



IO Monad & Error management
From Exceptions to Cats MTL
@bogardguillaume - guillaumebogard.dev

Bonjour !

My name is **Guillaume Bogard**. I'm a Scala Developer
@Linkvalue.

I love functional programming, roller-coasters, and Age of Empires.

You can follow me on Twitter @bogardguillaume and on
guillaumebogard.dev

Let's talk about IO monads

The *M Word*, a quick recap

A Monad $M[A]$ is an immutable data structure used to describe the computation of one or more values of type A

- Values of type A can be turned into *monadic values* $M[A]$
- Monads can chain subsequent computations (i.e solve big problems out of smaller problems)
- They describe some *functional effect*: Option describes optionality, Either describes failure ...

Why do we need IO anyway ?

- IOs are **programs as values**.

```
def getUser(id: String): IO[User]
```

- They turn impure programs into referentially transparent values.
- They reveal the presence of sneaky side effects 
- They **compose** :

```
def getFavoritePet(user: User): IO[Pet]
```

```
val marksFavoritePet: IO[Pet] = getUser("Mark") flatMap  
getFavoritePet
```

When things go wrong

Cats effect allows to raise Throwables inside the IO context, propagate them across all the IO chain, and recover them later.

```
val failedIO: IO[Int] = IO.raiseError(new Exception("Boom"))
```

```
failedIO.recoverWith( {  
    case e => IO {  
        logger.error("Something went wrong", e)  
        42  
    }  
} ).unsafeRunSync() // => 42
```

Use case : Modeling an authentication flow

I want to authenticate a user using a name and a password. I need to return the user's information.

- I need to find the user information (maybe from a database)
- Check that the password is valid by comparing hashes
- I need to check that the user subscription is valid (maybe through a billing service)
- And the user must not be banned from our service

```
case object WrongUserName extends RuntimeException("No user with that name")
case object WrongPassword extends RuntimeException("Wrong password")
case class ExpiredSubscription(expirationDate: Date) extends
  RuntimeException("Expired subscription")
case object BannedUser extends RuntimeException("User is banned")
```

```
def findUserByName(username: String): IO[User] = ???
def checkPassword(user: User, password: String): IO[Unit] = ???
def checkSubscription(user: User): IO[Unit] = ???
def checkUserStatus(user: User): IO[Unit] = ???
```

```
def authenticate(userName: String, password: String): IO[User] =
  for {
    user <- findUserByName(userName)
    _     <- checkPassword(user, password)
    _     <- checkSubscription(user)
    _     <- checkUserStatus(user)
  } yield user
```

```
authenticate("john.doe", "foo.bar")
  . flatMap(user => IO {
    println(s"Success! $user")
  })
  . recoverWith( {
    case WrongUserName => IO { /* Do stuff ... */ }
    case WrongPassword => IO { /* Do stuff ... */ }
    case ExpiredSubscription(date) => IO { /* Do stuff ... */ }
    case BannedUser => IO { /* Do stuff ... */ }
    case _ => IO {
      println("Another exception was caught !")
    }
  })
}
```

The issues with Exception

- ✗ Exceptions are invisible
- ✗ One can forget to recover them
- ✗ They must be explicitly documented
- ✗ They can be ambiguous :
 - IOs only raise and recover Throwables. They don't distinguish between `java.util.concurrent.TimeoutException` & `AuthenticationException` at compile-time.
- ✗ You get no proper exhaustivity check

This is a lie

```
def authenticate(userName: String, password: String): IO[User]
```

The method's signature doesn't convey anything about possible error cases.

Unhandled errors will be propagated across the whole application once the IO is ran like good ol' Java when you forget to try/catch.

Requires more reading and more testing.

**Make exceptions
exceptional again**

⚠️ Opinionated statements ahead

Domain errors are not exceptions

- Domain errors are documented edge cases that can happen as part of the user experience.
e.g.: The user hasn't paid their subscription
- Exceptions should be reserved for unexpected, purely technical failures.
e.g.: The database server is unreachable.

**When a user is breaking a business rule,
don't fail**

When you need to fail, fail fast

Exceptions should be propagated to the upper levels of the app and actively monitored.

Don't expose technical errors to your users

Modeling errors using an ADT

```
sealed trait AuthenticationError
case object WrongUserName extends AuthenticationError
case object WrongPassword extends AuthenticationError
case class ExpiredSubscription(expirationDate: Date)
  extends AuthenticationError
case object BannedUser extends AuthenticationError
```

```
// Then our method could look like this :
def authenticate(
  userName: String,
  password: String
): IO[Either[AuthenticationError, User]]
```

What we've achieved

```
def authenticate(  
    userName: String,  
    password: String  
): IO[Either[AuthenticationError, User]]
```

-  Side effects are obvious
-  Domain errors are visible and cannot be forgotten
-  Technical errors can still be raised and recovered
-  No need to check the documentation for unhandled edge cases
-  We have clearly distinct error families

A woman with dark hair, wearing a red dress, is shown from the chest up. She is looking down and slightly to her left, with her hands clasped together in front of her. The background is a soft-focus landscape of hills and trees.

**But we've lost something very
important along the way**

We can't compose anymore!

✗ This does not compile

```
def findUserByName(username: String): IO[Either[AuthenticationError, User]] = ???  
def checkPassword(user: User, password: String): IO[Either[AuthenticationError, Unit]] = ???  
def checkSubscription(user: User): IO[Either[AuthenticationError, Unit]] = ???  
def checkUserStatus(user: User): IO[Either[AuthenticationError, Unit]] = ???  
  
def authenticate(userName: String, password: String): IO[Either[AuthenticationError, User]] =  
for {  
    user <- findUserByName(userName)  
    _     <- checkPassword(user, password)  
    _     <- checkSubscription(user)  
    _     <- checkUserStatus(user)  
} yield user
```

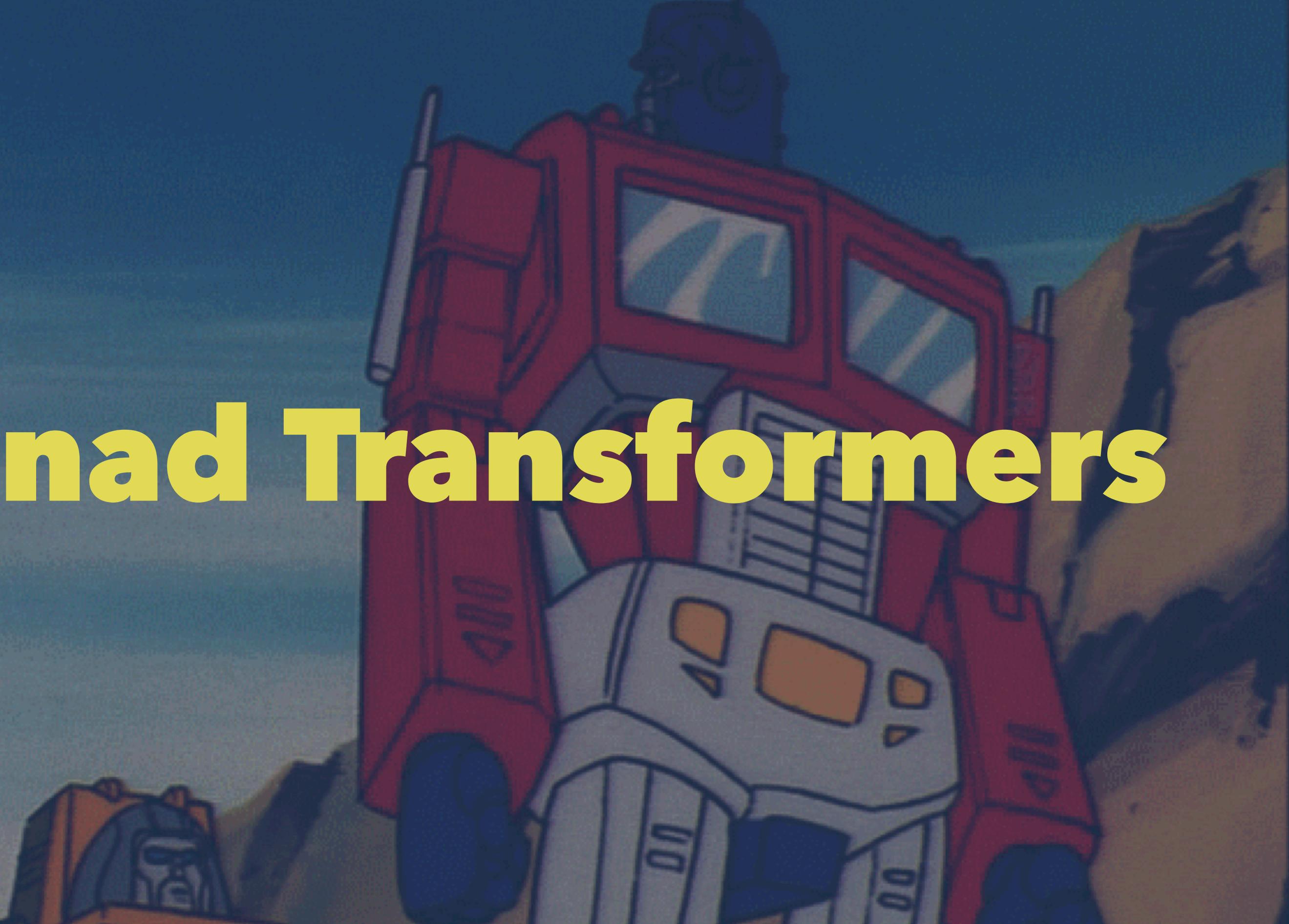
**We can't compose many
IO[Either[A, B]] together.** 😞

We need something like this instead

```
def authenticate(userName: String, password: String): IO[Either[AuthenticationError, User]] =  
  findUserByName(userName).flatMap({  
    case Right(user) => checkPassword(user, password).flatMap({  
      case Right(_) => checkSubscription(user).flatMap({  
        case Right(_) => checkUserStatus(user).map(_.map(_ => user))  
        case Left(err) => IO.pure(Left(err))  
      })  
      case Left(err) => IO.pure(Left(err))  
    })  
    case Left(err) => IO.pure(Left(err))  
  })
```

Error handling shouldn't be this painful.

Monad Transformers



Monad transformers add new behavior to an underlying monad while preserving compositionality.

E.g : OptionT[F, A] creates a new monad which adds the effect of absence to a monad F.

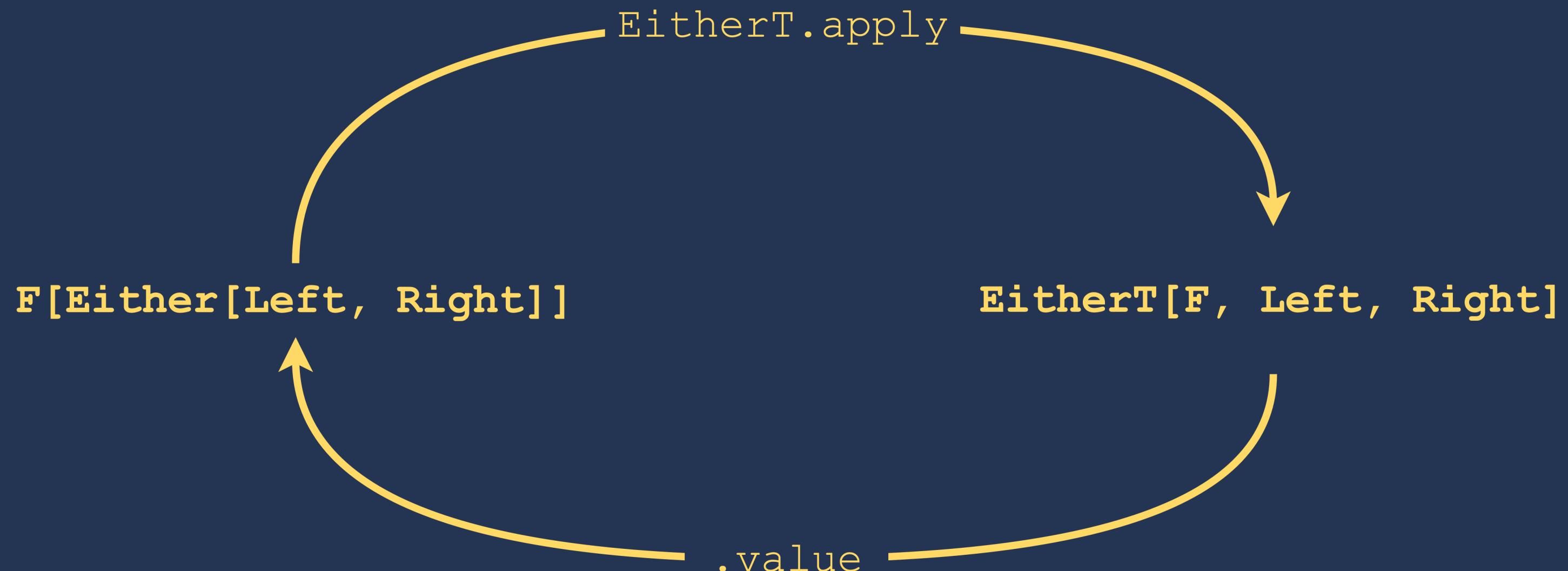
They are type constructors that take a monad as an argument and return a monad.

From F[Either[A, B]] to EitherT[F, A, B]

EitherT[F, L, R] is a light wrapper around F[Either[A, B]] that makes it easy to compose Eithers and Fs together.

It has bidirectional transformation from/to F[Either[A, B]] via the apply and value methods respectively.

```
val a: IO[Either[AuthenticationError, User]] = ???  
val b: EitherT[IO, AuthenticationError, User] = EitherT(a)
```



Rewriting our authentication method

```
def findUserByName(username: String): EitherT[IO, AuthenticationError, User] = ???  
def checkPassword(user: User, password: String): EitherT[IO, AuthenticationError, Unit] = ???  
def checkSubscription(user: User): EitherT[IO, AuthenticationError, Unit] = ???  
def checkUserStatus(user: User): EitherT[IO, AuthenticationError, Unit] = ???  
  
def authenticate(userName: String, password: String): EitherT[IO, AuthenticationError, User] =  
  for {  
    user <- findUserByName(userName)  
    _   <- checkPassword(user, password)  
    _   <- checkSubscription(user)  
    _   <- checkUserStatus(user)  
  } yield user
```

EitherT will short-circuit computation on the first encountered error, a pattern sometimes called *Railway-oriented programming*



```
def findUserByName(username: String): IO[Either[AuthenticationError, User]] = ???  
def checkPassword(user: User, password: String): IO[Either[AuthenticationError, Unit]] = ???  
def checkSubscription(user: User): IO[Either[AuthenticationError, Unit]] = ???  
def checkUserStatus(user: User): IO[Either[AuthenticationError, Unit]] = ???  
  
def authenticate(userName: String, password: String): EitherT[IO, AuthenticationError, User] =  
for {  
    user <- EitherT(findUserByName(userName))  
    _   <- EitherT(checkPassword(user, password))  
    _   <- EitherT(checkSubscription(user))  
    _   <- EitherT(checkUserStatus(user))  
} yield user
```

Look how far we've come!

We've met all of our goals :

-  Side effects are visible
-  IOs and errors can be composed, railway style
-  We still get the benefit of having two distinct error channels :
 - Exceptions thrown inside the IO for purely technical failures
 - The *Left* of the Either for business-related errors

This way we can *fail fast* on technical failures and easily provide good feedback to the user for business edge cases.

We've won, let's have
a drink!



**Wait, but what about
Cats MTL then?**

Challenges yet to address

- What about nested transformers ? What if I want to model mutable state **and** potential absence for example ?
- What about type inference and expressivity ?
 - Monad transformers requires many type annotations to work properly. The more you nest, the worst inference gets!

Can you guess what this code does ?

```
// Retrieves document from a super secure data store
def getDocument: IO[SecretDocument] = ???

type Count = Int
val readSecretDocument: User => EitherT[IO, String, SecretDocument] = {
  val state: StateT[ReaderT[IO, User, *], Count, Either[String, SecretDocument]] =
    StateT[ReaderT[IO, User, *], Int, Either[String, SecretDocument]](currentAttemptsCount =>
      ReaderT[IO, User, (Count, Either[String, SecretDocument])](user =>
        if (currentAttemptsCount >= 3) IO.pure((currentAttemptsCount, Left("Max attempts exceeded")))
        else if (user.isAdmin) getDocument.map(doc => (currentAttemptsCount, Right(doc)))
        else IO.pure((currentAttemptsCount + 1, Left("Access denied"))))
    )
)
}

state.run(0).map(_.2).mapF(EitherT(_)).run
}
```

Me neither.

When we need to combine effects (e.g short-circuiting AND mutable state), monad transformers alone only get us so far.

Scala's inference system can't keep up with nested monad transformers stack, requiring a ridiculous amount of boilerplate to get simple things done.

The idea of Cats MTL

Remember that Monad transformers add some effect to a monad, e.g. :

- EitherT encodes the effect of short-circuiting on error
- ReaderT (i.e. Kleisli) encode the effect of accessing a read-only value from a context, and producing a value from it

**Cats MTL encodes the effect of the most common
Monad Transformers in type classes.**

It gives the ability to combine effects together, without the drawback of bad inference.

How would one encode the effect of raising errors ?

```
def readSecretDocument[F[_] : Applicative](user: User)  
(implicit F: FunctorRaise[F, String]): F[SecretDocument] =  
  if (user.isAdmin) SecretDocument().pure[F]  
  else F.raise("Access Denied!")
```

We've turned our EitherT into a generic F[_] Applicative. All we know about this F[_] is that there is an instance of FunctorRaise defined for it.

We'll need to provide a concrete implementation of F to run the program.

What about recovering ?

```
def getDocumentContent[F[_] : Applicative](user: User)  
(implicit A: ApplicativeHandle[F, String]): F[String] =  
readSecretDocument[F](user)  
  .map(_.content)  
  .handle[String](_ => "Default content")
```

ApplicativeHandle extends FunctorRaise with the ability to handle errors.

We still get a dedicate channel for technical failures

By adding a context bound on `ApplicativeError`, we can raise Exceptions in our IOs, and segregate technical failures from domain errors 🙌

```
def findUserByName[F[_]](name: String)
  (implicit AE: ApplicativeError[F, Throwable]) = {
  AE.raiseError(new RuntimeException("Database not reachable!"))
}
```

Implementing the authenticate method

```
def checkPassword[F[_]](user: User, password: String)
  (implicit F: FunctorRaise[F, AuthenticationError]): F[Unit] =
  F.raise(WrongPassword)

def checkSubscription[F[_]](user: User): F[User] = ???
def checkUserStatus[F[_]](user: User): F[User] = ???

def authenticate[F[_]](userName: String, password: String)
  (implicit F: FunctorRaise[F, AuthenticationError], AE: ApplicativeError[F, Throwable]): F[User] =
for {
  user <- findUserByName[F](userName)
  _ <- checkPassword[F](user, password)
  _ <- checkSubscription[F](user)
  _ <- checkUserStatus[F](user)
} yield user
```

Interpreting the program



It's time to provide a concrete implementation for the type classes we used.

```
object Main extends App {  
    type F[A] = EitherT[IO, AuthenticationError, A]  
    authenticate[F]("john.doe", "123456")  
}
```

Summing up

- Shit happens, we need to handle it carefully
 - Don't let technical details mess up your domain
 - Monad transformers let you add effects to existing monads, to create more *badass* monads
 - Cats MTL gives you this without the syntax headache
 - Challenge your approach, there are plenty of error management strategies out there!
- Cats MTL is cool, but you might not need it
- Have fun!

Thank you!

Keep calm and curry on

This talk is on GitHub : [gbogard/cats-mtl-talk](#)