Chain Replication for Supporting High Throughput and Availability

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Abstract

“Chain replication is a new approach to coordinating clusters of fail-stop storage servers. The approach is intended for supporting large-scale storage services that exhibit high throughput and availability without sacrificing strong consistency guarantees.”

Abstract

- A Storage Service Interface
- Chain Replication
- Comparison to Primary/Backup
- Simulation Experiments
- Concluding Remarks

A Storage Service Interface

A Storage Service Interface

- persistent map from objId to value
- query(objId) -> value
  - retrieve current value of objId
- update(objId, newVal) -> value
  - update value of objId
  - value := f(oldVal, newVal)
  - not necessarily just PUT (ie CAS, ...)
  - but no cross-object transactions

A Storage Service Interface

State:

- Hist[objId]
  - History of all updates to objId
  - query(objId) = f(Hist[objId])
- Pending[objId]
  - Set of pending requests for objId

A Storage Service Interface

Transitions:

- T1: Client request ‘r’ arrives
  - Pending[objId] += r
- T2: Client request ‘r’ ignored
  - Pending[objId] -= r
- T3: Client request processed
  - Pending[objId] -= r
  - if (update) Hist[objId] += r

A Storage Service Interface

Desirable Properties:

- High Availability
- High Throughput
- Strong Consistency
  - Operations are linearizable
  - Read-your-own-writes

Chain Replication

Chain Replication

Assumptions:

- Servers are fail-stop
  - More or less reasonable
  - (minus bugs, attackers, magnets, etc)
- Failures can be detected
  - Trickier than it sounds

Chain Replication

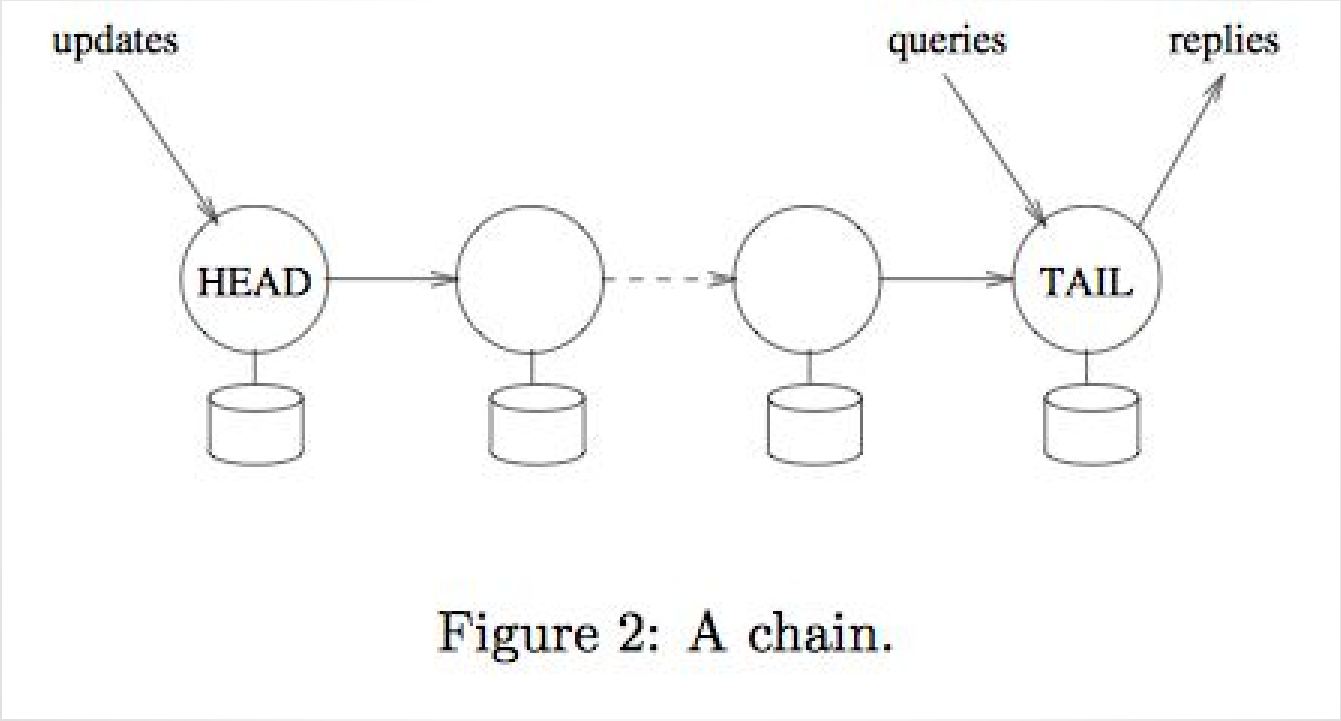


Figure 2: A chain.

Chain Replication

Node State:

- Hist[i] = list of updates processed by node ‘i’
- Sent[i] = updates seen by ‘i’ but not ACKed

System state:

- Pending = requests seen by any node but not yet processed by TAIL
- Hist = Hist[TAIL]

Chain Replication

Invariants:

- Hist[i] >= Hist[i+1]
  - (Update Invariant)
- Hist[i] = Hist[i+1] + Sent[i]
  - (In-process Requests Invariant)

Chain Replication

The Happy Case

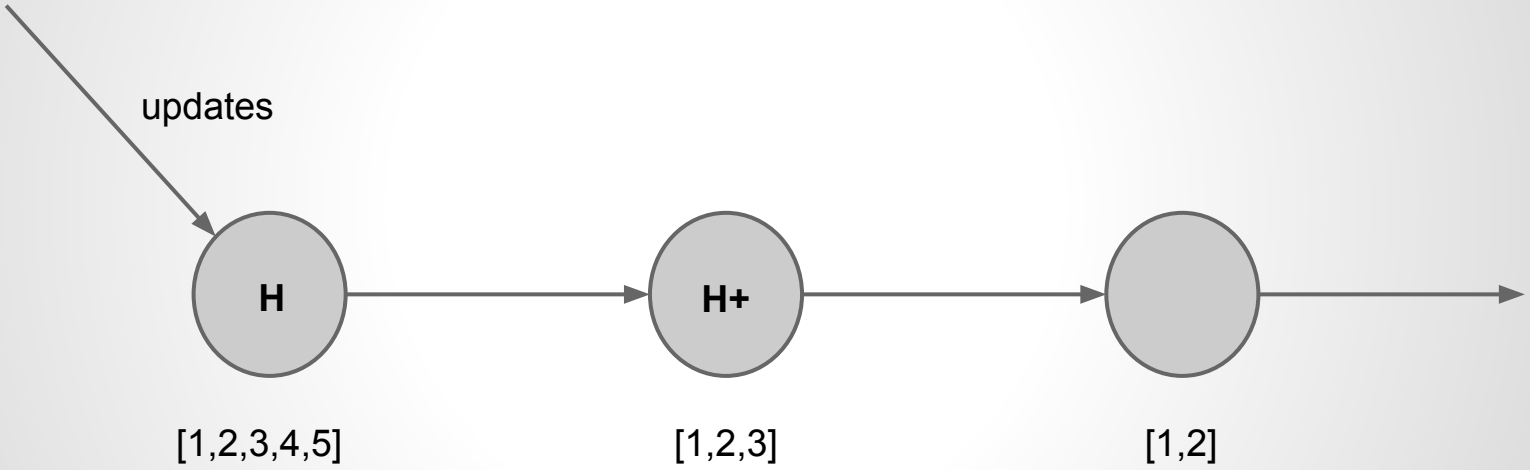
- HEAD/TAIL receive a request
  - Added to Pending (T1)
- Query processed by TAIL
  - Removed from Pending (T3a)
- Update processed by TAIL
  - Removed from Pending, added to Hist (T3b)

Chain Replication

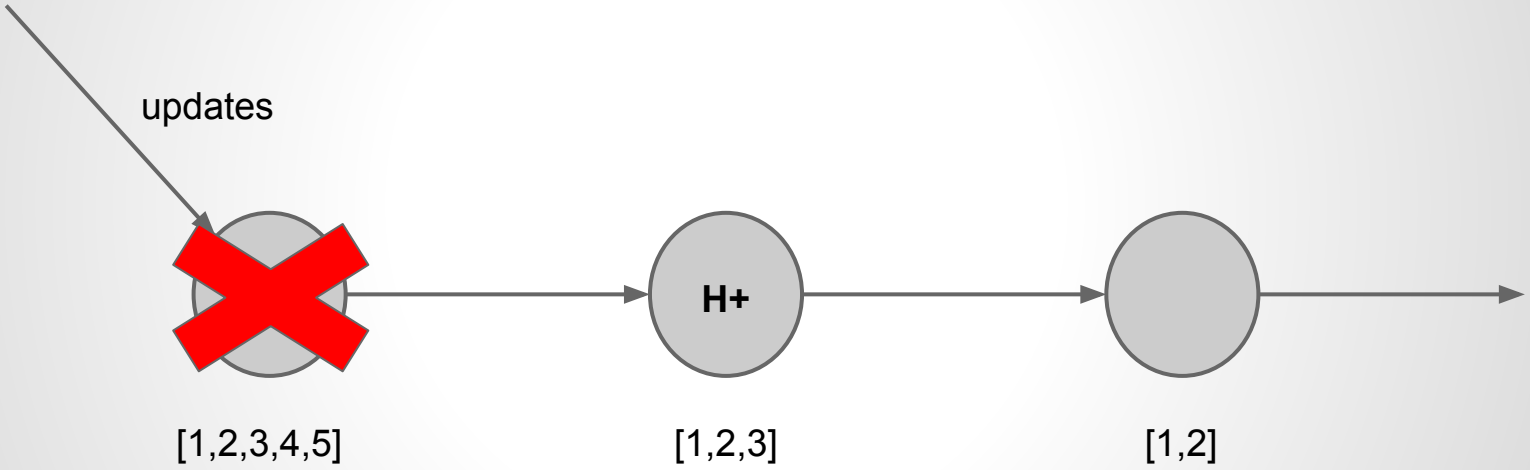
Dealing with Failure

- “Single” master
  - AKA Zookeeper
- Detects failed nodes
- Reconfigures the chain
- Points clients to HEAD and TAIL

Chain Replication - Failure of HEAD

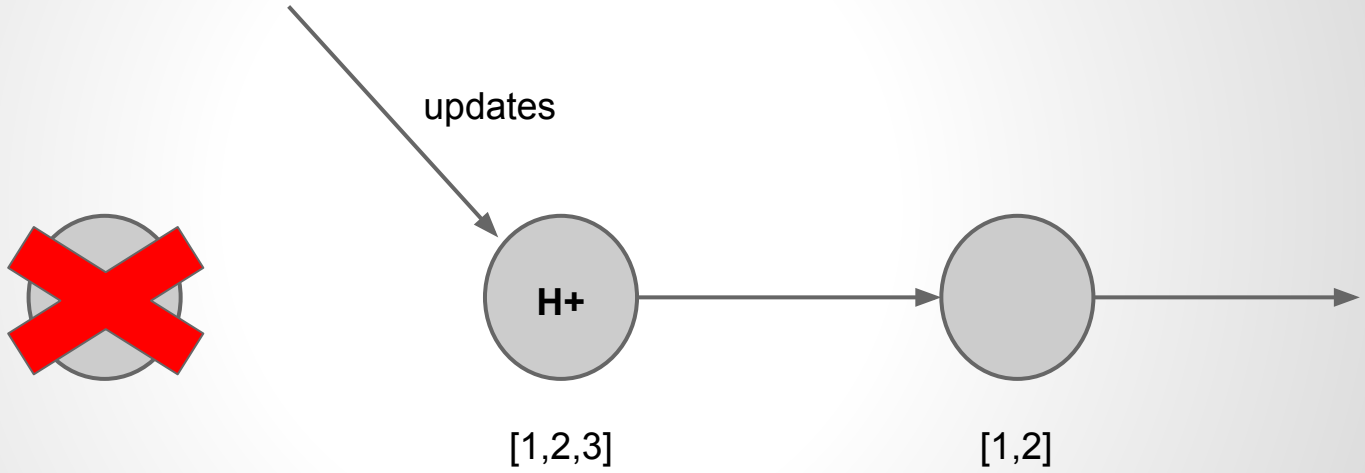


Chain Replication - Failure of HEAD



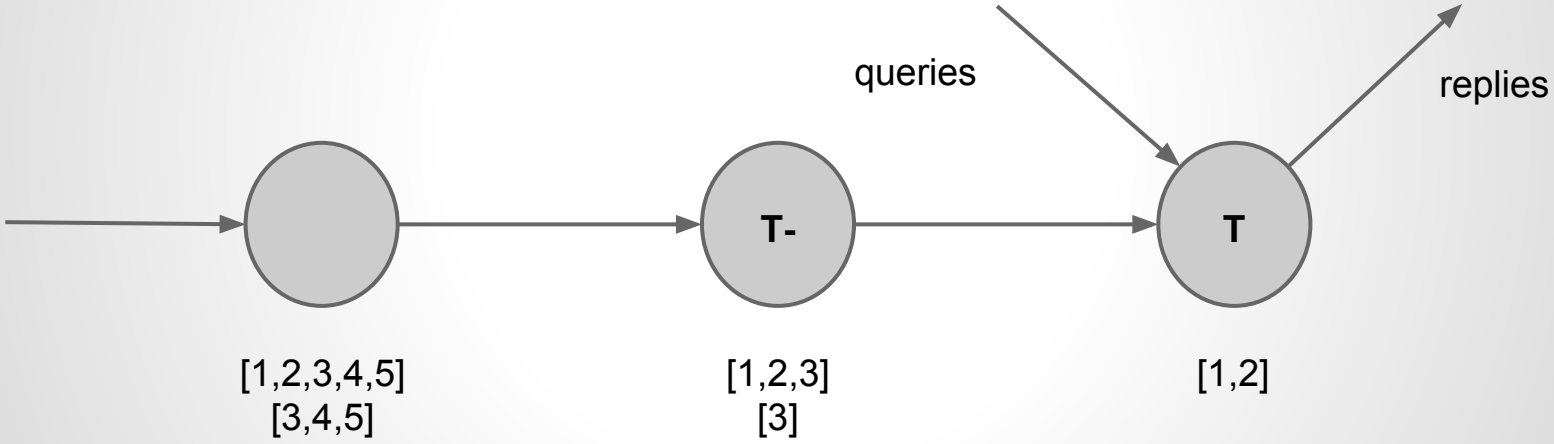
Master detects that H is dead, removes it from the chain

Chain Replication - Failure of HEAD

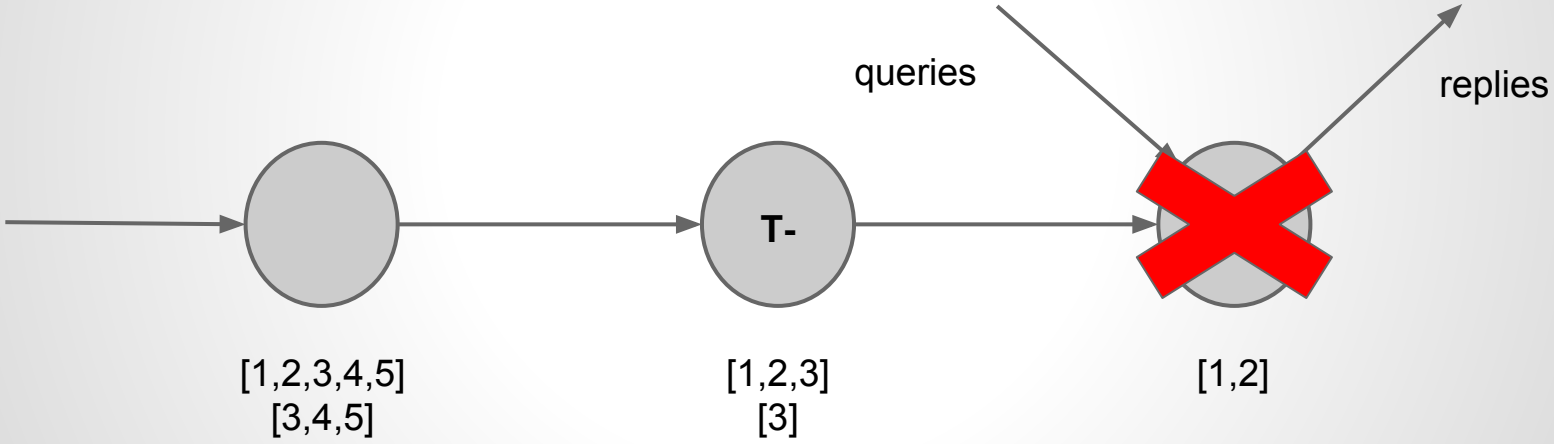


4 and 5 are lost - this is just (T2)

Chain Replication - Failure of TAIL

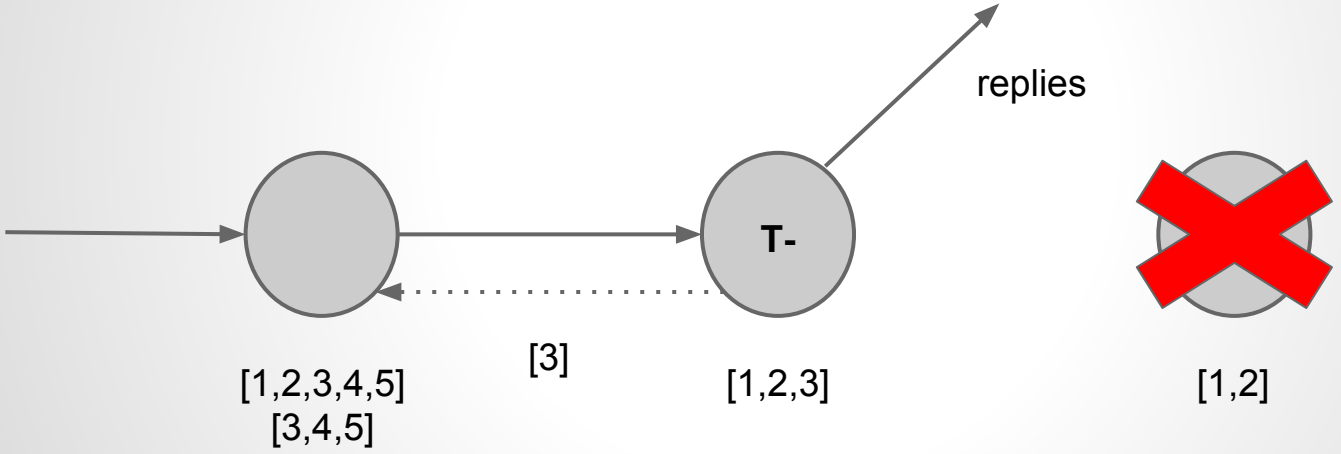


Chain Replication - Failure of TAIL



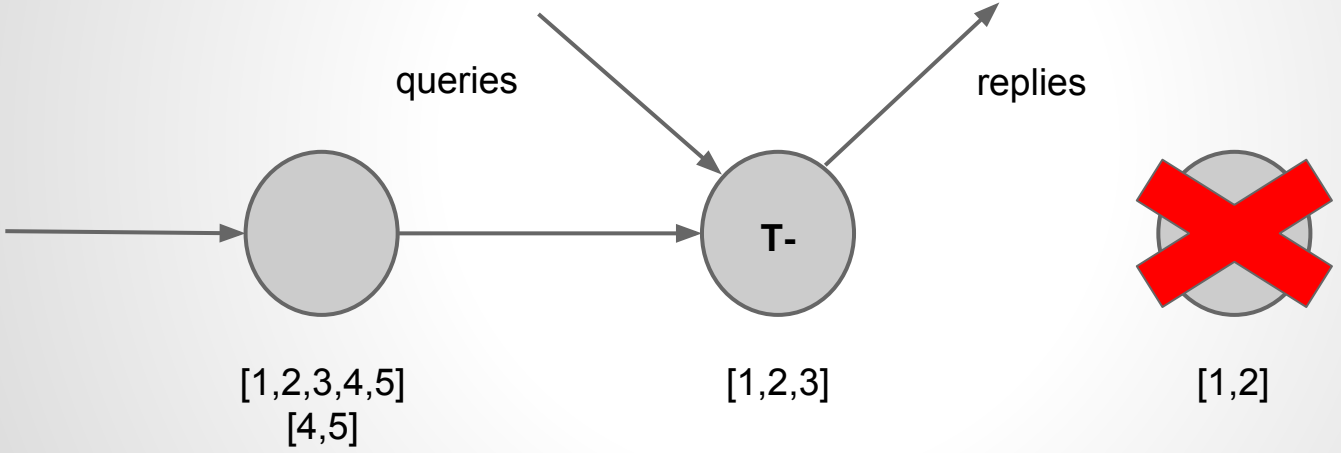
Master detects that T is dead, removes it from the chain

Chain Replication - Failure of TAIL



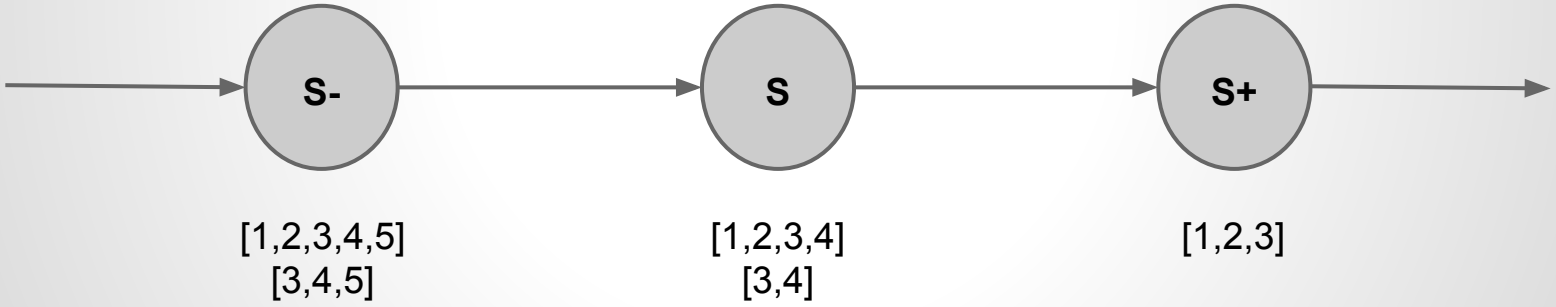
3 has now been processed by a tail - this is just (T3b)

Chain Replication - Failure of TAIL

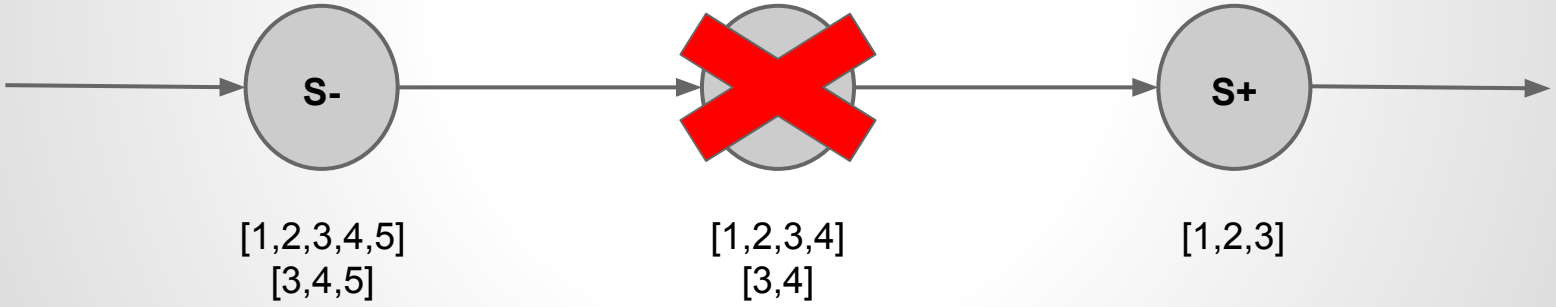


Queries now go to T-

Chain Replication - Failure of Interior

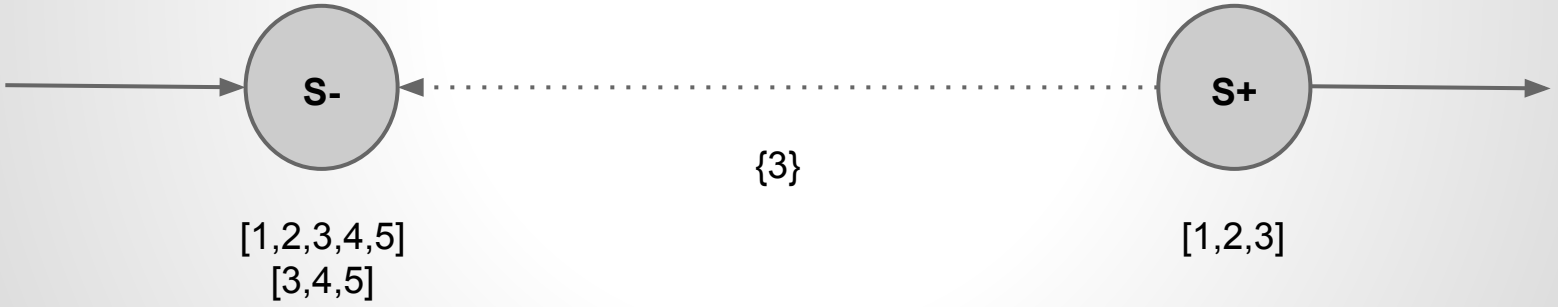


Chain Replication - Failure of Interior



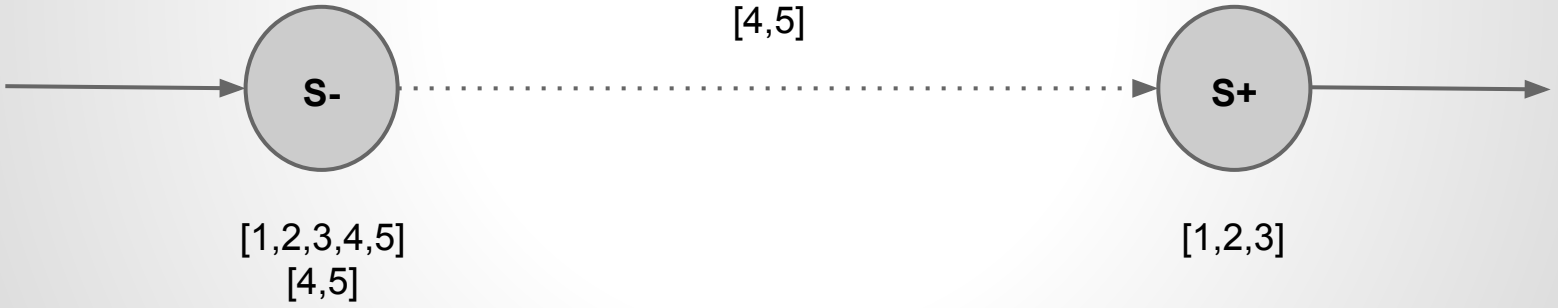
Master detects that S is dead

Chain Replication - Failure of Interior



Master asks S+ for its largest seqId, tells it to S-

Chain Replication - Failure of Interior

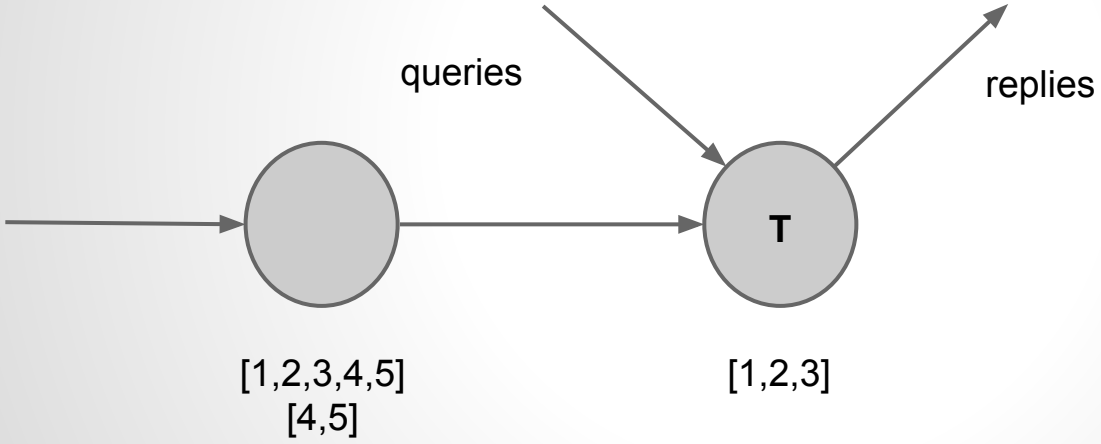


S- forwards missing updates to S+

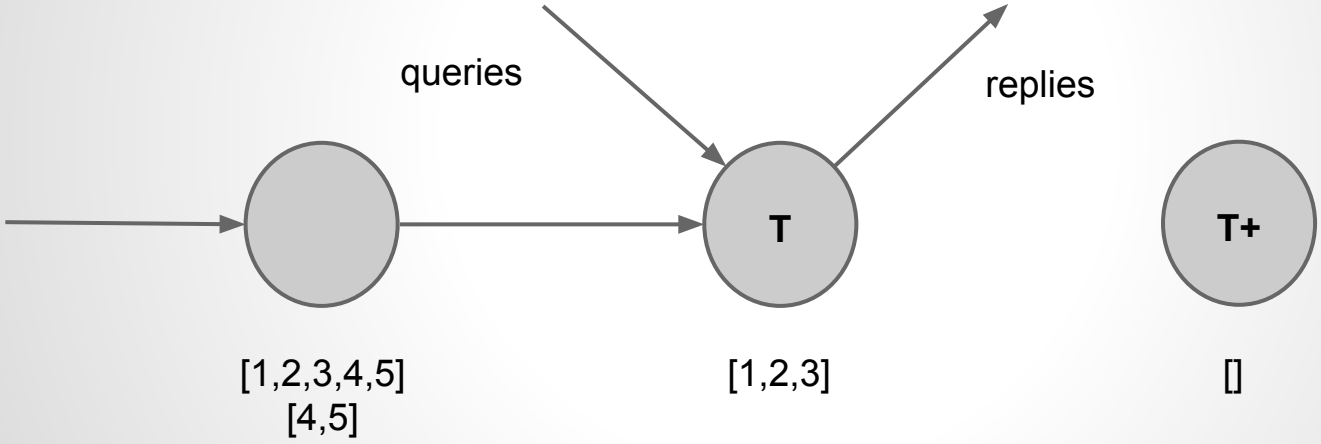
Chain Replication - Failure of Interior

Then continues forwarding additional updates in order

Chain Replication - Extending

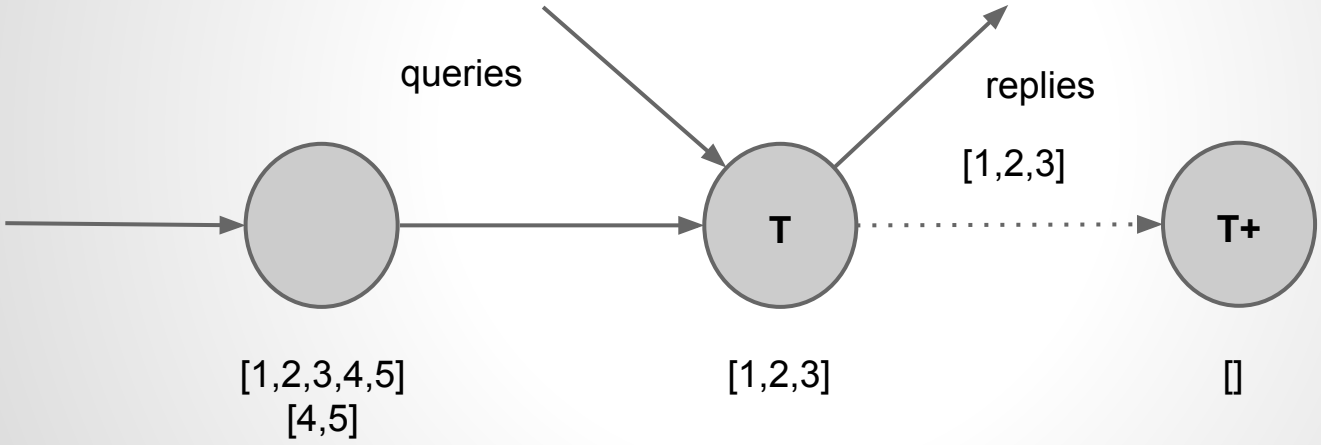


Chain Replication - Extending



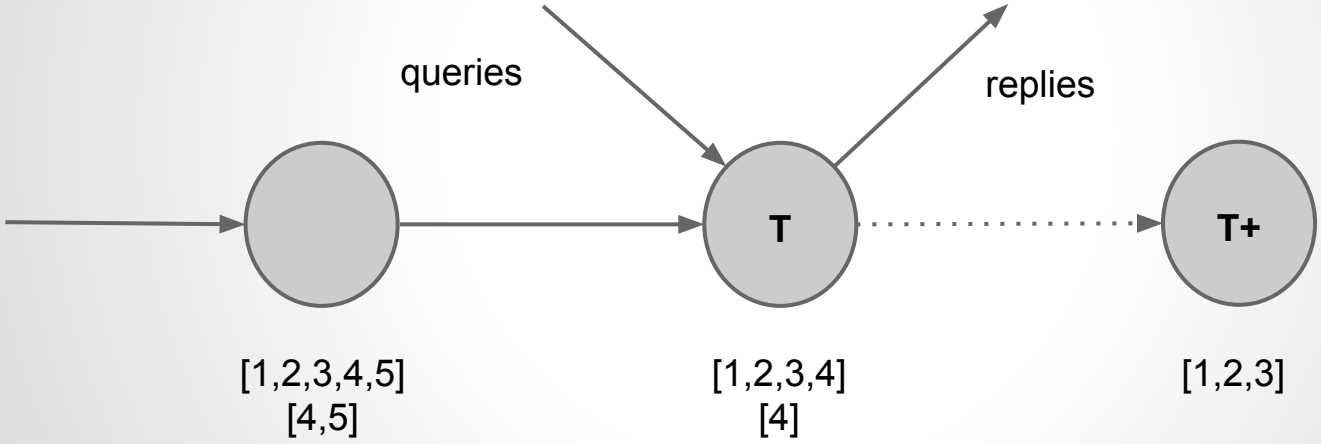
New node added at T+, state initially empty

Chain Replication - Extending



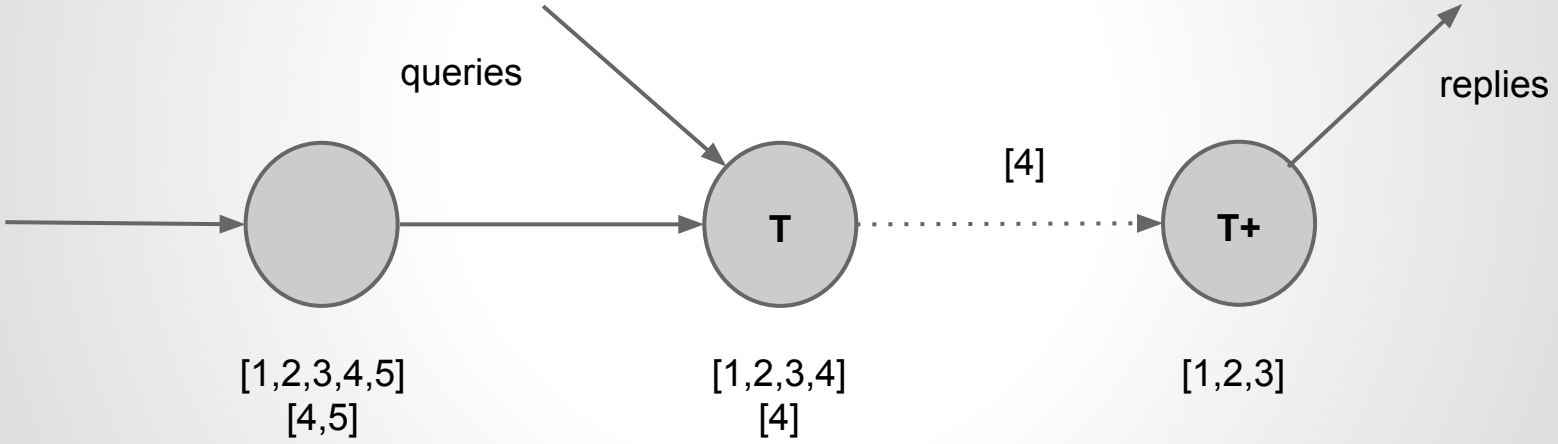
T forwards Hist to T+, starts tracking Sent[T]

Chain Replication - Extending



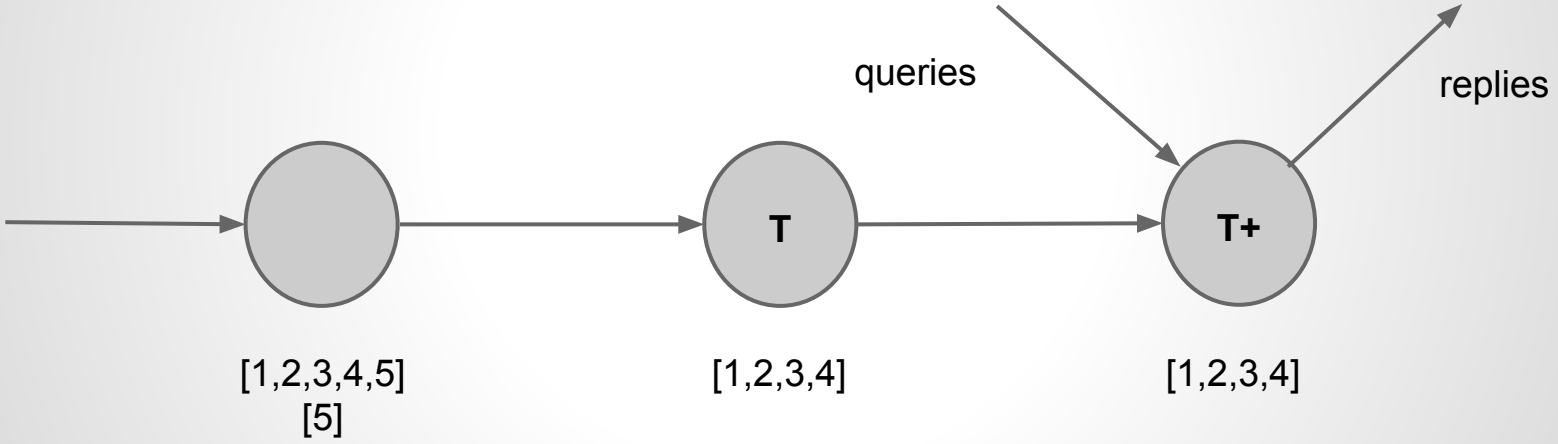
Once done, In-process Updates Invariant holds

Chain Replication - Extending



T stops acting as tail, forwards Sent[T] to T+

Chain Replication - Extending

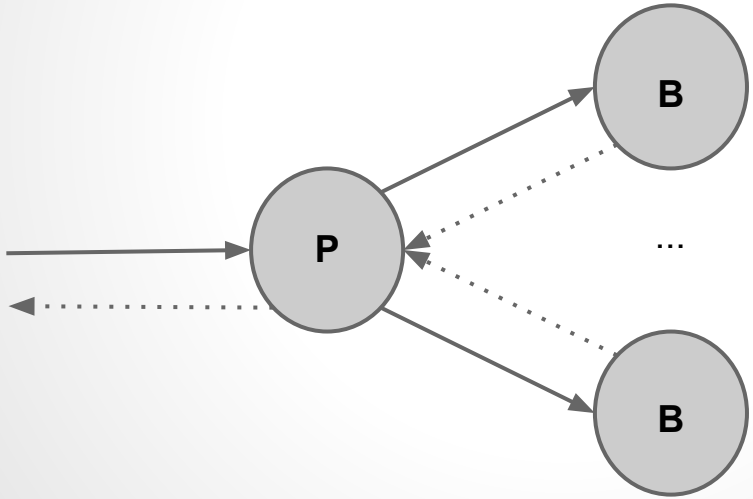


Once T+ has all of Hist, it's the new TAIL

Comparison to Primary/Backup

Comparison to Primary/Backup

Primary/Backup:



Comparison to Primary/Backup

- CR splits P’s work between HEAD and TAIL
  - HEAD sequences/applies updates
  - TAIL interleaves queries
  - -> better overall throughput
- CR distributes updates serially
  - -> better throughput
  - -> higher latency

Comparison to Primary/Backup

Failure Recovery: CR

- Head failure
  - Updates unavailable for 2x message time
- Middle failure
  - Updates delayed for 4x message time
- Tail failure
  - Query unavailable for 2x message time
  - (updates delayed in the meantime)

Comparison to Primary/Backup

Failure Recovery: P/B

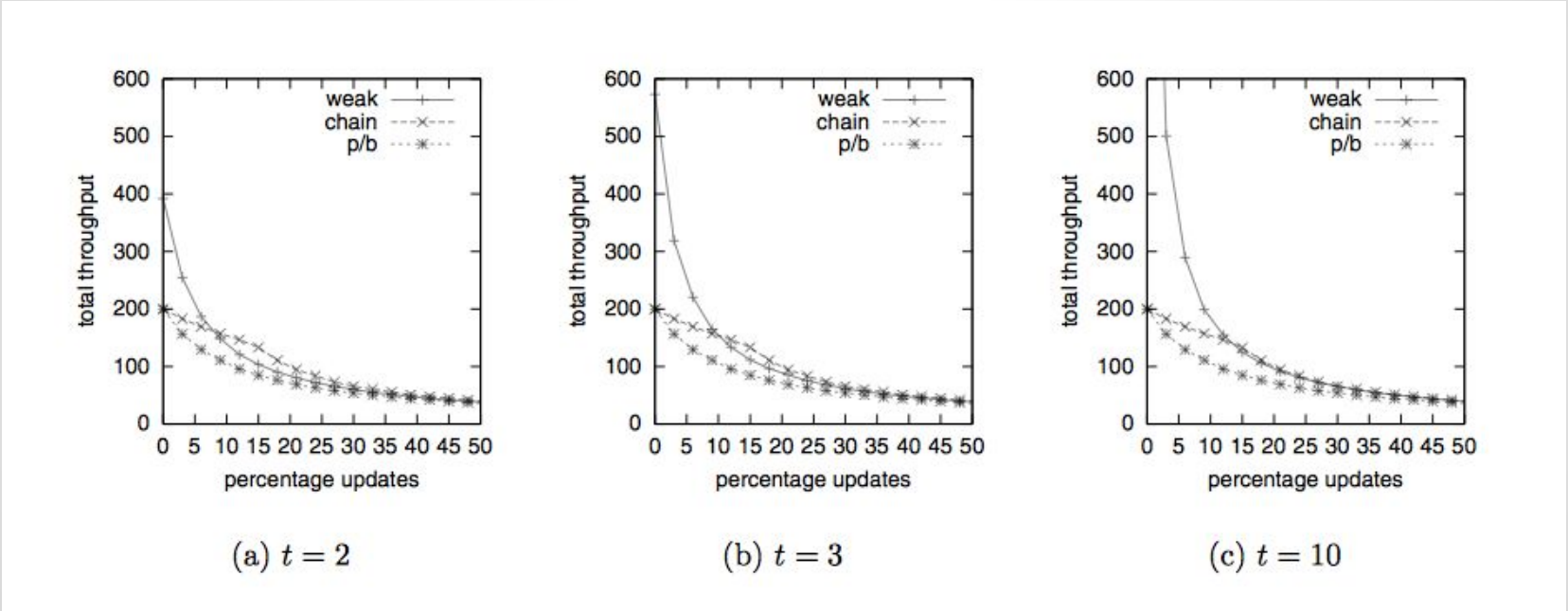
- Primary failure
  - Everything down for 5x message time
- Backup failure
  - Updates down for 1x message time
  - Queries for ‘dirty’ rows down 1x message time
  - Queries for ‘clean’ rows unaffected

Simulation Experiments

Simulation Experiments

- Infinite bandwidth
- Message latency = 1ms
- Query latency = 5ms
- Update latency = 50ms
- Applying a pre-calculated update = 20ms
- 25 clients, 1 concurrent request per client

Simulation Experiments



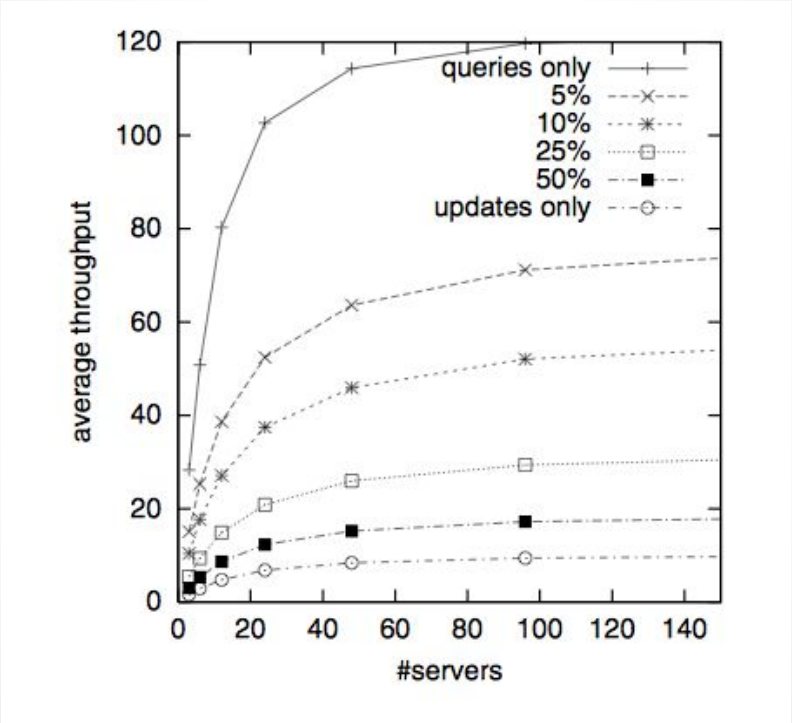
Single chain, no failures: better throughput than P/B

Simulation Experiments

Multiple chains:

- Each chain manages a subset of objects
- Consistent hashing from objId to chain
- Servers may participate in multiple chains
- 5000 chains, each with 3 servers
- Same 25-client load, randomly distributed

Simulation Experiments



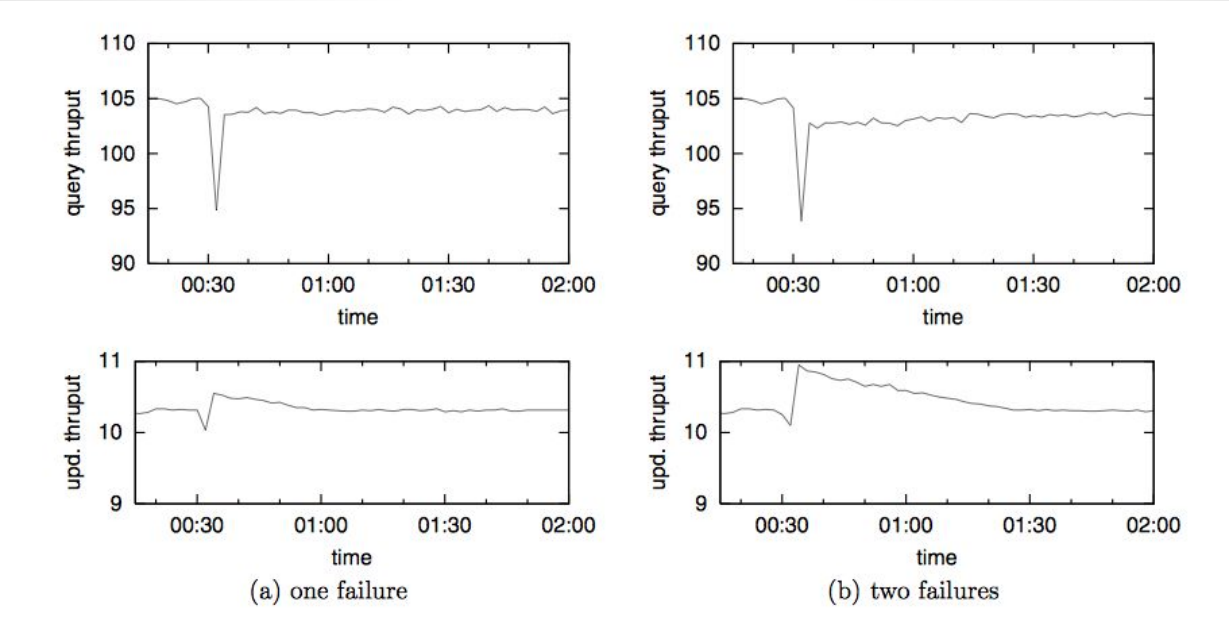
Multiple chains: horizontal scalability

Simulation Experiments

Effects of failures:

- 24 servers
- 5000 chains (length 3)
- 150 GB/server
- 6.25 MB/s max bandwidth for recovery
- 10 minutes to reboot failed server

Simulation Experiments



Throughput with failures (at 00:30)

Concluding Remarks

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- CR supports strong consistency
- CR has better throughput than P/B
  - Sharing load between head and tail
  - More even bandwidth distribution
- CR has better availability than P/B
  - Mainly via faster recovery
  - Not partition tolerant though
- (worse latencies though)

Concluding Remarks

Subsequent work:

- Object Storage on CRAQ
  - Read from middle nodes to scale out
  - ‘Dirty’ reads require a check with the tail
- ChainReaction
  - Add additional nodes after the tail to scale out reads
  - Reads from post-tail are eventually consistent

Questions?