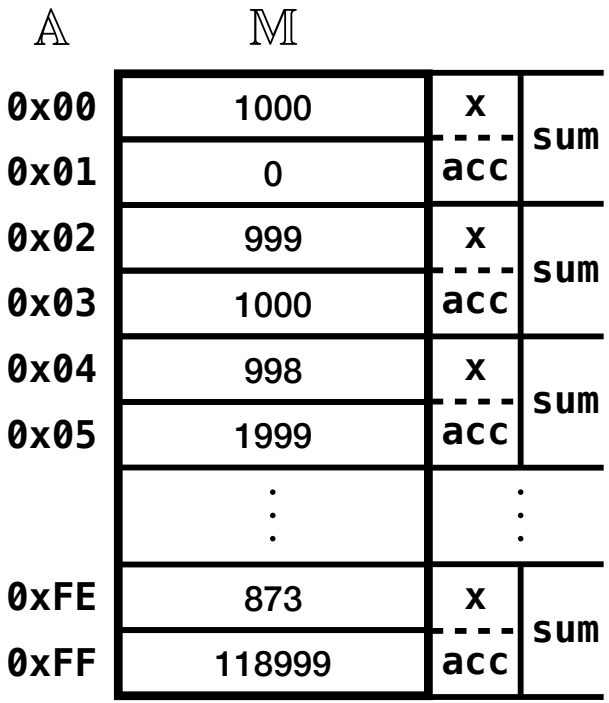

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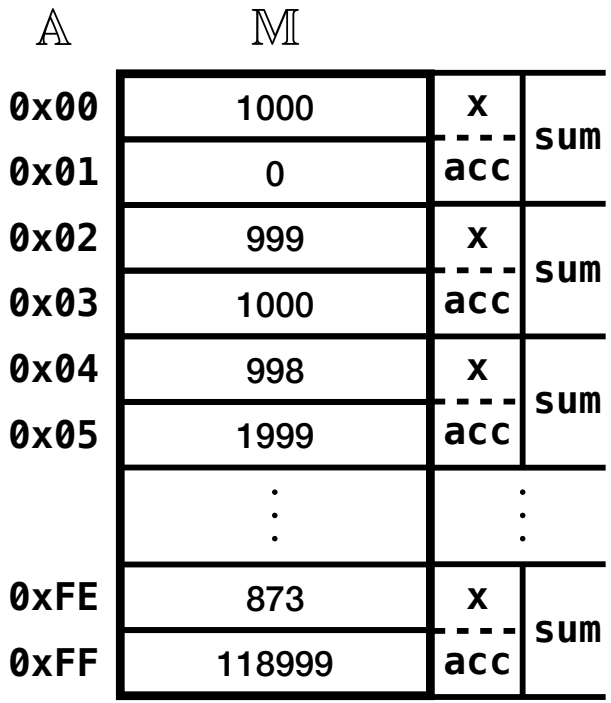

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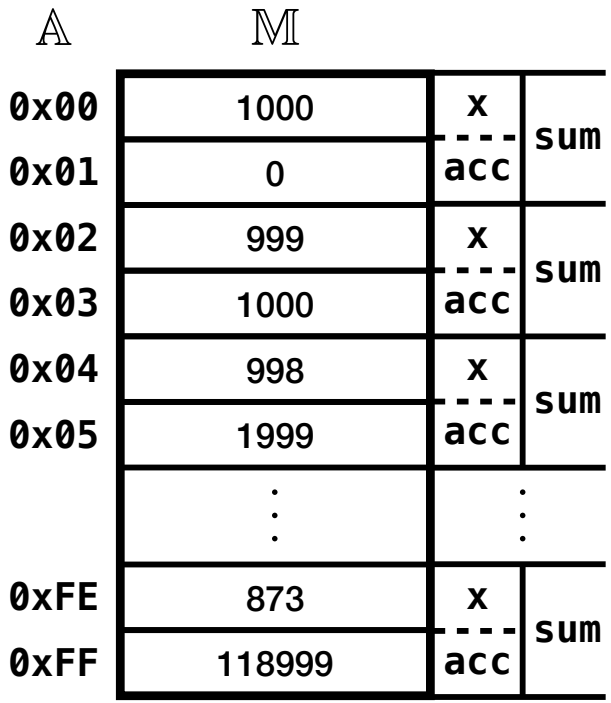

It fails with a **stack overflow** error.

However, is it really necessary to keep **all the stack frames**? **No!**

Scala supports **tail-call optimization** (TCO).

Tail-Call Optimization

Here is a Scala code example with a **recursive method**:

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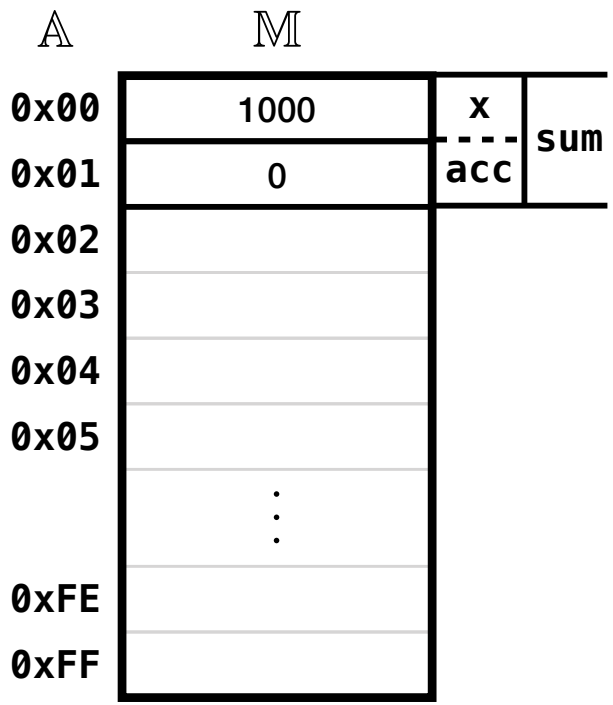

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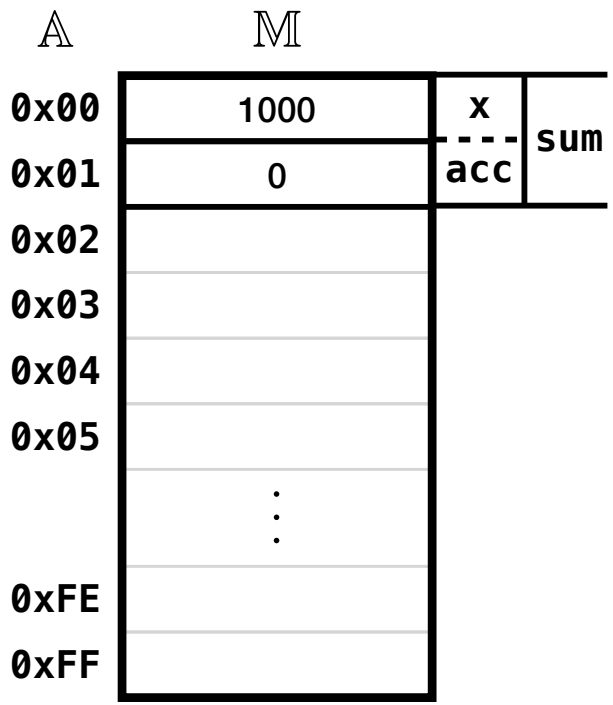

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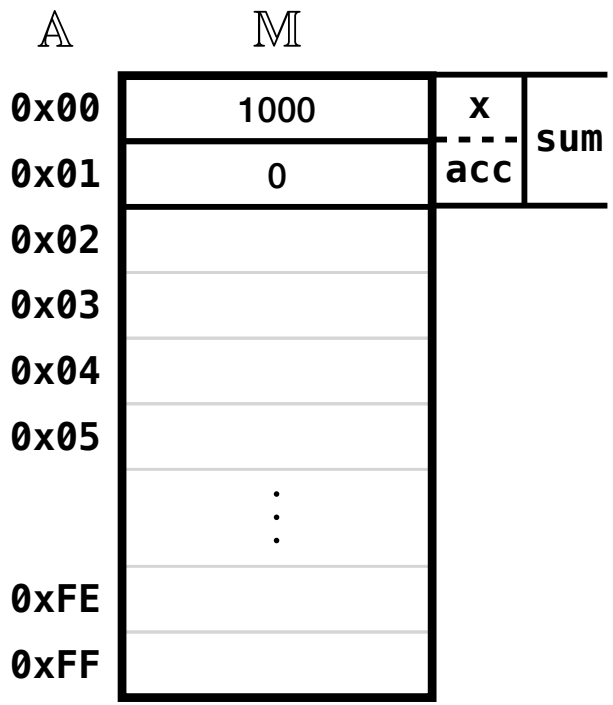

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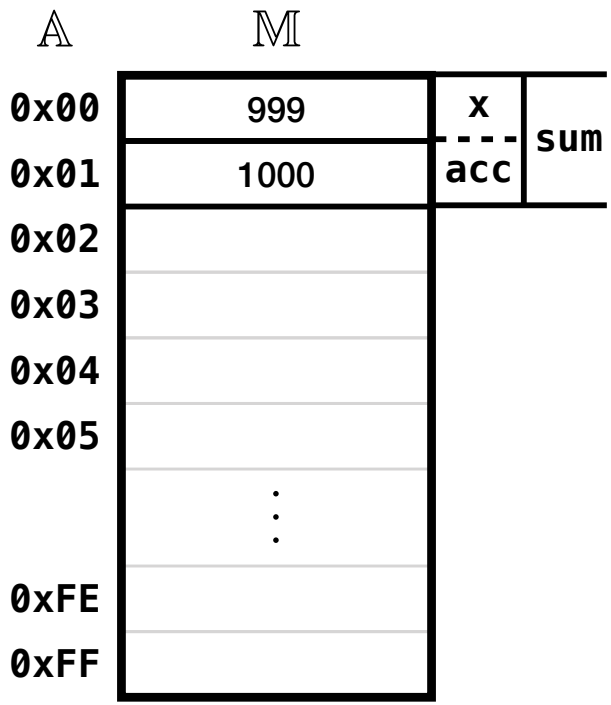

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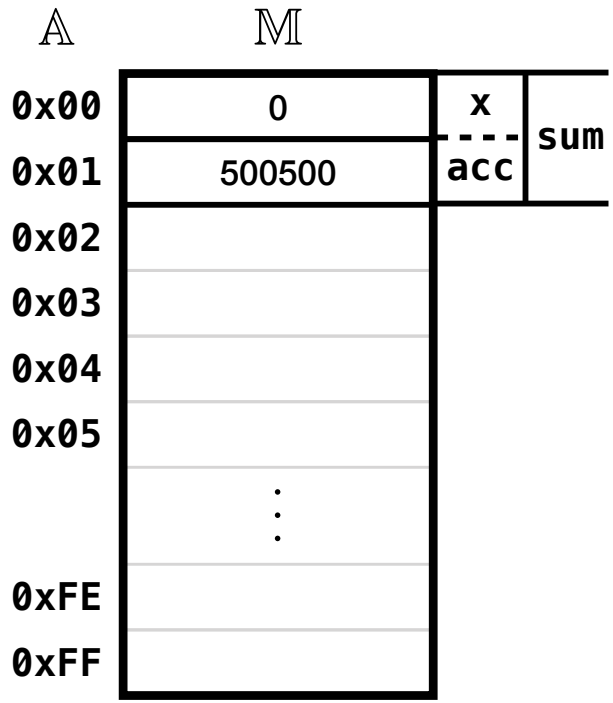

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To ensure that the function call is in **tail-call position**, we can utilize the `scala.annotation.tailrec` annotation in Scala.

```scala
import scala.annotation.tailrec

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def sum(n: Int, acc: Int): Int =
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```
@tailrec
def sum(n: Int): Int =
  if (n < 1) 0
  else n + sum(n - 1) // not a tail-call
```

If the function is not in the **tail-call position**, the compiler will **reject** the program during compilation.

Default Parameter Values

However, passing the **accumulated value** `acc` to the function is not user-friendly.

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One possible solution is to use a **default parameter value** for the accumulated value.

```
@tailrec
def sum(n: Int, acc: Int = 0): Int =
  if (n < 1) acc
  else sum(n - 1, n + acc) // tail-call

sum(1000)               // 500500
sum(1000, 0)            // 500500
```

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```

We can call it using the **named argument** syntax to improve readability.

```
sum(1000, acc = 0)      // 500500
sum(acc = 0, n = 1000)  // 500500
```

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```
def sum(n: Int): Int = {

  // nested method supporting tail-call optimization
  @tailrec
  def aux(n: Int, acc: Int): Int =
    if (n < 1) acc
    else aux(n - 1, n + acc) // tail-call

  aux(n, 0)
}

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  aux(n, 0)
}

sum(1000)       // 500500
```

It is another way of **encapsulation** in functional programming paradigm.

We **cannot access** the **nested method** (aux) from outside the enclosing method (sum).

Multiple Parameter Lists

We learned that functions are **first-class citizens** in Scala, and we can define a function that returns another function.

```
// `add` takes two arguments and returns an integer
val add = (x: Int, y: Int) => x + y
// `addN` takes a single argument and returns a function
val addN = (x: Int) => (y: Int) => x + y
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Currying is the technique of converting a function that takes multiple arguments into a sequence of functions that each take a single argument.

We can use **multiple parameter lists** to define a curried method similar to the curried function.

```
def addN(x: Int)(y: Int): Int = x + y

val add3 = addN(3)
add3(5)          // 3 + 5 = 8
addN(4)(6)        // 4 + 6 = 10
```

Contents

Pattern Matching

PLRG

We learned that Scala supports **pattern matching** to match a value against a pattern. It is a **more powerful** and **safer** version of the `switch` statement in Java.

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

// Load all constructors of the Tree enum
import Tree.*

// A recursive method counts the number of the given integer 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(Branch(Leaf(1), 2, Leaf(3)), 4, Leaf(5)))      // 15 : Int
```

Pattern Matching

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We can define a function using **pattern matching**.

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We can utilize this concept with **multiple parameter lists** as follows:

```
  // `List.foldLeft` has two parameter lists:
  //   (1) the initial value and
  //   (2) a function used to fold the list.
  List(1, 2, 3, 4, 5).foldLeft(0)((x, y) => x + y)
  List(1, 2, 3, 4, 5).foldLeft(0)(_ + _)      // placeholder syntax
```

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```

```
  // Add only even numbers by using pattern matching
  List(1, 2, 3, 4, 5).foldLeft(0) {
    case (acc, n) if n % 2 == 0 => acc + n
    case (acc, _) => acc
  }
```

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- **Enhanced readability** – It makes the code more readable and maintainable.

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- **Simple and concise code** – Compared to the traditional `if-else` statements or `switch` statements, it supports more complex patterns with 1) nested patterns, 2) guards, and 3) matching on tuples.
- **Enhanced readability** – It makes the code more readable and maintainable.
- **Reducing bugs** – The compiler can check if all cases are covered (exhaustive pattern matching) and warn if some cases are missing.

Pattern Matching – Tuples

We can perform **pattern matching** on **tuples** to consider multiple different values at once in a single pattern.

```
// Merge two lists
val merge: (List[Int], List[Int]) => List[Int] = {
  case (lh :: lt, rh :: rt) => (lh + rh) :: merge(lt, rt)
  case (Nil, right) => right
  case (left, Nil) => left
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We can **safely extract** the values from a tuple using the **pattern matching** syntax and ignore some values using the underscore (_).

```
val triple = (1, "abc", true)

// Extract values from a tuple
val (x, y, z) = triple
// x = 1, y = "abc", z = true

// Ignore the second value
val (a, _, c) = triple
```

Pattern Matching – Case Classes

Similarly, we can perform **pattern matching** on **case classes** to extract the values from the case class without using the dot notation.

```
case class Person(name: String, age: Int)
val person = Person("Jihyeok Park", 32)

// Extract values from a case class
val Person(name, age) = person    // name = "Jihyeok Park", age = 32
```

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// Extract values from a case class
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```

We can also use the **nested pattern matching** to extract the values from the case class.

```
case class Card(person: Person, number: Int)
val card = Card(Person("Jihyeok Park", 32), 1234)

// Safely extract the all information of the card at once
val Card(Person(name, age), number) = card
// val name   = card.person.name
// val age    = card.person.age
// val number = card.number
```

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Then, the compiler will warn us the pattern matching is **not exhaustive**:

```
[E029] Pattern Match Exhaustivity Warning:
  case (lh :: lt, rh :: rt) => (lh + rh) :: merge(lt, rt)
  ^
  match may not be exhaustive.

  It would fail on pattern case: (List(_, _*), Nil)
```

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Then, the compiler will warn us the pattern matching is **not exhaustive**:

```
[E029] Pattern Match Exhaustivity Warning:
  case (lh :: lt, rh :: rt) => (lh + rh) :: merge(lt, rt)
  ^
  match may not be exhaustive.

  It would fail on pattern case: (List(_, _*), Nil)
```

Exhaustive matching is a powerful feature that can prevent many bugs.

Exhaustive Matching and Reachability

Scala compiler also checks whether each case is **reachable** or not.

Exhaustive Matching and Reachability

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Assume we accidentally added the already covered case `(Nil, Nil)` in `merge` function.

```
val merge: (List[Int], List[Int]) => List[Int] = {
  case (lh :: lt, rh :: rt) => (lh + rh) :: merge(lt, rt)
  case (Nil, right) => right
  case (left, Nil) => left
  case (Nil, Nil) => Nil
}
```

Exhaustive Matching and Reachability

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  case (Nil, right) => right
  case (left, Nil) => left
  case (Nil, Nil) => Nil
}
```

Then, the compiler will warn us the last case is **unreachable**:

```
[E030] Match case Unreachable Warning:
  case (Nil, Nil) => Nil
       ^^^^^^^^^^
       Unreachable case
```

Pattern Matching – Sealed Types

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To ensure the pattern matching is **exhaustive**, we can use the **sealed** keyword to restrict the possible subtypes of a supertype.

Pattern Matching – Sealed Types

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To ensure the pattern matching is **exhaustive**, we can use the **sealed** keyword to restrict the possible subtypes of a supertype.

```
sealed trait Shape
case class Circle(radius: Double) extends Shape
case class Rectangle(width: Double, height: Double) extends Shape
case class Triangle(base: Double, height: Double) extends Shape

// Calculate the area of the shape
def area(shape: Shape): Double = shape match
  case Circle(r) => math.Pi * r * r
  case Rectangle(w, h) => w * h
  // Triangle(_, _) case is missing and the compiler will warn us
```

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```

The **sealed** type can only be extended in the **same file** and prevents the creation of new subtypes outside the file.

Pattern Matching – Sealed Types

Conceptually, **enums** is a **syntactic sugar** for a **sealed** type with a set of **case classes** (or **objects**).

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

will be conceptually desugared into:

```
sealed abstract class Tree
object Tree:
  case class Leaf(value: Int) extends Tree
  case class Branch(left: Tree, value: Int, right: Tree) extends Tree
```

Thus, the **exhaustiveness** of the pattern matching is guaranteed also for the **enums** in Scala.

Regular Expression Patterns

Scala supports **regular expressions** with a method `r` on a string.

```
// email pattern: <username>@<domain>
val emailPattern: Regex = """^(\w+)@(\w+(.\w+)+)$""".r
// phone pattern: <area code>-<exchange code>-<number>
val phonePattern: Regex = """^(\d{3}-\d{3}-\d{4})$""".r
```

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```

We can use **regular expression patterns** in Scala to match a string against a regular expression.

```
def detectContact(contact: String): String = contact match
  case emailPattern(username, domain) => s"Email: $username at $domain"
  case phonePattern(phone) => s"Phone: $phone"
  case _ => "Unknown contact"
```

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```

```
detectContact("abc@domain.com")       // Email: abc at domain.com
detectContact("123-456-7890")         // Phone: 123-456-7890
detectContact("abc#domain.com")       // Unknown contact
detectContact("123-45-43")            // Unknown contact
detectContact("invalid")              // Unknown contact
```

Extractor Objects

We can define **user-defined patterns** using **extractor objects**.

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Extractor Objects

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Extractor objects are objects that define a method called `unapply` or `unapplySeq` to extract values from a given object.

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

// An extractor object for the leaf node whose value is even
object EvenLeaf:
  def unapply(tree: Tree): Option[Int] = tree match
    case Leaf(n) if n % 2 == 0 => Some(n)
    case _ => None

def sumEvenLeaves(tree: Tree): Int = tree match
  case EvenLeaf(n) => n       // extract only if the leaf value is even
  case Branch(l, _, r) => sumEvenLeaves(l) + sumEvenLeaves(r)
  case Leaf(_) => 0
sumEvenLeaves(Branch(Leaf(2), 3, Branch(Leaf(4), 6, Leaf(7))))    // 6
```

Extractor Objects

The `unapplySeq` method can be used to extract a **sequence of values**.

Extractor Objects

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The unapplySeq method can be used to extract a **sequence of values**.

```
// An extractor object for string sequence split by a comma
object CommaSeparated:
  def unapplySeq(s: String): Option[Seq[String]] =
    Some(s.split(',').toSeq)

// Parse a string having at most three parts separated by a comma
def parse(s: String): String = s match
  case CommaSeparated(a, b, c) => s"Three parts: $a, $b, $c"
  case CommaSeparated(a, b) => s"Two parts: $a, $b"
  case CommaSeparated(a) => s"One part: $a"
  case _ => "Invalid format"

parse("a,b,c")      // Three parts: a, b, c
parse("x,y")        // Two parts: x, y
parse("k")          // One part: k
parse("a,b,c,d")    // Invalid format
```

Contents

Functional Error Handling

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In general, we can handle the exception with the try-catch block:

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def makeInt(s: String): Int =
  try Integer.parseInt(s)
  catch case _: Exception => 0
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Functional Error Handling

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```

However, it is not really accurate. If we get 0 as a result, we don't know whether it is because the string was not a valid integer or the input is `"0"`.

We can use the **Option** type to handle this situation more accurately.

Option Type

The `Option[T]` type is a **container** that may contain a single value of type `T` or no value.

- **Some(x)** – a container that holds a single value `x` of type `T`
- **None** – a container that holds no value

```
def makeInt(s: String): Option[Int] =
  try Some(Integer.parseInt(s))
  catch case _: Exception => None
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```
def makeInt(s: String): Option[Int] =
  try Some(Integer.parseInt(s))
  catch case _: Exception => None
```

We can apply pattern matching to handle the `Option` type.

```
val x: String = ...

makeInt(x) match
  case Some(n) => println(s"Integer: $n")
  case None => println("Not an integer")
```

Option Type

We can utilize `for` **comprehension** to handle multiple `Option` values.

```
def addStrings(s1: String, s2: String, s3: String): Option[Int] = for {
  a <- makeInt(s1)
  b <- makeInt(s2)
  c <- makeInt(s3)
} yield a + b + c

addStrings("1", "2", "3")       // Some(6)
addStrings("x", "2", "3")       // None
```

`Option` is not the only solution for error handling in Scala.

Option Type

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We will learn how it works later in this course.

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```

`Option` is not the only solution for error handling in Scala.

We will learn how it works later in this course.

In addition, Scala supports other types like `Try` or `Either` types for functional error handling.

Try Type

We can keep which exception occurred using the `Try[T]` type.

- **Success(x)** – a container that holds a single value `x` of type `T`
- **Failure(e)** – a container that holds an exception `e`

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```
import scala.util.Try

def makeInt(s: String): Try[Int] = Try(Integer.parseInt(s))
makeInt("123")              // Success(123)
makeInt("abc")              // Failure(java.lang.NumberFormatException)
```

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def makeInt(s: String): Try[Int] = Try(Integer.parseInt(s))
makeInt("123")              // Success(123)
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```

```
def addStrings(s1: String, s2: String, s3: String): Try[Int] = for {
  a <- makeInt(s1)
  b <- makeInt(s2)
  c <- makeInt(s3)
} yield a + b + c

addStrings("1", "2", "3") // Success(6)
addStrings("x", "2", "3") // Failure(java.lang.NumberFormatException)
```

Either Type

We can keep our own data for failure cases using the `Either[L, R]` type.

- **Left(x)** – a value `x` of type `L` for failure cases
- **Right(x)** – a value `x` of type `R` for success cases

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```
def divide(x: Int, y: Int): Either[String, Int] =
  if (y == 0) Left("Cannot divide by zero")
  else Right(x / y)

divide(10, 2)             // Right(5)
divide(10, 0)             // Left("Cannot divide by zero")
```

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def divide(x: Int, y: Int): Either[String, Int] =
  if (y == 0) Left("Cannot divide by zero")
  else Right(x / y)

divide(10, 2)             // Right(5)
divide(10, 0)             // Left("Cannot divide by zero")
```

```
def divideThree(x: Int, y: Int, z: Int): Either[String, Int] = for {
  a <- divide(x, y)
  b <- divide(a, z)
} yield b

divideThree(10, 2, 5)     // Right(1)
divideThree(10, 0, 5)     // Left("Cannot divide by zero")
```

Summary

PLRG

1. Functions
    - Methods vs Functions
    - Eta Expansion
    - Recursive Functions
    - Tail-Call Optimization
    - Default Parameter Values
    - Nested Methods
    - Multiple Parameter Lists
2. Pattern Matching
    - Sealed Types
    - Regular Expression Patterns
    - Extractor Objects
3. Functional Error Handling
    - Option Type
    - Try Type
    - Either Type

Next Lecture

- Immutable Collections

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