Just Say NO to Paxos Overhead: Replacing Consensus with Network Ordering

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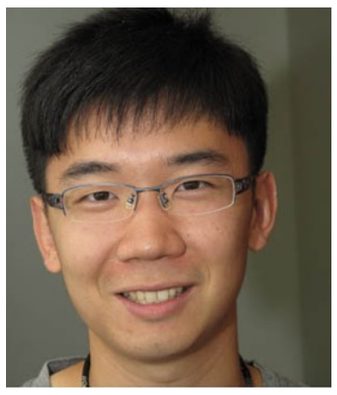


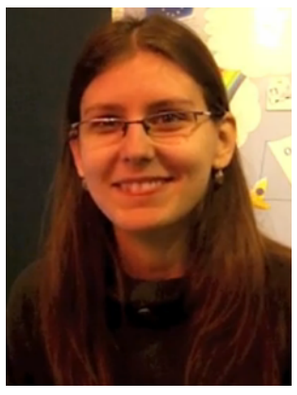


Server failures are the common case in data centers

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Cloud News Daily

Lightning Strikes Disrupt Google Data Center

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Amazon's Cloud Crash Disaster Permanently Destroyed Many Customers' Data

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State Machine Replication

Operation A

Operation B

Operation C

State Machine Replication

Operation A

Operation B

Operation C

Operation A

Operation B

Operation C

Operation A

Operation B

Operation C

State Machine Replication

Operation A

Operation B

Operation C

Operation A

Operation B

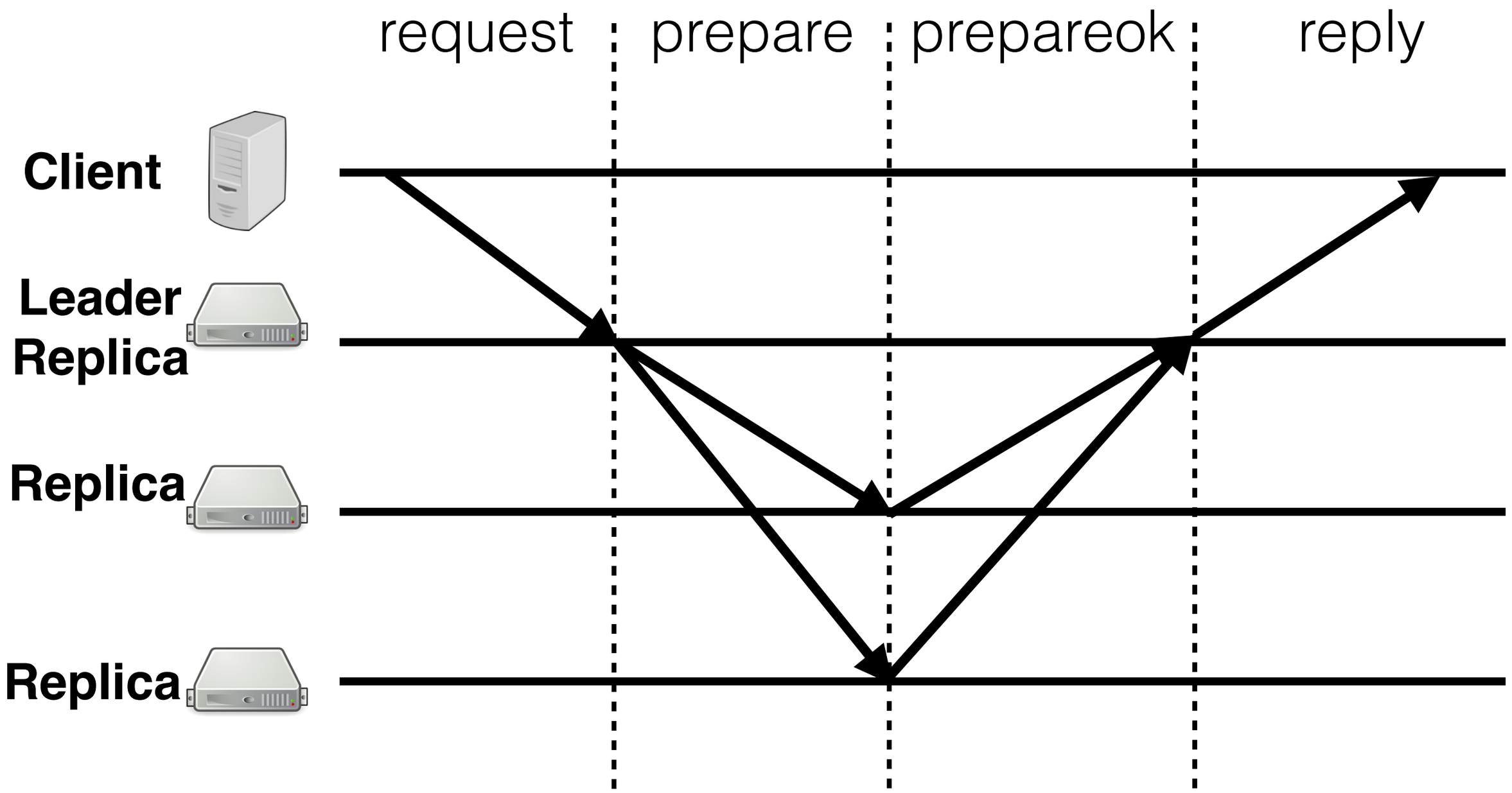
Operation C

Operation A

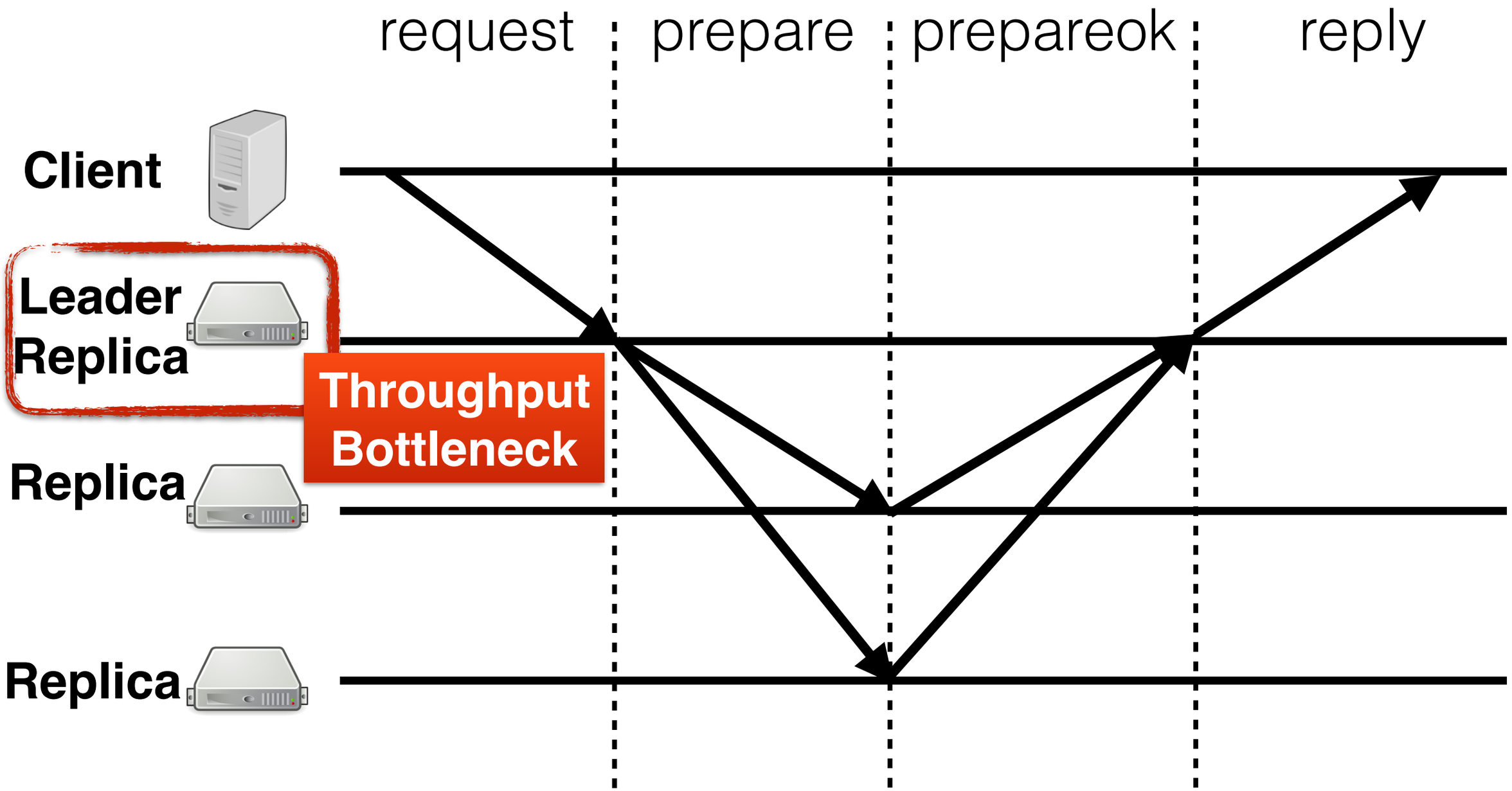
Operation B

Operation C

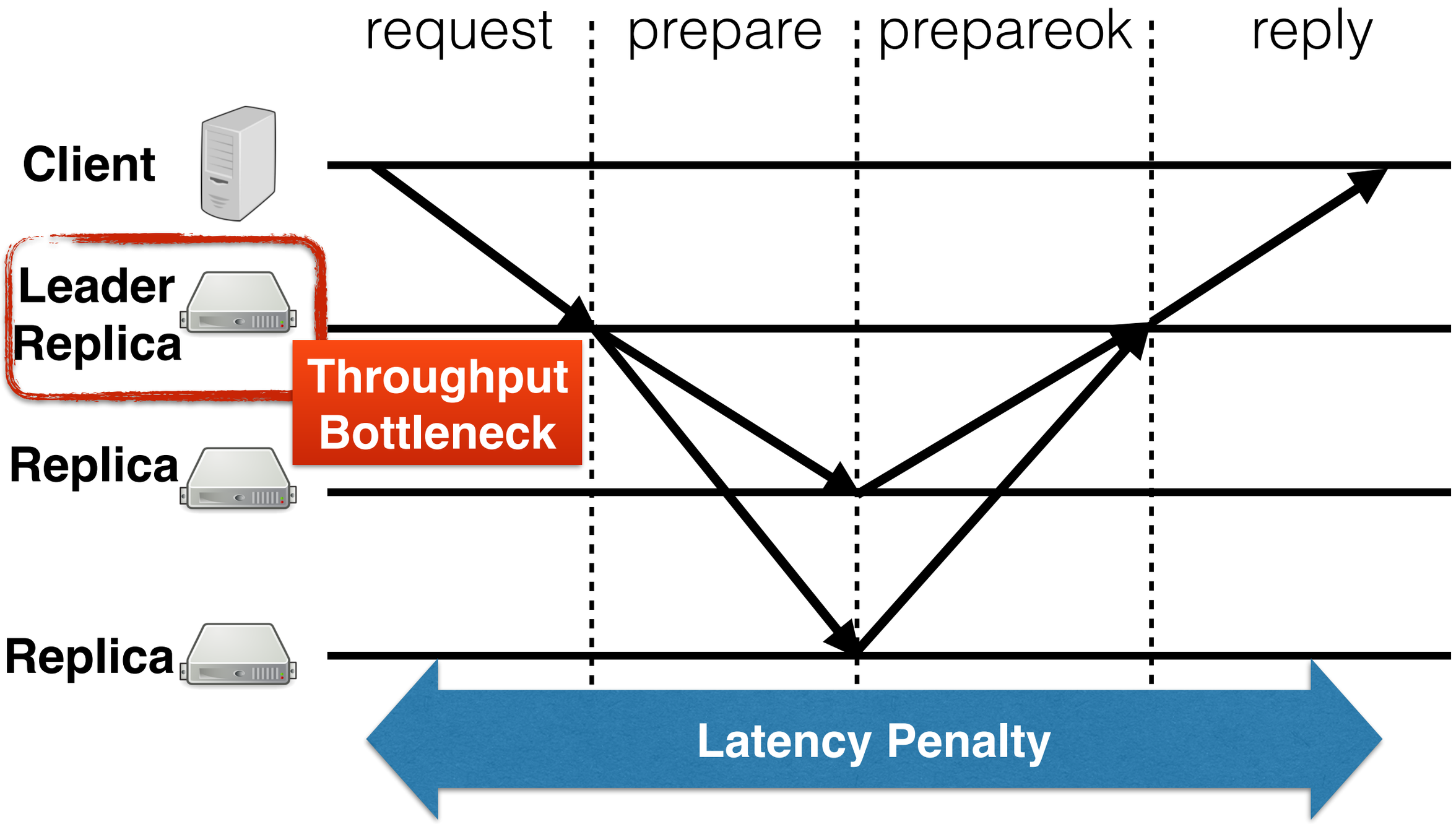
Paxos for state machine replication



Paxos for state machine replication



Paxos for state machine replication



Can we eliminate Paxos overhead?

Performance overhead due to **worst-case** network assumptions

- valid assumptions for the Internet
- data center networks are different

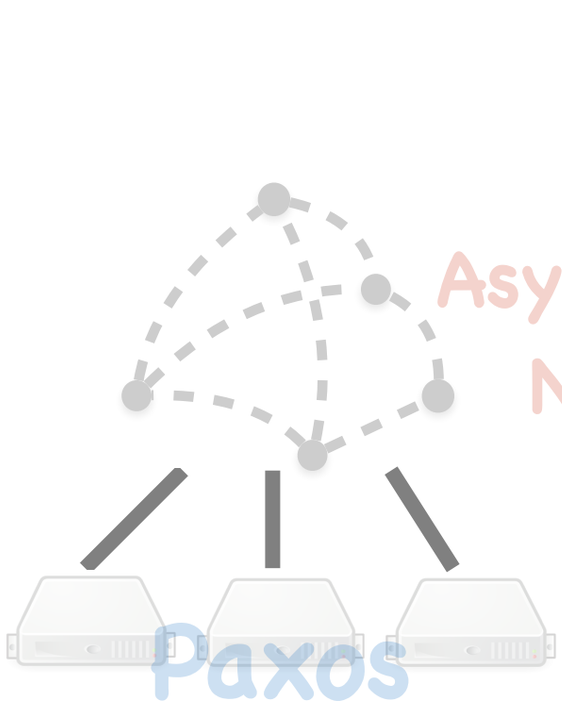
What properties should the network have to enable faster replication?

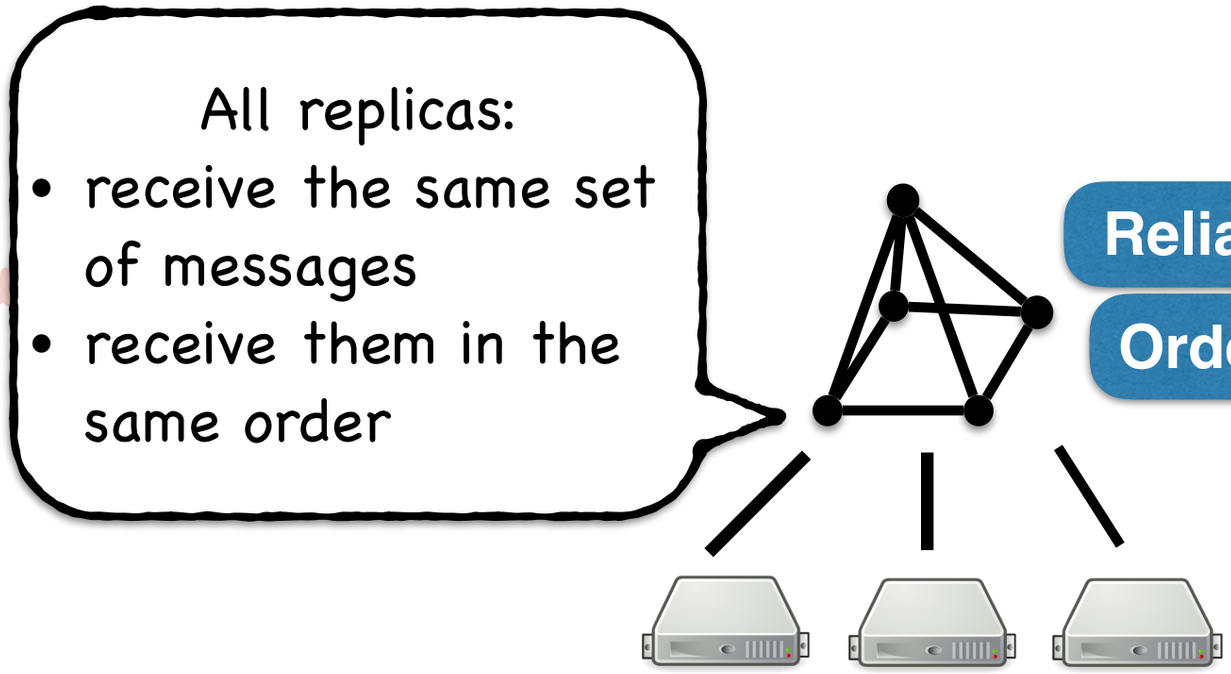
Network properties determine replication complexity

Messages may be:
- dropped
- reordered
- delivered with arbitrary latency

- Paxos protocol on every operation
- High performance cost

Network properties determine replication complexity





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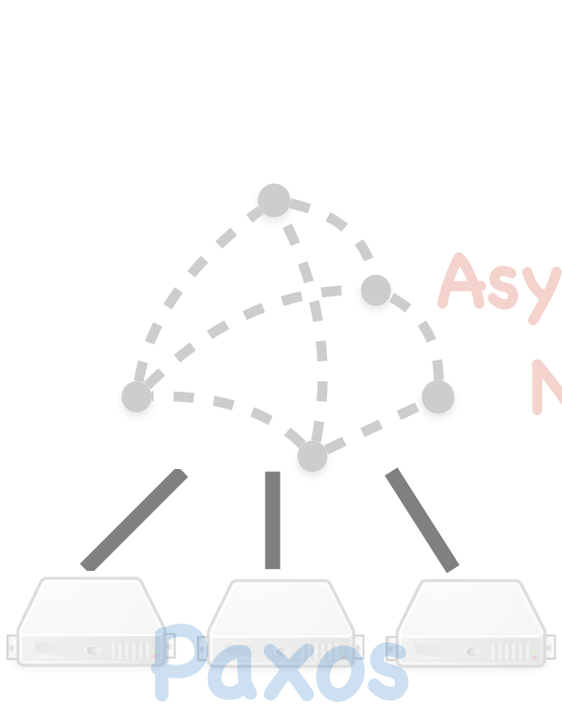
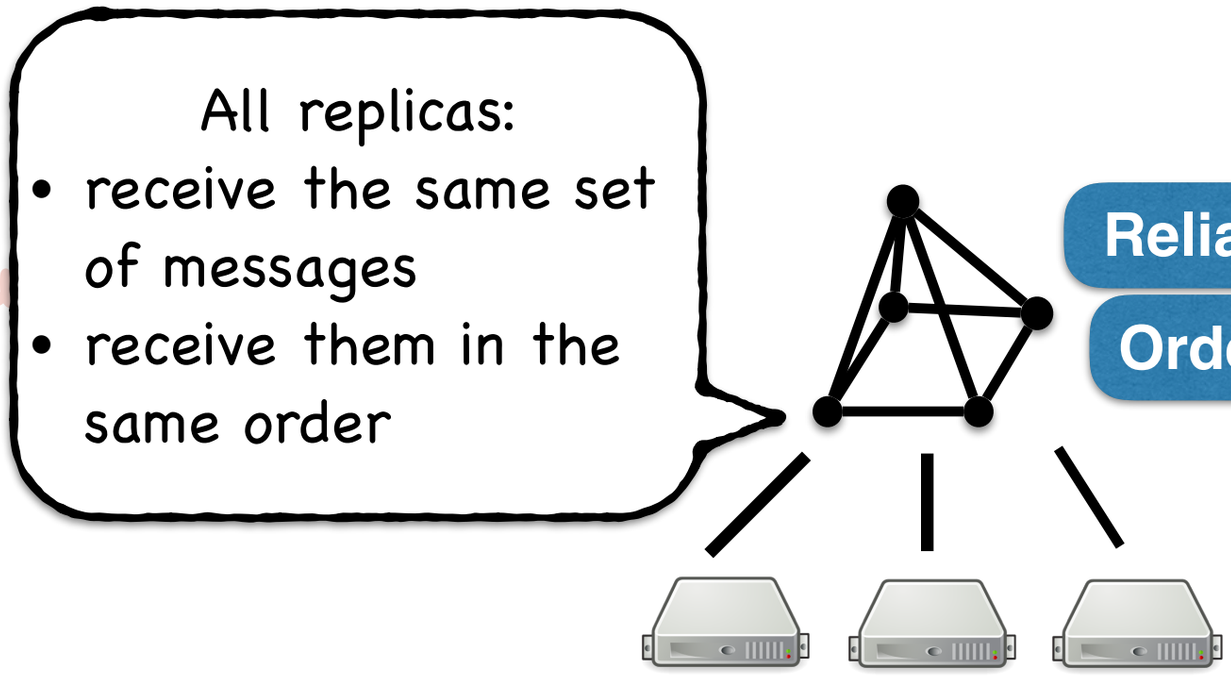
Network properties determine replication complexity

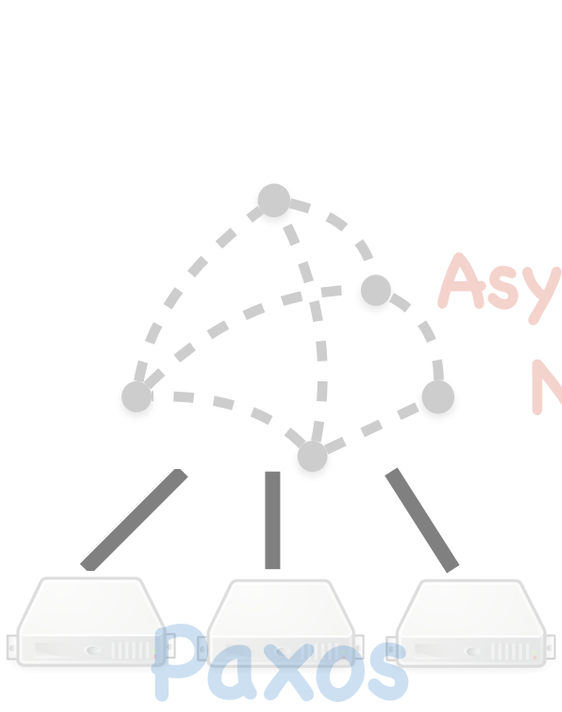




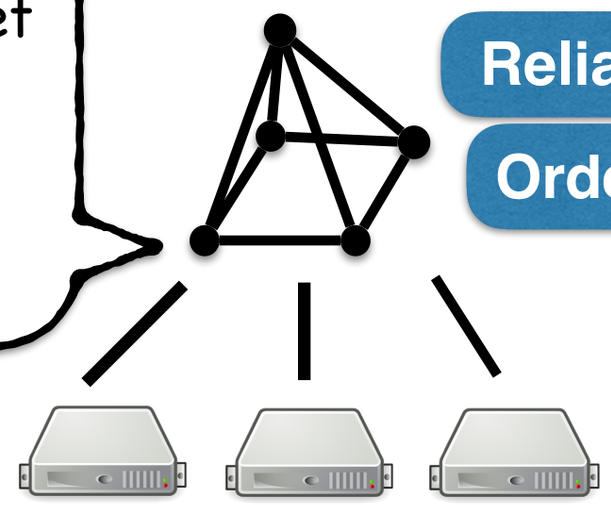
- Paxos protocol on every operation
- High performance cost

- Replication is trivial

Network properties determine replication complexity



All replicas:
- receive the same set of messages
- receive them in the same order

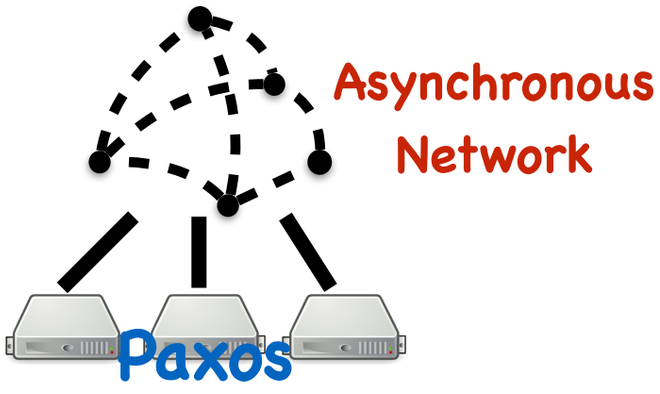


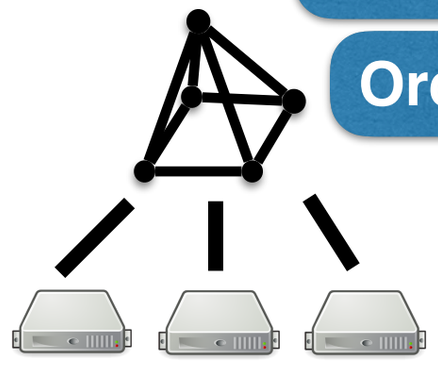
Reliability

Ordering

- Paxos protocol on every operation
- High performance cost

- Replication is trivial
- Network implementation has the same complexity as Paxos





Reliability

Ordering

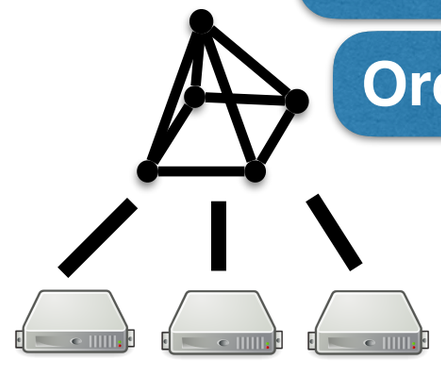
Weak

Strong

Network Guarantee

Reliability

Ordering



Weak

Strong

Network Guarantee

Can we build a network model that:

- provides **performance benefits**
- can be implemented more **efficiently**

This Talk

This Talk

A new network model with ***near-zero-cost*** implementation:
Ordered Unreliable Multicast

This Talk

A new network model with ***near-zero-cost*** implementation:
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+

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A new network model with ***near-zero-cost*** implementation:
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A ***coordination-free*** replication protocol:
Network-Ordered Paxos

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A new network model with ***near-zero-cost*** implementation:
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=

replication within **2%** throughput overhead

Outline

1. Background on state machine replication and data center network
2. Ordered Unreliable Multicast
3. Network-Ordered Paxos
4. Evaluation

Towards an ordered but unreliable network

Key Idea: Separate **ordering** from **reliable delivery** in state machine replication

Network provides **ordering**

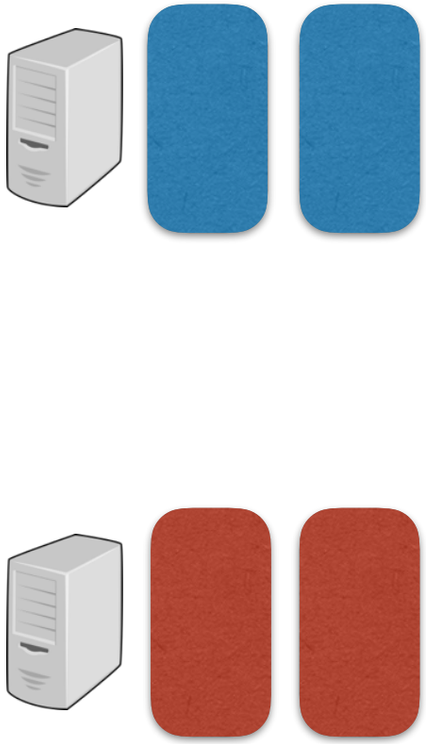
Replication protocol handles **reliability**

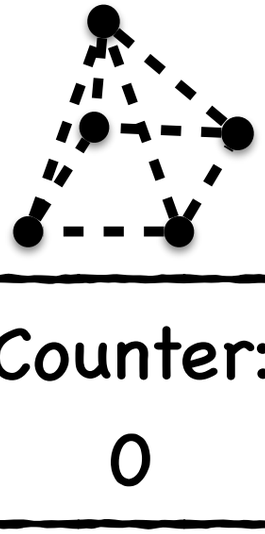
OUM Approach

- Designate one **sequencer** in the network
- Sequencer maintains a counter for each OUM group

1. Forward OUM messages to the sequencer
2. Sequencer increments counter and writes counter value into packet headers
3. Receivers use sequence numbers to detect **reordering** and **message drops**

Ordered Unreliable Multicast



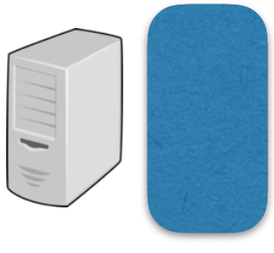


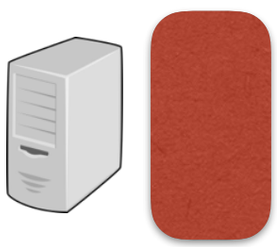
Counter:
0

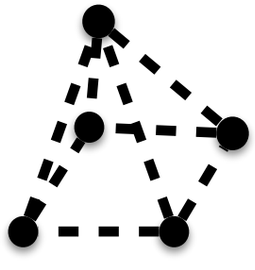
Senders

Receivers

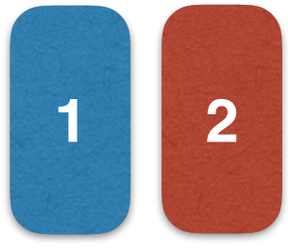
Ordered Unreliable Multicast

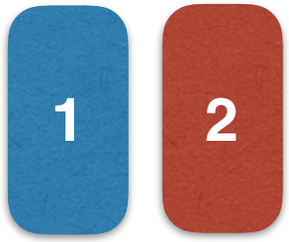


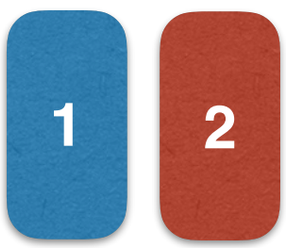




Counter:
2







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Receivers

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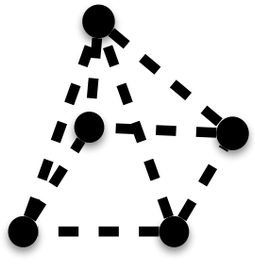
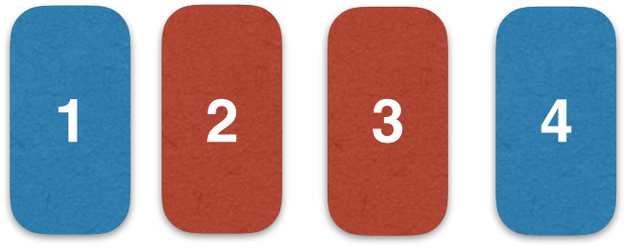
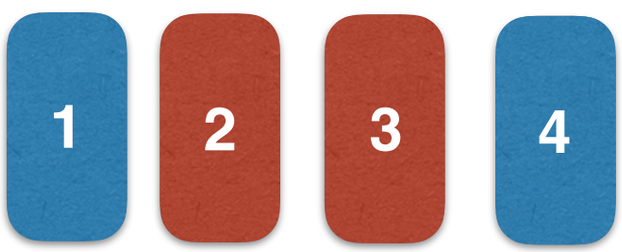


Counter:
4





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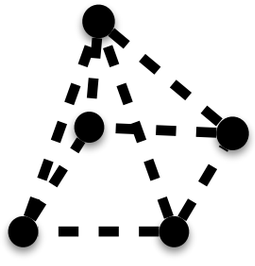

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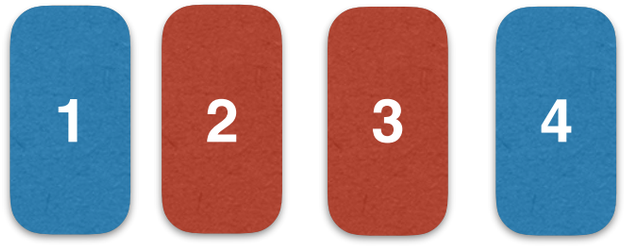
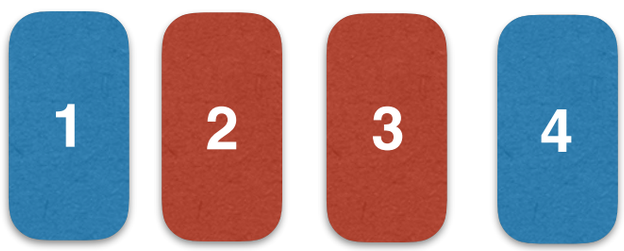




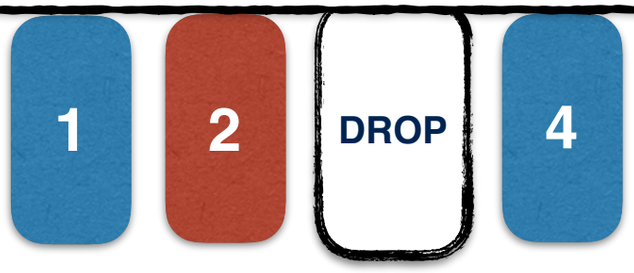
Senders

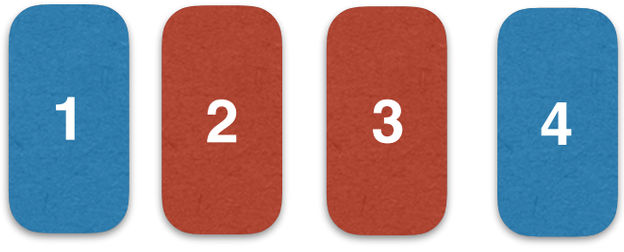
Receivers

Ordered Unreliable

Ordered Multicast:
no coordination required to determine order of messages

Counter:
4





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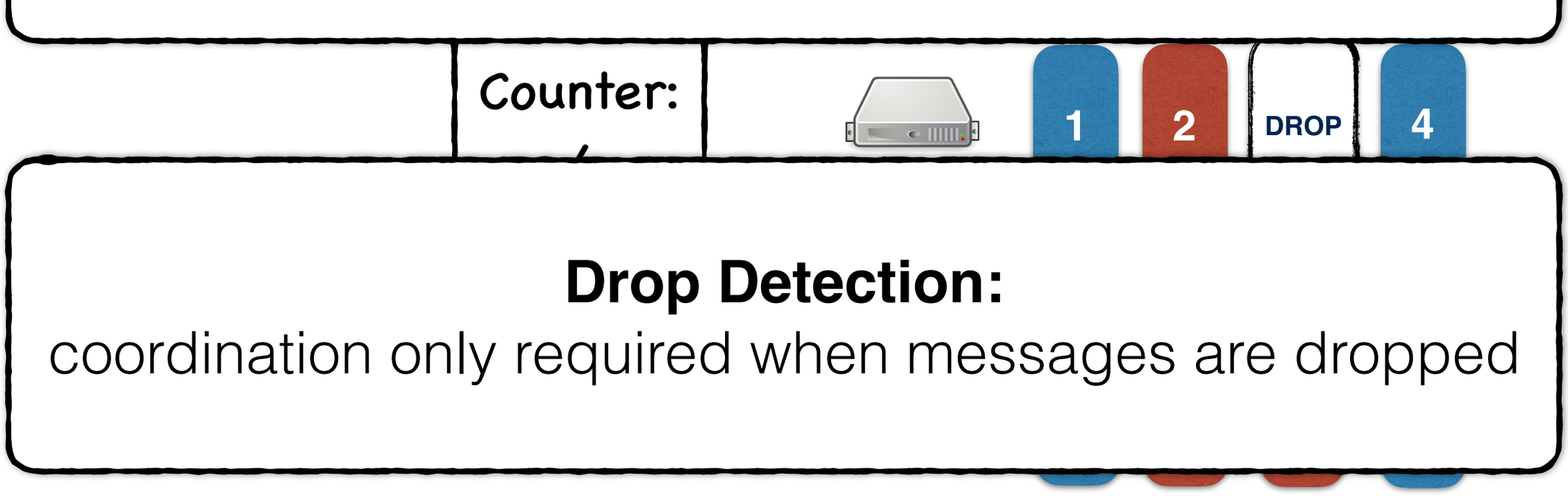


Drop Detection:
coordination only required when messages are dropped

Senders

Receivers

Sequencer Implementations

In-switch sequencing

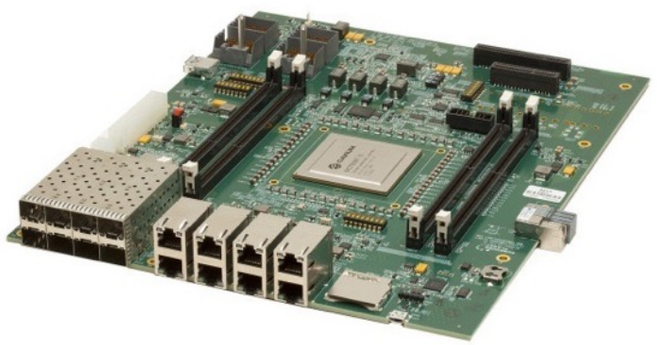
- next generation programmable switches
- implemented in P4
- nearly **zero cost**

Middlebox prototype

- Cavium Octeon network processor
- connects to root switches
- adds 8 us latency

End-host sequencing

- no specialized hardware required
- incurs higher latency penalties
- similar throughput benefits



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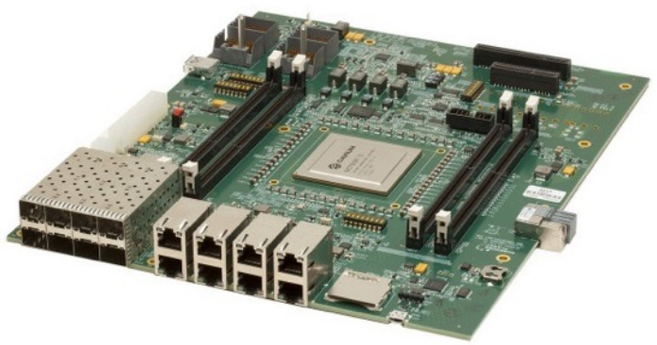

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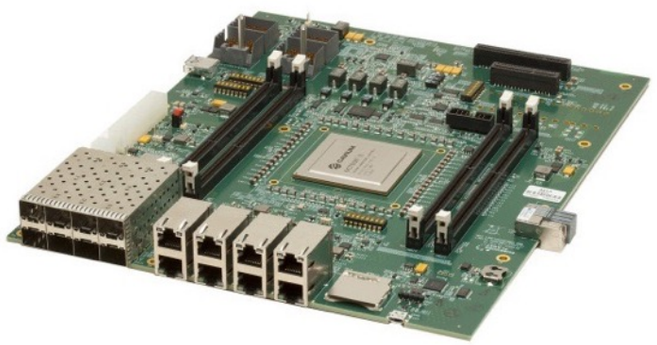

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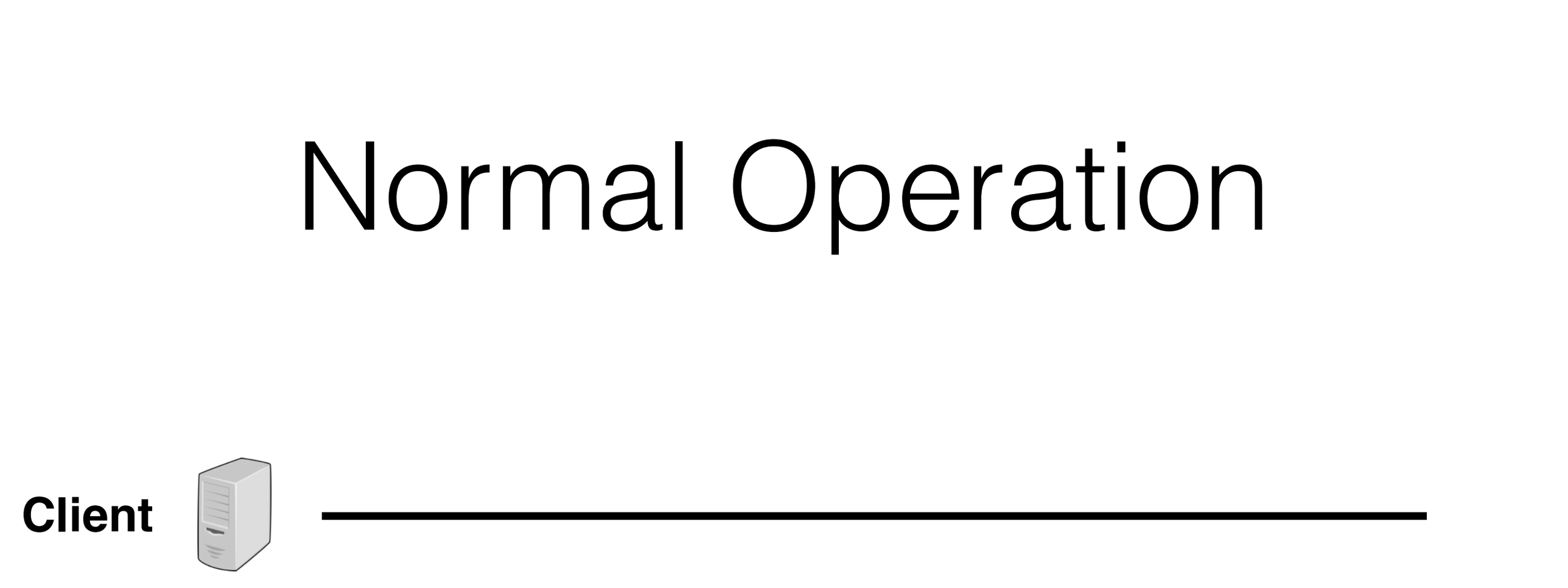
NOPaxos Overview

- Built on top of the guarantees of OUM
- Client requests are **totally ordered** but can be dropped
- **No coordination** in the common case
- Replicas run agreement on drop detection
- View change protocol for leader or sequencer failure

Normal Operation



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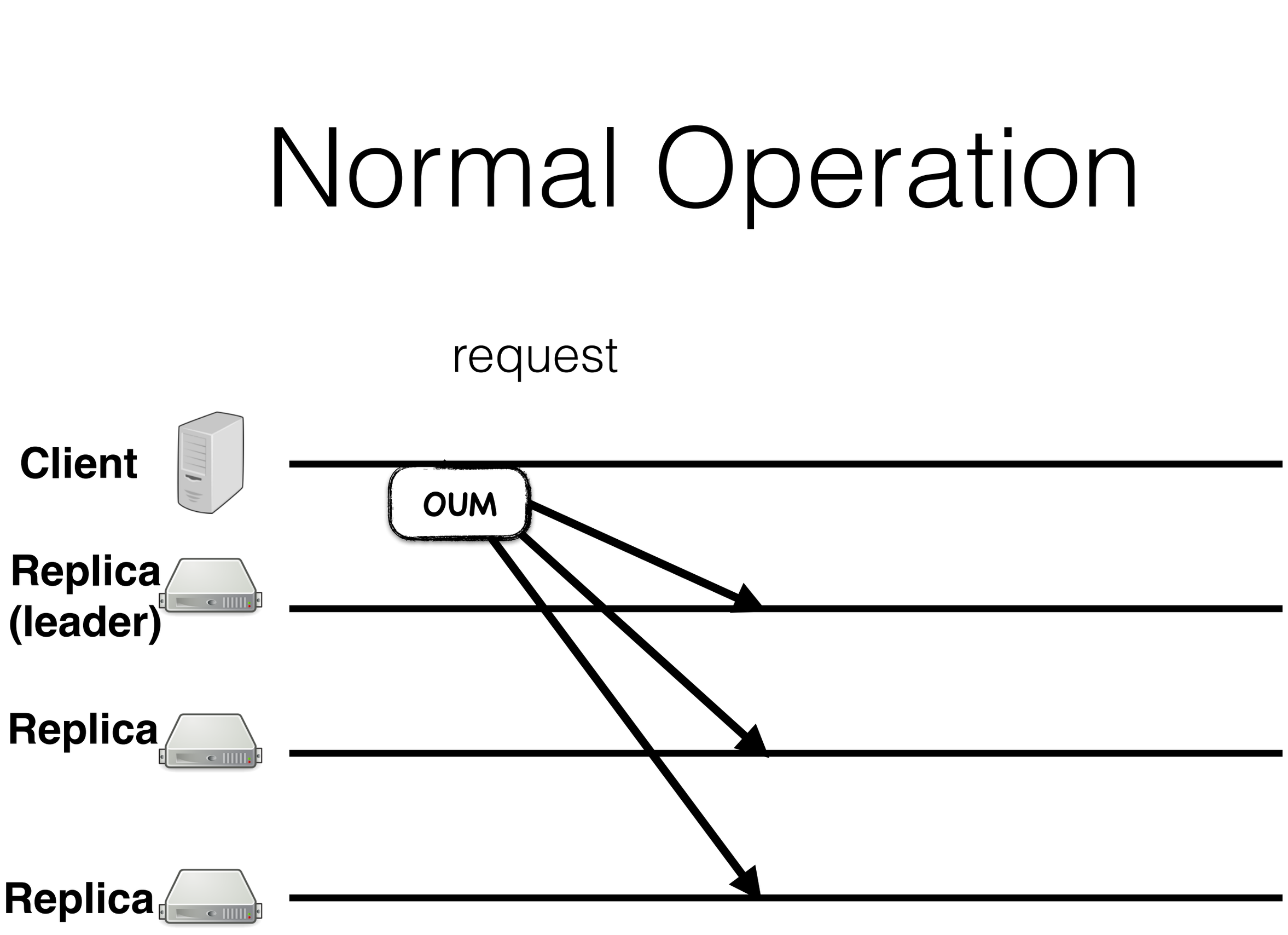

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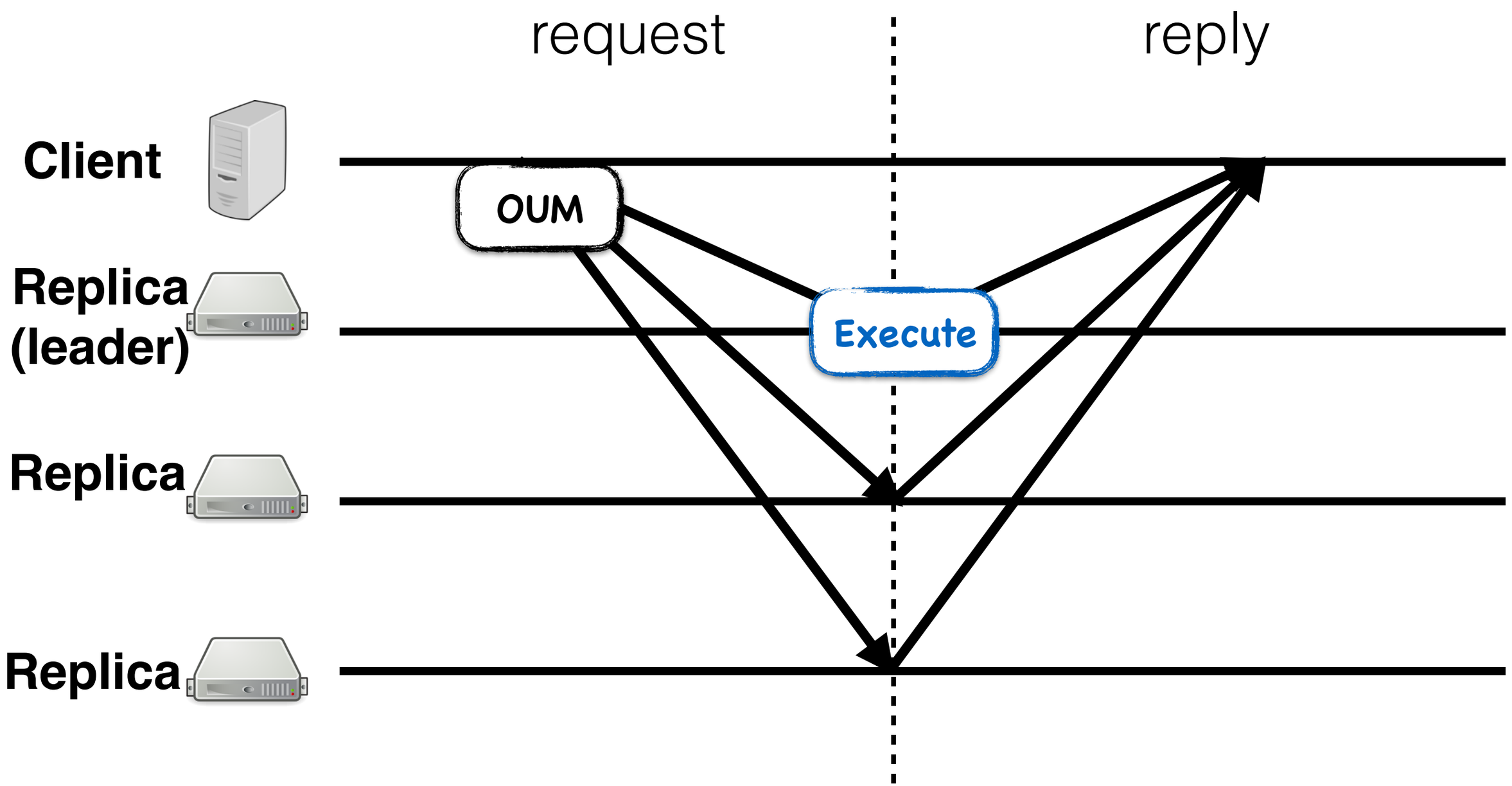

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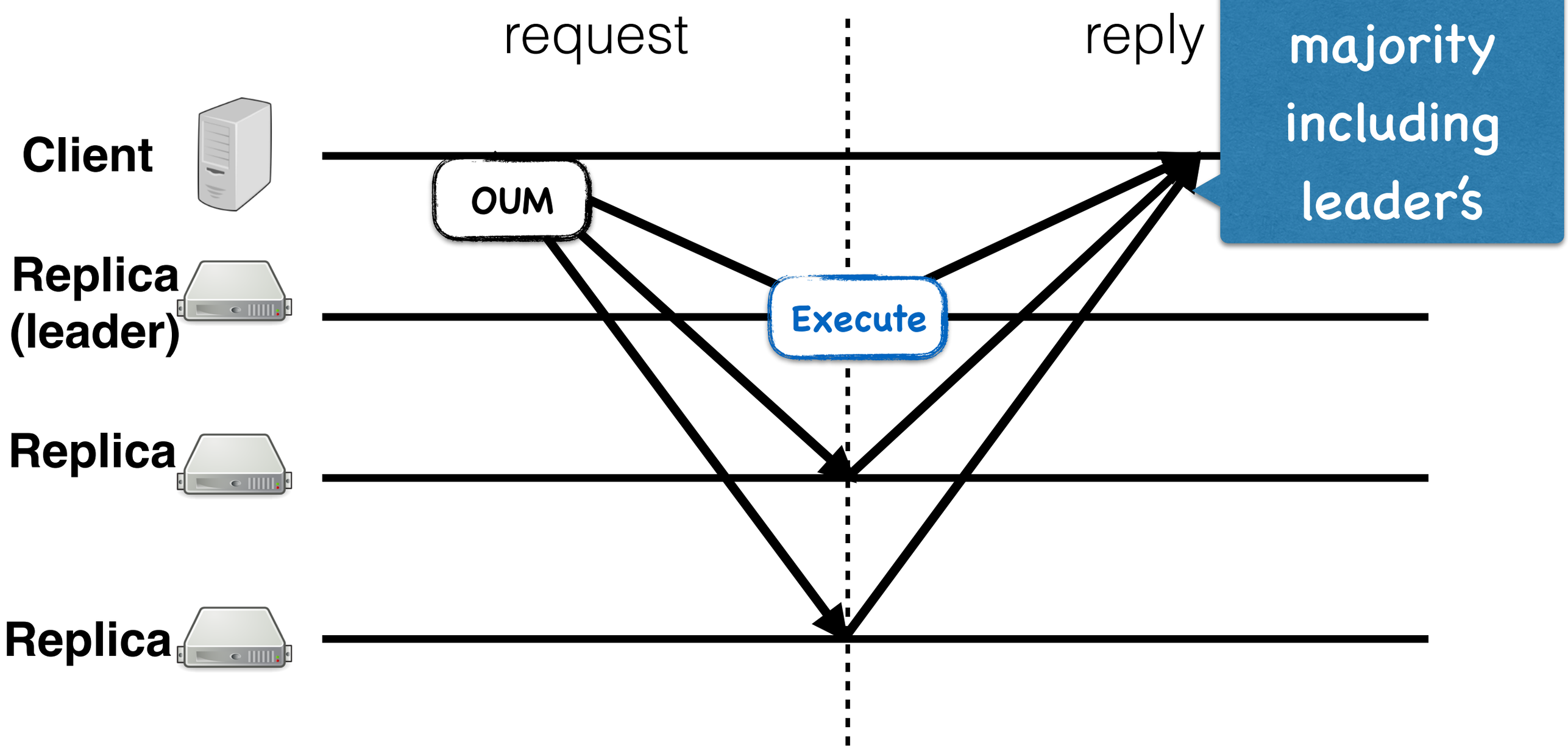

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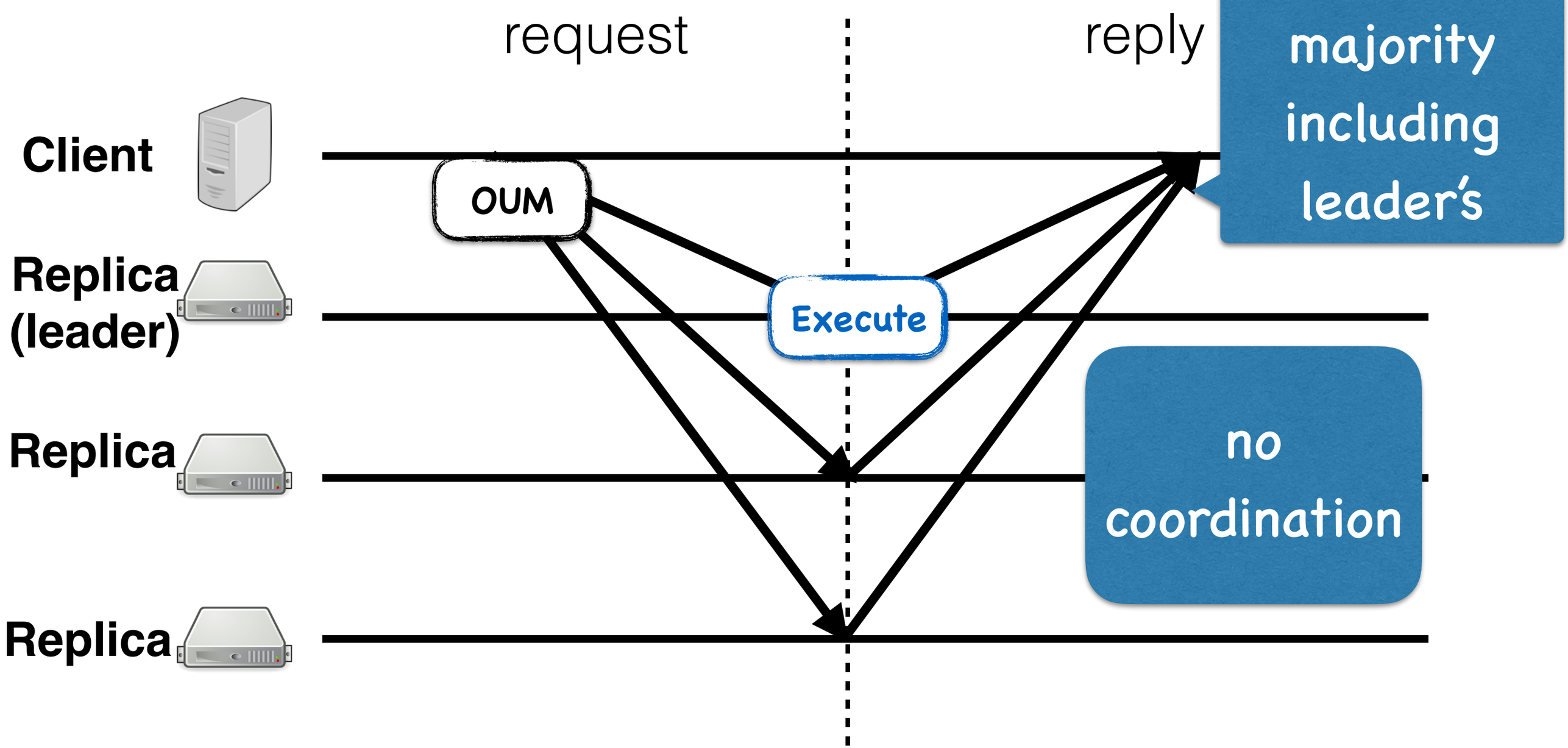

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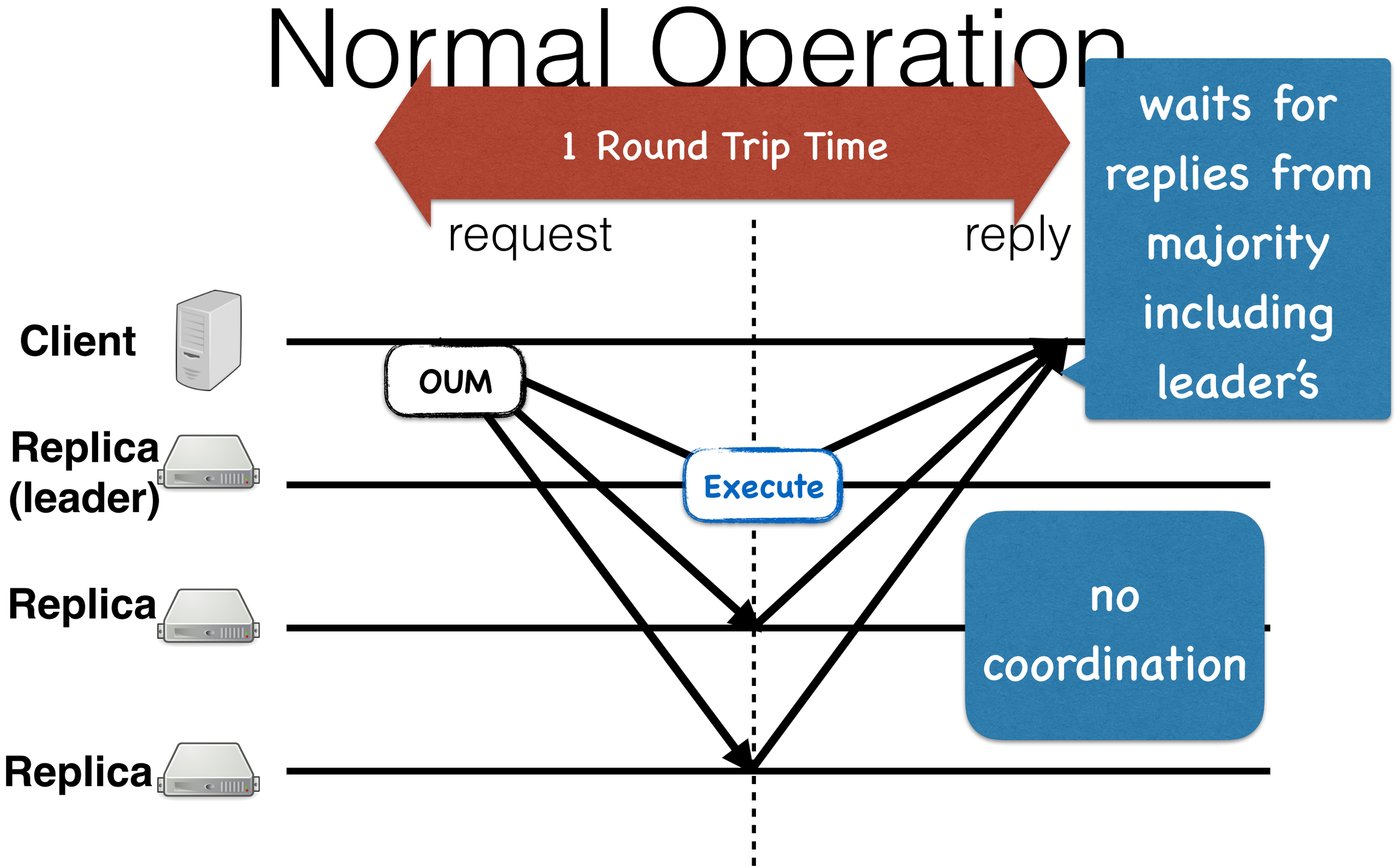

Gap Agreement

Replicas detect message drops

- **Non-leader replicas:** recover the missing message from the leader
- **Leader replica:** coordinates to commit a NO-OP (Paxos)

- Efficient recovery from network anomalies

View Change

- Handles leader or sequencer failure
- Ensures that all replicas are in a **consistent state**
- Runs a view change protocol similar to VR
- *view-number* is a tuple of *<leader-number, session-number>*

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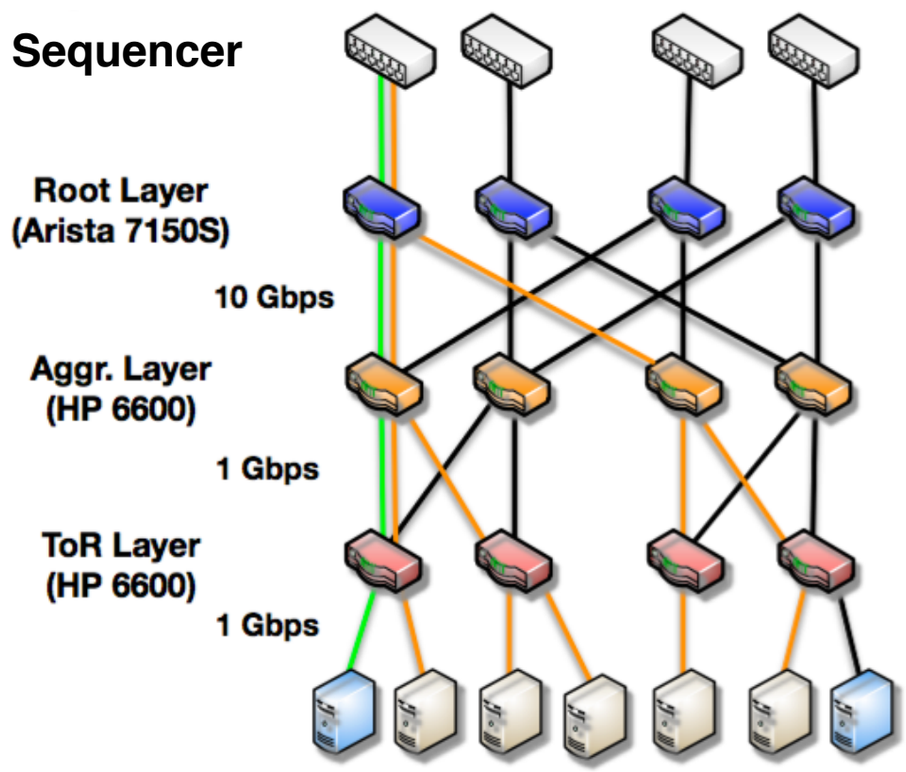
Evaluation Setup

- 3-level fat-tree network testbed
- 5 replicas with 2.5 GHz Intel Xeon E5-2680
- Middle box sequencer



NOPaxos achieves better throughput **and** latency

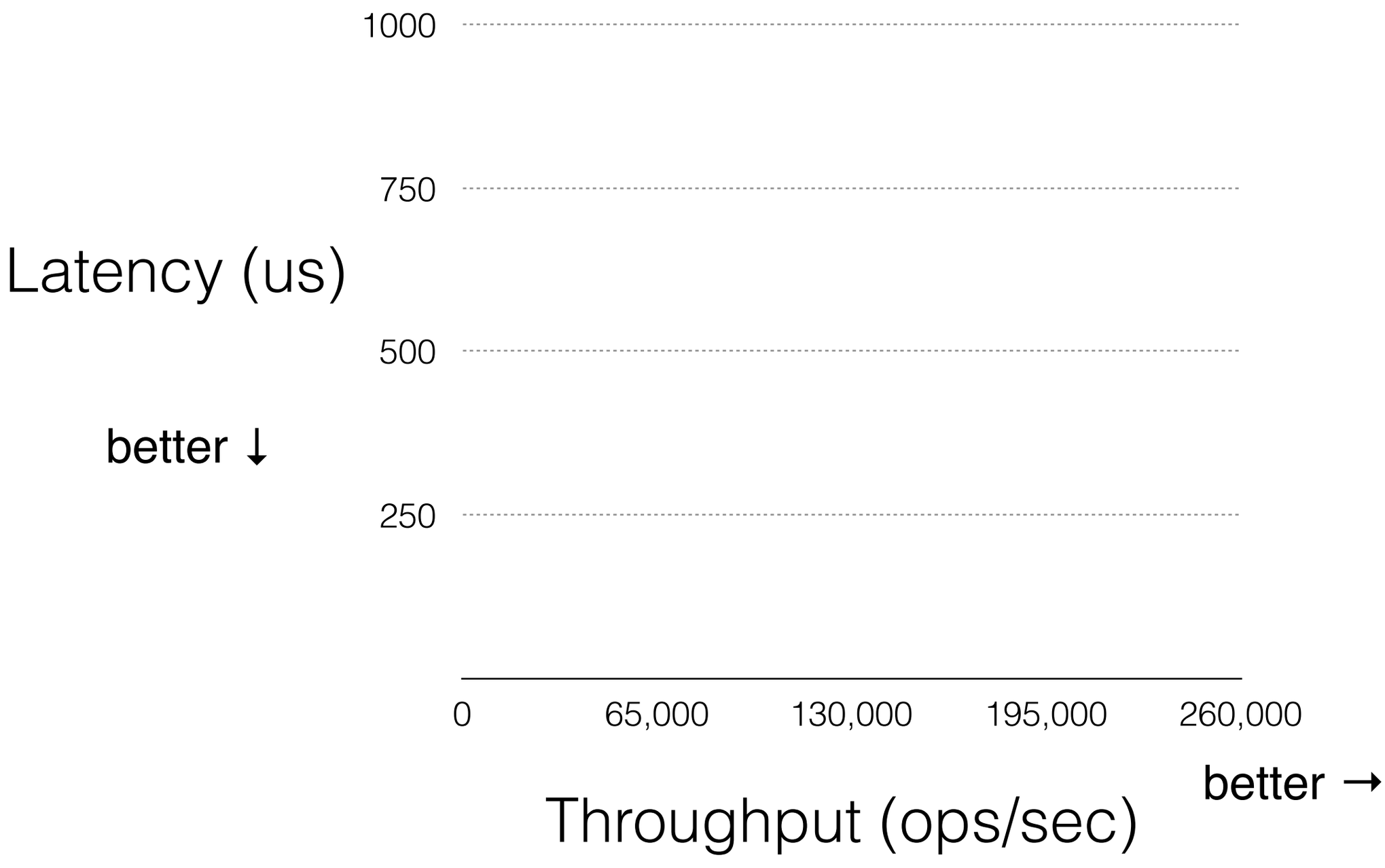
Latency (us)

better ↓

Throughput (ops/sec)

better →

NOPaxos achieves better throughput **and** latency



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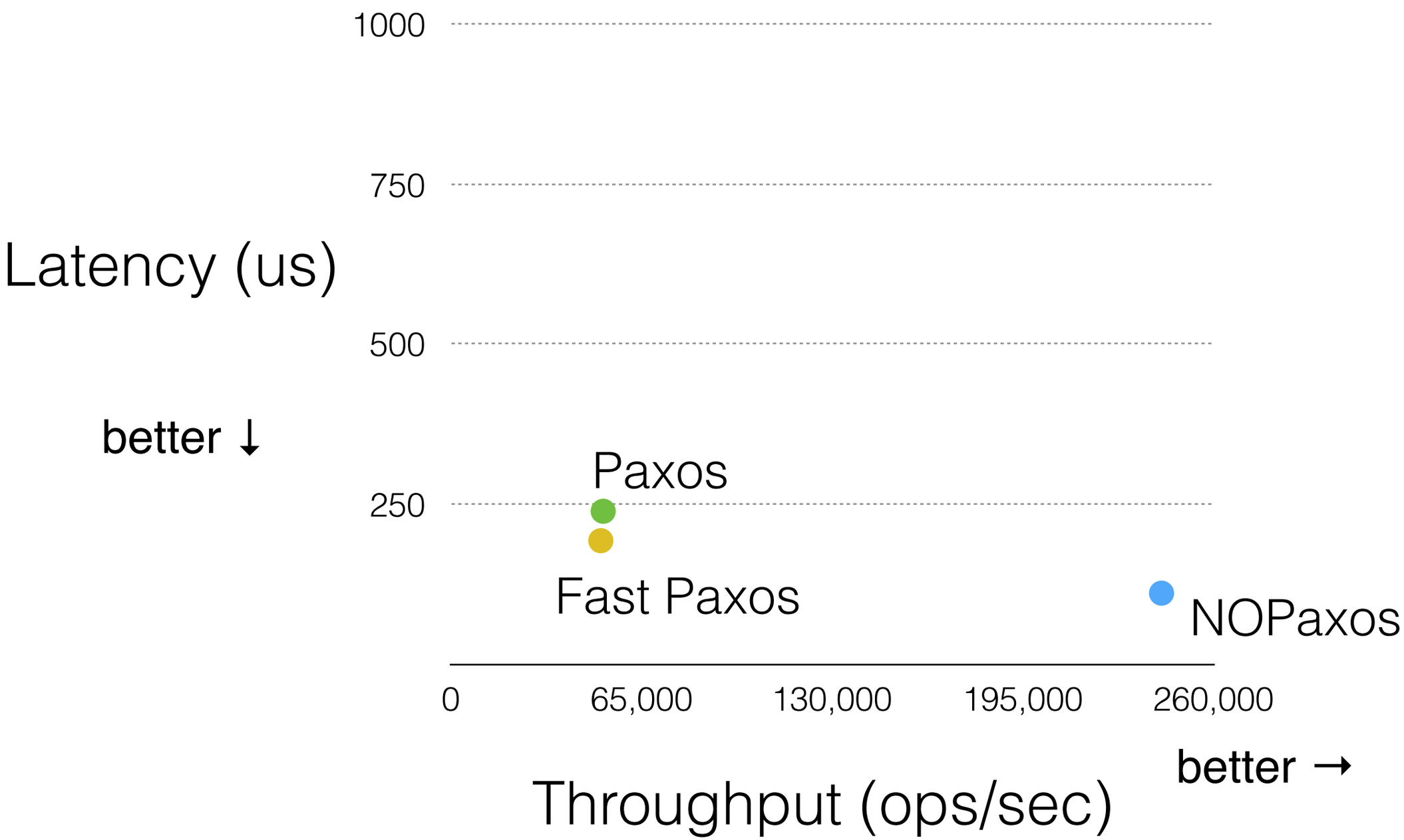

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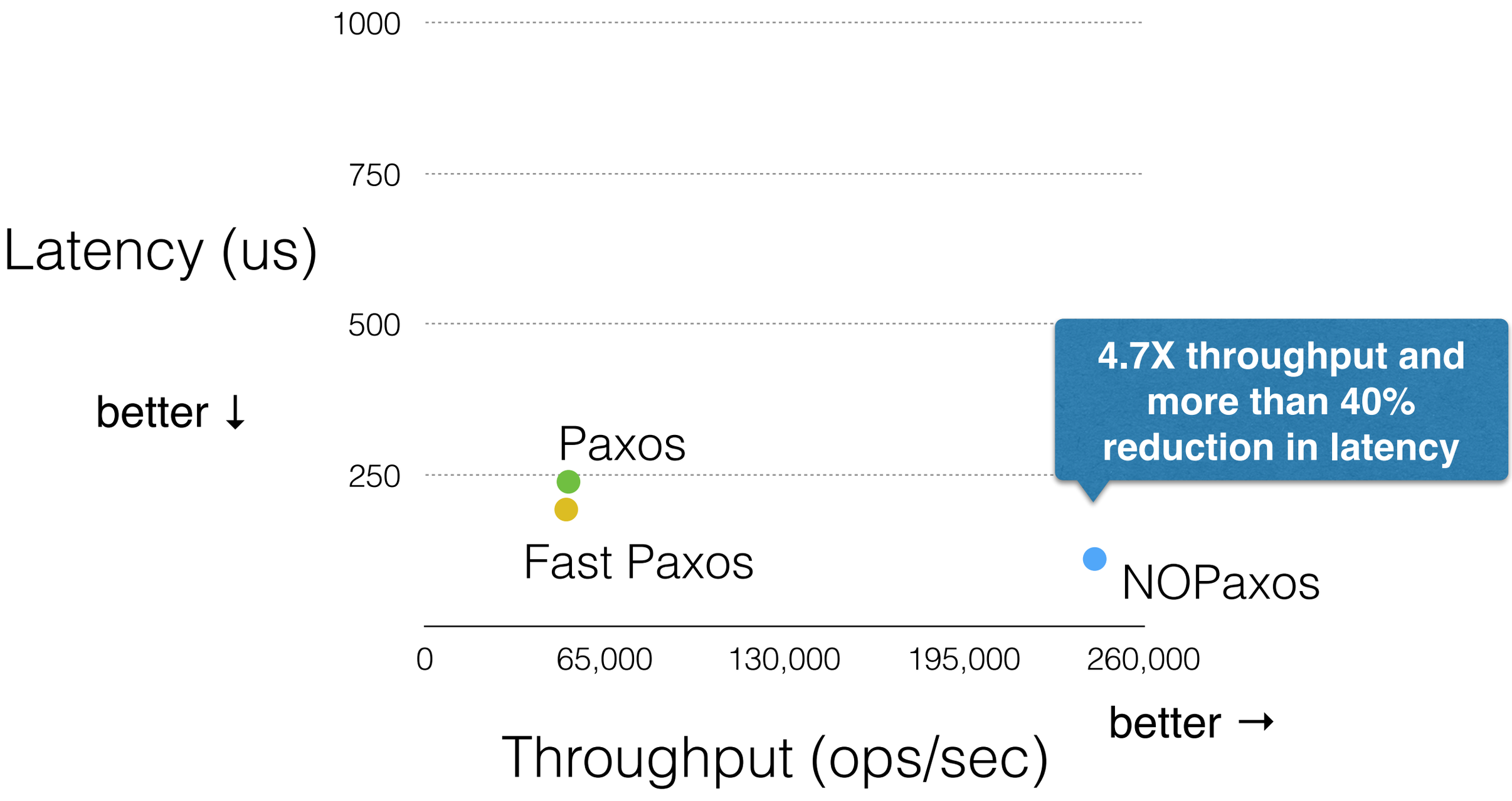

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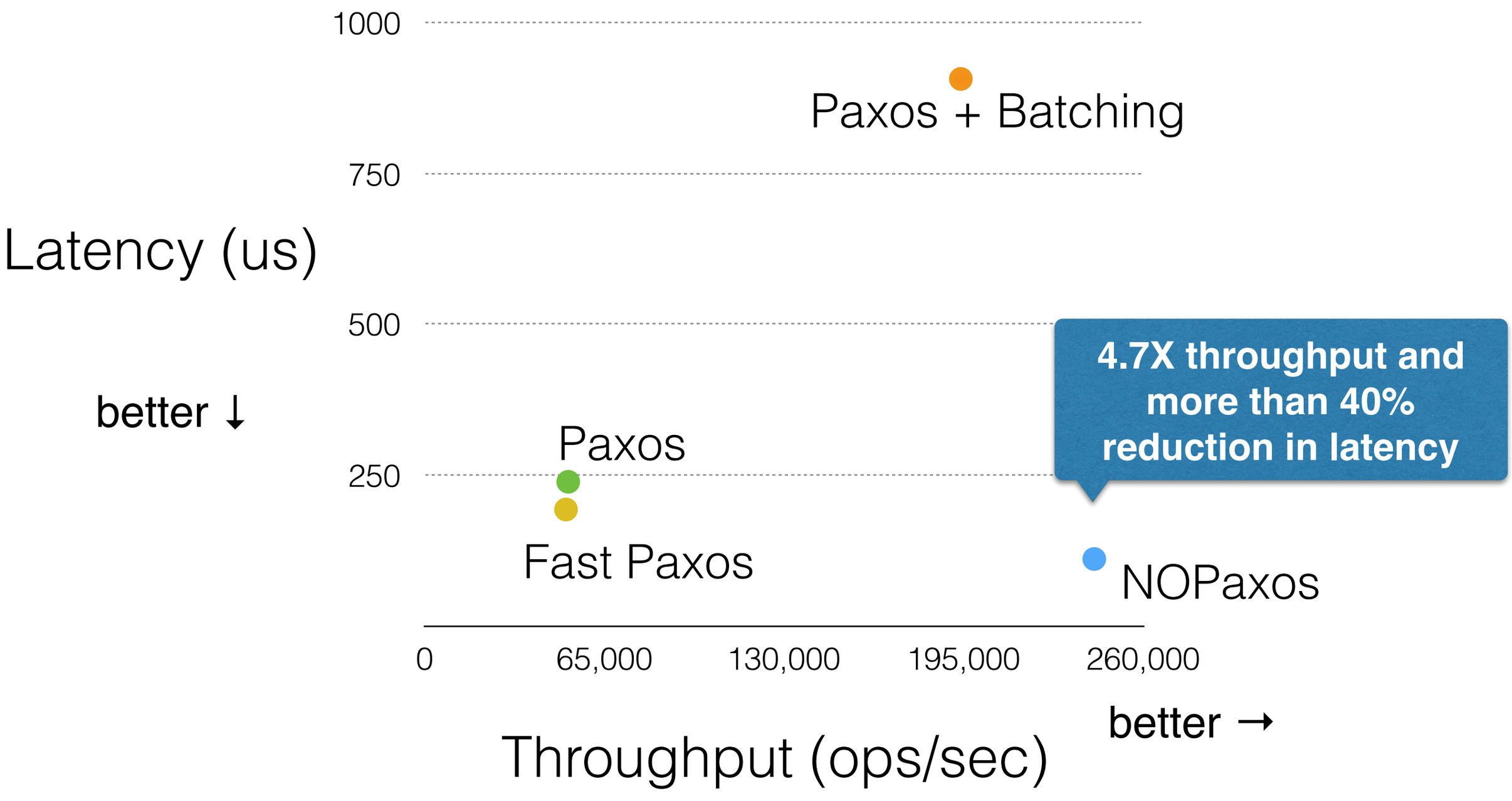

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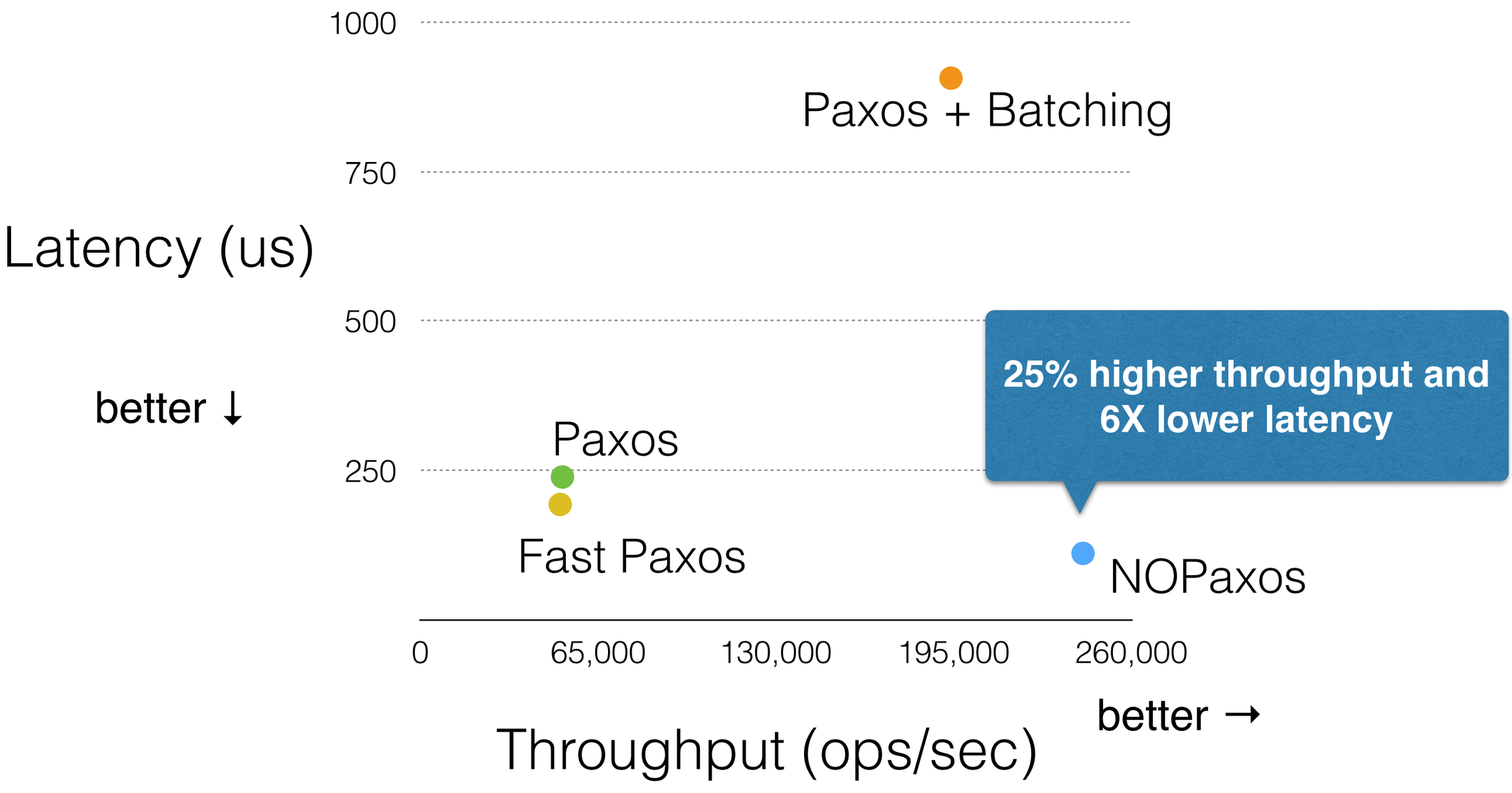
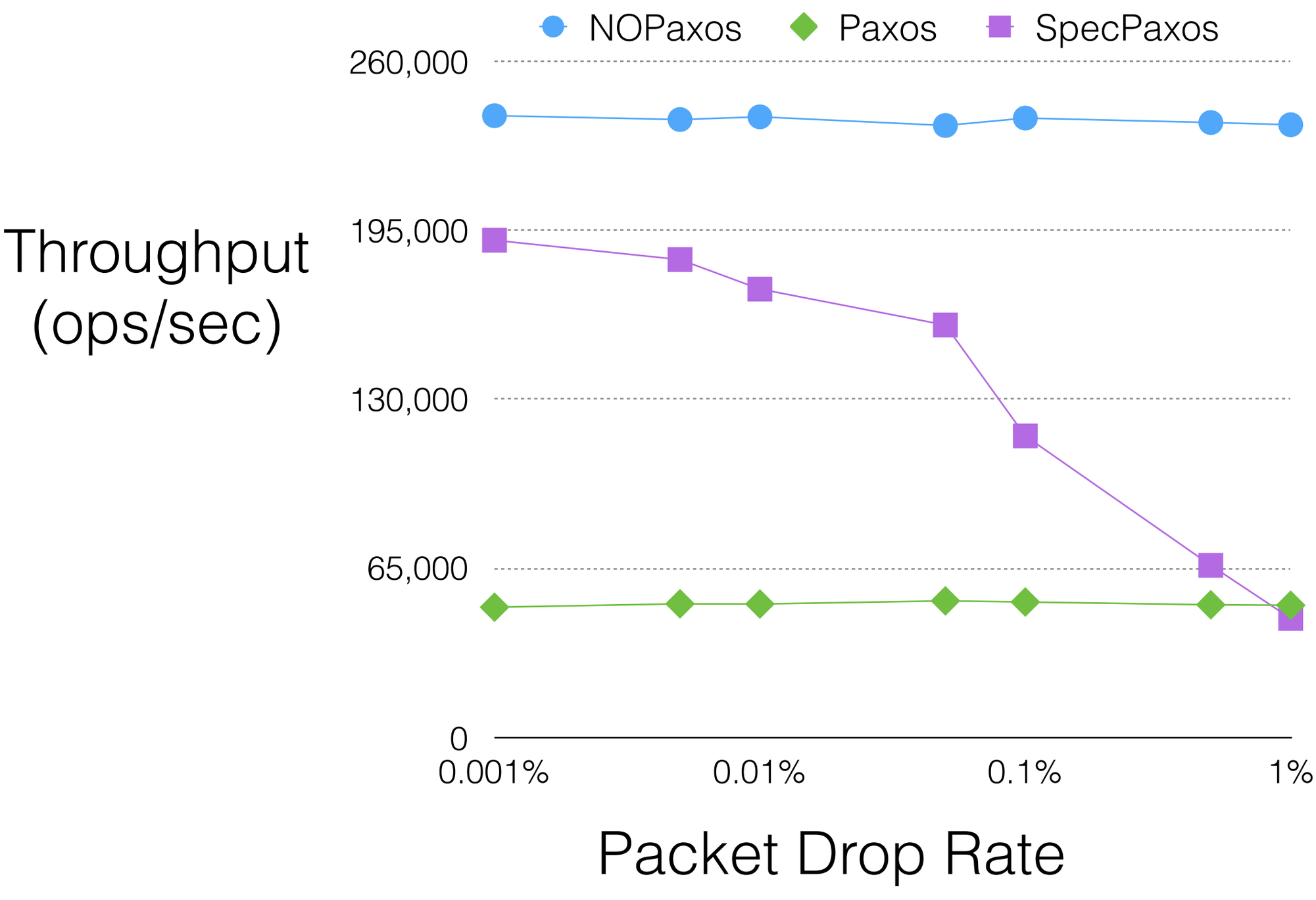


NOPaxos is resilient to network anomalies



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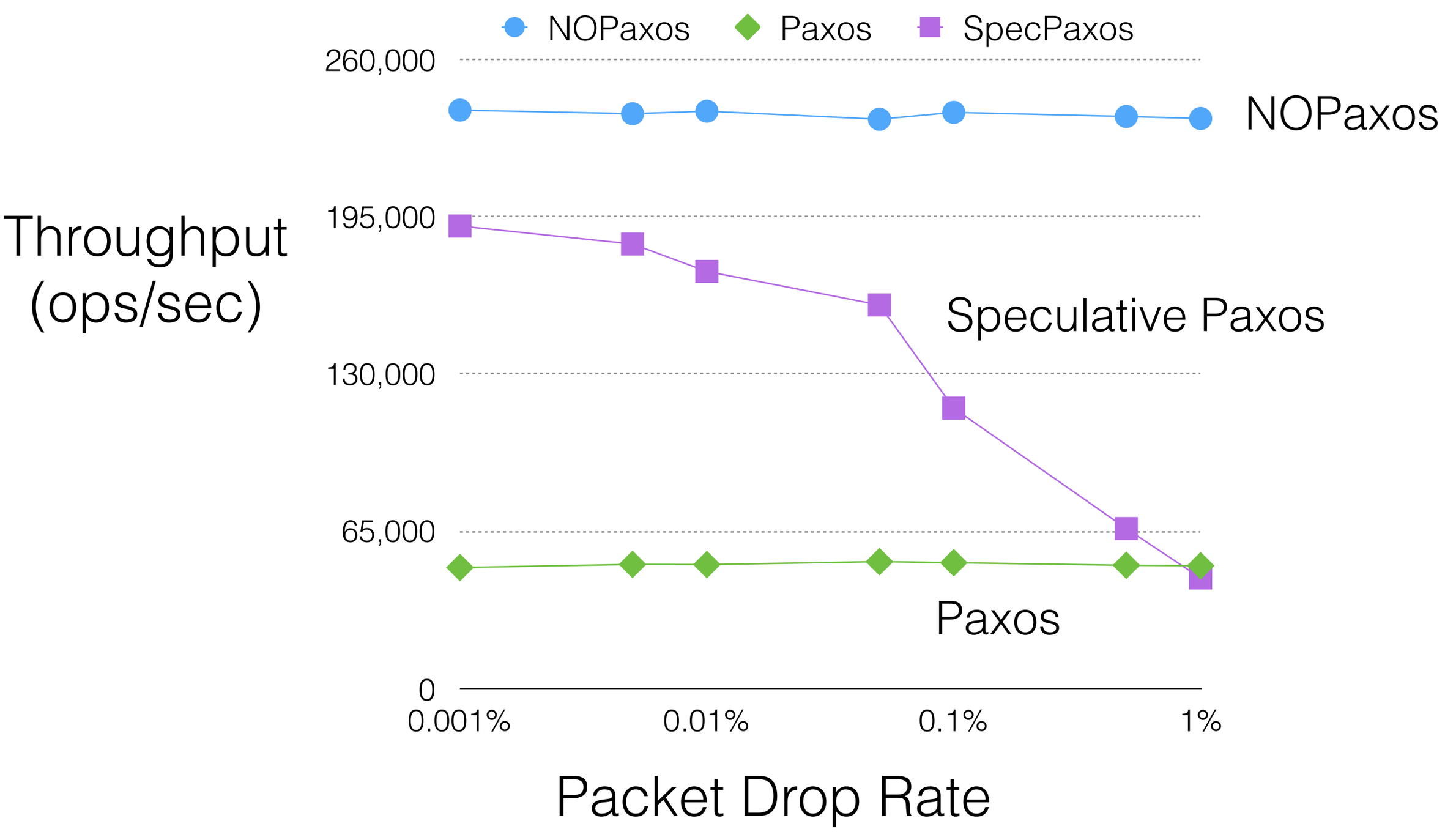
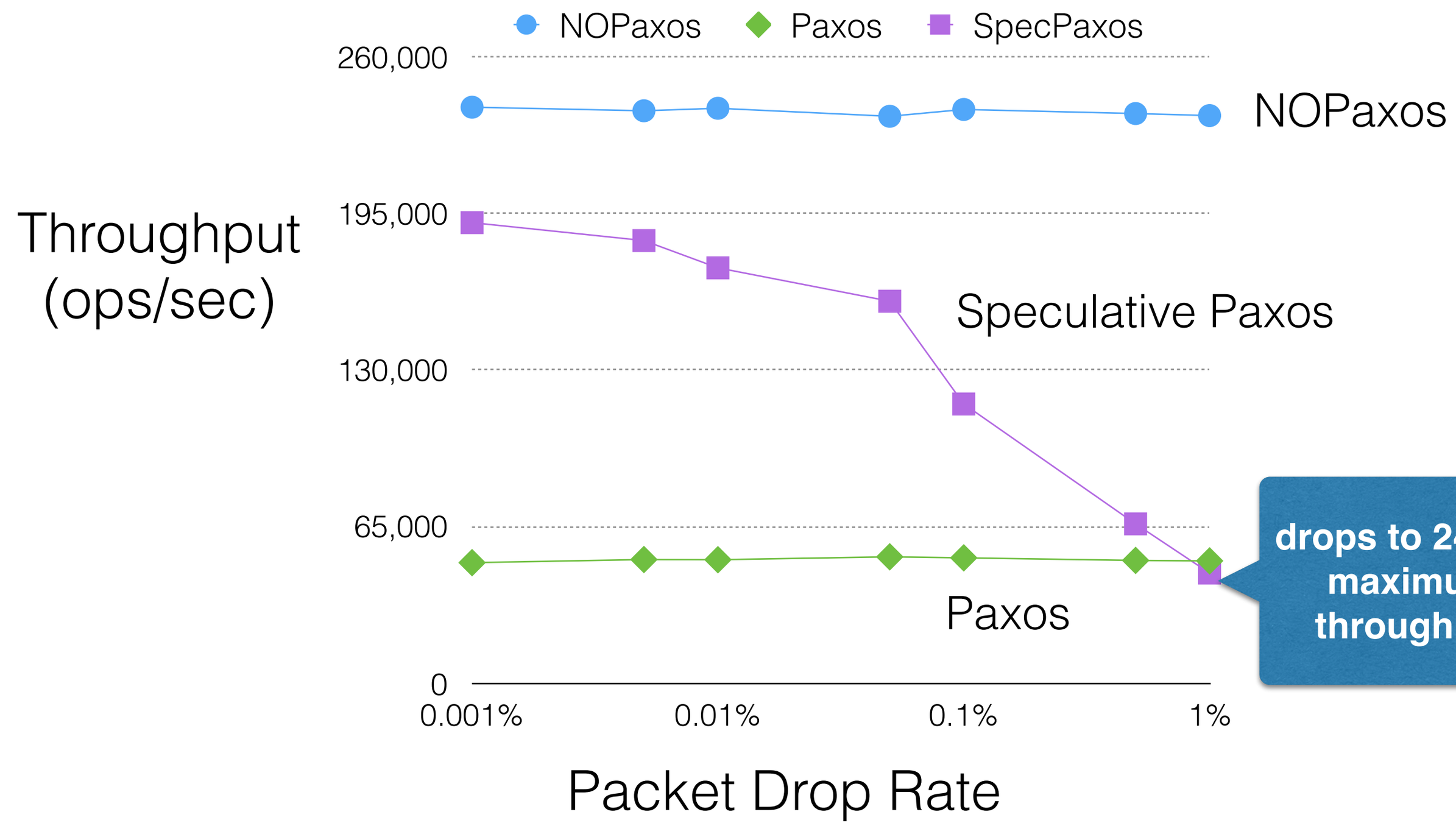


NOPaxos is resilient to network anomalies



NOPaxos attains throughput within **2%** of an **unreplicated** system

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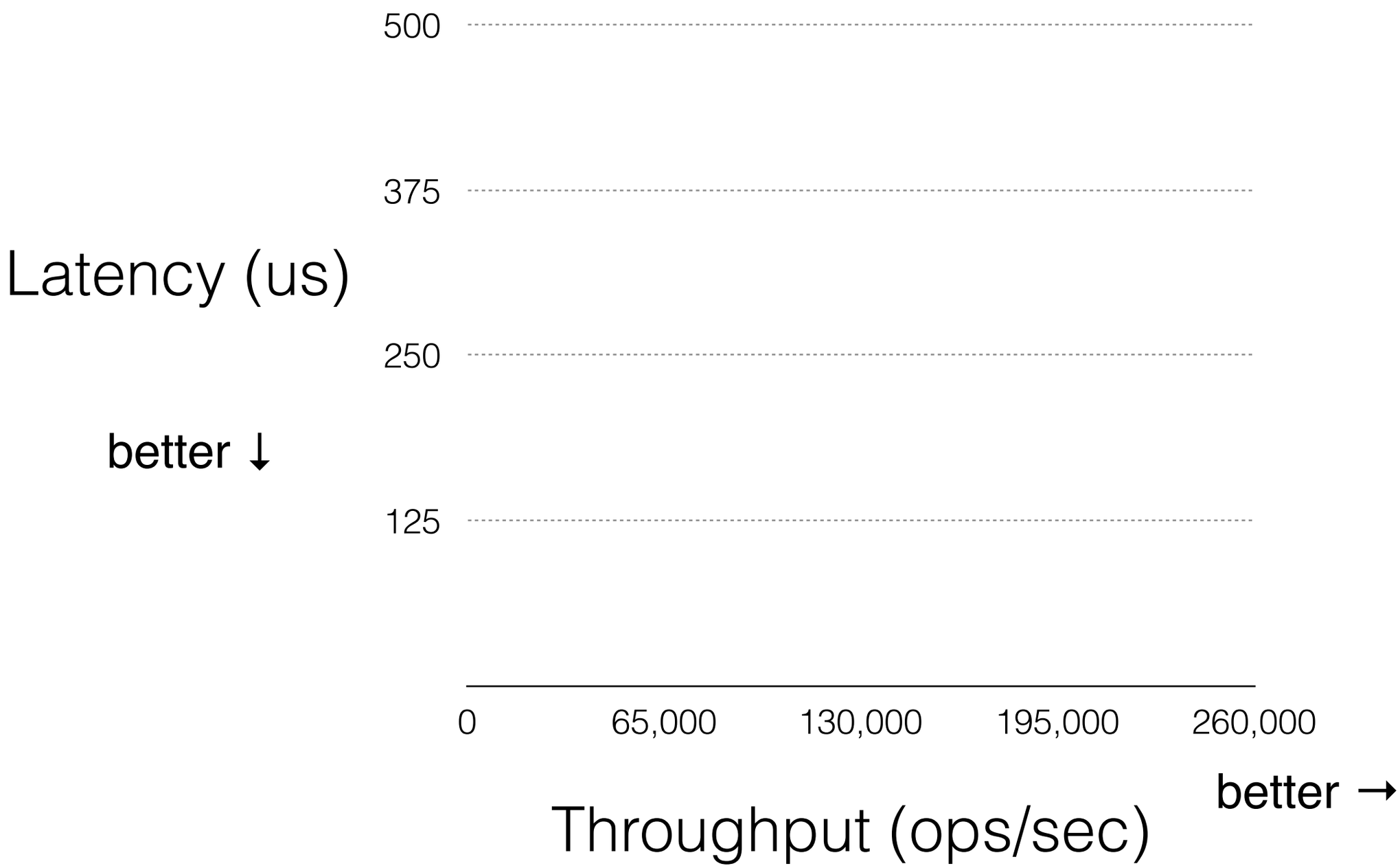

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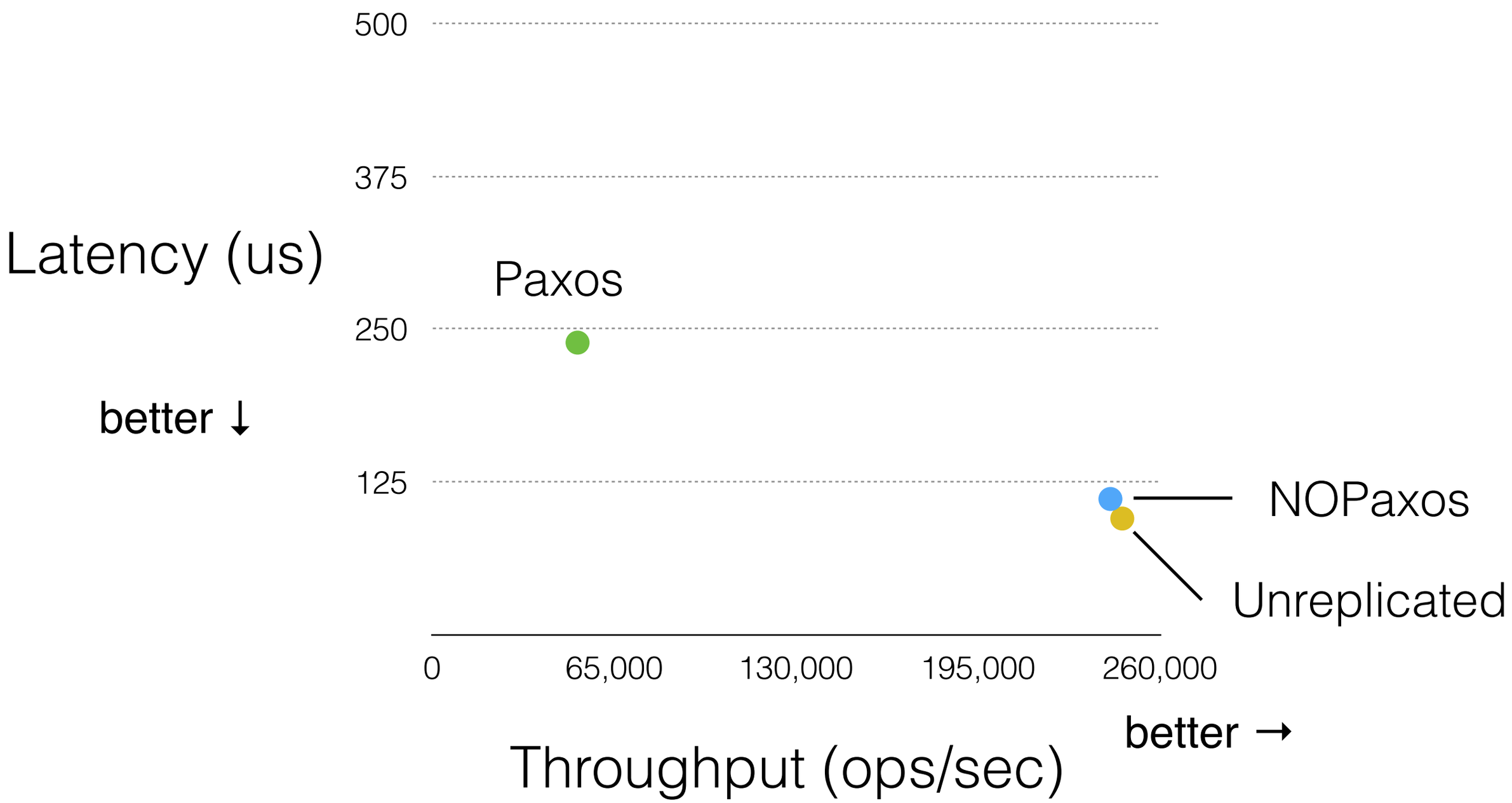

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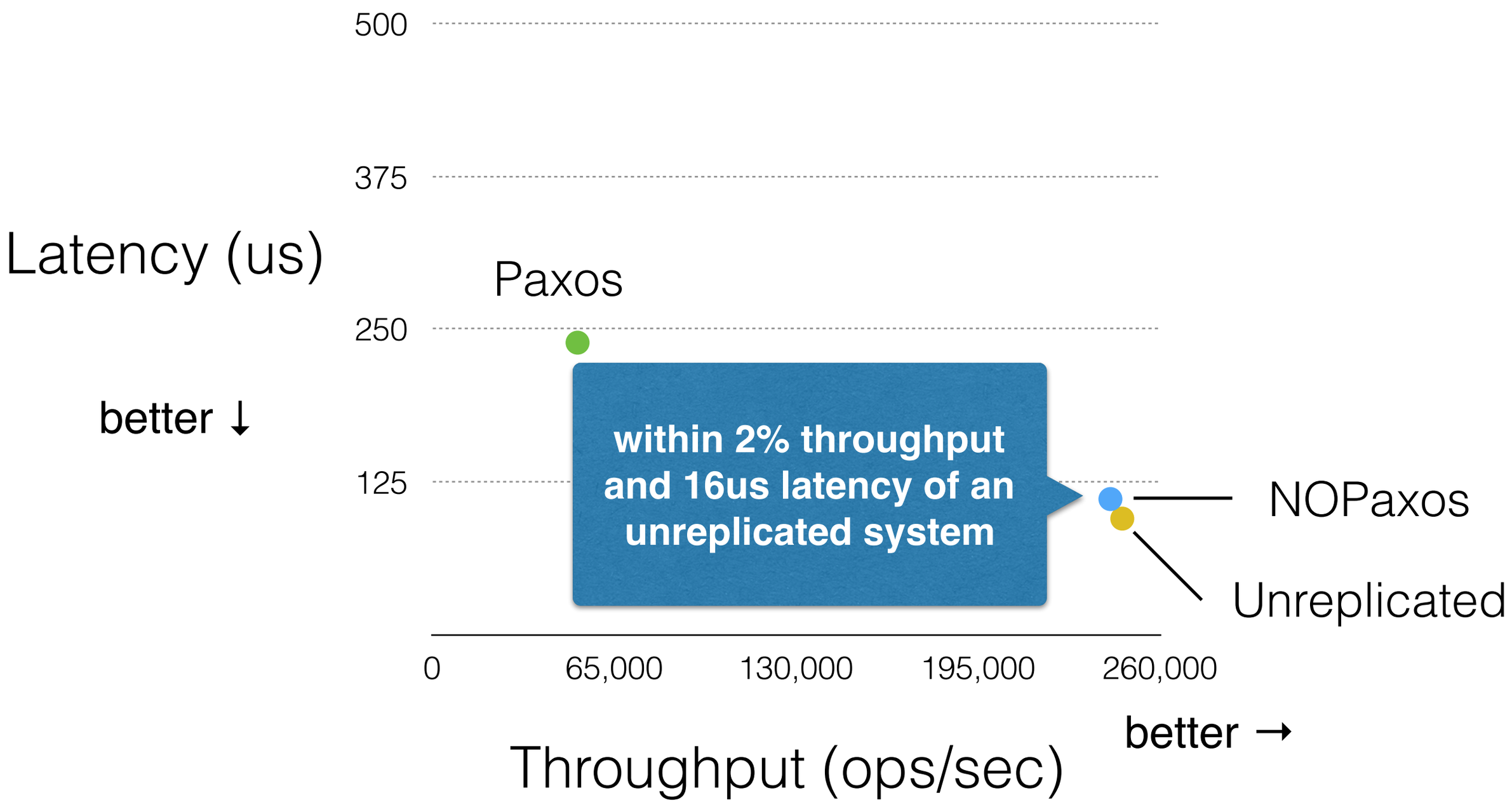

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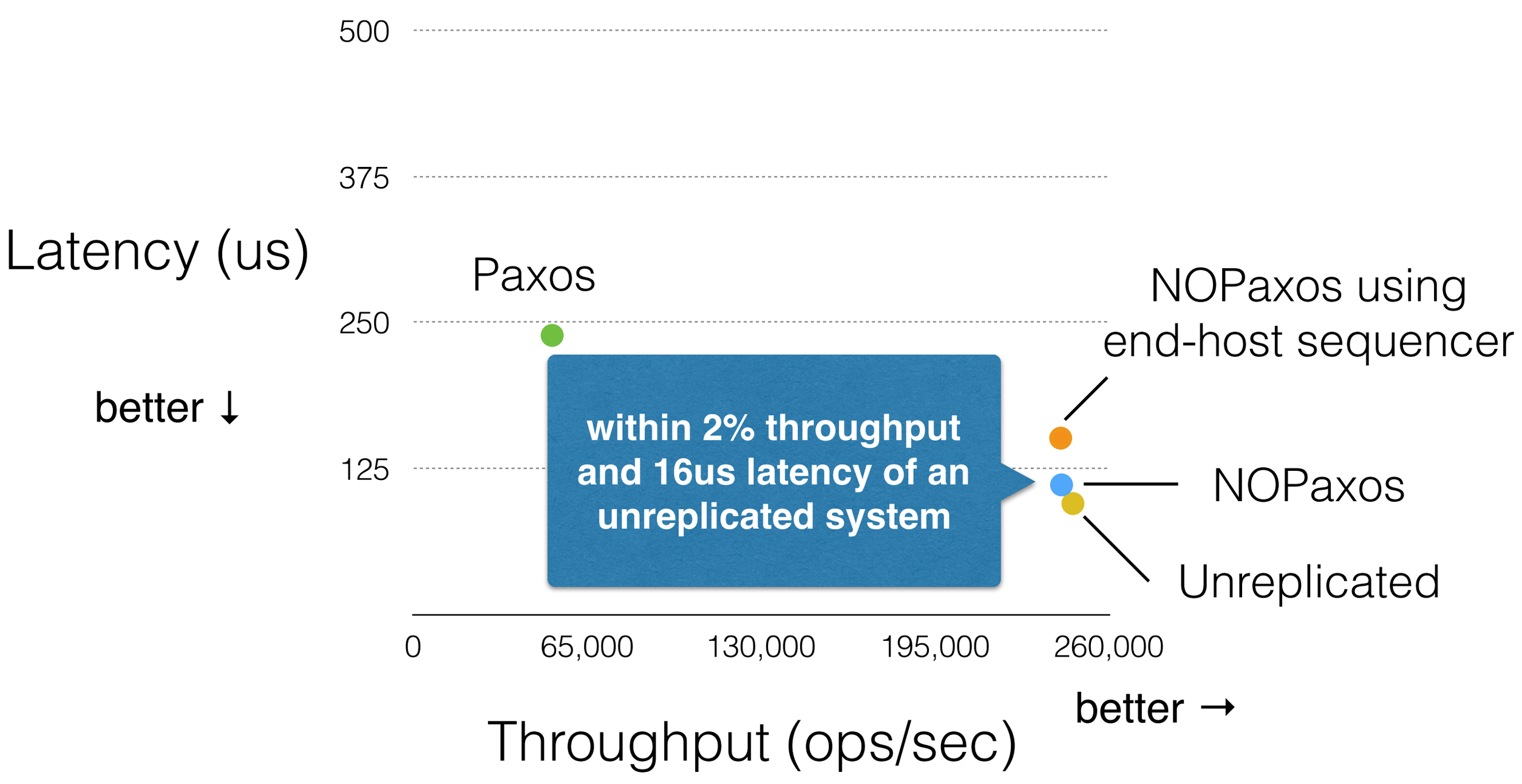
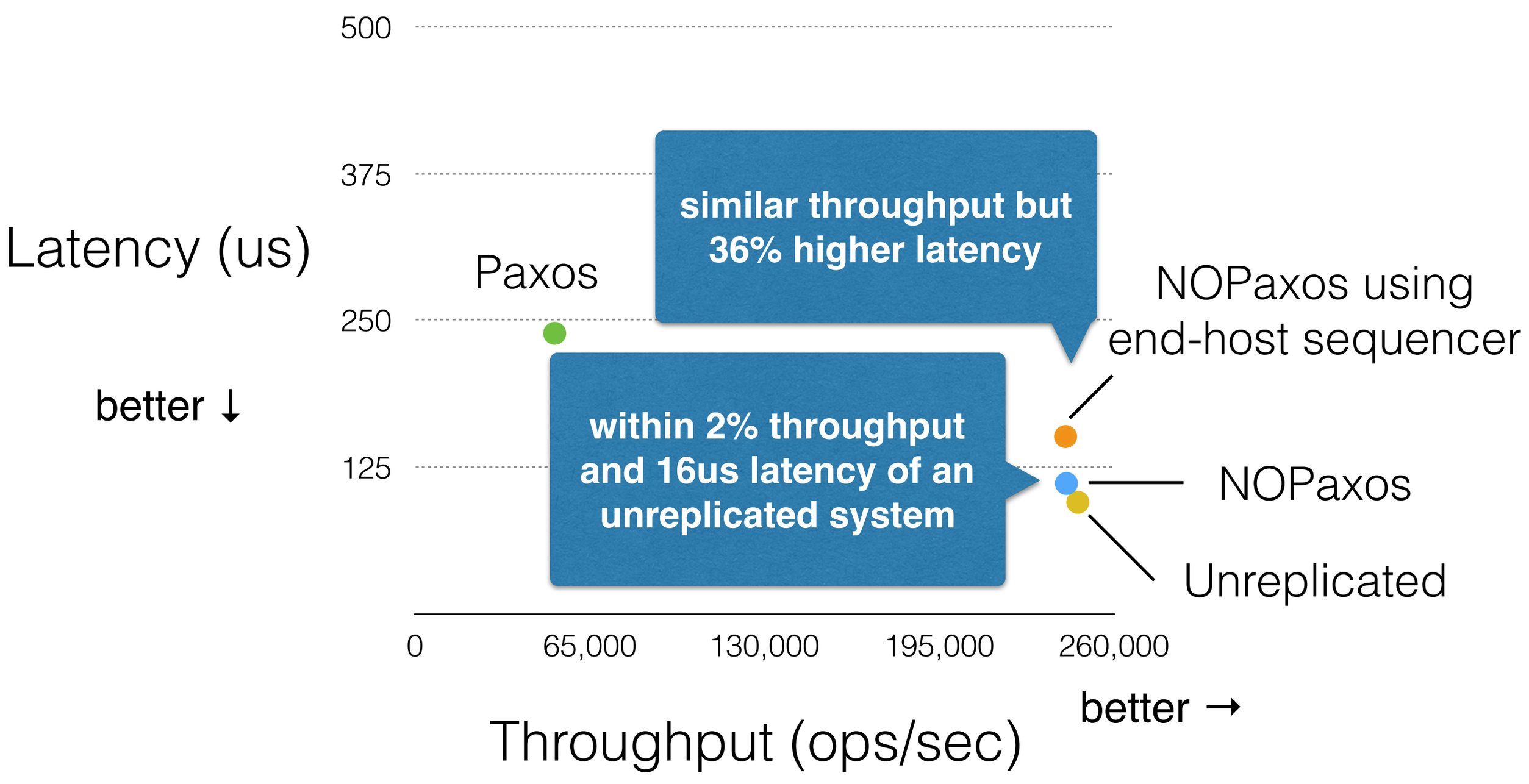


NOPaxos attains throughput within **2%** of an **unreplicated** system



Related Work

Group communication systems

- Virtual Synchrony [Birman, et al.], CATOCS [Cheriton, et al.], Amoeba [Kaashoek, et al.]

Consensus protocols

- Fast Paxos [Lamport], Optimistic Atomic Broadcast [Pedone, et al.], Speculative Paxos [Ports, et al.]
- Egalitarian Paxos [Moraru, et al.], Tapir [Zhang, et al.]

Network and Hardware support for distributed systems

- SwitchKV [Li, et al.], NetPaxos [Dang, et al.], FaRM [Dragojevic, et al.], Consensus in a Box [Istvan, et al.]

Summary

- Separate ordering from reliable delivery in state machine replication
- A new network model OUM that provides ordered but unreliable message delivery
- A more efficient replication protocol NOPaxos that ensures reliable delivery
- The combined system achieves performance equivalent to an unreplicated system