Lecture 2 – Testing and Documentation

SWS121: Secure Programming

Jihyeok Park

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Recall

We learned basics of Scala programming in the last lecture.

- Basic Features
  - Basic Data Types
  - Variables
  - Methods
  - Recursion
- Algebraic Data Types (ADTs)
  - Product Types – Case Classes
  - Algebraic Data Types (ADTs) – Enumerations
  - Pattern Matching
  - Methods
- First-Class Functions
- Immutable Collections
  - Lists
  - Options and Pairs
  - Maps and Sets
  - For Comprehensions

Contents

Contents

Scala Project with `scalac`

In Scala, a library or a program is compiled using the Scala compiler, `scalac`, as documented in Scala 3 Book.[1]

```
@main def main: Unit = println("Hello, world!")  /* hello.scala */
```

[1] https://docs.scala-lang.org/scala3/book/taste-hello-world.html

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```
@main def main: Unit = println("Hello, world!")  /* hello.scala */
```

```
$ scalac hello.scala

$ ls -1
# hello$package$.class
# hello$package.class
# hello$package.tasty
# hello.class
# hello.scala
# hello.tasty

$ scala hello
# Hello, world!
```

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# hello$package.tasty
# hello.class
# hello.scala
# hello.tasty

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# Hello, world!
```

How to handle **multiple files**, **dependencies**, **testing**, etc.?

[1] https://docs.scala-lang.org/scala3/book/taste-hello-world.html

Simple Build Tool (sbt)

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- Rather than using `scalac` directly, `sbt` provides a more convenient way to **compile**, **run**, **test**, **document**, and **package** Scala programs.

Simple Build Tool (`sbt`)

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- `sbt` is a **simple build tool** for Scala and Java projects. It is similar to Maven or Ant, but it is designed for **Scala**.
- Rather than using `scalac` directly, `sbt` provides a more convenient way to **compile**, **run**, **test**, **document**, and **package** Scala programs.
- `sbt` supports a **domain-specific language (DSL)** called **`build.sbt` DSL** for defining the build process of a Scala project.

Example Project

Here is a **simple example `sbt` project** that includes a simple **arithmetic expression** `Expr` and a tree `Tree` data structure:

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```

Please check you have JDK 8 or later and `sbt` installed on your system.

```
$ java -version
# java version "21.0.2" 2024-01-16 LTS

$ sbt --script-version
# 1.9.4
```

Project Structure

A typical sbt project has the following structure:

```
build.sbt                    # build definition
project
  build.properties           # sbt version
  plugins.sbt                # sbt plugins
src/
  main/
    resources/               # resources
    scala/                   # main Scala sources
  test/
    scala/                   # test Scala sources
```

Project Structure – build.sbt

We can define the build process of the project in the build.sbt file:

```
ThisBuild / scalaVersion := "3.3.3"
ThisBuild / scalacOptions ++= Seq(...)
lazy val root = project
  .in(file("."))
  .settings(
    name := "scala-example",
    libraryDependencies += "org.scalatest" %% "scalatest" % "3.2.15" %
    Test,
    coverageEnabled := true,
    ...
  )
...
```

We can freely utilize Java (JVM-based) libraries in Scala projects:

```
libraryDependencies += "org.scalatest" %% "scalatest" % "3.2.15" % Test,
```

Project Structure – `project`

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The `project` directory contains the following files:

```
project/
  build.properties              # sbt version
  plugins.sbt                   # sbt plugins
```

The example project uses `1.9.9` version of `sbt`:

```
sbt.version=1.9.9
```

and uses the following plugins:

```
addSbtPlugin("org.wartremover" % "sbt-wartremover" % "3.1.6")
addSbtPlugin("org.scoverage" % "sbt-scoverage" % "2.0.11")
```

- `wartremover` is used to **block non-funcional Scala features**.
- `scoverage` is used to measure **code coverage**.

Project Structure – Main and Test Sources

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The example project has **three main Scala files**:

- `App.scala` – Main Application
- `Expr.scala` – Arithmetic Expression
- `Tree.scala` – Tree Data Structure

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- `App.scala` – Main Application
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- `Tree.scala` – Tree Data Structure

and **two test Scala files**:

- `ExprSpec.scala` – Test Suite for Arithmetic Expression
- `TreeSuite.scala` – Test Suite for Tree Data Structure

Building a Project

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# [success] Total time: 0 s, completed ...
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```

It is better to use the following command to start the `sbt` shell:

```
$ sbt
# [info] ...
sbt:scala-example> compile
# [info] ...
# [success] Total time: 0 s, completed ...
sbt:scala-example>
```

Running a Project

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# Hello, world!
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$ sbt console
```

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```
$ sbt console
```

Then, it shows the following prompt:

```
scala> import kuplrg.{ Expr, Tree }, import Expr.*

scala> val expr: Expr = Mul(Num(2), Add(Var("x"), Var("y")))
val expr: kuplrg.Expr = Mul(Num(2),Add(Var(x),Var(y)))

scala> expr.eval(Map("x" -> 3, "y" -> 5), 0)
val res1: Int = 16

scala>
```

Contents

Why Documentation for Secure Programming?

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- It guides to automatically **test** or **analyze** the code for security vulnerabilities in an effective and systematic way.

`scaladoc` – Scala Documentation Tool

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`scaladoc` – Scala Documentation Tool

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Scaladoc

- Let's use `scaladoc` to **automatically generate documentation** from **comments** in Scala source code.

- It provides similar features to other comment based documentation systems like `javadoc`, `jekyll`, `docusaurus`, etc.

Generating Documentation

To **generate the documentation**, you can run the following command:

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Please enter the directory and run the server to see the documentation using `python3`:

```
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$ python3 -m http.server 8080
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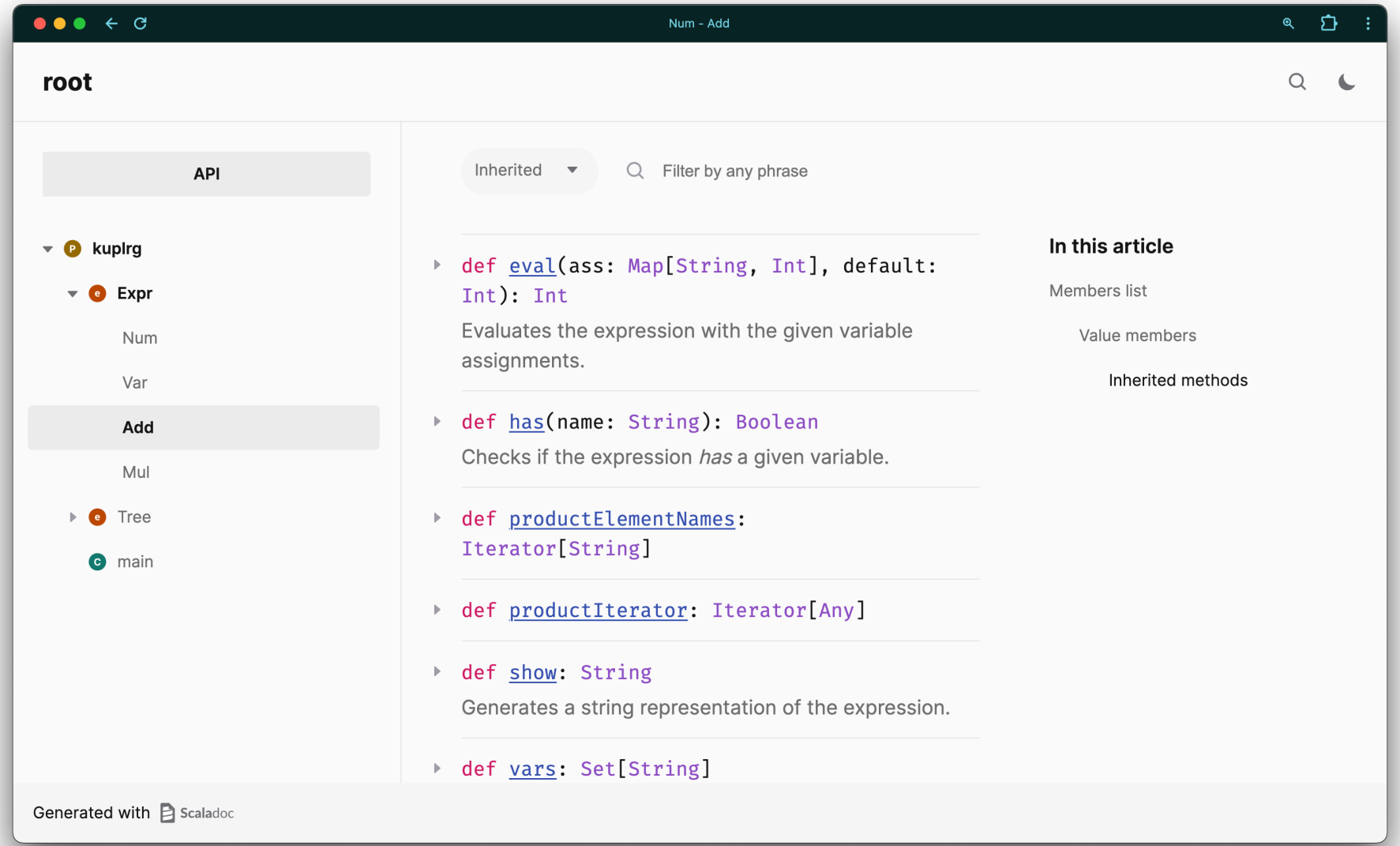
Then, you can open the following URL in your web browser:

http://localhost:8080

Generating Documentation



Writing Documentation

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You can write documentation using **comments** in the Scala source code for `scaladoc` with the following **tags**:

- Class/Method specific tags
  - `@constructor` – constructor
  - `@return` – which value is returned
  - `@throws` – which exceptions are thrown
  - `@param` – parameters
  - `@tparam` – type parameters

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  - `@example` – example code
- Other tags
  - `@since` – when the feature was added
  - `@deprecated` – deprecated feature

Writing Documentation

PLRG

You can use **HTML tags** or **markup** in the comments for scaladoc:

```
`monospace`
''italic text''
'''bold text'''
__underline__
^superscript^
,,subscript,,
[[entity link]],
    e.g. [[scala.collection.Seq]]
[[https://external.link External Link]],
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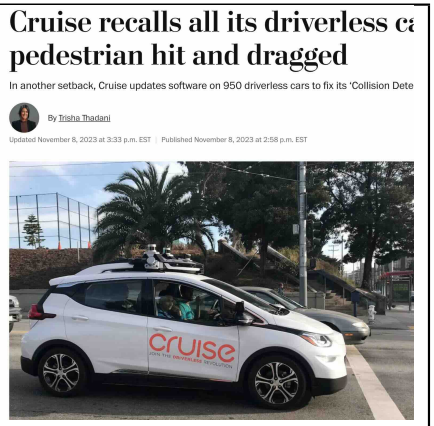
There are other formatting supported by scaladoc:

- **paragraphs** – started with one (or more) blank lines.
- **code blocks** – enclosed by {{{ and }}}.
- **table** – please refer to **here**.
- **list blocks** – "-" for unordered list and "1." for ordered list.

Contents

Errors in Safety-Critical Software

Unexpected faults in **safety-critical software** cause serious problems:

			
Rocket	**Financial**	**Airport**	**Auto. Vehicle**
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			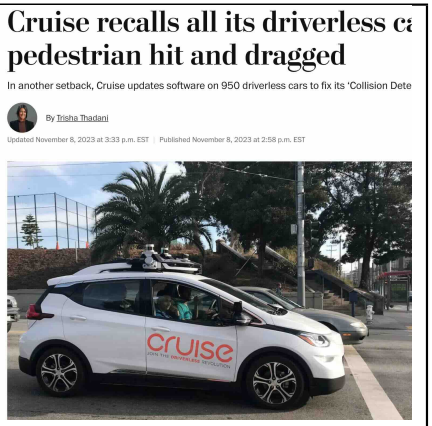
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			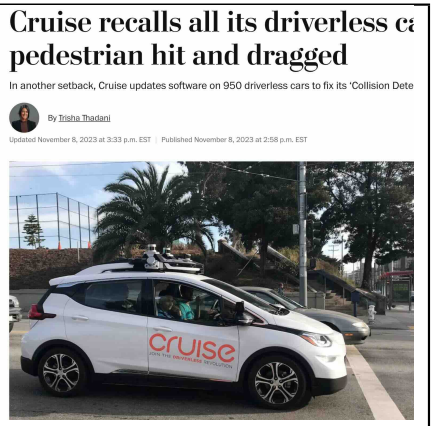
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Then, how can we **prevent** such software faults?

Can we **automatically check** whether a program does not have any software faults?

Detecting Software Faults

How do we know whether a software is correct?

Detecting Software Faults

How do we know whether a software is correct?

Empiricists – Francis Bacon

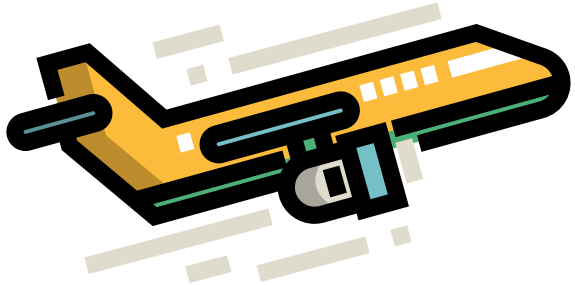
It is correct because I **TESTED** *several times but no error was found!*

vs.

Rationalists – René Descartes

It is correct because I formally **PROVED** *that no error exists!*

Why Software Testing?



- Imagine you have two choices when boarding a airplane:
  - While an airplane A has **never been proven** to have any run-time errors, it has been **tested** with a finite number of test flights.
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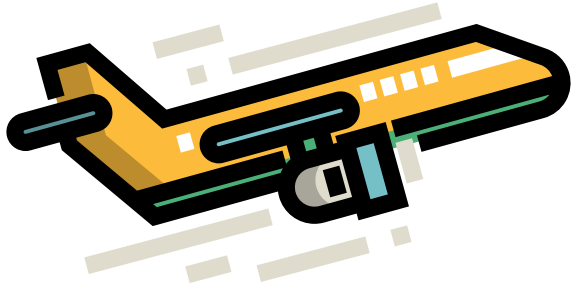

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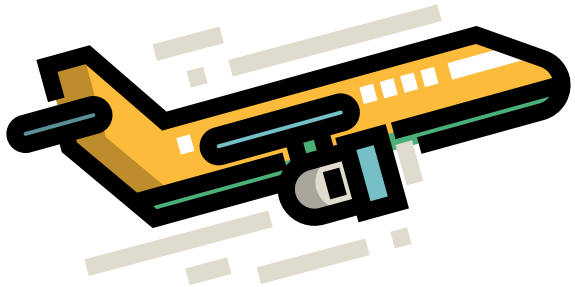

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  - While an airplane B has been **formally verified** to have no run-time errors, it has **never been tested** in the real world.
- Some people may choose A, while others may choose B.
- In addition, some properties only can be **tested** but not **verified** (e.g., energy consumption, usability, etc.).

ScalaTest – Test Framework for Scala

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`ScalaTest` – Test Framework for Scala

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- It is designed to be **easy to learn** and **easy to use**.
- It is designed to be **easy to integrate** with other tools and libraries.
- It supports **different styles** of testing (e.g., `FunSuite`, `FlatSpec`, etc.).

Running Tests

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We can **test the project** with the following command on sbt:

```
$ sbt test
# [info] TreeSuite:
# [info] - The `has` should return if the tree has the value
# [info] - The `map` should map the tree with the given function
# [info] ...
# [info] ExprSpec:
# [info] `vars`
# [info] - should returns the set of variables in the expression
# [info] `show`
# [info] - should generate a string representation of the expression
# [info] ...
# [info] Run completed in 107 milliseconds.
# [info] Total number of tests run: 8
# [info] Suites: completed 2, aborted 0
# [info] Tests: succeeded 8, failed 0, canceled 0, ignored 0, pending 0
# [info] All tests passed.
# [success] Total time: 0 s, completed ...
```

Writing Tests – FlatSpec Style

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For example, we can define a test suite for the arithmetic expression (Expr) using FlatSpec style as follows:

```
import org.scalatest.flatspec.AnyFlatSpec

class ExprSpec extends AnyFlatSpec {
  import Expr.*

  // 2 * (x + y)
  val expr3: Expr = Mul(Num(2), Add(Var("x"), Var("y")))

  "`vars`" should "returns the set of variables in the expression" in {
    assert(expr3.vars == Set("x", "y"))
  }
  "`show`" should "generate a string representation of the expression"
    in {
    assert(expr3.show == "2 * (x + y)")
  }
}
```

Writing Tests – FunSuite Style

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Or, we can define a test suite for the tree data structure (`Tree`) using `FunSuite` style as follows:

```
import org.scalatest.funsuite.AnyFunSuite

class TreeSuite extends AnyFunSuite {
  import Tree.*
  //   1
  //  / \
  // 2   3
  val tree2: Tree = Node(1, List(Leaf(3), Leaf(2)))

  test("The `has` should return if the tree has the value") {
    assert(tree2.has(8) == false)
  }

  test("The `map` should map the tree with the given function") {
    assert(tree2.map(_ * 2) == Node(2, List(Leaf(6), Leaf(4))))
  }
}
```

Measuring Code Coverage

- How to measure the **quality** of the tests?

Measuring Code Coverage

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- One possible way is to measure the **code coverage** of the tests.

Measuring Code Coverage

PLRG

- How to measure the **quality** of the tests?

- One possible way is to measure the **code coverage** of the tests.

- We can **measure the code coverage** of the project using `scoverage`, the **code coverage tool** for Scala.

Measuring Code Coverage

First, we need to add `scoverage` as a plugin in the `project/plugins.sbt` file:

```
addSbtPlugin("org.scoverage" % "sbt-scoverage" % "2.0.11")
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and turn on the **coverage mode** in the `build.sbt` file:

```
coverageEnabled := true
```

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Then, we need to run the tests with enabled coverage:

```
$ sbt clean coverage test
```

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```
$ sbt clean coverage test
```

Finally, we can generate the coverage report:

```
$ sbt coverageReport
```

and open the following file in your web browser:

```
<project-dir>/target/scala-3.3.3/scoverage-report/index.html
```

Measuring Code Coverage

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It shows the **overall code coverage** of the project:

All packages	91.09%
kuplrg	91.09%

Class	Source file	Lines	Methods	Statements	Invoked	Coverage		Branches	Invoked	Coverage	
App$	App.scala	11	1	2	0		0.00 %	0	0		0.00 %
Expr	Expr.scala	130	4	55	49		89.09 %	22	19		86.36 %
Tree	Tree.scala	190	7	44	43		97.73 %	15	14		93.33 %

For example, we can see which parts are **not covered** by the tests:

```
91     *
92     * Add(Var("x"), Num(1))                  // x + 1 = 3 + 1 = 4
93     *
94     * Mul(Num(2), Add(Var("x"), Var("y"))) // 2 * (x + y) = 2 * (3 + 5) = 16
95     * }}}
96     */
97    def eval(ass: Map[String, Int], default: Int): Int = this match
98      case Num(n)    => n
99      case Var(x)    => ass.get(x) match
100       case Some(n) => n
101       case None    => default
102     case Add(l, r) => l.eval(ass, default) + r.eval(ass, default)
103     case Mul(l, r) => l.eval(ass, default) * r.eval(ass, default)
```

Real-world Example

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ESMeta is a framework that extracts a mechanized specification from a given version of ECMAScript/JavaScript specification (ECMA-262) developed using Scala and sbt.

https://github.com/es-meta/esmeta

Summary

PLRG

1. Simple Build Tool (`sbt`) for Scala
   - Example Project
   - Project Structure
   - Building a Project
   - Running a Project
2. Scala Documentation
   - `scaladoc` – Scala Documentation Tool
   - Generating Documentation
   - Writing Documentation
3. Scala Test Framework
   - Why Software Testing?
   - `ScalaTest` – Test Framework for Scala
   - Running Tests
   - Writing Tests
   - Measuring Code Coverage

Exercise #1

- Please see this document on GitHub:

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

- It is just an exercise, and it is **NOT** included in your grade.

Next Lecture

- Classes, Traits, and Objects

Jihyeok Park
jihyeok_park@korea.ac.kr
https://plrg.korea.ac.kr