Bullshark

DAG BFT Protocols Made Practical

Alberto Sonnino

Byzantine Fault Tolerance

Consensus on top of Narwhal

Goal of this project

Simple

- Zero-message overhead
- No view-change
- No common-coin

Performant

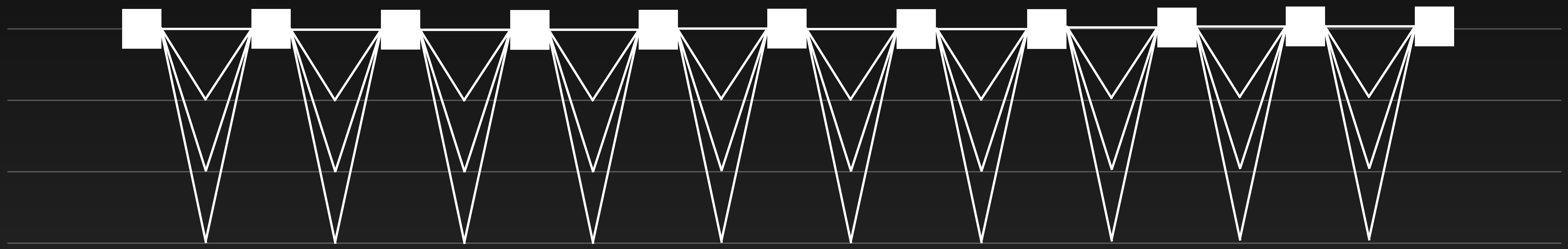
- Take advantage of Narwhal
- Exploit periods of synchrony

Current Designs

- Monolithic protocol sharing transaction data as part of the consensus
- Optimize overall message complexity of the consensus protocol
- Complex & Error-prone view-change protocol

Current Designs

Typical leader-based protocols



Current Designs

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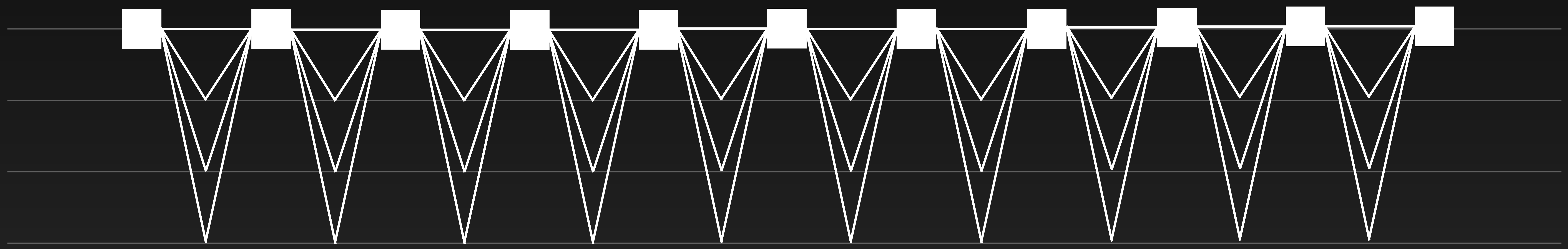

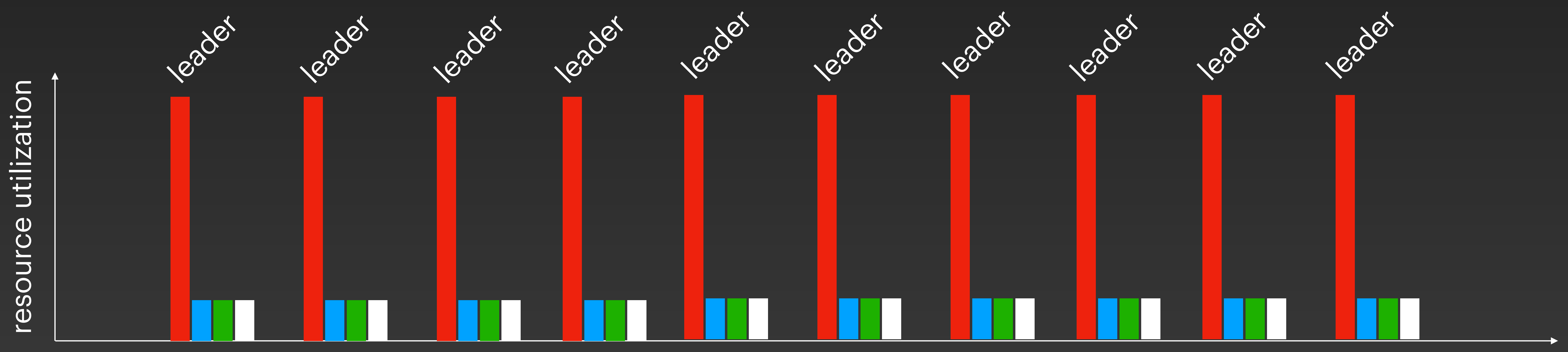

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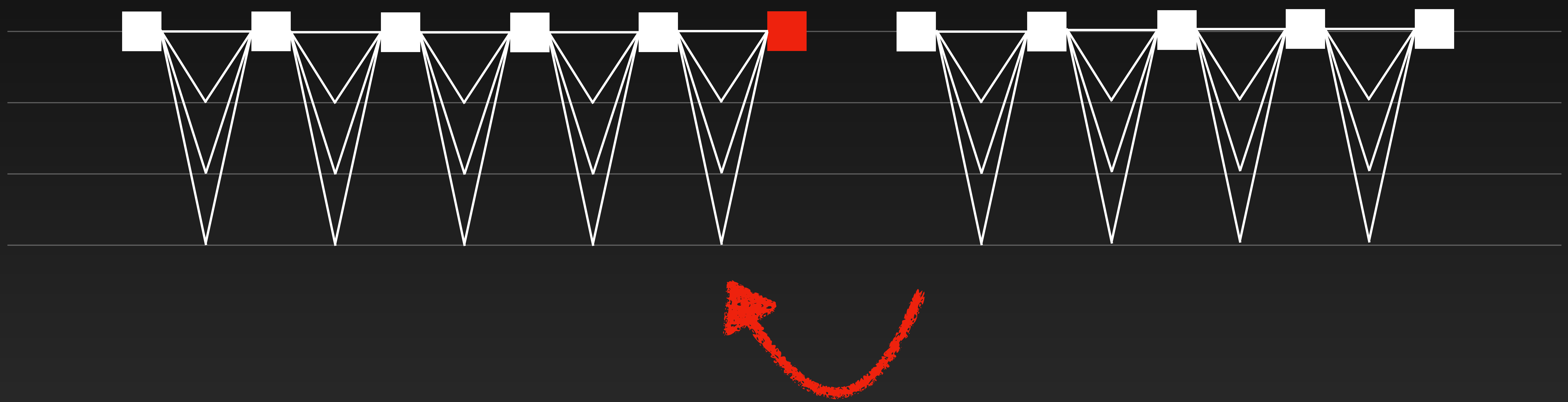

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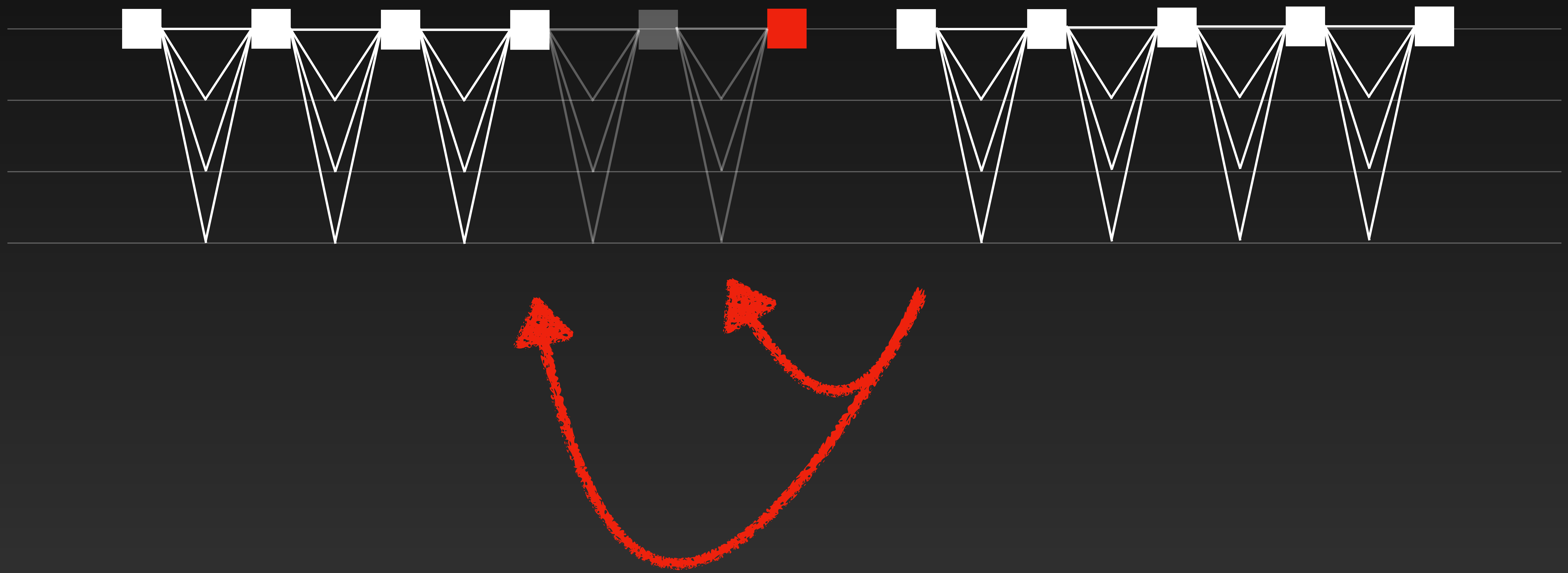


Narwhal

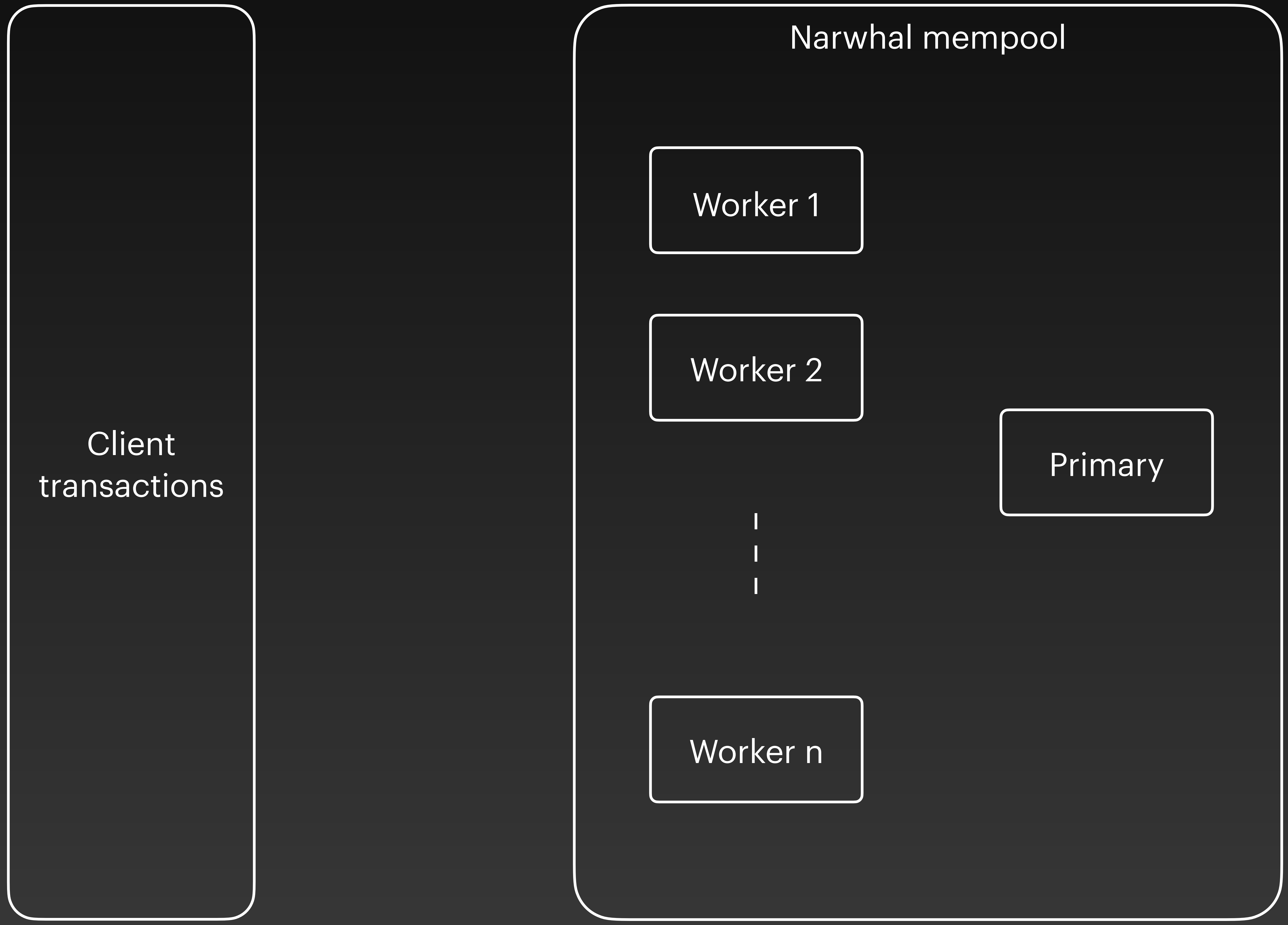
Dag-based mempool

The mempool is the key

Reaching consensus on metadata is cheap

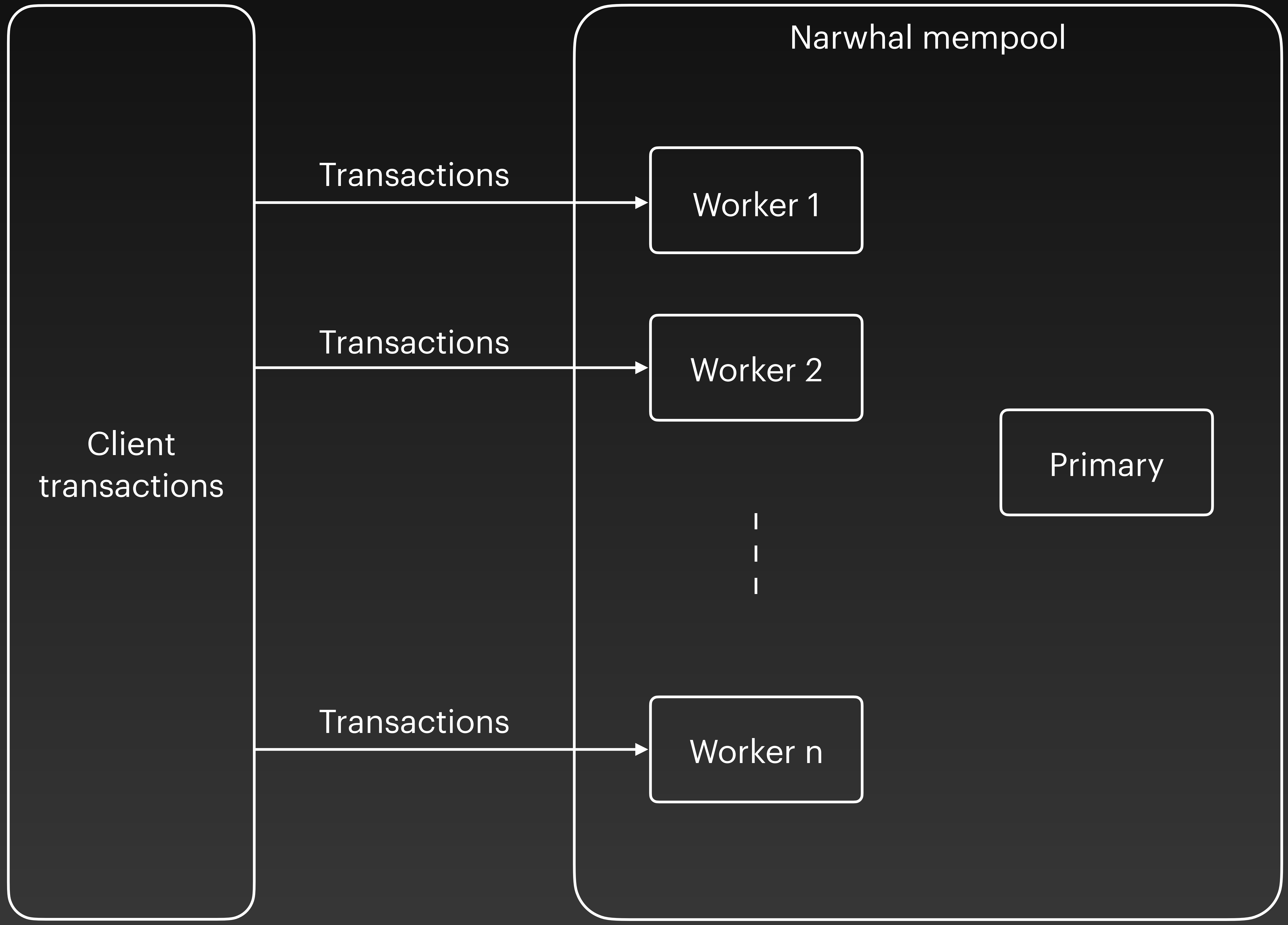
Narwhal

The workers and the primary



Narwhal

The workers and the primary



Narwhal

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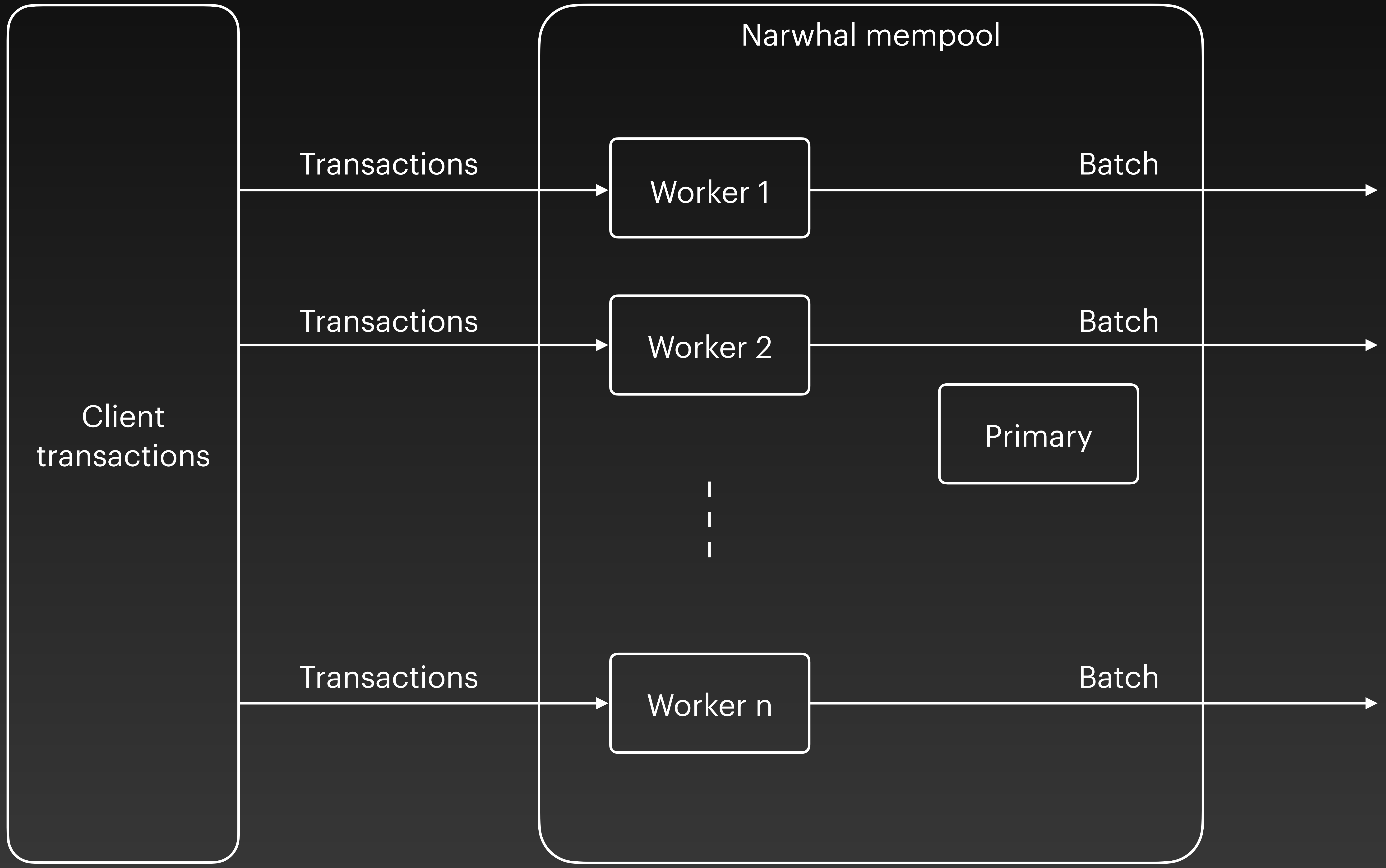

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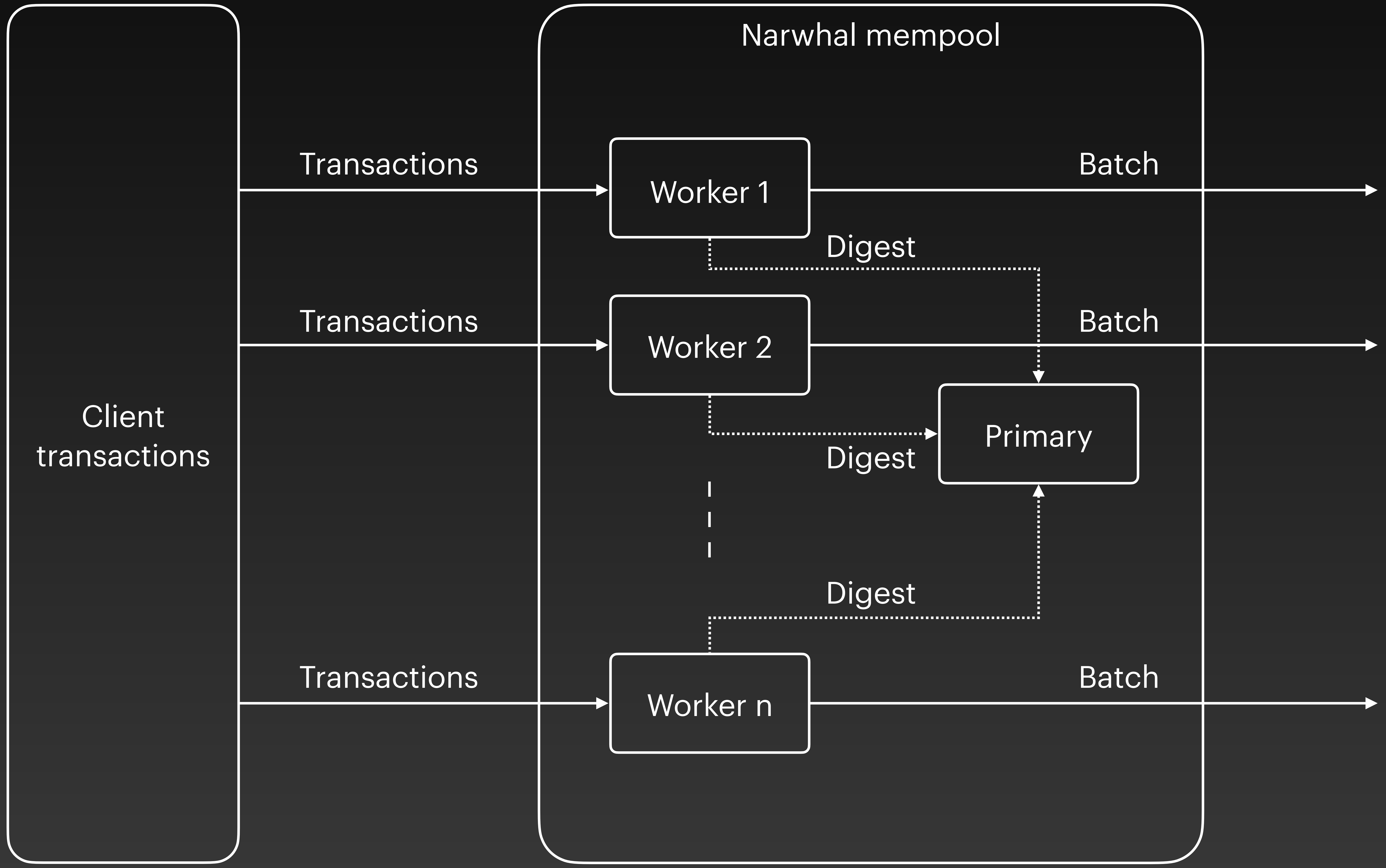

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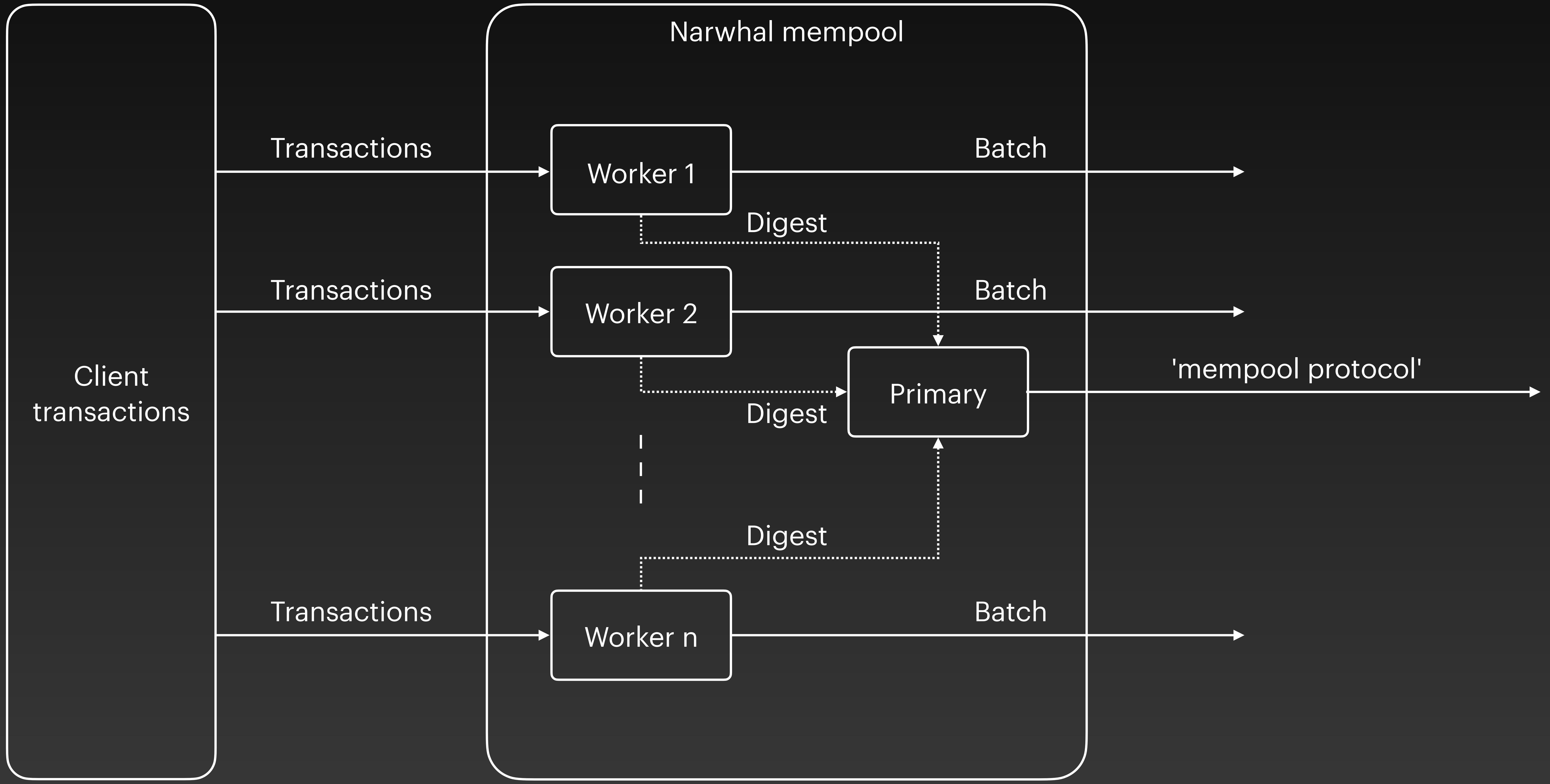
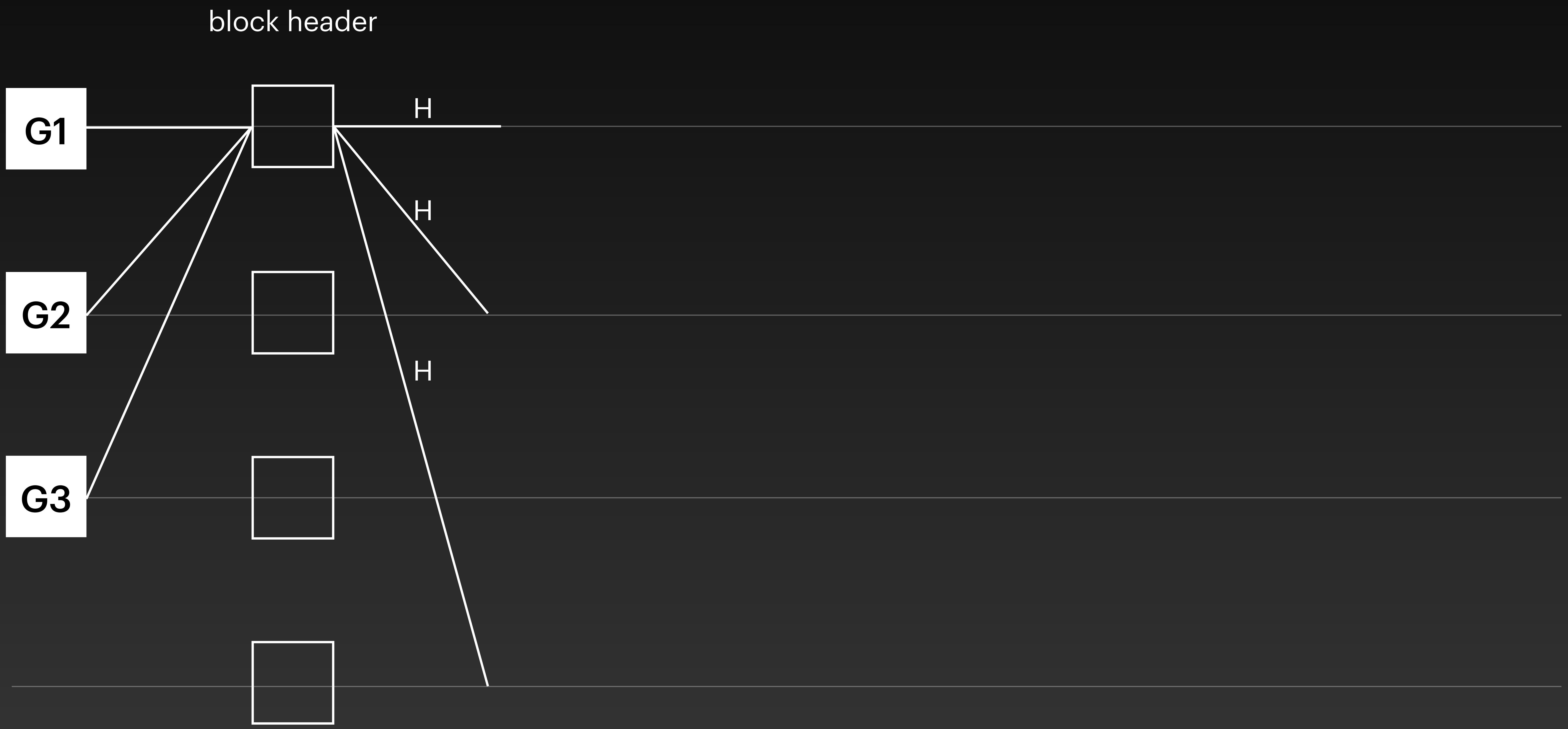


Narwhal

The primary machine



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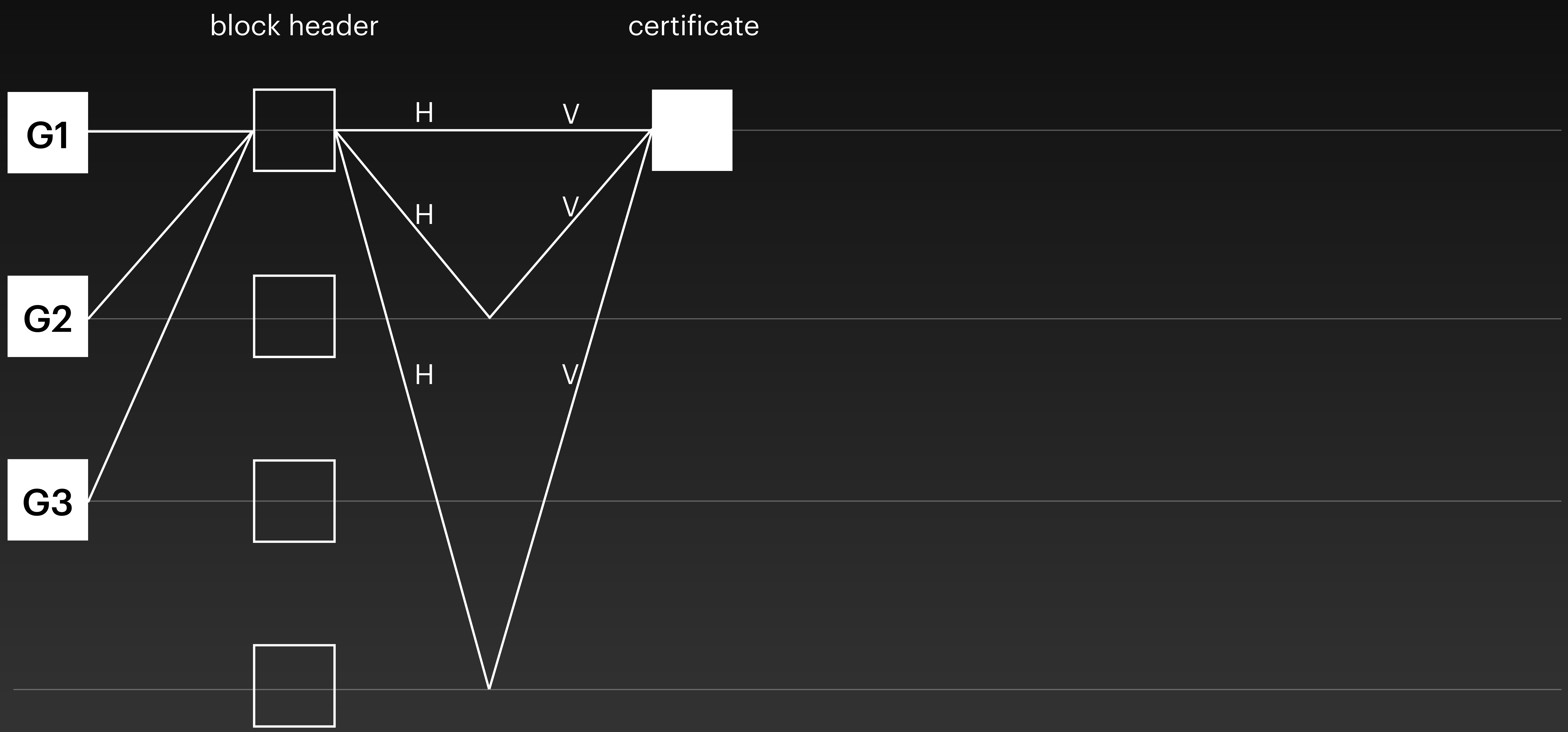
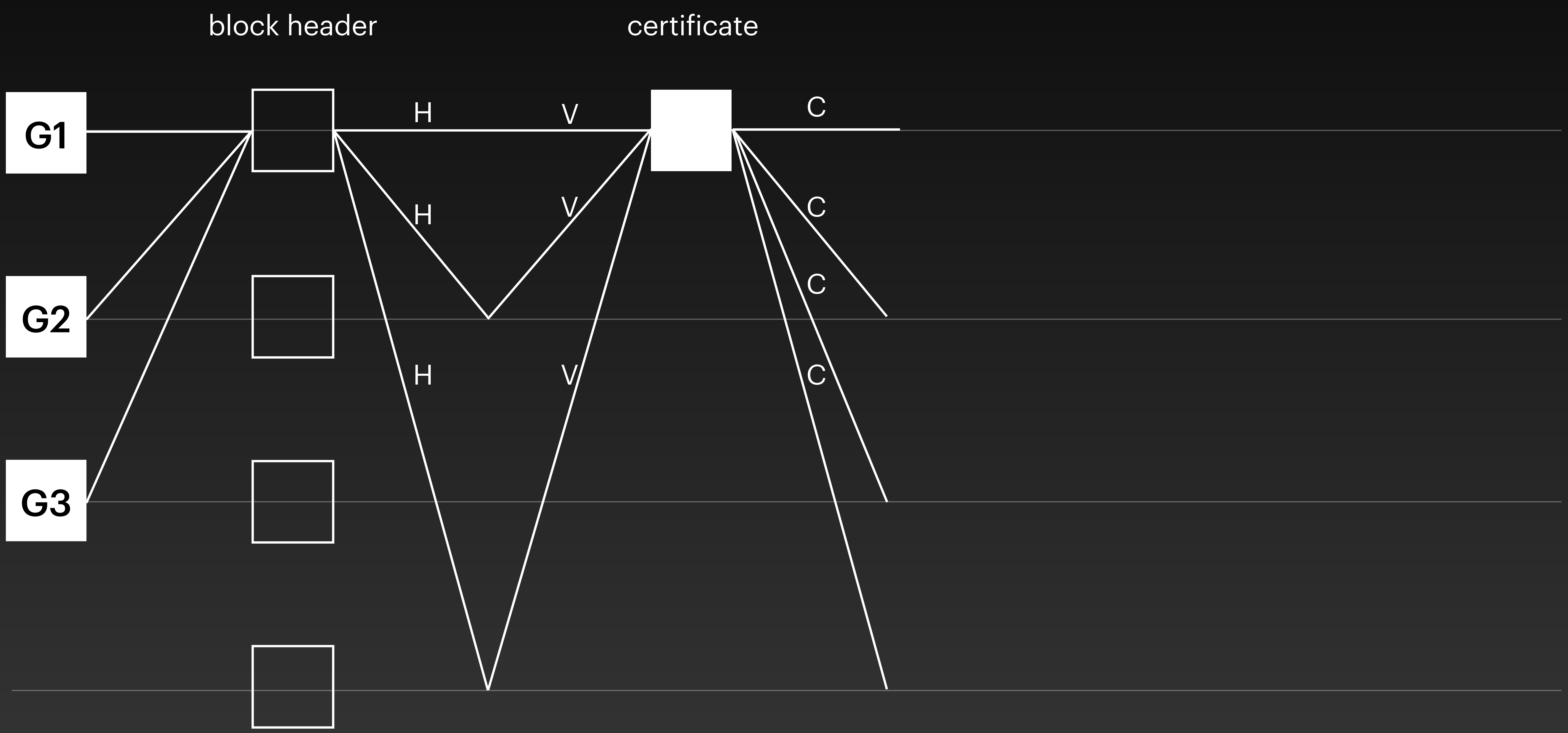


Narwhal
The primary machine



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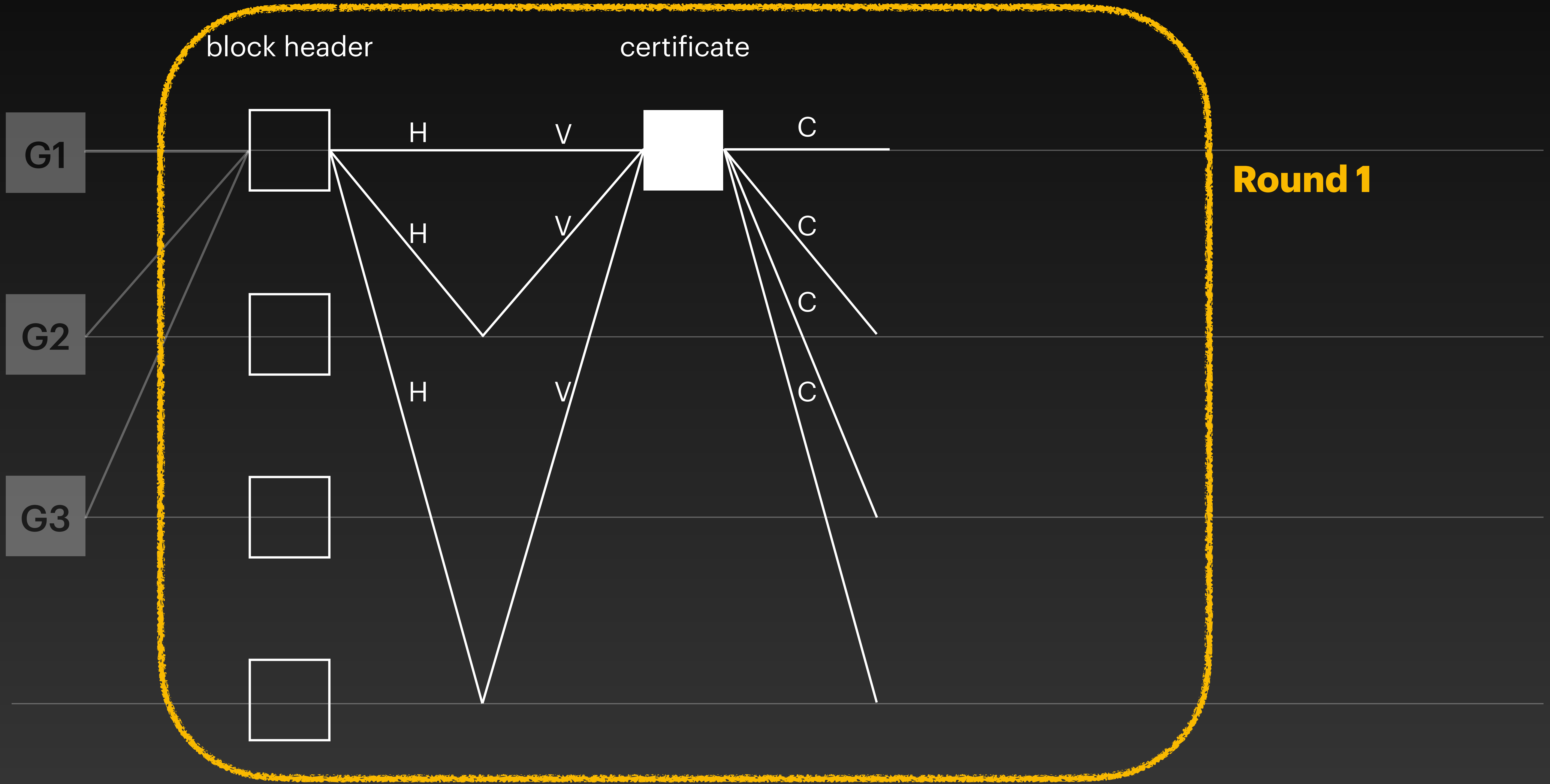

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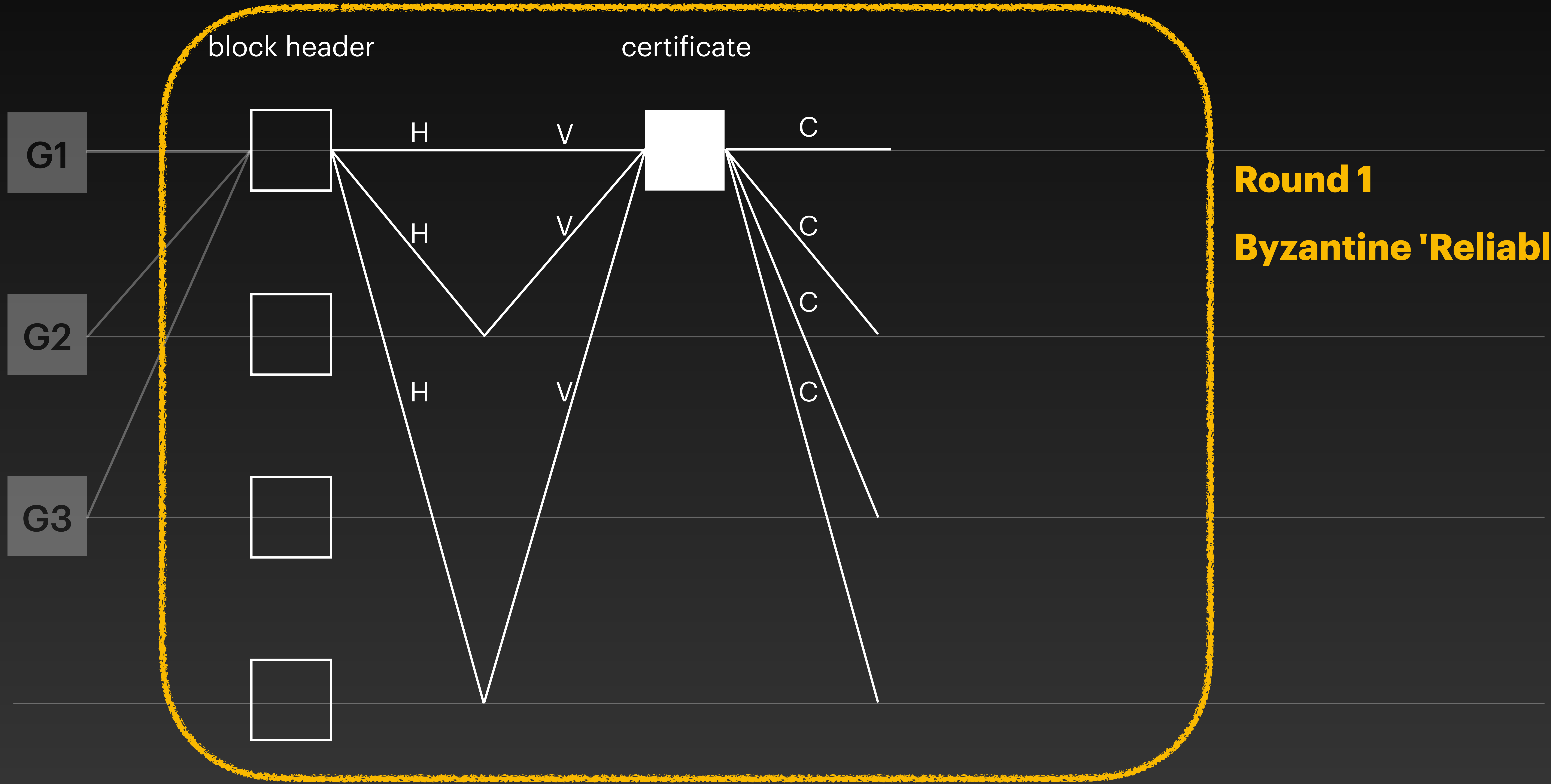
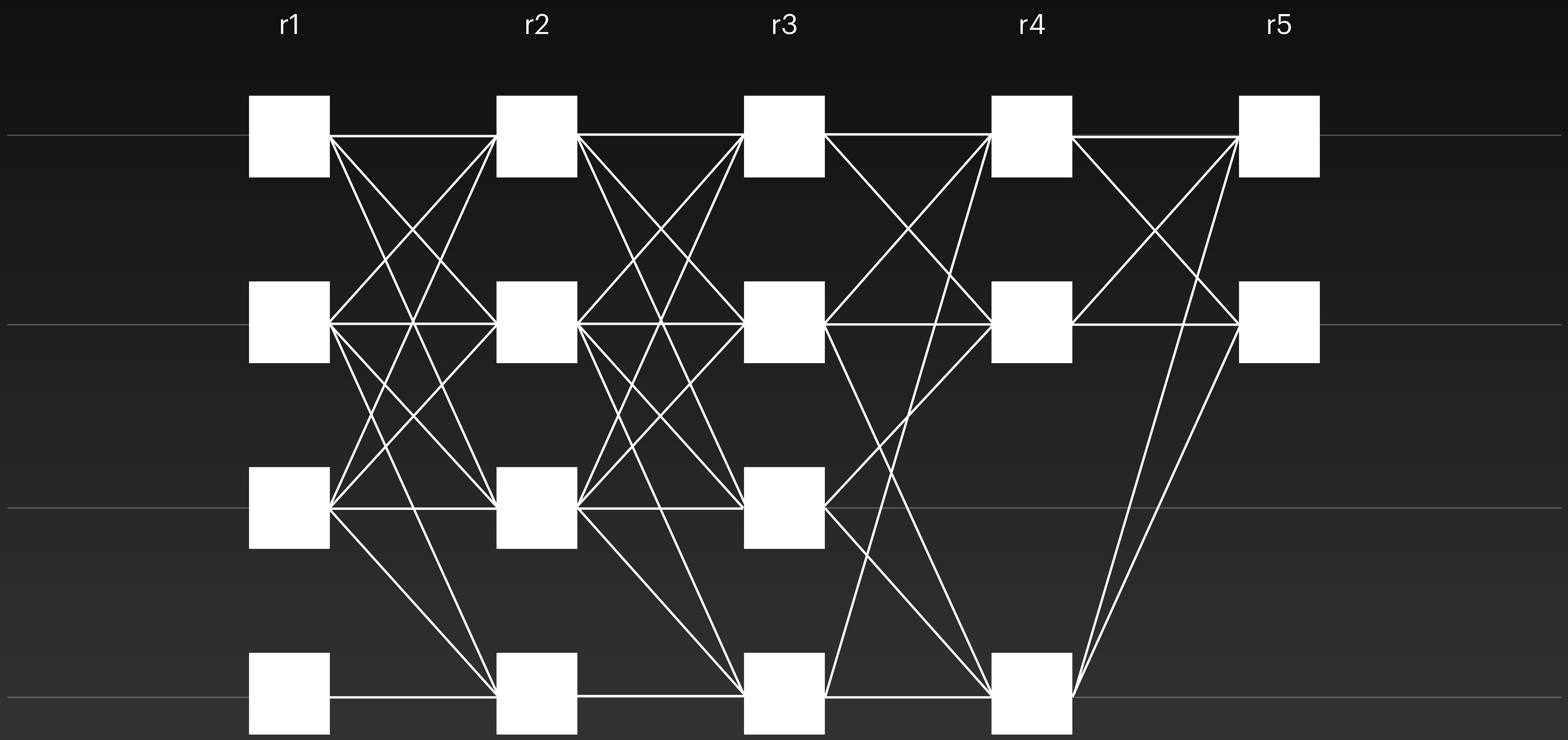
The primary machine



Round 1

Byzantine 'Reliable' Broadcast

Narwhal
The primary machine

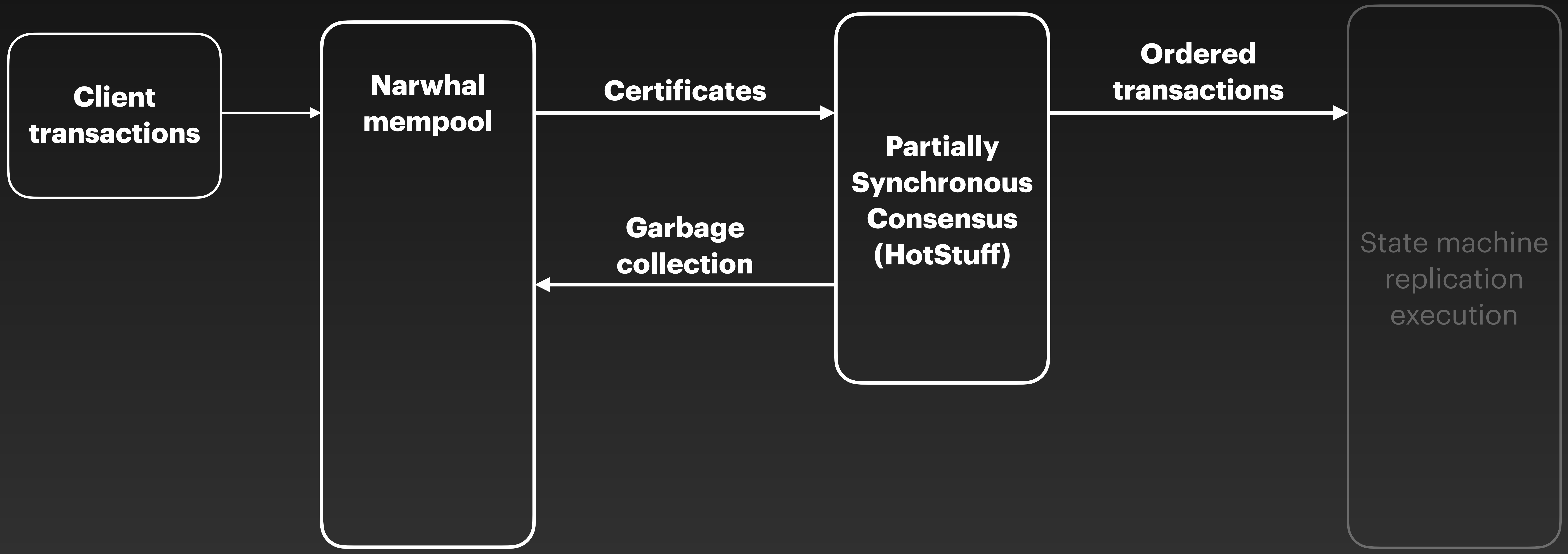


HotStuff on Steroids

Just by replacing the mempool

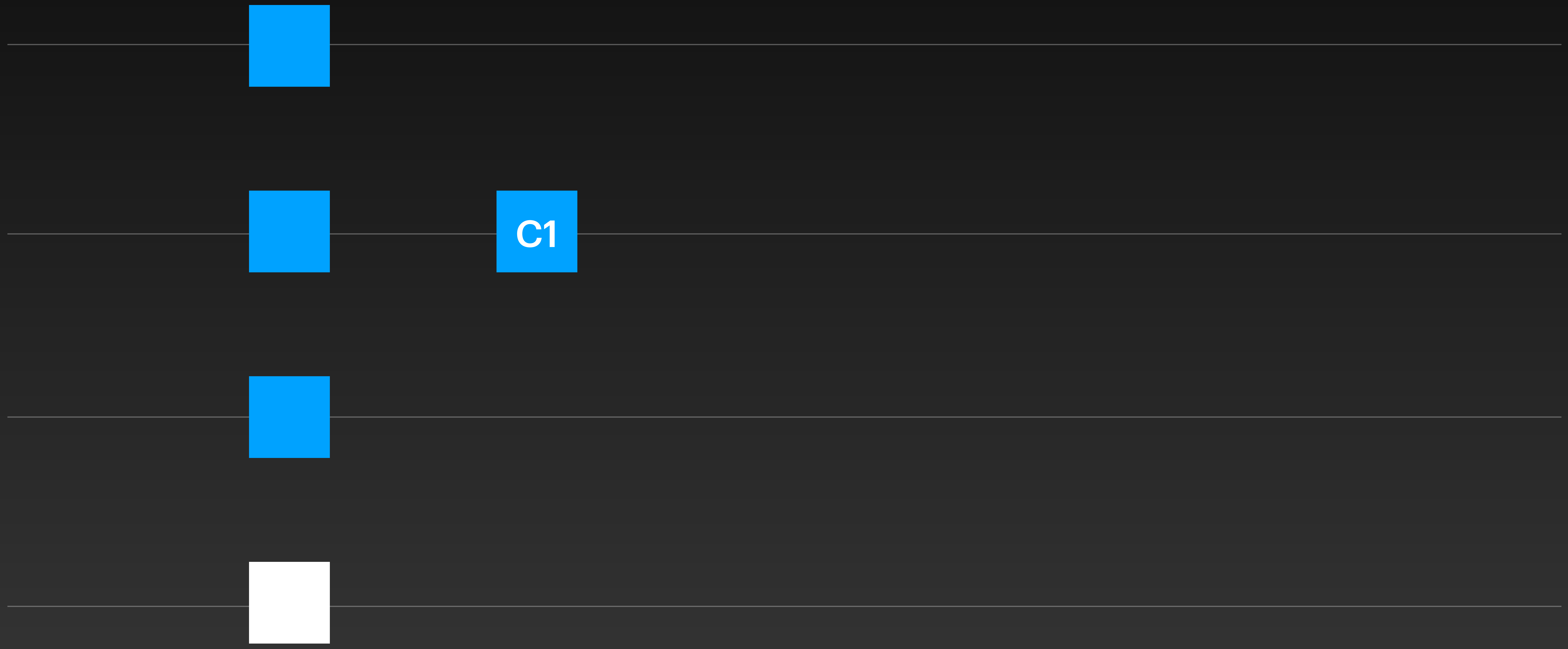
HotStuff on Narwhal

Overview



HotStuff on Narwhal

Enhanced commit rule



HotStuff on Narwhal

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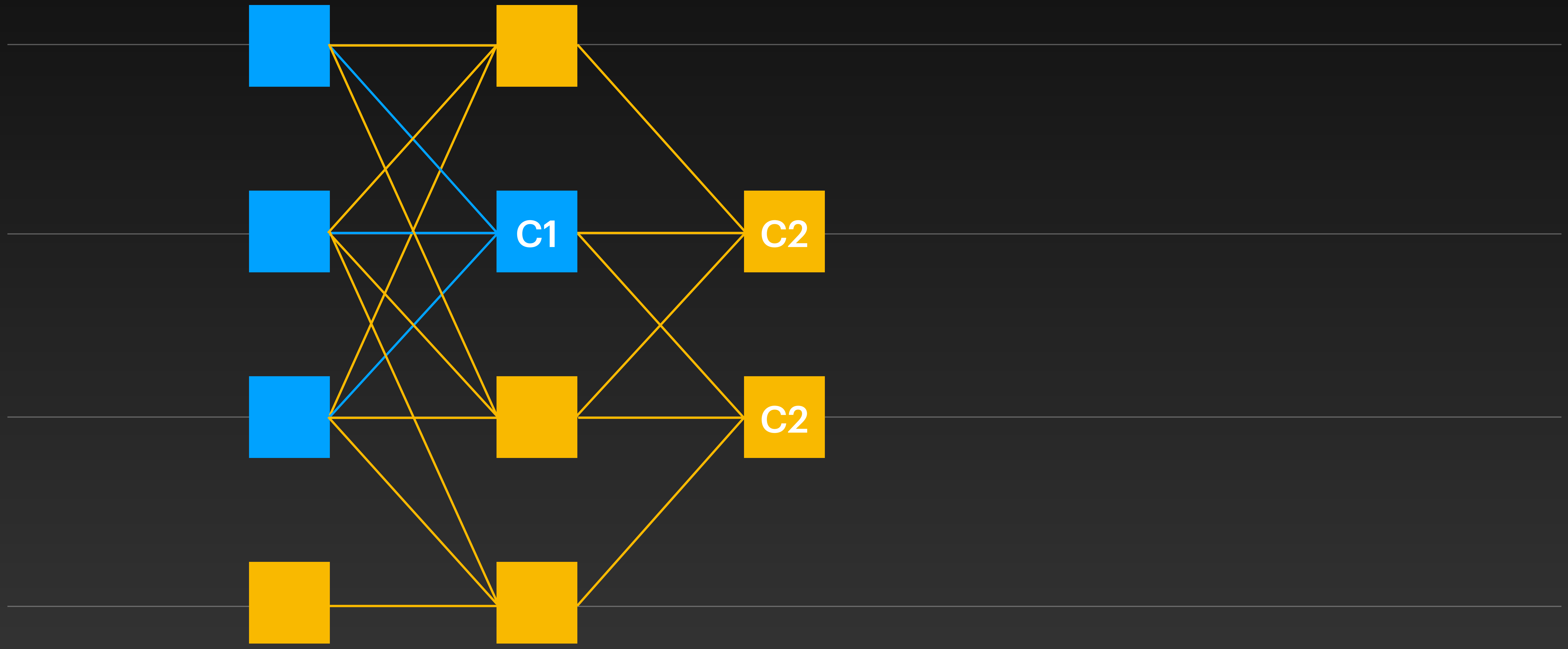

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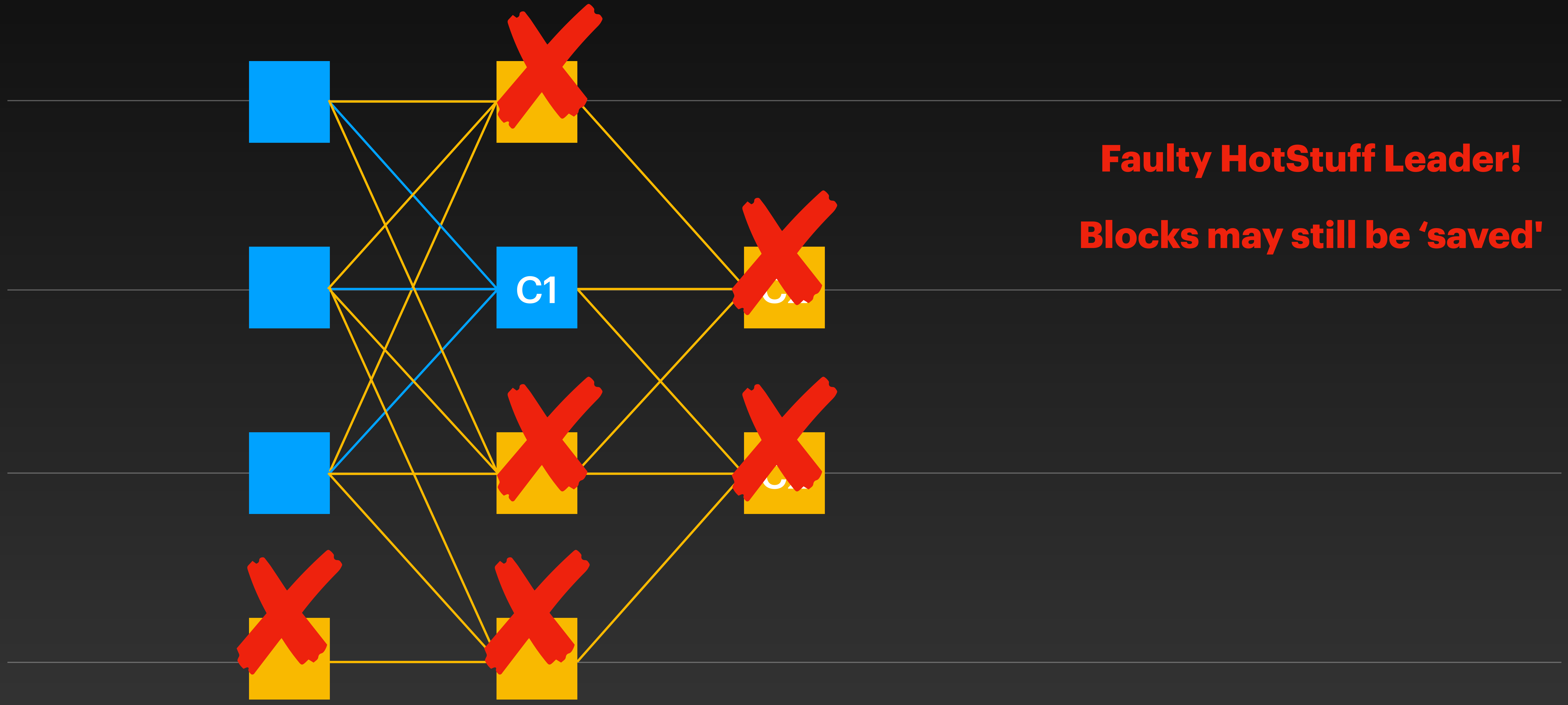
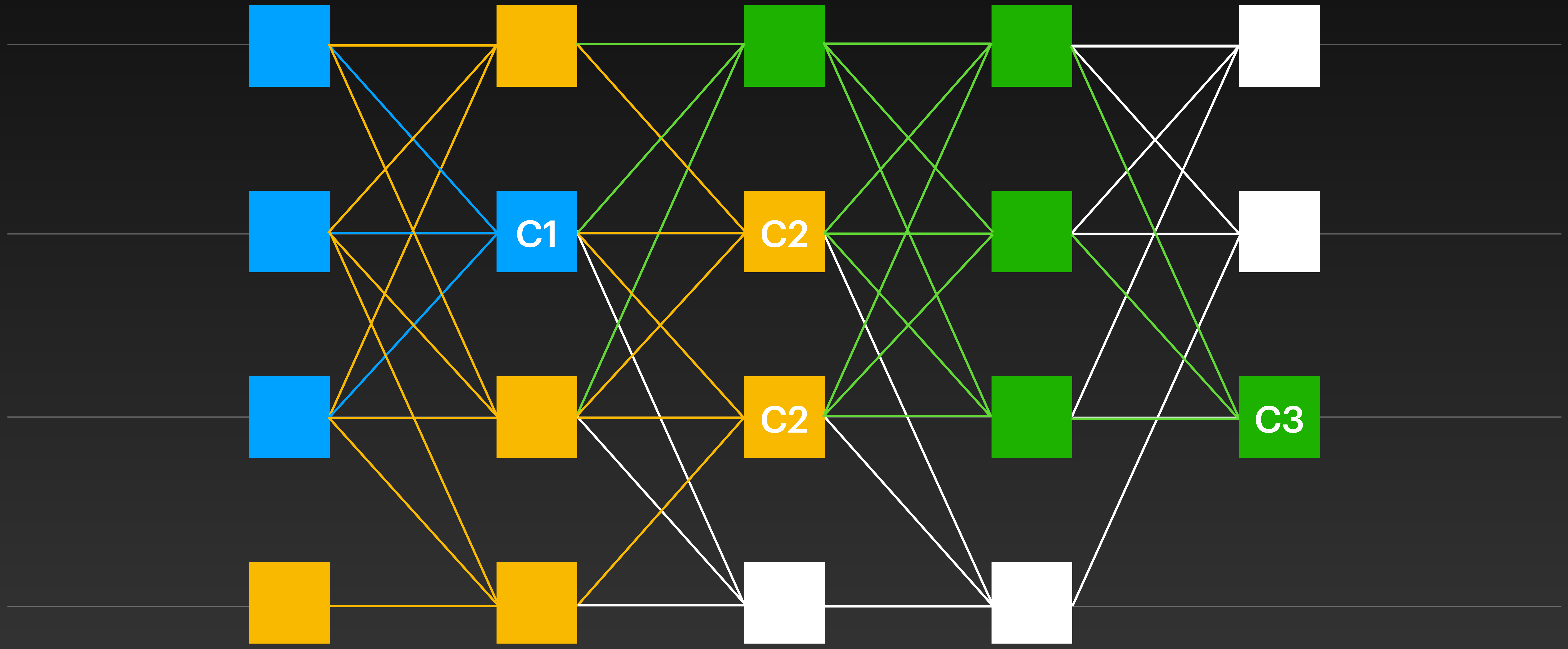


Faulty HotStuff Leader!

Blocks may still be ‘saved'

HotStuff on Narwhal

Enhanced commit rule

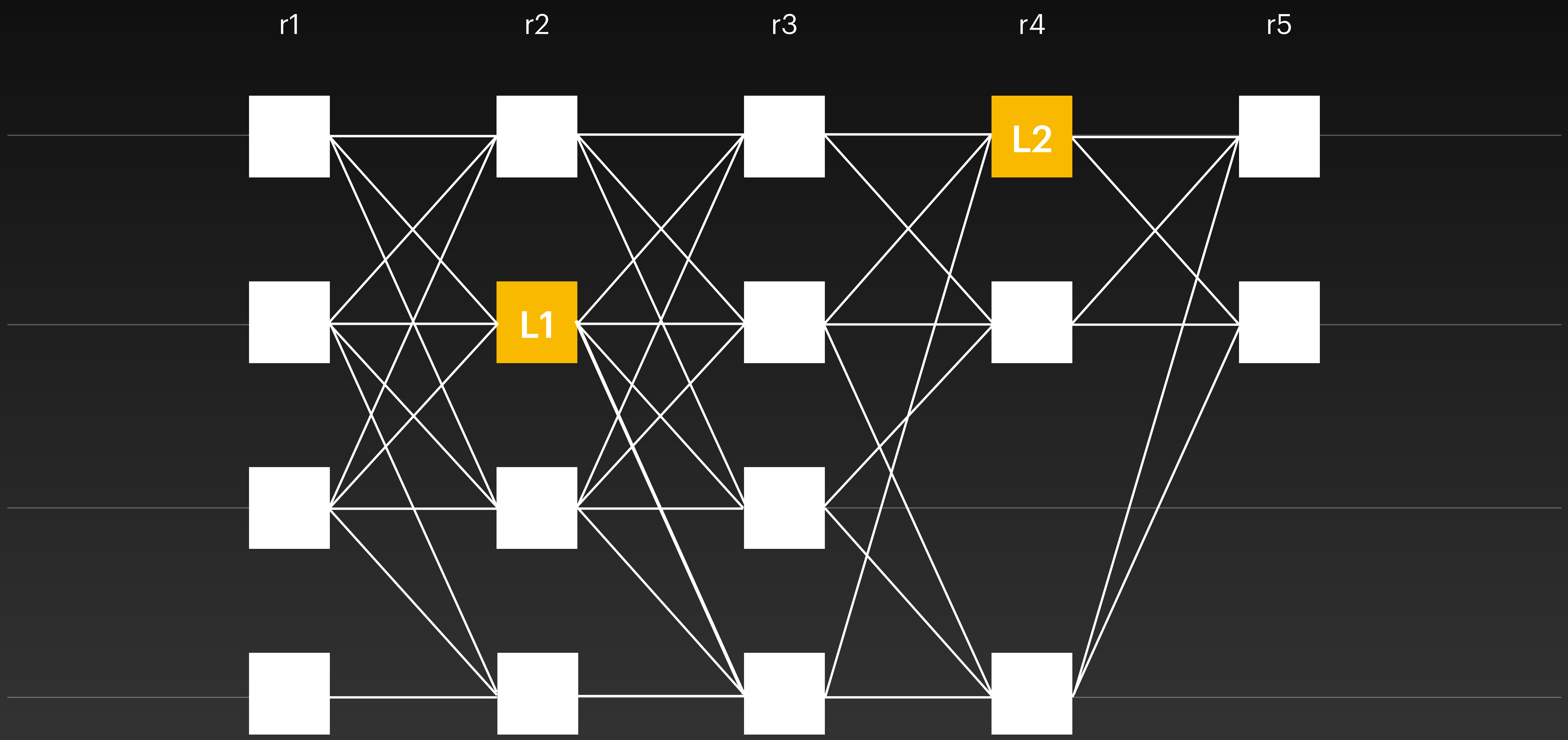


Modified Narwhal

Adapt Narwhal for partial-synchronous networks

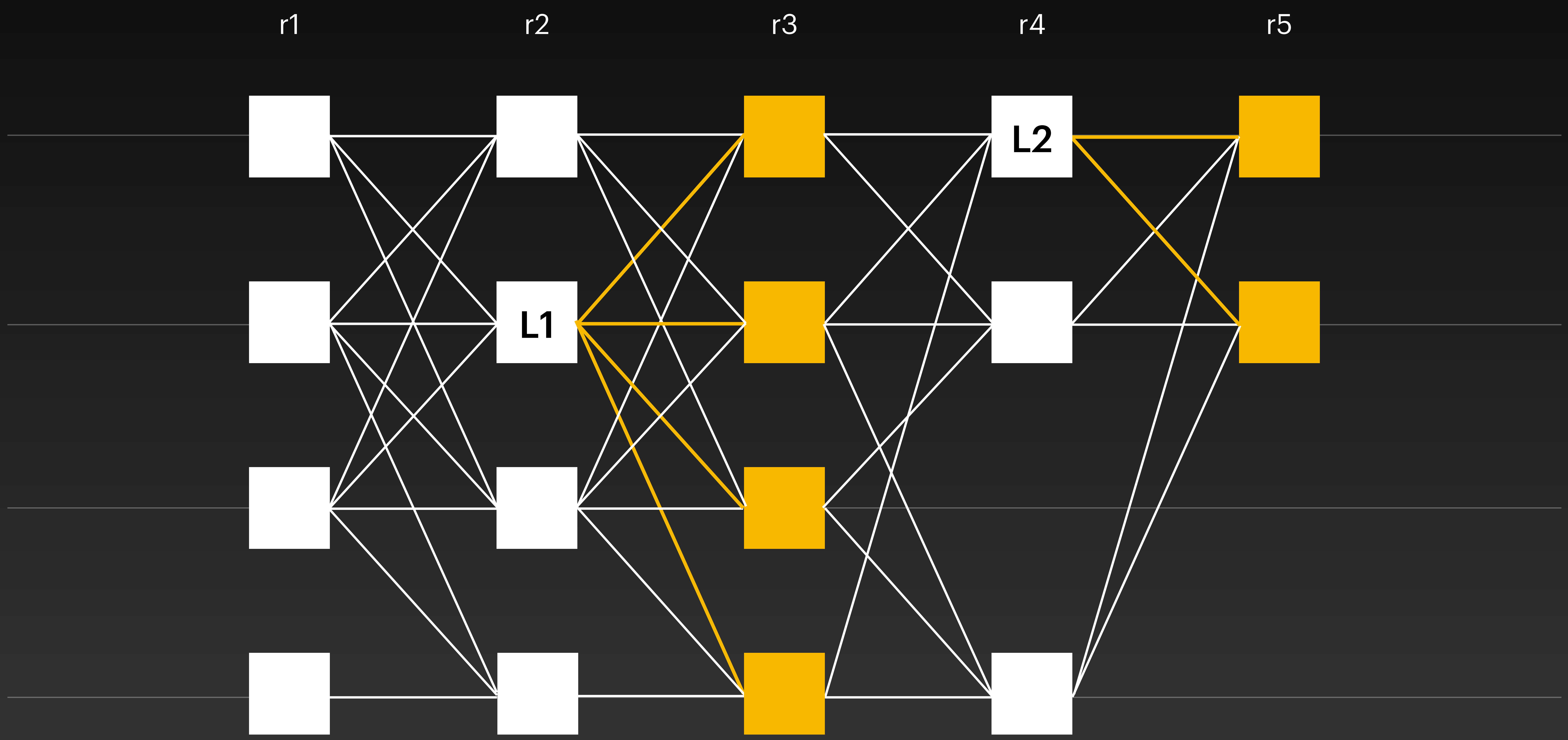
Modified Narwhal

Even rounds: wait for the leader (or to timeout)



Modified Narwhal

Odd rounds: wait for enough votes (or to timeout)



Bullshark

Zero-message partially-synchronous consensus

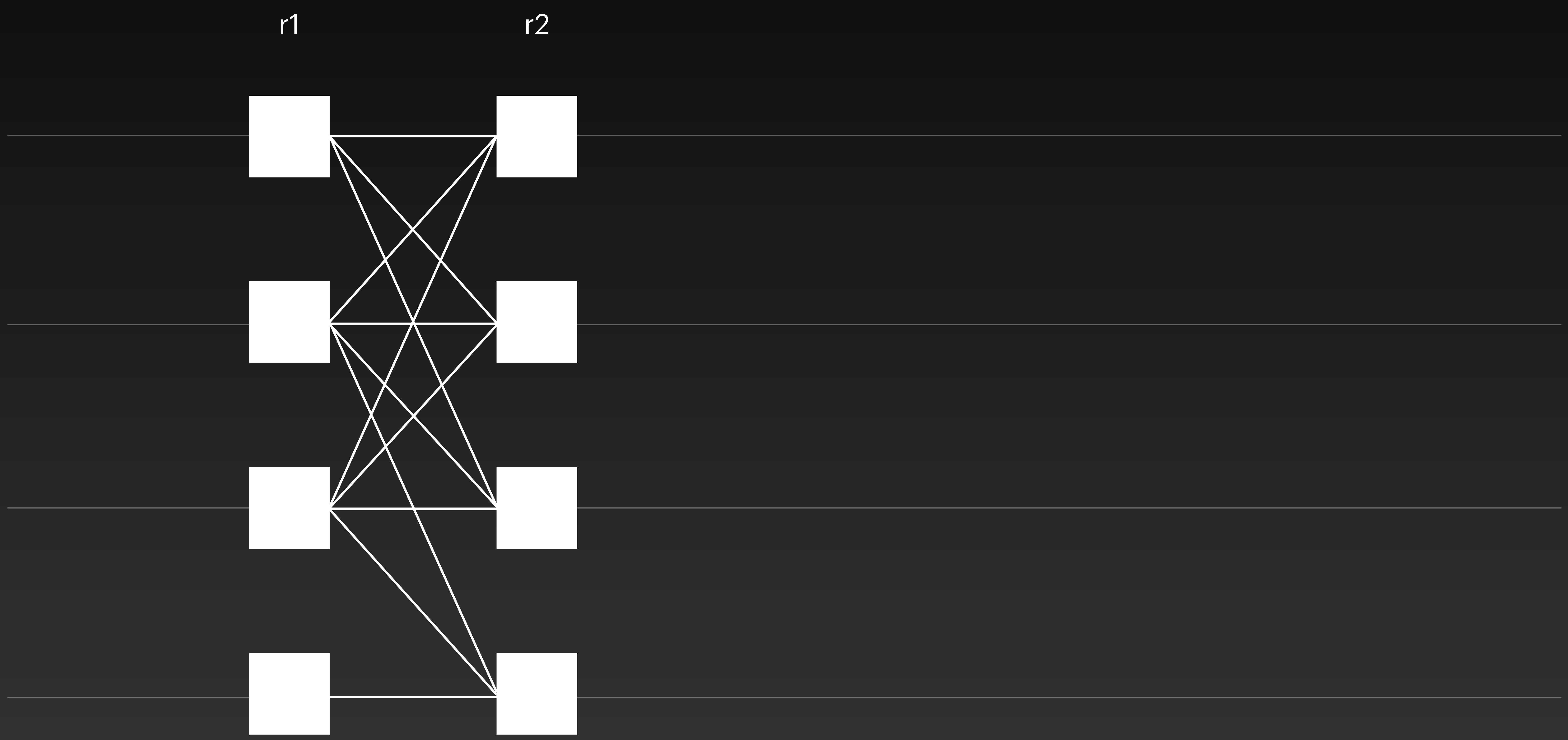
Bullshark

Zero-message partially-synchronous consensus

* without asynchronous fallback

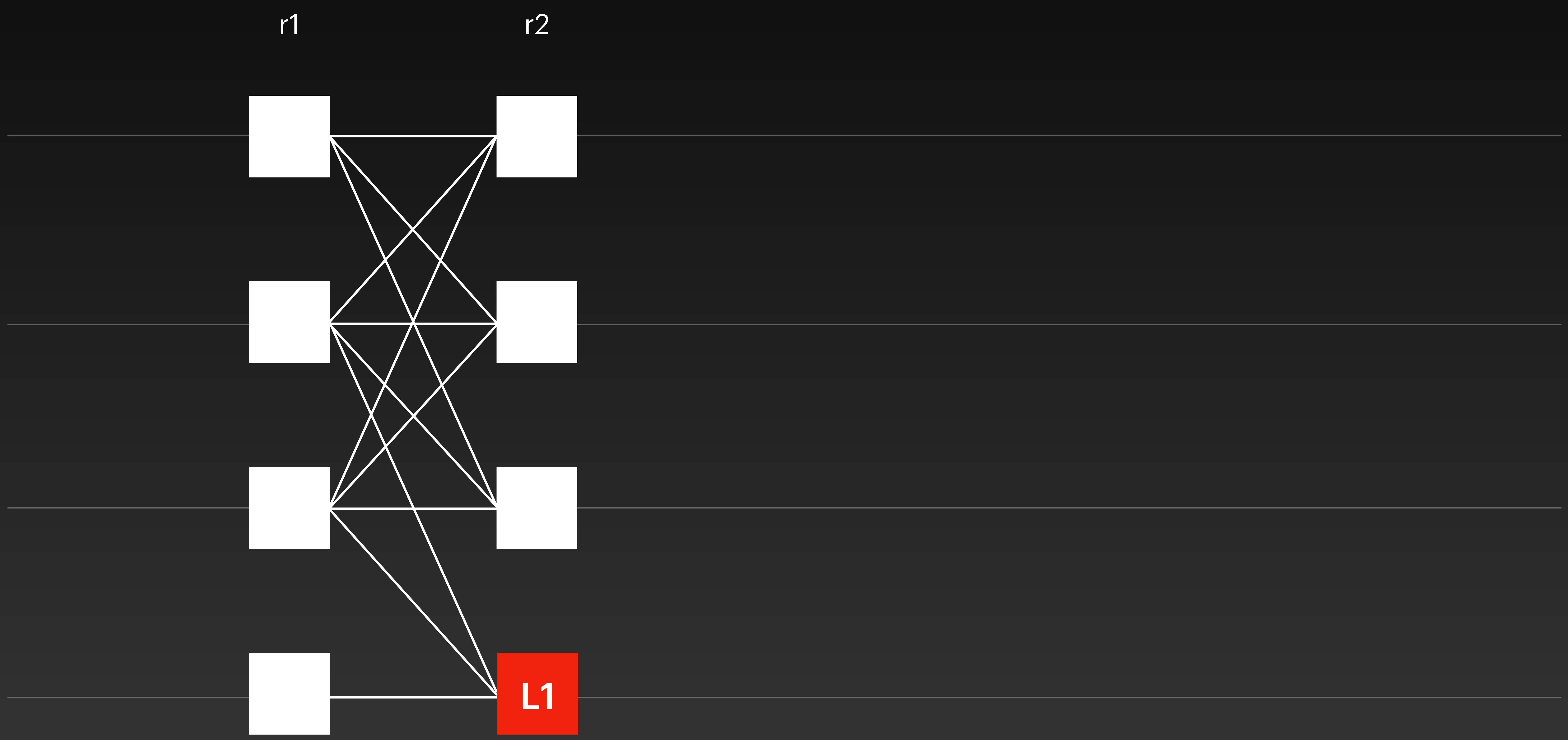
Bullshark

Just interpret the DAG



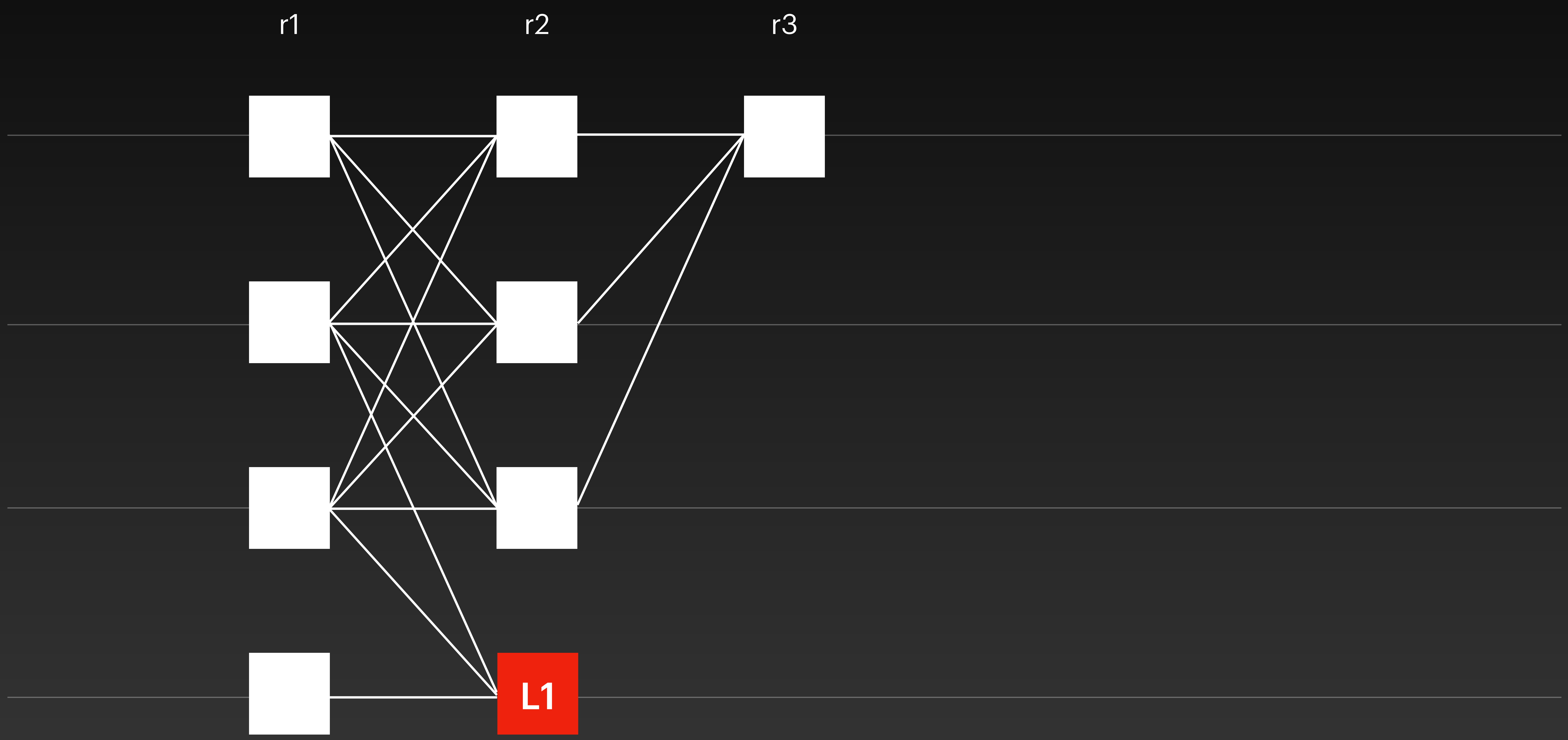
Bullshark

Deterministic leader every 2 rounds



Bullshark

The leader needs f+1 links from round r



Bullshark

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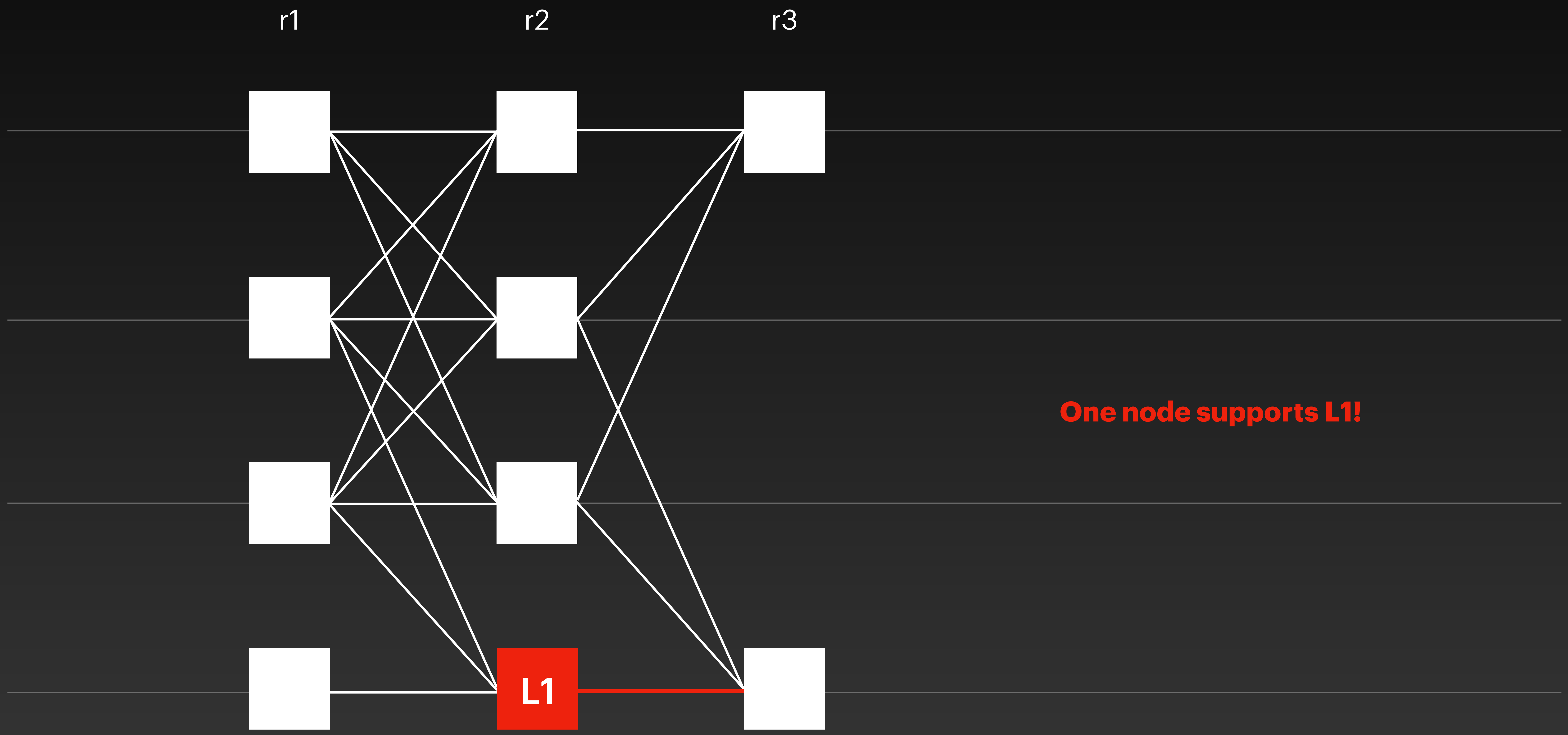
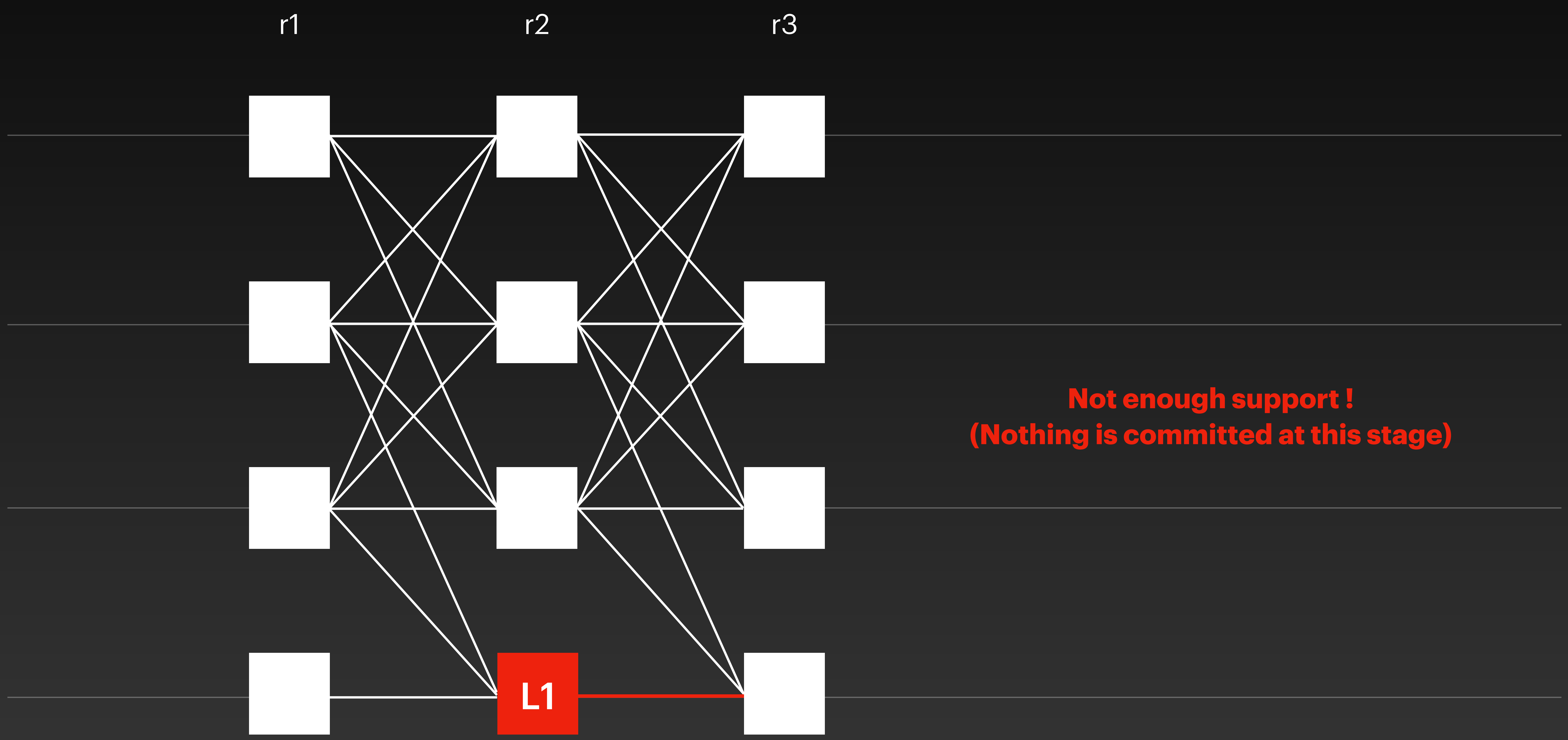


One node supports L1!

Bullshark

The leader needs f+1 links from round r



Not enough support !
(Nothing is committed at this stage)

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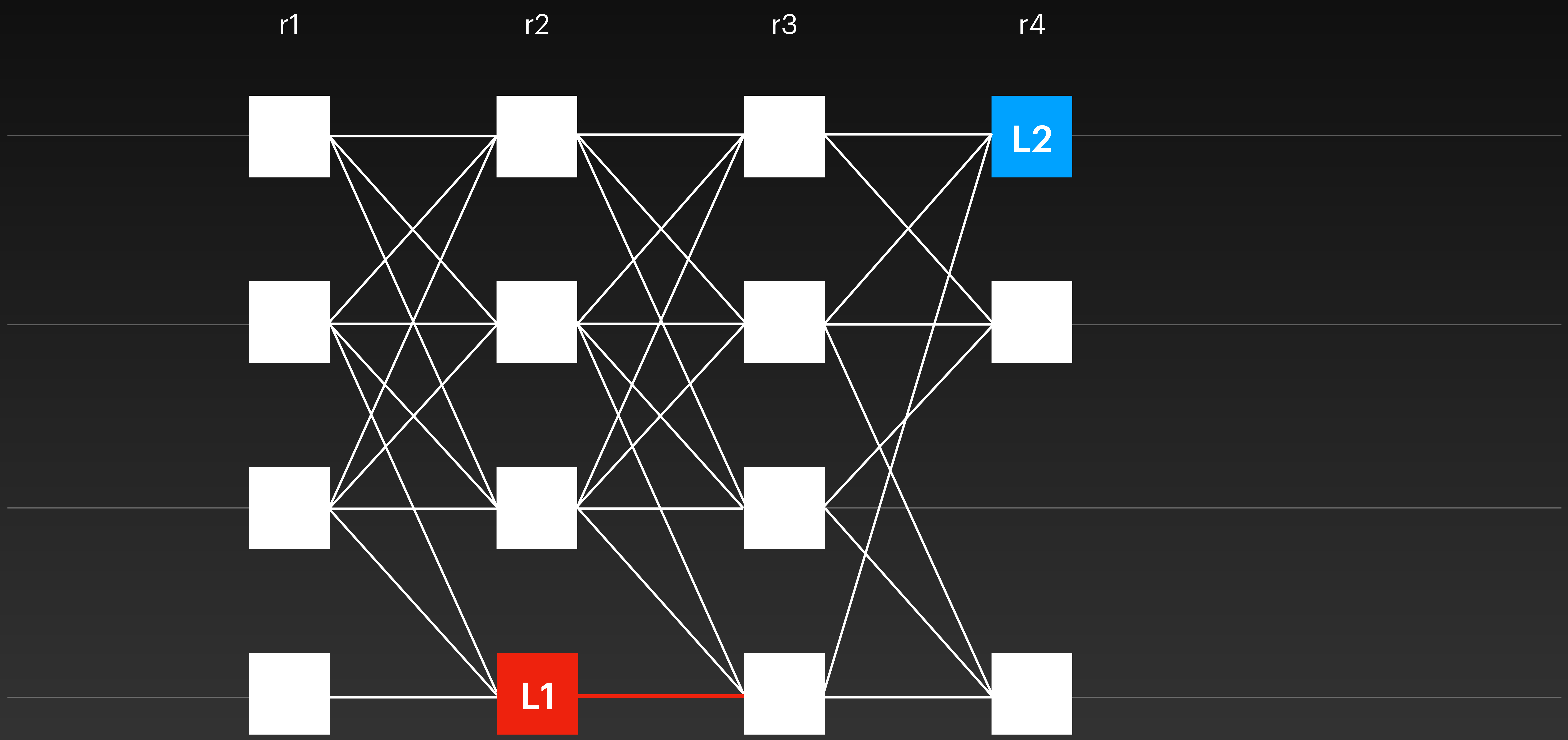
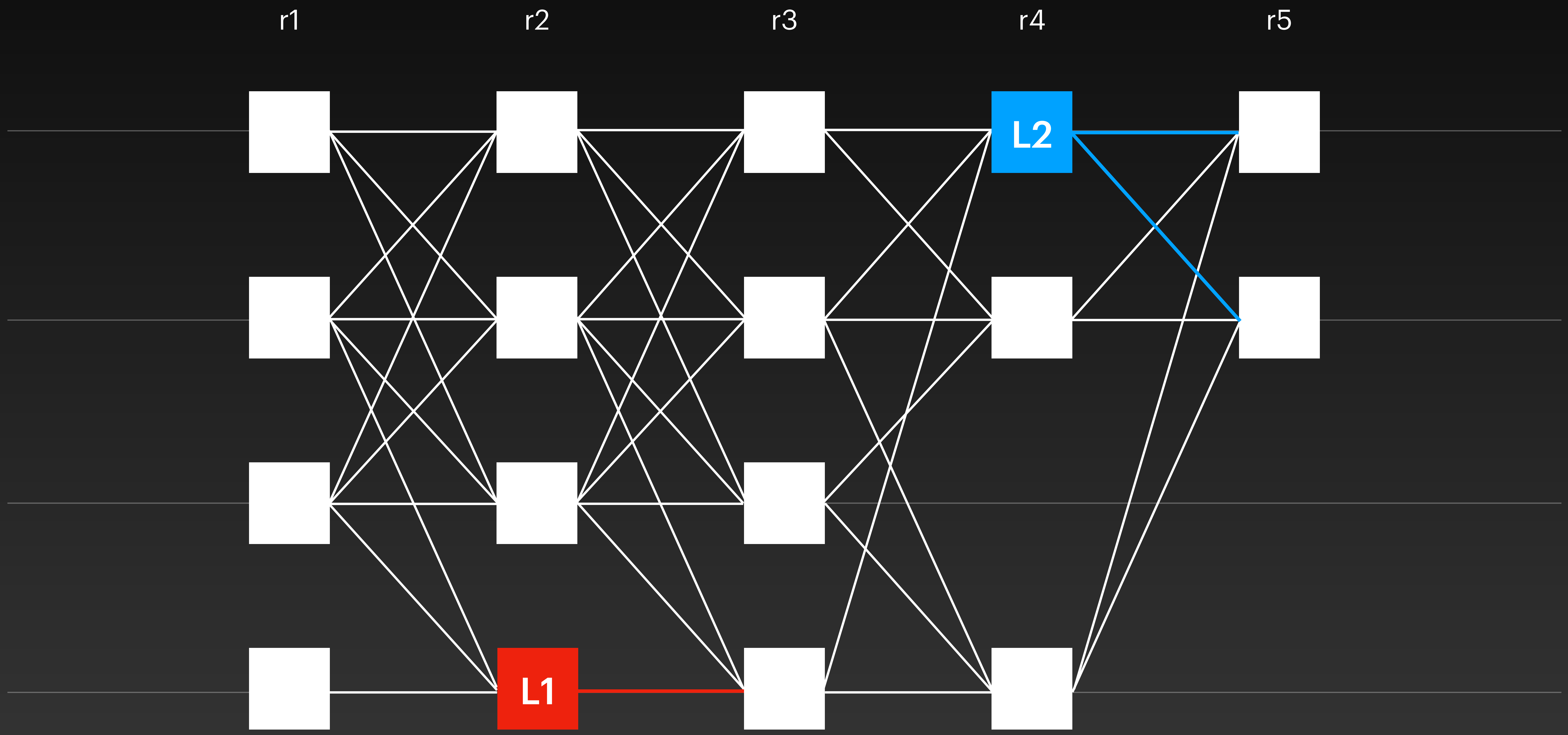
Elect the leader of r4



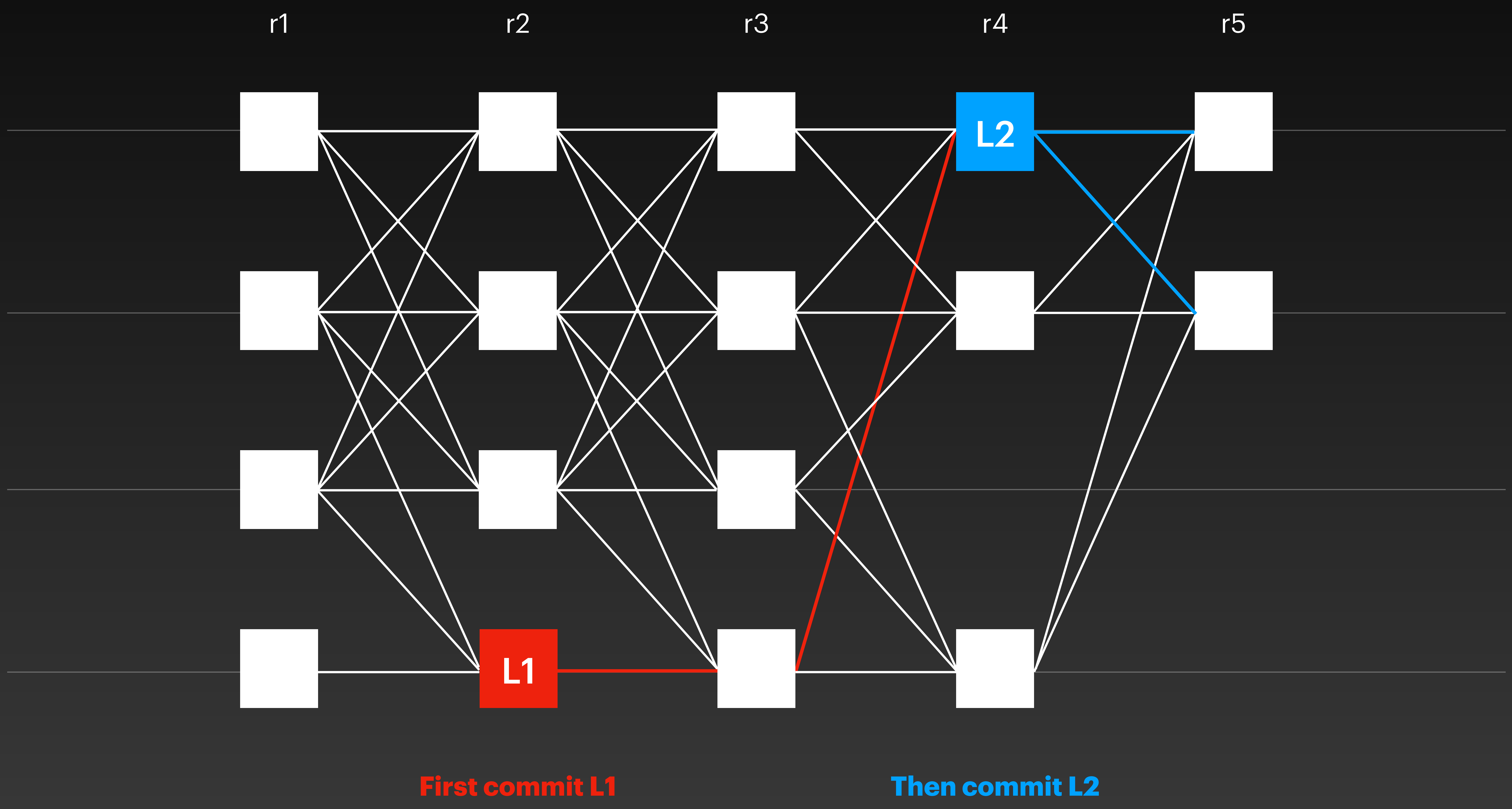
Bullshark

Leader L2 has enough support



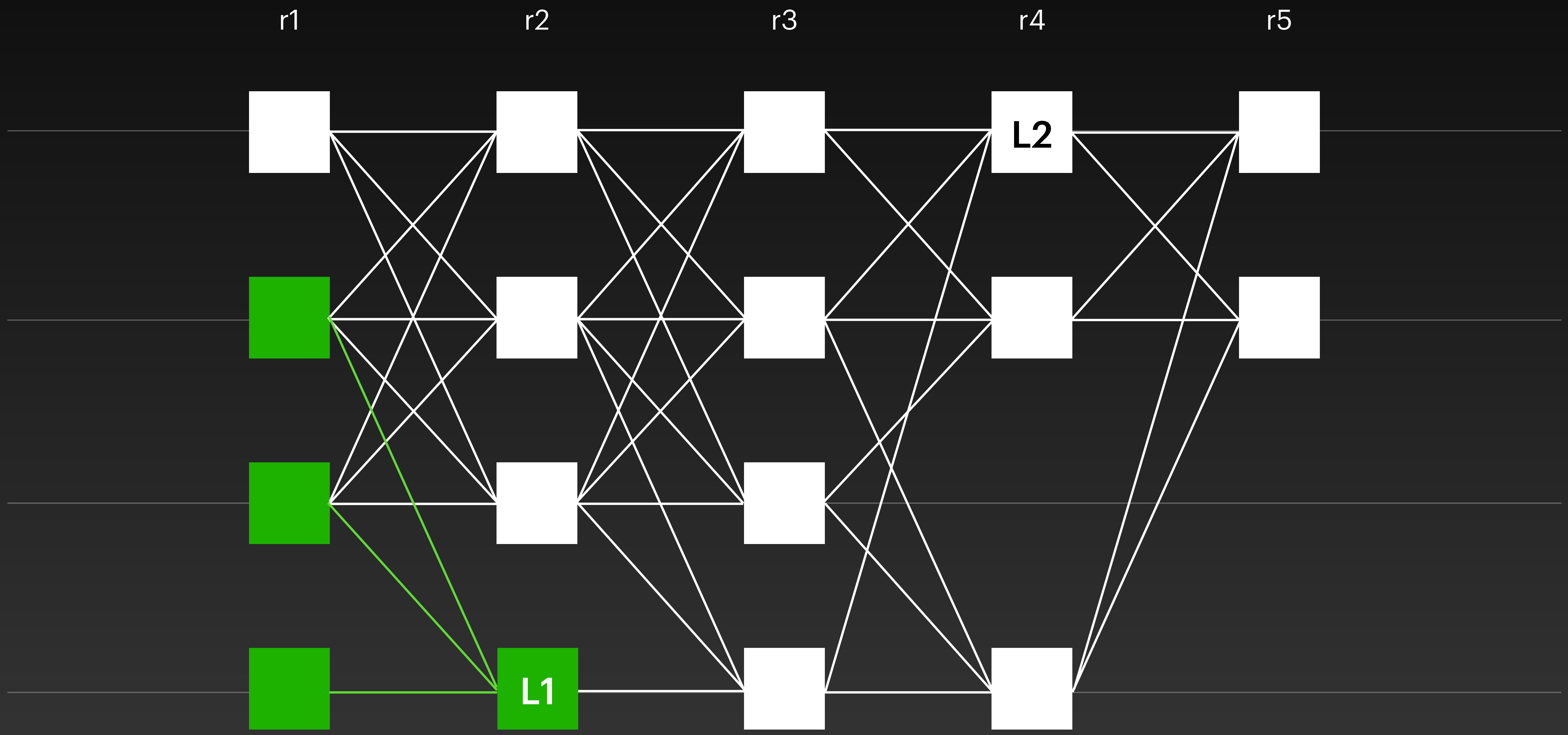
Bullshark

Leader L2 has links to leader L1



Bullshark

Commit all the sub-DAG of the leader



Bullshark

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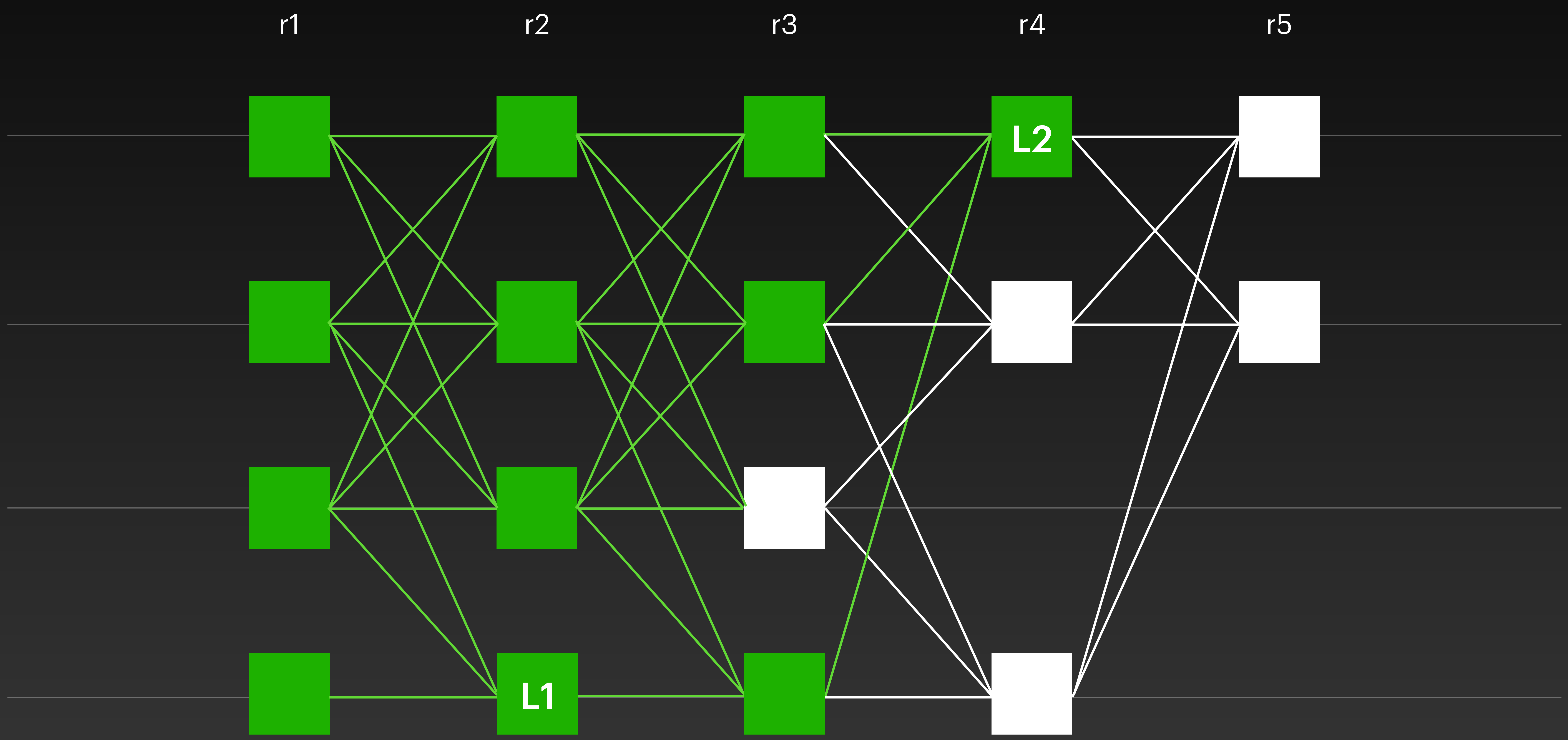


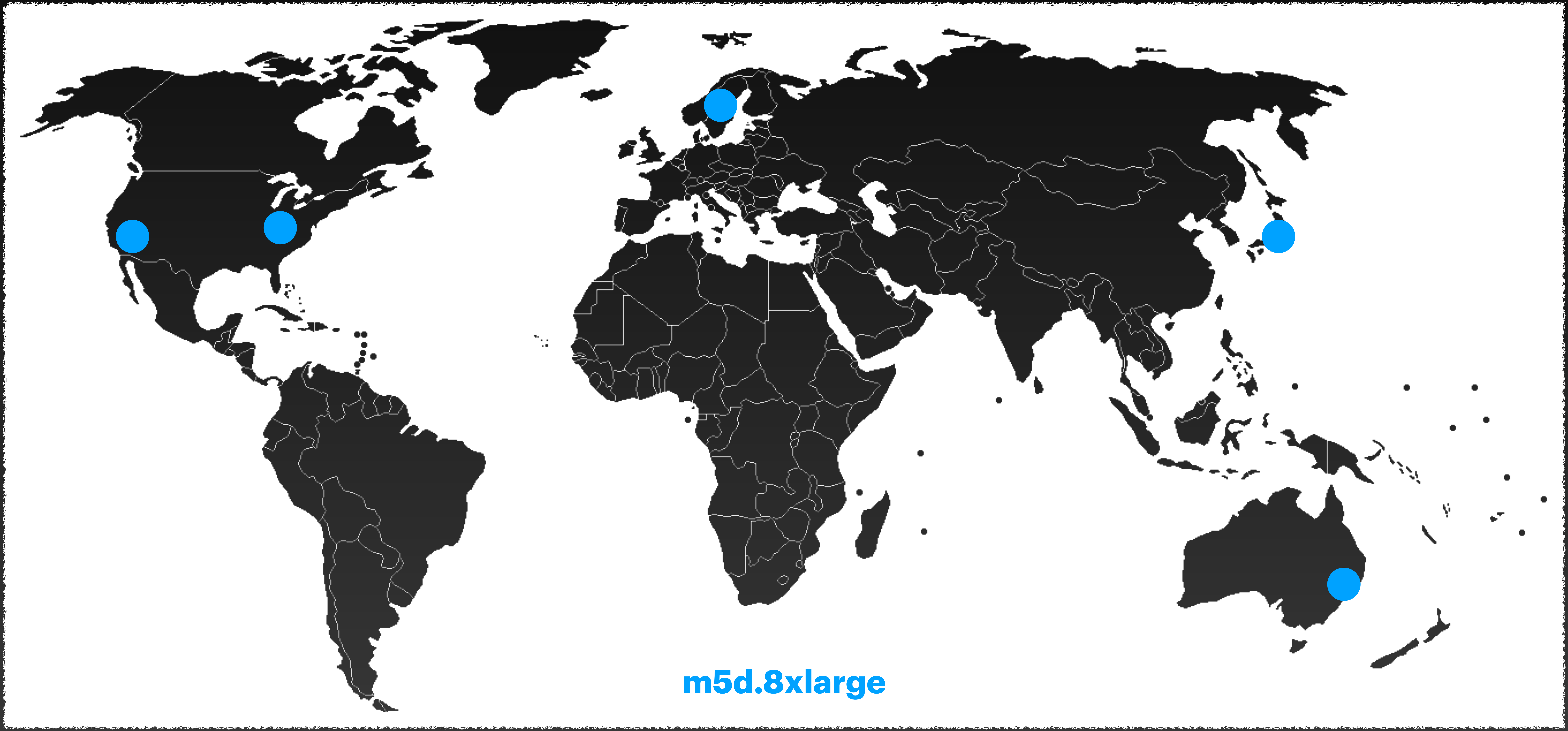
Implementation

- Written in Rust
- Networking: Tokio (TCP)
- Storage: RocksDB
- Cryptography: ed25519-dalek

https://github.com/asonnino/narwhal

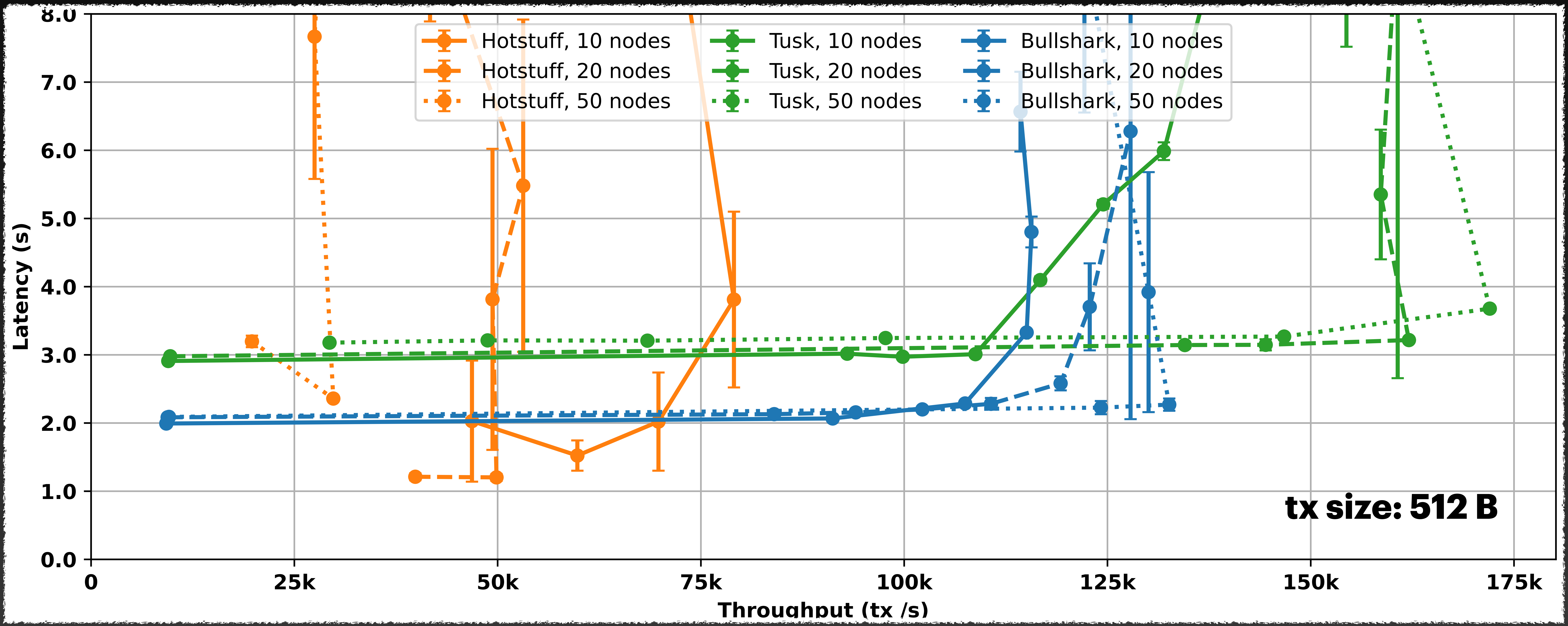
Evaluation

Experimental setup on AWS



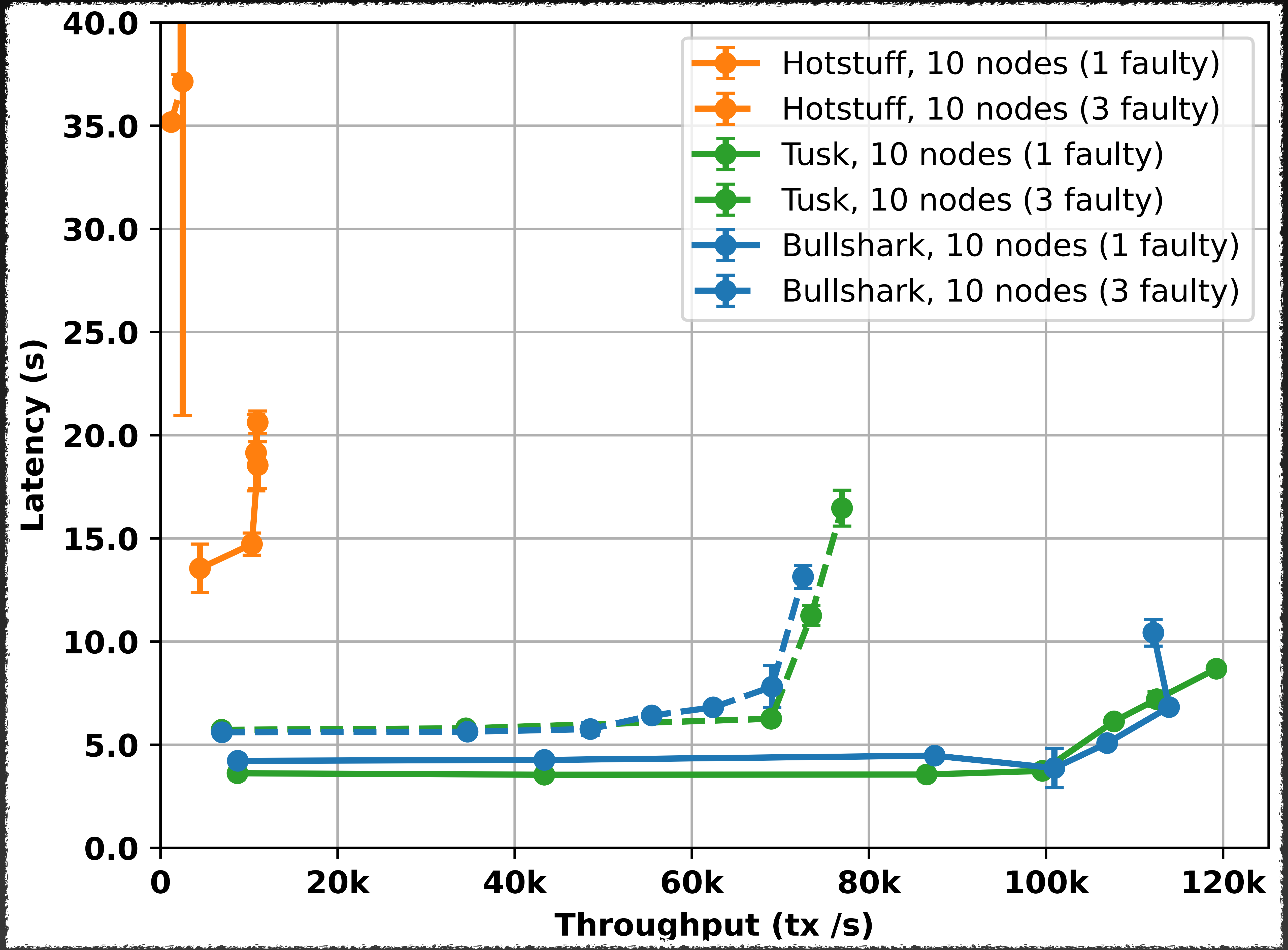
Evaluation

Throughput latency graph



Evaluation

Performance under faults



Summary

Bullshark

- Zero-message overhead, no view-change, no common-coin
- Disseminate data with Narwhal, exploits periods of synchrony

- **Paper:** https://sonnino.com/papers/bullshark.pdf
- **Code:** https://github.com/asonnino/narwhal

Engineering

Lessons Learned

Evaluation

Our biggest mistakes

- 😫 Add crash-recovery after-the-fact
- 😫 Add the synchroniser after-the-fact
- 😫 Add epoch changes after-the-fact
- 😫 Do not benchmark from day 1
- 😫 Start with fancy crypto
- 😫 Hide away serialisation
- 😫 Complex networked systems
- 😫 Isolate modules as in papers
- 😫 (Use grpc and magic network stack)

Evaluation

Our biggest mistakes

😫 Add crash-recovery after-the-fact

😫 Add the synchroniser after-the-fact

😫 Add epoch changes after-the-fact

- **What is the minimum state you need to persist across crash-recovery?**
- **The synchroniser will eventually be your bottleneck / source of instability**
- **Epoch changes are more complex than they look (sync new validators/ update configs from chain) — Advise: kill the node and reboot it.**

Evaluation

Our biggest mistakes

😫 Add crash-recovery after-the-fact

😫 Add the synchroniser after-the-fact

😫 Add epoch changes after-the-fact

😫 Do not benchmark from day 1

- **Many concurrency bugs found on WAN benchmarks under high load**
- **Spent months optimising blinding**

Evaluation

Our biggest mistakes

😫 Add crash-recovery after-the-fact

😫 Add the synchroniser after-the-fact

😫 Add epoch changes after-the-fact

😫 Do not benchmark from day 1

😫 Start with fancy crypto

😫 Hide away serialisation

- **Huge complexity; resulted redundant crypto operations**
- **Crypto serialisation was a bottleneck**

Evaluation

Our biggest mistakes

- 😫 Add crash-recovery after-the-fact
- 😫 Add the synchroniser after-the-fact
- 😫 Add epoch changes after-the-fact
- 😫 Do not benchmark from day 1
- 😫 Start with fancy crypto
- 😫 Hide away serialisation
- 😫 Complex networked systems
  - **Harder crash-recovery / should start with collocated workers**

Evaluation

Our biggest mistakes

- 😫 Add crash-recovery after-the-fact
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- 😫 Add epoch changes after-the-fact
- 😫 Do not benchmark from day 1
- 😫 Start with fancy crypto
- 😫 Hide away serialisation
- 😫 Complex networked systems
- **Debugging / perf improvement nightmare**

- 😫 Isolate modules as in papers
- 😫 (Use grpc and magic network stack)

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Alberto Sonnino

EXTRA

Benchmark of BFT Systems

Evaluation

Typical mistakes

- 😫 Forgo persistent storage
- 😫 Do not sanitise messages
- 😫 Local/LAN benchmark + ping
- 😫 Many nodes on same machine
- 😫 Change parameters across runs
- 😫 Set transaction size to zero
- 😫 Preconfigure nodes with txs
- 😫 Send a single burst of transactions
- 😫 Benchmark for a few seconds
- 😫 Start timer in the batch maker
- 😫 Evaluate latency w/ only the first tx
- 😫 Separate latency and throughput
- 😫 Only benchmark happy path

Evaluation

Set the benchmark parameters

```
Faults: 0 node(s)

Committee size: 10 node(s)

Transaction size: 512 B
```

Evaluation

Set the benchmark parameters

Faults: 0 node(s)

Committee size: 10 node(s)

Transaction size: 512 B

Header size: 1,000 B

Max header delay: 200 ms

GC depth: 50 round(s)

Sync retry delay: 5,000 ms

Sync retry nodes: 3 node(s)

batch size: 500,000 B

Max batch delay: 200 ms

Evaluation

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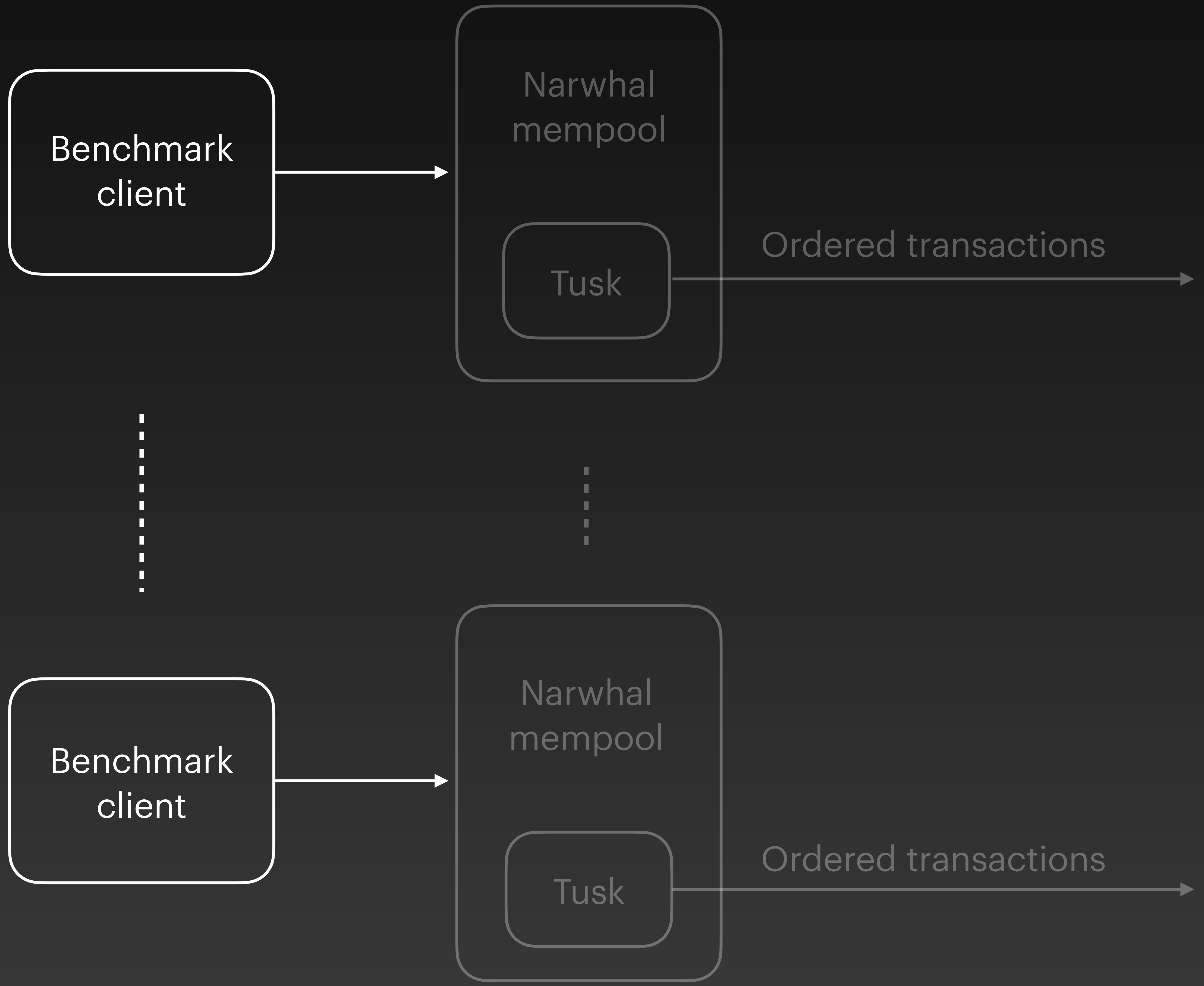
Evaluation

Benchmark clients

Fixed input rate

For a long time (minutes)



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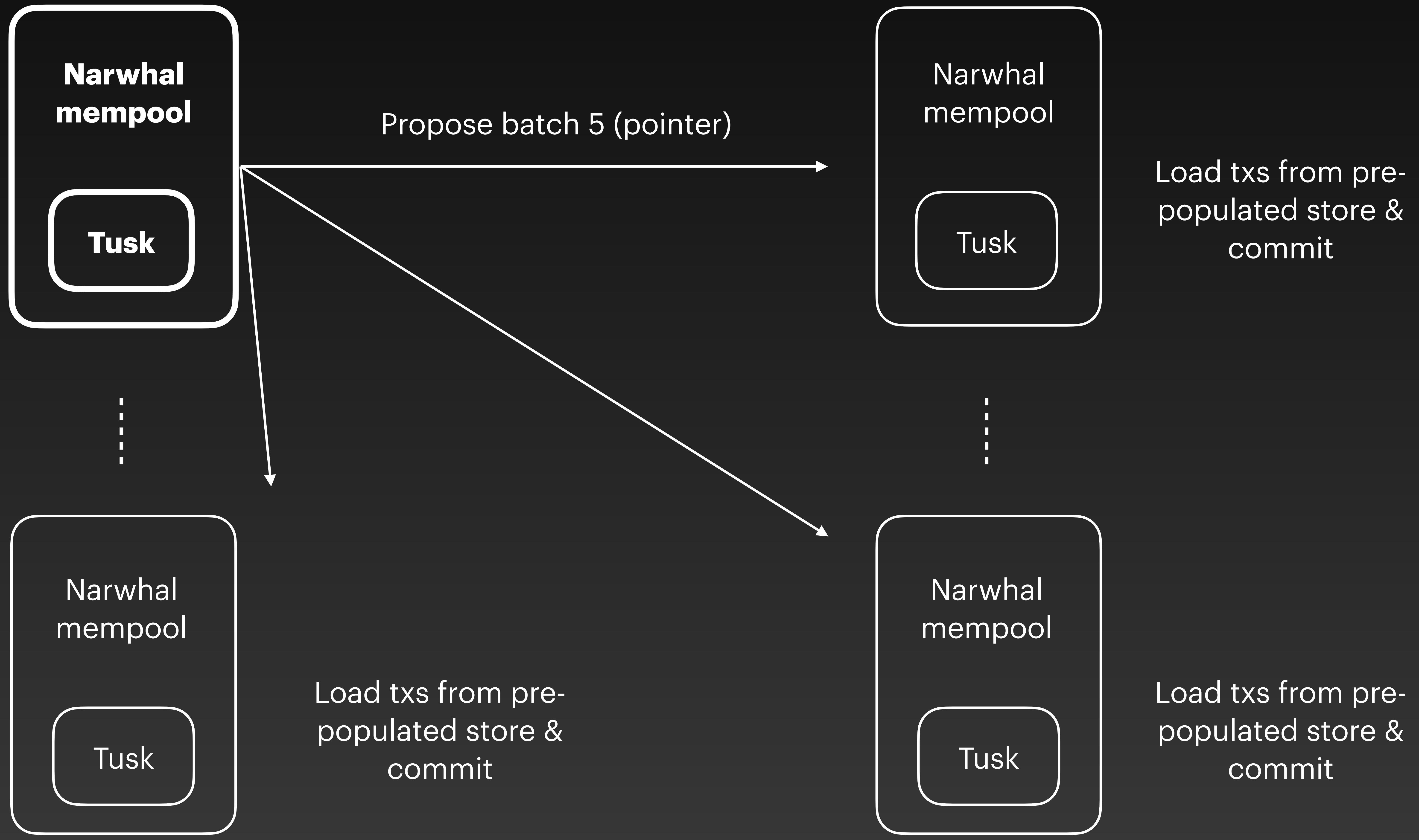
Evaluation
Typical mistake



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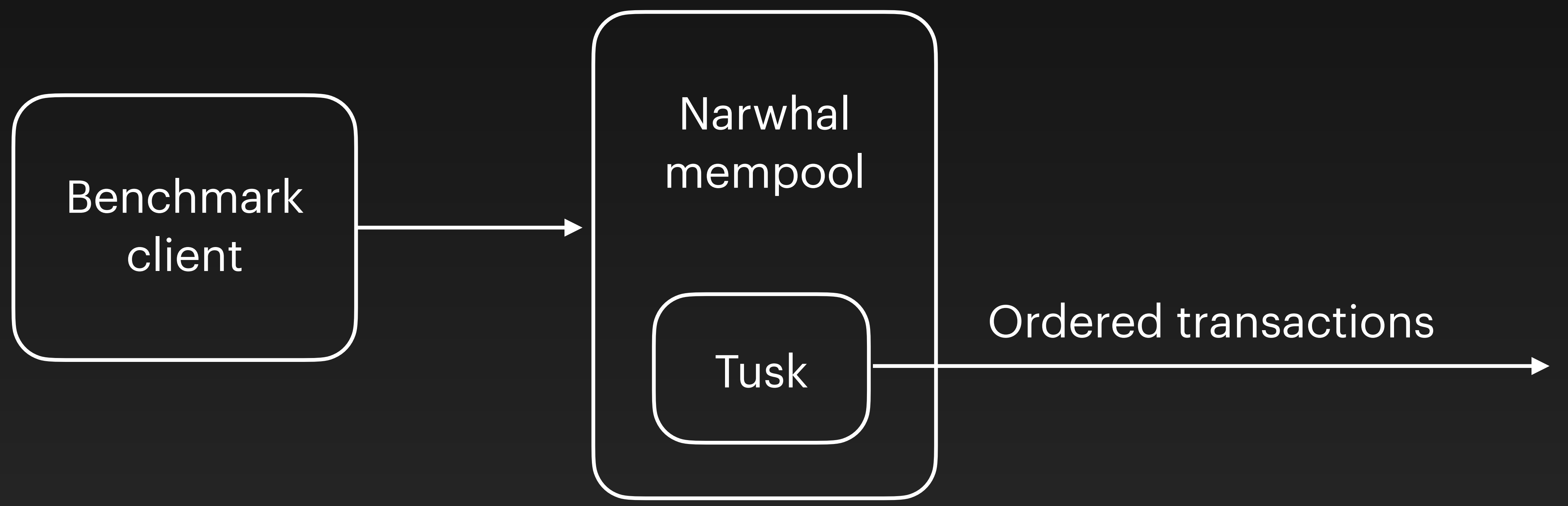
Evaluation

Typical mistake

send 50k txs (once)

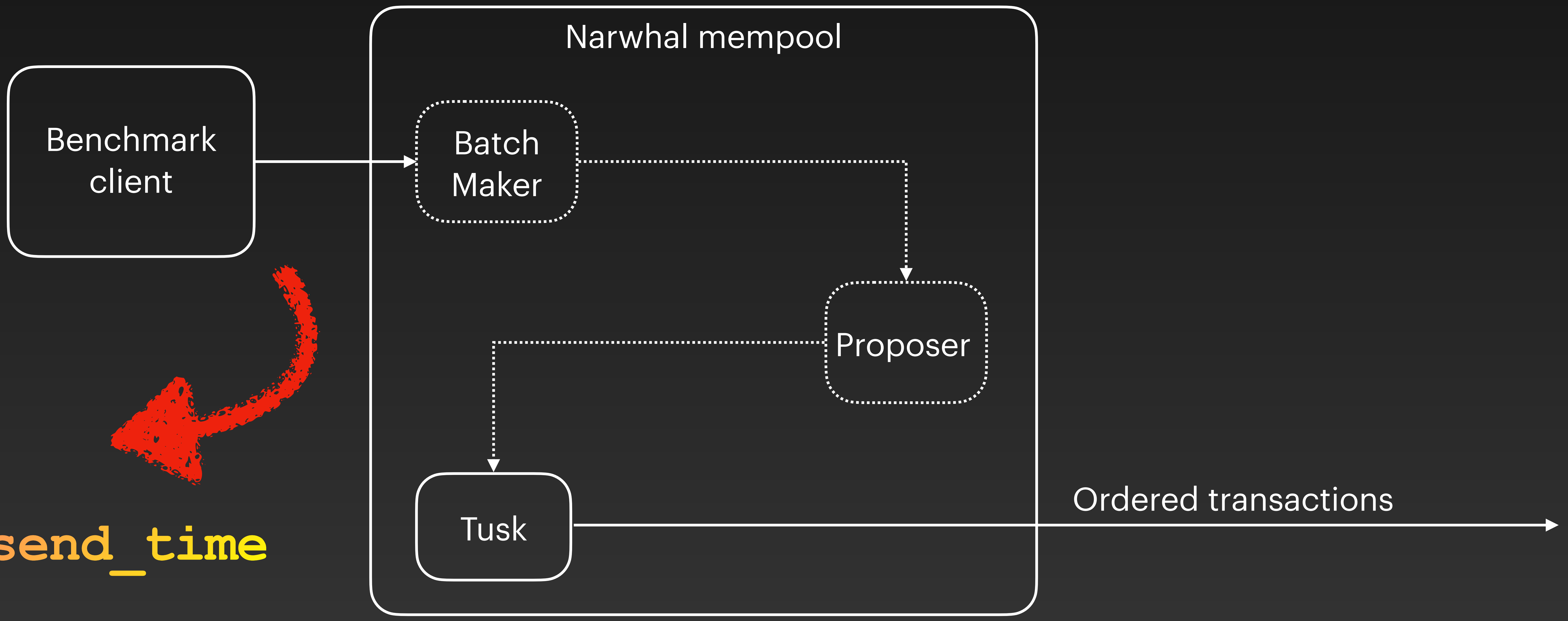


output after 400 ms

😫 TPS = 50k / 400ms = 125k tx/s 😫

Evaluation

Instrument the codebase



`bench_start_time`

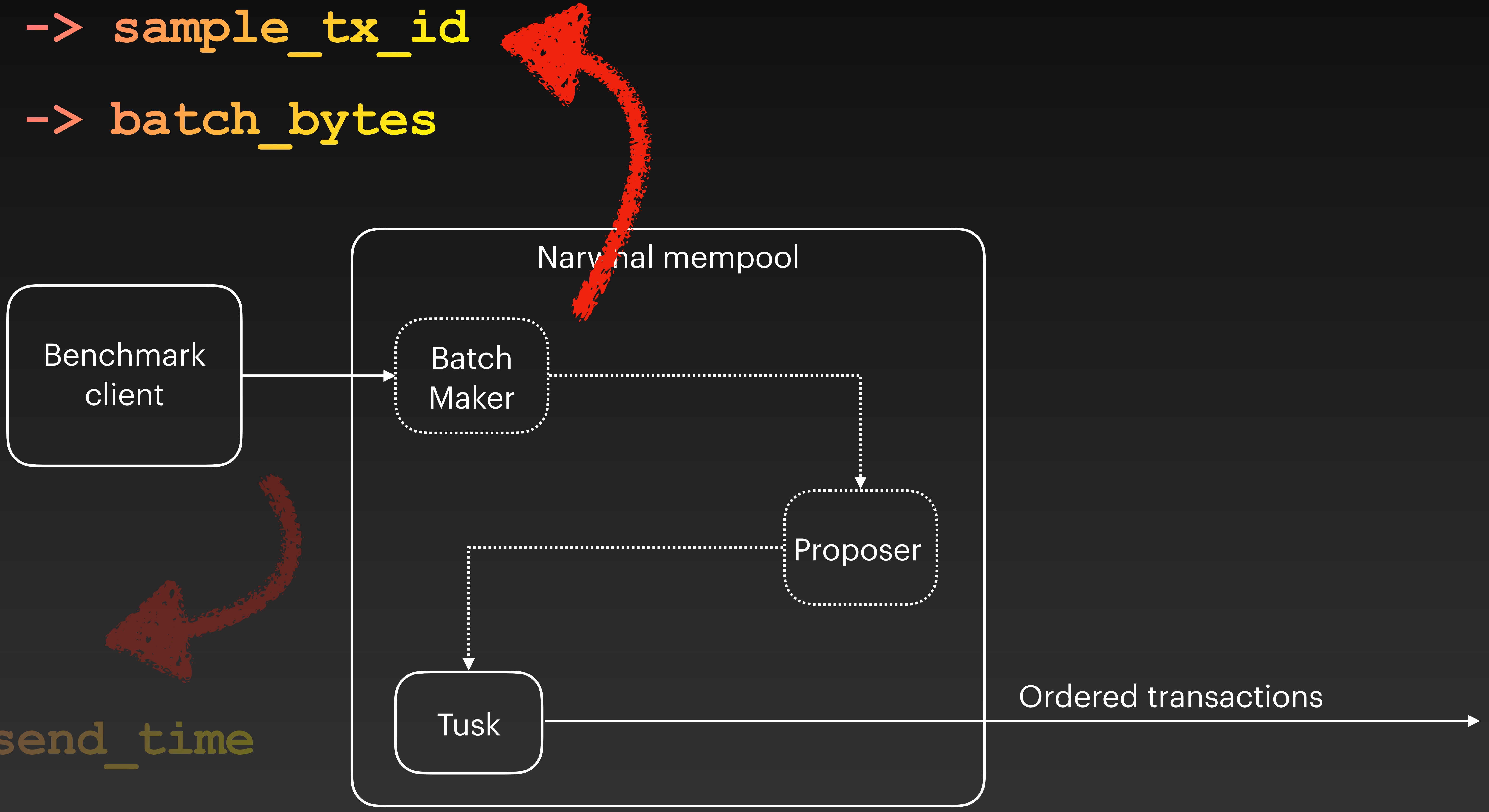
`sample_tx_id -> send_time`

Evaluation

Instrument the codebase

`batch_digest -> sample_tx_id`

`batch_digest -> batch_bytes`



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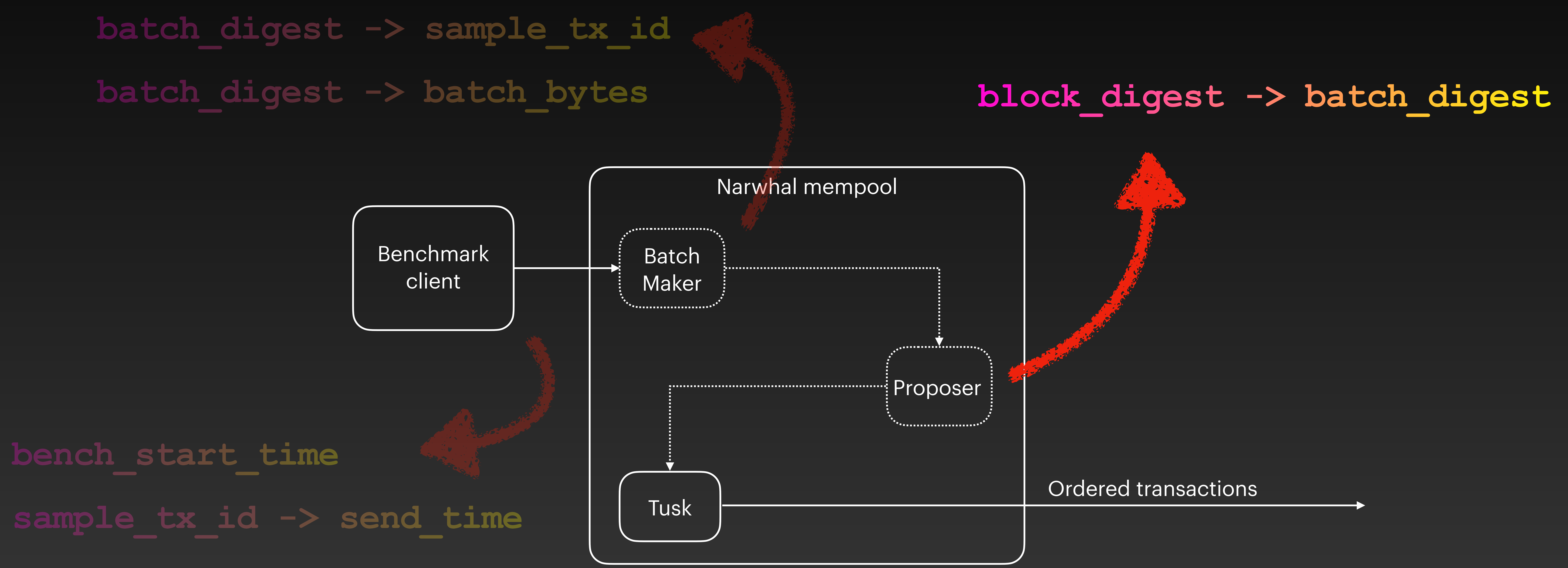
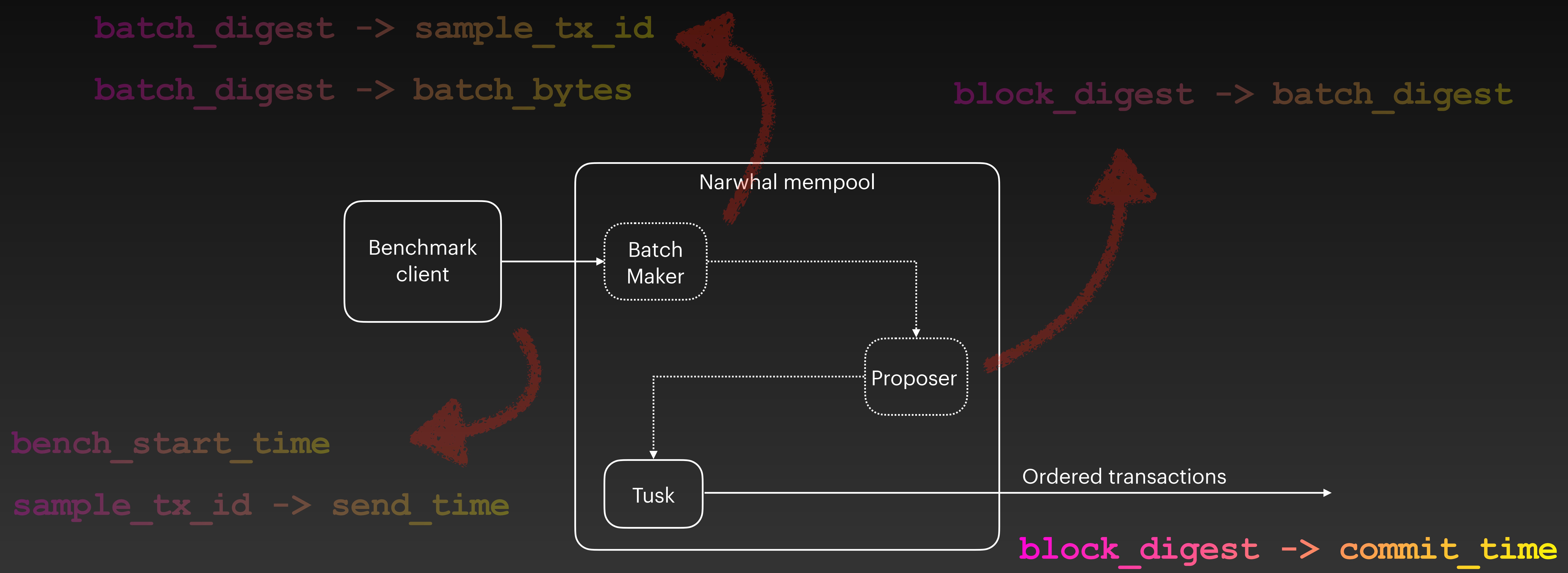
Evaluation

Instrument the codebase



Evaluation

Instrument the codebase

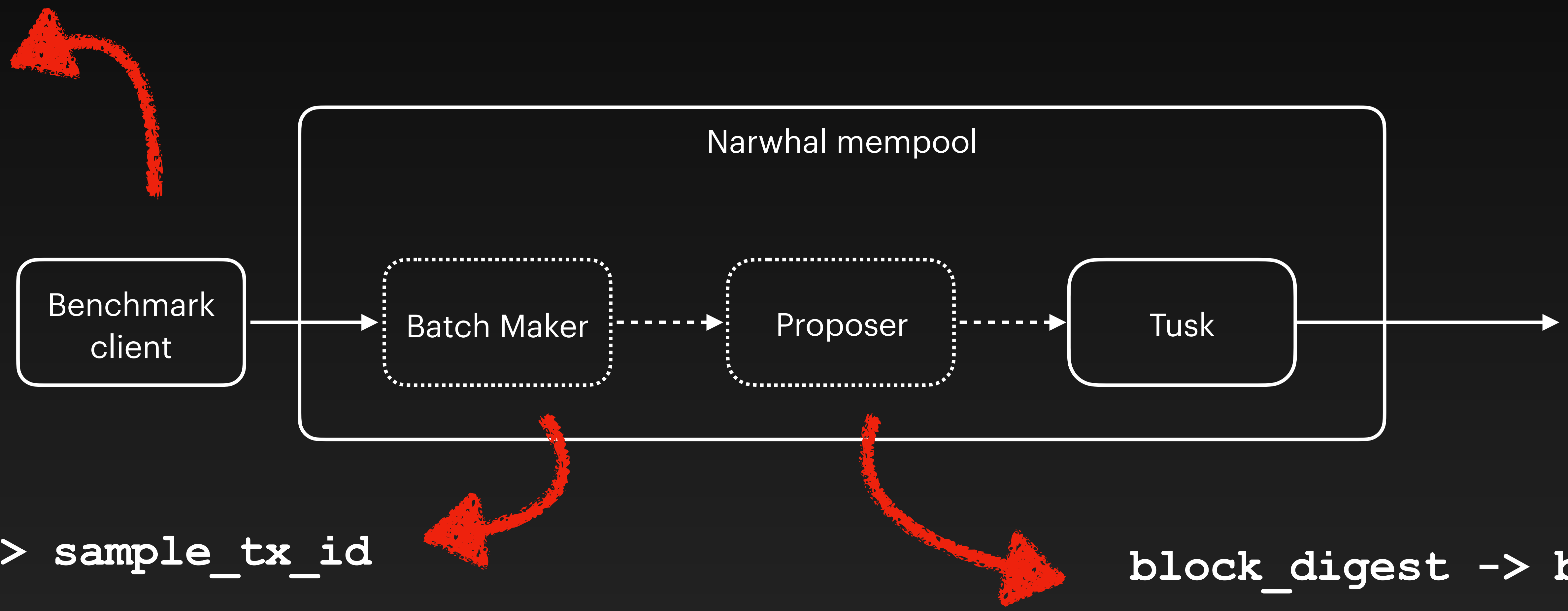


Evaluation

Compute throughput

bench_start_time

sample_tx_id -> send_time



block_digest -> commit_time

batch_digest -> sample_tx_id

batch_digest -> batch_bytes

block_digest -> batch_digest

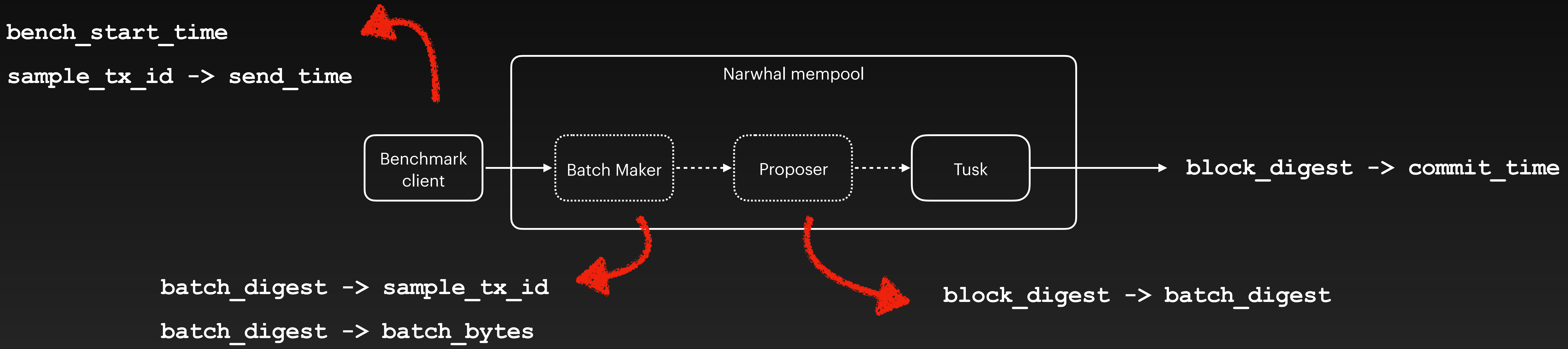
total_time = last_commit_time - bench_start_time

BPS = total_bytes / total_time

TPS = BPS / transaction_size

Evaluation

Compute latency




```
samples = commit_time - send_time

latency = average(samples)
```

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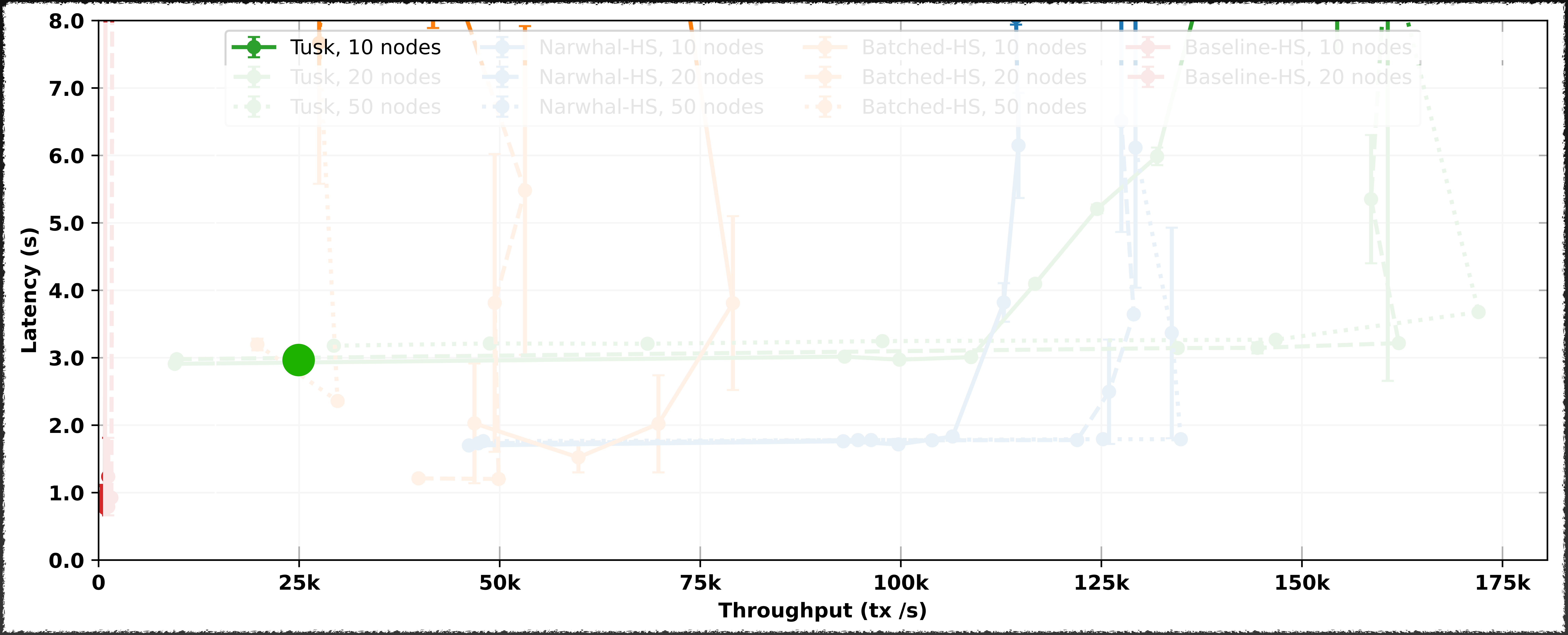
Evaluation

Throughput latency graph



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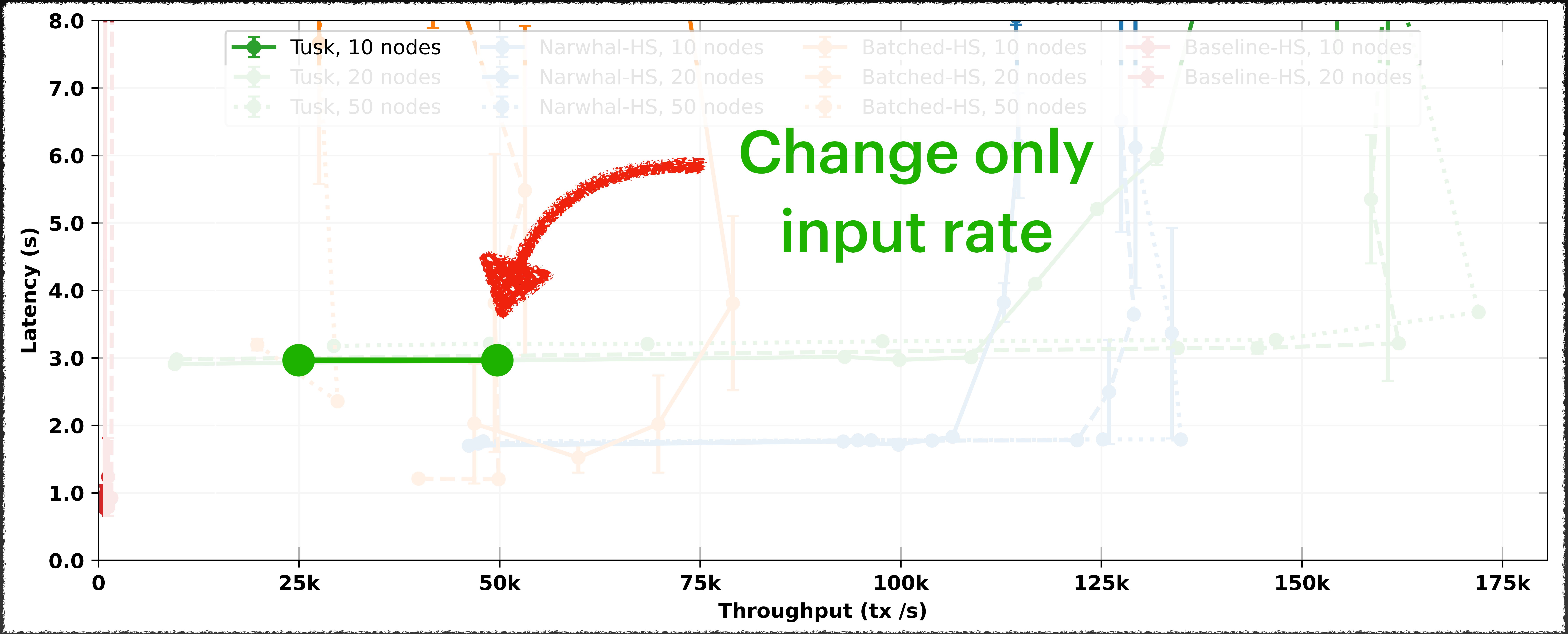

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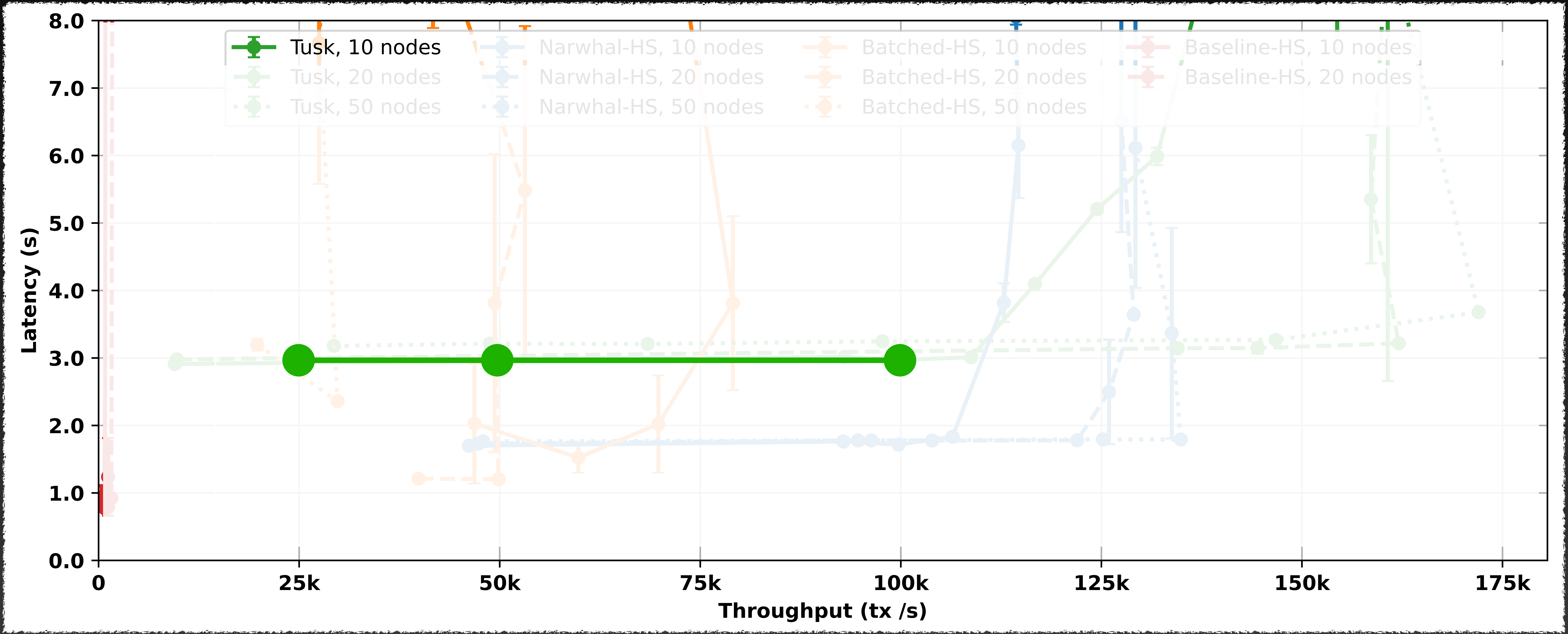

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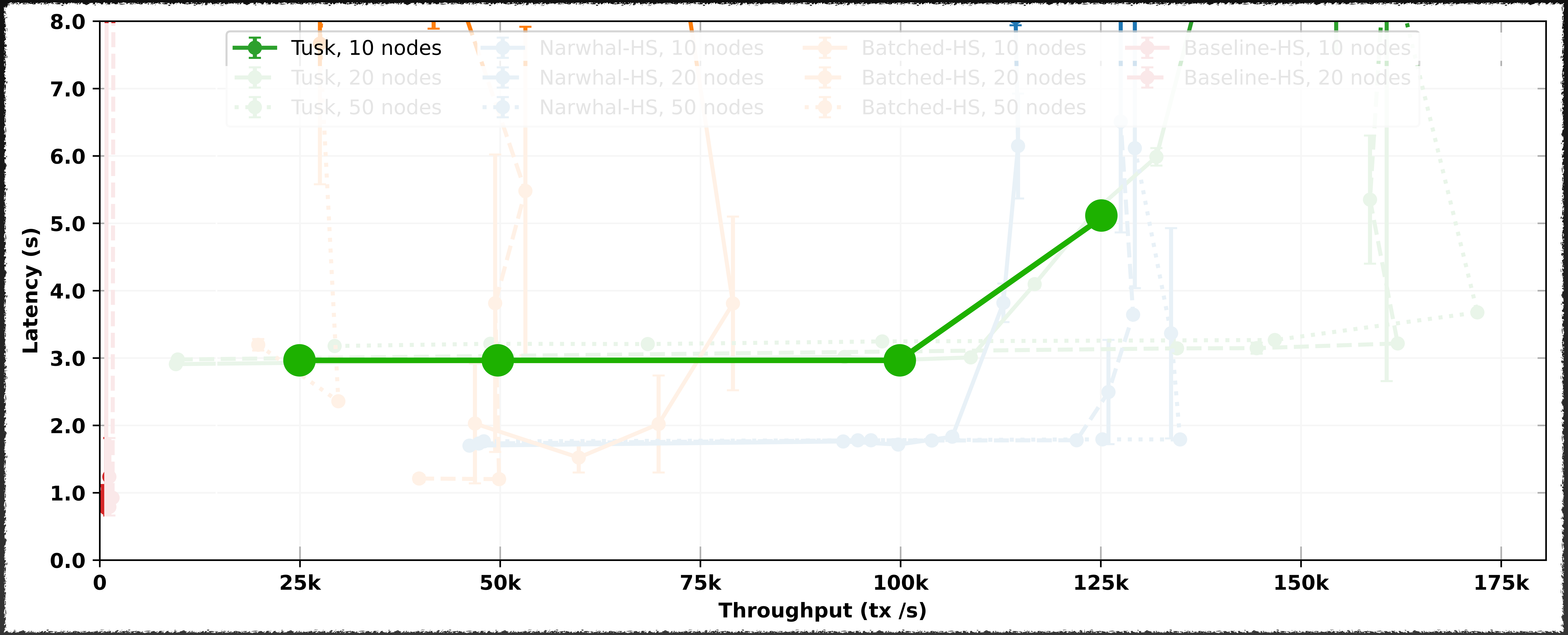

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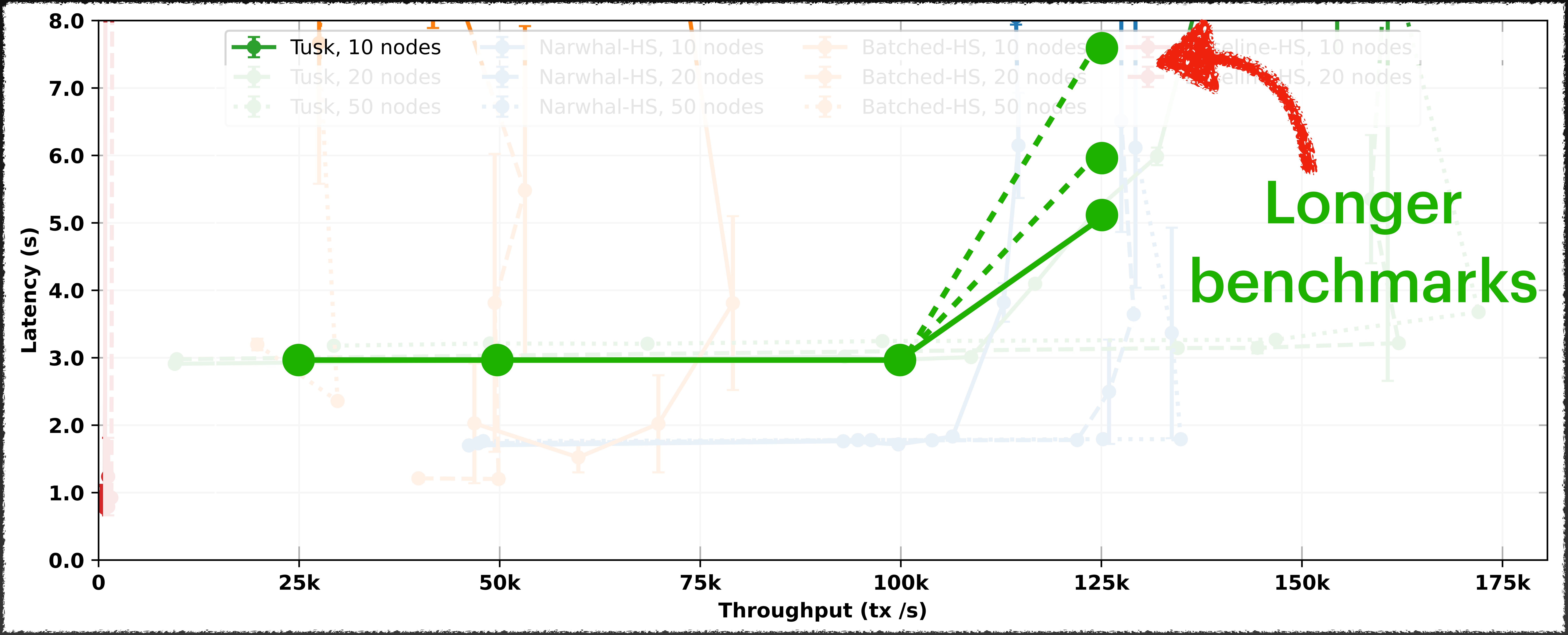

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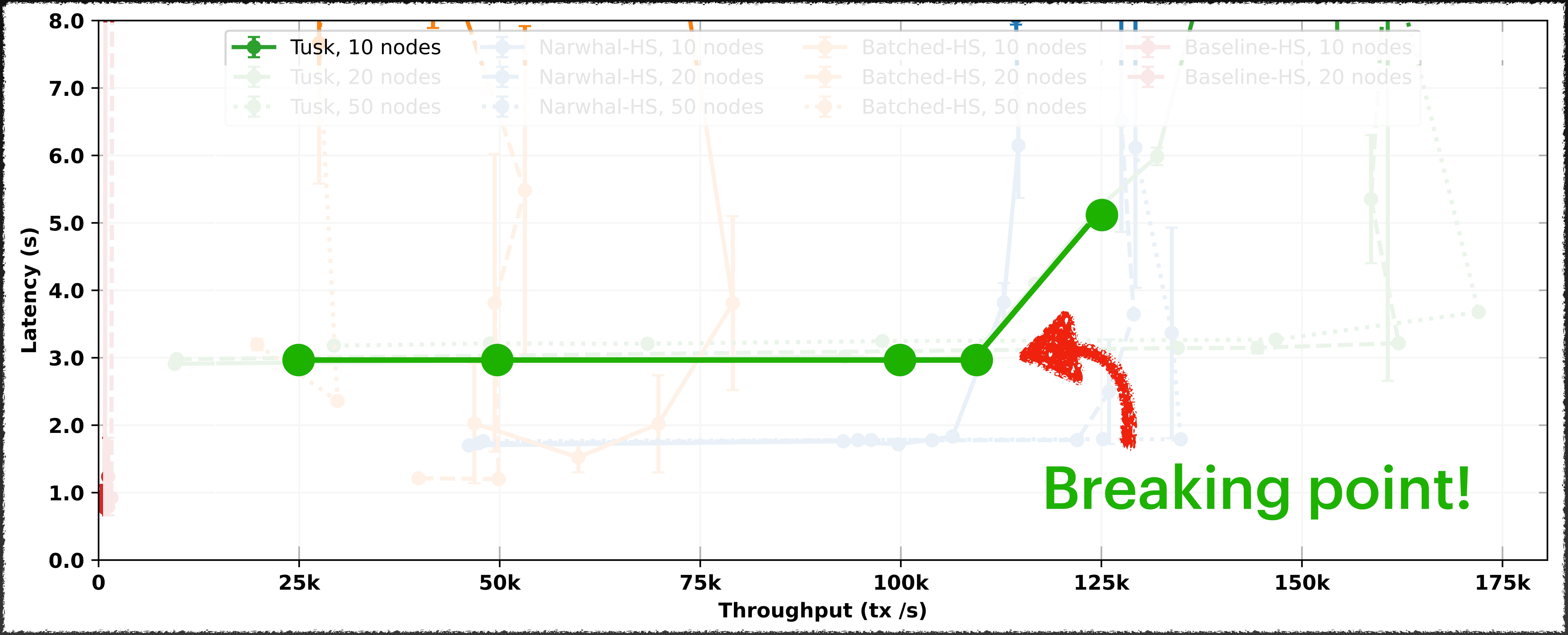


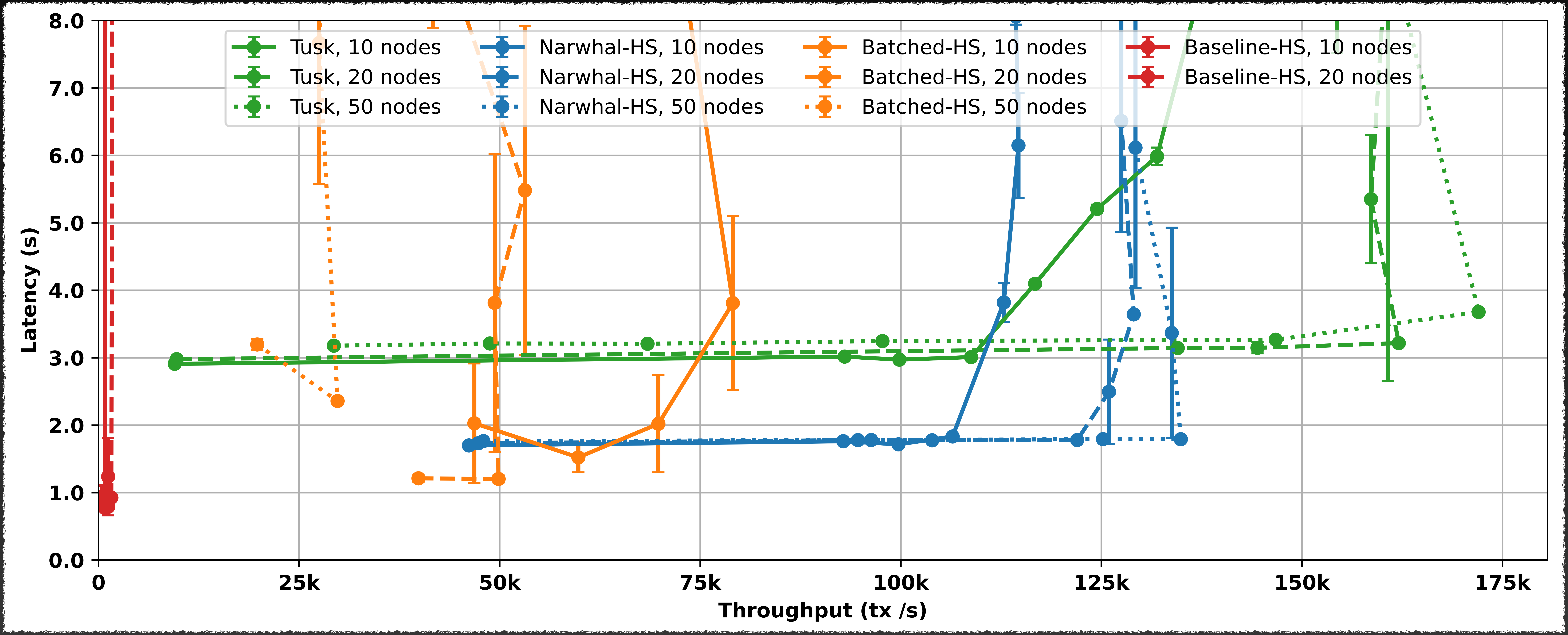
Evaluation

Typical mistakes

- 😫 Forgo persistent storage
- 😫 Do not sanitise messages
- 😫 Local/LAN benchmark + ping
- 😫 Many nodes on same machine
- 😫 Change parameters across runs
- 😫 Set transaction size to zero
- 😫 Preconfigure nodes with txs
- 😫 Send a single burst of transactions
- 😫 Benchmark for a few seconds
- 😫 Start timer in the batch maker
- 😫 Evaluate latency w/ only the first tx
- 😫 Separate latency and throughput
- 😫 Only benchmark happy path

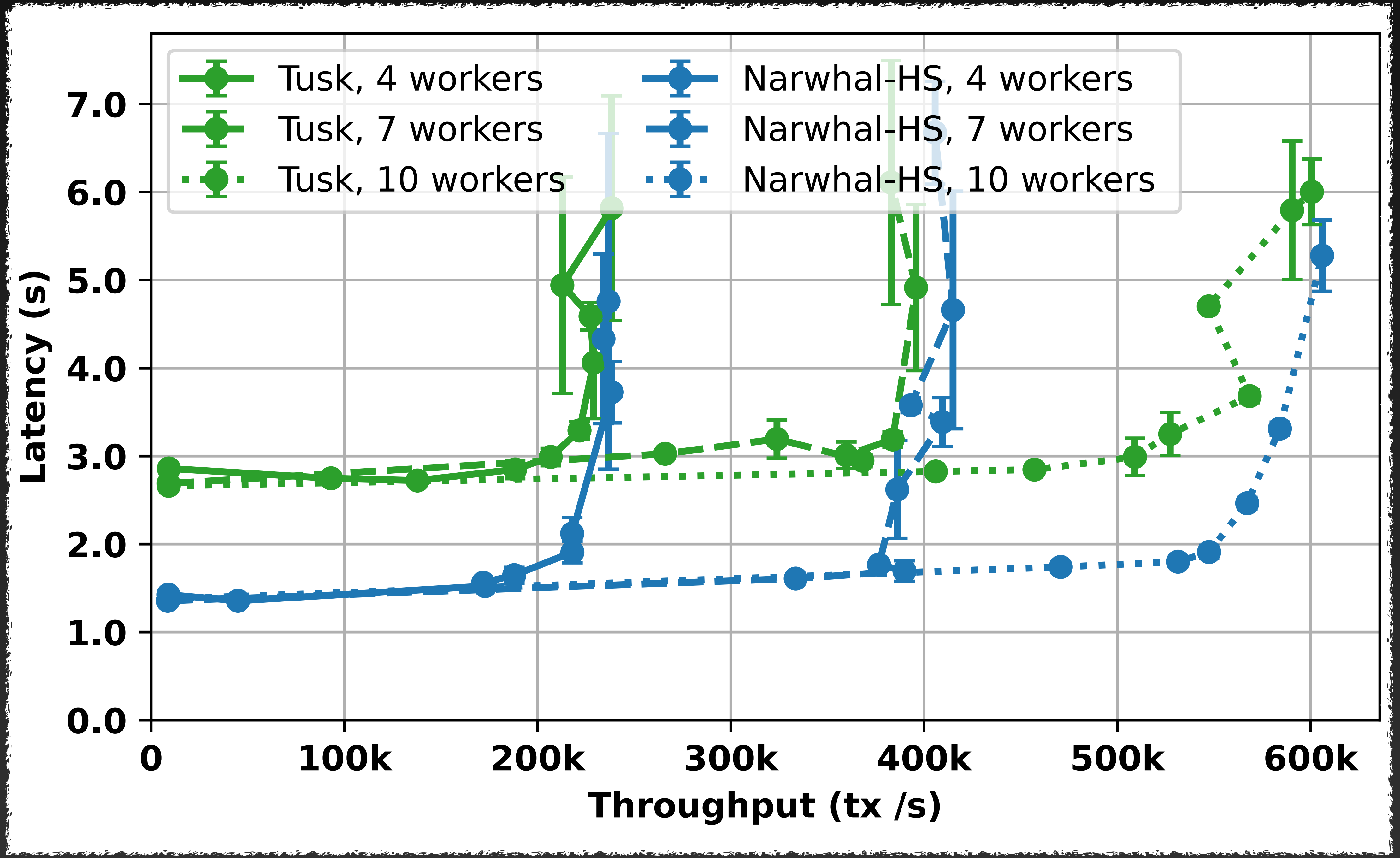
Evaluation

Throughput latency graph



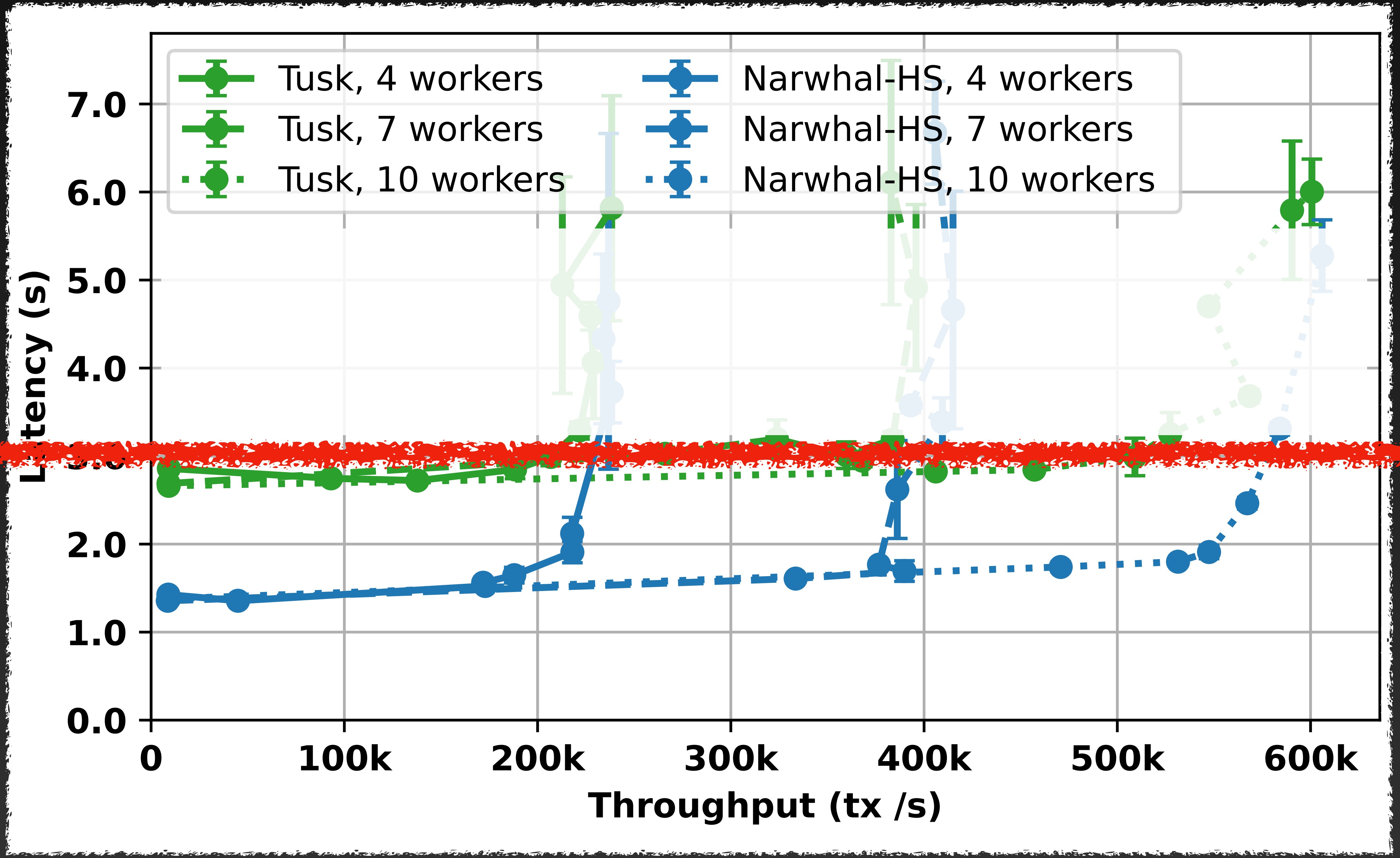
Evaluation

Scalability



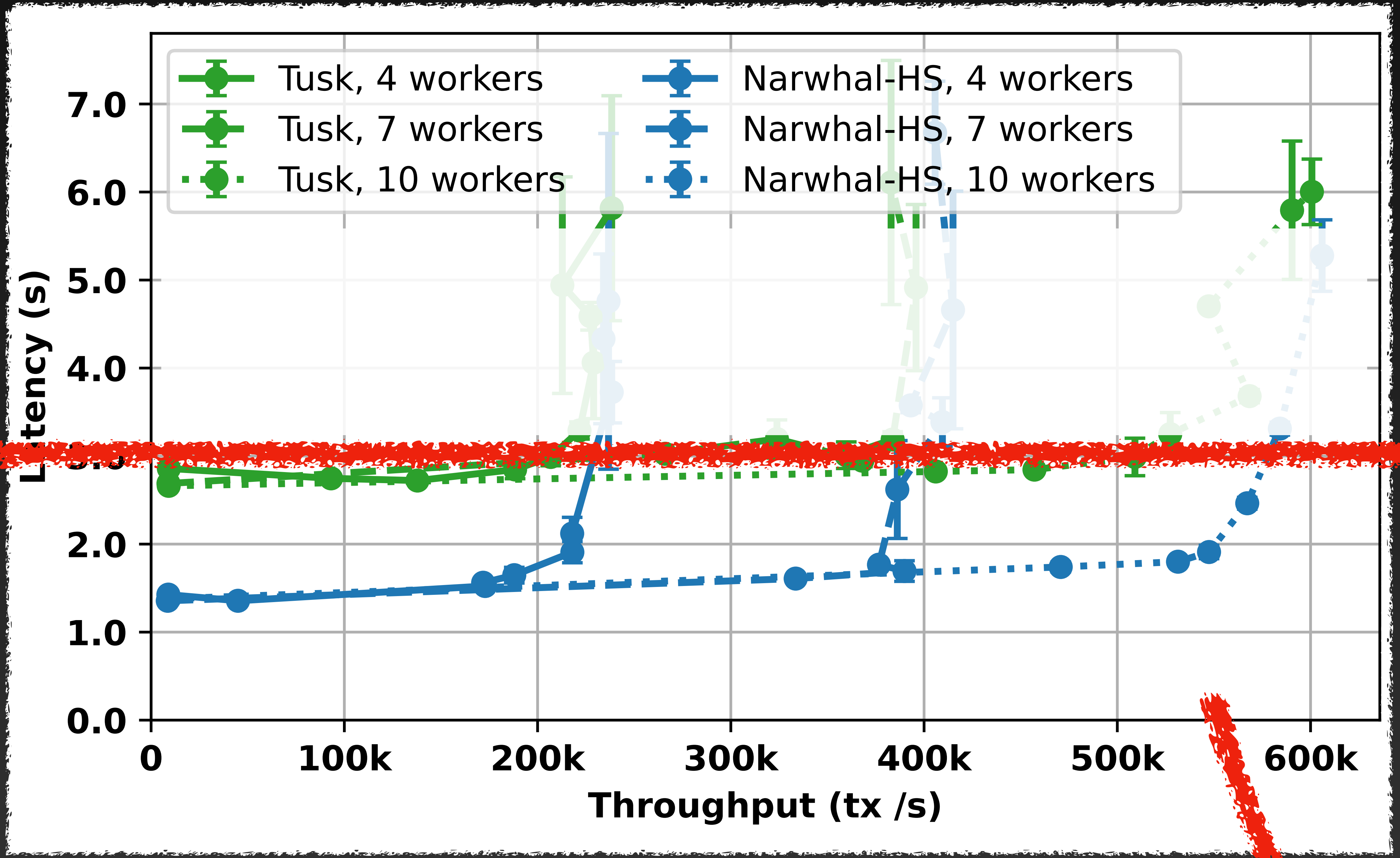
Evaluation

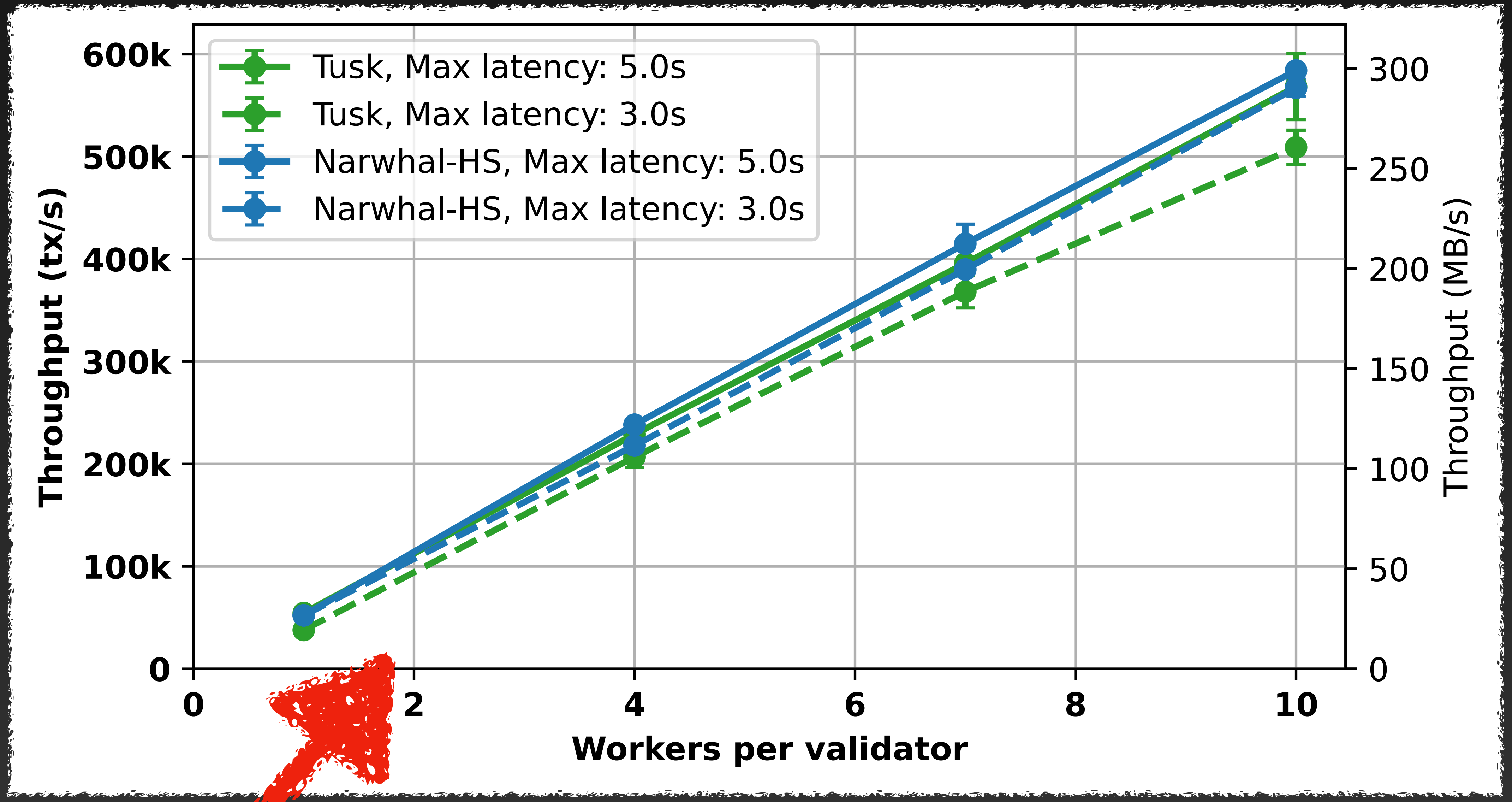
Scalability



Evaluation

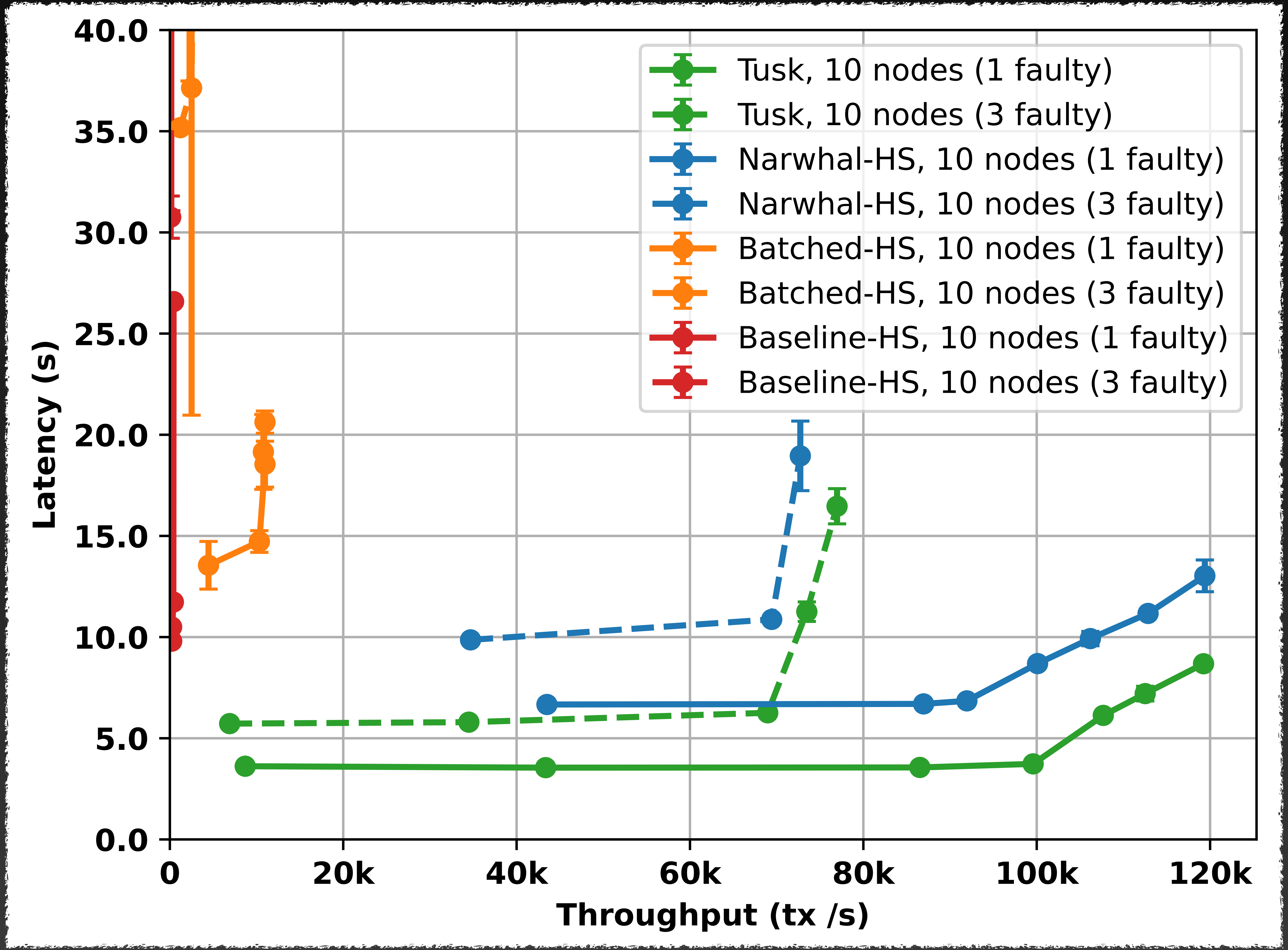
Scalability





Evaluation

Performance under faults



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Evaluation

Still many caveats

- Perfect load balance
- Transaction deduplication
- Synthetic load
- No Byzantine adversary
- No network adversary
- Only AWS network