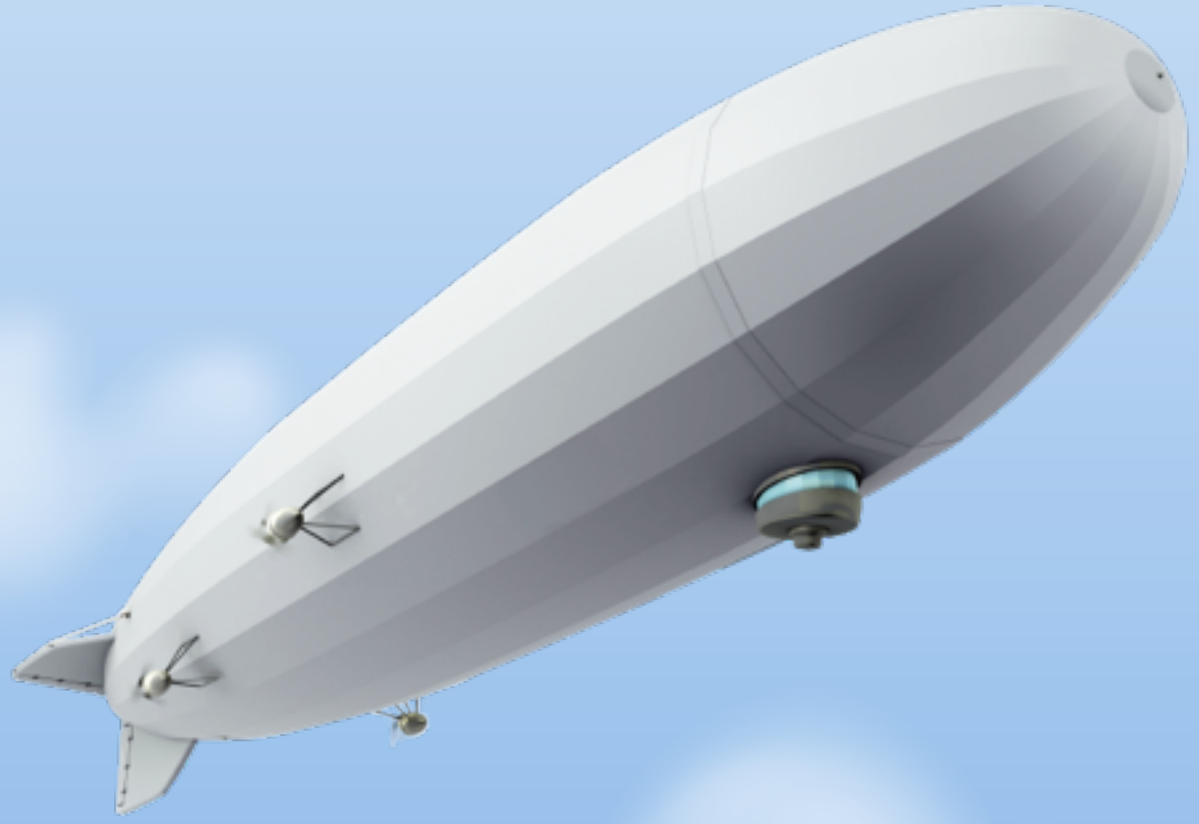
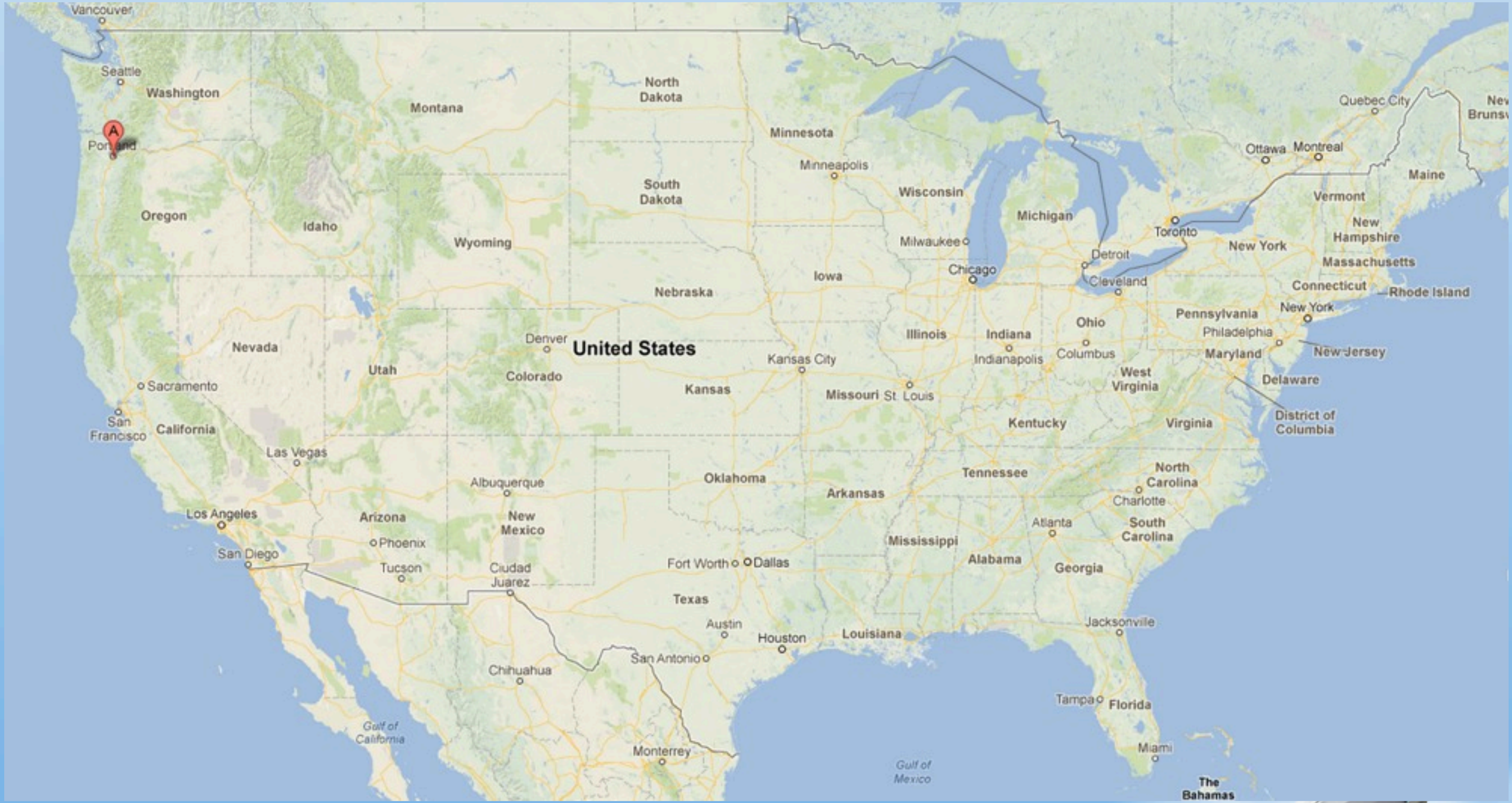


High Performance Network Programming on the JVM

GeeCON, May 2013

Erik Onnen

About Me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Louisiana
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San Antonio
Chihuahua
Tampa
Florida
Gulf of California
Monterrey
Miami
Gulf of Mexico
The Bahamas

About Me

- Vice President, Architecture at Urban Airship
- Most of my career biased towards performance and scale
- Java, C++, Python in service oriented architectures

In this Talk

- Terminology and Key Theorems
- Foundations for this talk (WTF is an “Urban Airship”?)
- Networked Systems on the JVM
- Choosing a framework
- Critical learnings
- Q&A

Lexicon

What makes something “High Performance”?

Lexicon

What makes something “High Performance”?

- Low Latency - I initiate an action with a service, how long does that take
- Throughput - how many of those operations can I drive through my architecture at one time?
- Scalability - how far can we push one service, how does it fail
- Productivity - how quickly can I create a new operation? A new service?
- Sustainability - when a service breaks, what’s the time to RCA

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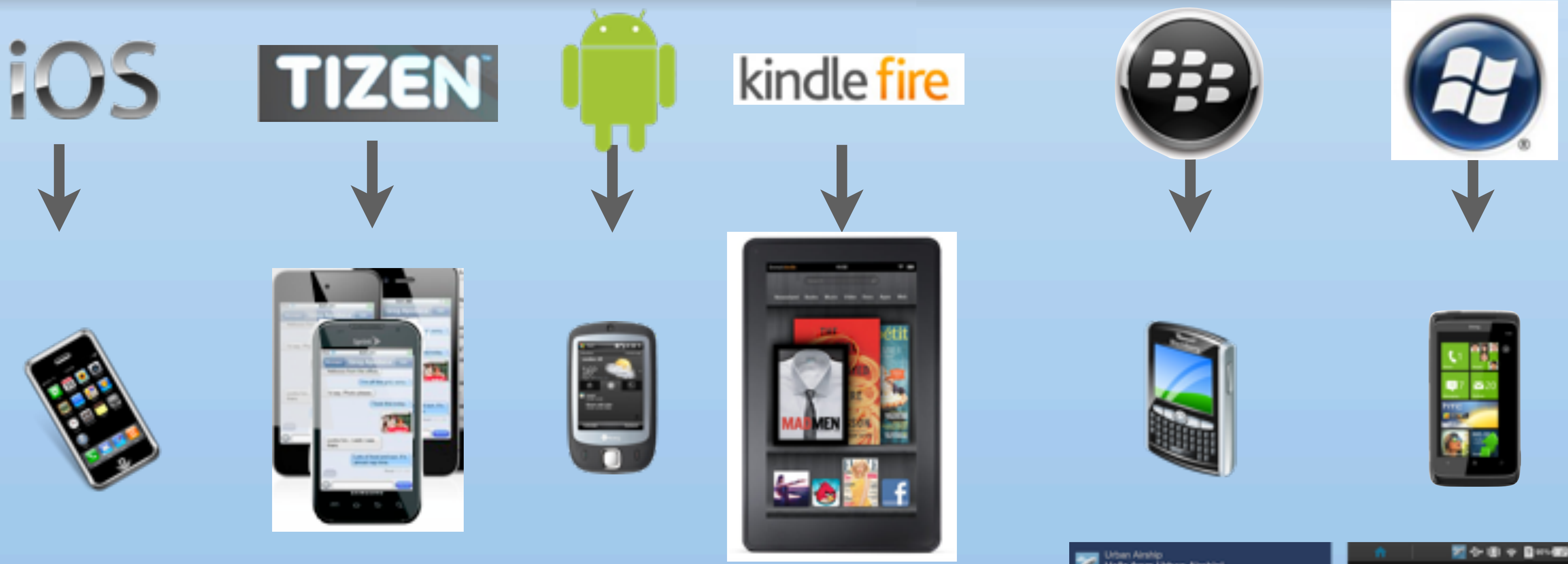
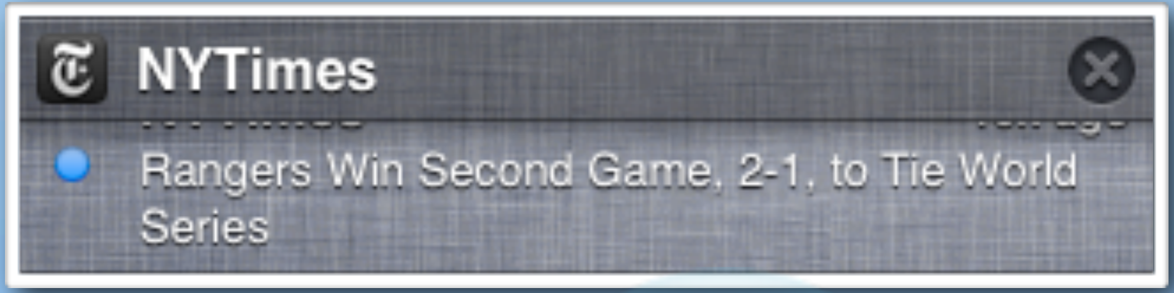
- Deviations in any of these can lead to more CoGS (bad for startups)
- Mobile makes all of these harder

WTF is an Urban Airship?

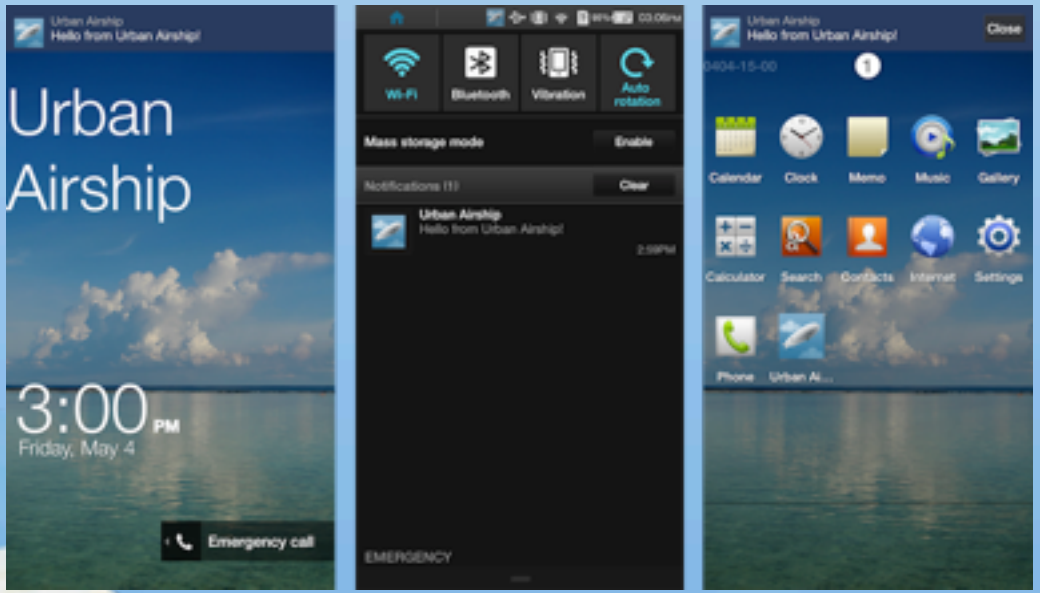
- Fundamentally, an engagement platform
- Buzzword compliant - Cloud Service providing an API for Mobile
- Unified API for services across platforms for messaging, location, content entitlements, digital wallet assets
- SLAs for throughput, latency
- Heavy users and contributors to HBase, ZooKeeper, Cassandra

WTF is an Urban Airship?




NYTimes

Rangers Win Second Game, 2-1, to Tie World Series


Urban Airship
Hello from Urban Airship!

Urban Airship

3:00 PM
Friday, May 4

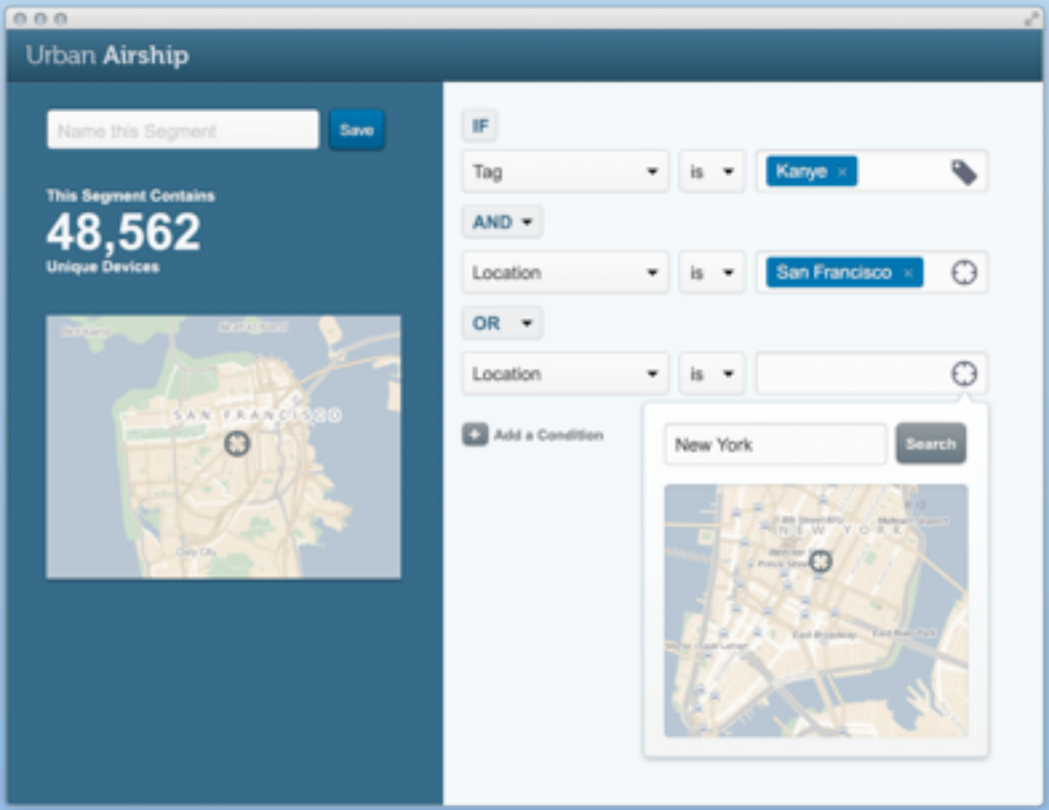
Emergency call

Urban Airship
Hello from Urban Airship!
2:59PM

Urban Airship
Hello from Urban Airship!

What is Push?

- Cost
- Throughput and immediacy
- The platform makes it compelling
  - Push can be intelligent
  - Push can be precisely targeted
- With great power comes great DoS flood



This Segment Contains
48,562
Unique Devices

IF
Tag is Kanye
AND
Location is San Francisco
OR
Location is
New York

How does this relate to the JVM?

- We deal with **lots** of heterogeneous connections from the public network, the vast majority of them are handled by a JVM
- Ingress:
  - 28K HTTPS requests handled every second
  - > 20 million devices connected at any one time
- Internally:
  - Millions of operations per second across our LAN
  - > 20 billion operational metrics a day

Life in Interesting Times

- Fundamentally, SSDs are changing how we think about developing for the JVM
- Similarly, the cost of RAM has made 256GB memory a practical thing but harder to make good use with JVM
- These concerns are not “Big Data”

Distributed Systems on the JVM

- Platform has several tools baked in
  - HTTP Client and Server
  - RMI (Remote Method Invocation) or better JINI
  - CORBA/IIOP
  - JDBC
- Lower level
  - Sockets + streams, channels + buffers
  - Reader/Writer for text
  - Java5 brought NIO which included Async I/O

Distributed Systems on the JVM

- Java 7 brought Asynchronous(Server)SocketChannel
    - Thread pool-backed buffered connect, reads, writes
    - Nicer abstraction than dealing with buffered offsets, spurious wake-up manually
- Fundamentally, the JVM suffers from lowest common denominator problems with the NIO/NIO.2 abstractions

Synchronous vs. Async I/O

Synchronous vs. Async I/O

- Synchronous Network I/O on the JRE
  - Sockets (InputStream, OutputStream)
  - Channels and Buffers
- Asynchronous Network I/O on the JRE
  - Selectors (async)
  - Buffers fed to Channels which are asynchronous
  - Almost all asynchronous APIs are for Socket I/O
- Can operate on direct, off heap buffers
- Offer decent low-level configuration options

Synchronous vs. Async I/O

- Synchronous I/O has many upsides on the JVM
  - Clean streaming - good for moving around really large things
  - Sendfile support for MMap'd files (FileChannel::transferTo)
  - Vectored I/O support
  - No need for additional SSL/TLS abstractions (except for maybe Keystore cruft)
  - No idiomatic impedance for RPC

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  - Favor direct ByteBufffers and NIO Channels

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    - Minimize trips across the system boundary
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    - Vector I/O if possible
    - MMap if possible
  - Favor direct ByteBufffers and NIO Channels
  - Manage timeout expectations

Synchronous vs. Async I/O

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- Async I/O
  - On Linux, implemented via epoll as the “Selector” abstraction with async Channels
  - Async Channels feed buffers, you have to tend to fully reading/writing them (addressed in Java 7)
- Async I/O - doing it well
  - Again, favor direct ByteBuffers, especially for large data
  - Consider the application - what do you gain by not waiting for a response?
  - Avoid manual TLS operations

Sync vs. Async - FIGHT!

Async I/O Wins:

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- Server with large numbers of clients

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Async I/O Wins:

- Server with large numbers of clients
- Only way to be notified if a socket is closed without trying to read it
- Large number of open sockets
- Lightweight proxying of traffic

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- Context switching, CPU cache pipeline loss can be substantial overhead for simple protocols

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Async I/O Loses:

- Context switching, CPU cache pipeline loss can be substantial overhead for simple protocols
- Not always the best option for raw, full bore throughput
- Complexity, ability to reason about code diminished

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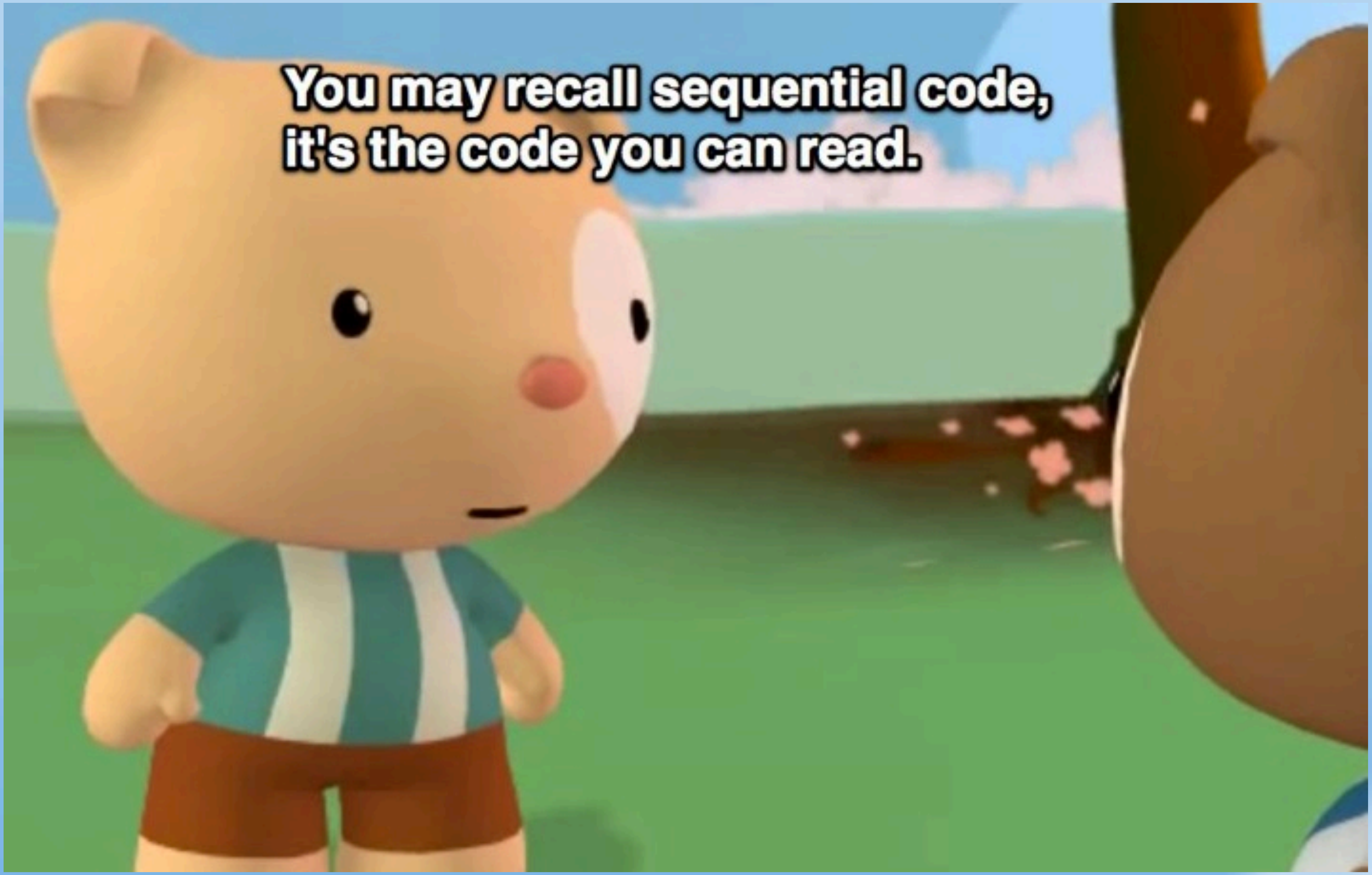

http://www.youtube.com/watch?v=bzkRVzciAZg&feature=player_detailpage#t=133s

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Sync vs. Async - FIGHT!

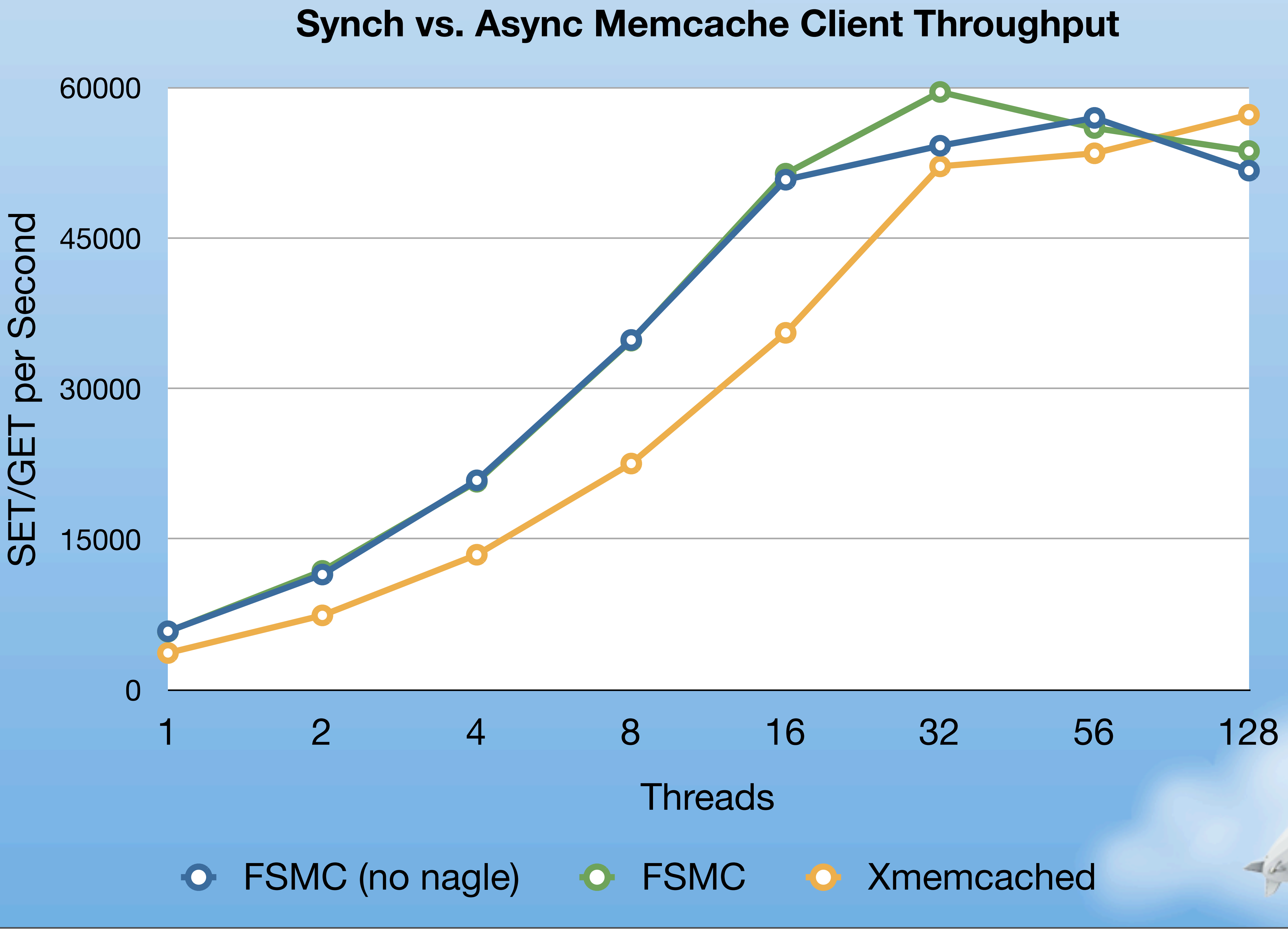
Sync I/O Wins:

- Simplicity, readability
- Better fit for dumb protocols, less impedance for request/reply
- Squeezing every bit of throughput out of a single host, small number of threads

Sync vs. Async - Memcache

- UA uses memcached heavily
- memcached is an awesome example of why choosing Sync vs. Async is hard
- Puts **always** should be completely asynchronous
- Reads are fairly useless when done asynchronously
- Protocol doesn’t lend itself well to Async I/O
- For Java clients, we experimented with Xmemcached but didn’t like its complexity, I/O approach
- Created FSMC (freakin’ simple memcache client)

FSMC vs. Xmemcached



FSMC vs. Xmemcached

```
FSMC:
% time     seconds  usecs/call     calls    errors syscall
------ ----------- ----------- --------- --------- ----------------
 99.97  143.825726      11811     12177      2596 futex
  0.01    0.014143          0    402289           read
  0.01    0.011088          0    200000           writev
  0.01    0.008087          0    200035           write
  0.00    0.002831          0     33223           mprotect
  0.00    0.001664         12       139           madvise
  0.00    0.000403          1       681           brk
  0.00    0.000381          0      1189           sched_yield
  0.00    0.000000          0       120        59 open
  0.00    0.000000          0        68           close
  0.00    0.000000          0       108        42 stat
  0.00    0.000000          0        59           fstat
  0.00    0.000000          0       124         3 lstat
  0.00    0.000000          0      2248           lseek
  0.00    0.000000          0       210           mmap
```

```
14:37:31,568  INFO [main]
[com.urbanairship.oscon.memcache.FsmcTest] Finished
800000 operations in 12659ms.

real  0m12.881s
user  0m34.430s
sys   0m22.830s
```

```
Xmemcached:
% time     seconds  usecs/call     calls    errors syscall
------ ----------- ----------- --------- --------- ----------------
 54.87  875.668275       4325    202456           epoll_wait
 45.13  720.259447        454   1587899    130432 futex
  0.00    0.020783          3      6290           sched_yield
  0.00    0.011119          0    200253           write
  0.00    0.008682          0    799387         2 epoll_ctl
  0.00    0.003759          0    303004    100027 read
  0.00    0.000066          0      1099           mprotect
  0.00    0.000047          1        81           madvise
  0.00    0.000026          0        92           sched_getaffinity
  0.00    0.000000          0       126        59 open
  0.00    0.000000          0       148           close
  0.00    0.000000          0       109        42 stat
  0.00    0.000000          0        61           fstat
  0.00    0.000000          0       124         3 lstat
  0.00    0.000000          0      2521           lseek
  0.00    0.000000          0       292           mmap
```

```
14:38:09,912  INFO [main]
[com.urbanairship.oscon.memcache.XmemcachedTest]
Finished 800000 operations in 18078ms.

real  0m18.248s
user  0m30.020s
sys   0m16.700s
```

A Word on Garbage Collection

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    - Allocation is near free
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- Don’t buffer large things, stream or chunk
- When you must cache:
    - Cache early and don’t touch
    - Better, cache off heap or use memcached

A Word on Garbage Collection

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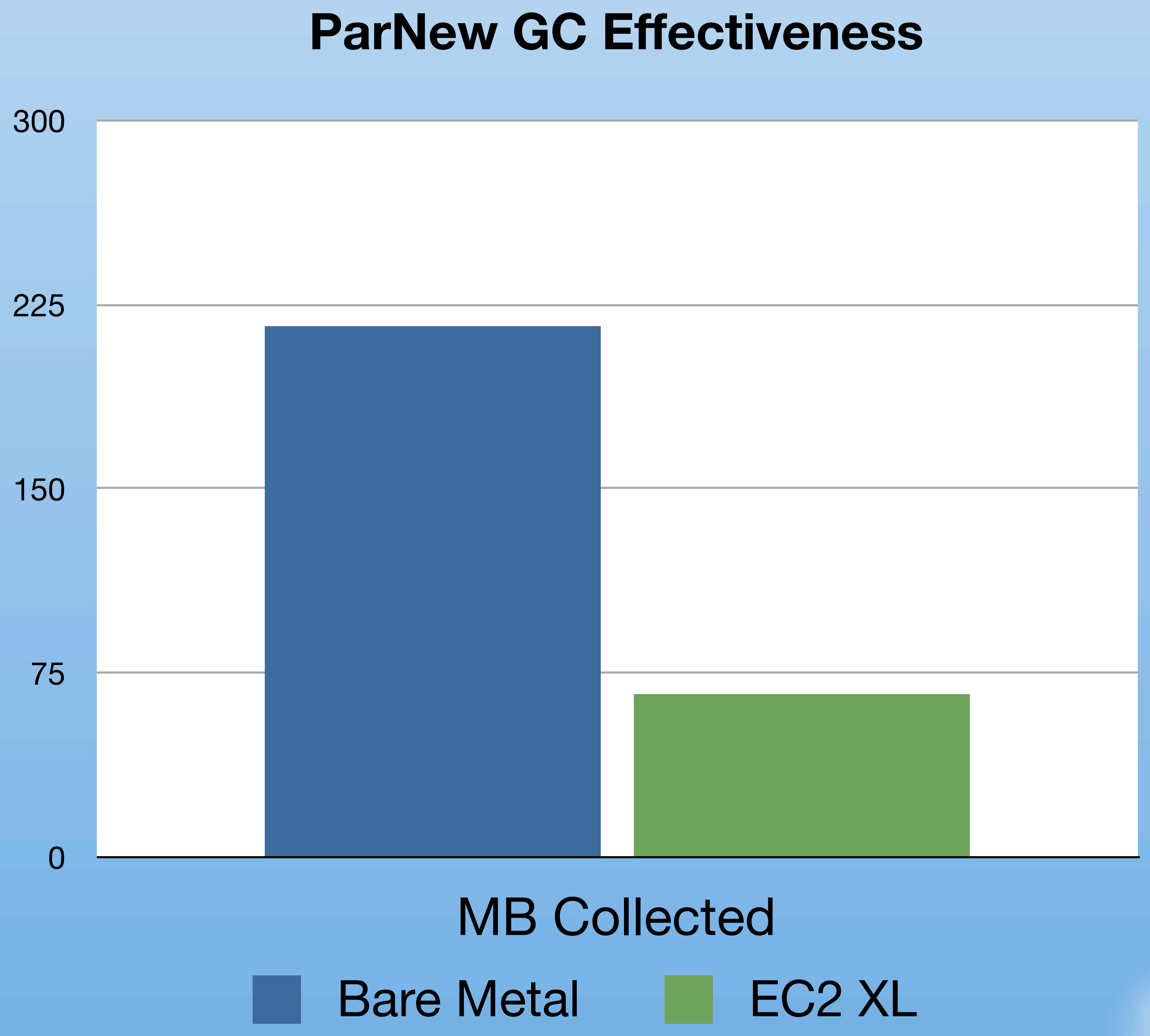
GOOD

A Word on Garbage Collection

About EC2...

When you care about throughput, the virtualization tax is high



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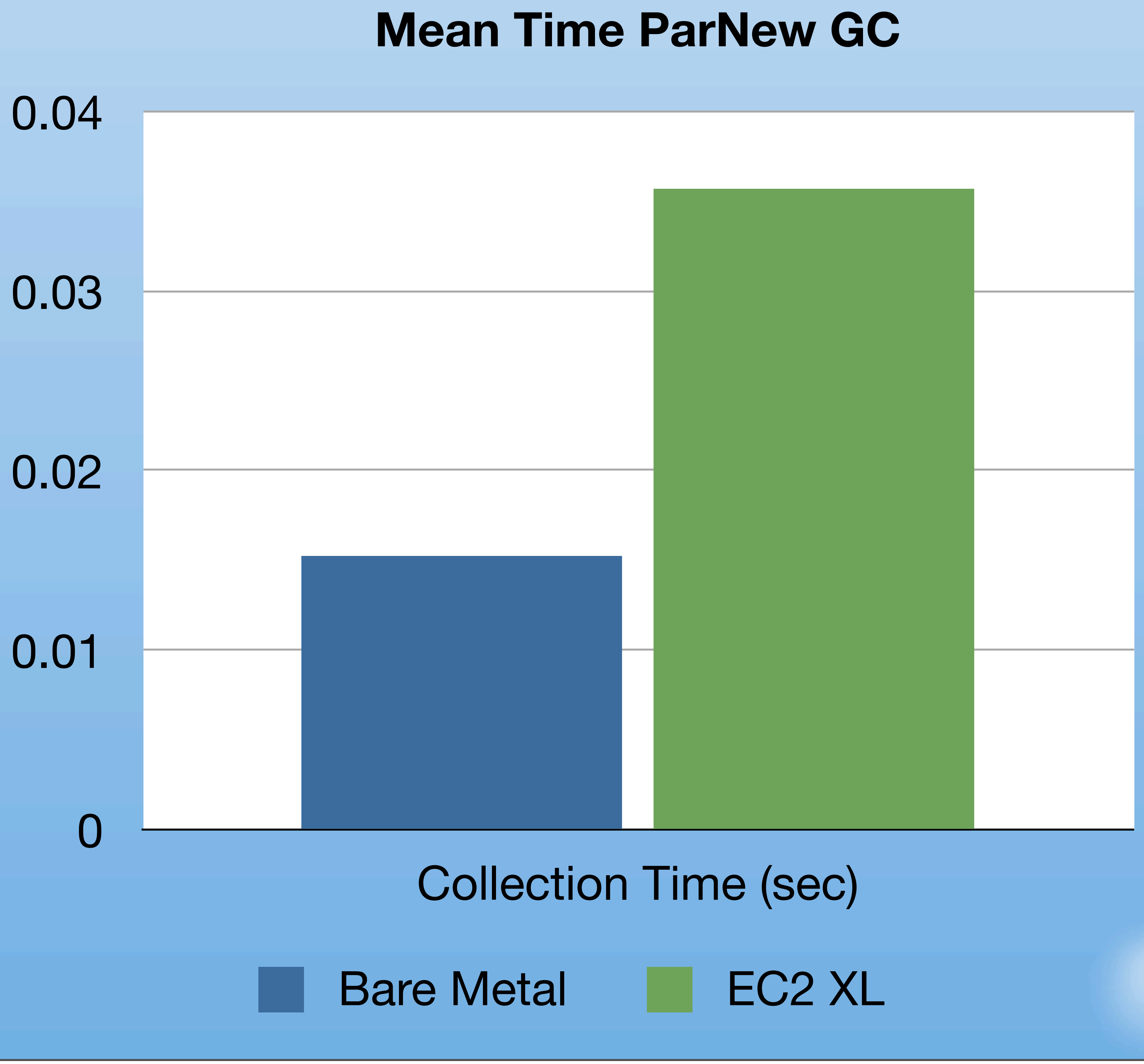

How we do at UA

- Originally our codebase was mostly one giant monolithic application, over time several databases
- Difficult to scale, technically and operationally
- Wanted to break off large pieces of functionality into coarse grained services encapsulating their capability and function
- Most message exchange was done using beanstalkd after migrating off RabbitMQ
- Fundamentally, our business is message passing we need to do that efficiently

Choosing A Framework

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  - Intelligent logging - next level down from metrics
  - How does the framework play with peers?

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  - Support for multiple languages (Python, Java, C++)
  - Simple configuration

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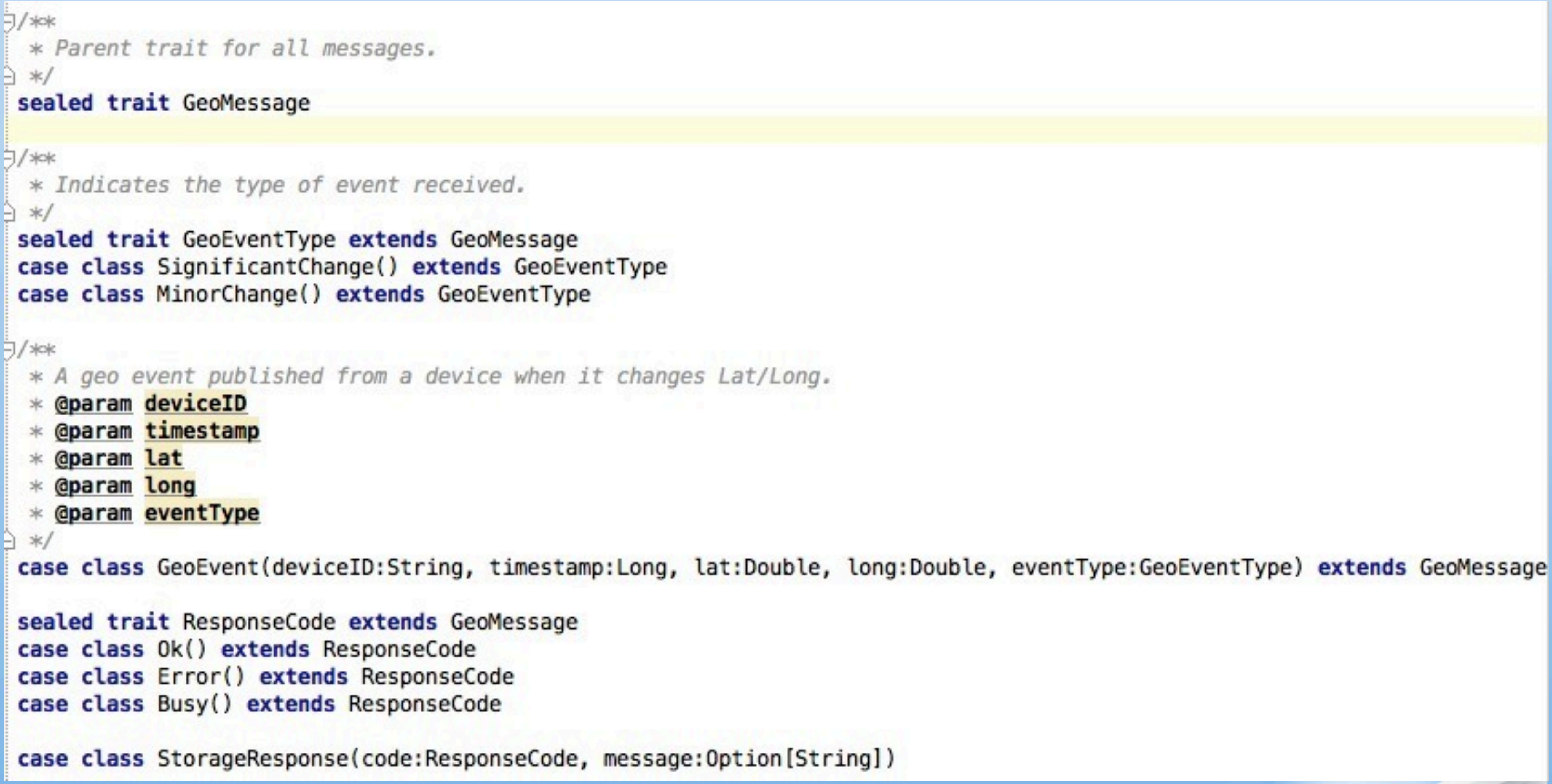
Frameworks - DO IT LIVE!

- Requirements:
  - Discovery mechanism for finding/discarding services
  - Application congestion control combined with clear responsibility contracts
- Optional:
  - Adaptive load balancing
  - Automated network partition recovery

Frameworks - Akka

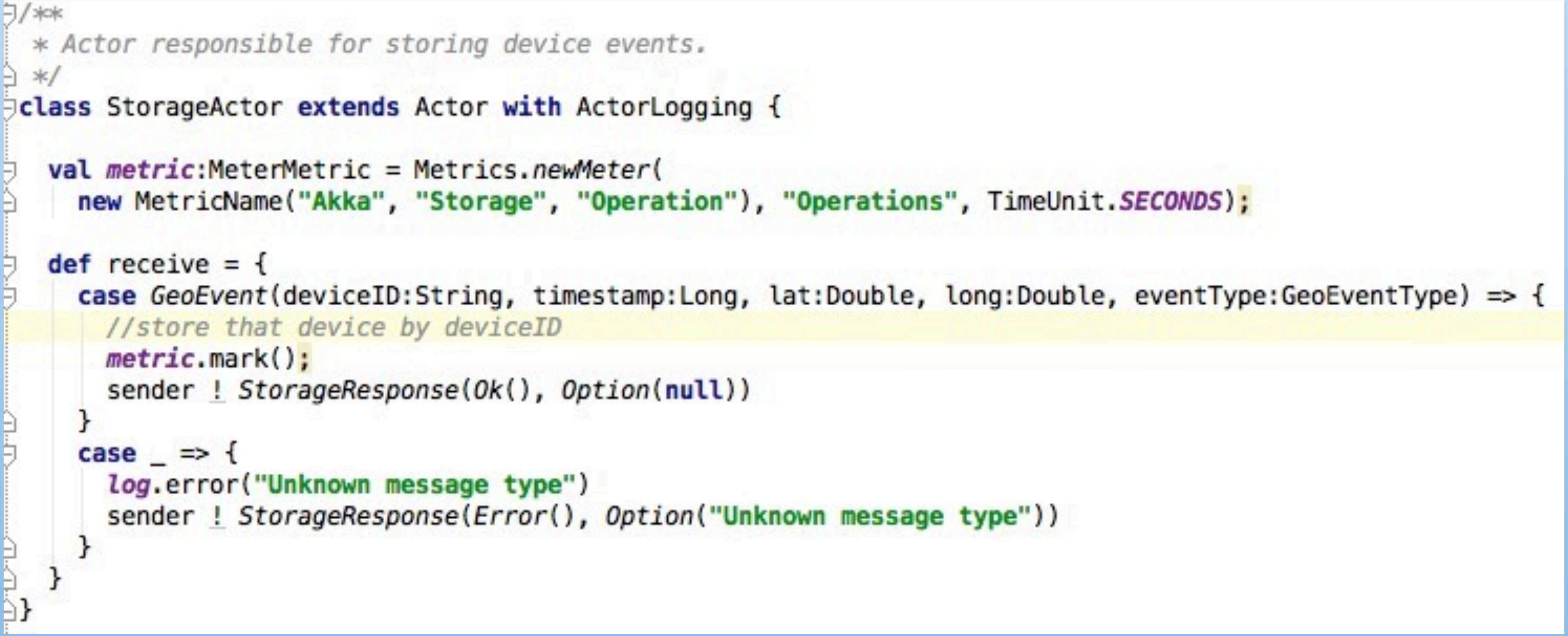
- Predominantly Scala platform for sending messages, distributed incarnation of the Actor pattern
- Message abstraction tolerates distribution well
- If you like OTP, you'll probably like Akka

Frameworks - Akka



```
/**
 * Parent trait for all messages.
 */
sealed trait GeoMessage

/**
 * Indicates the type of event received.
 */
sealed trait GeoEventType extends GeoMessage
case class SignificantChange() extends GeoEventType
case class MinorChange() extends GeoEventType

/**
 * A geo event published from a device when it changes Lat/Long.
 * @param deviceID
 * @param timestamp
 * @param lat
 * @param long
 * @param eventType
 */
case class GeoEvent(deviceID:String, timestamp:Long, lat:Double, long:Double, eventType:GeoEventType) extends GeoMessage

sealed trait ResponseCode extends GeoMessage
case class Ok() extends ResponseCode
case class Error() extends ResponseCode
case class Busy() extends ResponseCode

case class StorageResponse(code:ResponseCode, message:Option[String])
```

Frameworks - Akka



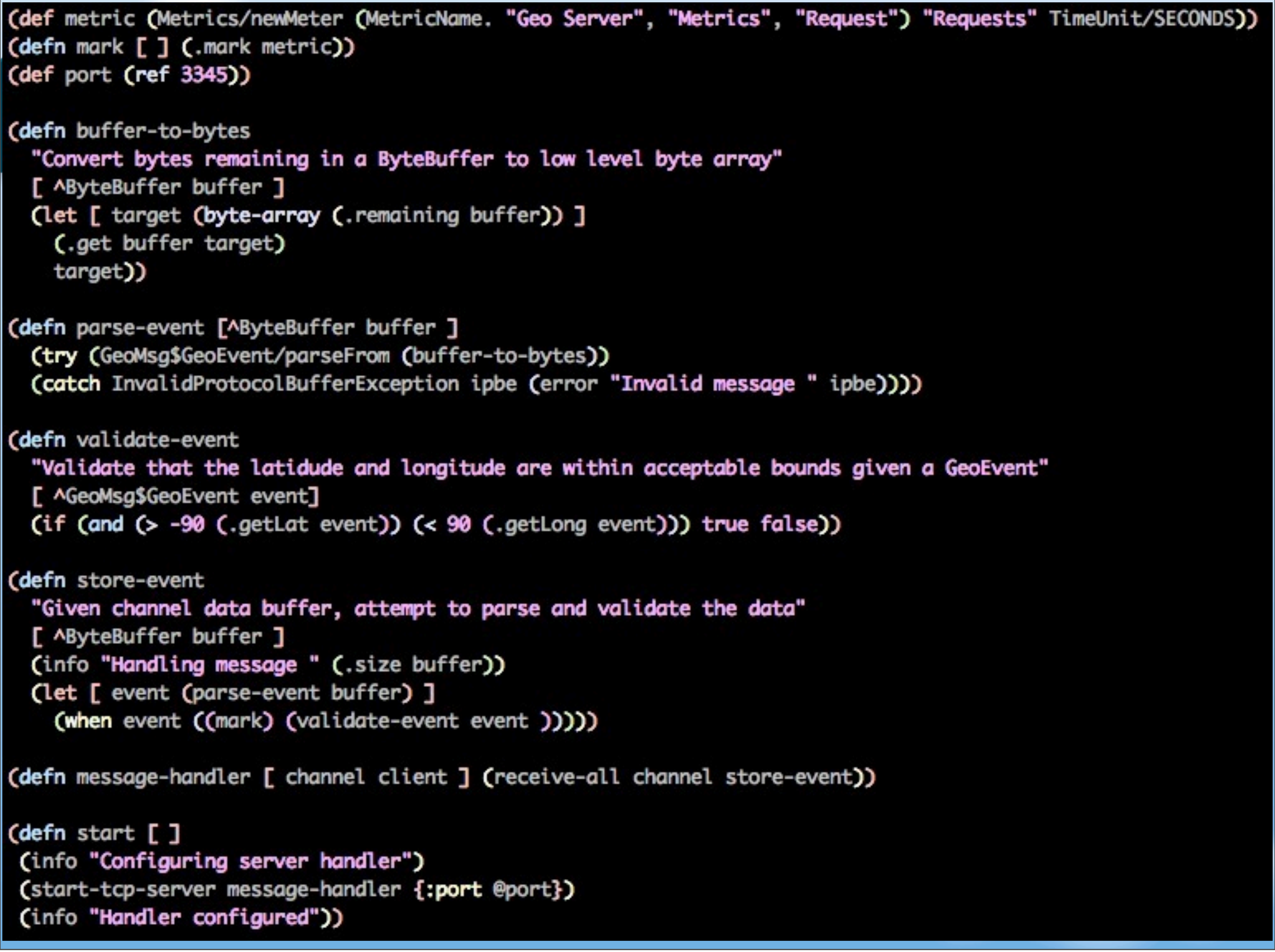
```scala
/**
 * Actor responsible for storing device events.
 */
class StorageActor extends Actor with ActorLogging {

  val metric:MeterMetric = Metrics.newMeter(
    new MetricName("Akka", "Storage", "Operation"), "Operations", TimeUnit.SECONDS);

  def receive = {
    case GeoEvent(deviceID:String, timestamp:Long, lat:Double, long:Double, eventType:GeoEventType) => {
      //store that device by deviceID
      metric.mark();
      sender ! StorageResponse(Ok(), Option(null))
    }
    case _ => {
      log.error("Unknown message type")
      sender ! StorageResponse(Error(), Option("Unknown message type"))
    }
  }
}
```

Frameworks - Akka

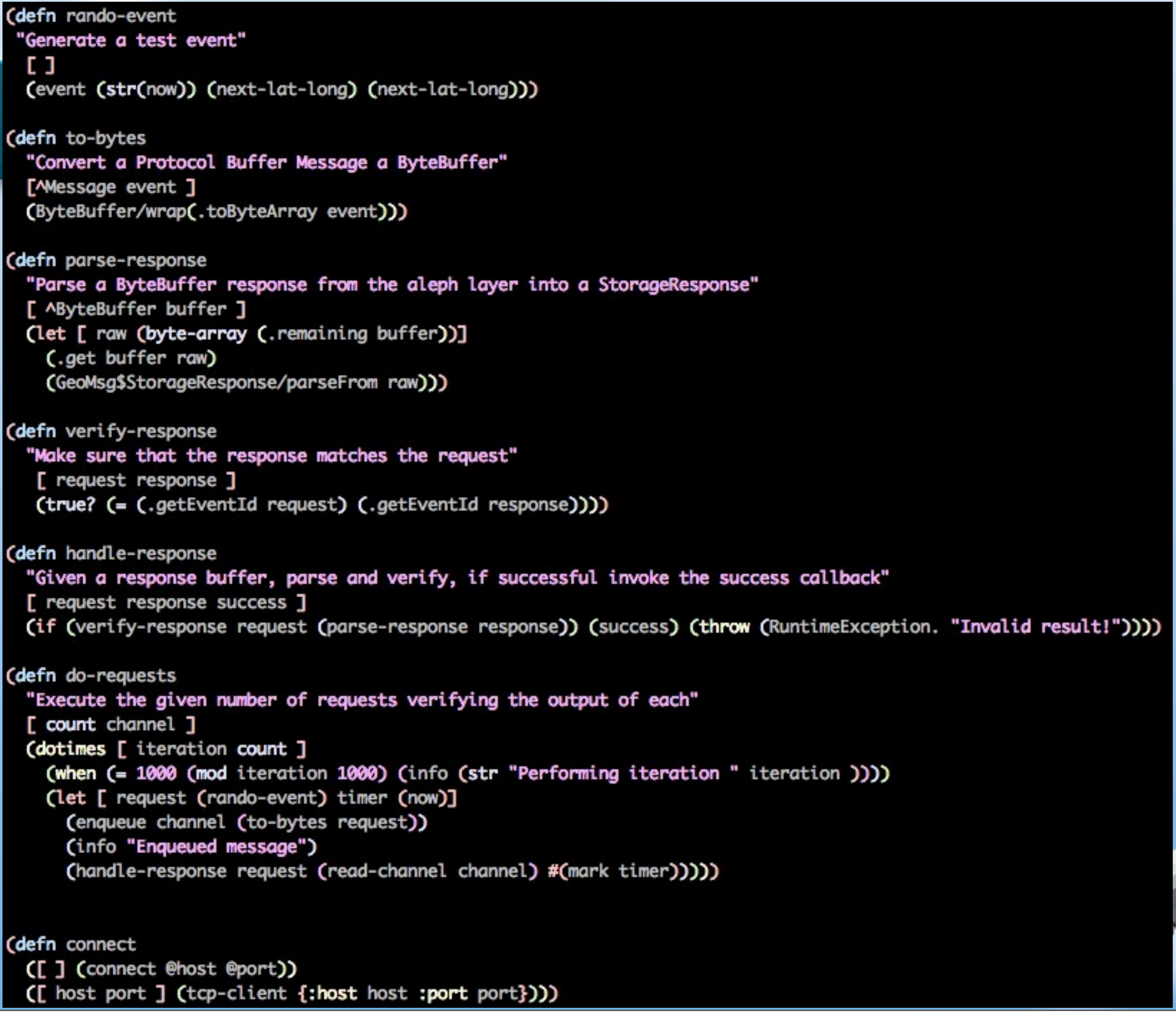
- Cons:
  - We don’t like reading other people’s Scala
  - Some pretty strong assertions in the docs that aren’t substantiated
  - Bulky wire protocol, especially for primitives
  - Configuration felt complicated
  - Sheer surface area of the framework is daunting
  - Unclear integration story with Python
  - Don’t want Dynamo for simple RPC

Frameworks - Aleph

- Clojure framework based on Netty, Lamina
- Conceptually funs are applied to channels to move around messages
- Channels are refs that you realize when you want data
- Operations with channels very easy
- Concise format for standing up clients and services using text protocols



```
(def metric (Metrics/newMeter (MetricName. "Geo Server", "Metrics", "Request") "Requests" TimeUnit/SECONDS))
(defn mark [ ] (.mark metric))
(def port (ref 3345))

(defn buffer-to-bytes
  "Convert bytes remaining in a ByteBuffer to low level byte array"
  [ ^ByteBuffer buffer ]
  (let [ target (byte-array (.remaining buffer)) ]
    (.get buffer target)
    target))

(defn parse-event [^ByteBuffer buffer ]
  (try (GeoMsg$GeoEvent/parseFrom (buffer-to-bytes))
  (catch InvalidProtocolBufferException ipbe (error "Invalid message " ipbe))))

(defn validate-event
  "Validate that the latidude and longitude are within acceptable bounds given a GeoEvent"
  [ ^GeoMsg$GeoEvent event]
  (if (and (> -90 (.getLat event)) (< 90 (.getLong event))) true false))

(defn store-event
  "Given channel data buffer, attempt to parse and validate the data"
  [ ^ByteBuffer buffer ]
  (info "Handling message " (.size buffer))
  (let [ event (parse-event buffer) ]
    (when event ((mark) (validate-event event )))))

(defn message-handler [ channel client ] (receive-all channel store-event))

(defn start [ ]
 (info "Configuring server handler")
 (start-tcp-server message-handler {:port @port})
 (info "Handler configured"))
```



```clojure
(defn rando-event
 "Generate a test event"
  [ ]
  (event (str(now)) (next-lat-long) (next-lat-long)))

(defn to-bytes
  "Convert a Protocol Buffer Message a ByteBuffer"
  [^Message event ]
  (ByteBuffer/wrap(.toByteArray event)))

(defn parse-response
  "Parse a ByteBuffer response from the aleph layer into a StorageResponse"
  [ ^ByteBuffer buffer ]
  (let [ raw (byte-array (.remaining buffer))]
    (.get buffer raw)
    (GeoMsg$StorageResponse/parseFrom raw)))

(defn verify-response
  "Make sure that the response matches the request"
   [ request response ]
   (true? (= (.getEventId request) (.getEventId response))))

(defn handle-response
  "Given a response buffer, parse and verify, if successful invoke the success callback"
  [ request response success ]
  (if (verify-response request (parse-response response)) (success) (throw (RuntimeException. "Invalid result!"))))

(defn do-requests
  "Execute the given number of requests verifying the output of each"
  [ count channel ]
  (dotimes [ iteration count ]
    (when (= 1000 (mod iteration 1000)) (info (str "Performing iteration " iteration )))
    (let [ request (rando-event) timer (now)]
      (enqueue channel (to-bytes request))
      (info "Enqueued message")
      (handle-response request (read-channel channel) #(mark timer)))))


(defn connect
  ([ ] (connect @host @port))
  ([ host port ] (tcp-client {:host host :port port})))
```

Frameworks - Aleph

- Cons:
  - Very high level abstraction, knobs are buried if they exist
  - Channel concept leaky for large messages, unclear how to stream
  - Documentation, tests

Frameworks - Netty

- **The** preeminent framework for doing Async Network I/O on the JVM
- Netty Channels backed by pipelines on top of lower level NIO Channels
- Pros:
  - Abstraction doesn’t hide the important pieces
  - The only sane way to do SSL with Async I/O on the JVM
  - Protocols well abstracted into pipeline steps
  - Clean callback model for events of interest but optional in simple cases - no death by callback

Frameworks - Netty

- Cons:
  - Easy to make too many copies of the data
  - Some old school bootstrap idioms
  - Writes can occasionally be reordered
  - Failure conditions can be numerous, difficult to reason about
  - Simple things can feel difficult - UDP, simple request/reply
  - Sync timeout implementation heavy-handed

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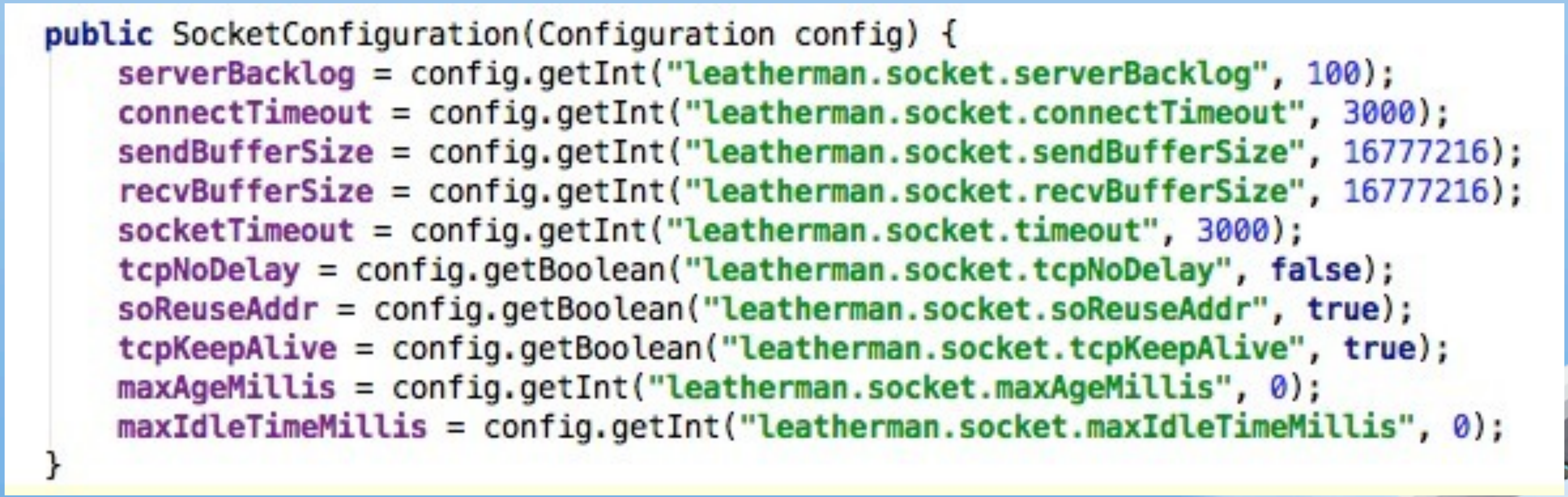
- Core service traits are part of the framework
- Service instances quiesce gracefully
- Netty made UDP, Sync, Async. easy

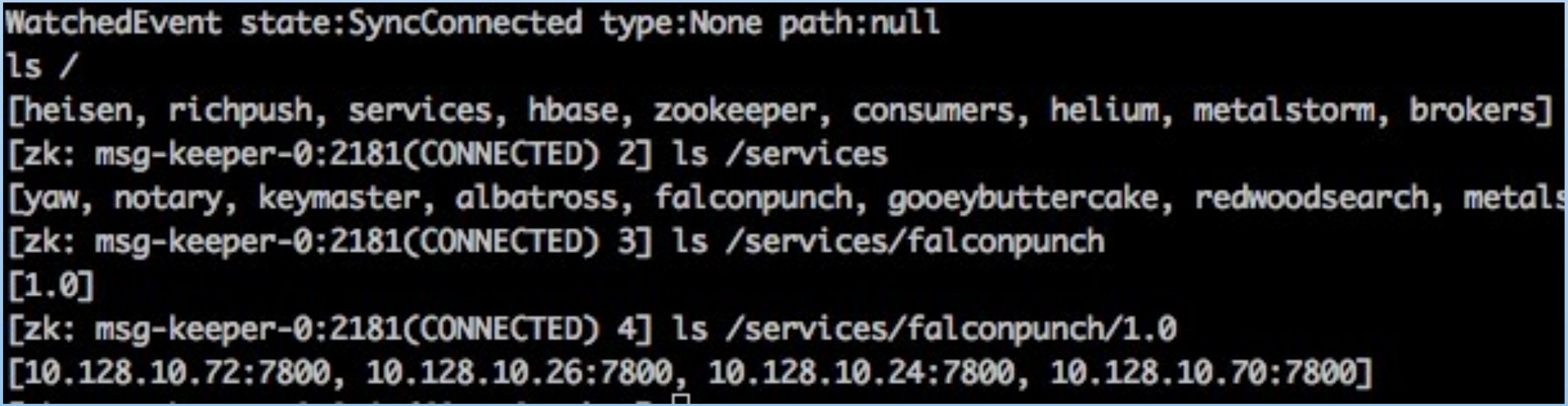
Frameworks - DO IT LIVE!

- All operations are Callables, services define a mapping b/t a request type and a Callable
- Client API always returns a Future, sometimes it’s already materialized
- Precise tuning from config files



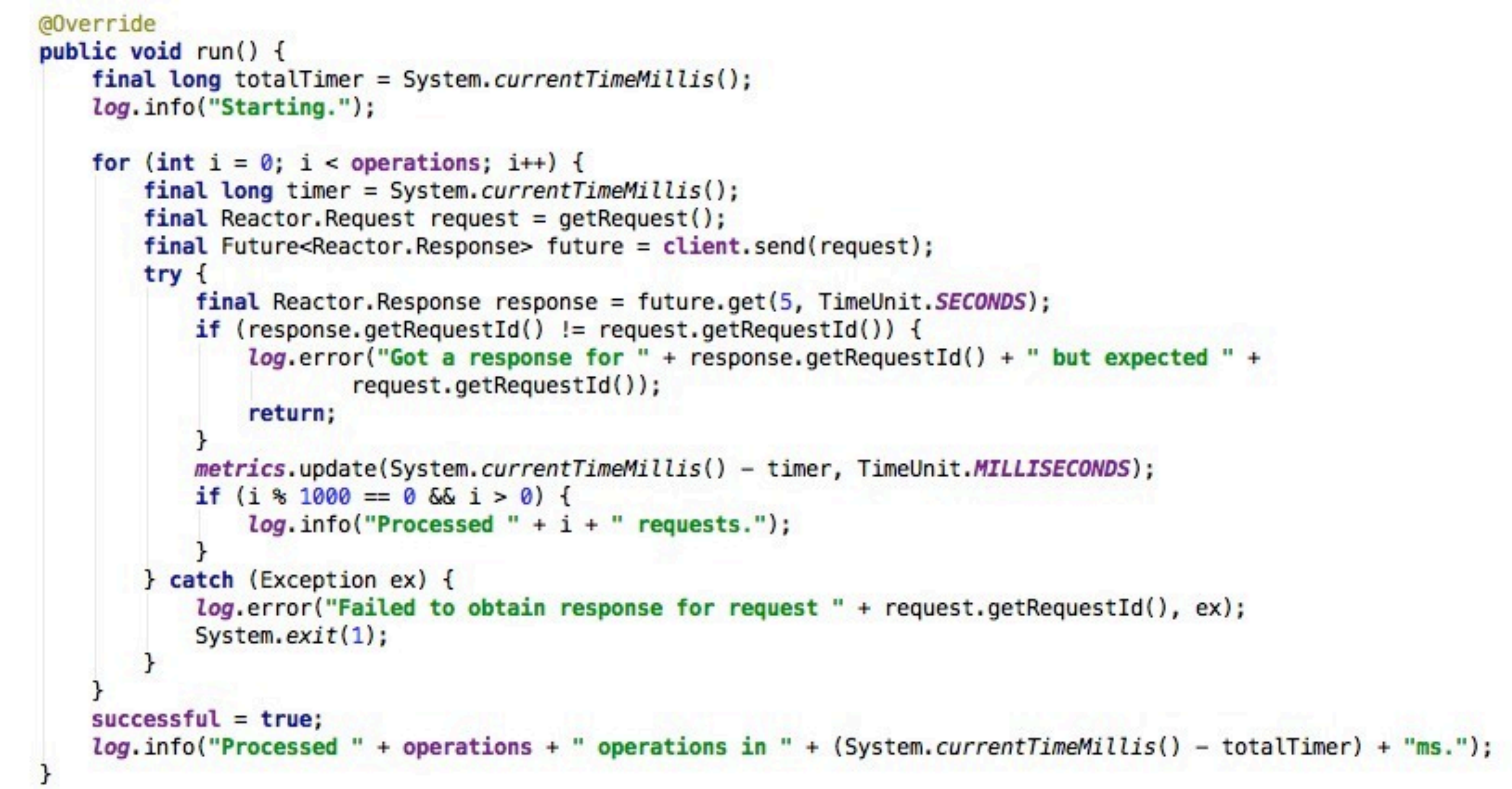
```
public SocketConfiguration(Configuration config) {
    serverBacklog = config.getInt("leatherman.socket.serverBacklog", 100);
    connectTimeout = config.getInt("leatherman.socket.connectTimeout", 3000);
    sendBufferSize = config.getInt("leatherman.socket.sendBufferSize", 16777216);
    recvBufferSize = config.getInt("leatherman.socket.recvBufferSize", 16777216);
    socketTimeout = config.getInt("leatherman.socket.timeout", 3000);
    tcpNoDelay = config.getBoolean("leatherman.socket.tcpNoDelay", false);
    soReuseAddr = config.getBoolean("leatherman.socket.soReuseAddr", true);
    tcpKeepAlive = config.getBoolean("leatherman.socket.tcpKeepAlive", true);
    maxAgeMillis = config.getInt("leatherman.socket.maxAgeMillis", 0);
    maxIdleTimeMillis = config.getInt("leatherman.socket.maxIdleTimeMillis", 0);
}
```

What We Learned - In General



```
WatchedEvent state:SyncConnected type:None path:null
ls /
[heisen, richpush, services, hbase, zookeeper, consumers, helium, metalstorm, brokers]
[zk: msg-keeper-0:2181(CONNECTED) 2] ls /services
[yaw, notary, keymaster, albatross, falconpunch, gooeybuttercake, redwoodsearch, metals
[zk: msg-keeper-0:2181(CONNECTED) 3] ls /services/falconpunch
[1.0]
[zk: msg-keeper-0:2181(CONNECTED) 4] ls /services/falconpunch/1.0
[10.128.10.72:7800, 10.128.10.26:7800, 10.128.10.24:7800, 10.128.10.70:7800]
```

Frameworks - DO IT LIVE!



```java
@Override
public void run() {
    final long totalTimer = System.currentTimeMillis();
    log.info("Starting.");

    for (int i = 0; i < operations; i++) {
        final long timer = System.currentTimeMillis();
        final Reactor.Request request = getRequest();
        final Future<Reactor.Response> future = client.send(request);
        try {
            final Reactor.Response response = future.get(5, TimeUnit.SECONDS);
            if (response.getRequestId() != request.getRequestId()) {
                log.error("Got a response for " + response.getRequestId() + " but expected " +
                        request.getRequestId());
                return;
            }
            metrics.update(System.currentTimeMillis() - timer, TimeUnit.MILLISECONDS);
            if (i % 1000 == 0 && i > 0) {
                log.info("Processed " + i + " requests.");
            }
        } catch (Exception ex) {
            log.error("Failed to obtain response for request " + request.getRequestId(), ex);
            System.exit(1);
        }
    }
    successful = true;
    log.info("Processed " + operations + " operations in " + (System.currentTimeMillis() - totalTimer) + "ms.");
}
```

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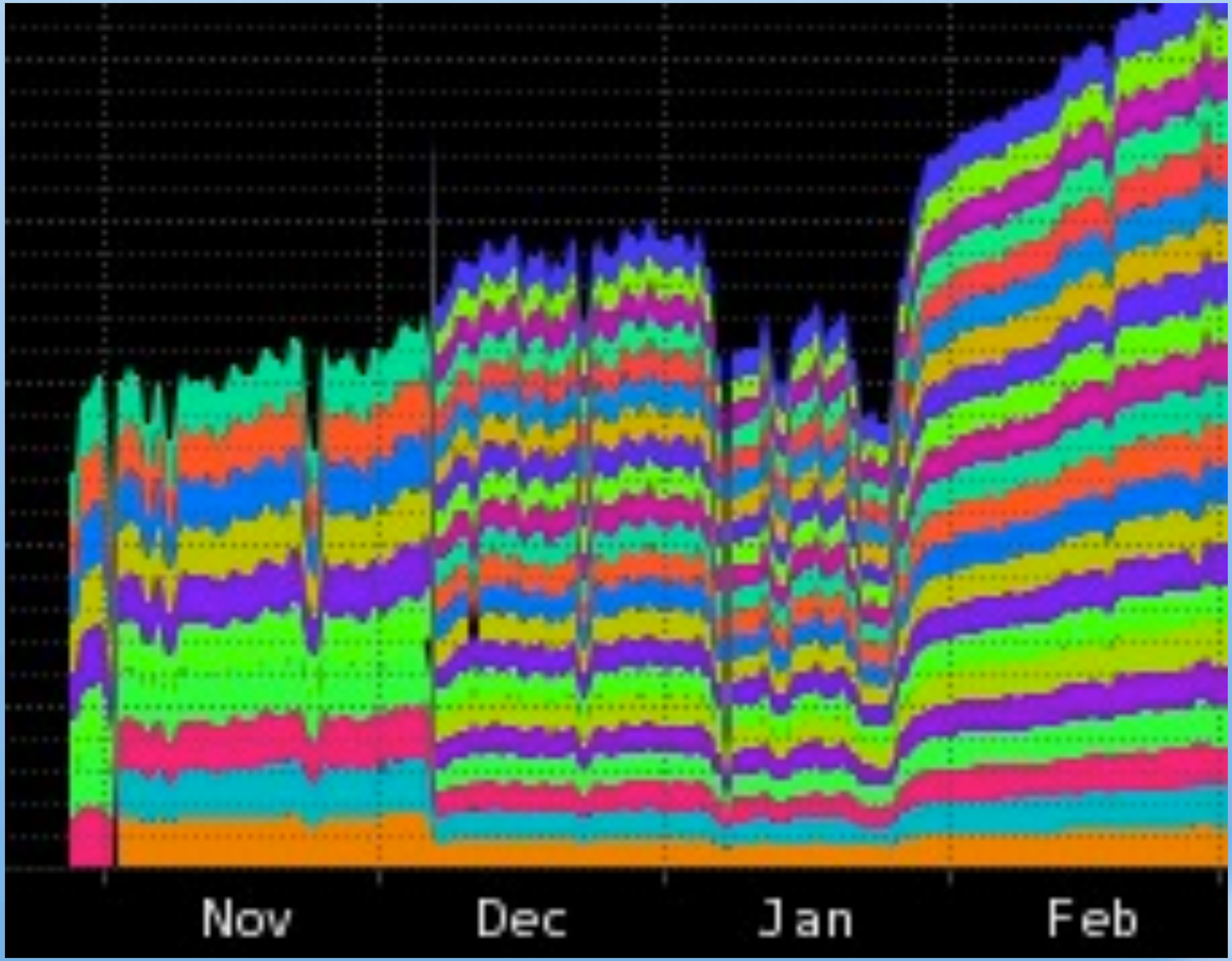

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- Nagle! Non-duplex protocols can benefit significantly
- Example: 19K message deliveries per second vs. 2K
- Example: our protocol has a size frame, w/o Nagle that went in its own packet

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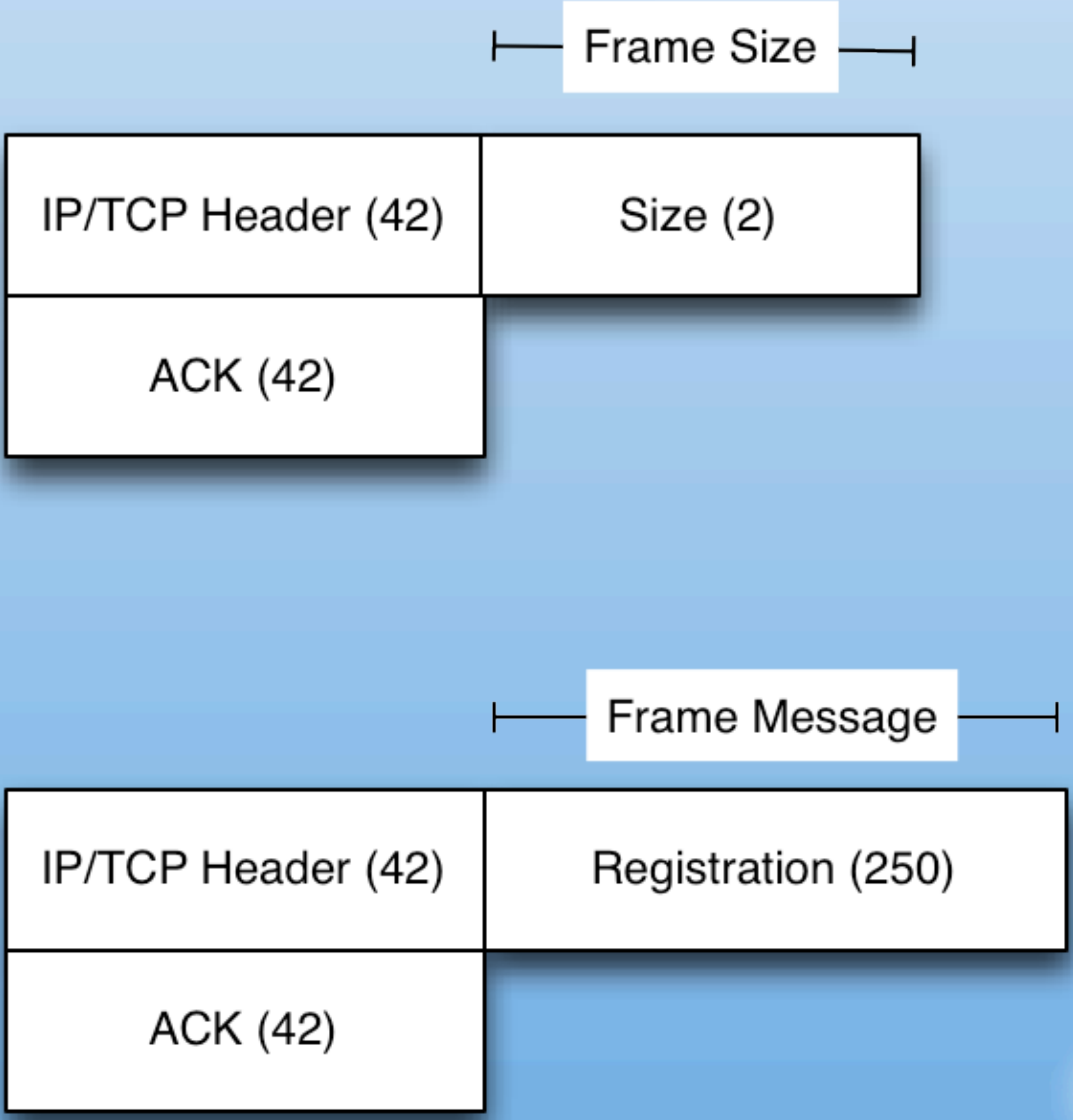

Frame Size

IP/TCP Header (42)

Size (2)

ACK (42)

Frame Message

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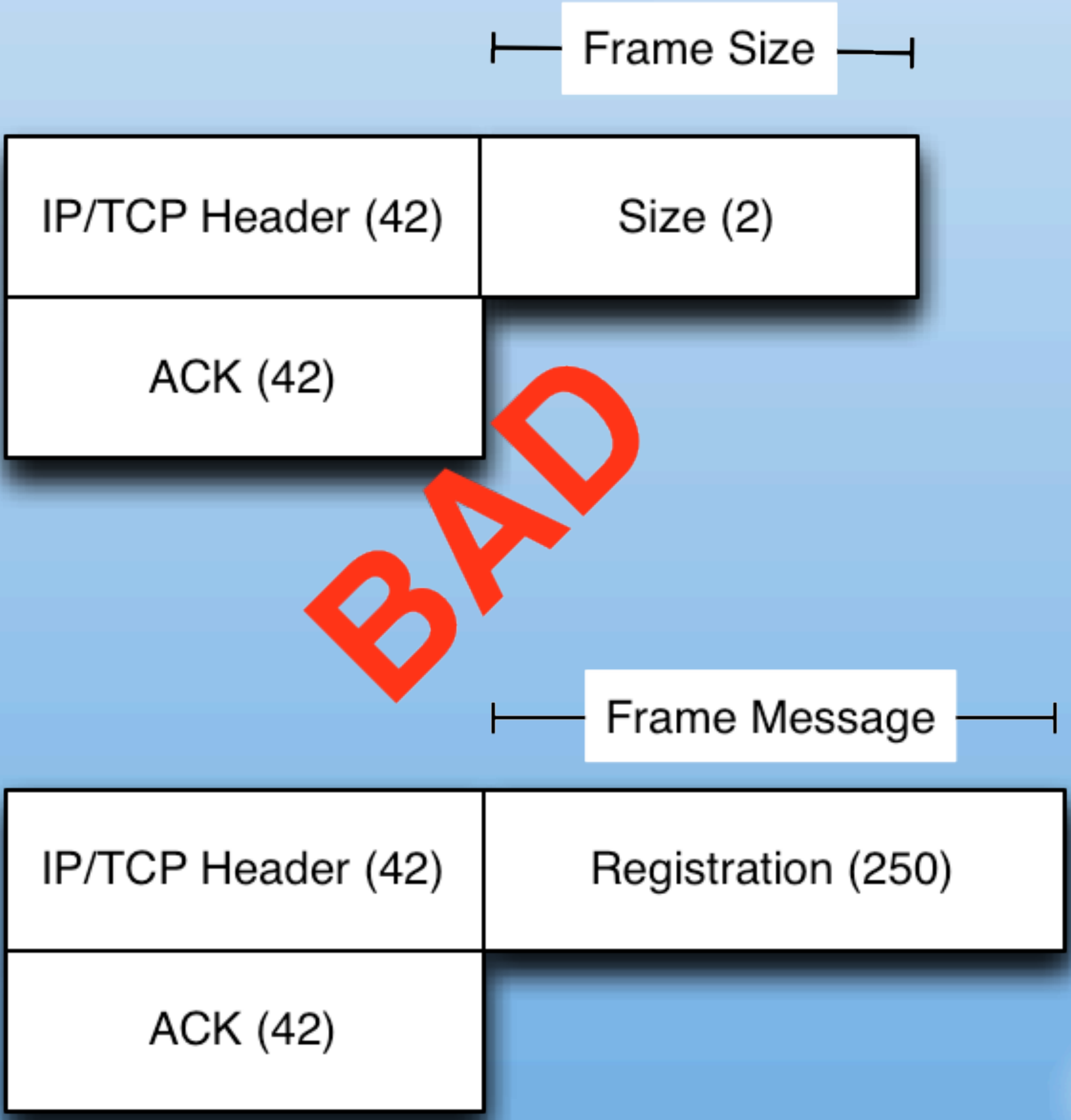

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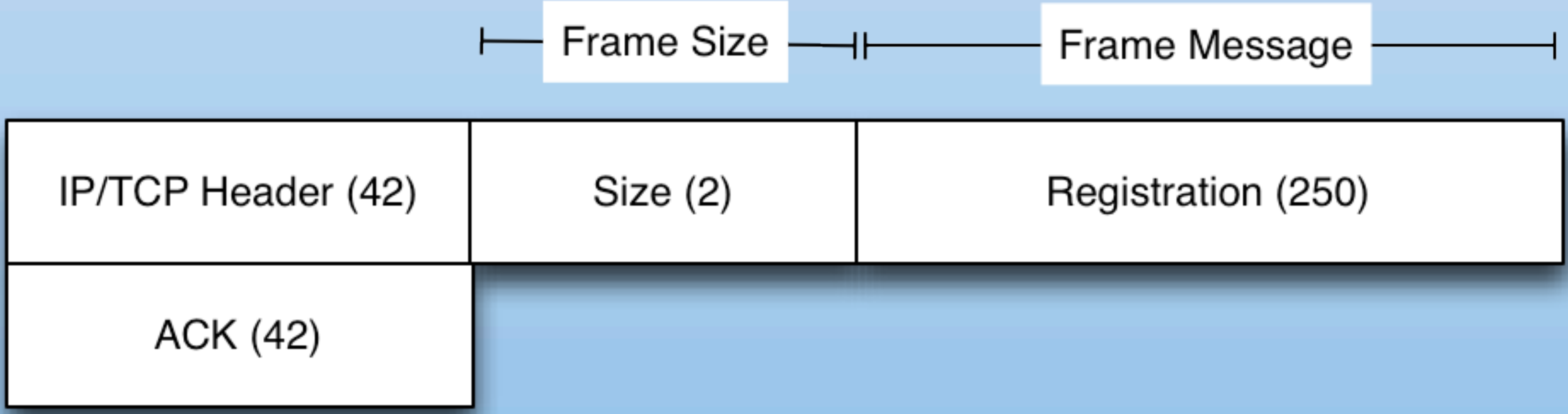

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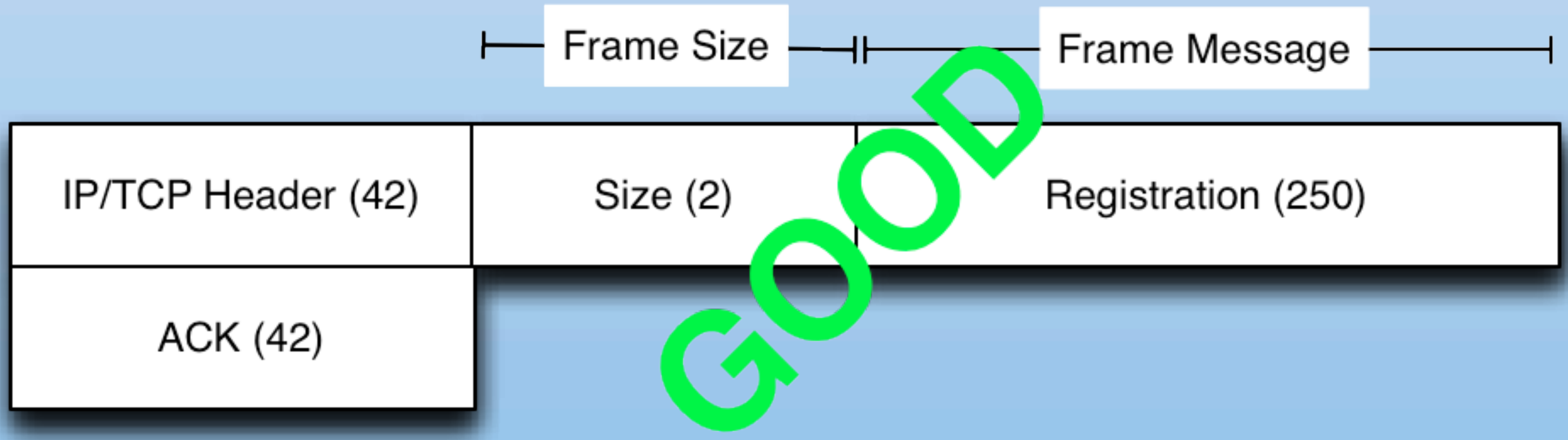

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Saves 84 bytes, 1 round trip

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TLS source: http://netsekure.org/2010/03/tls-overhead/

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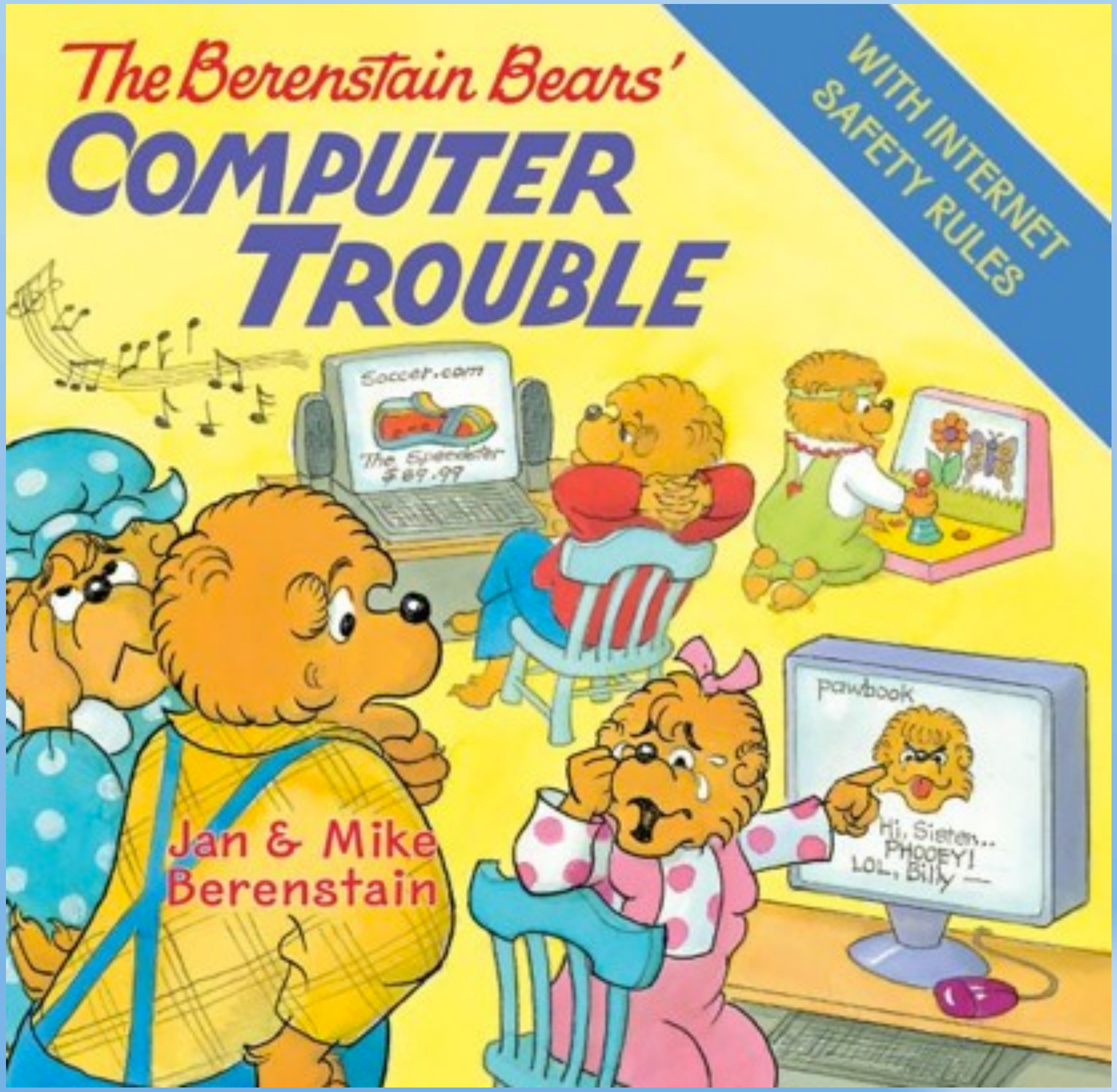

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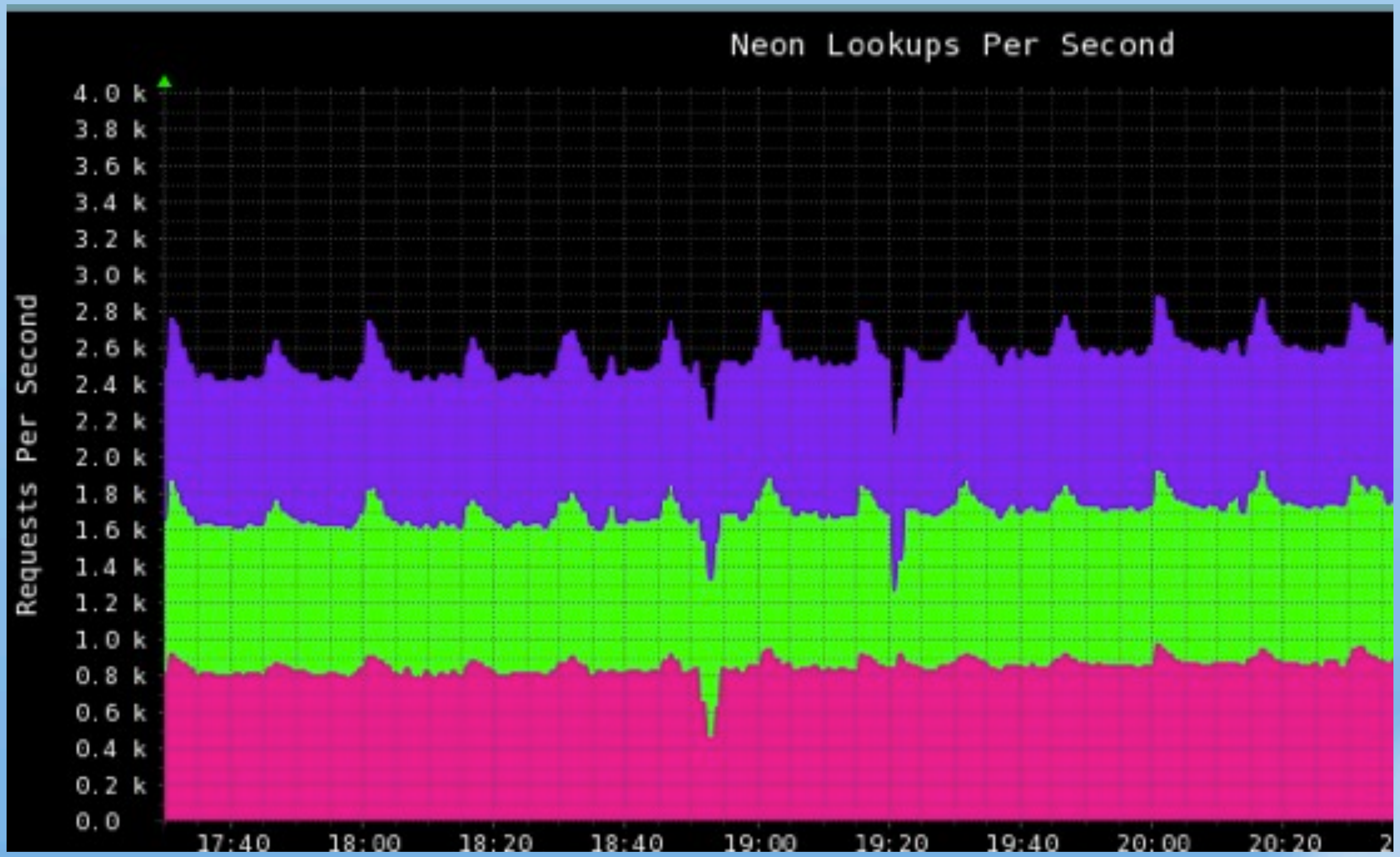

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- Those reconnections are expensive for us and the devices

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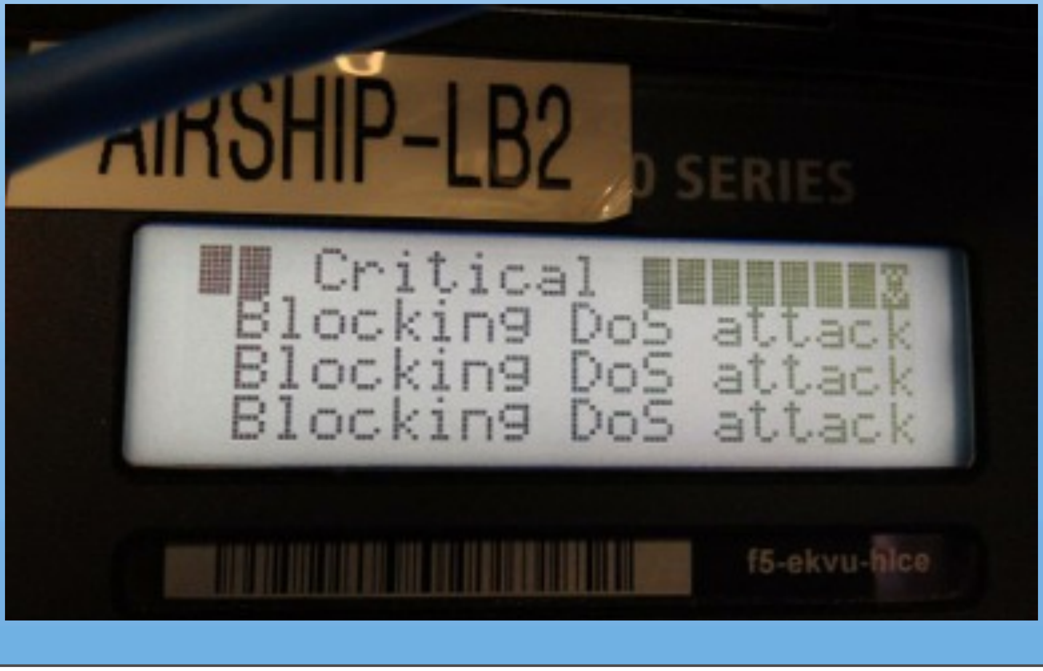
- Great for surge capacity
- Don’t split services into the virtual domain

Lessons Learned - Failing Well

- Scale vertically **and** horizontally
- Scale vertically but remember...
  - We can reliably take one Java process up to 990K open connections
  - What happens when that one process fails?
  - What happens when you need to do maintenance?



```
Critical
Blocking DoS attack
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```

Thanks!

- Urban Airship http://urbanairship.com/
- Me @eonnen on Twitter or erik@urbanairship.com
- We’re hiring! http://urbanairship.com/company/jobs/

Additional UA Reading

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- Infrastructure Improvements - http://urbanairship.com/blog/2012/05/17/scaling-urban-airships-messaging-infrastructure-to-light-up-a-stadium-in-one-second/

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- Infrastructure Improvements - http://urbanairship.com/blog/2012/05/17/scaling-urban-airships-messaging-infrastructure-to-light-up-a-stadium-in-one-second/
- C500K - http://urbanairship.com/blog/2010/08/24/c500k-in-action-at-urban-airship/