Efficient DAG-Based Consensus

FAB 22

Alberto Sonnino

Byzantine Fault Tolerance

> 2/3

How to build (really) high performance blockchains

The goal of this talk

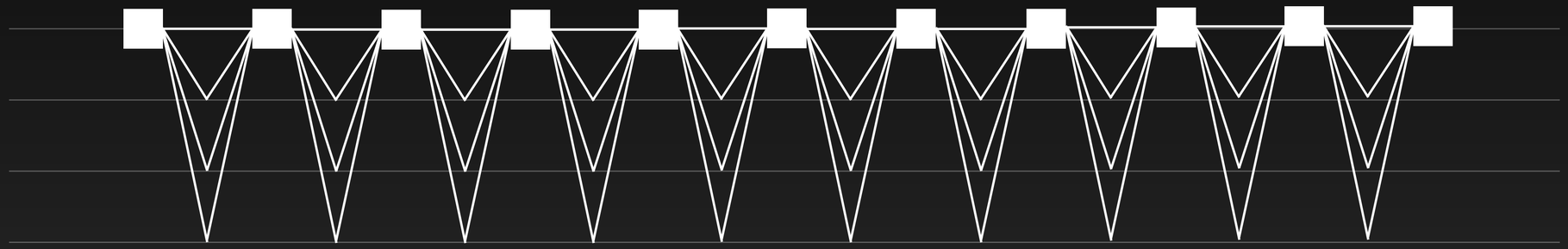
Traditional Designs

Observation

- Monolithic protocol sharing transaction data as part of the consensus
- Optimize overall message complexity of the consensus protocol

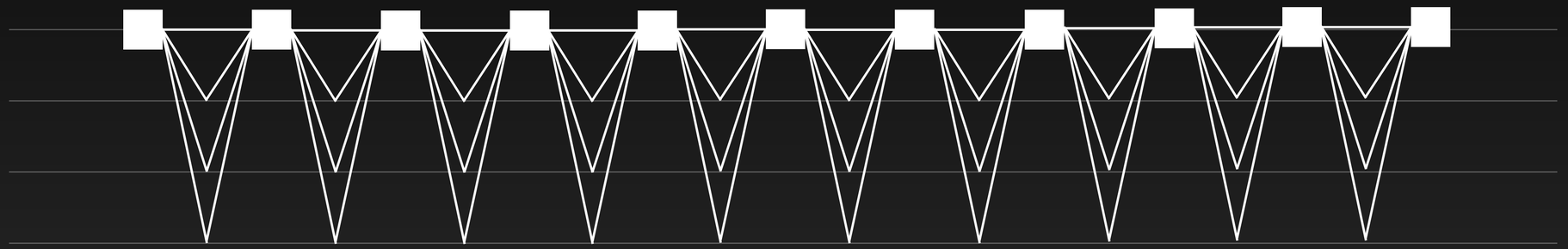
Current Designs

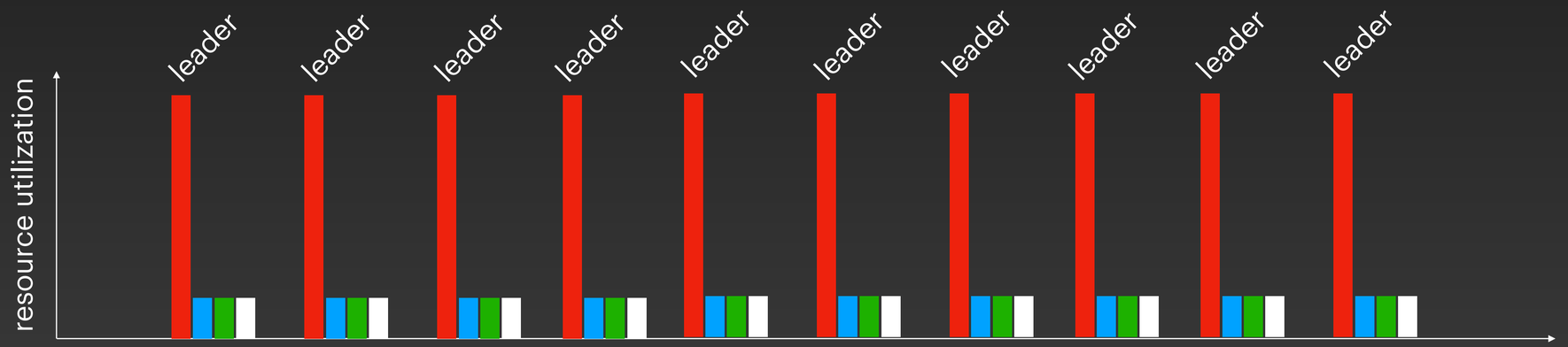
Typical leader-based protocols



Current Designs

Typical leader-based protocols





Data dissemination is the key

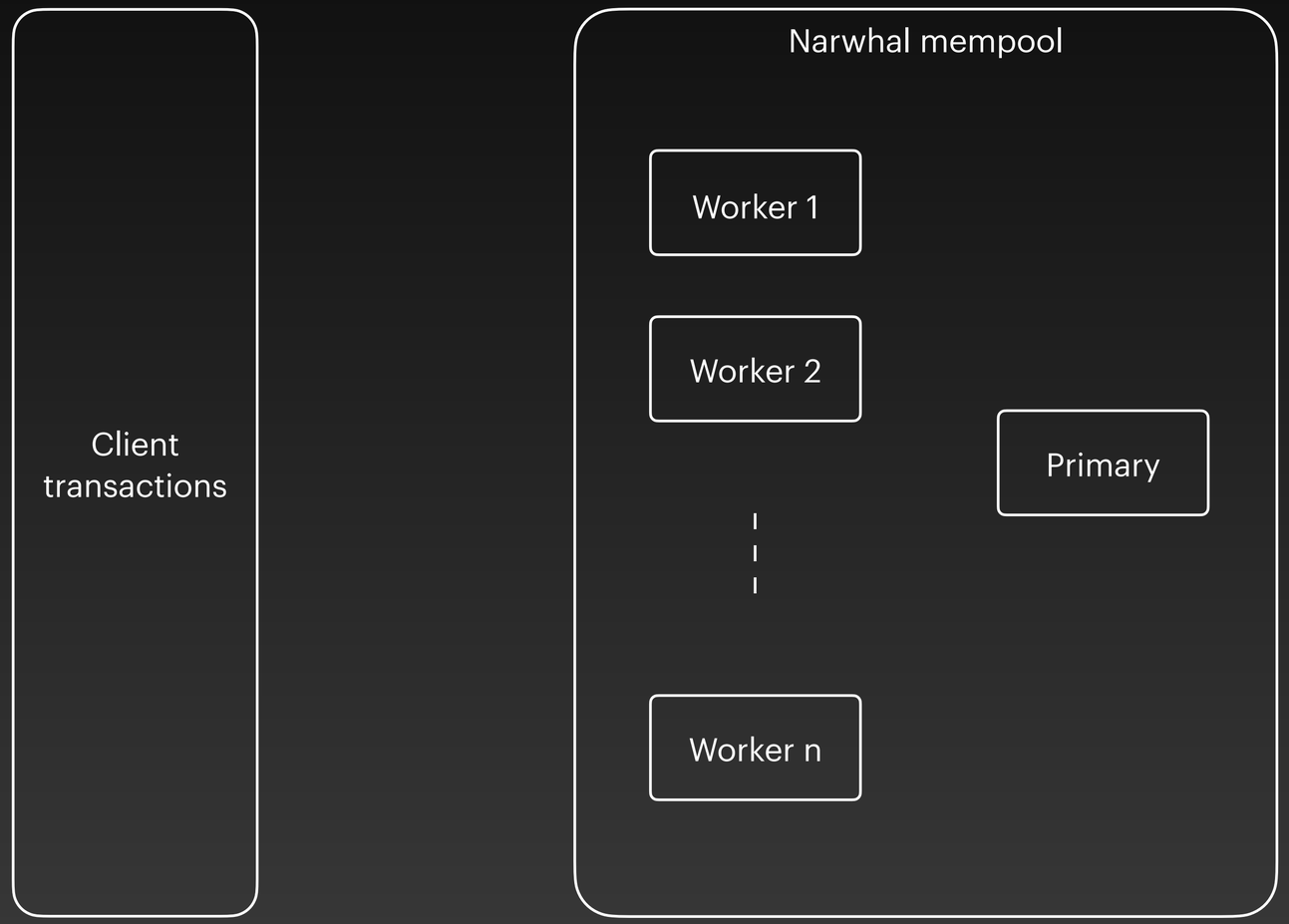
Reaching consensus on metadata is cheap

Narwhal

Dag-based mempool

Narwhal

The workers and the primary



Narwhal

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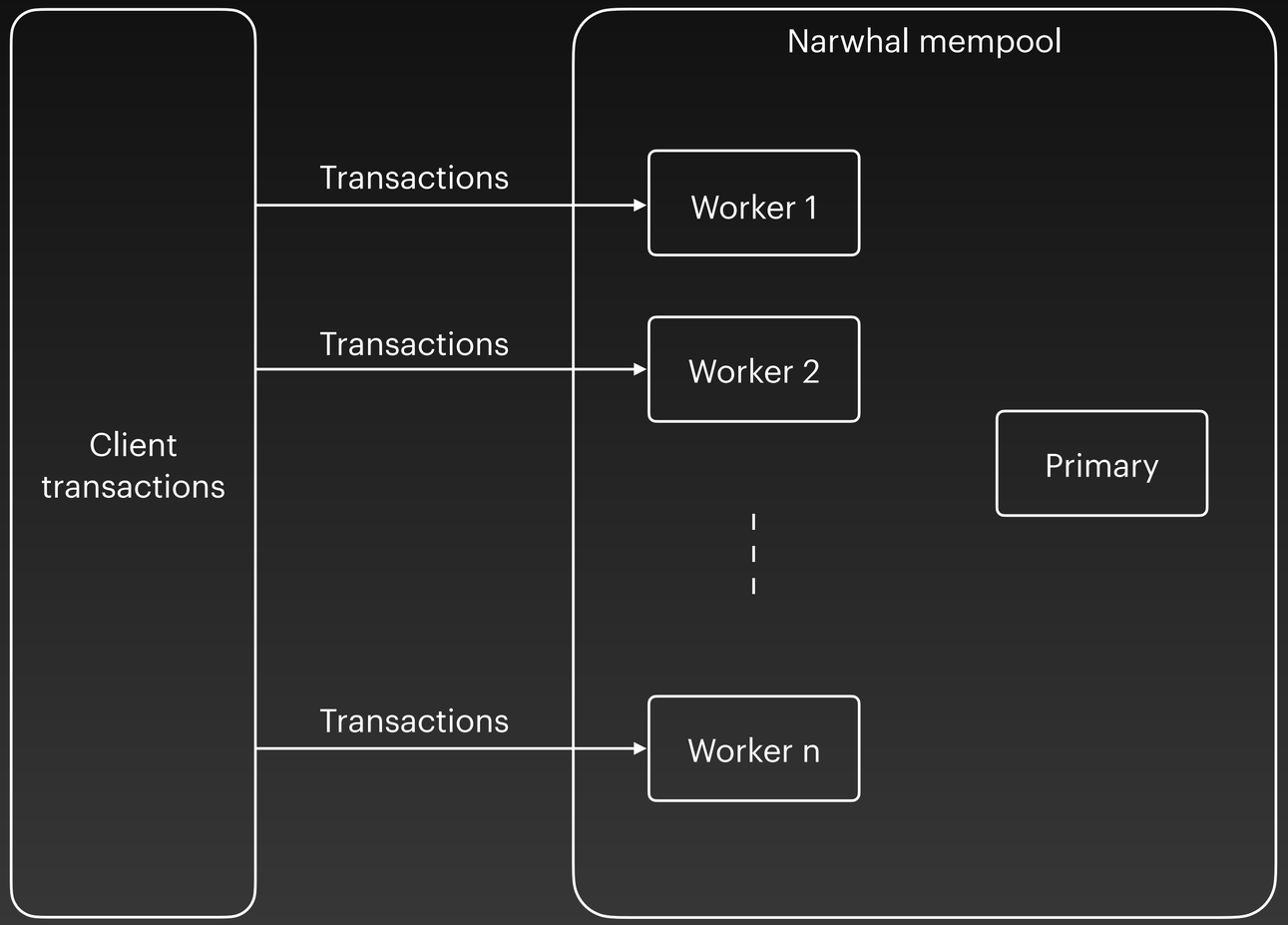

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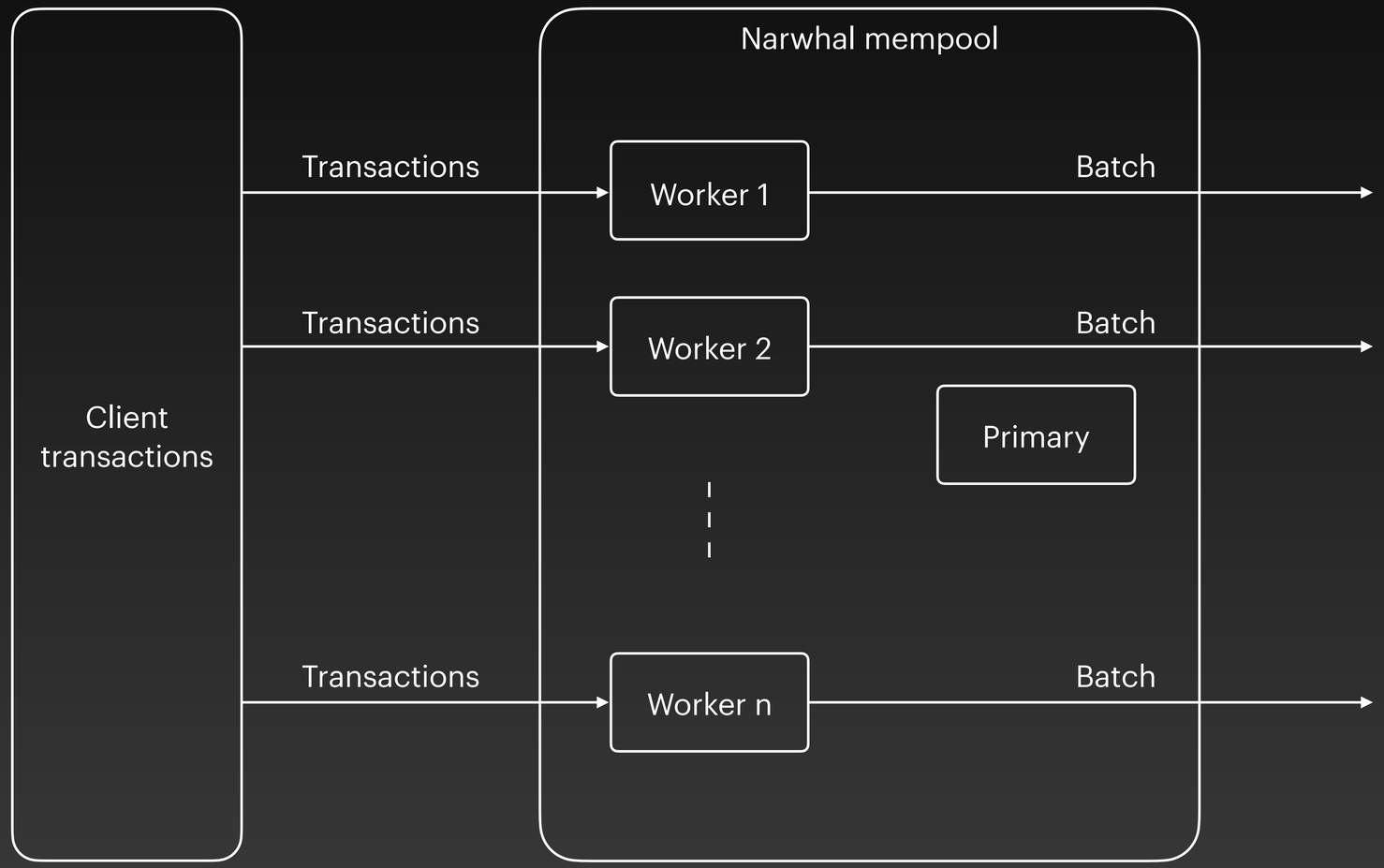

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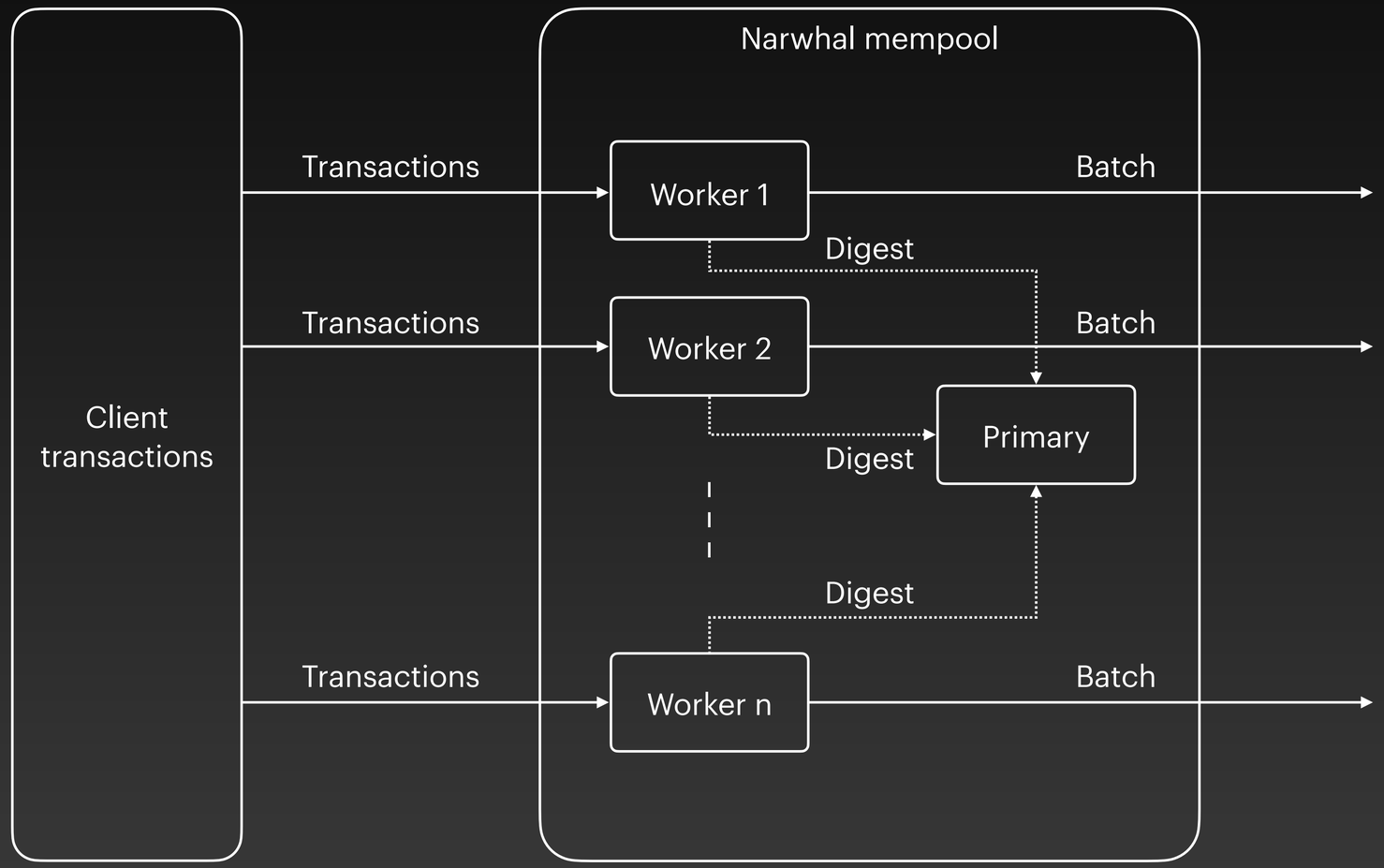

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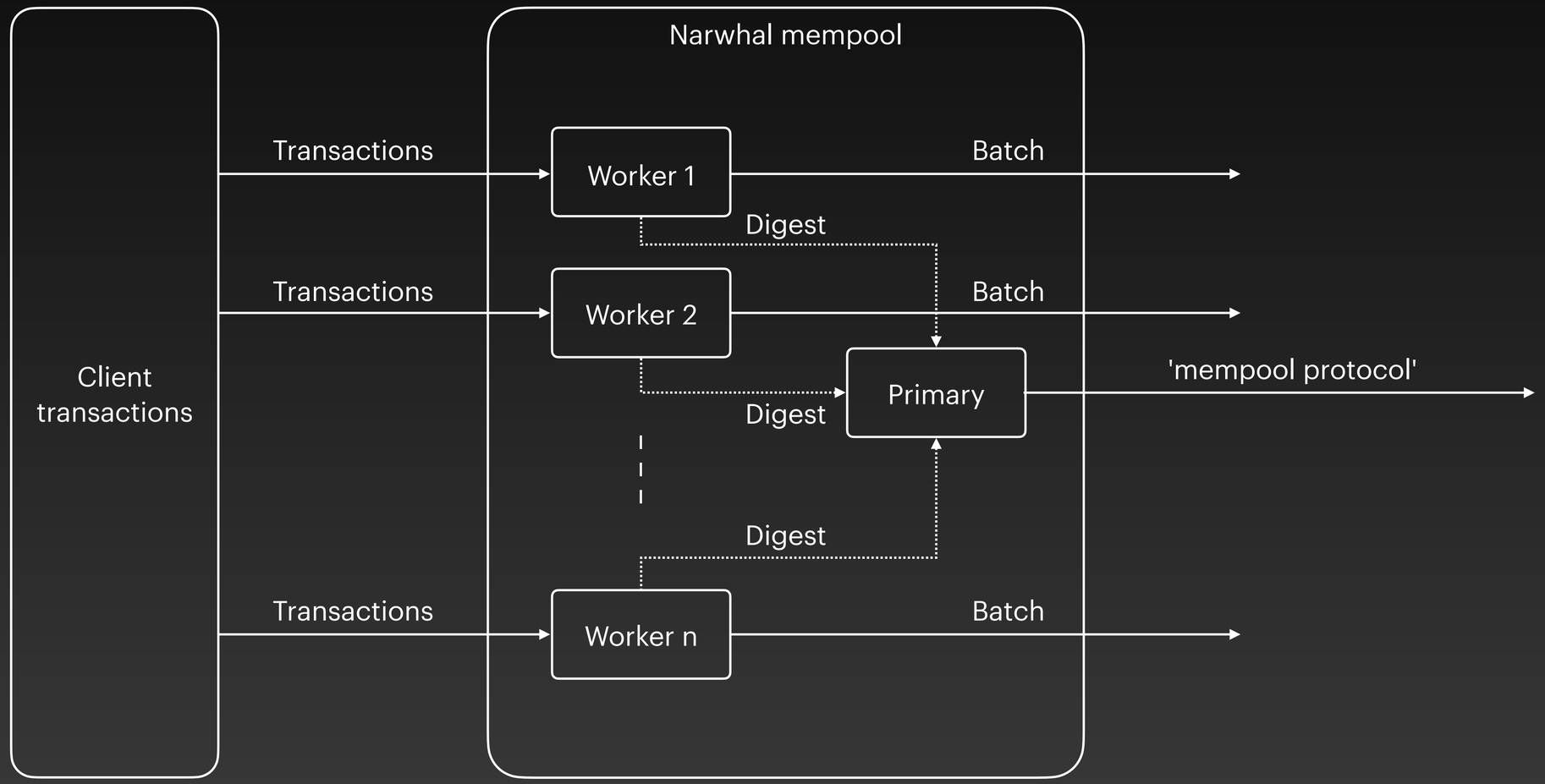
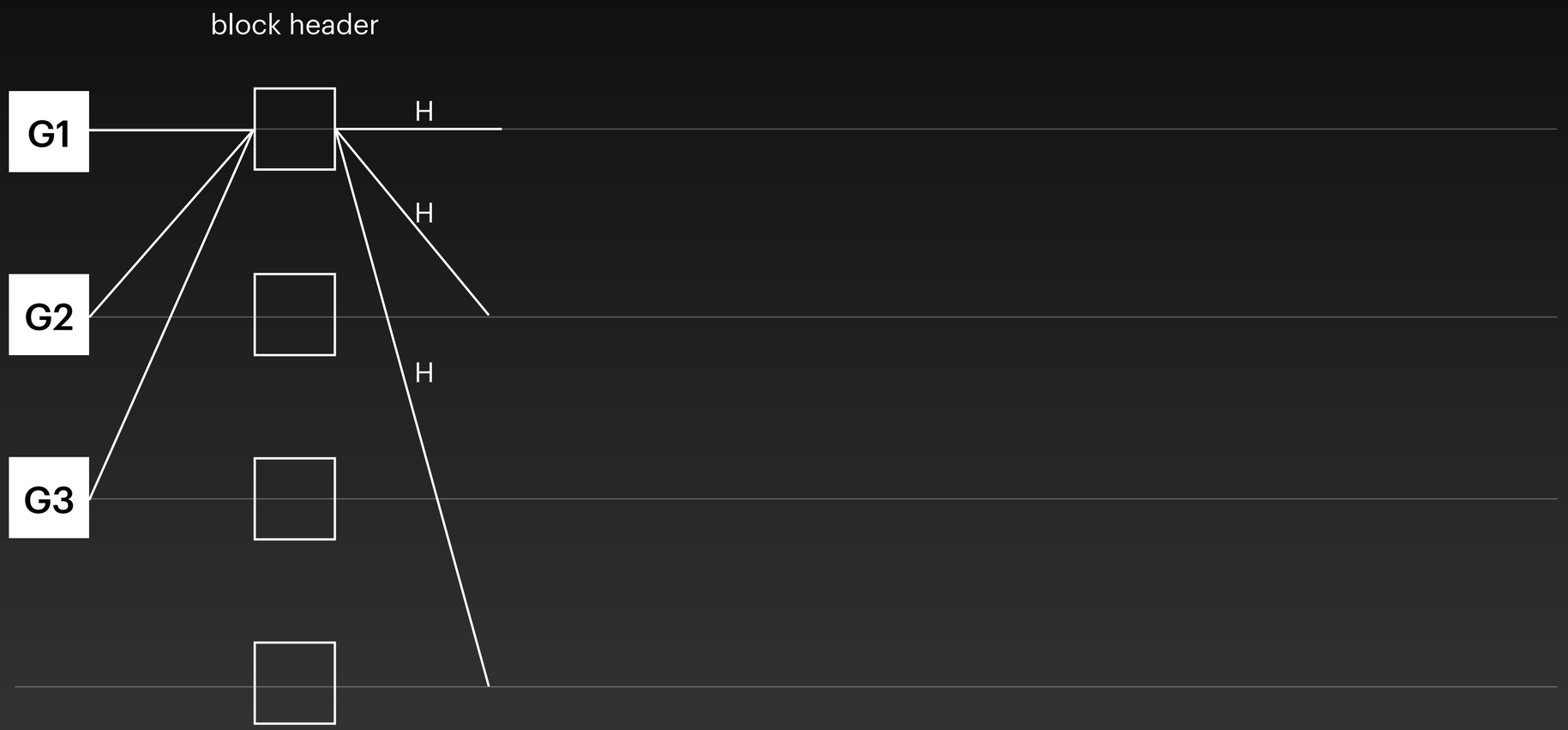


Narwhal

The primary machine



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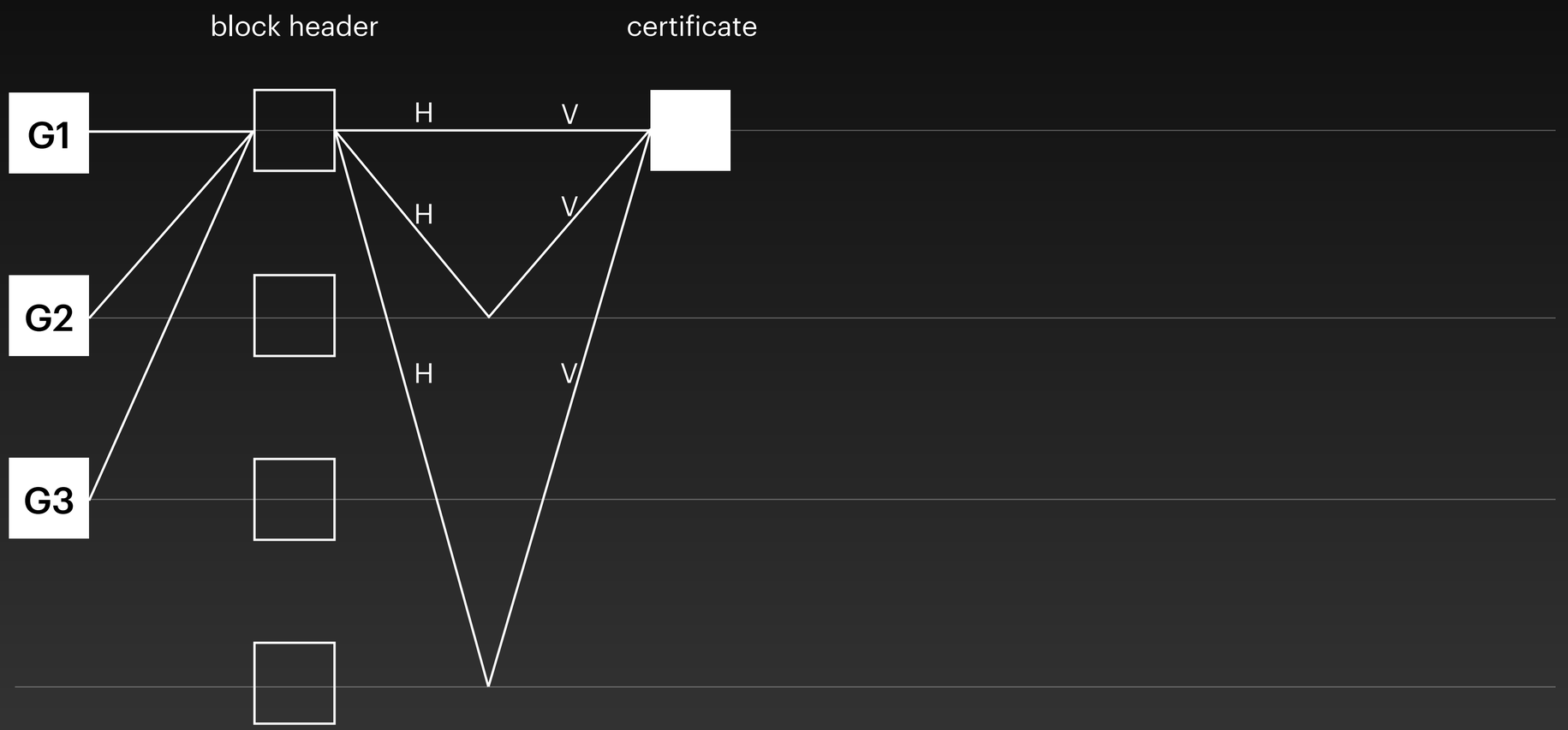

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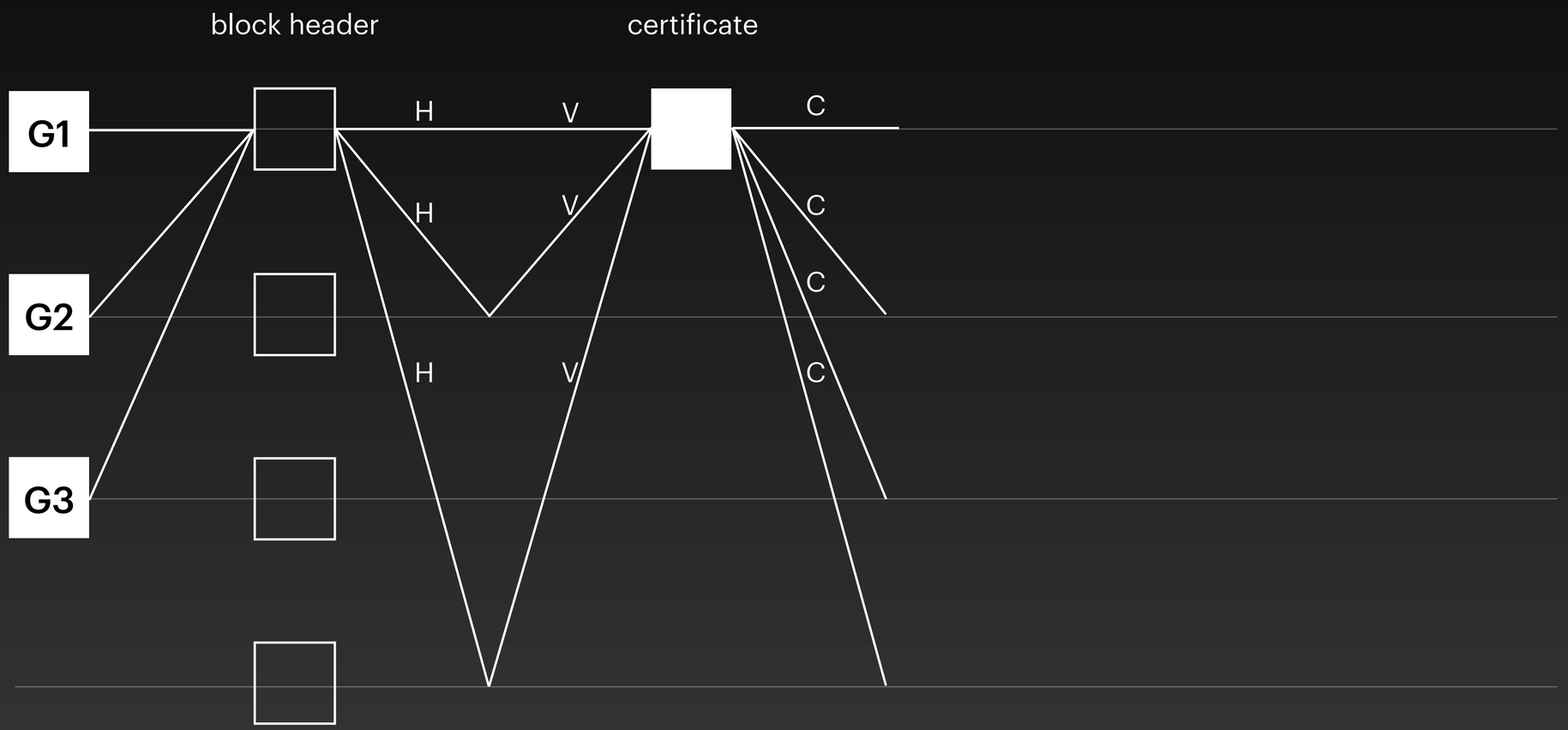

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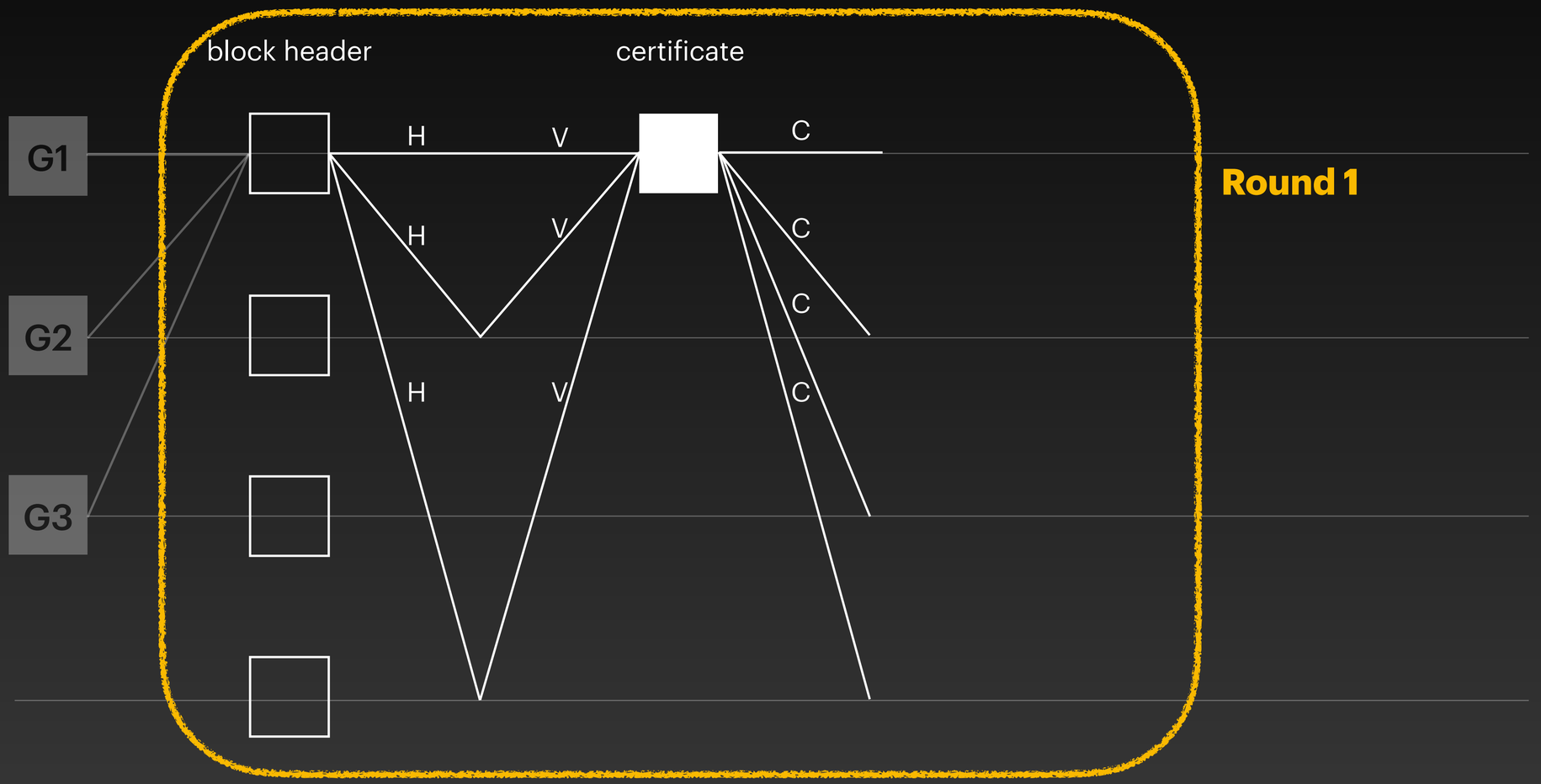

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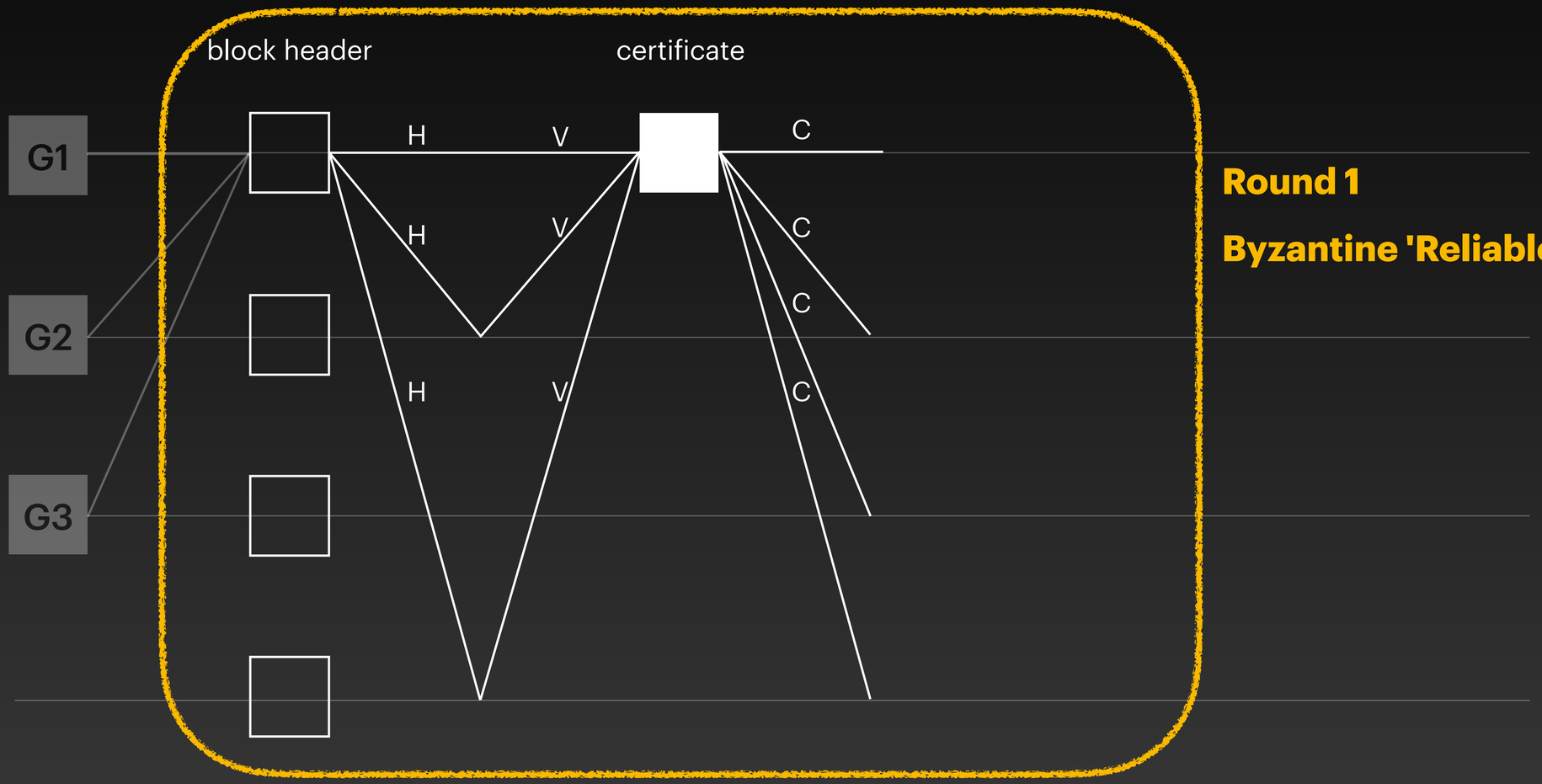
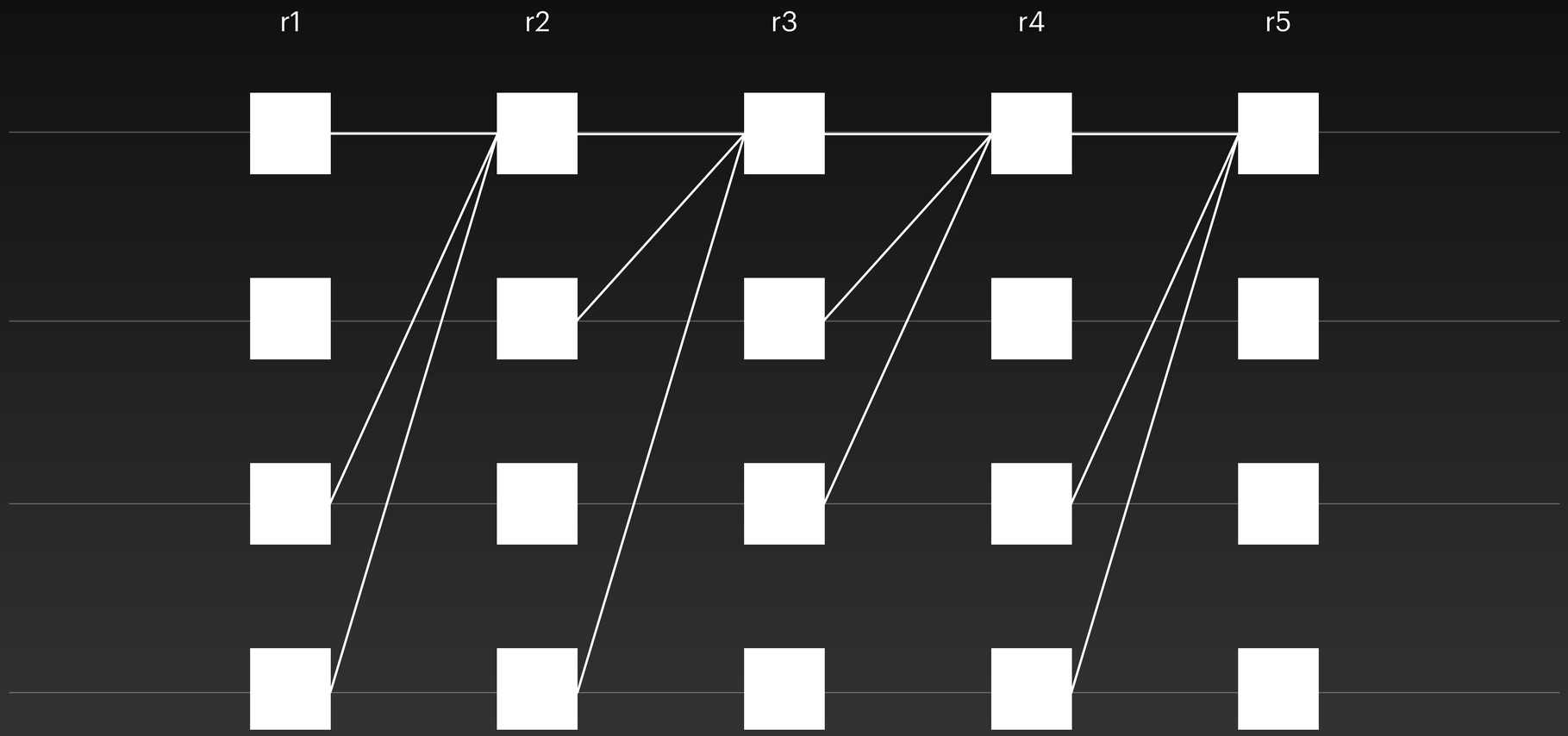


Round 1

Byzantine 'Reliable' Broadcast

Narwhal

The primary machine



Narwhal

Data Dissemination & Proof of Availability

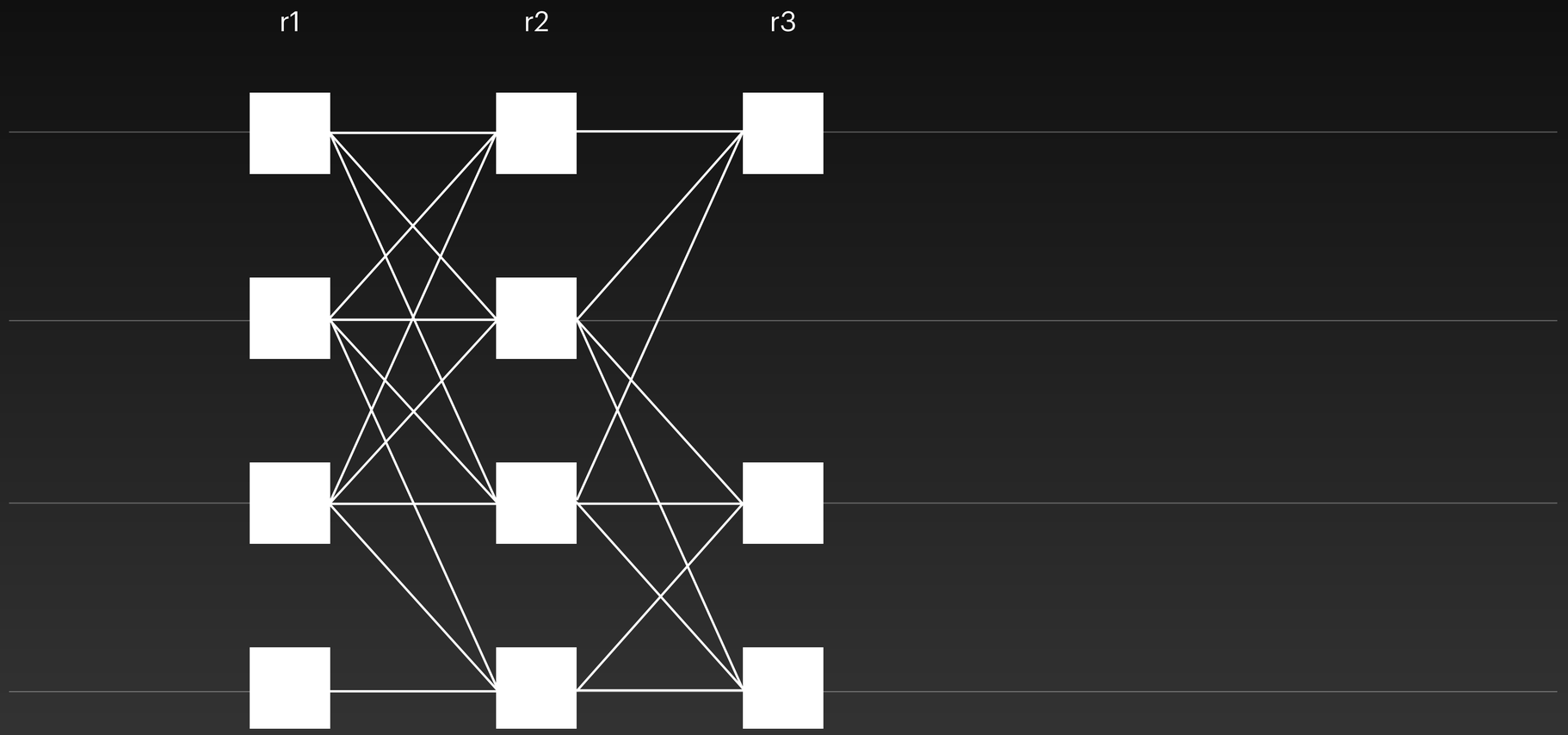
- The workers ship batch of transactions
- Many workers to scale out and use resources concurrently
- The primary constantly broadcasts the batch digests
- Headers at round *r* contains references to *2f+1* certificates of round *r-1*
- Build a structured DAG of certificates

Tusk

Zero-message asynchronous consensus

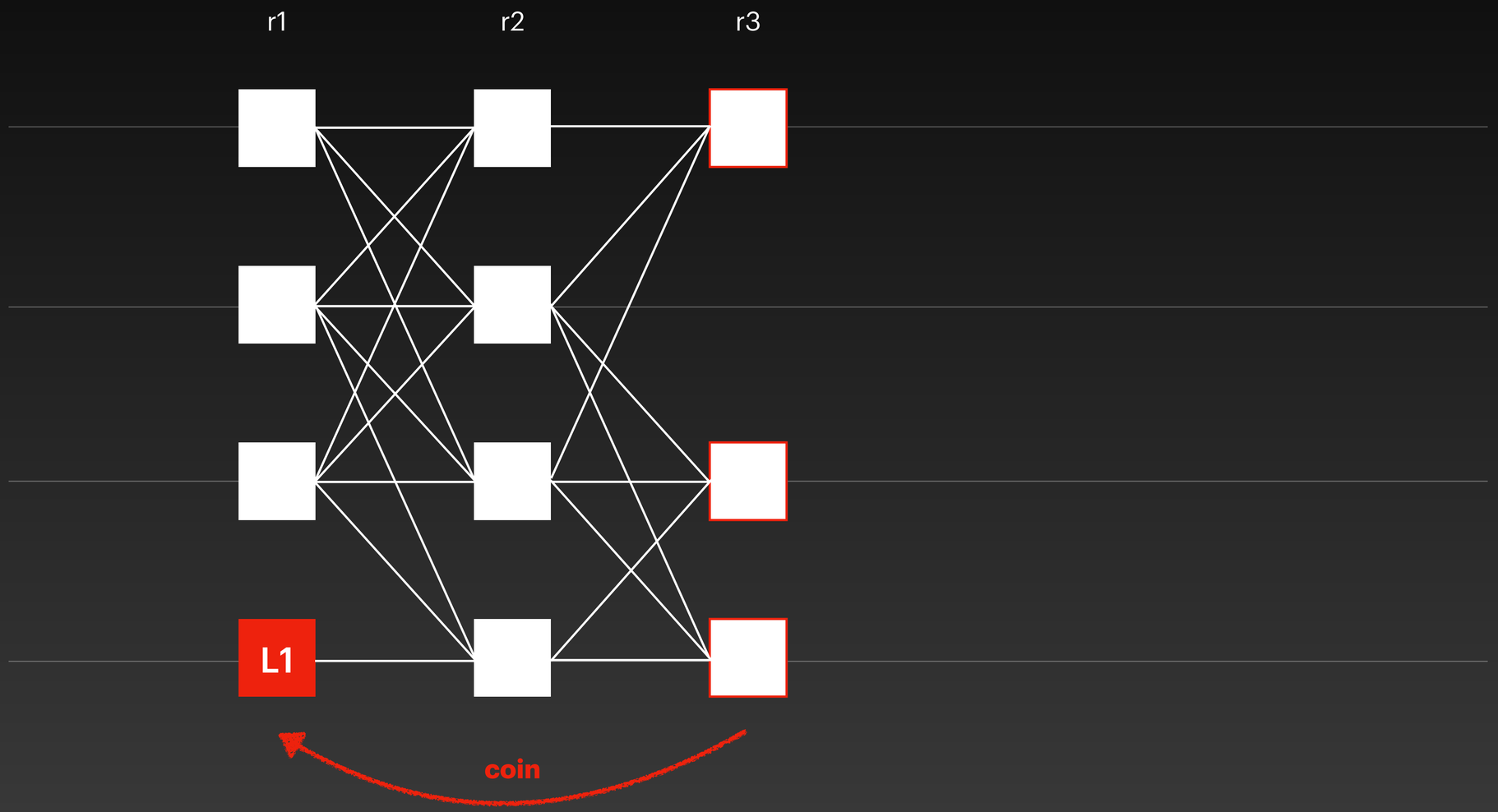
Tusk

Add common coin & Interpret the DAG



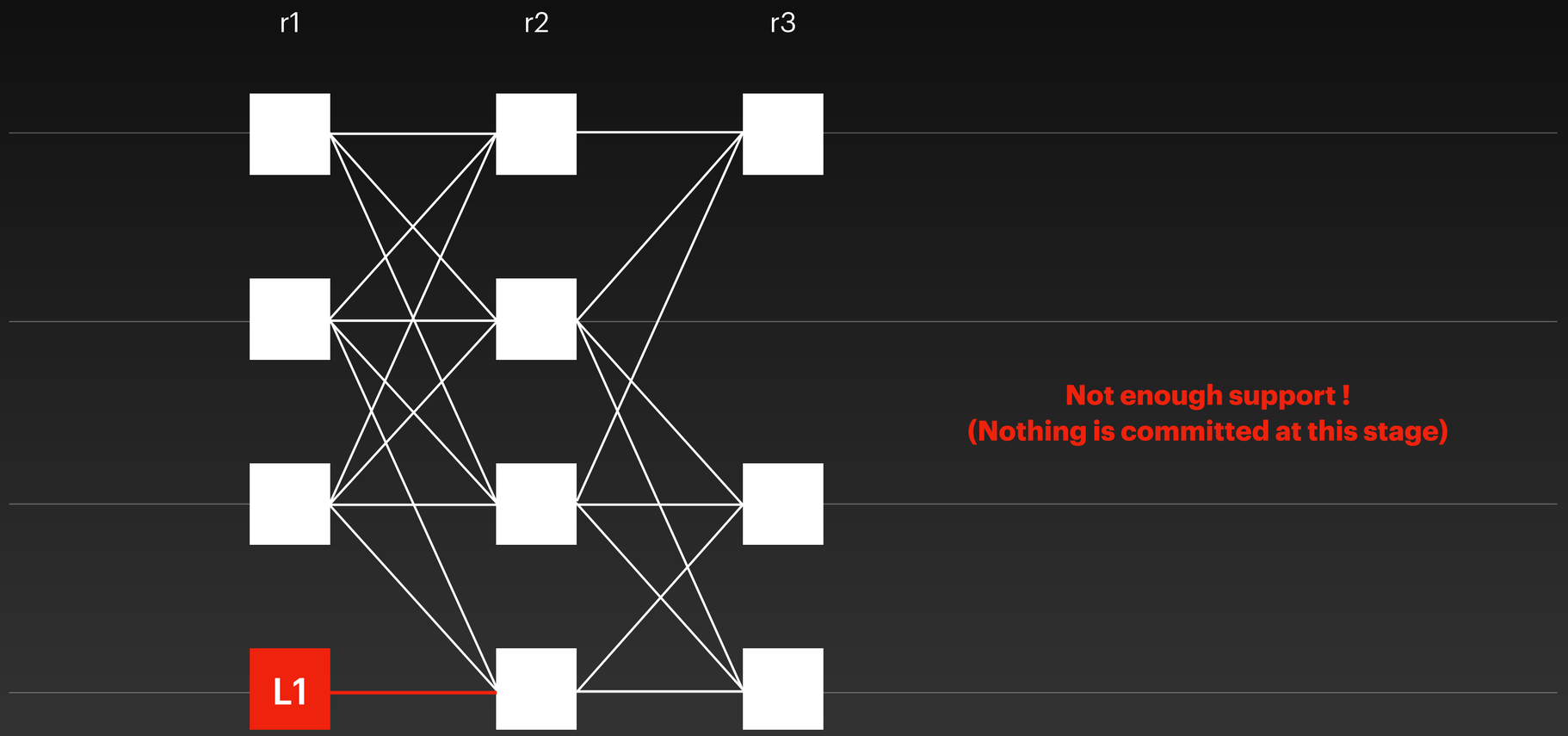
Tusk

The random coin elects the leader of r-2



Tusk

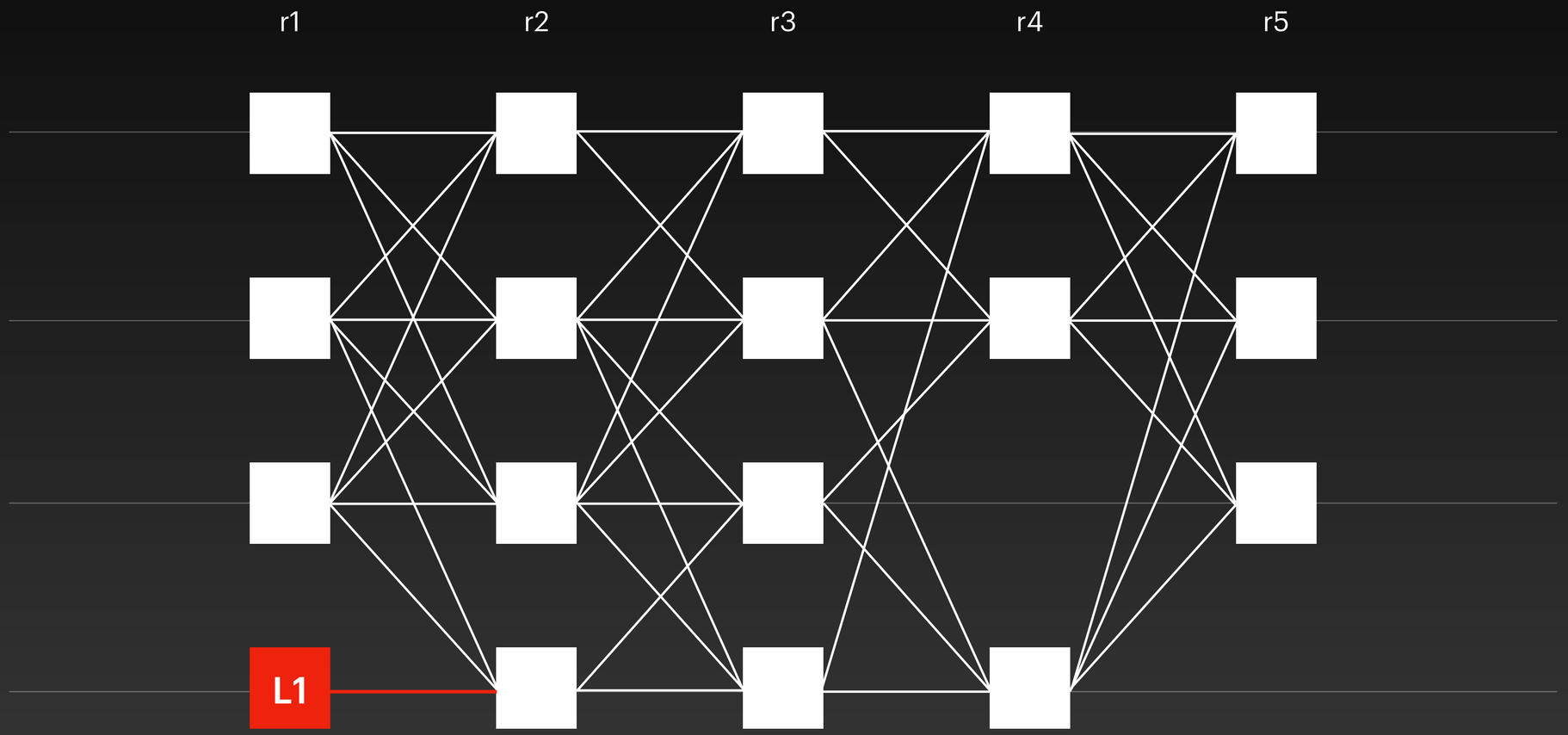
The leader needs f+1 links from round r-1



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

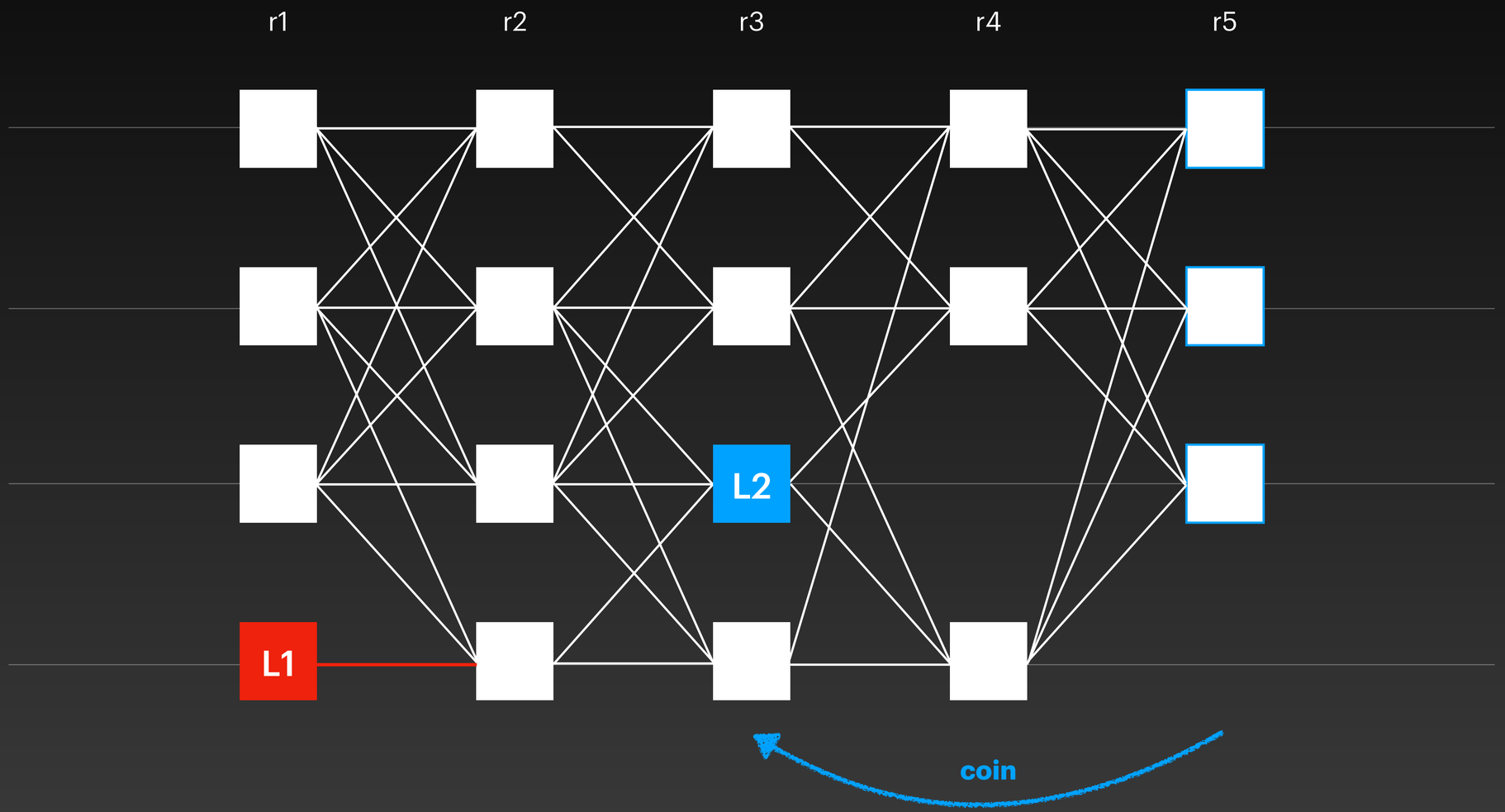
Tusk

Nothing is committed and we keep build the DAG



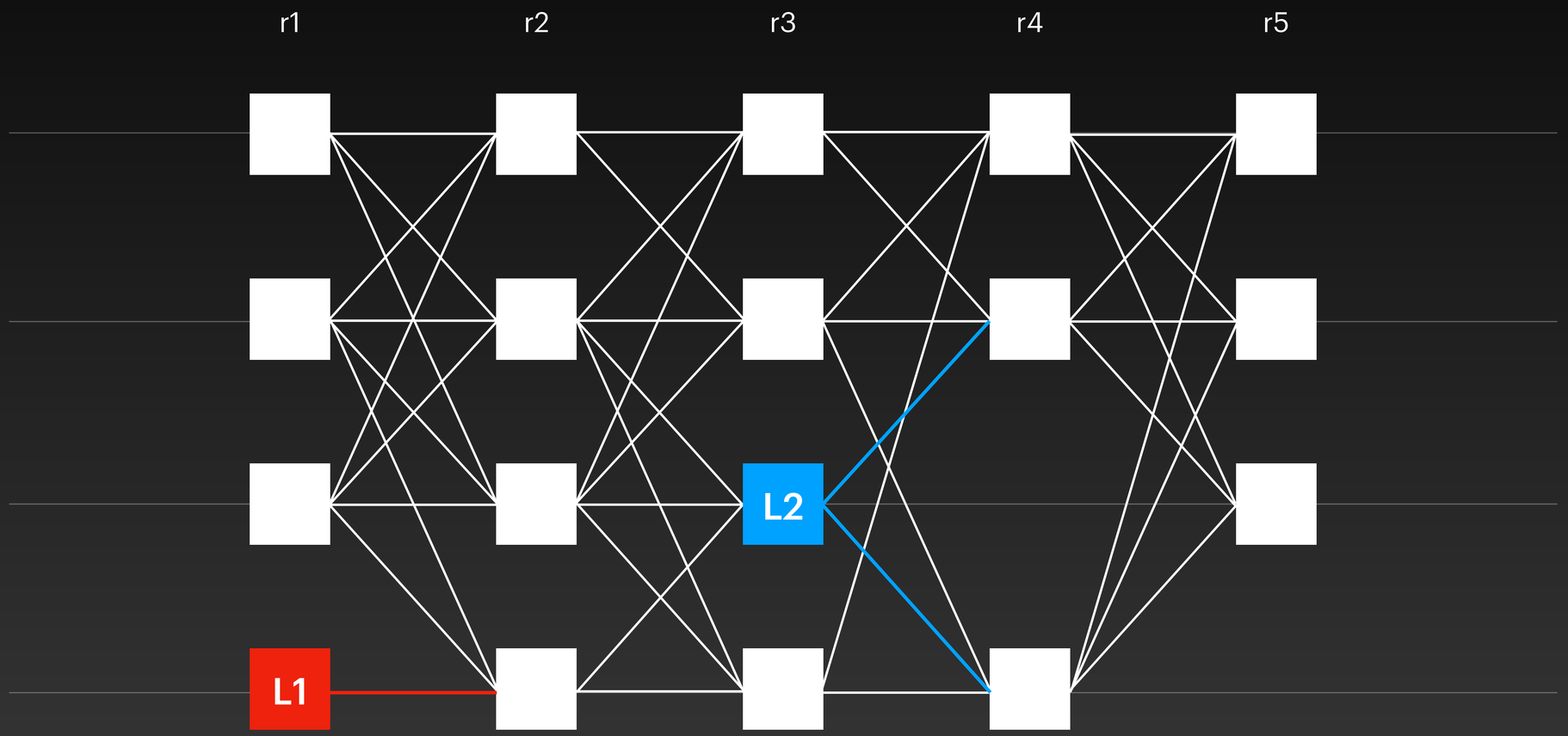
Tusk

Elect the leader of r3



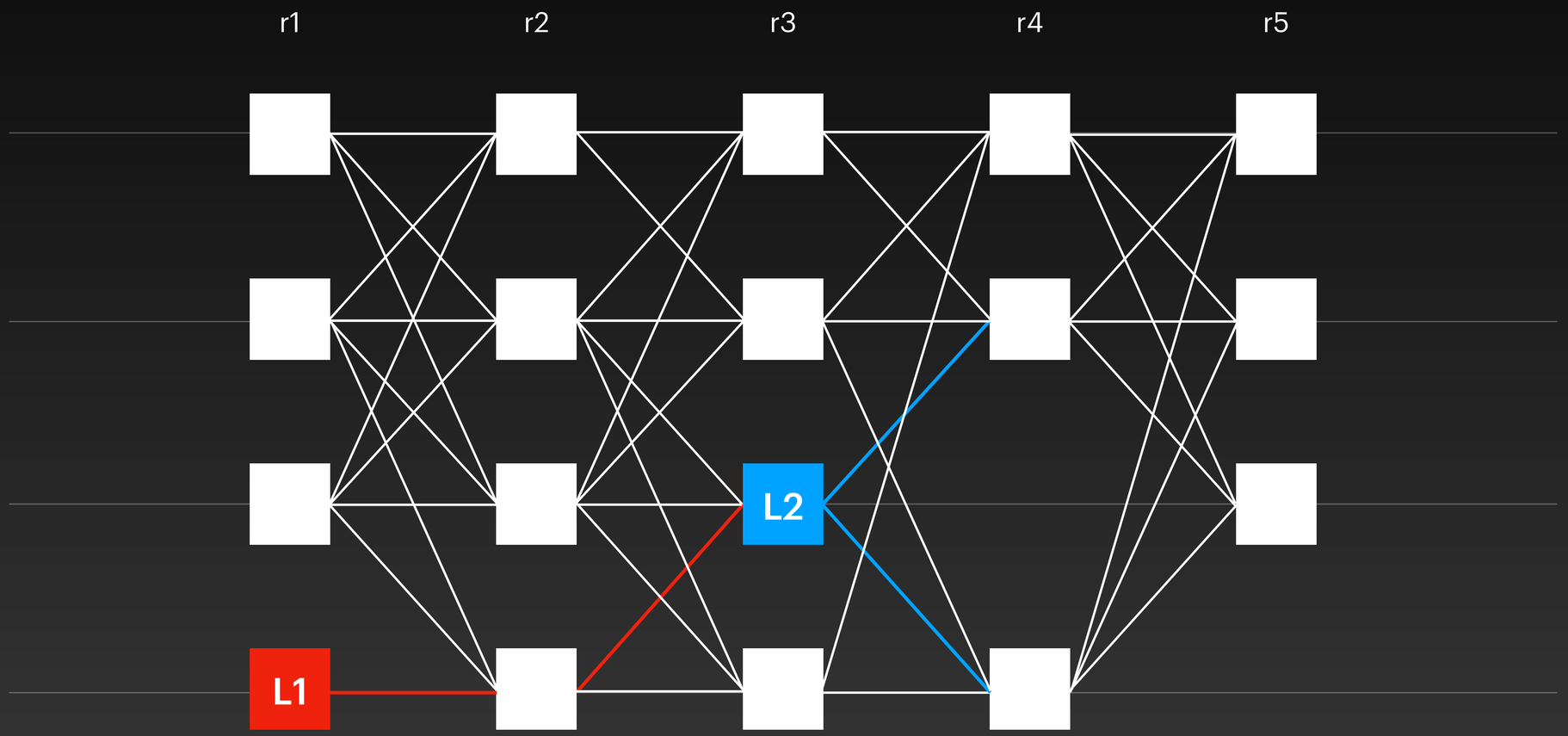
Tusk

Leader L2 has enough support



Tusk

Leader L2 has links to leader L1

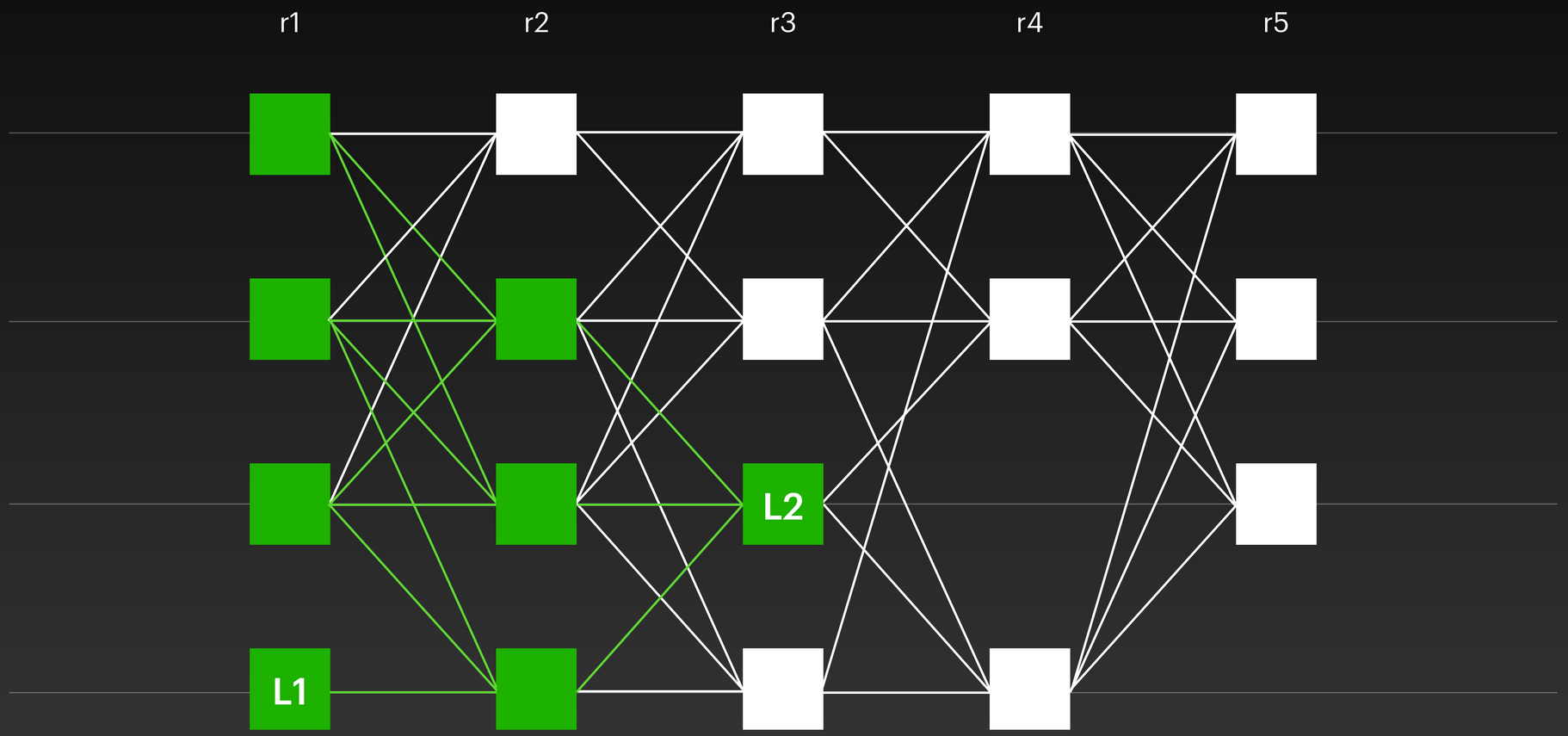


First commit L1

Then commit L2

Tusk

Commit all the sub-DAG of the leader

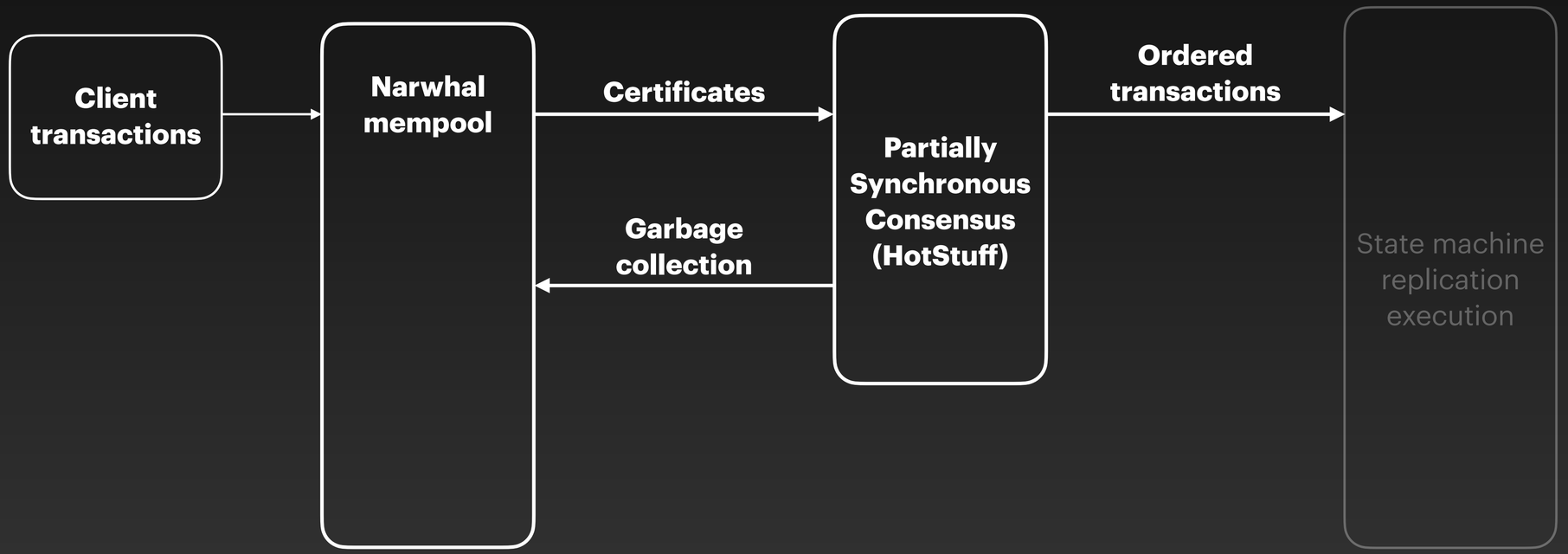


HotStuff on Steroids

Just by replacing the mempool

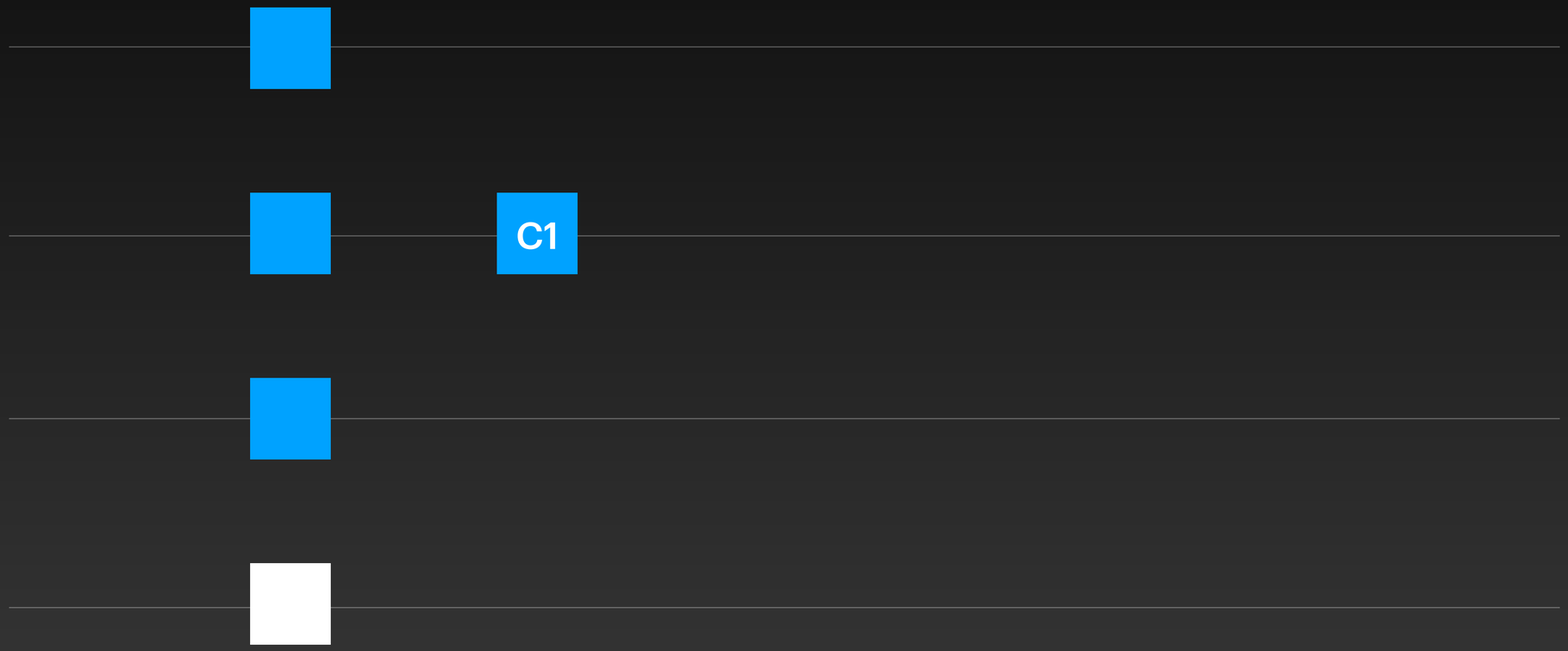
HotStuff on Narwhal

Overview



HotStuff on Narwhal

Enhanced commit rule



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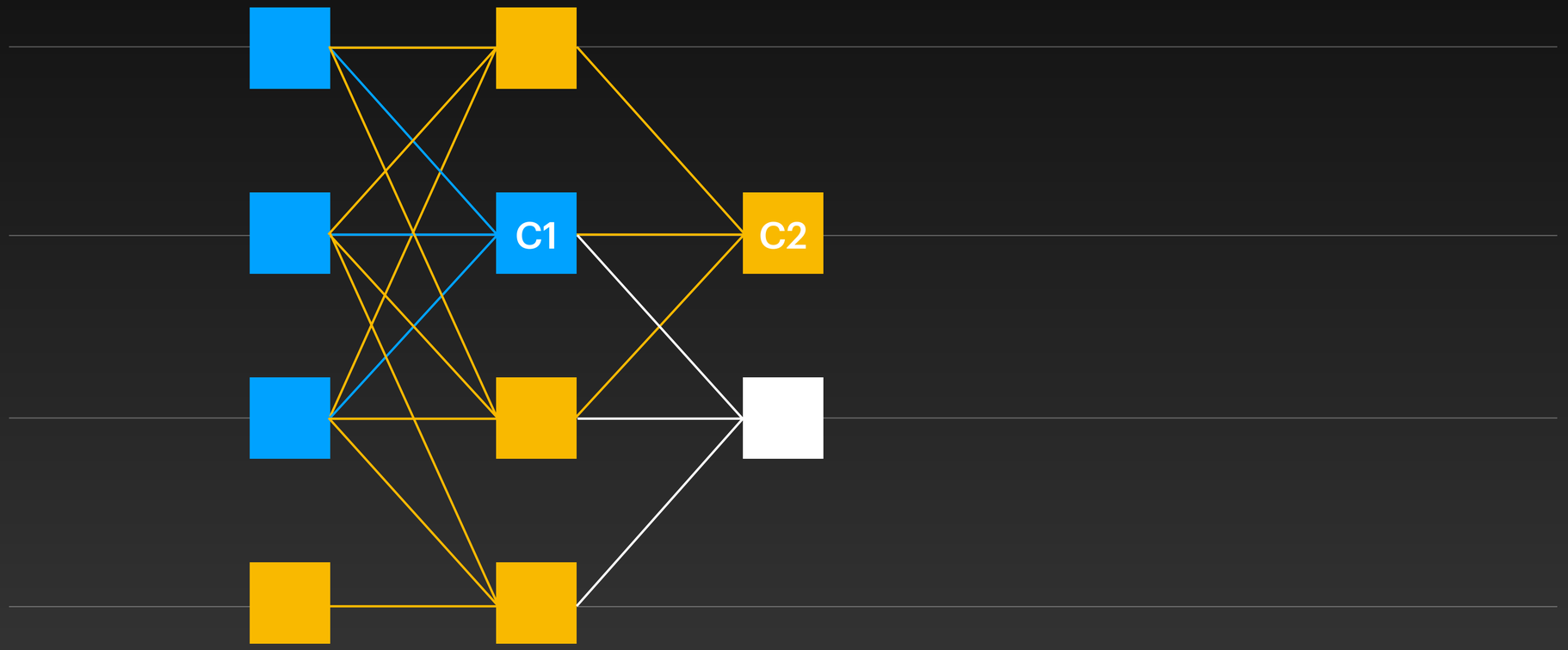

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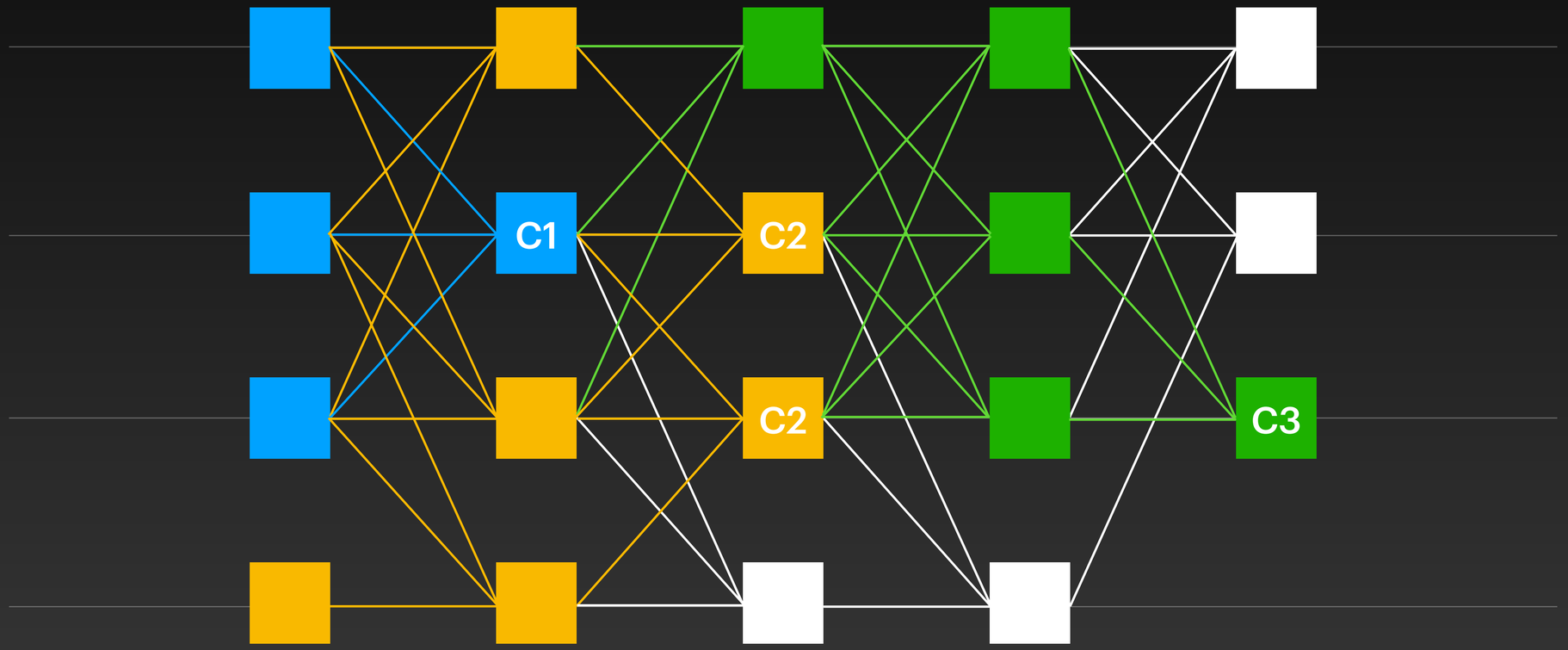


Evaluation

How to properly benchmark consensus protocols

Implementation

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

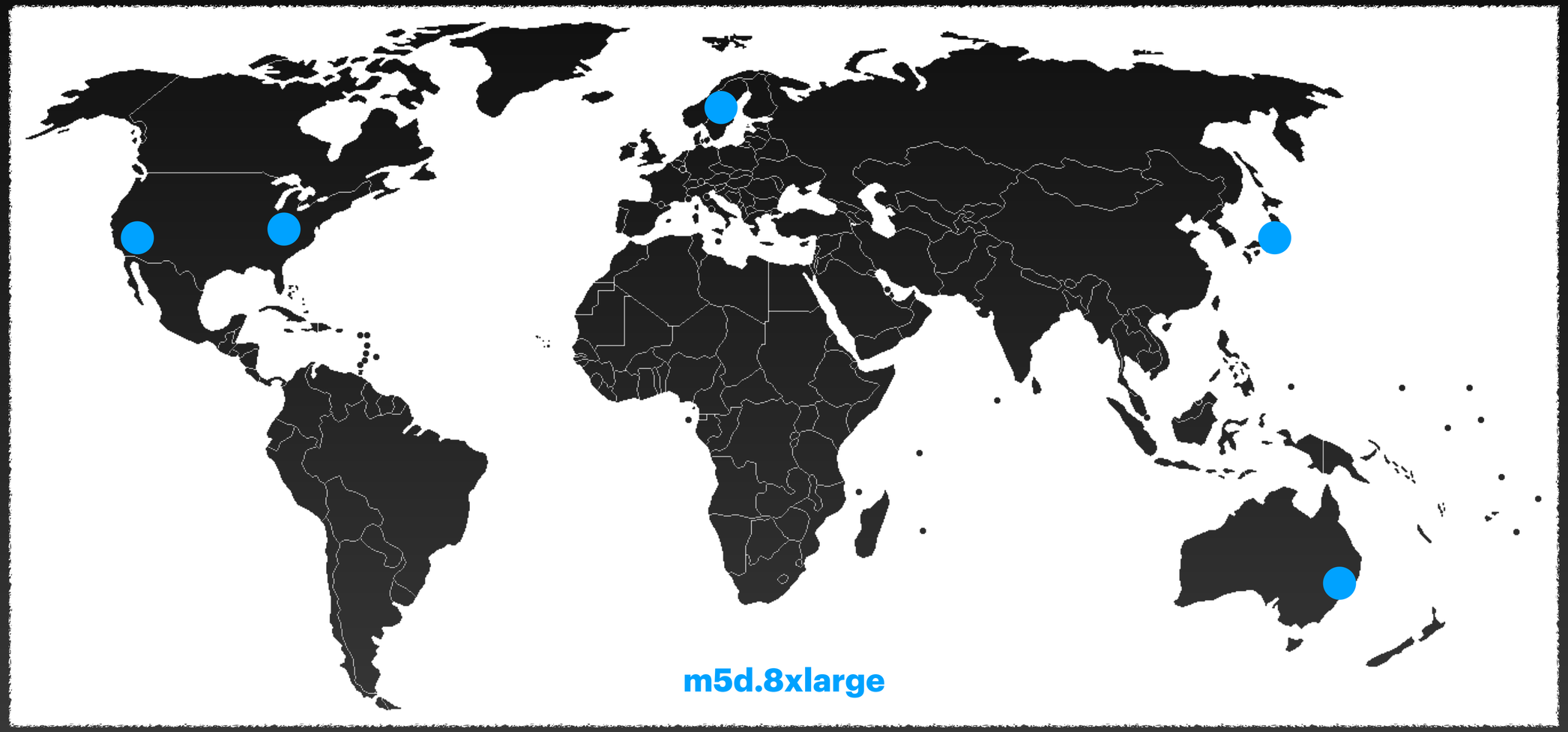
https://github.com/asonnino/narwhal

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

Experimental setup on AWS



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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
```

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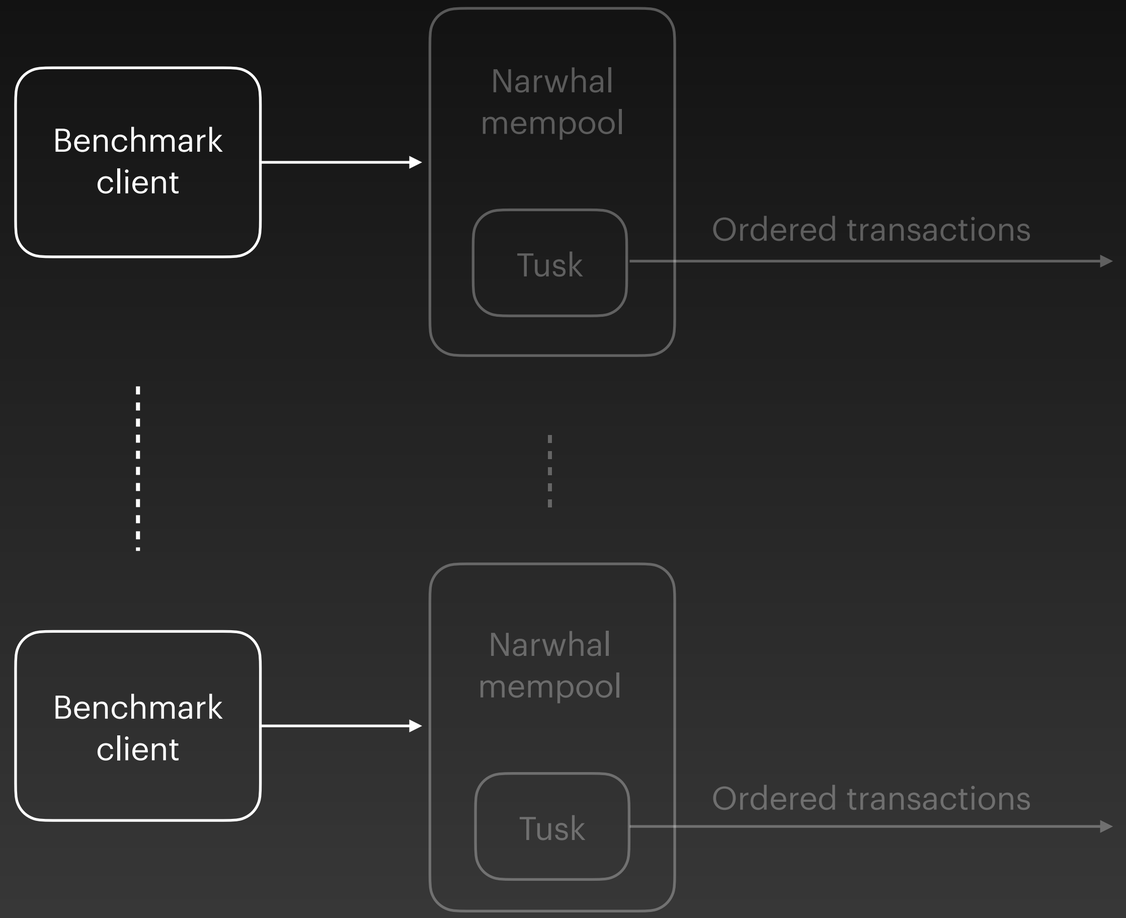
Evaluation

Benchmark clients

Fixed input rate

For a long time (minutes)



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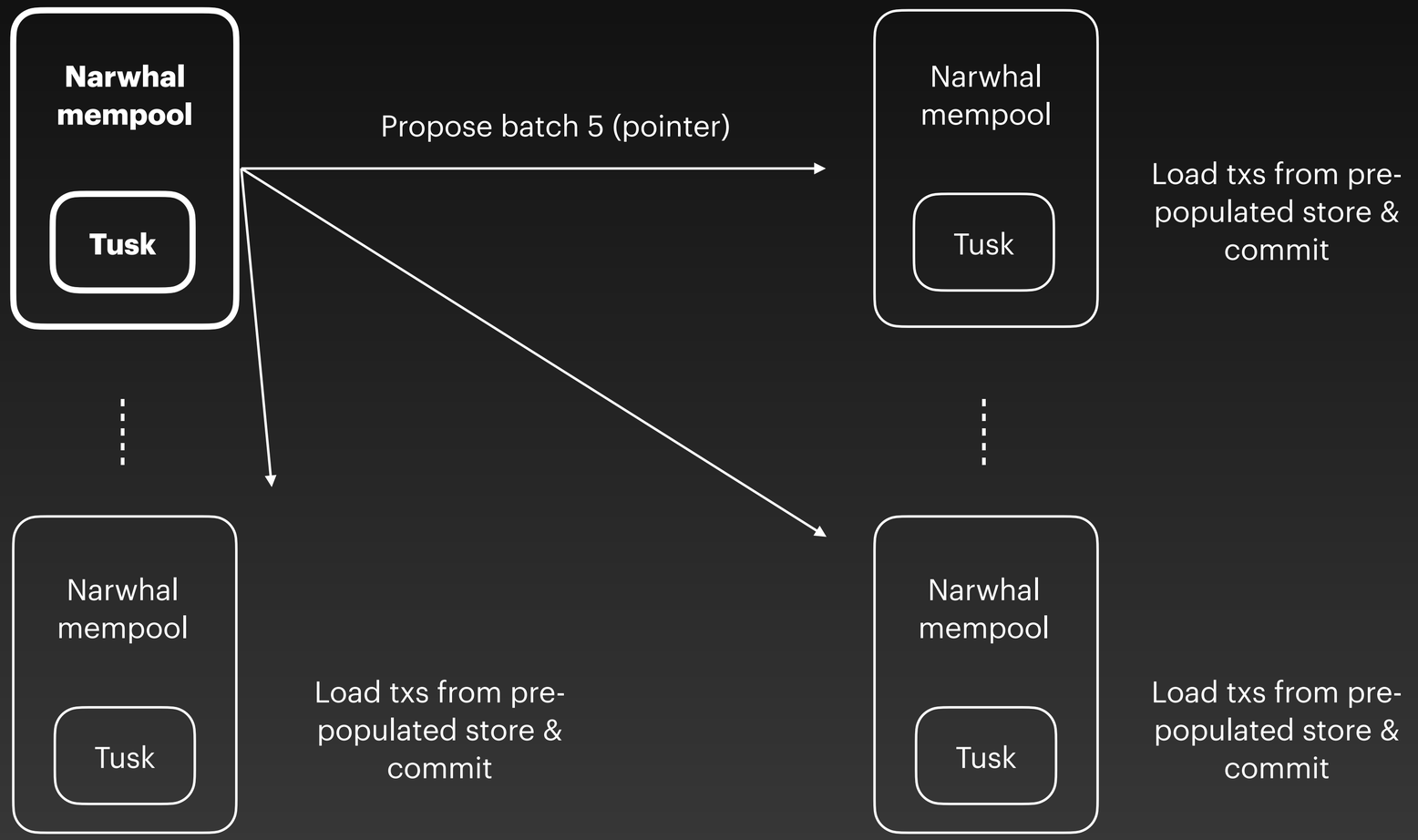

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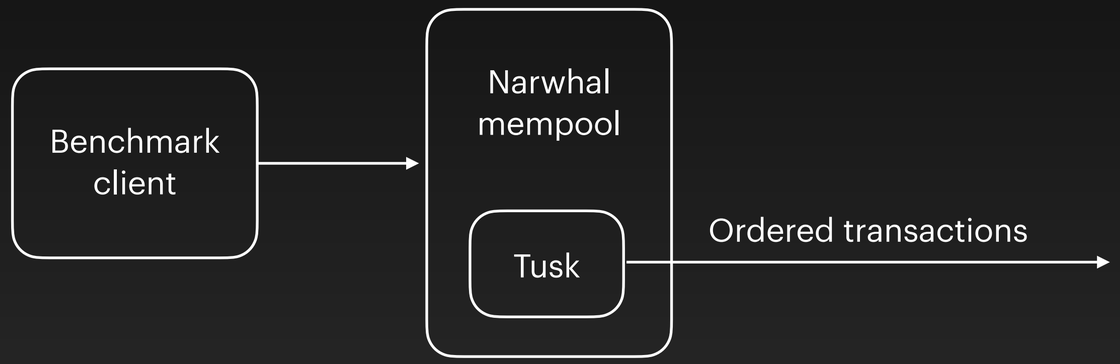
Evaluation

Typical mistake

send 50k txs (once)

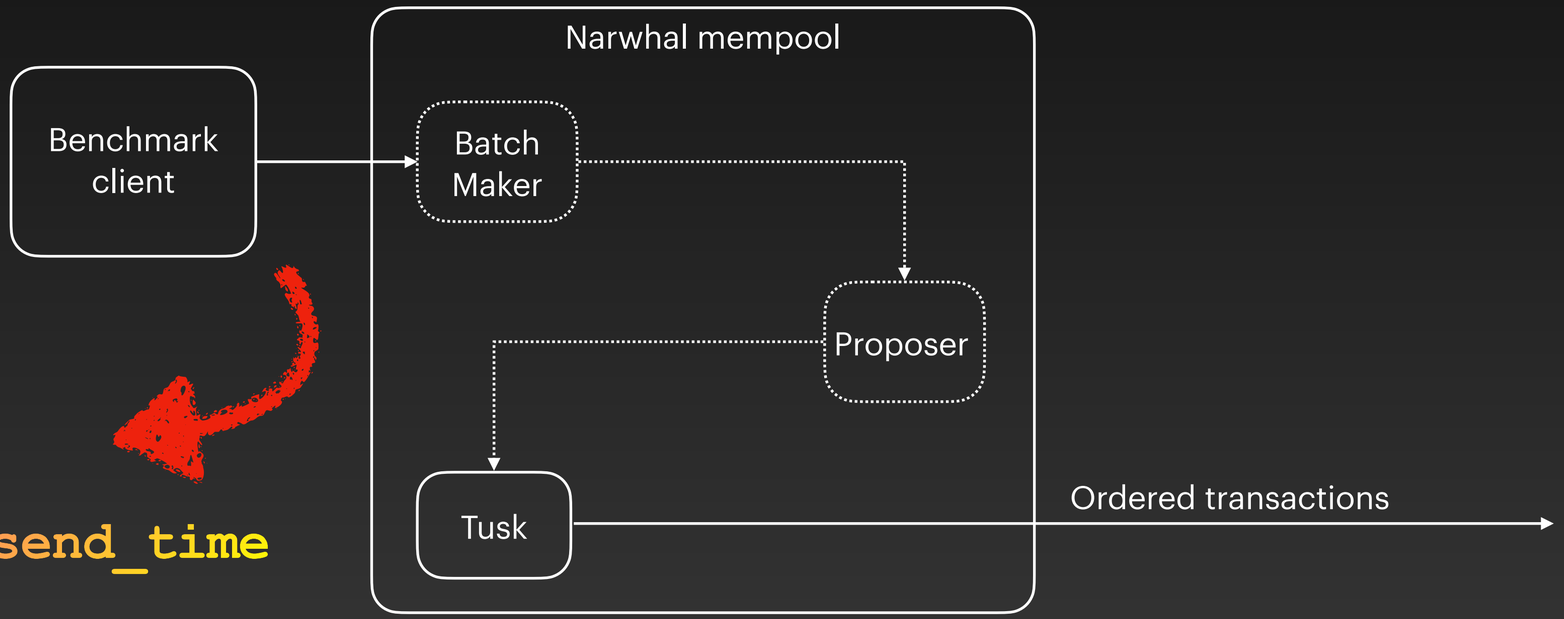


output after 400 ms

😫 **TPS = 50k / 400ms = 125k tx/s** 😫

Evaluation

Instrument the codebase

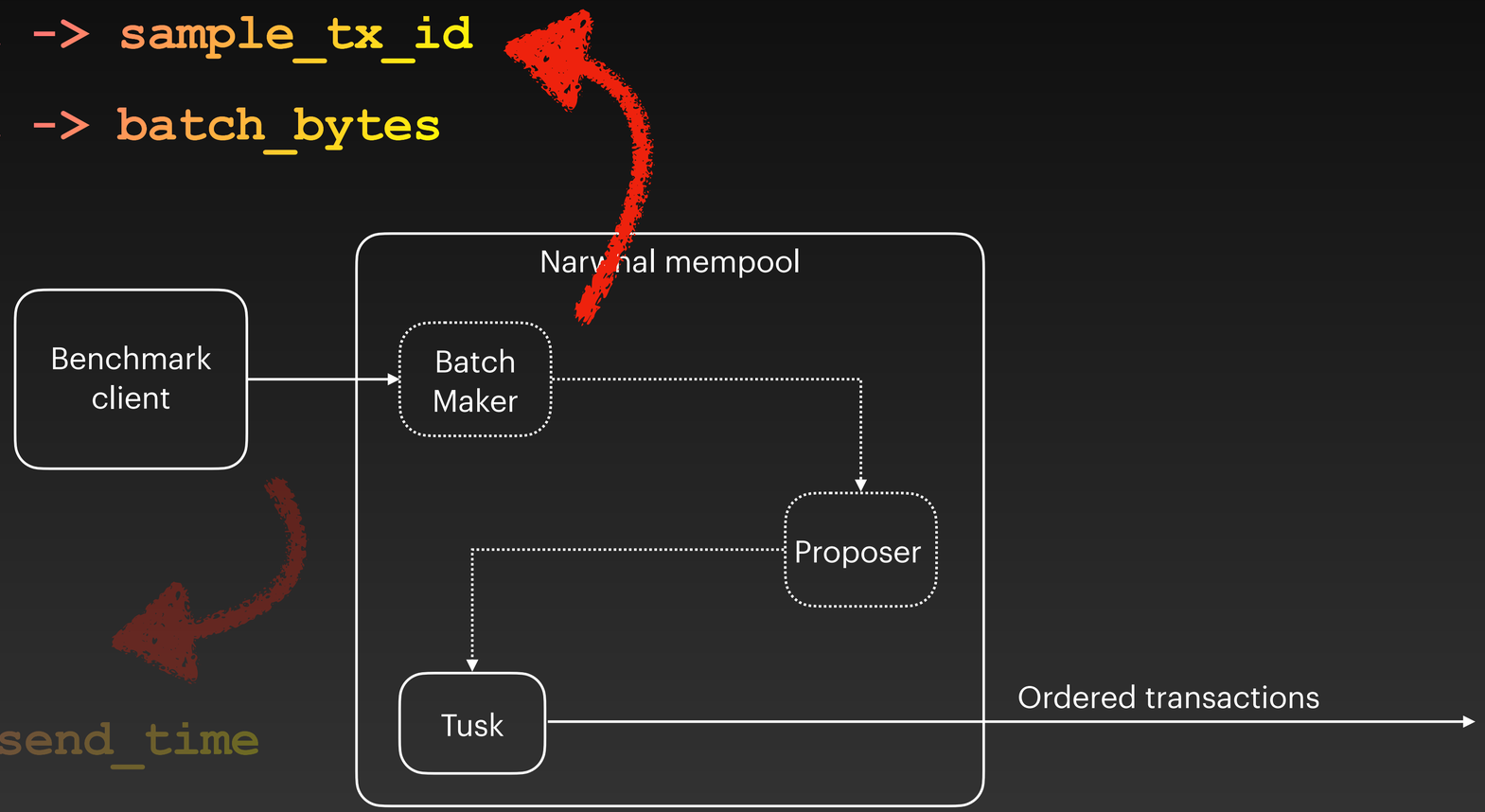



```
bench_start_time
sample_tx_id -> send_time
```

Evaluation

Instrument the codebase

```
batch_digest -> sample_tx_id
batch_digest -> batch_bytes
```



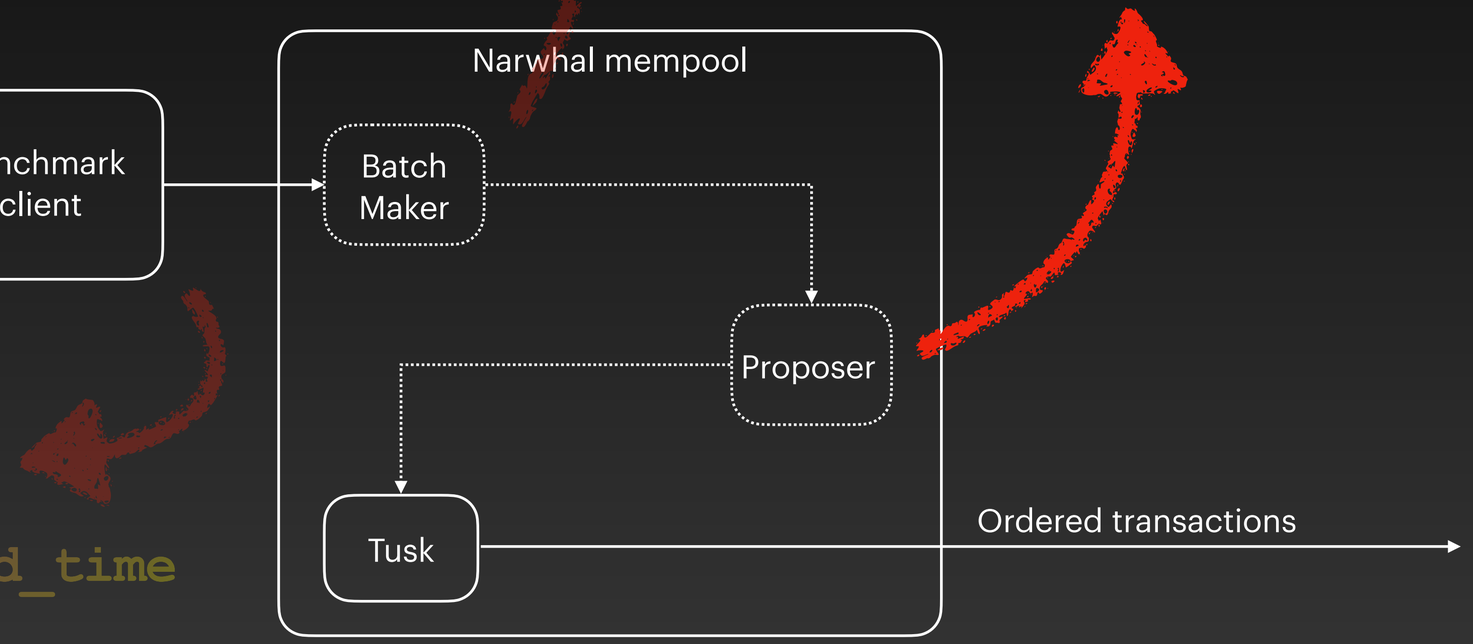

```
bench_start_time
sample_tx_id -> send_time
```

Evaluation

Instrument the codebase

```
batch_digest -> sample_tx_id
batch_digest -> batch_bytes
```

```
block_digest -> batch_digest
```

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bench_start_time
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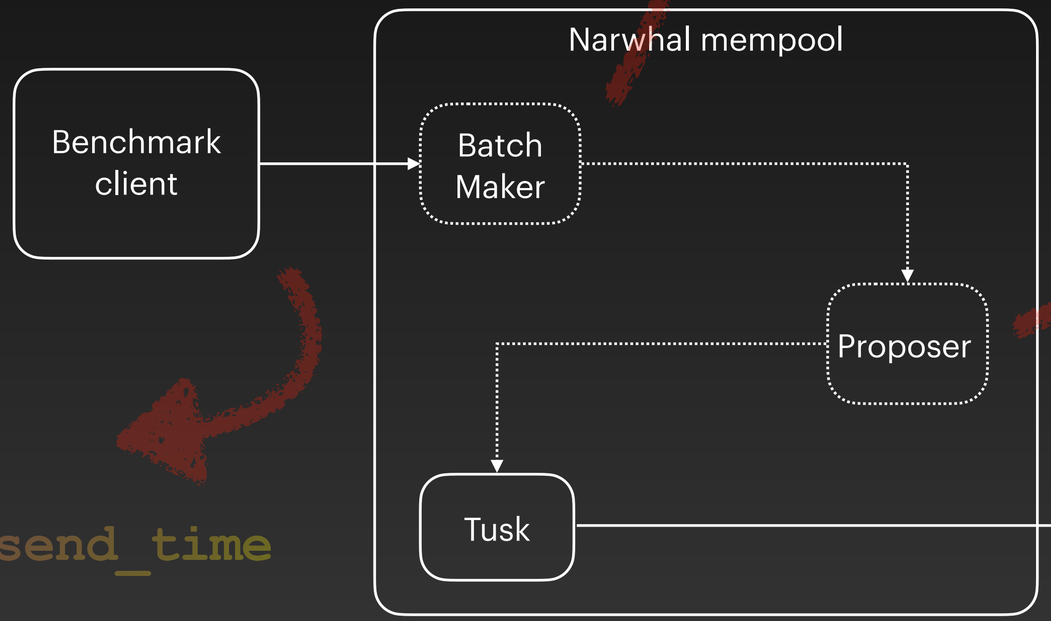
Instrument the codebase

`batch_digest -> sample_tx_id`

`batch_digest -> batch_bytes`

`block_digest -> batch_digest`



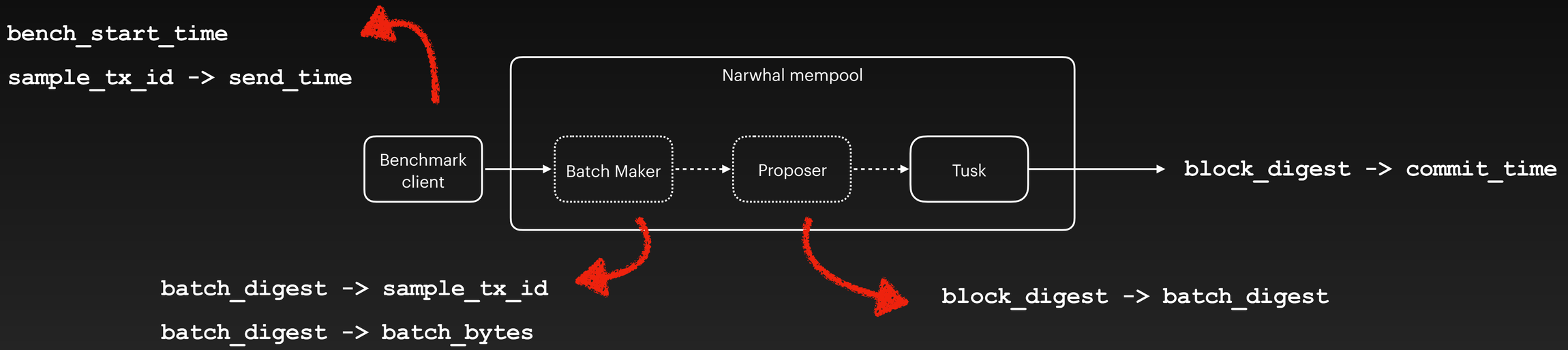
`bench_start_time`

`sample_tx_id -> send_time`

`block_digest -> commit_time`

Evaluation

Compute throughput



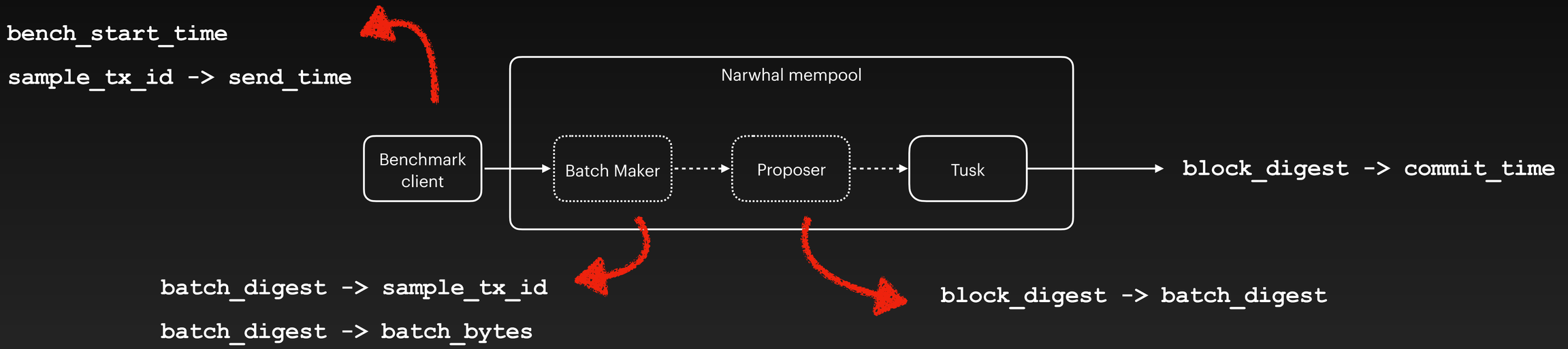

```
total_time = last_commit_time - bench_start_time

BPS = total_bytes / total_time

TPS = BPS / transaction_size
```

Evaluation

Compute latency




```
samples = commit_time - send_time

latency = average(samples)
```

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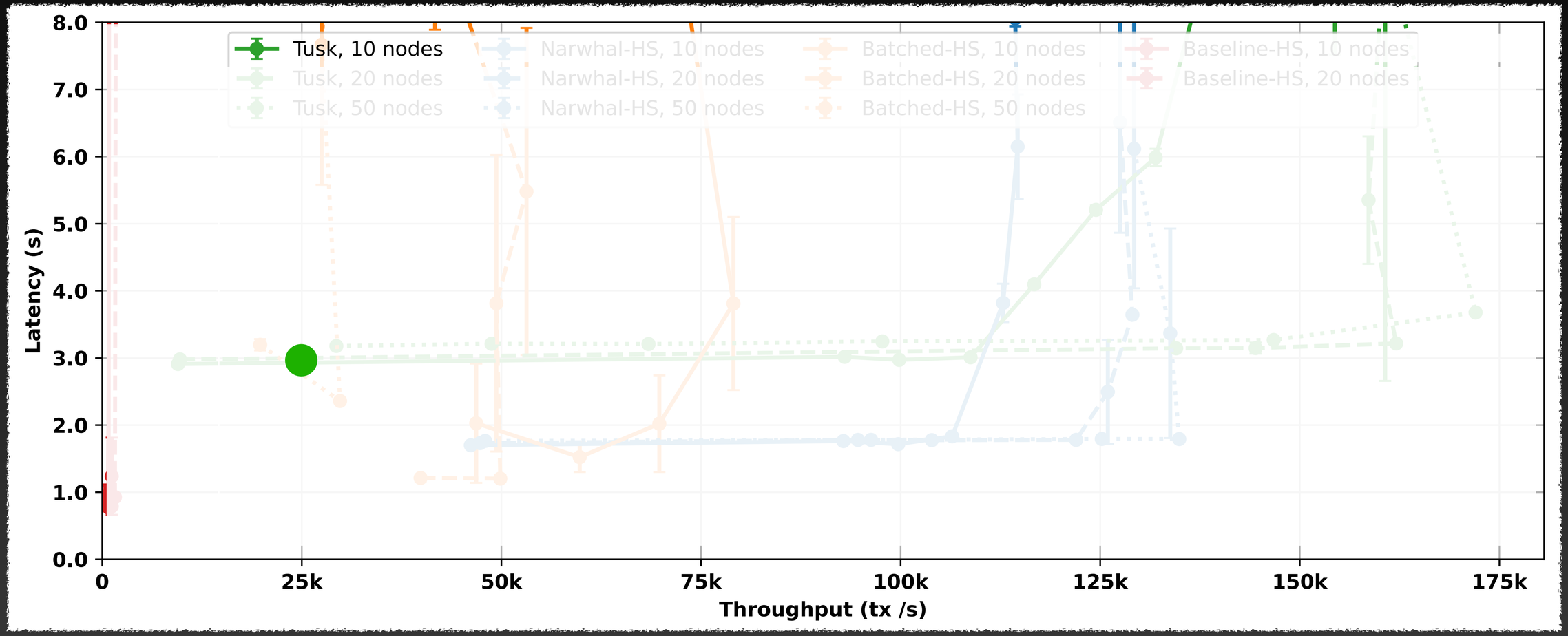
Throughput latency graph



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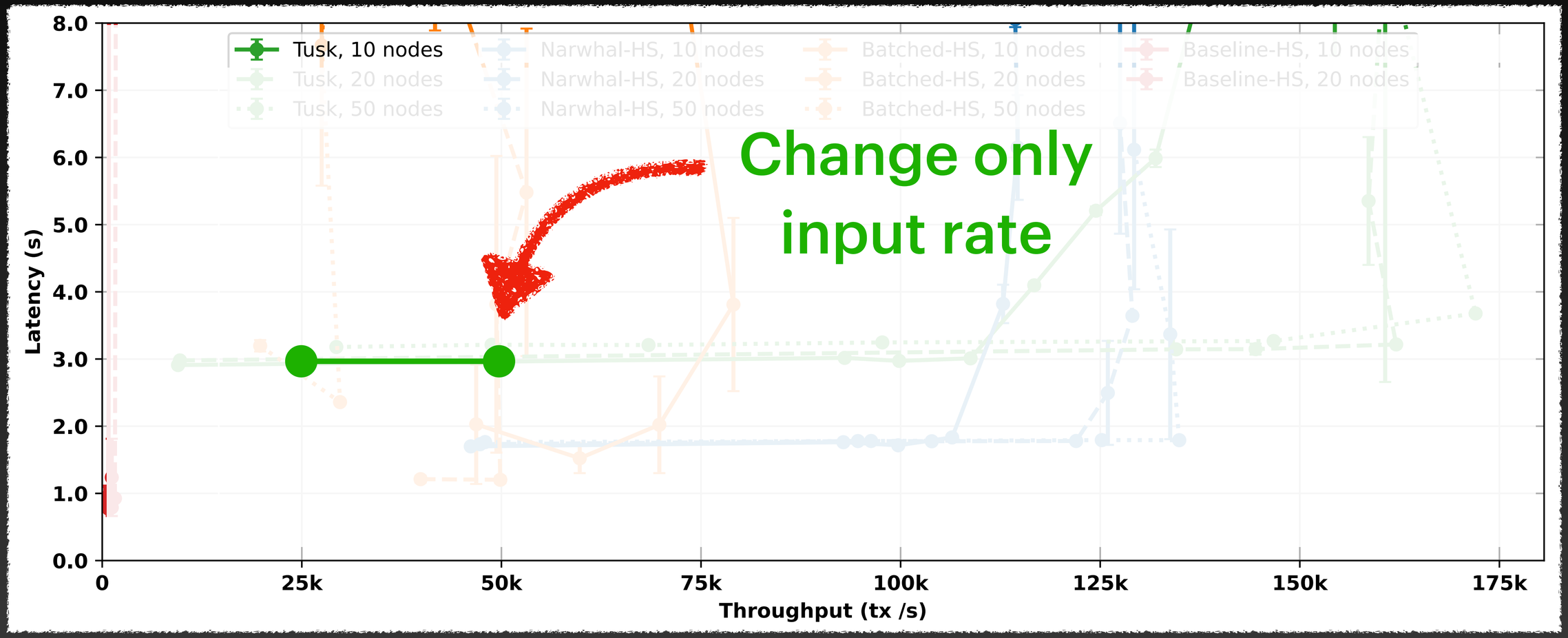

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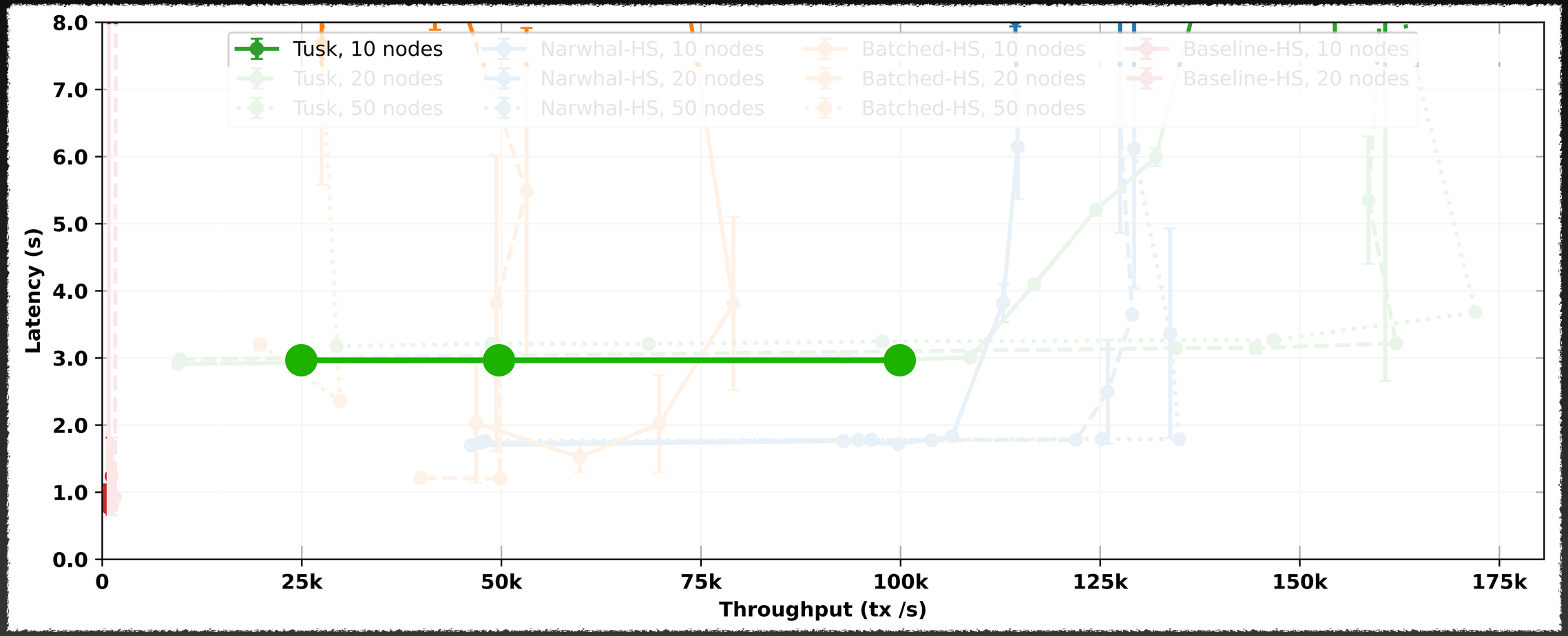

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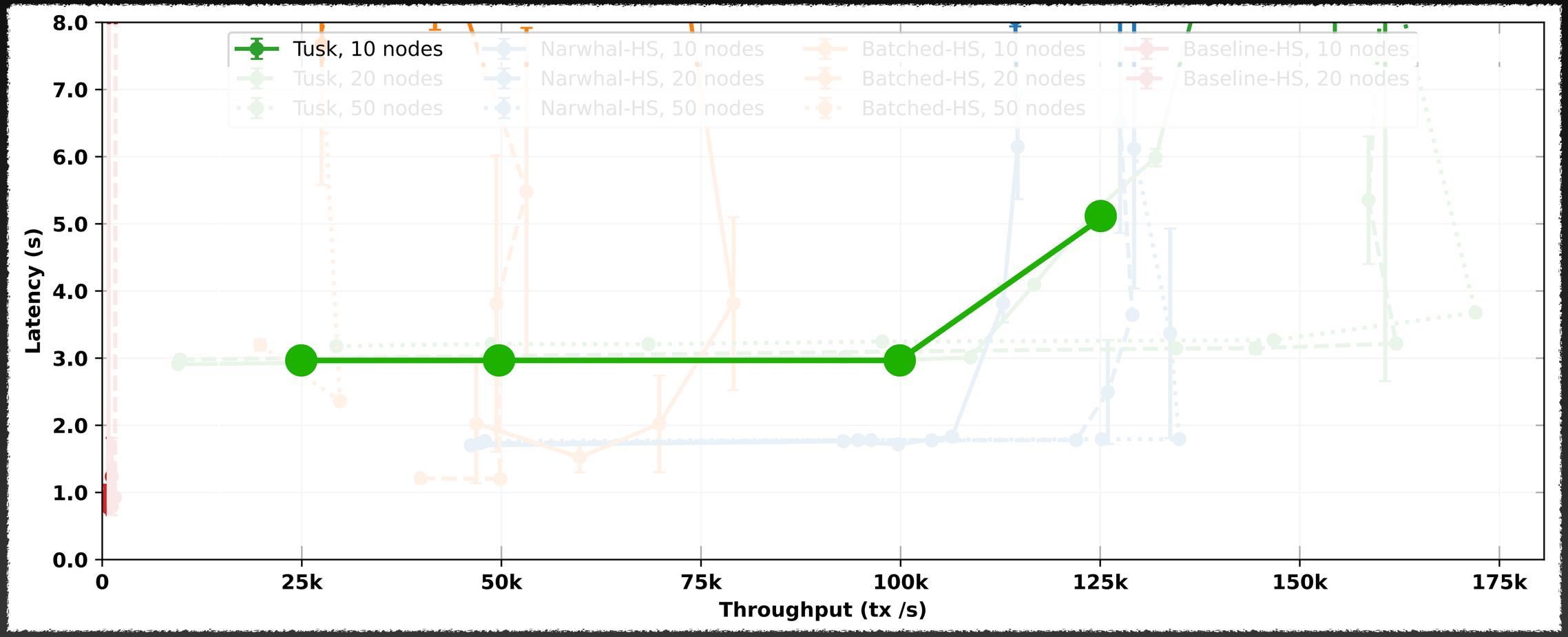

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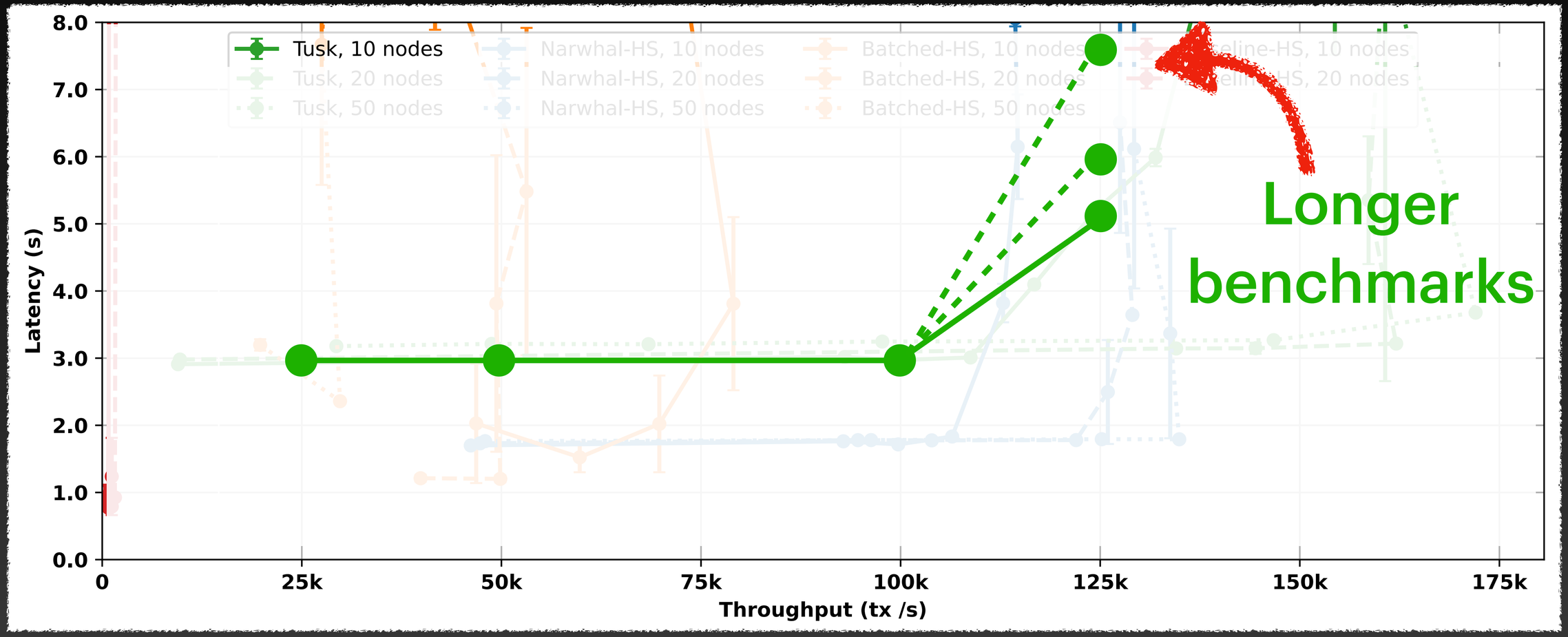

Evaluation

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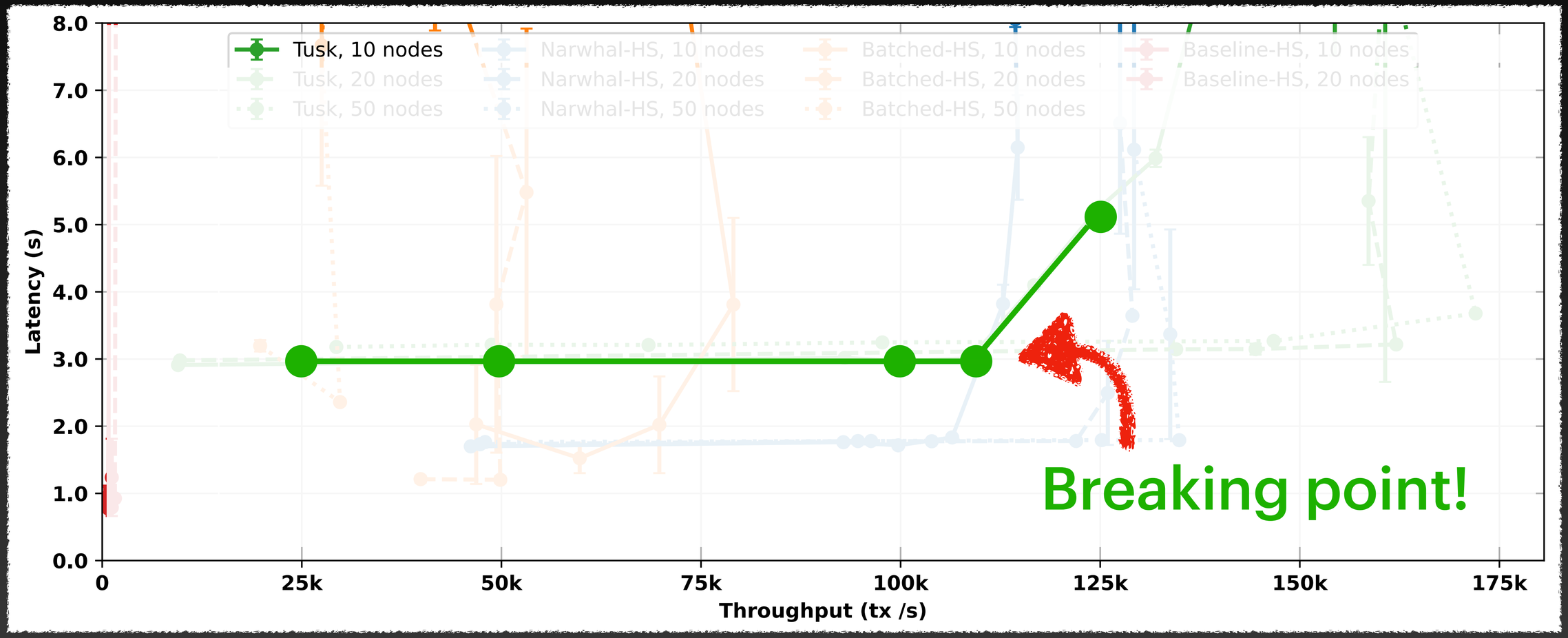

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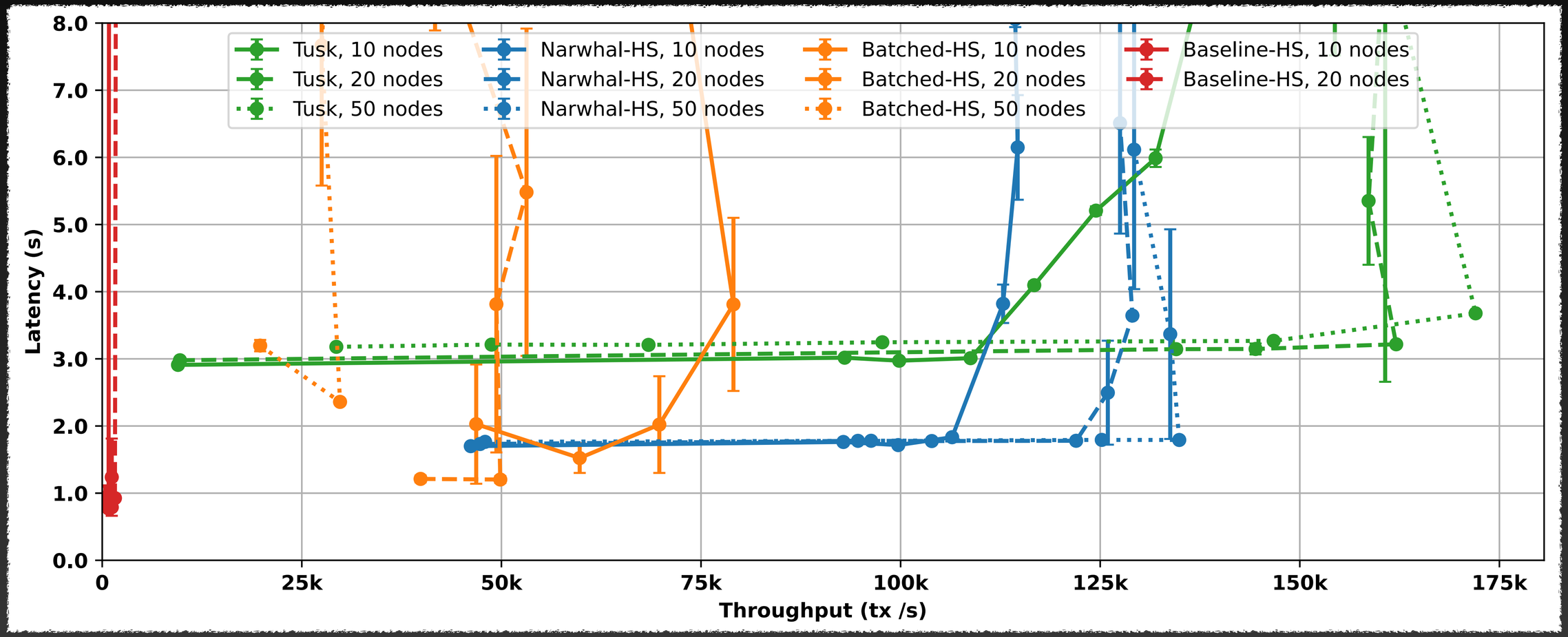
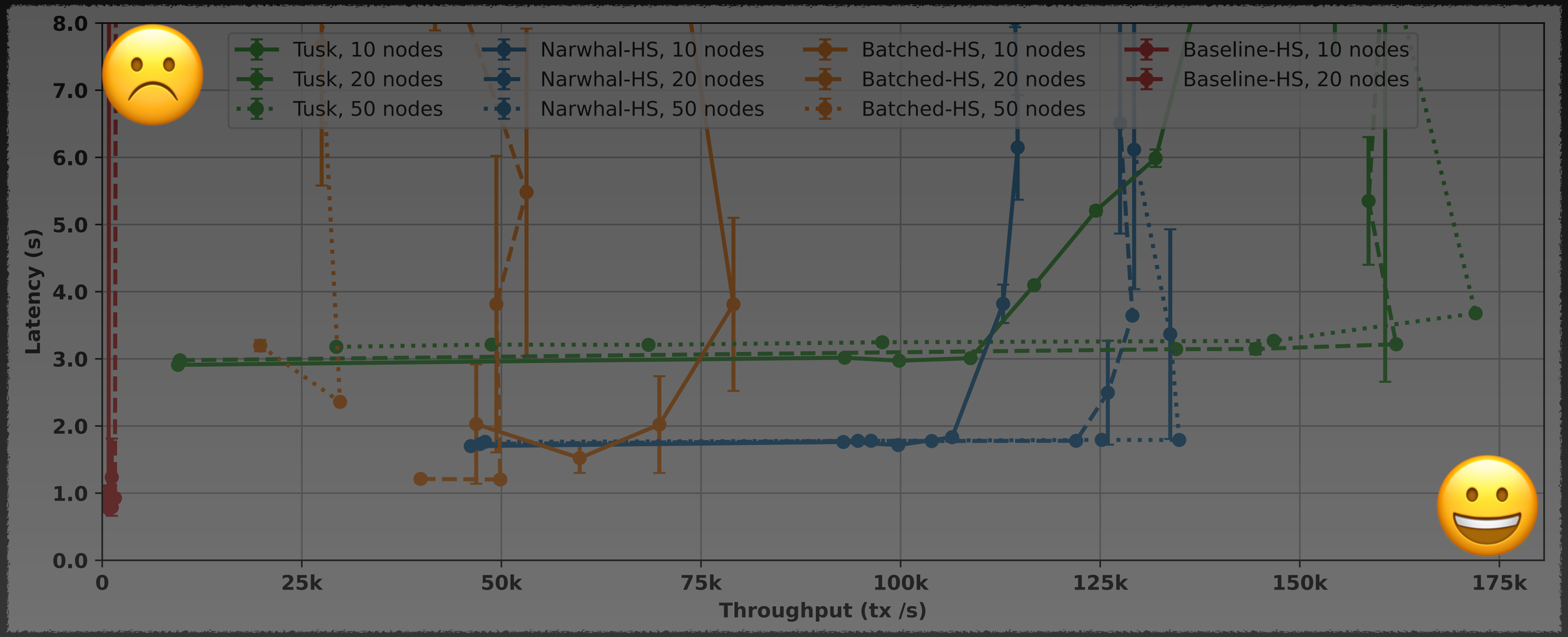
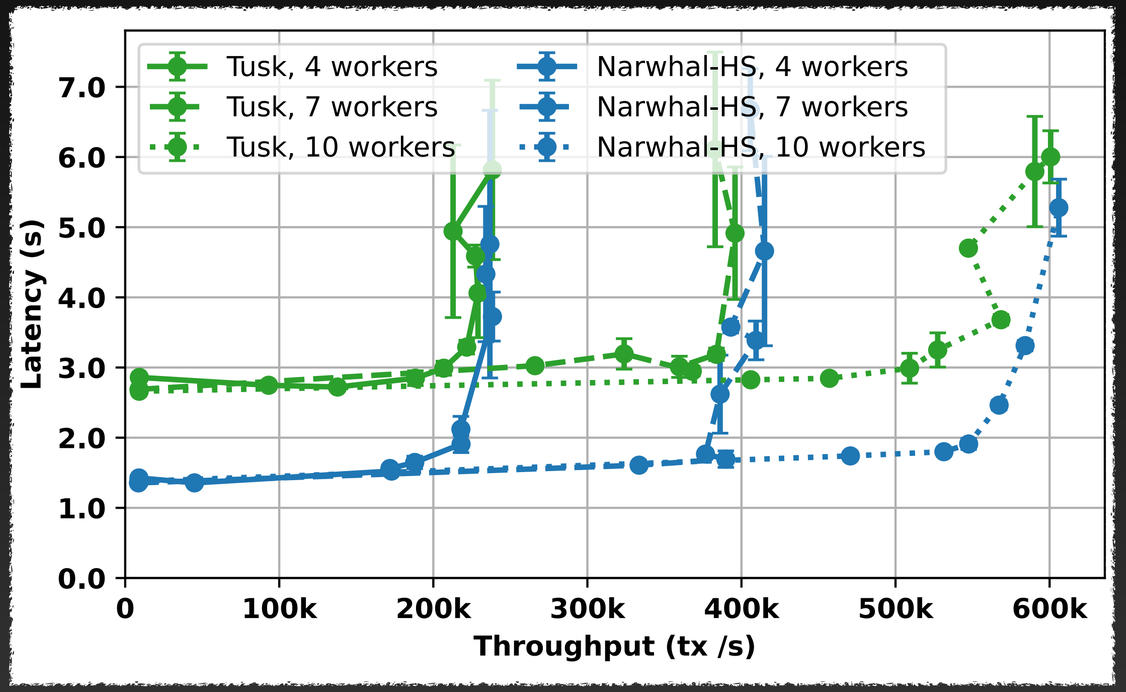


Evaluation

Throughput latency graph

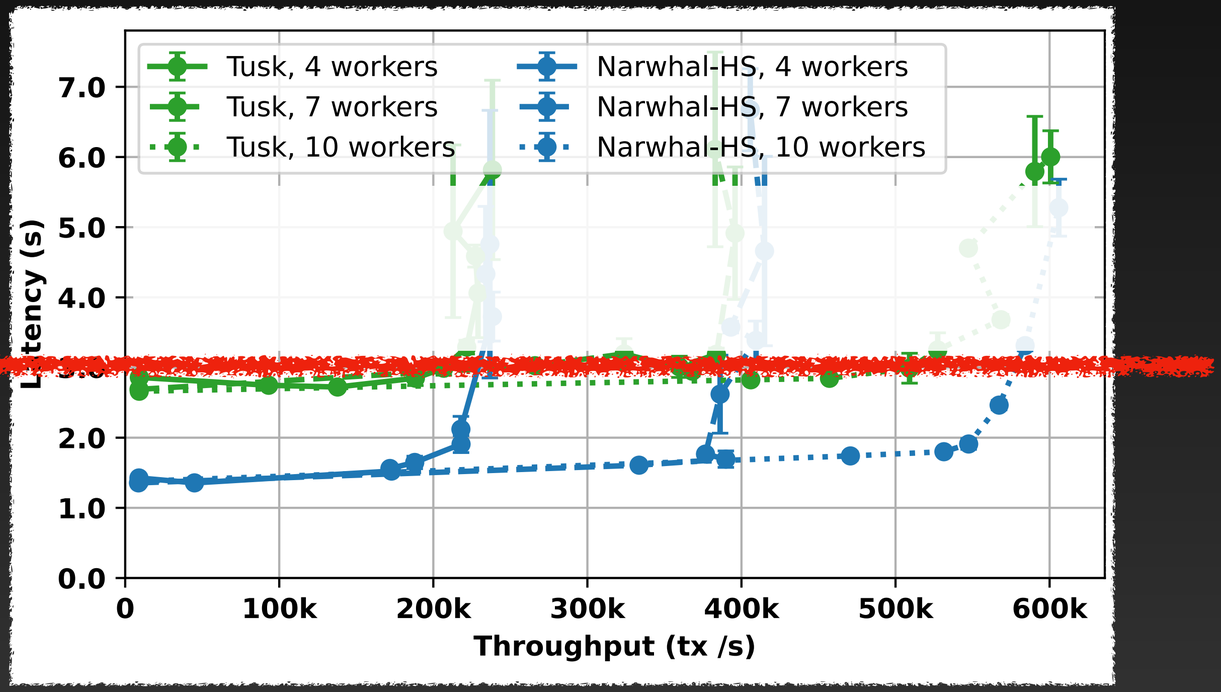


Evaluation
Scalability



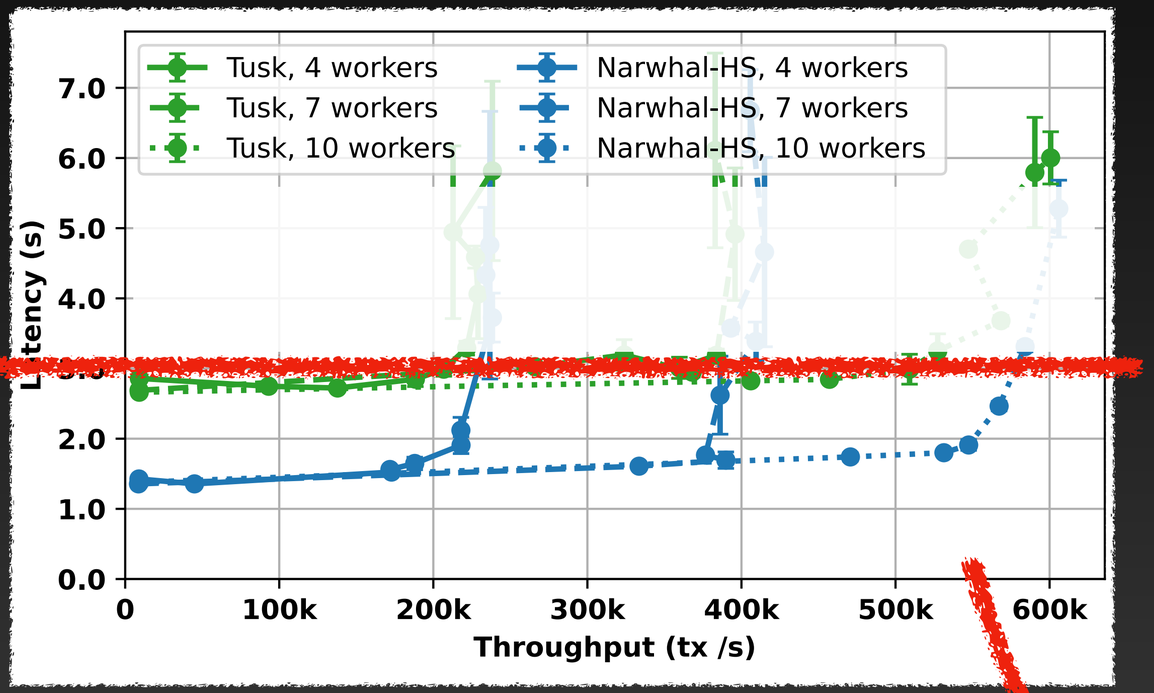
Evaluation

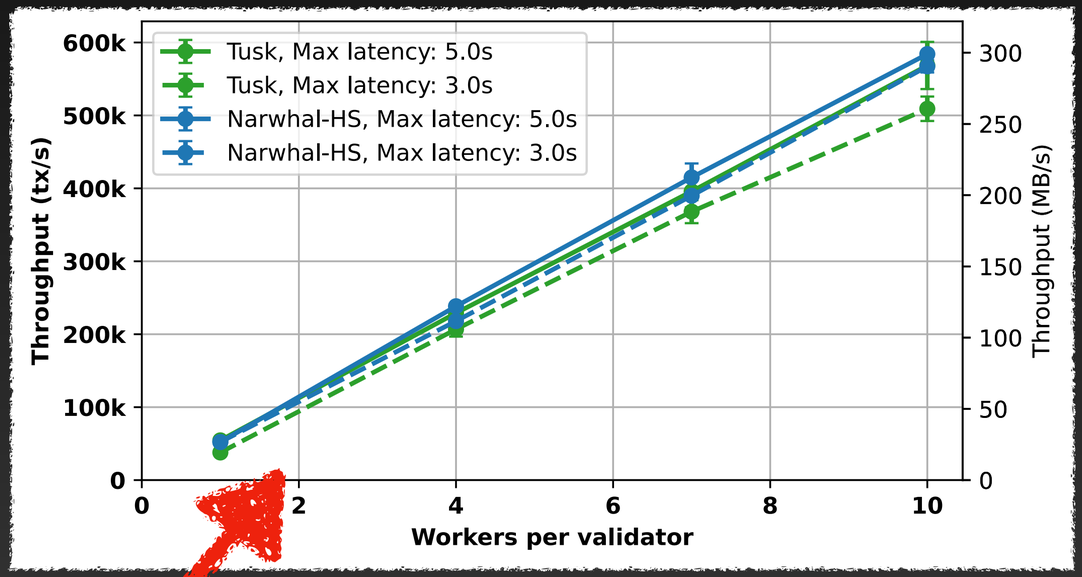
Scalability



Evaluation

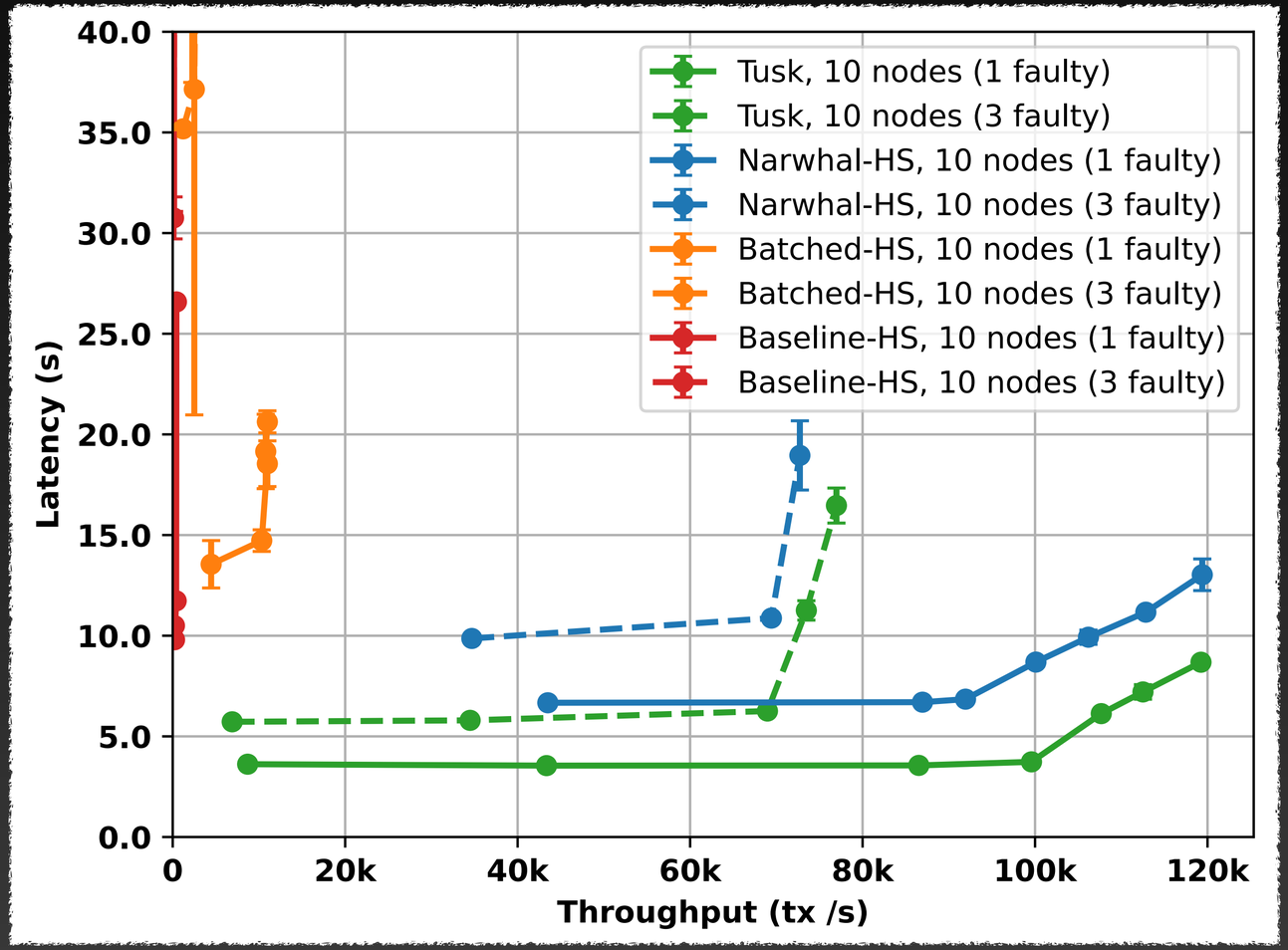
Scalability





Evaluation

Performance under faults



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

Still many caveats

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

Conclusion

Narwhal & Tusk

- Separate consensus and data dissemination for high performance
- Scalable design, egalitarian resource utilisations

- **Paper:** https://arxiv.org/pdf/2105.11827.pdf
- **Code:** https://github.com/asonnino/narwhal

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Future Works

Come talk to us!

- Performance under DDoS attack?
- How to implement scalable execution?

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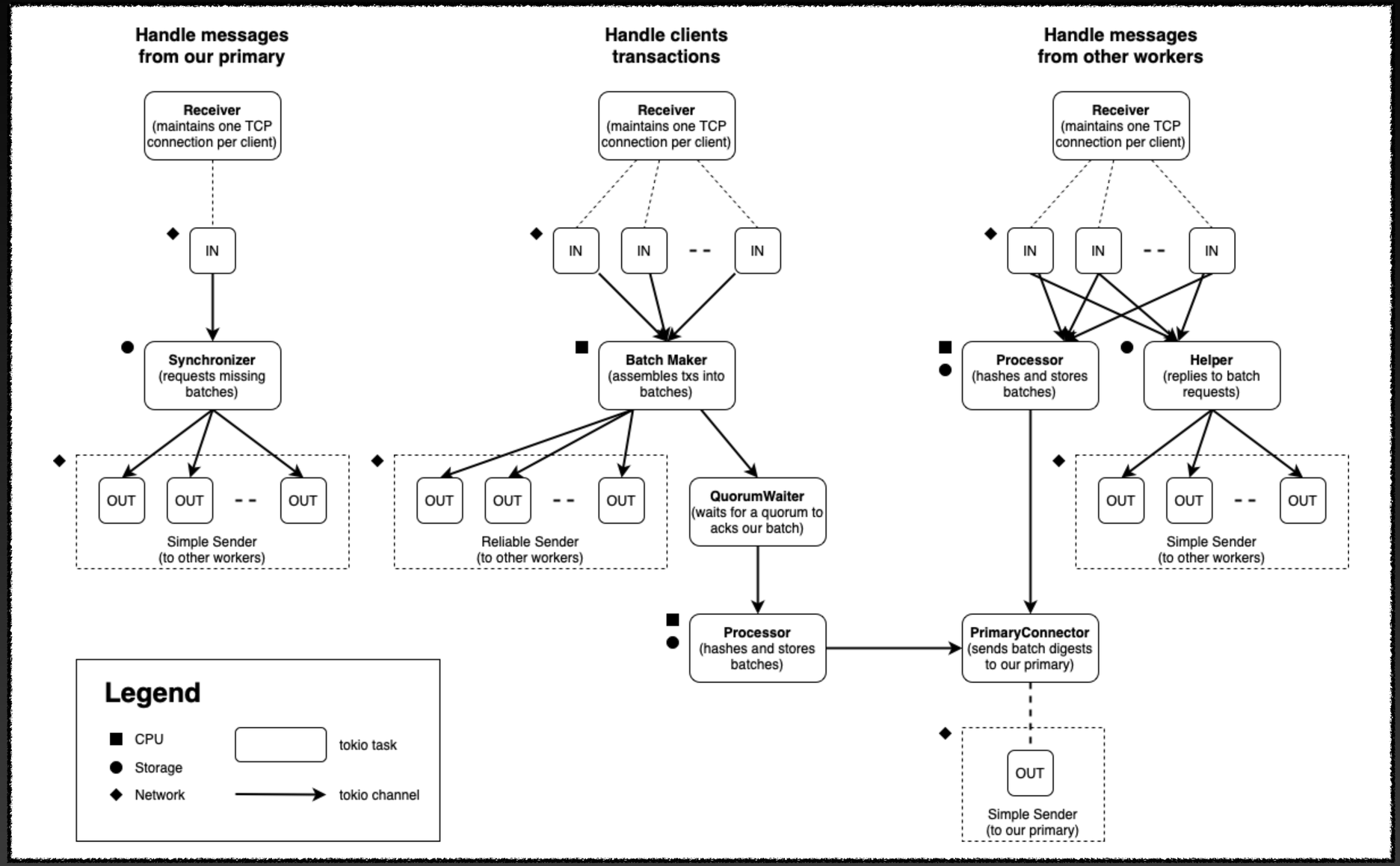
EXTRA

Worker Implementation



Primary Implementation