Reactive Slick
for Database Programming

Stefan Zeiger

Typesafe

Introduction

Slick 3.0 – *Reactive Slick*

- Completely new API for executing database actions
- Old API (*Invoker*, *Executor*) deprecated
  - Will be removed in 3.1
- Execution is asynchronous
  (*Futures*, *Reactive Streams*)

Application Performance

- Keep the CPU busy

The Problem With Threads

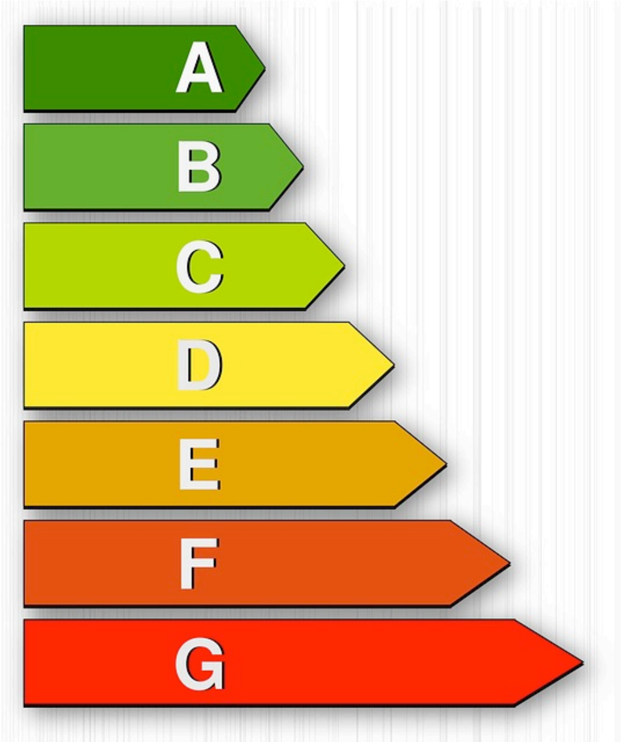
- Context Switching is expensive
- Memory overhead per thread
- Lock contention when communicating between threads

Does not scale!

Application Performance

- Keep the CPU busy

- Be efficient

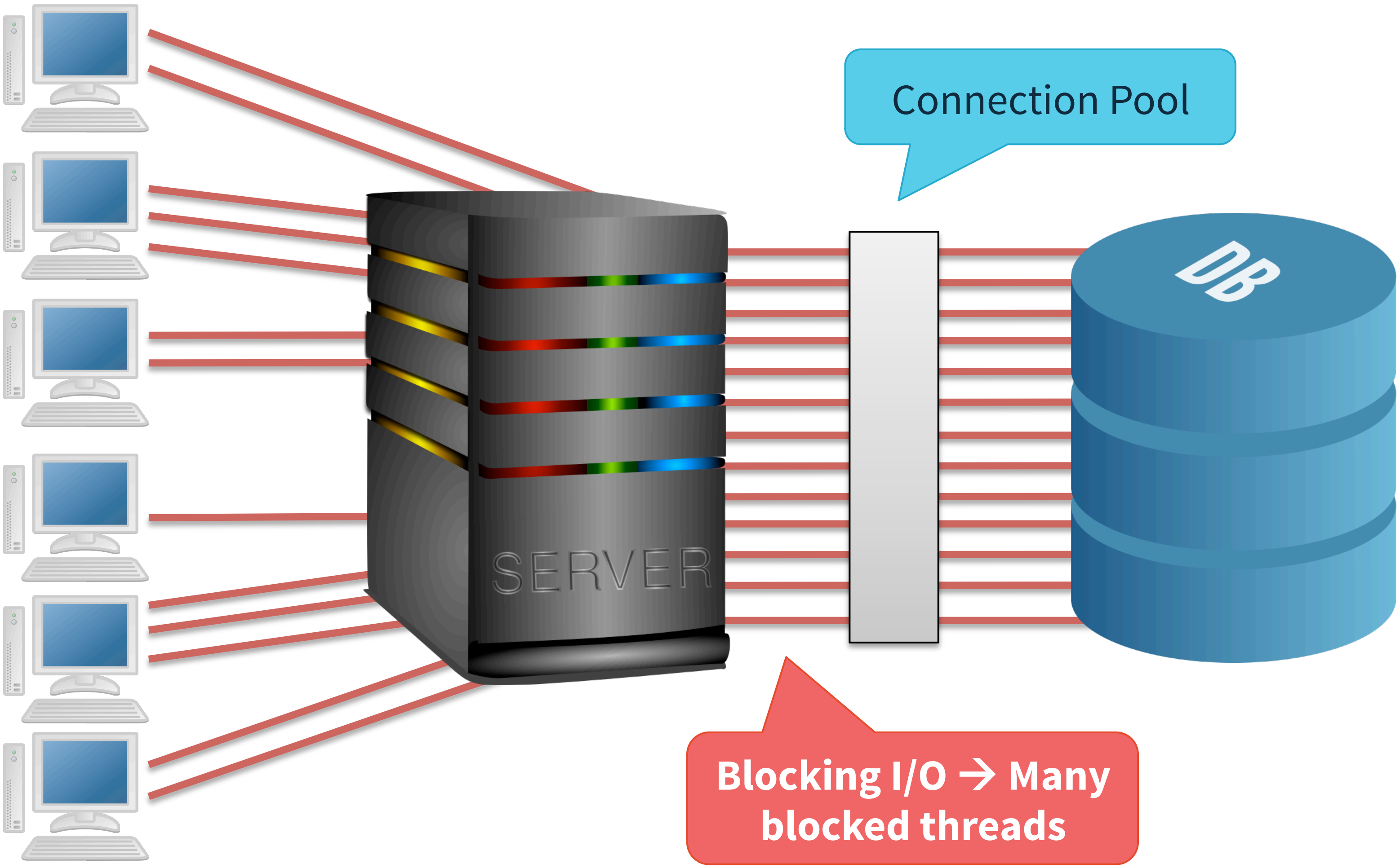


Blocking I/O

- JDBC is inherently blocking (and blocking ties up threads)
- How much of a problem is it really?

Connection Pools

Web Application Architecture: Connections



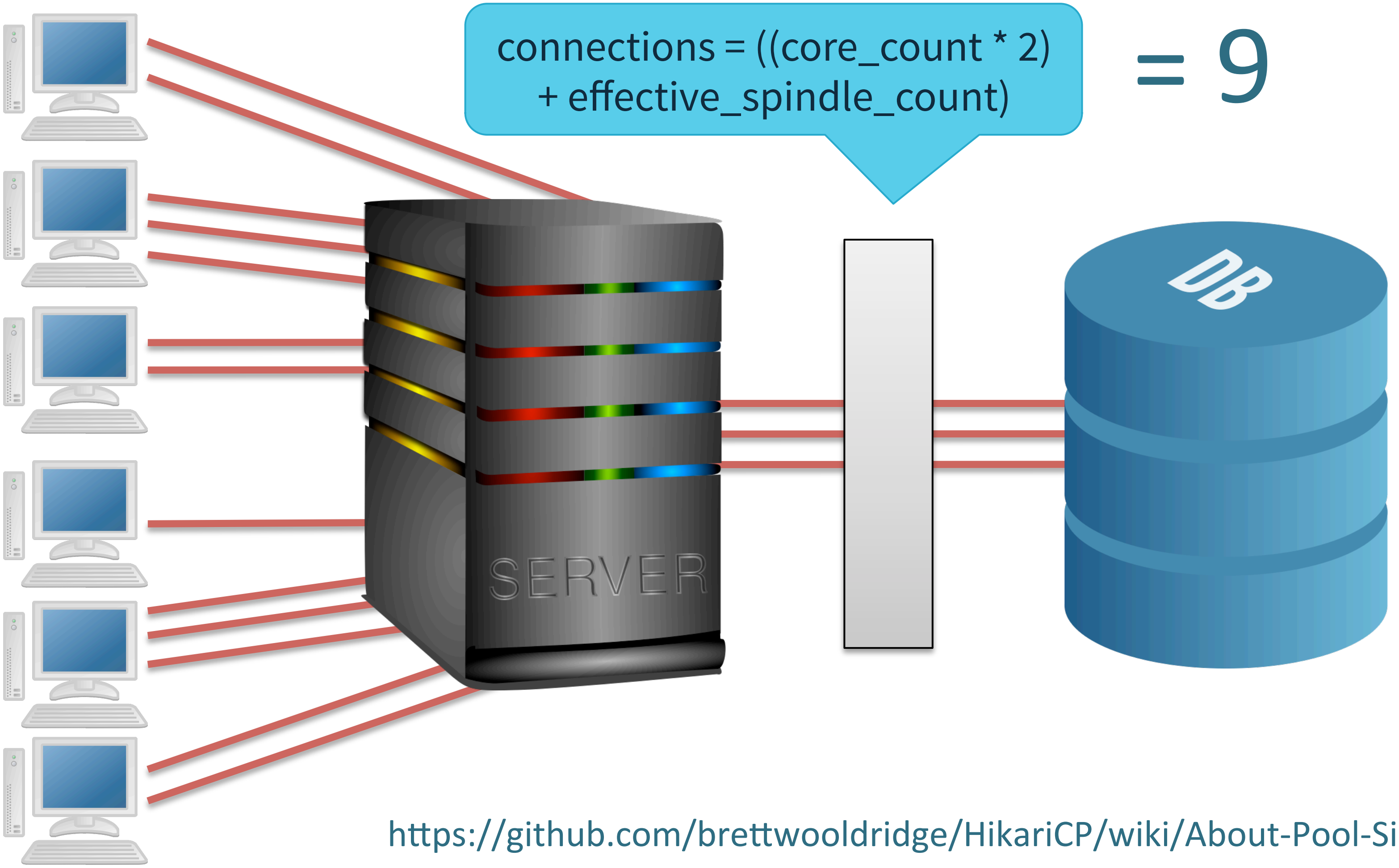
Quiz: Connection Pool Size

- Database server: Latest i7-based Xeon, 4 cores (8 with HyperThreading)
- 2 enterprise-grade 15000 RPM SAS drivers in RAID-1 configuration
- Beefy app server
- 10.000 concurrent connections from clients

What is a good connection pool size?

- 10
- 100
- 1.000
- 10.000

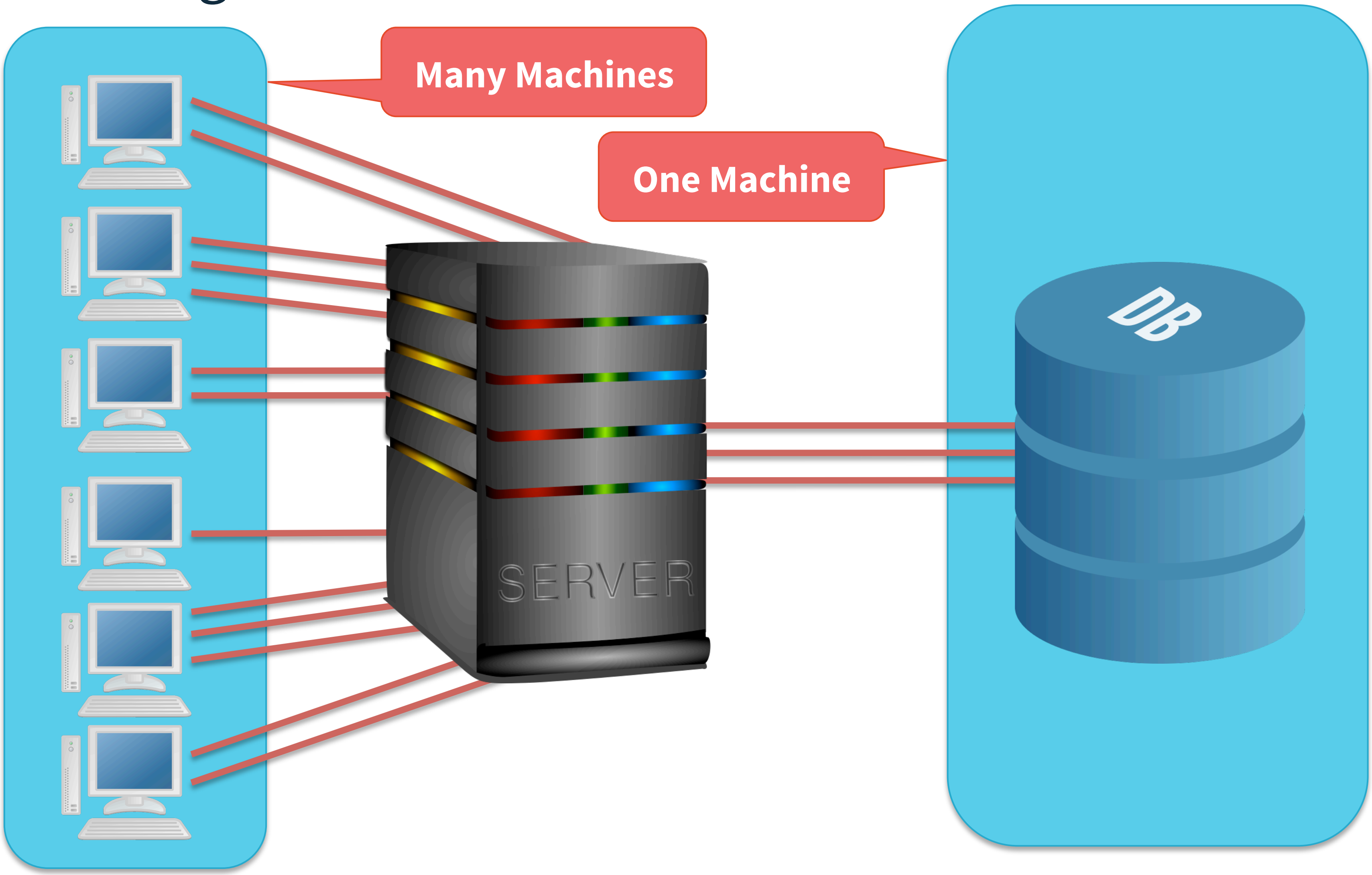
Web Application Architecture: Connections



https://github.com/brettwooldridge/HikariCP/wiki/About-Pool-Sizing

Threading Models

Blocking Web Server Doesn't Scale – But DB Can



The Traditional Model (e.g. JEE)

- Fully synchronous
- One thread per web request
- **Contention for Connections** (`getConnection` blocks)
- Database back-pressure creates more blocked threads

- Problem: Doesn't scale

Asynchronous Web App: Naive Approach

- Blocking database calls in `Future(blocking( ... ))`
- **Contention for Connections**
  (but may be limited by the ExecutionContext)
- A saturated thread pool blocks *all* I/O

- Problem: Scalability depends on correct configuration of ExecutionContext and connection pool
- Back-pressure on one kind of I/O stops other kinds from working

Asynchronous Web App: *Play-Slick Plugin*

- Special *ExecutionContext* per database
  - Thread pool size limited by connection pool size
- **Contention for Threads**

Remaining Problems

- No clean separation of I/O and CPU-intensive work:

```
table1.insert(table2.filter(...))(session)
```

- Streaming with back-pressure handling either blocks or has a lot of overhead (everything done through `Future`)

- Resource management is hard to get right with asynchronous code:

```
db.withSession { session => Future(...) }
```

Because of explicit mutable state

Pure Functional I/O

THIS OBJECT IS JUST A MONOID IN THE CATEGORY OF ENDOFUNCTORS

What is a Monad?

In functional programming, a monad is ***a structure that represents computations defined as sequences of steps****: a type with a monad structure defines what it means to chain operations, or nest functions of that type together. This allows the programmer to build pipelines that process data in steps, in which each action is decorated with additional processing rules provided by the monad. As such, monads have been described as "****programmable semicolons****"*

(Wikipedia)

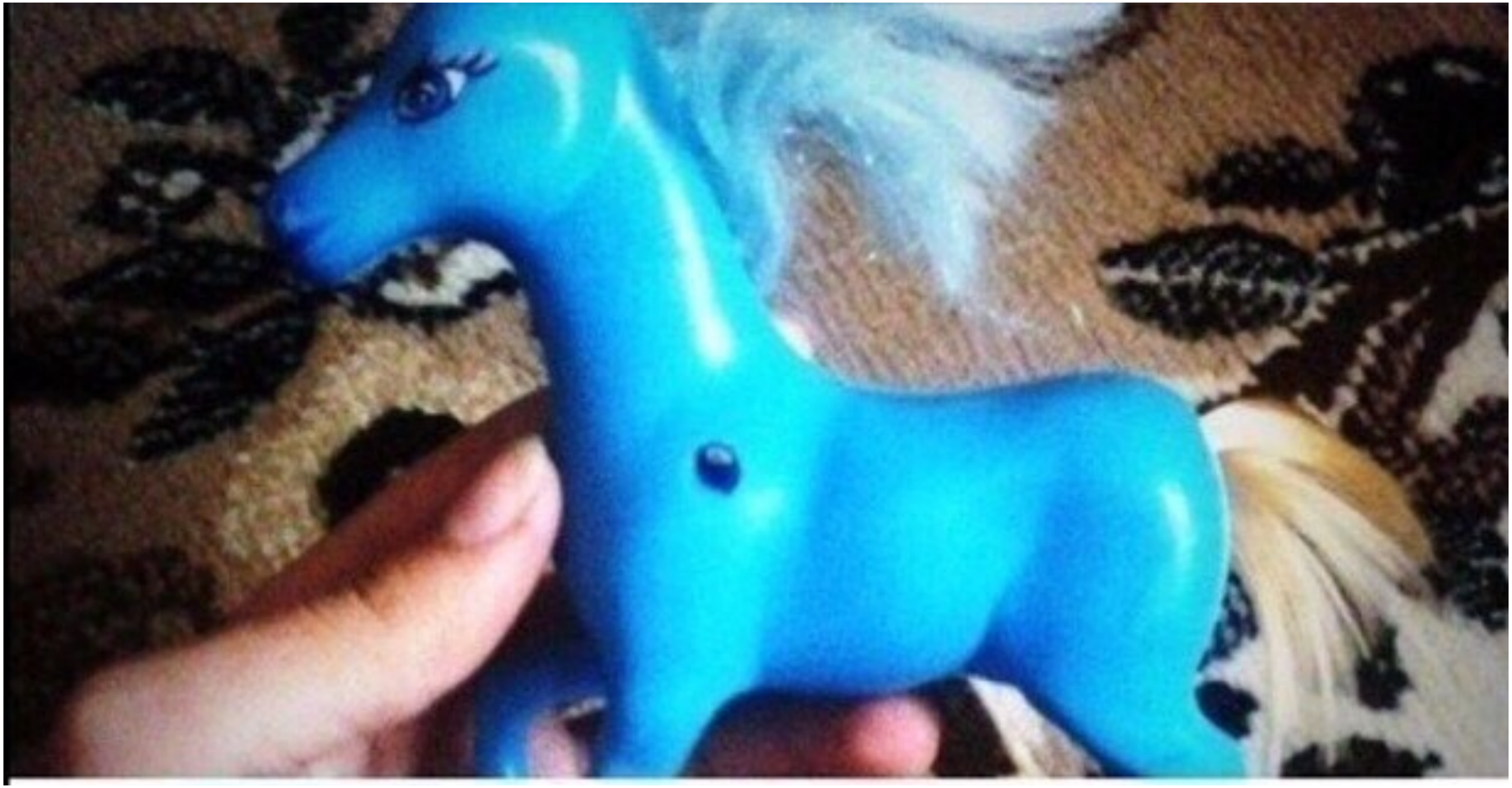
The *State* Monad

```scala
val st = for {
  i <- State.get[Int]
  _ <- State.set(i + 3)
  j <- State.get
  _ <- State.set(j - 2)
  k <- State.get
} yield k
```

```
def st = {
  i = get[Int] ;
      set(i + 3) ;
  j = get ;
      set(j - 2) ;
  k = get ;
  return k
}
```

```scala
State.run(41, st)    ➔    42
```

The *State* Monad



The *State* Monad

The *State* Monad

```
trait State[S, R] extends (S => (S, R))

object State {
  def apply[S, R](v: R): State[S, R] = new State[S, R] {
    def apply(s: S) = (s, v)
  }

  def get[S]: State[S, S] = new State[S, S] {
    def apply(s: S) = (s, s)
  }

  def set[S](v: S): State[S, Unit] = new State[S, Unit] {
    def apply(s: S) = (v, ())
  }

  def run[S, R](s: S, st: State[S, R]): R = st(s)._2
}
```

The *State* Monad

```
trait State[S, R] extends (S => (S, R)) { self =>

  def flatMap[R2](f: R => State[S, R2]): State[S, R2] =
    new State[S, R2] {
      def apply(s: S) = {
        val (s2, r) = self.apply(s)
        f(r)(s2)
      }
    }

  def map[R2](f: R => R2): State[S, R2] =
    flatMap[R2](r => State(f(r)))
}
```

The *IO* Monad

```
val io = for {
  i <- IO.get
  _ <- IO.set(i + 3)
  j <- IO.get
  _ <- IO.set(j - 2)
  k <- IO.get
} yield k

new DB(41).run(io)    ➔     42

class DB(var i: Int) {
  def run[R](io: IO[R]): R = io(this)
}
```

The *IO* Monad

```
trait IO[R] extends (DB => R)

object IO {
  ...

  def set(v: Int): IO[Unit] = new IO[Unit] {
    def apply(db: DB) = db.i = v
  }
}
```

The *IO* Monad

```
trait IO[R] extends (DB => R) { self =>

  def flatMap[R2](f: R => IO[R2]): IO[R2] =
    new IO[R2] {
      def apply(db: DB) = f(self.apply(db))(db)
    }

  def map[R2](f: R => R2): IO[R2] =
    flatMap[R2](r => IO(f(r)))
}
```

Hiding The Mutable State

```
trait IO[R] extends (DB => R)
```

Hiding The Mutable State

```
trait IO[R] {
  def flatMap[R2](f: R => IO[R2]): IO[R2] =
    new FlatMapIO[R2](f)
}

class FlatMapIO[R, R2](f: R => IO[R2]) extends IO[R2]

class DB(var i: Int) {
  def run[R](io: IO[R]): R = io match {
    case FlatMapIO(f) => ...
    case ...
  }
}
```

Asynchronous Programming

The *Future* Monad

- You already use monadic style for asynchronous programming in Scala
- Futures abstract over blocking:

```
f1.flatMap { _ => f2 }
```

f1 could block, run synchronously or asynchronously, or finish immediately

- But Futures are not sequential
  - Only their results are used sequentially

Asynchronous Database I/O

```
trait DatabaseDef {

  def run[R](a: DBIOAction[R, NoStream, Nothing])
            : Future[R]
}
```

- Lift code into `DBIO` for sequential execution in a database session
- Run `DBIO` to obtain a `Future` for further asynchronous composition

DBIO Combinators

- ```
  val a1 = for {
    _ <- (xs.schema ++ ys.schema).create
    _ <- xs ++= Seq((1, "a"), (2, "b"))
    _ <- ys ++= Seq((3, "b"), (4, "d"), (5, "d"))
  } yield ()
  ```
- ```
  val a2 =
    (xs.schema ++ ys.schema).create >>
    (xs ++= Seq((1, "a"), (2, "b"))) >>
    (ys ++= Seq((3, "b"), (4, "d"), (5, "d")))
  ```
  andThen
- ```
  val a3 = DBIO.seq(
    (xs.schema ++ ys.schema).create,
    xs ++= Seq((1, "a"), (2, "b")),
    ys ++= Seq((3, "b"), (4, "d"), (5, "d"))
  )
  ```
  ```

ExecutionContexts

```
trait DBIO[+R] { // Simplified

  def flatMap[R2](f: R => DBIO[R2])
                 (implicit executor: ExecutionContext)
                 : DBIO [R2] =
    FlatMapAction[R2, R](this, f, executor)

  def andThen[R2](a: DBIO[R2])
                 : DBIO[R2] =
    AndThenAction[R2](this, a)

}
```

Fuse synchronous DBIO actions

Streaming Results

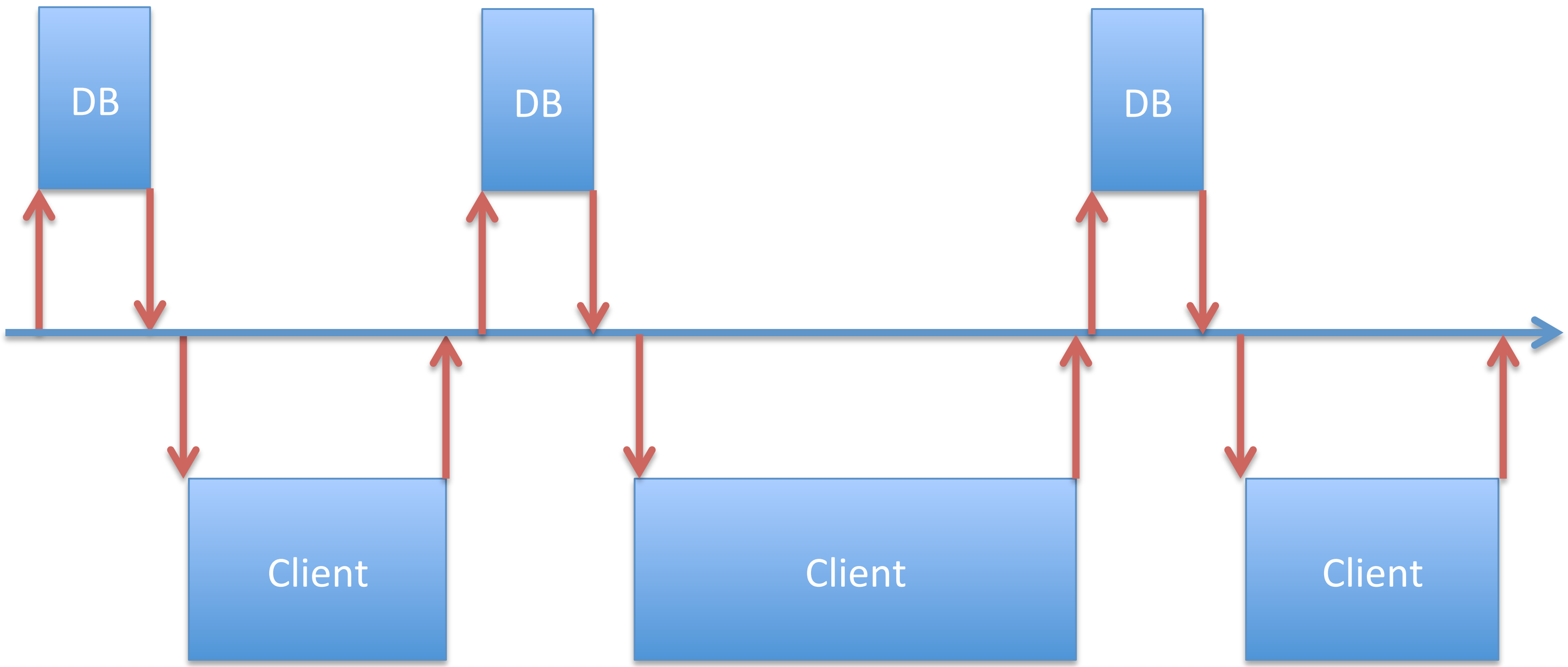
Streaming Queries

- `val q = orders.filter(_.shipped).map(_.orderID)`
- `val a = q.result`
- `val f: Future[Seq[Int]] = db.run(a)`
- `db.stream(a).foreach(println)`

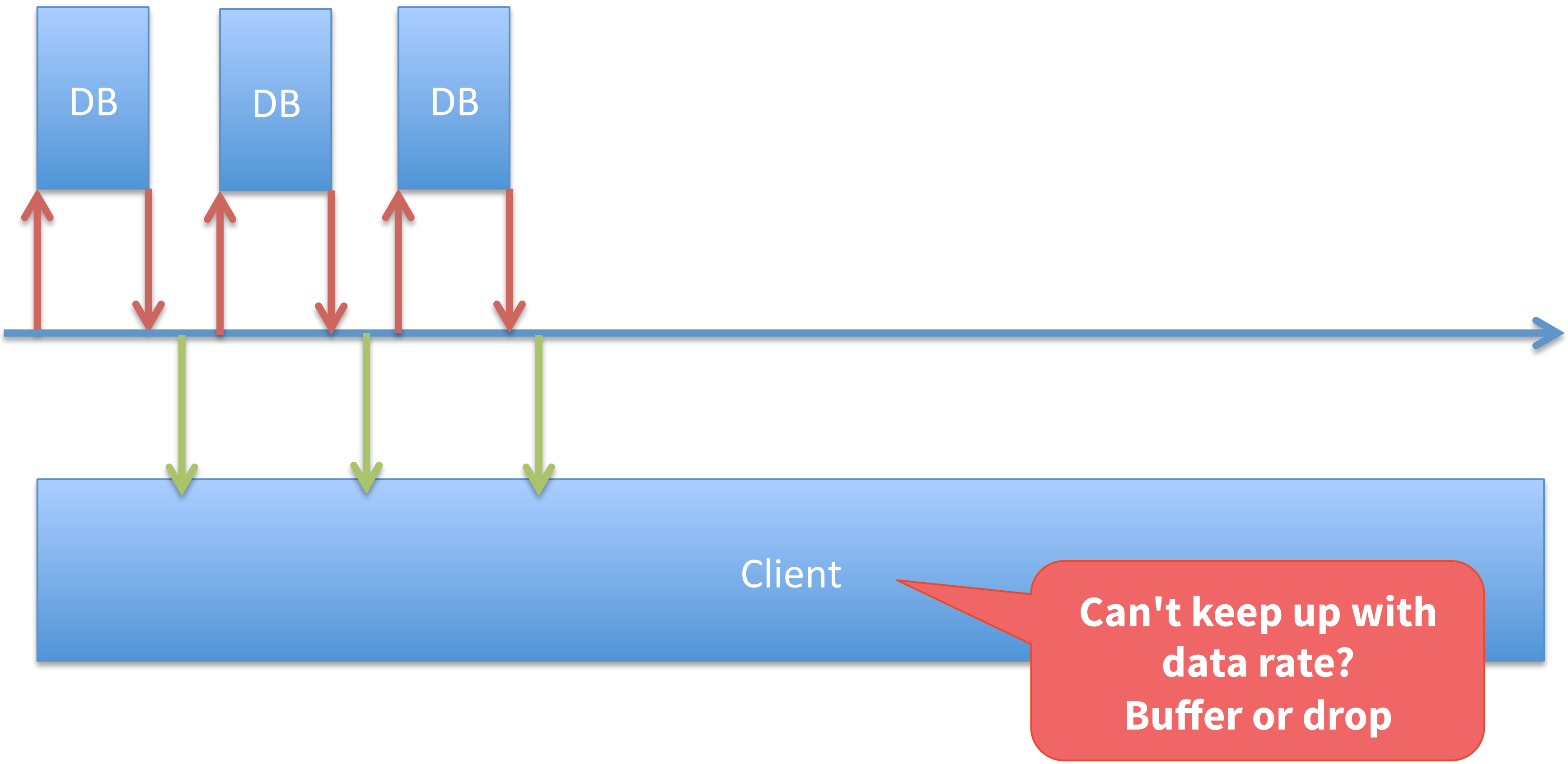
Reactive Streams

- Reactive Streams API: http://www.reactive-streams.org/
- Slick implements `Publisher` for database results
- Use *Akka Streams* for transformations
- *Play* 2.4 will support Reactive Streams
- Asynchronous streaming with back-pressure Handling

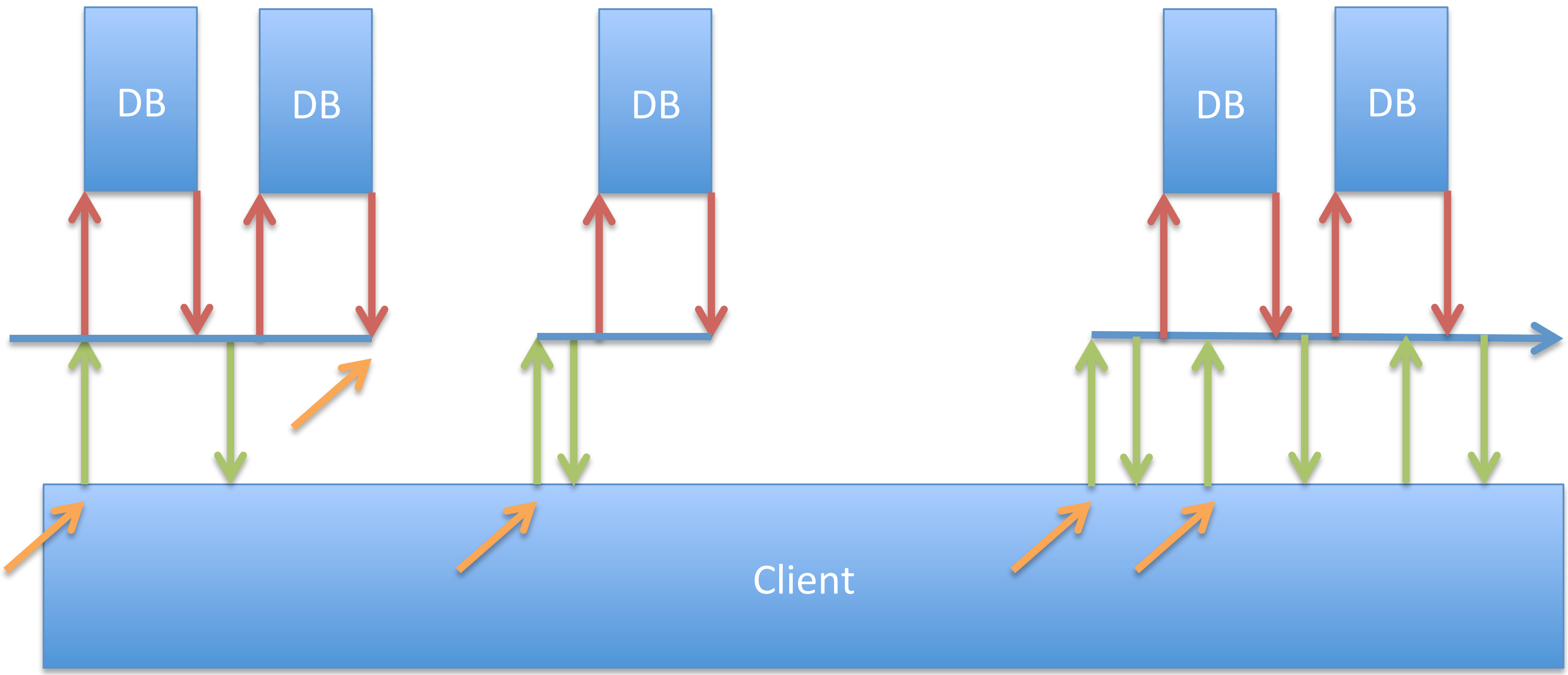
Synchronous (Blocking) Back-Pressure



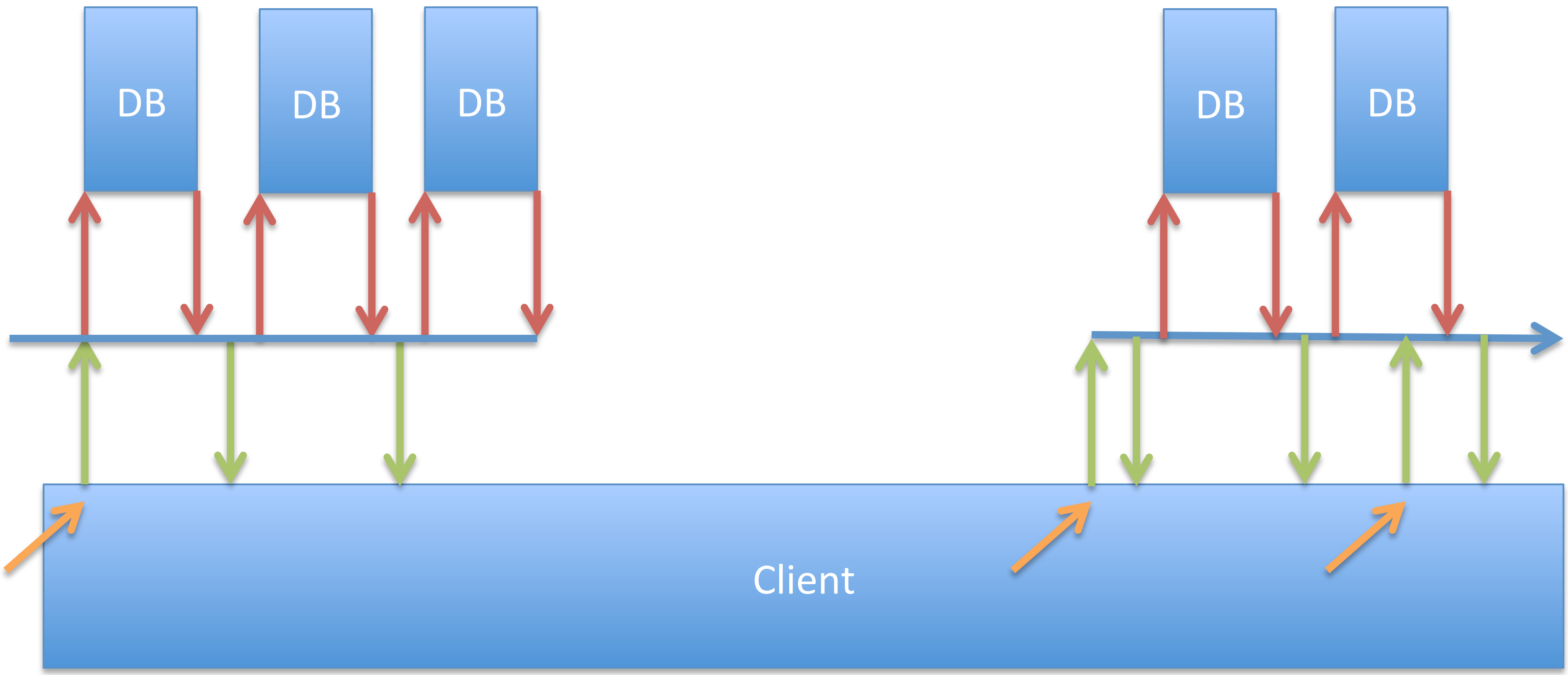
Asynchronous Client: Naive Approach



Asynchronous Client: Request 1



Asynchronous Client: Request 2



Asynchronous Database I/O

```
trait DatabaseDef {

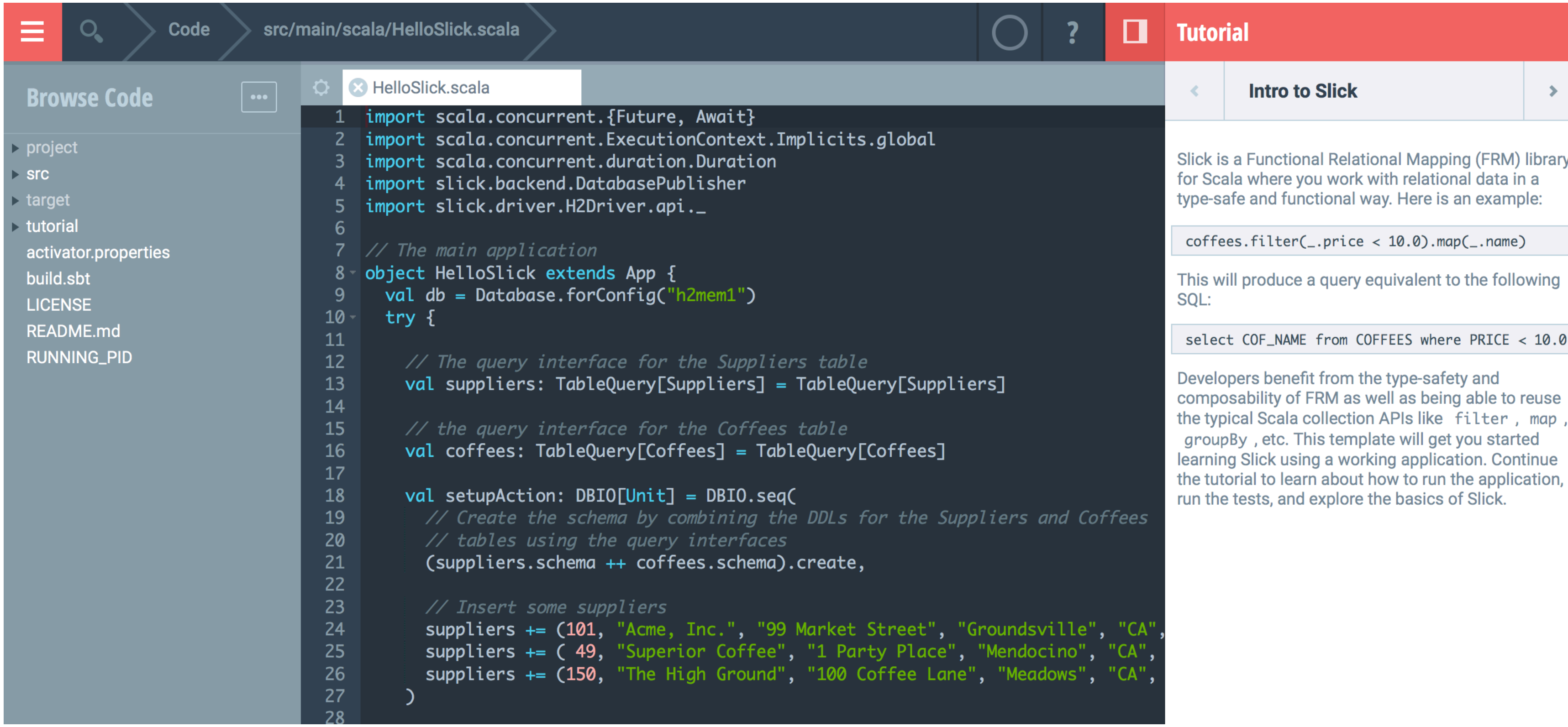
  def run[R](a: DBIOAction[R, NoStream, Nothing])
          : Future[R]

  def stream[T](a: DBIOAction[_, Streaming[T], Nothing])
                : DatabasePublisher[T]
}
```

- Every *Streaming* action an be used as *NoStream*
- Collection-valued database results are *Streaming*
- The action runs when a *Subscriber* is attached

Try it Yourself

Hello Slick (Slick 3.0)



- Typesafe Activator: https://typesafe.com/get-started

Slick 3.0

- DBIO Action API
- Improved Configuration via *Typesafe Config*
- Nested Options and Properly Typed Outer Joins
- Type-Checked Plain SQL Queries

- ~~RC2 Available Now!~~
- RC1 Available Now!

slick.typesafe.com

@StefanZeiger

Typesafe