Real Logic
ACCELERATING SOFTWARE

Aeron
High-Performance Open Source Message Transport

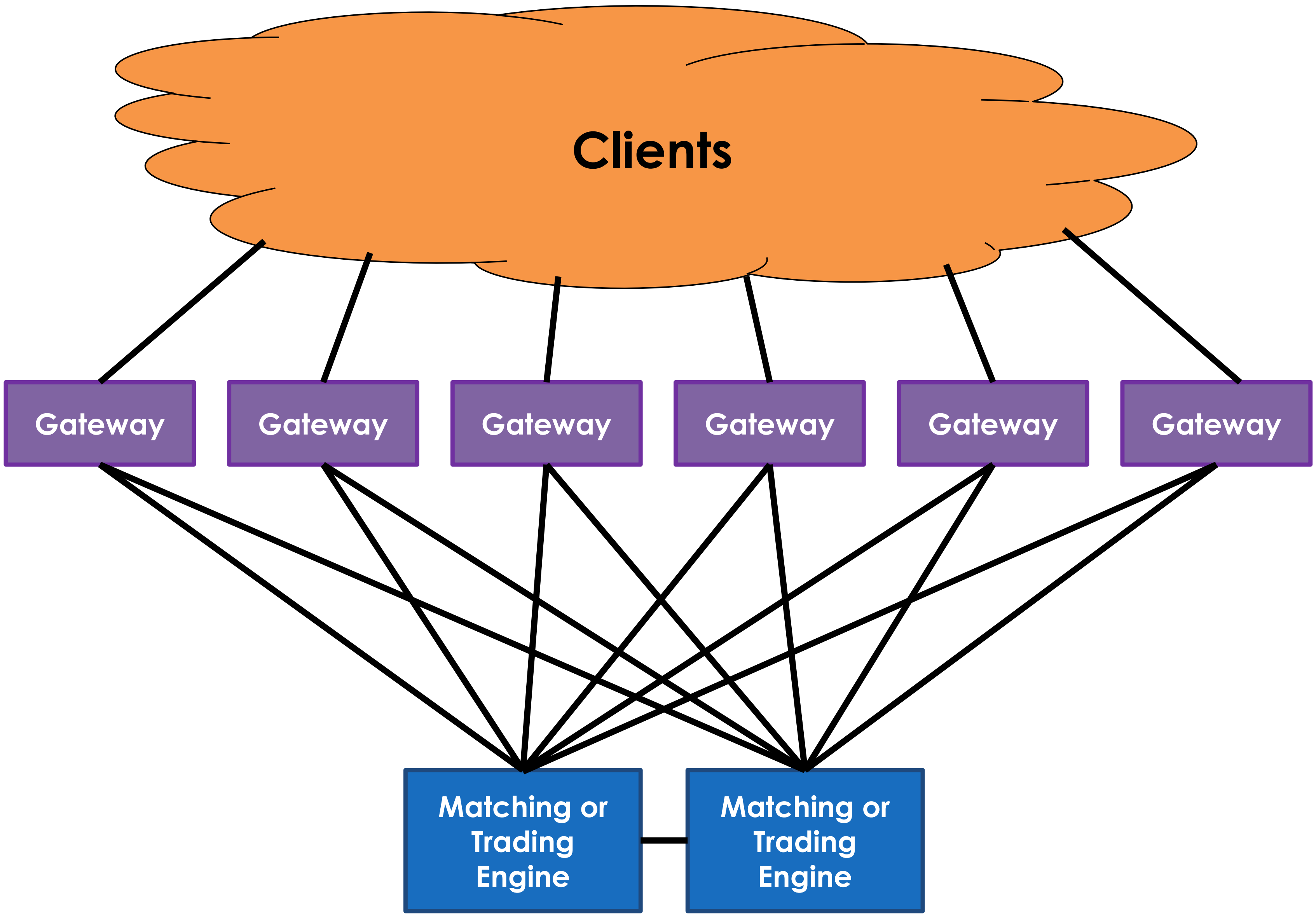
Martin Thompson - @mjpt777

1. Why build another Product?
2. What Features are really needed?
3. How does one Design for this?
4. What did we Learn on the way?
5. What's the Roadmap?

1. Why build another product?

Not Invented Here!

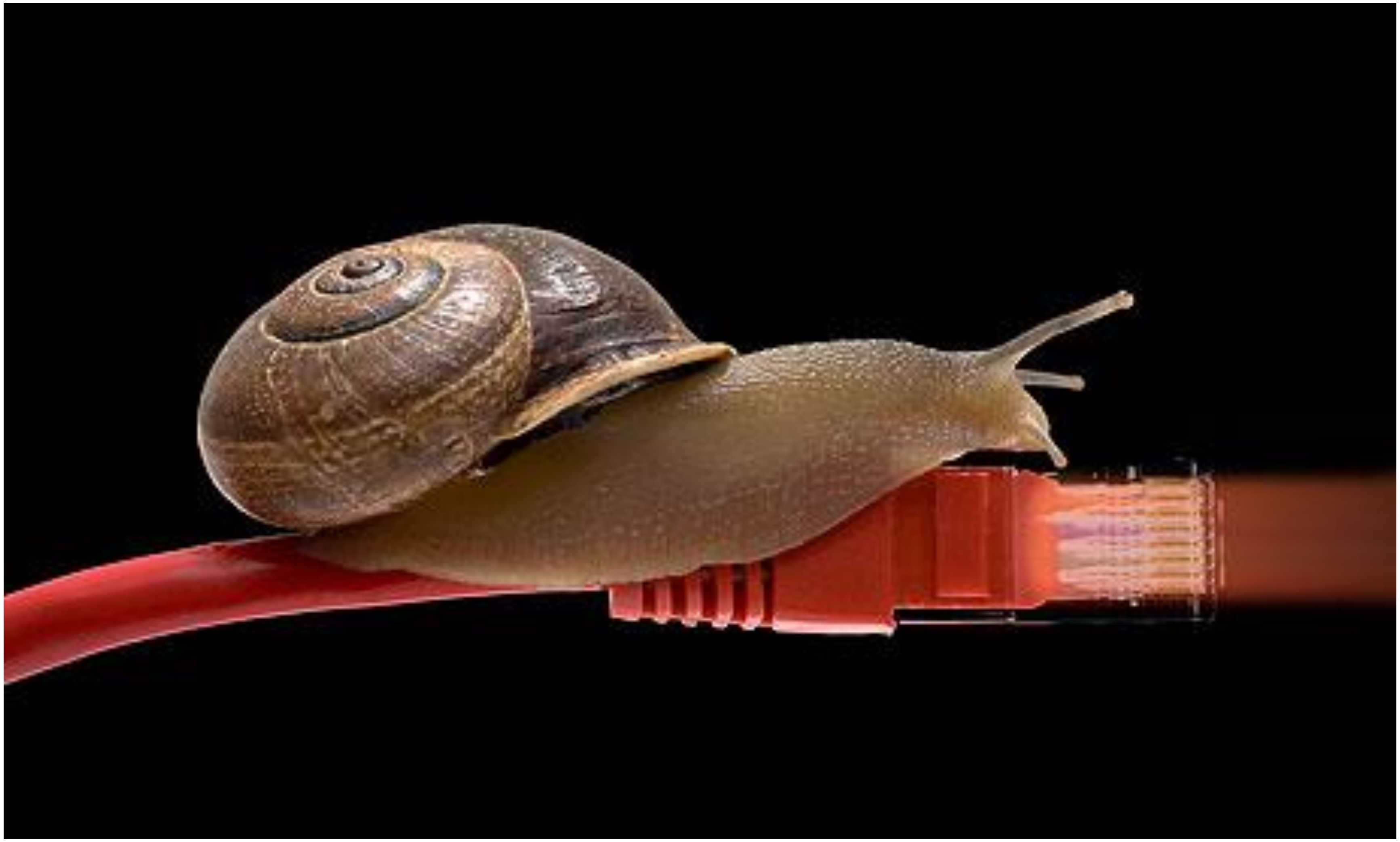
There's a story here...


Clients
Gateway
Gateway
Gateway
Gateway
Gateway
Gateway
Matching or Trading Engine
Matching or Trading Engine

But many others could benefit

Feature Bloat & Complexity

Not Fast Enough



Low-Latency is key

We are in a new world

Multi-core, Multi-socket, Cloud…

We are in a new world

Multi-core, Multi-socket, Cloud...

UDP, IPC, InfiniBand, RDMA, PCI-e

Aeron is trying a new approach

The Team

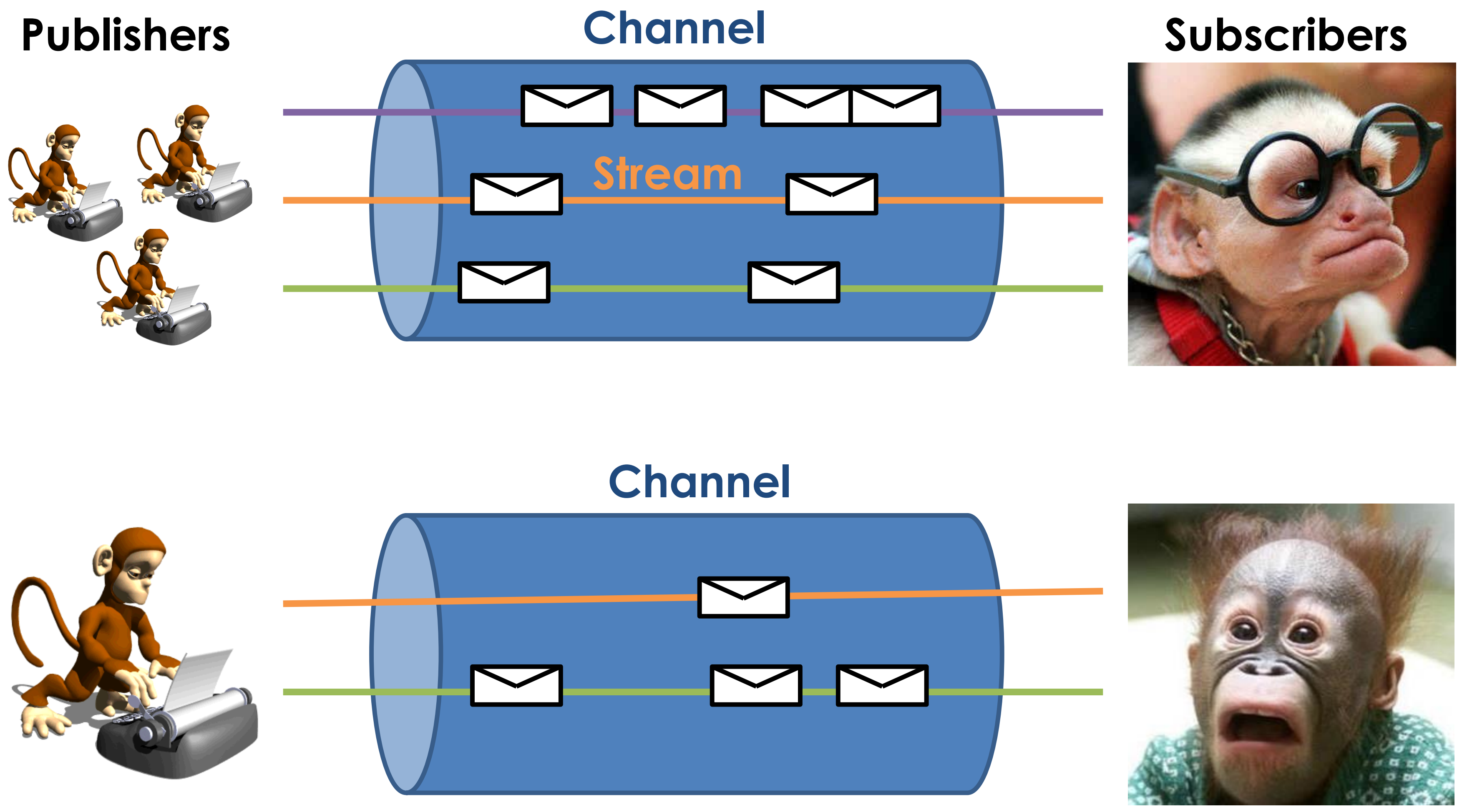
Todd Montgomery

Richard Warburton

Martin Thompson

2. What features are really needed?

Messaging



A library, not a framework, on which other abstractions and applications can be built

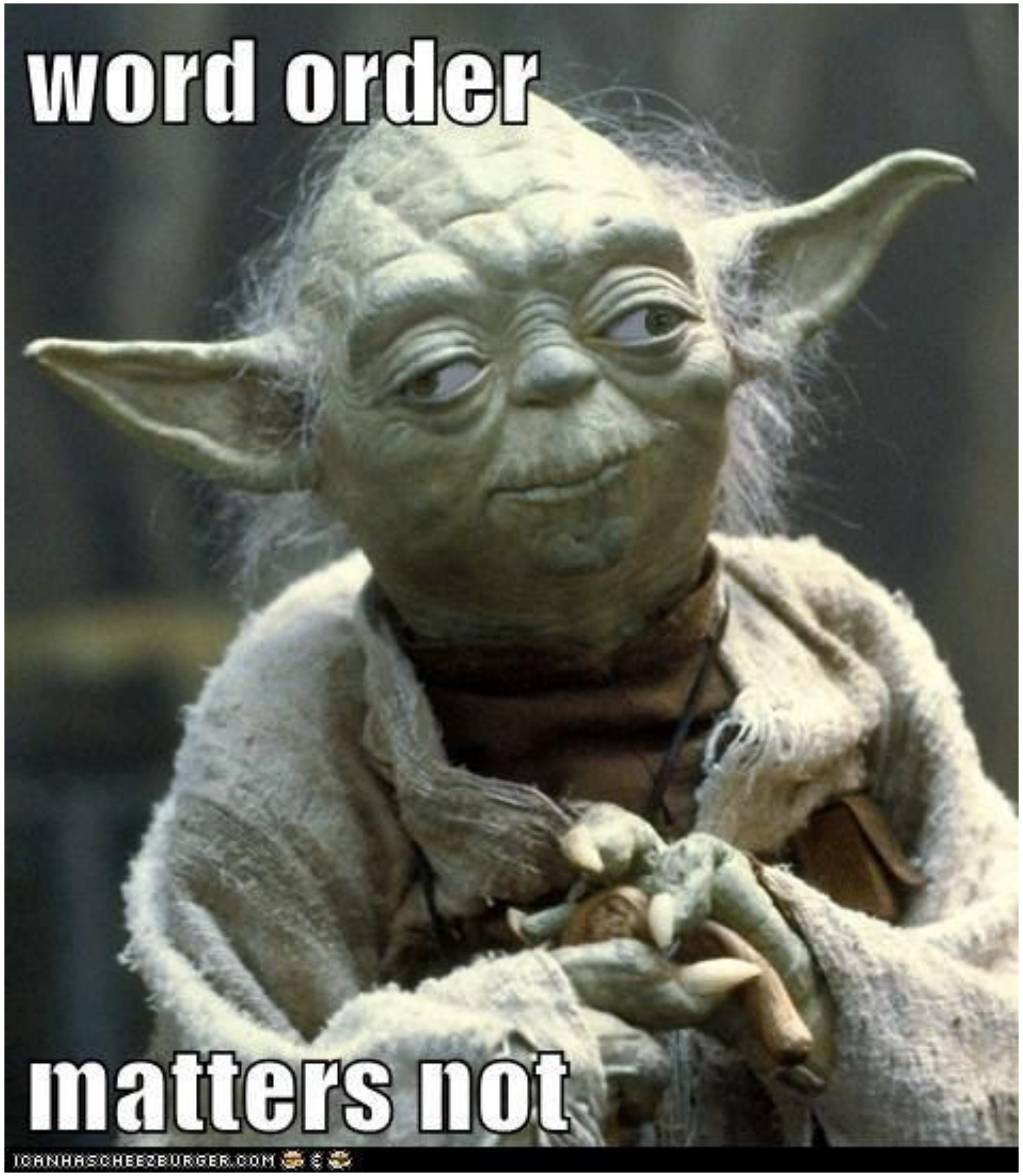
Composable Design

OSI layer 4 Transport for message oriented streams

OSI Layer 4 (Transport) Services

1. Connection Oriented Communication
2. Reliability
3. Flow Control
4. Congestion Avoidance/Control
5. Multiplexing

Connection Oriented Communication

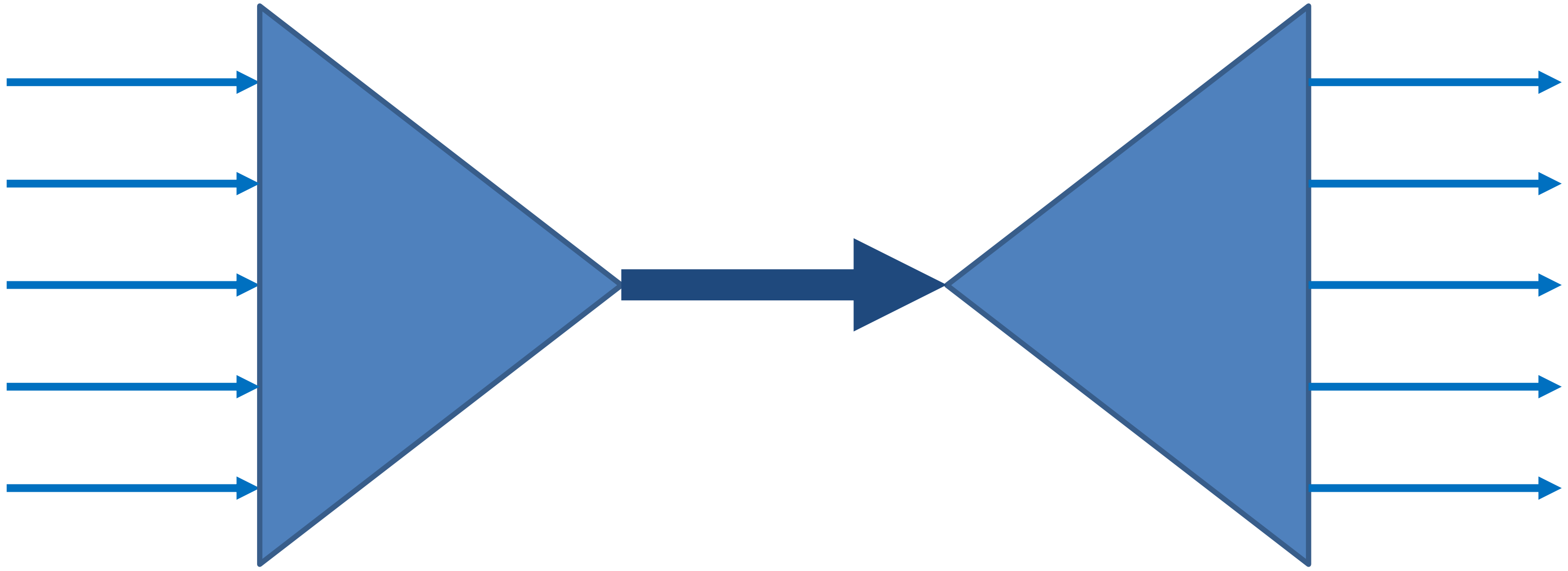


Reliability

Flow Control

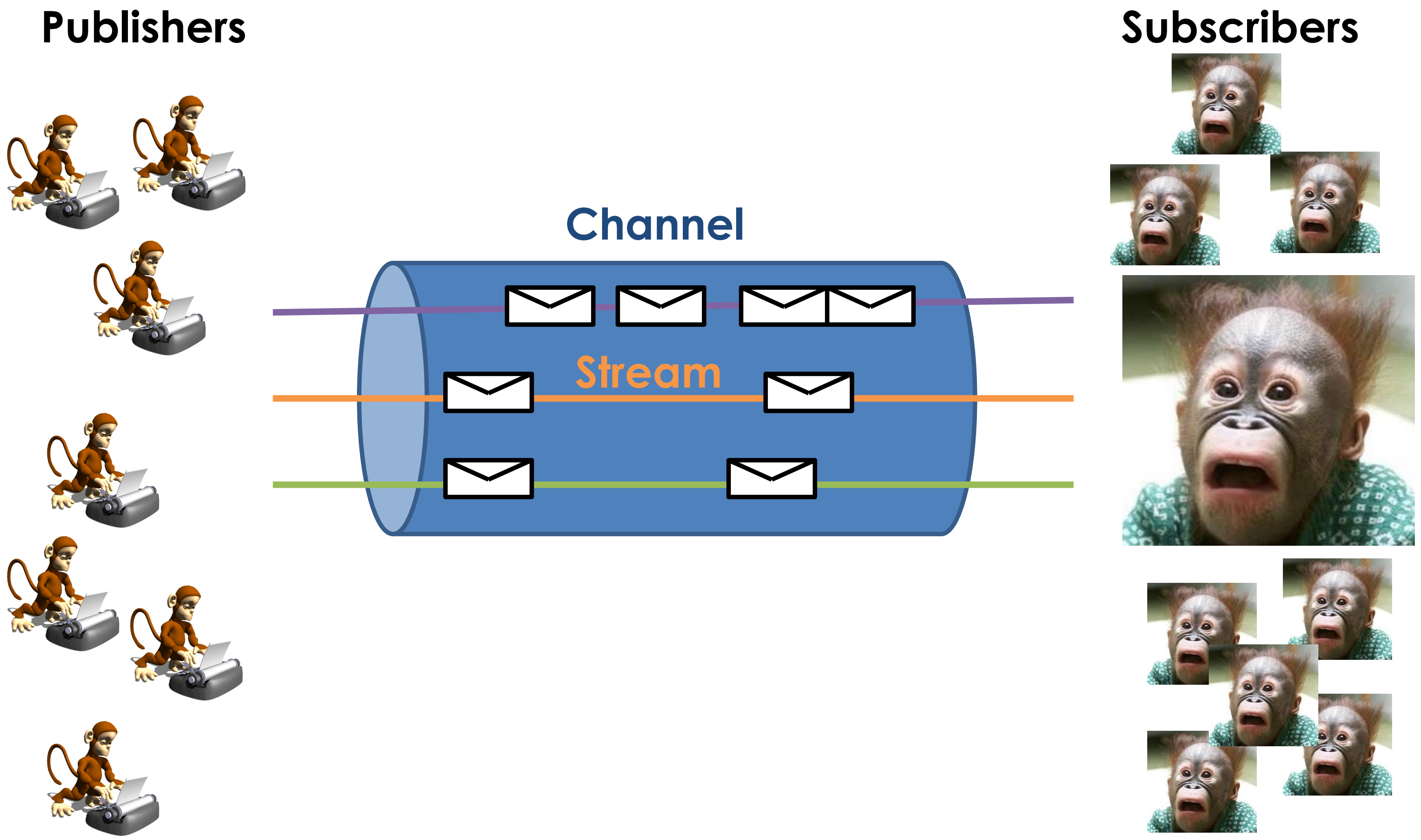
Congestion Avoidance/Control

Multiplexing



Multi-Everything World!

Multi-Everything World



Endpoints that scale

3. How does one design for this?

Design Principles

1. Garbage free in steady state running
2. Smart Batching in the message path
3. Wait-free algos in the message path
4. Non-blocking IO in the message path
5. No exceptional cases in message path
6. Apply the *Single Writer Principle*
7. Prefer unshared state
8. Avoid unnecessary data copies

It’s all about 3 things

It’s all about 3 things

1. System Architecture

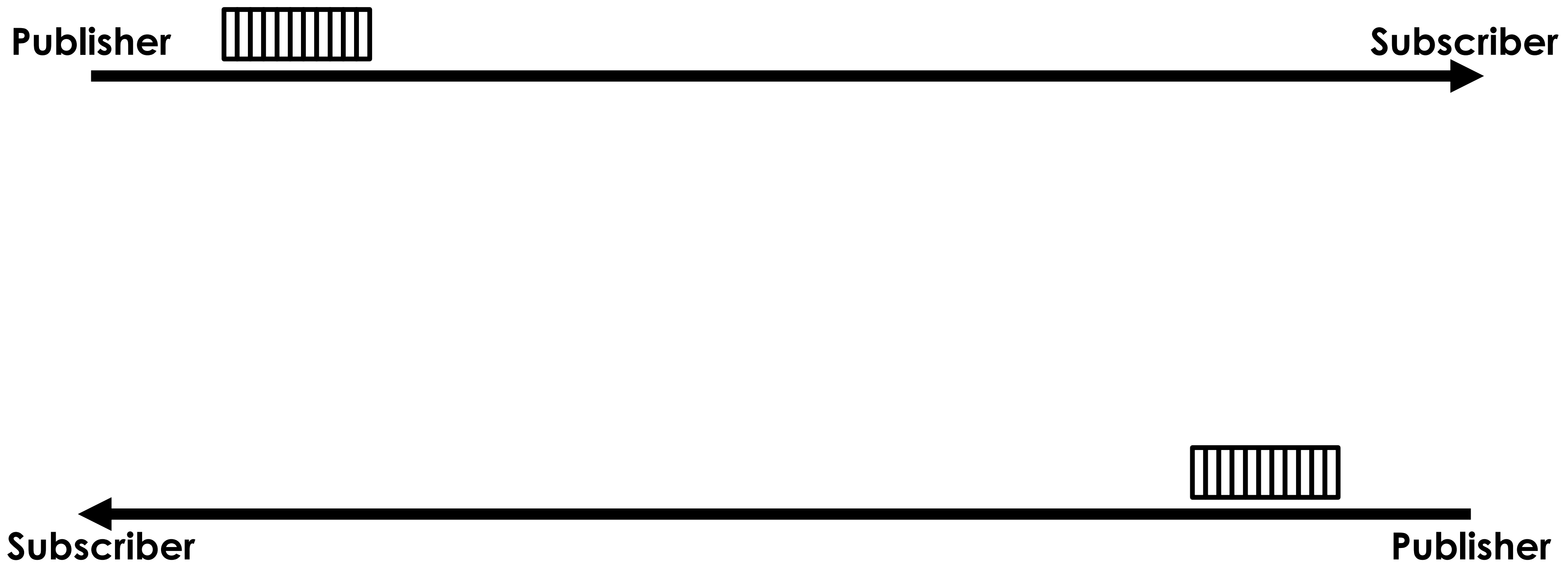
It’s all about 3 things

1. System Architecture
2. Data Structures

It’s all about 3 things

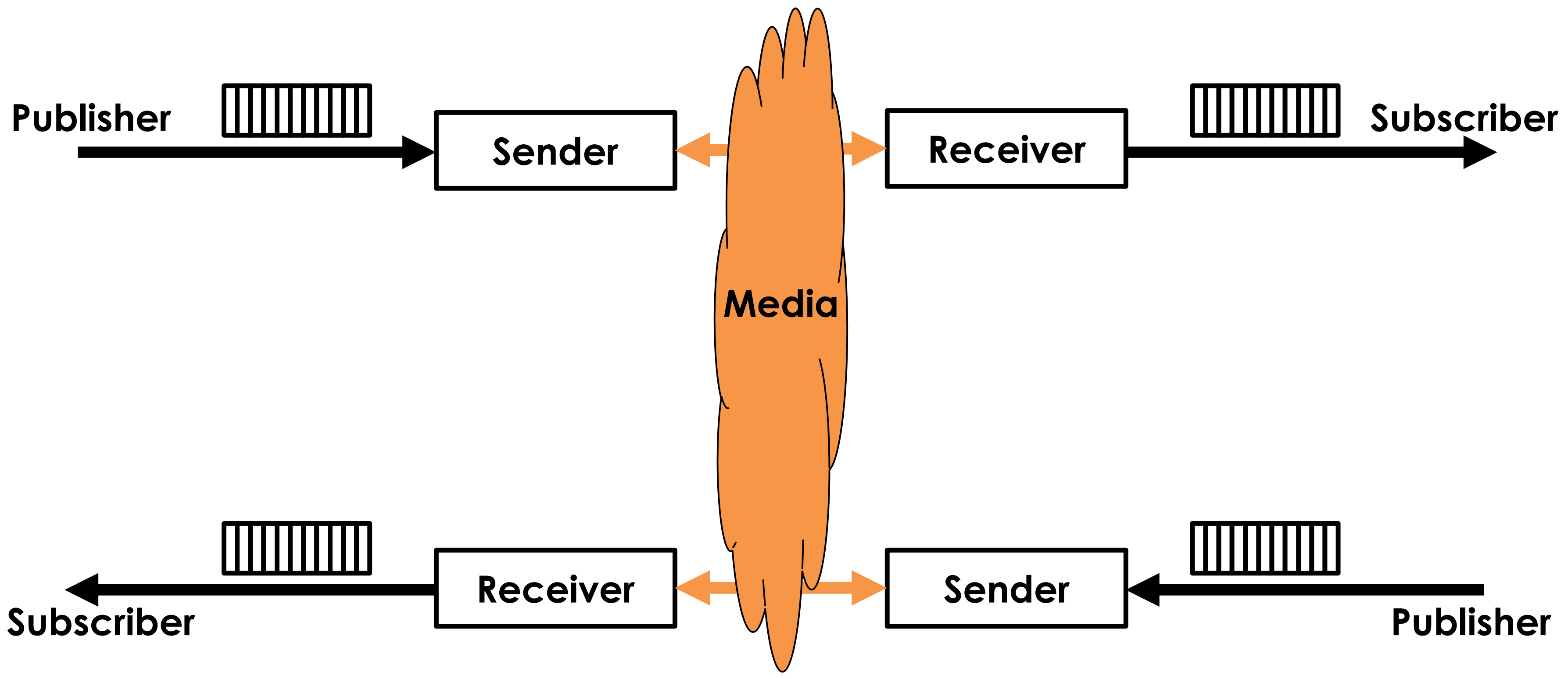
1. System Architecture
2. Data Structures
3. Protocols of Interaction

Architecture



— IPC Log Buffer

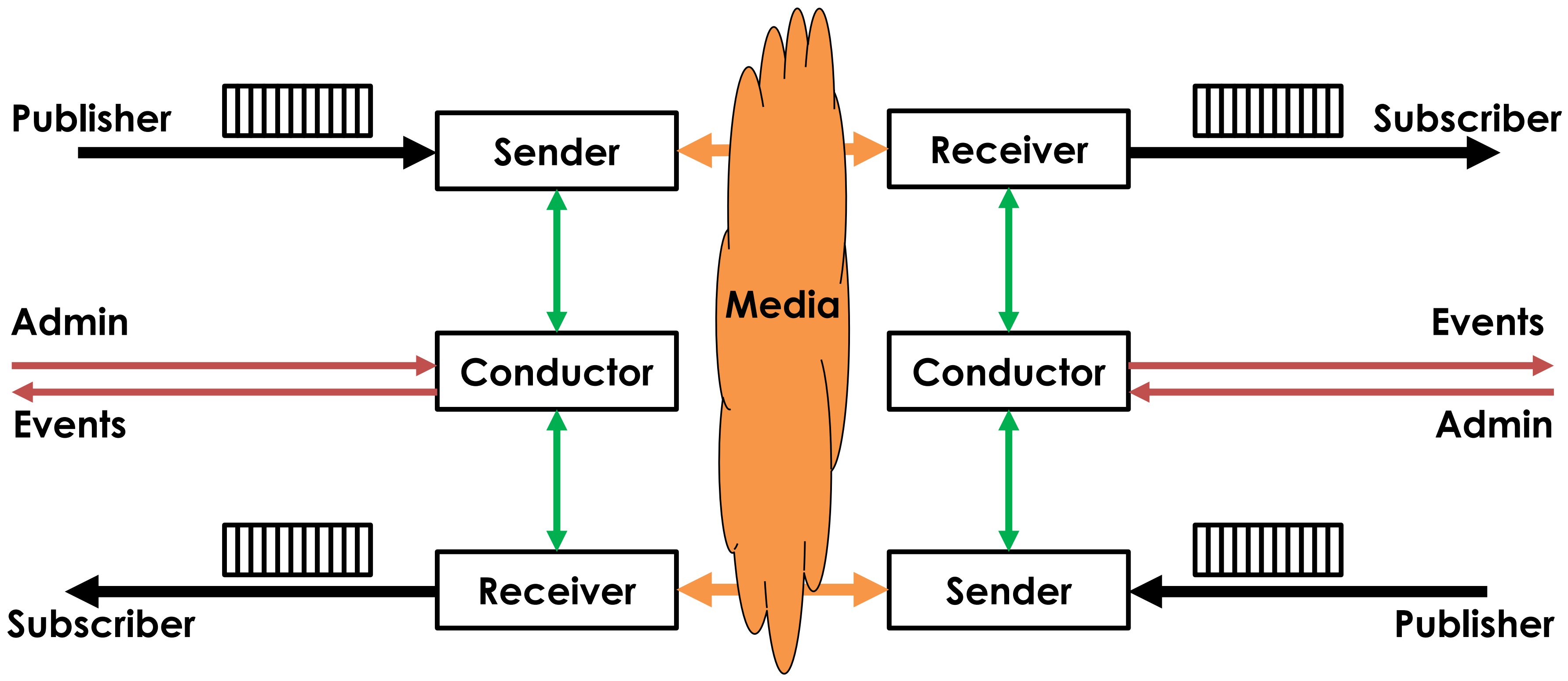
Architecture



— IPC Log Buffer

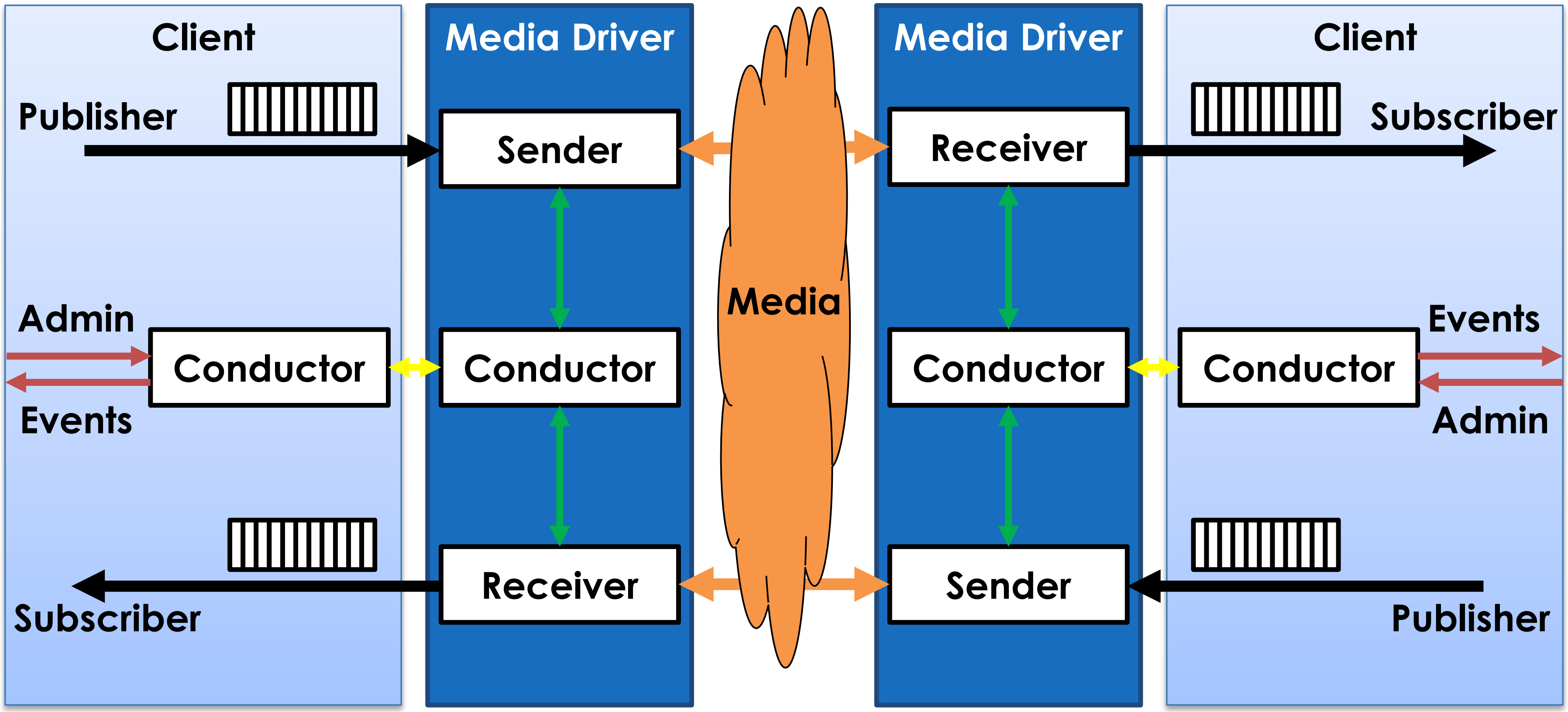
— Media (UDP, InfiniBand, PCI-e 3.0)

Architecture



- IPC Log Buffer
- Media (UDP, InfiniBand, PCI-e 3.0)
- Function/Method Call
- Volatile Fields & Queues

Architecture



- ▬ IPC Log Buffer
- ▬ Media (UDP, InfiniBand, PCI-e 3.0)
- ▬ Function/Method Call
- ▬ Volatile Fields & Queues
- ▬ IPC Ring/Broadcast Buffer

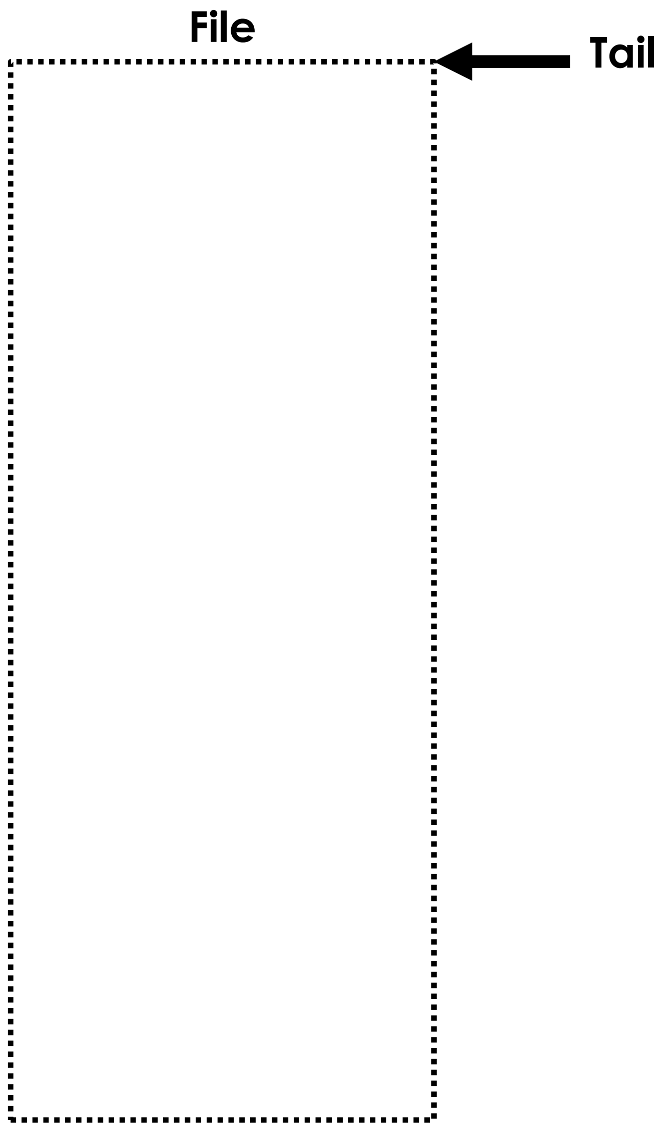
Data Structures

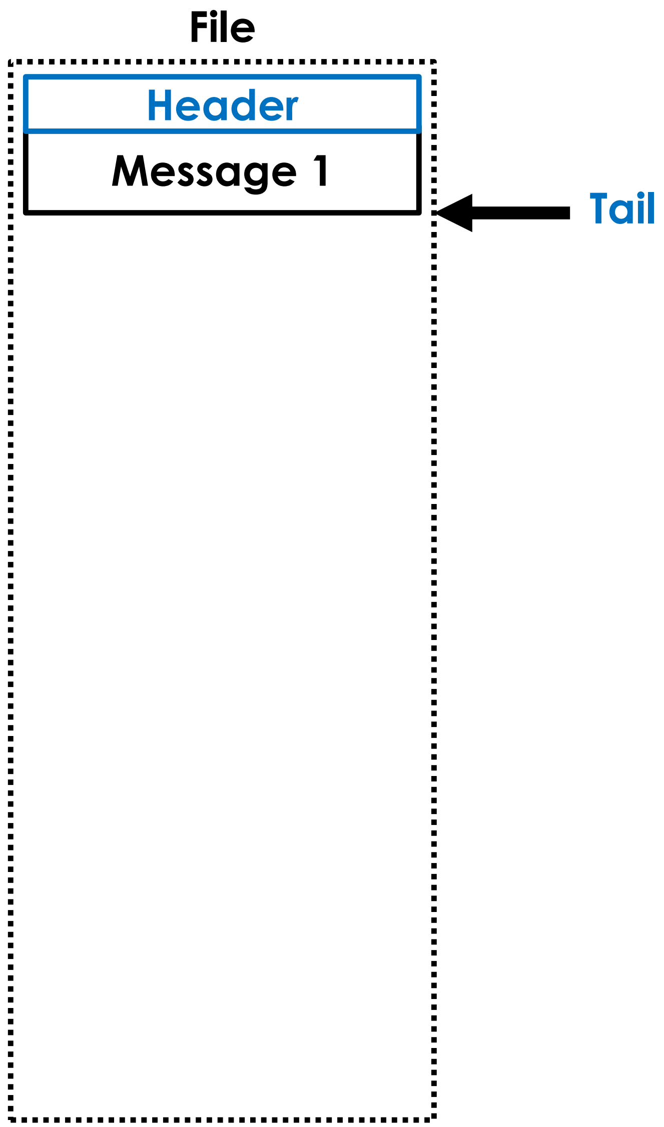
- Maps
- IPC Ring Buffers
- IPC Broadcast Buffers
- ITC Queues
- Dynamic Arrays
- Log Buffers

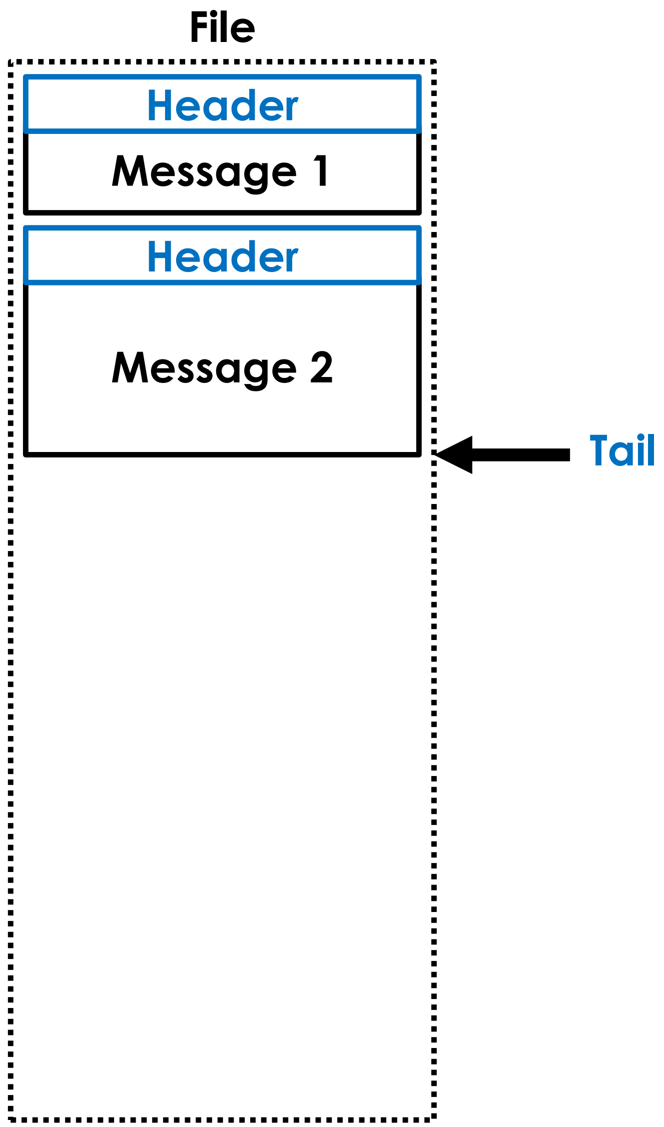
What does Aeron do?

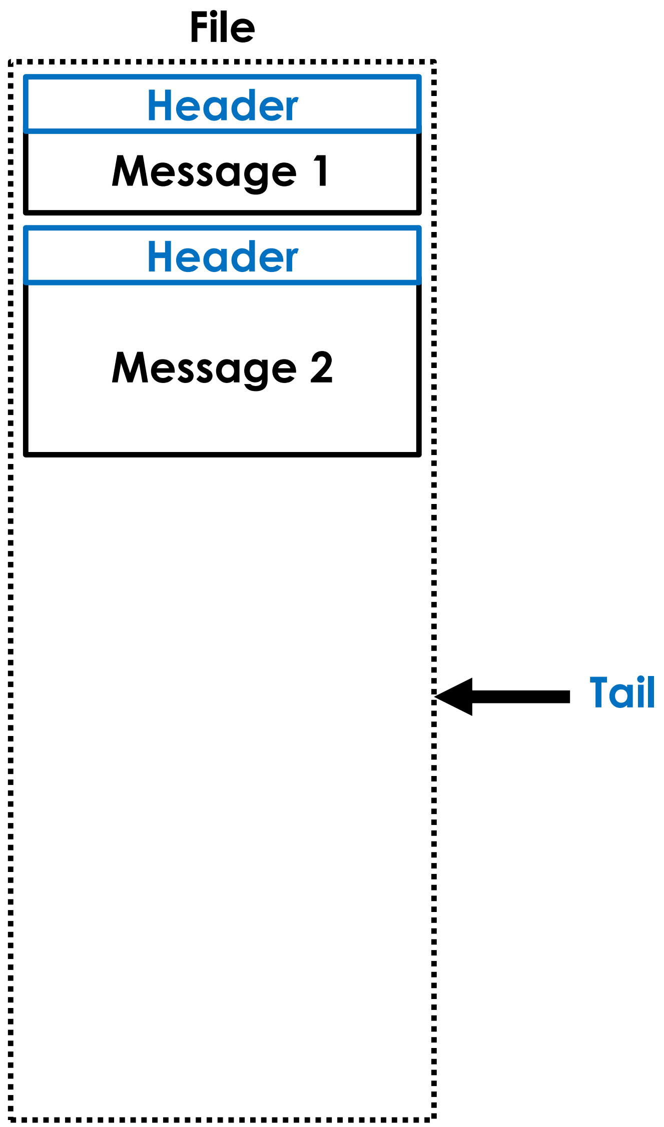
Creates a
replicated persistent log
of messages

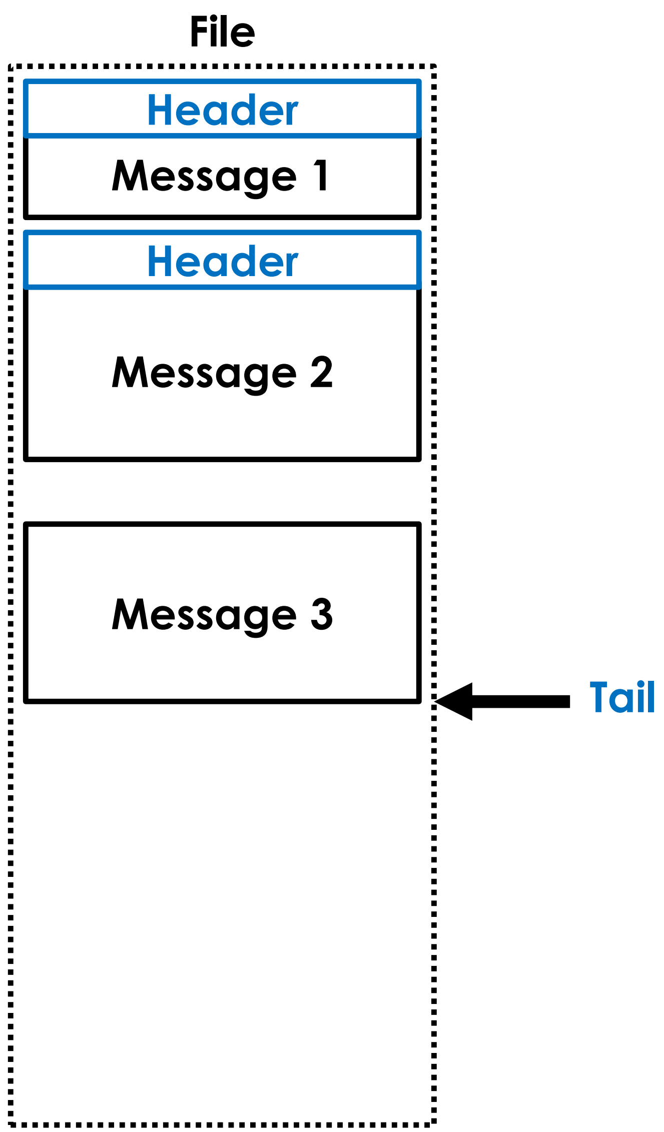
How would you design a log?

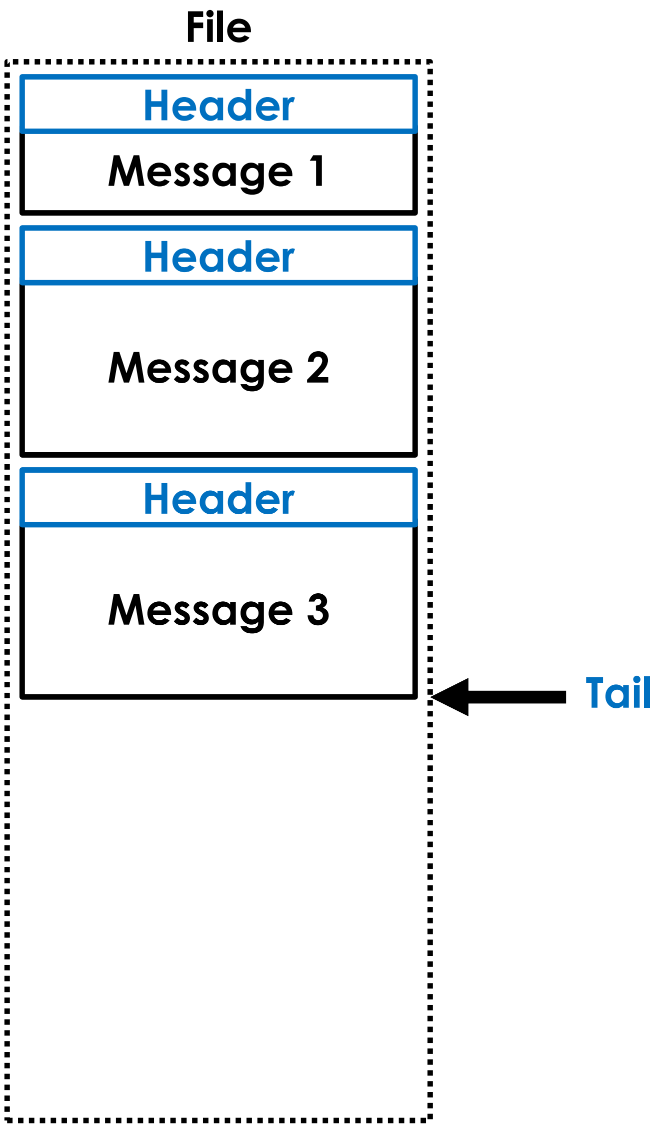

File
Tail


File
Header
Message 1
Tail


File
Header
Message 1
Header
Message 2
Tail


File
Header
Message 1
Header
Message 2
Tail


File
Header
Message 1
Header
Message 2
Message 3
Tail

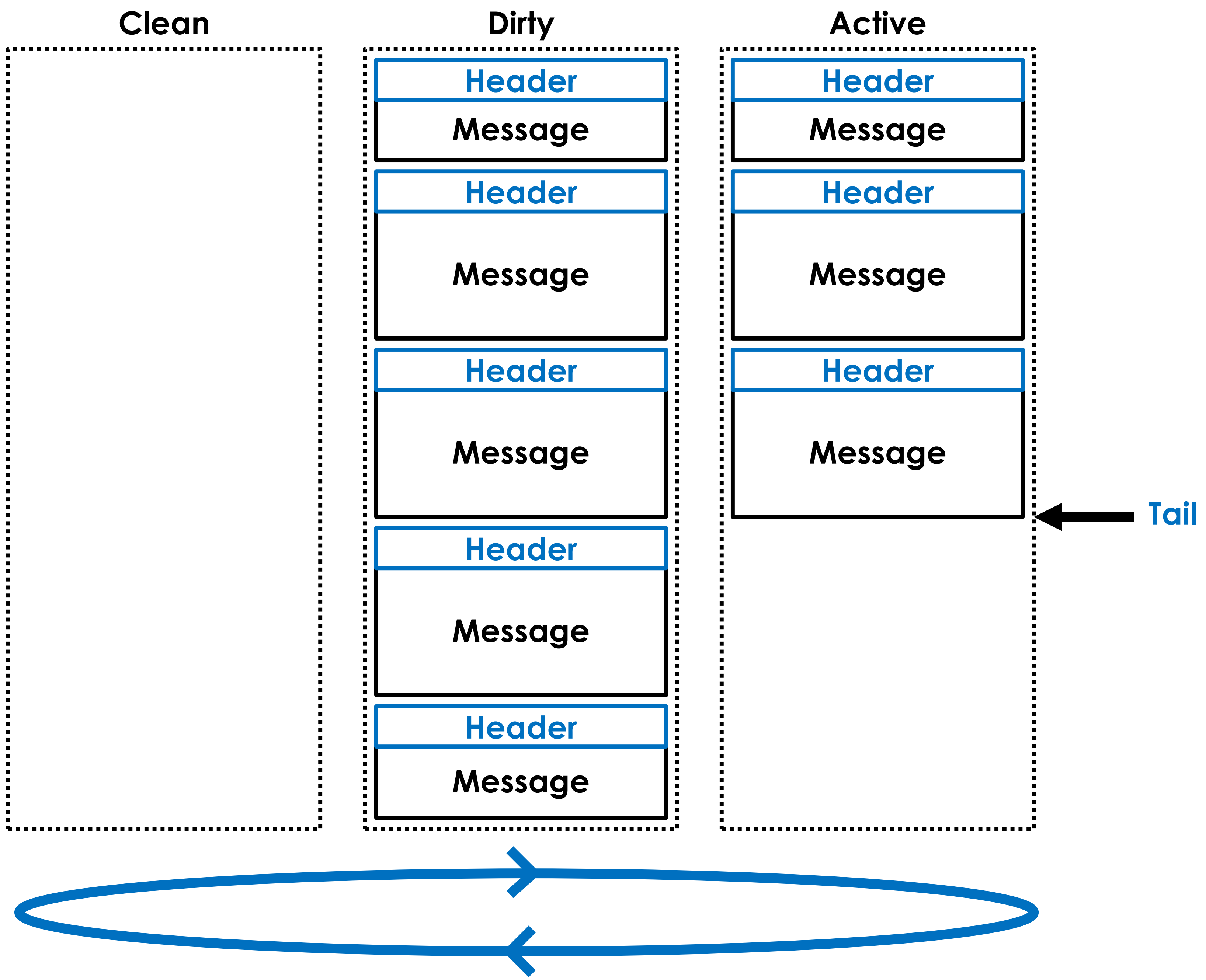

File
Header
Message 1
Header
Message 2
Header
Message 3
Tail

Persistent data structures can be safe to read without locks

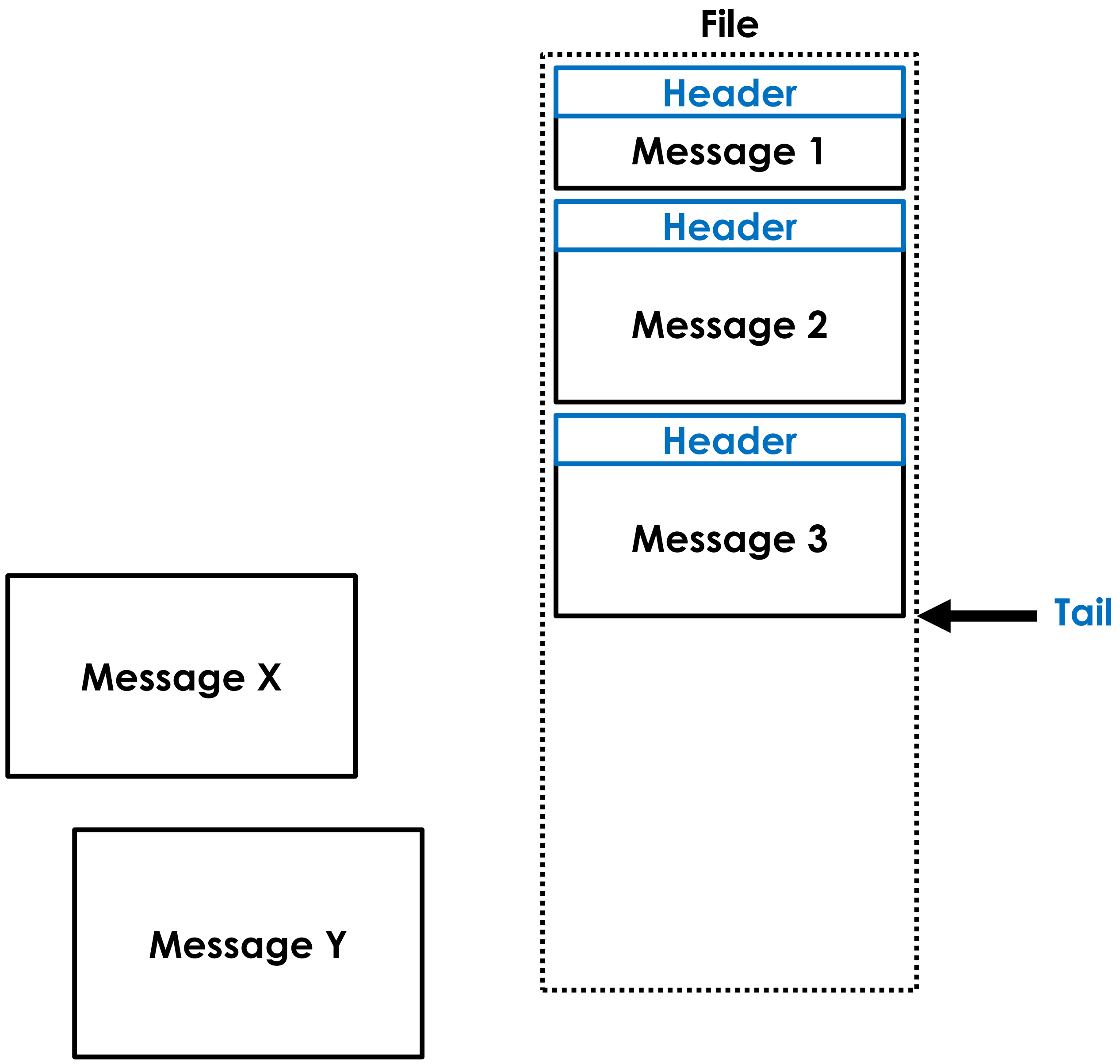
One big file that goes on forever?

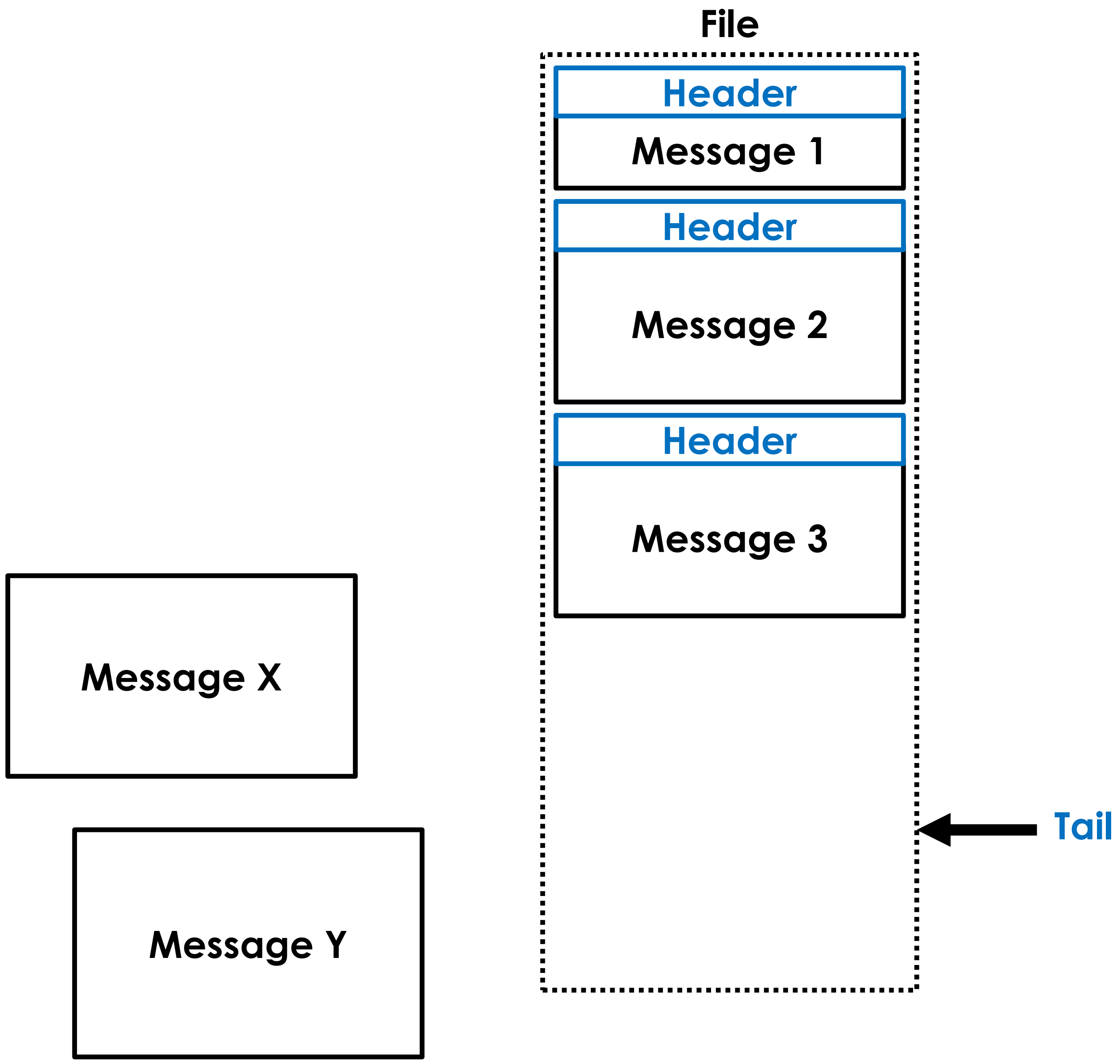
No!!!

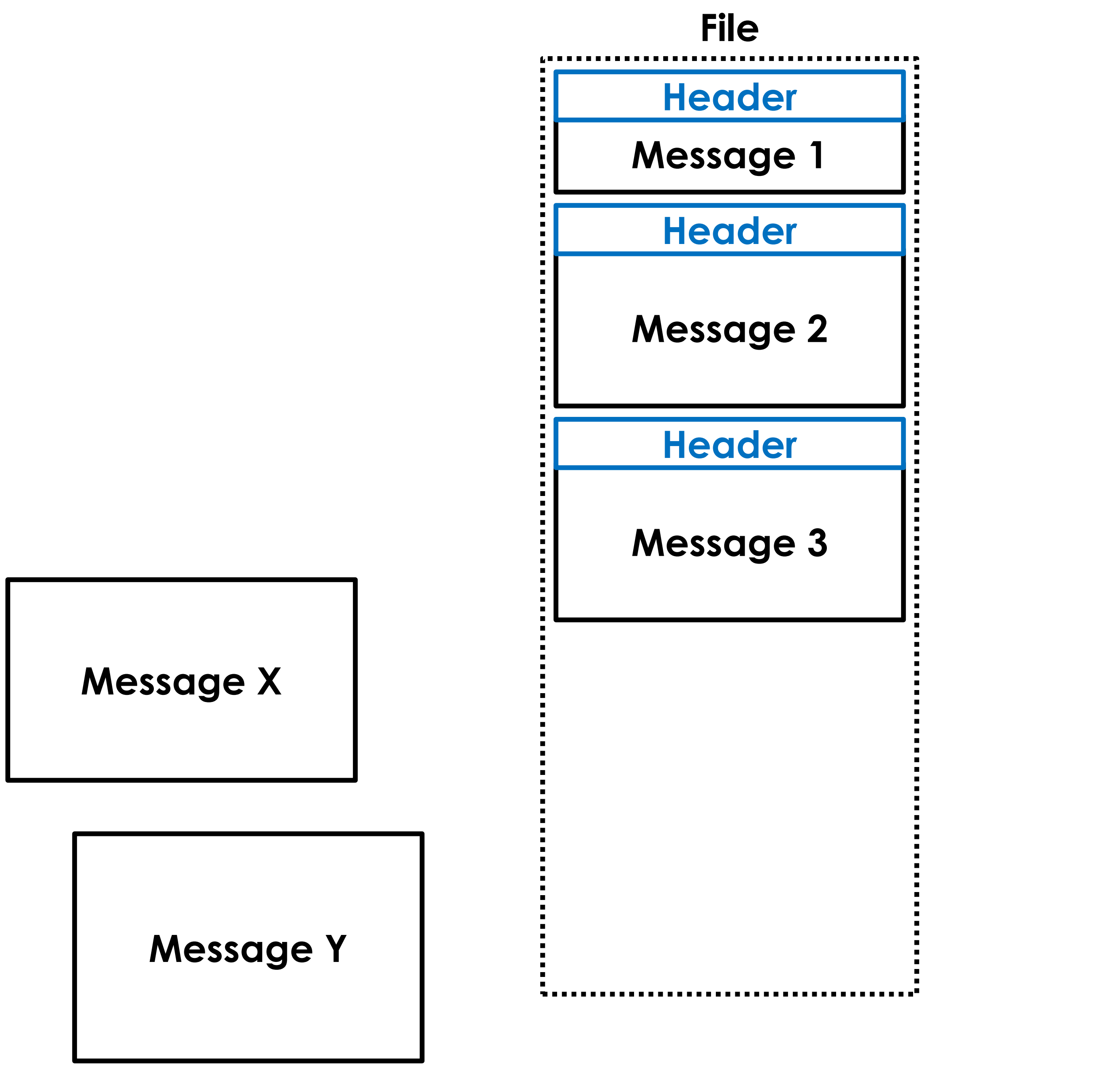
Page faults, page cache churn, VM pressure, ...

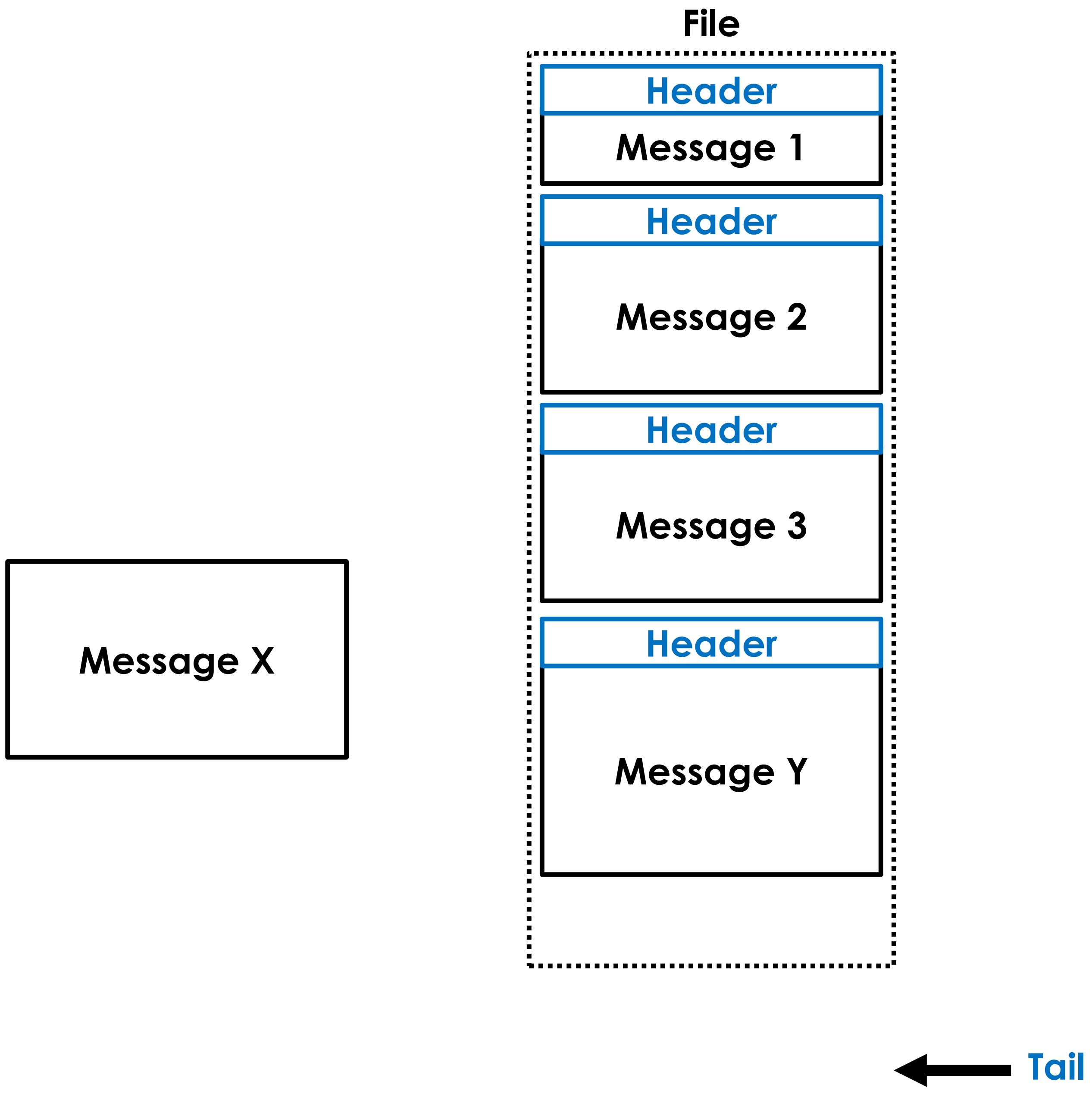

Clean
Dirty
Active
Header
Message
Header
Message
Header
Message
Header
Message
Header
Message
Header
Message
Header
Message
Header
Message
Tail

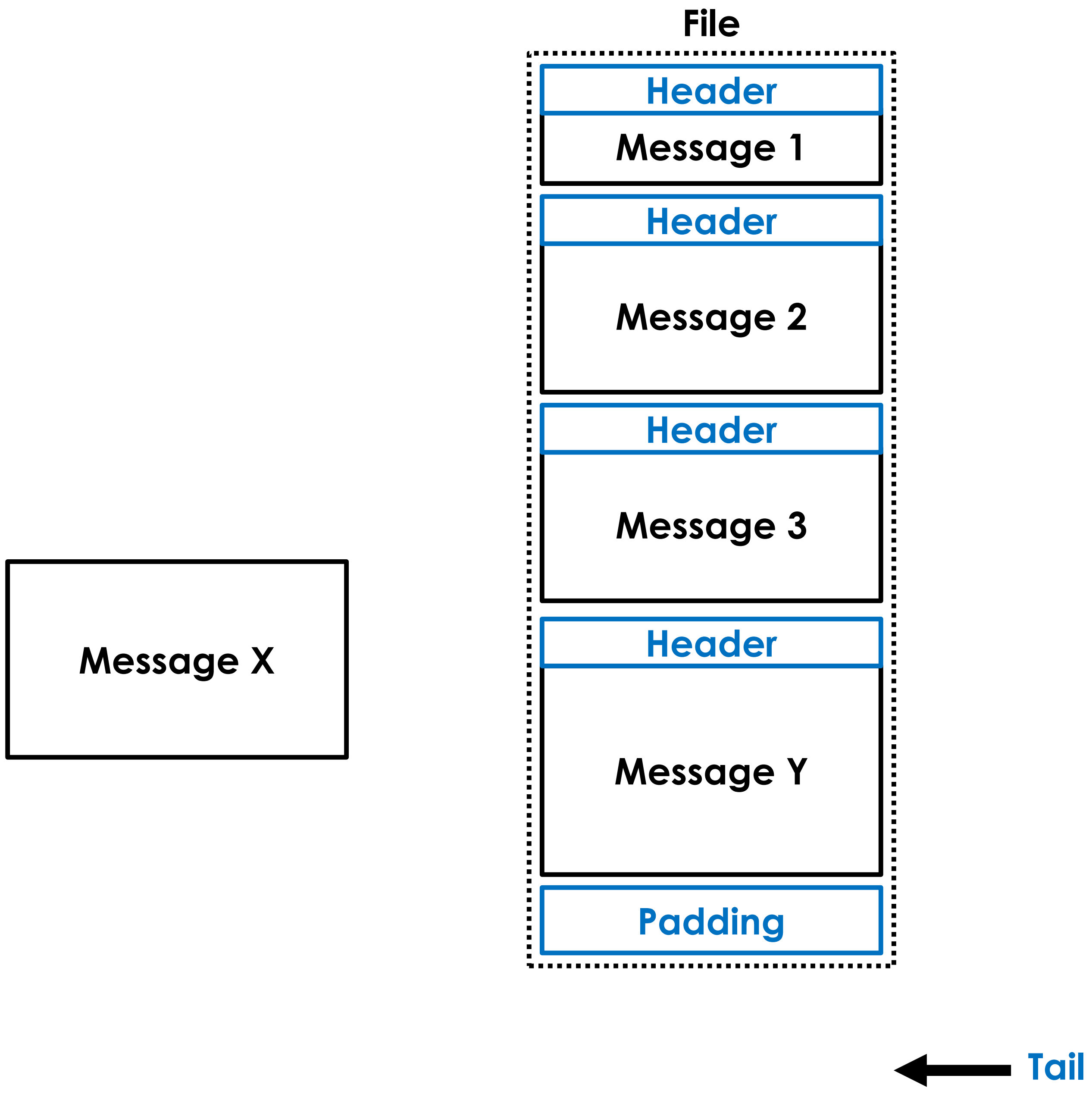
How do we stay “wait-free”?

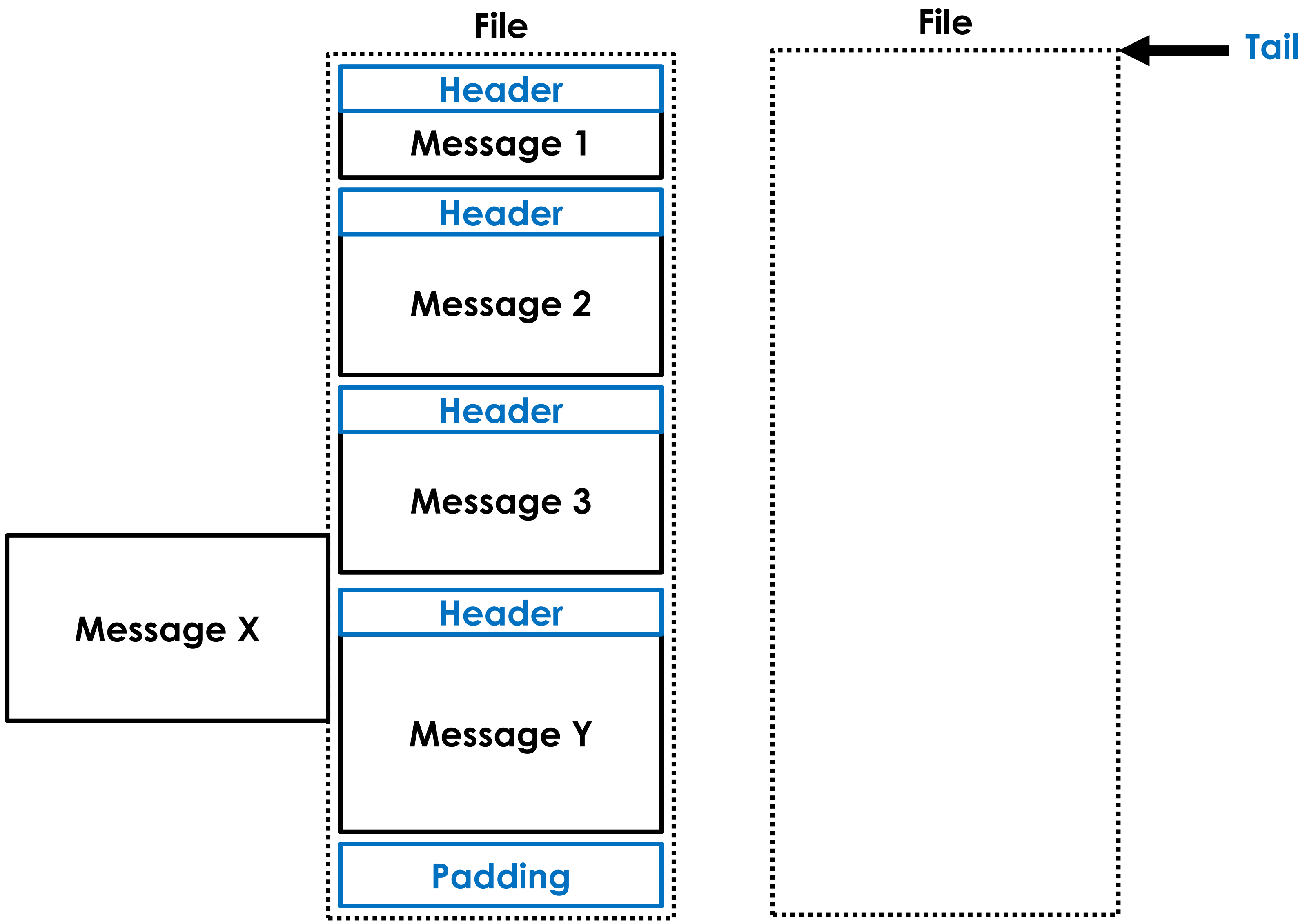

File
Header
Message 1
Header
Message 2
Header
Message 3
Tail
Message X
Message Y

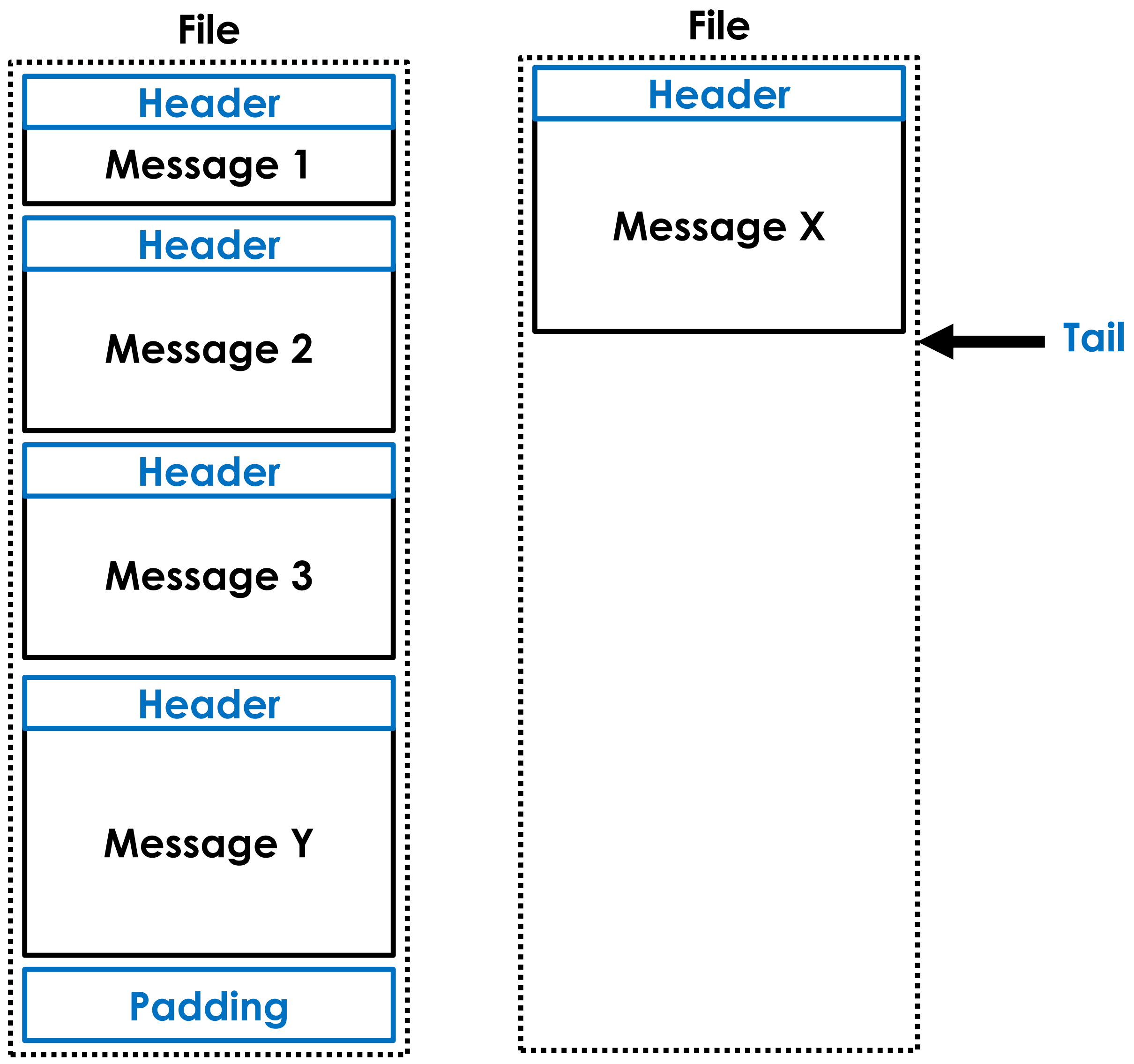

File
Header
Message 1
Header
Message 2
Header
Message 3
Message X
Message Y
Tail


File
Header
Message 1
Header
Message 2
Header
Message 3
Message X
Message Y
Tail


File
Header
Message 1
Header
Message 2
Header
Message 3
Header
Message Y
Message X
Tail


File
Header
Message 1
Header
Message 2
Header
Message 3
Header
Message Y
Padding
Message X
Tail


File
Header
Message 1
Header
Message 2
Header
Message 3
Message X
Header
Message Y
Padding
File
Tail


File
Header
Message 1
Header
Message 2
Header
Message 3
Header
Message Y
Padding
File
Header
Message X
Tail

What's in a header?

Data Message Header

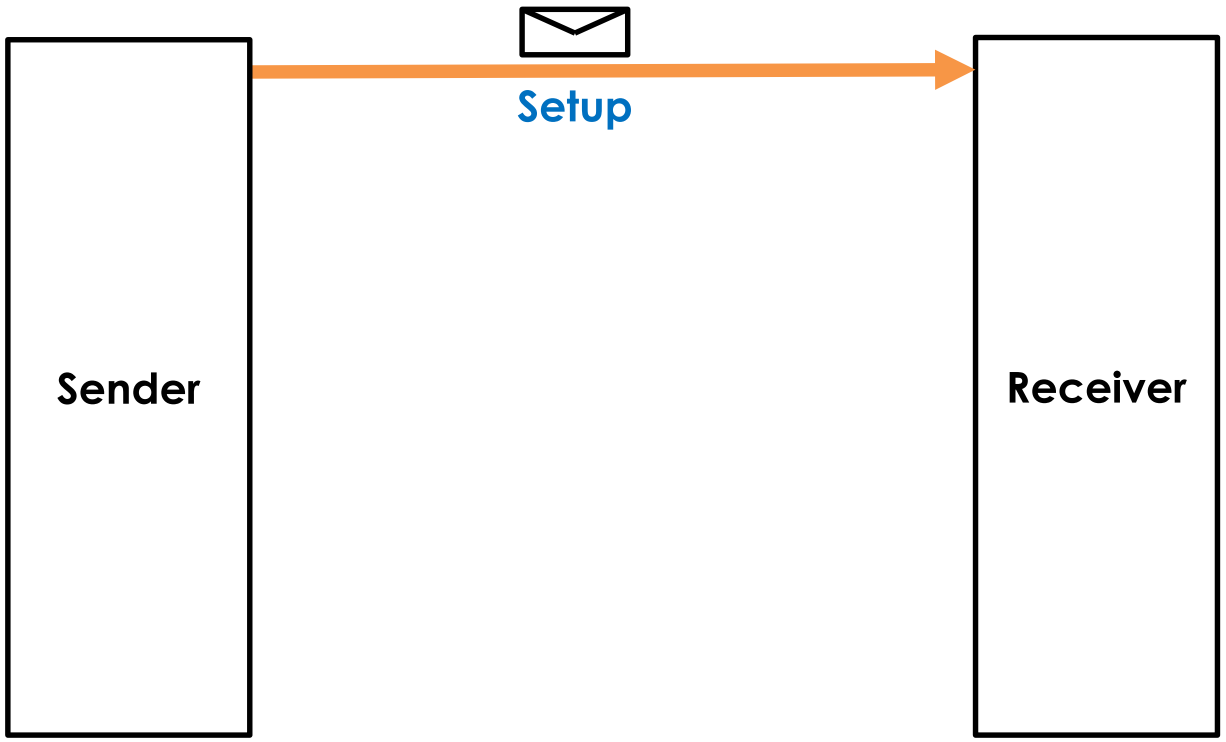
```
 0                   1                   2                   3
 0 1 2 3 4 5 6 7 8 9 0 1 2 3 4 5 6 7 8 9 0 1 2 3 4 5 6 7 8 9 0 1
+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
|    Version    |B|E|   Flags   |             Type              |
+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-------------------------------+
|R|                       Frame Length                          |
+-+-------------------------------------------------------------+
|R|                       Term Offset                           |
+-+-------------------------------------------------------------+
|                          Session ID                           |
+---------------------------------------------------------------+
|                           Stream ID                           |
+---------------------------------------------------------------+
|                            Term ID                            |
+---------------------------------------------------------------+
|                        Encoded Message                       ...
...                                                             |
+---------------------------------------------------------------+
```

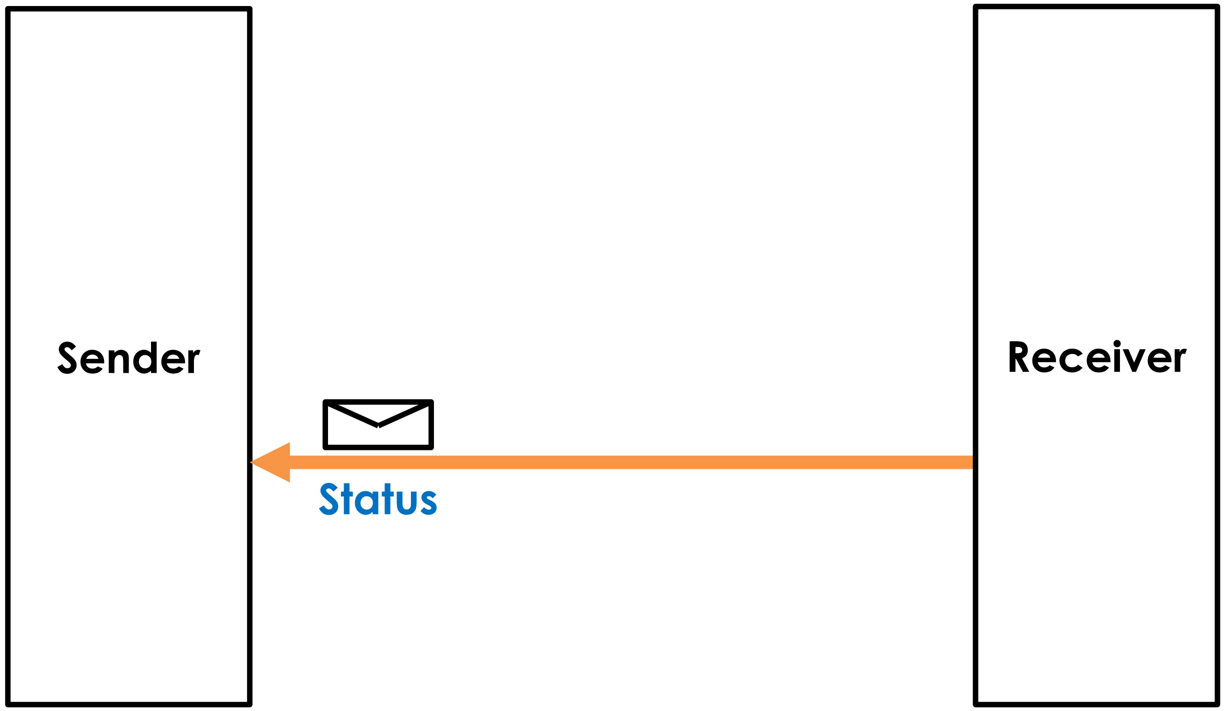
Unique identification of a byte within each stream across time (`streamId, sessionId, termId, termOffset`)

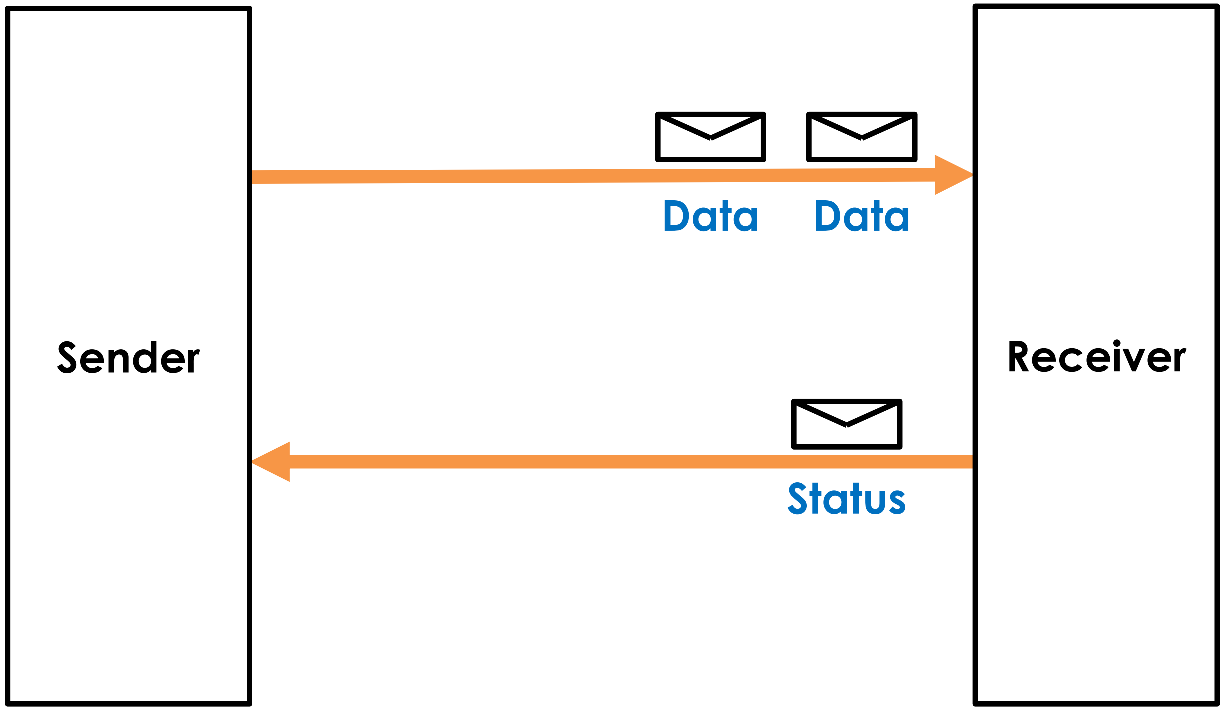
How do we replicate a log?

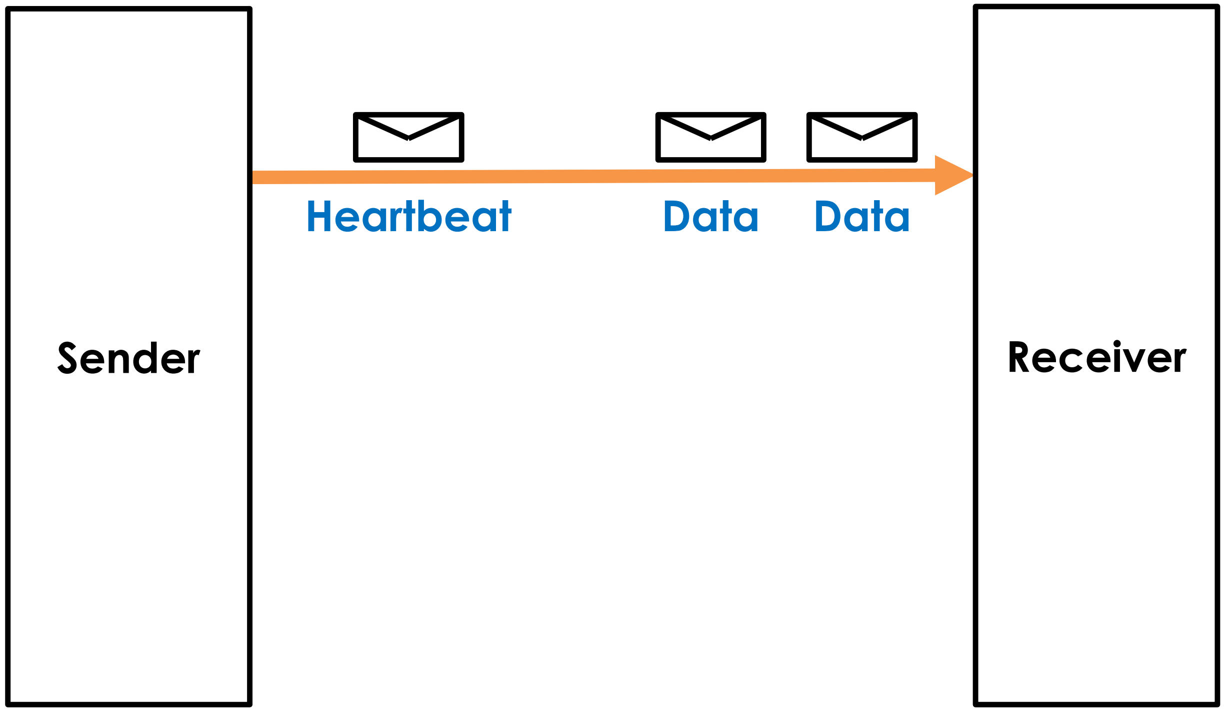
We need a protocol of messages

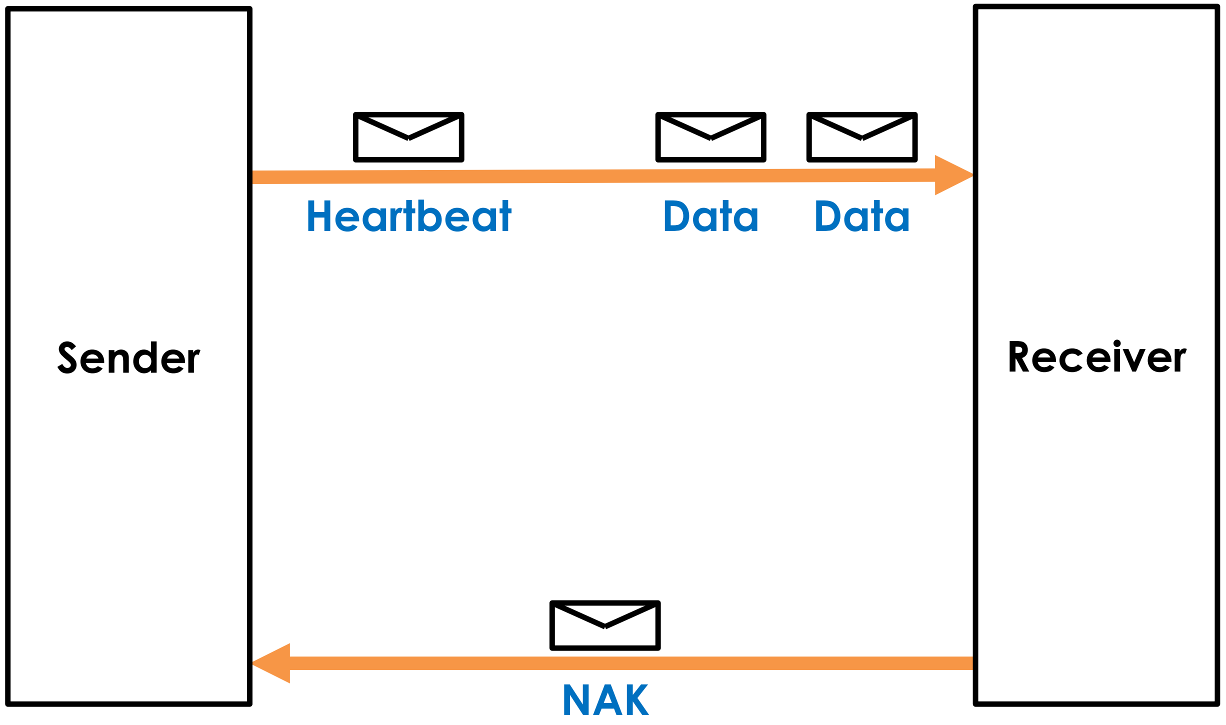
Sender
Receiver


Setup
Sender
Receiver

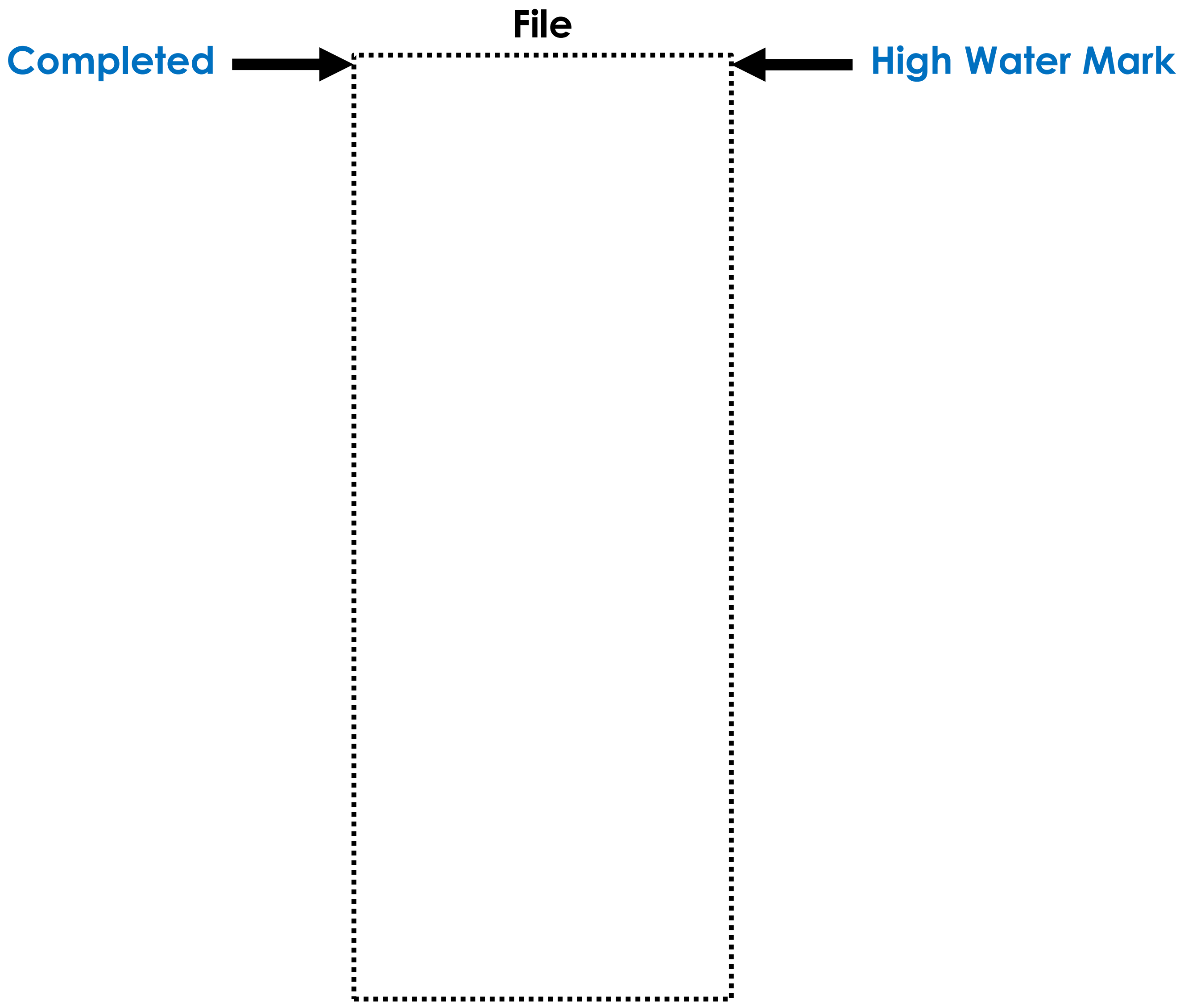

Sender
Receiver
Status

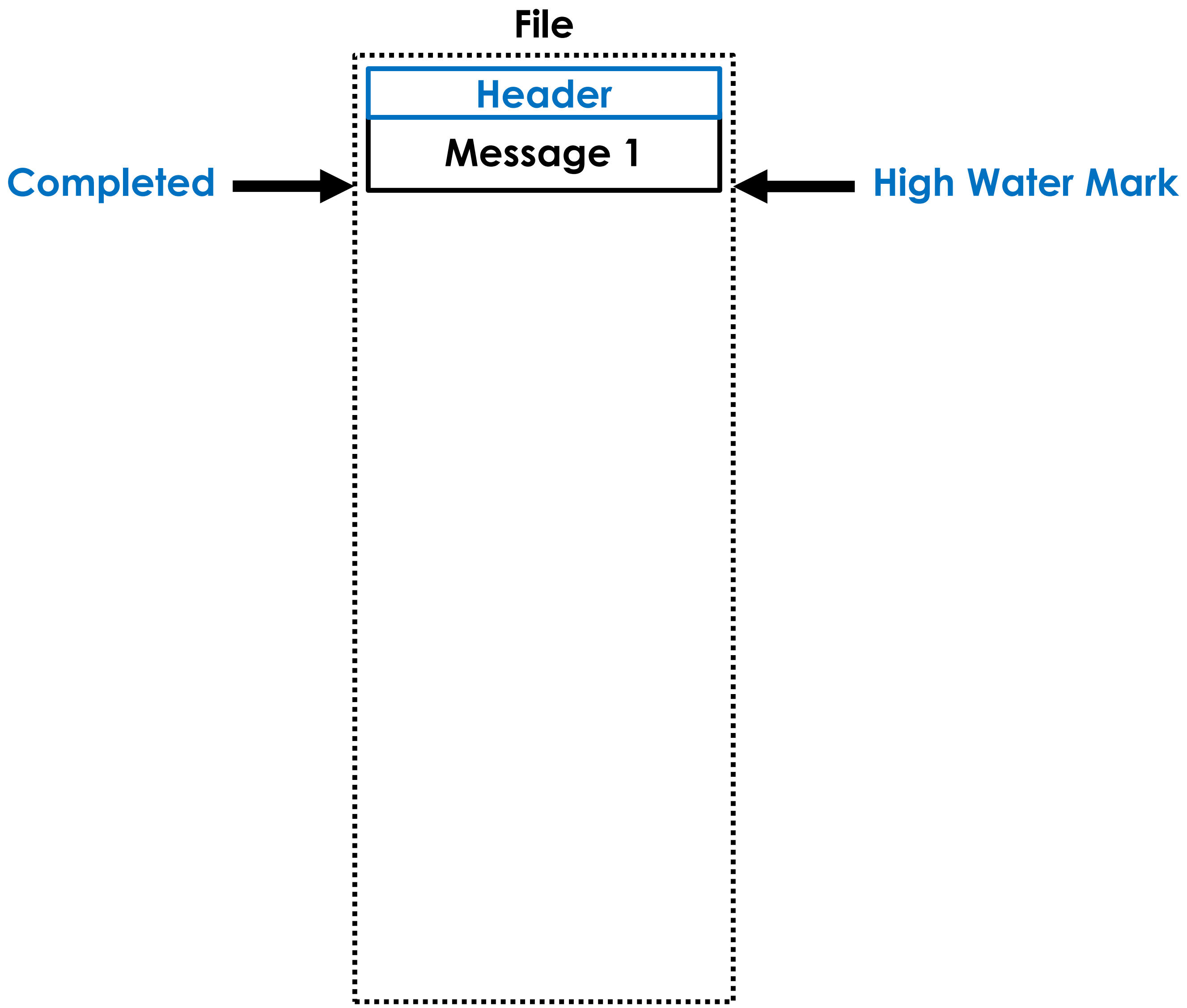

Sender
Data
Data
Receiver
Status

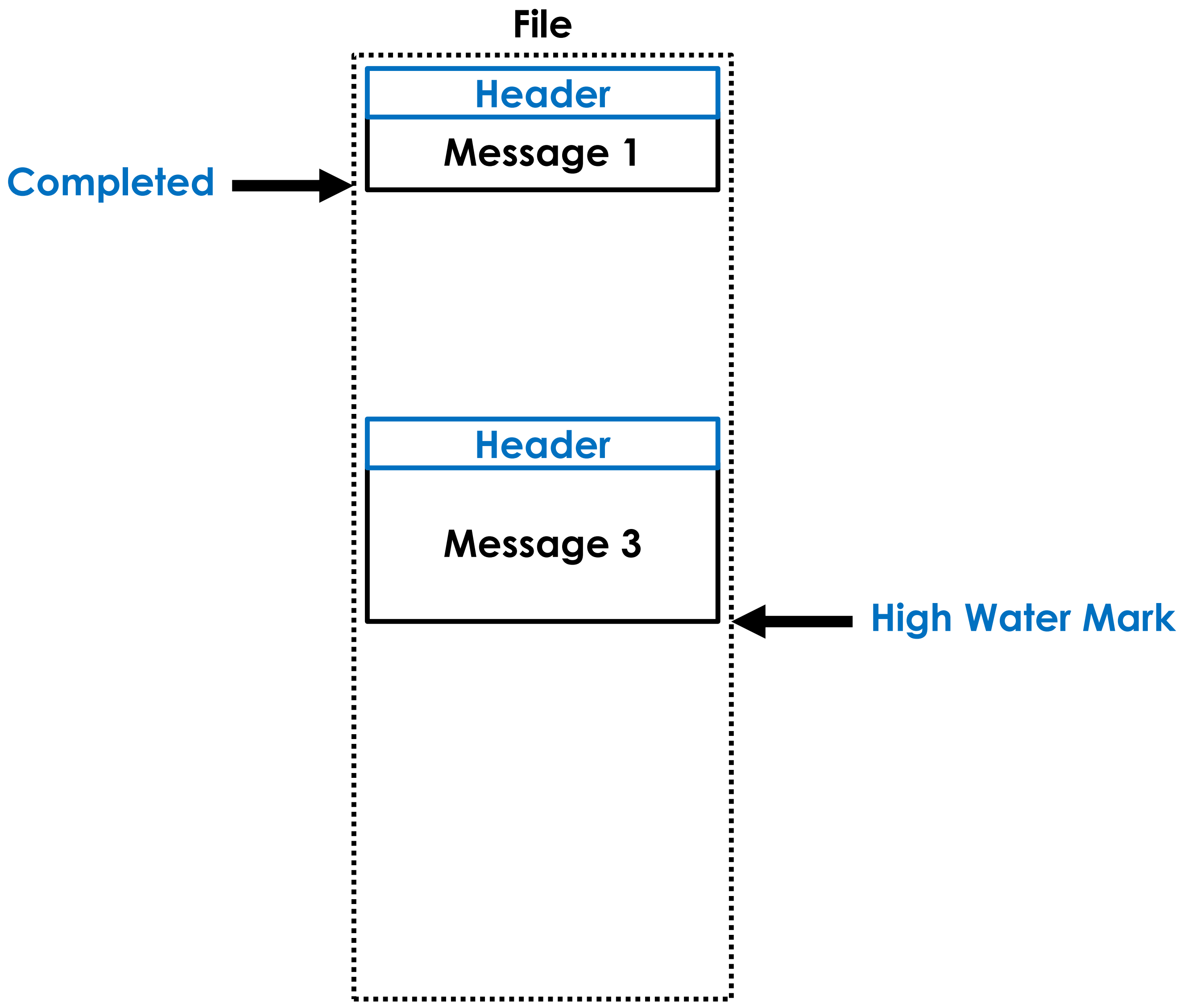

Sender
Heartbeat
Data
Data
Receiver

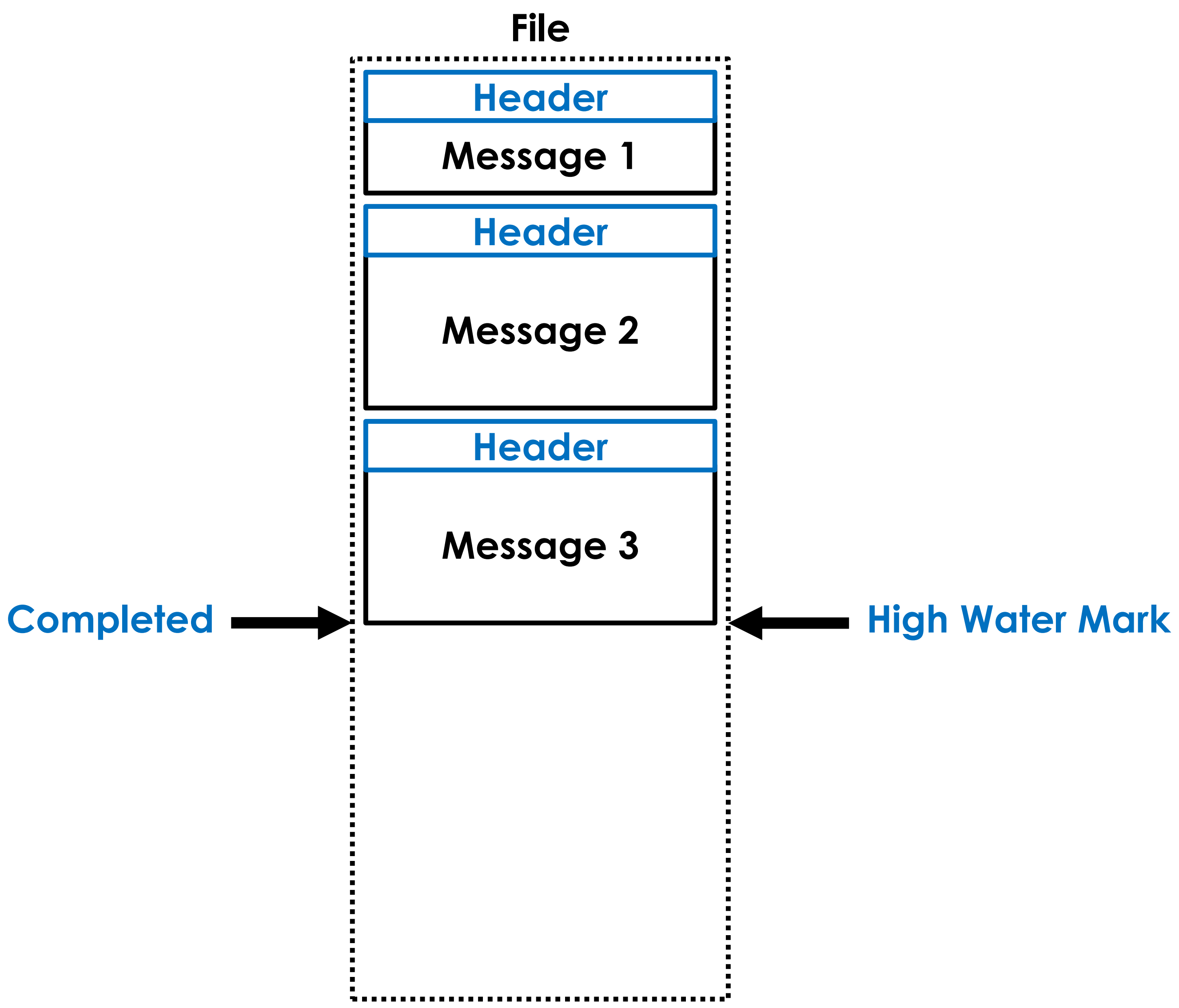

Sender
Heartbeat
Data
Data
Receiver
NAK

How are message streams reassembled?


File
Completed
High Water Mark


File
Header
Message 1
Completed
High Water Mark


File
Header
Message 1
Completed
Header
Message 3
High Water Mark


File
Header
Message 1
Header
Message 2
Header
Message 3
Completed
High Water Mark

What if a gap is never filled?

How do we know what is consumed?

Publishers, Senders, Receivers, and Subscribers all keep position counters

Counters are the key to flow control and monitoring

Protocols can be more subtle than you think…

What about “Self similar behaviour”?

4. What did we learn on the way?

Humans suck at estimation!!!

Building distributed systems is Hard!

We have more defensive code than feature code

This does not mean the code is riddled with exception handlers – Yuk!!!

Building distributed systems is Rewarding!

Monitoring and Debugging

Loss, throughput, and buffer size are all strongly related!!!

Pro Tip: Know your OS network parameters and how to tune them

We can track application consumption – No need for the Disruptor

Some parts of Java really suck!

Some parts of Java really suck!

Unsigned Types?

Some parts of Java really suck!

Unsigned Types?

NIO (most of) - Locks

Some parts of Java really suck!

Unsigned Types?

NIO (most of) - Locks

Off-heap, PAUSE, Signals, etc.

Some parts of Java really suck!

Unsigned Types?

NIO (most of) - Locks

Off-heap, PAUSE, Signals, etc.

String Encoding

Some parts of Java really suck!

Unsigned Types?

NIO (most of) - Locks

Off-heap, PAUSE, Signals, etc.

String Encoding

Managing External Resources

Some parts of Java really suck!

Unsigned Types?

NIO (most of) - Locks

Off-heap, PAUSE, Signals, etc.

String Encoding

Managing External Resources

Selectors - GC

Bytes!!!

```
public void main(final String[] args)
{
    byte a = 0b0000_0001;
    byte b = 0b0000_0010;

    byte flags = a | b;

    System.out.printf(
        "flags=%s\n",
        Integer.toBinaryString(flags));
}
```

Bytes!!!

```
public void main(final String[] args)
{
    byte a = 0b0000_0001;
    byte b = 0b0000_0010;

    byte flags = a | b;

    System.out.printf(
        "flags=%s\n",
        Integer.toBinaryString(flags));
}
```

Bytes!!!

```
public void main(final String[] args)
{
    byte a = 0b0000_0001;
    byte b = 0b0000_0010;

    byte flags = a | b;

    System.out.printf(
        "flags=%s\n",
        Integer.toBinaryString(flags));
}
```

Error:(8, 24) java: incompatible types: possible lossy conversion from int to byte

Some parts of Java are really nice!

Some parts of Java are really nice!

Tooling *– IDEs, Gradle, HdrHistogram*

Some parts of Java are really nice!

Tooling – IDEs, Gradle, HdrHistogram

Lambdas & Method Handles

Some parts of Java are really nice!

***Tooling** – IDEs, Gradle, HdrHistogram*

Lambdas & Method Handles

Bytecode Instrumentation

Some parts of Java are really nice!

***Tooling** – IDEs, Gradle, HdrHistogram*

Lambdas & Method Handles

Bytecode Instrumentation

Unsafe!!! + Java 8

Some parts of Java are really nice!

***Tooling** – IDEs, Gradle, HdrHistogram*

Lambdas & Method Handles

Bytecode Instrumentation

Unsafe!!! + Java 8

The Optimiser

Some parts of Java are really nice!

Tooling – IDEs, Gradle, HdrHistogram

Lambdas & Method Handles

Bytecode Instrumentation

Unsafe!!! + Java 8

The Optimiser – Love/Hate

Some parts of Java are really nice!

***Tooling** – IDEs, Gradle, HdrHistogram*

Lambdas & Method Handles

Bytecode Instrumentation

Unsafe!!! + Java 8

The Optimiser – Love/Hate

Garbage Collection!!!

5. What’s the Roadmap?

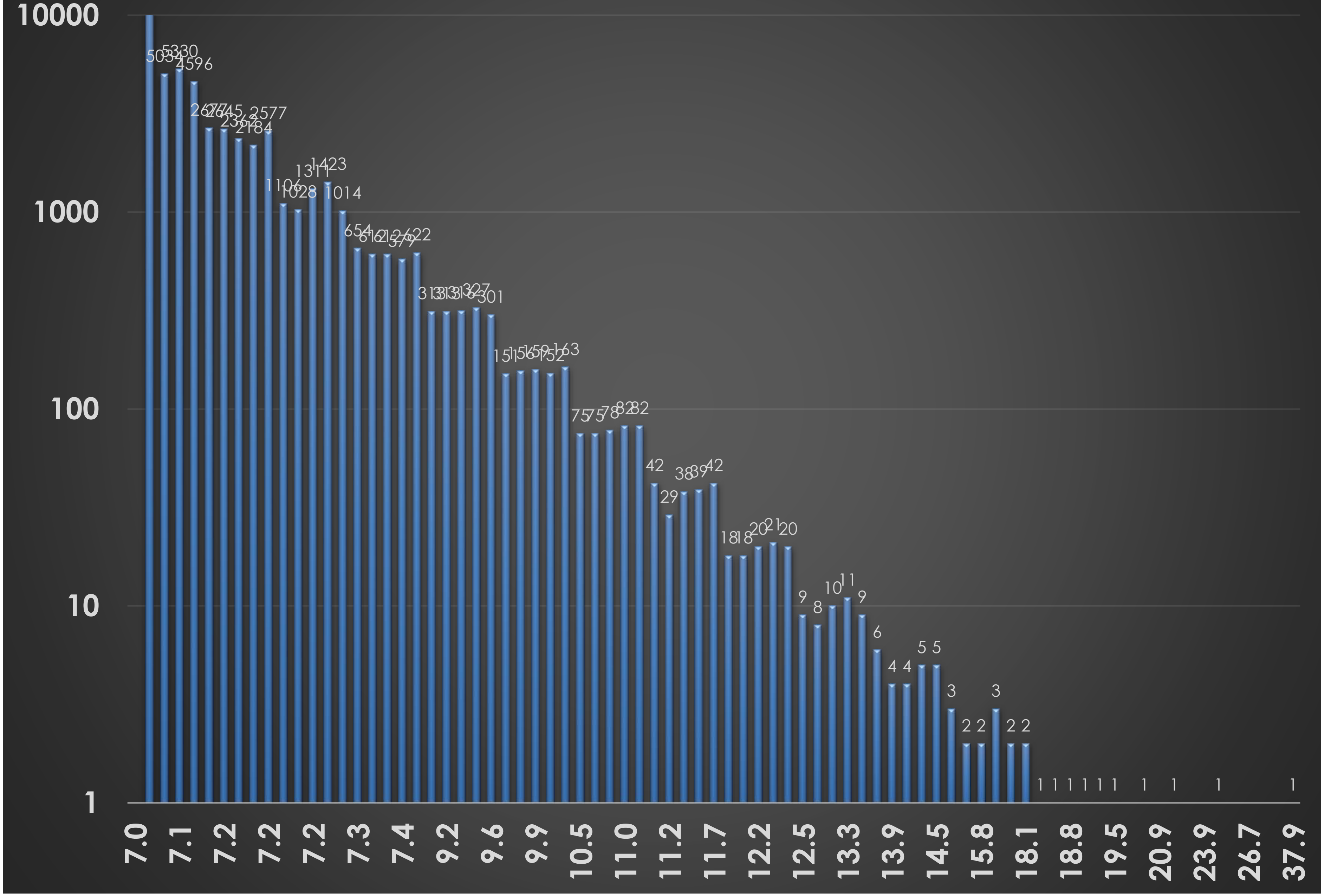
We are major feature complete!

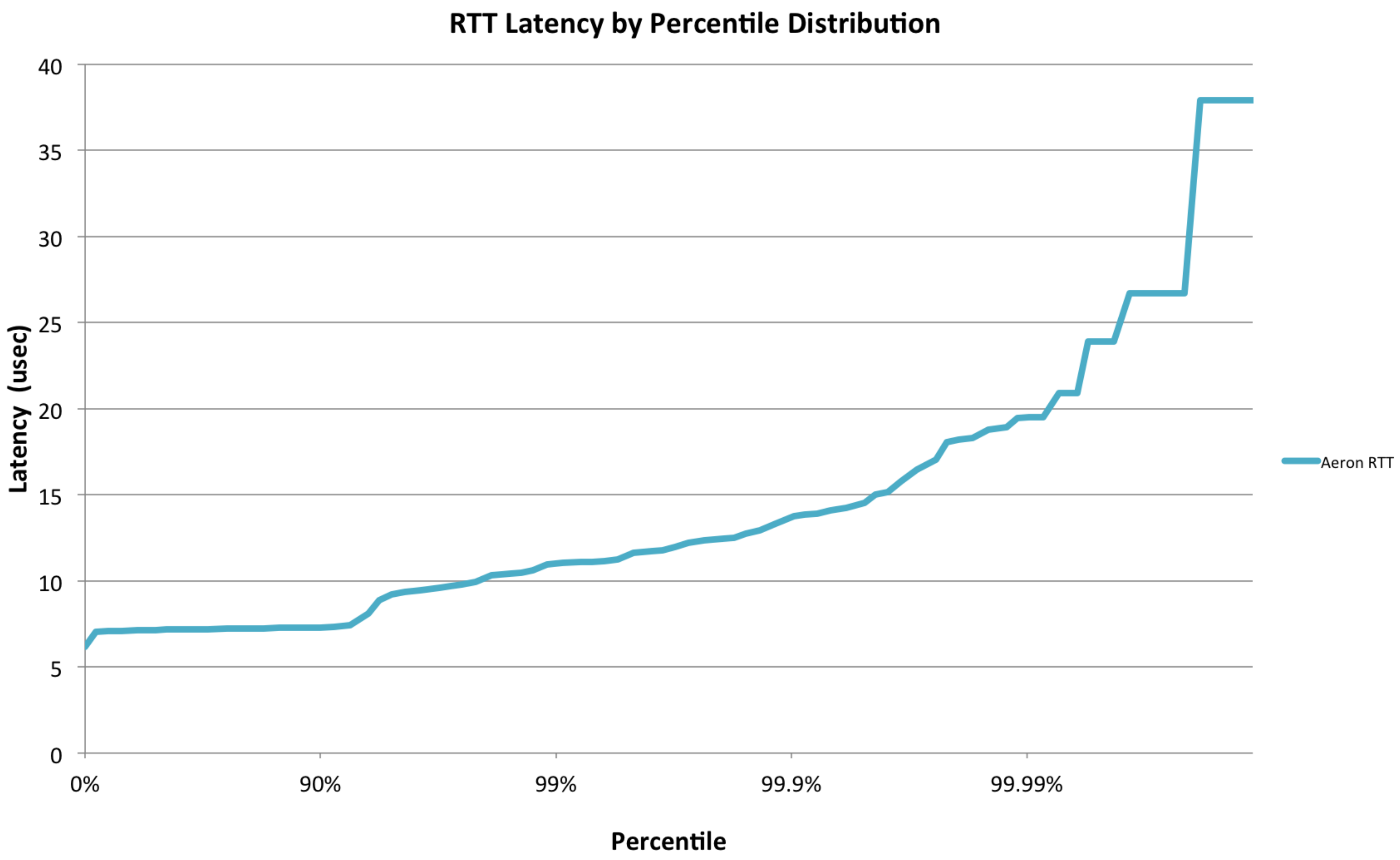
Just finished
Profiling and Tuning

Things are looking* very *good

20 Million 40 byte messages per second!!!

Latency Distribution (µs)




RTT Latency by Percentile Distribution
Latency (usec)
40
35
30
25
20
15
10
5
0
0%
90%
99%
99.9%
99.99%
Percentile
Aeron RTT

C++ Port coming next

Then IPC and Infiniband

Have discussed FPGA implementations with 3rd Parties

In closing…

Do epic shit,
or die trying.

Where can I find it?

https://github.com/real-logic/Aeron

Questions?

Blog: http://mechanical-sympathy.blogspot.com/

Twitter: @mjpt777

"Any intelligent fool can make things bigger, more complex, and more violent.

It takes a touch of genius, and a lot of courage, to move in the opposite direction."

- Albert Einstein