**Goal of the exercises**

The goal of this week’s exercises is to get acquainted with some core features of the Scala programming language.

Do exercises 46.1, 46.2, 46.3, 46.4, and 46.5. Hand in the solutions.

**Do this first**

Download Scala from [http://www.scala-lang.org/downloads](http://www.scala-lang.org/downloads) and unpack it for your platform (Windows, MacOS, Linux). To run Scala, you must have a Java Virtual Machine installed too.

**Exercise 46.1** Recall the very simple expression language shown in the lecture:

```scala
sealed abstract class Expr
case class CstI(value: Int) extends Expr
case class Prim(op: String, e1: Expr, e2: Expr) extends Expr

def eval0(expr: Expr): Int =
  expr match {
    case CstI(i) => i
    case Prim(op, e1, e2) =>
      val v1 = eval0(e1)
      val v2 = eval0(e2)
      op match {
        case "+" => v1 + v2
        case "+" => v1 * v2
      }
  }
```

(i) Extend the evaluator `eval0` with new cases to handle also operators for division (`/`), less than (`<`), greater than (`>`) and logical and (`&`). In the evaluator, use 1 to represent true and 0 to represent false. Try the new evaluator on several examples, for instance `7 * (10 - 6 + 5)` and `7 * (10 < 6 + 5)`.

(ii) Extend the abstract syntax for expressions with a new case class `Var` to represent named variables. Extend the evaluator `eval0` to create a new evaluator `eval1(expr: Expr, env: Map[String, Int]): Int` that can evaluate expressions involving variables. The variable environment `env` is represented by an instance of Scala’s immutable Map class.

An environment that maps variable `x` to 27 and `y` to 42 can be written `Map("x" -> 27, "y" -> 42).

**Exercise 46.2** Write a Scala function `simplify(expr: Expr): Expr` to perform expression simplification on the extended `Expr` type from exercise 46.1. For instance, it should simplify `(x + 0)` to `x`, and simplify `(1 + 0)` to 1. The more ambitious student may want to simplify `(1 + 0) * (x + 0)` to `x`. Hint 1: Pattern matching is your friend. Hint 2: Don’t forget the case where you cannot simplify anything.

You might consider the following simplifications, plus any others you find useful and correct. The last one below is trickier than the others:

<table>
<thead>
<tr>
<th>Expression</th>
<th>Simplified</th>
</tr>
</thead>
<tbody>
<tr>
<td>0 + e</td>
<td>e</td>
</tr>
<tr>
<td>e + 0</td>
<td>e</td>
</tr>
<tr>
<td>e - 0</td>
<td>e</td>
</tr>
<tr>
<td>1 * e</td>
<td>e</td>
</tr>
<tr>
<td>e * 1</td>
<td>e</td>
</tr>
<tr>
<td>0 * e</td>
<td>0</td>
</tr>
<tr>
<td>e * 0</td>
<td>0</td>
</tr>
<tr>
<td>e - e</td>
<td>0</td>
</tr>
</tbody>
</table>
Exercise 46.3  Extend the evaluator eval1 from exercise 46.1 to create a new evaluator eval2(expr: Expr, env: Map[String, Int]): Option[Int] that returns Some(r) if the evaluation succeeds with result r, and returns None if the evaluation fails.

The evaluation may fail because it divides by zero or uses a variable that is not in the environment env.

As in Java, you can check whether x is a key in the map env by evaluating env.contains(x), or more Scala-ish, env contains x. Alternatively, calling env.get(x) returns Some(v) if x maps to v in env, or None if x is not contained in env.

Hint: Use pattern matching on the results returned by the recursive calls to eval2.

Exercise 46.4 In exercise 46.3 you end up with nested pattern matching on the results of eval2. Create a new evaluator eval3(expr: Expr, env: Map[String, Int]): Option[Int] that works exactly as eval2 but uses Scala’s for expressions instead of pattern matching on None and Some.

Hint 1: When v1 and v2 have type Option[Int], then

```scala
for (i1 <- v1; i2 <- v2)
yield i1+i2
```

has the same meaning as the more verbose

```scala
v1 match {
  case None    => None
  case Some(i1) => {
    v2 match {
      case None    => None
      case Some(i2) => Some(i1+i2)
    }
  }
}
```

If v1 has value None, the for expression has value None; and if v1 has value Some(17), then i1 will be bound to 17, and the next clauses in the for expression will be evaluated in a similar manner.

Hint 2: Your solution will probably need three bindings inside the for expression.

Exercise 46.5  Let us return to the simplest expression language at the beginning of exercise 46.1 (i). That language is untyped, because it is possible to write expressions corresponding to $7 \ast (2 < 4)$ which mixes numbers and truth values in an unhealthy way.

In Scala, it is possible for a subclass to inherit from a superclass that has one or more type parameters instantiated. Using this, one can define the abstract syntax so that it can represent only strongly typed expressions. Types such as Expr are sometimes called algebraic datatypes, and types such as TypedExpr below that use this Scala feature are called generalized algebraic datatypes.

```scala
sealed abstract class TypedExpr[T]
case class CstI(n: Int) extends TypedExpr[Int]
case class Plus(e1: TypedExpr[Int], e2: TypedExpr[Int]) extends TypedExpr[Int]
case class Times(e1: TypedExpr[Int], e2: TypedExpr[Int]) extends TypedExpr[Int]
case class LessThanEq(e1: TypedExpr[Int], e2: TypedExpr[Int]) extends TypedExpr[Boolean]
case class IfThenElse[T](cond: TypedExpr[Boolean], e1: TypedExpr[T], e2: TypedExpr[T]) extends TypedExpr[T]
```

The type parameter T in TypedExpr[T] represents the type that the expression should return when evaluated. By filling in specific types for T, we guarantee that eval will return the correct type.

In fact, the datatypes contain the same information as the typing rules on page 69 of Programming Language Concepts. For example, CstI corresponds to the rule:

$$\rho \vdash i : \text{int}$$
and IfThenElse corresponds to the rule

\[
\frac{\rho \vdash e_1 : \text{bool} \quad \rho \vdash e_2 : t \quad \rho \vdash e_3 : t}{\rho \vdash \text{if } e_1 \text{ then } e_2 \text{ else } e_3 : t}
\]

where the type \( t \) corresponds to the Scala type parameter \( T \).

The evaluation function takes a type parameter \( T \), which represents the type of the desired result. Then, the argument is constrained to be an expression that evaluates to the correct type (that is, \( \text{TypedExpr}[T] \)):

```scala
def eval[T](e: TypedExpr[T]): T = e match {
  case CstI(n) => n
  case Plus(e1, e2) => eval(e1) + eval(e2)
  case Times(e1, e2) => eval(e1) * eval(e2)
  case LessThanEq(e1, e2) => eval(e1) <= eval(e2)
  case IfThenElse(cond, e1, e2) => if (eval(cond)) eval(e1) else eval(e2)
}
```

(i) Construct the following expressions in abstract syntax (that is, as vals). Note that type errors occur at Scala’s compile-time. Comment out those that do not type check.

- \( 2 + 13 \times 4 \)
- \( \text{if } 23 \leq 17 \text{ then } 7 \text{ else } 3 + 21 \)
- \( \text{if } 0 \text{ then } 1 \text{ else } 2 \)
- \( \text{if } 12 \leq 3 \text{ then } 42 \text{ else } 3 \leq 7 \)
- \( \text{if } 12 \leq 3 \text{ then } 42 \leq 1000 \text{ else } 3 \leq 7 \)

(ii) Add constant Booleans, subtraction, the remaining comparison operators, and short-circuiting AND and OR to the abstract syntax. Modify the evaluator to evaluate these correctly. It should be a Scala type error to attempt to construct expressions that do not type check.

(iii) Replace the separate abstract syntax for integer and Boolean constants with a single generic constant class that takes a type parameter and a value of that type. Update the evaluator accordingly. Leave the original data type commented out for your submission.

Hint: begin with \( \text{case class Const}[T](\ldots) \).