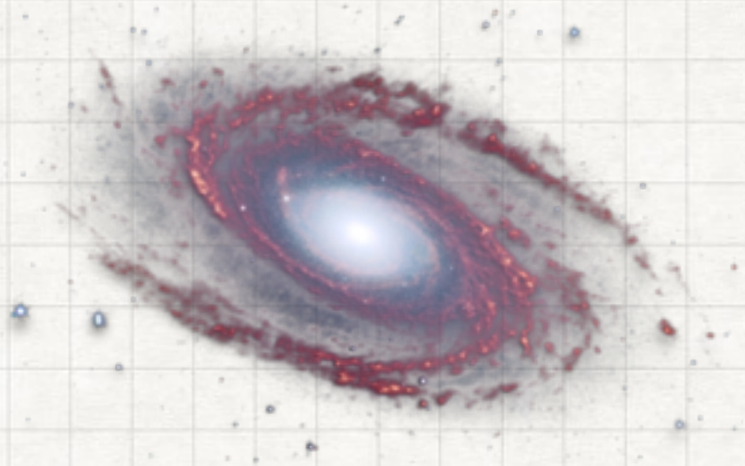
BUILDING STATEFUL SYSTEMS WITH FUNCTIONAL PROGRAMMING

BEN HUTCHISON, V2.0, FEB 2022

IN THE BEGINNING..



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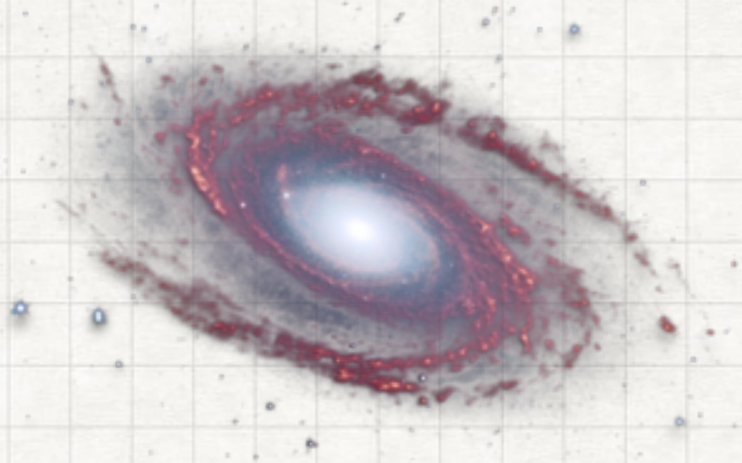

THERE WERE FUNCTIONS

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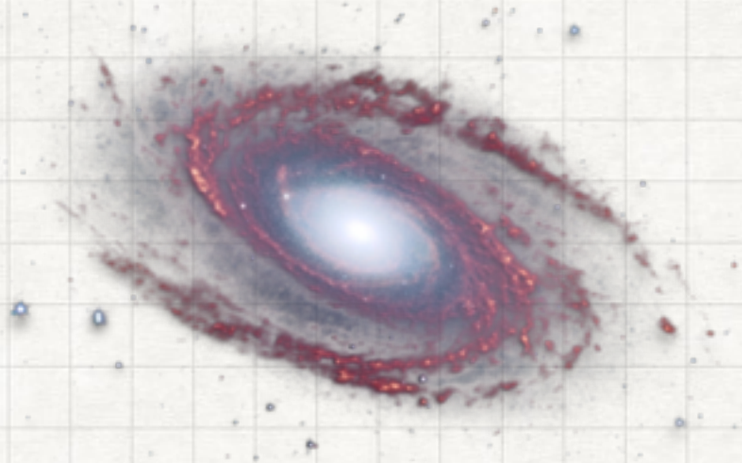

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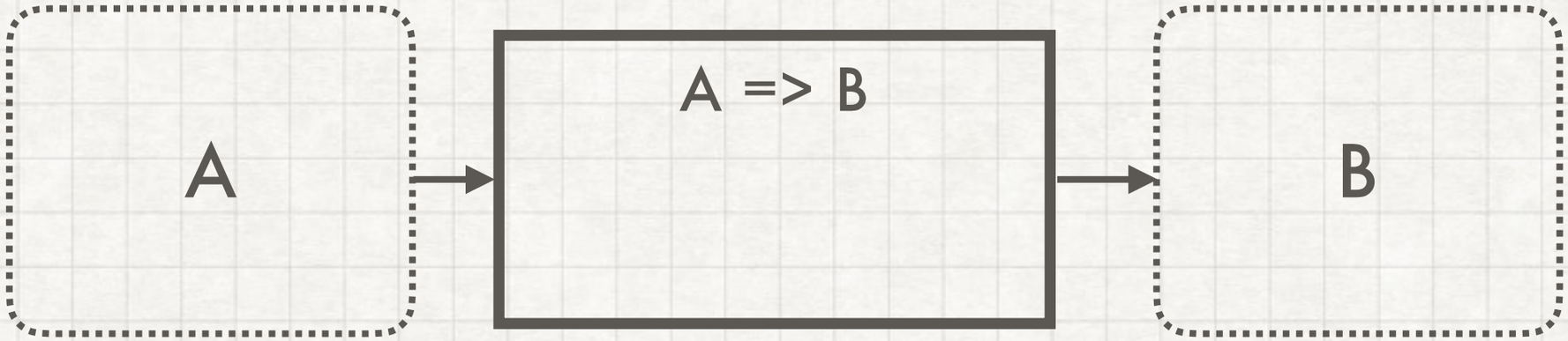

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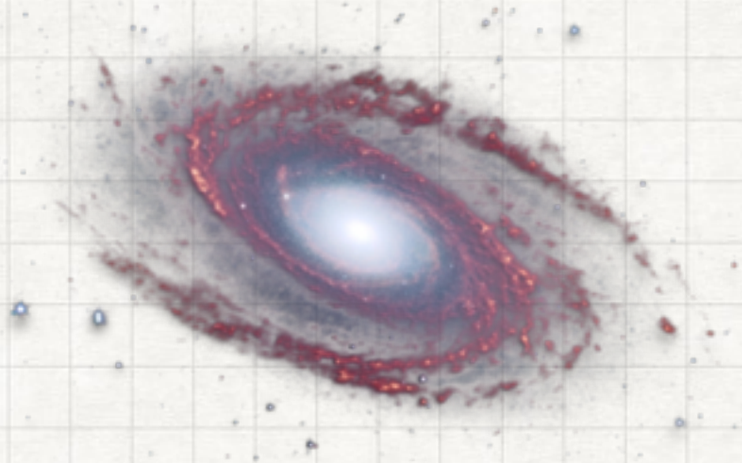

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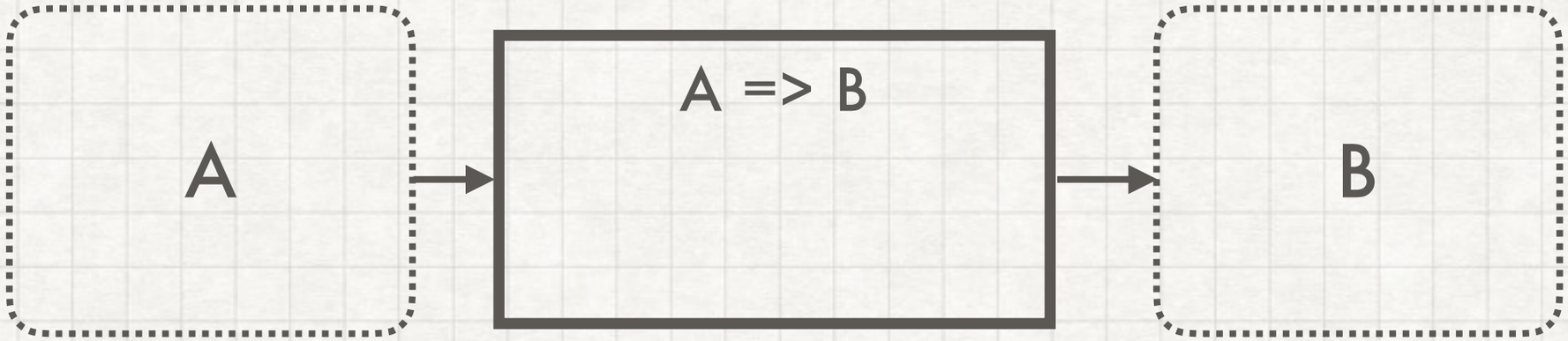

FUNCTIONAL PROGRAMMING = PROGRAMMING WITH FUNCTIONS

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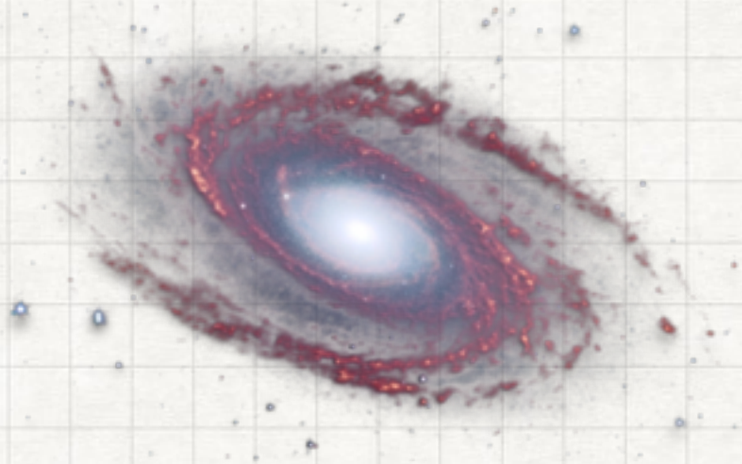

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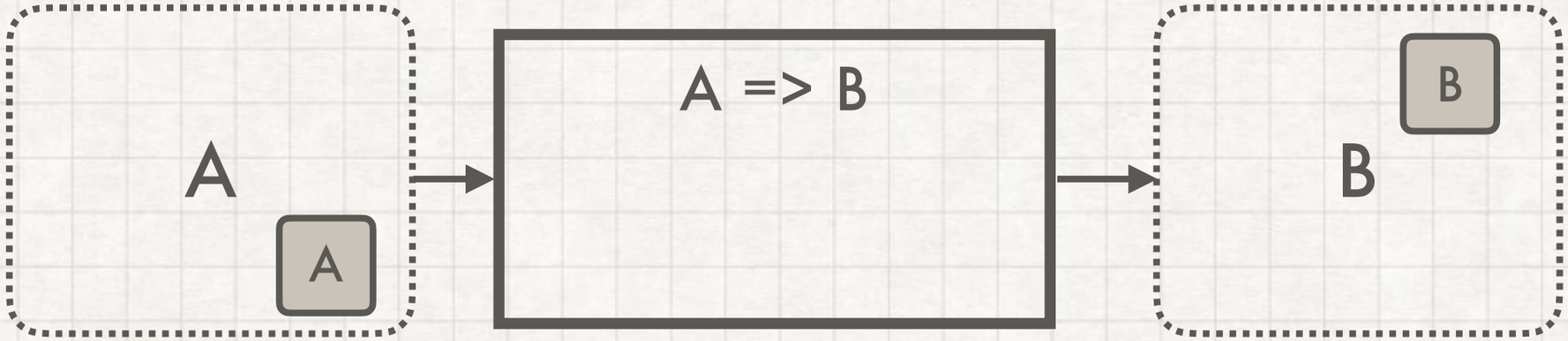

DETERMINISTIC & STATELESS

FUNCTIONAL PROGRAMMING = PROGRAMMING WITH FUNCTIONS

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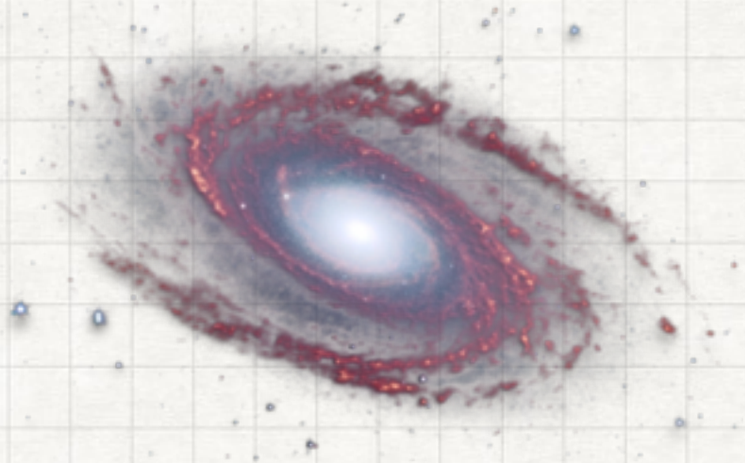

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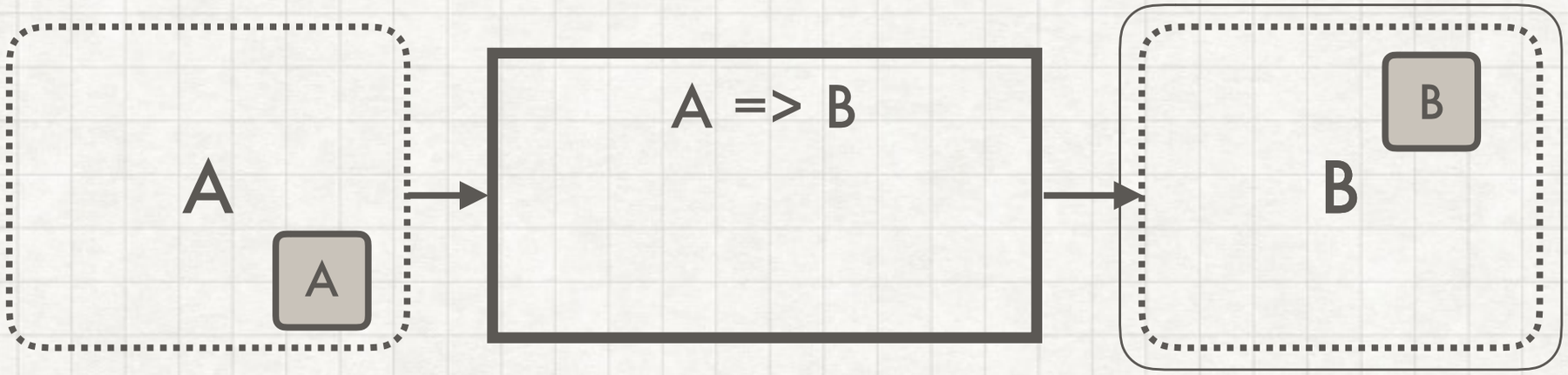

DETERMINISTIC & STATELESS

PURE

FUNCTIONAL PROGRAMMING = PROGRAMMING WITH FUNCTIONS

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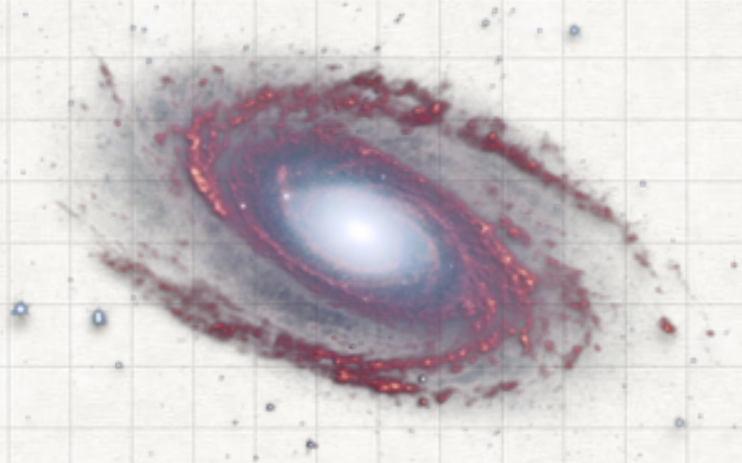

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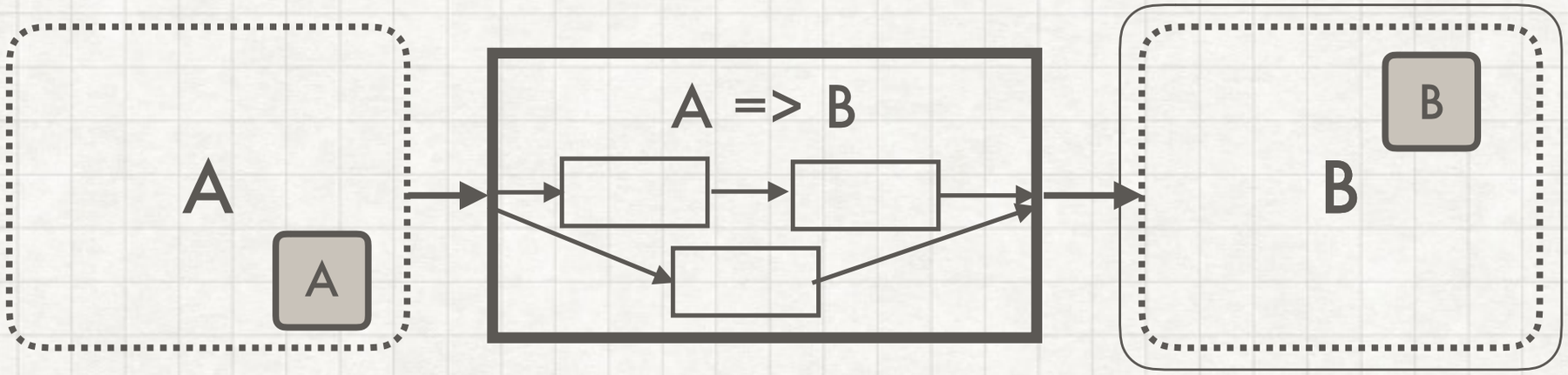

DETERMINISTIC & STATELESS

PURE

COMPOSABLE

FUNCTIONAL PROGRAMMING = PROGRAMMING WITH FUNCTIONS

COMBINING FUNCTIONS WITH STATE

BEN HUTCHISON, V2.0, FEB 2022

STATEFUL SYSTEMS..

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REMEMBER THEIR PAST

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CAN RETURN DIFFERENT VALUES EACH CALL

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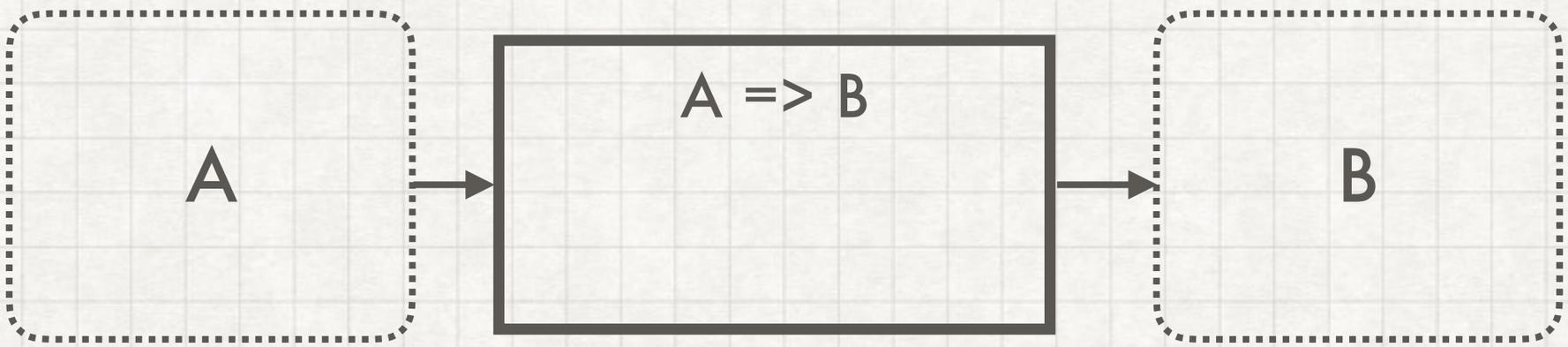
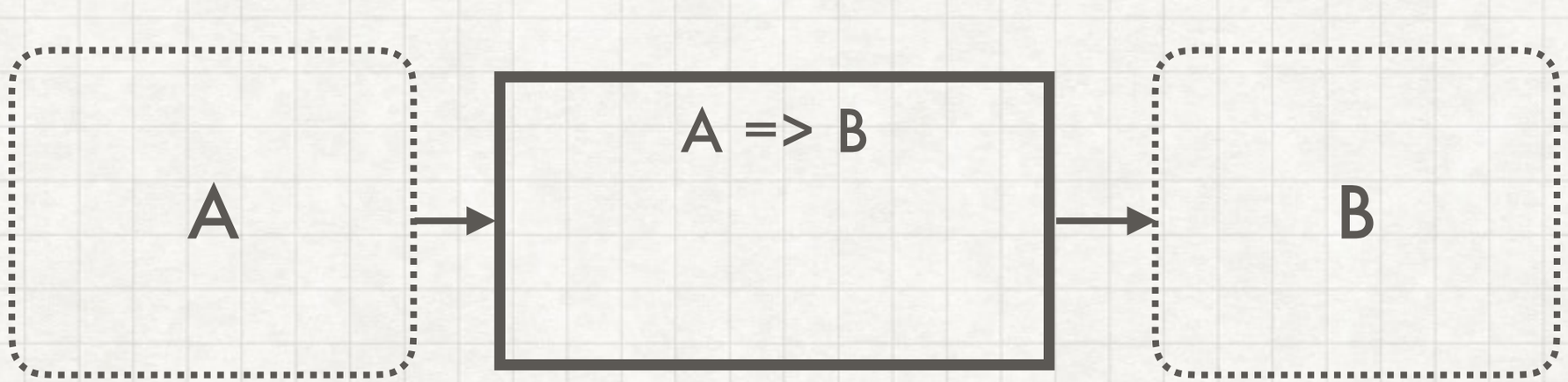
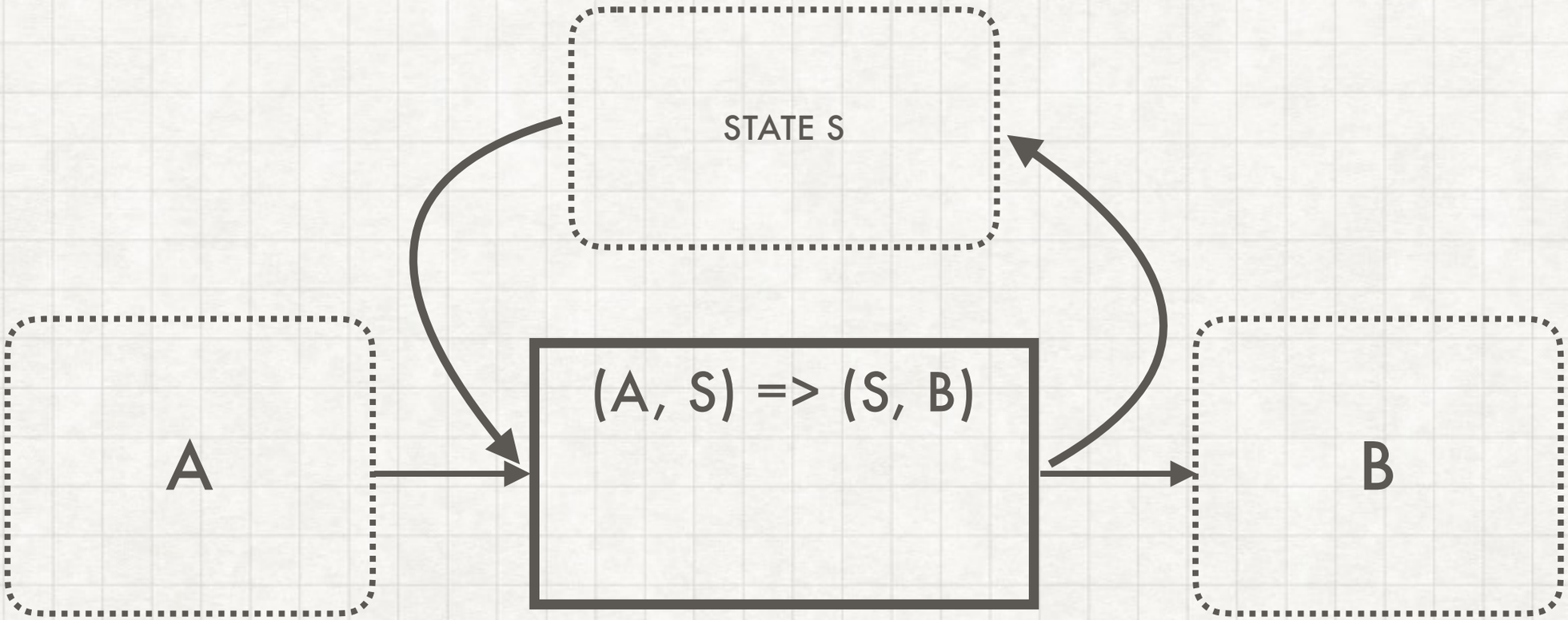


WHAT DO WE NEED TO ADD TO THIS PICTURE?

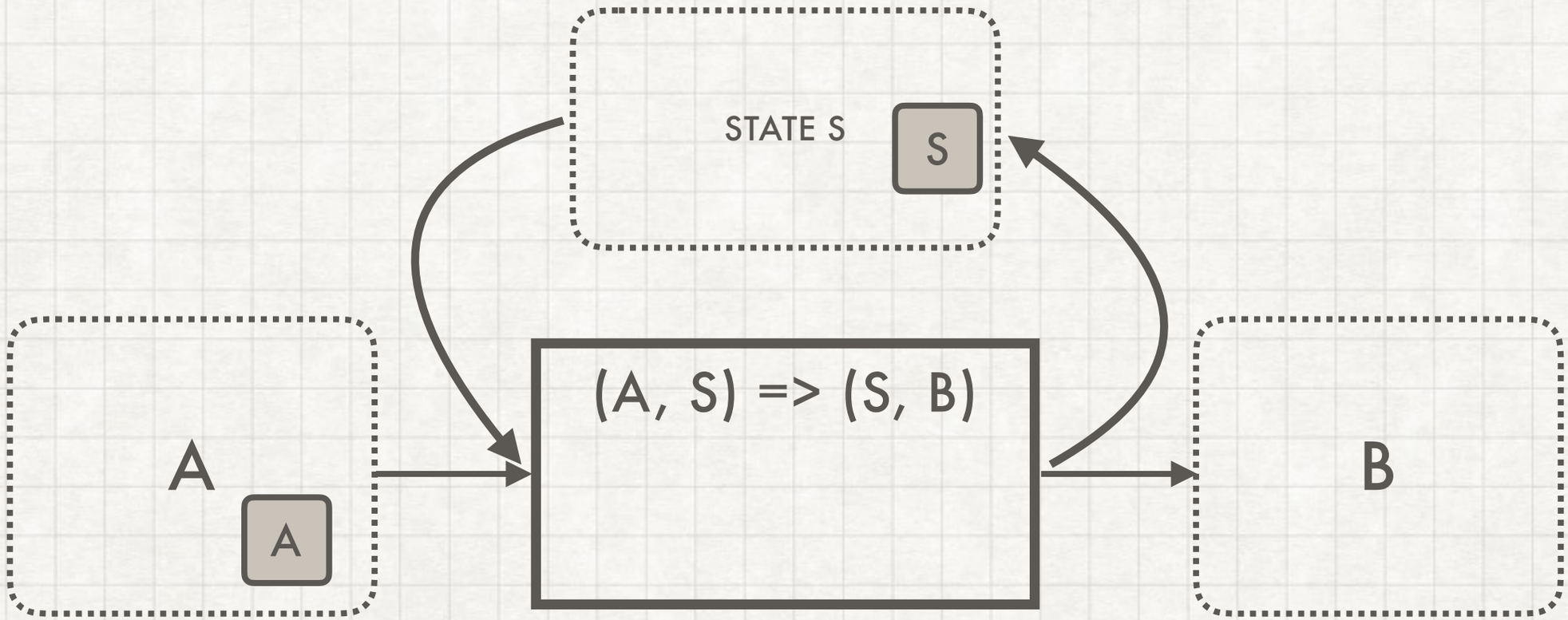

A
A => B
B

PAIR: PURE FUNCTION + STATE STORE



PAIR: PURE FUNCTION + STATE STORE

IN: INPUT A + CURRENT STATE S



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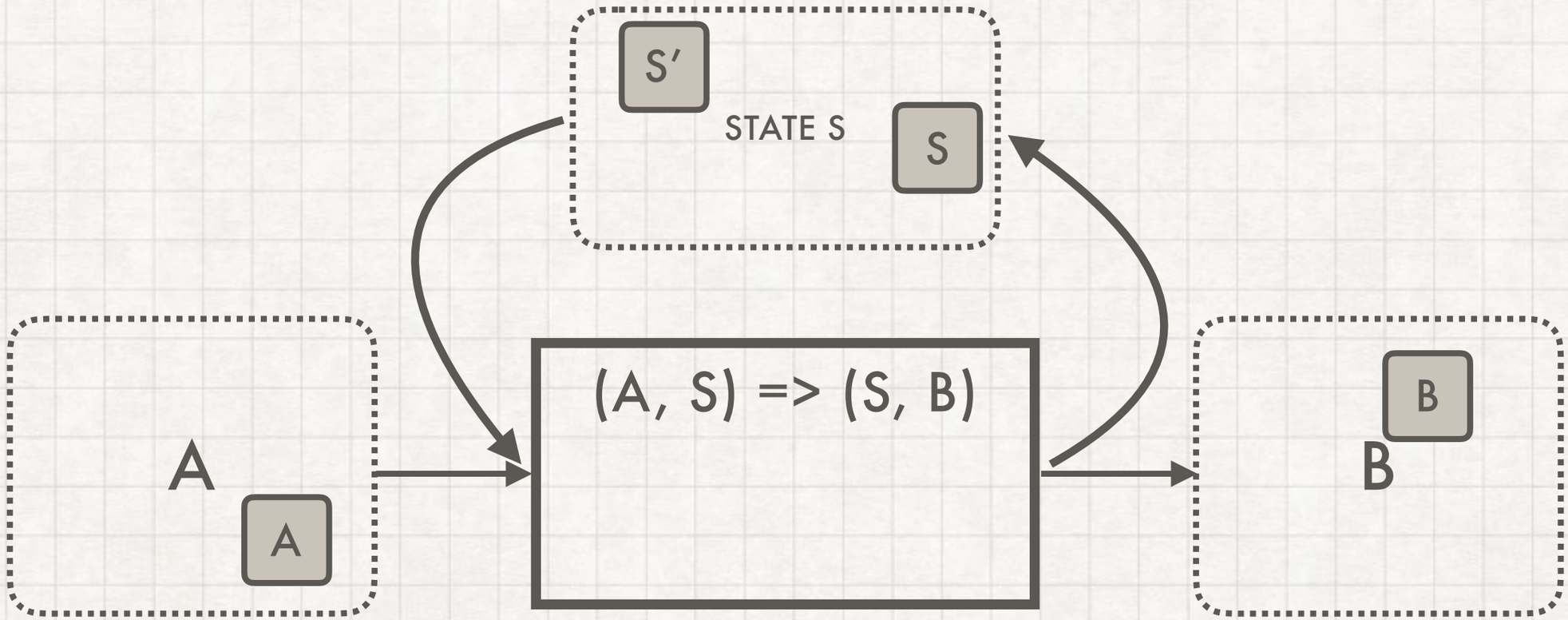
OUT: OUTPUT B + NEXT STATE S′



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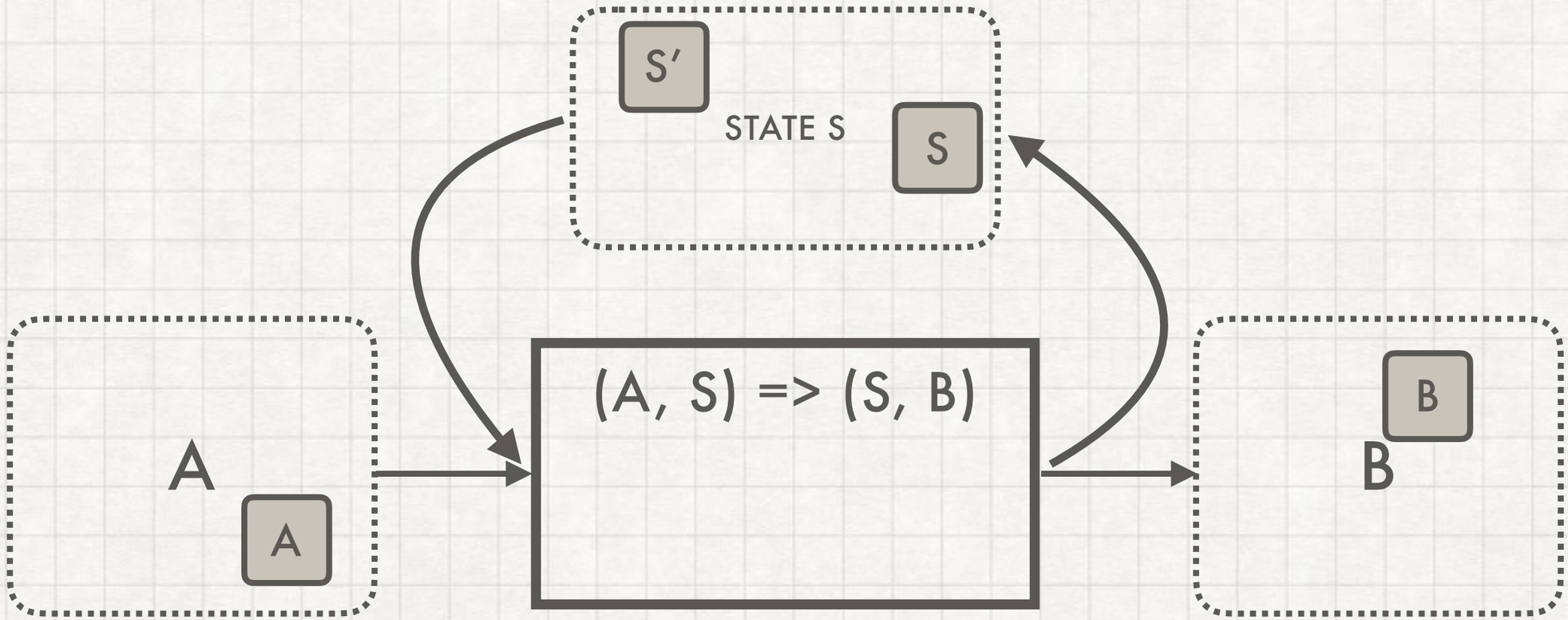

THE KEY IDEA OF THIS TALK

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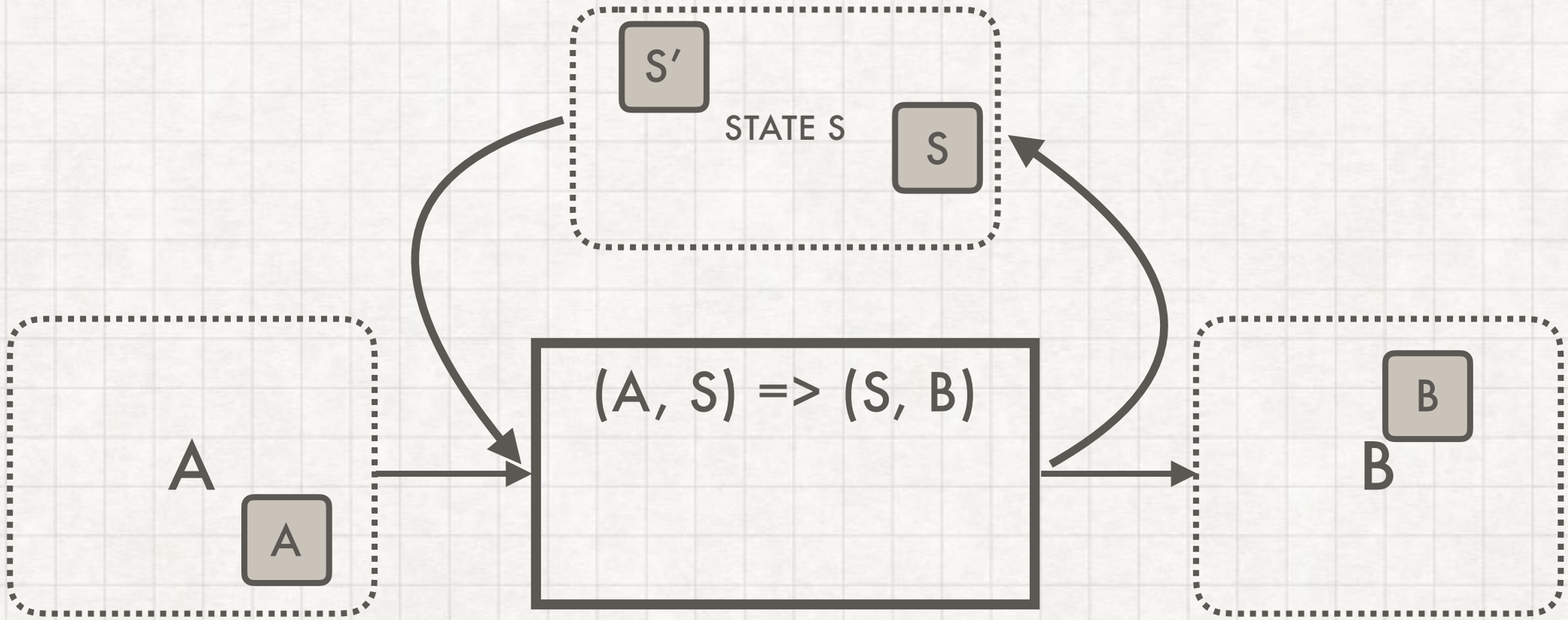


THE KEY IDEA OF THIS TALK

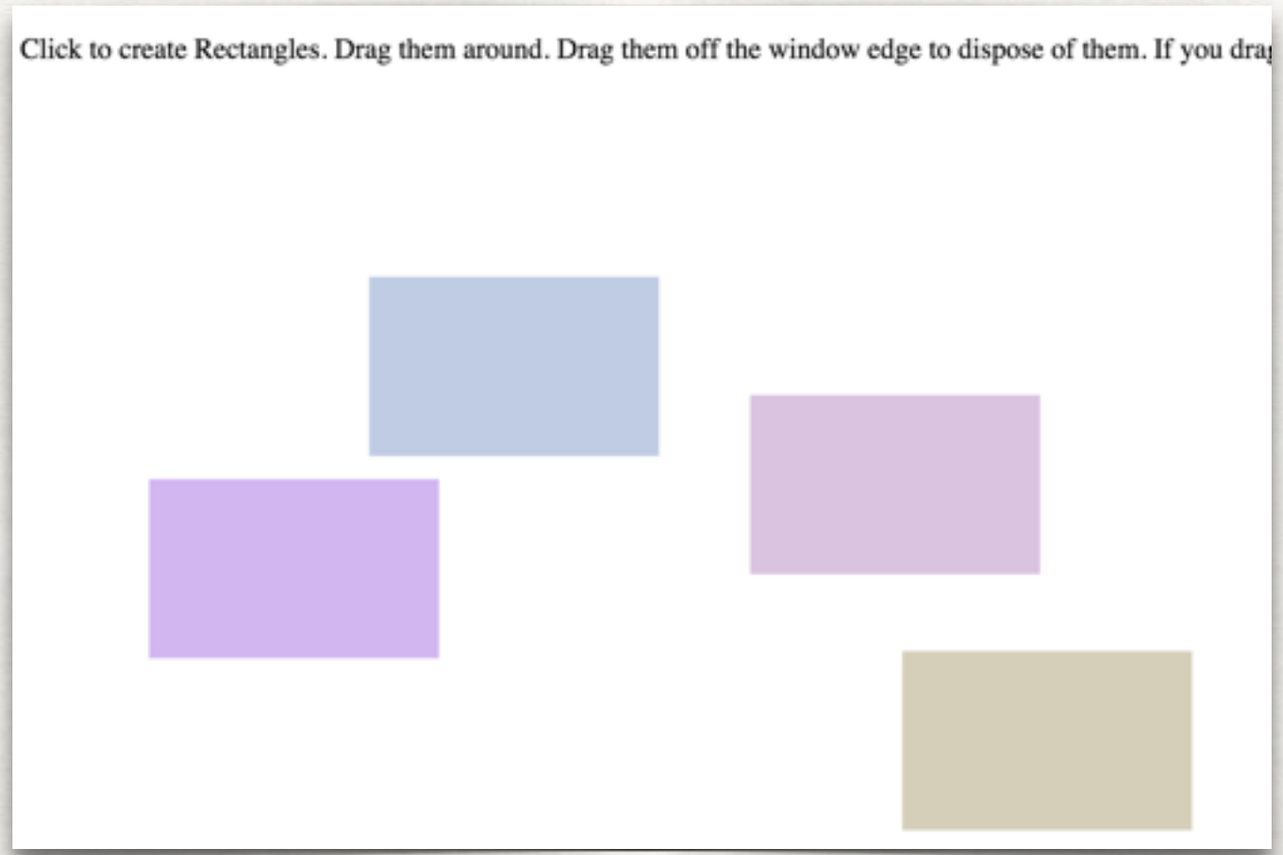
THE REST IS “COLOURING IN” THIS PICTURE

CASE STUDY: POINTER GESTURE RECOGNITION

BEN HUTCHISON, V2.0, FEB 2022

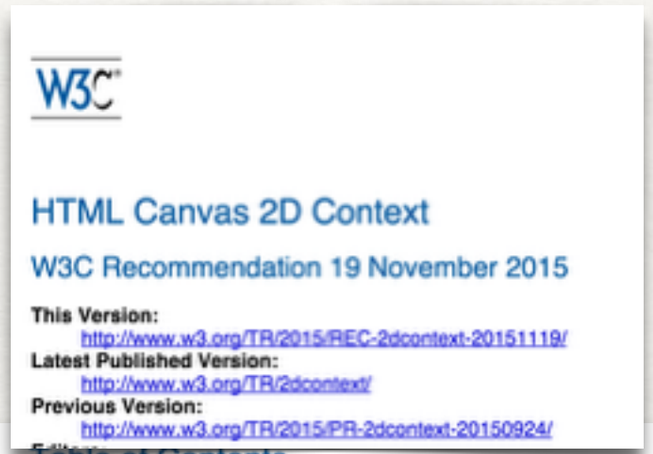
Dragging On An Html Canvas

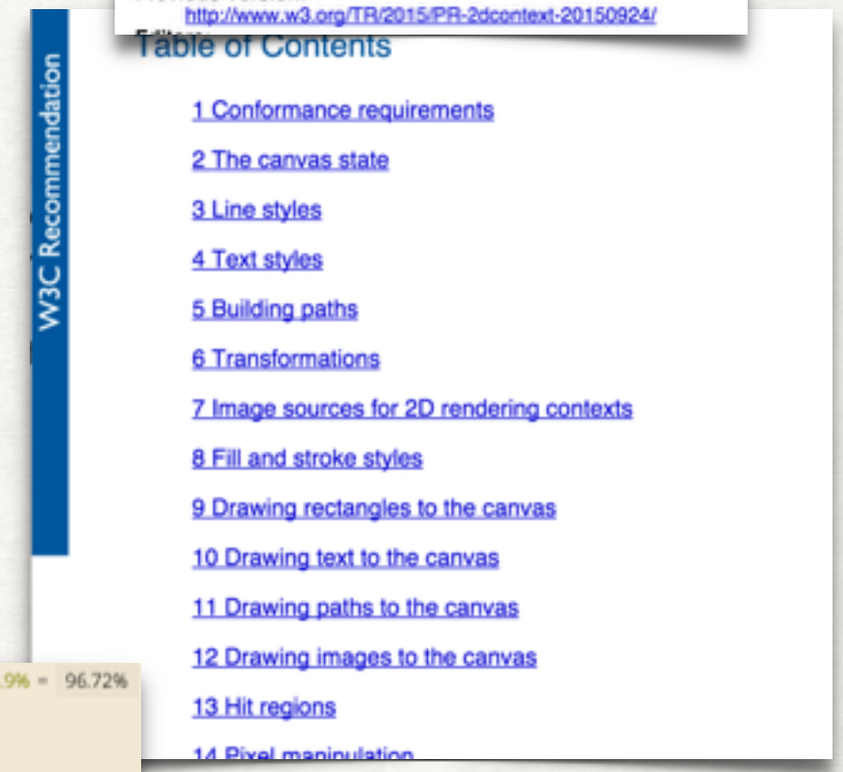
- To support drag and drop type behaviors using Scala.js and the HTML Canvas

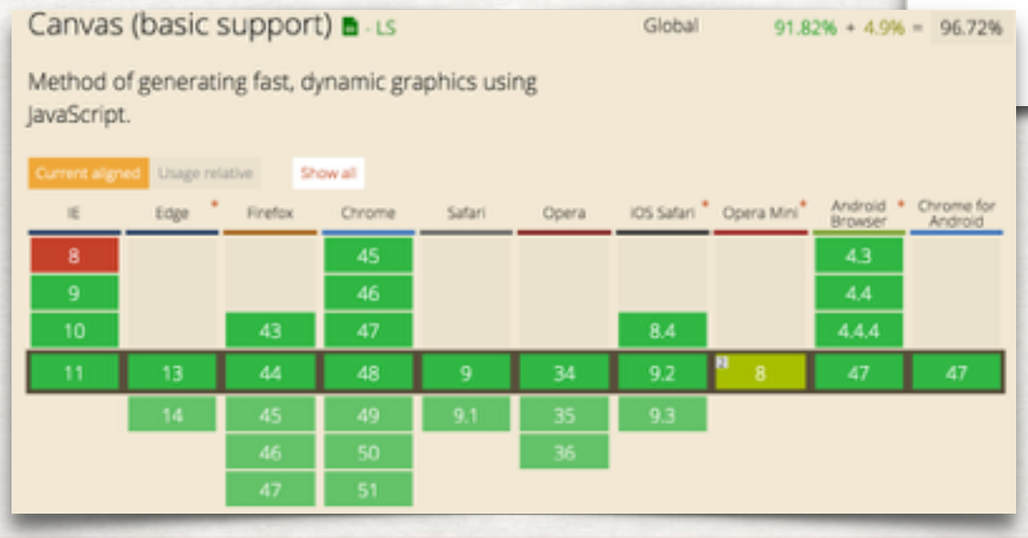


Html Canvases

- Performant, portable and versatile API for drawing vector graphics
  - Its imperative, based on commands e.g.
    - fillRect(x, y, w, h)
    - lineTo(x, y)
    - fillStyle=(cssColor)
    - transform(a, b, c, d, e, f)
- A canvas has no internal structure other than what the programmer creates
- No drag support

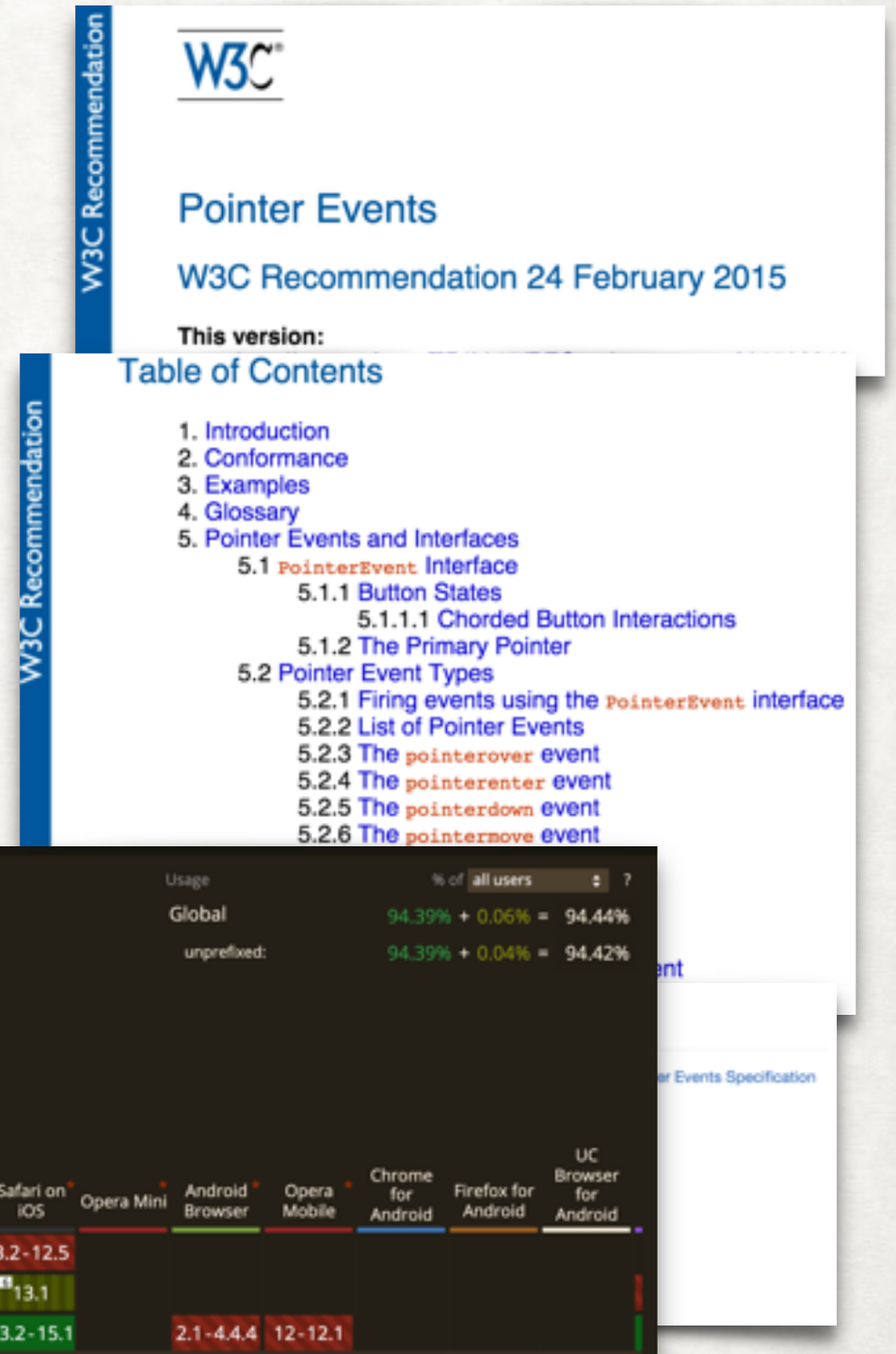






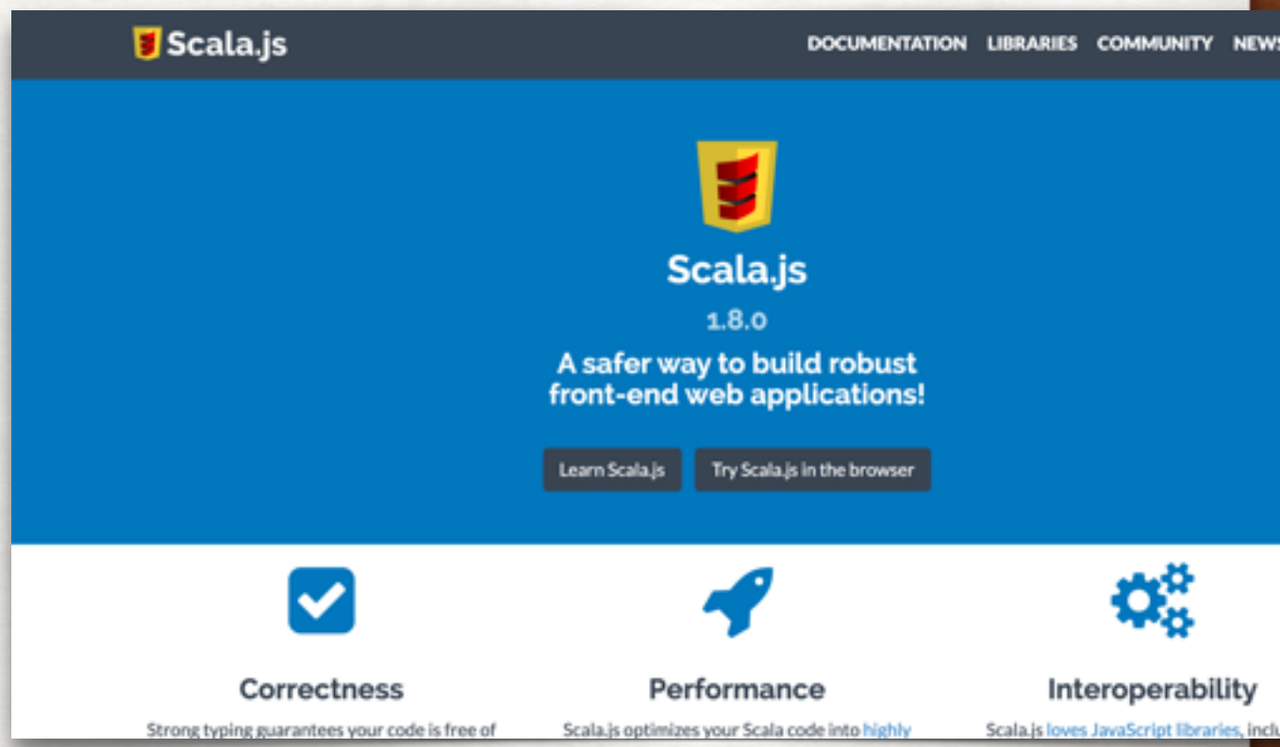
Pointer Events

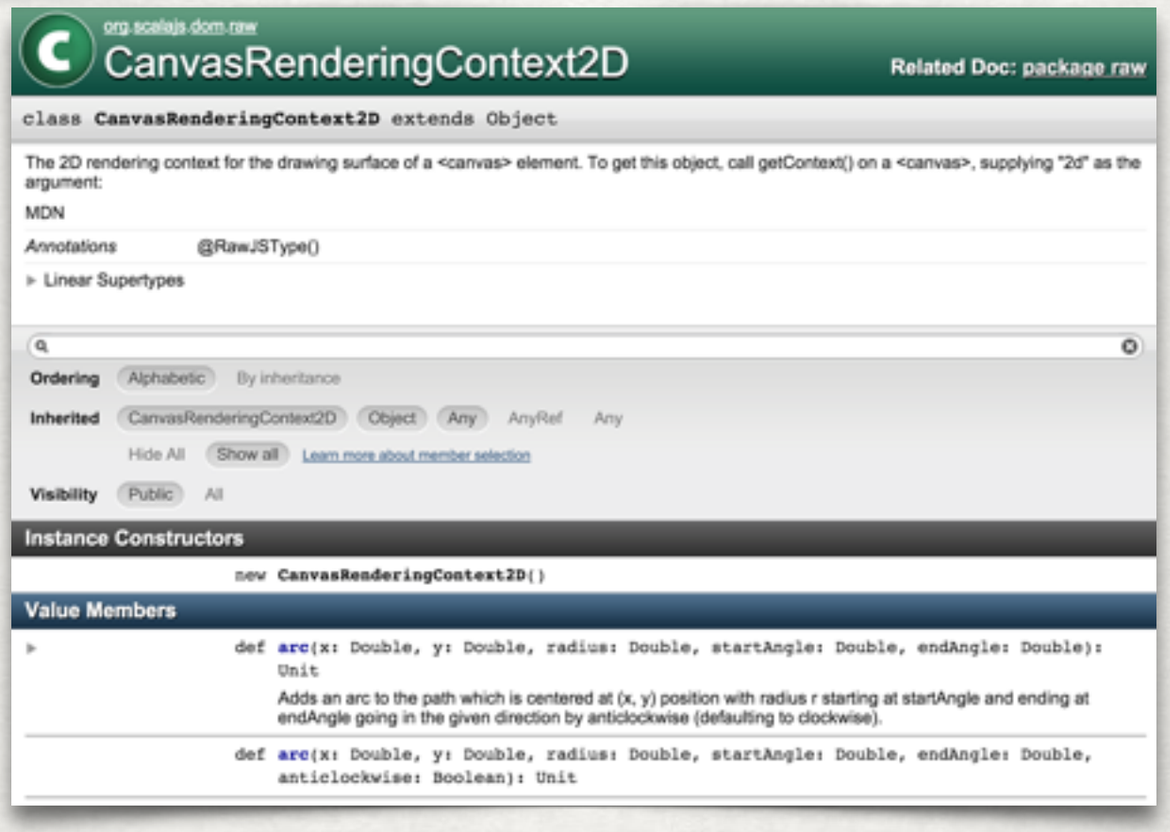
- I want to target all web-capable devices, whether touch or mouse based
- The W3C Pointer Events API abstracts over mouse & touch events
- Because a canvas has no internal structure, the only events we'll get inside are "raw" e.g.
  - pointerdown
  - pointerup
  - pointermove
  - pointerleave



Scala.Js And Scala-Js-Dom

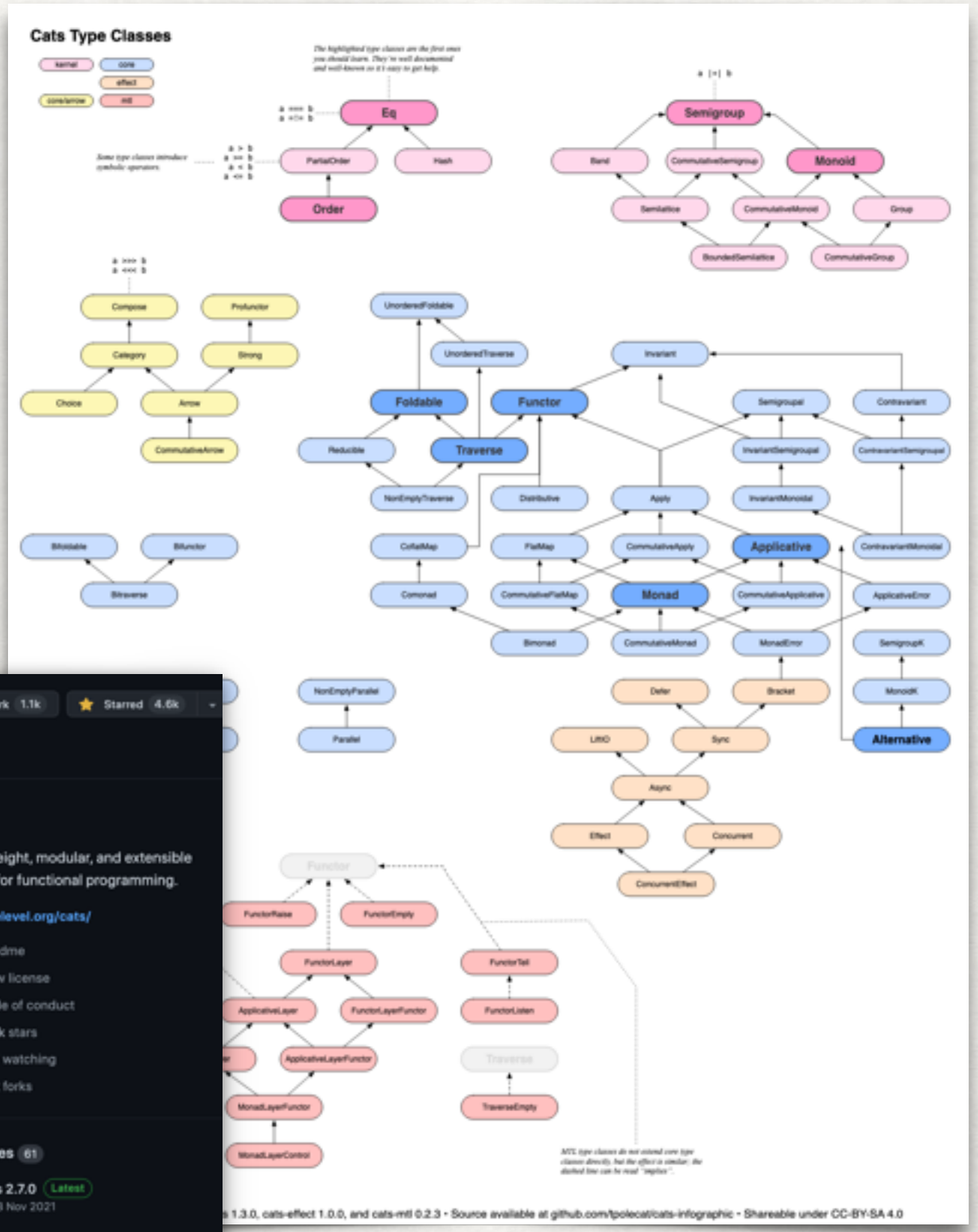
- Scala.js compiles Scala code to Javascript
  - Near-transparent interop with native JS code
- Facade libraries put a typed interface over JS APIs
  - scala-js-dom covers a lot of core W3C browser APIs including canvas and pointer events

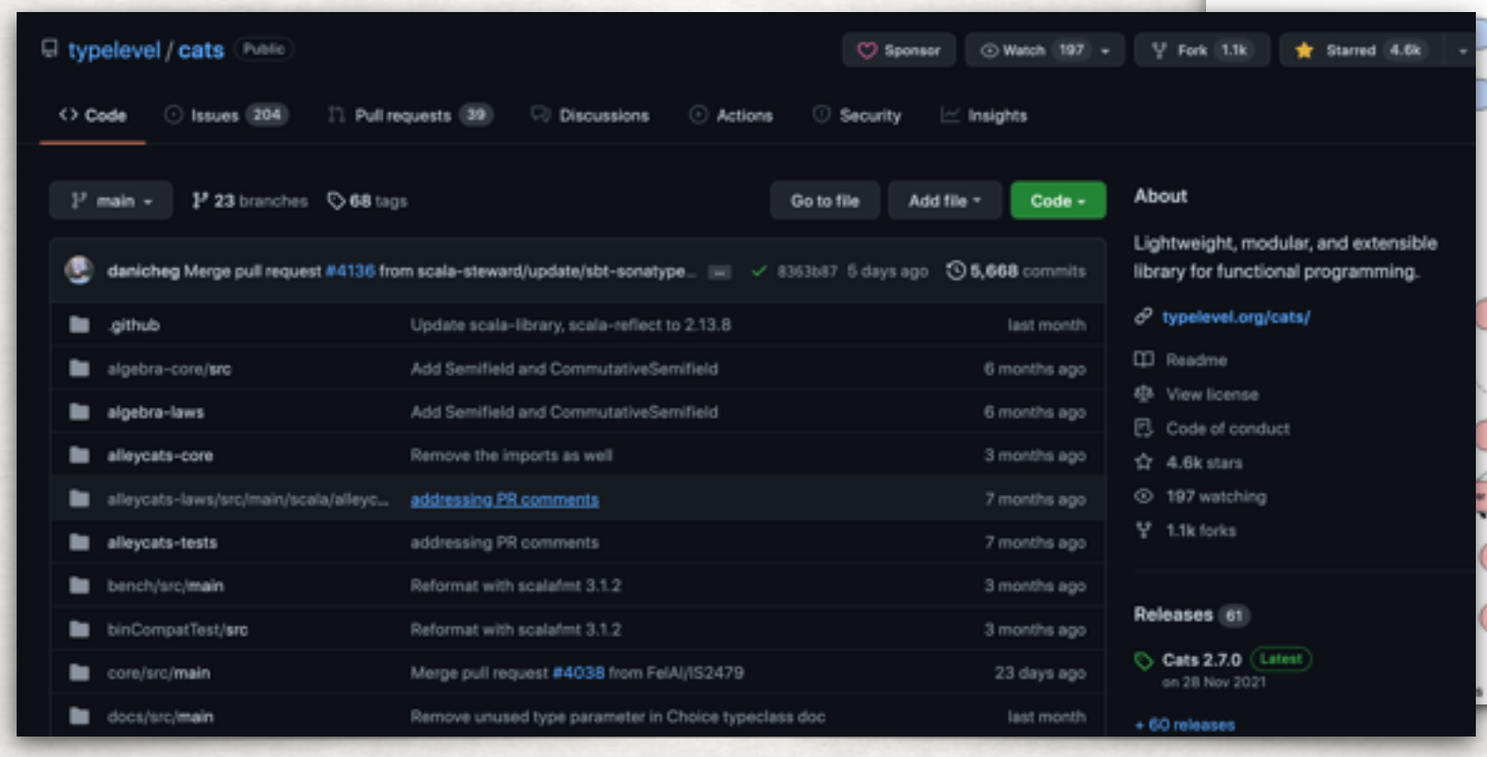




Cats: A Functional Programming Library For Scala

- Representations of State transitions
- Operators for composing stateful computations
  - eg Monad & Applicative type classes





Gesture Recognition

- The process of recognising patterns in a stream of low-level events and emitting higher-level gesture events
  - Inherently *stateful* process
  - An incomplete gesture may be ambiguous

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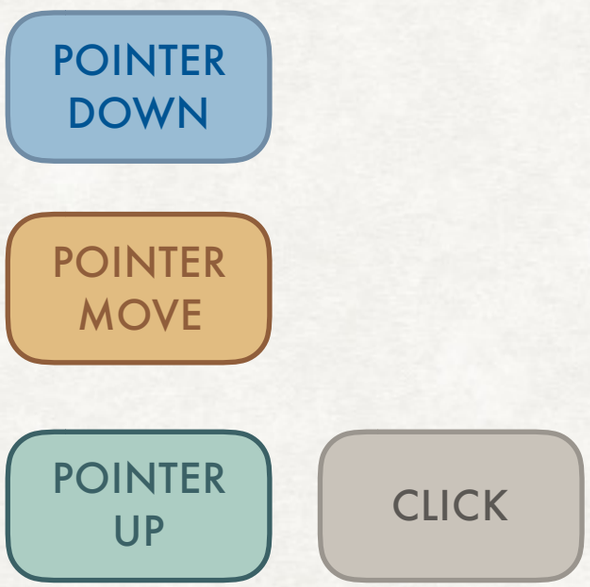

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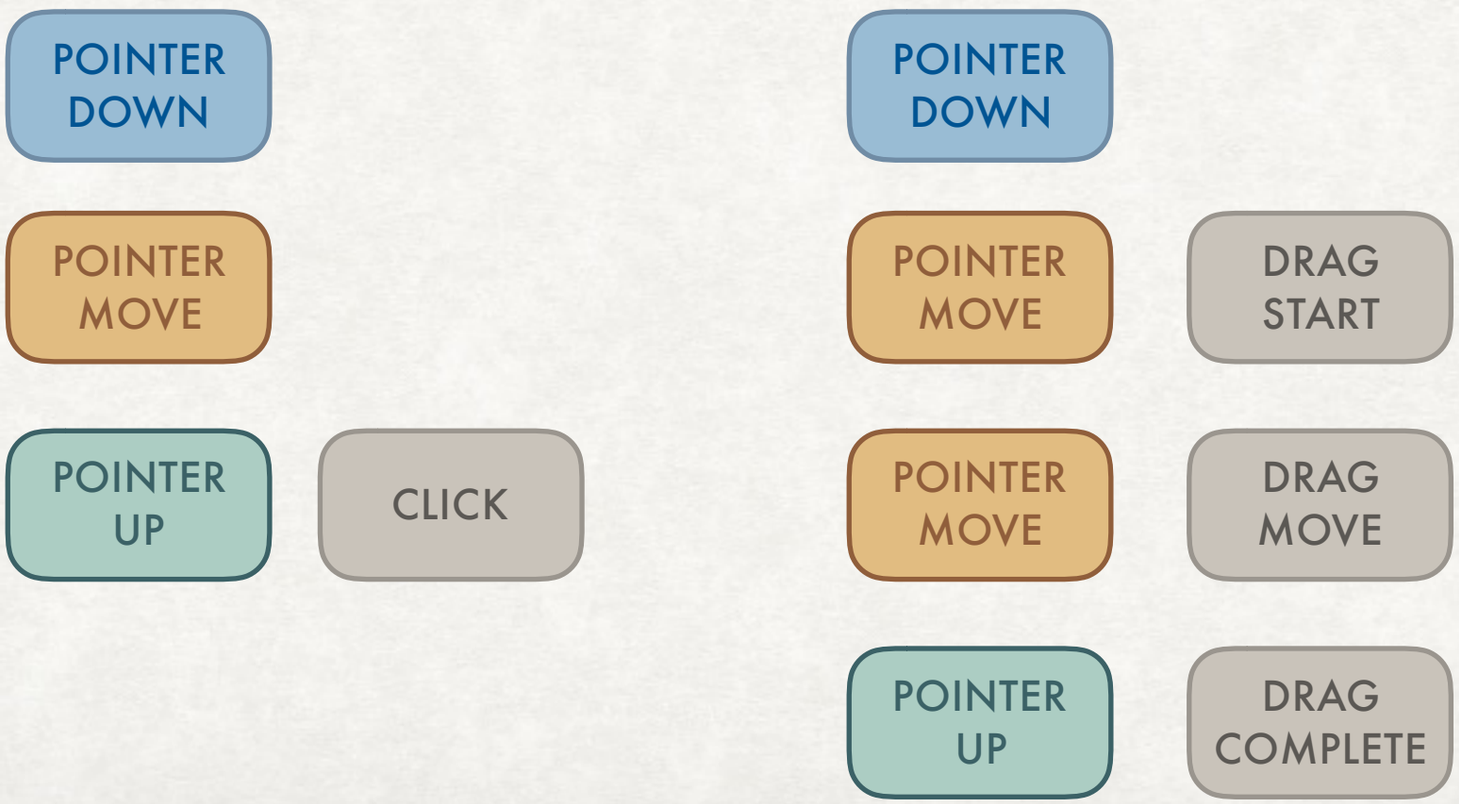

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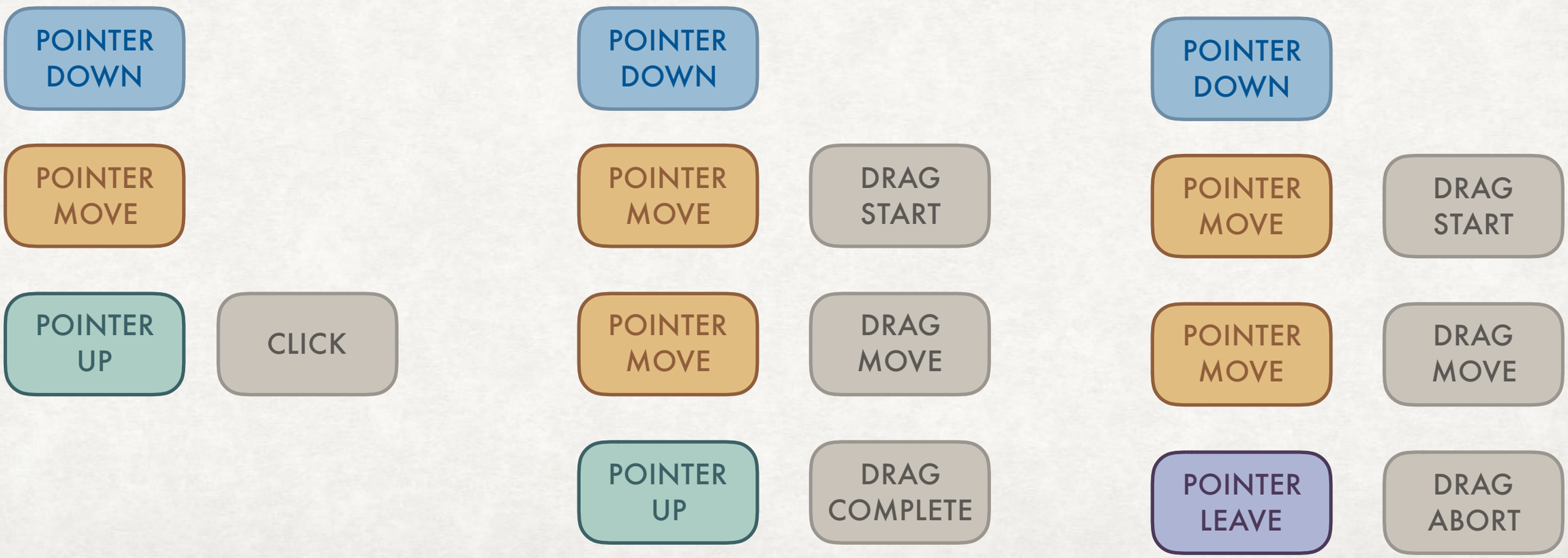
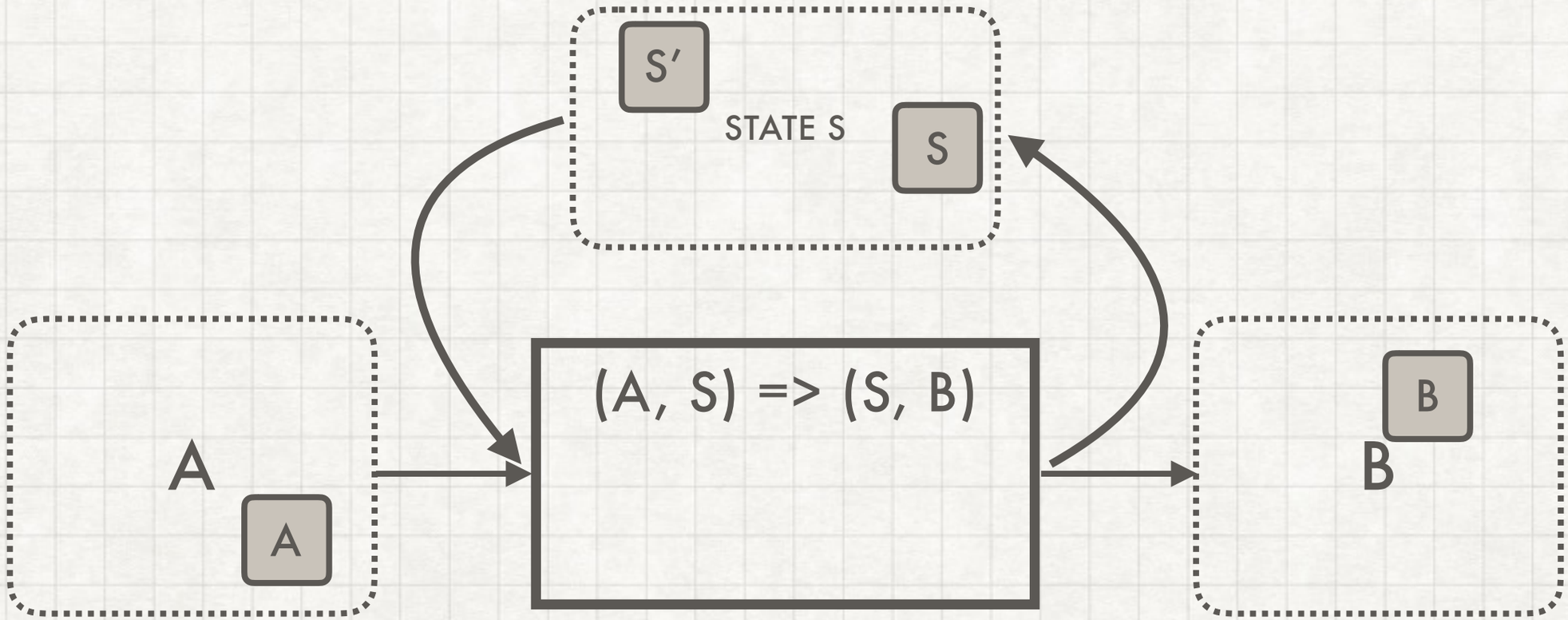


REPRESENTING STATE: FINITE STATE MACHINES

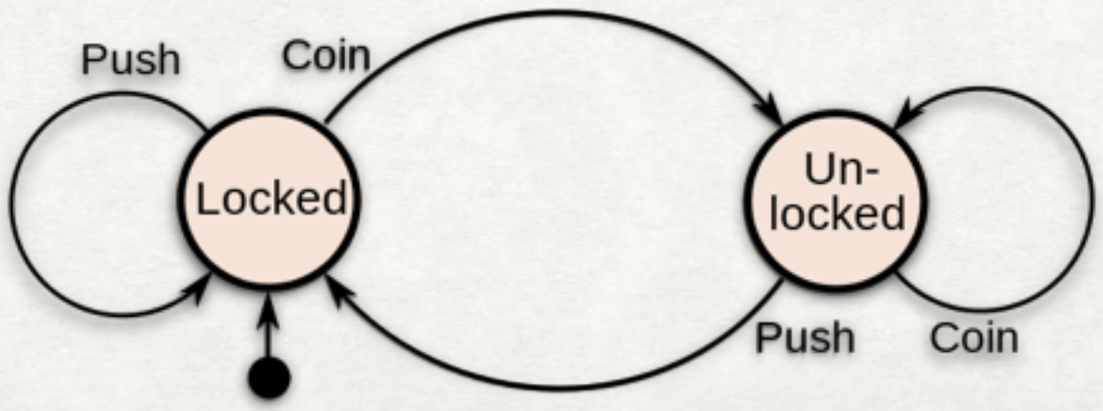
BEN HUTCHISON, V2.0, FEB 2022

PAIR: PURE FUNCTION + STATE STORE



Finite State Machines

- FSMs are my favourite way to think about state
  - What are all the states the system can be in?
    - (at least two, or it's stateless)
  - How does it transition between states?
  - What should happen upon transition?
  - State diagram for a turnstile



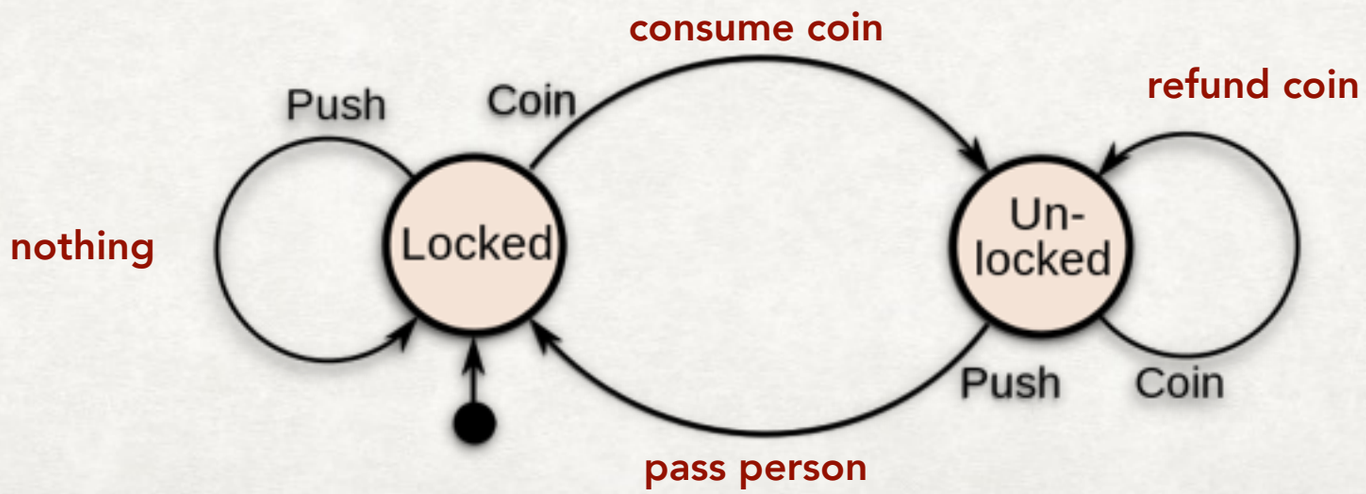
Modelling States & Transitions

- A finite set of state are well modelled using a case class hierarchy

```
sealed trait TurnstileState
case object Locked extends TurnstileState
case object Unlocked extends TurnstileState
```

- While transitions *could* be modelled as
  f: (Input, TurnstileState) => TurnstileState

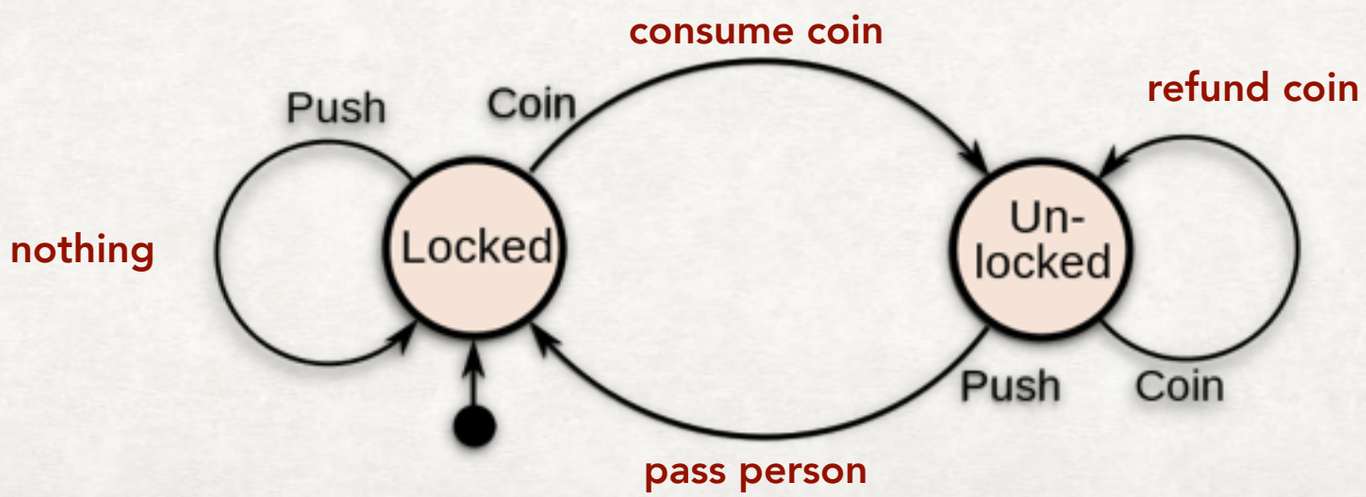
- ..typically we also want output actions to occur upon state change, so
  f: (Input, TurnstileState) => (TurnstileState, Output)



State Transitions

- **cats.data.State** models a state-transition function **S**tate => (**S**tate, **A**ction)
  - represents a *transition path* in a FSM.
  - (terminology can be confusing: **cats.data.State** is not a state, but a *transition*).
- Using currying, we can write functions that accept required input and yield the State

```
def insertCoin(c: Coin): TurnstileState => (TurnstileState, Action)
```



States

```
sealed trait PointerState

case class Up() extends PointerState

case class Down(p: Vec2d, timestamp: Long) extends PointerState

case class Drag(from: Vec2d, fromTimestamp: Long,
                to: Vec2d, toTimestamp: Long) extends
PointerState
```

Gestures: Representing The Output

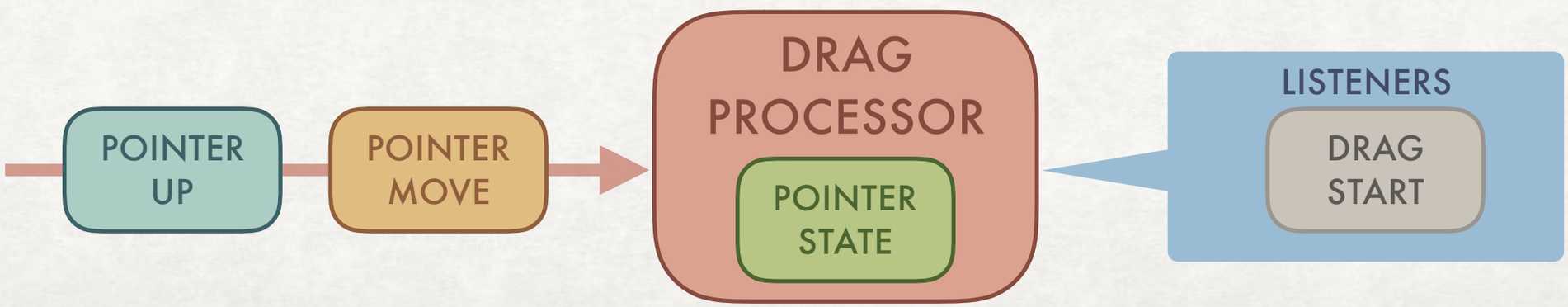
```
sealed trait GestureEvent

case class Click(p: Vec2d, timestamp: Long) extends GestureEvent

case class DragStart(from: Vec2d, fromTimestamp: Long,
  to: Vec2d, toTimestamp: Long, delta: Vec2d) extends GestureEvent

case class DragMove(from: Vec2d, fromTimestamp: Long,
  to: Vec2d, toTimestamp: Long, delta: Vec2d) extends GestureEvent

case class DragComplete(from: Vec2d, fromTimestamp: Long,
  to: Vec2d, toTimestamp: Long, delta: Vec2d) extends GestureEvent

case class DragAbort(from: Vec2d, fromTimestamp: Long,
  to: Vec2d, toTimestamp: Long) extends GestureEvent

case class Invalid(msg: String, pointerEvent2: PointerEvent)
extends
  GestureEvent

case object Noop extends GestureEvent
```

STATEFUL FUNCTIONAL PROGRAMMING IN GESTURE

BEN HUTCHISON, V2.0, FEB 2022

Why Not The Classic Object-Oriented Approach?

- Functional design was in fact my *second* attempt
- Initially I used a DragProcessor written in object-oriented style
- Main problem: it was harder to test
- PointerState encapsulated away inside processor
- Need to mock out listeners to verify emitted events



What Does "Easy To Test" Look Like?

- IMO the easiest code to test would be
  - Specify the current state
  - Specify the input PointEvent
- and it returns
  - The new state
  - The recognised gesture, if any

Input, Current State => (Next State, Gesture)

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- IMO the easiest code to test would be
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Input, Current State => (Next State, Gesture)

```
val (s, g) = eventSequence(initialState = Up())(
  PointerDown((0, 0), 0L), PointerMove((20, 20), 10L), PointerUp((30, 30), 20L))

(s must_== Up()) and (g must_== DragComplete((0, 0), 0L, (30, 30), 20L, (10,
10)))
```

Responding To Pointerdown

- The State[S, A] data type just wraps a function you define with signature f: S => (S, A), providing some useful state monad operations
  - S means “state”, action means “Action”
  - Typically you pattern match on the initial state
- PointerDown rules in prose and then in code
  - “if we’re in an Up state, transition to Down state, recording when and where, and emit no gesture”
  - “a PointerDown event doesn’t make sense if we’re already down or dragging”

```
def pointerDown(pe: PointerDown) = State[PointerState, GestureEvent](ps => ps match {
  case Up() =>
    (Down(pe.p, pe.timestamp), Noop)
  case _ => invalid(pe, ps)
})
```

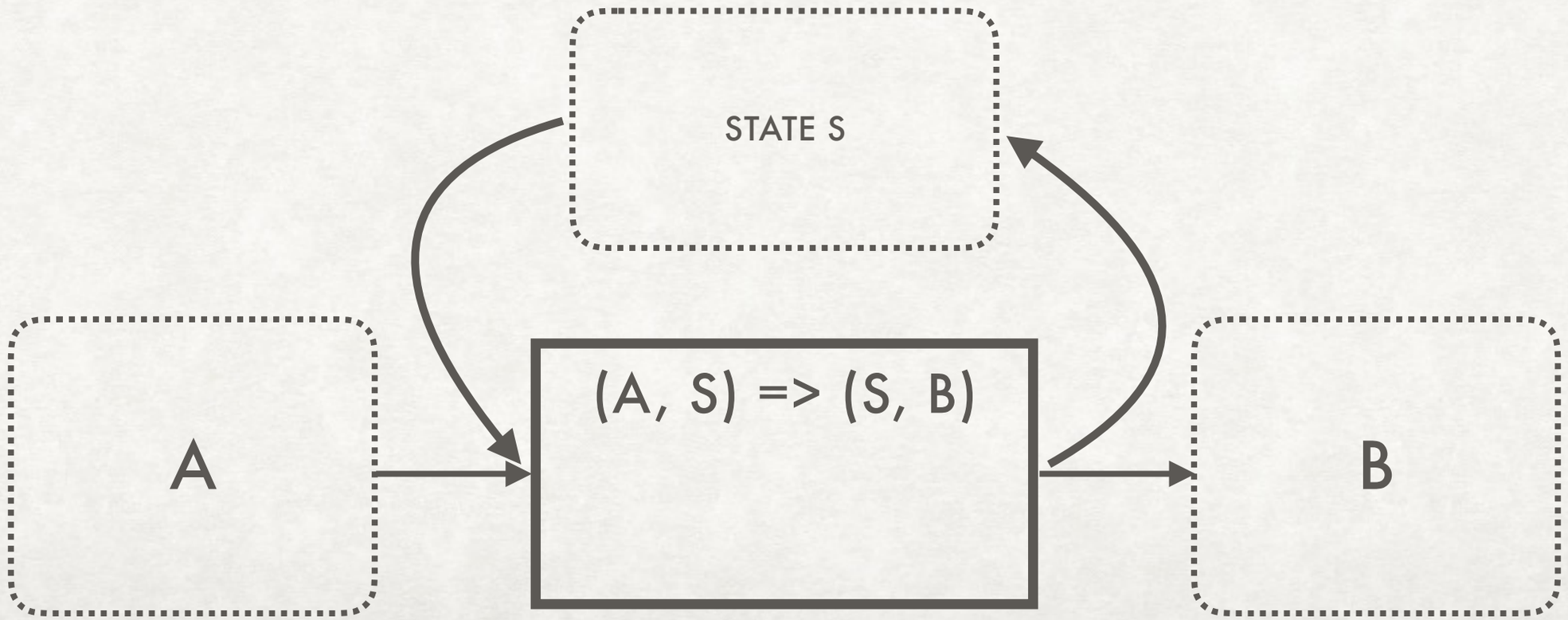
Responding To Pointermove

- PointerMove rules in prose and then in code
  - “if we’re in an Up state, stay there and emit no gesture”
  - “if we’re Down, check how far we’ve travelled since we went down. If its enough to count as a drag, enter Drag state and emit a DragStart gesture”
  - “if we’re already Dragging, extend the Drag to the new location and emit a DragMove”

```
def pointerMove(pe: PointerMove) = State[PointerState, GestureEvent](ps => ps match {
  case Up() => (Up(), Noop)
  case Down(p, timestamp) =>
    if (p.distanceTo(pe.p) > dragThreshold)
      (Drag(p, timestamp, pe.p, pe.timestamp), DragStart(p, timestamp, pe.p, pe.timestamp, pe.p -
p))
    else
      (ps, Noop)
  case Drag(from, fromTimestamp, to, toTimestamp) =>
    (Drag(from, fromTimestamp, pe.p, pe.timestamp), DragMove(from, fromTimestamp, pe.p,
pe.timestamp, pe.p - to))
})
```

The Imperative Rind

- An remark by Simon Peyton Jones early in my FP journey left a mark on me
  - roughly “functional programs have a functional interior and an imperative rind (exterior)”
- The new state computed by a state function needs to be **stored**
- The action emitted by the stateful function needs to be **executed**



Gesture Demo

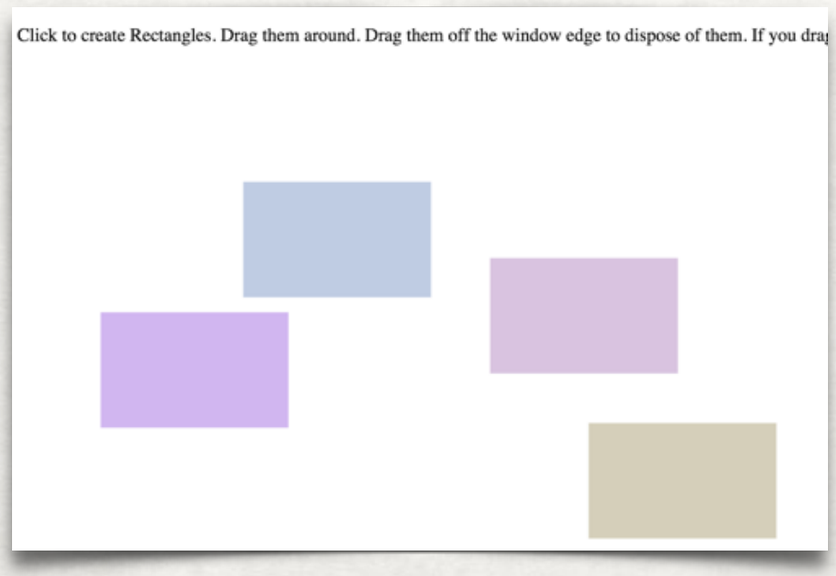
```
def handlePointerEvent(pe: PointerEvent) = {
  val (newState, gestureAndRegions) = gestureRegionProcessor.
    handlePointerEvent(pe, search).run(pointerAndRegionState).run

  pointerAndRegionState = newState
  interpret(gestureAndRegions)
}

def interpret(gr: GestureAndRegions[Rect]) = {
  gr match {
    case GestureAndRegions(Click(p, timestamp), None, None) =>
      def randLightValue = 180 + Random.nextInt(60)
      val randomColor = s"rgb($randLightValue, $randLightValue, $randLightValue)"
      val r = new Rect(p, Width, Height, randomColor)
      rectangles = rectangles :+ r
      draw()
    case GestureAndRegions(d: DragMove, Some(Rect(_, _, _, _, id)), _) =>
      rectangles = rectangles.map(r =>
        if (r.id == id)
          r.copy(topLeft = r.topLeft + d.delta)
        else r)
    case GestureAndRegions(d: DragAbort, Some(Rect(_, _, _, _, id)), _) =>
      rectangles = rectangles.filterNot(_.id == id)
    case GestureAndRegions(d: DragComplete, Some(Rect(_, _, _, _, srcId)), Some(Rect(_, _, _, _,
targetId))) =>
      rectangles = rectangles.map(r =>
        if (srcId != targetId && r.id == targetId)
          r.copy(cssColorString = RedColorString)
        else r)
    case _ => Noop
  }
  draw()
}
```

TRACKING DRAG REGIONS

BEN HUTCHISON, FEB 2022, V2.0

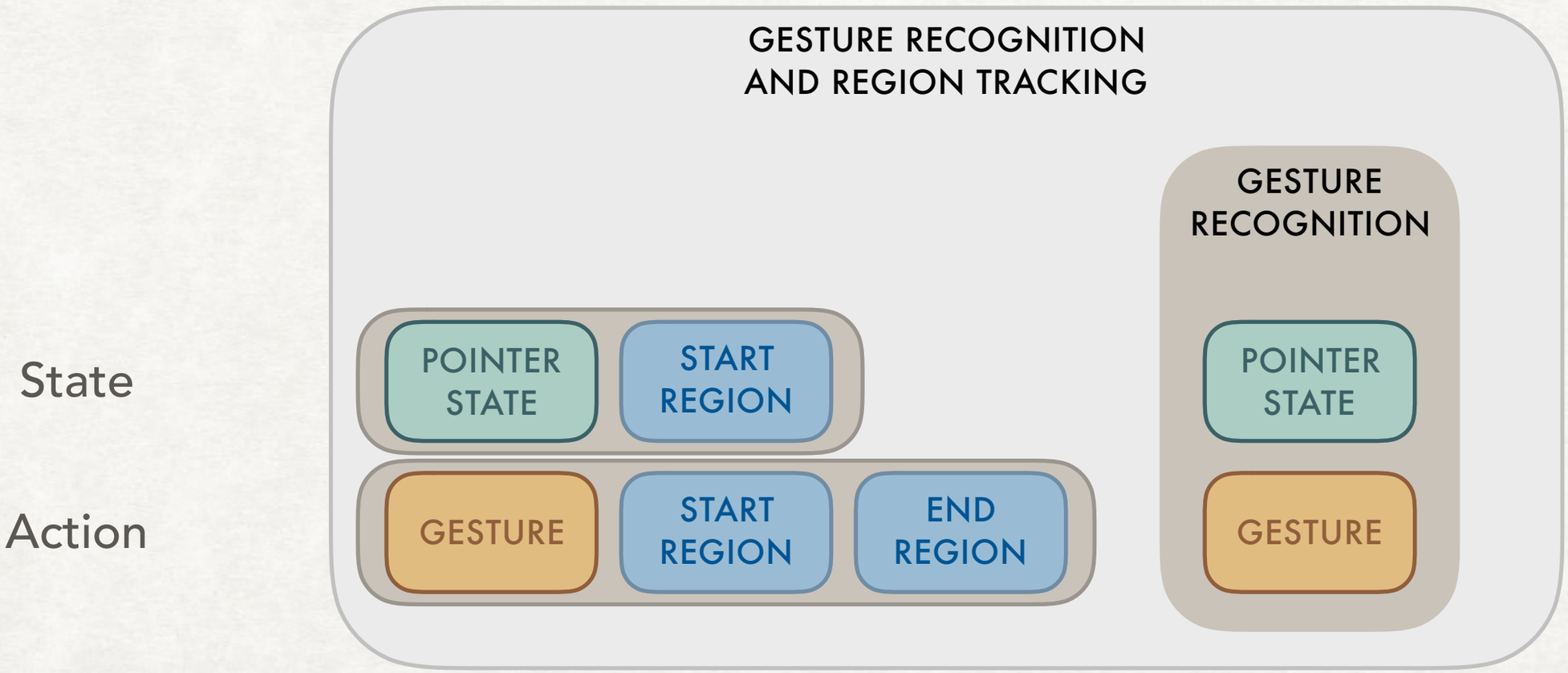
Tracking Drag Regions

- For most applications, its not enough to know that drags have happened
  - We want to know about the object where they began, completed or passed over
  - Gesture keeps track of these objects, which it calls “Regions”, and it actually doesn’t care what they are
  - You give it a function to convert a point into a region of arbitrary type R, and it calls it and tracks the values



State[PointerRegionState, GestureAndRegions[R]]

- The region-tracking State wraps the simpler gesture recognition State



State[PointerRegionState, GestureAndRegions[R]]

- The region-tracking State wraps the simpler gesture recognition State

```
case class GestureAndRegions[R](
    gesture: GestureEvent, from: Option[R], to: Option[R])

type PointerRegionState = (PointerState, Option[R])

def handlePointerEvent(pe: PointerEvent, regionSearch: Vec2d => Option[R]) =
  State[PointerRegionState, GestureAndRegions[R]] {
  case (ps, optRegion) =>
    val (ps2, g) = gestureProcess.handlePointerEvent(pe).run(ps).run
    g match {
      case DragStart(from, _, to, _, _) =>
        val fromR = regionSearch(from)
        val s = (ps2, fromR)
        val a = GestureAndRegions(g, fromR, regionSearch(to))
        (s, a)
      case DragMove(_, _, to, _, _) =>
        val s = (ps2, optRegion)
        val a = GestureAndRegions(g, optRegion, regionSearch(to))
        (s, a)
//more cases for other gestures…
}}
```

SCALING UP WITH STATEFUL FUNCTIONAL PROGRAMMING

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Scaling Up With Stateful Fp

- What if the whole client application was purely functional?
  - Input: PointerEvent | Server Messages | Time
  - State: ApplicationState(PointerRegionState, AnimationState, ...)
    - Actions..? ..maybe UpdateView | ServerCall | SetCookie ..
- Need a way to compose local State updates (like State[PointerRegionState, GestureAndRegions[R]]) into app-wide State[ApplicationState, AppAction]

Scaling Up With Stateful Fp

- A *Lens* is a pair of functions
  - get: S => T
  - set: (S, T) => S
- Interpretation: if S is global state, T is the subsystem state, the lens *extracts* the local state with get, and *updates* the local state with set

```
def lift[T, S, A](
  s: State[T, A],
  l: Lens[S, T]
): State[S, A] = State { inputS =>
    val inputT = l.get(inputS)
    val (outputT, a) = s.run(inputS).run
    val outputS  = l.set(inputS, outputT)
    (outputS, a)
})
```

THE END

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