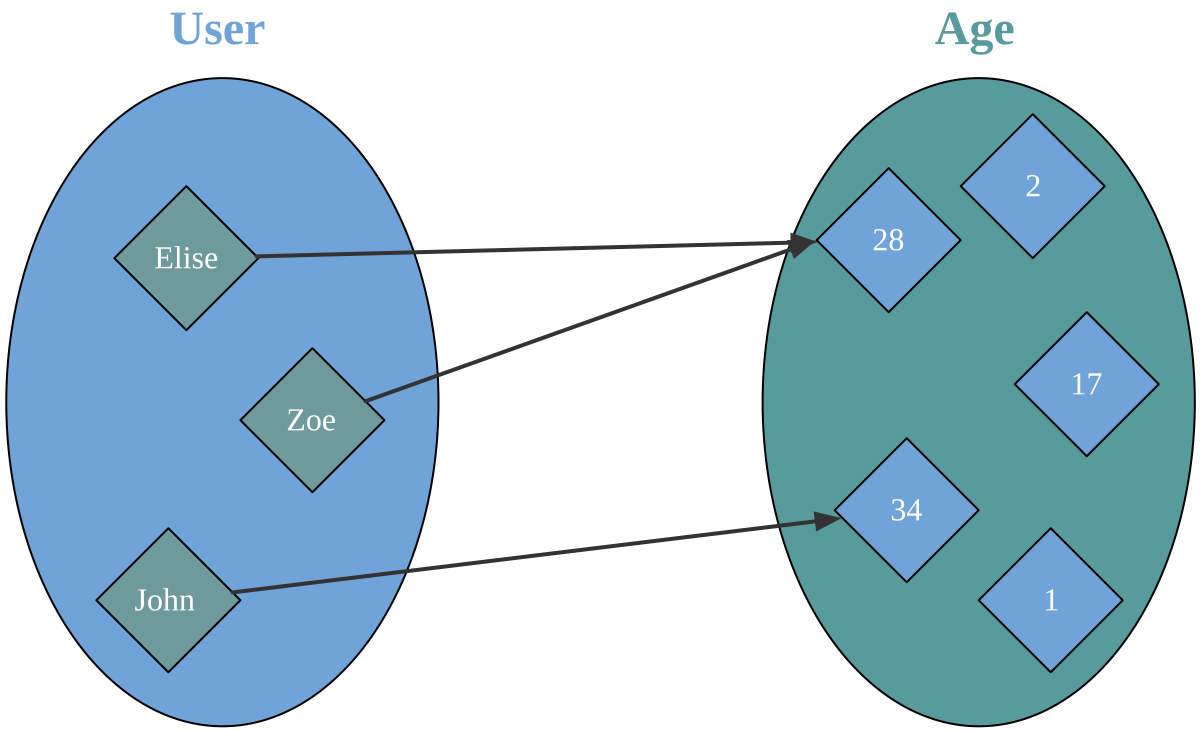
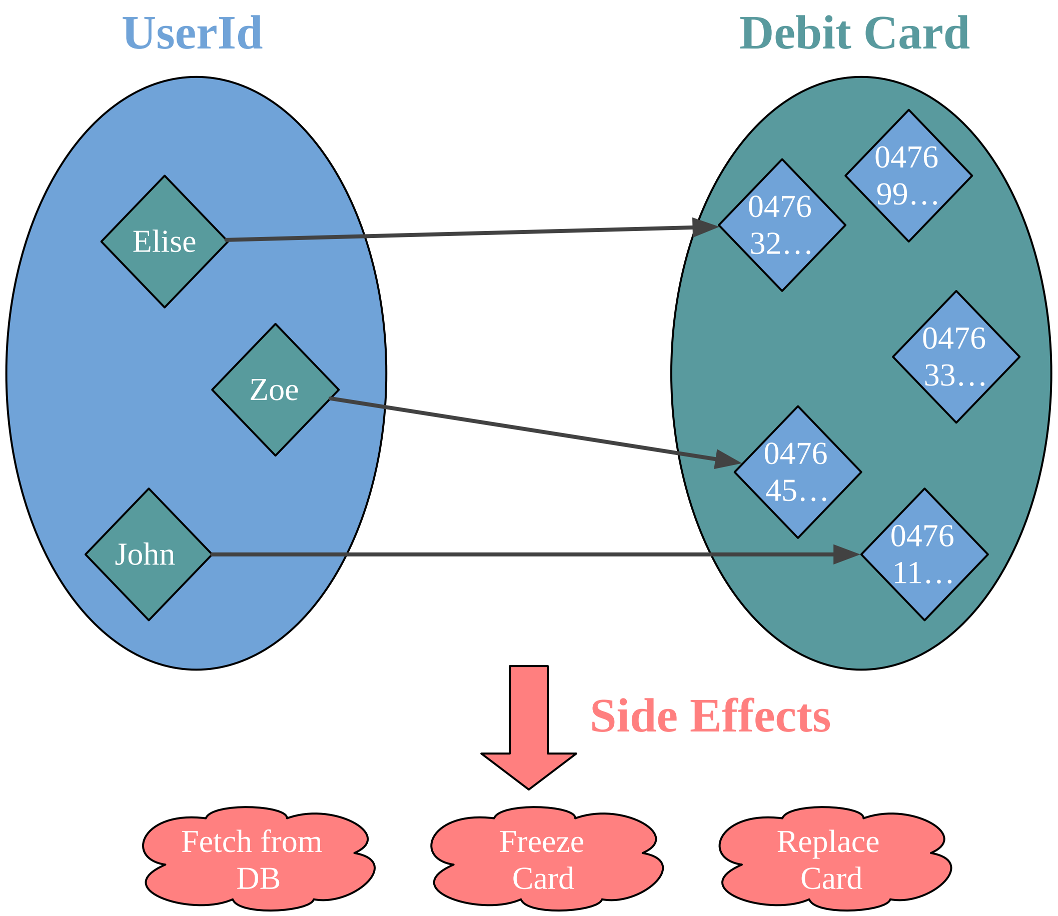
FOUNDATION

Side Effect

Pure function



Functions with side effects are not pure



Functional programming is useless *

Simon Peyton Jones co-author of haskell

A pure function cannot do anything

it can only produce a value

Create a value that describes actions

Create a value that describes actions

Interpret this value in Main

1. Encode description of actions

```
trait Description[A]
```

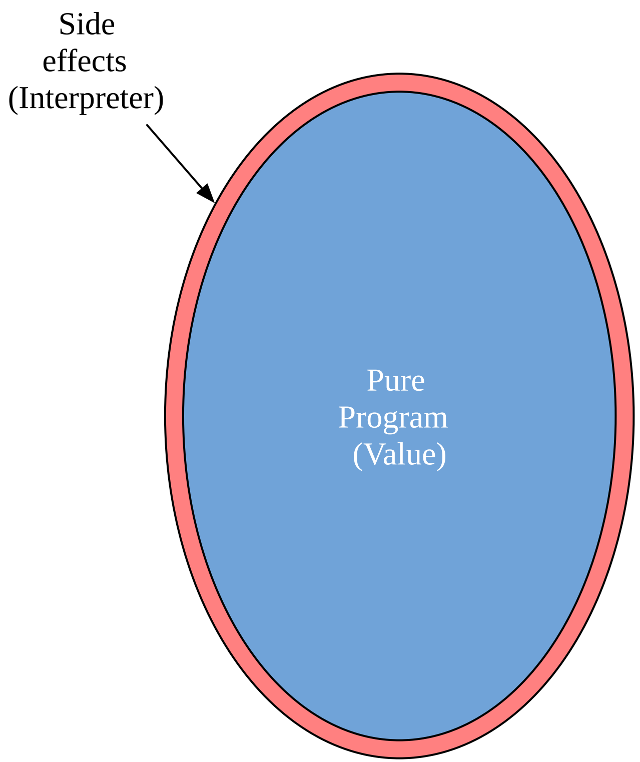
2. Define an interpreter of Description

```
def unsafeRun[A](fa: Description[A]): A = ???
```

3. Combine everything in Main

```
object Main extends App {
  val description: Description[Unit] = ???
  unsafeRun(description)
}
```

Run side effects at the edges



Examples of description / evaluation

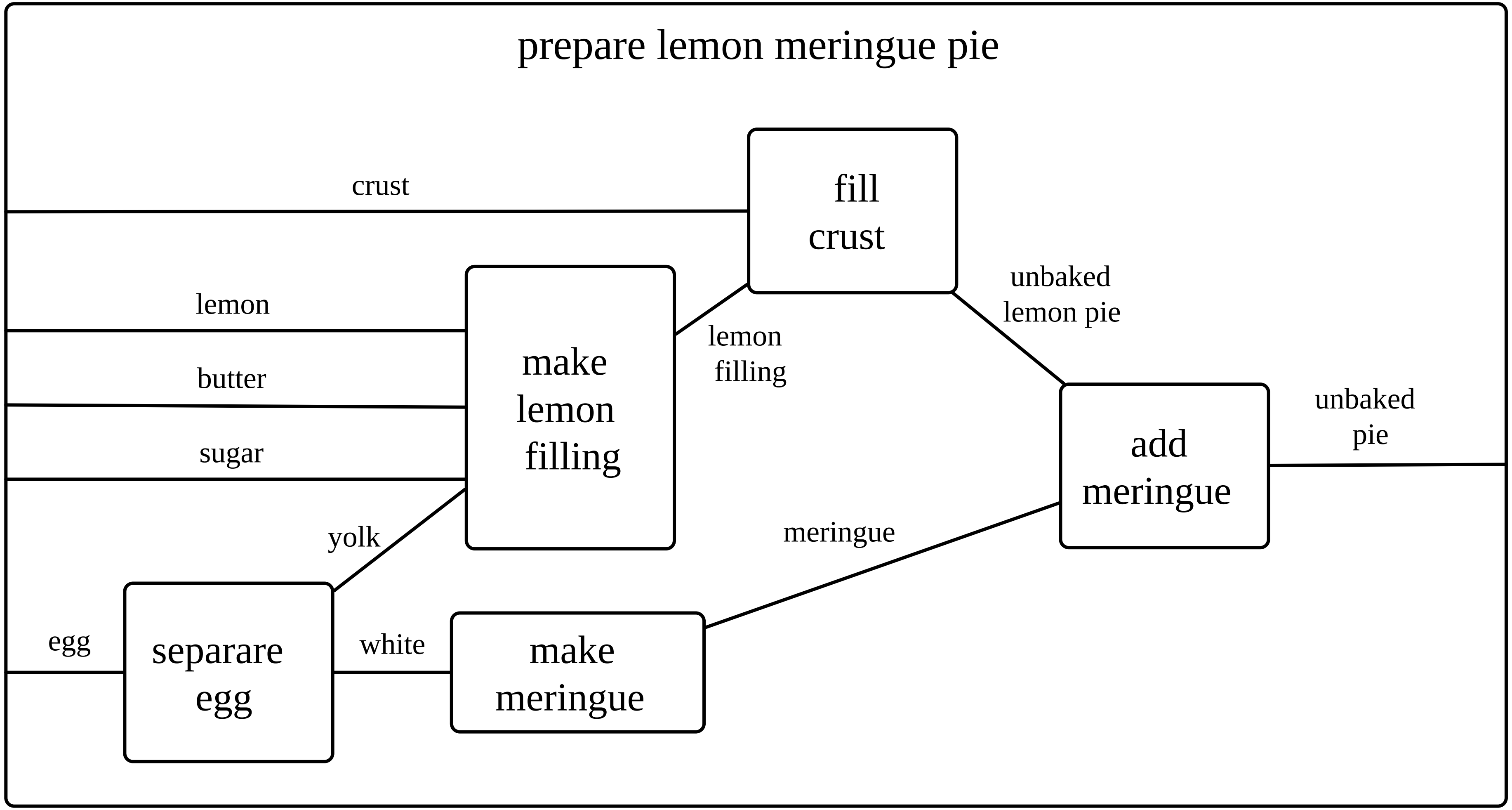
Cooking

1. Secret pasta recipe (Description)

1. Boil 200 ml of water
2. Add 250 g of dry pasta
3. Wait 11 minutes
4. Drain the pasta

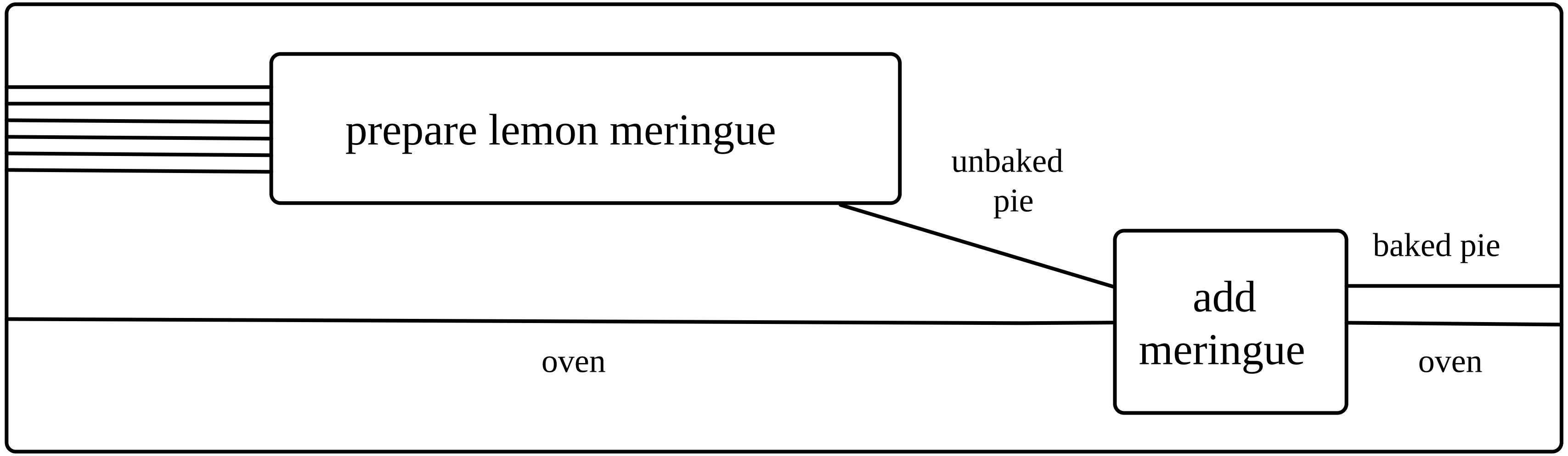
2. Cook (Unsafe evaluation)

Take the recipe and do it at home



[Seven Sketches in Compositionality: An Invitation to Applied Category Theory]

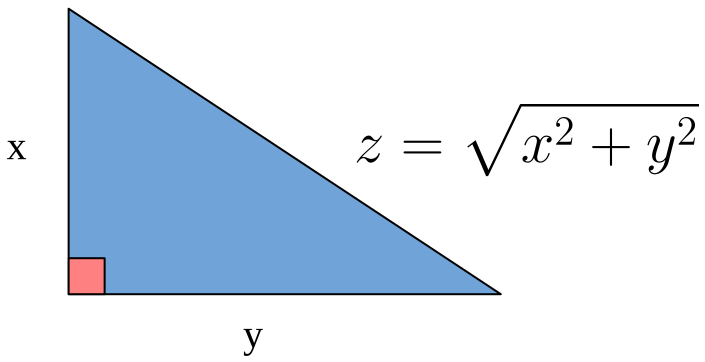
String diagrams compose



Seven Sketches in Compositionality: An Invitation to Applied Category Theory

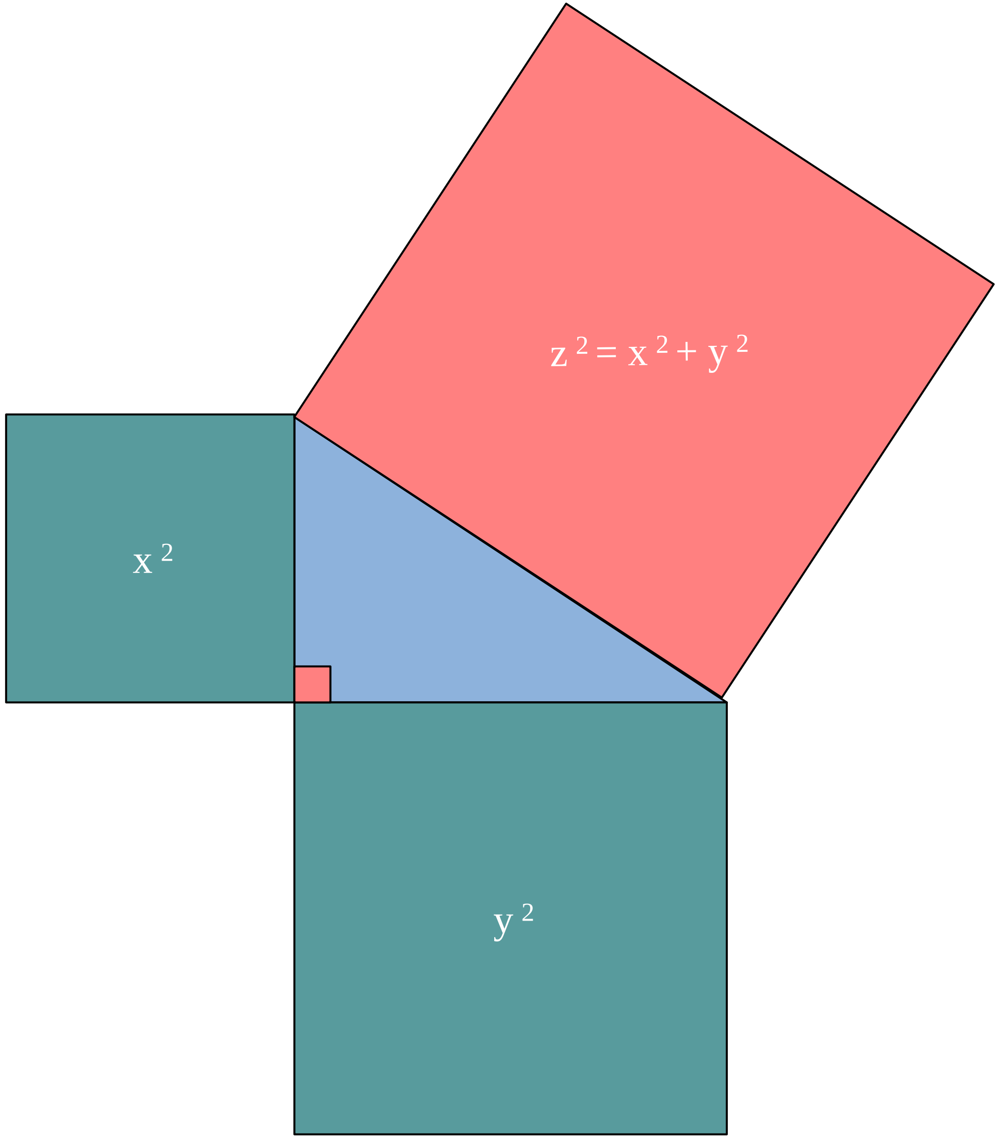
Mathematical formula

```
scala> val x = 2
x: Int = 2

scala> val y = 3
y: Int = 3

scala> val x2 = Math.pow(x, 2)
x2: Double = 4.0

scala> val y2 = Math.pow(y, 2)
y2: Double = 9.0

scala> val z  = Math.sqrt(x2 + y2)
z: Double = 3.605551275463989
```



Mathematical formula

```
scala> val x2 = Math.pow(x, 2)
x2: Double = 4.0

scala> val y2 = Math.pow(y, 2)
y2: Double = 9.0

scala> val z  = Math.sqrt(x2 + y2)
z: Double = 3.605551275463989

scala> Math.pow(z, 2)
res0: Double = 12.999999999999998

scala> x2 + y2
res1: Double = 13.0
```



[Constraints Liberate, Liberties Constrain]

How to encode description?

```scala
trait Description[A]

def unsafeRun[A](fa: Description[A]): A = ???
```

Thunk

```scala
type Thunk[A] = () => A  // Unit => A

def writeLine(message: String): Thunk[Unit] =
  () => println(message)

val today: Thunk[LocalDate] =
  () => LocalDate.now()

def fetch(url: String): Thunk[Iterator[String]] =
  () => scala.io.Source.fromURL(url)("ISO-8859-1").getLines
```

Thunk

```scala
type Thunk[A] = () => A  // Unit => A

def writeLine(message: String): Thunk[Unit] =
  () => println(message)

val today: Thunk[LocalDate] =
  () => LocalDate.now()

def fetch(url: String): Thunk[Iterator[String]] =
  () => scala.io.Source.fromURL(url)("ISO-8859-1").getLines
```

```scala
def unsafeRun[A](fa: Thunk[A]): A = fa()
```

Thunk

```scala
type Thunk[A] = () => A  // Unit => A

def writeLine(message: String): Thunk[Unit] =
  () => println(message)

val today: Thunk[LocalDate] =
  () => LocalDate.now()

def fetch(url: String): Thunk[Iterator[String]] =
  () => scala.io.Source.fromURL(url)("ISO-8859-1").getLines
```

```scala
def unsafeRun[A](fa: Thunk[A]): A = fa()
```

```scala
scala> val google = fetch("http://google.com")
google: Thunk[Iterator[String]] = $$Lambda$4438/0x0000000101817c40@764f44ce

scala> unsafeRun(google).take(1).toList
res2: List[String] = List(<!doctype html><html itemscope="" itemtype="http://schema.org/WebPage" lang="en"><head><me
```

IO

```scala
trait IO[A] {

  def unsafeRun(): A // unique abstract method

  def map[B](f: A => B): IO[B] = ???
  def flatMap[B](f: A => IO[B]): IO[B] = ???
  def retry: IO[A] = ???
}
```

IO

```scala
trait IO[A] {

  def unsafeRun(): A // unique abstract method

  def map[B](f: A => B): IO[B] = ???
  def flatMap[B](f: A => IO[B]): IO[B] = ???
  def retry: IO[A] = ???
}
```

```scala
def writeLine(message: String): IO[Unit] =
  new IO[Unit] {
    def unsafeRun(): Unit = println(message)
  }
```

```scala
scala> val helloWorld = writeLine("Hello World")
helloWorld: IO[Unit] = $anon$1@4b88d15b

scala> helloWorld.unsafeRun()
Hello World
```

Implement our own IO

Smart constructors

```scala
object IO {

  def succeed[A](constant: A): IO[A] = ???

  def effect[A](block: => A): IO[A] = ???

  def fail[A](error: Throwable): IO[A] = ???

}

trait IO[A] {
  def unsafeRun(): A
}
```

IO Exercises

`exercises.sideeffect.IOExercises.scala`

IO Summary

- An `IO` is a thunk of potentially impure code
- Composing `IO` is referentially transparent, nothing get executed
- It is easier to test `IO` if they are defined in a interface

IO Execution

IO execution

```scala
case class UserId (value: String)
case class OrderId(value: String)

case class User(userId: UserId, name: String, orderIds: List[OrderId])
```

```scala
def getUser(userId: UserId): IO[User] =
  IO.effect{
    val response = httpClient.get(s"http://foo.com/user/${userId.value}")
    if(response.status == 200) parseJson[User](response.body)
    else throw new Exception(s"Invalid status ${response.status}")
  }

def deleteOrder(orderId: OrderId): IO[Unit] =
  IO.effect{
    val response = httpClient.delete(s"http://foo.com/order/${orderId.value}")
    if(response.status == 200) () else throw new Exception(s"Invalid status ${response.status}")
  }
```

How is it executed?

```
def deleteAllUserOrders(userId: UserId): IO[Unit] =
  for {
    user <- getUser(userId)
    _    <- traverse(user.orderIds)(deleteOrder)
  } yield ()

object Main extends App {

  deleteAllUserOrders(UserId("1234")).unsafeRun()

}
```

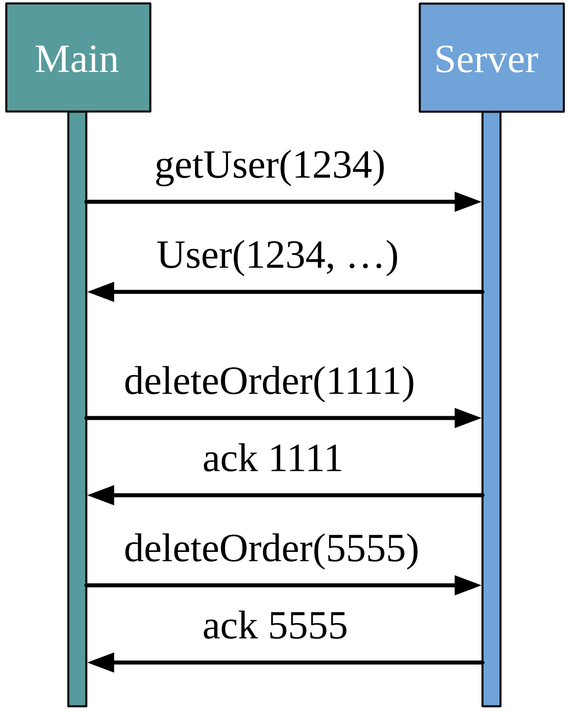
Discuss with your neighbour 3-4 min

How is it executed?

```
def deleteAllUserOrders(userId: UserId): IO[Unit] =
  for {
    user <- getUser(userId)
    // User("1234", "Rob", List("1111", "5555"))
    _    <- deleteOrder(user.orderIds(0)) // 1111
    _    <- deleteOrder(user.orderIds(1)) // 5555
  } yield ()

object Main extends App {

  deleteAllUserOrders(UserId("1234")).unsafeRun()

}
```

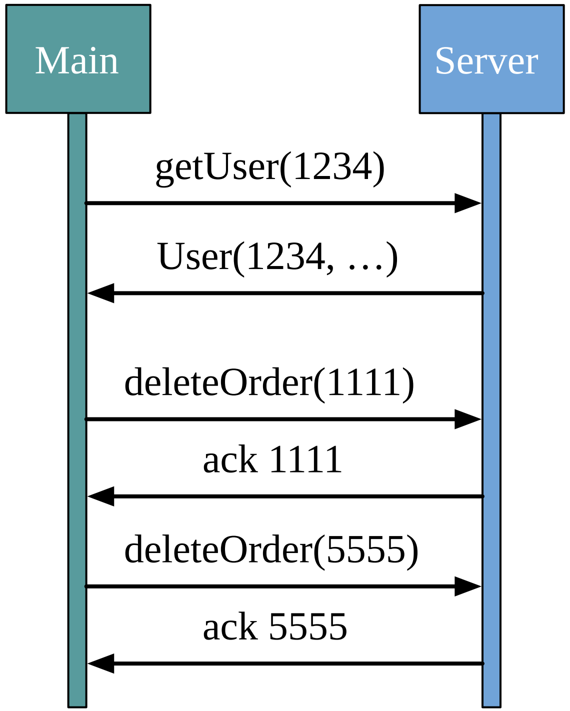
IO execution is sequential

```scala
def deleteAllUserOrders(userId: UserId): IO[Unit] =
  for {
    user <- getUser(userId)
    // User("1234", "Rob", List("1111", "5555"))
    _    <- deleteOrder(user.orderIds(0)) // 1111
    _    <- deleteOrder(user.orderIds(1)) // 5555
  } yield ()

object Main extends App {

  deleteAllUserOrders(UserId("1234")).unsafeRun()

}
```



Which IO could be evaluated concurrently?

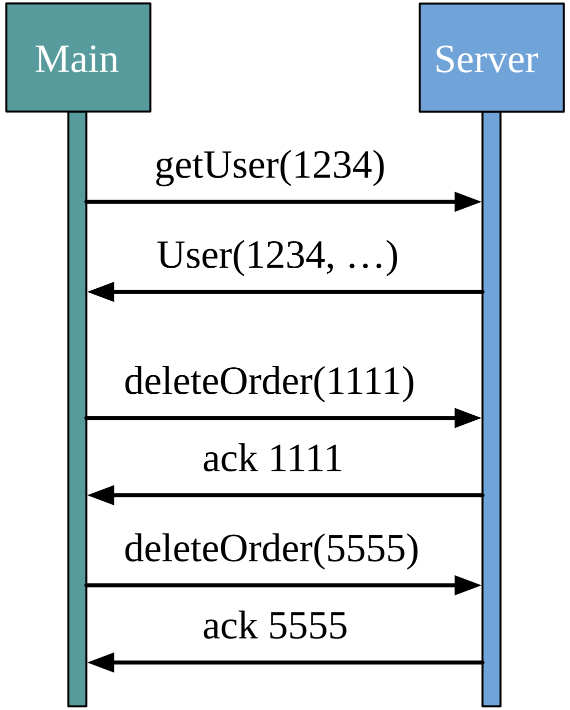
```scala
def deleteAllUserOrders(userId: UserId): IO[Unit] =
  for {
    user <- getUser(userId)
    // User("1234", "Rob", List("1111", "5555"))
    _    <- deleteOrder(user.orderIds(0)) // 1111
    _    <- deleteOrder(user.orderIds(1)) // 5555
  } yield ()

object Main extends App {

  deleteAllUserOrders(UserId("1234")).unsafeRun()

}
```



Discuss with your neighbour 3-4 min

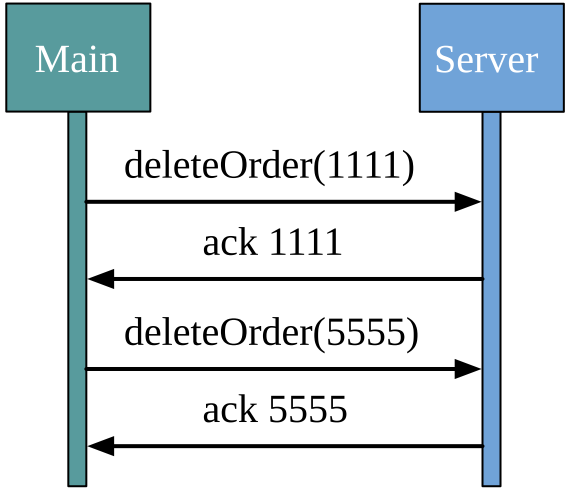
For comprehension cannot be done concurrently

```scala
def deleteAllUserOrders(userId: UserId): IO[Unit] =
  for {
    user <- getUser(userId)
    // User("1234", "Rob", List("1111", "5555"))
    _    <- deleteOrder(user.orderIds(0)) // 1111
    _    <- deleteOrder(user.orderIds(1)) // 5555
  } yield ()
```



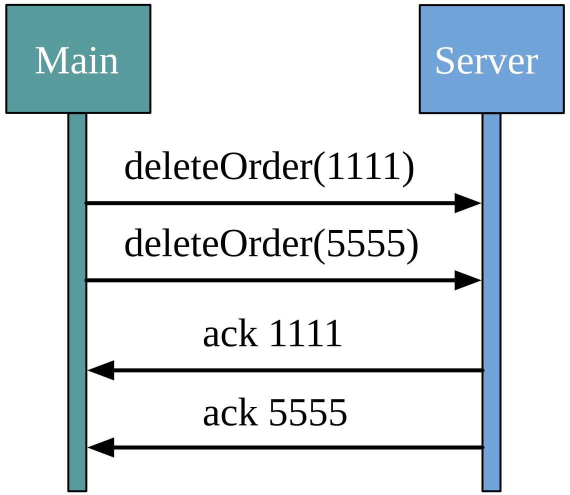
For comprehension cannot be done concurrently

```
def delete2Orders(orderId1: OrderId, orderId2: OrderId): IO[Unit] =
  for {
    ackOrder1 <- deleteOrder(orderId1)
    ackOrder2 <- deleteOrder(orderId2)
  } yield ()
```



Concurrent execution

```scala
def concurrentExec(io1: IO[Unit], io2: IO[Unit]): IO[Unit] = ???


def delete2Orders(orderId1: OrderId, orderId2: OrderId): IO[Unit] =
  concurrentExec(deleteOrder(orderId1), deleteOrder(orderId2))
```

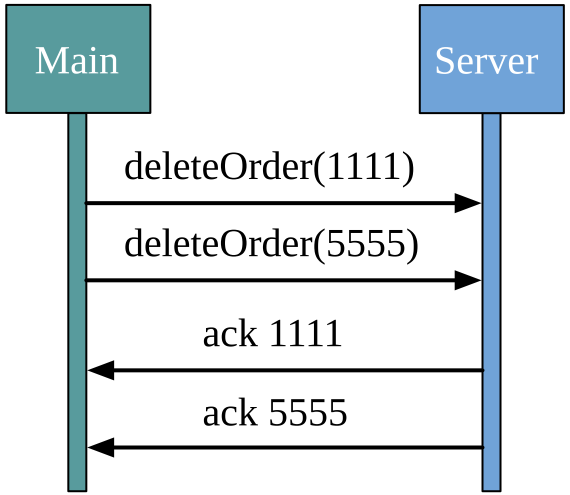


concurrentExec is loosely defined

```scala
def concurrentExec(io1: IO[Unit], io2: IO[Unit]): IO[Unit] =
  io1

def concurrentExec(io1: IO[Unit], io2: IO[Unit]): IO[Unit] =
  io2

def concurrentExec(io1: IO[Unit], io2: IO[Unit]): IO[Unit] =
  for {
    _ <- io1
    _ <- io2
  } yield ()

def concurrentExec(io1: IO[Unit], io2: IO[Unit]): IO[Unit] =
  IO.succeed(())
```

Parametricity

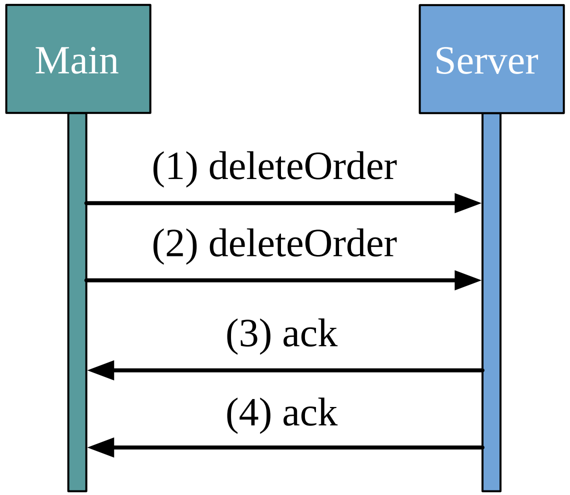
```
def concurrentMap2[A, B, C](fa: IO[A], fb: IO[B])
                           (f: (A, B) => C): IO[C] = ???

def delete2Orders(orderId1: OrderId, orderId2: OrderId): IO[Unit] =
  concurrentMap2(
    deleteOrder(orderId1),
    deleteOrder(orderId2)
  )((_,_) => ())
```



How concurrency is done with Future?

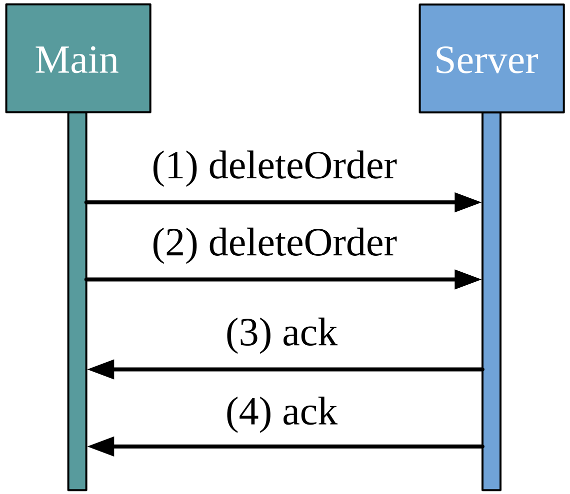
Future

```scala
import scala.concurrent.{ExecutionContext, Future}

def deleteOrder(orderId: OrderId)
  (implicit ec: ExecutionContext): Future[Unit] =
  Future { ??? }

def delete2Orders(
  orderId1: OrderId,
  orderId2: OrderId
)(implicit ec: ExecutionContext): Future[Unit] = {

  val delete1: Future[Unit] = deleteOrder(orderId1) // (1) side effect
  val delete2: Future[Unit] = deleteOrder(orderId2) // (2) side effect

  for {
    _ /* (3) */ <- delete1
    _ /* (4) */ <- delete2
  } yield ()
}
```

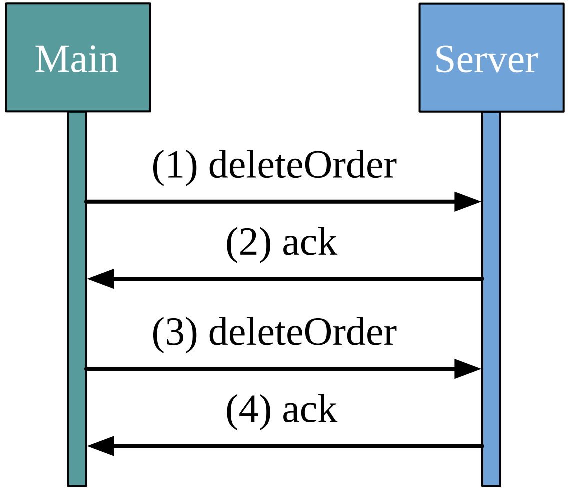


Creating a Future is a side effect

```scala
def deleteOrdersConcurrent(orderId1: OrderId,orderId2: OrderId)
  (implicit ec: ExecutionContext): Future[Unit] = {

  val delete1 = deleteOrder(orderId1) // (1)
  val delete2 = deleteOrder(orderId2) // (2)

  for {
    _ /* (3) */ <- delete1
    _ /* (4) */ <- delete2
  } yield ()
}
```



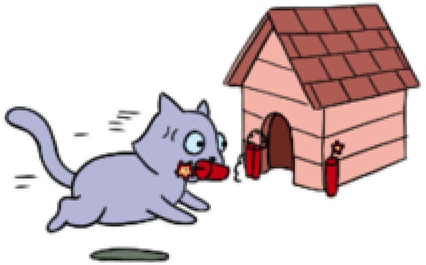

```scala
def deleteOrdersSequential(orderId1: OrderId,orderId2: OrderId)
  (implicit ec: ExecutionContext): Future[Unit] =
  for {
    _ /* (2) */ <- deleteOrder(orderId1) // (1)
    _ /* (4) */ <- deleteOrder(orderId2) // (3)
  } yield ()
```



@impurepics

FUTURE

1. CREATE YOUR FUTURES

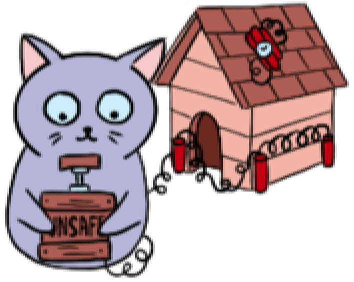


2. WIRE THEM TOGETHER

3. OOPS! SEEMS LIKE WE FORGOT SMTH

IO

1. CREATE YOUR IOS

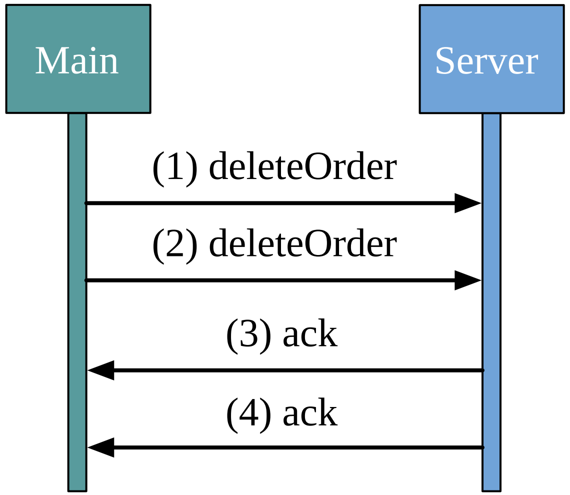


2. WIRE THEM TOGETHER

3. PROFIT!

Execution Context

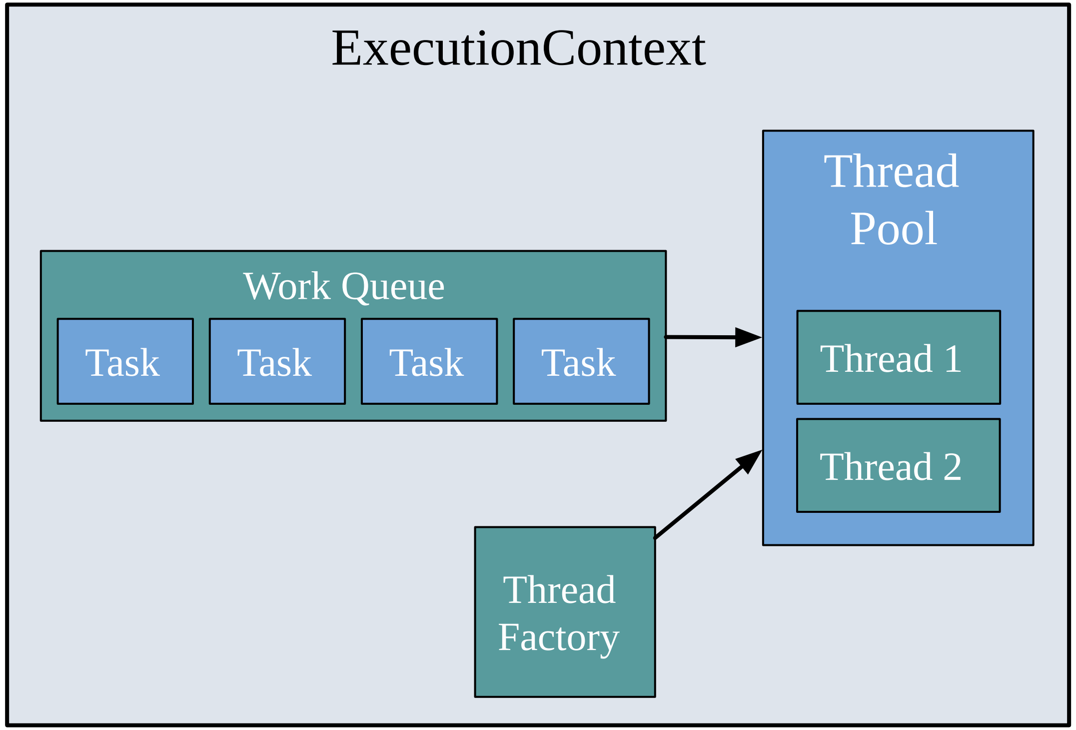
```scala
import scala.concurrent.{ExecutionContext, Future}

def deleteOrder(orderId: OrderId)(ec: ExecutionContext): Future[Unit] =
  Future { ??? }(ec)

def delete2Orders(
  orderId1: OrderId,
  orderId2: OrderId
)(ec: ExecutionContext): Future[Unit] = {

  val delete1 = deleteOrder(orderId1)(ec) // (1) side effect
  val delete2 = deleteOrder(orderId2)(ec) // (2) side effect

  delete1.flatMap(_ =>        // (3)
    delete2.map(_ => ())(ec) // (4)
  )(ec)
}
```



Execution Context

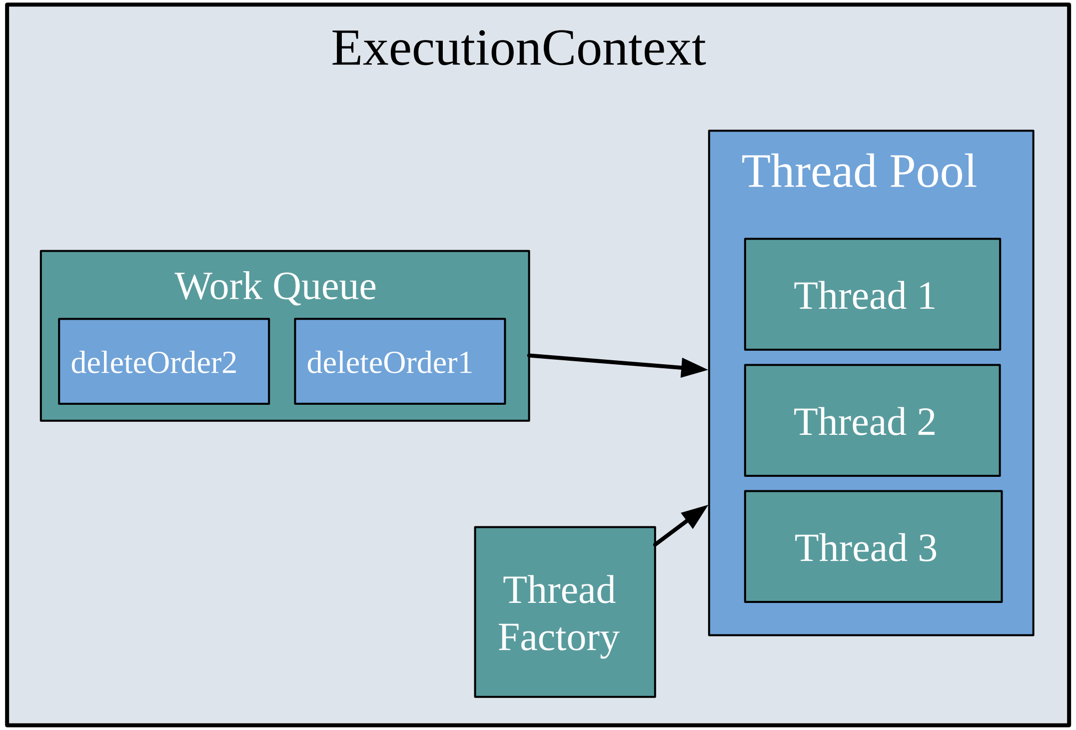
```scala
import java.util.concurrent.Executors
import scala.concurrent.ExecutionContext

val factory = threadFactory("test")
val pool = Executors.newFixedThreadPool(2, factory)
val ec = ExecutionContext.fromExecutorService(pool)

var x: Int = 0

val inc: Runnable = new Runnable {
  def run(): Unit = x += 1
}
```

```
scala> x
res4: Int = 0

scala> (1 to 10).foreach(_ => ec.execute(inc))

scala> x
res6: Int = 10
```



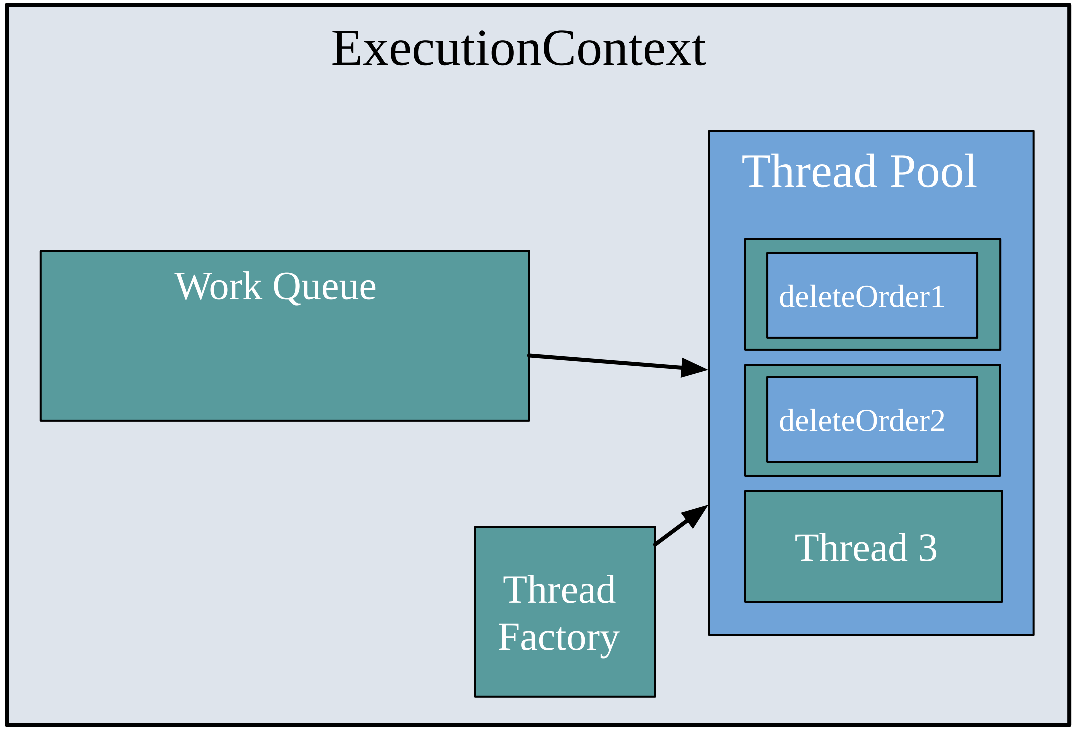
Execution Context

```scala
def delete2Orders(
  orderId1: OrderId,
  orderId2: OrderId
)(ec: ExecutionContext): Future[Unit] = {

  val delete1 = deleteOrder(orderId1)(ec) // (1)
  val delete2 = deleteOrder(orderId2)(ec) // (2)

  delete1.flatMap(_ =>         // (3)
    delete2.map(_ => ())(ec) // (4)
  )(ec)
}
```



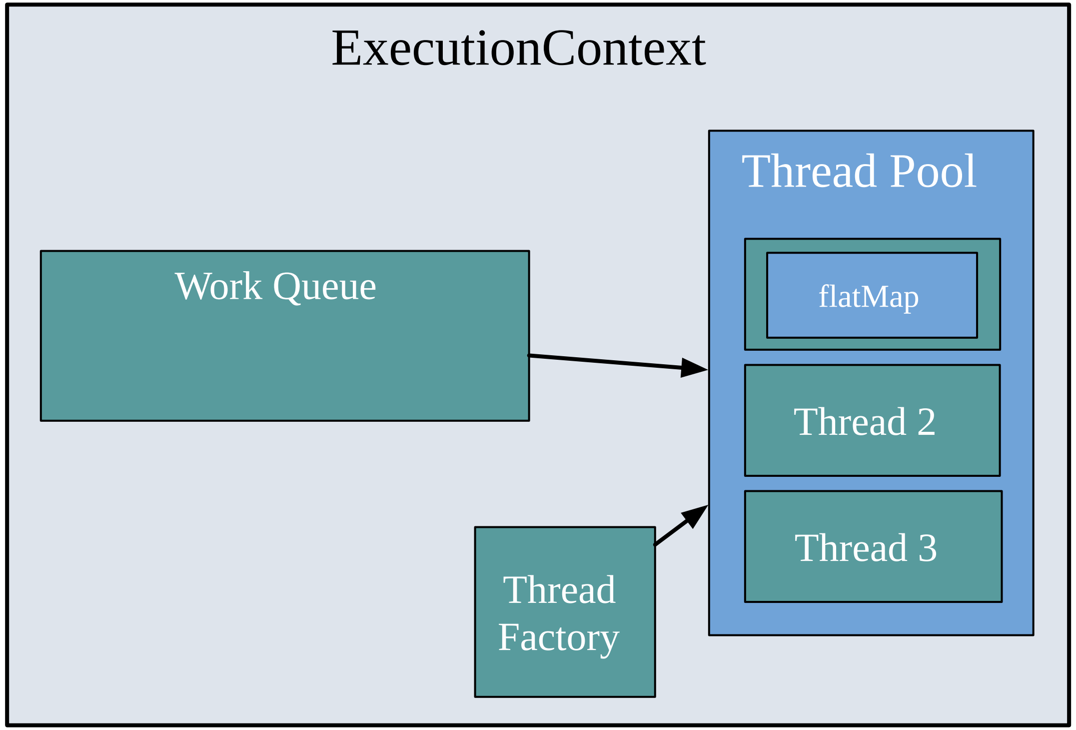
Execution Context

```scala
def delete2Orders(
  orderId1: OrderId,
  orderId2: OrderId
)(ec: ExecutionContext): Future[Unit] = {

  val delete1 = deleteOrder(orderId1)(ec) // (1)
  val delete2 = deleteOrder(orderId2)(ec) // (2)

  delete1.flatMap(_ =>        // (3)
    delete2.map(_ => ())(ec) // (4)
  )(ec)
}
```



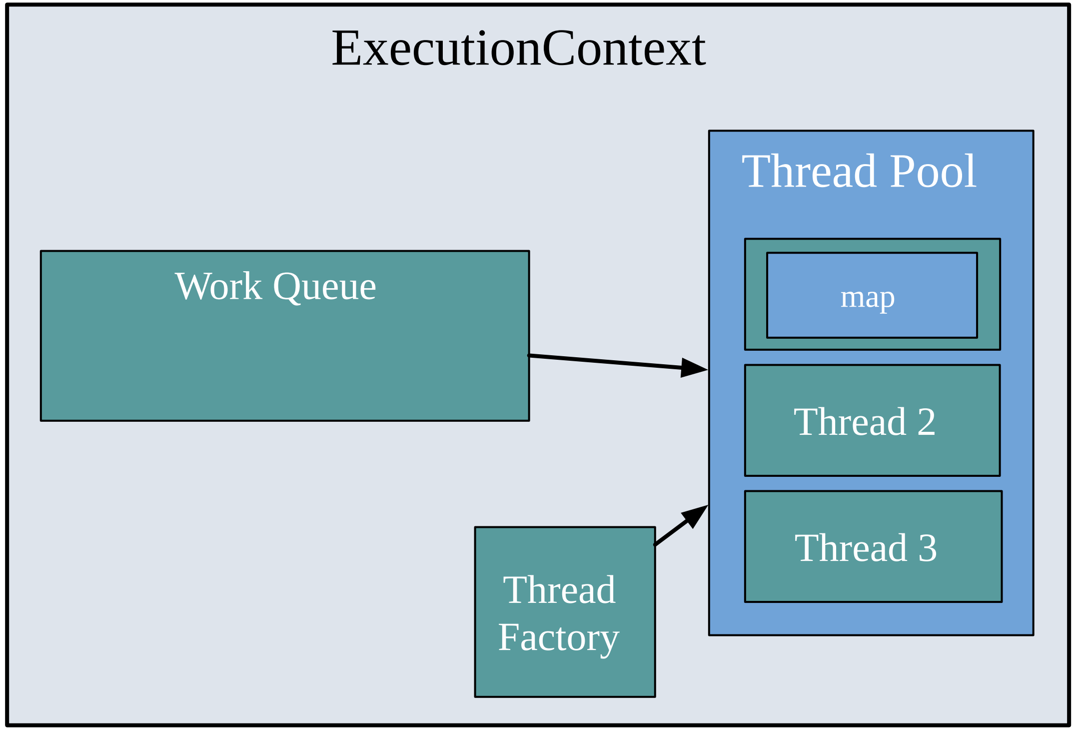
Execution Context

```
def delete2Orders(
  orderId1: OrderId,
  orderId2: OrderId
)(ec: ExecutionContext): Future[Unit] = {

  val delete1 = deleteOrder(orderId1)(ec) // (1)
  val delete2 = deleteOrder(orderId2)(ec) // (2)

  delete1.flatMap(_ =>        // (3)
    delete2.map(_ => ())(ec) // (4)
  )(ec)
}
```



Execution Context

```scala
def delete2Orders(
  orderId1: OrderId,
  orderId2: OrderId
)(ec: ExecutionContext): Future[Unit] = {

  val delete1 = deleteOrder(orderId1)(ec) // (1)
  val delete2 = deleteOrder(orderId2)(ec) // (2)

  delete1.flatMap(_ =>          // (3)
    delete2.map(_ => ())(ec) // (4)
  )(ec)
}
```



How can we adapt Future behaviour to pure IO?

Concurrent IO

```
trait IO[+A] {
  def start(ec: ExecutionContext): ???
}
```

Discuss with your neighbour 3-4 min

Concurrent IO

```
trait IO[+A] {
  def start(ec: ExecutionContext): IO[???]
}
```

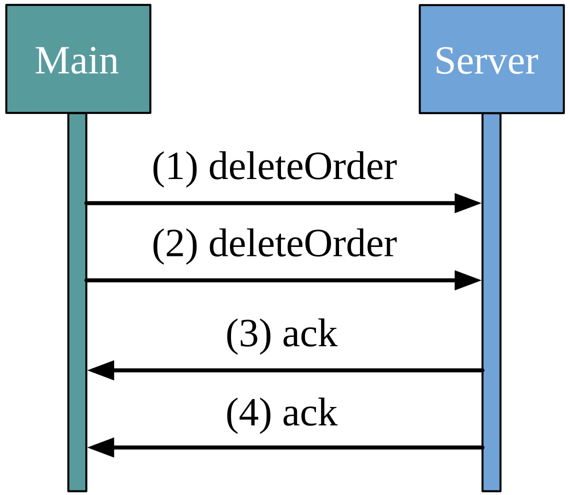
Concurrent IO

```scala
trait IO[+A] {
  def start(ec: ExecutionContext): IO[IO[A]]
}
```

Concurrent IO: concurrentMap2

```scala
trait IO[+A] {
  def start(ec: ExecutionContext): IO[IO[A]]
}
```

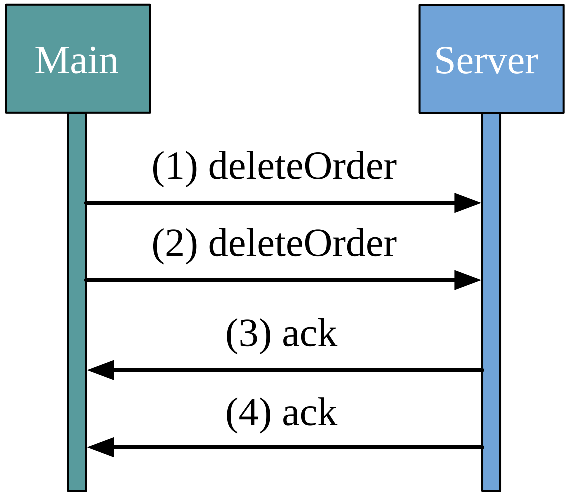
```scala
def concurrentMap2[A, B, C](
  fa: IO[A],
  fb: IO[B]
)(f: (A, B) => C)(ec: ExecutionContext): IO[C] = ???
```



Concurrent IO: concurrentMap2

```
trait IO[+A] {
  def start(ec: ExecutionContext): IO[IO[A]]
}
```

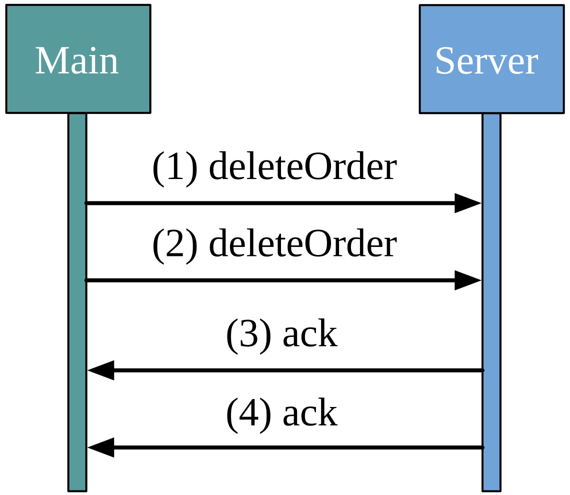
```
def concurrentMap2[A, B, C](
  fa: IO[A],
  fb: IO[B]
)(f: (A, B) => C)(ec: ExecutionContext): IO[C] =
  for {
    awaitForA <- fa.start(ec) // (1)
    awaitForB <- fb.start(ec) // (2)
    a         <- awaitForA    // (3)
    b         <- awaitForB    // (4)
  } yield f(a, b)
```



Concurrent IO is referentially transparent

```scala
trait IO[+A] {
  def start(ec: ExecutionContext): IO[IO[A]]
}
```

```scala
def concurrentMap2[A, B, C](
  fa: IO[A],
  fb: IO[B]
)(f: (A, B) => C)(ec: ExecutionContext): IO[C] = {

  val asyncIOA = fa.start(ec)
  val asyncIOB = fb.start(ec)

  for {
    awaitForA <- asyncIOA     // (1)
    awaitForB <- asyncIOB     // (2)
    a         <- awaitForA    // (3)
    b         <- awaitForB    // (4)
  } yield f(a, b)
}
```



Concurrent IO with Async

```scala
type Callback[-A] = Either[Throwable, A] => Unit

sealed trait IO[+A]

object IO {
  case class Thunk[+A](f: () => A) extends IO[A]

  case class Async[+A](f: Callback[A] => Unit, ec: ExecutionContext) extends IO[A]
}
```

Concurrent IO with Async

```
type Callback[-A] = Either[Throwable, A] => Unit

sealed trait IO[+A]

object IO {
  case class Thunk[+A](f: () => A) extends IO[A]

  case class Async[+A](f: Callback[A] => Unit, ec: ExecutionContext) extends IO[A]
}
```

An IO is either a Thunk or a Async computation with a CallBack

Concurrent IO with Async

```
type Callback[-A] = Either[Throwable, A] => Unit

sealed trait IO[+A]

object IO {
  case class Thunk[+A](f: () => A) extends IO[A]

  case class Async[+A](f: Callback[A] => Unit, ec: ExecutionContext) extends IO[A]
}
```

An IO is either a Thunk or a Async computation with a CallBack

More details in [How do Fibers work](#) from Fabio Labella

IO Async Exercises

`exercises.sideeffect.IOAsyncExercises.scala`

Libraries do much more

- Stack safety and JVM optimisation
- Cancellation, e.g. race two IO and cancel the loser
- Safe resource shutdown, e.g. close file, shutdown server
- Efficient Timer, retry utilities
- Help to chose right thread pool for different type of work: blocking, compute, dispatcher

Resources and further study

- Seven Sketches in Compositionality: An Invitation to Applied Category Theory
- Constraints Liberate, Liberties Constrain
- How do Fibers work

Module 3: Error Handling