Scalable Causal Consistency

COS 418/518: (Advanced) Distributed Systems
Lecture 15

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Consistency Hierarchy (review)

Linearizability — e.g., RAFT

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Sequential Consistency

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Causal+ Consistency — e.g., Bayou

↓

Eventual Consistency — e.g., Dynamo

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

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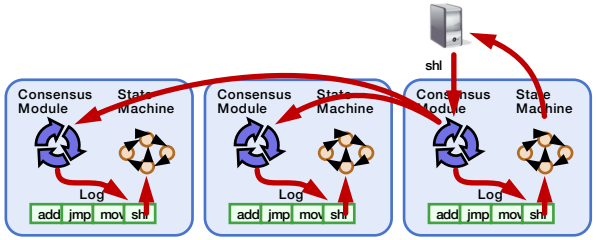
Implications of laziness on consistency



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

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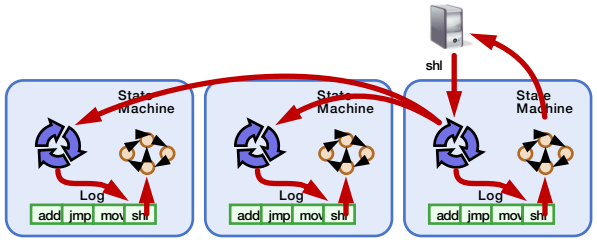
Implications of laziness on consistency



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

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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

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Geo-Replicated Storage
serves requests quickly

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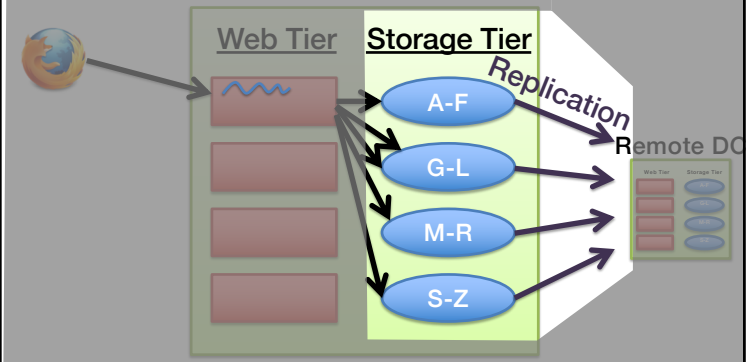
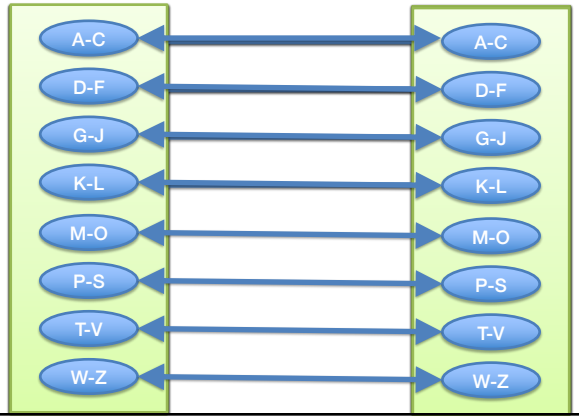
Inside the Datacenter



Scalability through Sharding

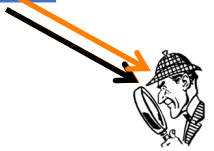


Causality By Example

Remove boss from friends group

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

Friend reads post



Causality (→)
Same process
Reads-From
(message receipt)
Transitivity

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Bayou's Causal Consistency

- Log-exchange based

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

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Sharded Log Exchange

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

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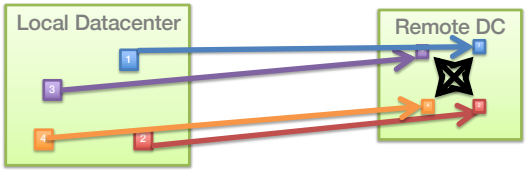
Scalability Key Idea

- Capture causality with explicit dependency metadata

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



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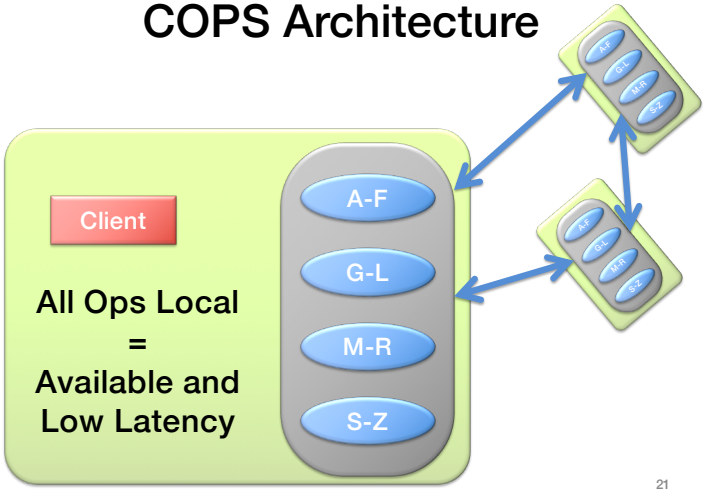
COPS Architecture



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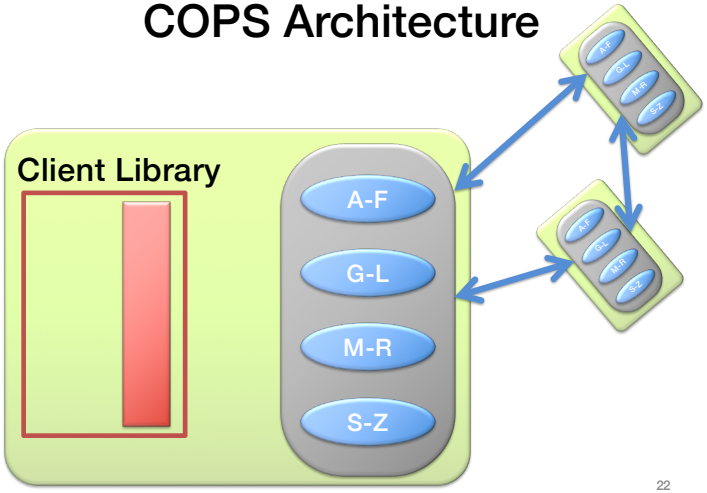
COPS Architecture



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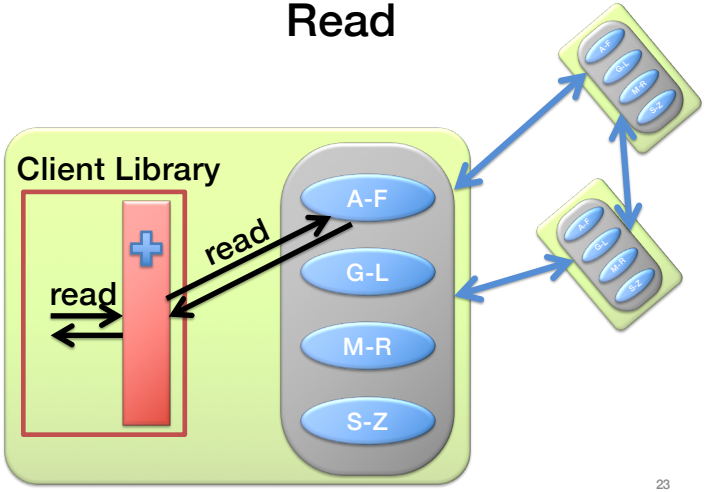
Read



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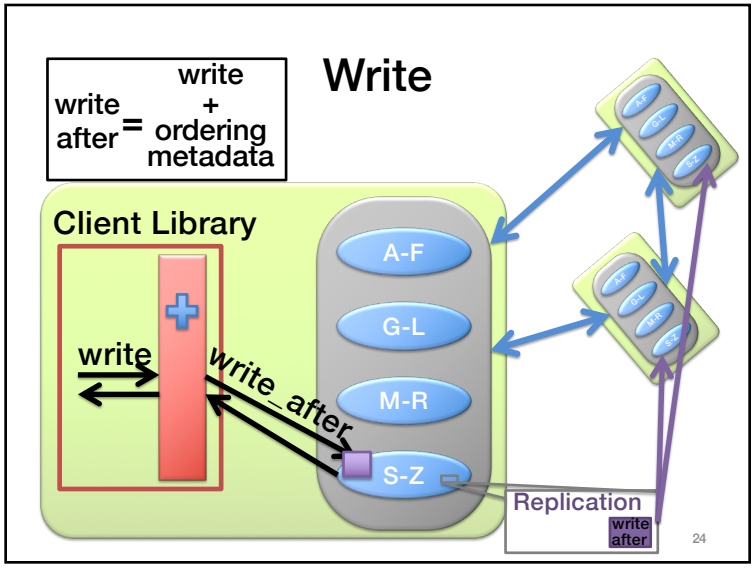

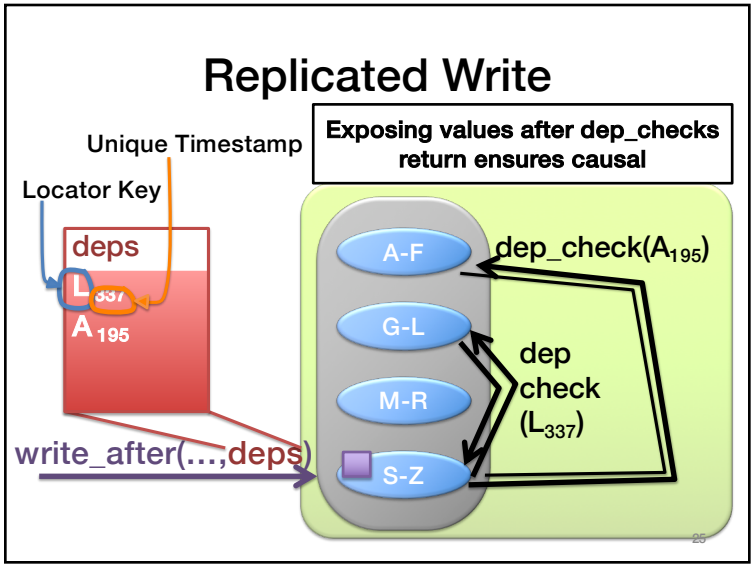

Basic Architecture Summary

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

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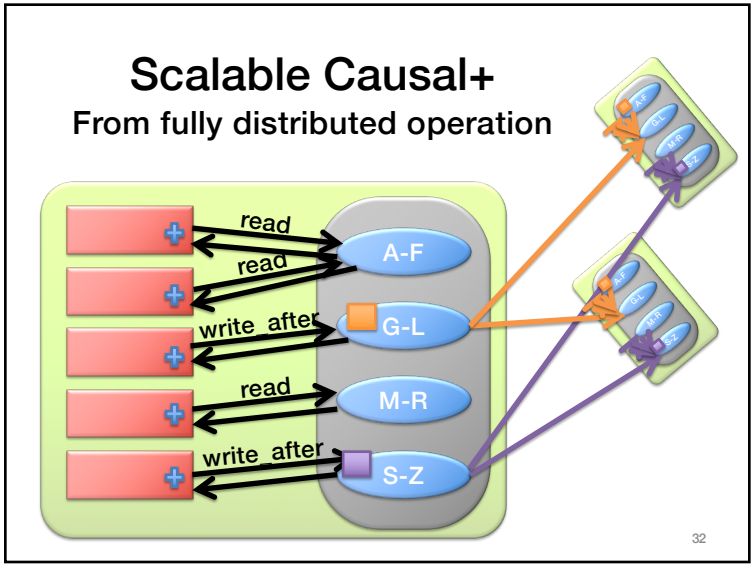

Scalability

- 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…

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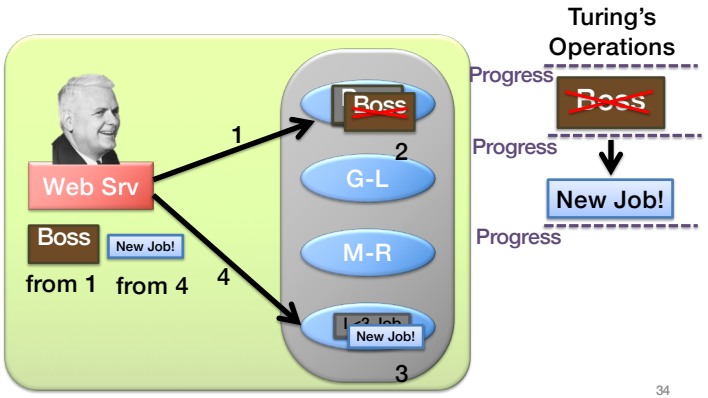
Reads Aren't Enough

Asynchronous requests + distributed data = ??



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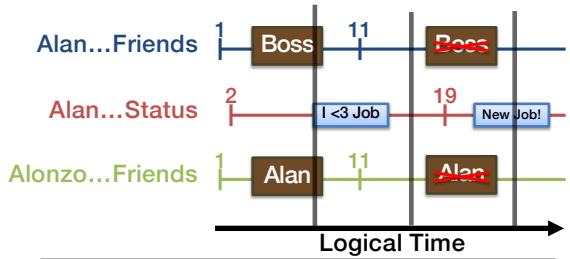
Read-Only Transactions

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



More on transactions next time!

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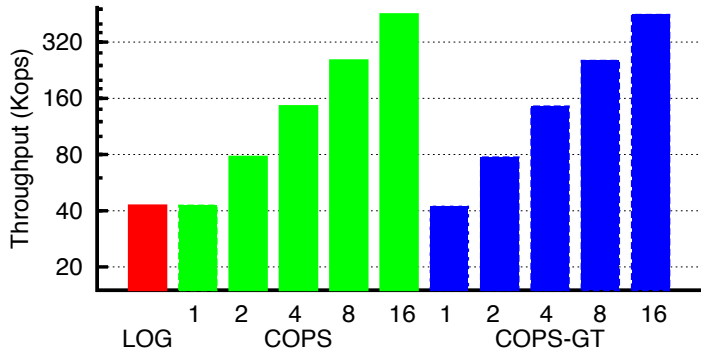
COPS Scaling Evaluation



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

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