Tapsen

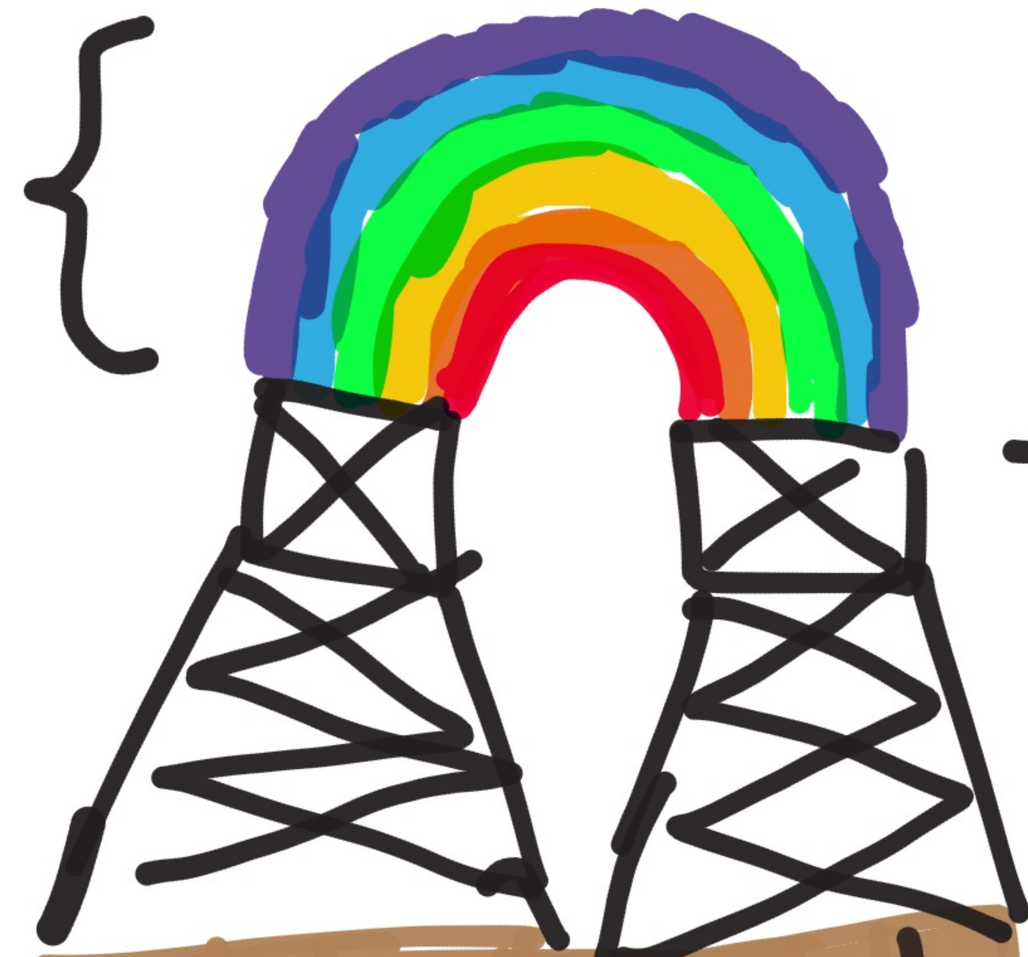
a fsyncing feeling

Kyle Kingsbury

@aphyr

I break databases!

Public API {



} API code

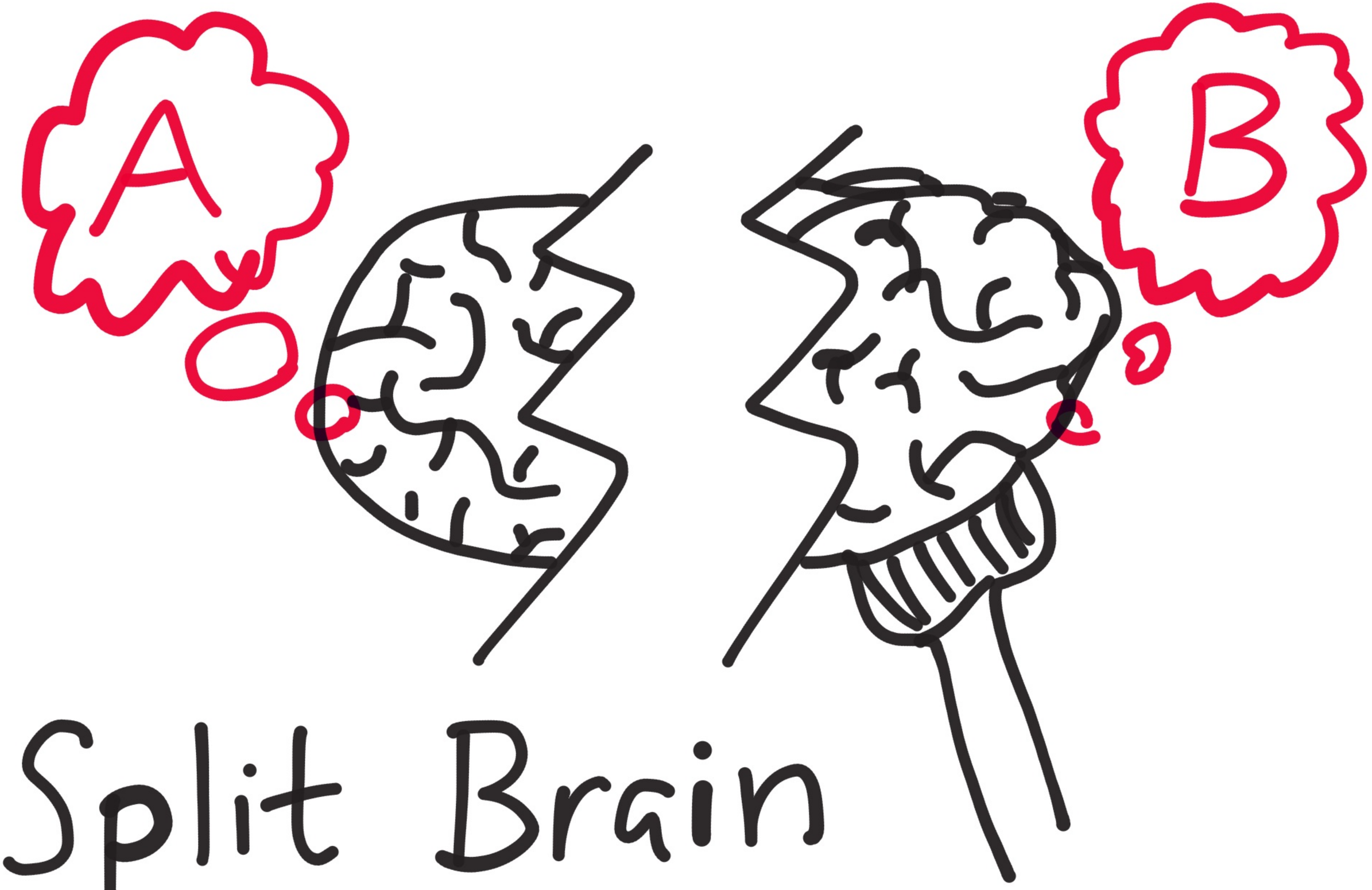
Ruby {

DBs

Every thing is fine!

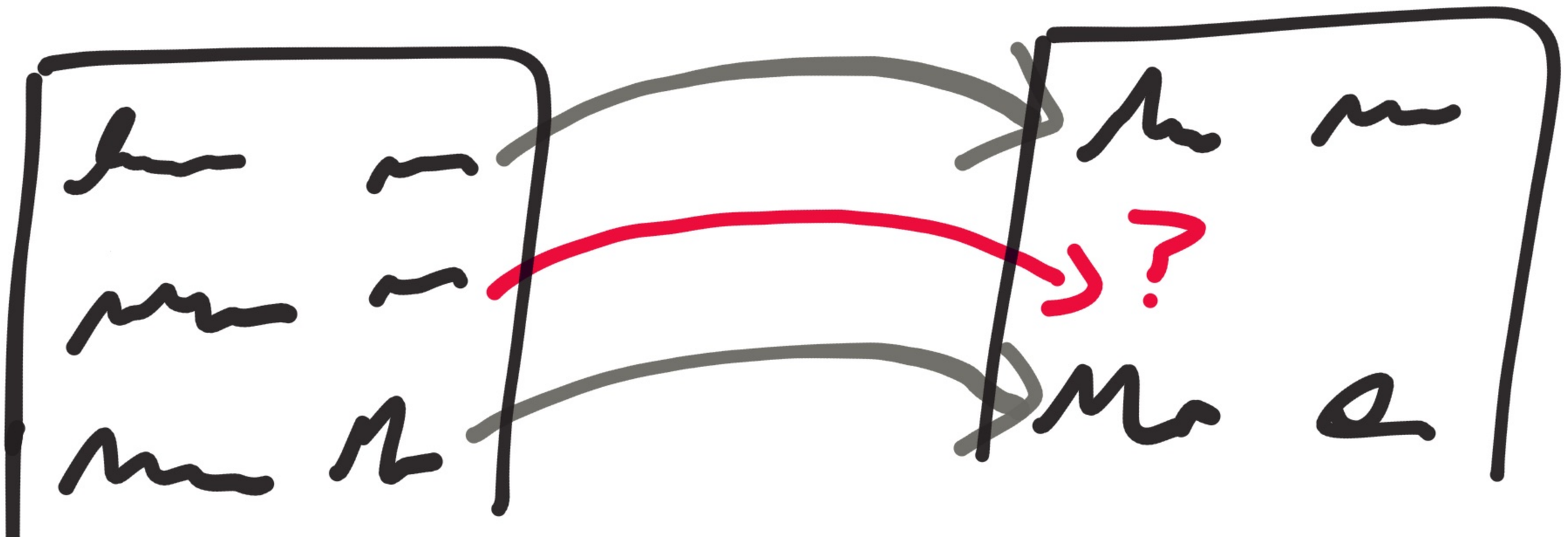
Databases!
Queues!
Discovery!

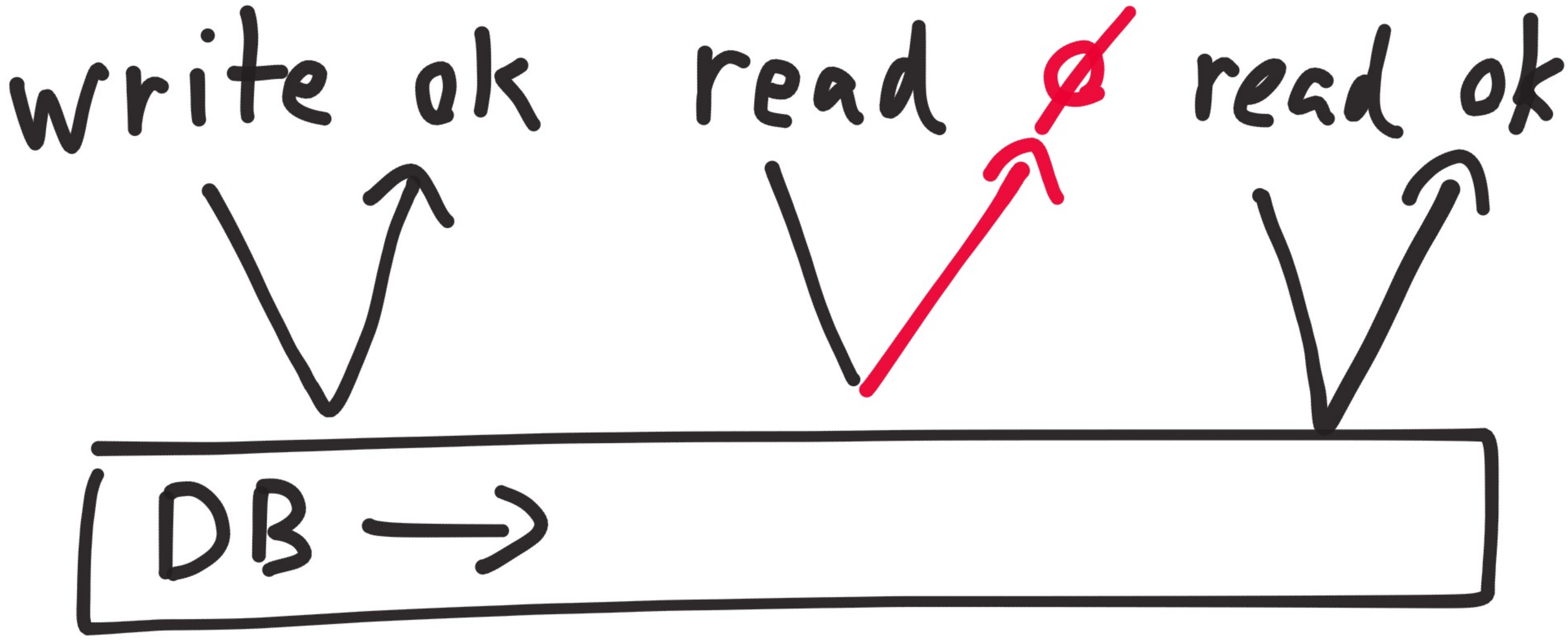
THE HORROR



Split Brain

Broken Foreign Keys

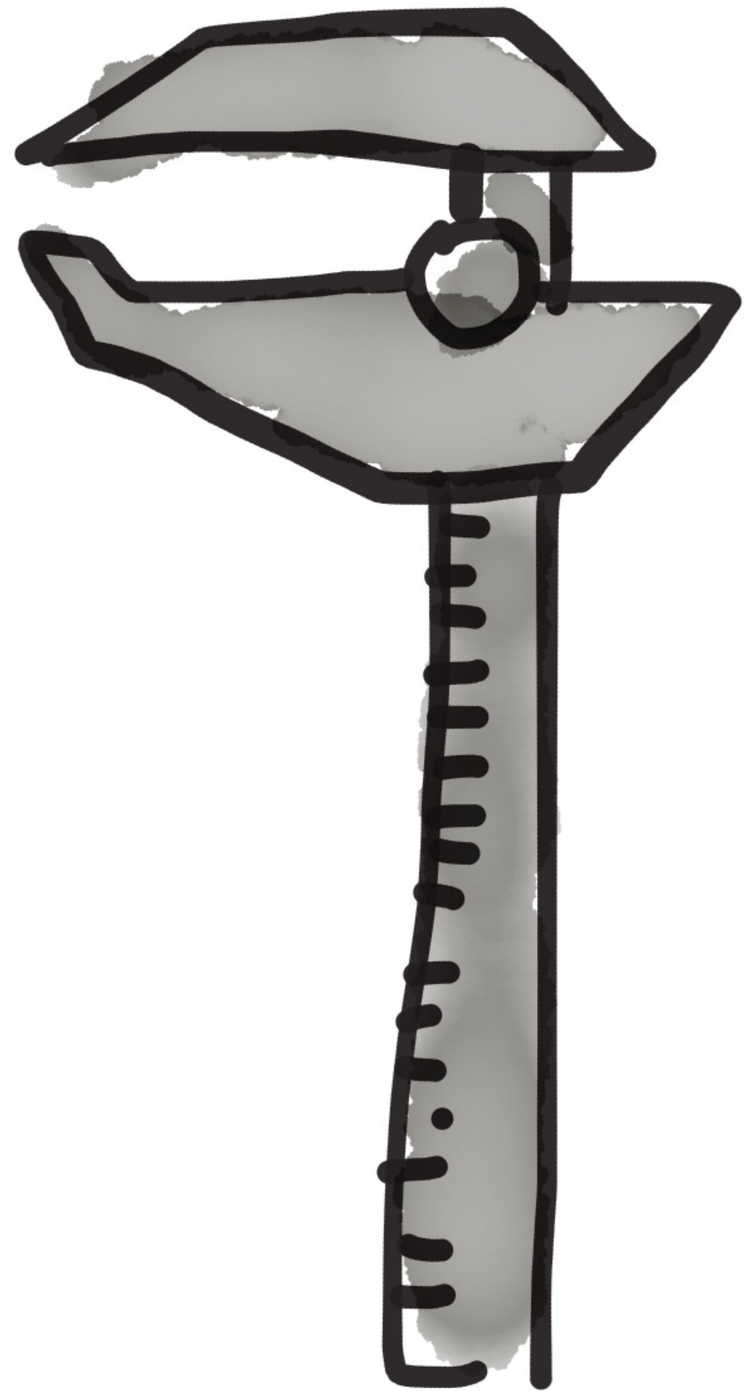




Anomalies

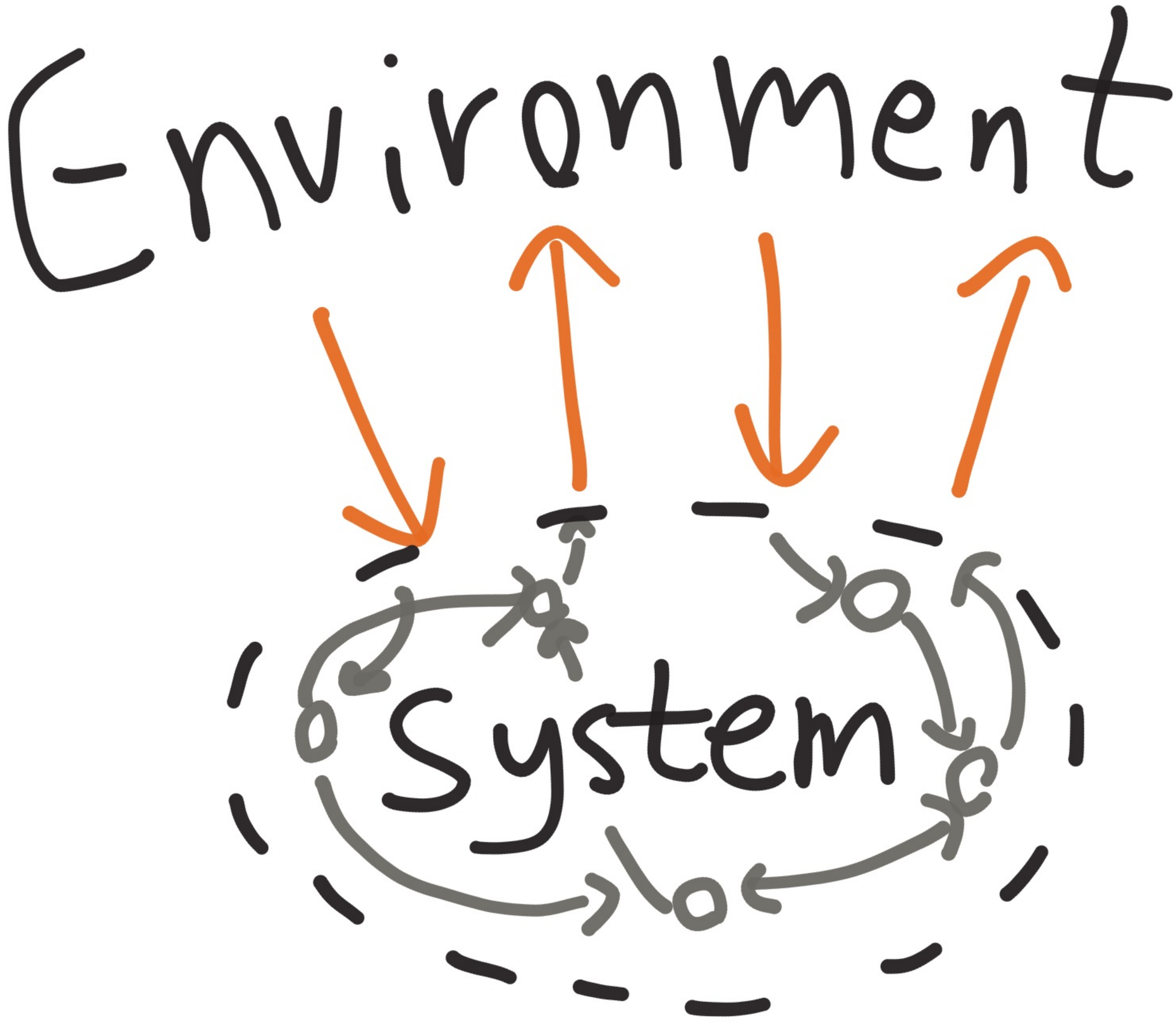
How do you
know if a
system is safe?

Measure your Systems

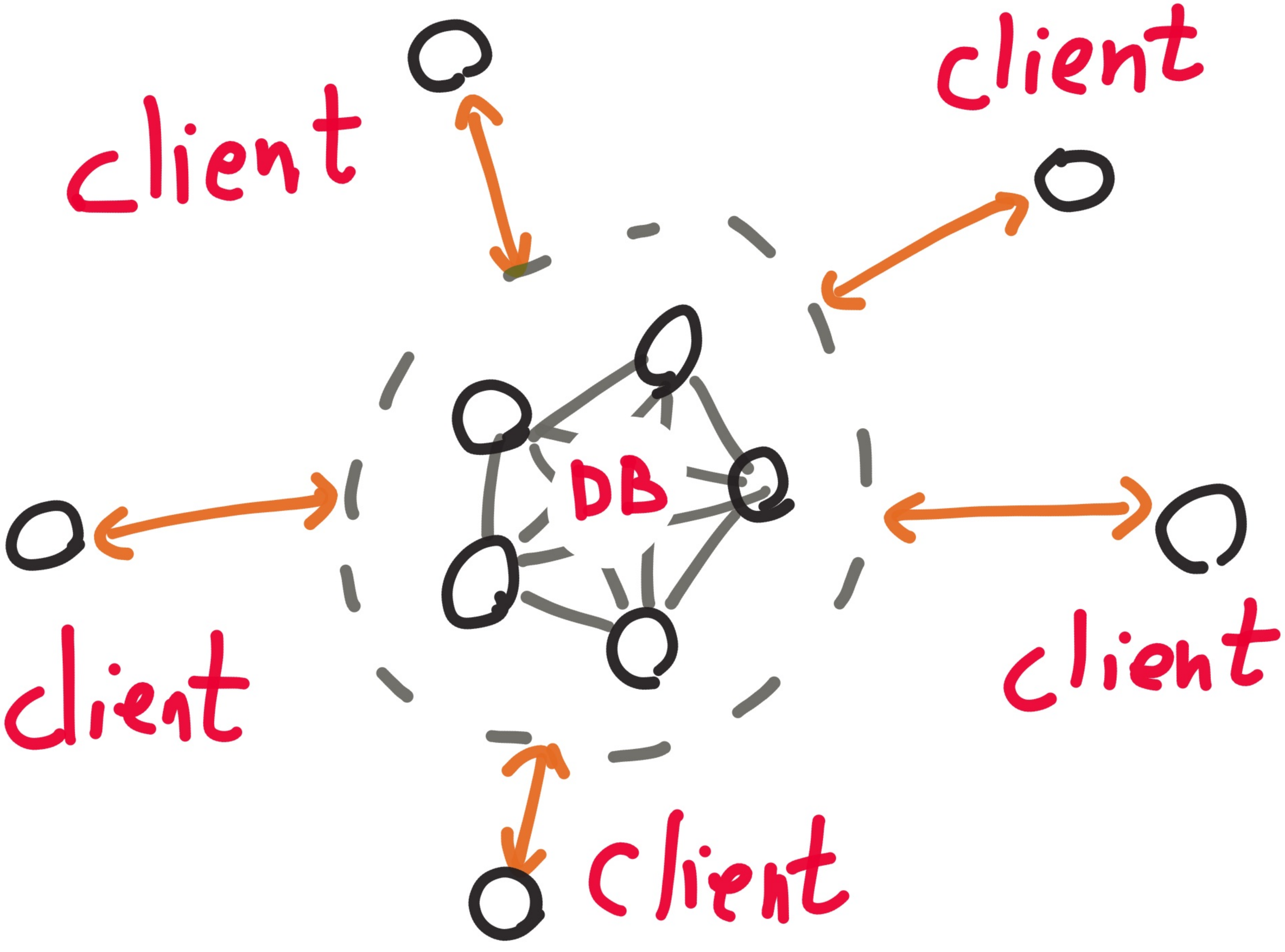


Jepsen

github.com/aphyr/jepsen


Environment
System

-INVARIANTS-

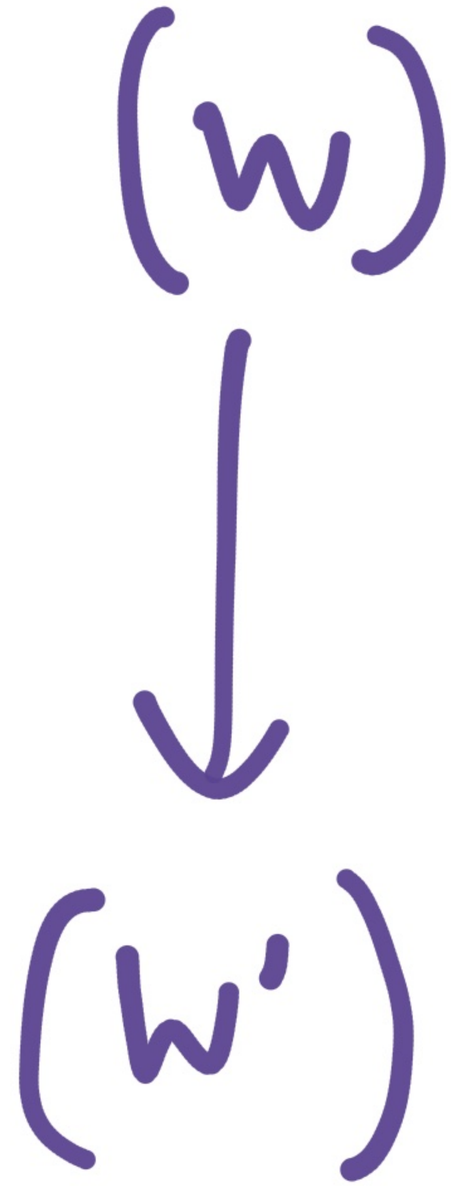

client
client
DB
client
client
client

client: w—w' r—r' w—w'

DB:

client: w —— w' w ——— - - -

Clients Generate random operations (w) and apply them to the system



invoke ok

invoke fail

invoke ? ? info ? ? ?

invoke ok

invoke fail

invoke ok

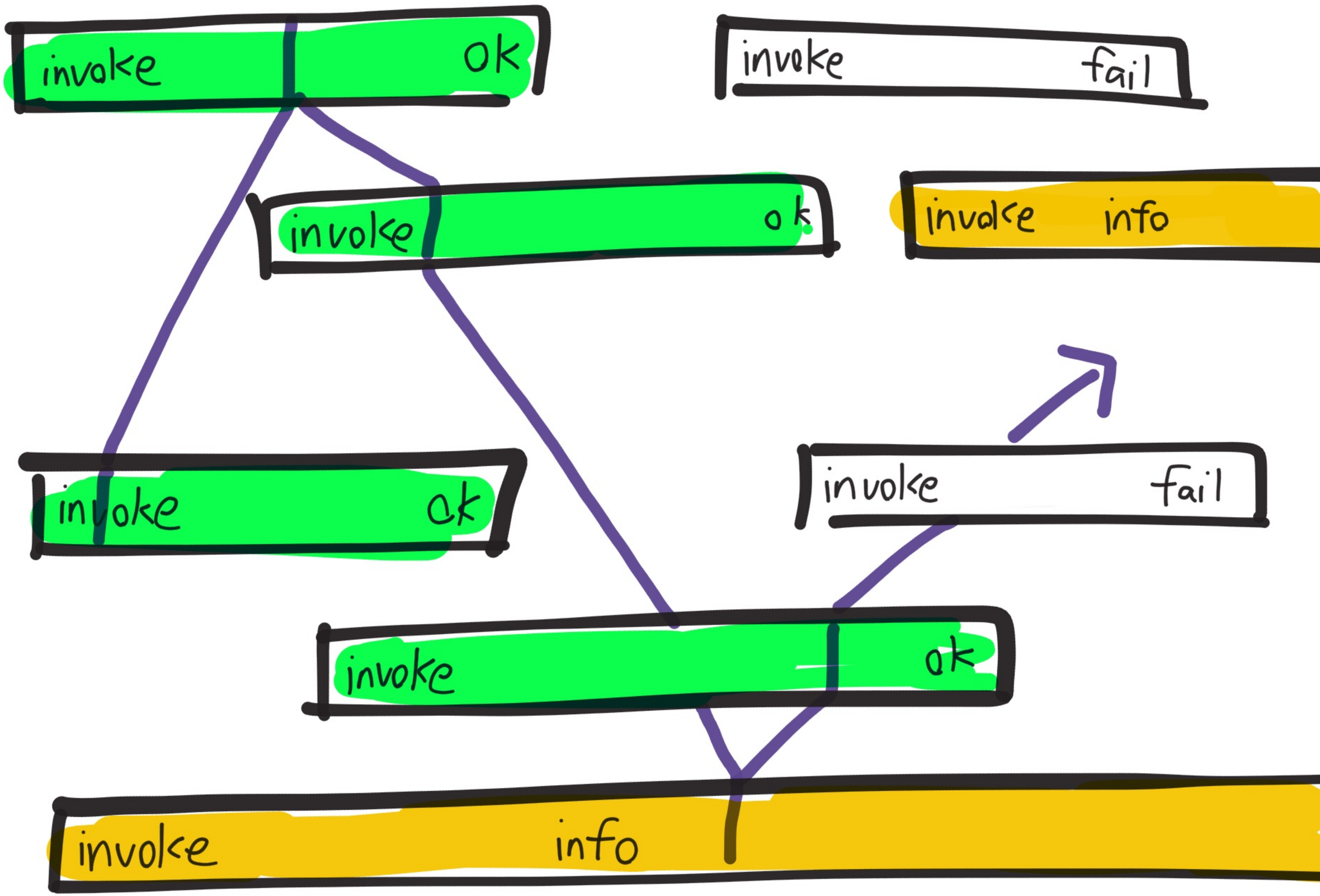
invoke info

invoke ok

invoke fail

invoke ok

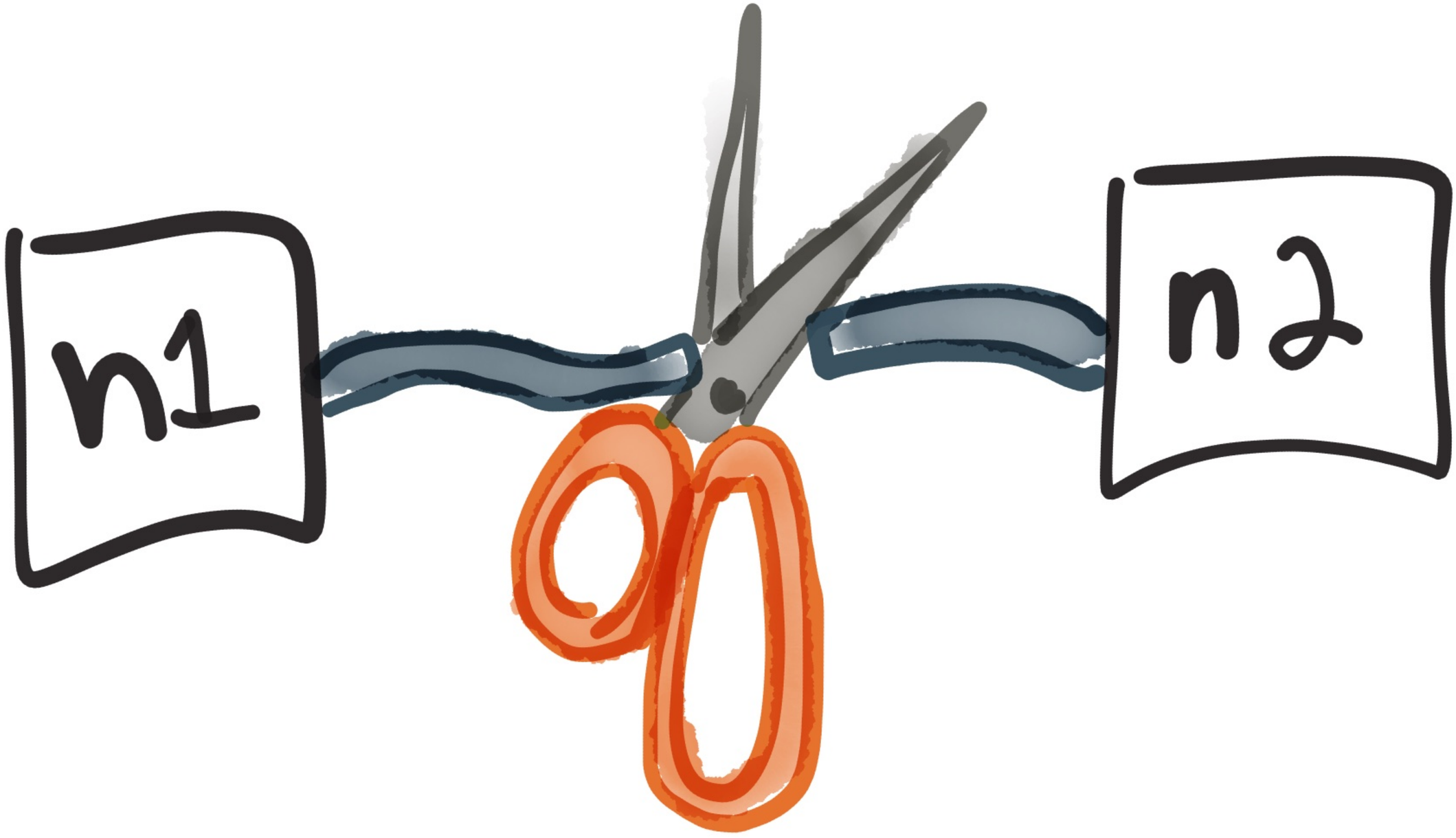
invoke info


invoke
ok
invoke
fail
invoke
ok
invoke
info
invoke
ok
invoke
fail
invoke
ok
invoke
info

1. Generate ops

2. Record history

3. Verify history is consistent w/ model



Partitions!

“So, what have you found?”

Riak

5/13

LWW → lost write

CRDTs → safe

5/13

Mongo

Data loss at all

Write concerns

Redis Sentinel

Split brain,

massive write loss

Cassandra

9/13

- LWW write loss
- Row isolation broken
- Transaction deadlock, data loss

NuoDB

9/13

Beat CAP by buffer-ing all requests in RAM during partition

Kafka

In-sync Replica Set could shrink to 0 nodes, causing msg loss.

Zookeeper

9/13

Works.

etcd / Consul

6/14

stale reads

Elasticsearch

Loses documents in every class of partition tested.

RabbitMQ

Split brain, massive

message loss

5/15

Aerospike

Claims "ACID", was really LWW.

Elasticsearch 1.5.0

5/15

Still loses data

in every test case

MongoDB 2.6.7

5/15

stale reads

dirty reads

Chronos

8/15

- Breaks forever after losing quorum

Percona XtraDB/Galera 9/15

- "Snapshots" weren't
- First-committer-wins not preserved
- Read locks broken

RethinkDB

- Basic tests passed
- Reconfiguration could destroy cluster in rare cases

VoltDB 6.3

- Stale reads
- Dirty reads
- Lost writes

Crate.io

2016

- Stale reads
- Dirty reads
- Lost/corrupt updates
- Lost inserts

CockroachDB

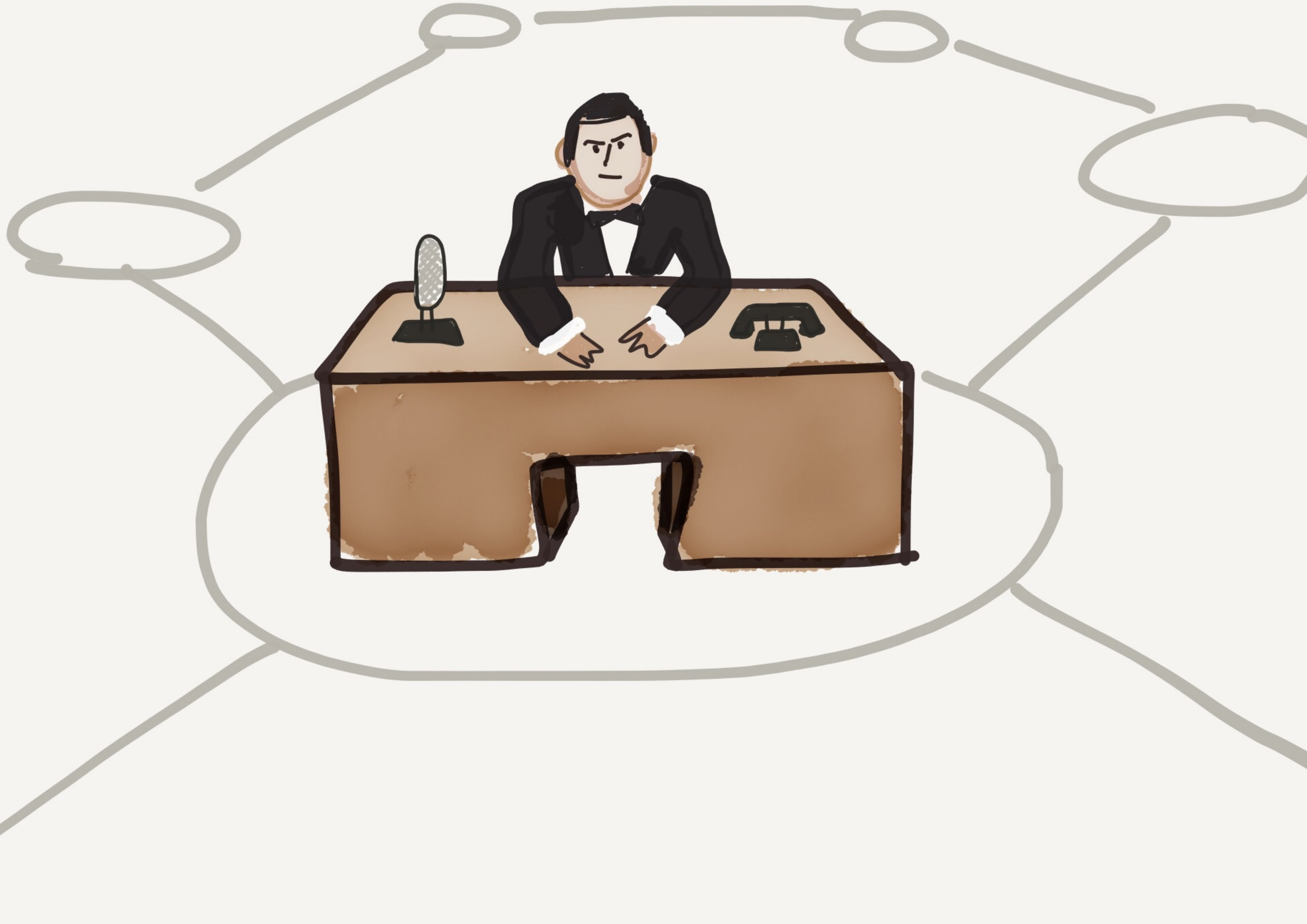
2017

- phantoms
- Double inserts

MongoDB

2017

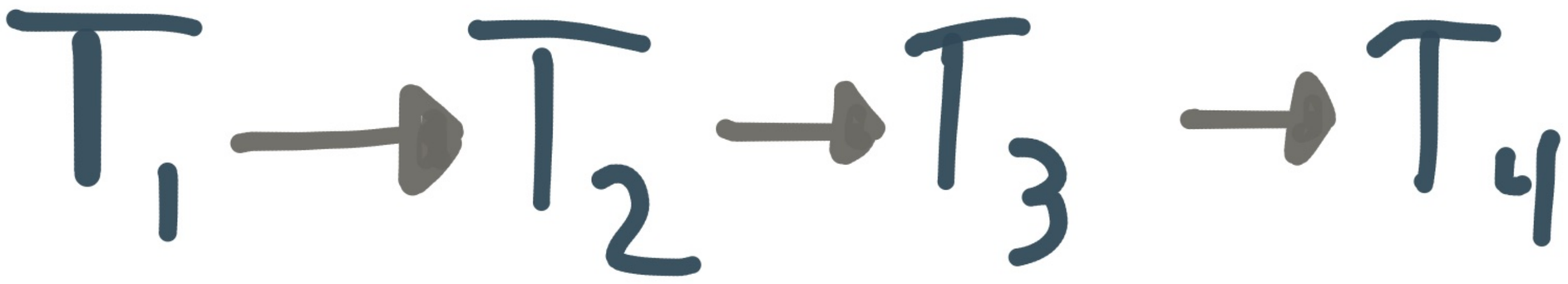
- v0 protocol broken, loses data
- Multiple data loss bugs in v1 protocol



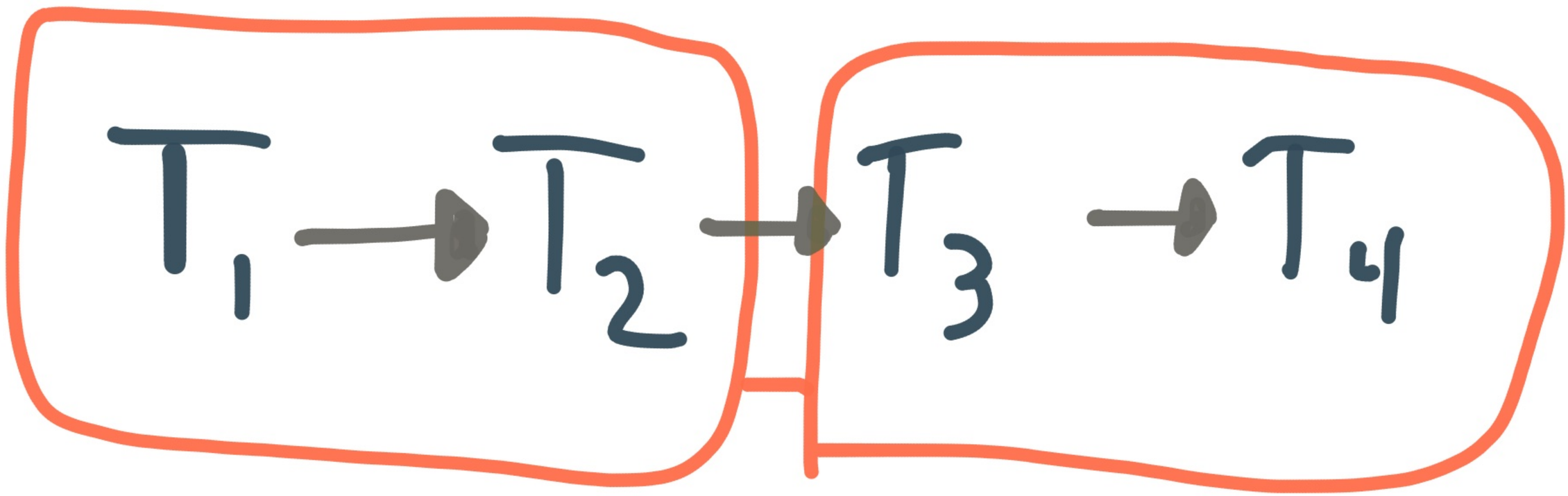
- Transaction replication
- Pluggable FSMs
- Byzantine fault tolerant

"Raft Meets Blockchain"

Like e.g. Raft, forms a linearizable order of txns



Like Raft, provides a linearizable order of txns



blockchain!

Byzantine Fault Tolerant!

shun!

shun!

shun!

shun!

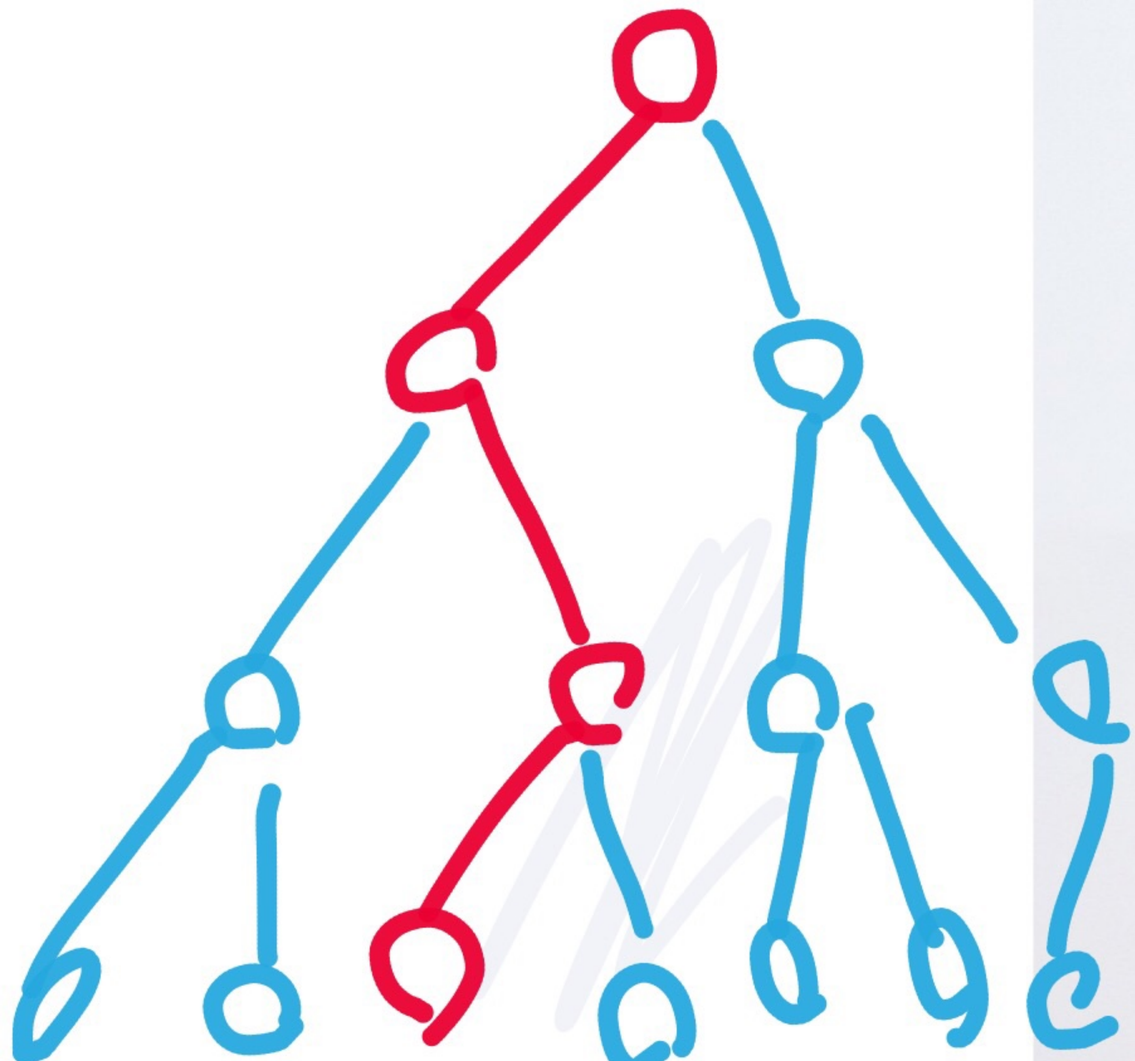
Pluggable State Machines

validator

validator

state

state



merkle eyes

cas-register

- read(2)
- write(5)
- cas(1,4)

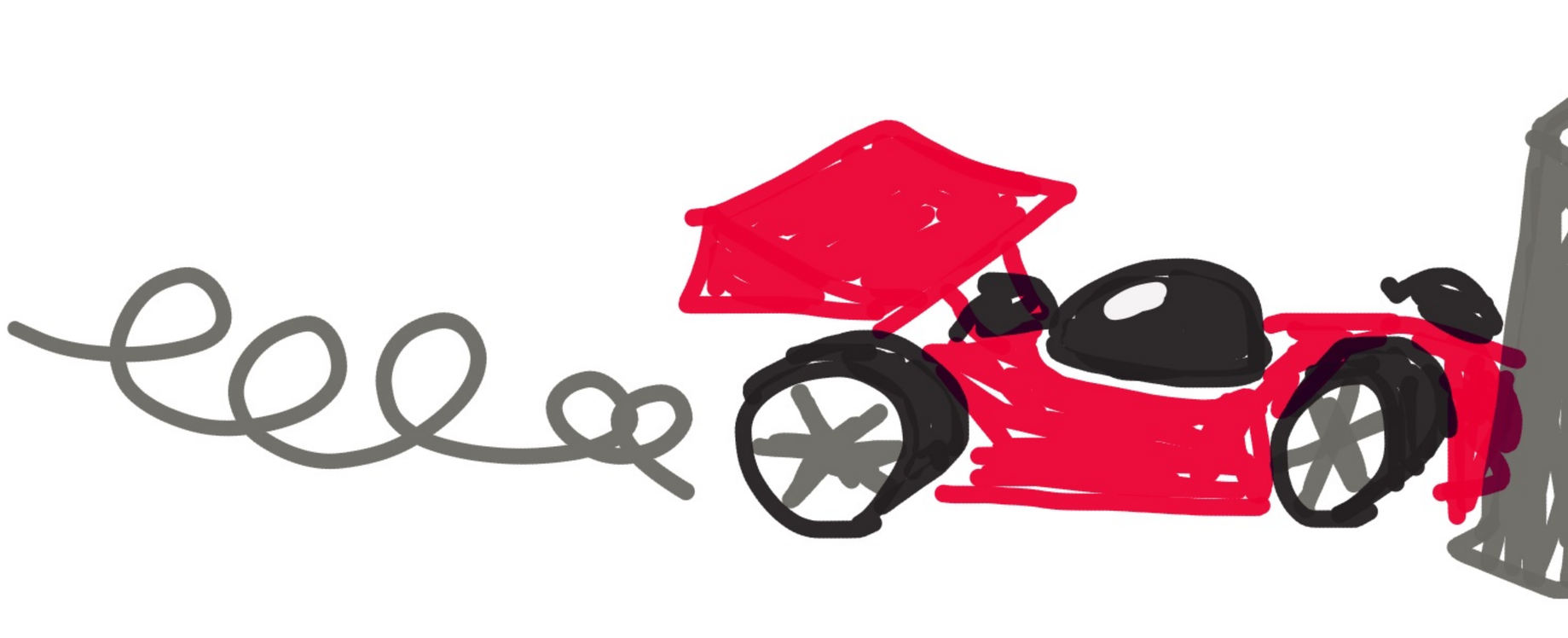
set

- add(6)

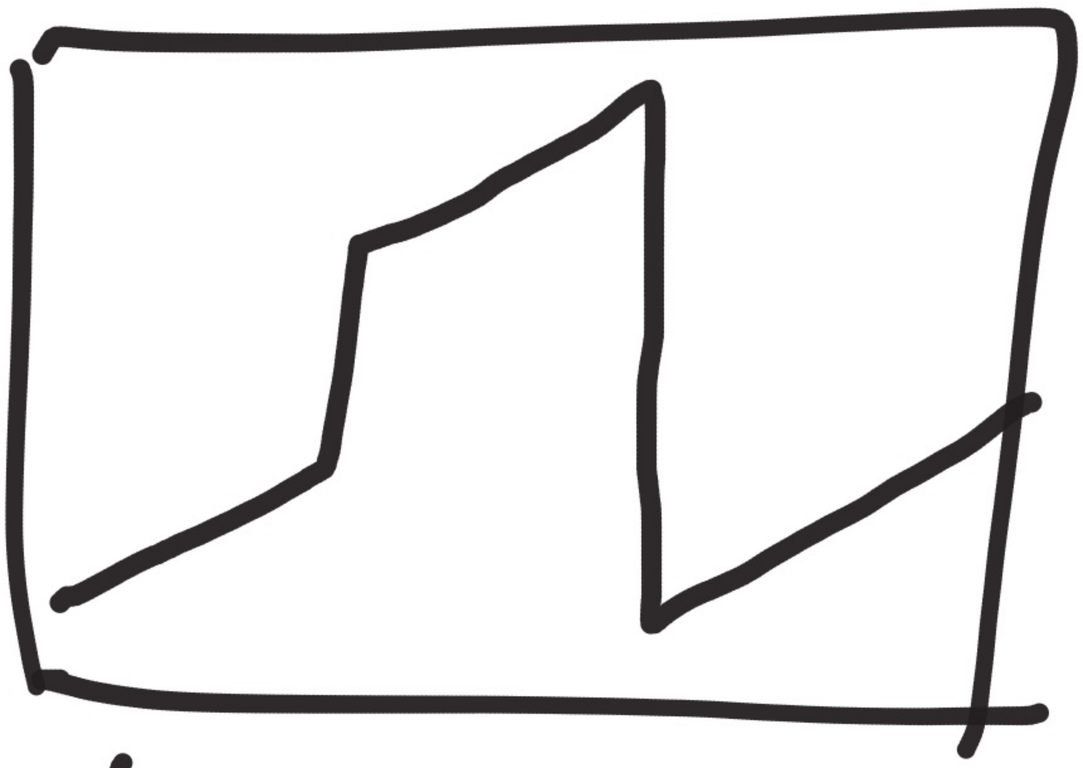
  [read({1,2,3})
  cas({1,2,3}, {1,2,3,6})]

- read({1,2,3, ...})

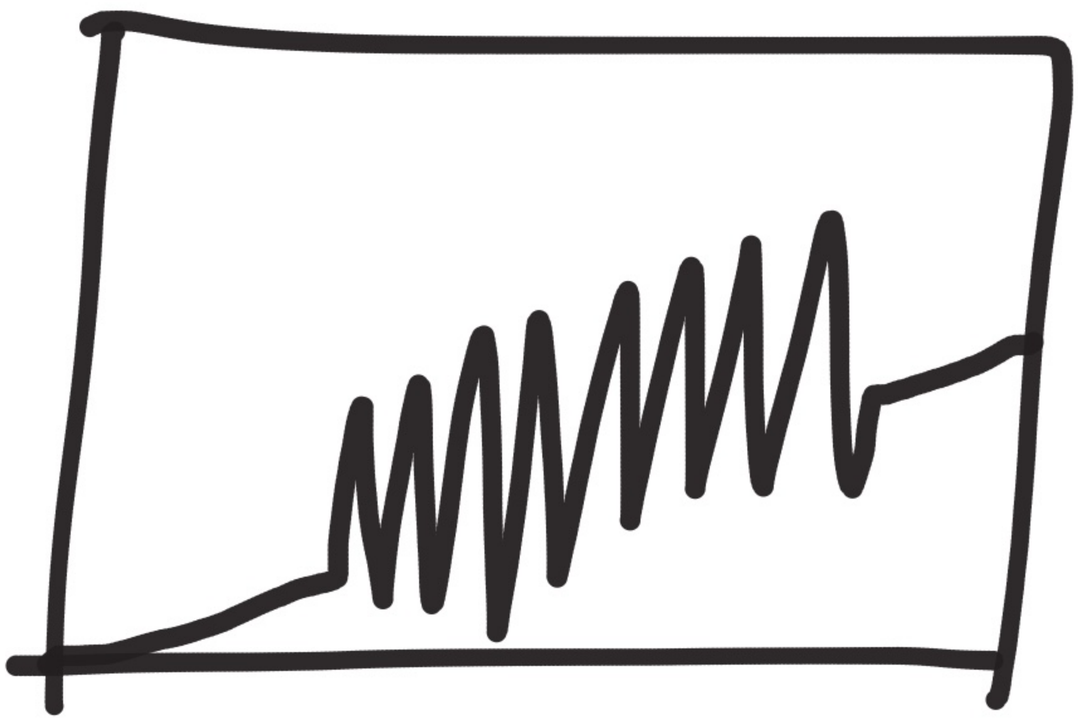
Merkleeyes Race



clock skew

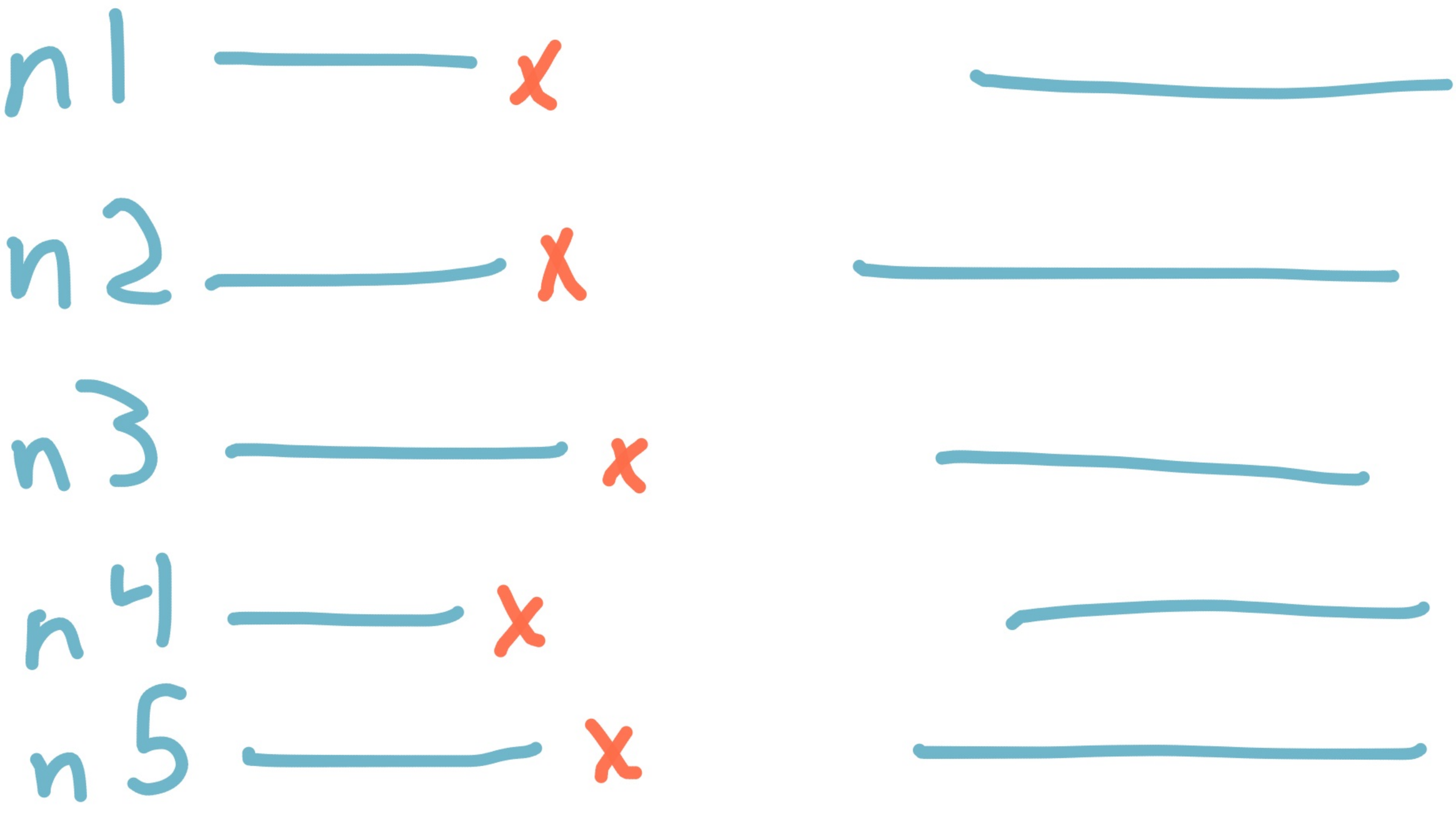


bump

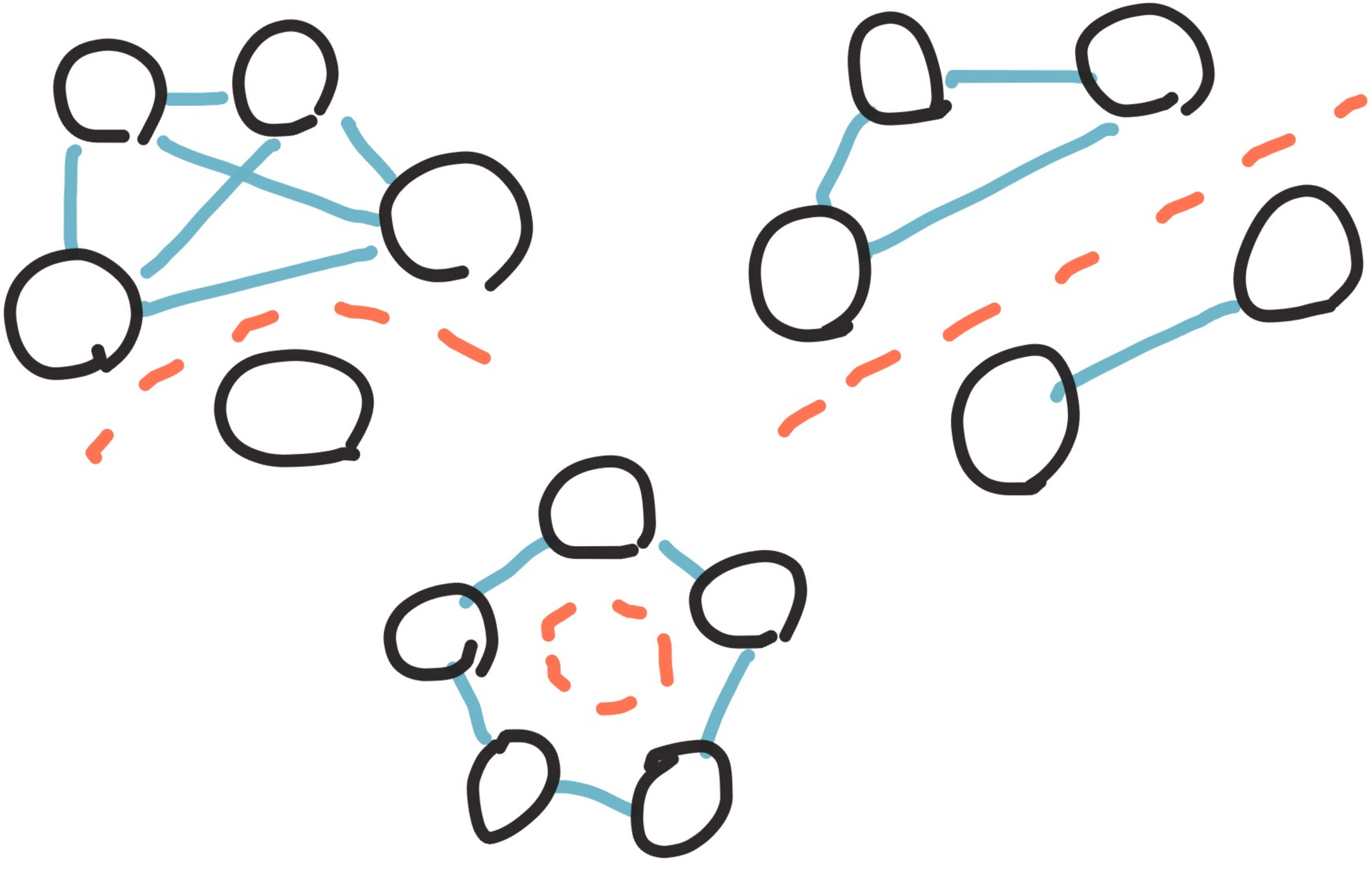


strobe

crashes



partitions



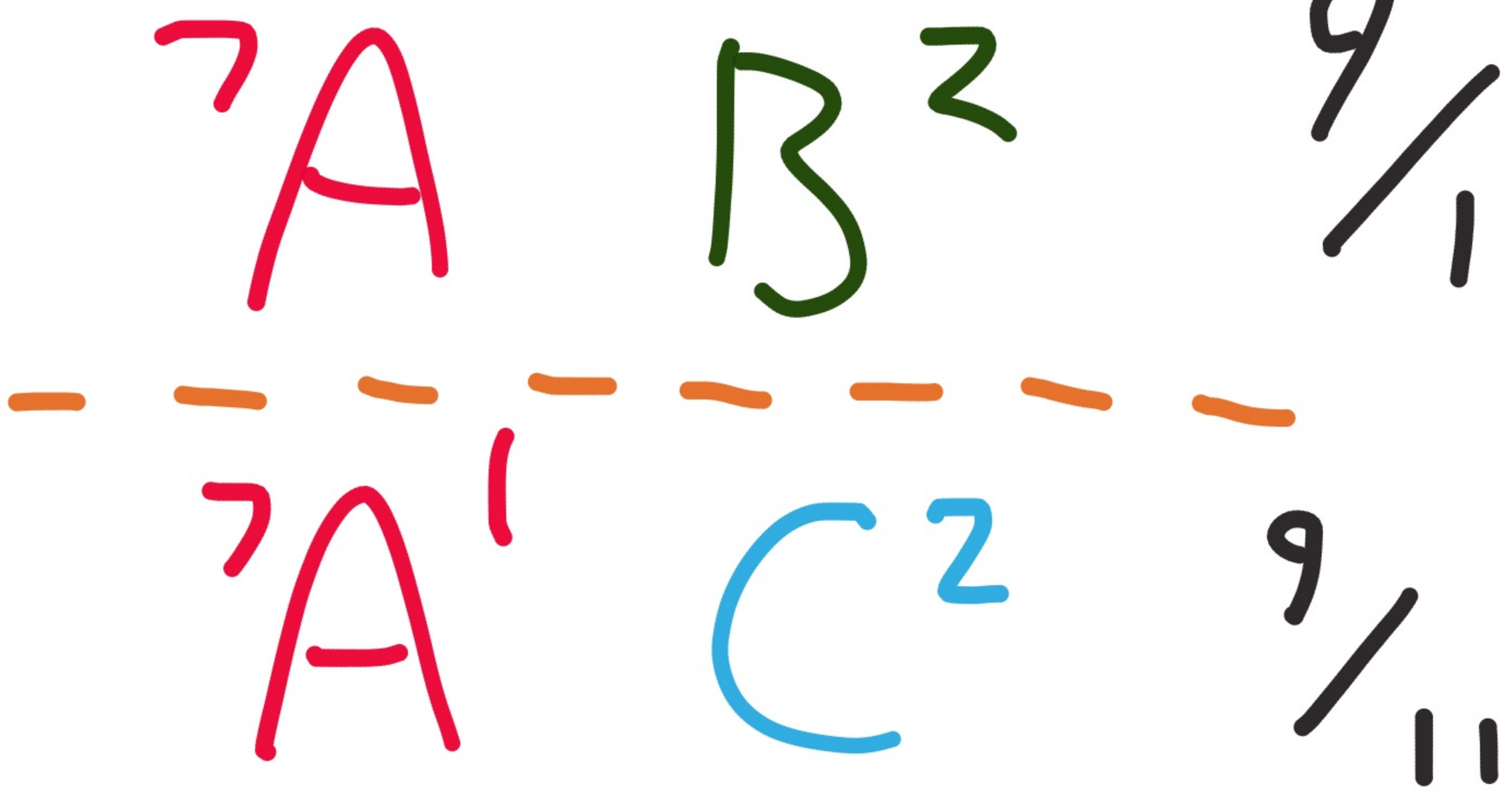
Duplicate Validators

$7A^{2}\ B^{2}$

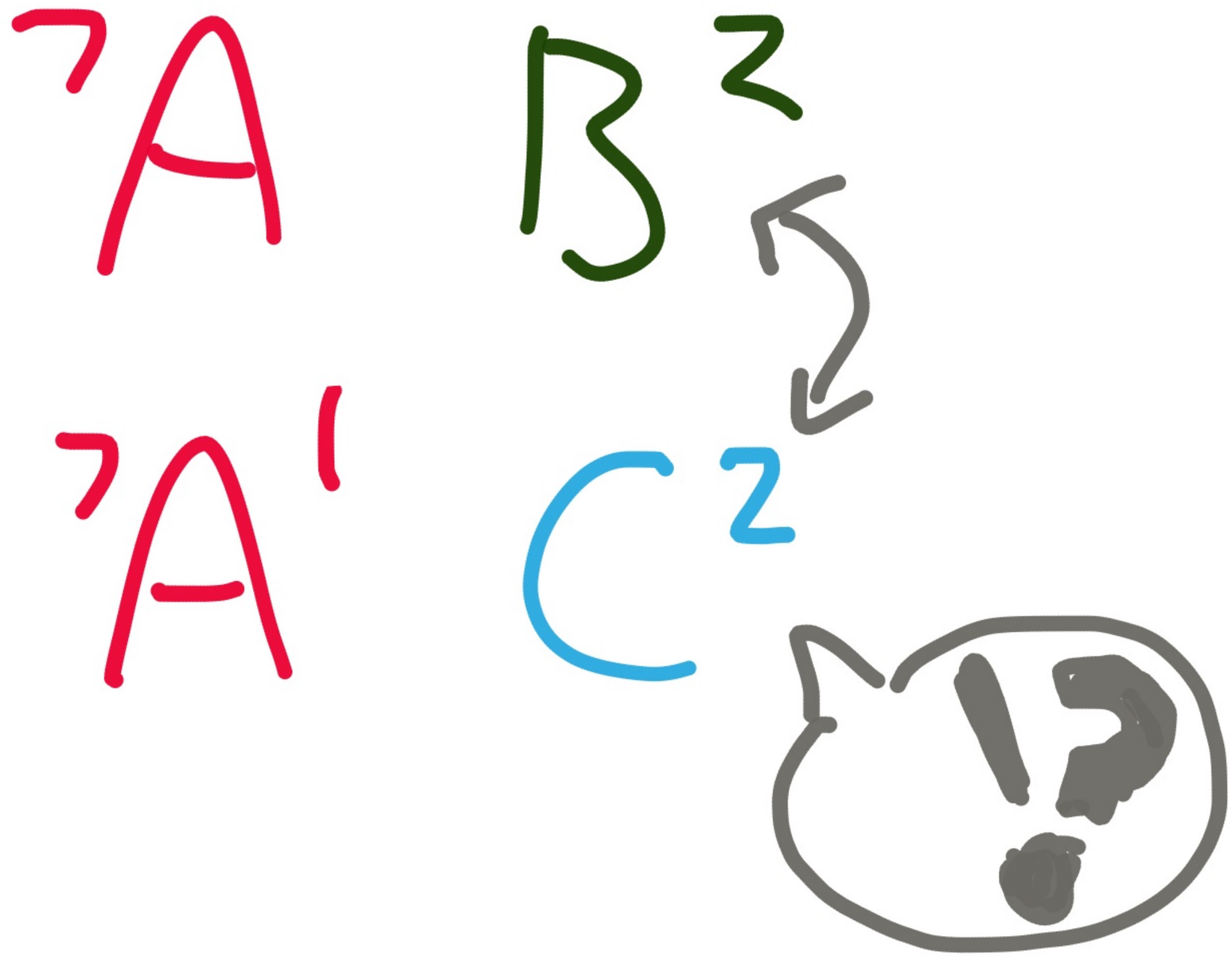
$7A^{1}\ C^{2}$

$7 + 2 + 2 = 11$

Duplicate Validators



Duplicate Validators



Lost Documents

iff

$\geq 1/3$

of votes

file truncation

merkleeyes crash!

(goleveldb bug)

Tendermint

Doesn't fsync to disk!

Dynamic Reconfig

Data corruption & crashes are to be expected — Tendermint is still in beta

Team working to fix these issnes

hazelcast

3.8.3

In-memory

Sets

Lists

IDs

Semaphores

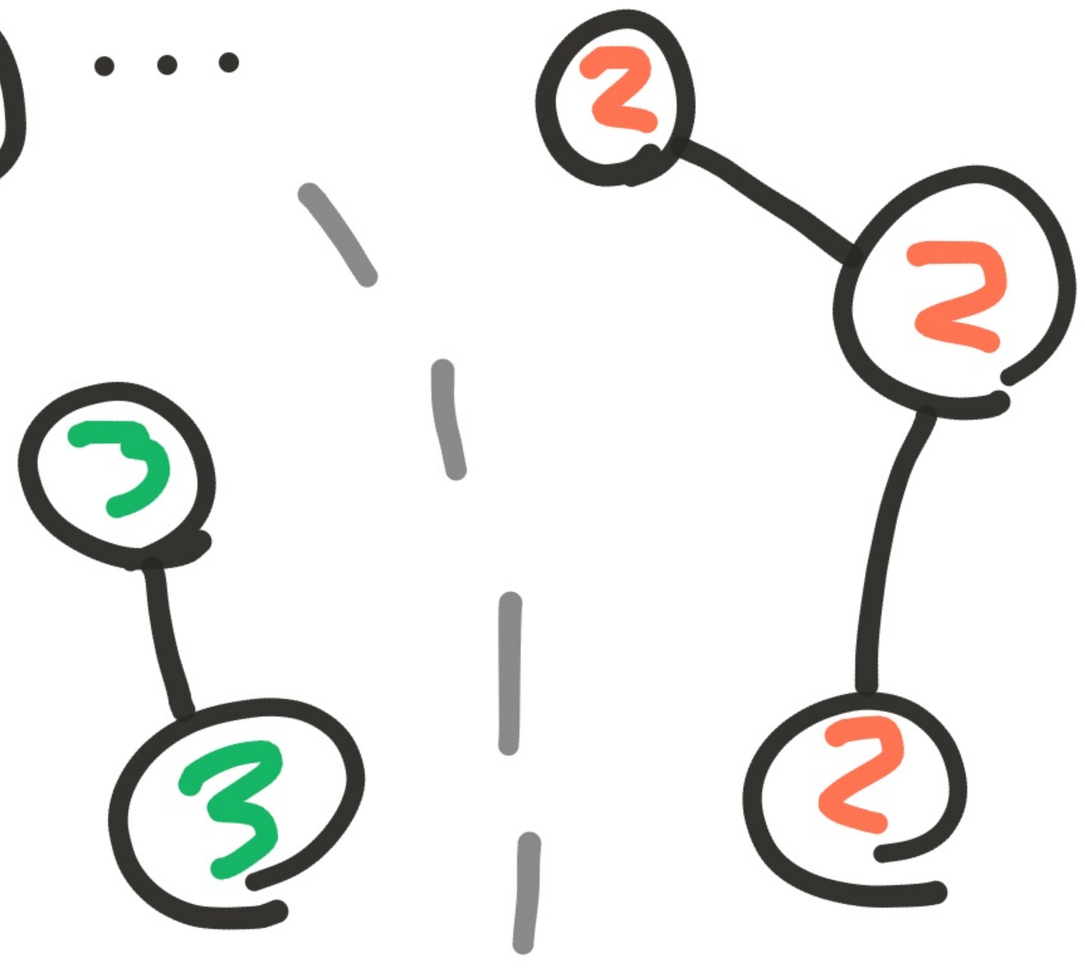
Queues

Maps

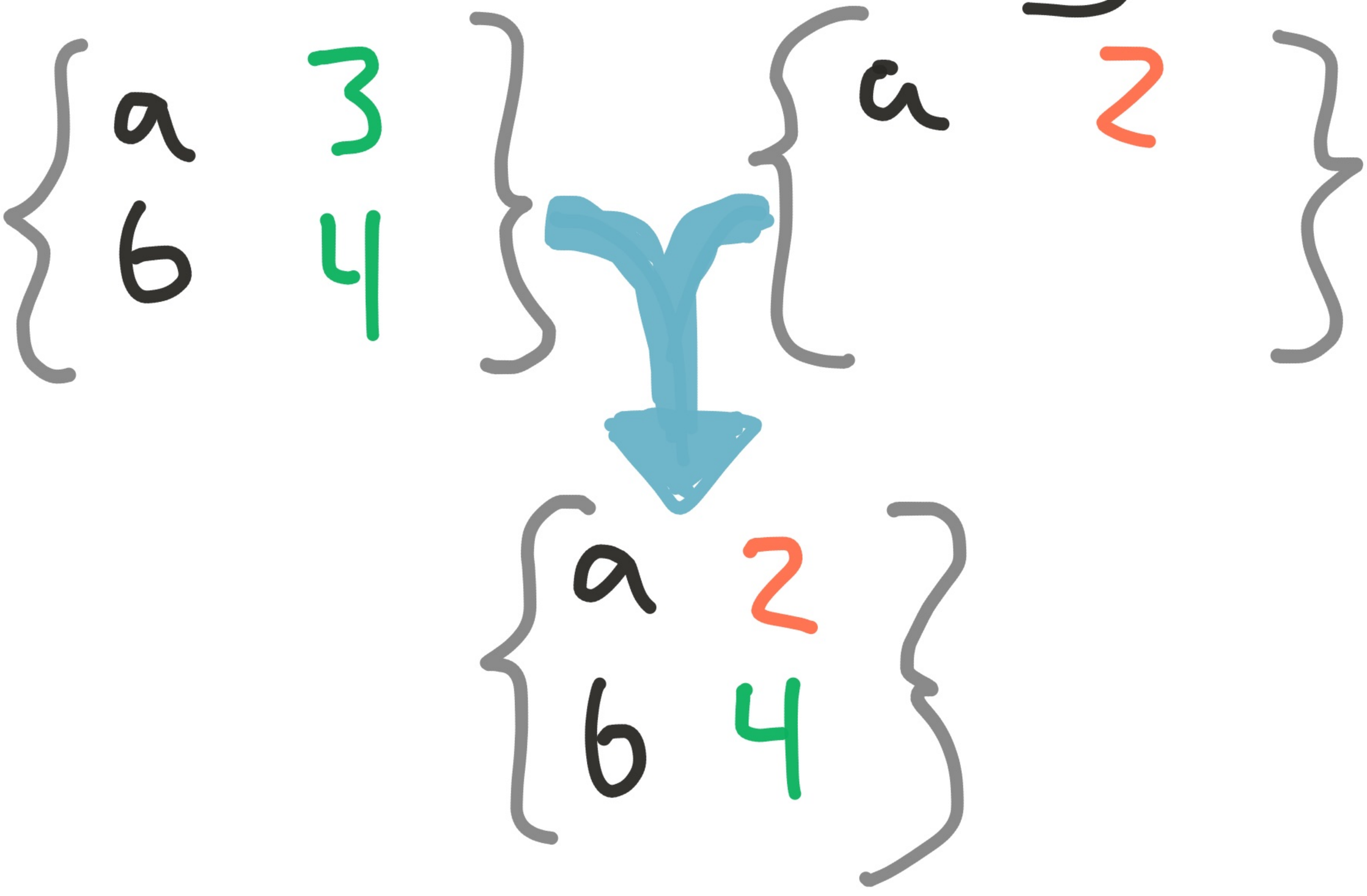
Locks

Atomic Longs

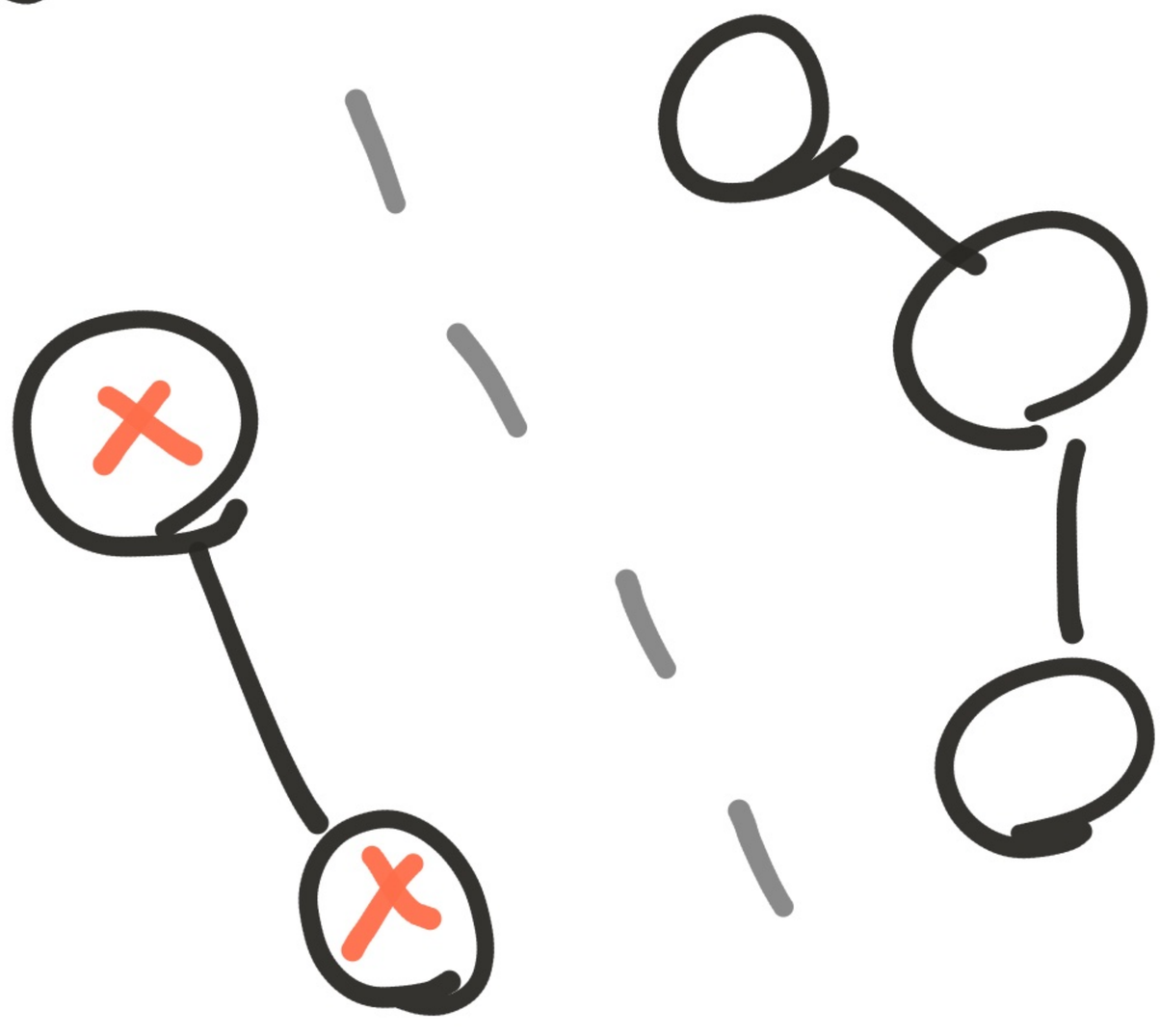
But in a partition, components run independently...



Maps have merge



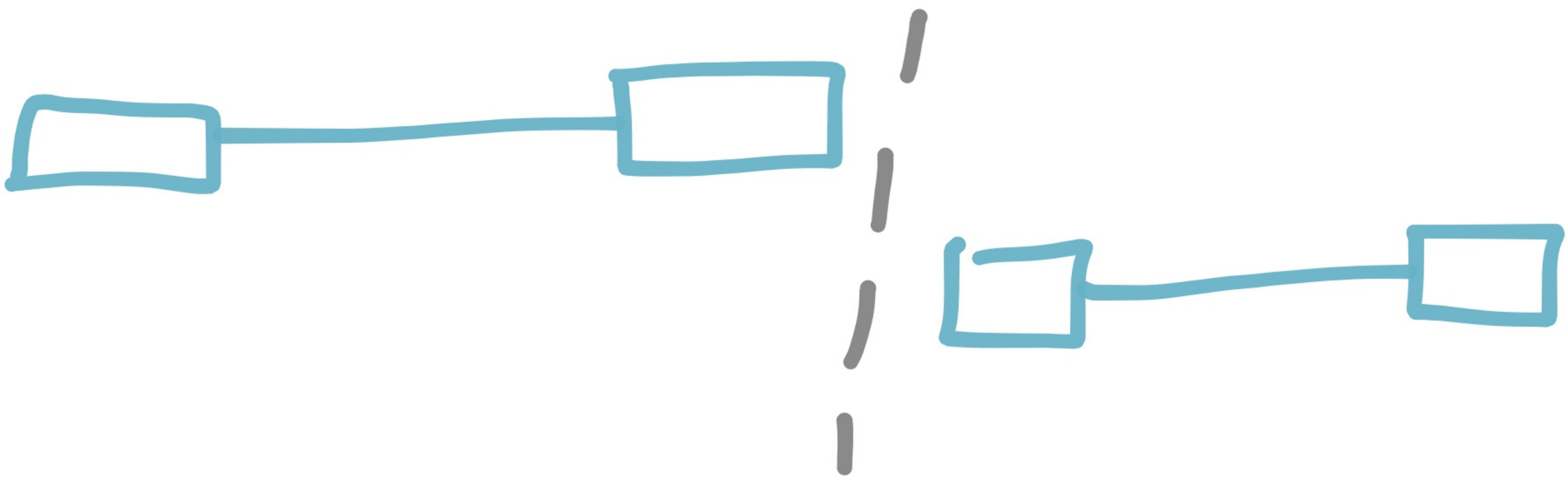
Split-Brain Protection

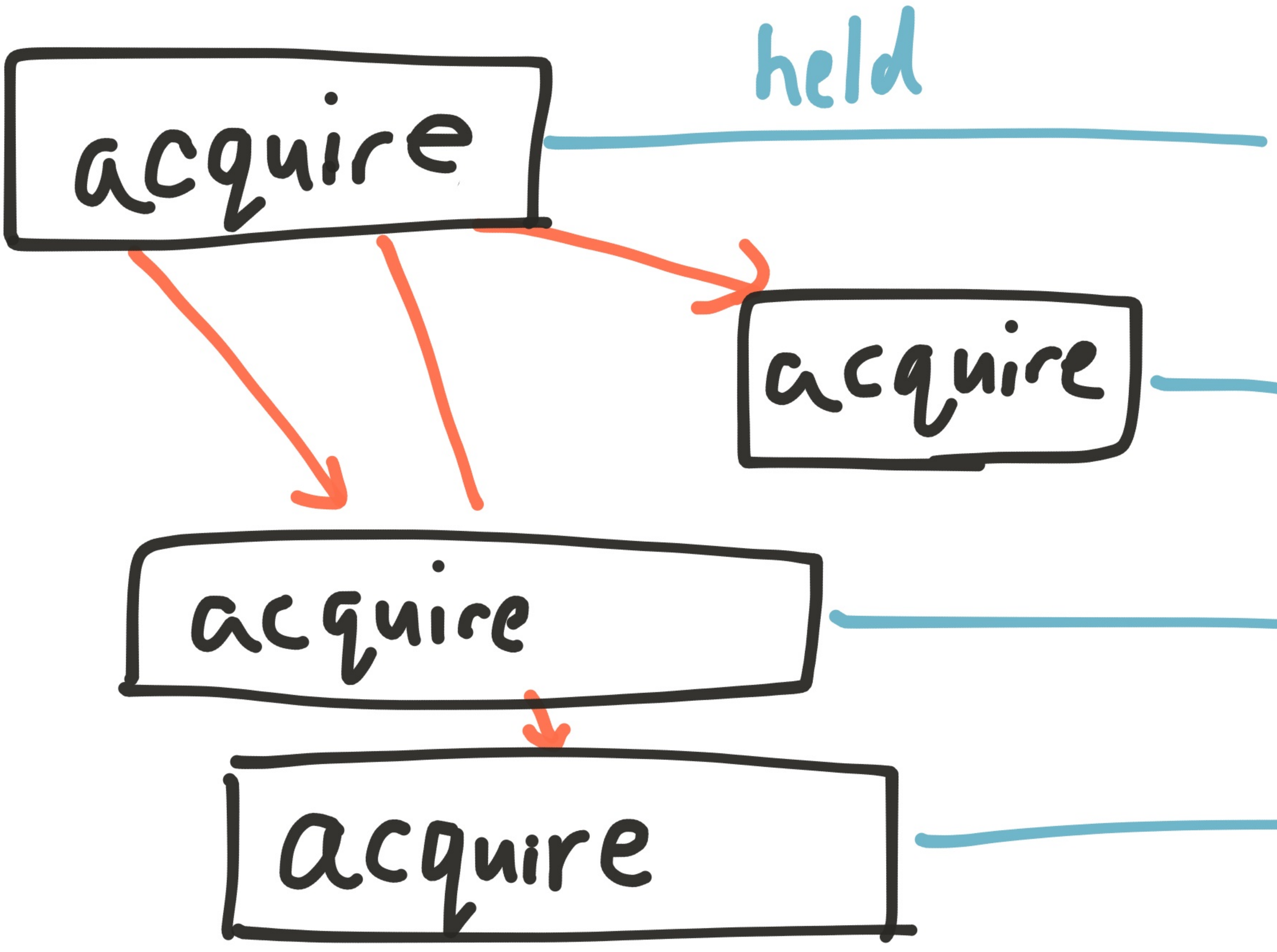


(10^{+} seconds)

Locks

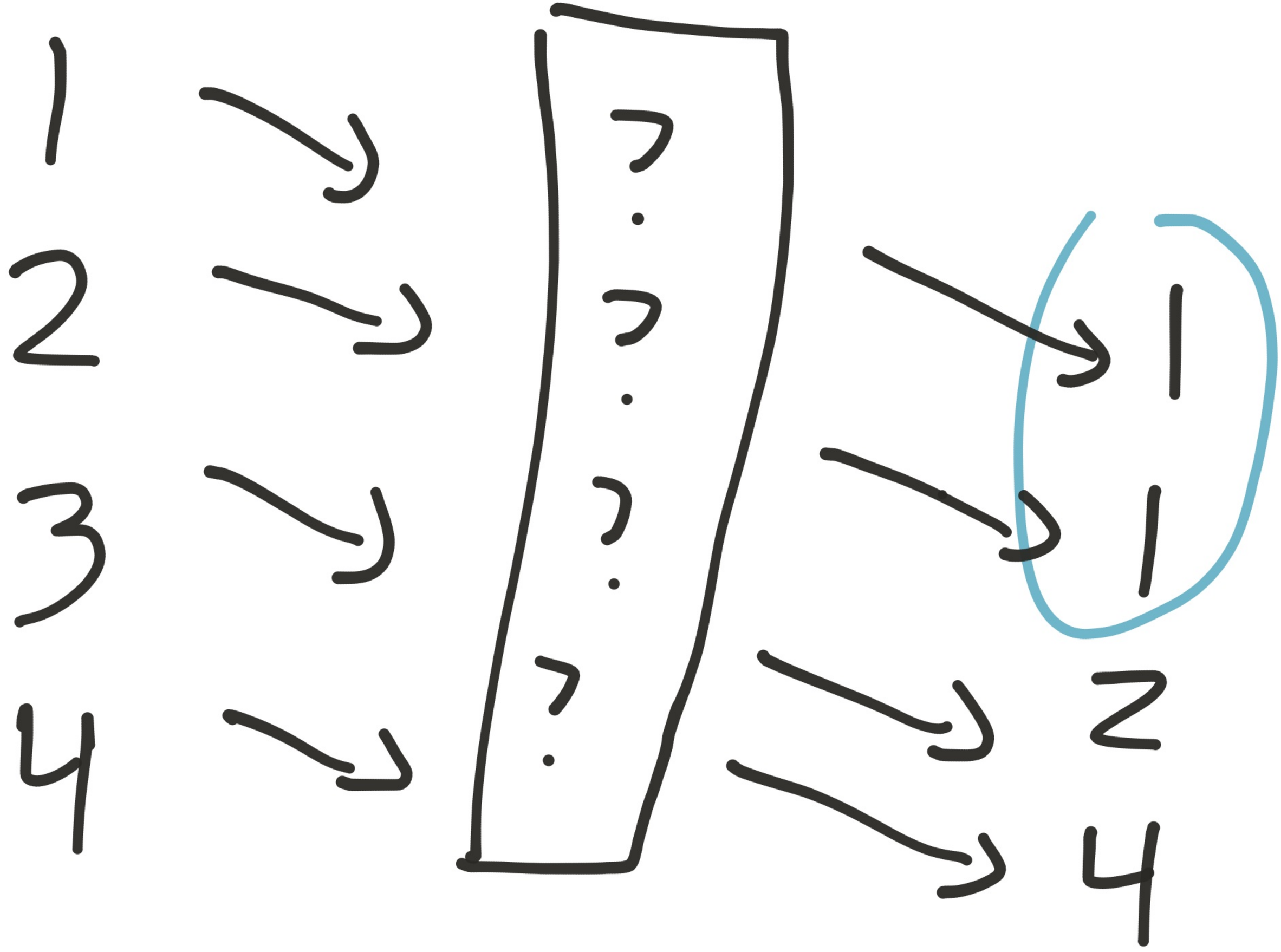
"Guaranteed to be exec-
-uted by only one thread
in the cluster"




held
acquire
acquire
acquire
acquire

Queues

"...you can add an item in one machine and remove it from another one"


1
2
3
4
?
?
?
?
1
1
2
4

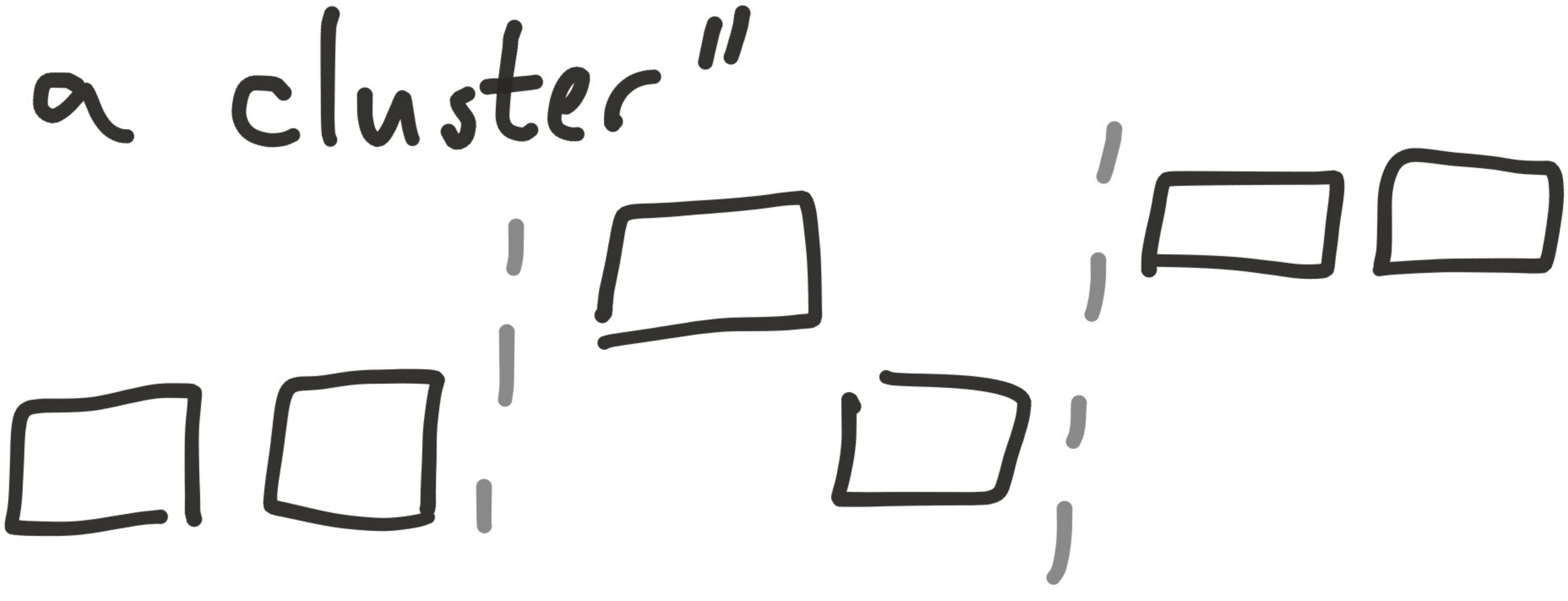
~2% duplicated

~2% lost

worse with default timeouts

Atomic Reference

"Guaranteed atomic compare and set across a cluster"



increment

2+1=3

"still 2?"
"yes!"

2

3

"still 2?"
"nope!"

increment

2+1=3

increment

2+1=3

"still 2?"
"yes!"

2

3

3

increment

2+1=3

increment

2+1=3

"still 2?"
"yes!"

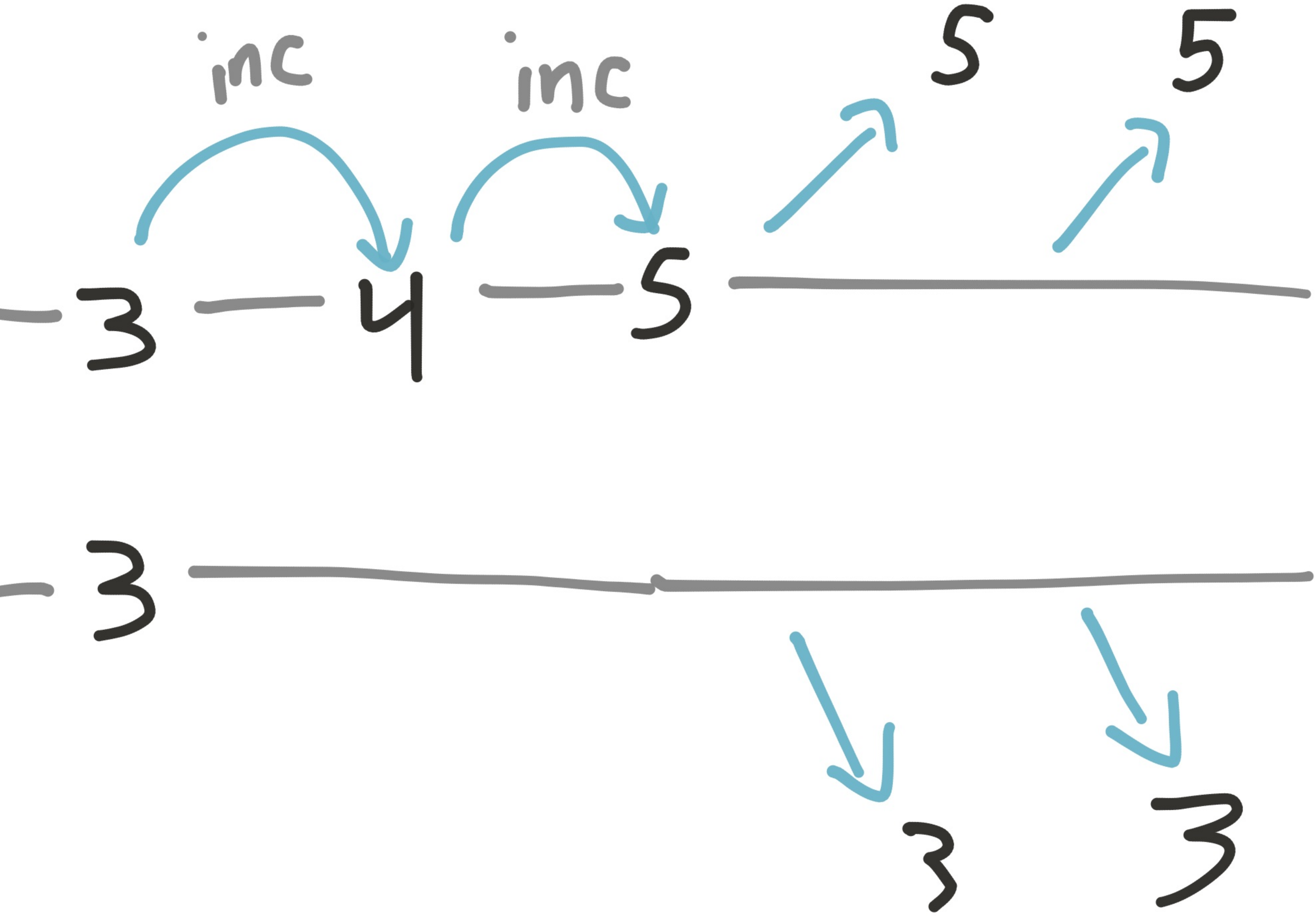
2 — 3

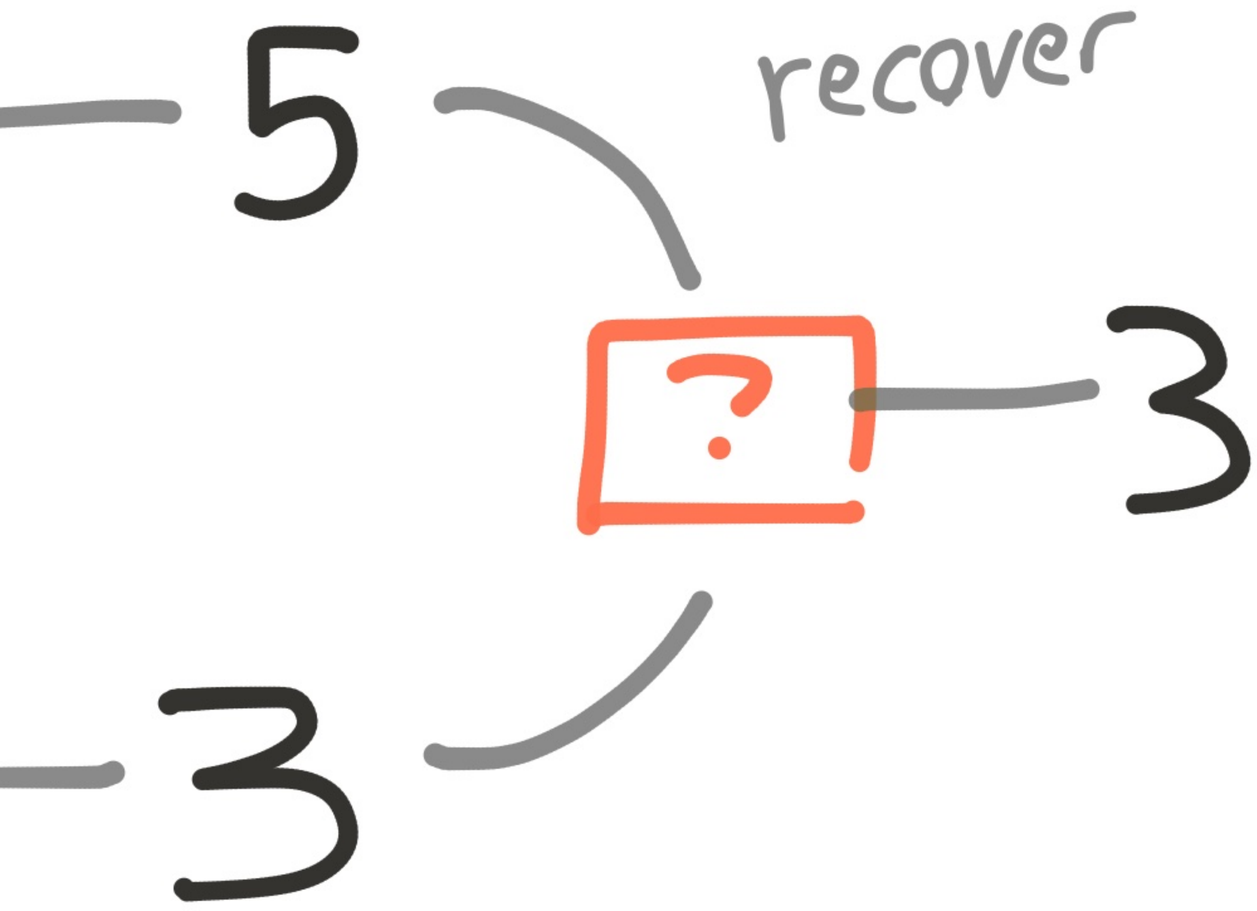
— 2

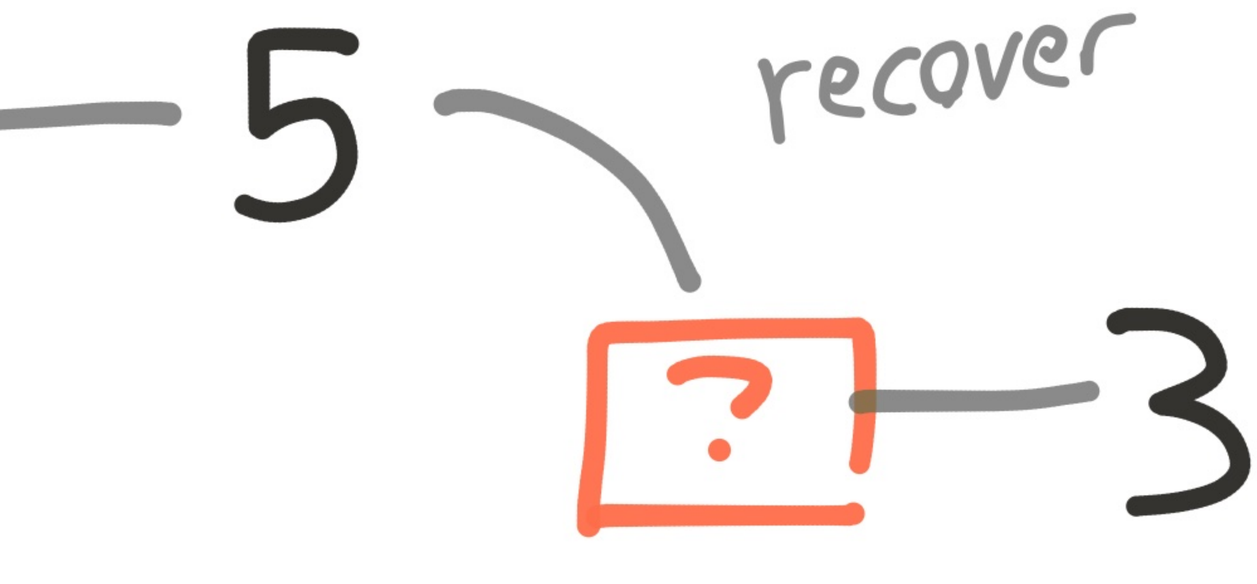
increment

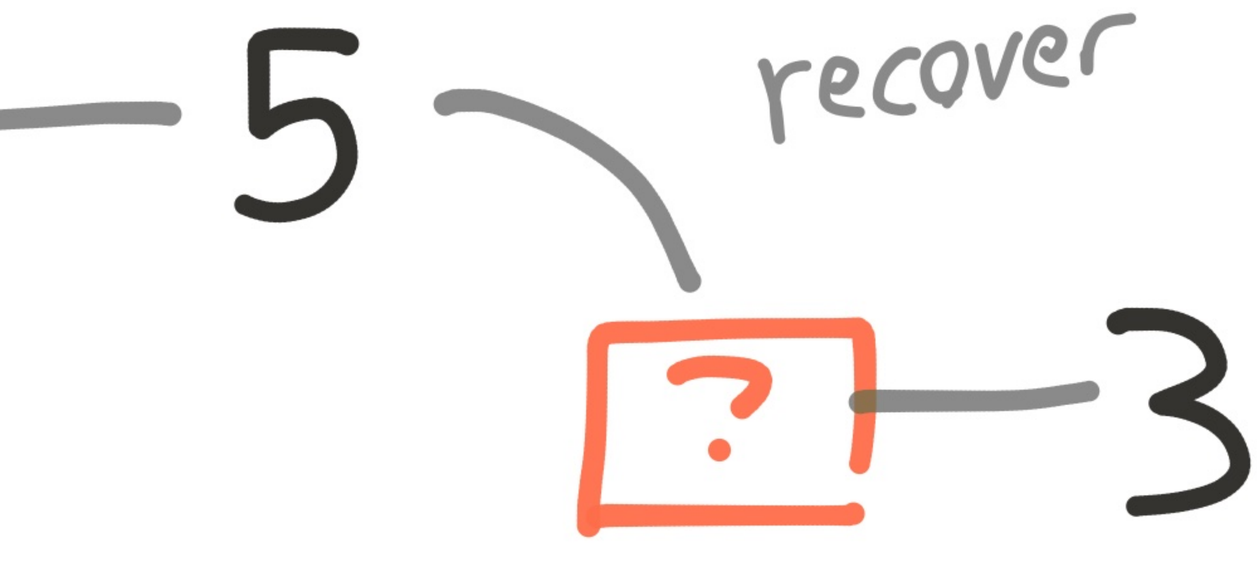
2+1=3

2 — 3


inc
inc
5
5
3
4
5
3
3


5
recover
?
3
3


5
recover
?
3
3



LOOK AT
your
LIFE

5

recover

?

3

LOOK AT
—your—
LIFE

3

LOOK at yan
CHOICES

ID Generator

- Same deal

~91,000 dup ids in 30s

834,000 generated

Maps

- putIfAbsent(k, v)
- replace(k, v, v')

Lost updates!

Even with quorum protection

However...

w/ custom merge function, can build safe CRDTs

Recommendations

- Choose replication algo appropriate for datatype
- Flake IDs, PN-Counters, Paxos

- Don't rely on Hz for safety!
  - BagriDB txn IDs
  - OrientDB cluster state (used to be txns!)

DISTRIBUTED

LOCKS

aren't

REAL

Distributed, sharded

{ Document }

store

3.5.4:

- Trivial split-brain
- Lost updates
- Stale & Dirty reads

2 Years of fundamental redesign work...

4.0: Linearizable Mode

- Custom Consensus protocol

- Reduced loss in AP mode

start of test

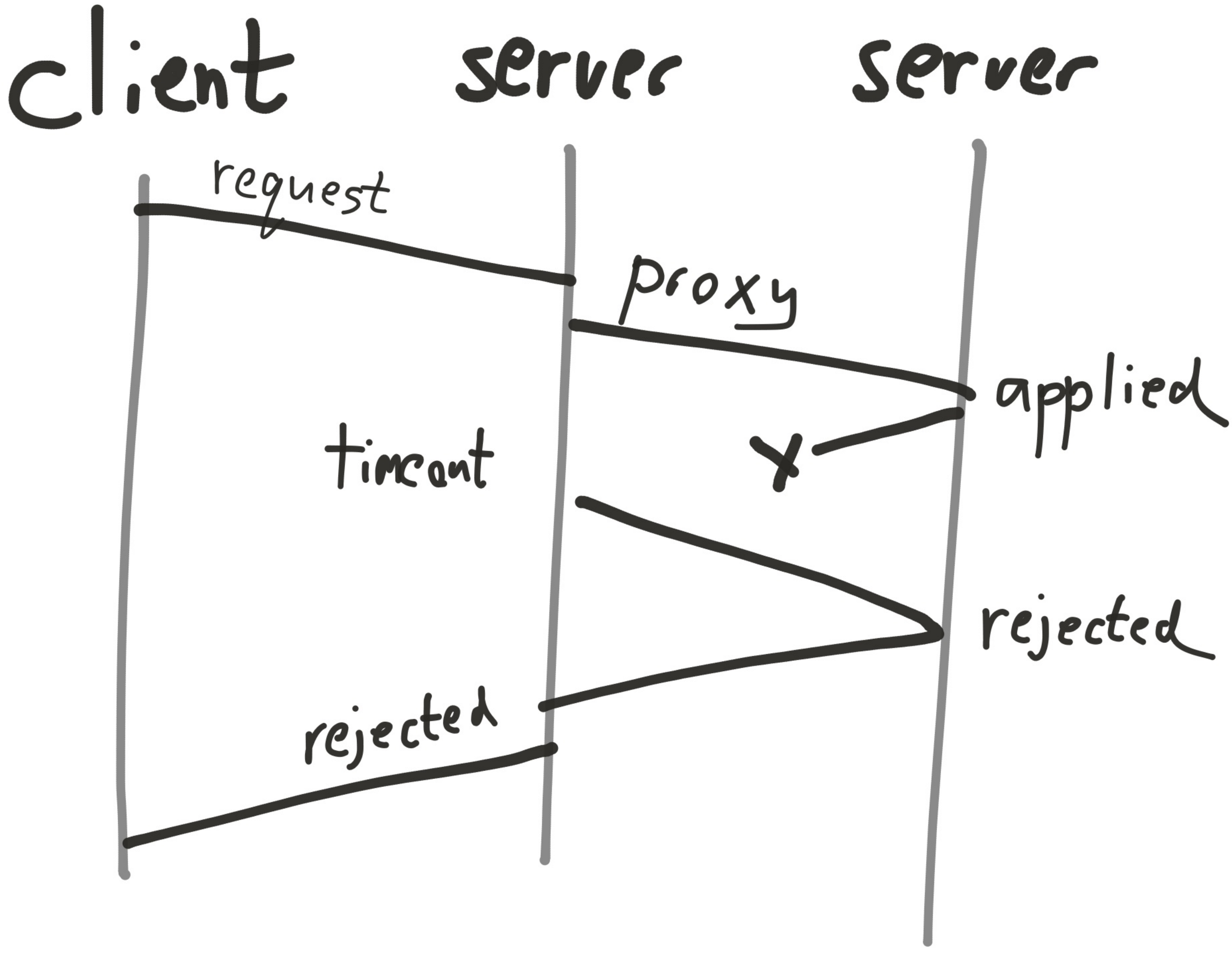
read 2

fail

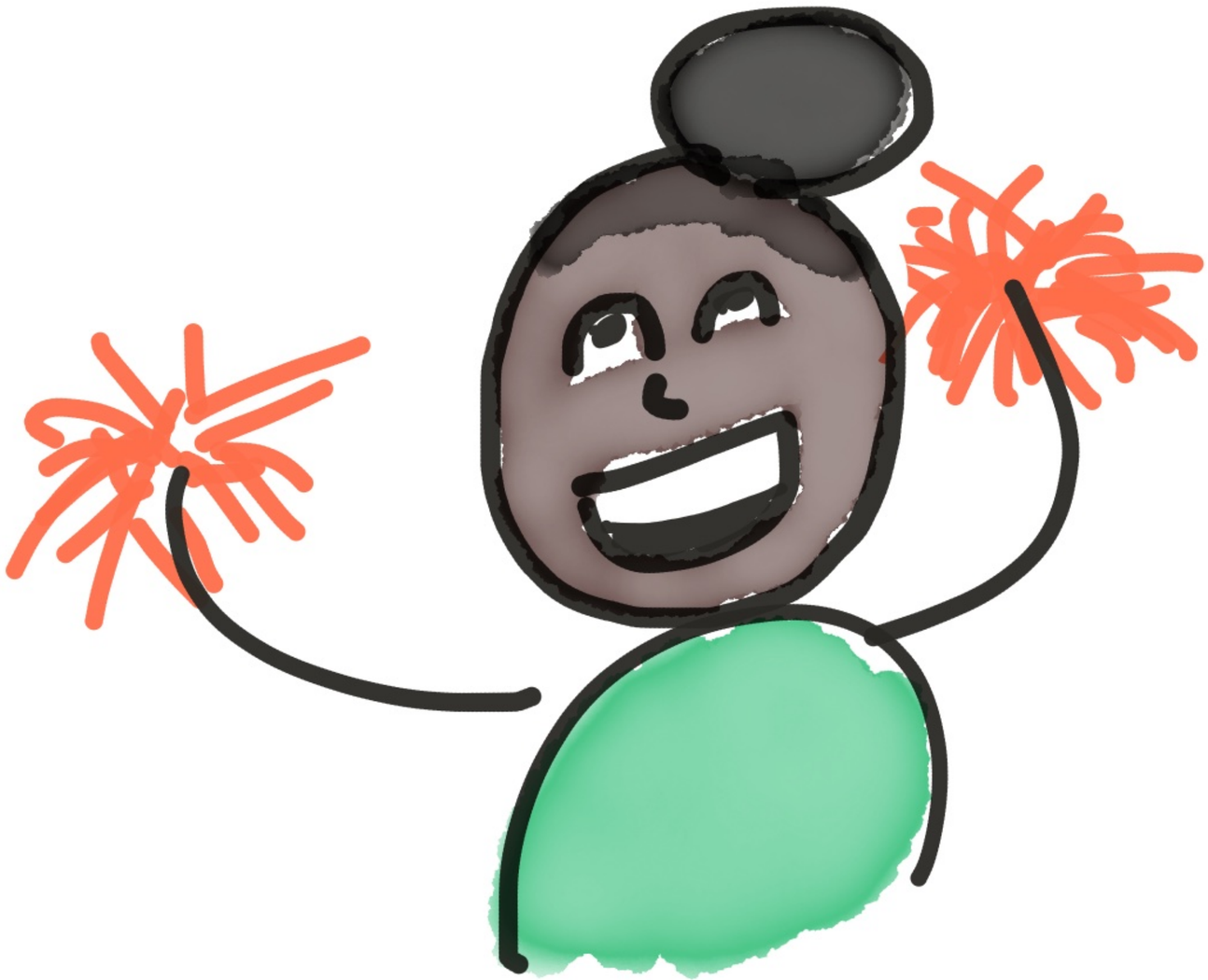
write 2

ok

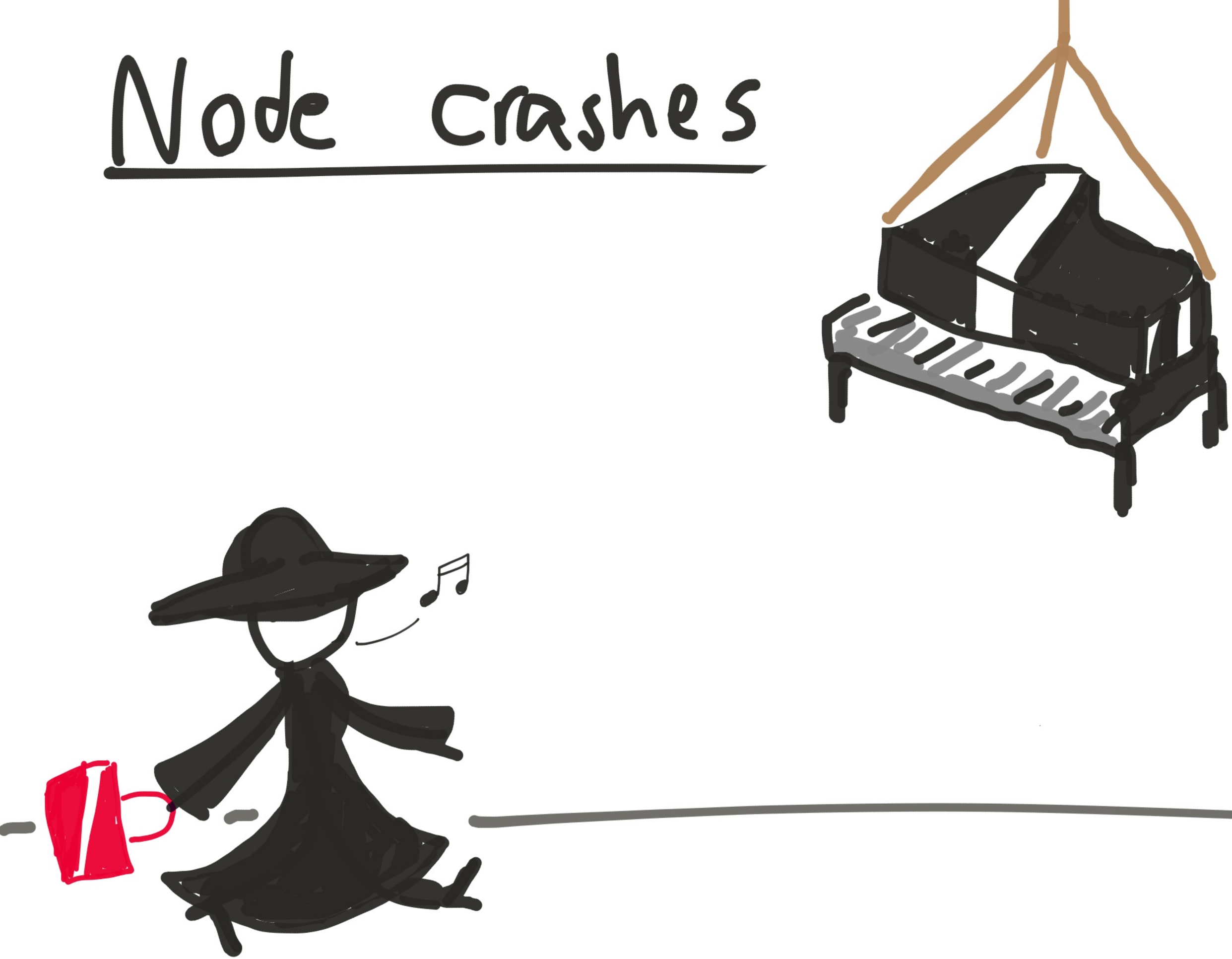
read 2

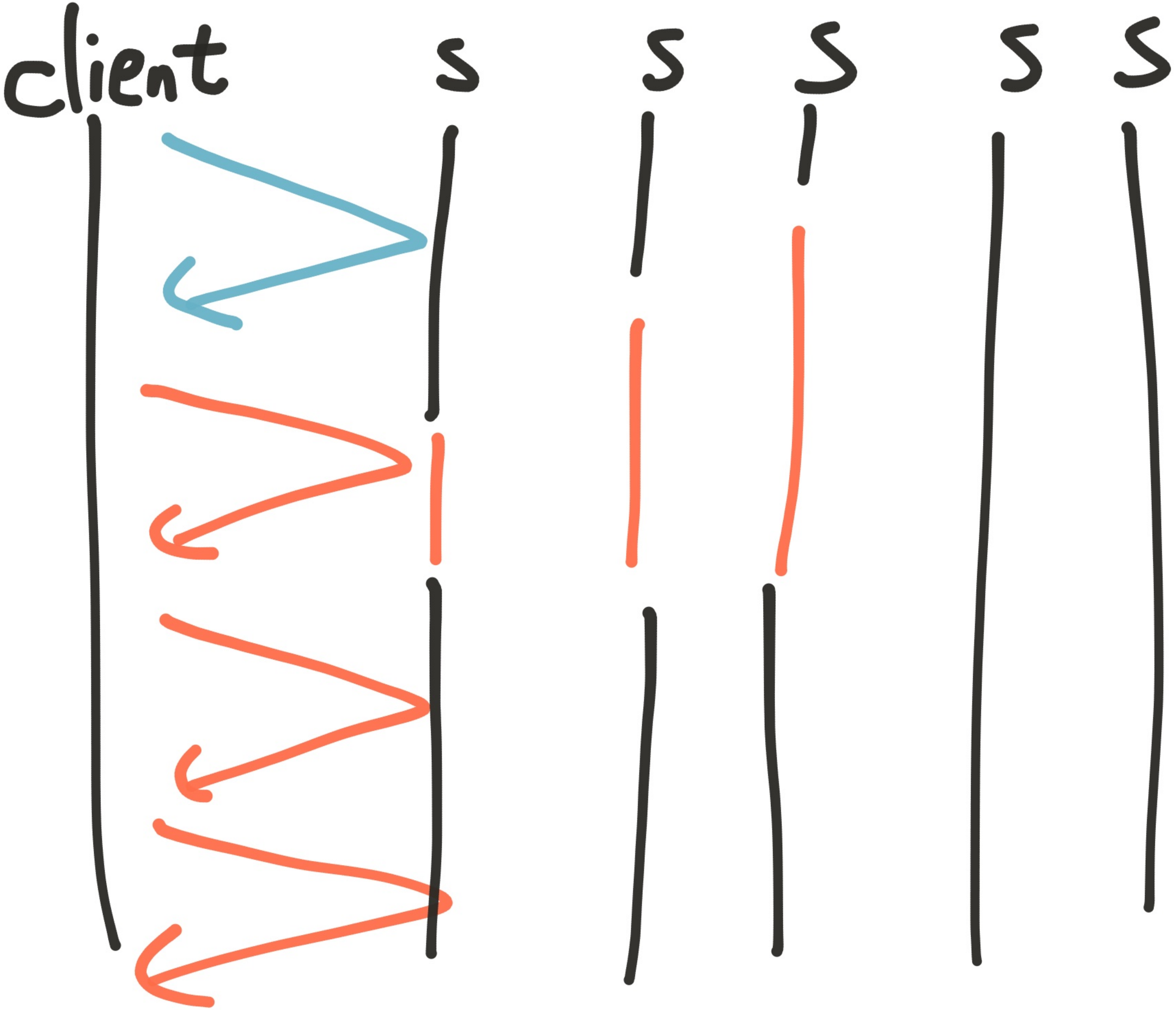

client
server
server
request
proxy
applied
timeout
X
rejected
rejected

fixed in 3.99.1.5



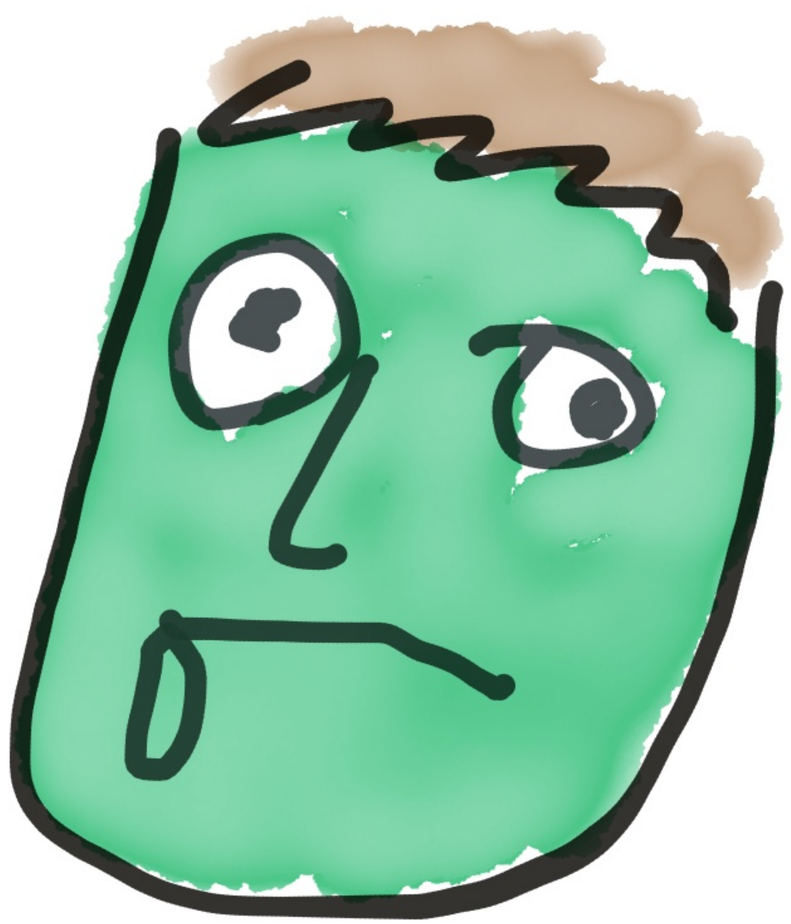
Node crashes




client
S
S
S
S
S

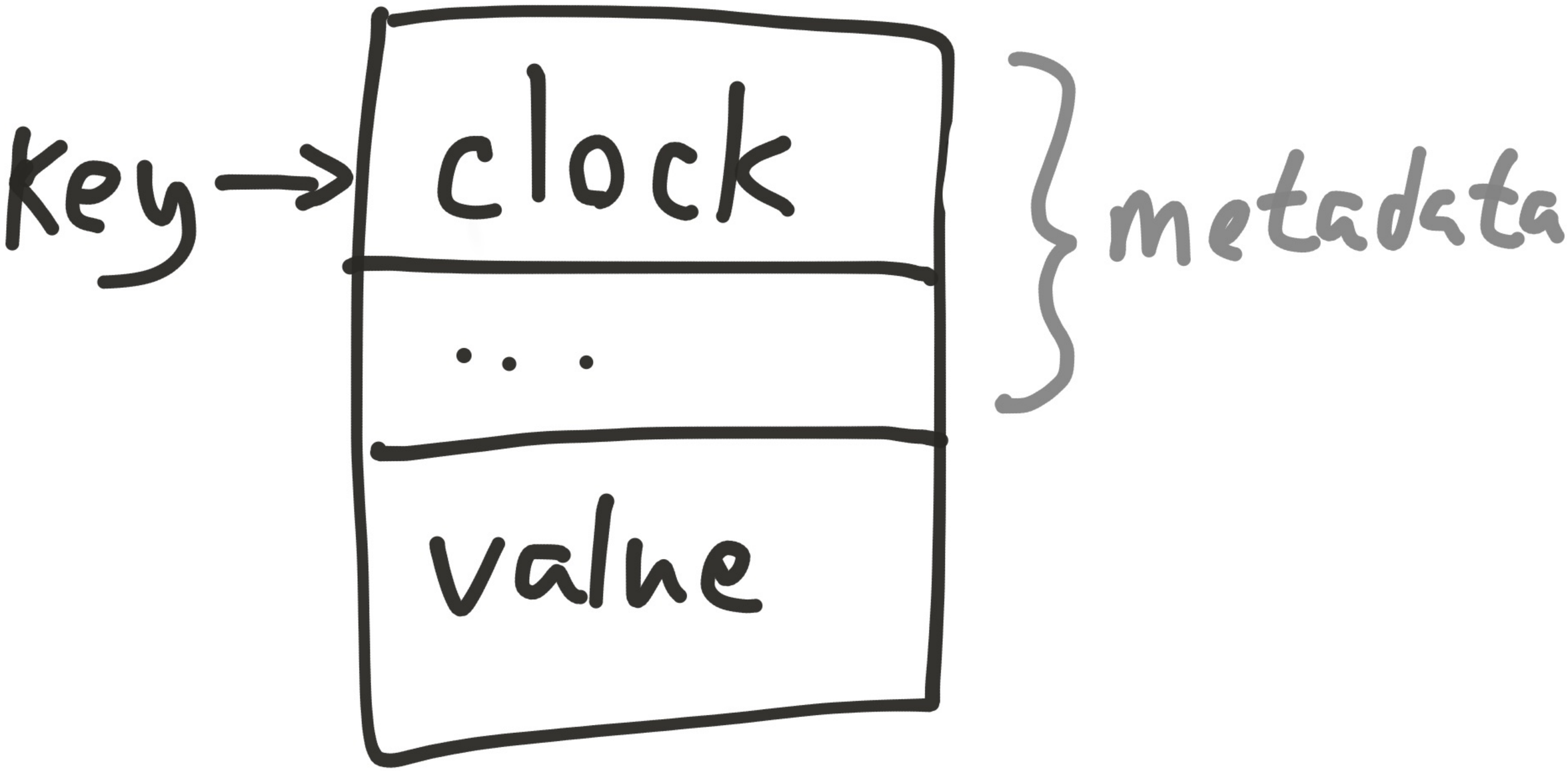
[press E to revive]

Dead partitions may not be all there...



AS didn't flush
writes to disk
before acknowledging
(fixed in 3.99.2.1)

Clock Skew can lead to Lost updates


key
clock
...
value
metadata

clock

regime	wall-clock	counter

increment on election

node local

for mult. updates in same clock

fits in cache line

regime	wall-clock	counter

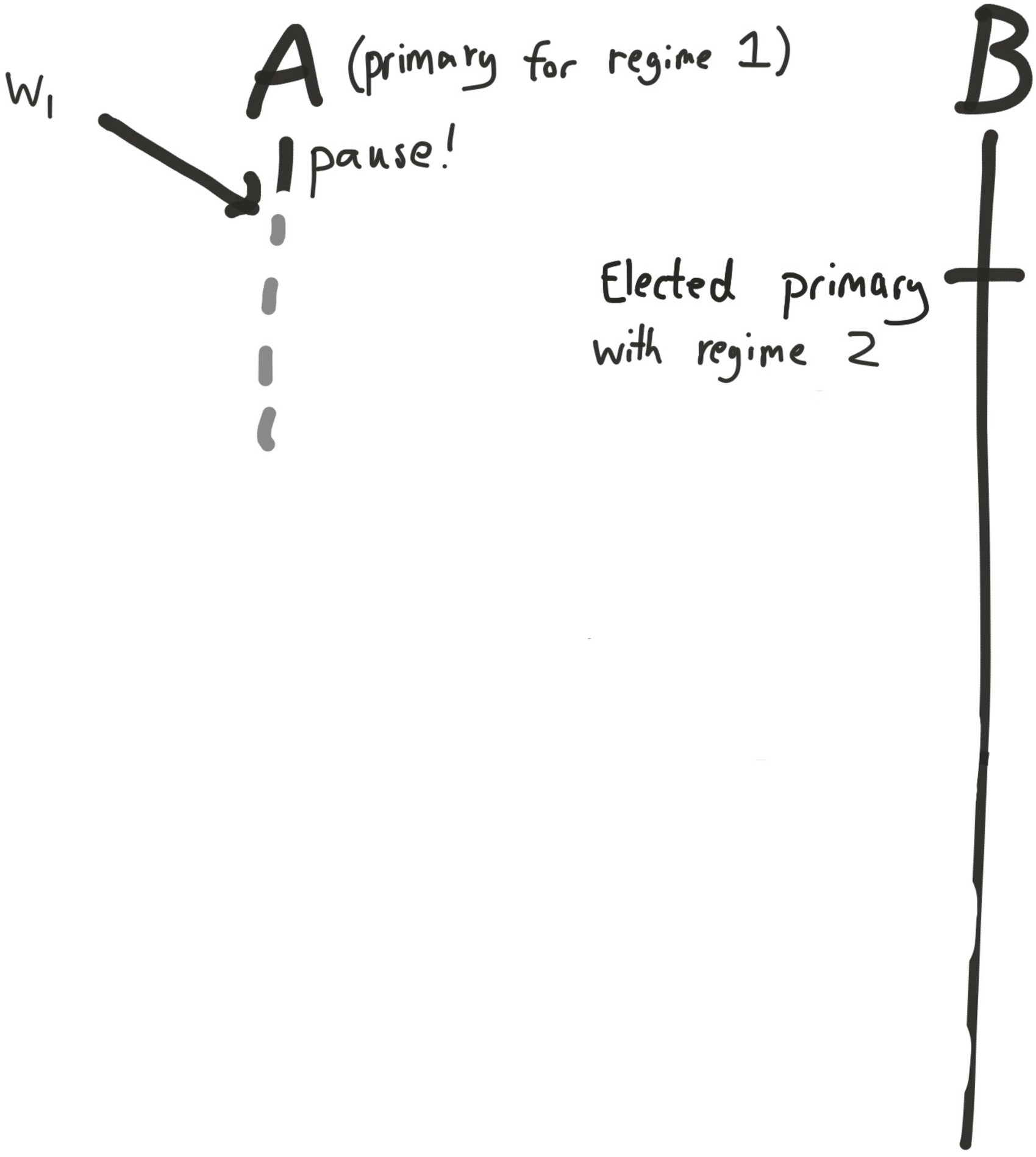
6 bits

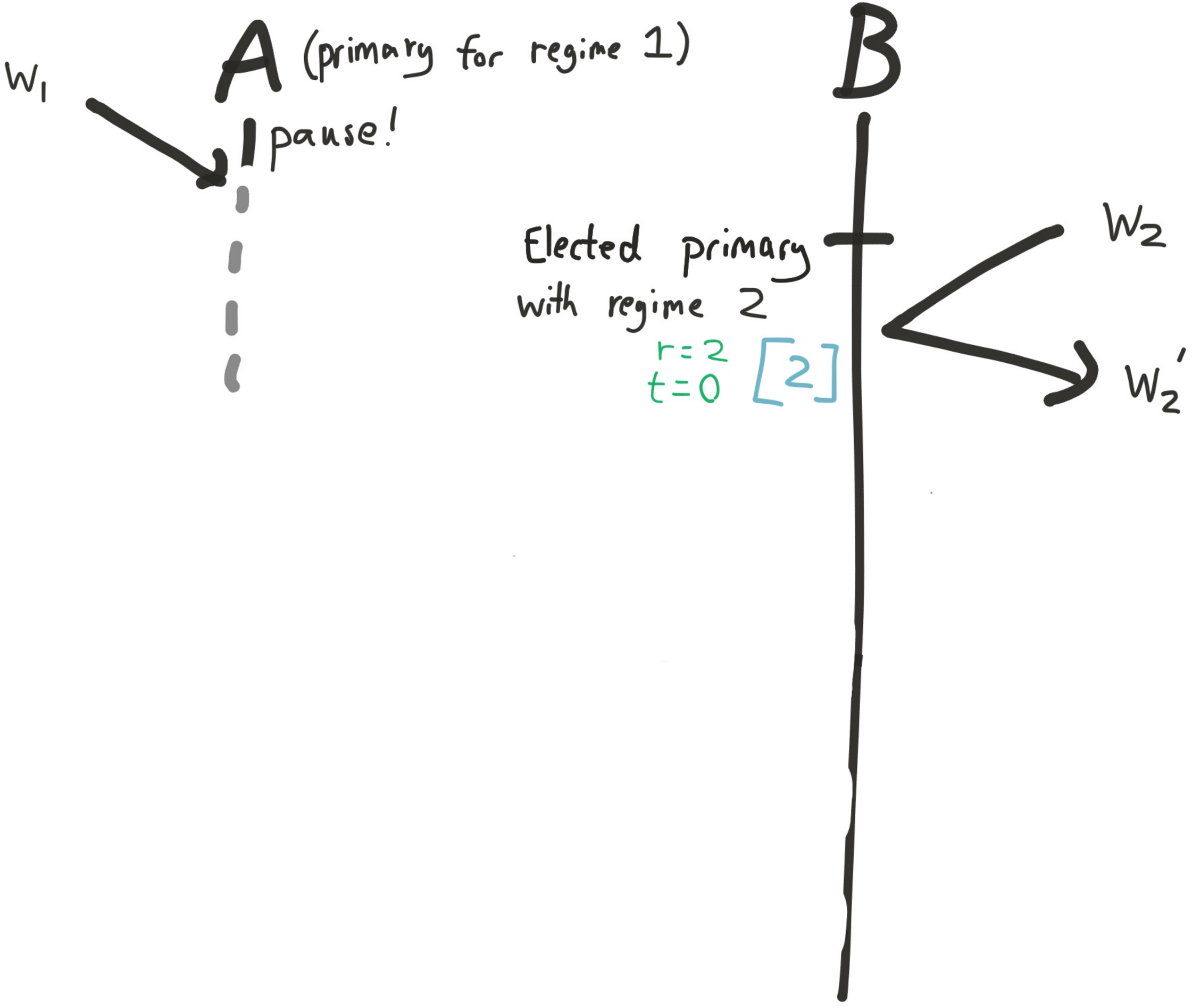
W_1

A (primary for regime 1)

pause!

B


A (primary for regime 1)
B
W_1
pause!
Elected primary
with regime 2


A (primary for regime 1)
B
W_1
pause!
Elected primary
with regime 2
r=2
t=0
[2]
W_2
W_2'

A (primary for regime 1)

B

W_1

pause!

Elected primary with regime 2

r=2
t=0 [2]

W_2

W_2'

Wake up process W_1

[1] r=1
t=27

replicate W_1

[2] r=2
t=0

A (primary for regime 1)

B

W_1

pause!

Elected primary with regime 2

r=2
t=0 [2]

W_2

W_2'

Wake up process W_1

[1] r=1
t=27

replicate W_1

[2] r=2
t=0

regime 1 < 2

W_1'

A (primary for regime 1)

B

W_1

pause!

Elected primary with regime 2

r=2
t=0 [2]

W_2

W_2'

Wake up process W_1

[1] r=1
t=27

replicate W_1

[2] r=2
t=0

regime 1 < 2

reconcile

W_1'

r=1
t=27 [1]

[1] r=1
t=27

REALLY?

Both clock skew &
not using fsync were
known failure modes

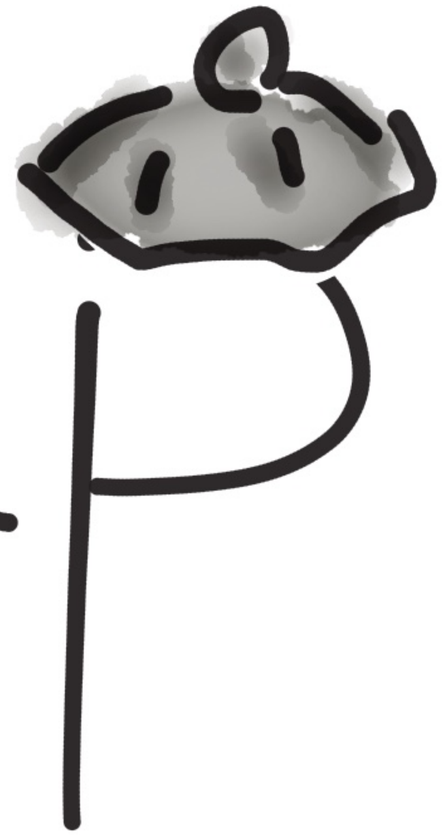
Stay in clock-skew bounds & use durable flag...

looks linearizable!

But XDR scans UDFs don't go through the SC mechanism yet

future work!

Recap



Read the docs!

CAREFULLY

Then test it

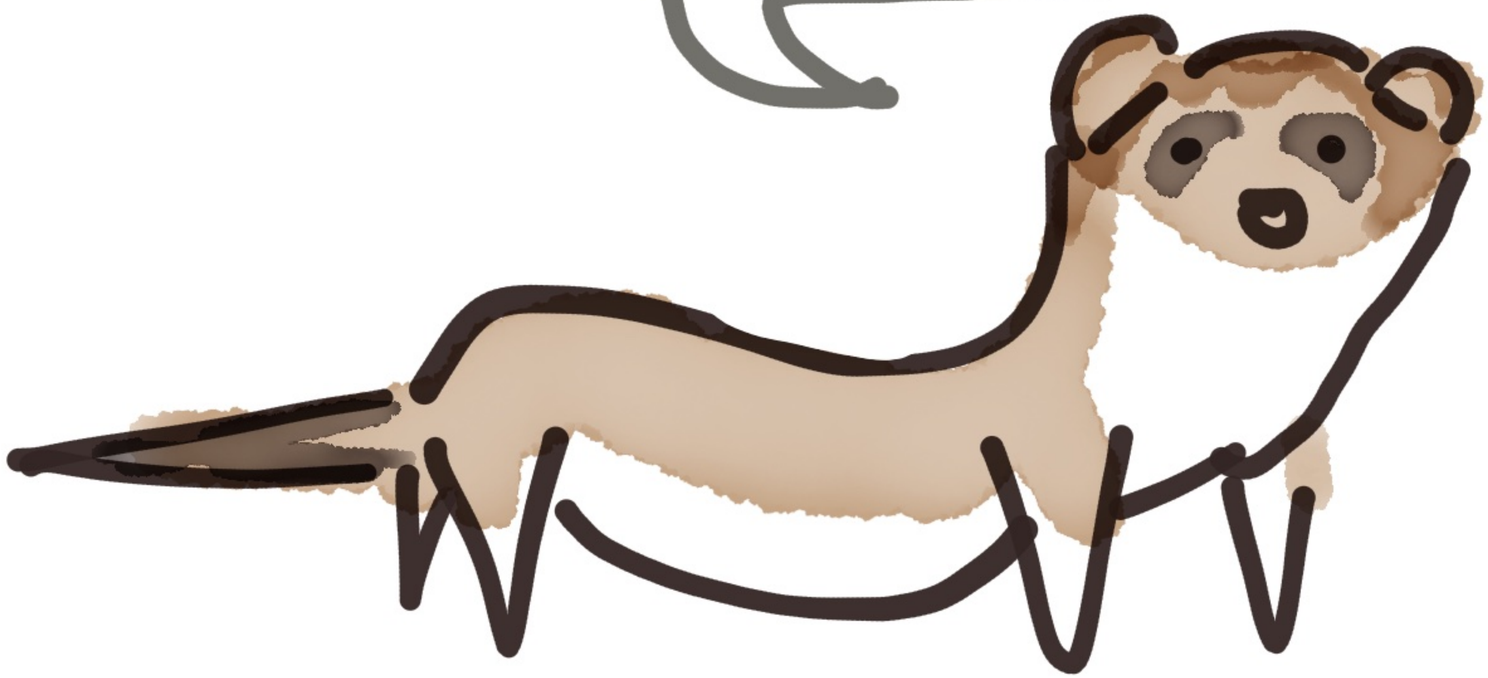
— for —

YOURSELF

"Strict"

"ACID"

"Strong"



Be Formal

&

Be Specific!

Figure out the invariants your system needs

Consider your failure modes

Process Crash

```
#kill -9 1234
```

Node failure

- AWS terminate
- Physical power switch

Clock Skew

date 10280000

faketime ...

SC/IO Pause

```
# killall -s STOP foo
# killall -s CONT foo
```

Network Partition

```
# iptables -j DROP
```

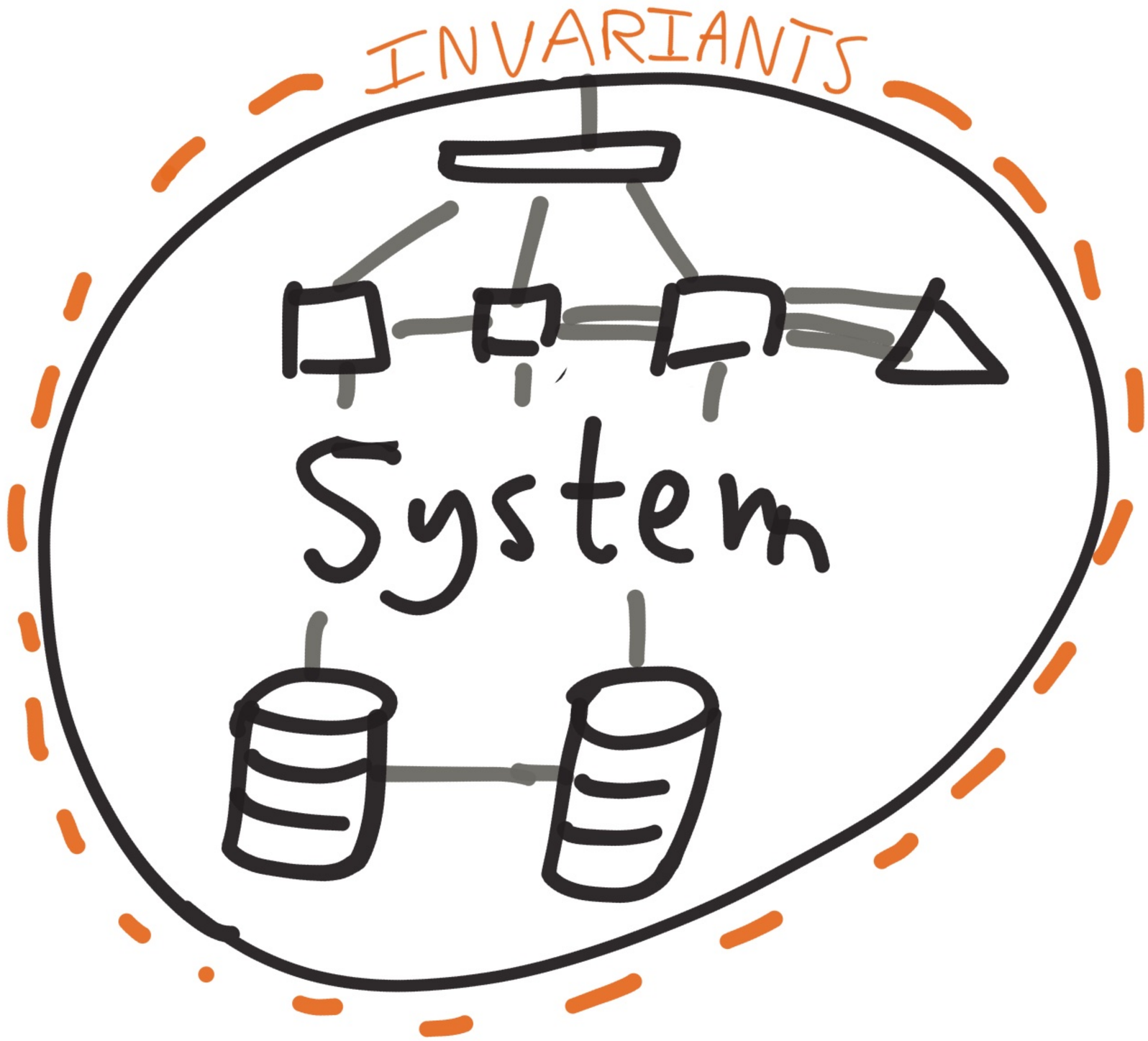
```
# tc qdisc ... delay ...
                drop ...
```

Test your

Systems

end ——— to ——→ end

vs.



If you look for

perfection

you will never be

content

- Property testing
- High-level invariants
- With distsys failure modes

Thanks

Tendermint

Hazelcast

Jordan Halterman

Luigi Dell'Aquila

Luca Gamlli

Thanks

Denis Sukhoreslov

Aerospike

Peter Alvaro

http://jepsen.io