Exploiting Nil-Externality for Fast Replicated Storage

Artifacts Available acm V1.1

Artifacts Evaluated acm Functional V1.1

Results Reproduced acm V1.1

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Interfaces

> "Defining interfaces is the most important part of system design"
>
> – Butler Lampson, Hints for Computer System Design

Well-designed interfaces lead to desirable properties

- idempotent interfaces make failure recovery simple [Sandberg, 1986]
- commutative interfaces enable scalable implementation [Clements et al., 2013]

Do some storage interfaces enable higher performance than others?

Nil-Externality

Nil-externalizing (or nilext) interface

can modify storage system state in any way
but does not externalize its effects or state immediately

A system can defer executing a nilext operation, improving performance

Nilext interfaces are prevalent in storage systems

all updates are nilext in key-value stores such as RocksDB and LevelDB
Twemcache production traces reveal in 80% clusters, 90% updates are nilext

This Work

In this paper, we exploit nilext interfaces for fast replicated storage

Current replication protocols are oblivious to storage interfaces

- involve expensive coordination to order requests
- updates incur two roundtrips

We build Skyros, a nilext-aware replication protocol

Key insight: defer coordination until state is externalized

- complete nilext updates in one roundtrip

Skyros offers linearizability and achieves up to 3x lower latencies compared to Paxos (w/ batching)

Outline

Introduction

➡ Strongly consistent storage background

Nilext-aware replication

Evaluation

Strongly Consistent Storage Systems

A standard approach to building strongly consistent storage

Local Storage System

RocksDB

levelDB

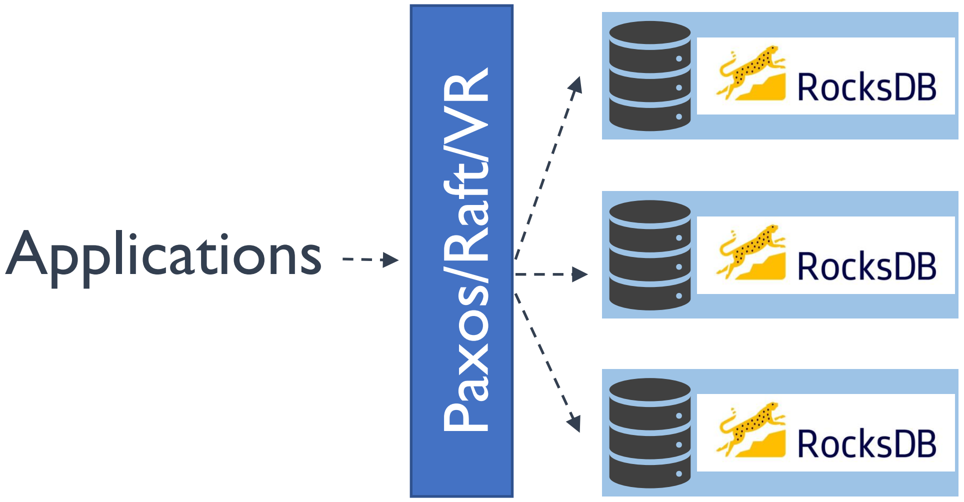
+

Replication Protocol

Paxos

raft

Replicated Storage

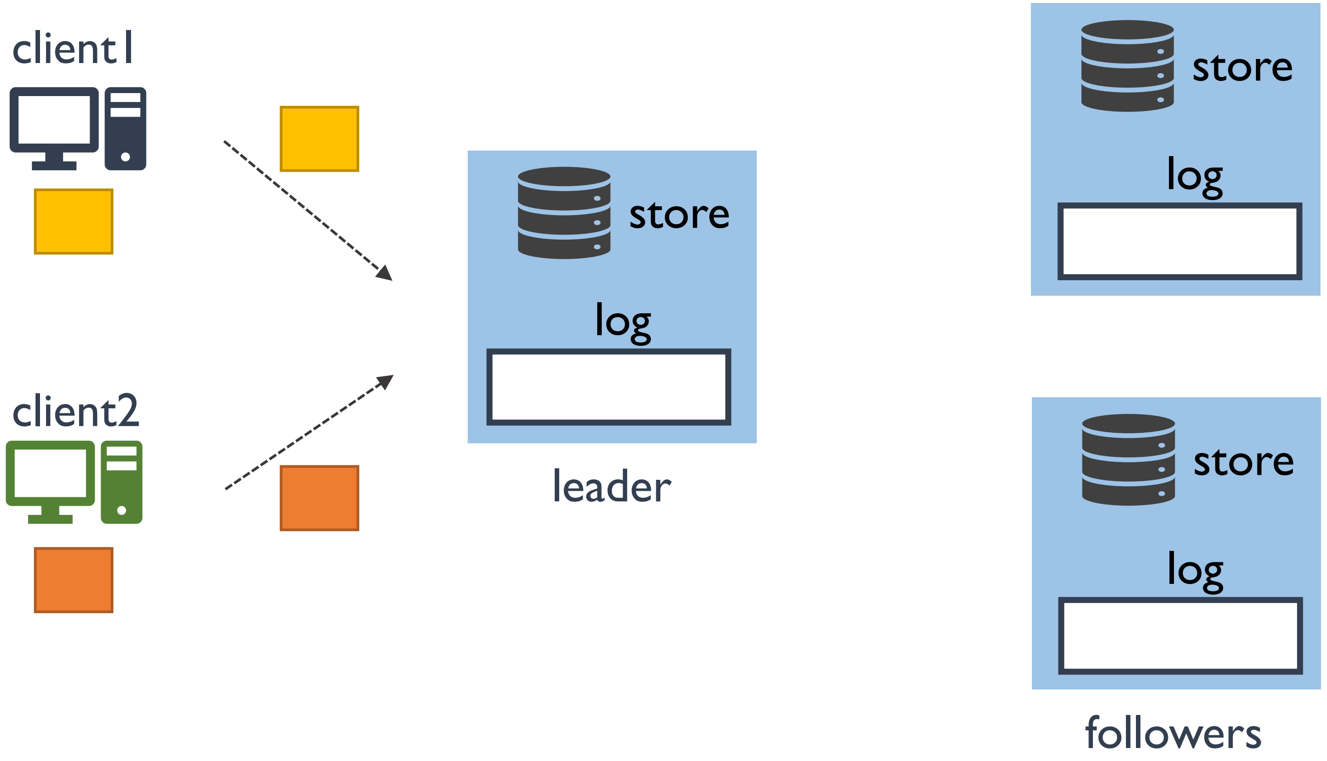


Replicas execute same operations in same order – ensures linearizability

Examples: ZippyDB (Paxos-replicated RocksDB), Harp (VR-replicated FS)

Ordering is Expensive

Several steps to update replicated data



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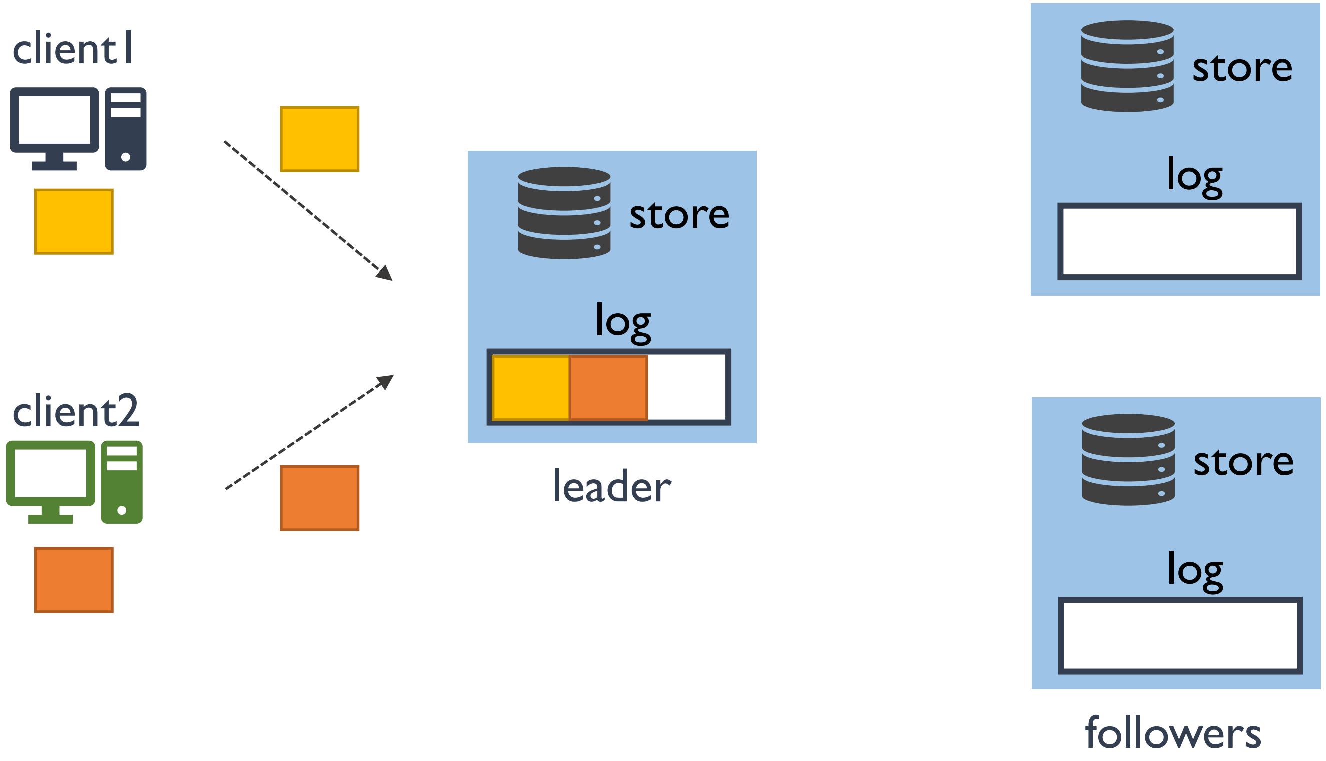

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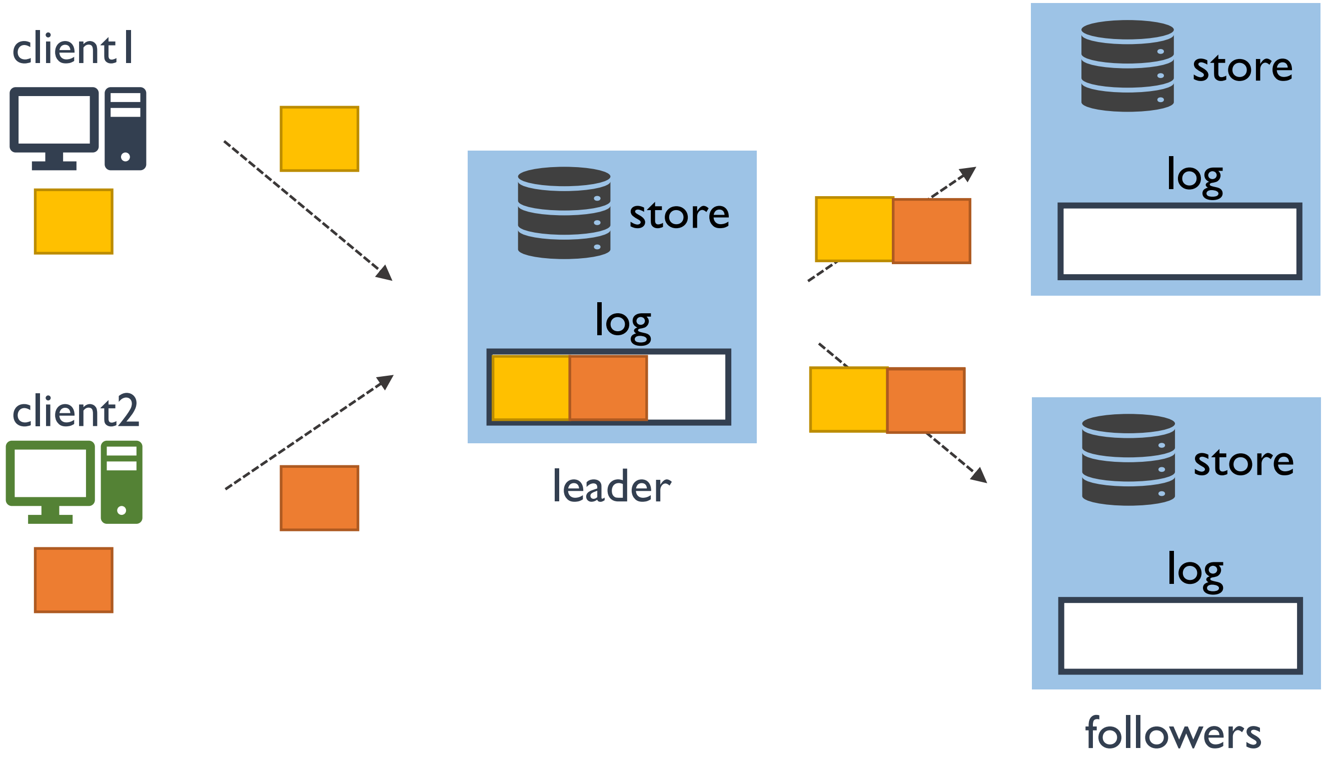

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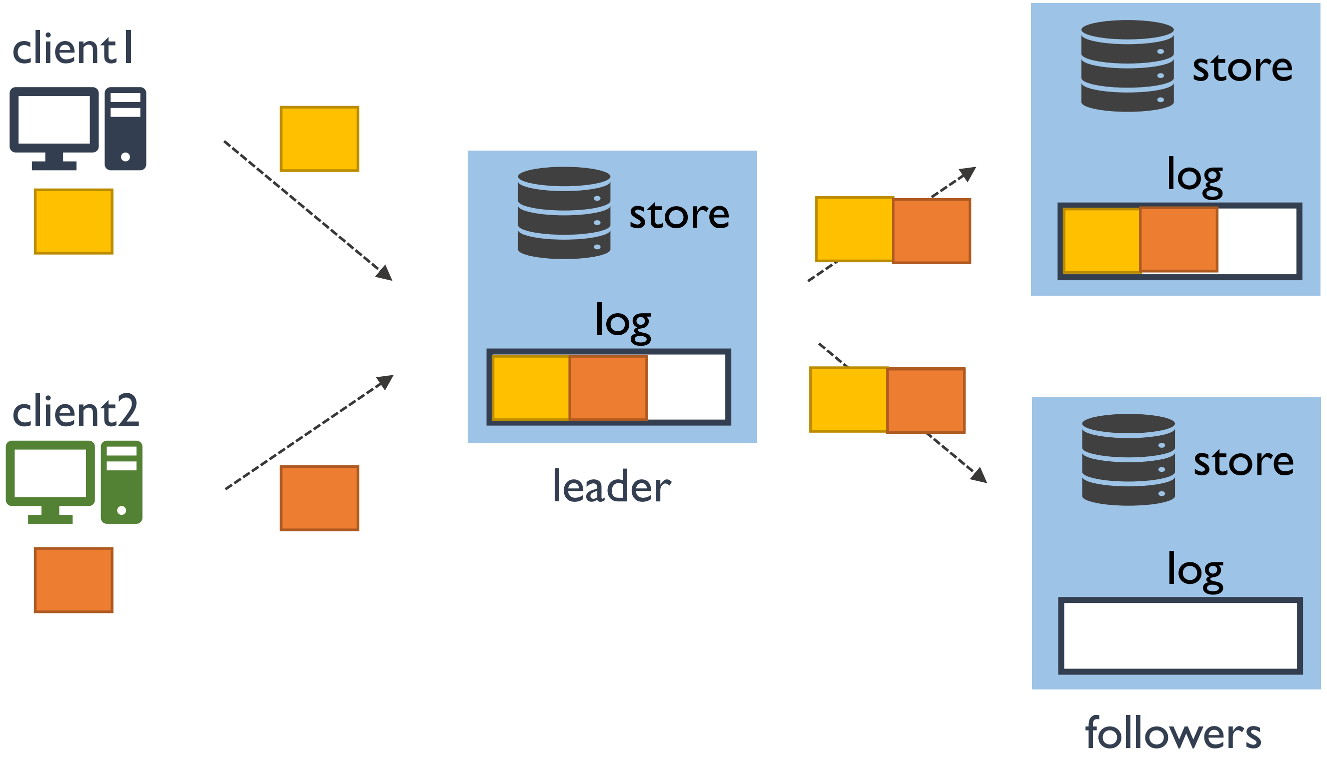

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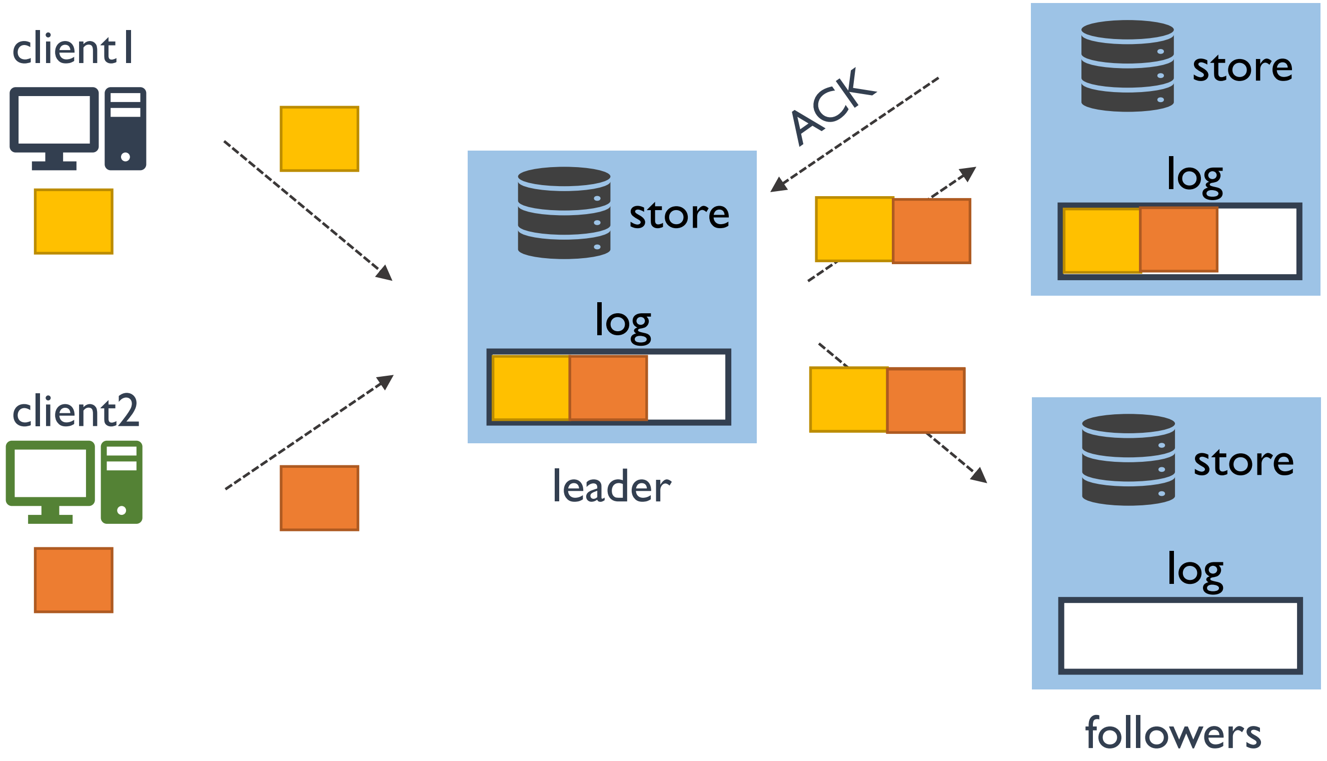

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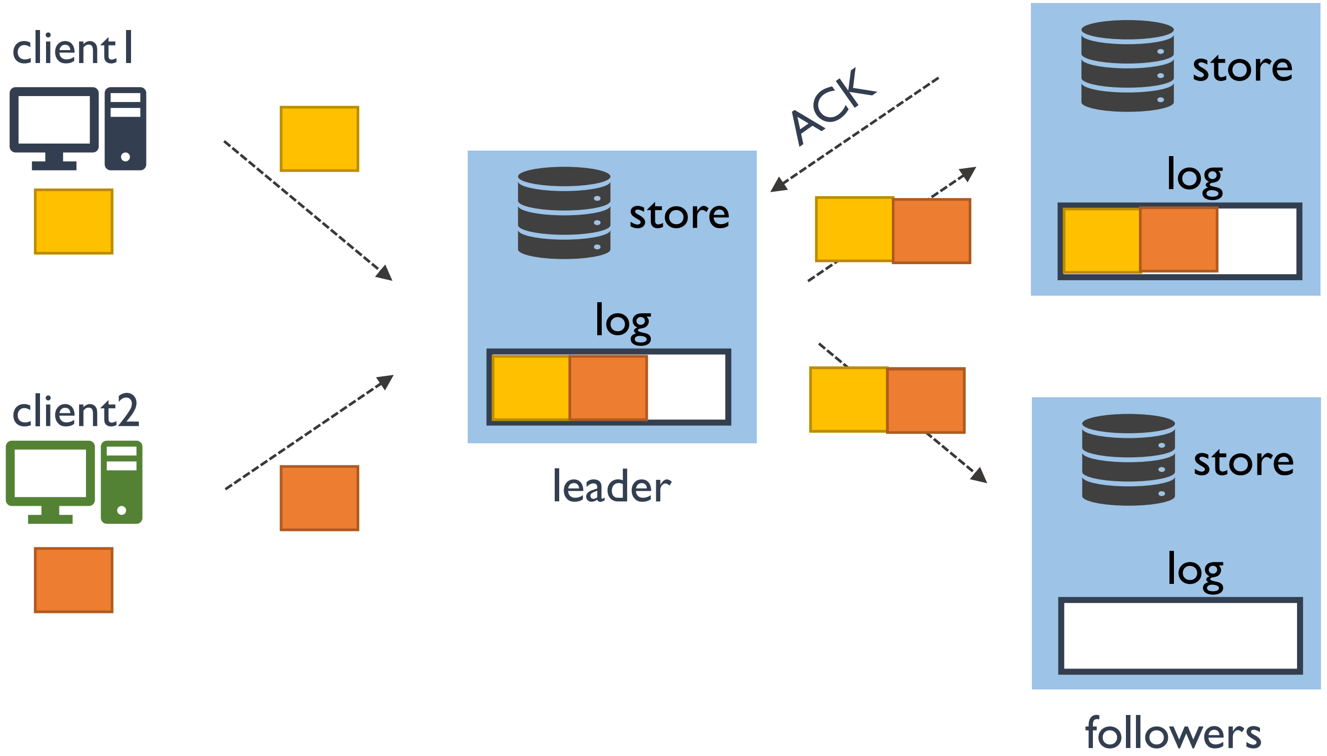

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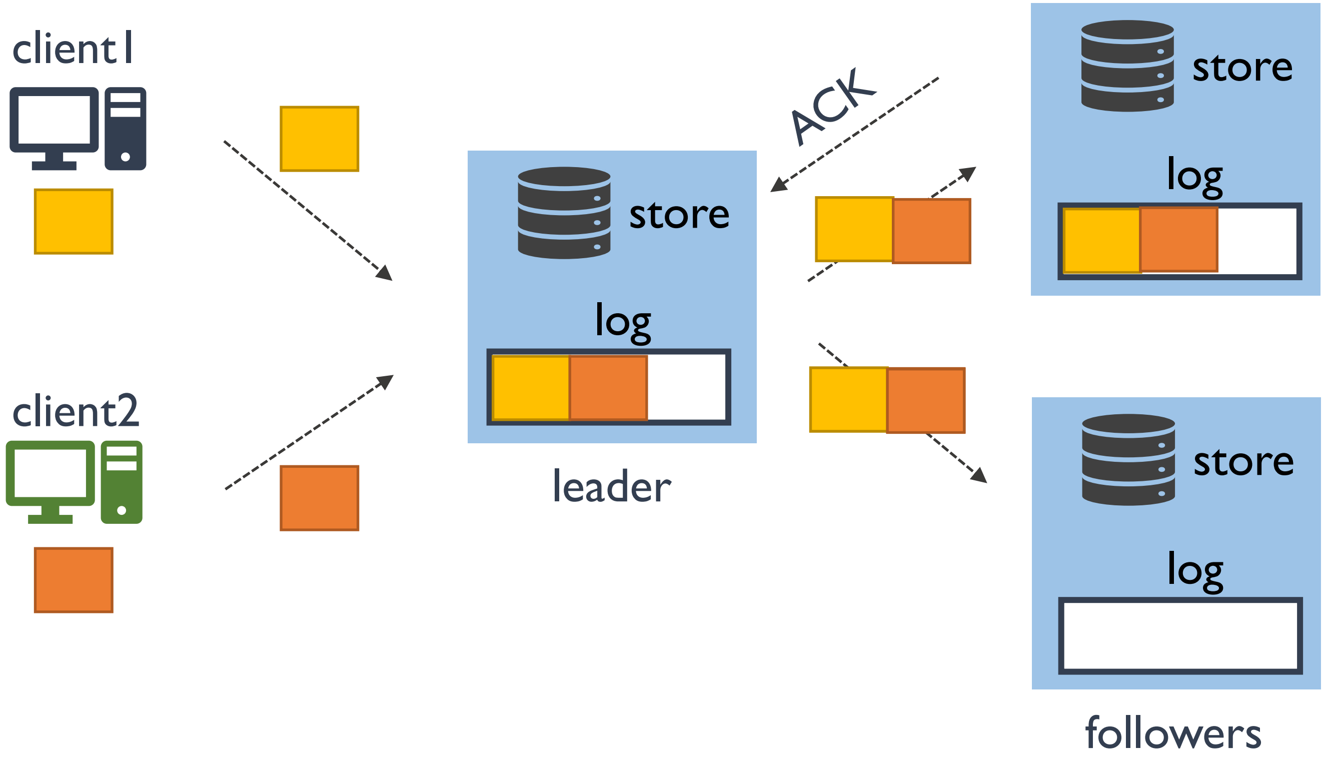

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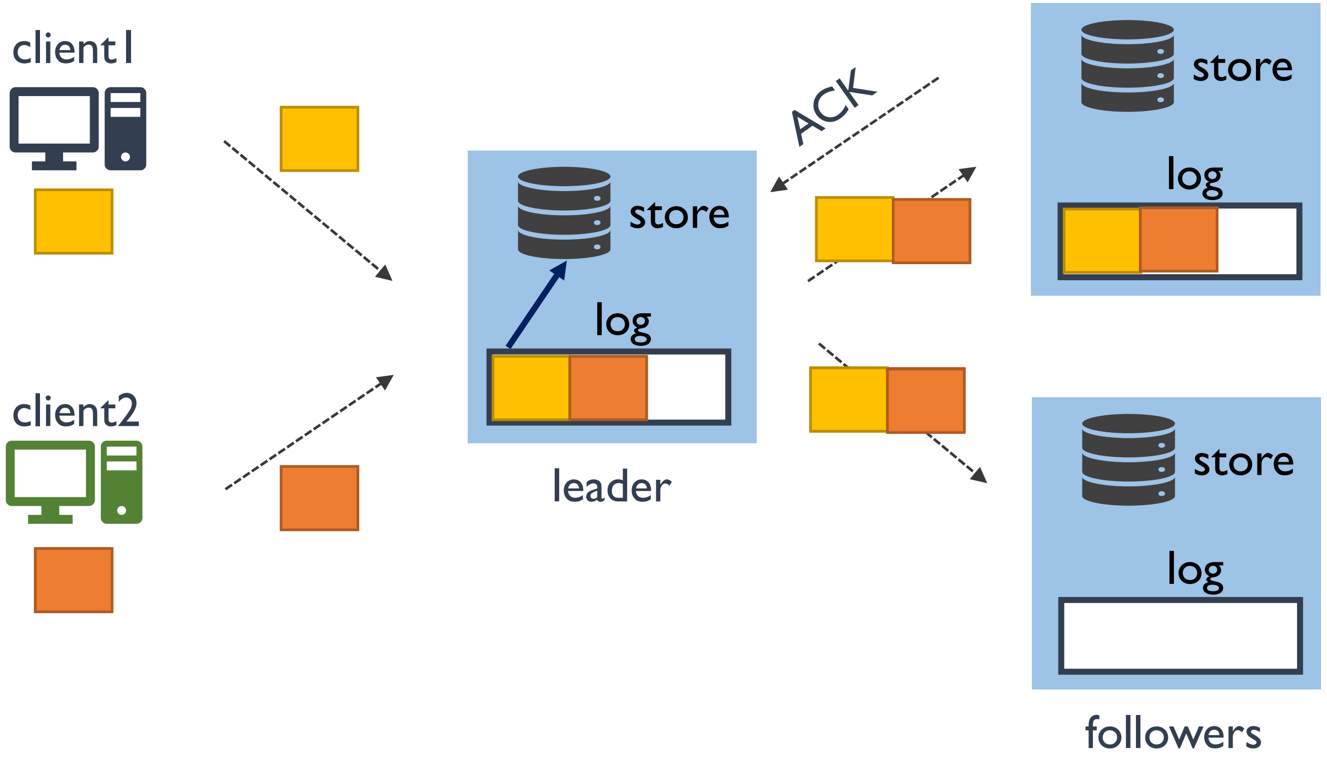

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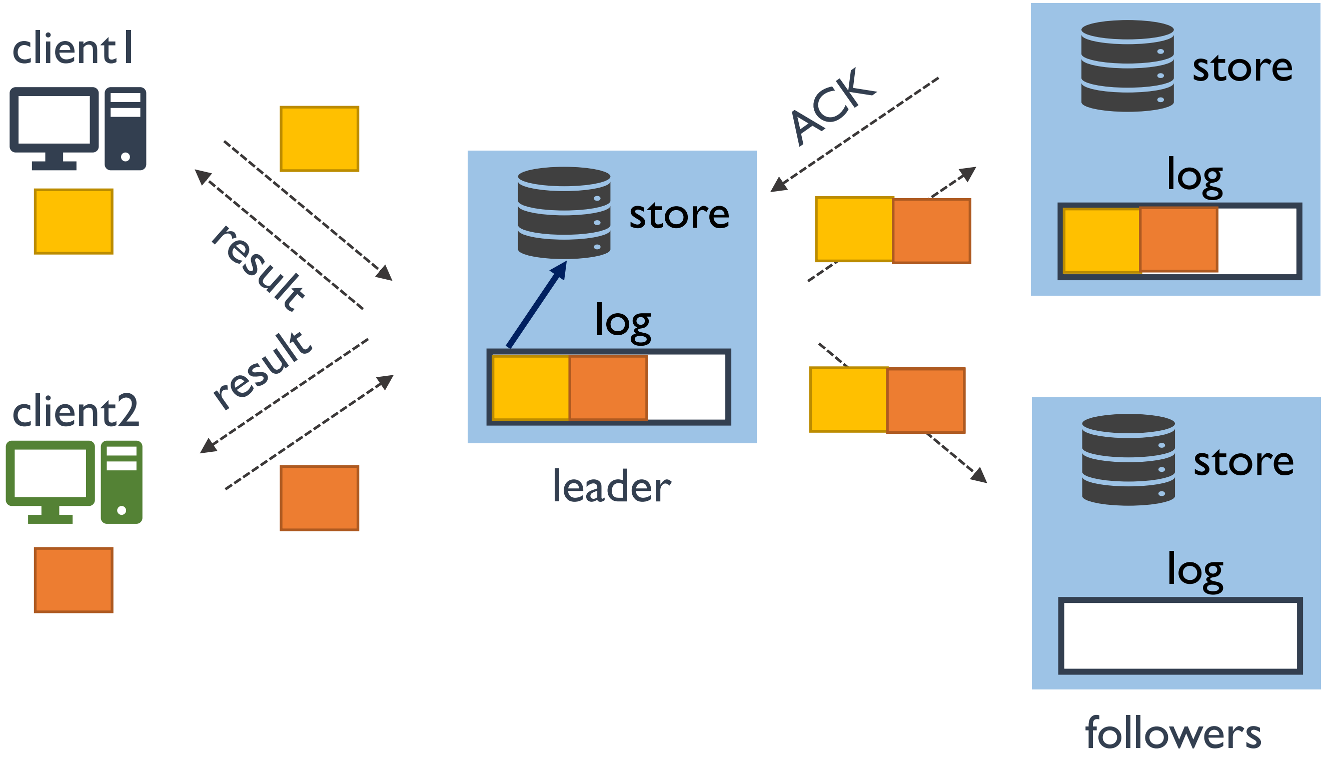

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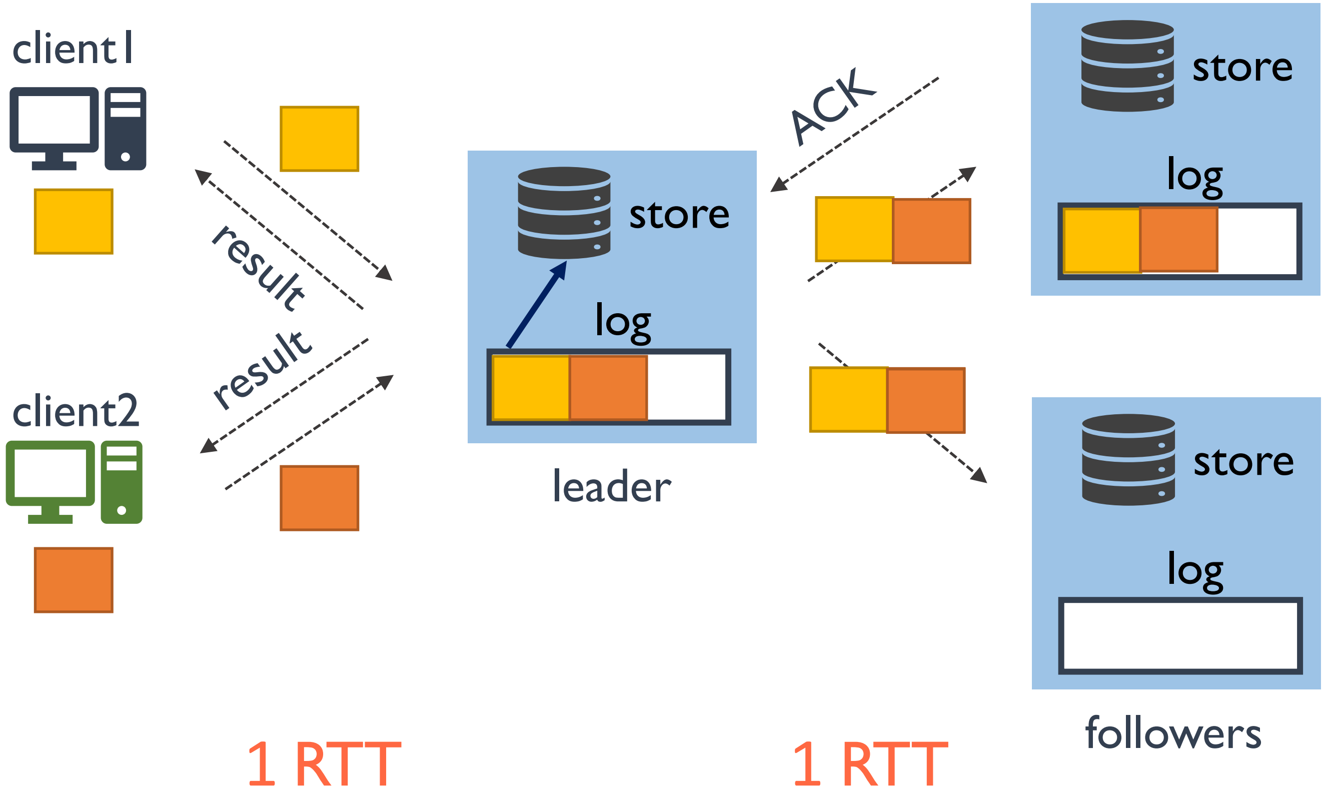

Multi round-trip agreement

Network roundtrips critical for application performance

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➡ Nilext-aware replication

Evaluation

Nilext Interfaces

A nil-externalizing or nilext interface

- may modify state in any way: blind write, or read-modify-write
- does not externalize storage-system state
  - does not return an execution result or an execution error
- usually returns an ack

Example: `Put` interface in KV API

- does not return execution result (only an ack)
- does not return execution error (e.g., by checking if key is already present)

Nilext Interfaces are Prevalent

All updates are nilext in key-value stores (e.g., RocksDB, LevelDB) built upon write-optimized structures such as LSM and B^e-trees

Interface	Nilext?	
Put, Write(multi-put)	Yes	No error if key(s) already present
Delete	Yes	No error if key absent – insert tombstone
Merge (RMW)	Yes	Not applied immediately – insert message specifying how to modify value
Get	No	Returns value or error

avoid query before update

[Bender et al., 2015]

Some systems have a mix of nilext and non-nilext interfaces (e.g., Memcached)

Real-world traces show most updates are nilext

- 90% updates are nilext in 80% clusters (Twemcache production traces)
- more analysis in the paper …

Exploiting Nil-Externality for Replication: Insights

Problem: coordination for ordering incurs multiple RTTs

store
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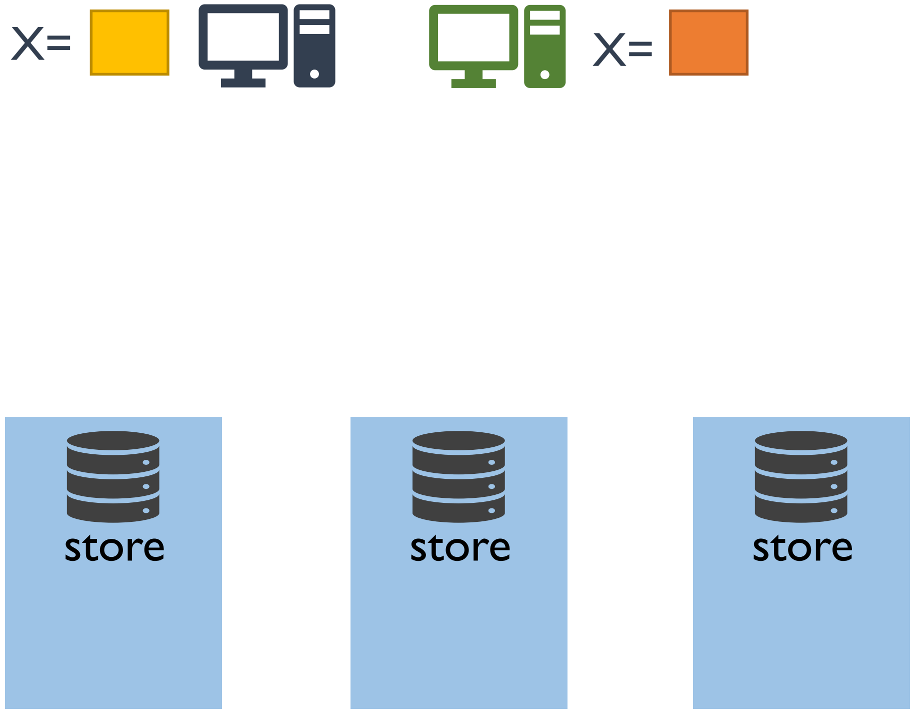

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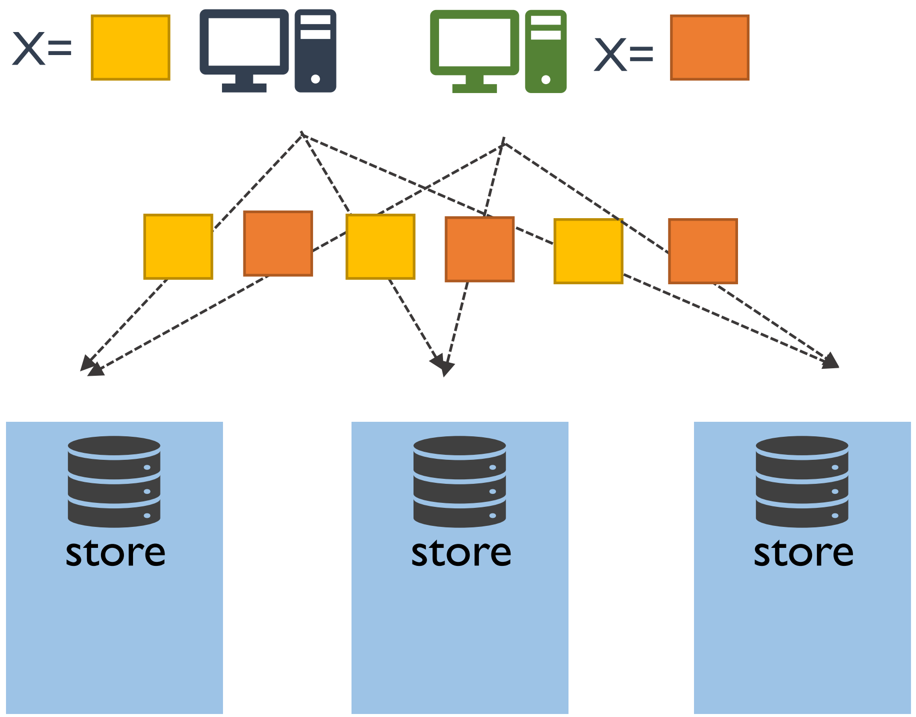

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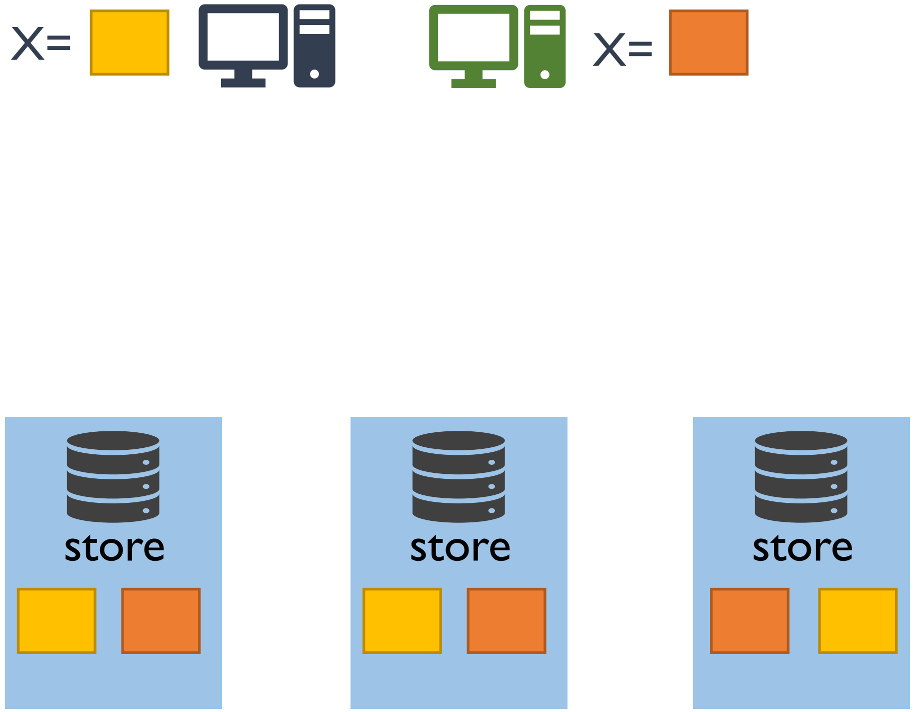

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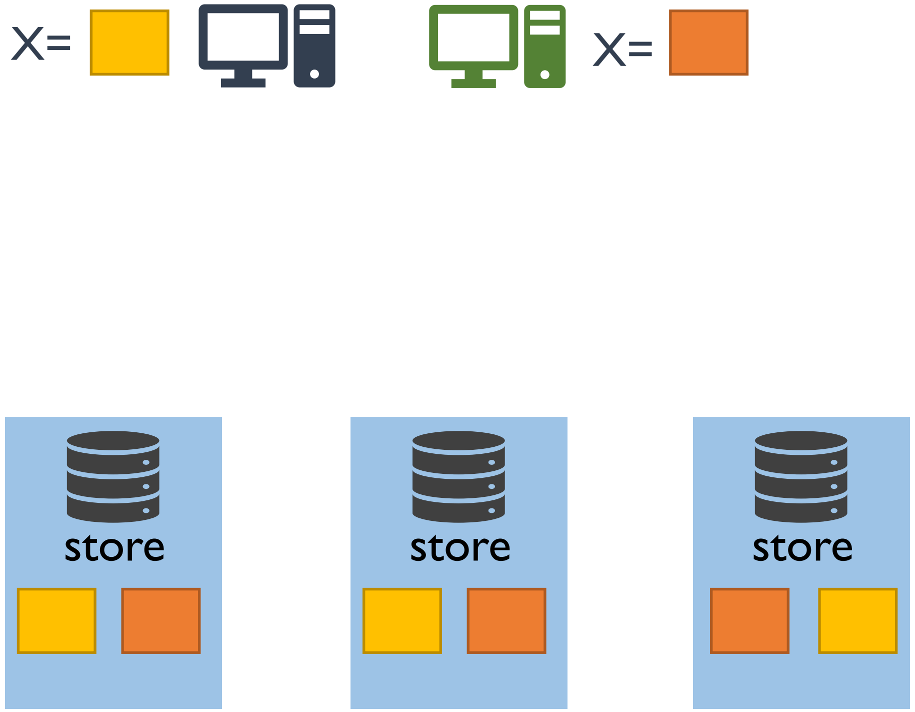

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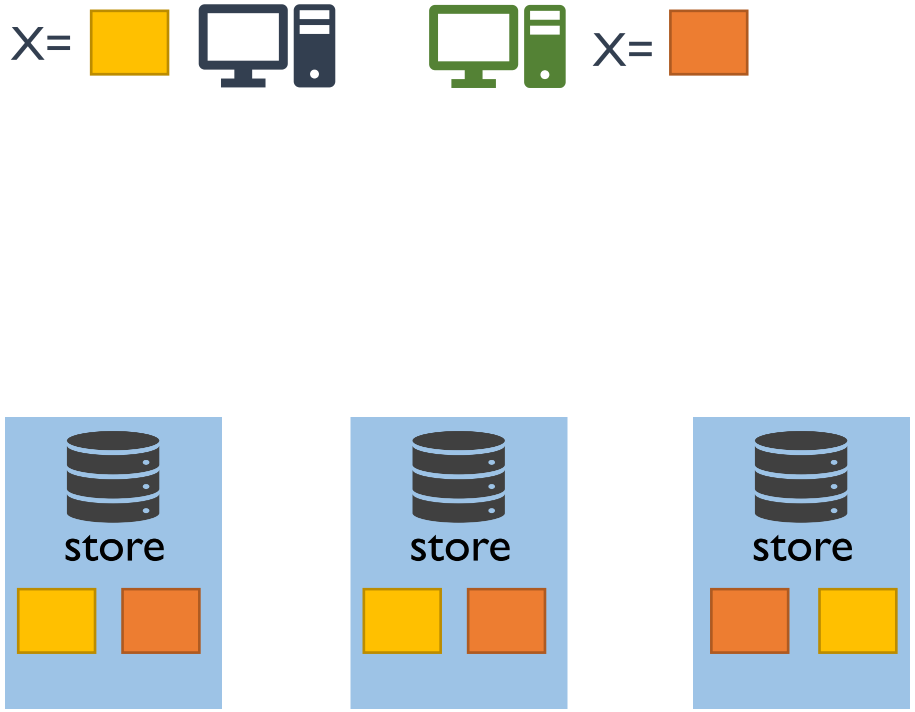

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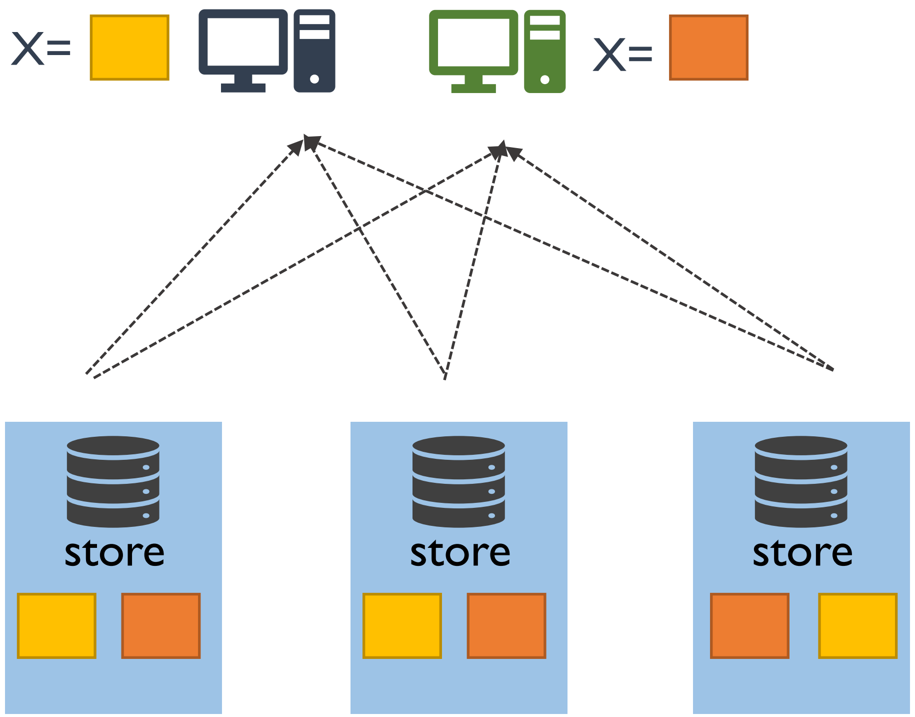

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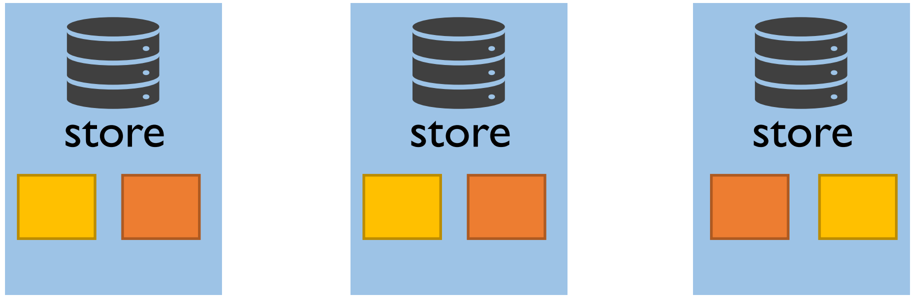

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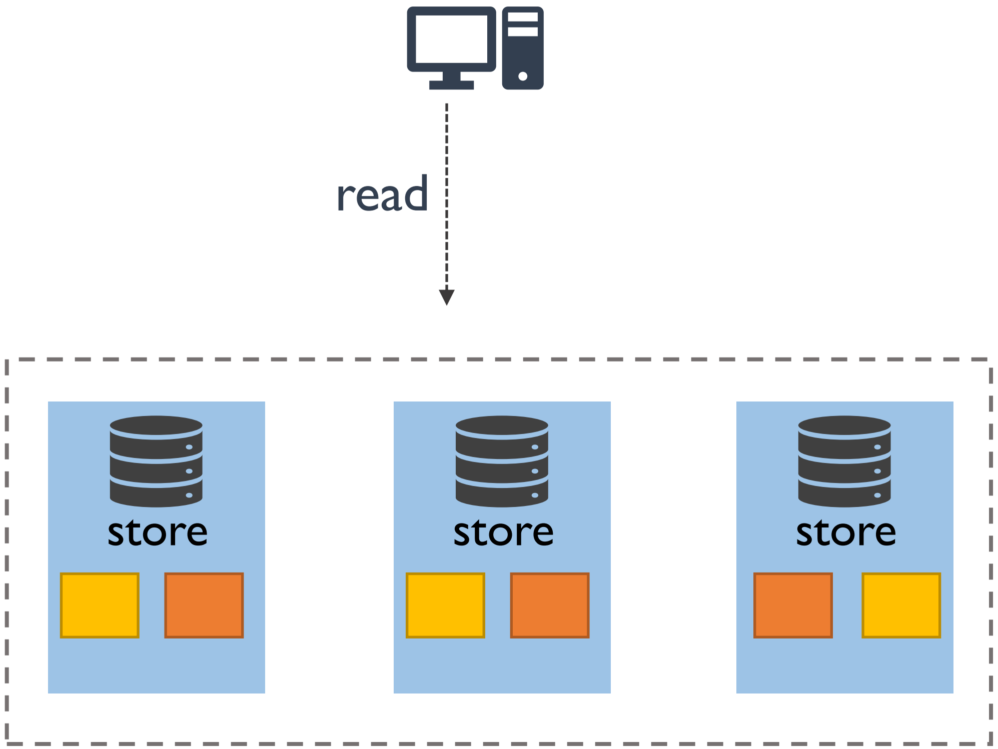

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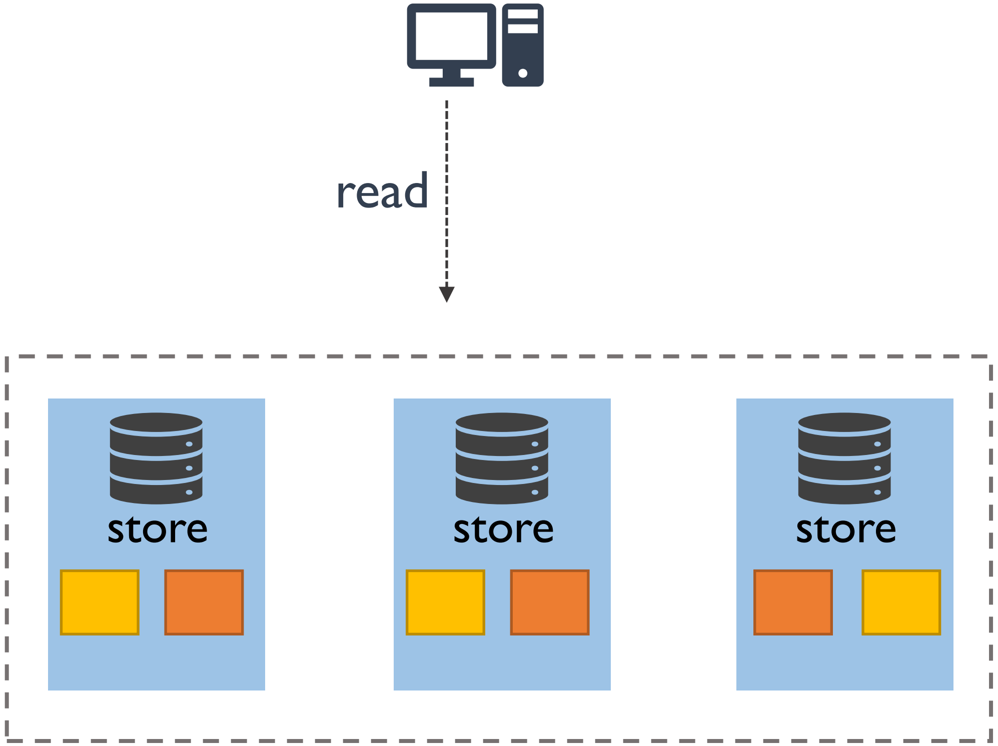
   enforce ordering and execution before state is externalized → strong consistency



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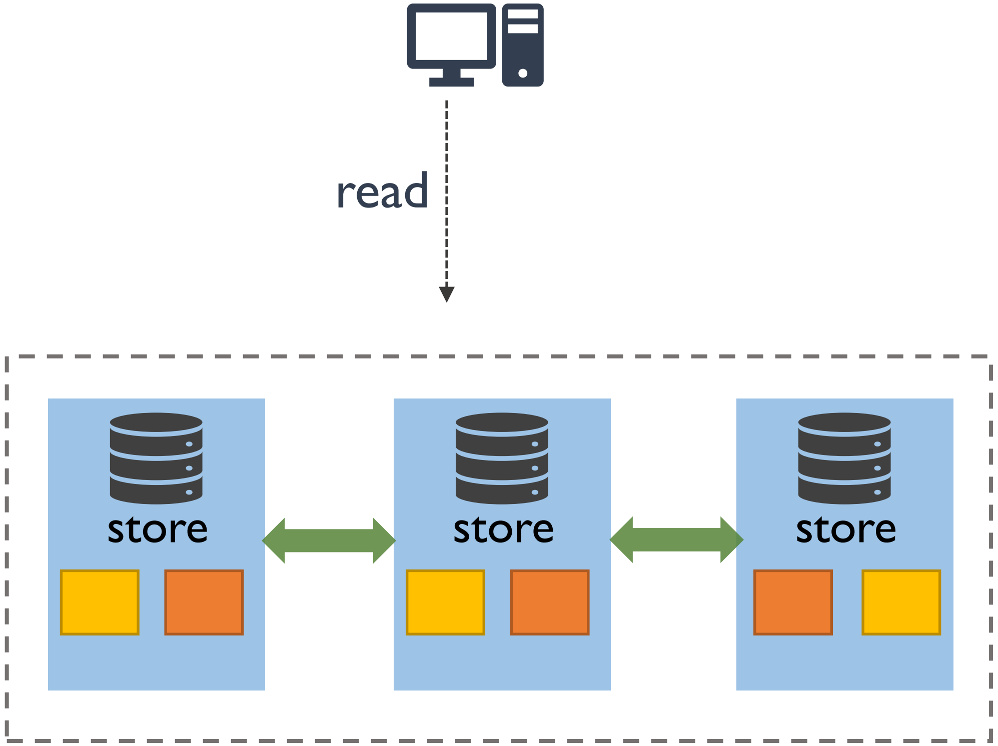

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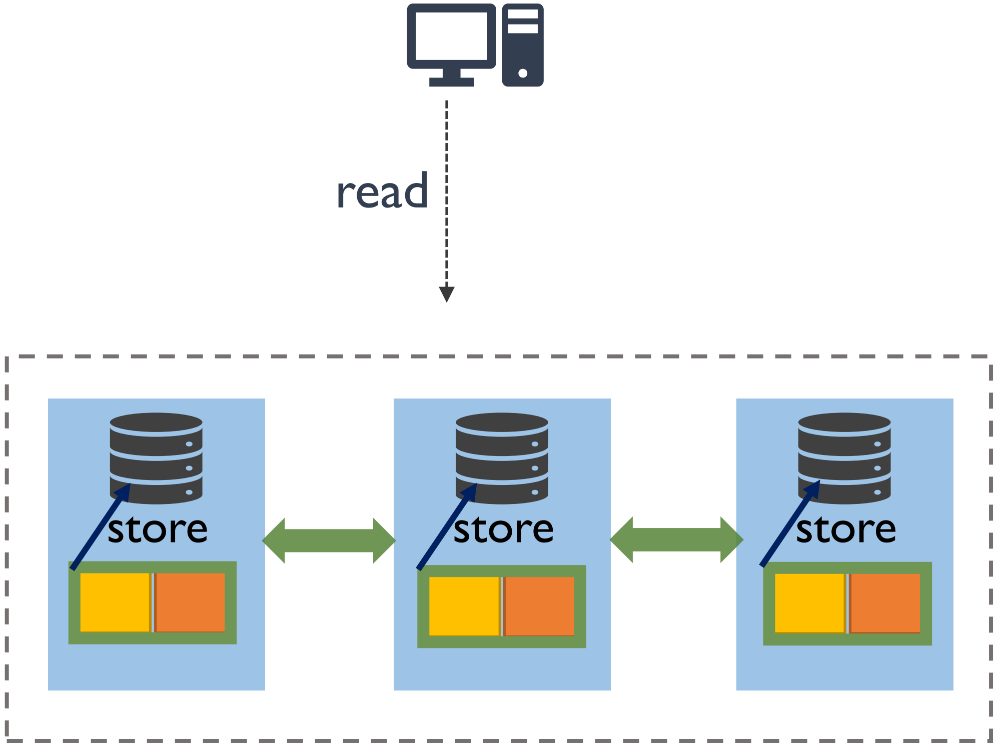

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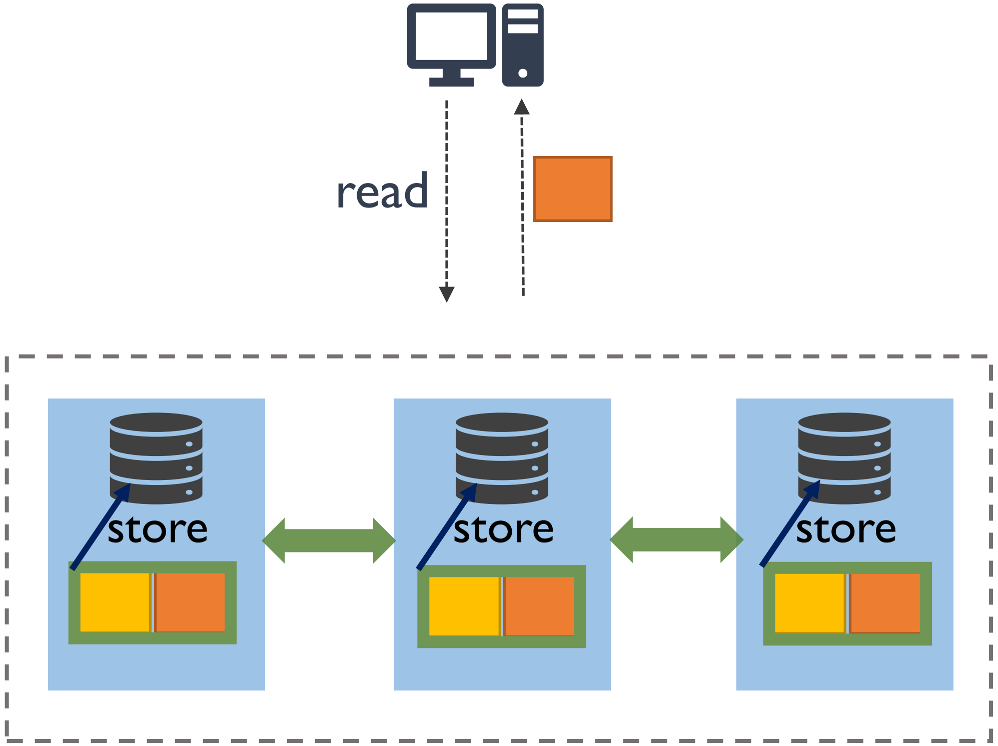

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   order and execute in the background

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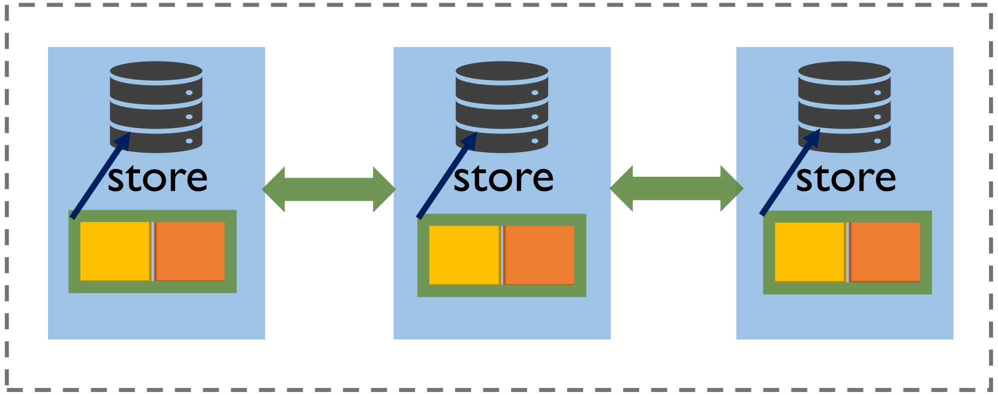

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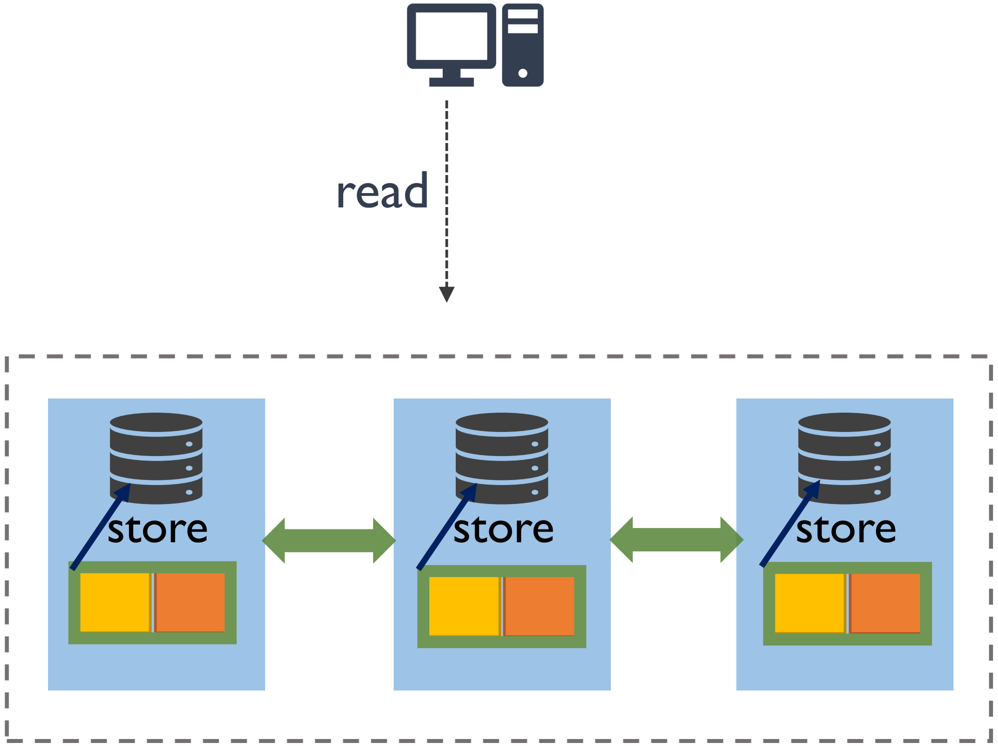

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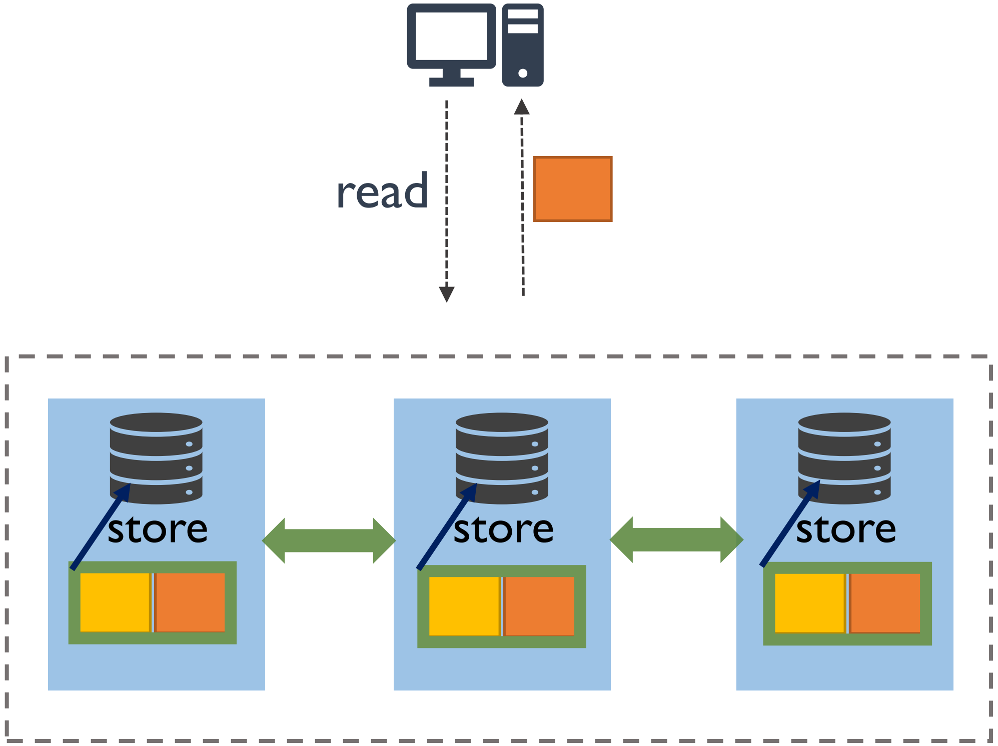


Deferring Work in Other Contexts

Defer work until observed has proven beneficial in other contexts

- programming languages [Henderson and Morris, 1976] [Friedman and Wise, 1976]
- file systems [Nightingale et al., 2006]
- databases [Faleiro et al., 2014]

Our work:

- applies this general idea in the context of replication
- identifies an interface-level property in storage systems that enables deferring work

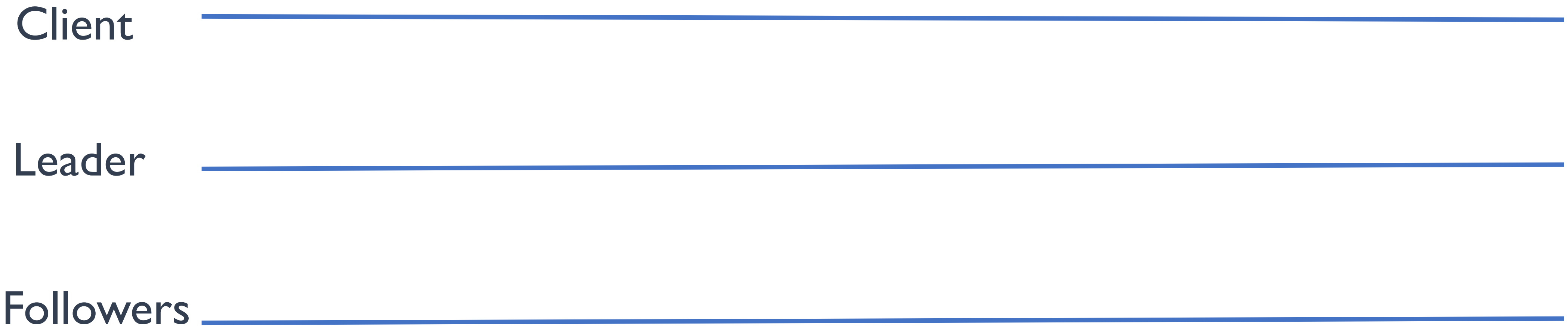
Skyros

Skyros is a new nilext-aware replication protocol

Based on viewstamped replication (VR) [Oki and Liskov, 1988] [Liskov and Cowling, 2012]

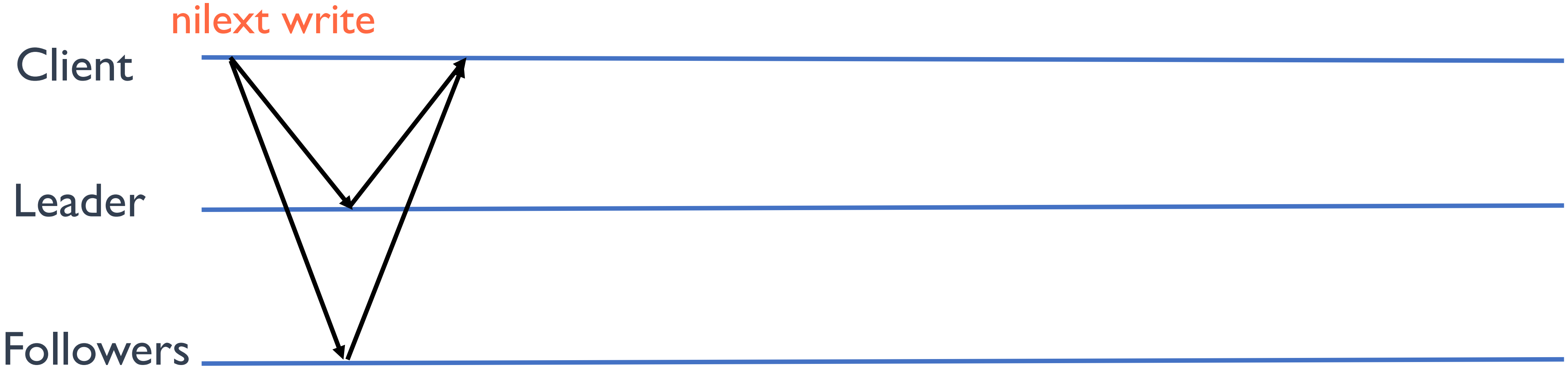
- leader based
- provides linearizability
- available when majority replicas alive

Skyros Overview



Skyros Overview

Nilext updates: clients write to replicas directly and make durable in 1 RTT



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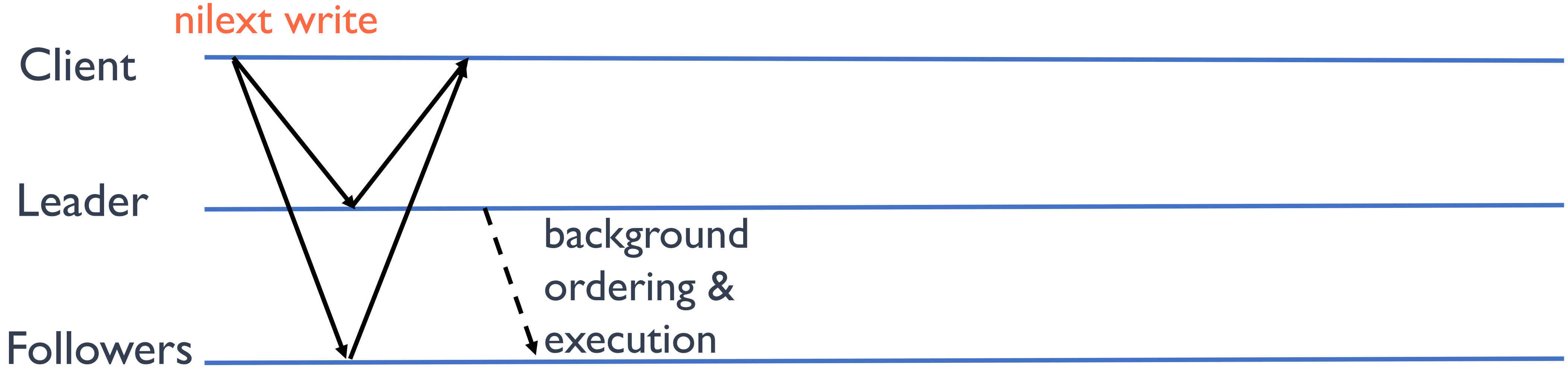

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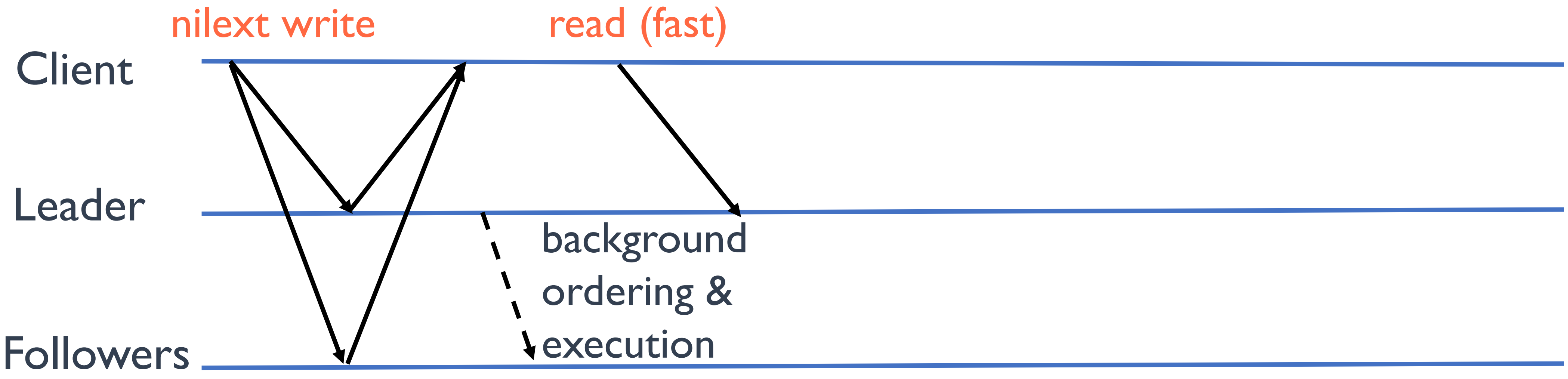

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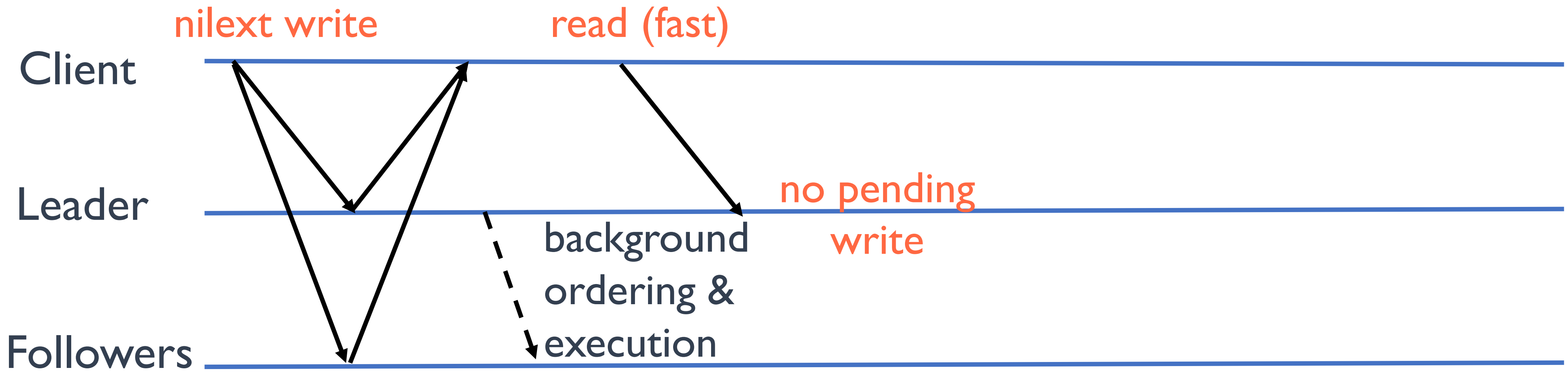

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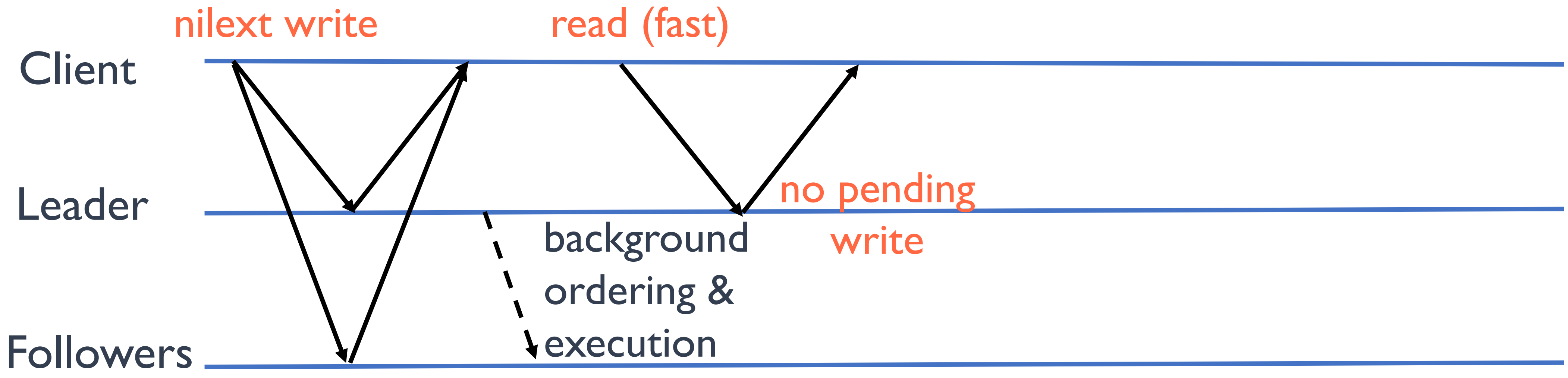

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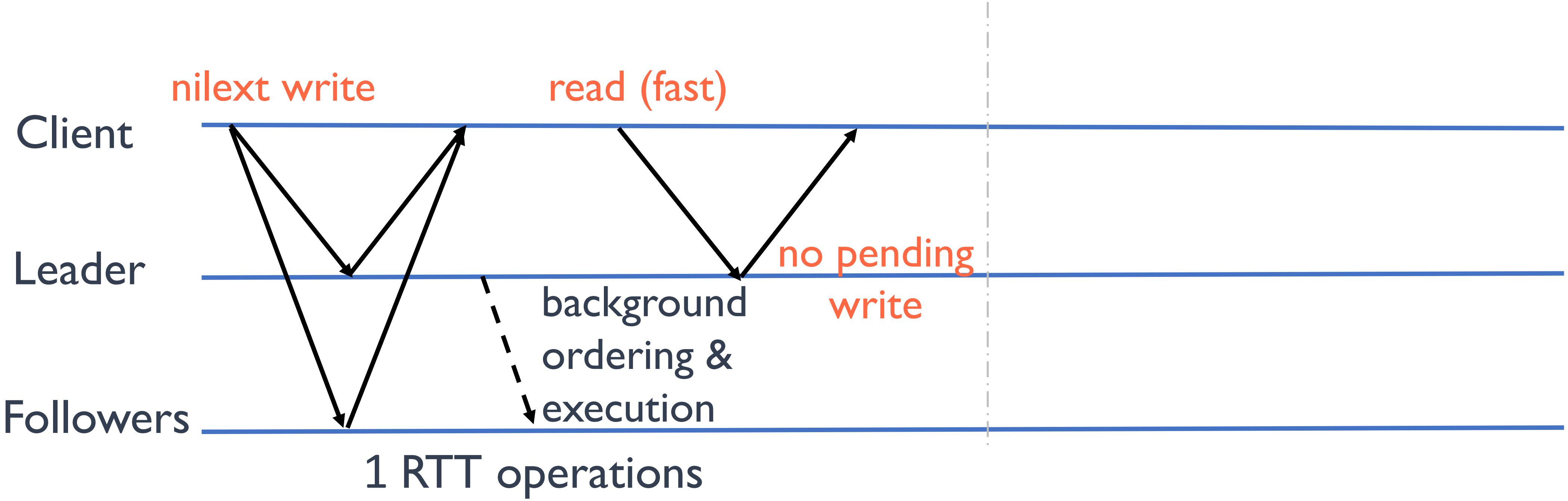

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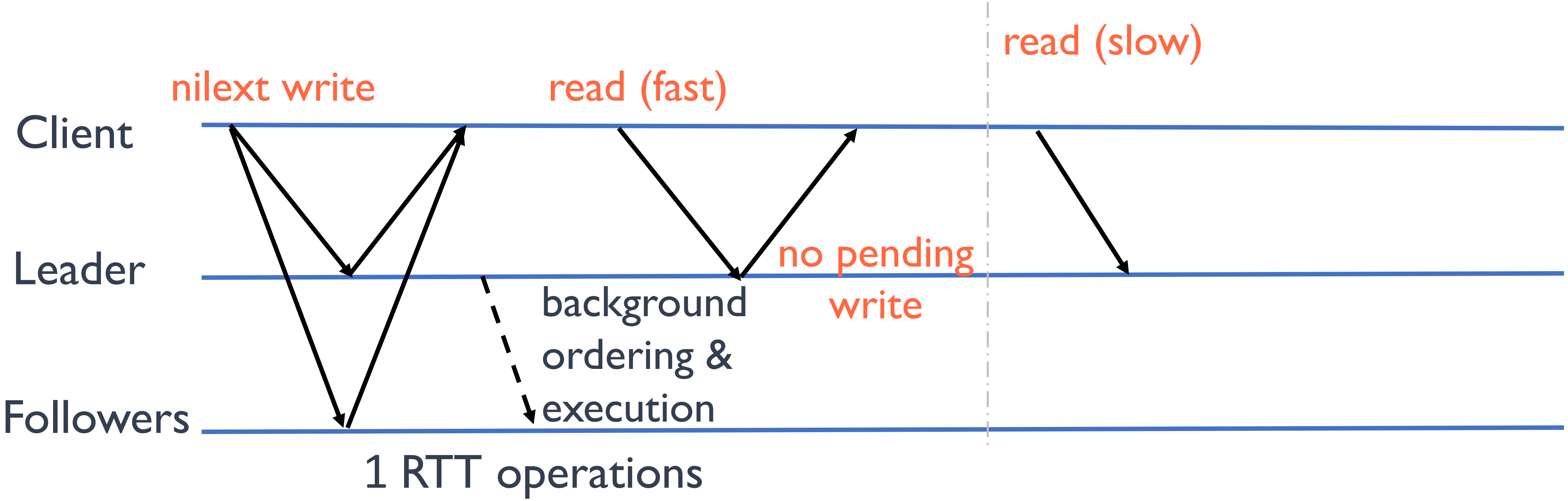

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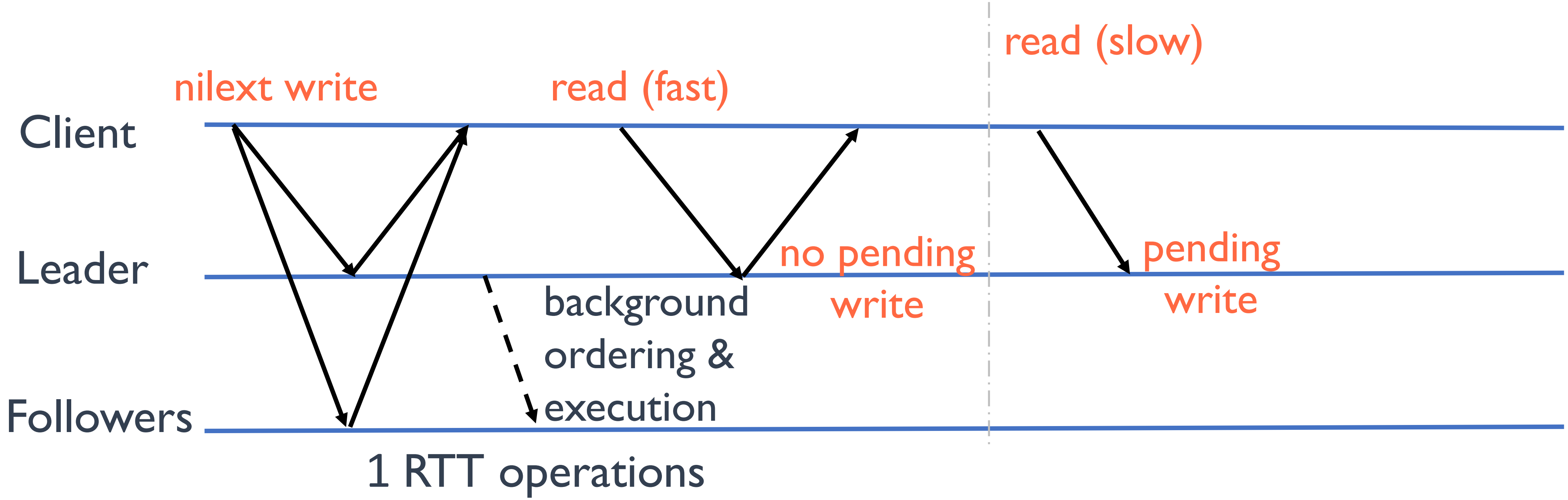

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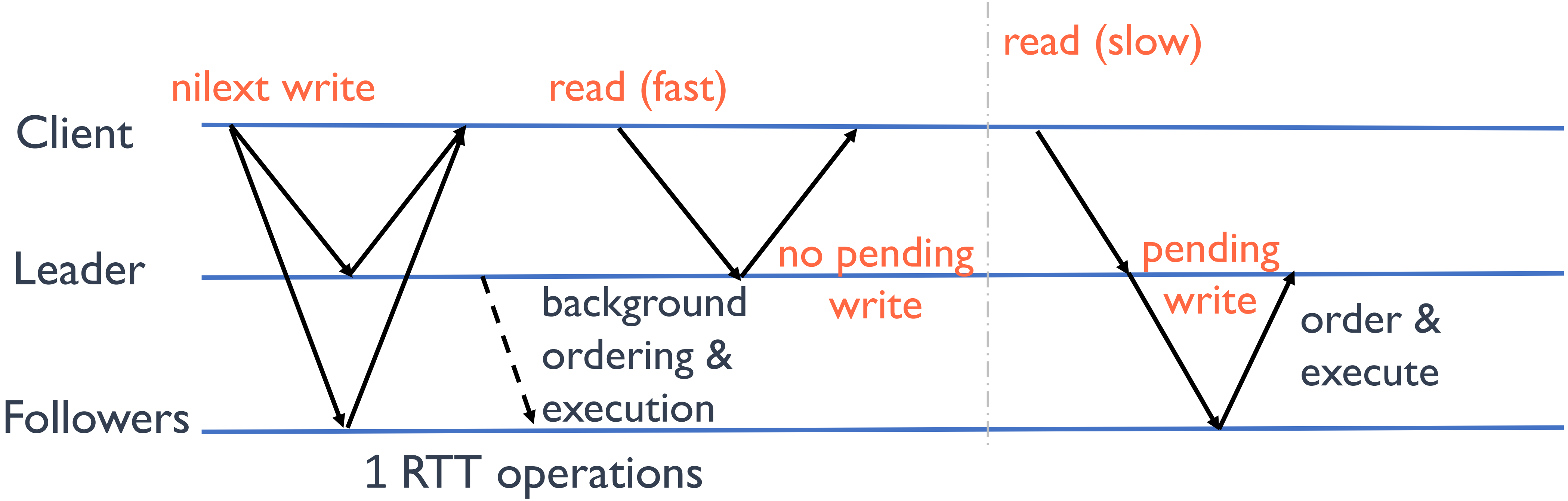

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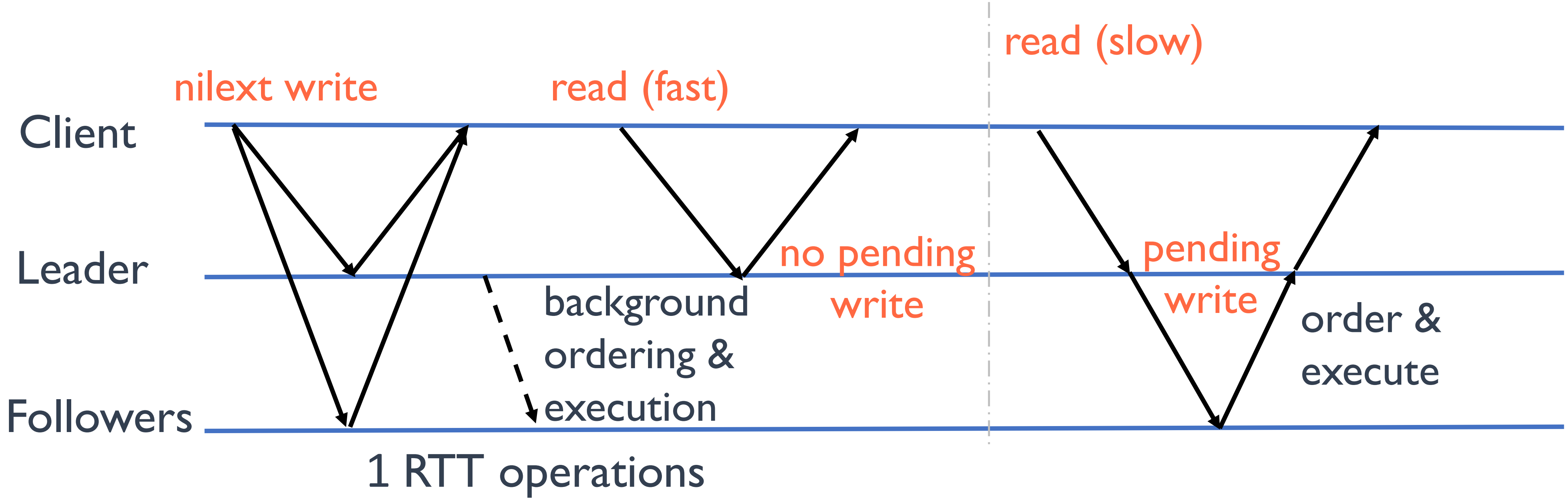

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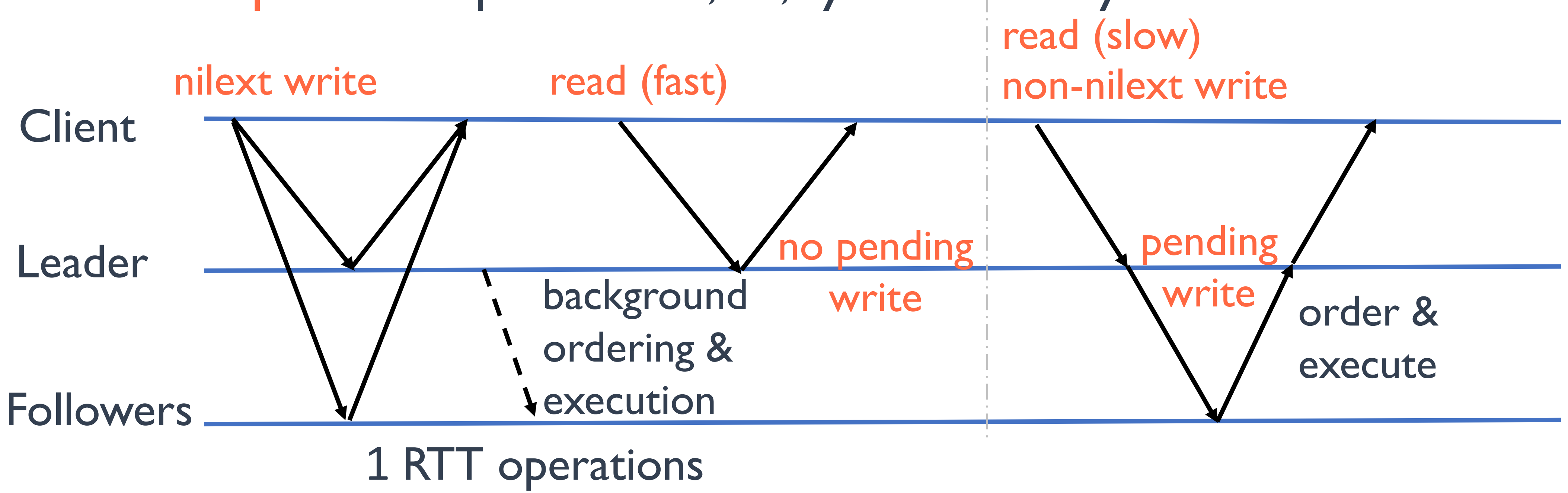

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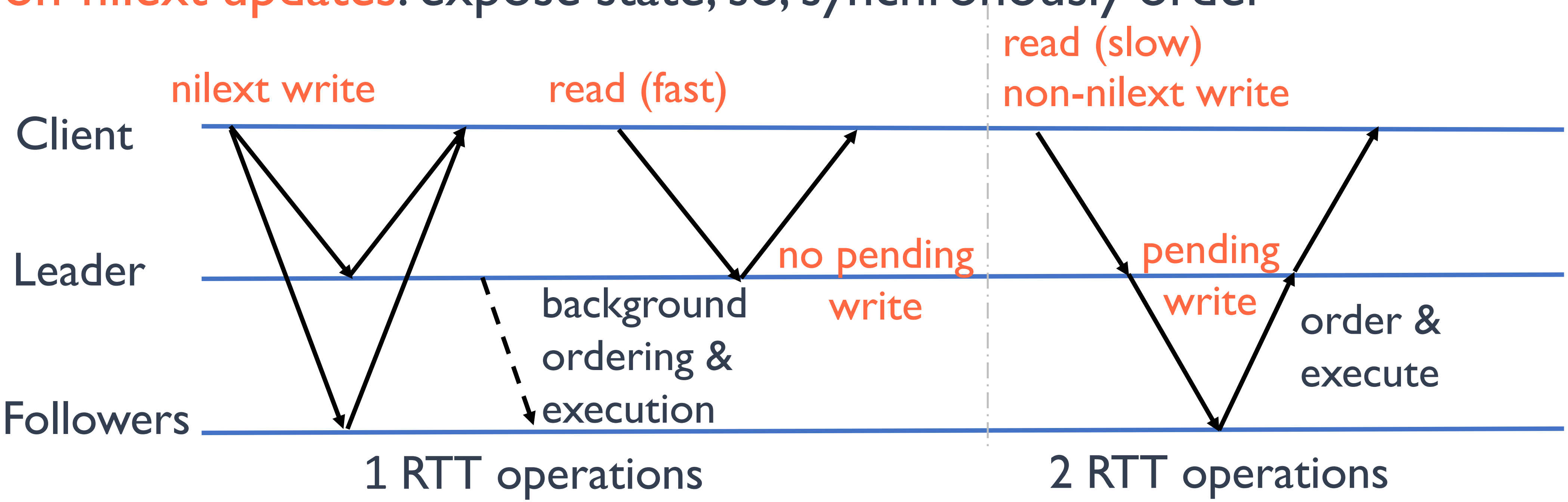

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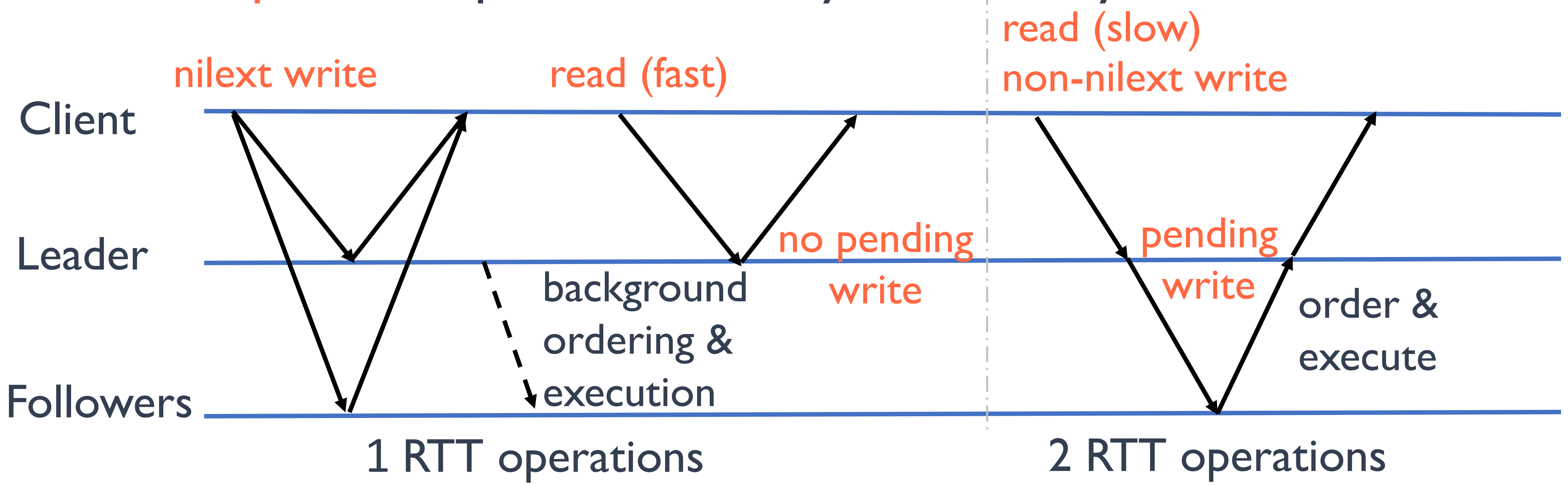

Real-world traces show fast case is common

Skyros Design

Skyros uses several techniques in its design

- durability log and supermajority quorums to complete nilext writes in one RTT
- ordering-and-execution check to serve reads mostly in one RTT
- DAG-based order-resolution to reconstruct linearizable order during view changes
- a variant that exploits commutativity [Lamport, 2004] in addition to nil-externality to quickly commit non-nilext updates

Please see paper …

Outline

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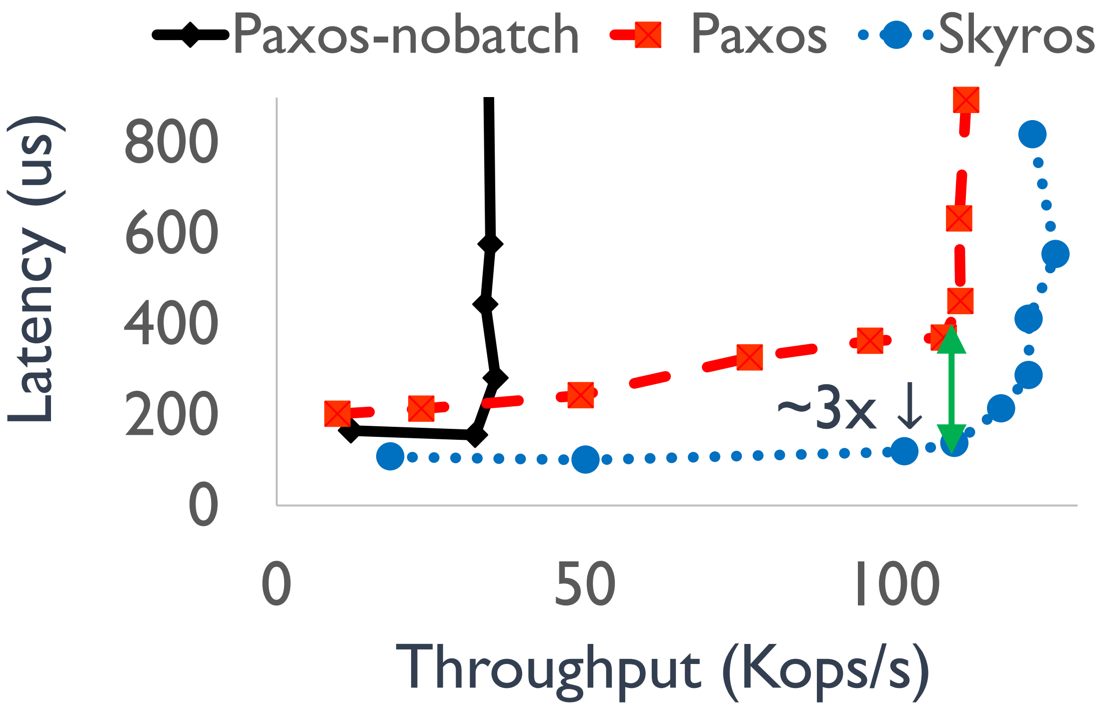
Nilext-aware replication

➡ Evaluation

What are the Benefits of Exploiting Nil-Externality?

Workload: nilext-only updates; vary number of clients

Compare Skyros with Paxos-nobatch and Paxos (with batching, default)



Significant reduction in latency over Paxos w/ batching

More in the paper …

Microbenchmarks varying many factors

- outperforms Paxos in most cases
- at extremes, performs as well as Paxos

Write-heavy YCSB workloads: up to 2x lower latencies

Read-heavy workloads: 70% lower p99 latency

Compare with Curp, a commutative protocol [Park and Ousterhout, 2019]

- 2.7x lower p99 latency for write-only workload

Concluding Thoughts

We identify nil-externality, a property prevalent in storage systems

Skyros, a new replication protocol

- defers coordination until state is externalized
- improves performance for a range of workloads while providing linearizability

Paying attention to what is observable to external clients is key

Useful to exploit properties of an underlying layer

Thank you!

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are on the academic job market this year