

Practical

Pure I/O

in Java... and in Scala with *ZIO*





Previously on Practical Immutability...

- Immutable **Classes**
- Immutable **Collections** and **Options**
- Immutable **Variables**
- Expressions
- Algebraic Data Types (**ADT**)
- Pattern Matching

Functional Programming

- FP is programming with **functions**.
- Functions are:
 - **Deterministic**: same arguments implies same result
 - **Total**: result always available for arguments
 - **Pure**: no side-effects, only effect is computing result
- A consequence of FP is **referential transparency**.

Referential Transparency

- FP programs are **referentially transparent**.
- **Typical refactorings cannot break a working program** 👍.
- Applies to the following refactorings:
 -  **Extract Variable**
 -  **Inline Variable**
 -  **Extract Method**
 -  **Inline Method**

Refactorings Break Impure Programs

Console Operations

```
public class Console {  
    public static String getStrLn() {  
        return new Scanner(System.in).nextLine();  
    }  
  
    public static void putStrLn(final String line) {  
        System.out.println(line);  
    }  
}
```

A Working Program

```
public class ConsoleApp {  
    public static void main(String[] args) {  
        putStrLn("What's player 1 name?");  
        final String player1 = getStrLn();  
        putStrLn("What's player 2 name?");  
        final String player2 = getStrLn();  
        putStrLn(String.format("Players are %s and %s.", player1, player2));  
    }  
}
```

What's player 1 name?

> Paul

What's player 2 name?

> Mary

Players are Paul and Mary.

Broken Extract Variable Refactoring

```
public class BrokenExtractVariableConsoleApp {  
    public static void main(String[] args) {  
        final String s = getStrLn();  
        putStrLn("What's player 1 name?");  
        final String player1 = s;  
        putStrLn("What's player 2 name?");  
        final String player2 = s;  
        putStrLn(String.format("Players are %s and %s.", player1, player2));  
    }  
}
```

> Paul

What's player 1 name?

What's player 2 name?

Players are Paul and Paul.

Broken Inline Variable Refactoring

```
public class BrokenInlineVariableConsoleApp {  
    public static void main(String[] args) {  
        putStrLn("What's player 1 name?");  
        putStrLn("What's player 2 name?");  
        final String player2 = getStrLn();  
        putStrLn(String.format("Players are %s and %s.", getStrLn(), player2));  
    }  
}
```

What's player 1 name?

What's player 2 name?

> Paul

> Mary

Players are Mary and Paul.

Building a Pure Program from the Ground Up

in Java with *Immutables* and *Vavr*

Describing a Program

```
public abstract class Program<A> { /* ... */ }
```

- Describes a **program** performing I/Os
- When run, will eventually yield a **result** of type A

Program as Immutable Object

```
@Value.Immutable
public abstract class Program<A> { // ...
    @Value.Parameter
    public abstract Supplier<A> unsafeAction();

    public static <A> Program<A> of(final Supplier<A> unsafeAction) {
        return ImmutableProgram.of(unsafeAction);
    } // ...
}
```

Program Yielding a Value

```
@Value.Immutable  
public abstract class Program<A> { // ...  
    public static <A> Program<A> yield(final A a) {  
        return Program.of(() -> a);  
    } // ...  
}
```

Chaining Programs

```
@Value.Immutable
public abstract class Program<A> { // ...
    public <B> Program<B> thenChain(final Function<A, Program<B>> f) {
        final Program<A> pa = this;
        final Program<B> pb = Program.of(() -> {
            final A a = pa.unsafeAction().get();
            final Program<B> _pb = f.apply(a);
            final B b = _pb.unsafeAction().get();
            return b;
        });
        return pb;
    } // ...
}
```

Transforming Result of Program

```
@Value.Immutable
public abstract class Program<A> { // ...
    public <B> Program<B> thenTransform(final Function<A, B> f) {
        final Program<A> pa = this;
        final Program<B> pb = pa.thenChain(a -> {
            final B b = f.apply(a);
            final Program<B> _pb = Program.yield(b);
            return _pb;
        });
        return pb;
    } // ...
}
```

Elementary Console Programs

```
public class Console {  
    public static Program<String> getStrLn() {  
        return Program.of(() -> {  
            final String line = new Scanner(System.in).nextLine();  
            return line;  
        });  
    }  
  
    public static Program<Unit> putStrLn(final String line) {  
        return Program.of(() -> {  
            System.out.println(line);  
            return Unit.of();  
        });  
    }  
}
```


A Value Containing Void (Unit)

```
@Value.Immutable(singleton = true)
public abstract class Unit {
    public static Unit of() {
        return ImmutableUnit.of();
    }
}
```

- Cannot use Void
- Cannot create instances (private constructor 🙄)
- Can just use null 😈

Instantiating a Program

```
public class ConsoleApp {  
    public static final Program<Unit> helloApp =  
        putStrLn("What's your name?").thenChain(__ -> {  
            return getStrLn().thenChain(name -> {  
                return putStrLn("Hello " + name + "!");  
            });  
        });  
  
    public static void main(String[] args) {  
        final Program<Unit> program = helloApp;  
    }  
}
```

But Program Does Not Run 🤔

```
public class ConsoleApp {  
    // ...  
    public static void main(String[] args) {  
        final Program<Unit> program = helloApp;  
        System.out.println(program);  
    }  
}
```

- Will print something like `Program{unsafeAction=pureio.console.pure.Program$
$Lambda$3/511754216@5197848c}`
- This is just an **immutable object**, it does no side-effect, it's **pure** 😇.
- Need an **interpreter** to run!

Interpreting a Program

```
@Value.Immutable
public abstract class Program<A> {
    // ...

    public static <A> A unsafeRun(final Program<A> program) {
        return program.unsafeAction().get();
    }
}
```

Running a Program

```
public class ConsoleApp {  
    // PURE ...  
    public static void main(String[] args) {  
        final Program<Unit> program = helloApp; // PURE  
        Program.unsafeRun(program); // IMPURE!!! But that's OK!  
    }  
}
```

- Sure, unsafeRun call point (***end of the world***) is **impure** 😈...
- But the **rest of the code** is fully **pure** 😇!

Counting Down

```
public static final Program<Unit> countdownApp =
    getIntBetween(10, 100000).thenChain(n -> {
        return countdown(n);
    });

public static Program<Unit> countdown(final int n) {
    if (n == 0) {
        return putStrLn("BOOM!!!");
    } else {
        return putStrLn(Integer.toString(n)).thenChain(__ -> {
            return /* RECURSE */ countdown(n - 1);
        });
    }
}
```

Displaying Menu and Getting Choice

```
public static final Program<Unit> displayMenu =  
    putStrLn("Menu")  
        .thenChain(__ -> putStrLn("1) Hello"))  
        .thenChain(__ -> putStrLn("2) Countdown"))  
        .thenChain(__ -> putStrLn("3) Exit"));
```

```
public static final Program<Integer> getChoice =  
    getIntBetween(1, 3);
```

Launching Menu Item

```
public static Program<Boolean> launchMenuItem(final int choice) {  
    switch (choice) {  
        case 1: return helloApp.thenTransform(__ -> false);  
        case 2: return countdownApp.thenTransform(__ -> false);  
        case 3: return Program.yield(true); // Should exit  
        default: throw new IllegalArgumentException("Unexpected choice");  
    }  
}
```


Looping over Menu

```
public static Program<Unit> mainApp() {  
    return displayMenu.thenChain(__ -> {  
        return getChoice.thenChain(choice -> {  
            return launchMenuItem(choice).thenChain(exit -> {  
                if (exit) {  
                    return Program.yield(Unit.of());  
                } else {  
                    return /* RECURSE */ mainApp();  
                }  
            });  
        });  
    });  
}
```

Parsing an Integer with a Total Function

```
public static Option<Integer> parseInt(final String s) {  
    return Try.of(() -> Integer.valueOf(s)).toOption();  
}
```

- parseInt is defined for any String, it's **total**.
- No exception! 😊

Expression

Result

parseInt("3")

Some(3)

parseInt("a")

None

Getting Integer from Console

```
public static Program<Integer> getInt() {
    return getStrLn()
        .thenTransform(s -> parseInt(s))
        .thenChain(maybeInt -> {
            return maybeInt.isDefined() ? Program.yield(maybeInt.get()) : /* RECURSE */ getInt();
        });
}

public static Program<Integer> getIntBetween(final int min, final int max) {
    final String message = String.format("Enter a number between %d and %d", min, max);
    return putStrLn(message).thenChain(__ -> {
        return getInt().thenChain(i -> {
            return min <= i && i <= max ? Program.yield(i) : /* RECURSE */ getIntBetween(min, max);
        });
    });
}
```

Just a Toy

- What's **good**
 - Rather efficient
 - Unlimited refactorings 👍
- What's **not so good**
 - Not stack safe 👎
 - Nesting can be annoying (extract variables and methods!)
 - Not testable 👎

Business-Ready Pure IO in Scala with *ZIO*

ZIO

Type-safe, composable, asynchronous and concurrent programming for Scala

– <https://scalaz.github.io/scalaz-zio/>

- **Synchronicity** and **Asynchronicity** (handled reactively), combine seamlessly
- **Concurrency**, based on lightweight fibers
- **Resiliency**, can recover from errors
- **Interruptibility**, can interrupt any program
- **Resource Safety**, ensure resources will never leak (threads, sockets, file handles...)
- **Performance**, extremely fast given features and strong guarantees
- And also **Composability** and **Testability**

IO[E, A]

`IO[+E, +A]` // `IO<E, A>` `E = Error, A = Result`

- An immutable object that **describes** a **program performing side-effects**.
- An IO does nothing, it's just a **value** holding a program.
- It must be interpreted by a **runtime system** or **RTS**
- Only when **run** by the RTS, it will either
 - fail with an **error** of type E,
 - or eventually produce a **result** of type A.

Hello World!

```
object HelloWorldApp extends App {  
  // Wraps synchronous (blocking) side-effecting code in an IO  
  val helloWorld: IO[Nothing, Unit] =  
    IO.effectTotal(/* () => */ Console.println("Hello World!"))  
  // The IO just holds a lambda but does not run it for now.  
  
  def run(args: List[String]): IO[Nothing, Int] = {  
    helloWorld.either.fold(_ => 1, _ => 0)  
  }  
}
```


Wrapping in IO

Simple Success in IO

```
val success: IO[Nothing, Int] = IO.succeed(42)
val successLazy: IO[Nothing, Int] = IO.succeedLazy(/* () => */ 40 + 2)

// Will never fail (Nothing)
// Will always succeed with result 42 (Int)
```

Simple Failure in IO

```
val failure: IO[String, Nothing] = IO.fail("Failure")  
// Will always fail with error "Failed" (String)  
// will never succeed (Nothing)  
  
val exceptionFailure: IO[IllegalStateException, Nothing] =  
    IO.fail(new IllegalStateException("Failure"))  
// Error can be an exception (but just as a value, never thrown!)
```

Wrapping in IO as the Great Unifier

- IO integrates any kind of IO seamlessly into the same **unified model**.
- Abstracts over how **success** is returned and **failure** is signaled
 - Synchronous return and throw
 - Synchronous Try or Either
 - Asynchronous **callback**
 - Asynchronous Future
- Abstracts over **synchronicity**
- Abstracts over **interruptibility**

Synchronous in IO

```
def randomBetween(min: Int, max: Int): IO[Nothing, Int] = {  
  // Side-effecting code updates the state of a random generator,  
  // and returns a random number (Int).  
  // It can never fail (Nothing).  
  IO.effectTotal(/* () => */ Random.nextInt(max - min) + min)  
}
```

```
def putStrLn(line: String): IO[Nothing, Unit] = {  
  // Side-effecting code prints a line,  
  // and returns void (Unit).  
  // It can never fail (Nothing).  
  IO.effectTotal(/* () => */ Console.println(line))  
}
```

Synchronous, Exception-Throwing in IO

```
def getStrLn: IO[IOException, String] = {  
  // Side-effecting code reads from keyboard until a line is available,  
  // and returns the line (String).  
  // It might throw an IOException. IO catches exception,  
  // and translates it into a failure containing the error (IOException).  
  // IOException is neutralized, it is NOT propagated but just used as a value.  
  IO.effect(/* () => */ scala.io.StdIn.readLine()).refineOrDie {  
    case e: IOException => e  
  }  
}
```

Asynchronous in IO

```
object Calculator {  
  private lazy val executor = Executors.newScheduledThreadPool(5)  
  
  def add(a: Int, b: Int): IO[Nothing, Int] = {  
    IO.effectAsync { (callback: IO[Nothing, Int] => Unit) =>  
      val completion: Runnable = { () => callback(IO.succeedLazy(a + b)) }  
      executor.schedule(completion, 5, TimeUnit.SECONDS)  
    }  
  }  
}
```

Asynchronous, Interruptible in IO

```
object Calculator {  
  private lazy val executor = Executors.newScheduledThreadPool(5)  
  
  def add(a: Int, b: Int): IO[Nothing, Int] = {  
    IO.effectAsyncInterrupt { (callback: IO[Nothing, Int] => Unit) =>  
      val complete: Runnable = { () => callback(IO.succeedLazy(a + b)) }  
      val eventualResult = executor.schedule(complete, 5, TimeUnit.SECONDS)  
      val canceler = IO.effectTotal(eventualResult.cancel(false))  
      Left(canceler)  
    }  
  }  
}
```


Combining IOs

Transforming IO (map)

```
val randomLetter: IO[Nothing, Char] =  
  randomBetween('A', 'Z').map { i /* Int */ =>  
    i.toChar /* Char */  
  }
```

Chaining IOs (broken map)

```
val printRolledDiceWRONG: IO[Nothing, IO[Nothing, Unit]] =  
  randomBetween(1, 6).map { dice /* Int */ =>  
    putStrLn(s"Dice shows $dice") /* IO[Nothing, Unit] */  
  }
```

- Wrong **nested** type `IO[Nothing, IO[Nothing, Unit]]`
- Needs to be made **flat** somehow as `IO[Nothing, Unit]`

Chaining IOs (flatMap)

```
val printRolledDice: IO[Nothing, Unit] =  
  randomBetween(1, 6).flatMap { dice /* Int */ =>  
    putStrLn(s"Dice shows $dice") /* IO[Nothing, Unit] */  
  }
```

Chaining and Transforming IOs

```
randomBetween(0, 20).flatMap { x =>
  randomBetween(0, 20).map { y =>
    Point(x, y)
  }
}
```

Pyramid of maps and flatMaps 🍆

```
val welcomeNewPlayer: IO[IOException, Unit] =  
  putStrLn("What's your name?").flatMap { _ =>  
    getStrLn.flatMap { name =>  
      randomBetween(0, 20).flatMap { x =>  
        randomBetween(0, 20).flatMap { y =>  
          randomBetween(0, 20).flatMap { z =>  
            putStrLn(s"Welcome $name, you start at coordinates($x, $y, $z).")  
          }  
        }  
      }  
    }  
  }
```

Flatten Them All 🙇

```
val welcomeNewPlayer: IO[IOException, Unit] =  
  for {  
    _ <- putStrLn("What's your name?")  
    name <- getStrLn  
    x <- randomBetween(0, 20)  
    y <- randomBetween(0, 20)  
    z <- randomBetween(0, 20)  
    _ <- putStrLn(s"Welcome $name, you start at coordinates($x, $y, $z).")  
  } yield ()
```

Intermediary Variable

```
val printRandomPoint: IO[Nothing, Unit] =  
  for {  
    x <- randomBetween(0, 20)  
    y <- randomBetween(0, 20)  
    point = Point(x, y) // Not running an IO, '=' instead of '<-'  
    _ <- putStrLn(s"point=$point")  
  } yield ()
```


Anatomy of for Comprehension

for comprehension is not a for loop.

It can be a for loop...

But it can handle **many other things**

like IO and ... Seq, Option, Future...

for Comprehension **Types**

```
val printRandomPoint: IO[Nothing, Point] = {  
  for {  
    x      /* Int */ <- randomBetween(0, 10)           /* IO[Nothing, Int] */  
    _      /* Unit */ <- putStrLn(s"x=$x")             /* IO[Nothing, Unit] */  
    y      /* Int */ <- randomBetween(0, 10)           /* IO[Nothing, Int] */  
    _      /* Unit */ <- putStrLn(s"y=$y")             /* IO[Nothing, Unit] */  
    point  /* Point */ = Point(x, y)                  /* Point */  
    _      /* Unit */ <- putStrLn(s"point.x=${point.x}") /* IO[Nothing, Unit] */  
    _      /* Unit */ <- putStrLn(s"point.y=${point.y}") /* IO[Nothing, Unit] */  
  } yield point /* Point */  
} /* IO[Nothing, Point] */
```

for Comprehension **Type Rules**

	val type	operator	expression type
generator	A	<-	IO[E, A]
assignment	B	=	B
	for comprehension type		yield expression type
production	IO[E, R]		R

- Combines **only** IO[E, T], **no mix** with Seq[T], Option[T], Future[T]...
- But it could be **only** Seq[T], **only** Option[T], **only** Future[T]...

for Comprehension **Scopes**

```
val printRandomPoint: IO[Nothing, Point] = {  
  for {  
    x <- randomBetween(0, 10)           /* x */  
    _ <- putStrLn(s"x=$x")              /* 0 */  
    y <- randomBetween(0, 10)           /* | y */  
    _ <- putStrLn(s"y=$y")              /* | 0 */  
    point = Point(x, y)                 /* 0 0 point */  
    _ <- putStrLn(s"point.x=${point.x}") /* | | 0 */  
    _ <- putStrLn(s"point.y=${point.y}") /* | | 0 */  
  } yield point                         /* | | 0 */  
}
```

for Comprehension **Implicit Nesting**

```
val printRandomPoint: IO[Nothing, Point] = {  
  for {  
    x <- randomBetween(0, 10)  
    /* | */ _ <- putStrLn(s"x=$x")  
    /* |   | */ y <- randomBetween(0, 10)  
    /* |   |   | */ _ <- putStrLn(s"y=$y")  
    /* |   |   |   | */ point = Point(x, y)  
    /* |   |   |   |   | */ _ <- putStrLn(s"point.x=${point.x}")  
    /* |   |   |   |   |   | */ _ <- putStrLn(s"point.y=${point.y}")  
  } /* |   |   |   |   |   |   | */ yield point  
}
```

Conditions and Loops

Behaving Conditionally

```
def describeNumber(n: Int): IO[Nothing, Unit] = {  
  for {  
    _ <- if (n % 2 == 0) putStrLn("Even") else putStrLn("Odd")  
    _ <- if (n == 42) putStrLn("The Answer") else IO.unit  
  } yield ()  
}
```


Looping with Recursion 🤔

```
def findName(id: Int): IO[Nothing, String] = ???

def findNames(ids: List[Int]): IO[Nothing, List[String]] = {
  ids match {
    case Nil => IO.succeed(Nil)

    case id :: restIds =>
      for {
        name      /* String */ <- findName(id)      /* IO[Nothing, String] */
        restNames /* List[String] */ <- findNames(restIds) /* IO[Nothing, List[String]] */
      } yield name :: restNames /* List[String] */
  }
}
```

Looping with foreach

```
def findName(id: Int): IO[Nothing, String] = ???
```

```
def findNames(ids: List[Int]): IO[Nothing, List[String]] =  
  IO.foreach(ids) { id => findName(id) }
```

- Recursion can be hard to read
- Prefer using simpler alternatives whenever possible
 - `IO.foreach`, `IO.collectAll`, `IO.reduceAll`, `IO.mergeAll`
 - Or `IO.foreachPar`, `IO.collectAllPar`, `IO.reduceAllPar`, `IO.mergeAllPar`
in **parallel** 👍

Further with *ZIO*

Keeping Resource Safe

```
class Resource {  
  def close: IO[Nothing, Unit] = ???  
  def read: IO[Int, String] = ???  
}
```

```
object Resource {  
  def open(name: String): IO[Int, Resource] = ???  
}
```

```
val program: IO[Nothing, Unit] =  
  IO.bracket(Resource.open("hello"))(_._close) { resource =>  
    for {  
      line <- resource.read  
      _ <- putStrLn(line)  
    } yield ()  
  }
```

Retrying after Error

```
object NameService {  
  def find(id: Int): IO[Int, String] = ???  
}  
  
val retrySchedule = Schedule.recurs(5) && Schedule.exponential(1.second)  
  
val program =  
  for {  
    name <- NameService.find(1).retry(retrySchedule)  
    _ <- putStrLn(s"name=$name")  
  } yield ()
```

- retry repeats in case of **failure**.
- There also exists repeat that repeats in case of **success**.

Forking and Interrupting

```
val analyze: IO[Nothing, String] = ???  
val validate: IO[Nothing, Boolean] = ???  
  
val program: IO[Nothing, String] =  
  for {  
    analyzeFiber <- analyze.fork  
    validateFiber <- validate.fork  
    validated <- validateFiber.join  
    _ <- if (validated) IO.unit else analyzeFiber.interrupt  
    analysis <- analyzeFiber.join  
    _ <- putStrLn(analysis)  
  } yield analysis
```

There's Much More in *ZIO*

- **Streaming**
 - `Stream`, a lazy, concurrent, asynchronous source of values
 - `Sink`, a consumer of values, which may produce a value when it has consumed enough
- **Software Transactional Memory (STM)**
- **Low Level Concurrency**
 - `FiberLocal`, a variable whose value depends on the fiber that accesses it
 - `Promise`, a variable that may be set a single time, and awaited on by many fibers
 - `Queue`, an asynchronous queue that never blocks
 - `Ref`, a mutable reference to a value
 - `Semaphore`, a semaphore