

A tropical island scene with a pink house and palm trees. The house has a red roof and the words "KAME HOUSE" written on its side. It is surrounded by lush greenery and palm trees. The island is situated in the middle of a turquoise ocean with white waves crashing against the shore. The sky is blue with scattered white clouds.

Do You Even Handle Effects?

Direct-Style Effect System in Scala

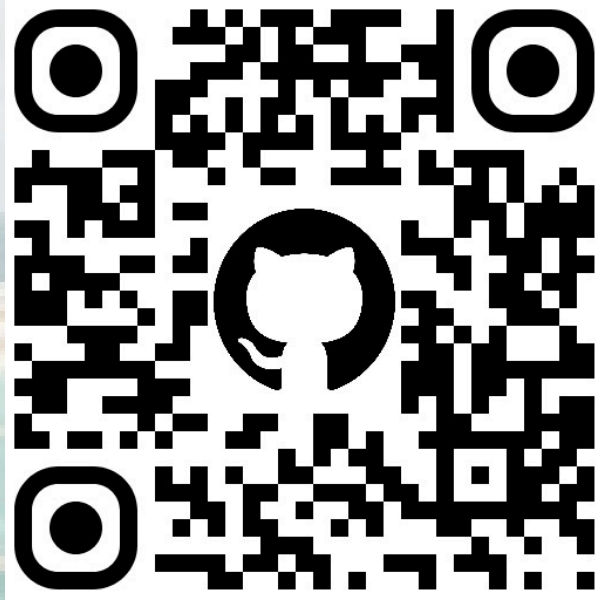


Agenda

- 🙌 Who Am I?
- ❤️ Effects and 💔 Side Effects
- 📦 Scala Monadic Effect Systems
- 🛠️ Build Your Own Effects System in Direct-Style
- ➕ Adding Monadic Operations
- 🏁 Conclusions and References

Who Am I?

- Hello there 🙋, I'm **Riccardo Cardin**,
 - An Enthusiastic Scala Lover since 2011 100



A tropical island scene featuring a small, single-story pink house with a red gabled roof and a green door. The house is situated on a sandy beach with lush greenery and several tall palm trees. The ocean is a vibrant turquoise color with white foam from the waves washing onto the shore. The sky is a pale blue with soft, white clouds. A semi-transparent white rectangular box is centered over the image, containing the title text.

Effects and Side Effects

Why We ❤️ Functional Programming

- We have the **substitution model** for reasoning about programs

```
def plusOne(i: Int): Int = i + 1
def timesTwo(i: Int): Int = plusOne(plusOne(i))
```

- The substitution model enables **local reasoning** and **referential transparency**
 - Original program and the substituted program are *equivalent*
- We call these functions *pure* functions

We Live in an Imperfect World

“ Model a coin toss, but with a twist: the gambler might be too drunk and lose the coin ”

```
import scala.util.Random

def drunkFlip(): String = {
  val caught = Random.nextBoolean()
  val heads =
    if (caught) Random.nextBoolean()
    else throw new Exception("We dropped the coin")
  if (heads) "Heads" else "Tails"
}
```


We Live in an Imperfect World

- We can't use the substitution model for all programs
 - If the `drunkFlip` function throws an *exception*, the substitution model breaks
- Programs that interact with a context outside the function
 - The result of the `drunkFlip` function depends on the state of the world
- Multiple calls to `drunkFlip` can return different results

Side Effects

- **Side Effect:** An *unpredictable change* in the state of the world
 - *Unmanaged*, they just happen

```
// What happens if b is equal to zero?  
def divide(a: Int, b: Int): Int = a / b
```

- We call `divide` an *impure* function
- The best we can do is to **track** and push them to the *boundaries* of our system

The Effect Pattern

When a side effect is *tracked* and *controlled* we call it an **effect**

1. The *type* of the function should tell us what effects it can perform and what's the type of the result
 - The `drunkFlip` deals with *non-determinism* and *errors*
2. We must separate the *description* from making it happen
 - We want a *recipe* of the program.
 - **Deferred execution**

The pattern lets us use the **substitution model** again 🚀 🎉

The Effect Pattern

Effect Pattern Checklist

1. Does the type of the program tell us
 - a. what **kind of effects** the program will perform; and
 - b. what **type of value** it will produce?
2. When externally-visible side effects are required, is the effect description **separate** from the execution?

© Adam Rosien, Essential Effects

Fun Fact 🤡

Do you know which is the first try of an effect system on the JVM? 🤔

😜 Java Checked Exceptions 😜

```
String readFile(String path) throws IOException { /*... */ }
```

- 🔥 They *tracks* the side effects with the *exception type*
- 🔥 We must provide a *handler* for the effect (exception)
- 👦 They *don't defer* the execution and are *hard to compose*

An Effect Example

We can use **Monads**, `F[A]`, (which fits well for the task)

- Composing function returning effects is not trivial
 - `F[_]`: We can use `flatMap` and `map`
 - Different monads are *hard to compose* (Monad Transformers)
- The `Option[A]` type models the conditional lack of a value

```
val maybeInt: Option[Int] = Some(42)
val maybeString: Option[String] = maybeInt.map(_.toString)
```

Effect Systems

An **Effect System** is the implementation of the *Effect Pattern*

- It expresses side effects with **dedicated types**
- It replaces side-effecting operations in standard libraries
- It provides structures to manage effects

In an effect system, a side effect 👎 becomes a **tracked** effect 👍

A tropical island scene featuring a small pink house with a red roof and a green door, surrounded by palm trees and lush greenery. The house is situated on a sandy beach with turquoise water and white waves in the foreground. The sky is blue with scattered white clouds.

Scala Monadic Effect Systems

Cats Effect

- Cats Effect uses the `IO[A]` data type to model effects
 - `IO[A]` is an *über effect* that models any effectful computation that returns a value of type `A` and can fail with a `Throwable`
 - It's a *monad* so we must use `flatMap` and `map` to compose effectful functions
 - `IO[A]` is **referentially transparent** and **lazy**
 - Redefines the effectful part of the Standard Library
 - Implements *structured concurrency*

Cats Effect

Let's rewrite the `drunkFlip` function using the `IO` effect

```
def drunkFlip: IO[String] =  
  for {  
    random <- Random.scalaUtilRandom[IO]  
    caught <- random.nextBoolean  
    heads <-  
      if (caught) random.nextBoolean  
      else IO.raiseError(RuntimeException("We dropped the coin"))  
  } yield if (heads) "Heads" else "Tails"
```

The `drunkFlip` function returns a *recipe* of the program

Cats Effect

The library provides many ways to *run* the effect

```
object Main extends IOApp.Simple {  
  def run: IO[Unit] = drunkFlip.flatMap(result => IO.println(result))  
}
```

There are also some *unsafe* methods to run the effect

```
val result: String = drunkFlip.unsafeRunSync()  
val resultF: Future[String] = drunkFlip.unsafeToFuture()
```

Cats Effect

The `IO[A]` hides the exact side effects that were performed. We can make them explicit using *Tagless Final* syntax and an MTL library

```
def drunkFlipF[F[_]: Monad](using R: Raise[F, String], A: Random[F]): F[String] =  
  for {  
    caught <- A.nextBoolean  
    heads <-  
      if (caught) A.nextBoolean  
      else R.raise("We dropped the coin")  
  } yield if (heads) "Heads" else "Tails"
```

The cognitive load is higher here 🤯

ZIO

- `ZIO[R, E, A]` introduces the error type `E` and dependencies `R` in the effect definition
 - It's still a monad on the `A` type (`map` and `flatMap`)
 - It provides a *rich algebra* on the `ZIO` type to avoid monad transformers
 - It's a *referentially transparent* and *lazy* effect
 - It provides *structured concurrency* primitives
 - ...still a *über* effect

ZIO

The `drunkFlip` function using `ZIO` effect is the following:

```
def drunkFlip: ZIO[Random, String, String] =  
  for {  
    caught <- Random.nextBoolean  
    heads <-  
      if (caught) Random.nextBoolean  
      else ZIO.fail("We dropped the coin")  
  } yield if (heads) "Heads" else "Tails"
```

Effects are *explicit* in the `R` type, and we can fail with *custom errors*

ZIO

Running the effect means providing needed dependencies or *layers*

```
object Main extends ZIOAppDefault {  
  override def run =  
    drunkFlip.flatMap { result =>  
      Console.println(result)  
    }.provideLayer(ZLayer.succeed(RandomLive))  
}
```

- We can use intersection type: `Random & Console`
- We must fulfill *all the dependencies* at once to run the effect

Kyo: Meet Algebraic Effects

What if we can have types *listing Effect separately* and *handling* them virtually *once at a time*?

Algebraic Effects and Effect Handlers do exactly that 🎉

- The type of the function tells us exactly what effects it uses
- **Kyo** is a novel library implementing Algebraic Effects

```
def drunkFlip: String < (IO & Abort[String]) = ???
```

Kyo: Meet Algebraic Effects

- Each effect has its own *rich algebra* to describe the operations

```
def drunkFlip: String < (IO & Abort[String]) = for {  
  caught <- Random.nextBoolean  
  heads  <- if (caught) Random.nextBoolean else Abort.fail("We dropped the coin")  
} yield if (heads) "Heads" else "Tails"
```

- Kyo uses a *monad* to represent the effectful computation
 - The `<` type is an alias for a monad indeed 😊
 - We still have to use `flatMap` and `map`

Kyo: Meet Algebraic Effects

We can decide to *handle each effect separately* (no über effect)

```
val partialResult: Result[String, String] < IO = Abort.run { drunkFlip }
```

- `Abort.run` is called an **Effect Handler**
 - It executes the `Abort` effect. The `IO` effect is *left untouched*
- Virtually, we can define our effect handler without changing the original recipe
 - For example, for testing purposes

A tropical island scene featuring a small pink house with a red roof and a green door. The house has "KAM HOUSE" written on its side. Several palm trees are clustered behind the house. The island is surrounded by turquoise water with white waves crashing against the shore. The sky is blue with scattered white clouds.


Build Your Own Effects System

(with love ❤️)

Build Your Own Effects System

- All the effect systems we've seen are based on *monads* properties to *compose effectful functions*
 - They use combinators, `flatMap` and `map`, for sequencing
 - Programs are represented by **values**
 - They are *referentially transparent* and *lazy*

However, their step curve is *steep* and *hard to learn* for newbies 

Can we do better (or at least different)? 

What's the Direct-Style? 🛝

```
val caught = scala.util.Random.nextBoolean() // <- No monads here
```

However, we need **deferred execution** and to track the effects

```
val caught: Random => Boolean = r => r.nextBoolean
```

- Working with *functions* instead of *values* could be cumbersome 😞
 - ...or maybe not? 🤔

Let's try to build an effect system using *functions* instead of *values* 🛠️

Model the Effects' Algebra

We'll focus on the `drunkFlip` example. We need effects that model

- ✓ non-determinism (`Random`),
- ✓ errors (`Raise`)

```
trait Random {  
  def nextBoolean: Boolean // <- Algebra of the effect  
}  
  
trait Raise[-E] { // <- `E` represents the error type  
  def raise(error: => E): Nothing  
}
```


Access Std Library as an Effect

We need now to wrap the standard library with the effects

```
object Random {  
  private val unsafe = new Random {  
    override def nextBoolean: Boolean =  
      scala.util.Random.nextBoolean()  
  }  
}
```

We call the variable `unsafe` 🦠 because it gives *direct, uncontrolled* access to the side effect

Access Std Library as an Effect

We want to give tracked access to the side effects. Let's add some functions (a DSL) to our `object Random`

```
object Random {  
  def nextBoolean(using r: Random): Boolean = r.nextBoolean  
}
```

To generate a random `Boolean`, we need to *provide* an instance of the `Random` effect

- Calling `Random.nextBoolean` produces a *recipe* for the program

Wrap It All Together

We have now all the bricks to build the `drunkFlip` function again 🙌

```
def drunkFlip(using Random, Raise[String]): String = {  
  val caught = Random.nextBoolean  
  val heads =  
    if (caught) Random.nextBoolean  
    else Raise.raise("We dropped the coin")  
  if (heads) "Heads" else "Tails"  
}
```

Is it magic ✨? Variables `caught` and `heads` are treated as `Boolean` ?!



Welcome Context Functions 🙌

- Scala 3 introduces **Context Functions**, fancy anonymous functions with only *implicit context parameters*

```
val program: (Raise[String], Random) ?=> String = drunkFlip
```

- Treated as **values** in contexts with the same implicit parameters
 - However, they are *recipes* to obtain the result

```
def drunkFlip(using Random, Raise[String]): String = {  
  val caught: Boolean = Random.nextBoolean // 🤪  
}
```

Welcome Context Functions 🙌

Behind the scenes, the Scala compiler rewrites the context function using a *surrogate type, not visible to the user*

```
trait ContextFunctionN[-T1, ..., -TN, +R]:  
  def apply(using x1: T1, ..., xN: TN): R
```

Our `program` is rewritten as:

```
val program: new ContextFunction2[Raise[String], Random, String] {  
  def apply(using Raise[String], Random): String = drunkFlip  
}
```

Handle the Effects

- Handlers are the structures that effectively *run* effectful functions

```
object Raise {  
  def raise[E](error: => E)(using r: Raise[E]): Nothing = r.raise(error)  
  def run[E, A](program: Raise[E] ?=> A): E | A =  
    boundary {  
      given unsafe: Raise[E] = new Raise[E] {  
        override def raise(error: => E): Nothing = break(error)  
      }  
      program  
    }  
}
```

Handle the Effects

- The Handler for the `Raise[E]` effect provides the `given` instance of the context parameter
 - We used the `boundary` and `break` functions to *control* the effect

```
val program: Random => String | String = Raise.run { drunkFlip }
```

- The `Raise.run` handler *runs* the `Raise` effect, leaving the `Random` effect *untouched* 🥷
 - It's *curryfication*, but on a context parameters level

Handle the Effects

- Changing the handler changes the *behavior* of the program
 - We can handle a `Raise[E] ?=> A` as an `Either[E, A]`

```
object Raise {  
  def either[E, A](program: Raise[E] ?=> A): Either[E, A] =  
    boundary {  
      given r: Raise[E] = new Raise[E] {  
        override def raise(error: => E): Nothing = break(Left(error))  
      }  
      Right(program)  
    }  
}
```

Handle the Effects

Implementing the `Random` handler is relatively easy 👍

```
def run[A](program: Random => A): A = program(using Random.unsafe)
```

We can even provide a test version of the `Random` effect

```
def test(fixed: Boolean)(program: Random => Boolean) = {  
  program(using new Random() {  
    override def nextBoolean: Boolean = fixed  
  })  
}
```

Handle the Effects

- We can run all the effects of the `drunkFlip` function *stacking* the handlers
 - We should do it at the *boundaries* of the system

```
val result: Either[String, String] = Random.run {  
  Raise.either {  
    drunkFlip  
  }  
}
```

...and we're done 🎉

Properties of the Effect System

- We can say this Effect System uses **Direct-Style Effect Handlers**
- It implements the *Effect Pattern*
 - The type tells us the used *effects* and the type of the *result*
 - The execution is *deferred*

```
type Effect[E, A] = E ?=> A
```

- We have lost *referential transparency* 😞

Goodbye Referential Transparency 🙋

```
def drunkFlip(using Random, Raise[String]): String = {  
  val genRand = Random.nextBoolean  
  val caught = genRand  
  val heads =  
    if (caught) genRand  
    else Raise.raise("We dropped the coin")  
  if (heads) "Heads" else "Tails"  
}
```

- `genRand` is eagerly evaluated:
 - Is all hope lost? 🤖

The `def` Trick ✨

```
def drunkFlip(using Random, Raise[String]): String = {  
  def genRand = Random.nextBoolean  
  val caught = genRand  
  val heads =  
    if (caught) genRand  
    else Raise.raise("We dropped the coin")  
  if (heads) "Heads" else "Tails"  
}
```

- Using the `def` keyword, we can *defer* the evaluation of `genRand`
 - But do we need referential transparency? 🤔

Where's My **IO** Effect?

- Sometimes bad things happen. *Unpredictable* errors are thrown
- We want to execute an effectful function in a *dedicated process*

```
trait IO {} // Maybe Deferred would be a better name
```

```
object IO {  
  def apply[A](program: => A): IO ?=> A = program  
  def runBlocking[A](program: IO ?=> A): Try[A] = {  
    val es: ExecutorService = Executors.newVirtualThreadPerTaskExecutor()  
    Try { es.submit(() => program(using new IO {})).get() }  
  }  
}
```

Do We Like Direct-Style?

💔 We lost referential transparency, but...

👍 We still have **deferred execution**

👍 We can still **track effects**

👍 We have a syntax that is **easy to read and write**

👎 A novel approach with many unknowns

Probably, it is not the best solution for every problem, but it is a **valid alternative** in 80% of the cases 😊

Where's My **I/O** Effect?

- We can use Java Virtual Threads
 - Virtual Threads are implemented using *continuations*
 - They represent *fibers* 🧶, or *green threads* on the JVM
 - From Java 24, they are also safe for **synchronized** blocks 🎉
 - They support *structured concurrency* 🤝

```
val program: IO => Int = IO {  
    42 / 0  
}  
val result: Try[Int] = IO.runBlocking { program }
```

A tropical island scene featuring a small, single-story pink house with a red gabled roof and a green door. The house is situated on a sandy beach with several palm trees and lush greenery. The ocean is visible in the foreground with gentle waves, and the sky is blue with scattered white clouds. A semi-transparent white banner is overlaid across the middle of the image, containing the title text.

Adding Monadic Operations

Bonus Track

What if we can define `flatMap` and `map` in our Effect System 🧐?

We need to play some tricks. Let's define a class surrounding an effect and implement the `flatMap` and `map` functions on it

```
final class Effect[F](val unsafe: F)
object Effect {
  extension [F, A](eff: Effect[F] ?=> A) {
    inline def flatMap[B](inline f: A => Effect[F] ?=> B): Effect[F] ?=> B = f(eff)
    inline def map[B](inline f: A => B): Effect[F] ?=> B = eff.flatMap(a => f(a))
  }
}
```

Bonus Track

We need to refactor the effects and the handlers accordingly (the refactor of the `Raise[E]` effect is omitted)

```
object Random {  
  def nextBoolean(using r: Effect[Random]): Boolean = r.unsafe.nextBoolean  
  
  def run[A](program: Effect[Random] ?=> A): A = program(using unsafe)  
  
  val unsafe = new Effect(new Random {  
    override def nextBoolean: Boolean = scala.util.Random.nextBoolean()  
  })  
}
```

Bonus Track

We can rewrite the `drunkFlip` function using the new DSL:

```
def drunkFlip: (Effect[Random], Effect[Raise[String]]) ?=> String = for {  
  caught <- Random.nextBoolean  
  heads <-  
    if (caught) Random.nextBoolean  
    else Raise.raise("We dropped the coin")  
} yield if (heads) "Heads" else "Tails"
```

If we substitute `inline` functions, we return to the version of `drunkFlip` that doesn't use the `Effect` class ✨

A tropical island scene featuring a small pink house with a red roof and a green door, surrounded by palm trees and lush greenery. The house is situated on a sandy beach with turquoise water and white waves in the foreground. The sky is blue with scattered white clouds. A semi-transparent white banner is overlaid across the middle of the image, containing the title text.

Conclusions and References

Conclusions

- We defined what is a *side effect* and why we don't like it
- We introduced the *Effect Pattern* and the *Effect Systems* to manage side effects in a controlled way
- We explored the *Cats Effect* and *ZIO* libraries as examples of *über effects*
- We introduced the *Kyo* library as an example of *Algebraic Effects*
- We built our own *Effect System* on top of *Context Functions*
- We saw how we can still define `flatMap` and `map` in our *Effect System*

By the way...

YÆS, *Yet Another Effect System*,
is a library implementing what we've seen today 🤪



**So Long, and
Thanks for All the Fish 🐟!**



A tropical island scene with a pink house with a red roof and a green door. The house has "KANE HOUSE" written on its side. Several palm trees are behind the house. The island is surrounded by turquoise water with white waves crashing against the shore. The sky is blue with white clouds.

Final Thoughts?



Happy to take questions !

References

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- [YÆS, Yet Another Effect System](#), An experimental effect system in Scala using Direct-Style Effect Handlers