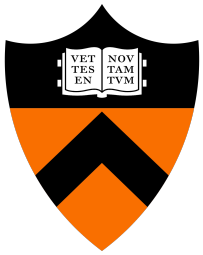
# Scalable Causal Consistency

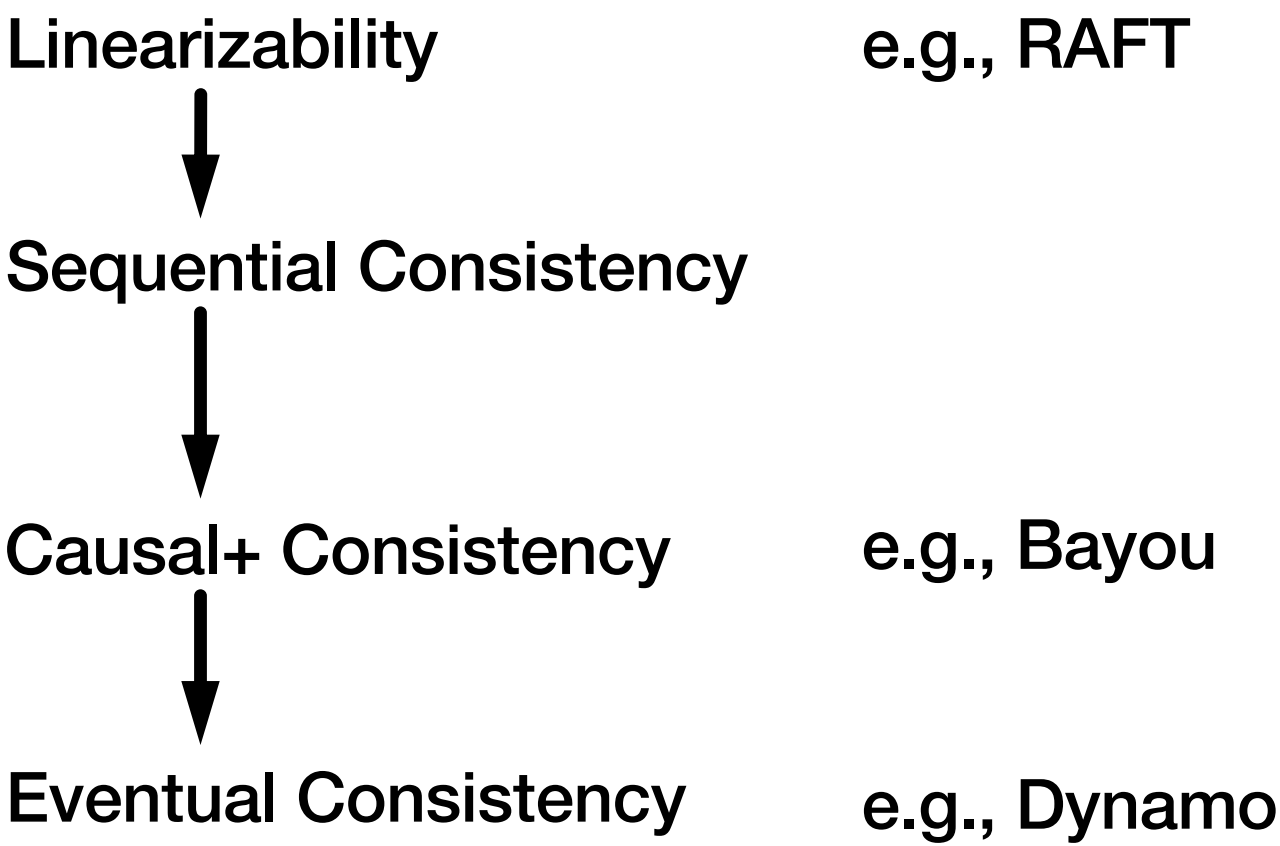



COS 418/518: Distributed Systems

Lecture 15

Wyatt Lloyd

# Consistency Hierarchy (review)



# Causal+ Consistency (review)

1. Writes that are potentially causally related must be seen by all processes in same order.
2. Concurrent writes may be seen in a different order on different processes.

- Concurrent: Ops not causally related

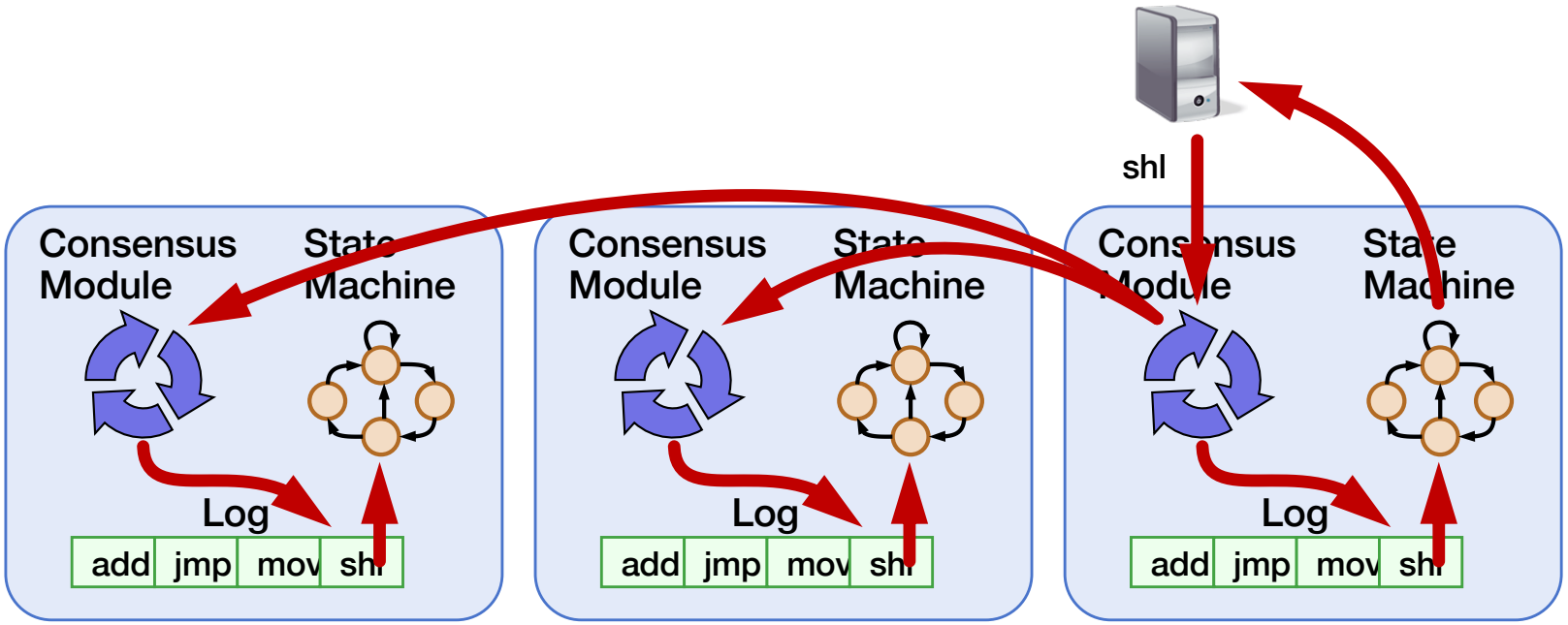
# Causal+ Consistency (review)

- Partially orders all operations, does not totally order them
  - Does not look like a single machine

- Guarantees
  - For each process, ∃ an order of all writes + that process's reads
  - Order respects the happens-before (→) ordering of operations
  - + replicas converge to the same state
    - Skip details, makes it stronger than eventual consistency

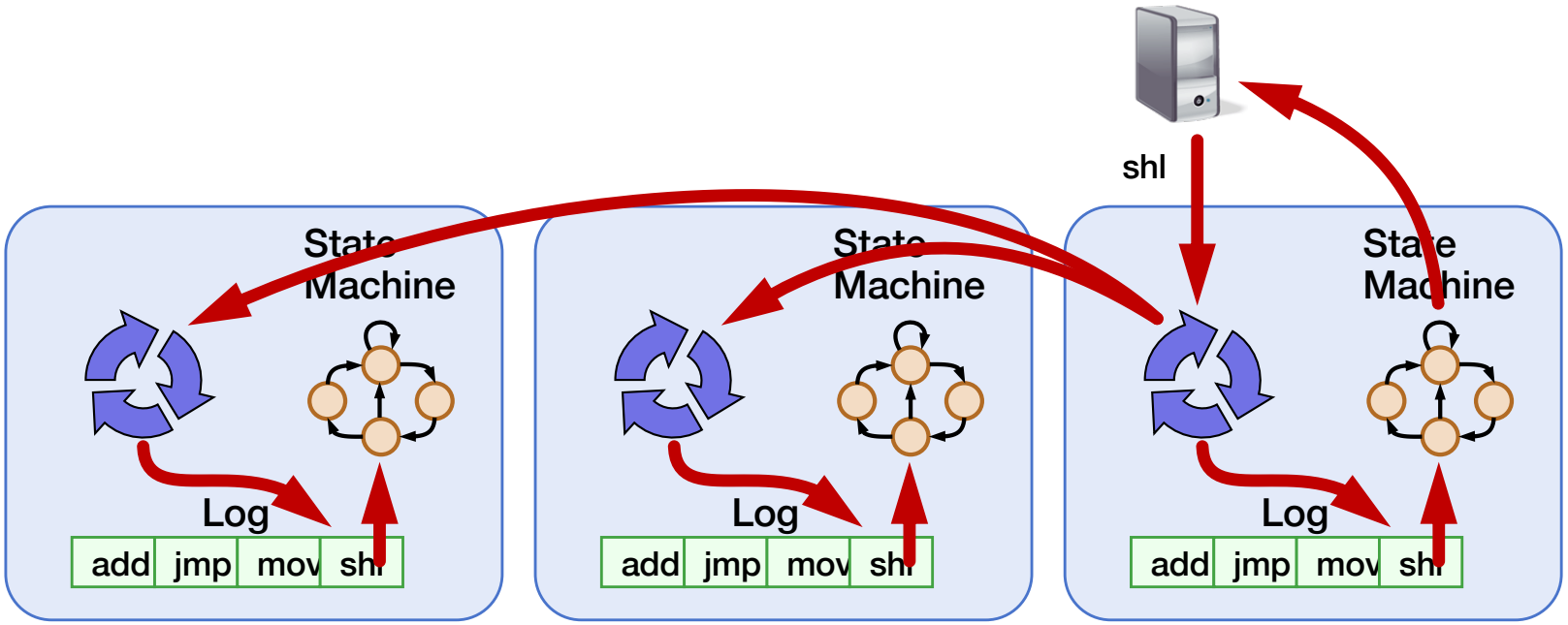
# Causal consistency within replicated systems

# Implications of laziness on consistency




- Linearizability / sequential:  Eager replication
- Trades off low-latency for consistency

# Implications of laziness on consistency




- Causal consistency:  Lazy replication
- Trades off consistency for low-latency
- Maintain local ordering when replicating
- Operations may be lost if failure before replication

# Consistency vs Scalability

Scalability: Adding more machines allows more data to be stored and more operations to be handled!

| System | Consistency | Scalable? |
|---|---|---|
| Paxos/RAFT | Linearizable | No |
| Bayou | Causal | No |
| Dynamo | Eventual | Yes |

It's time to think about scalability!

# Consistency vs Scalability

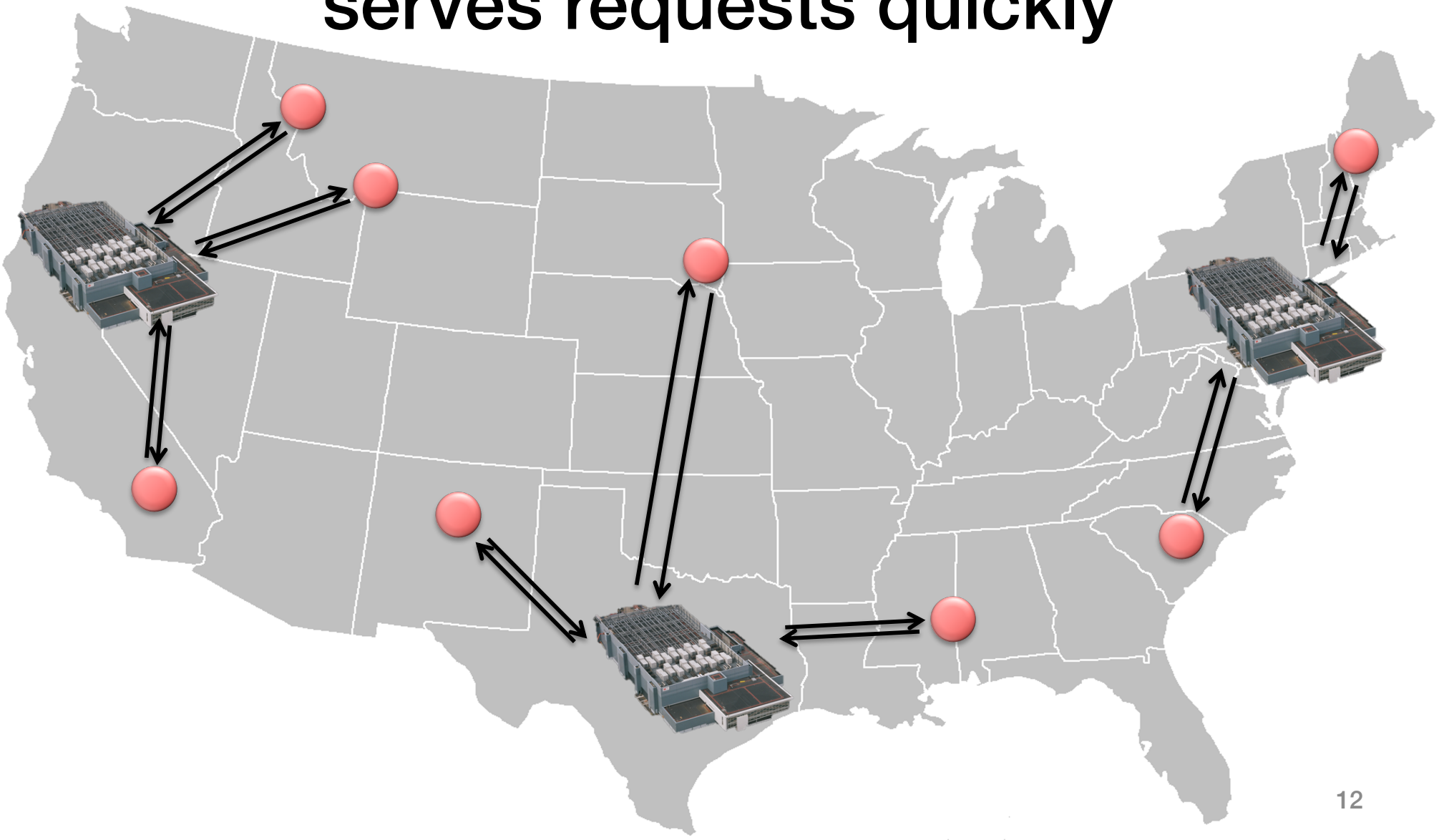
Scalability: Adding more machines allows more data to be stored and more operations to be handled!

| System | Consistency | Scalable? |
|---|---|---|
| Dynamo | Eventual | Yes |
| Bayou | Causal | No |
| COPS | Causal | Yes |
| Paxos/RAFT | Linearizable | No |
| | | Next Time! |

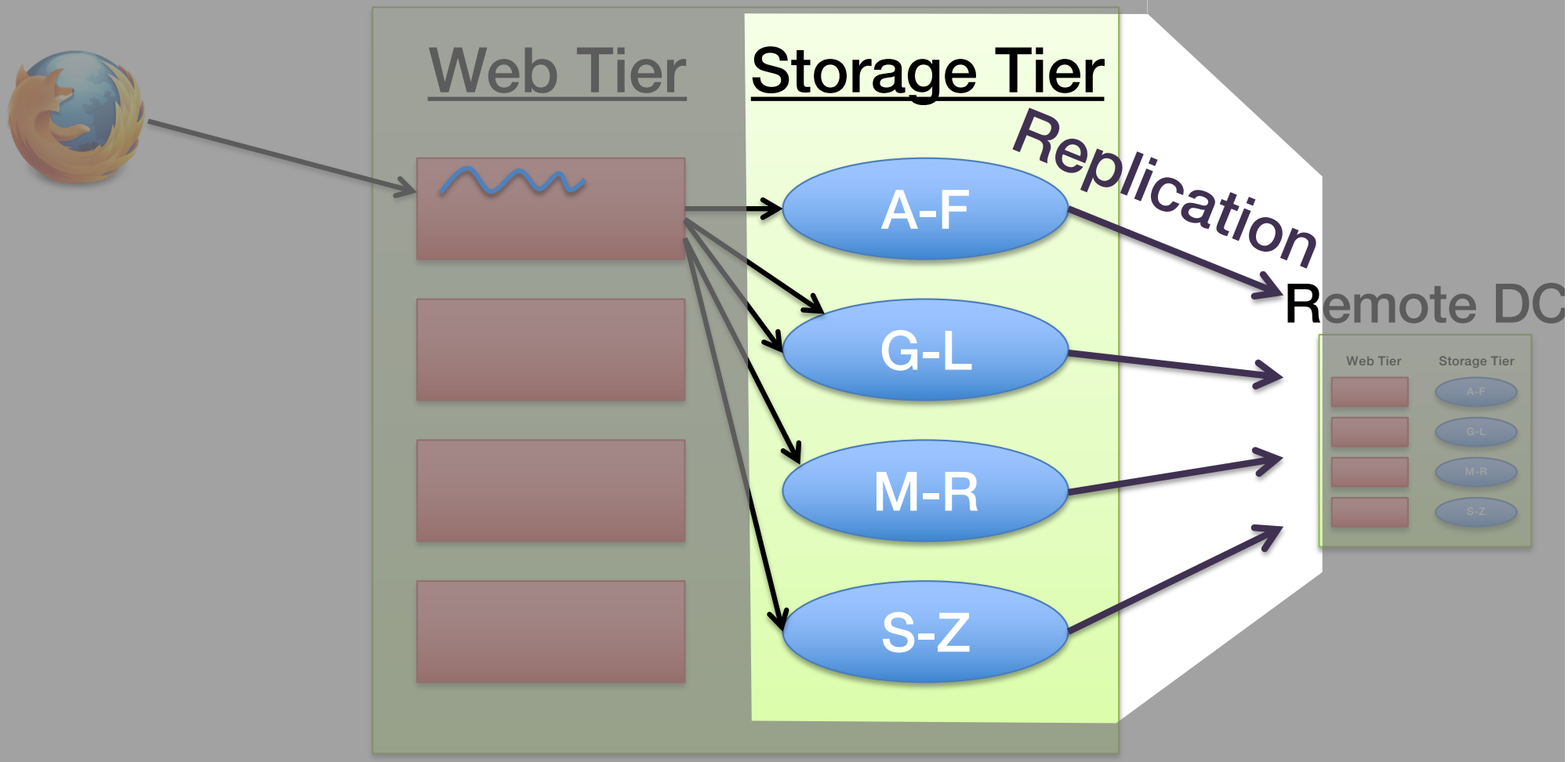
# COPS:
# Scalable Causal Consistency for Geo-Replicated Storage

# Geo-Replicated Storage

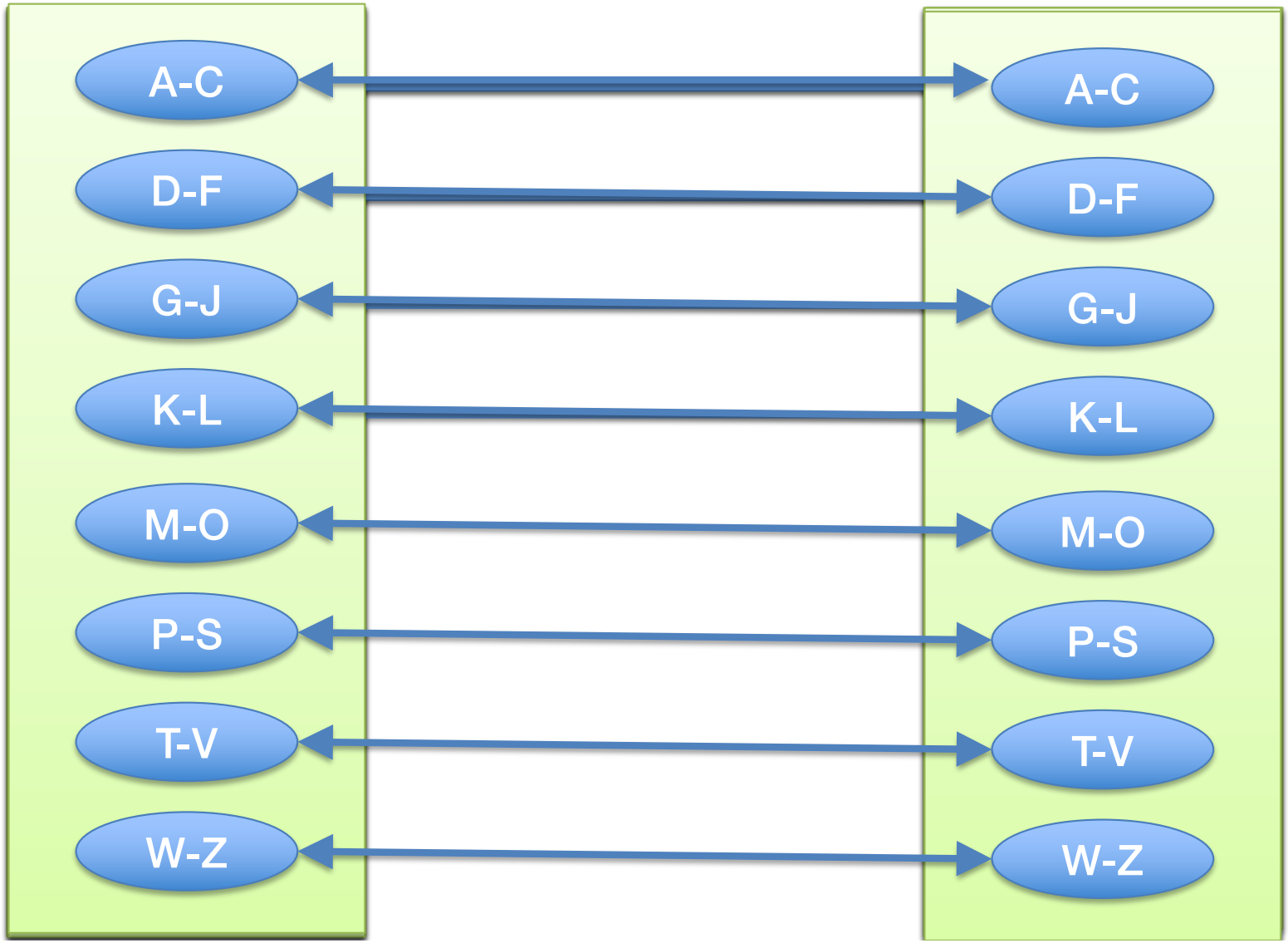
## serves requests quickly



# Inside the Datacenter



# Scalability through Sharding

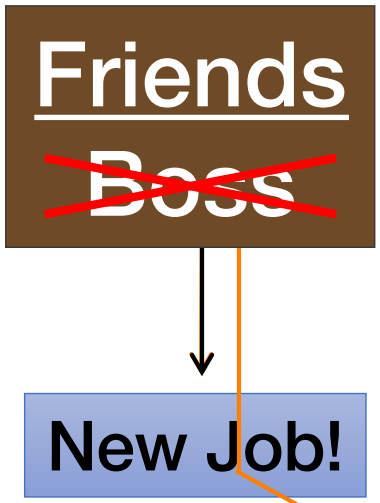


# Causality By Example

Remove boss from friends group

Post to friends: "Time for a new job!"

Friend reads post




Causality ($\longrightarrow$)

Same process

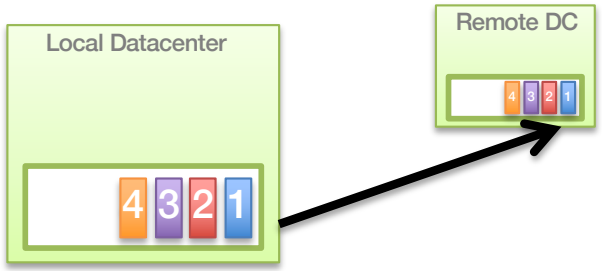
Reads-From

(message receipt)

Transitivity

# Bayou's Causal Consistency

- Log-exchange based




- Log is single serialization point within DC
  - √ **Implicitly** captures & enforces causal order

# Sharded Log Exchange

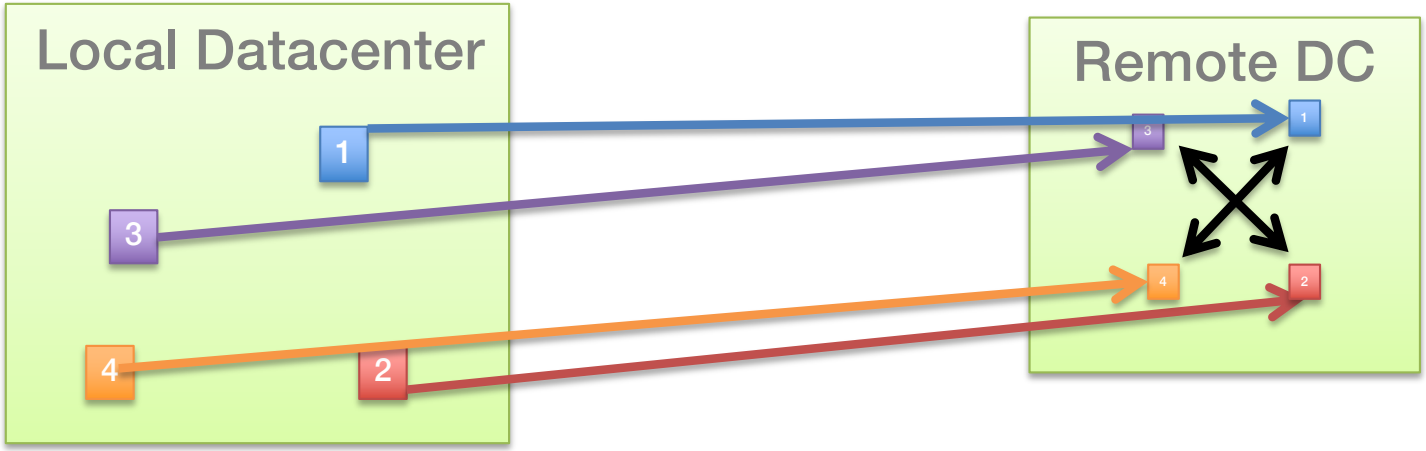
- What happens if we use a separate log per shard?

- What happens if we use a single log?

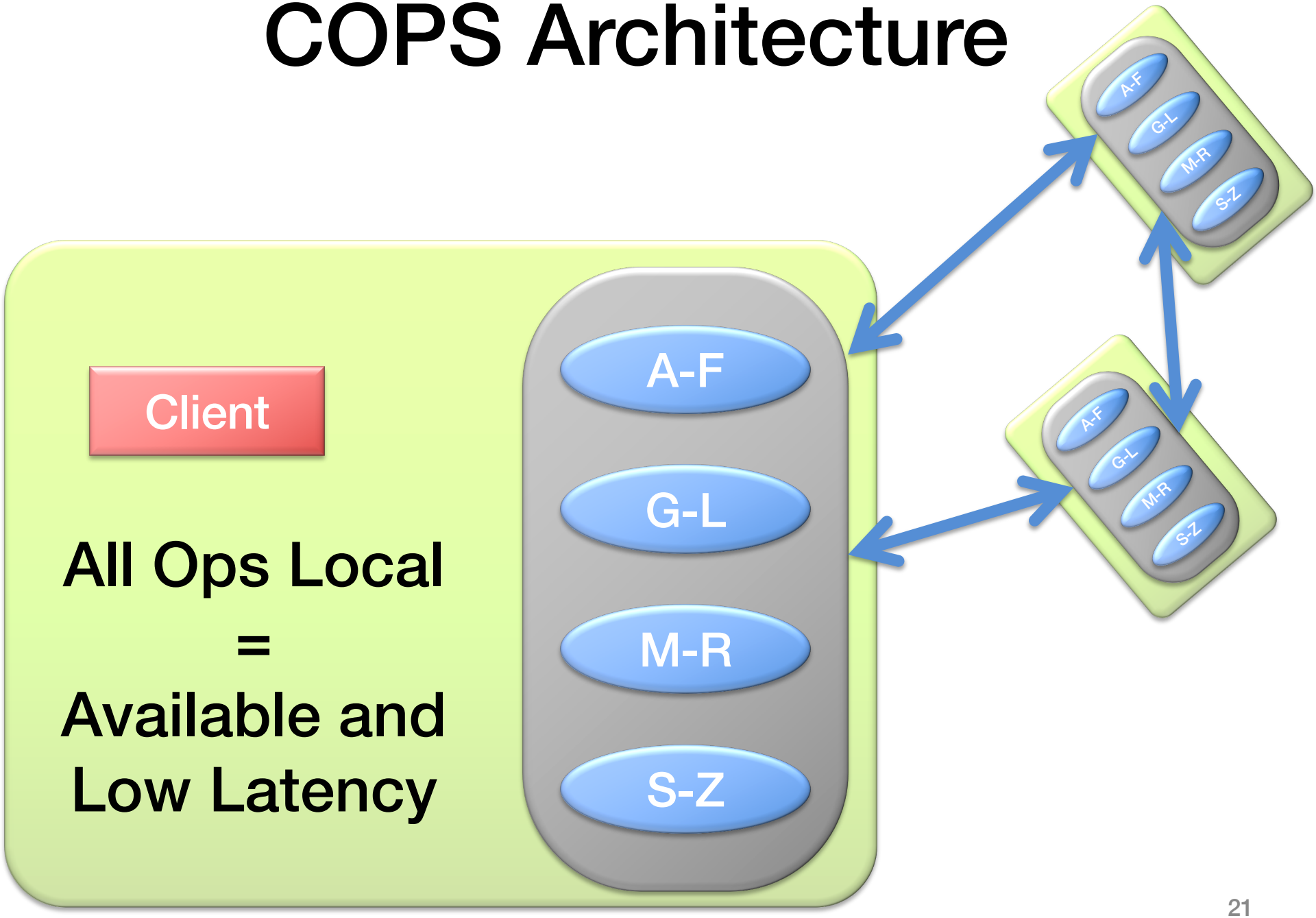
# Scalability Key Idea

- Capture causality with explicit dependency metadata

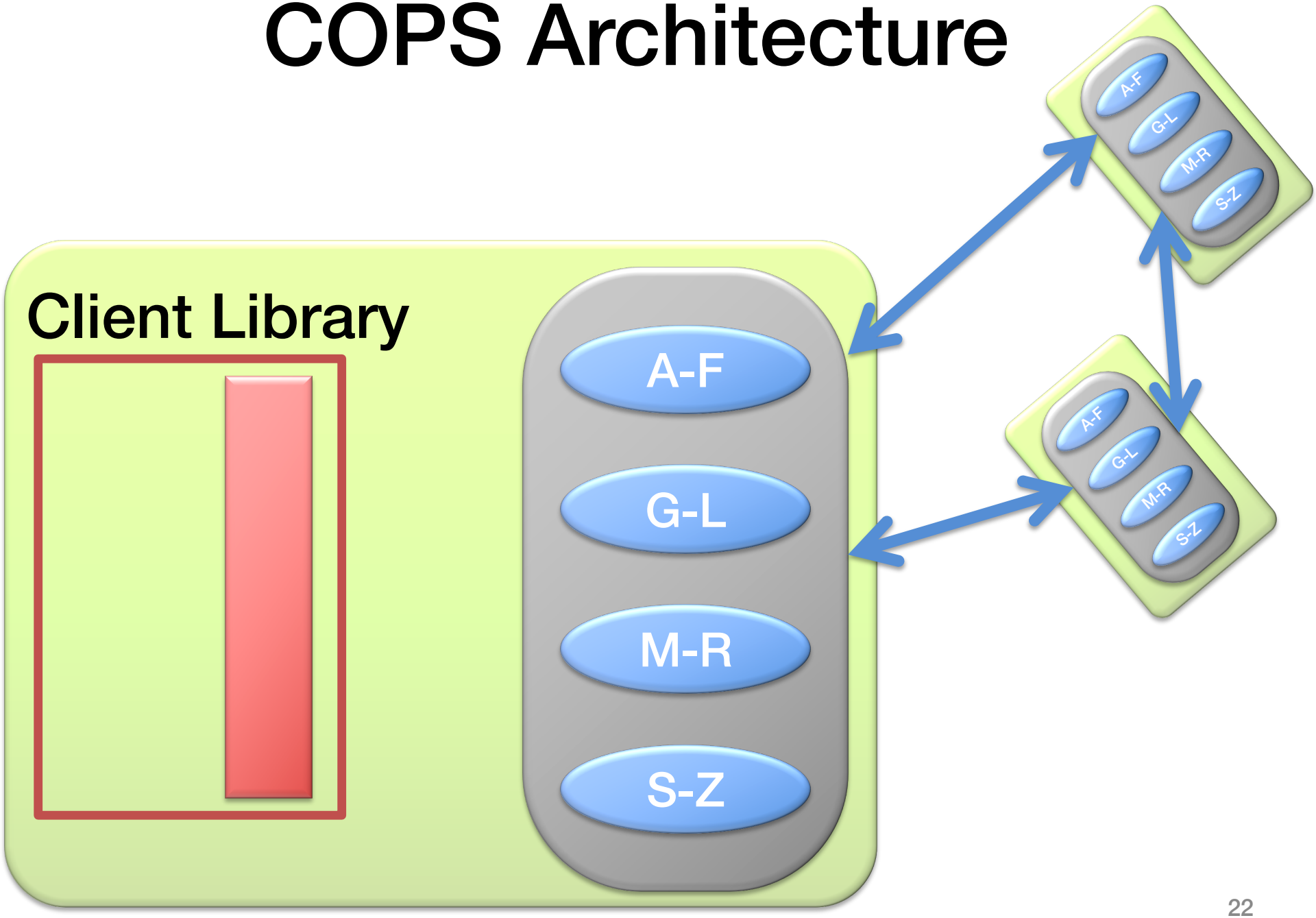

- Enforce with distributed verifications
  - Delay exposing replicated writes until all dependencies are satisfied in the datacenter



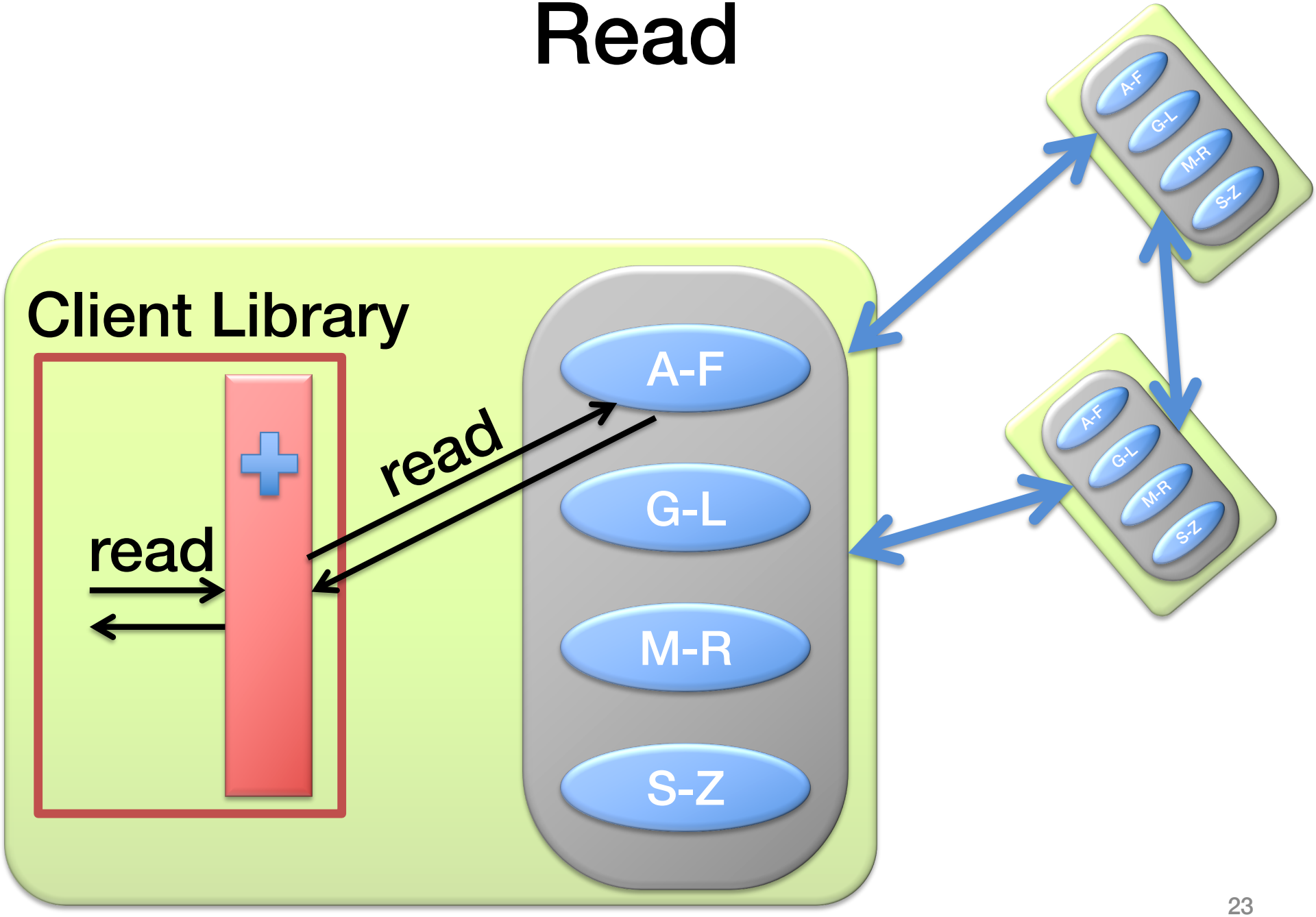
# COPS Architecture



# COPS Architecture

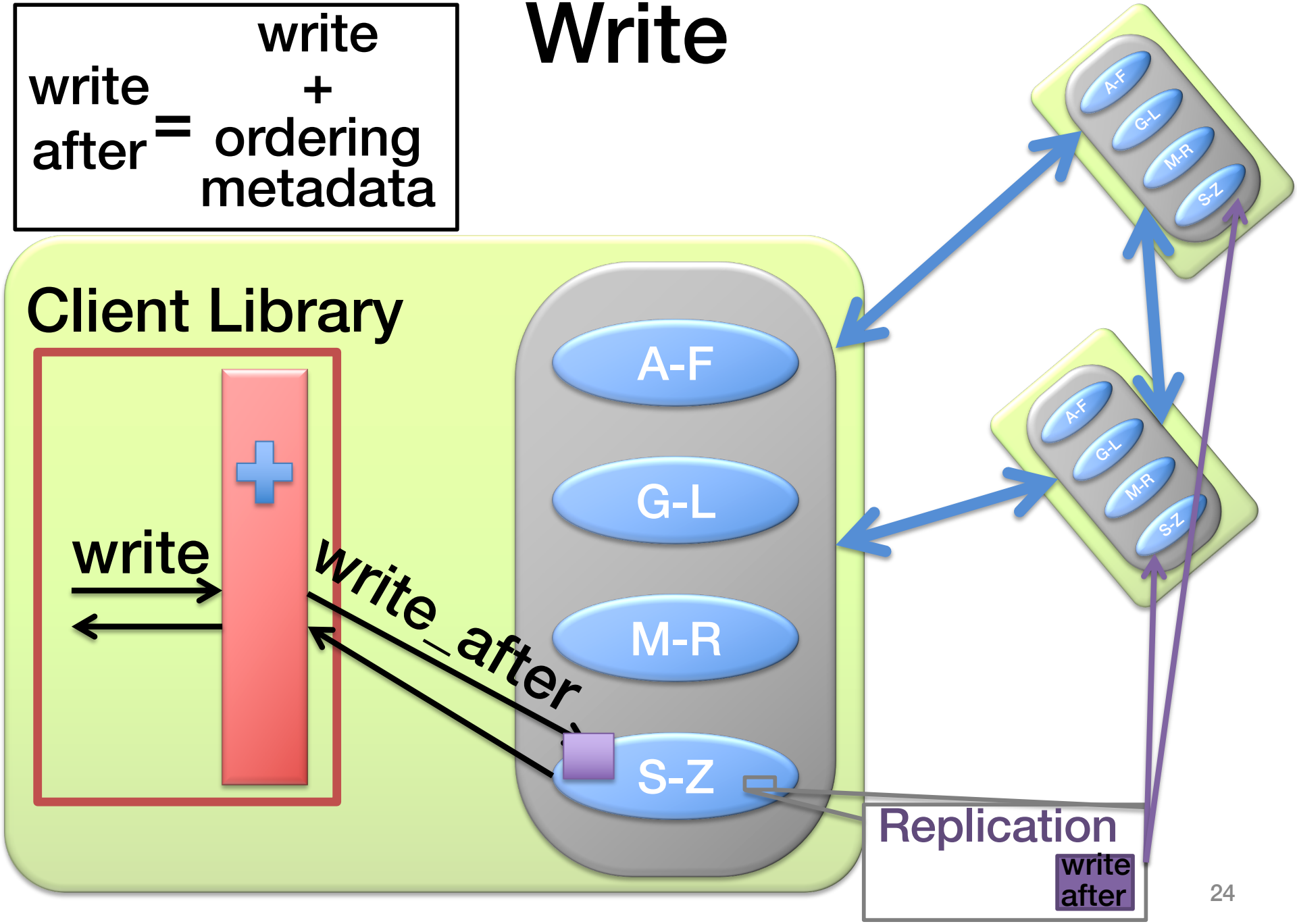


# Read

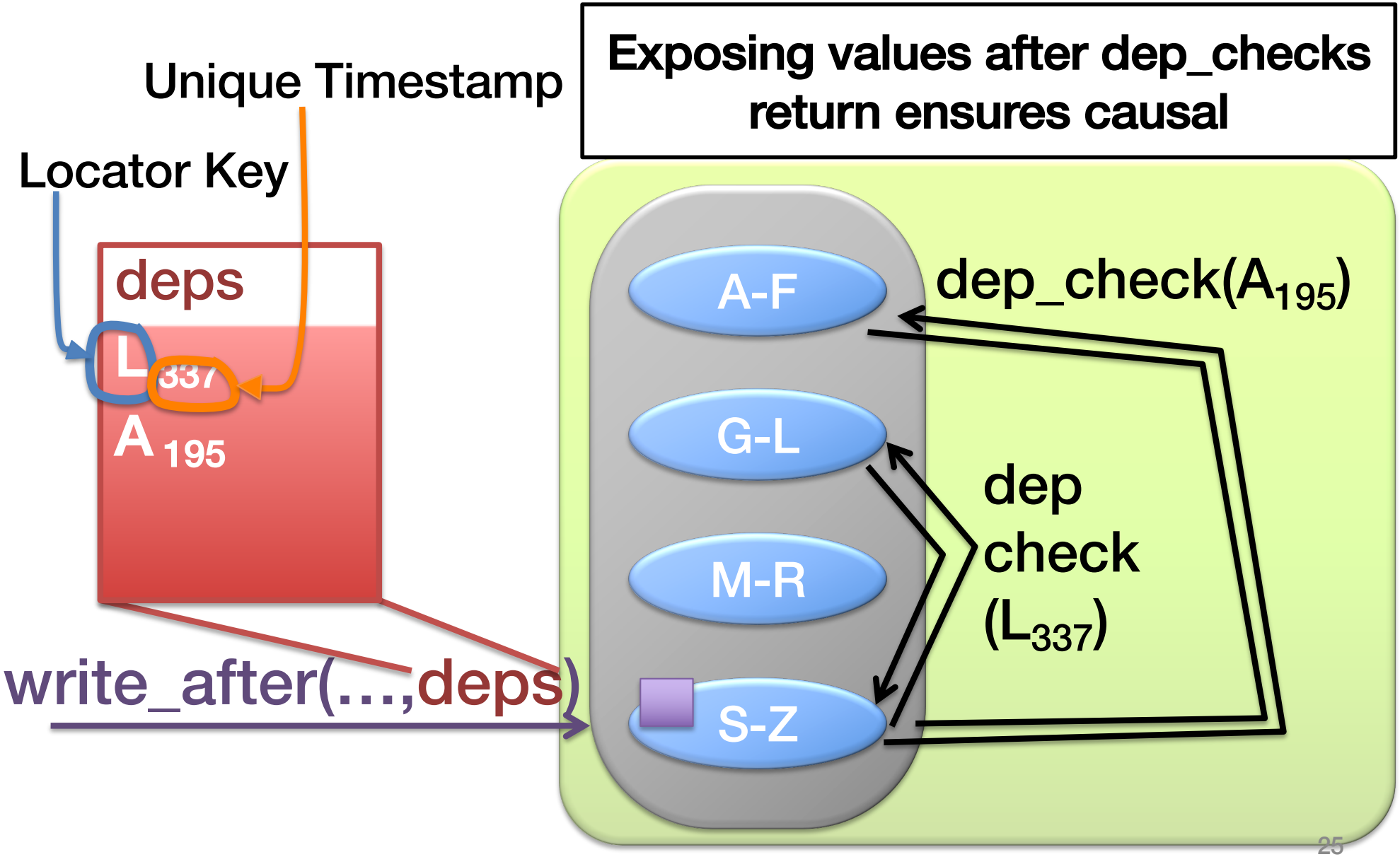


write after = write + ordering metadata

# Write



# Replicated Write

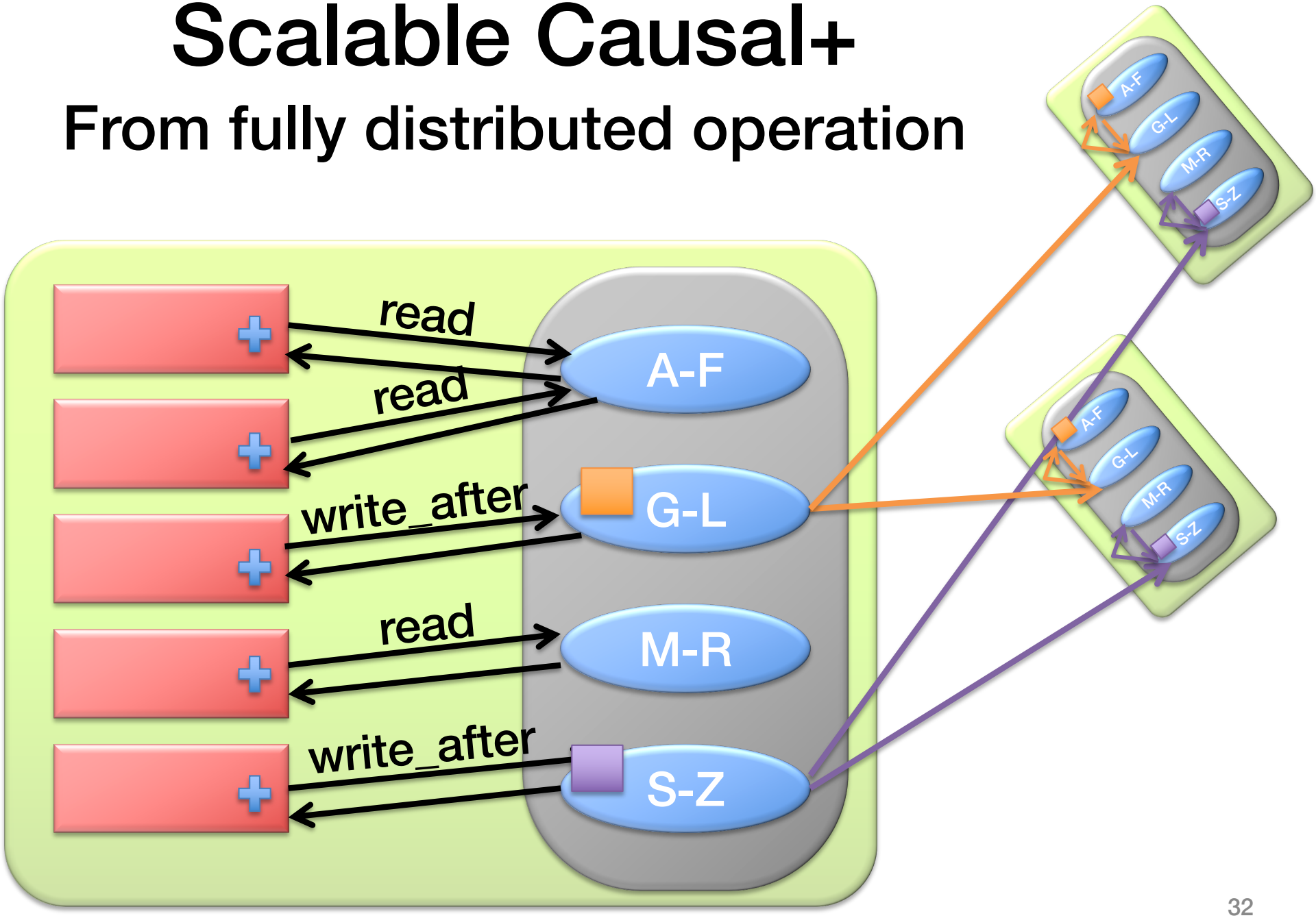


# Basic Architecture Summary

- All ops local, replicate in background
  - Availability and low latency
- Shard data across many nodes
  - Scalability
- Control replication with dependencies
  - Causal consistency

# Scalable Causal+

## From fully distributed operation

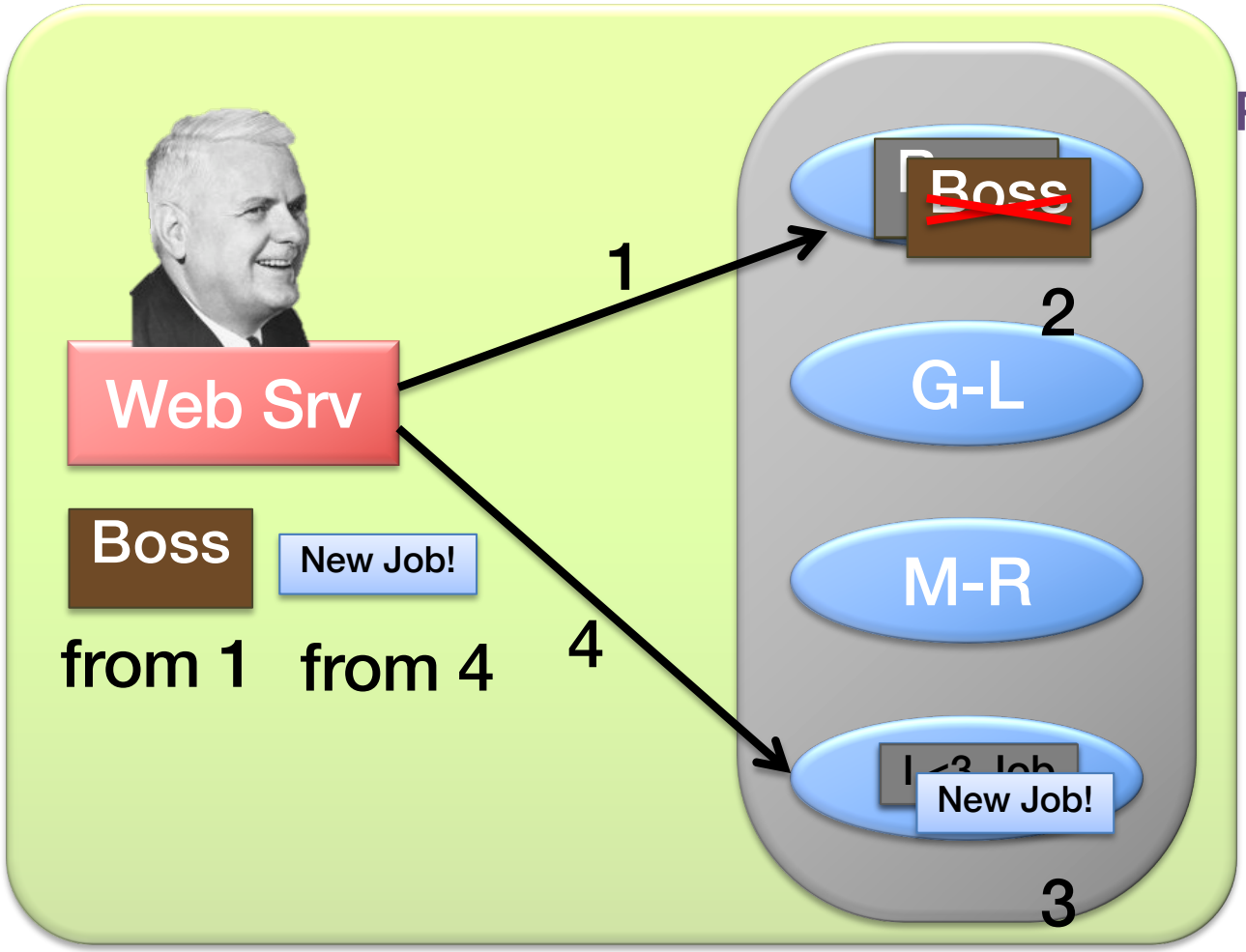


# Scalability

- Shard data for scalable storage
- New distributed protocol for scalably applying writes across shards
- Also need a new distributed protocol for consistently reading data across shards…

# Reads Aren't Enough

## Asynchronous requests + distributed data = ??




Turing's Operations

Progress

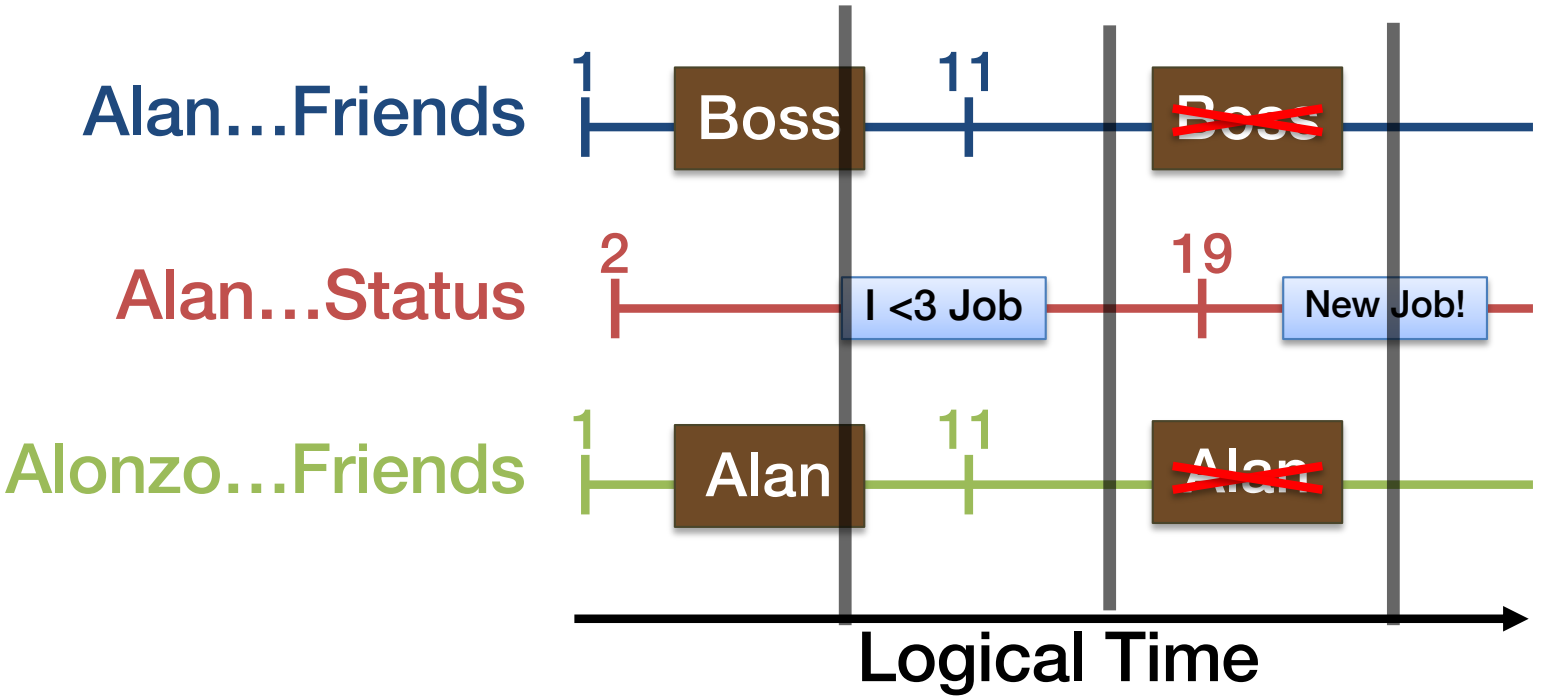
Progress

New Job!

Progress

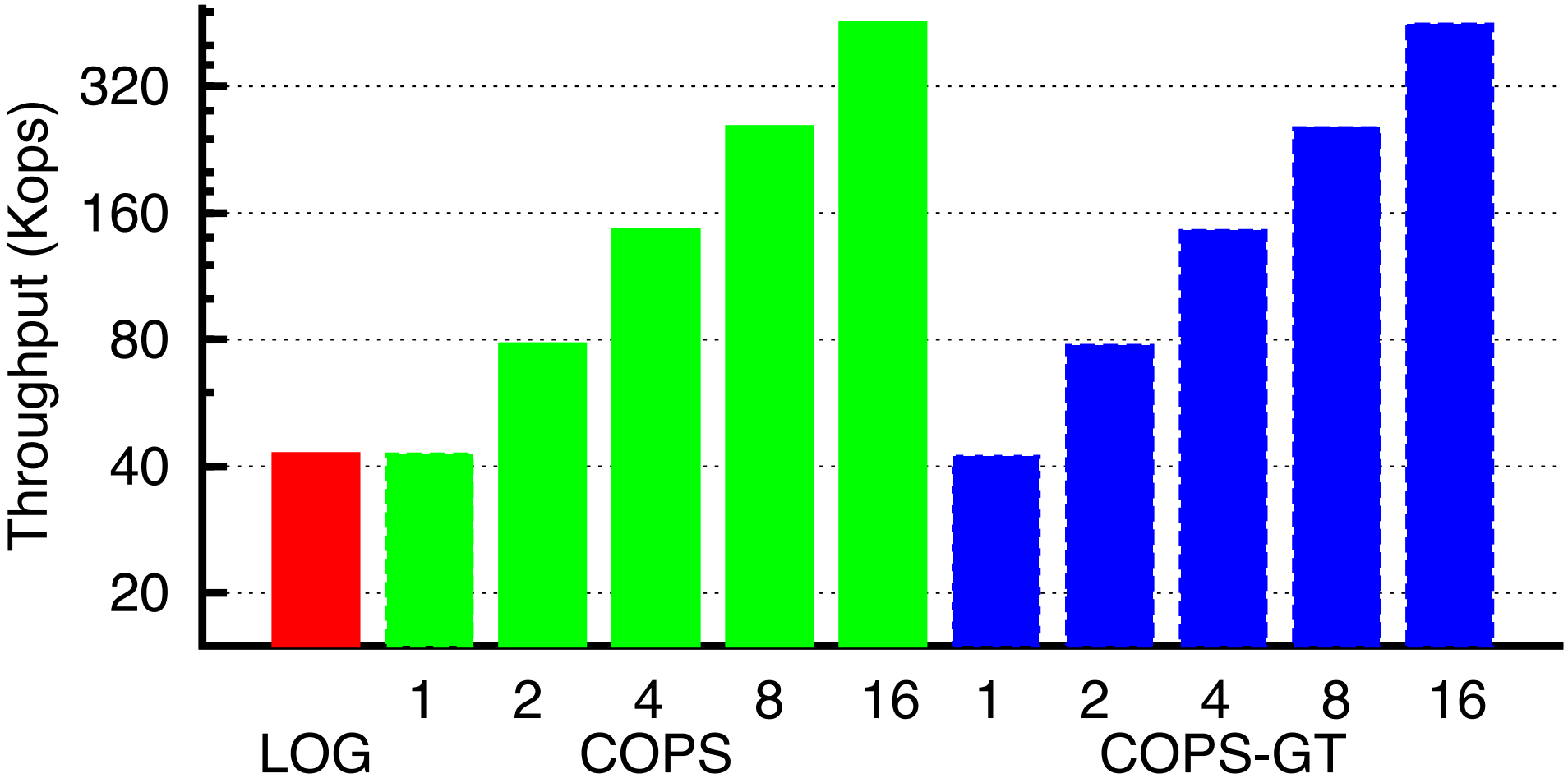
# Read-Only Transactions

- Consistent up-to-date view of data
  - Across many servers




More on transactions next time!

# COPS Scaling Evaluation




More servers => More operations/sec

# COPS

- Scalable causal consistency
  - Shard for scalable storage
  - Distributed protocols for coordinating writes and reads
    - Evaluation confirms scalability
- All operations handled in local datacenter
  - Availability
  - Low latency
- We’re thinking scalably now!
  - Next time: scalable strong consistency