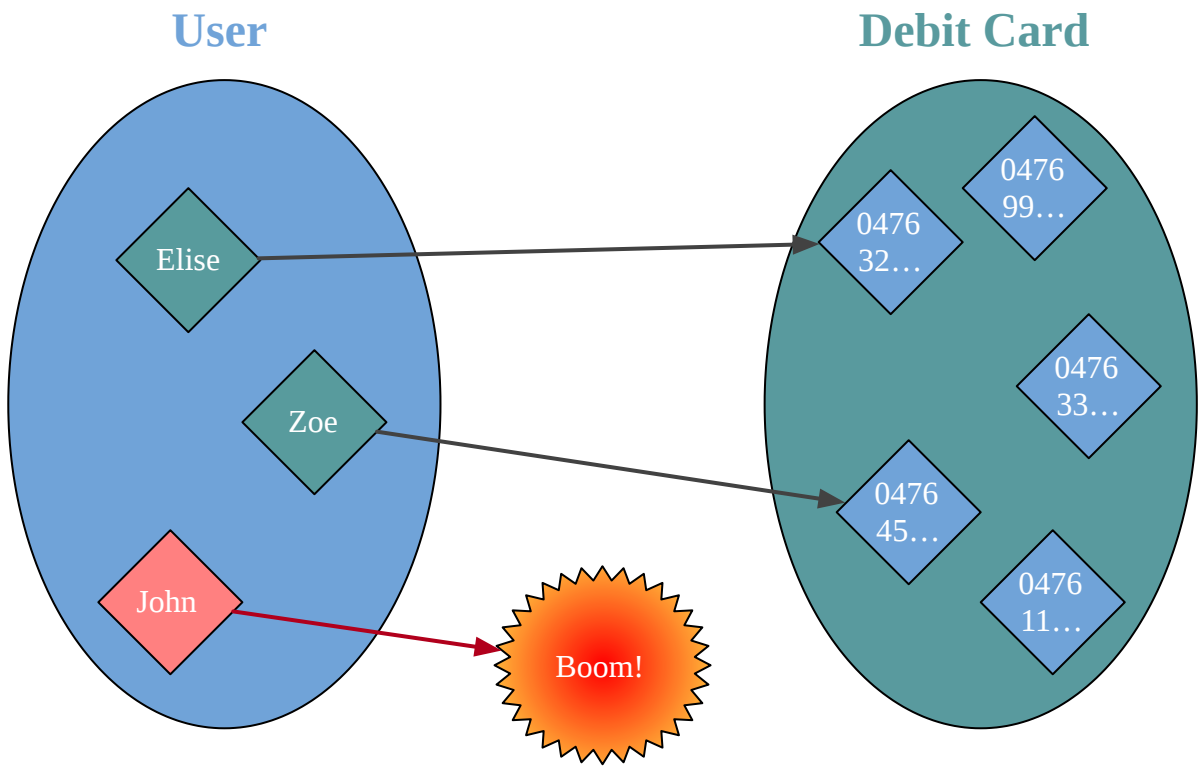
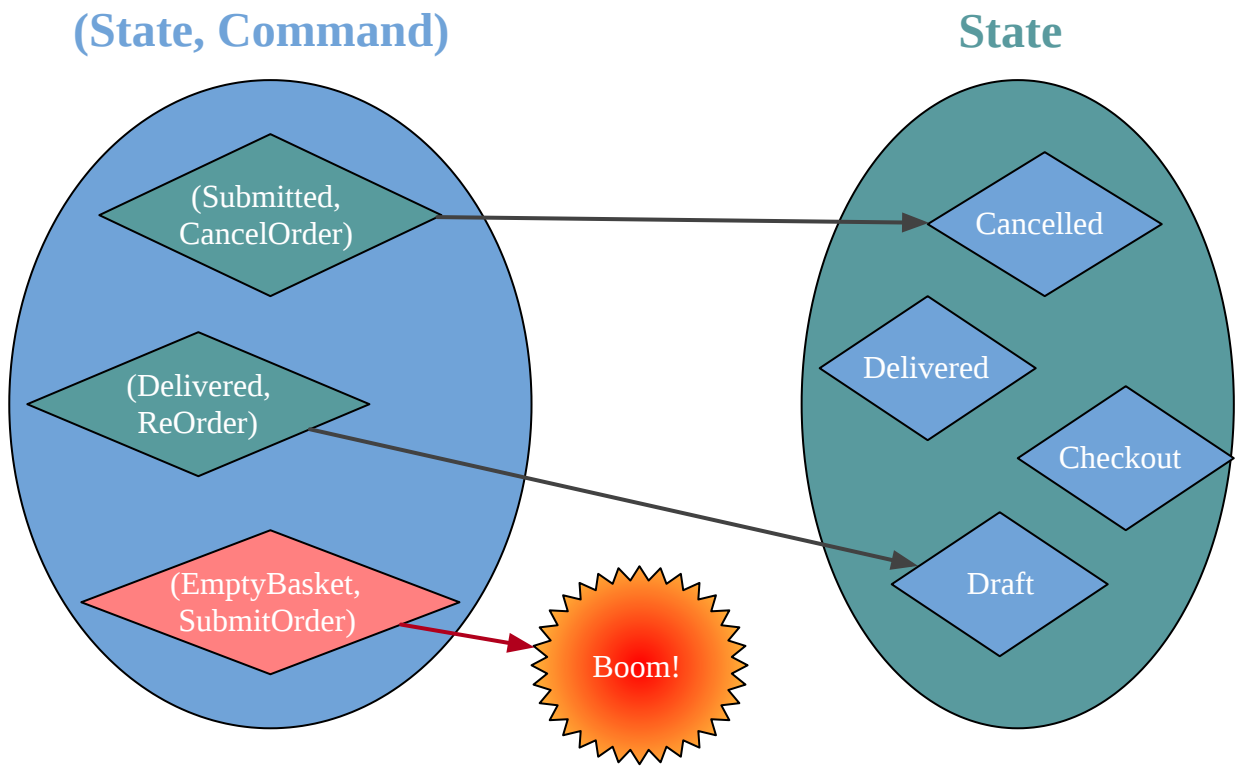
Error Handling

How to deal with runtime errors

Partial Function



Partial Function



Error handling objectives

1. Document when and what type of errors can occur
2. Force caller to deal with errors
3. Make it easy to fail

Exception

```
case class Item(id: Long, unitPrice: Double, quantity: Int)

case class Order(status: String, basket: List[Item])

def submit(order: Order): Order =
  order.status match {
    case "Draft" if order.basket.nonEmpty =>
      order.copy(status = "Submitted")
    case other =>
      throw new Exception("Invalid Command")
  }
```

```
scala> submit(Order("Draft", Nil))
java.lang.Exception: Invalid Command
  at .submit(<console>:7)
  ... 42 elided
```

Exception

```
case object EmptyBasketError extends Exception
case class InvalidCommandError(command: String, order: Order) extends Exception

def submit(order: Order): Order =
  order.status match {
    case "Draft" =>
      if(order.basket.isEmpty) throw EmptyBasketError
      else order.copy(status = "Submitted")
    case other =>
      throw new InvalidCommandError("submit", order)
  }
```

```
scala> submit(Order("Draft", Nil))
EmptyBasketError$
  ... 44 elided

scala> submit(Order("Delivered", Nil))
InvalidCommandError
  at .submit(<console>:8)
  ... 42 elided
```

Exceptions are not documented

```
def submit(order: Order): Order = ???

def canSubmit(order: Order): Boolean =
  try {
    submit(order)
    true
  } catch {
    case EmptyBasketError       => false
    case _: InvalidCommandError => false
    case _: ArithmeticException => true
    case _: Exception           => false
  }
```

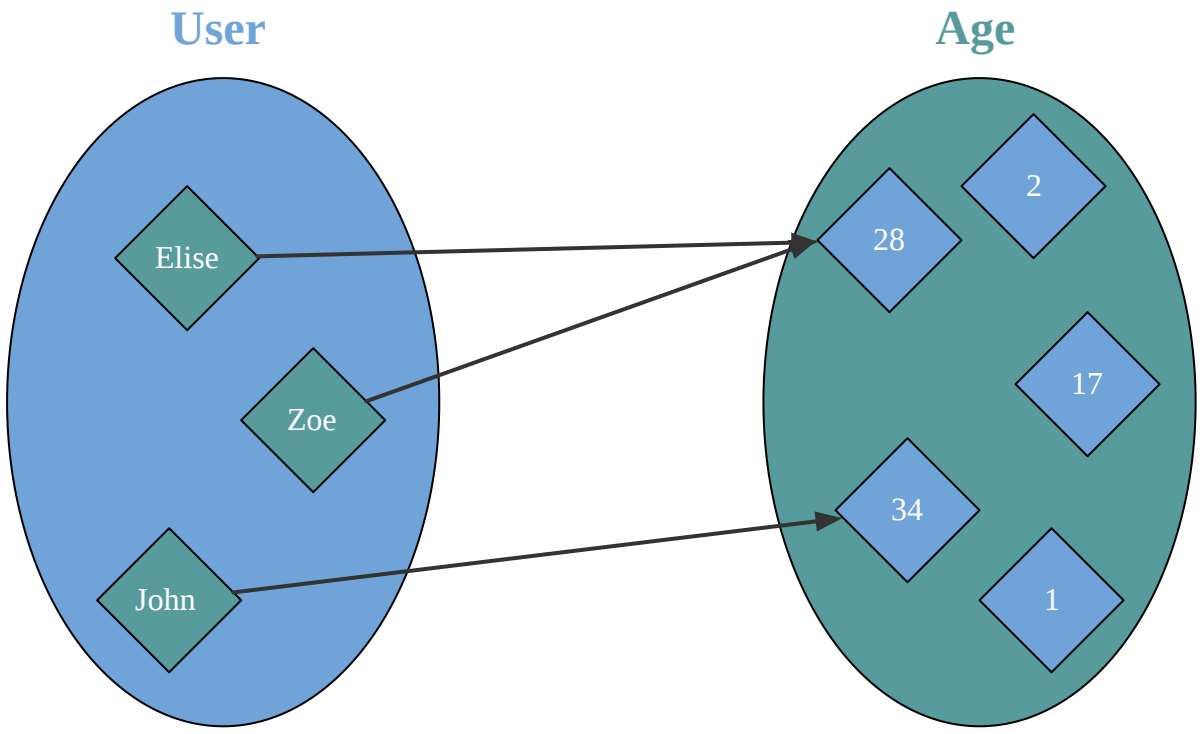
Exceptions are not documented

```
def submit(order: Order): Order = ???

def canSubmit(order: Order): Boolean =
  try {
    submit(order)
    true
  } catch {
    case EmptyBasketError       => false
    case _: InvalidCommandError => false
    case _: ArithmeticException => true
    case _: Exception           => false
  }
```

In Java, you have checked Exception

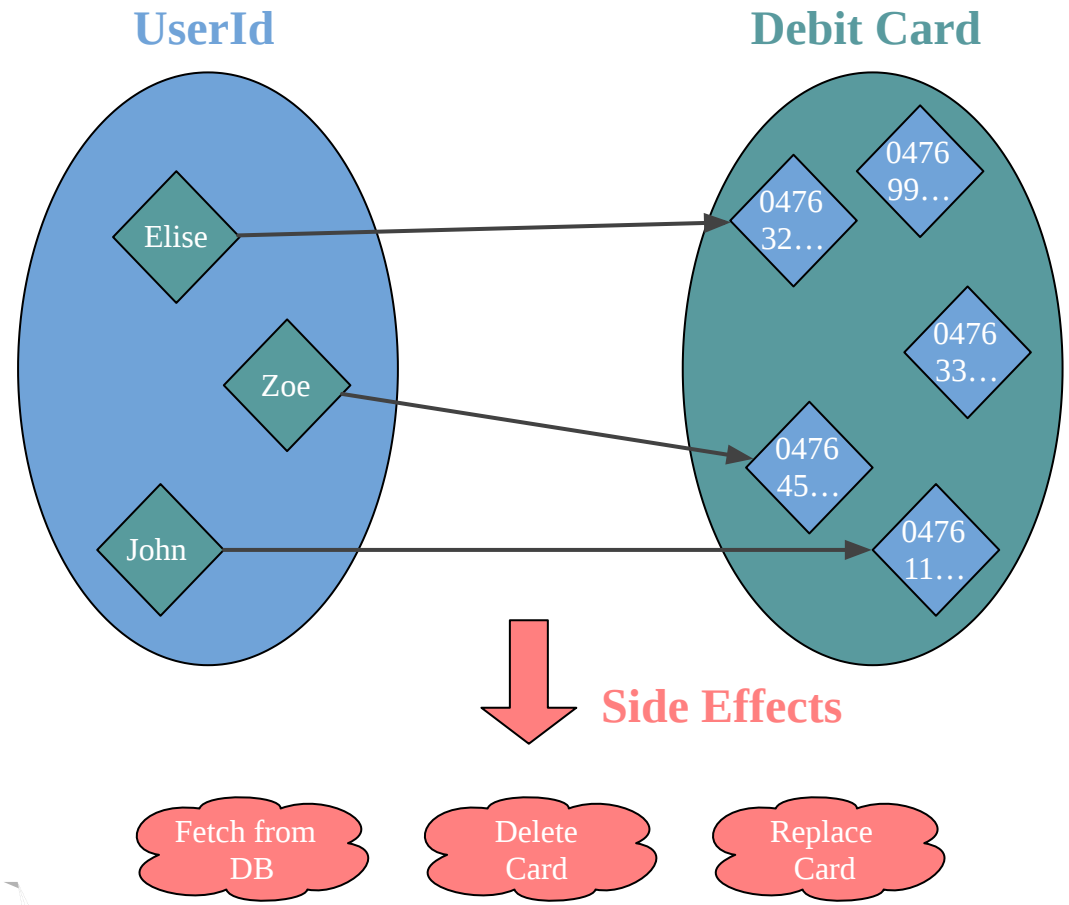
```
public Order submit(Order order) throws EmptyBasketError, InvalidCommandError
```

Pure Function is a mapping between types



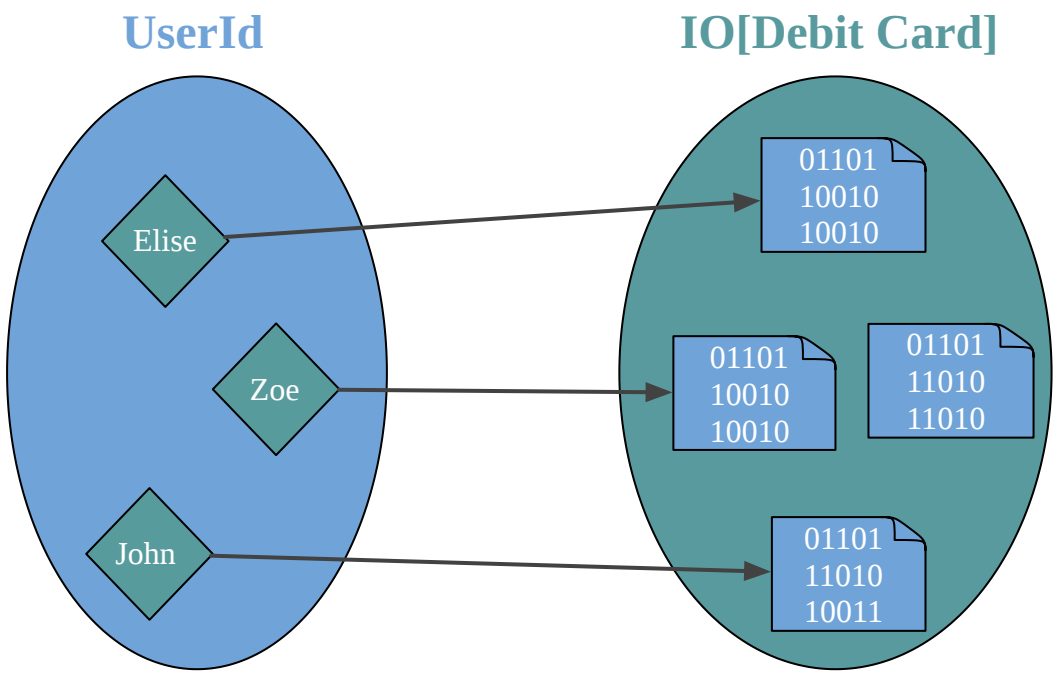
- Powerful refactoring
- Local reasoning
- Easier to test
- Potential performance optimisation
- Better documentation

Functions with side effects are not pure




```
def getDebitCard(userId: UserId): DebitCard = {
  val user = db.getUser(userId)
  user.debitCard
}


def deleteDebitCard(userId: UserId): DebitCard = {
  val user = db.getUser(userId)
  val debitCard = user.debitCard
  db.upsertDebitCard(userId, null)
  debitCard
}
```

Pure side effects and exceptions with IO



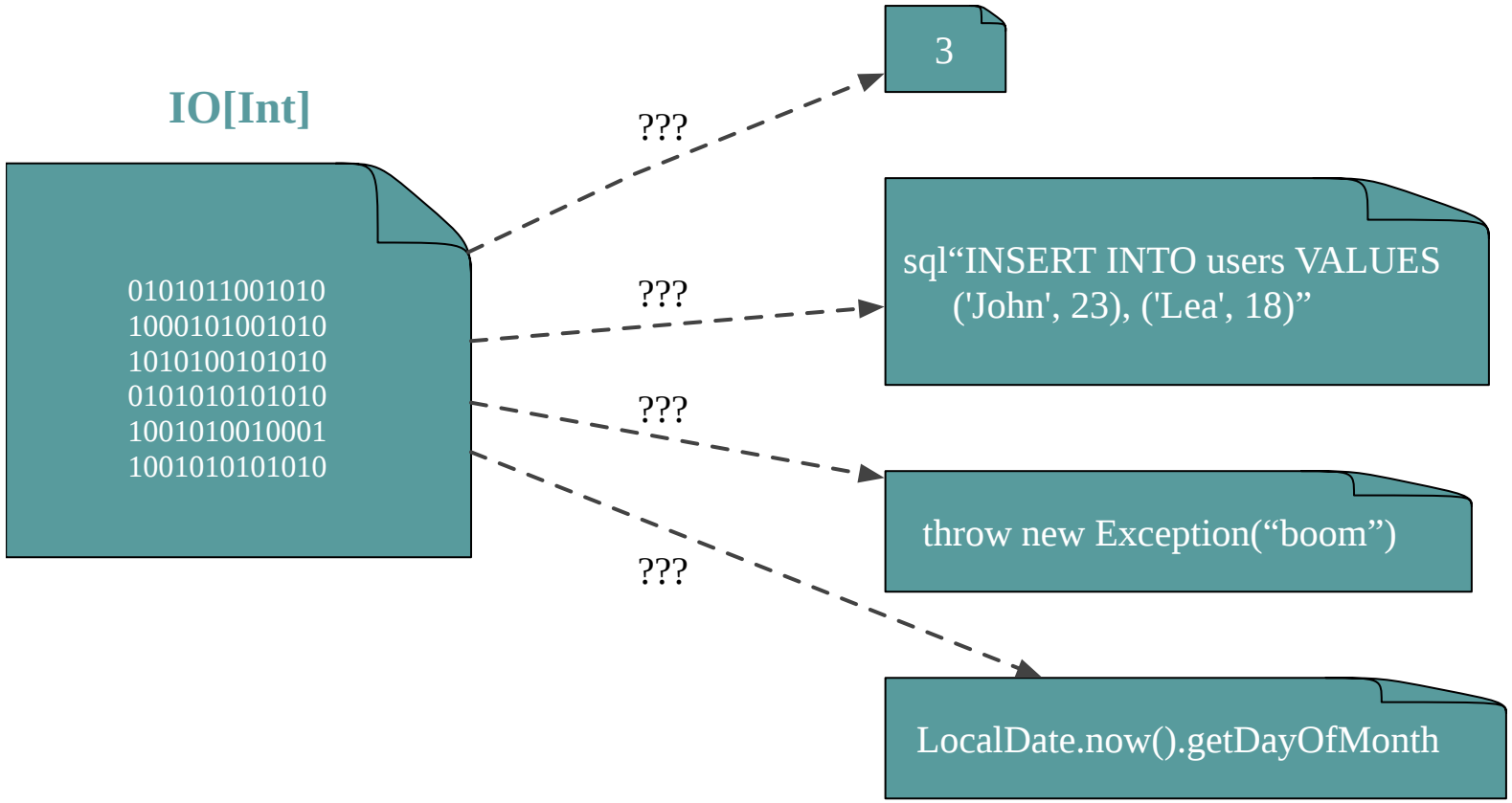

```
def extractDebitCard(user: User): IO[DebitCard] = {
  if(user.debitCard == null)
    IO.fail(new Exception("No debit card"))
  else
    IO.succeed(user.debitCard)
}


def deleteDebitCard(db: DbApi, userId: UserId): IO[Deb
  for {
    user      <- db.getUser(userId)
    debitCard <- extractDebitCard(user)
    _         <- db.upsertDebitCard(userId, null)
  } yield debitCard
```

IO error handling is fragile

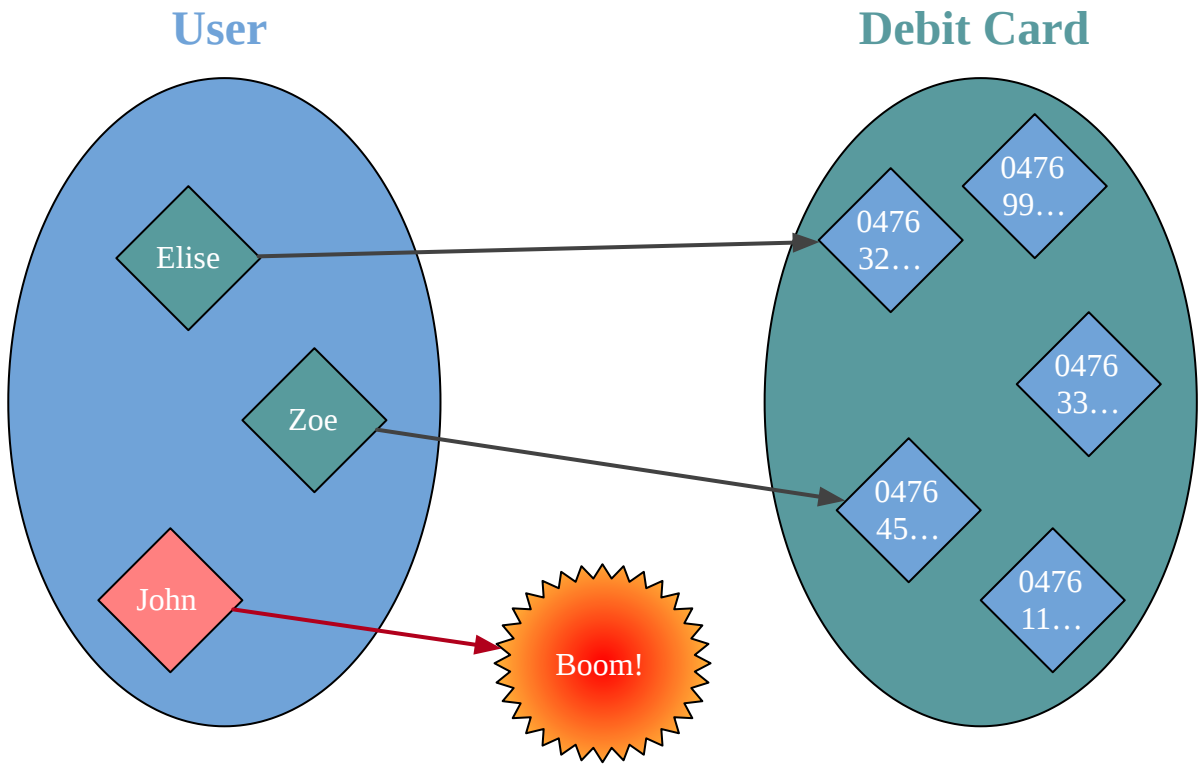
```
def deleteCard(userId: UserId): IO[DebitCard] = ???

val httpRoute = {
  case DELETE -> Root / "user" / UserId(x) / "card" =>
    deleteCard(x)
      .flatMap(Ok(_))
      .handleErrorWith {
        case _: UserMissing | _: CardMissing => NotFound()
        case _: ExpiredCard                  => BadRequest()
        case _: Throwable                    => InternalServerError()
      }
}
```

```
def handleErrorWith[A, B](io: IO[A])(f: Throwable => IO[B]): IO[B] = ???
```

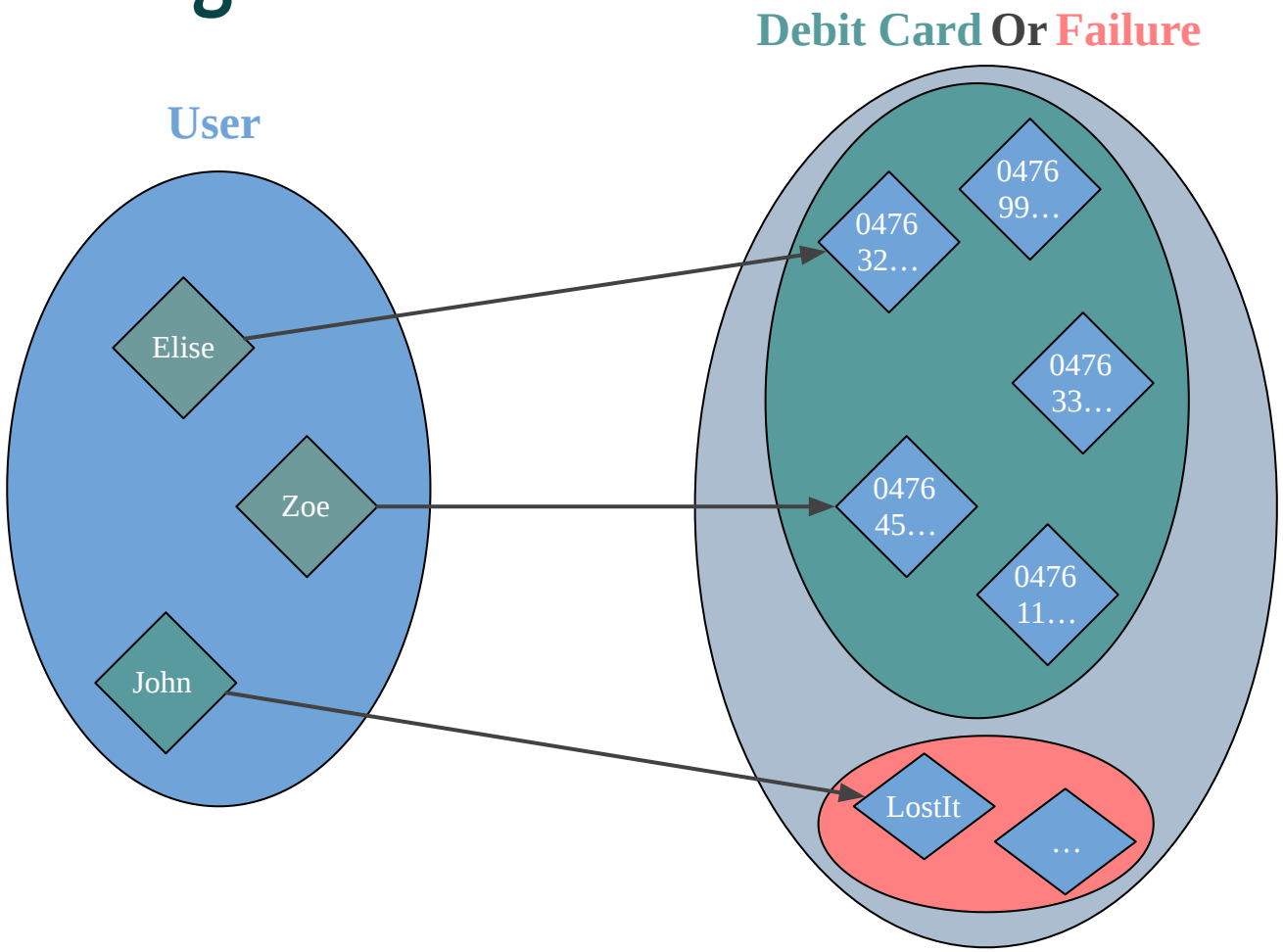
IO can be too many things



Can we use a type dedicated to error handling?



Pure Error Handling



Which types can we use?

Type constructors with an error channel

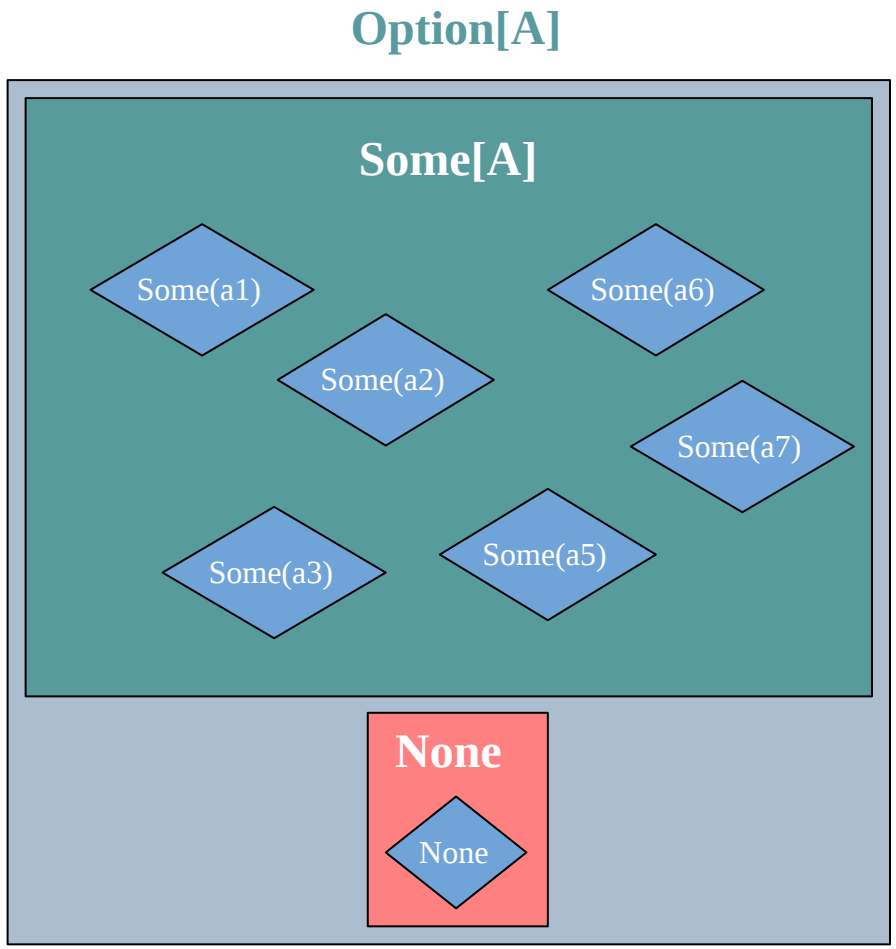
- `Option`
- `Try`
- `Either`

Plan

- Look at use cases for `Option`, `Try` and `Either`
- Practice the design of error ADTs (Algebraic Data Type)
- How to use `Option` and `Either` in conjunction with `IO`

Option

```
sealed trait Option[+A]

object Option {
  case class Some[+A](value: A) extends Option[A]
  case object None extends Option[Nothing]
}
```



Option documents which values are optional

```
case class User(
  id      : java.util.UUID,
  name    : String,
  age     : Int,
  email   : Option[String],
  address: Option[String]
)
```

```
CREATE TABLE users (
  id       UUID NOT NULL,
  name     TEXT NOT NULL,
  age      INT  NOT NULL,
  email    TEXT,
  address TEXT
)
```

Option forces us to think about empty case

```
def longest(xs: List[String]): Option[String] = {
  var current: Option[String] = None

  for (x <- xs) {
    current match {
      case Some(max) if max.length > x.length =>
        () // do nothing
      case _ =>
        current = Some(x)
    }
  }

  current
}
```

```
def longest(xs: List[String]): String = {
  var current: String = null

  for (x <- xs) {

    if(current != null && current.length > x.length) {
      () // do nothing
    } else {
      current = x
    }
  }

  current
}
```

Option is a List with at most one element

```
scala> Some("hello").toList
res3: List[String] = List(hello)

scala> None.toList
res4: List[Nothing] = List()

scala> List(Some(3), None, Some(4), None, None, Some(5)).flatMap(_.toList)
res5: List[Int] = List(3, 4, 5)
```

Option Exercise 1

`exercises.errorhandling.OptionExercises.scala`

Variance

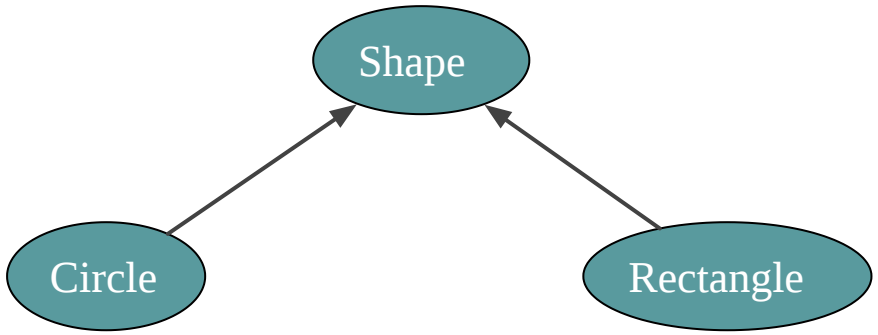
```
sealed trait Option[+A]

object Option {

  case class Some[+A](value: A) extends Option[A]

  case object None extends Option[Nothing]

}
```

Variance

```
sealed trait Option[+A]

object Option {

  case class Some[+A](value: A) extends Option[A]

  case object None extends Option[Nothing]

}
```

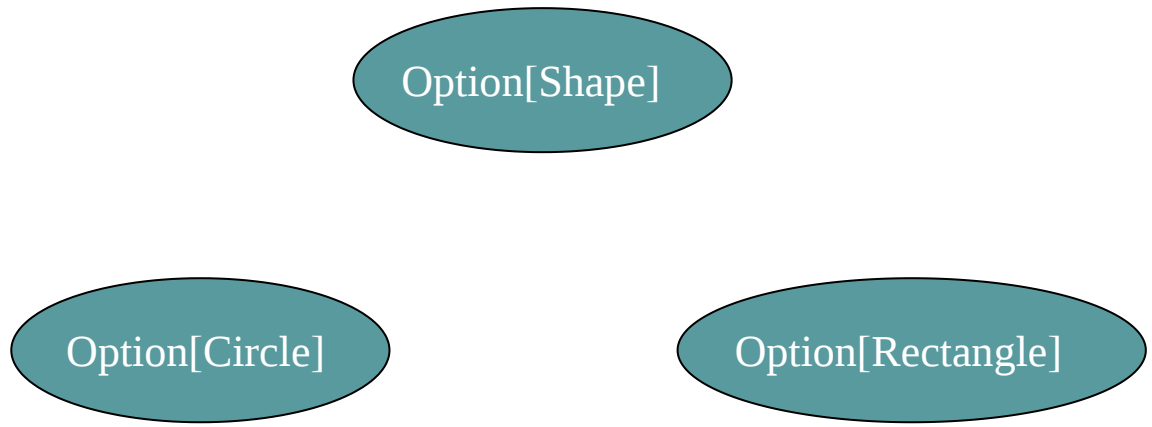
```
trait Foo[+A] // Foo is covariant
trait Foo[-A] // Foo is contravariant
trait Foo[ A] // Foo is invariant
```

Shape

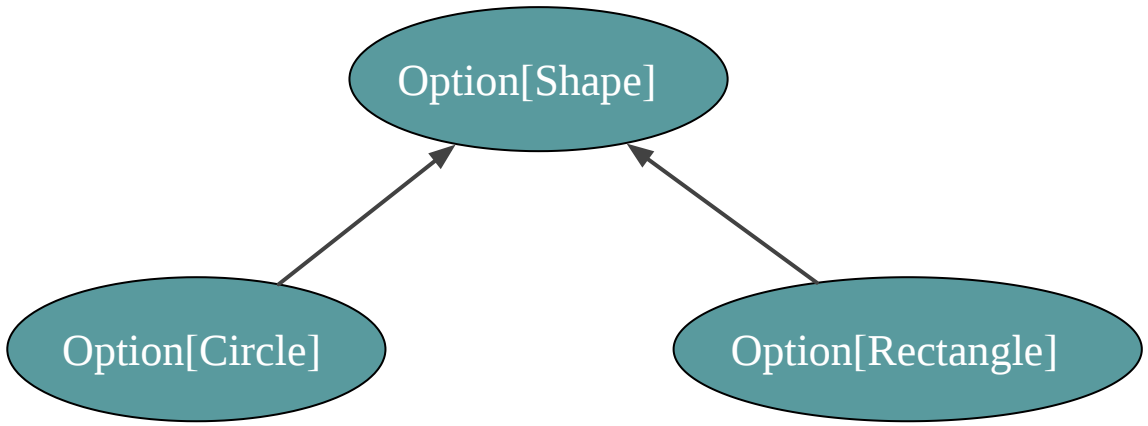



```
sealed trait Shape

case class Circle(radius: Int) extends Shape

case class Rectangle(width: Int, height: Int) extends Shape
```

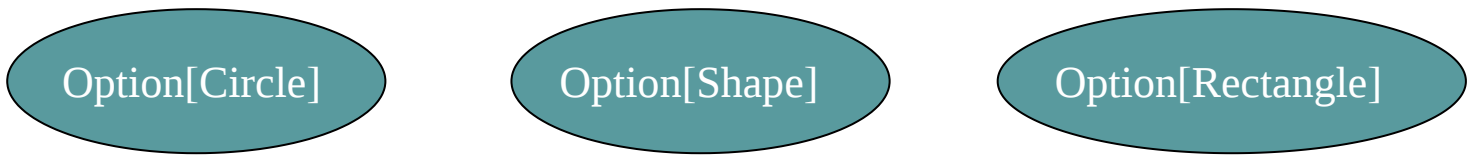
What is the relationship for Option[Shape]?



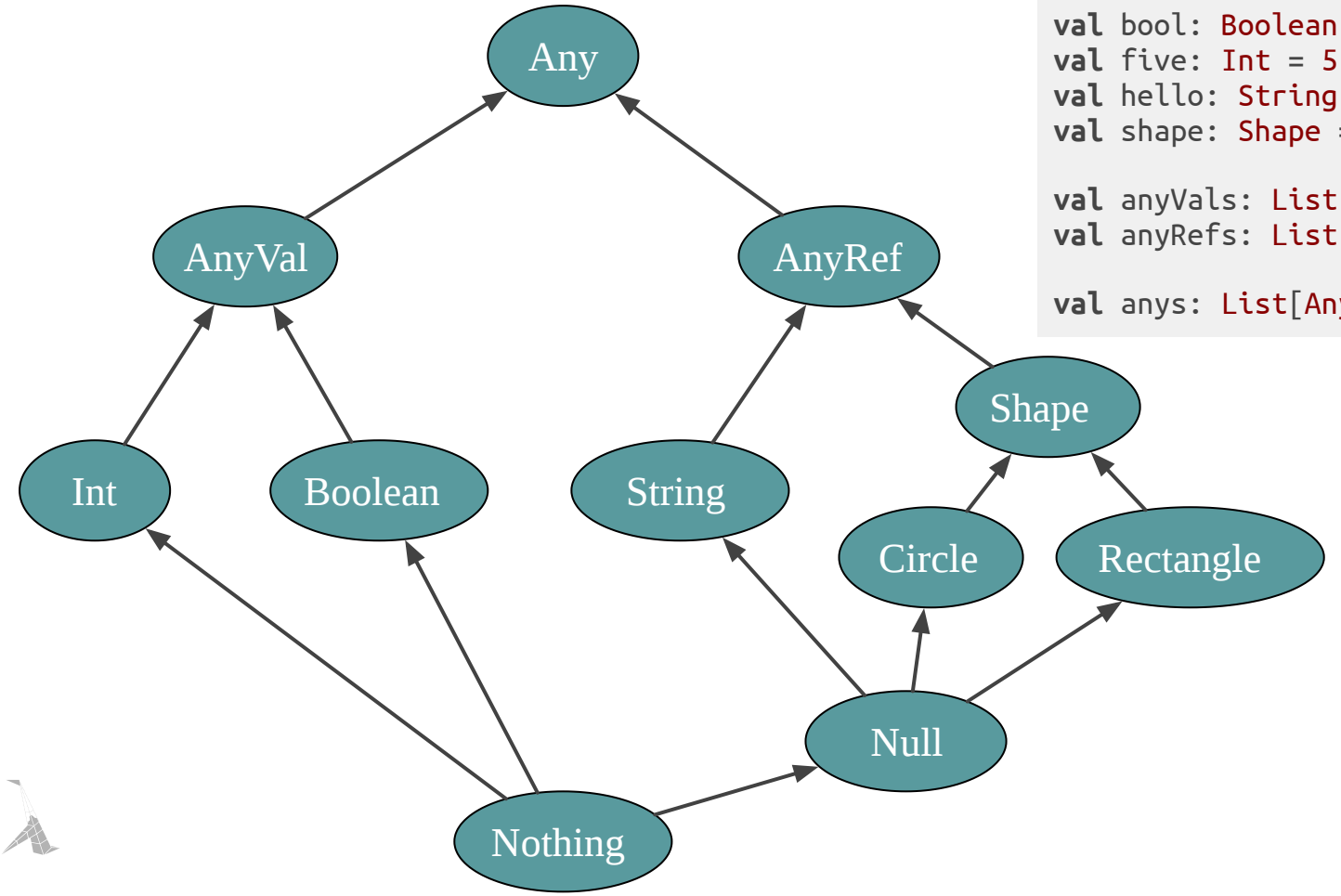
Option is covariant



If Option were invariant

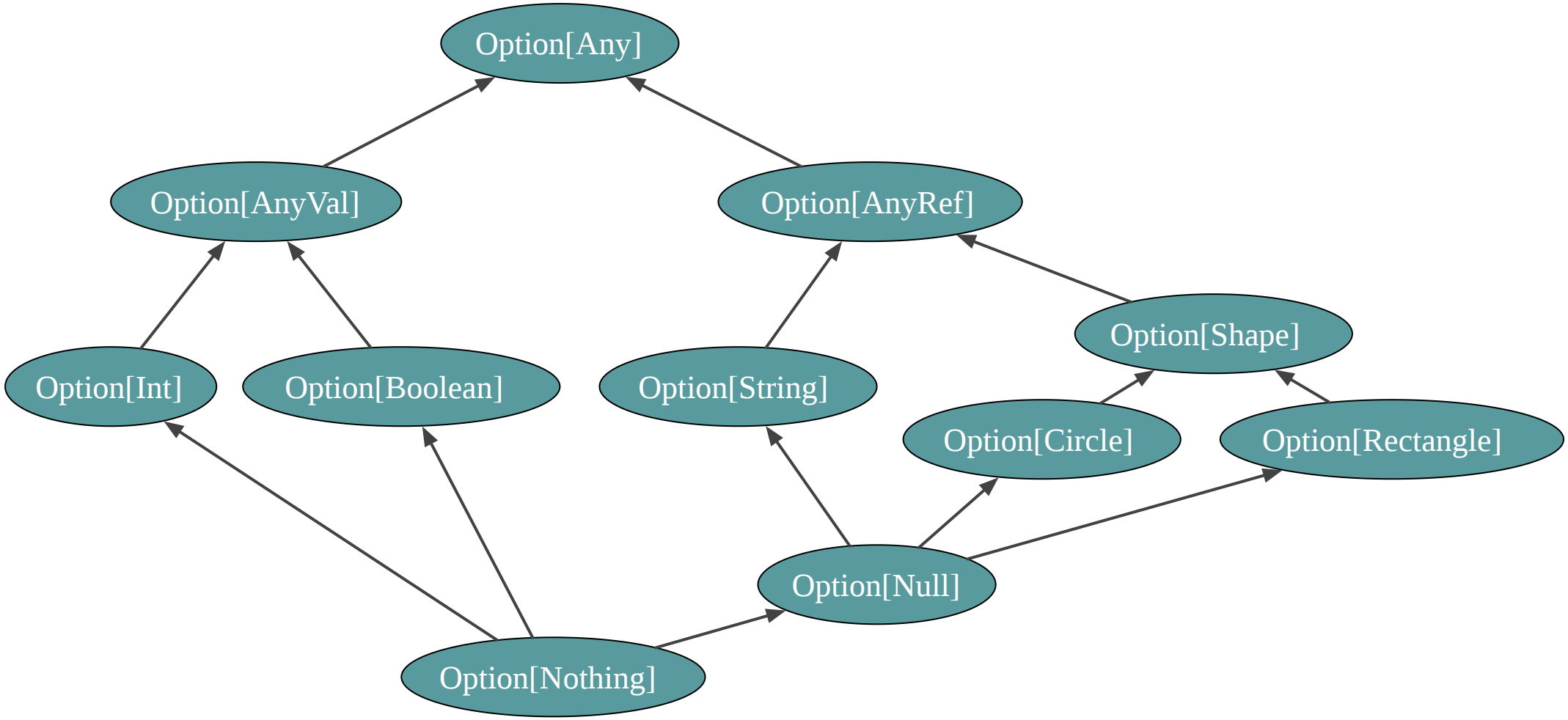


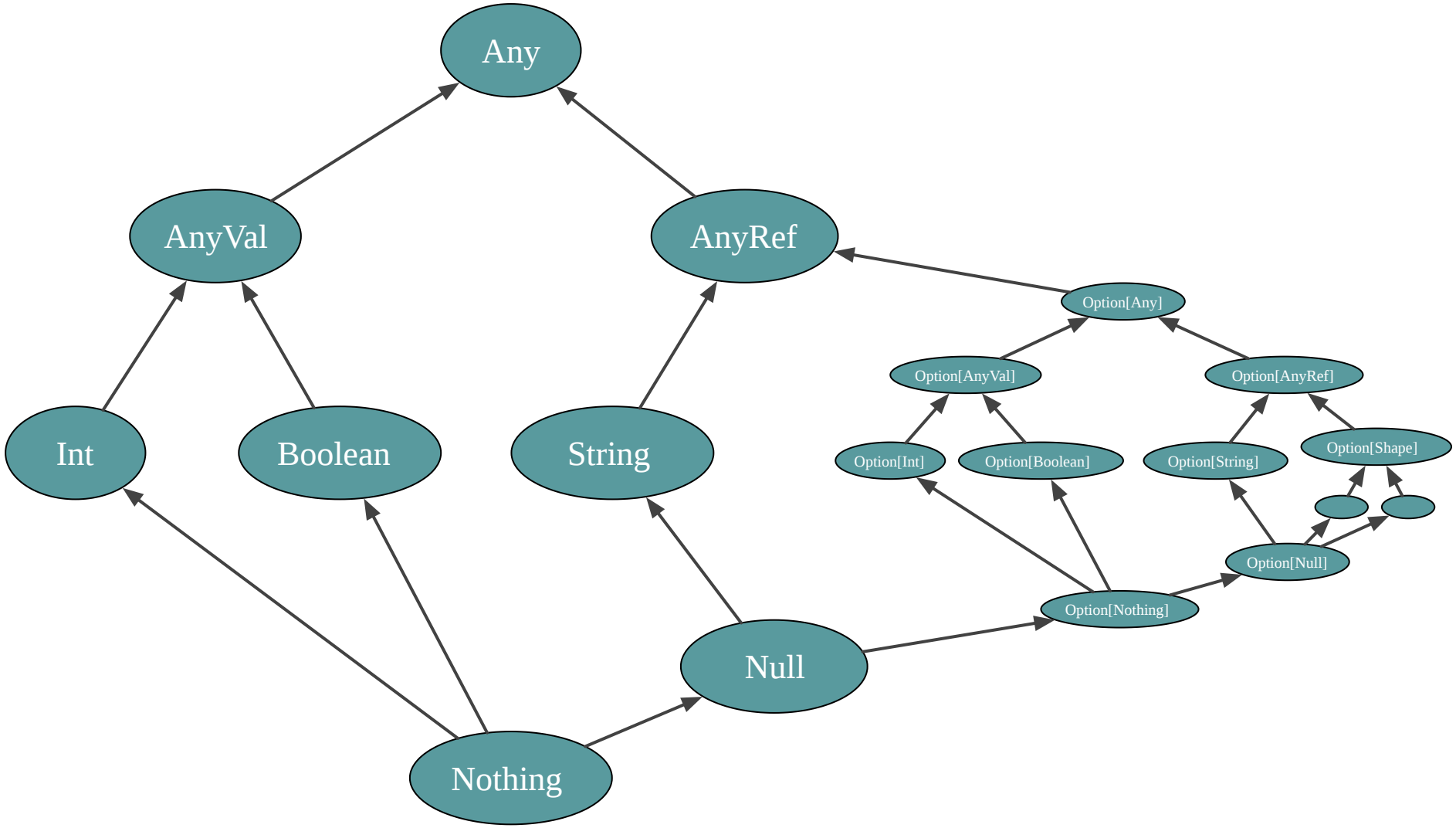
Type hierarchy




```scala
val bool: Boolean = true
val five: Int = 5
val hello: String = "Hello"
val shape: Shape = Circle(5)

val anyVals: List[AnyVal] = List(bool, five)
val anyRefs: List[AnyRef] = List(hello, shape, null)

val anys: List[Any] = anyVals ++ anyRefs
```

Covariance


Option[Any]
Option[AnyVal]
Option[AnyRef]
Option[Int]
Option[Boolean]
Option[String]
Option[Shape]
Option[Circle]
Option[Rectangle]
Option[Null]
Option[Nothing]


Any
AnyVal
AnyRef
Int
Boolean
String
Null
Nothing
Option[Any]
Option[AnyVal]
Option[AnyRef]
Option[Int]
Option[Boolean]
Option[String]
Option[Shape]
Option[Null]
Option[Nothing]

Variance is type checked

```
sealed trait Option[-A]

object Option {
  case class Some[-A](value: A) extends Option[A]
  case object None extends Option[Nothing]
}


scala> contravariant type A occurs in covariant position in type => A of value value
  case class Some[-A](value: A) extends Option[A]
```

Option Exercises 2, 3 and 4

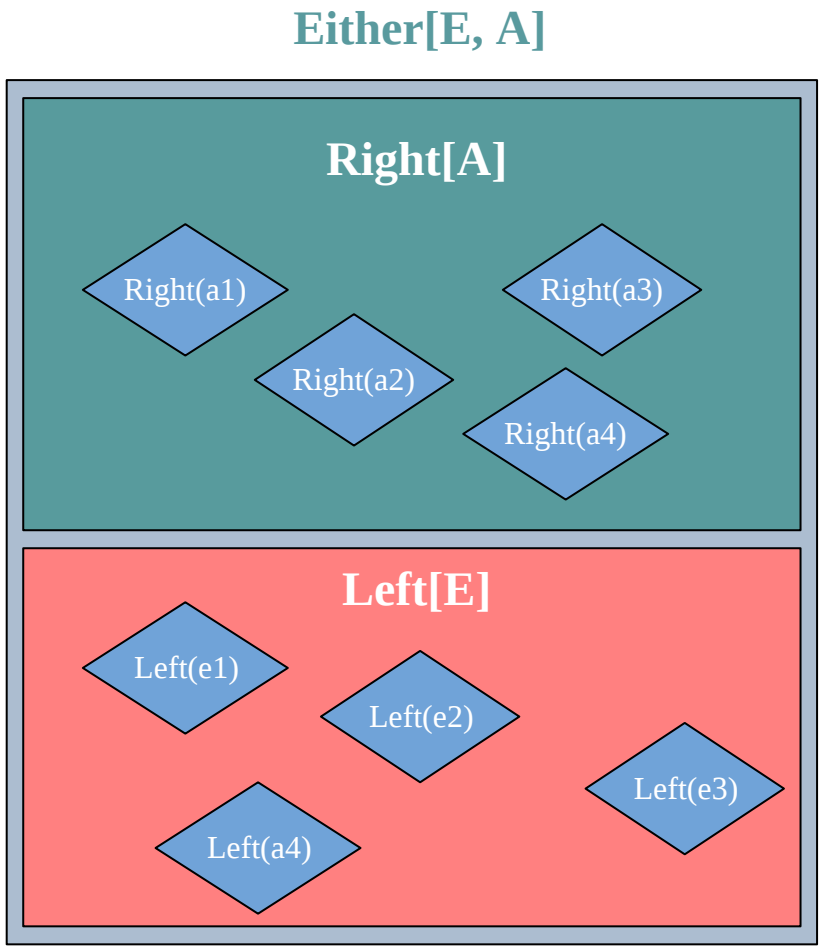
`exercises.errorhandling.OptionExercises.scala`

Use Option when

- A value may be missing
- An operation can fail in a unique obvious way
- An operation can fail in many ways but we don't need any information about the error

Either

```
sealed trait Either[+E, +A]

object Either {
  case class  Left[+E](value: E) extends Either[E, Nothing]
  case class Right[+A](value: A) extends Either[Nothing, A]
}
```



Either is the canonical encoding of OR

```
def getUser(userIdOrEmail: Either[UserId, Email]): IO[User] =
  userIdOrEmail match {
    case Left(userId) => db.getUserById(userId)
    case Right(email) => db.getUserByEmail(email)
  }
```

Either[UserId, Email] represents a UserId OR an Email

Either is the canonical encoding of OR

```
def getUser(userIdOrEmail: Either[UserId, Email]): IO[User] =
  userIdOrEmail match {
    case Left(userId) => db.getUserById(userId)
    case Right(email) => db.getUserByEmail(email)
  }
```

Either[UserId, Email] represents a UserId OR an Email

How would you encode a UserId AND an Email?

Either is the canonical encoding of OR

```
def getUser(userIdOrEmail: Either[UserId, Email]): IO[User] =
  userIdOrEmail match {
    case Left(userId) => db.getUserById(userId)
    case Right(email) => db.getUserByEmail(email)
  }
```

Either[UserId, Email] represents a UserId OR an Email

(UserId, Email) represents a UserId AND an Email

Either[???, A]

String Error

```
def submit(order: Order): Either[String, Order] =
  order.status match {
    case "Draft" =>
      if(order.basket.isEmpty) Left("Basket is empty")
      else Right(order.copy(status = "Submitted"))
    case _ =>
      Left(s"Cannot submit an order in ${order.status}")
  }
```

```
scala> submit(Order("Draft", List(Item(111, 12.25, 2))))
res6: Either[String,Order] = Right(Order(Submitted,List(Item(111,12.25,2))))

scala> submit(Order("Draft", Nil))
res7: Either[String,Order] = Left(Basket is empty)

scala> submit(Order("Delivered", Nil))
res8: Either[String,Order] = Left(Cannot submit an order in Delivered)
```

Enum Error

```
sealed trait OrderError
case object EmptyBasketError extends OrderError
case class InvalidAction(action: String, status: String) extends OrderError

def submit(order: Order): Either[OrderError, Order] =
  order.status match {
    case "Draft" =>
      if(order.basket.isEmpty) Left(EmptyBasketError)
      else Right(order.copy(status = "Submitted"))
    case _ =>
      Left(InvalidAction("submit", order.status))
  }
```

```
scala> submit(Order("Draft", List(Item(111, 12.25, 2))))
res9: Either[OrderError,Order] = Right(Order(Submitted,List(Item(111,12.25,2))))

scala> submit(Order("Draft", Nil))
res10: Either[OrderError,Order] = Left(EmptyBasketError)

scala> submit(Order("Delivered", Nil))
res11: Either[OrderError,Order] = Left(InvalidAction(submit,Delivered))
```

Enum Error

```
def canSubmit(order: Order): Boolean =
  submit(order) match {
    case Right(_)               => true
    case Left(EmptyBasket)      => false
    case Left(_: InvalidAction) => false
  }
```

Enum Error

```
def canSubmit(order: Order): Boolean =
  submit(order) match {
    case Right(_)               => true
    case Left(_: InvalidAction) => false
  }
```

```
On line 3: warning: match may not be exhaustive.
It would fail on the following input: Left(EmptyBasketError)
```

Throwable Error

```
import java.time.LocalDate
import java.time.format.DateTimeFormatter
import scala.util.Try

val formatter = DateTimeFormatter.ofPattern("uuuu-MM-dd")

def parseLocalDate(dateStr: String): Either[Throwable, LocalDate] =
  Try(LocalDate.parse(dateStr, formatter)).toEither
```

```
scala> parseLocalDate("2019-09-12")
res12: Either[Throwable,java.time.LocalDate] = Right(2019-09-12)

scala> parseLocalDate("12 July 1996")
res13: Either[Throwable,java.time.LocalDate] = Left(java.time.format.DateTimeParseException: Text '12 July 1996' cou
```

Why do we use Left for error and Right for success?

It is completely arbitrary

Either is Right biased

```
def map[E, A, B](either: Either[E, A])(f: A => B): Either[E, B] = ???
```

```
scala> parseLocalDate("2019-09-12").map(_.plusDays(2))
res14: scala.util.Either[Throwable,java.time.LocalDate] = Right(2019-09-14)
```

Either is Right biased

```
def map[E, A, B](either: Either[E, A])(f: A => B): Either[E, B] = ???
```

```
scala> parseLocalDate("2019-09-12").map(_.plusDays(2))
res14: scala.util.Either[Throwable,java.time.LocalDate] = Right(2019-09-14)
```

```
def flatMap[E, A, B](either: Either[E, A])(f: A => Either[E, B]): Either[E, B] = ???
```

```
scala> for {
     |   date1 <- parseLocalDate("2019-01-24")
     |   date2 <- parseLocalDate("2020-09-12")
     | } yield date1.isBefore(date2)
res15: scala.util.Either[Throwable,Boolean] = Right(true)
```

Either Exercises

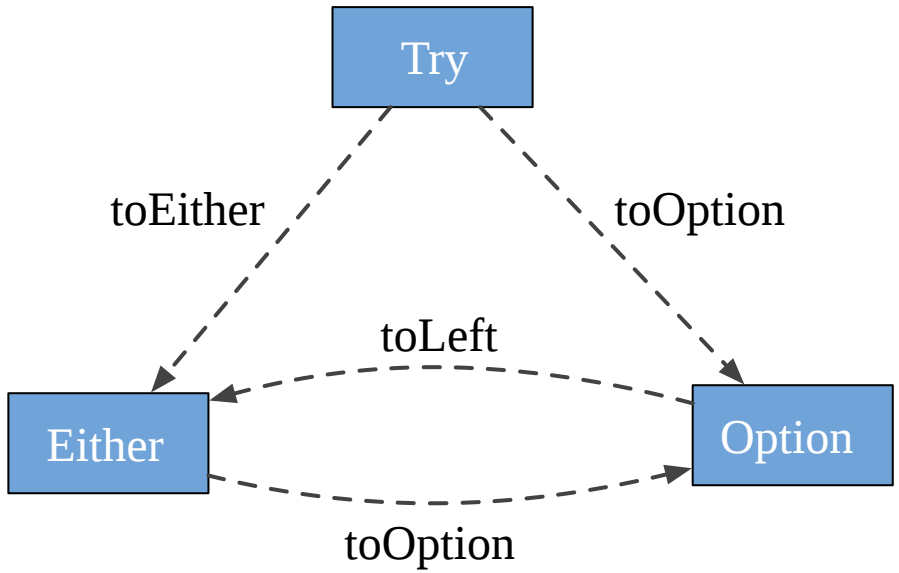
`exercises.errorhandling.EitherExercises.scala`

Either is an Option with polymorphic error type

Option is a special case of Either

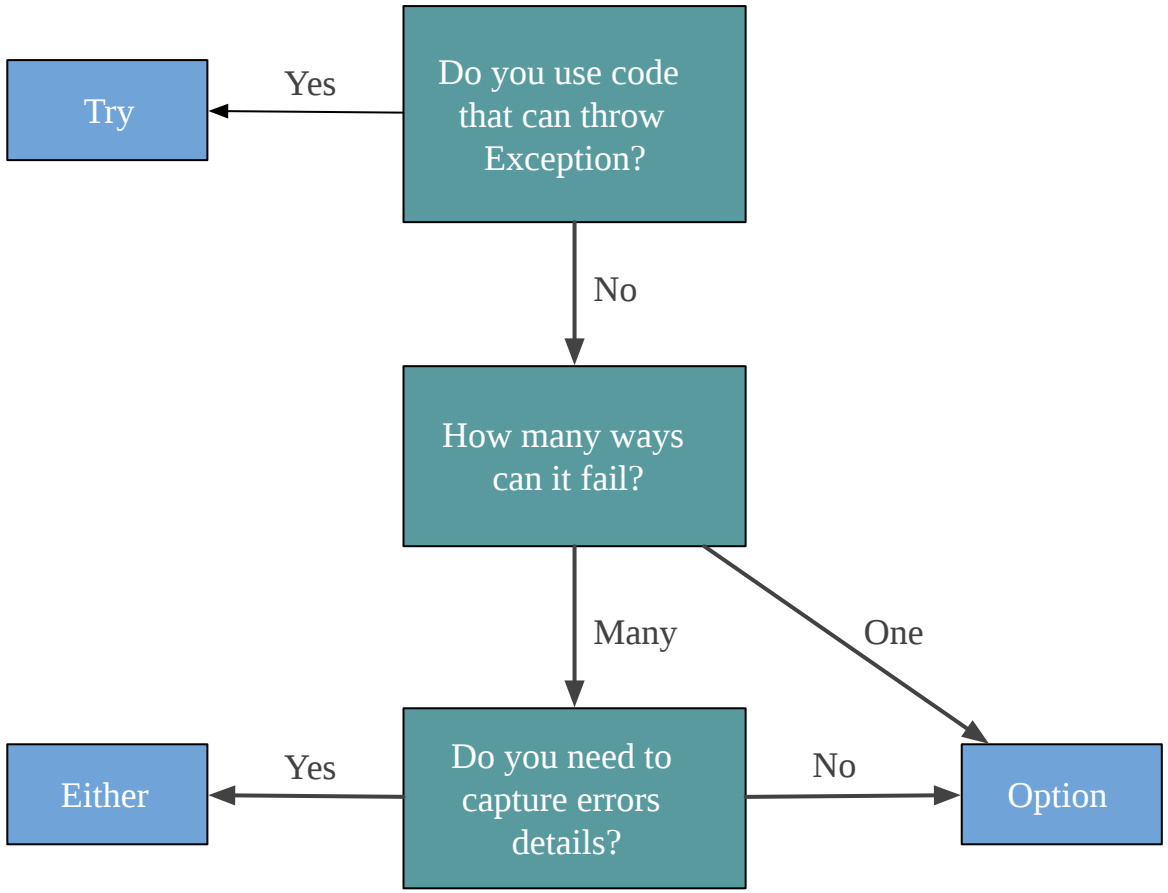
```
type Option[+A] = Either[Unit, A]
```

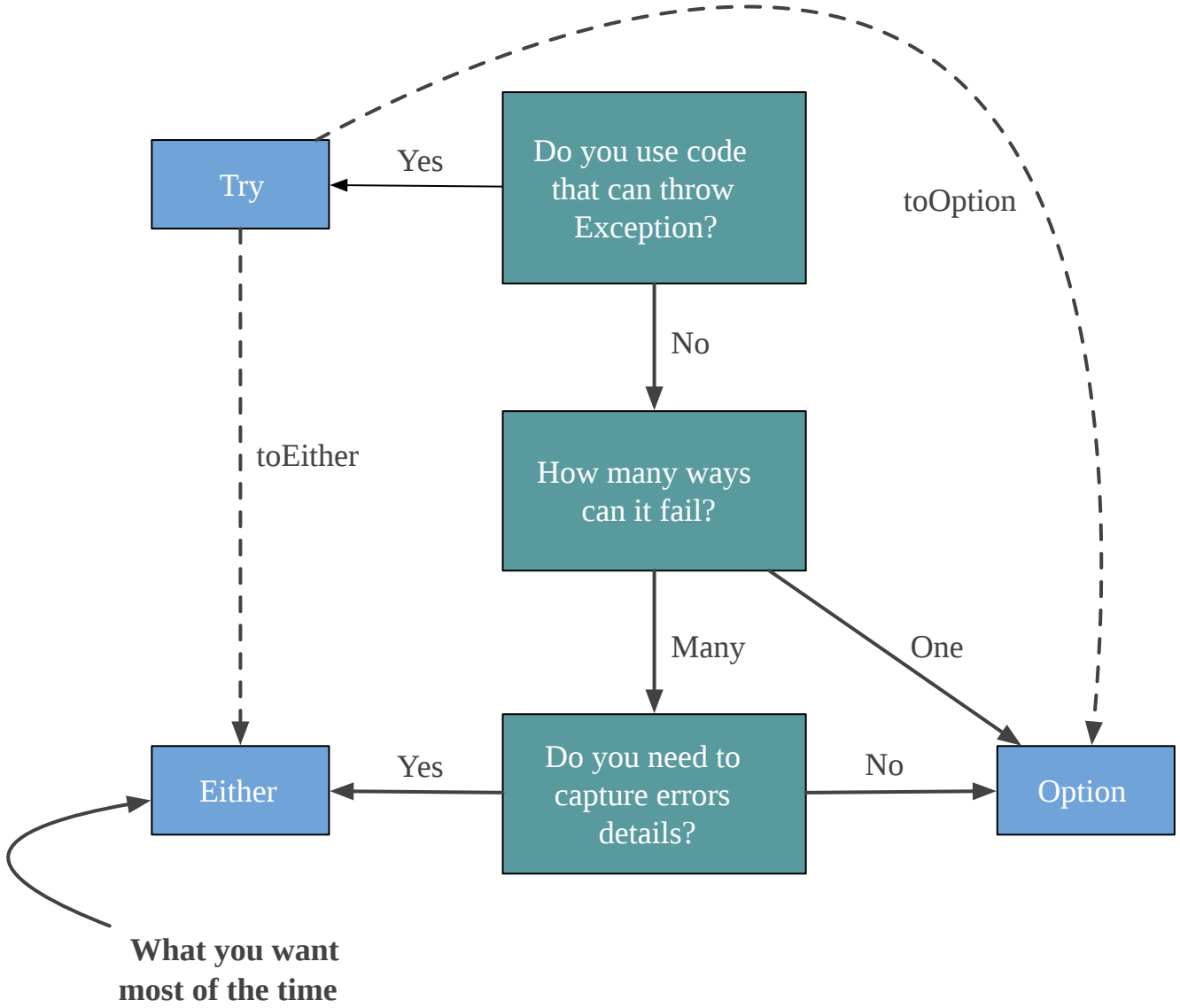
```
type Try[+A] = Either[Throwable, A]
```


Try
toEither
toOption
toLeft
Either
Option
toOption

Either Summary

- Use when you need to capture details about failure
- ADTs are generally the best way to encode errors
- Two modes:
  - Fail early with `flatMap`
  - Accumulate failures with `parMap`, `parSequence`


Do you use code that can throw Exception?
Yes
Try
No
How many ways can it fail?
Many
One
Do you need to capture errors details?
Yes
Either
No
Option


Try
Yes
Do you use code that can throw Exception?
toOption
No
toEither
How many ways can it fail?
Many
One
Either
Yes
Do you need to capture errors details?
No
Option
What you want most of the time

Option with IO

```
trait OrderApi {
  def getUser(userId: UserId): IO[Option[User]]
  def getOrder(orderId: OrderId): IO[Option[Order]]
}

def getOrderDetails(api: OrderApi)(userId: UserId, orderId: OrderId): IO[OrderDetails] =
  for {
    optUser  <- api.getUser(userId)
    optOrder <- api.getOrder(orderId)
  } yield ???
```

Option with IO

```
trait OrderApi {
  def getUser(userId: UserId): IO[Option[User]]
  def getOrder(orderId: OrderId): IO[Option[Order]]
}

def getOrderDetails(api: OrderApi)(userId: UserId, orderId: OrderId): IO[OrderDetails] =
  for {
    optUser  <- api.getUser(userId)
    optOrder <- api.getOrder(orderId)
    user     <- optUser match {
      case None    => IO.fail(new Exception(s"User not found $userId"))
      case Some(x) => IO.succeed(x)
    }
    order    <- optOrder match {
      case None    => IO.fail(new Exception(s"Order not found $orderId"))
      case Some(x) => IO.succeed(x)
    }
  } yield ???
```

Option with IO

```
trait OrderApi {
  def getUser(userId: UserId): IO[Option[User]]
  def getOrder(orderId: OrderId): IO[Option[Order]]
}

def fromOption[A](opt: Option[A])(error: => Throwable): IO[A] =
  opt match {
    case None    => IO.fail(error)
    case Some(x) => IO.succeed(x)
  }

def getOrderDetails(api: OrderApi)(userId: UserId, orderId: OrderId): IO[OrderDetails] =
  for {
    user  <- api.getUser(userId).flatMap(fromOption(_)(new Exception(s"User not found $userId")))
    order <- api.getOrder(orderId).flatMap(fromOption(_)(new Exception(s"Order not found $orderId")))
  } yield ???
```

Option with IO

```
sealed trait ApplicationError extends Exception
case class UserNotFound(userId: UserId) extends ApplicationError
case class OrderNotFound(orderId: OrderId) extends ApplicationError

trait OrderApi {
  def getUser(userId: UserId): IO[Option[User]]
  def getOrder(orderId: OrderId): IO[Option[Order]]
}

def getOrderDetails(api: OrderApi)(userId: UserId, orderId: OrderId): IO[OrderDetails] =
  for {
    user  <- api.getUser(userId).flatMap(fromOption(_)(UserNotFound(userId)))
    order <- api.getOrder(orderId).flatMap(fromOption(_)(OrderNotFound(orderId)))
  } yield ???
```

Option with IO

```
sealed trait ApplicationError extends Exception
case class UserNotFound(userId: UserId) extends ApplicationError
case class OrderNotFound(orderId: OrderId) extends ApplicationError

trait OrderApi {
  def getUserOpt(userId: UserId): IO[Option[User]]
  def getOrderOpt(orderId: OrderId): IO[Option[Order]]

  def getUser(userId: UserId): IO[User]     = getUserOpt(userId).flatMap(fromOption(_)(UserNotFound(userId)))
  def getOrder(orderId: OrderId): IO[Order] = getOrderOpt(orderId).flatMap(fromOption(_)(OrderNotFound(orderId)))
}

def getOrderDetails(api: OrderApi)(userId: UserId, orderId: OrderId): IO[OrderDetails] =
  for {
    user  <- api.getUser(userId)
    order <- api.getOrder(orderId)
  } yield ???
```

OptionT

```
case class OptionT[+A](value: IO[Option[A]]) {
  def map[B](f: A => B): OptionT[B] =
    OptionT(value.map(_.map(f)))

  def flatMap[B](f: A => OptionT[B]): OptionT[B] =
    OptionT(value.flatMap {
      case None    => IO.succeed(None)
      case Some(a) => f(a).value
    })
}
```

OptionT

```
case class OptionT[+A](value: IO[Option[A]]) {
  def map[B](f: A => B): OptionT[B] =
    OptionT(value.map(_.map(f)))

  def flatMap[B](f: A => OptionT[B]): OptionT[B] =
    OptionT(value.flatMap {
      case None    => IO.succeed(None)
      case Some(a) => f(a).value
    })
}
```

```
trait DbApi {
  def getUser(userId: UserId): OptionT[User]
  def getOrder(orderId: OrderId): OptionT[Order]
}

def getOrderDetails(db: DbApi)(userId: UserId, orderId: OrderId): OptionT[OrderDetails] =
  for {
    user  <- db.getUser(userId)
    order <- db.getOrder(orderId)
  } yield ???
```

More general pattern

```
case class OptionT[F[+_], +A](value: F[Option[A]])

type IOOptionT[A]   = OptionT[IO, A]
type ListOptionT[A] = OptionT[List, A]
```

```
case class EitherT[F[+_], +E, +A](value: F[Either[E, A]])

type IOEitherT[E, A]   = EitherT[IO, E, A]
type ListEitherT[E, A] = EitherT[List, E, A]
```

Conclusion

- Option and Either are the two main types to encode failures
- Try is a helpful tool to catch Exception
- Error ADTs can be as granular as we want
- Option and Either can be used in conjunction with IO

Resources and further study

- Scala Best Practices I Wish Someone'd Told Me About

Module 4: Type