CONCURRENCY IN PRACTICE

A CASE STUDY

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INTRODUCTION

WHO AM I?

Erik Rozendaal, software developer, etc.

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twitter: @erozendaal

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(... and I did not write that CQRS framework)

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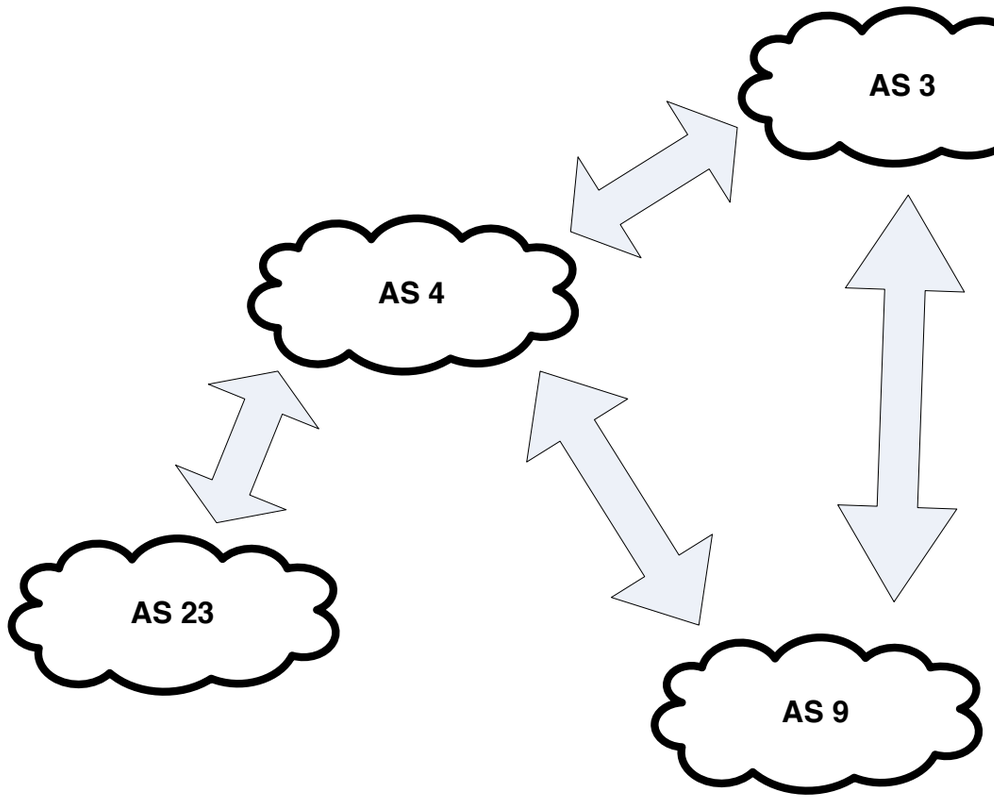
RPKI VALIDATOR

- Open Source (BSD license)
- Developed at the RIPE NCC (www.ripe.net)
- Aimed at Internet router administrators
- http://www.ripe.net/lir-services/resource-management/certification/tools-and-resources

Scalaz

- The RIPE NCC is one of five Regional Internet Registries (RIRs) providing Internet resource allocations, registration services and coordination activities that support the operation of the Internet globally.
- Basically, helps ensure that every Internet Address is uniquely distributed and the Internet keeps working

INTERNET ROUTING 101



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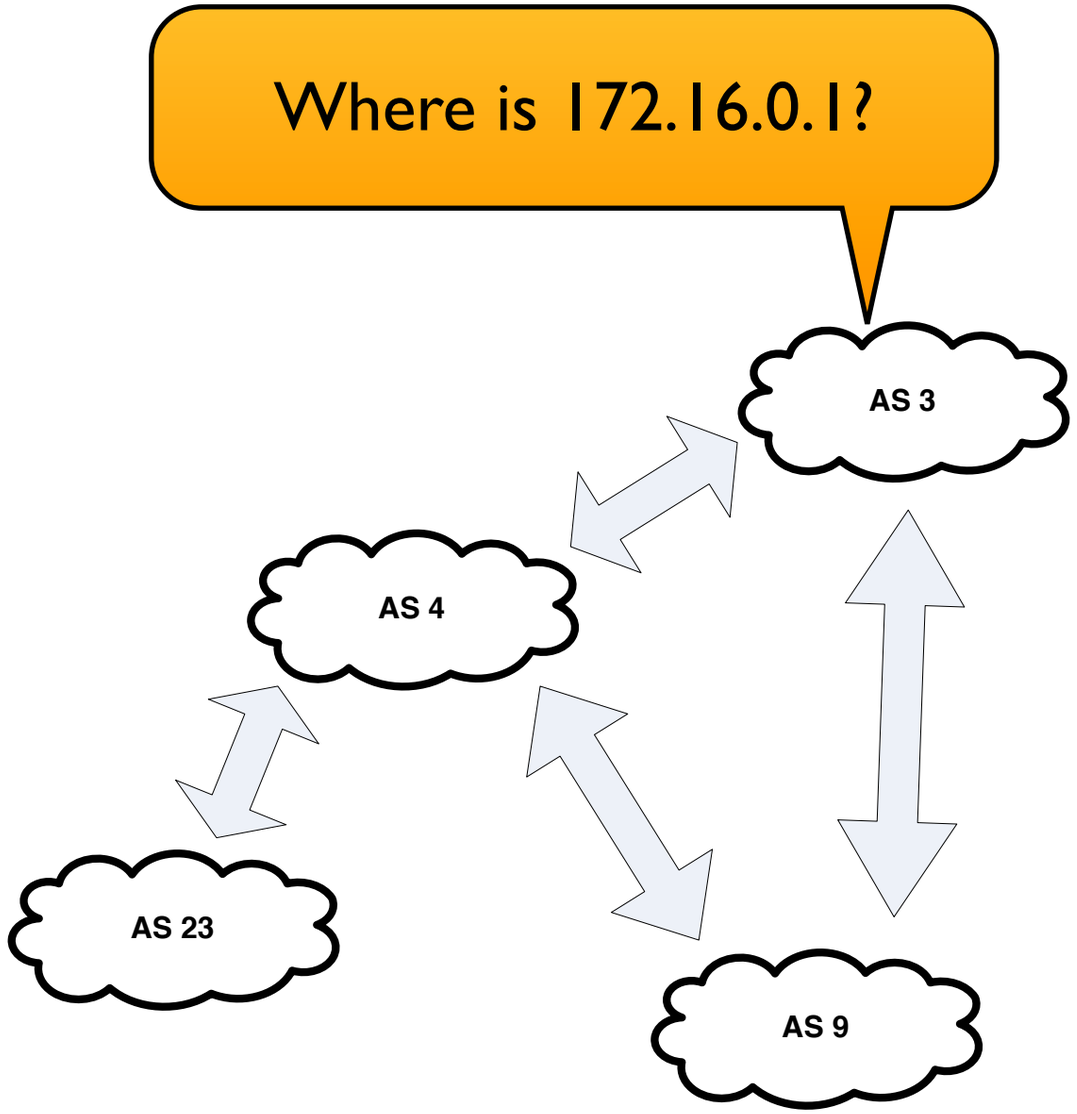

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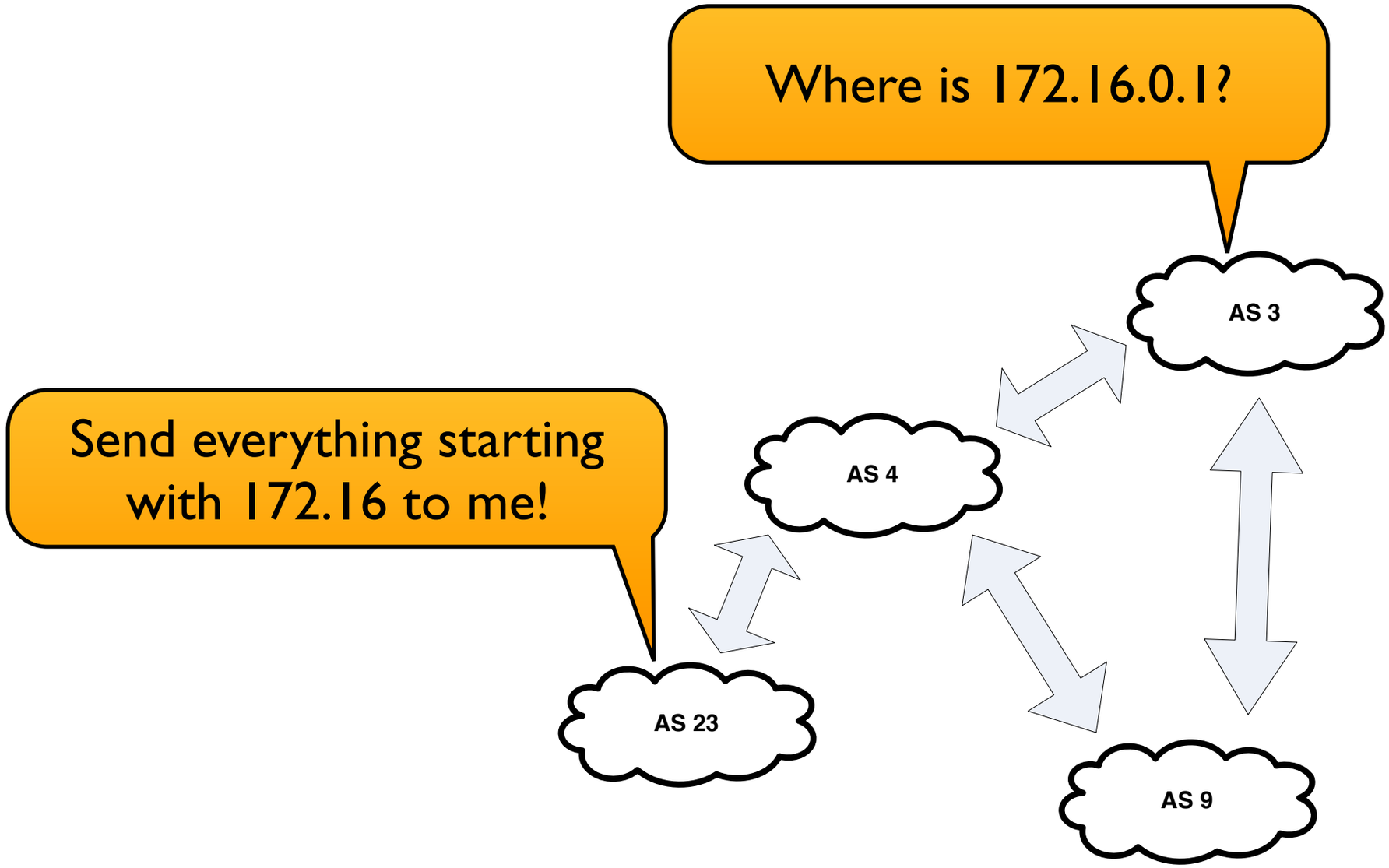

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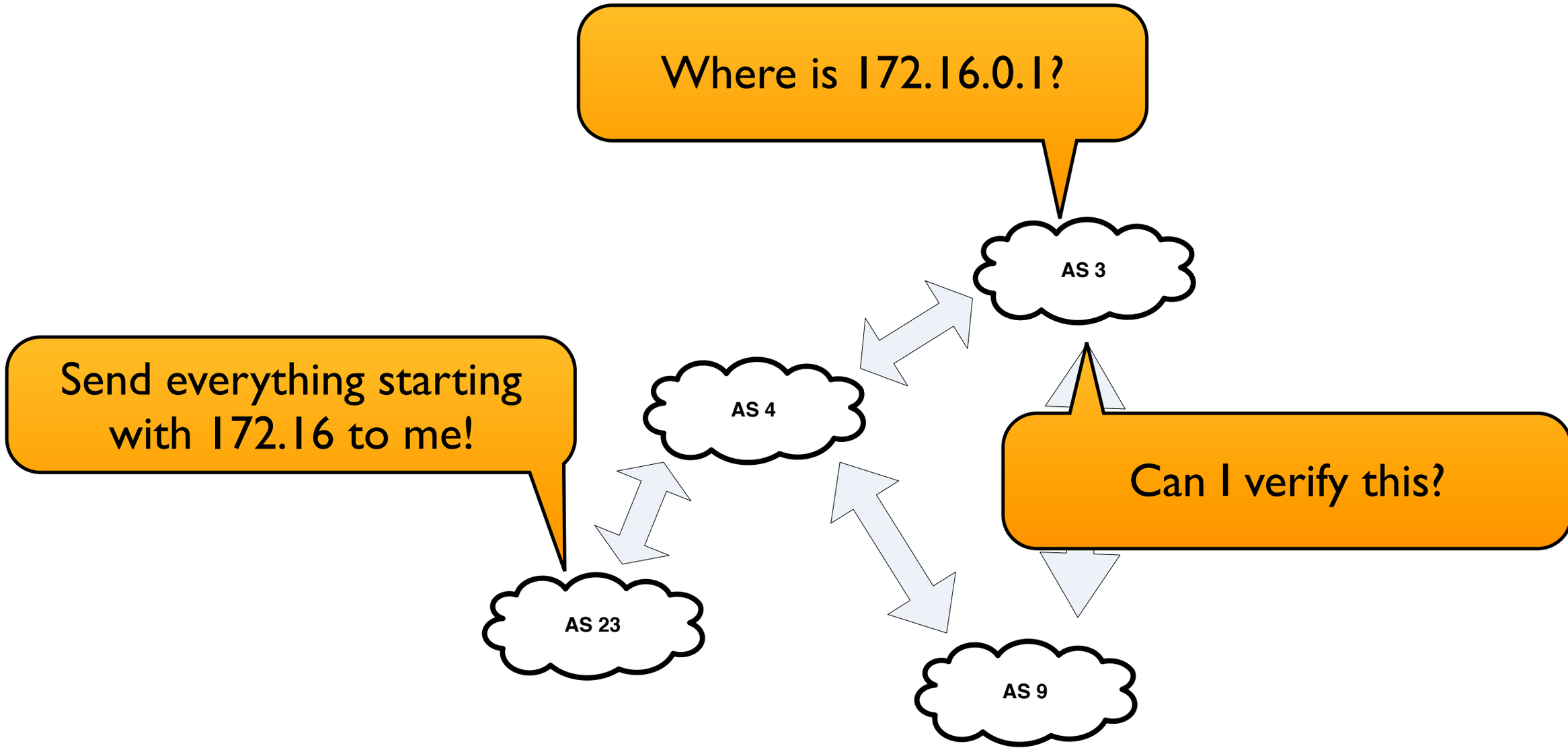

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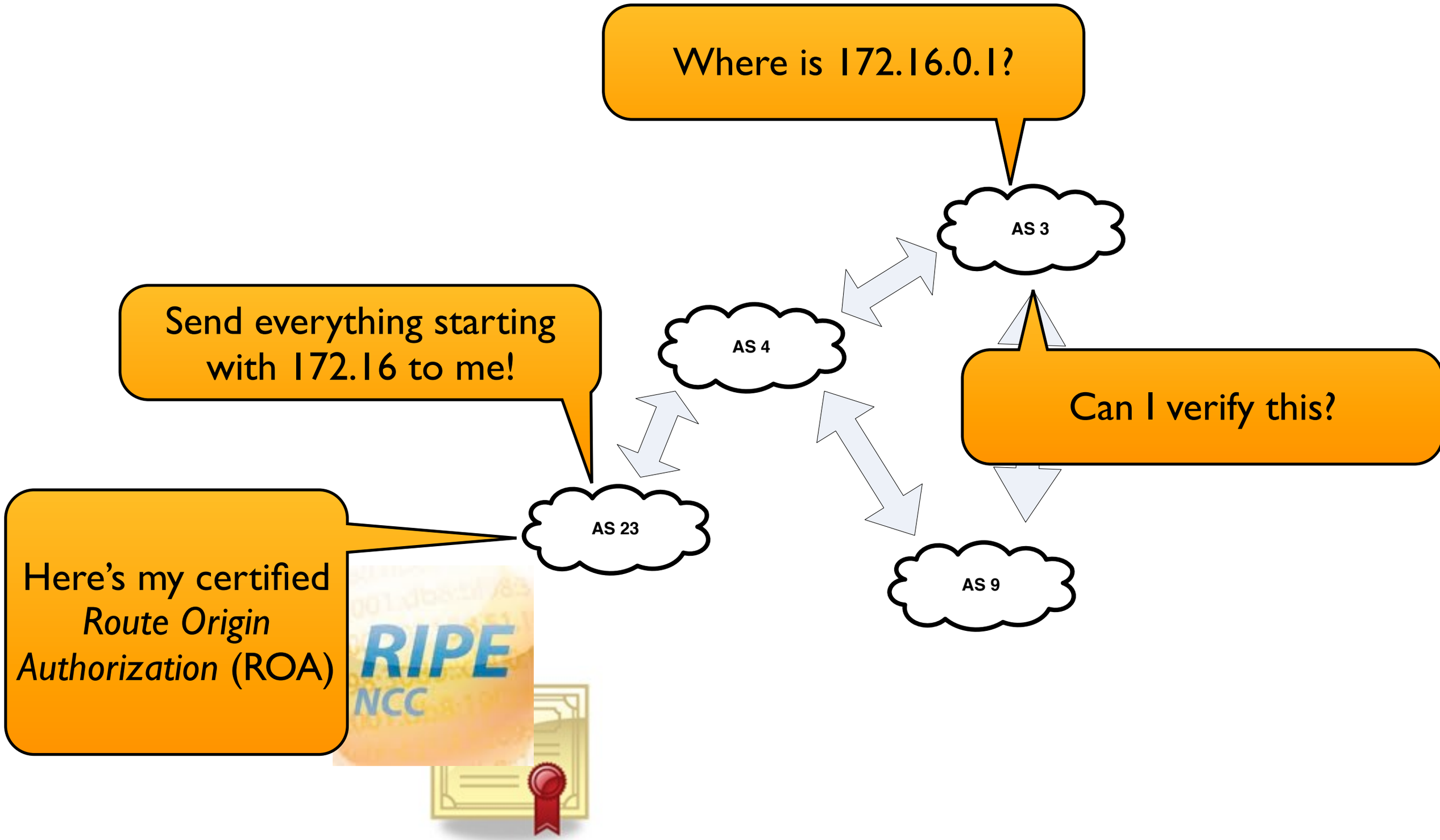
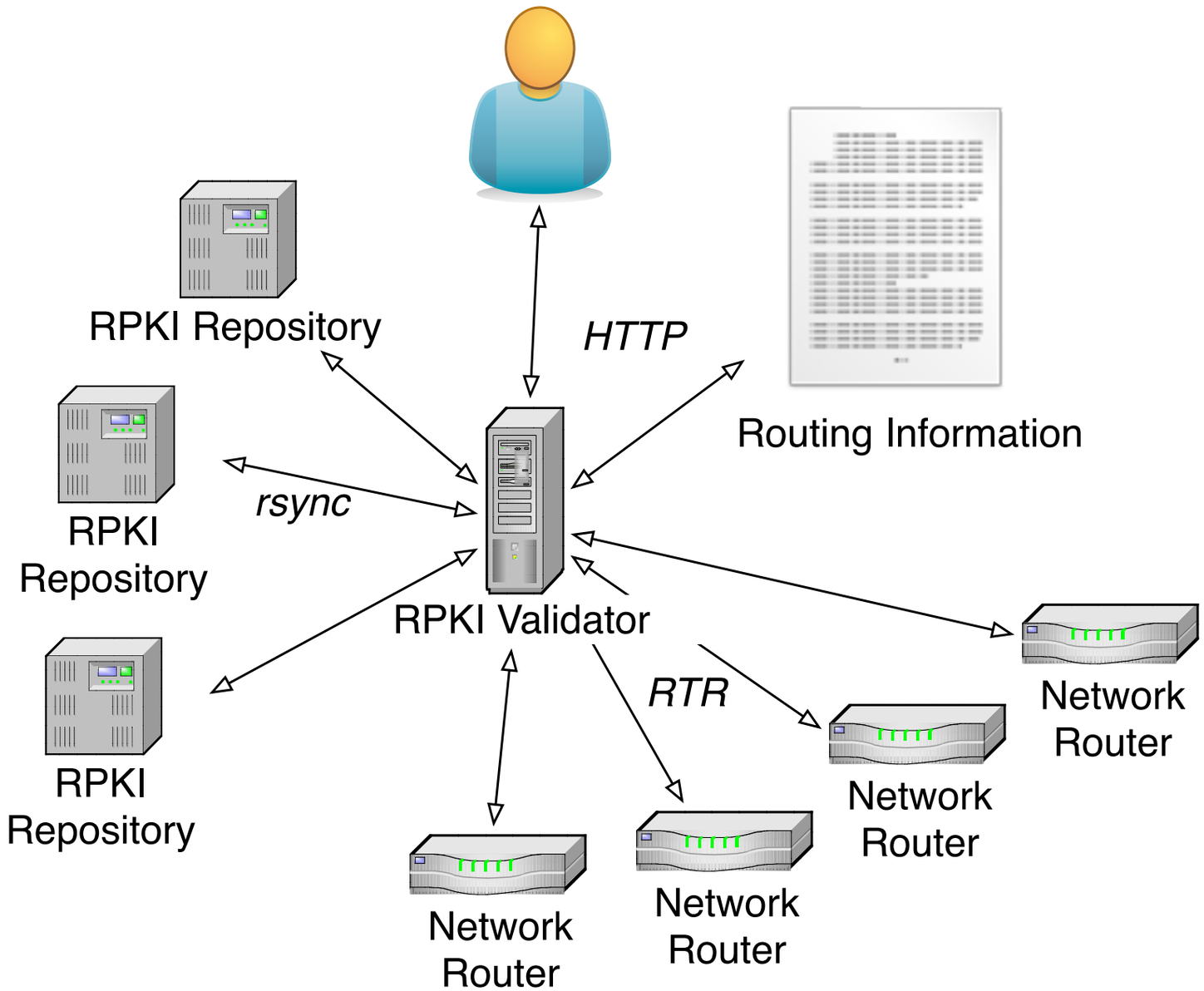


INTERNET RESOURCE PKI (RPKI)

- Distributed database of cryptographically signed statements about resources
- IETF standard
- Rooted at the five Regional Internet Registries (RIRs)
  - AfriNIC - Africa
  - ARIN - United States, Canada, ...
  - APNIC - Asia, Australia, New Zealand, ...
  - LACNIC - Latin America, ...
  - RIPE NCC - Europe, Russia, Middle East, ...

BIG PICTURE


RPKI Repository
HTTP
Routing Information
RPKI
Repository
rsync
RPKI Validator
RPKI
Repository
RTR
Network
Router
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Network
Router


DEMO

IMMUTABILITY

IMMUTABILITY

- An **immutable object** is an object whose state cannot be modified after it is created
- Immutable objects can be safely shared between multiple threads
- Scala makes it easy to define immutable objects and defaults to full set of immutable collection types

IMMUTABLE COLLECTIONS?

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def add(x: Int, y: Int) = {
  var result = 0
  result += x
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  val result = new ArrayList()
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```

Immutability is the difference between
`java.util.Calendar` and `org.joda.time.DateTime`

MEMORY IMAGE

```
case class MemoryImage(
  trustAnchors    : Vector[TrustAnchor],
  validatedObjects: Vector[ValidatedObject],
  filters         : Vector[Filter],
  whitelist       : Vector[WhitelistEntry],
  version         : Int = 0)
```

```
case class TrustAnchor(
  locator           : TrustAnchorLocator,
  status            : ProcessingStatus,
  enabled           : Boolean = true)

// Etc.
```

MEMORY IMAGE

- Initially access was controlled using a single `AtomicReference` containing the most recent instance
- http://martinfowler.com/bliki/MemoryImage.html

MEMORY IMAGE IMPLEMENTATION

```
object MemoryImage {
  private[this] val memoryImage =
    new AtomicReference(MemoryImage(...))
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object MemoryImage {
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  // Reading
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  // Updating
  @tailrec
  def modify(f: MemoryImage => MemoryImage): MemoryImage = {
    val current = memoryImage.get
    val updated = f(current)
    if (memoryImage.compareAndSet(current, updated)) updated
    else modify(f) // Retry
  }
}
```

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  }
}

// Example update
MemoryImage.modify { memoryImage =>
  memoryImage.copy(filters = /* updated filters */)
}
```

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- ... but `AtomicReferences` do not compose, hurting modularity
  - Try updating two `AtomicReferences` atomically...
  - (the same is true for locks)

SOFTWARE TRANSACTIONAL MEMORY

- Take the idea of a database transaction (ACID) and apply it to your in-memory data structures (ACI)
- Composable: bigger transactions can be created from existing, smaller transactions
- Not just for concurrency: mutations are automatically cleaned up on transaction rollback

http://nbronson.github.com/scala-stm/

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Represents current transaction

Parentheses and assignment to update

Parentheses to read the current value

STM PITFALLS

- Atomic block may be retried, so only mutate data managed by STM. Bad:

```
var start = false
atomic { implicit txn =>
  memoryImage().trustAnchors.
    find    { ta => ta.locator == trustAnchorLocator }.
    filter  { ta => ta.enabled && ta.status.isIdle }.
    foreach { ta =>
      memoryImage() = memoryImage().
        startProcessingTrustAnchor(ta.locator)
      start = true
    }
}
if (start) runValidation()
```

STM PITFALLS

- Atomic block may be retried, so only mutate data managed by STM. Good:

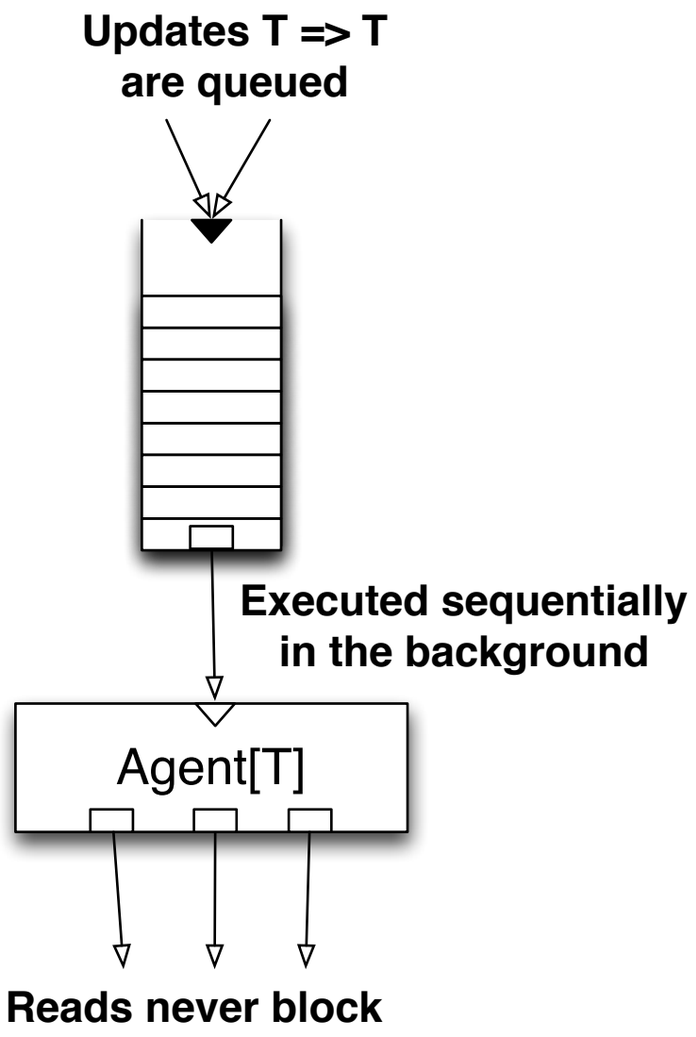
```
val start = atomic { implicit txn =>
  memoryImage().trustAnchors.
    find    { ta => ta.locator == trustAnchorLocator }.
    filter  { ta => ta.enabled && ta.status.isIdle }.
    map     { ta =>
      memoryImage() = memoryImage().
        startProcessingTrustAnchor(ta.locator)
    }.isDefined
}

if (start) runValidation()
```

AGENTS

AGENTS OF T

- Always share current state, reading is “free”
- Queue of pending updates, executed in the background, sequentially



AGENT EXAMPLE

```
private val _validatedAnnouncements =
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private val _validatedAnnouncements =
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def validatedAnnouncements = _validatedAnnouncements()

def revalidate(announcements: Seq[BgpAnnouncement],
               roas         : Seq[Roa]) {
  _validatedAnnouncements.sendOff {
    _ => validate(announcements, roas)
  }
}
```

AGENTS INTEGRATE WITH STM

- Allows you to update some state and send a computation to an Agent when a STM transaction commits
- Comparable to using a transactional database and message queue, but in-memory

AGENT EXAMPLE

```
private val memoryImage =
  Ref(MemoryImage(initial state))
private val bgpAnnouncements =
  Ref(Vector.empty[BgpAnnouncement])
private val validatedAnnouncements =
  Agent(Vector.empty[ValidatedAnnouncement])
```

```
// Update and start announcement validation
atomic { implicit txn =>
  memoryImage() = memoryImage().copy(filters = Vector.empty)
  val roas = memoryImage().validatedObjects.roas
  val announcements = bgpAnnouncements()
  _validatedAnnouncements.sendOff { _ =>
    validate(announcements, roas)
  }
}
```

FUTURES

FUTURE OF T

- Represents a value of type T that may not be available yet
  - Expensive computation, network access, asynchronous I/O, etc.

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def traverse[A, B](items: List[A])
                  (f: A => Future[B])
                  (implicit executor: ExecutionContext):
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- Represents a value of type T that may not be available yet
  - Expensive computation, network access, asynchronous I/O, etc.
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E.g. list of URLs to retrieve

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How much concurrency?

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def traverse[A, B](items: List[A])
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```

Completed when all complete

CONCURRENT DOWNLOAD

```
val bgpRisDumpUrls = List(
  "http://www.ris.ripe.net/dumps/riswhoisdump.IPv4.gz",
  "http://www.ris.ripe.net/dumps/riswhoisdump.IPv6.gz")
def downloadBgpRisDump(url: String): Future[BgpRisDump] = ...
```

```
Future.traverse(bgpRisDumpsUrls) { url =>
  downloadBgpRisDump(url)
}.foreach { bgpRisDump =>
  // All files have been downloaded, potentially in parallel.
}
```

PARALLELISM

Concurrency: program with multiple, independent threads of control. Non-deterministic, since the outcome may depend on the particular interleaving at runtime.

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Parallelism: runs on multiple processors, hopefully making it run faster. No other affect on program outcome.

PARALLEL COLLECTIONS

Problem: validate ~435,000 BGP announcements against ~2,000 route origin authorizations

```
val result = announcements.map { announcement =>
  val matching = roas.findMatching(announcement.prefix)
  val (validates, invalidates) =
    matching.partition { roa => roa.isValid(announcement) }

  ValidatedAnnouncement(
    announcement, validates, invalidates)
}
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  ValidatedAnnouncement(
    announcement, validates, invalidates)
}.seq
```

PARALLEL COLLECTIONS

- Sequential: ~1.4 seconds,
  Parallel: ~0.8 seconds (75% faster)
- Can be a quick win for CPU-bound tasks
- Deterministic in absence of side-effects, only the performance changes (same, better, worse)
- Often preferable to implementing a smarter algorithm
- We also use this in UI table filtering

ACTORS

ACTORS

- Aren't Akka and Scala all about actors?
- Planning to try actors to replace Validator-to-Router communication implementation
  - Currently uses Netty `ChannelHandlers`
  - Low-level, hard to test, hard to get right
  - Replace with Akka I/O manager and one actor per router?

CONCLUSION

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- Immutability is golden and so are side-effect free functions
- Concurrency is (still) hard
- But parallelism much easier, almost free
- No single solution to the concurrency problem, use the right tool for the problem at hand
- Scala (like Clojure and Haskell) provides lots of tools that mostly integrate well

... AND NOT COVERED

- Basic Java concurrency (synchronized, notify, wait), java.util.concurrent
- The LMAX Disruptor and the single writer principle
- Dataflow concurrency
- Reactive programming
- Events, event bus, event loops
- Etc.

QUESTIONS?

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