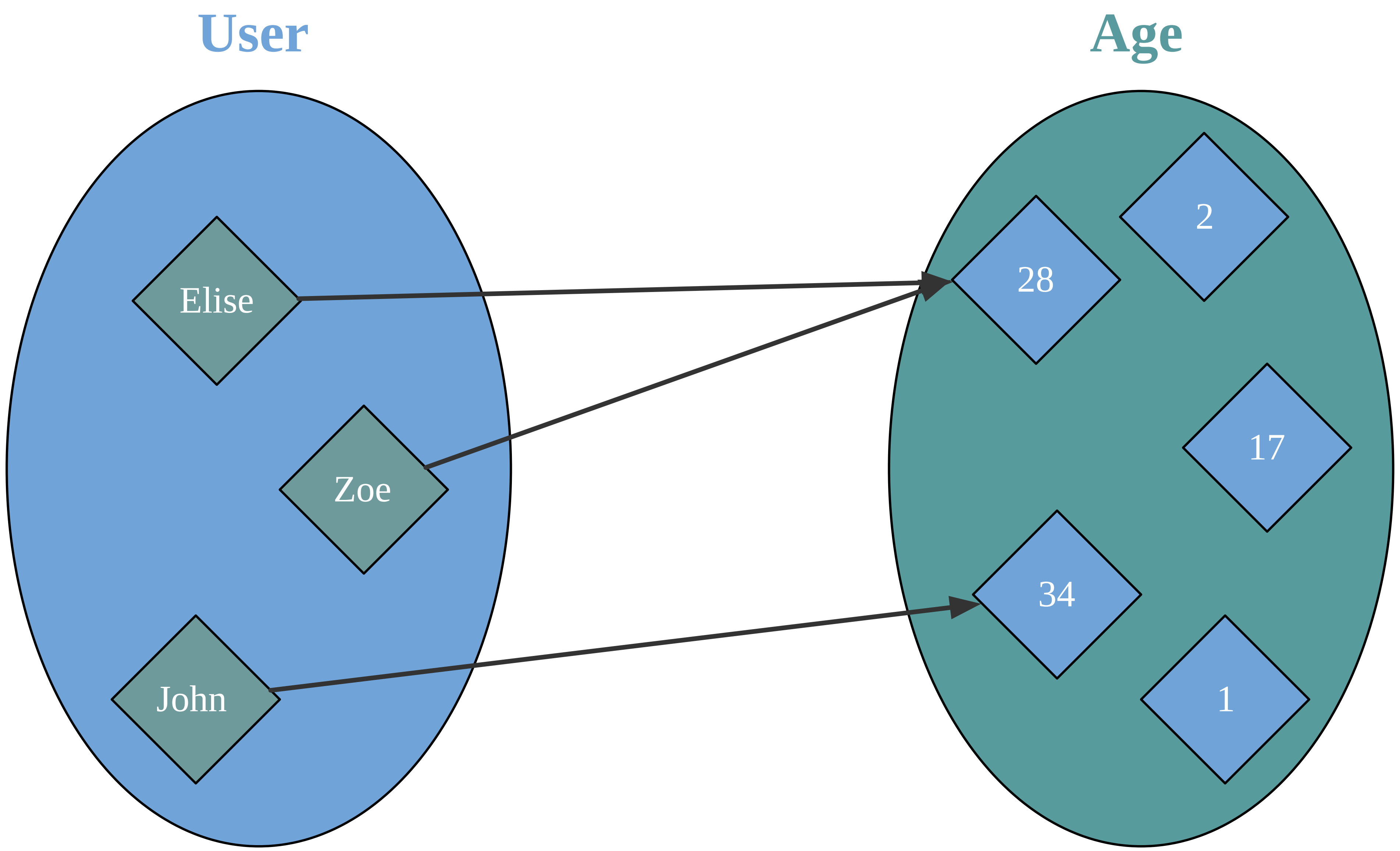
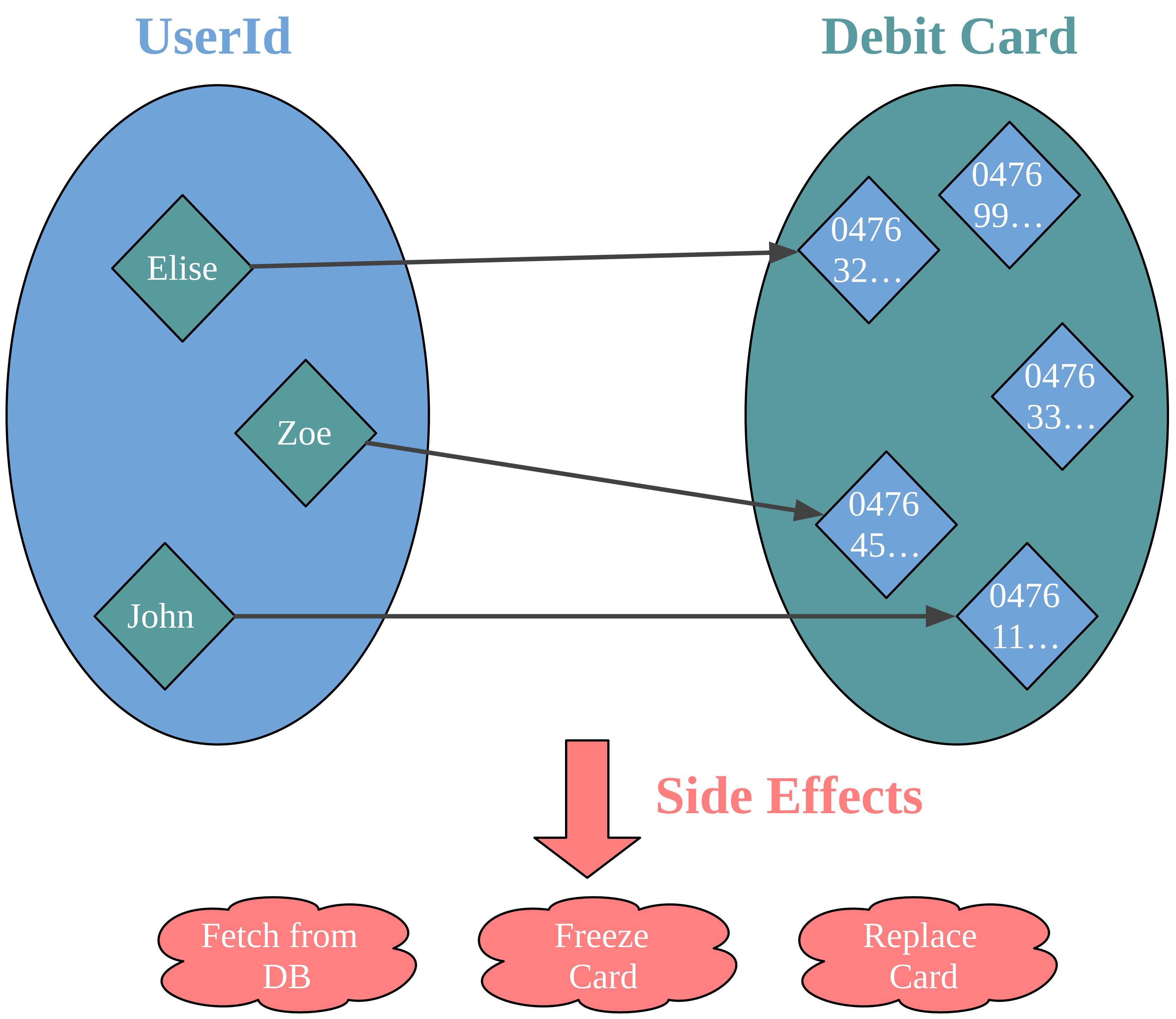
FOUNDATION

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

```scala
trait Description[A]
```

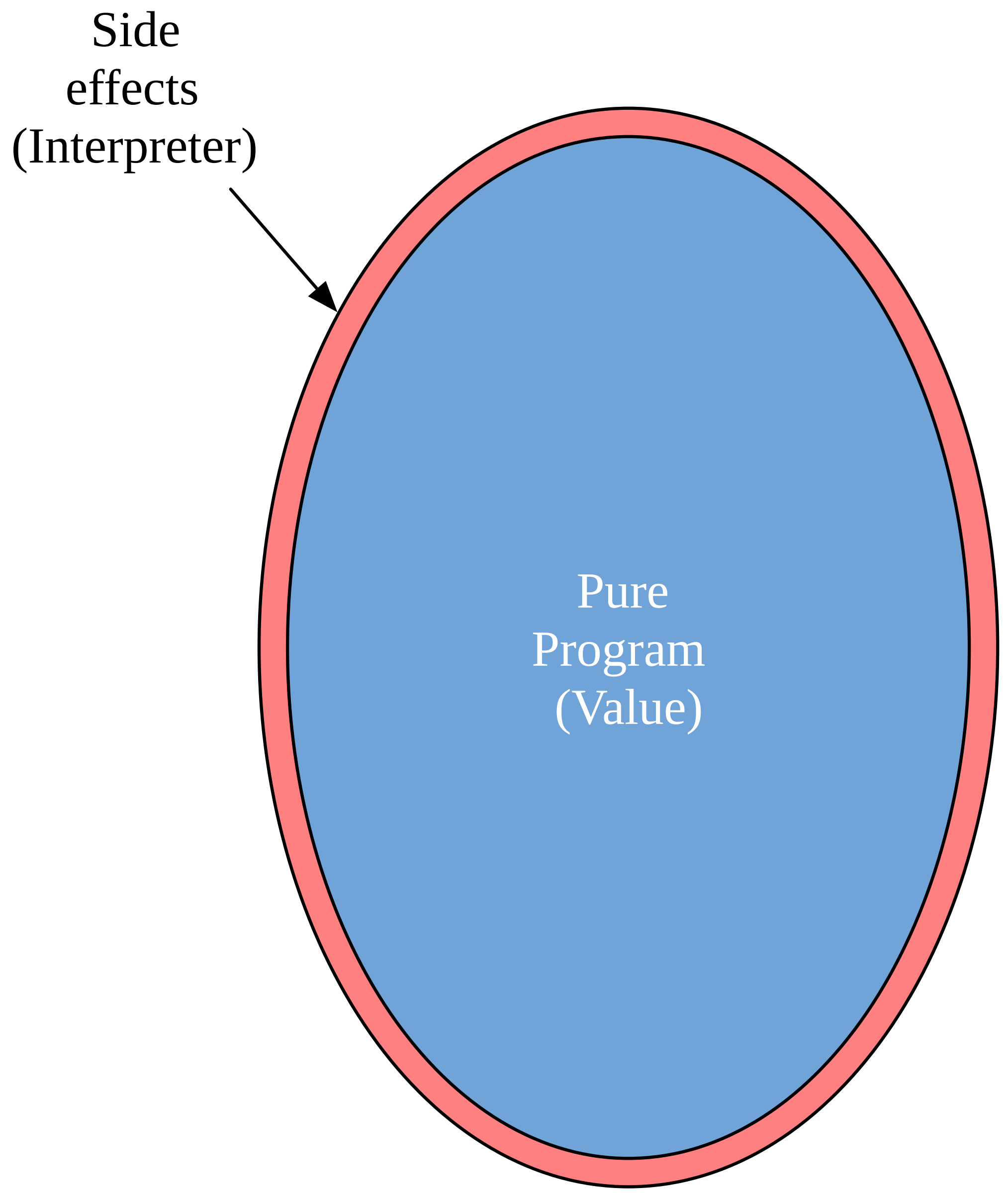
2. Define an interpreter of Description

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

3. Combine everything in Main

```scala
object Main extends App {

  val description: Description[Unit] = ???

  unsafeRun(description)

}
```

Run side effects at the edges



Examples of description / evaluation

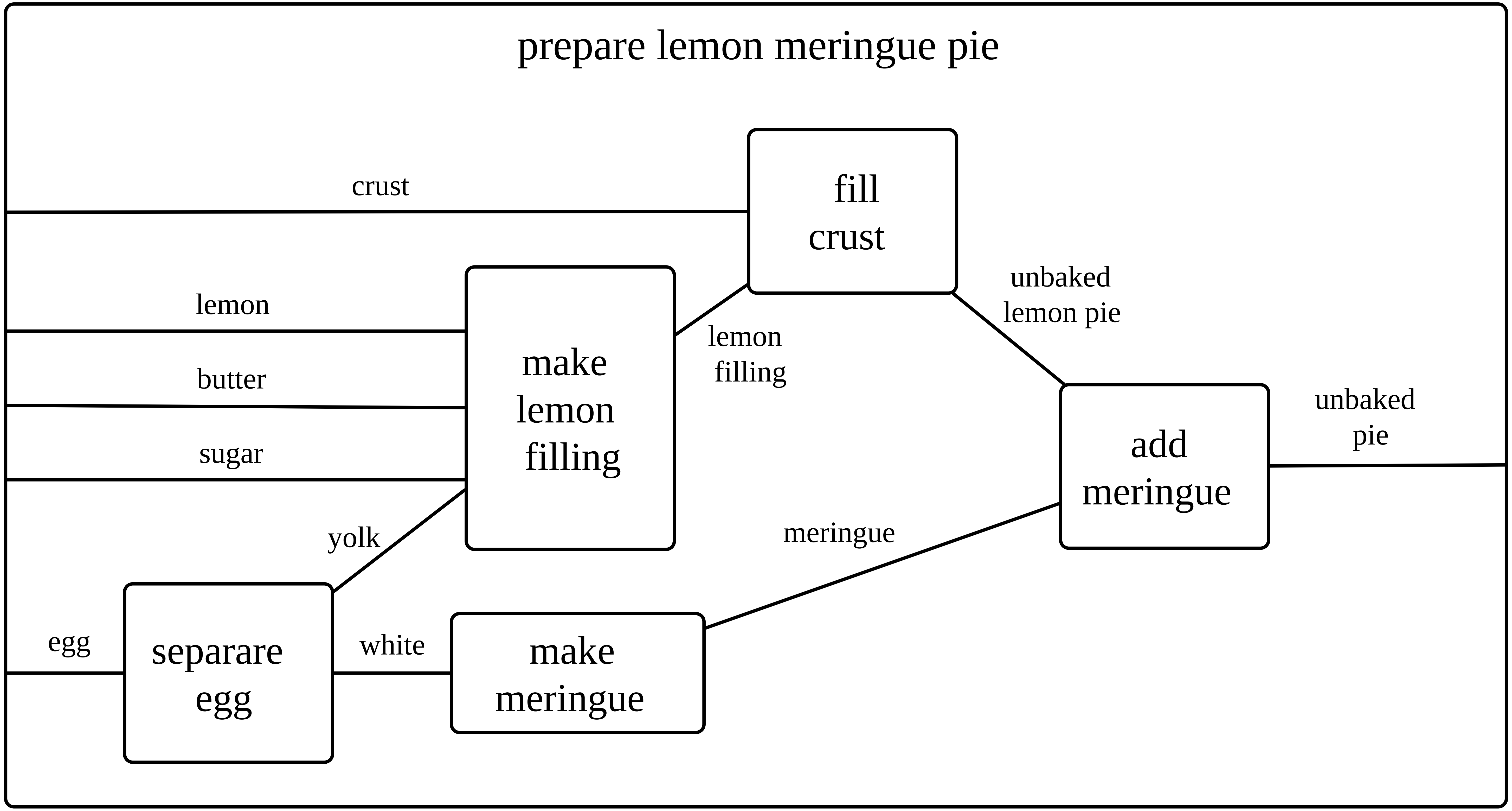
Cooking

1. Secret pasta recipe (Description)

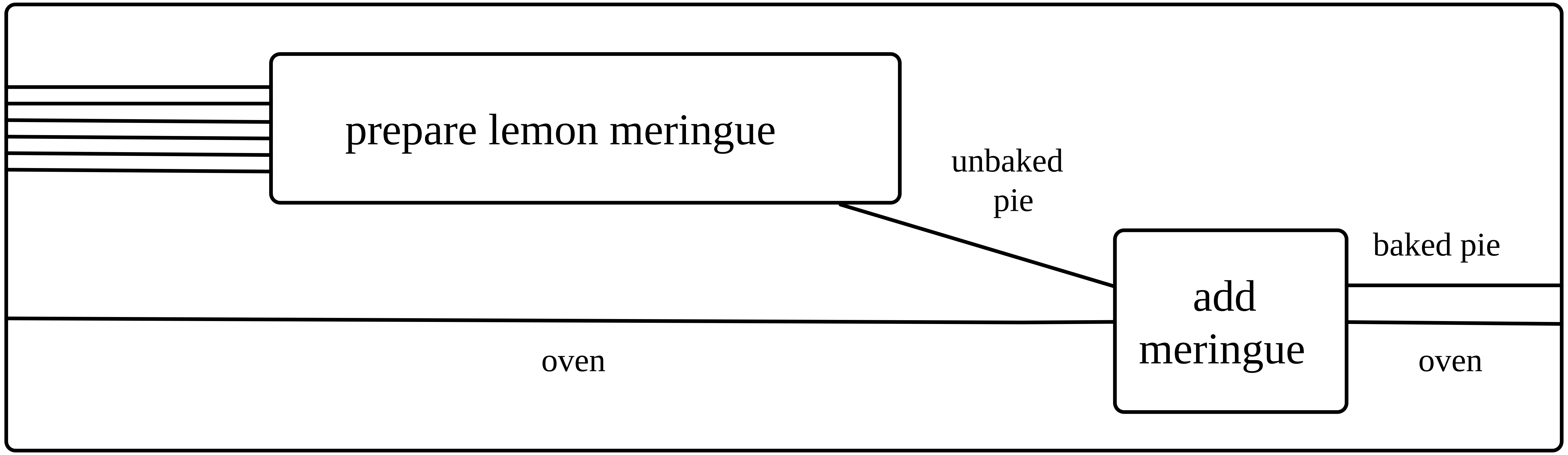
1. Boil 200 ml of water
2. Add 250 g of dry pasta
3. Wait 11 minutes
4. Drain the pasta

2. Cook (Unsafe evaluation)

Take the recipe and do it at home


prepare lemon meringue pie
crust
fill crust
lemon
butter
sugar
make lemon filling
lemon filling
unbaked lemon pie
add meringue
unbaked pie
yolk
meringue
egg
separare egg
white
make meringue

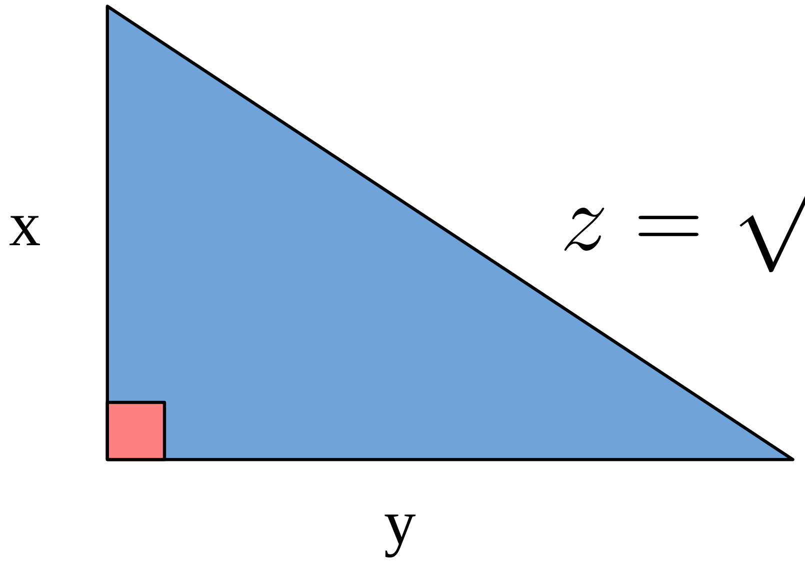
String diagrams compose



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

Mathematical formula

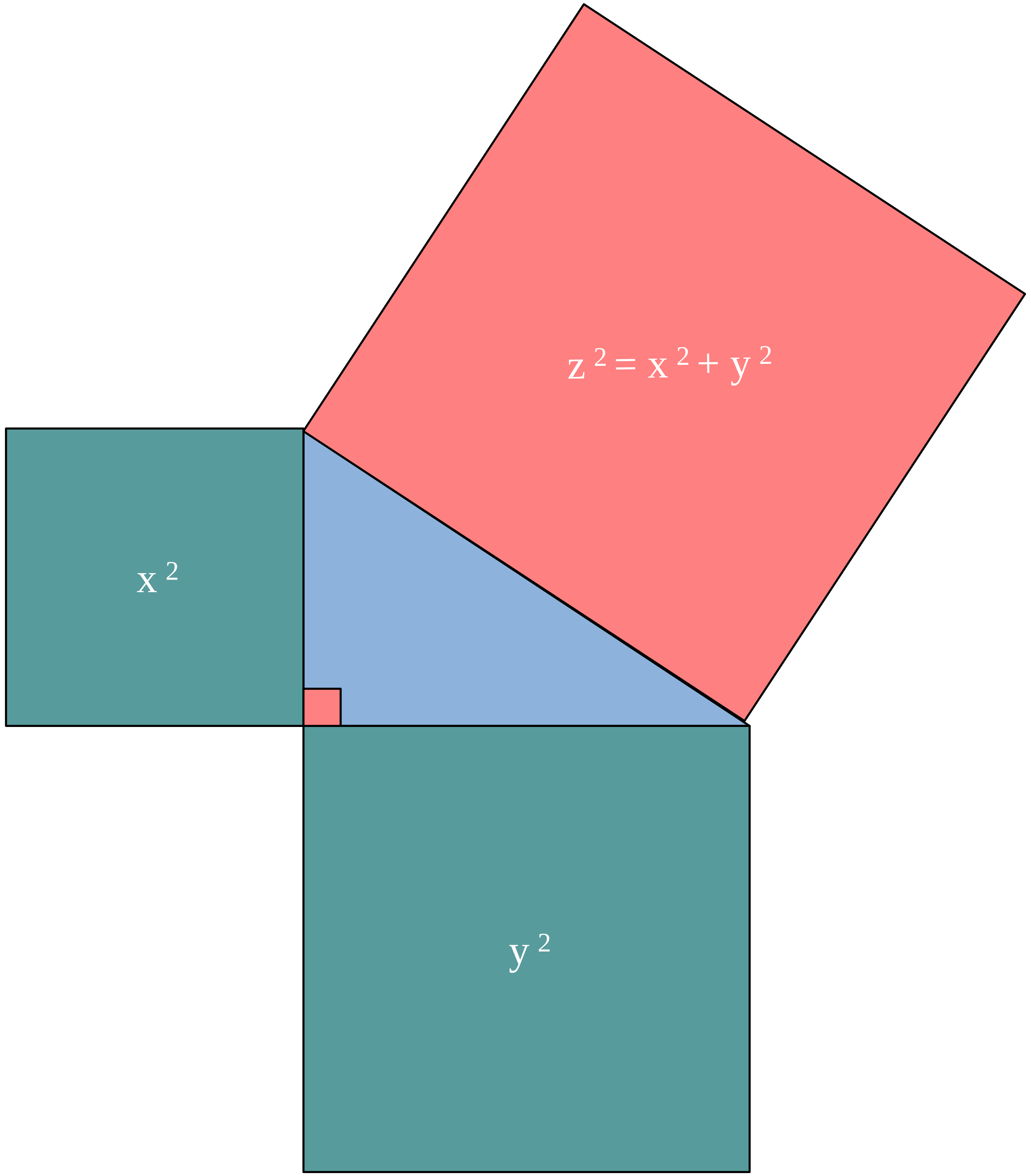
```scala
val x = 2
// x: Int = 2
val y = 3
// y: Int = 3
val x2 = Math.pow(x, 2)
// x2: Double = 4.0
val y2 = Math.pow(y, 2)
// y2: Double = 9.0
val z  = Math.sqrt(x2 + y2)
// z: Double = 3.605551275463989
```



$$z = \sqrt{x^2 + y^2}$$

Mathematical formula

```scala
val x2 = Math.pow(x, 2)
// x2: Double = 4.0
val y2 = Math.pow(y, 2)
// y2: Double = 9.0
val z  = Math.sqrt(x2 + y2)
// z: Double = 3.605551275463989

Math.pow(z, 2)
// res1: Double = 12.999999999999998
x2 + y2
// res2: Double = 13.0
```



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
val google = fetch("http://google.com")
// google: () => Iterator[String] = <function0>
unsafeRun(google).take(1).toList
// res3: List[String] = List(
//   "<!doctype html><html itemscope=\"\" itemtype=\"http://schema.org/WebPage\" lang=\"en\"><head><meta content=\"S
// )
```

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
val helloWorld = writeLine("Hello World")
// helloWorld: IO[Unit] = repl.Session$App4$$anon$1@7037bb81

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?

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

object Main extends App {

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

}
```

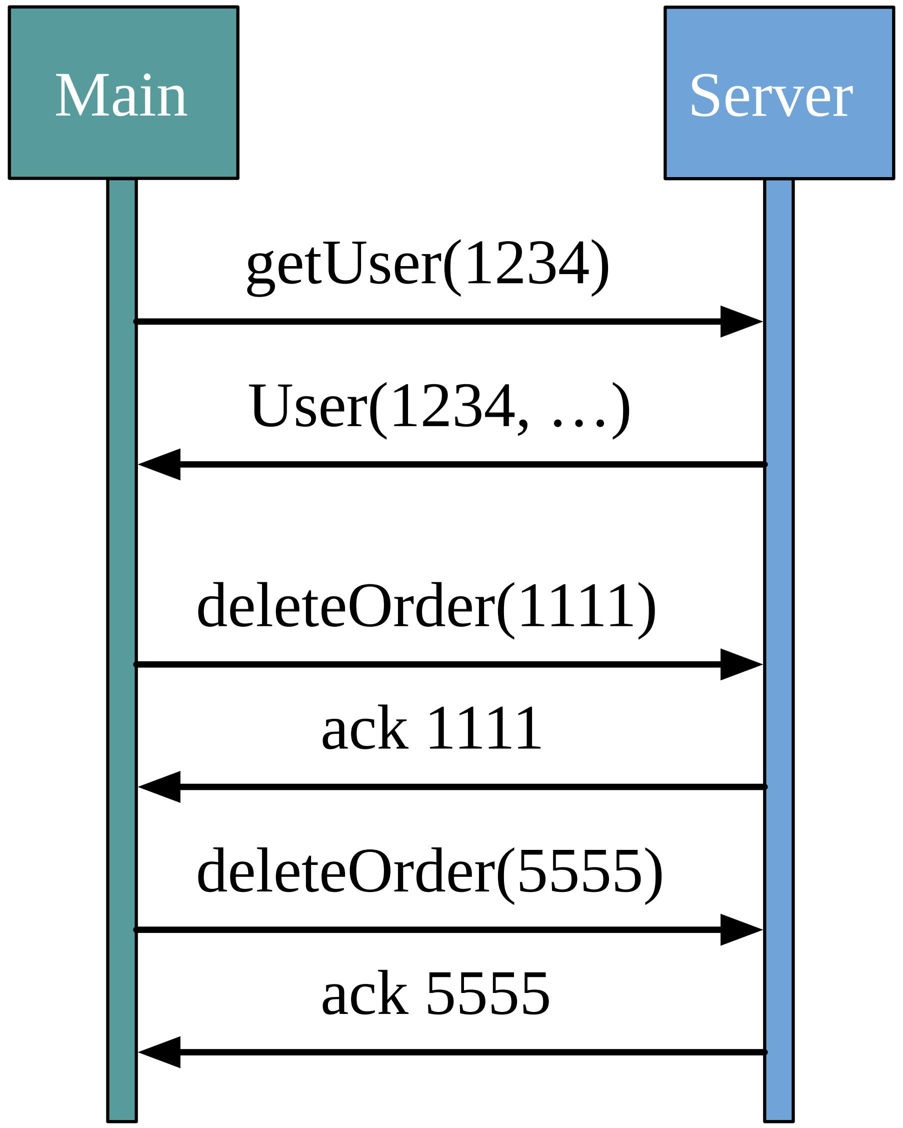
Discuss with your neighbour 3-4 min

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()

}
```

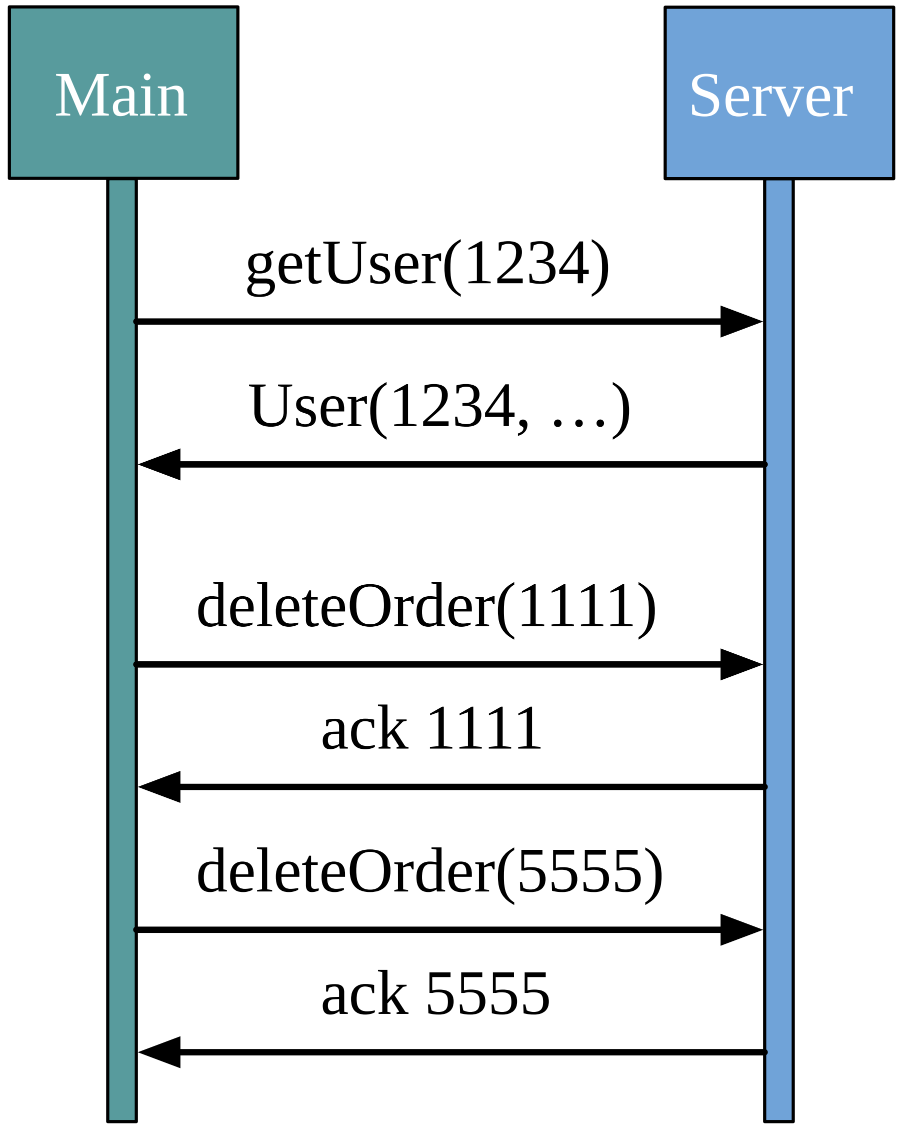
IO execution is sequential

```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?

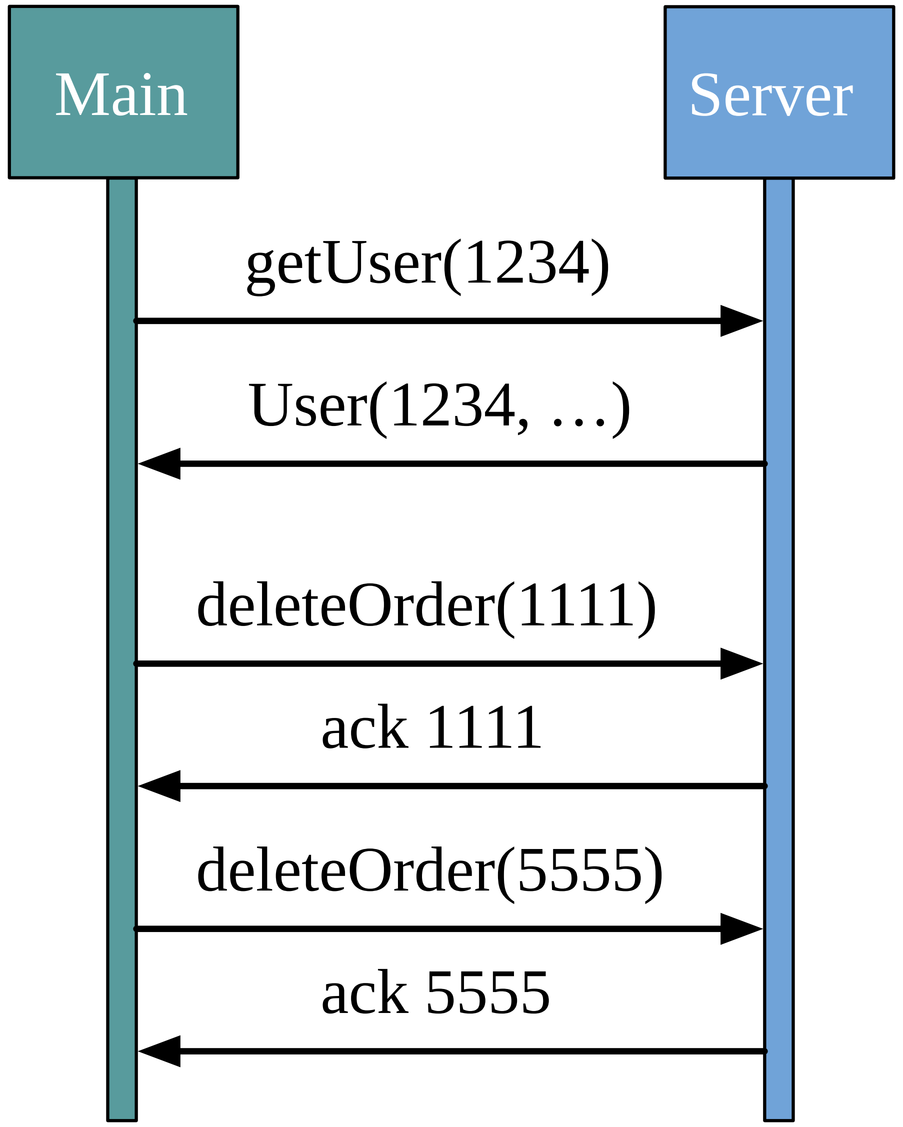
```scala
import answers.sideeffect.IOAnswers.IO

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

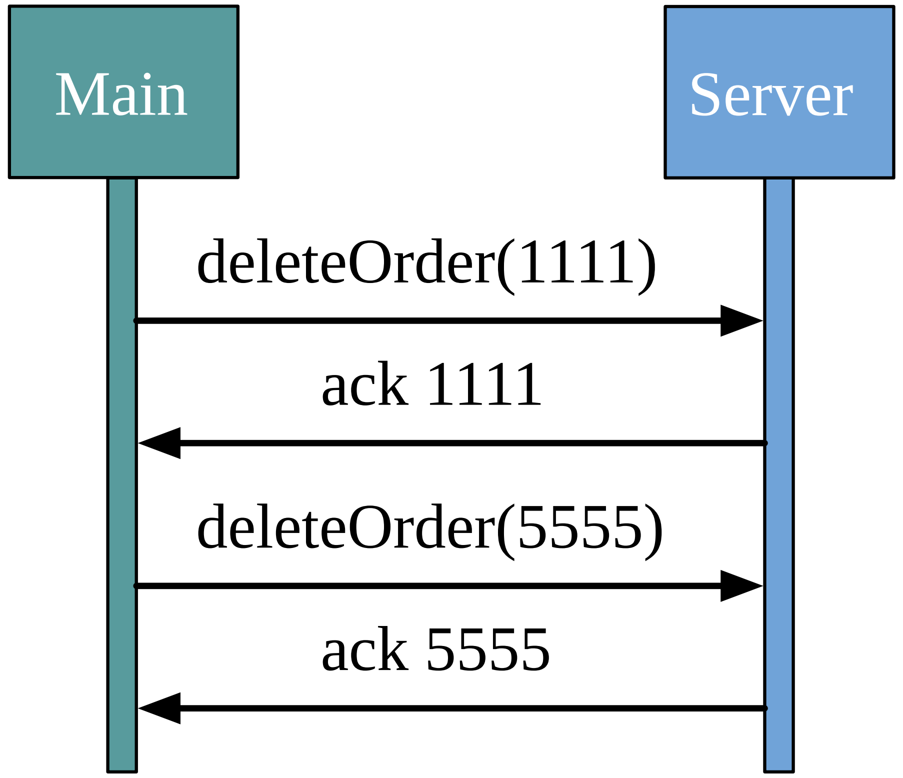
For comprehension cannot be done concurrently

```
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 ()
```



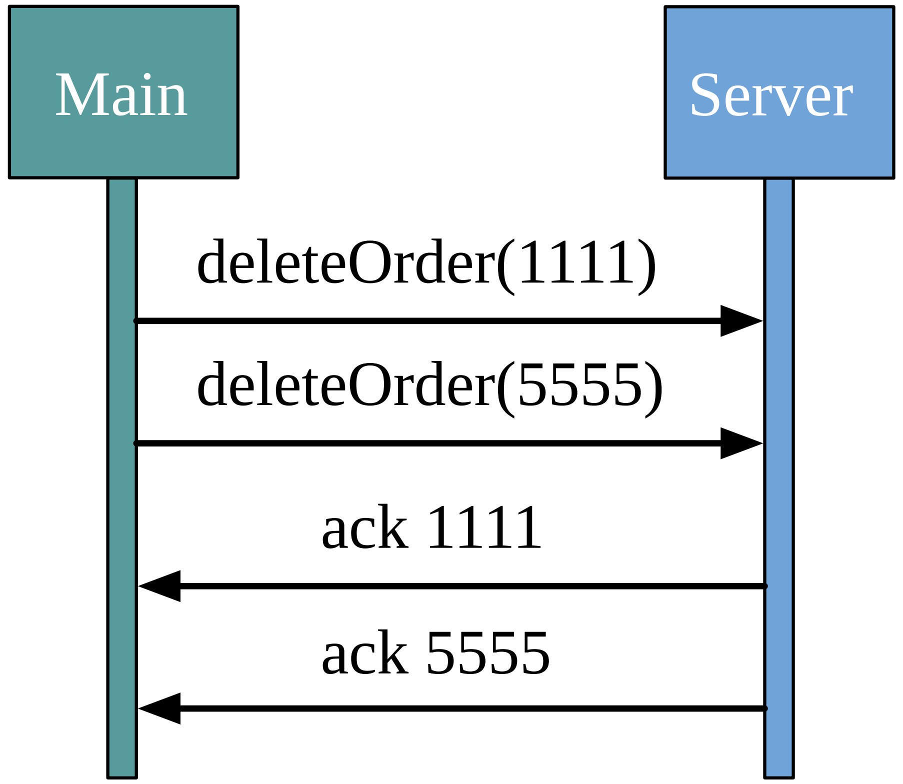
For comprehension cannot be done concurrently

```
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))
```



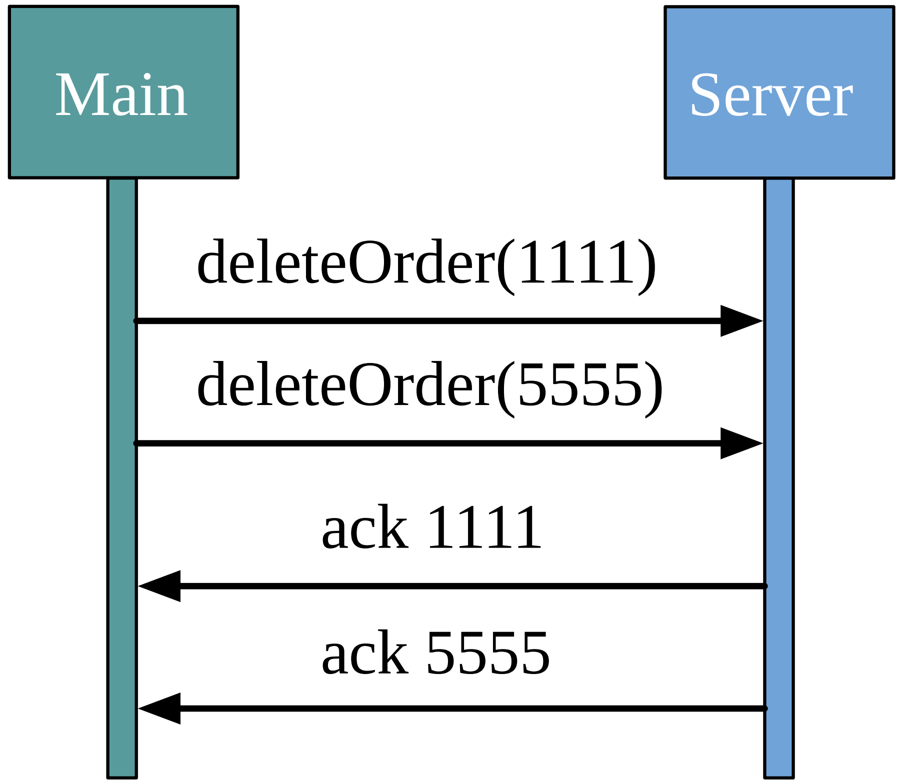
concurrentExec is loosely defined

```
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)
  )((_,_) => ())
```

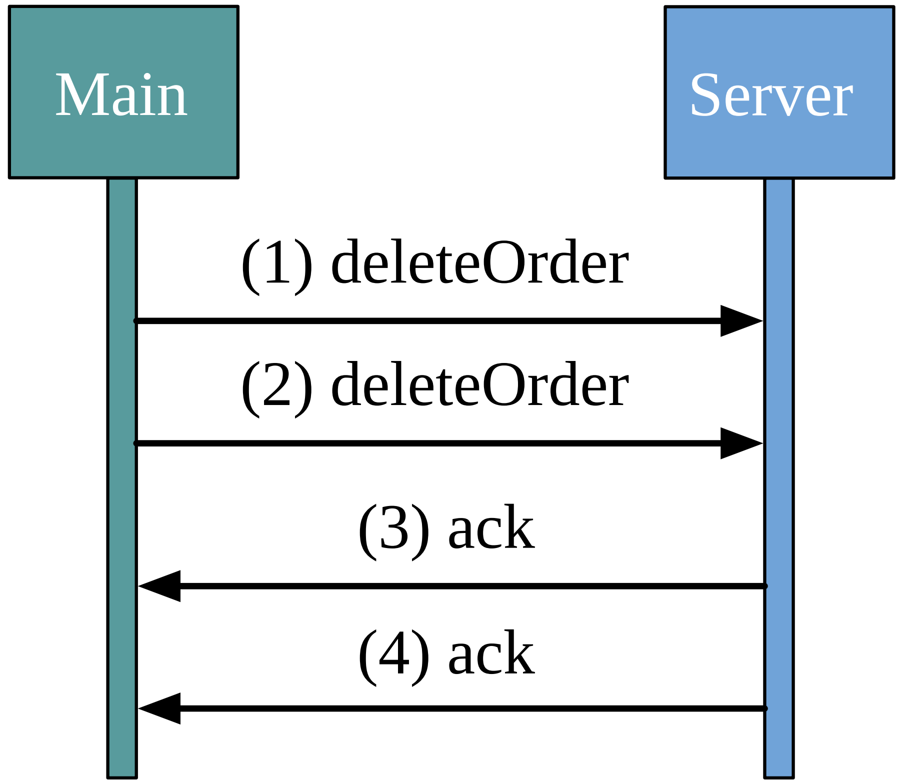
```
def concurrentMap2[A, B, C](fa: IO[A], fb: IO[B])
                           (f: (A, B) => C): IO[C] = ???

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



How concurrency is done with Future?

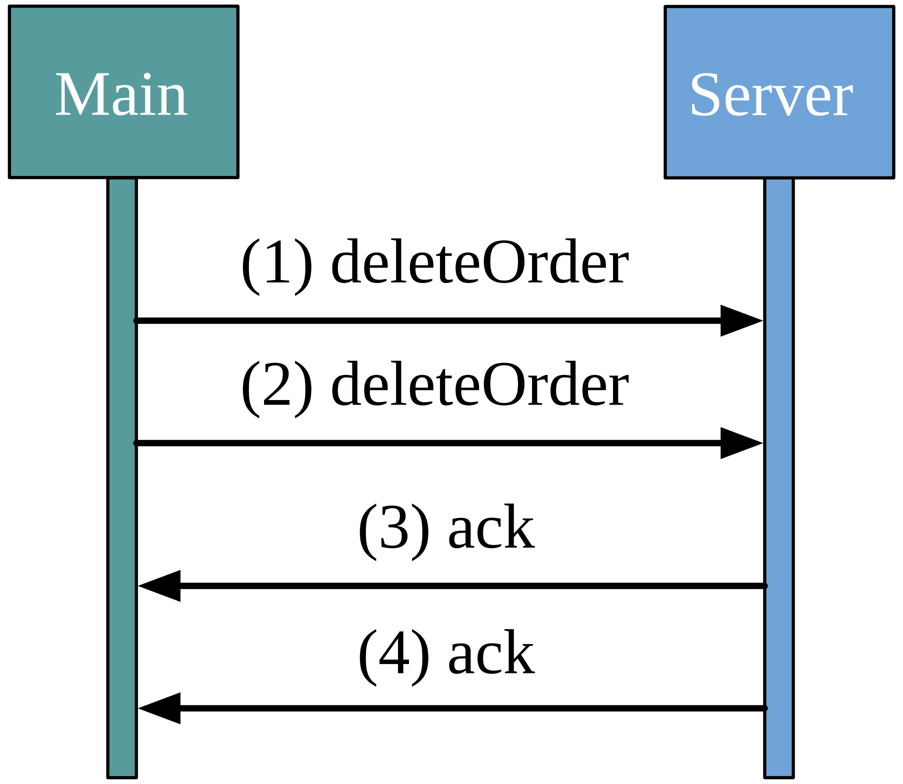
Future

```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 ()
}
```

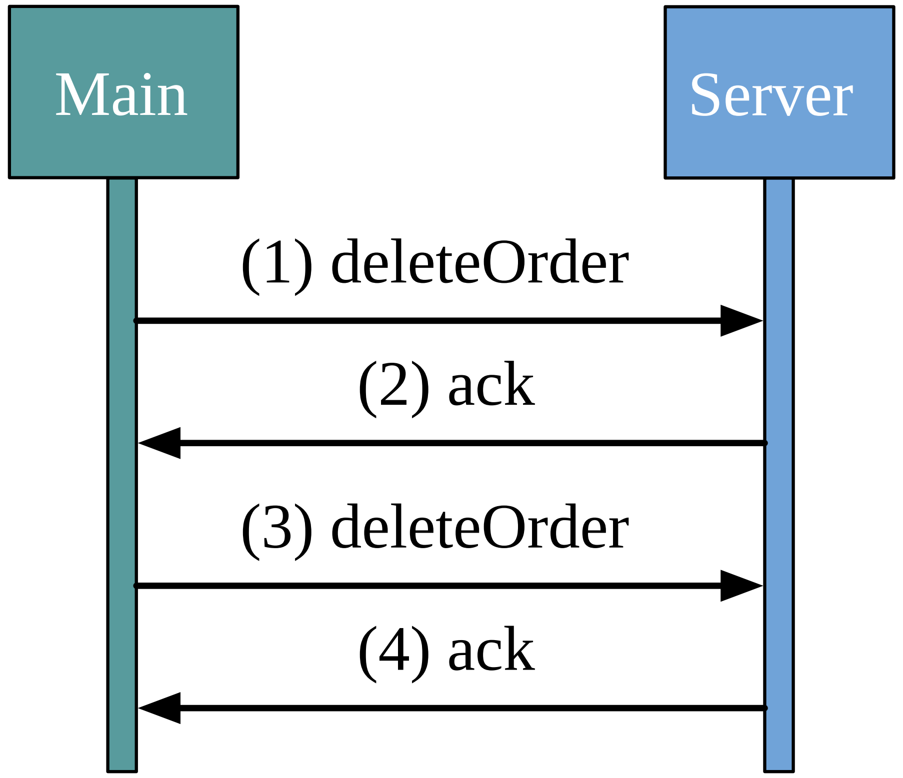


Creating a Future is a side effect

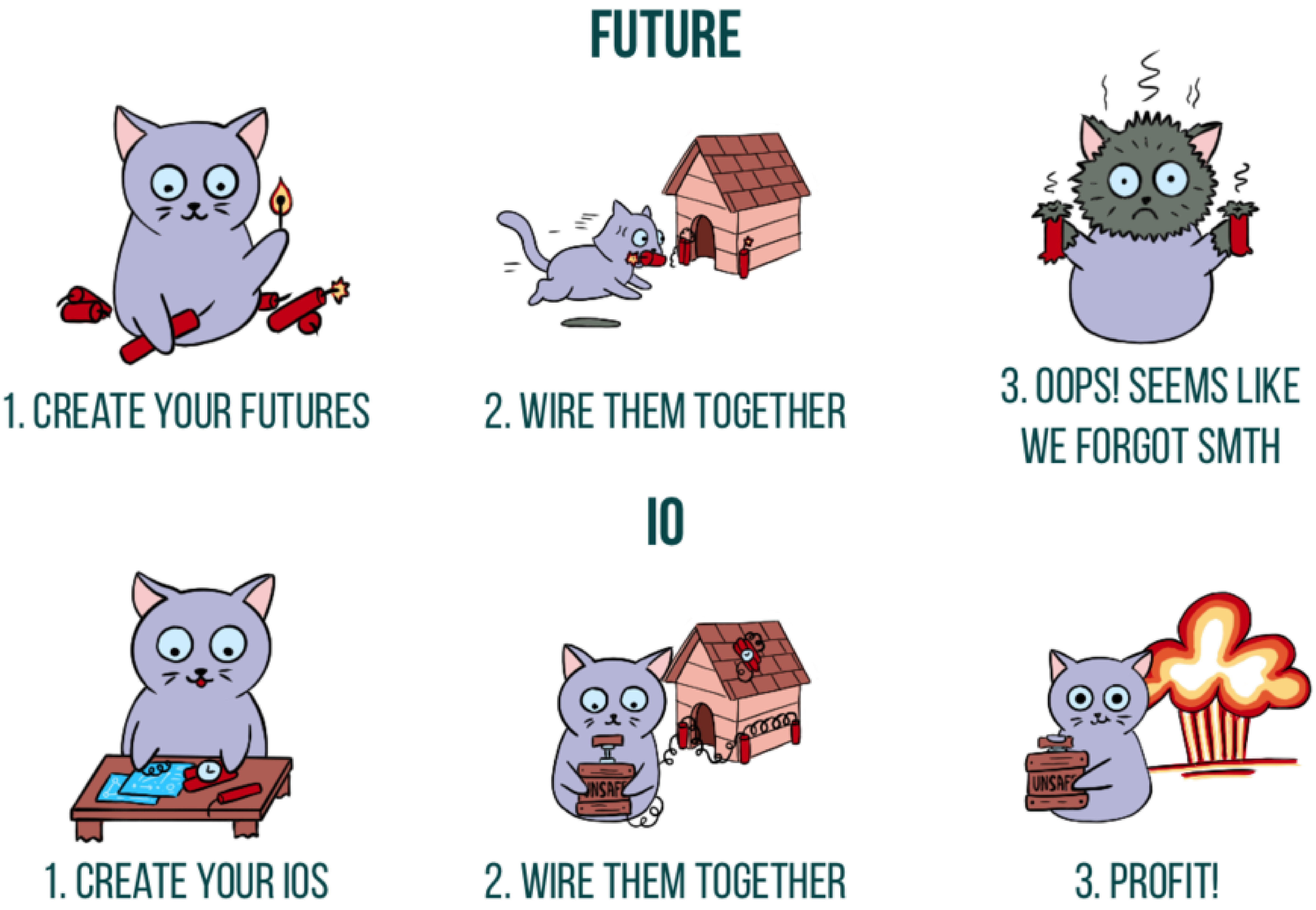
```scala
def deleteOrdersConcurrent(orderId1: OrderId,orderId2: OrderId)
  (implicit ec: ExecutionContext): Future[Unit] = {

  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 ()
```

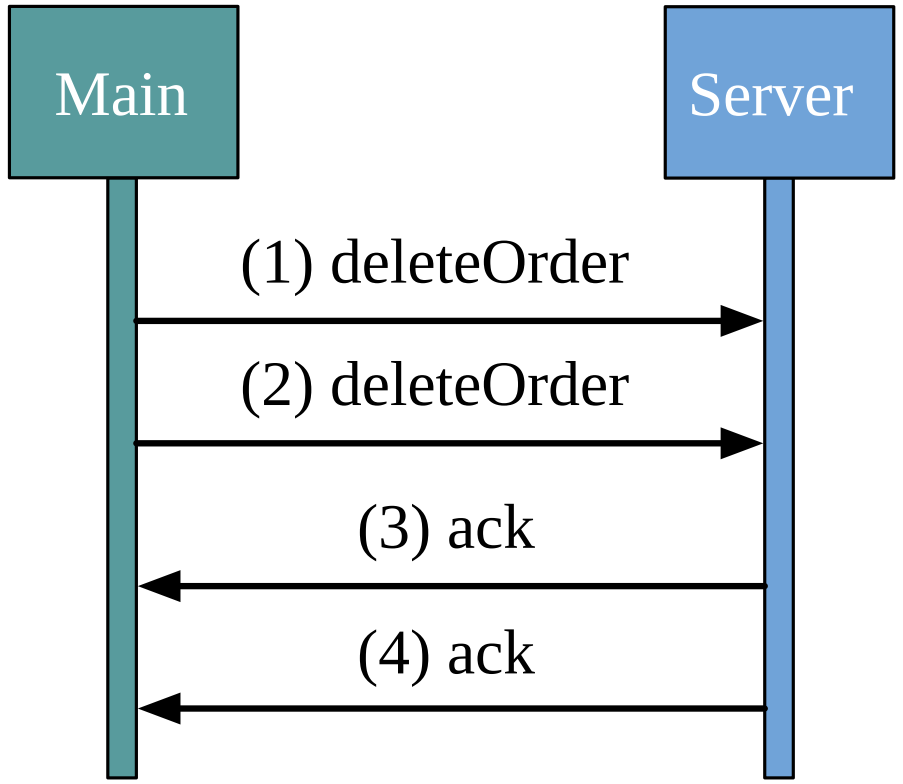


[@impurepics](https://twitter.com/impurepics)



Execution Context

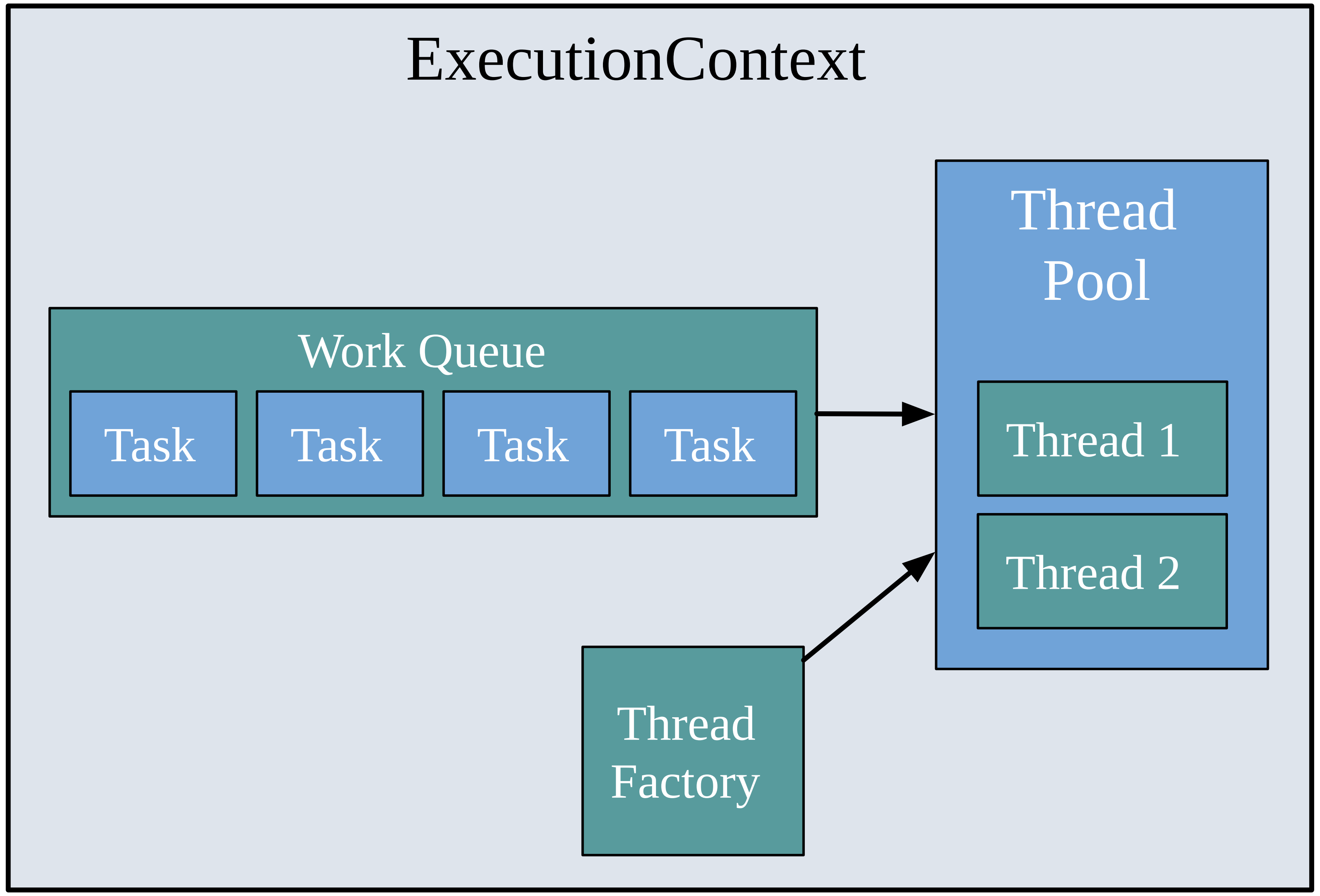
```scala
import scala.concurrent.{ExecutionContext, Future}

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

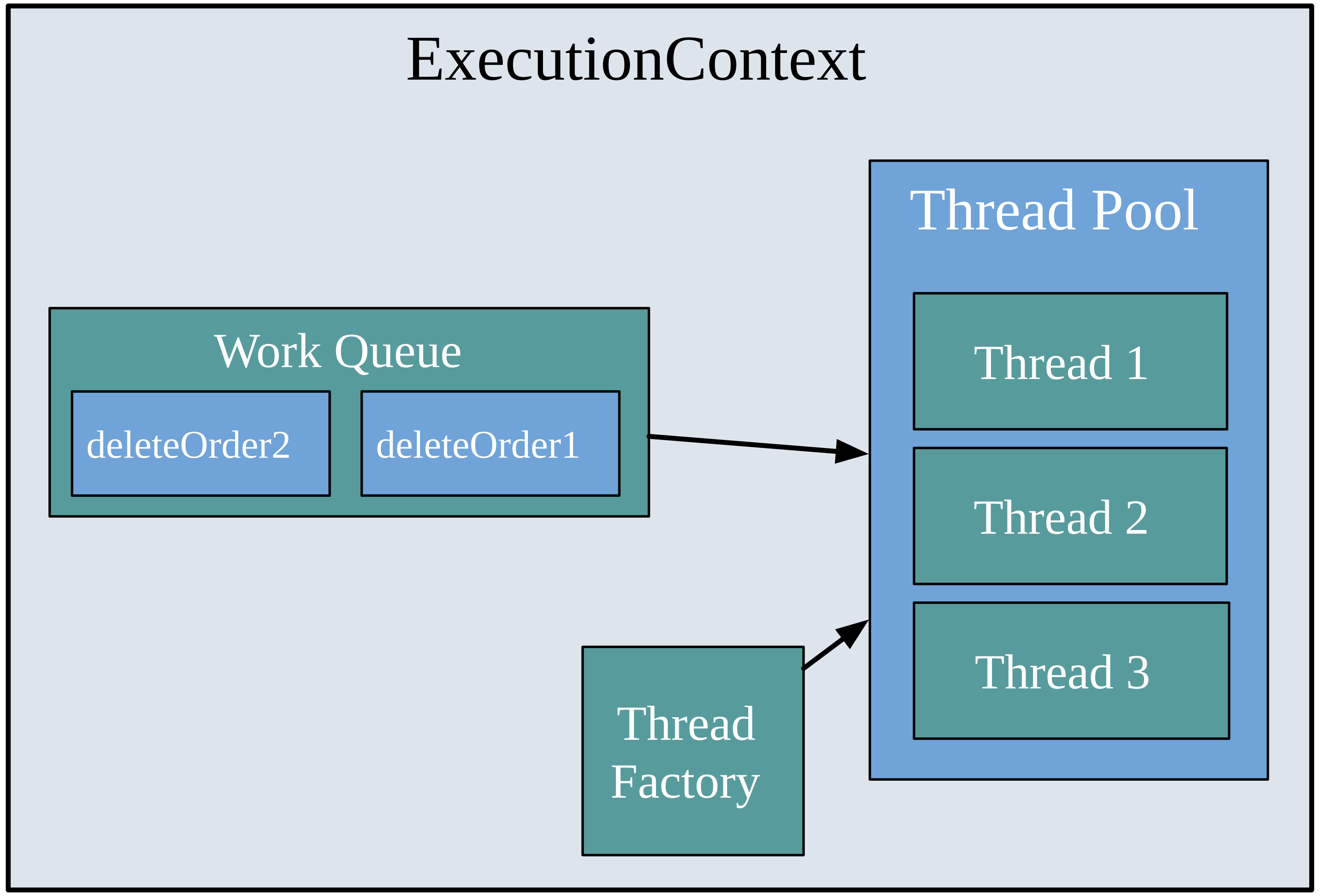
```scala
import java.util.concurrent.Executors
import scala.concurrent.ExecutionContext

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
// res14: Int = 0

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

x
// res16: Int = 1
```



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,
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)(ec: ExecutionContext): Future[Unit] = {

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

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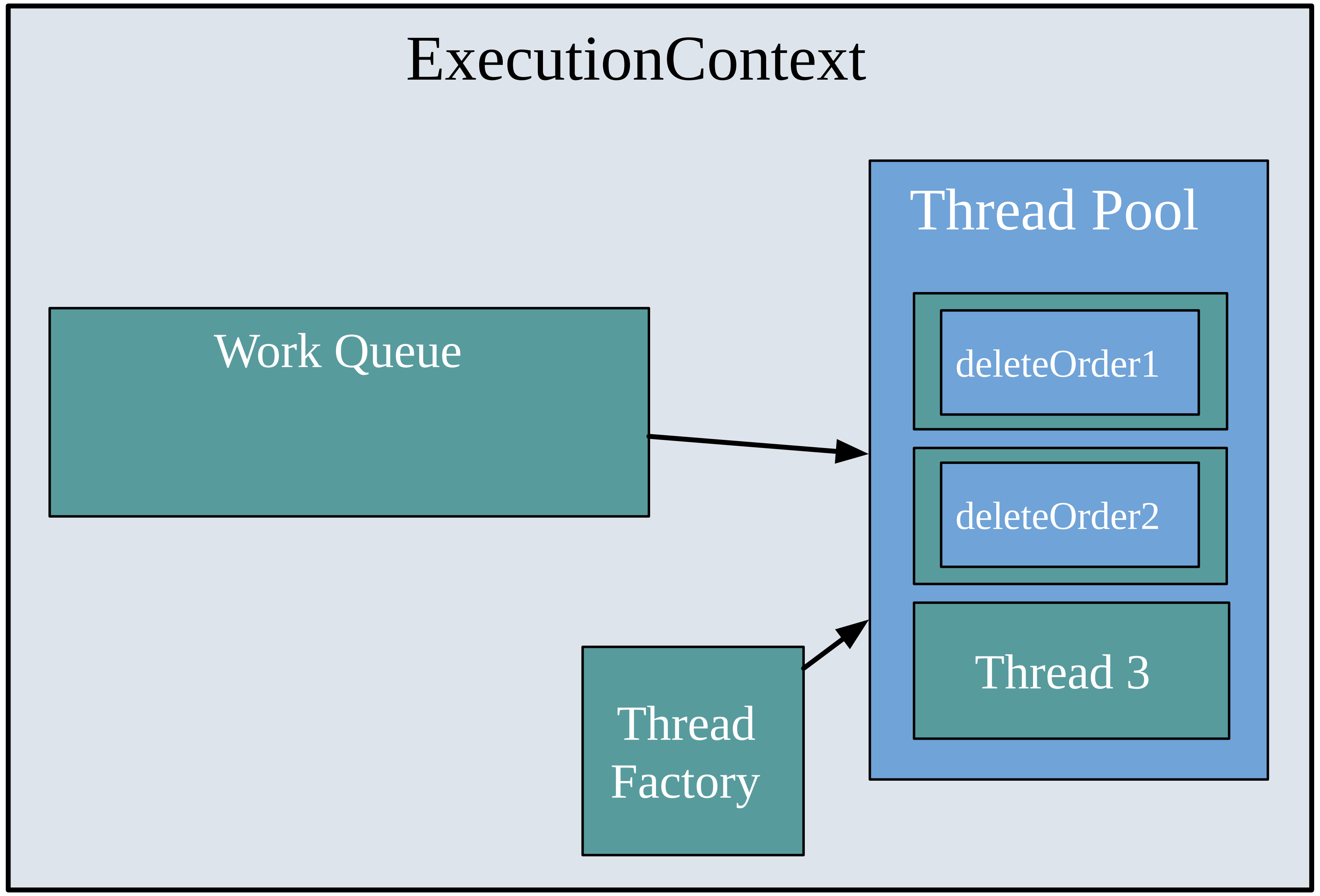
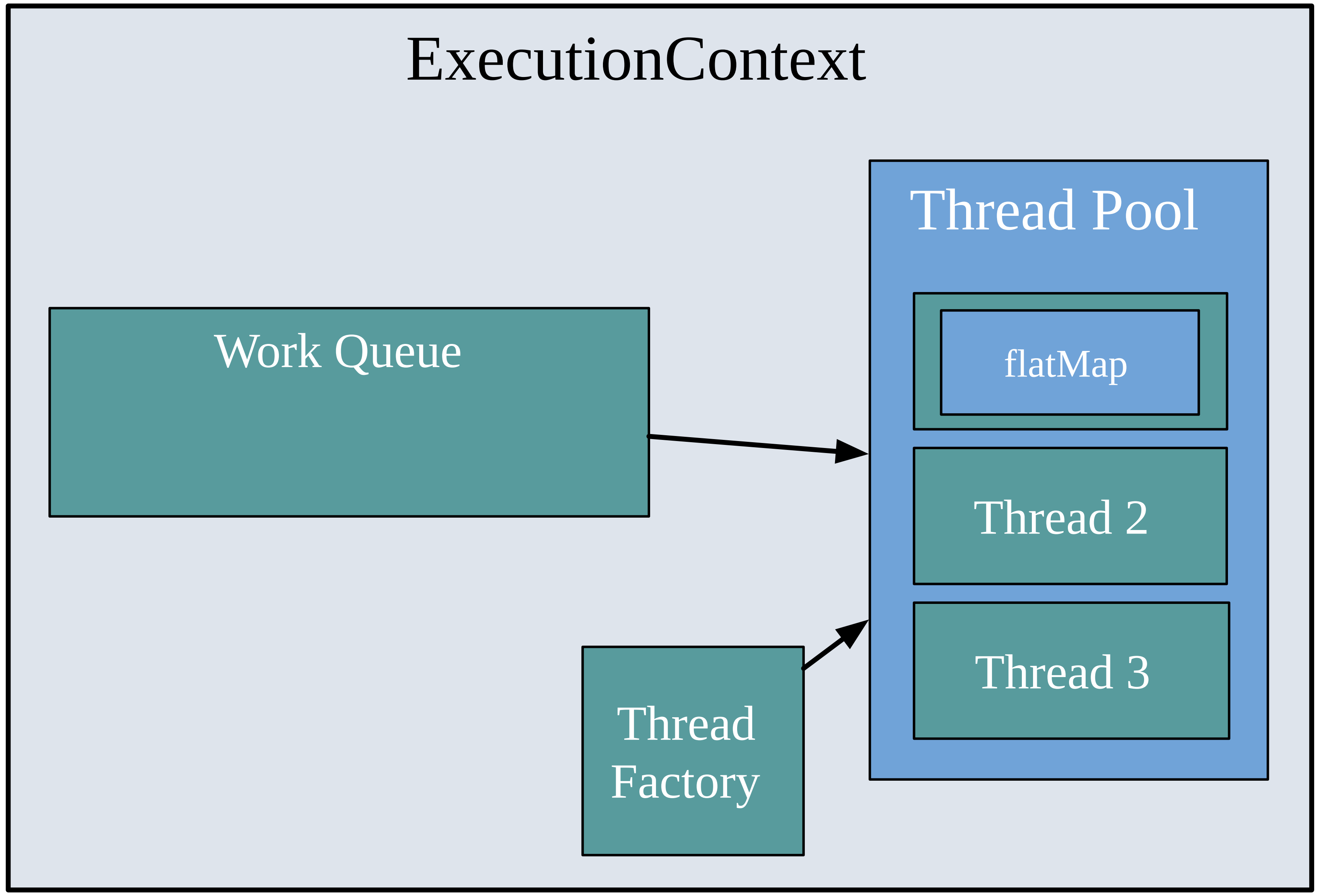



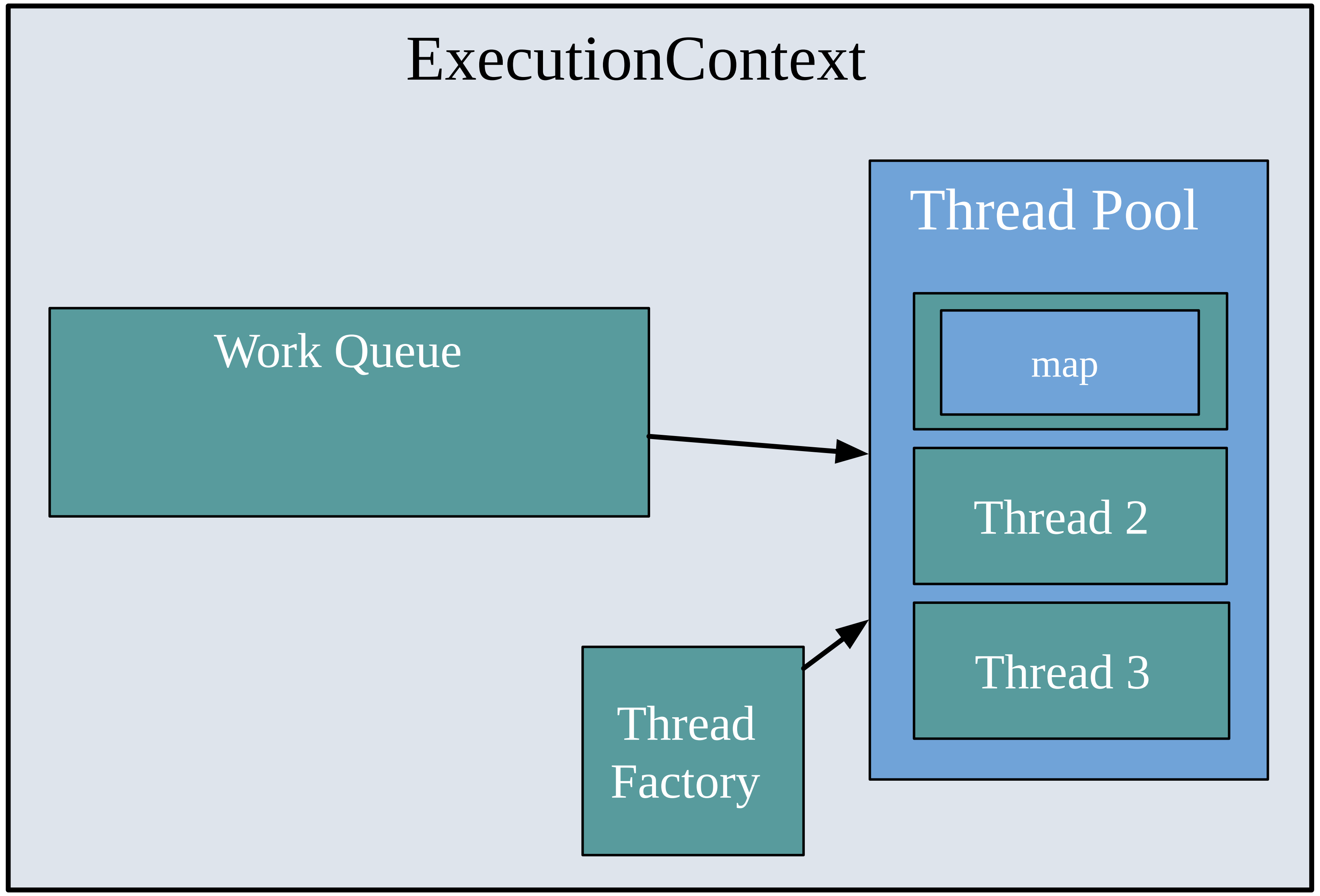
Execution Context

```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

```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[???]
}
```

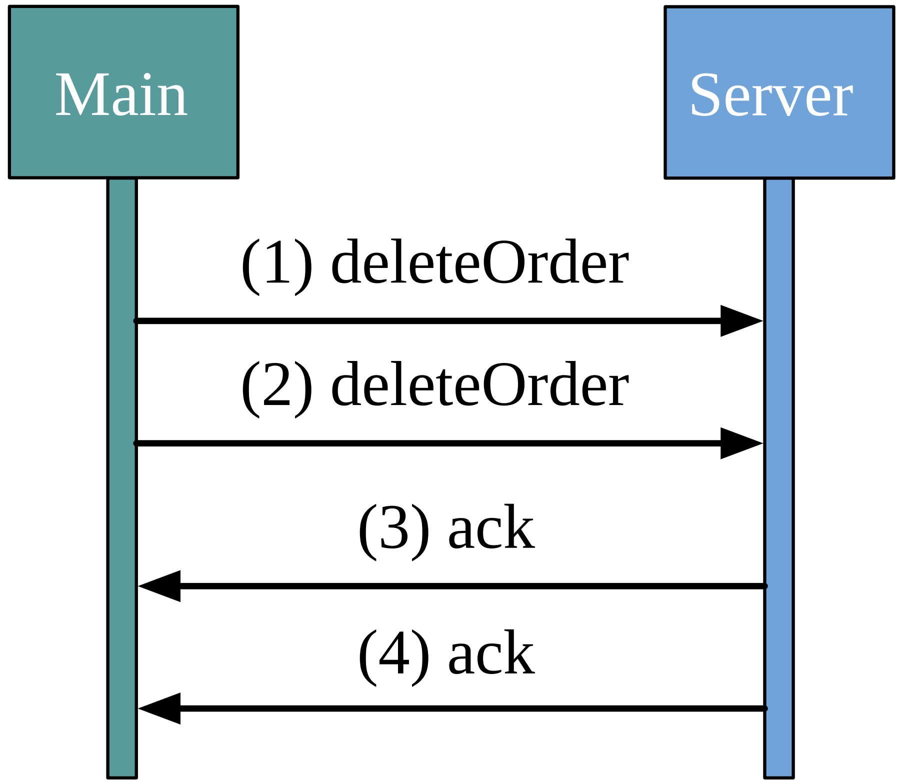
Concurrent IO

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

Concurrent IO: concurrentMap2

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

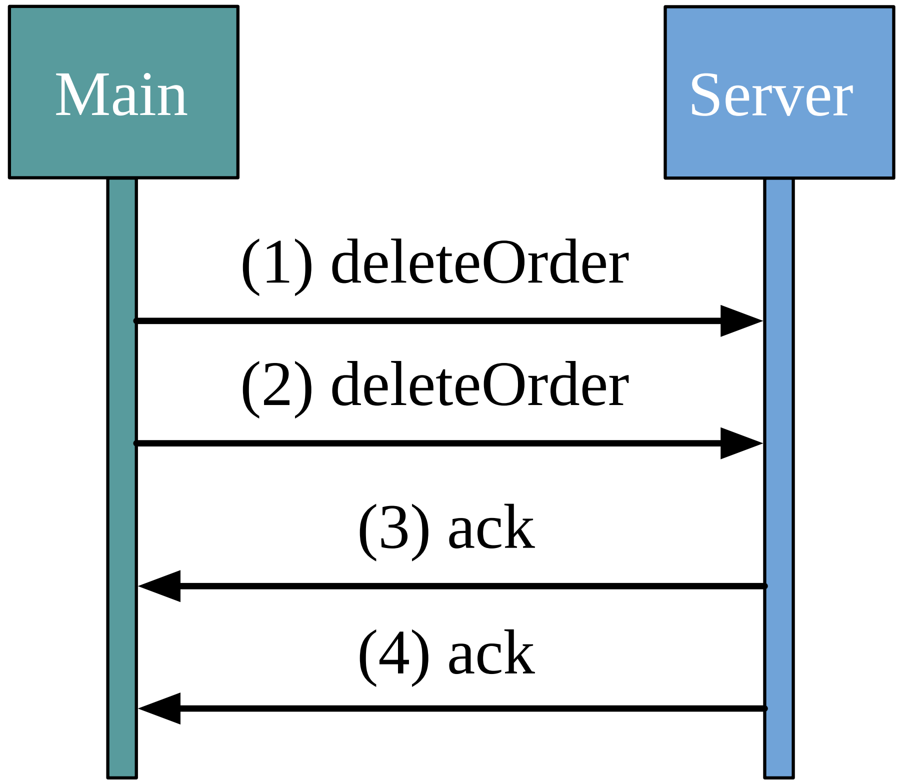
```scala
def concurrentMap2[A, B, C](
  fa: IO[A],
  fb: IO[B]
)(f: (A, B) => C)(ec: ExecutionContext): IO[C] = ???
```



Concurrent IO: concurrentMap2

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

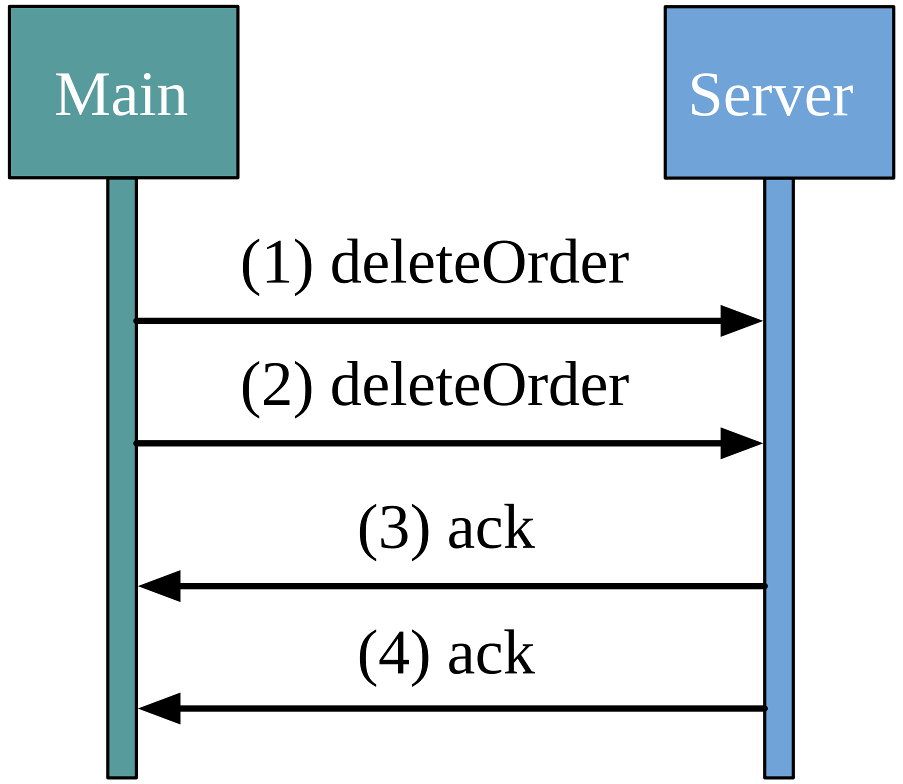
```scala
def concurrentMap2[A, B, C](
  fa: IO[A],
  fb: IO[B]
)(f: (A, B) => C)(ec: ExecutionContext): IO[C] =
  for {
    awaitForA <- fa.start(ec) // (1)
    awaitForB <- fb.start(ec) // (2)
    a         <- awaitForA    // (3)
    b         <- awaitForB    // (4)
  } yield f(a, b)
```



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

```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]
}
```

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

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]
}
```

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