Programs as Values

Pure Functional Database Access in Scala

Rob Norris • Gemini Observatory

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This is a talk about the **implementation** of **doobie**, a principled library for database access in Scala.

- JDBC programming is **terrible**.
- Free monads [over free functors] are **awesome**.
- Think of programs as **composable** values, rather than imperative processes.
- Lather, rinse, **repeat**. This is a great strategy for making terrible APIs tolerable.

The Problem

So what's wrong with this JDBC program?

```scala
case class Person(name: String, age: Int)

def getPerson(rs: ResultSet): Person = {
  val name = rs.getString(1)
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Managed Resource

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Composition?

The Strategy

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- Let's talk about primitive operations as **values** ... these are the smallest meaningful **programs**.
- Let's define rules for **combining** little programs to make bigger programs.
- Let's define an **interpreter** that consumes these programs and performs actual work.

Primitives

An algebra is just a set of objects, along with rules for manipulating them. Here our objects are the set of primitive computations you can perform with a JDBC ResultSet.

```
sealed trait ResultSetOp[A]

case object Next                 extends ResultSetOp[Boolean]
case class  GetInt(i: Int)       extends ResultSetOp[Int]
case class  GetString(i: Int) extends ResultSetOp[String]
case object Close                extends ResultSetOp[Unit]
// 188 more...
```

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Constructor per Method

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Constructor per Method

Parameterized on Return Type

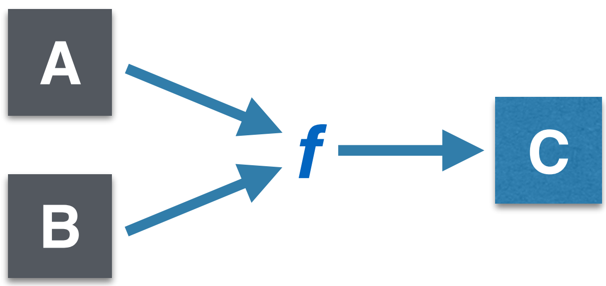
Operations

Operations

A

B

Operations



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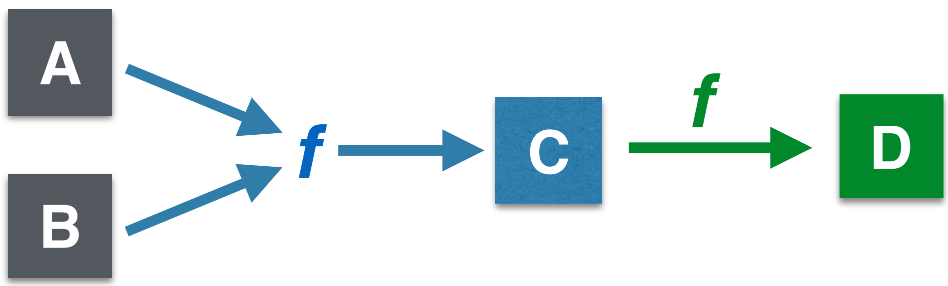

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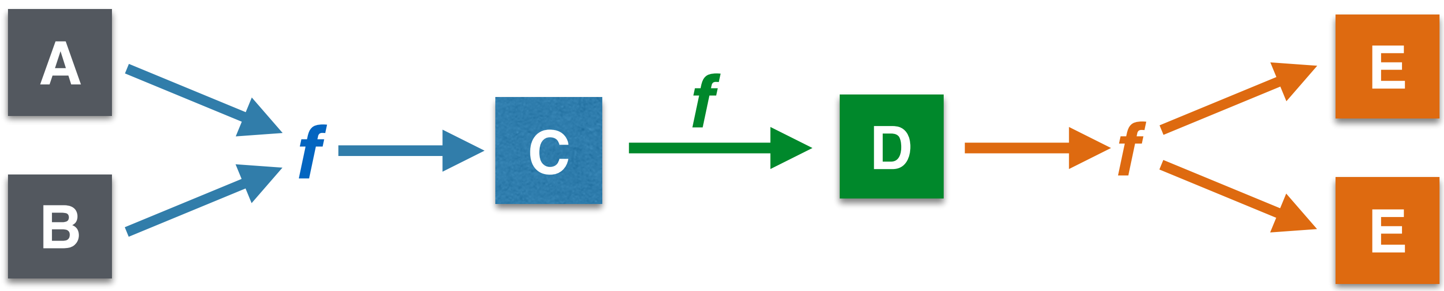

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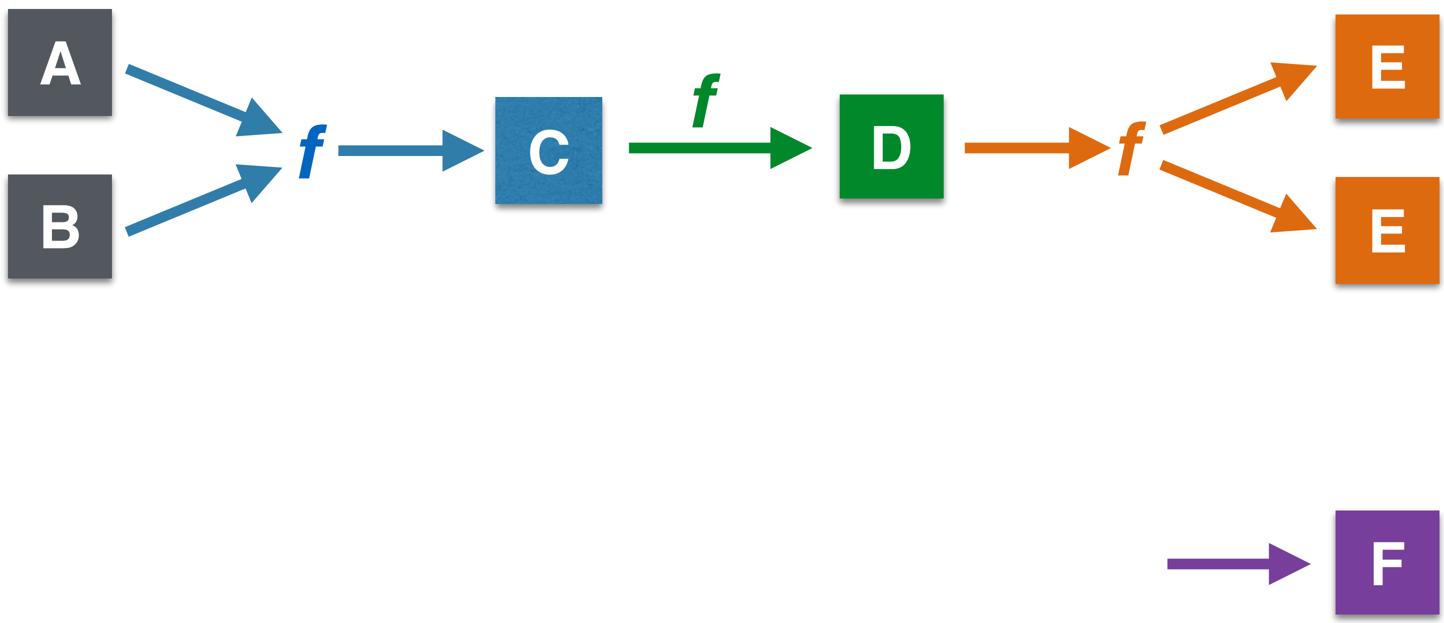

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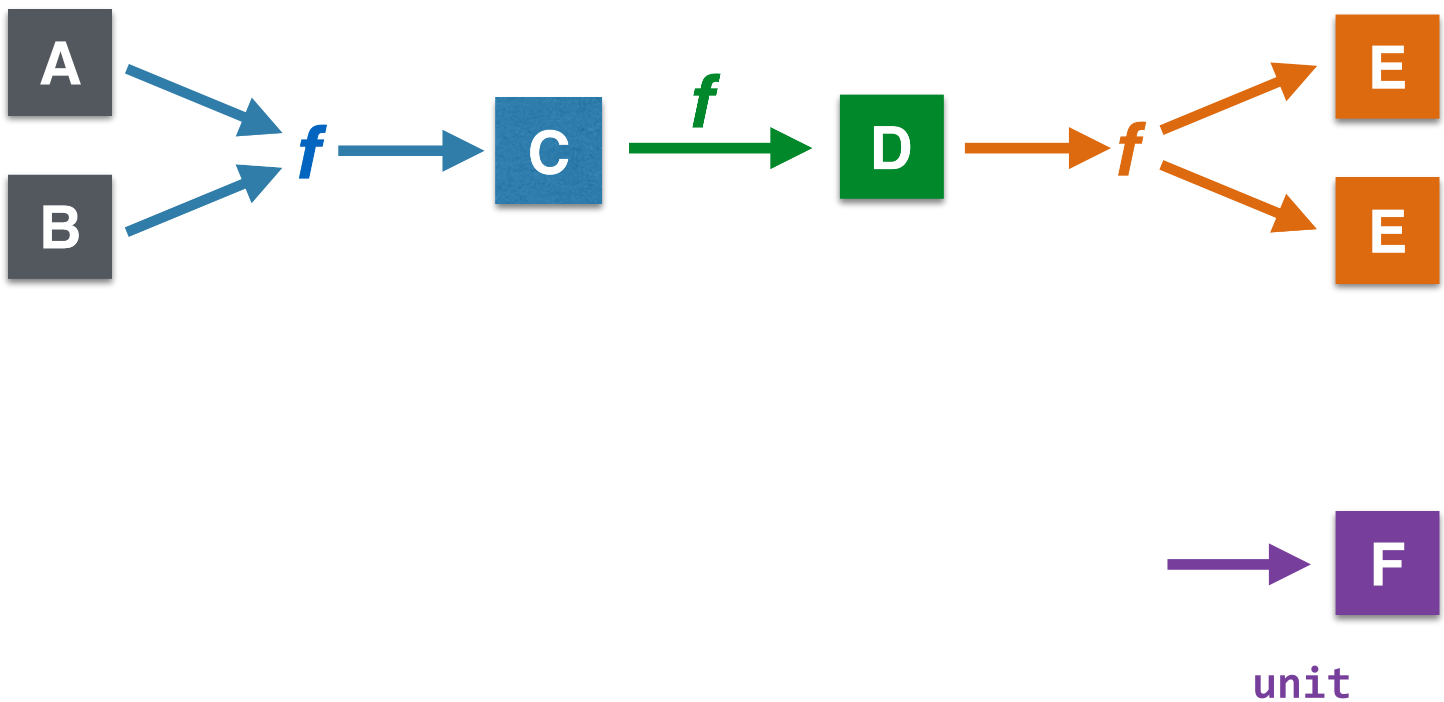

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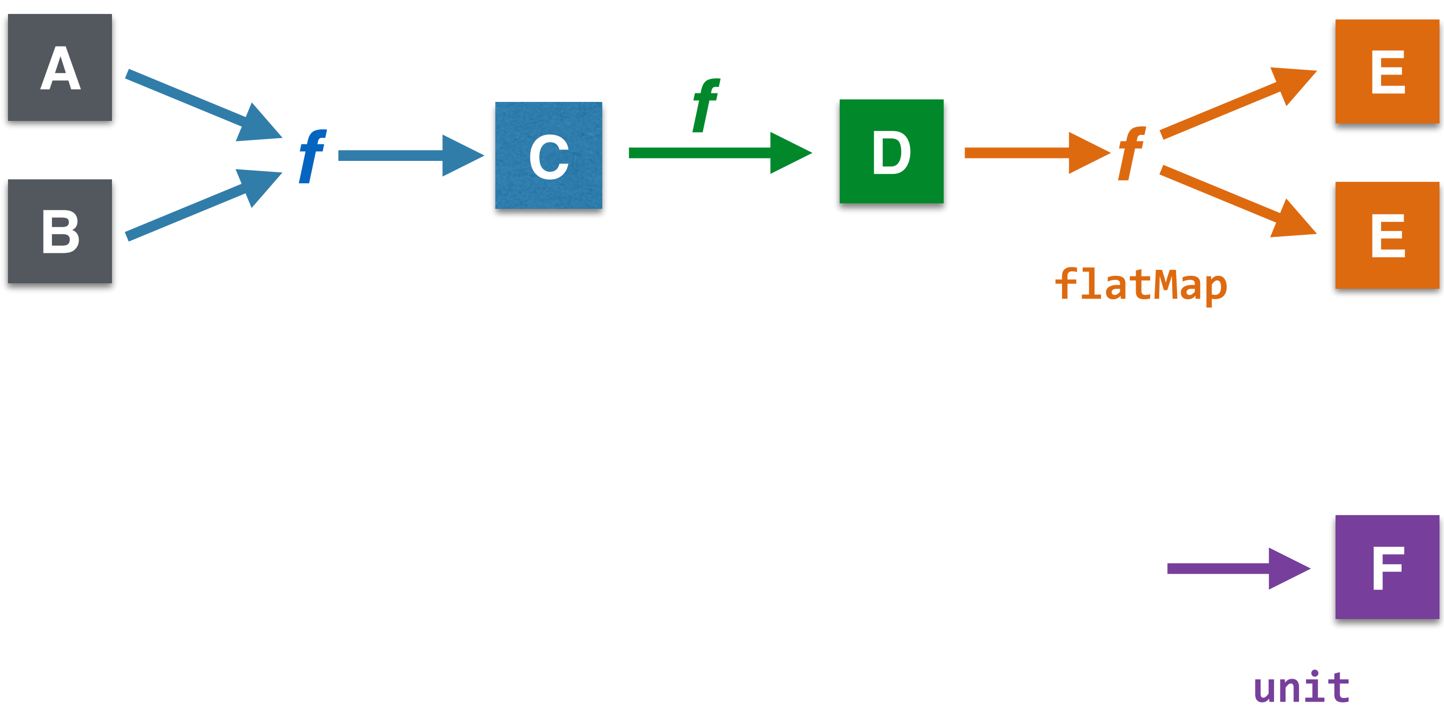

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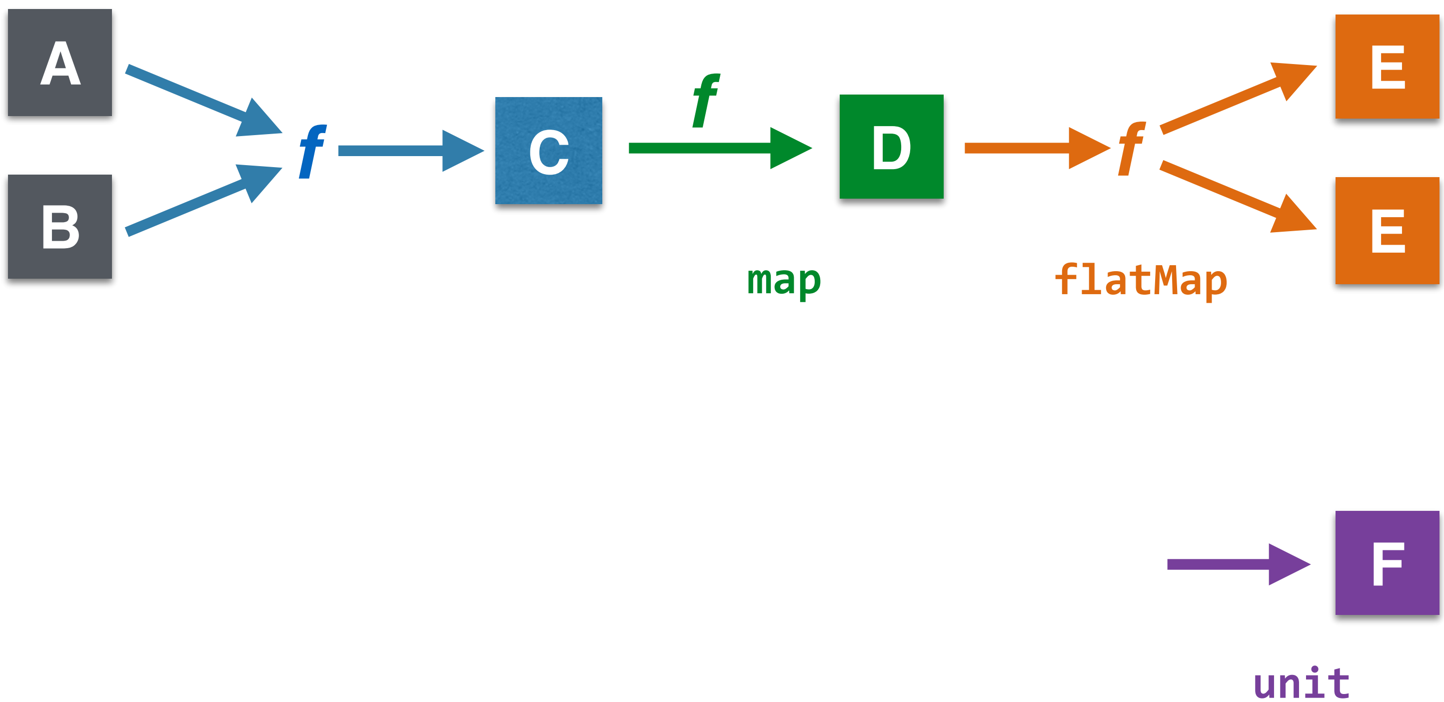

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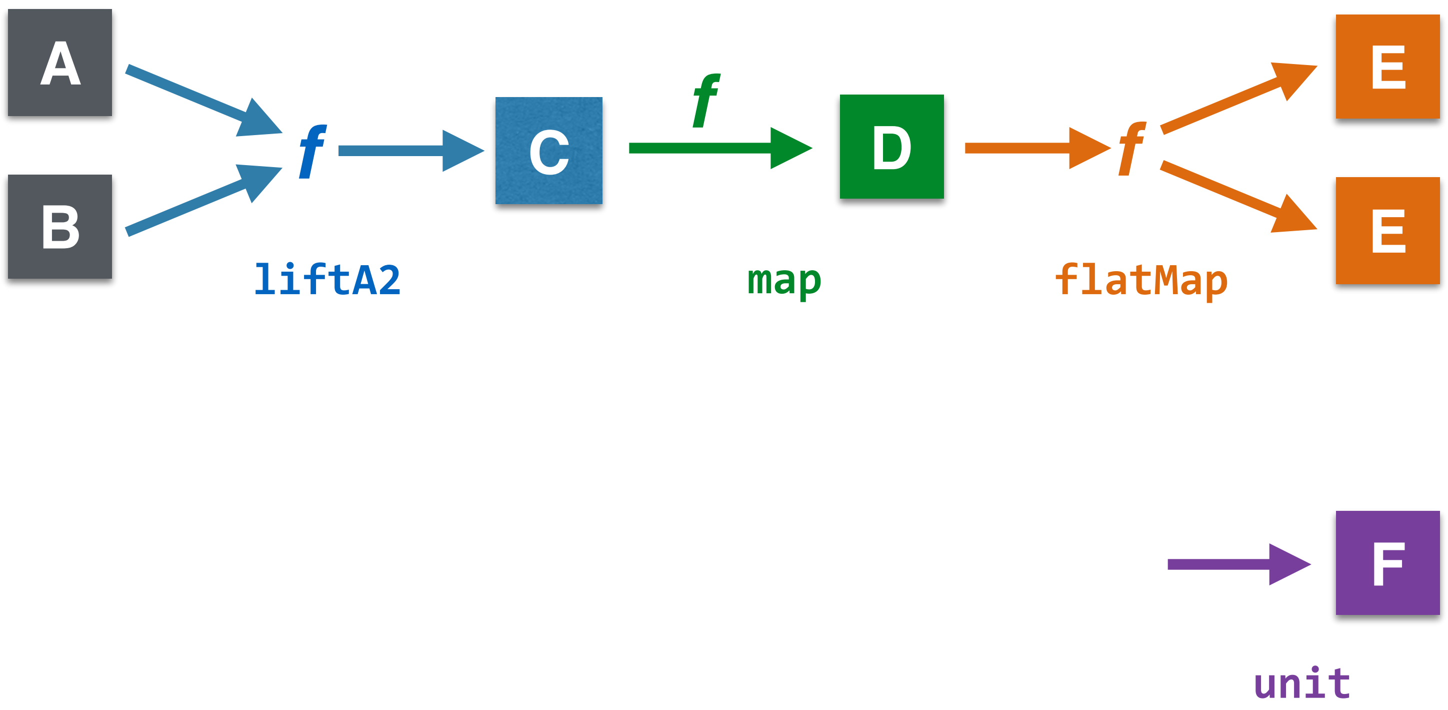

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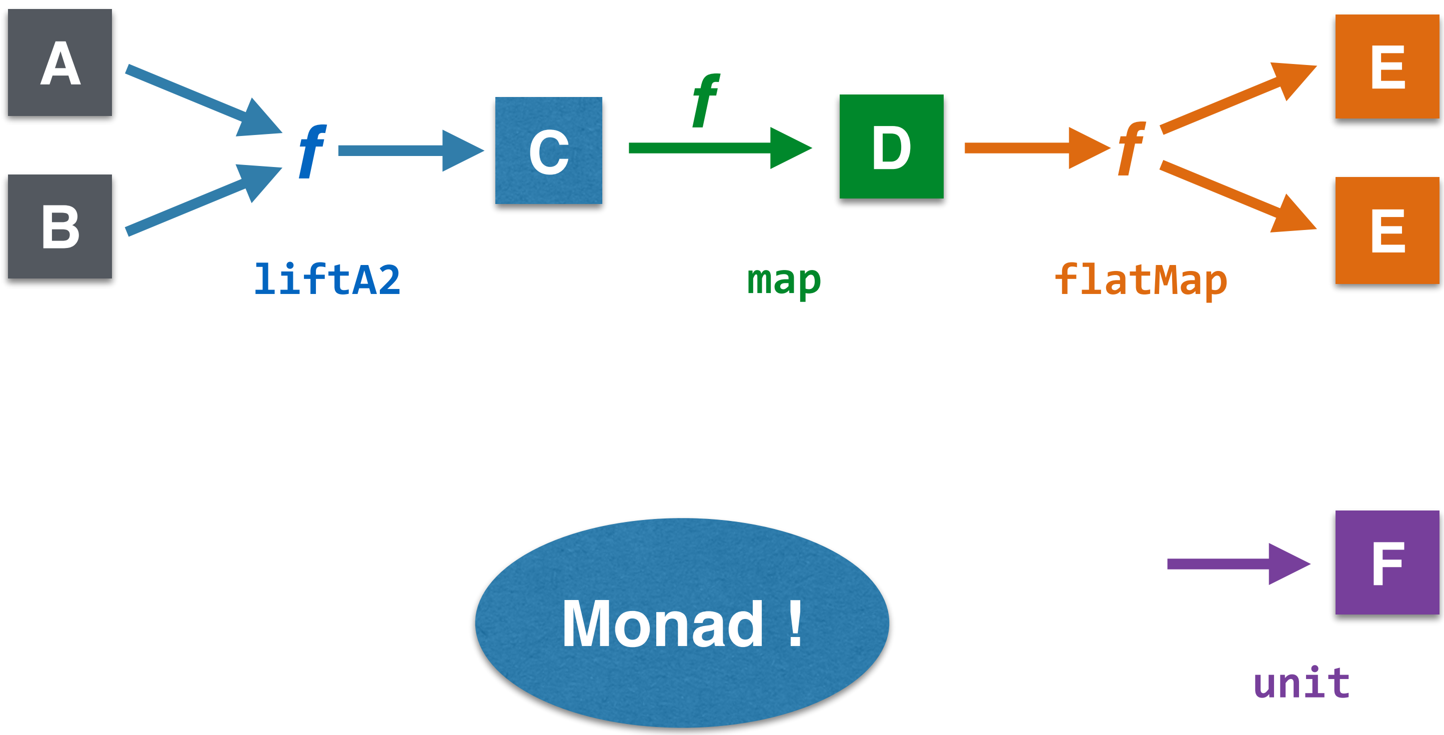

If only...

If we had **Monad[ResultSetOp]** we could do this:

```scala
case class Person(name: String, age: Int)

val getPerson: ResultSetOp[Person] =
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But we don't.

Spare a Monad?

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- scalaz abbreviates this type as `FreeC[S,?]`

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- By substitution, `Free[Coyoneda[S[_],?],?]` is a **monad** for any `S` at all.
- scalaz abbreviates this type as `FreeC[S,?]`
- Set `S` = `ResultSetOp` and watch what happens.

Wait, what?

```
import scalaz.{ Free, Coyoneda }
import scalaz.Free.{ FreeC, liftFC }

type ResultSetIO[A] = FreeC[ResultSetOp, A]
```

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val next:                 ResultSetIO[Boolean] = liftFC(Next)
def getInt(i: Int):    ResultSetIO[Int]     = liftFC(GetInt(a))
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Smart Ctors

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ResultSetOp

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Smart Ctors

ResultSetOp

Programming

Now we can write programs in **`ResultSetIO`** using familiar monadic style.

```
case class Person(name: String, age: Int)

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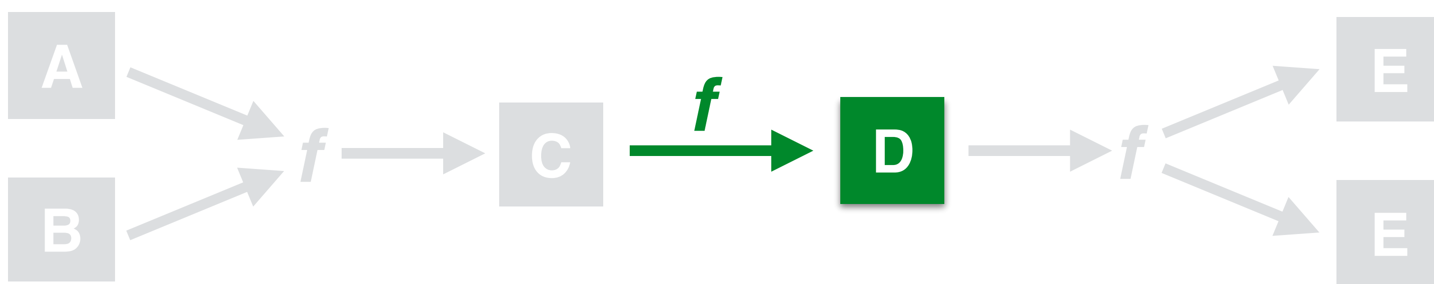
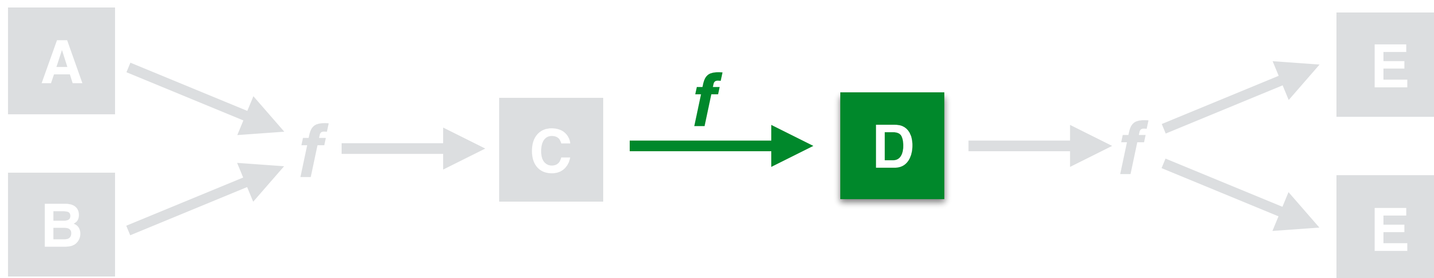
Values!

Composition!

Functor Operations

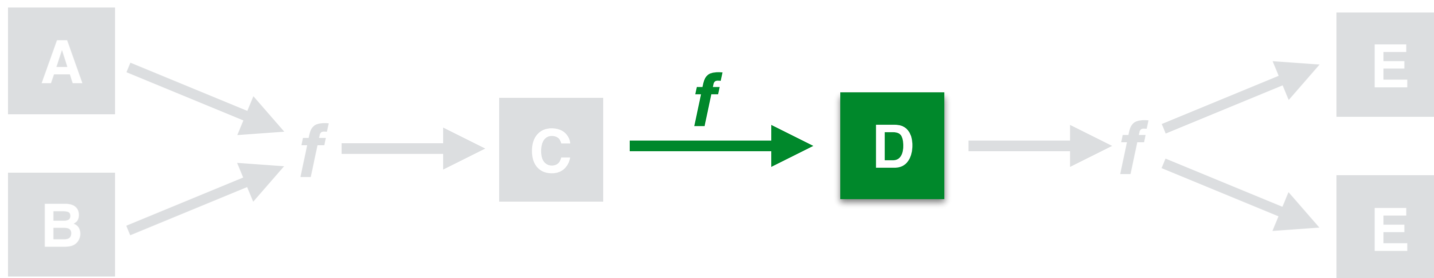


Functor Operations




```
// Construct a program to read a Date at column n
def getDate(n: Int): ResultSetIO[java.util.Date] =
  getLong(n).map(new java.util.Date(_))
```

Functor Operations

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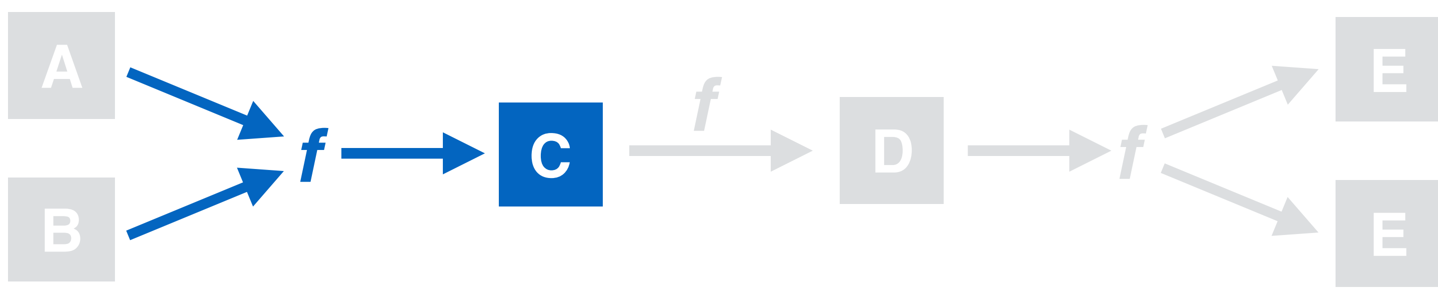
```

```
fpair
strengthL
strengthR
fproduct
as
void
```

Applicative Operations



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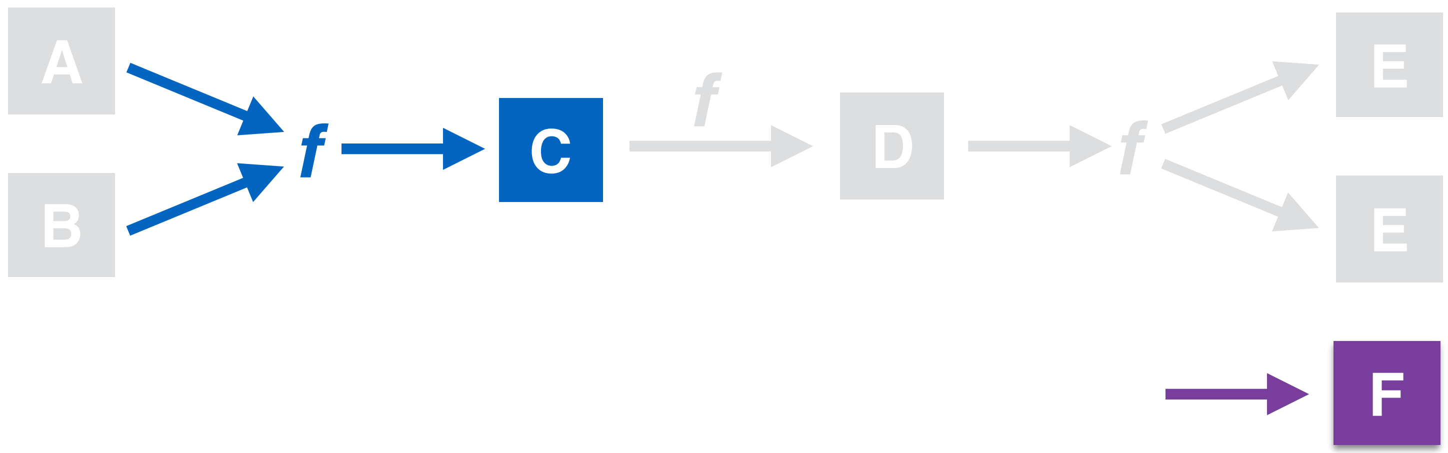

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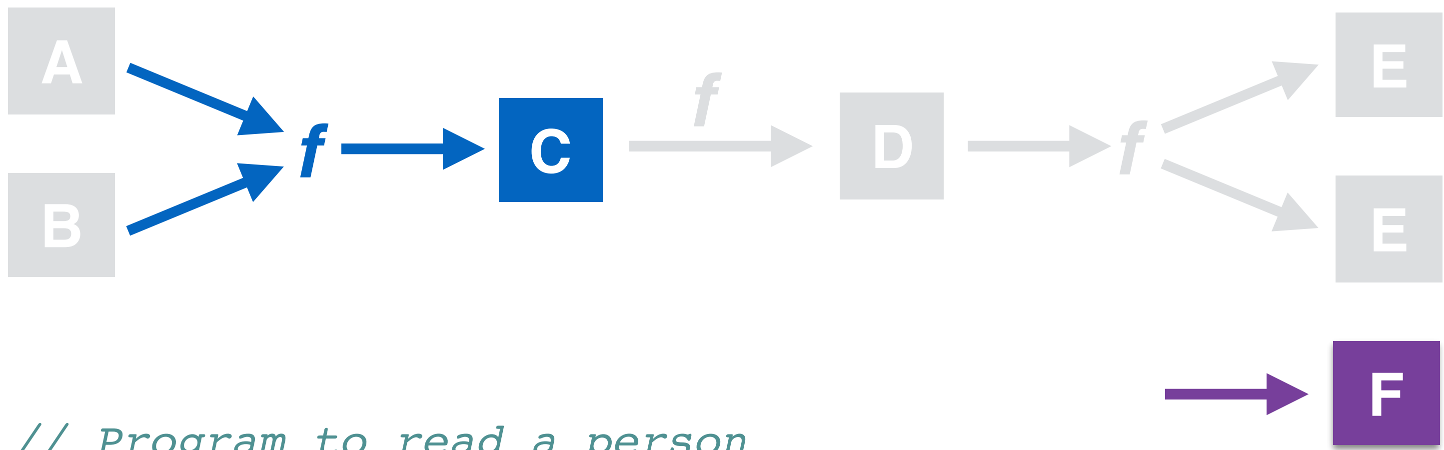
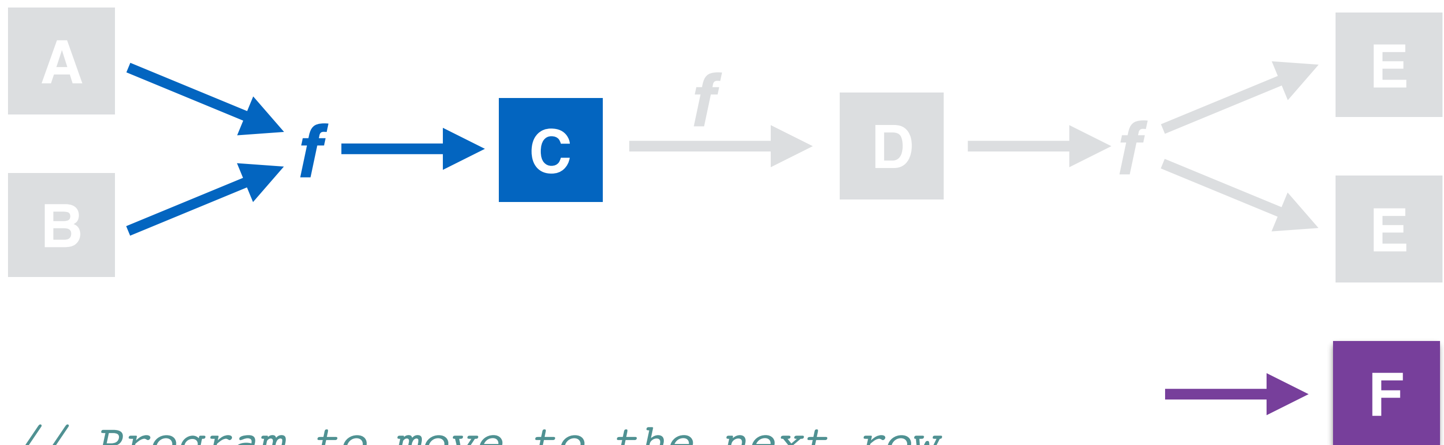


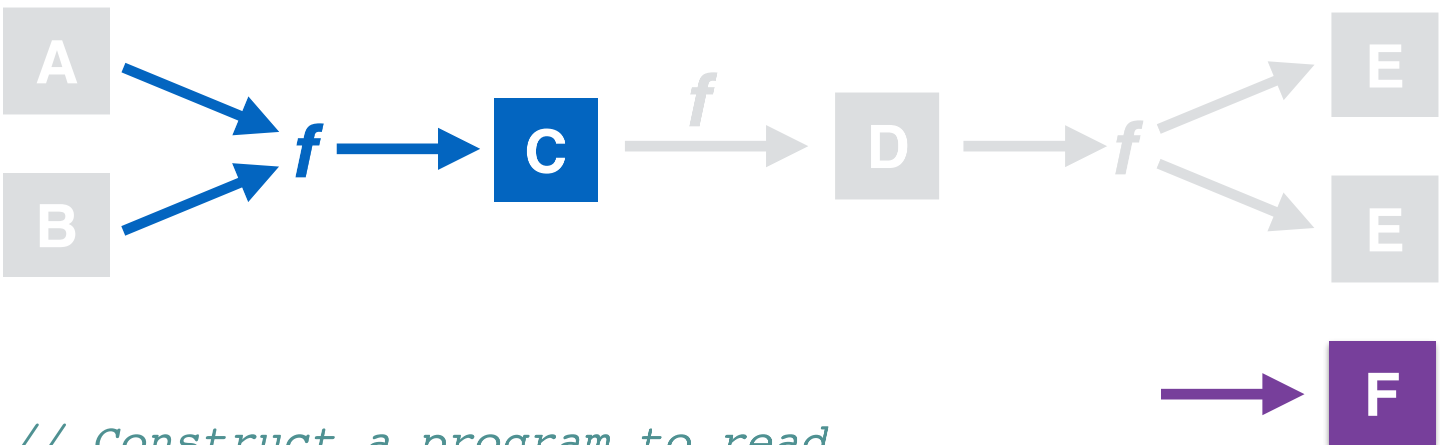

```
// Program to read a person
val getPerson: ResultSetIO[Person] =
  (getString(1) |@| getInt(2)) { (s, n) =>
    Person(s, n)
  }
```

Applicative Operations




```
// Program to move to the next row
// and then read a person
val getNextPerson: ResultSetIO[Person] =
  next *> getPerson
```

Applicative Operations




```
// Construct a program to read
// a list of people
def getPeople(n: Int): ResultSetIO[List[Person]] =
  getNextPerson.replicateM(n)
```

Applicative Operations

```scala
// Implementation of replicateM
def getPeople(n: Int): ResultSetIO[List[Person]] =
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```scala
// Implementation of replicateM
def getPeople(n: Int): ResultSetIO[List[Person]] =
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// List[ResultSetIO[Person]]
List.fill(n)(getNextPerson)
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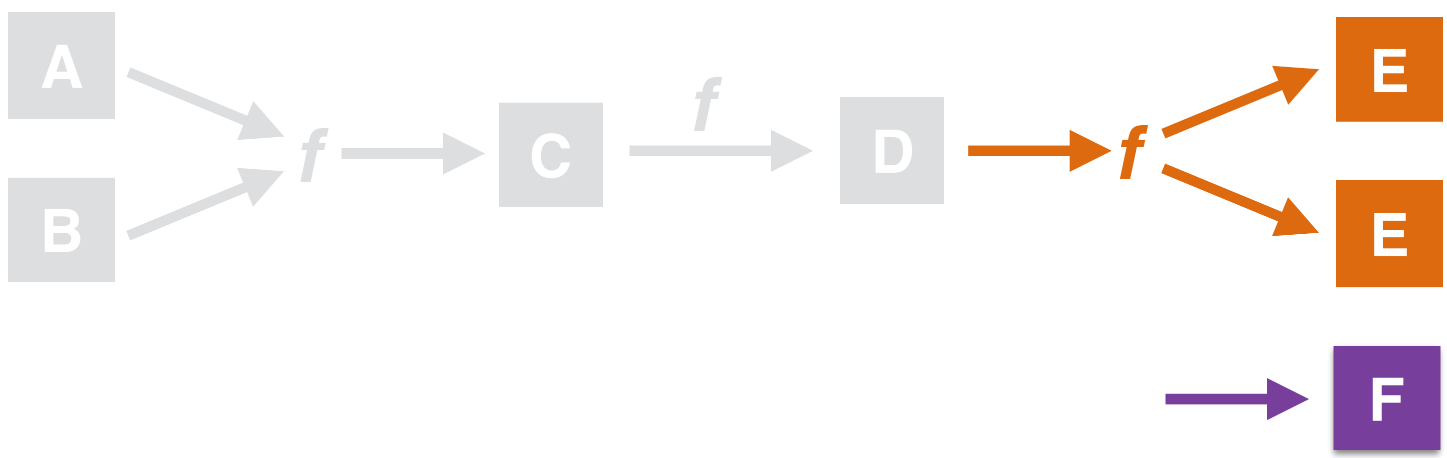
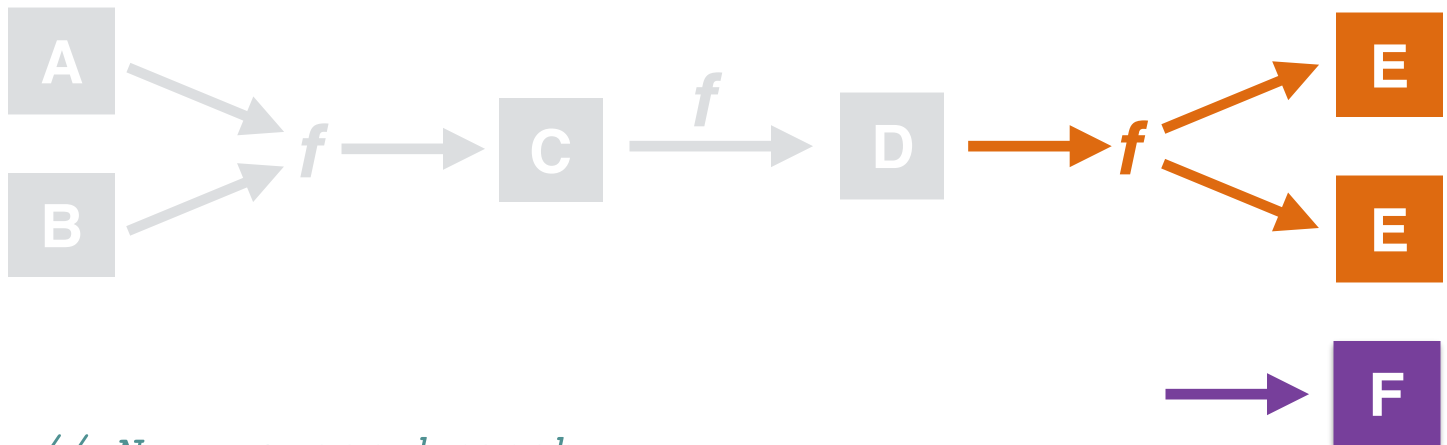
Traverse[List]

Awesome

Monad Operations

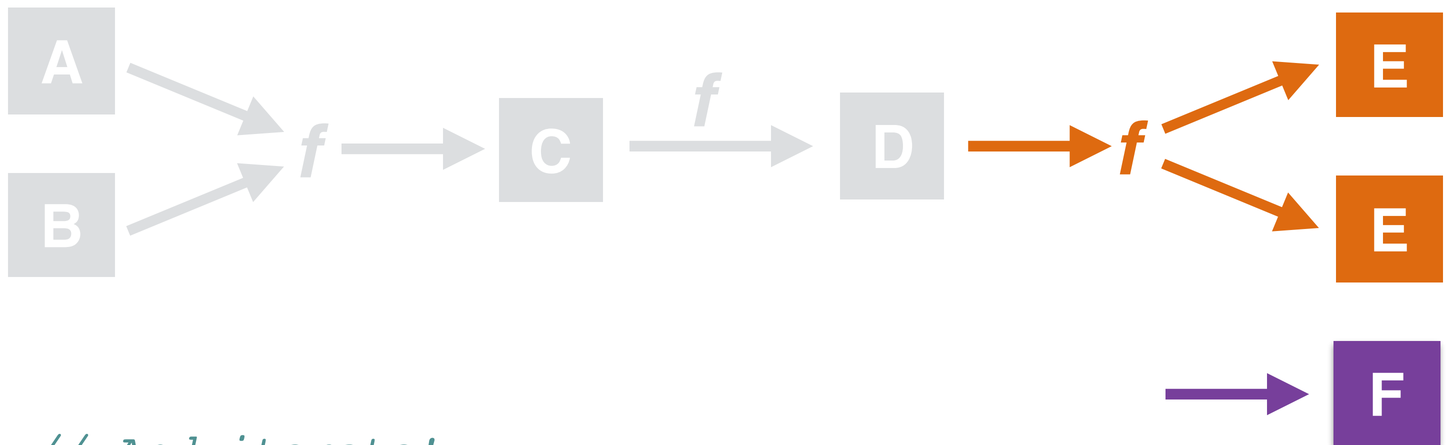


Monad Operations



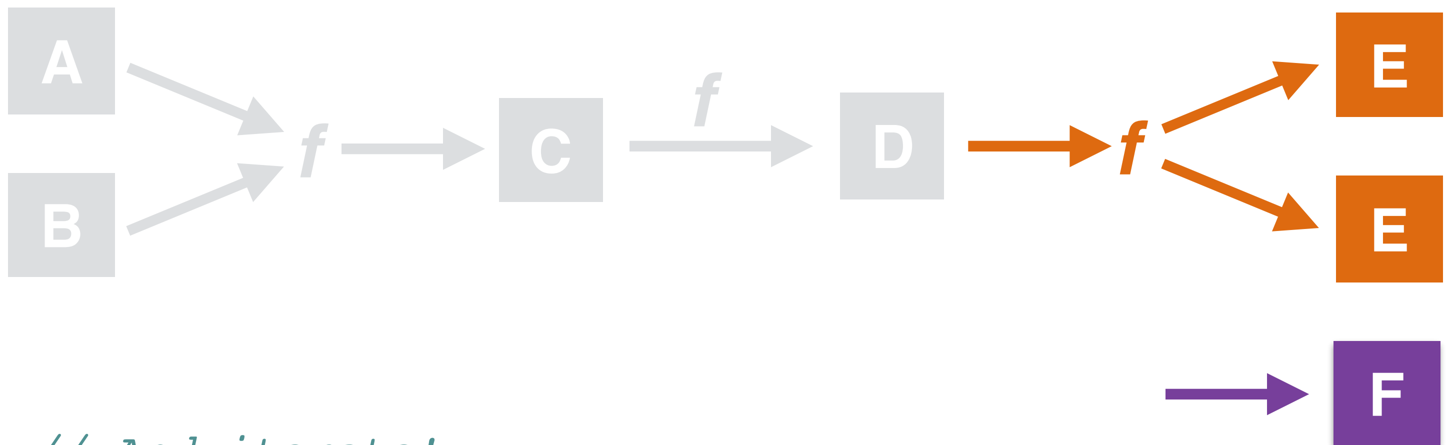

```
// Now we can branch
val getPersonOpt: ResultSetIO[Option[Person]] =
  next.flatMap {
    case true  => getPerson.map(_.some)
    case false => none.point[ResultSetIO]
  }
```

Monad Operations




```
// And iterate!
val getAllPeople: ResultSetIO[Vector[Person]] =
  next.whileM[Vector](getPerson)
```

Monad Operations

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- We can write little programs with this made-up data type and they are pure values and have nice compositional properties.
- But how do we, um ... run them?

Interpreting

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- This is called a **natural transformation** and is written `ResultSetOp ~> M`.

Interpreting

Here we interpret into **`scalaz.effect.IO`**

```
def trans(rs: ResultSet) =
  new (ResultSetOp ~> IO) {
    def apply[A](fa: ResultSetOp[A]): IO[A] =
      fa match {
        case Next         => IO(rs.next)
        case GetInt(i)    => IO(rs.getInt(i))
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      }
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ResultSetOp

Target Monad

Running

```scala
def toIO[A](a: ResultSetIO[A], rs: ResultSet): IO[A] =
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Program written in FreeC

Natural Transformation

Target

```scala
val prog = next.whileM[List](getPerson)
toIO(prog, rs).unsafePerformIO // List[Person]
```

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- Low-level API is basically exactly this, for **all** of JDBC.

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PreparedStatementIO[A]     RefIO[A]
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Fine. What's doobie?

- Low-level API is basically exactly this, for **all** of JDBC.

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- Pure functional support for all primitive operations.
- Machine-generated (!)

Exception Handling

```
val ma = ConnectionIO[A]

ma.attempt // ConnectionIO[Throwable \/ A]

// General
ma.attemptSome(handler)
ma.except(handler)
ma.exceptSome(handler)
ma.onException(action)
ma.ensuring(sequel)

// SQLException
ma.attemptSql
ma.attemptSqlState
ma.attemptSomeSqlState(handler)
ma.exceptSql(handler)
ma.exceptSqlState(handler)
ma.exceptSomeSqlState(handler)

// PostgreSQL (hundreds more)
ma.onWarning(handler)
ma.onDynamicResultSetsReturned(handler)
ma.onImplicitZeroBitPadding(handler)
ma.onNullValueEliminatedInSetFunction(handler)
ma.onPrivilegeNotGranted(handler)
...
```

Mapping via Typeclass

```scala
case class Person(name: String, age: Int)

val getPerson: ResultSetIO[Person] =
  for {
    name <- getString(1)
    age  <- getInt(2)
  } yield Person(name, age)
```

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  for {
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```

Abstract over return type

Mapping via Typeclass

```
case class Person(name: String, age: Int)

val getPerson: ResultSetIO[Person] =
  for {
    p <- get[(String, Int)](1)
  } yield Person(p._1, p._2)
```

Generalize to tuples

Mapping via Typeclass

```
case class Person(name: String, age: Int)

val getPerson: ResultSetIO[Person] =
  for {
    p <- get[Person](1)
  } yield p
```

Generalize to Products

Mapping via Typeclass

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case class Person(name: String, age: Int)

val getPerson: ResultSetIO[Person] =
  get[Person](1)
```

Mapping via Typeclass

```scala
case class Person(name: String, age: Int)

val getPerson: ResultSetIO[Person] =
  get[Person]
```

Mapping via Typeclass

```scala
case class Person(name: String, age: Int)

get[Person]
```

Mapping via Typeclass

```scala
case class Person(name: String, age: Int)

get[Person]
```

This is how you would really write it in doobie.

Streaming

Streaming

```scala
// One way to read into a List
val readAll: ResultSetIO[List[Person]] =
  next.whileM[List](get[Person])
```

Streaming

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// One way to read into a List
val readAll: ResultSetIO[List[Person]] =
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// Another way
val people: Process[ResultSetIO, Person] =
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Streaming

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// Another way
val people: Process[ResultSetIO, Person] =
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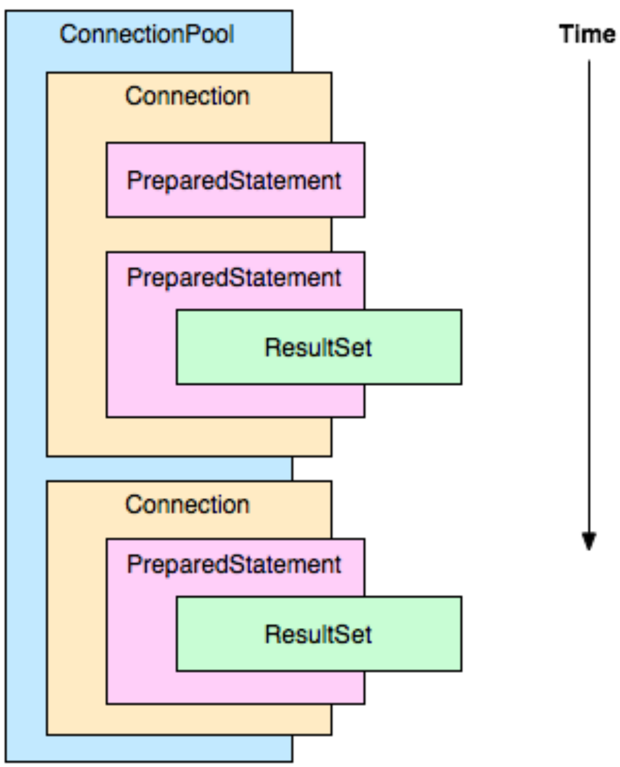
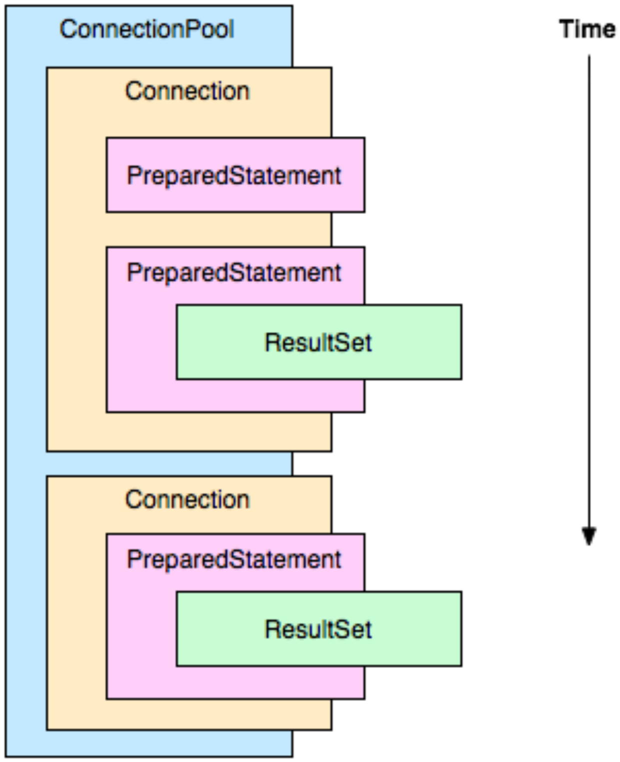
people
   .filter(_.name.length > 5)
   .take(20)
   .moreStuff
   .list         // ResultSetIO[List[Person]]
```

High-Level API



High-Level API



doobie programs can be nested, matching the natural structure of database interactions.

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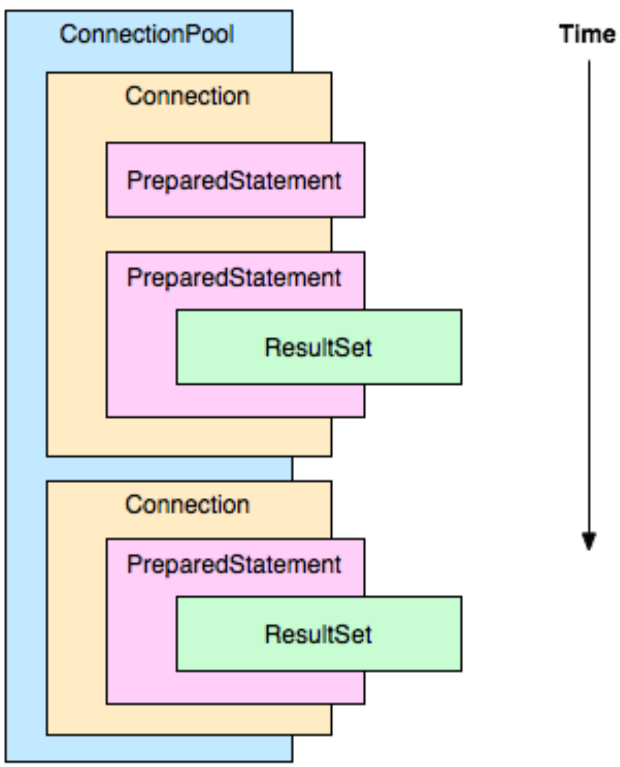

doobie programs can be nested, matching the natural structure of database interactions.

Some of the common patterns are provided in a high-level API that abstracts the lifting.

High-Level API

```
case class Country(name: String, code: String, pop: BigDecimal)


def biggerThan(pop: Int) =
  sql"""
    select code, name, gnp from country
    where population > $pop
  """.query[Country]
```

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Typed

Yields Countries

High-Level API

```
scala> biggerThan(100000000)
     |   .process       // Process[ConnectionIO, Person]
     |   .take(5)       // Process[ConnectionIO, Person]
     |   .list          // ConnectionIO[List[Person]]
     |   .transact(xa)  // Task[List[Person]]
     |   .run           // List[Person]
     |   .foreach(println)
Country(BGD,Bangladesh,32852.00)
Country(BRA,Brazil,776739.00)
Country(IDN,Indonesia,84982.00)
Country(IND,India,447114.00)
Country(JPN,Japan,3787042.00)
```

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Transactor[Task]

YOLO Mode

```
scala> biggerThan(100000000)
     |   .process       // Process[ConnectionIO, Person]
     |   .take(5)       // Process[ConnectionIO, Person]
     |   .quick         // Task[Unit]
     |   .run           // Unit
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Ambient Transactor
Just for Experimenting
in the REPL

YOLO MODE

```
scala> biggerThan(0).check.run

  select code, name, gnp from country where population > ?

  ✓ SQL Compiles and Typechecks
  ✓ P01 Int  →  INTEGER (int4)
  ✓ C01 code CHAR    (bpchar)  NOT NULL  → String
  ✓ C02 name VARCHAR (varchar) NOT NULL  → String
  ✕ C03 gnp  NUMERIC (numeric) NULL      → BigDecimal
    - Reading a NULL value into BigDecimal will result in a runtime
      failure. Fix this by making the schema type NOT NULL or by
      changing the Scala type to Option[BigDecimal]
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```

Can also do this in your unit tests!

Much More

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- Extremely simple **custom type mappings** for columns and composite types.

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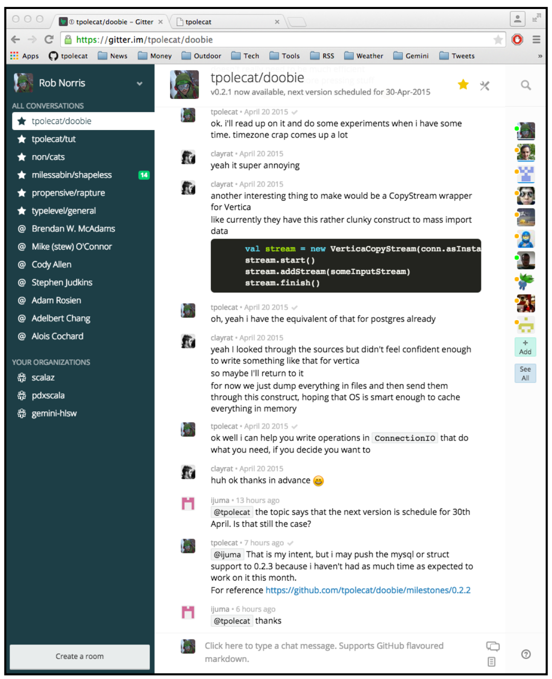
- **Connection Pooling** with HikariCP, easily extended for other pooling implementations.
- **Syntax aplenty**, to make fancy types easier to work with.
- **PostgreSQL Support**: Geometric Types, Arrays, PostGIS types, LISTEN/NOTIFY, CopyIn/Out, Large Objects, …

Moar Info

https://github.com/tpolecat/doobie

gitter



book of doobie