Fault-Tolerance, Fast and Slow: Exploiting Failure Asynchrony in Distributed Systems

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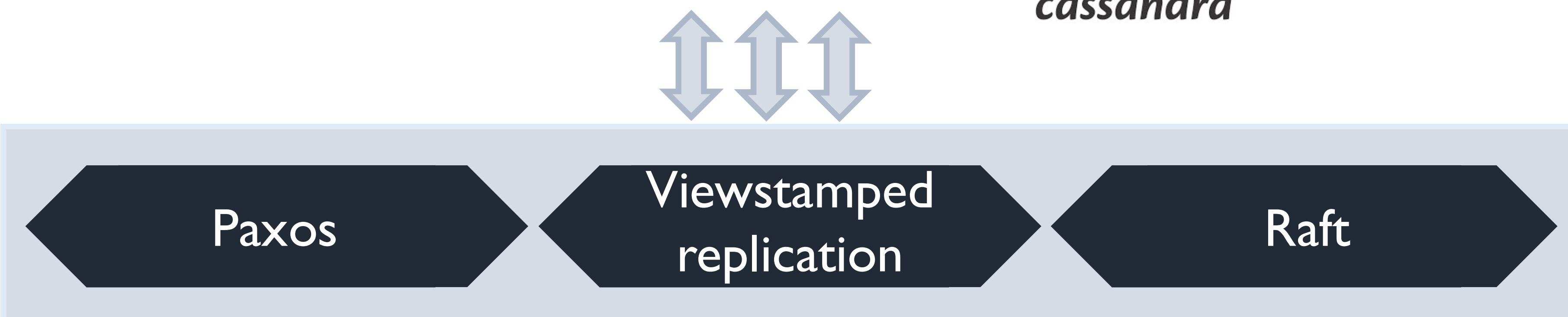
UNIVERSITY OF WISCONSIN–MADISON

Replication Protocols

Replication Protocols

Foundation upon which datacenter systems are built

GFS
Colossus
BigTable



The Two Different Worlds of Replication

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World-1

World-2

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How and where to store system state?

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performant but risk unsafety or unavailability

Neither approach is ideal: reliable *or* performant

Can a protocol provide strong reliability while maintaining high performance?

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Situation-Aware Updates and Crash Recovery

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- however, existing data hints they are extremely rare – the Non-Simultaneity Conjecture

Results

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Implemented in ZooKeeper

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SAUCR improves reliability compared to memory-durable systems

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Compared to disk-durable

- ➡ slight reduction in availability in extremely rare cases
- ➡ improves performance – 2.5x on SSDs, 100x on HDDs

Outline

Introduction

Distributed updates and crash recovery

- disk-durable protocols
- memory-durable protocols

Situation-aware updates and crash recovery

Results

Summary and conclusion

Disk-Durable Protocols

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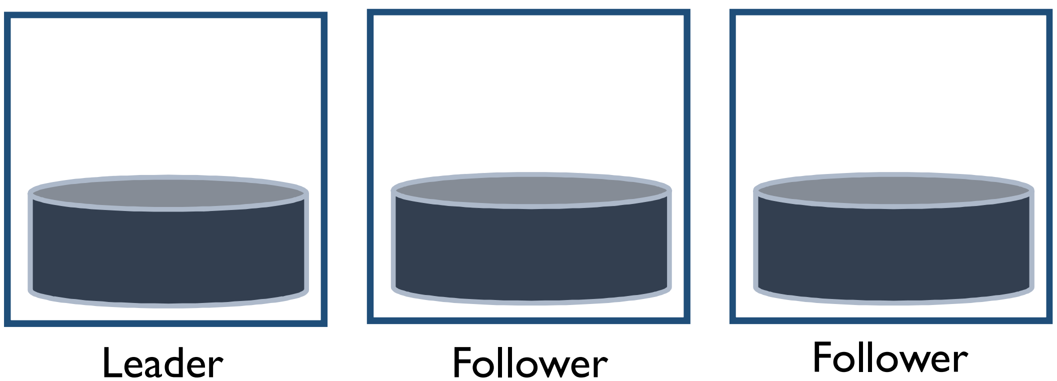
Update



Disk-Durable Protocols

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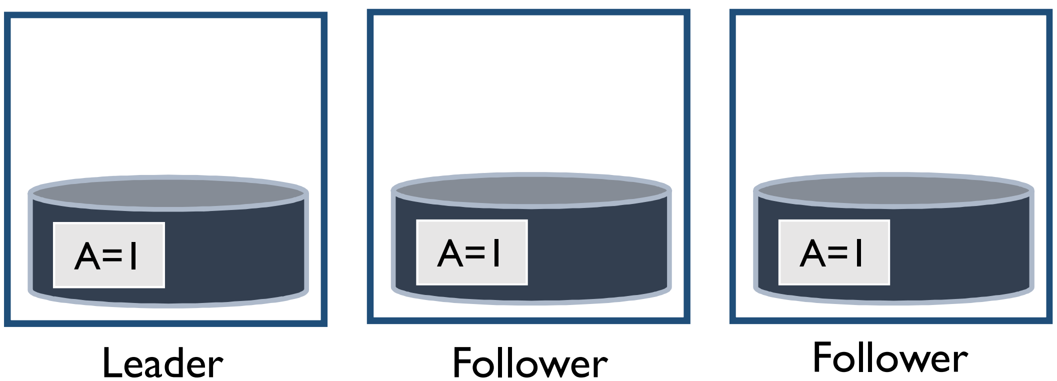

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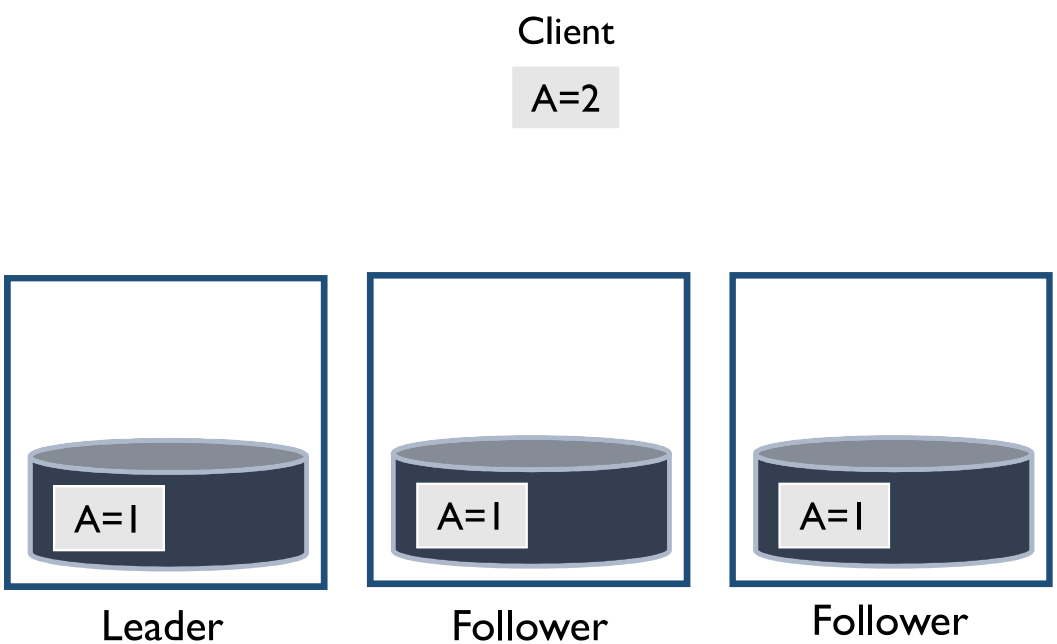

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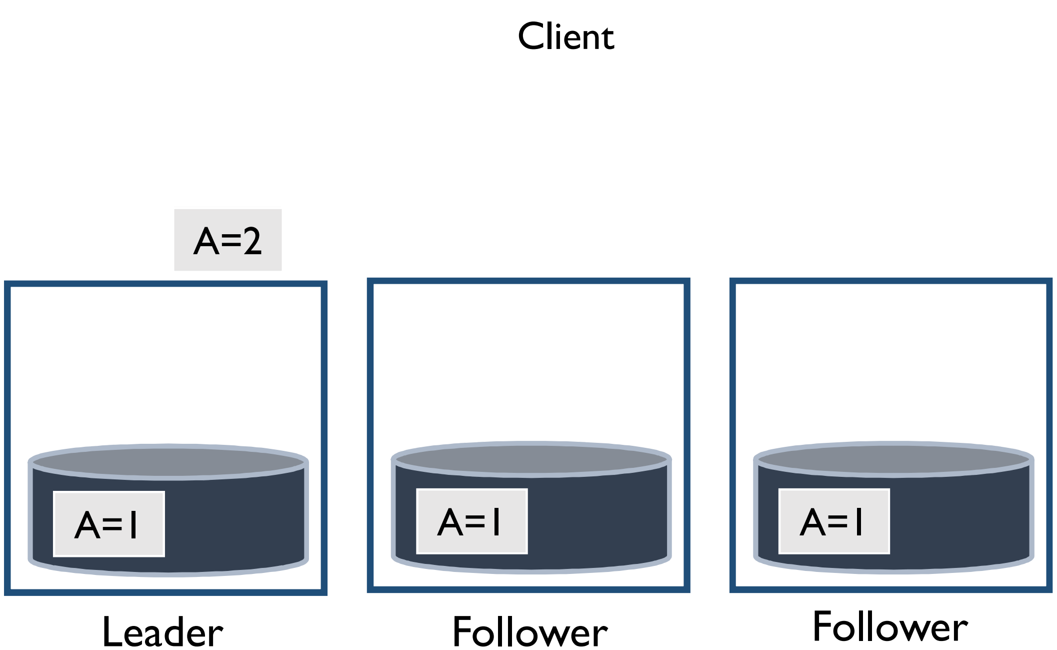

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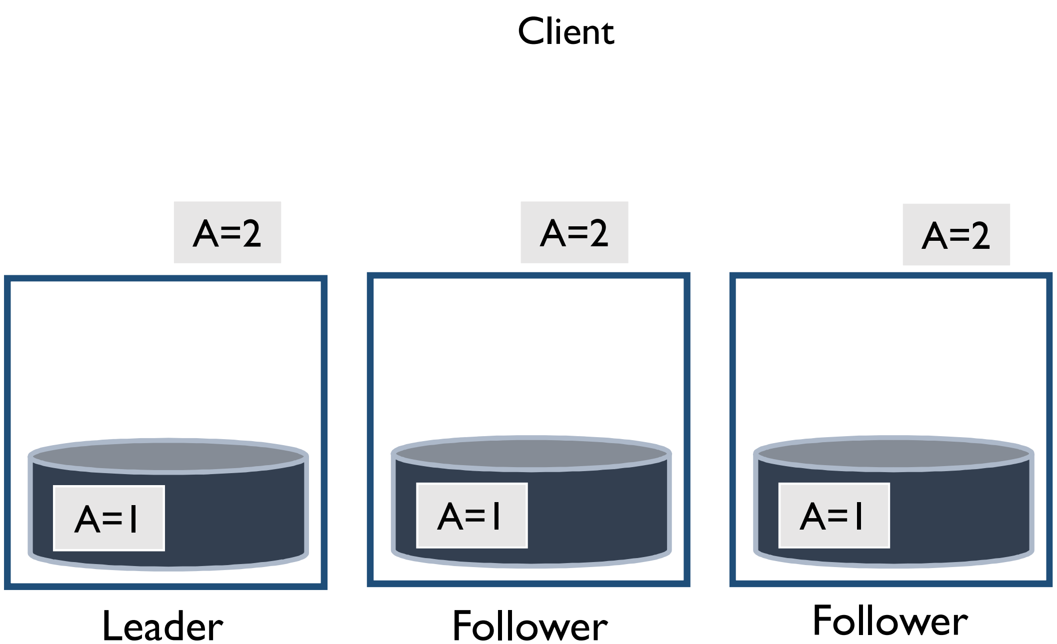

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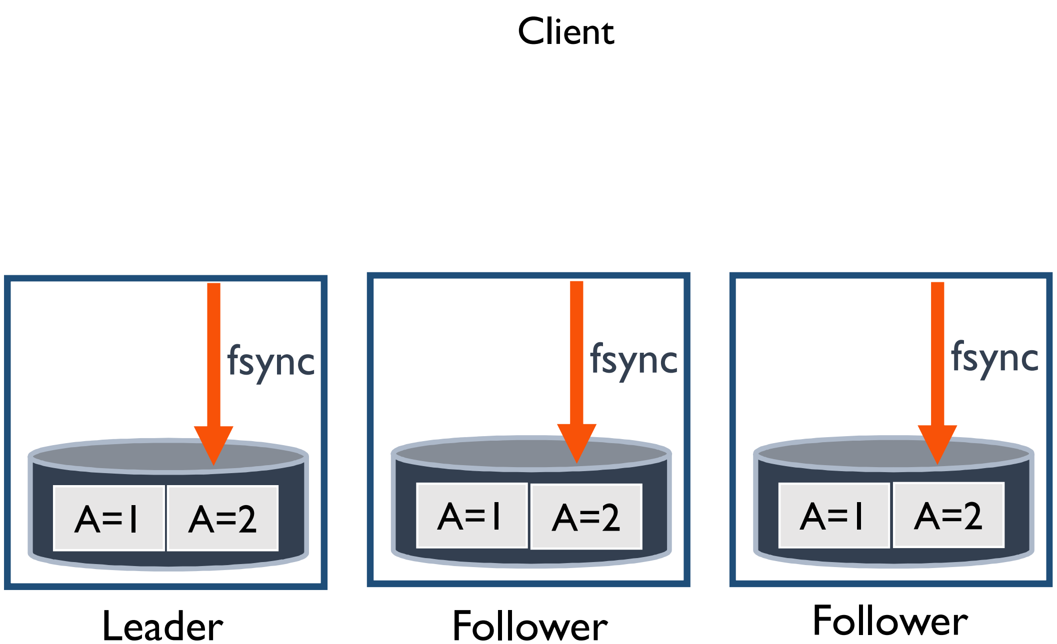

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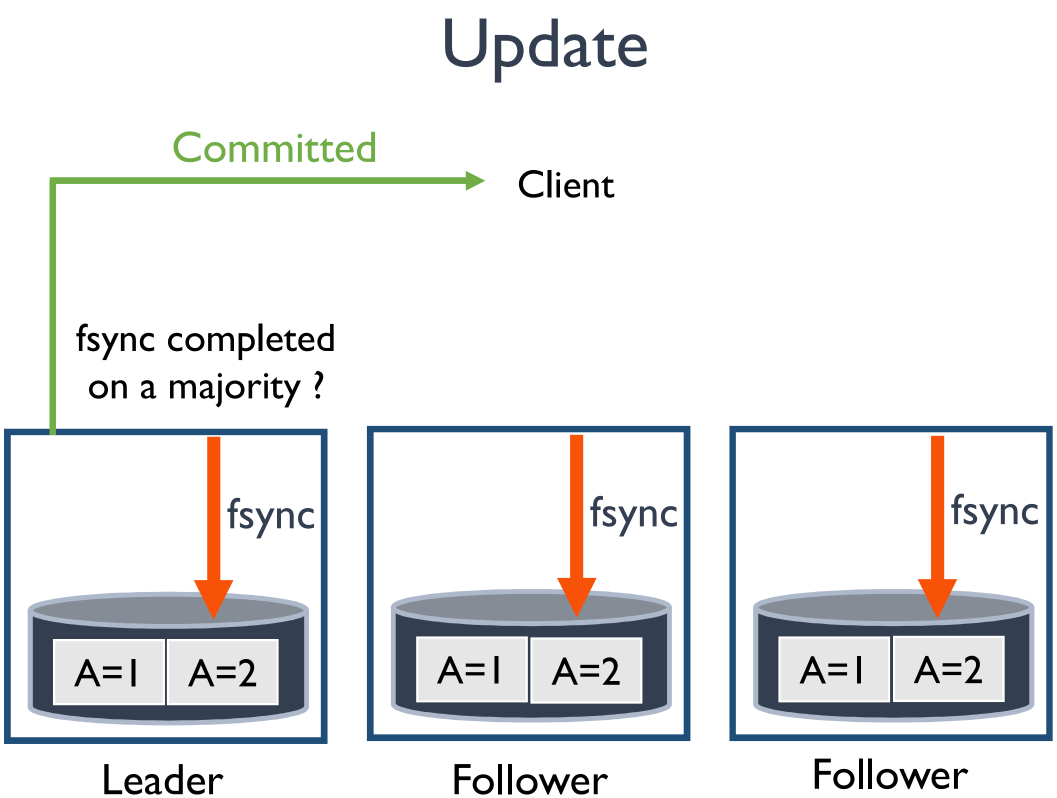

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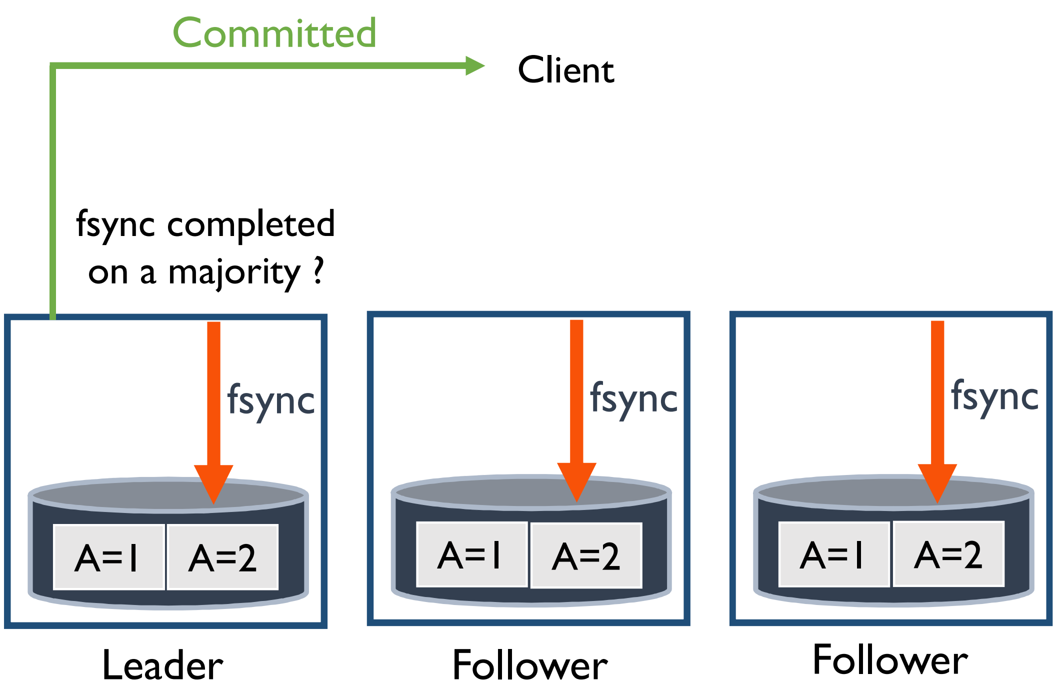

Recovery

Disk-Durable Protocols

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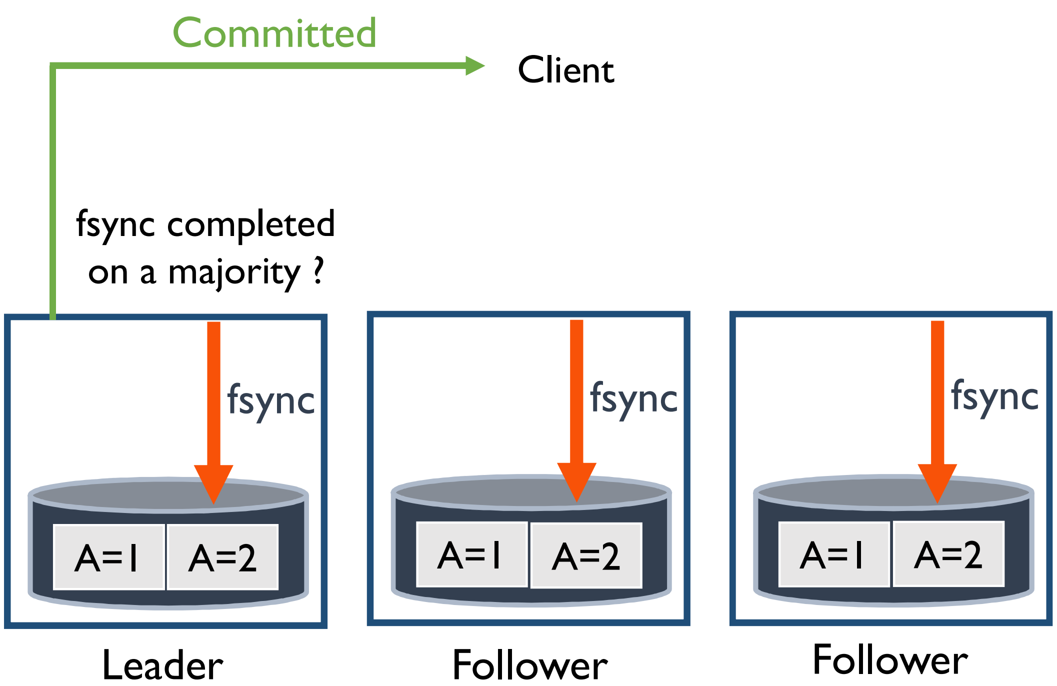

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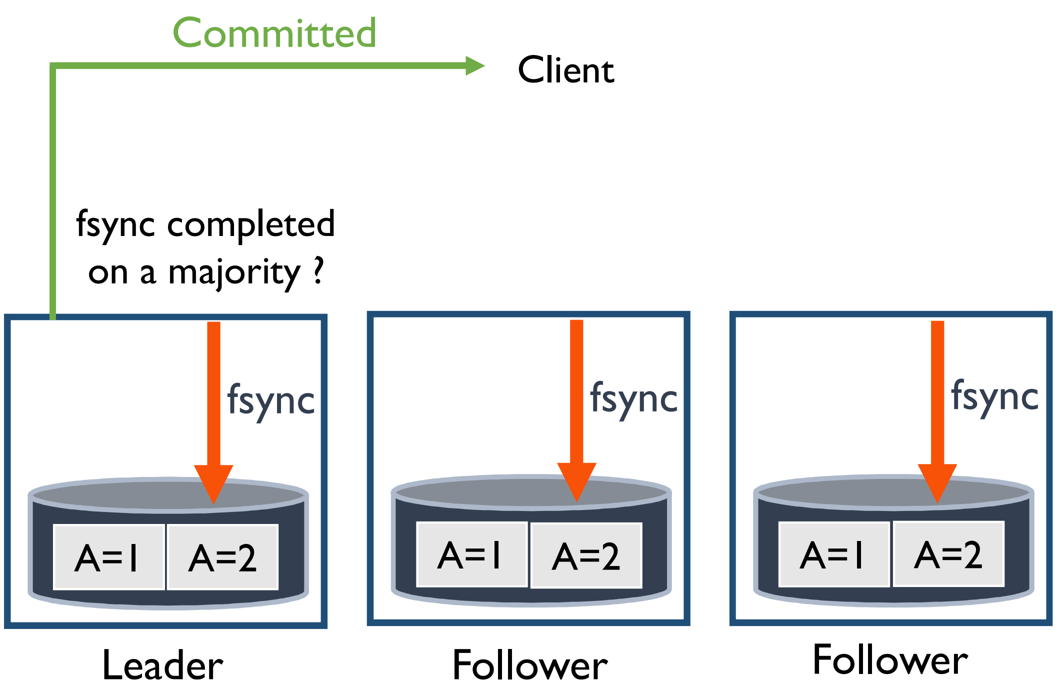

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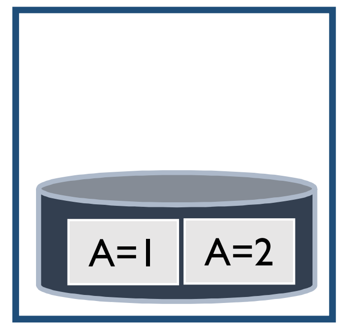

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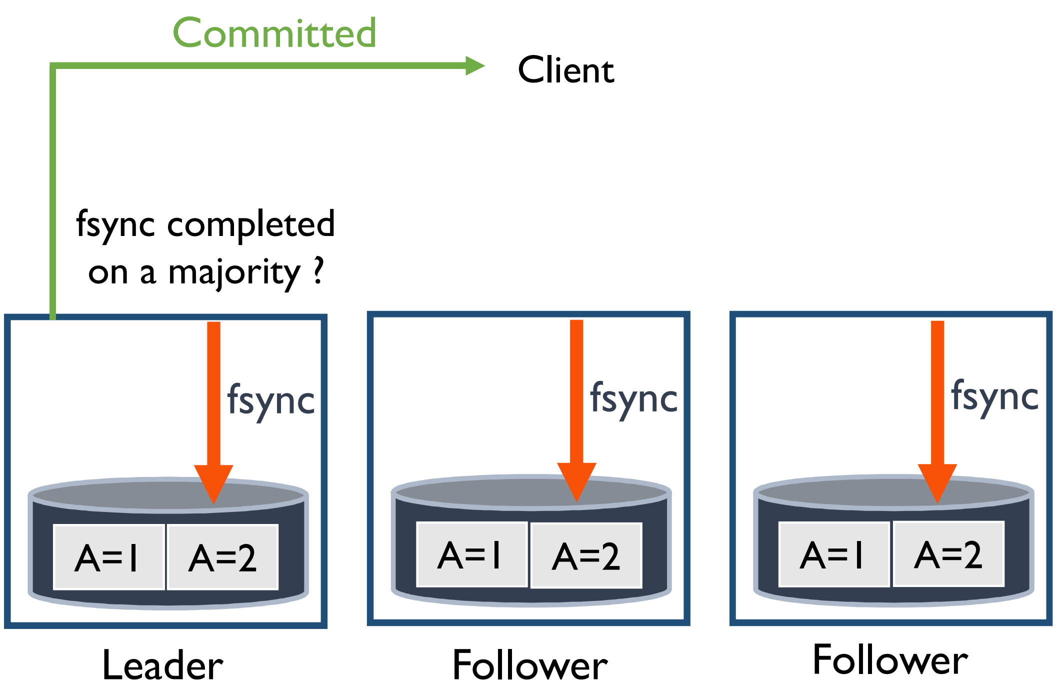

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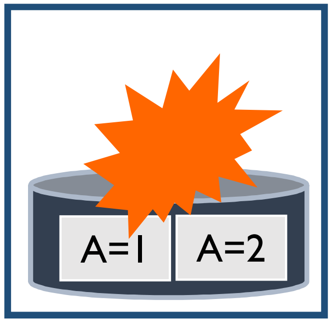

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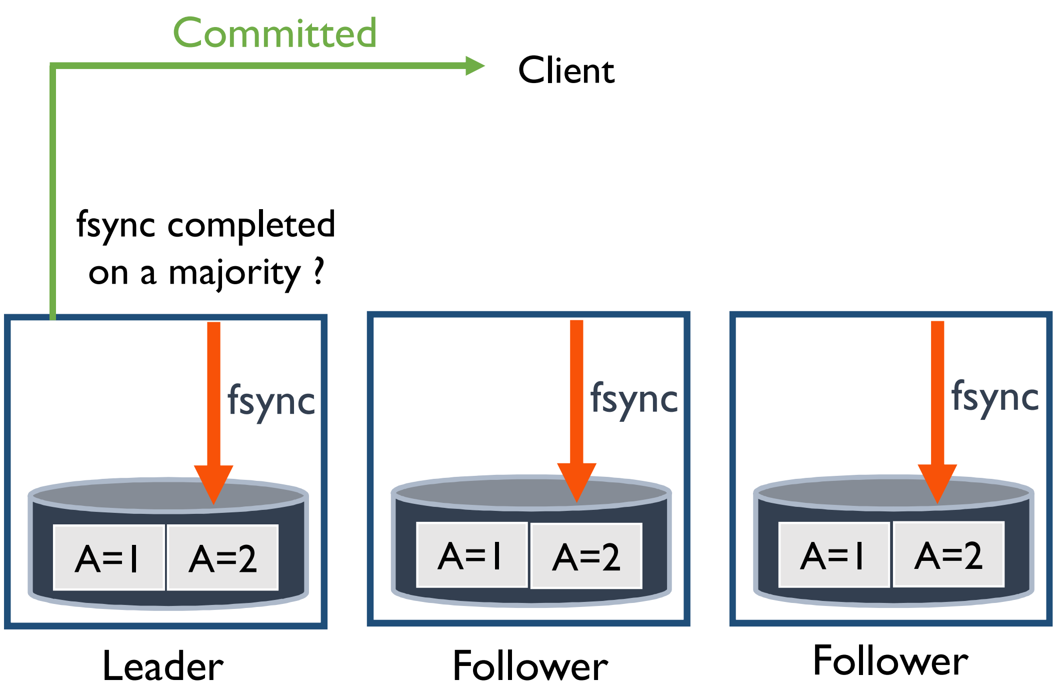

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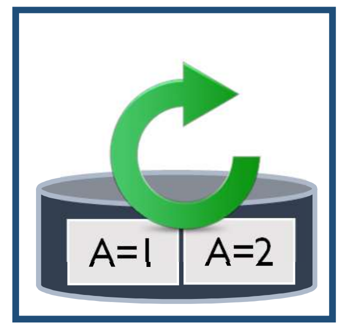

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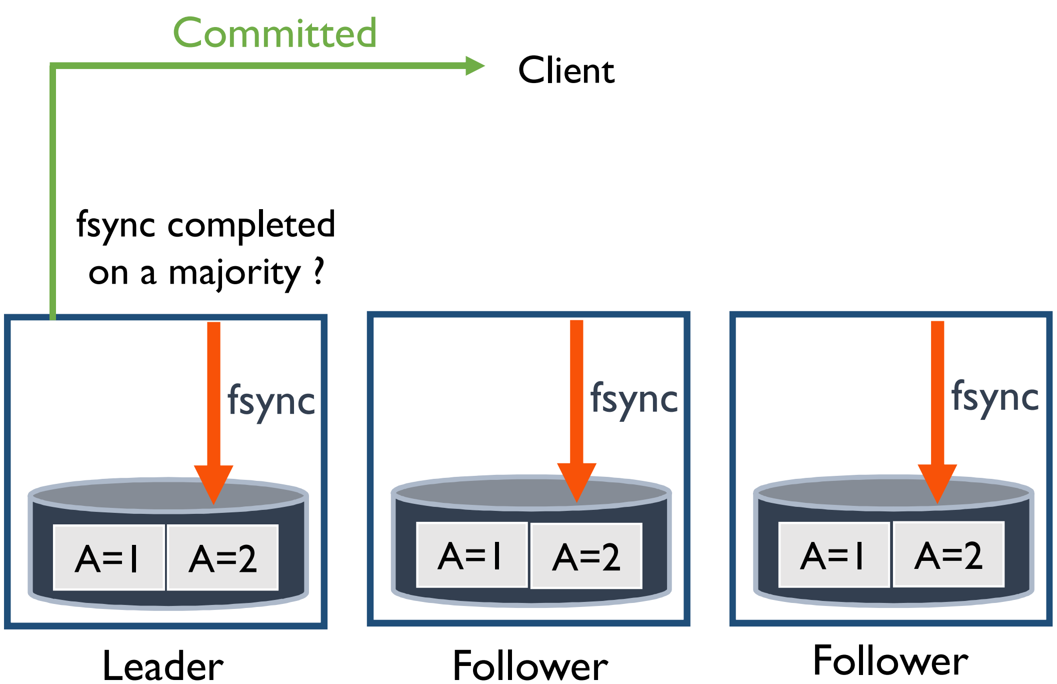

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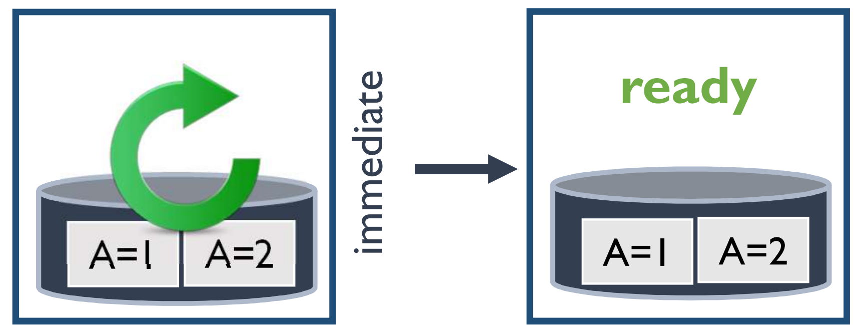

recovery: just read from local disk

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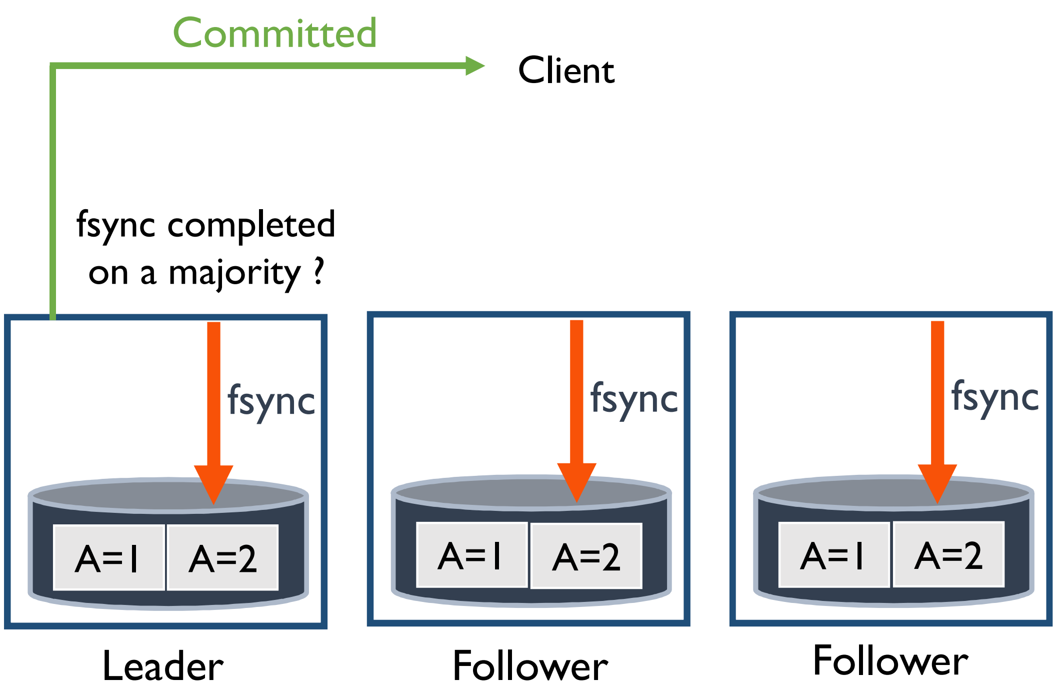

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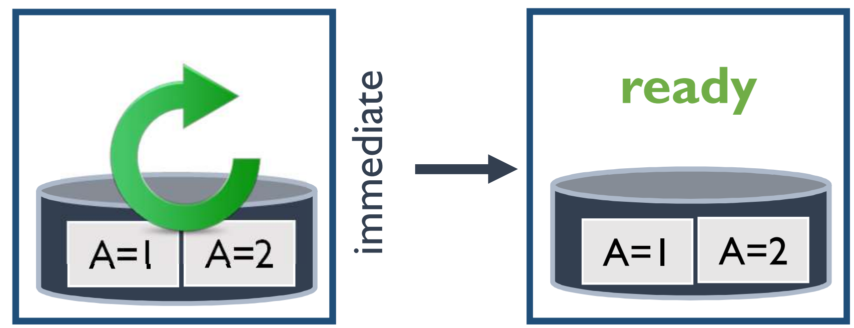

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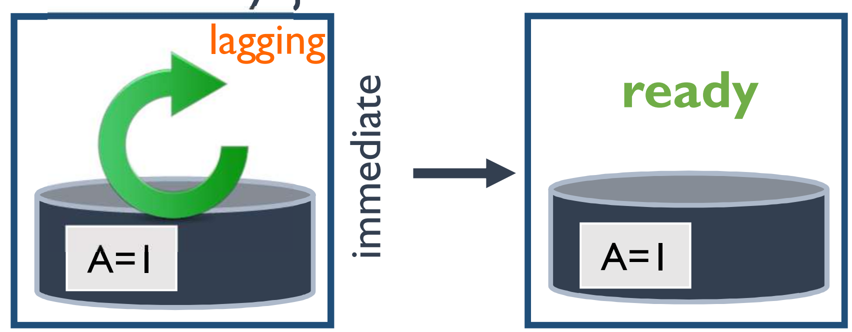

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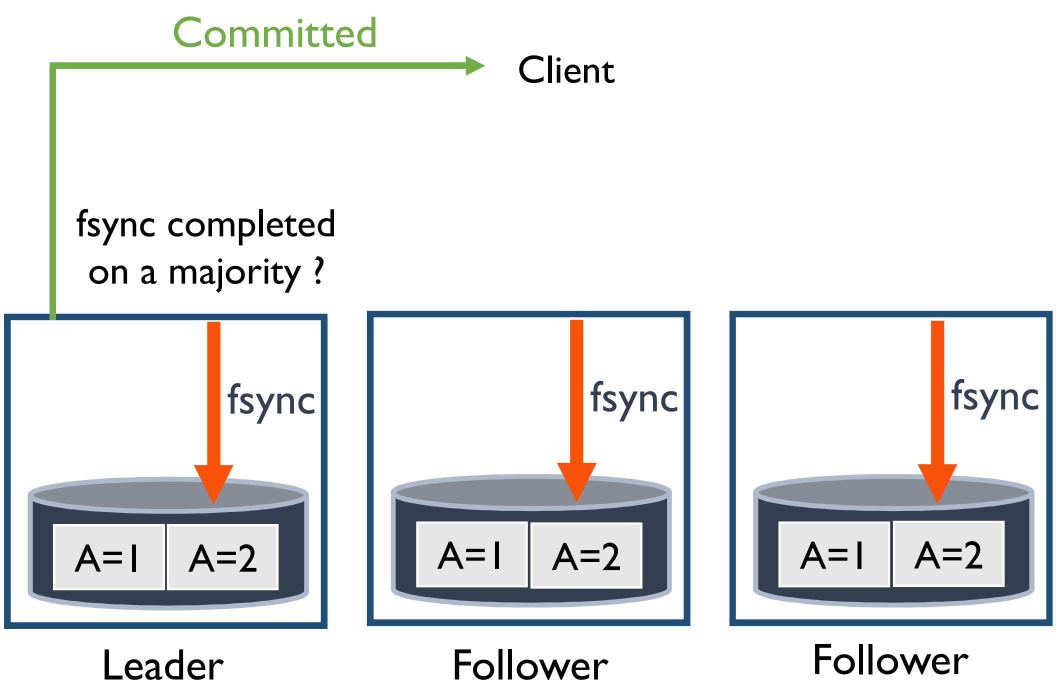

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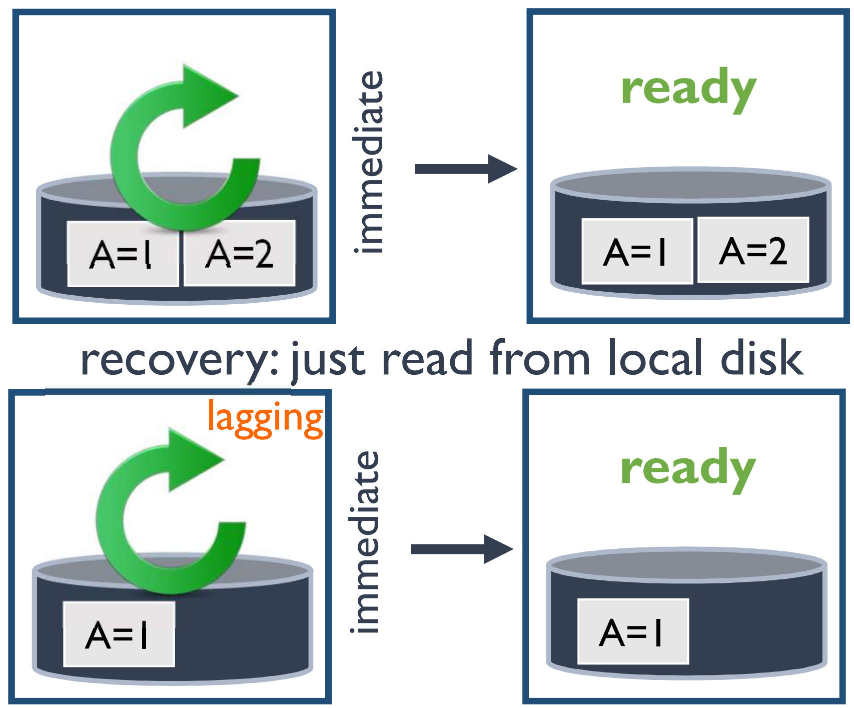

Safe and available

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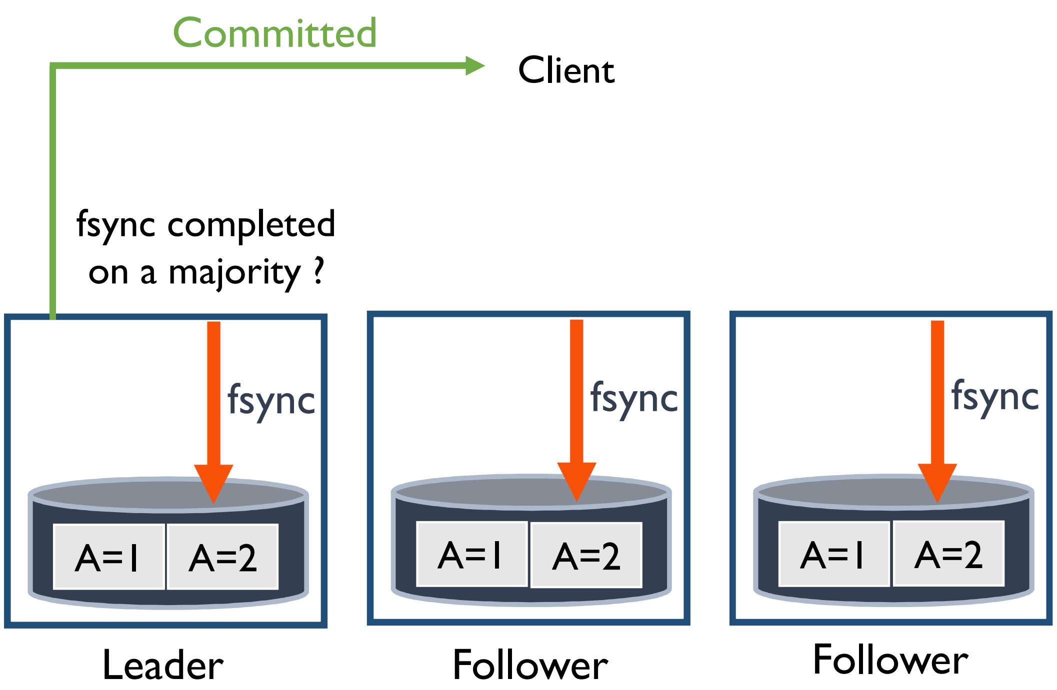

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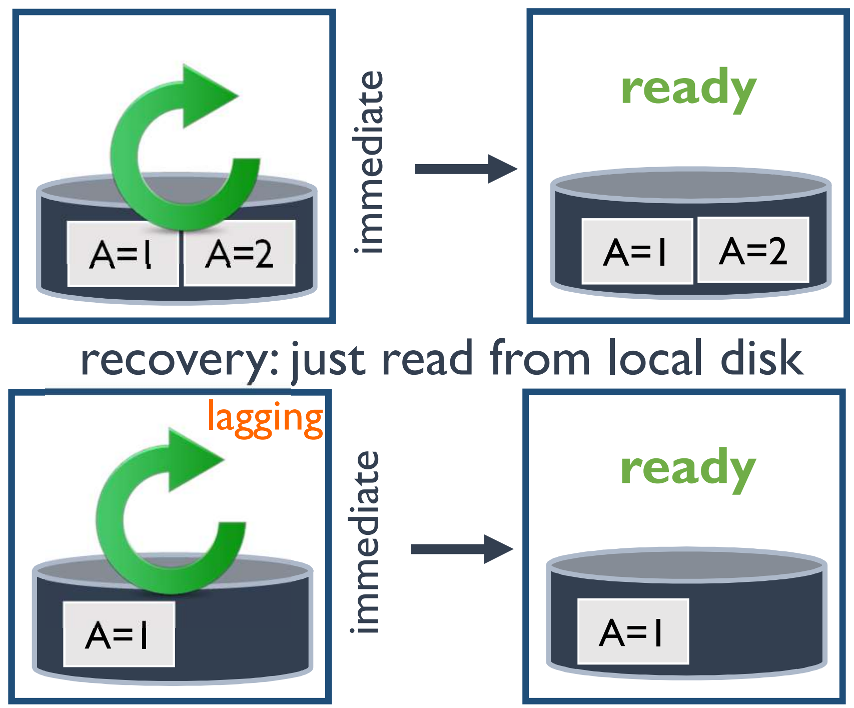

Safe and available

But poor performance due to fsync – 50x on HDDs, 2.5x on SSDs

Memory-Durable Protocols (Oblivious Recovery)

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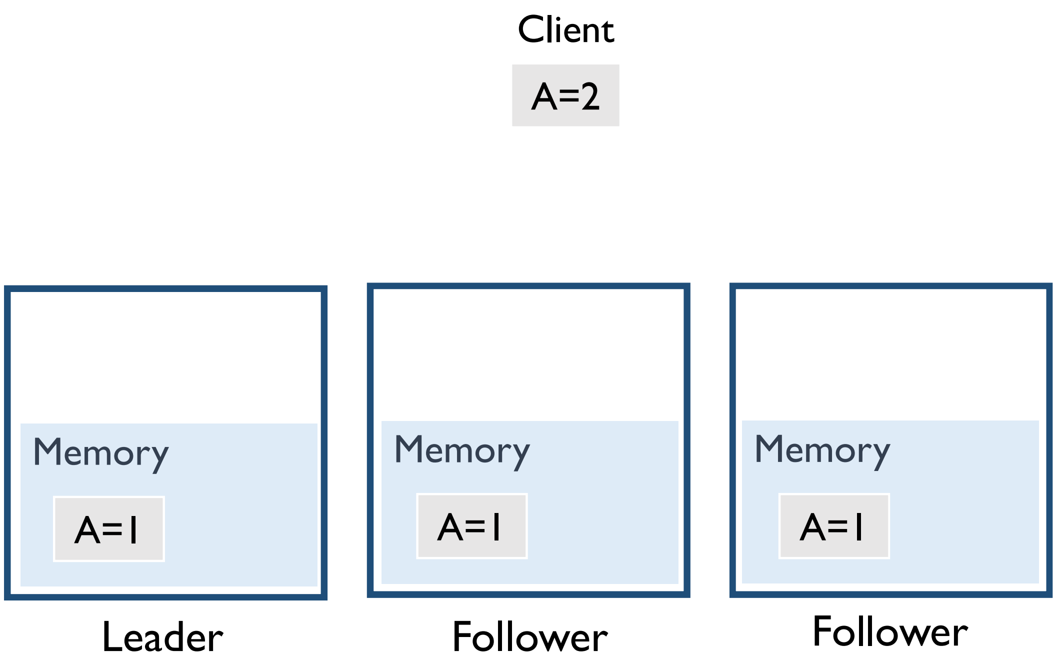

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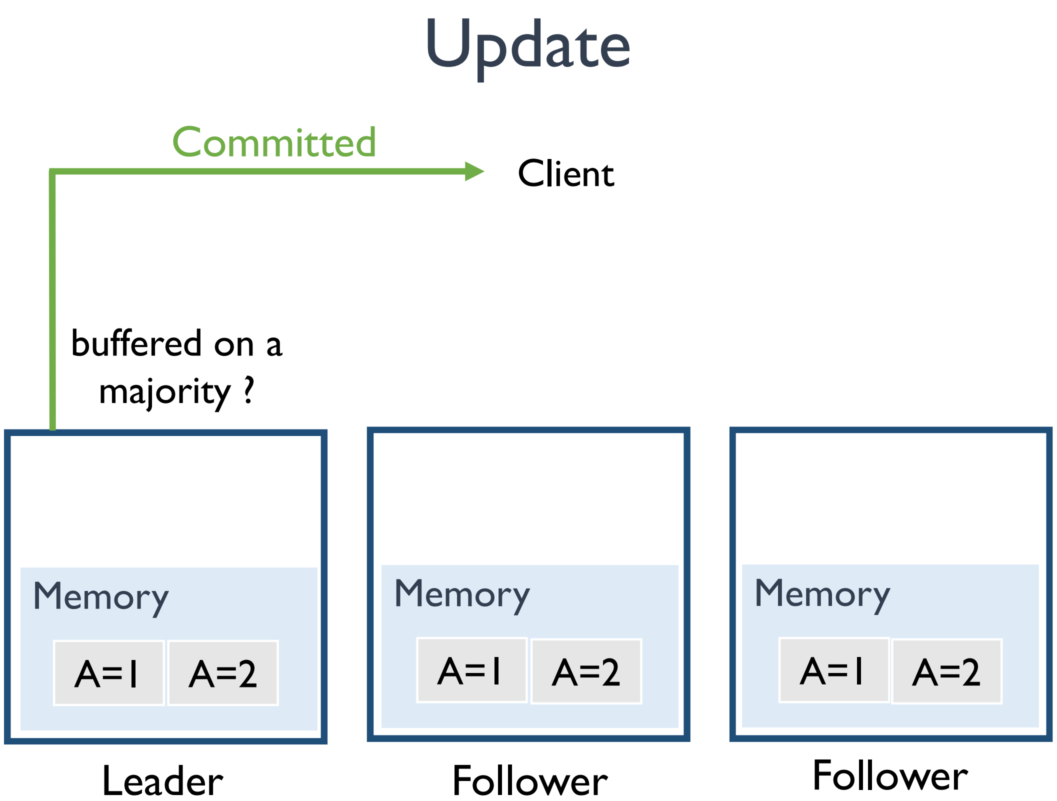

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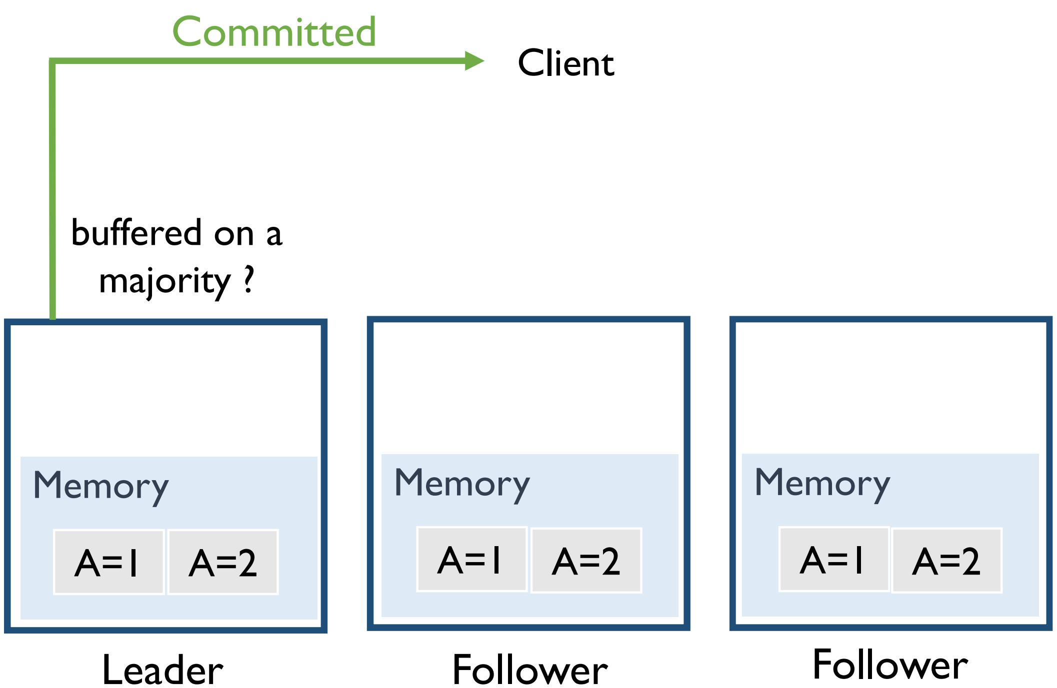

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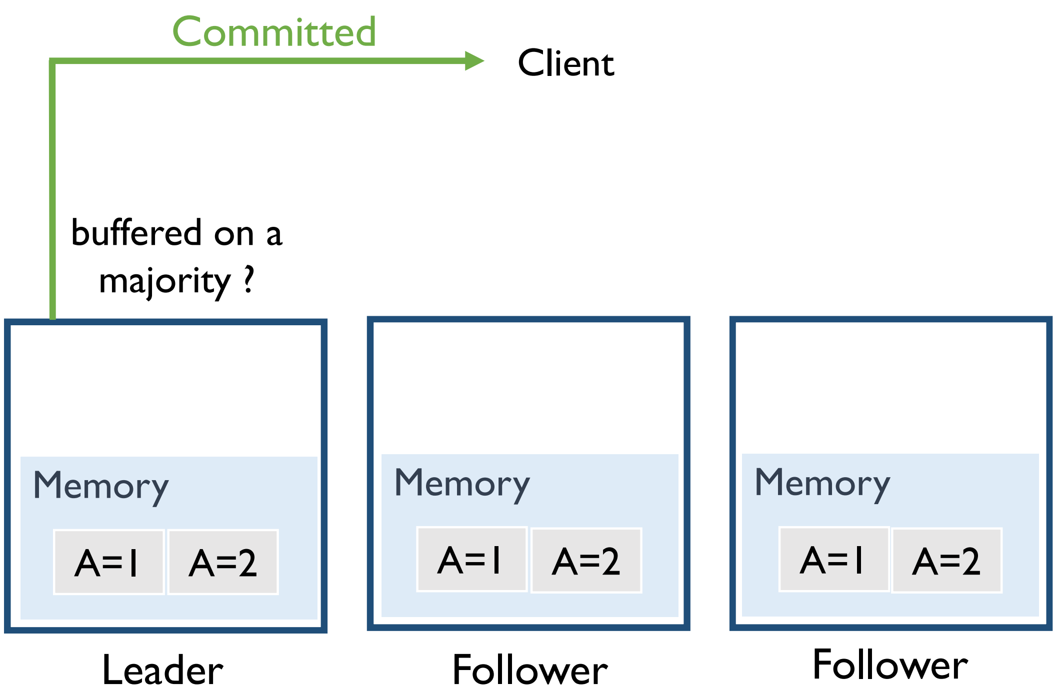

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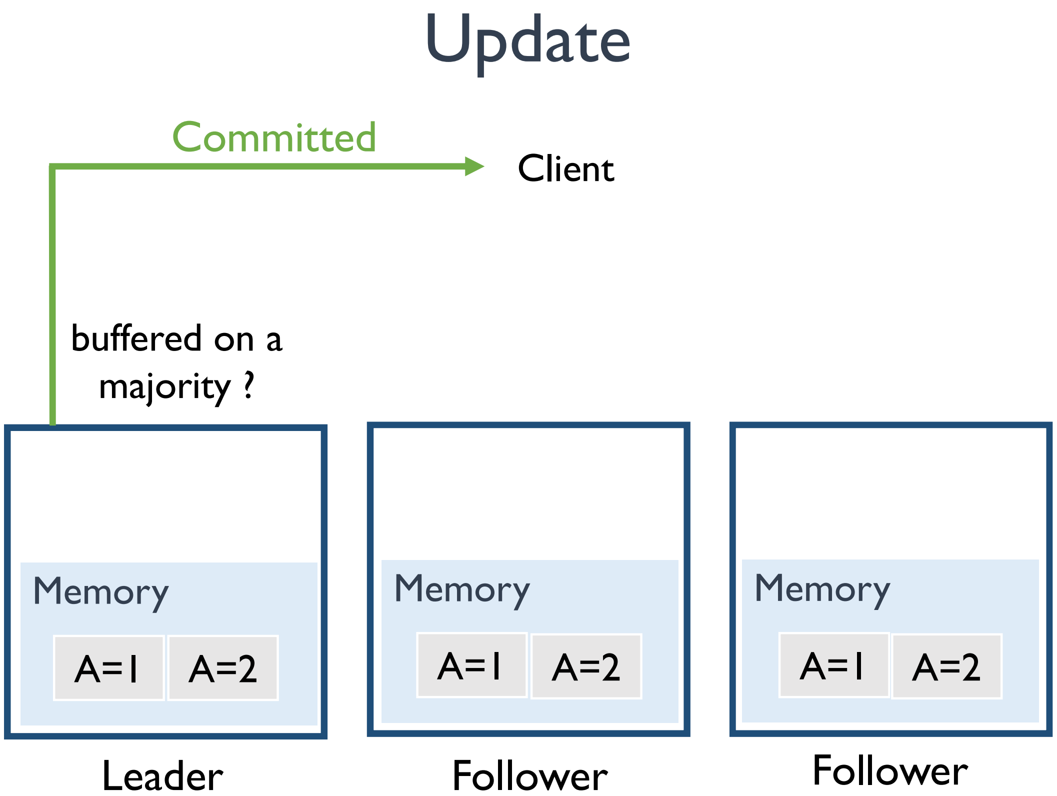

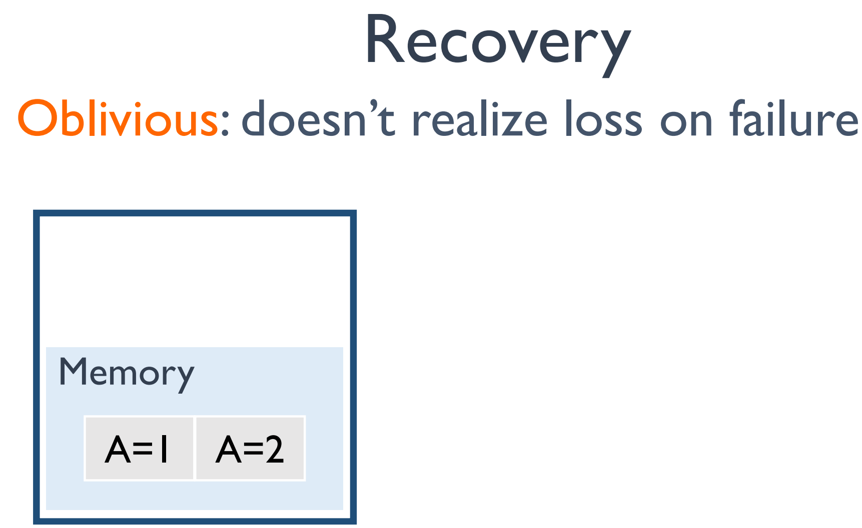

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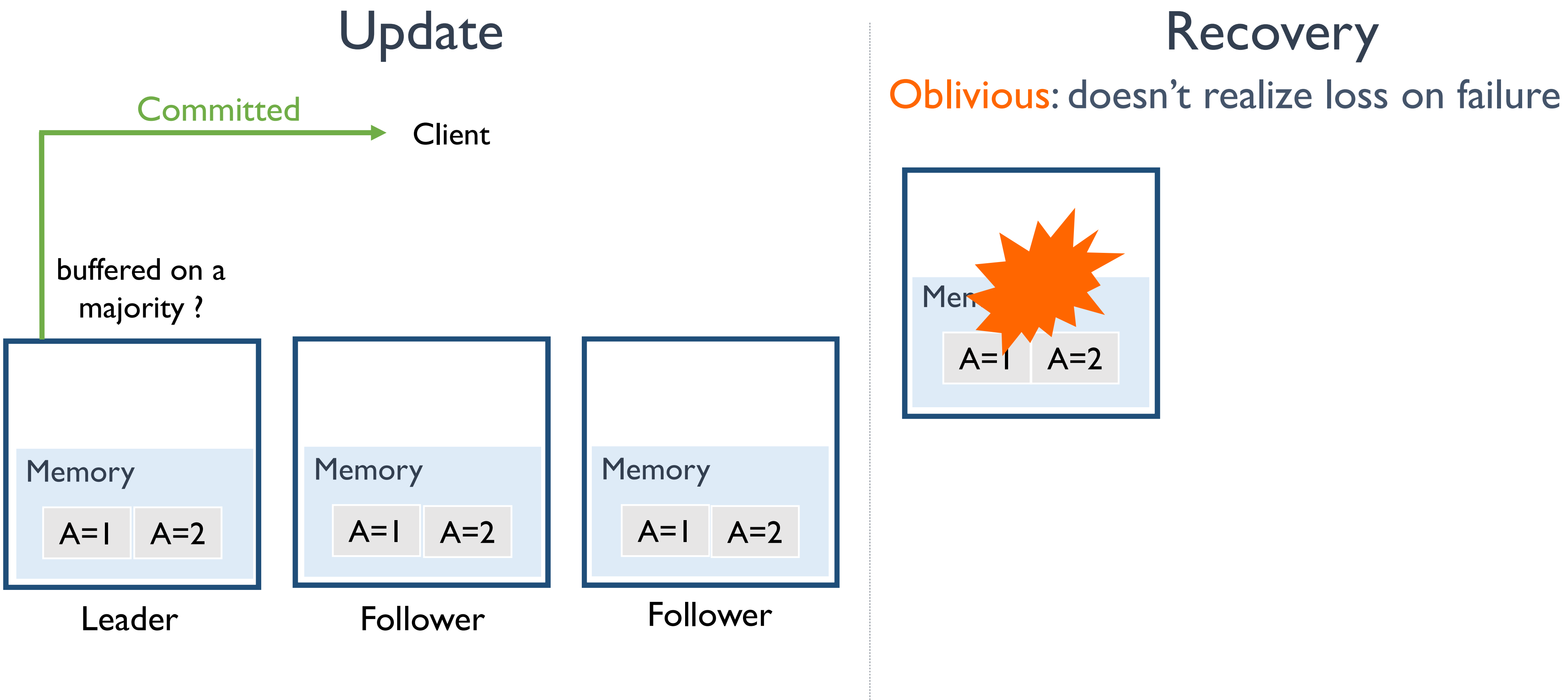

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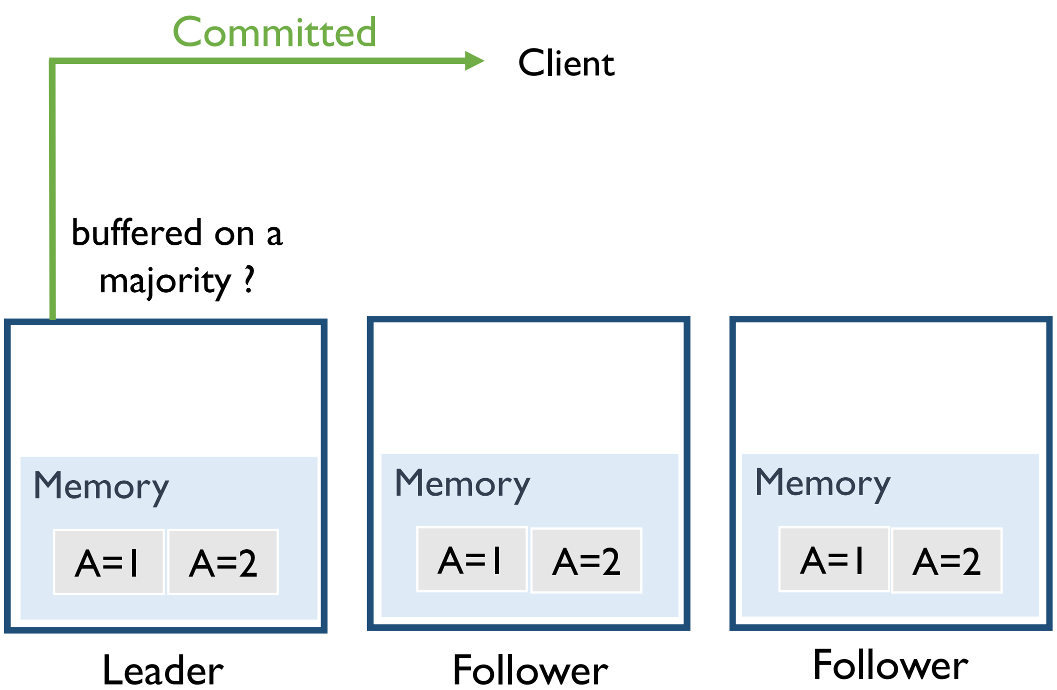

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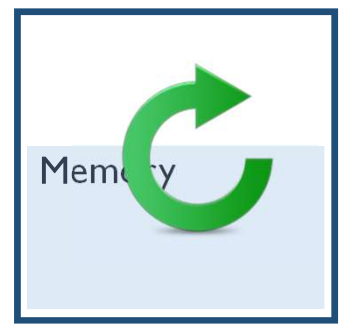

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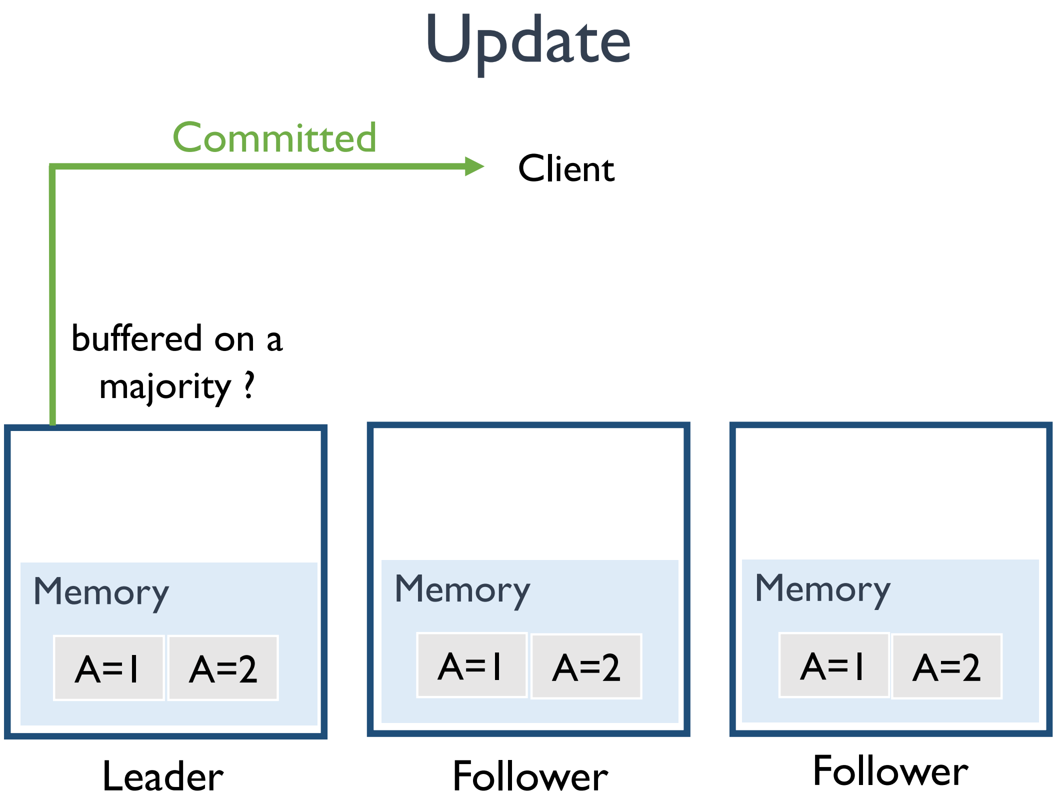

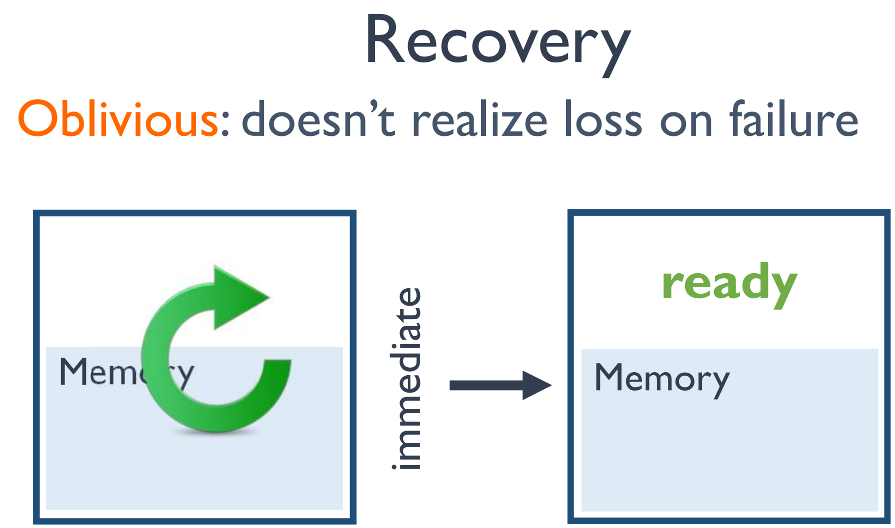

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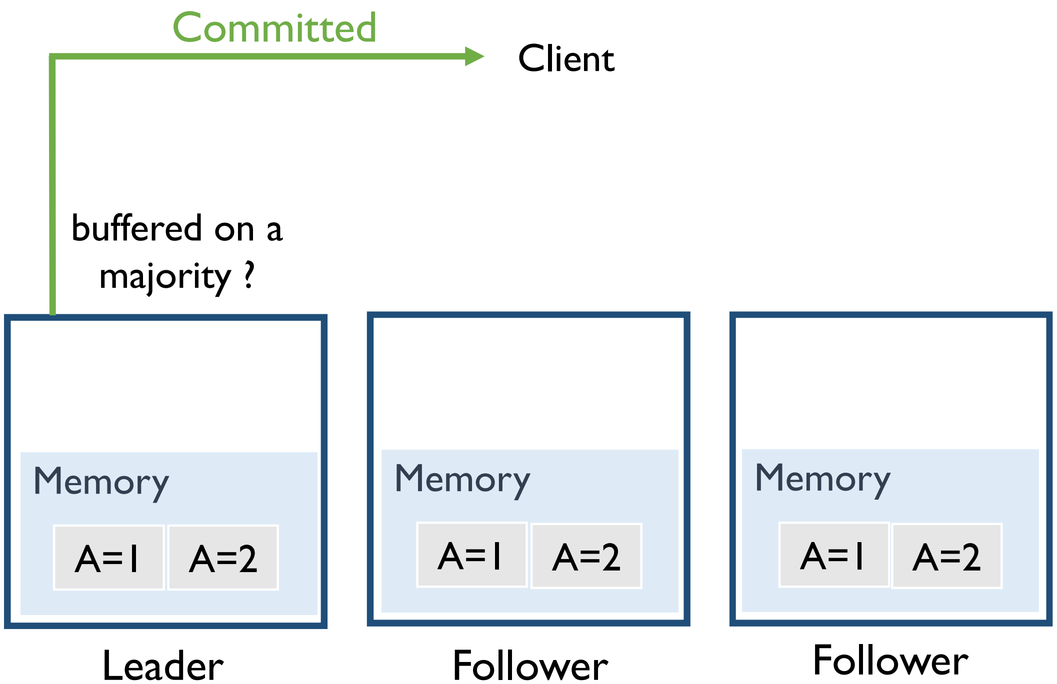

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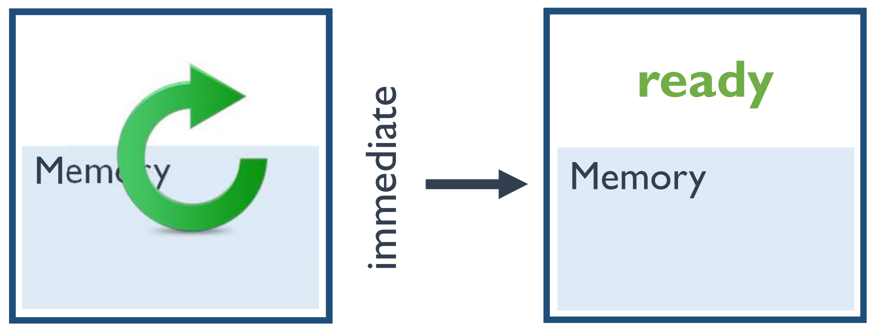

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practitioners do use this config!

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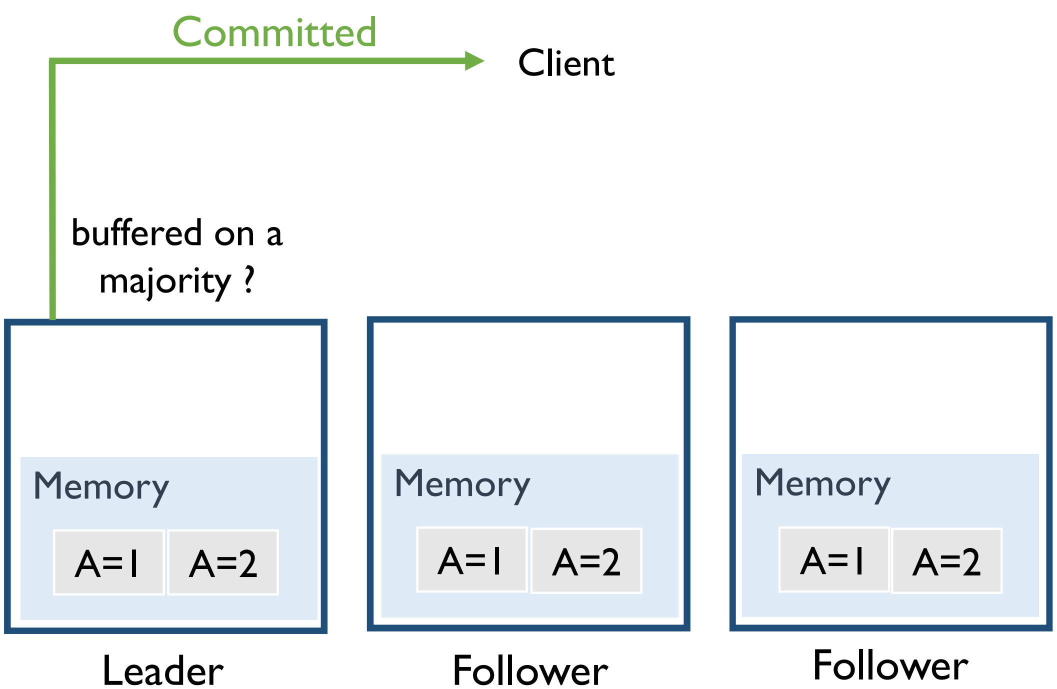

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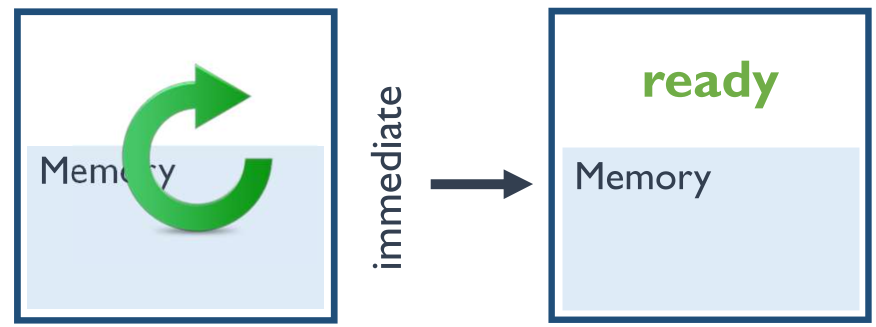

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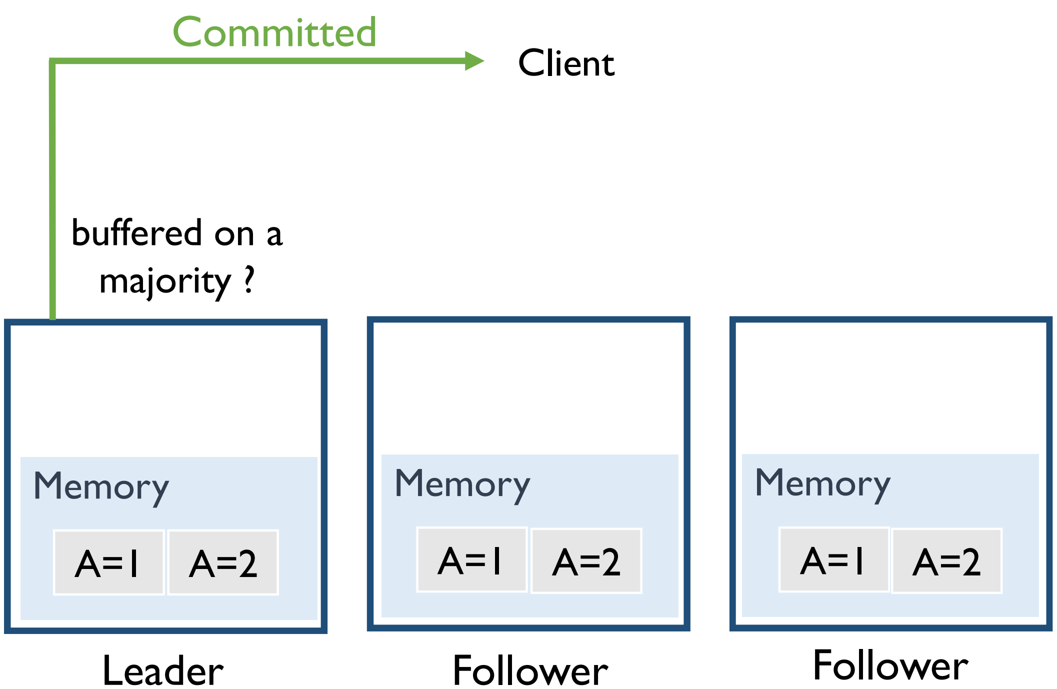

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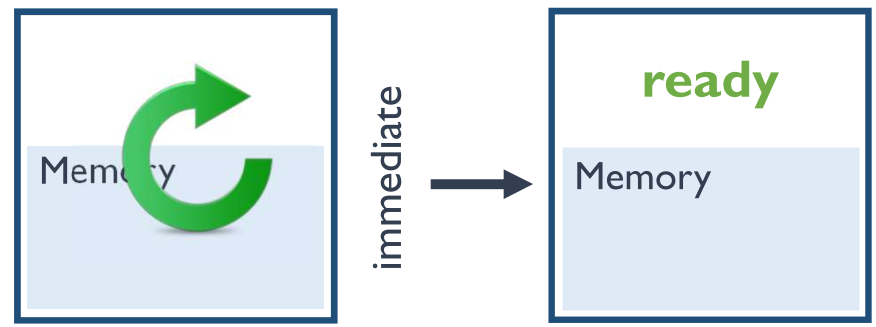

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Data Loss Example in Oblivious Approach

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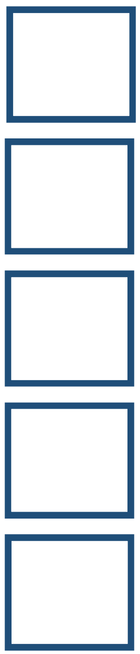

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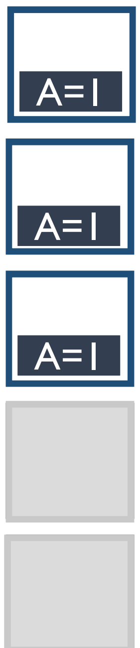

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two nodes slow or failed

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Data Loss Example in Oblivious Approach

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crashes

Data Loss Example in Oblivious Approach

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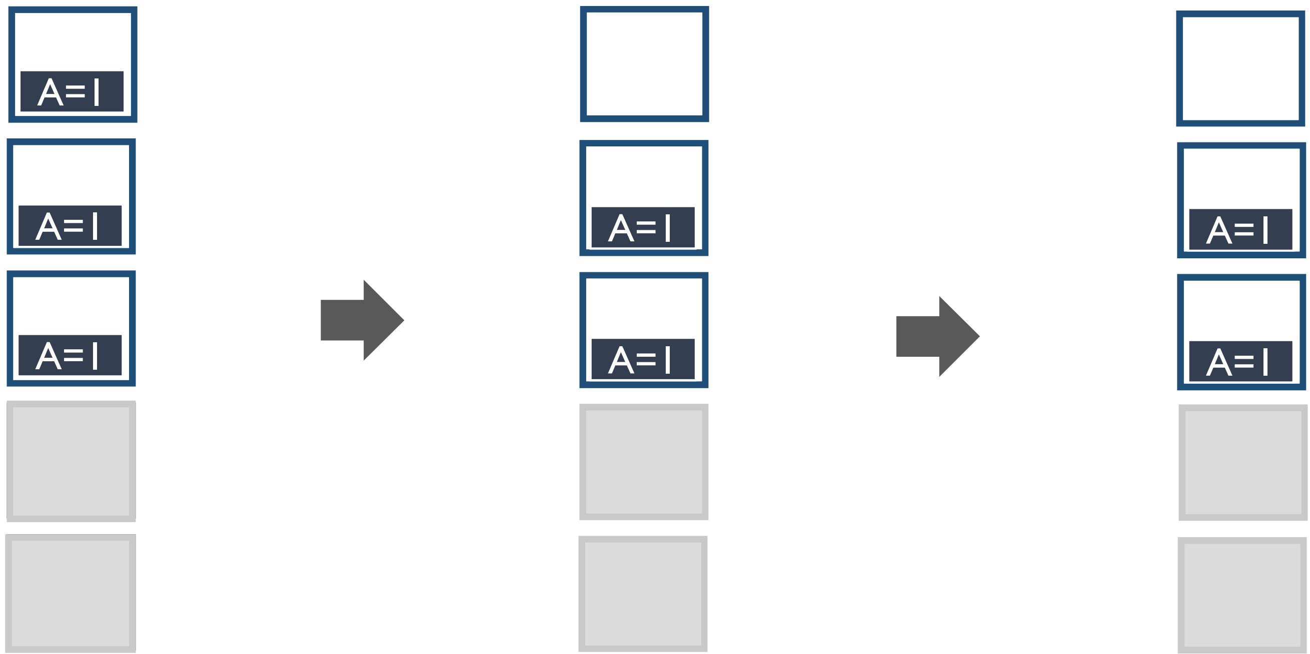

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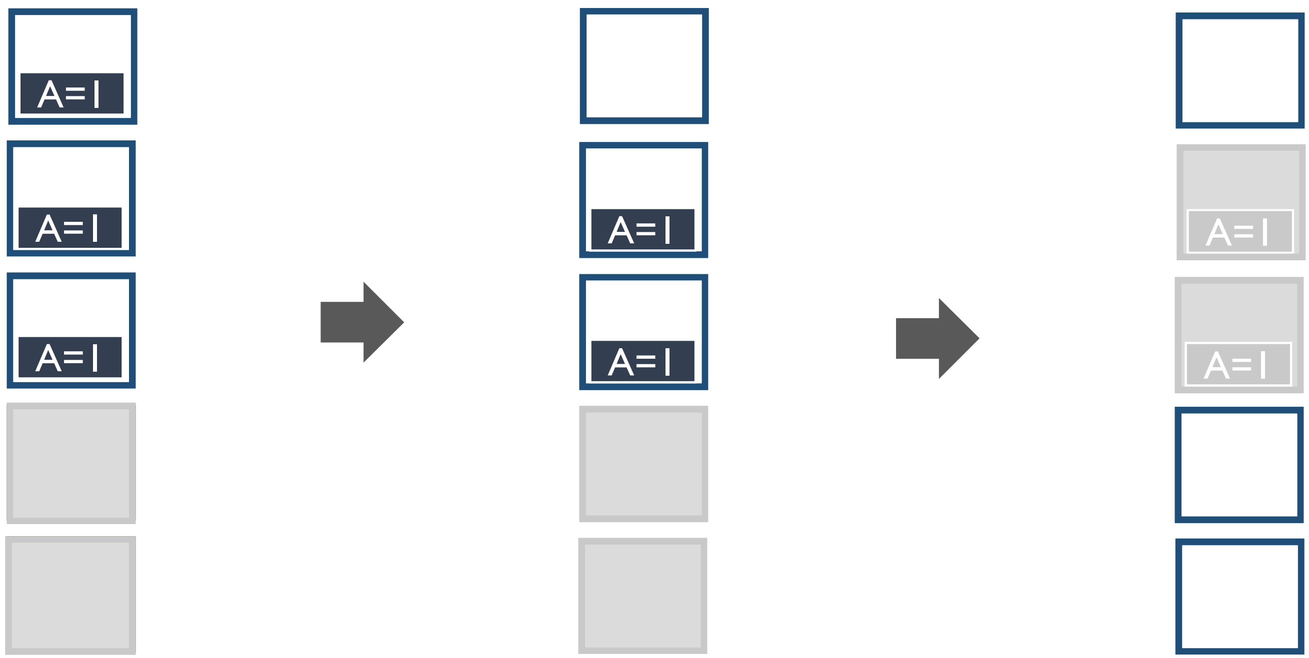

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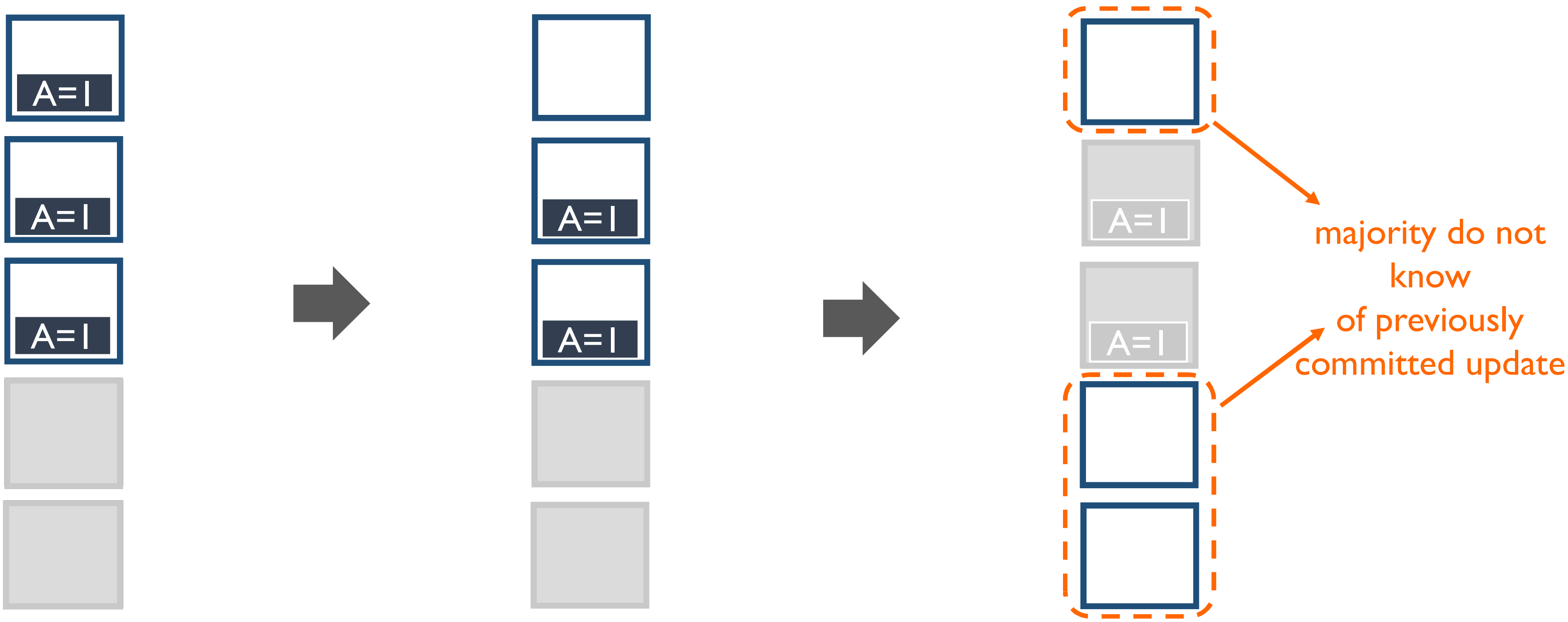

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lagging nodes along with recovered node form majority;
lose committed update

Memory-Durable Protocols (Loss-Aware Recovery)

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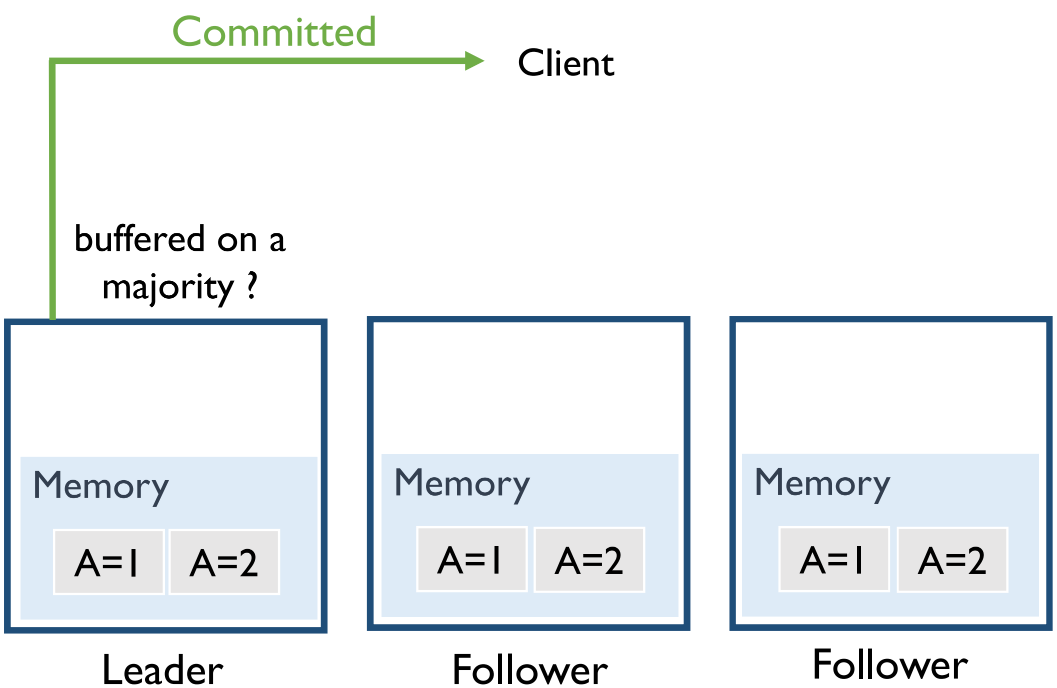

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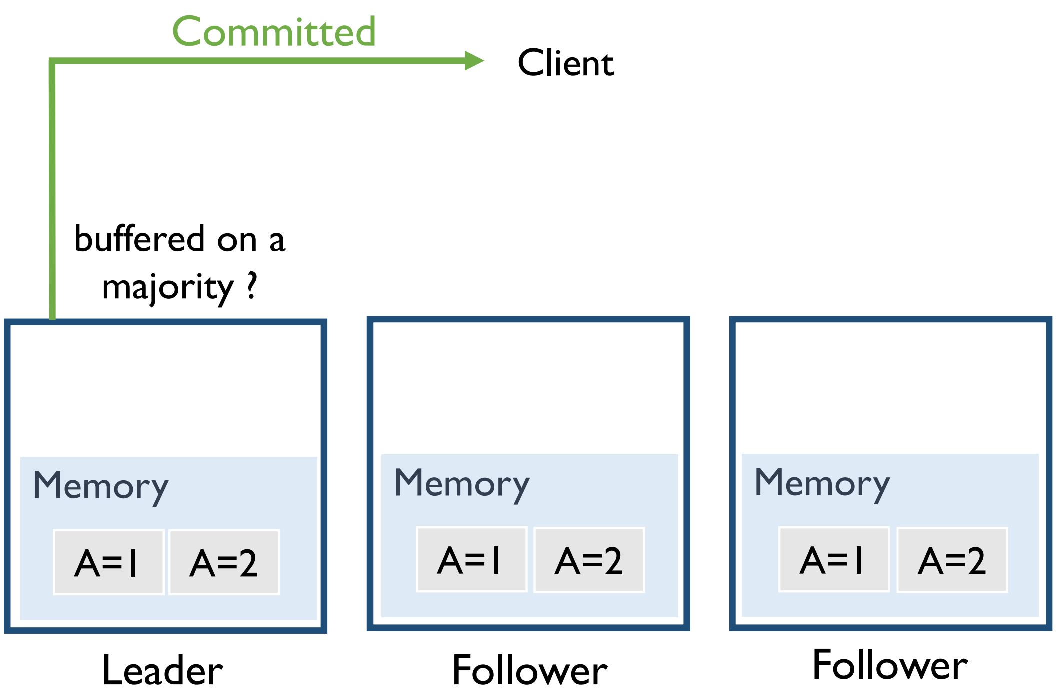

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Memory-Durable Protocols (Loss-Aware Recovery)

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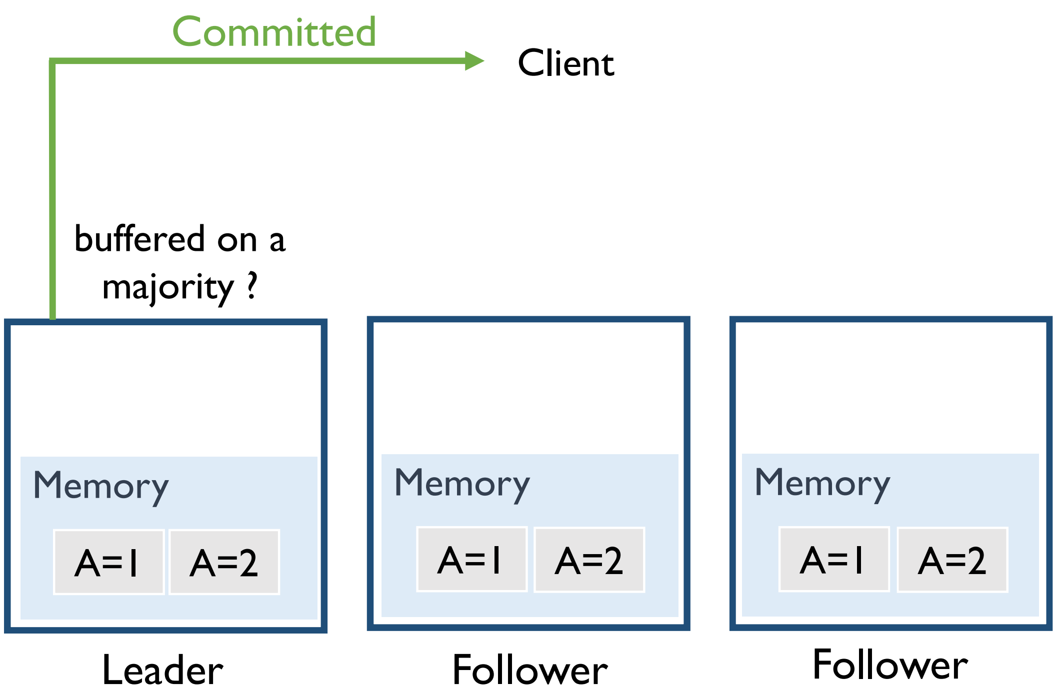

Recovery

Loss-aware: realizes loss, waits for majority

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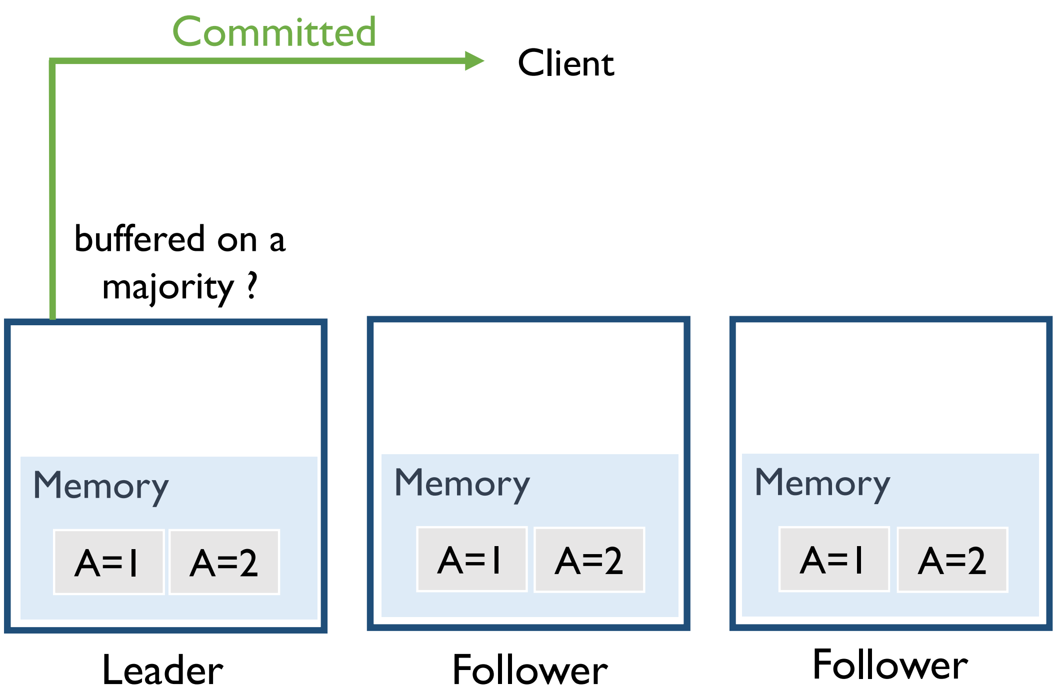

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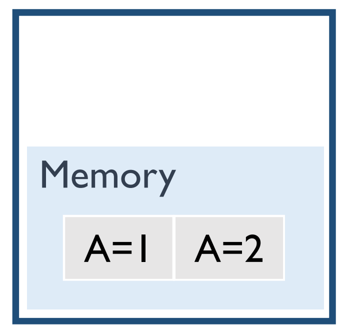

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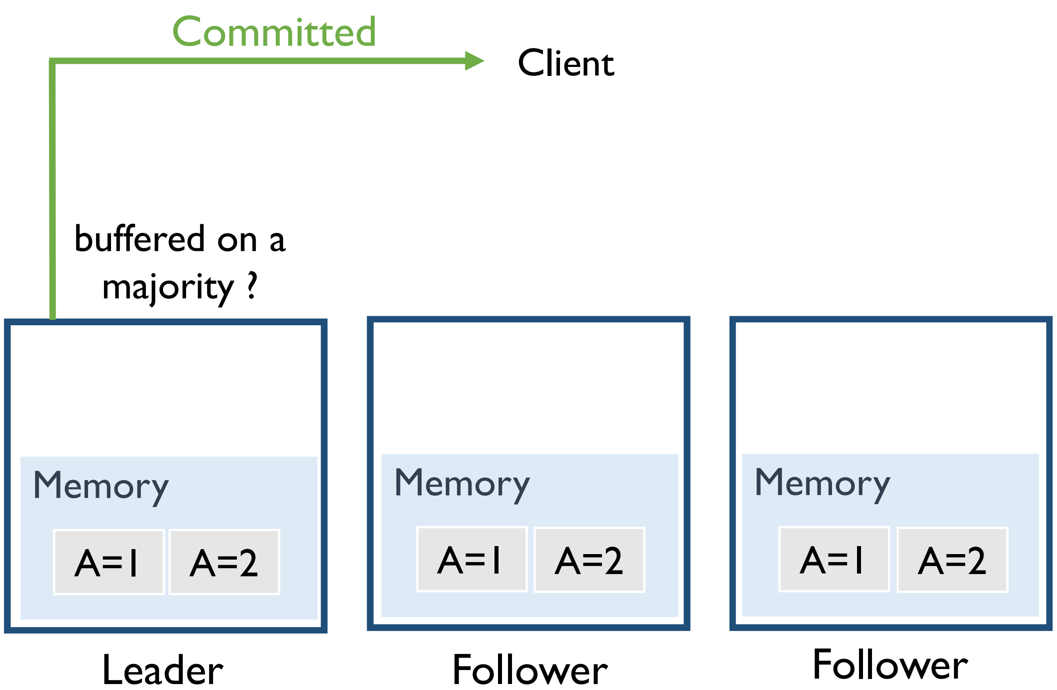

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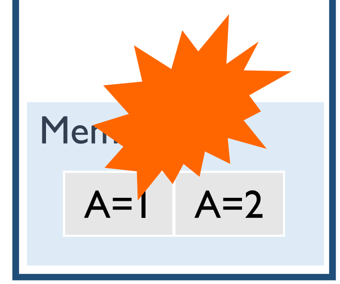

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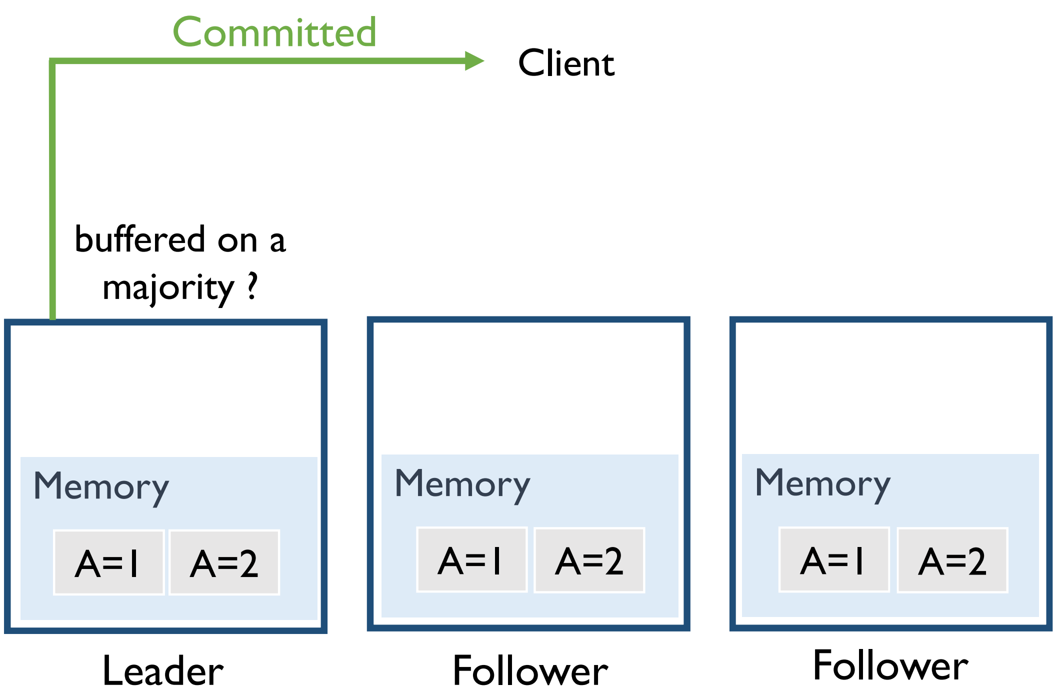

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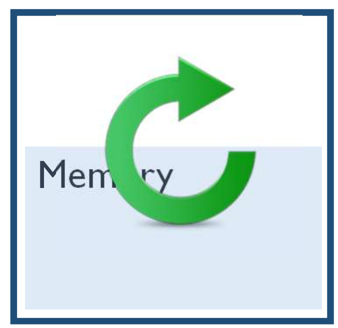

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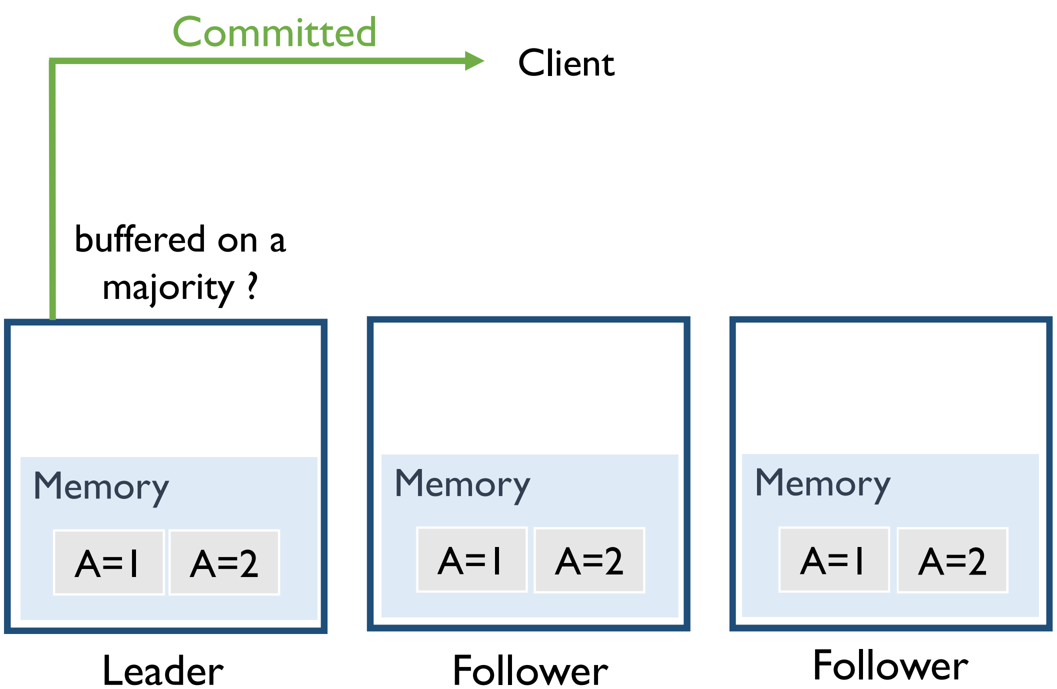

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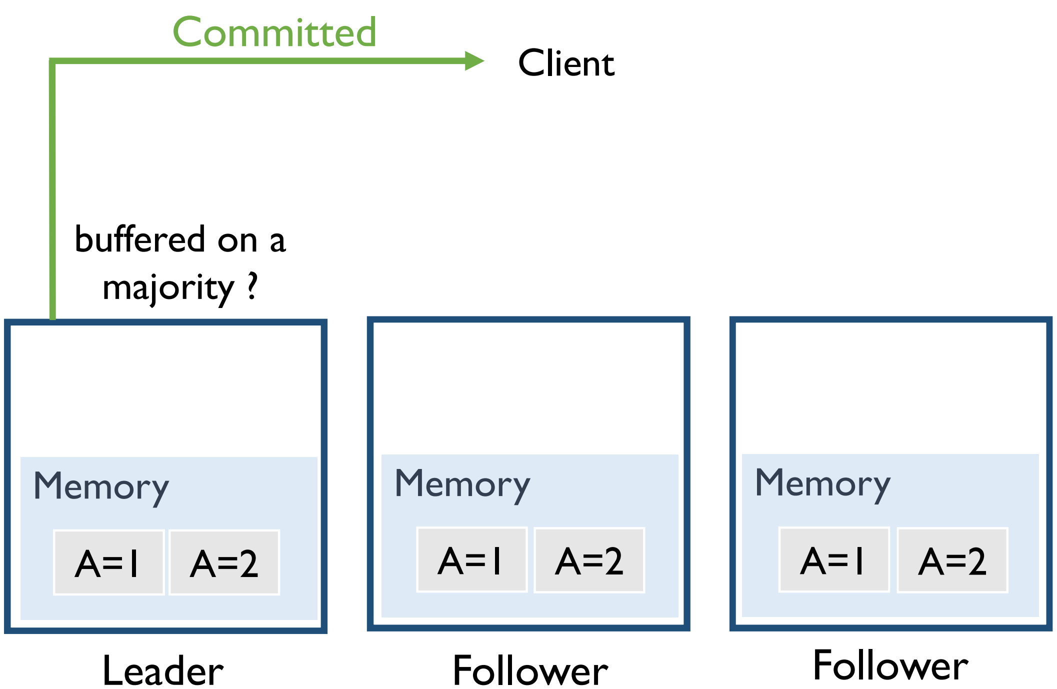

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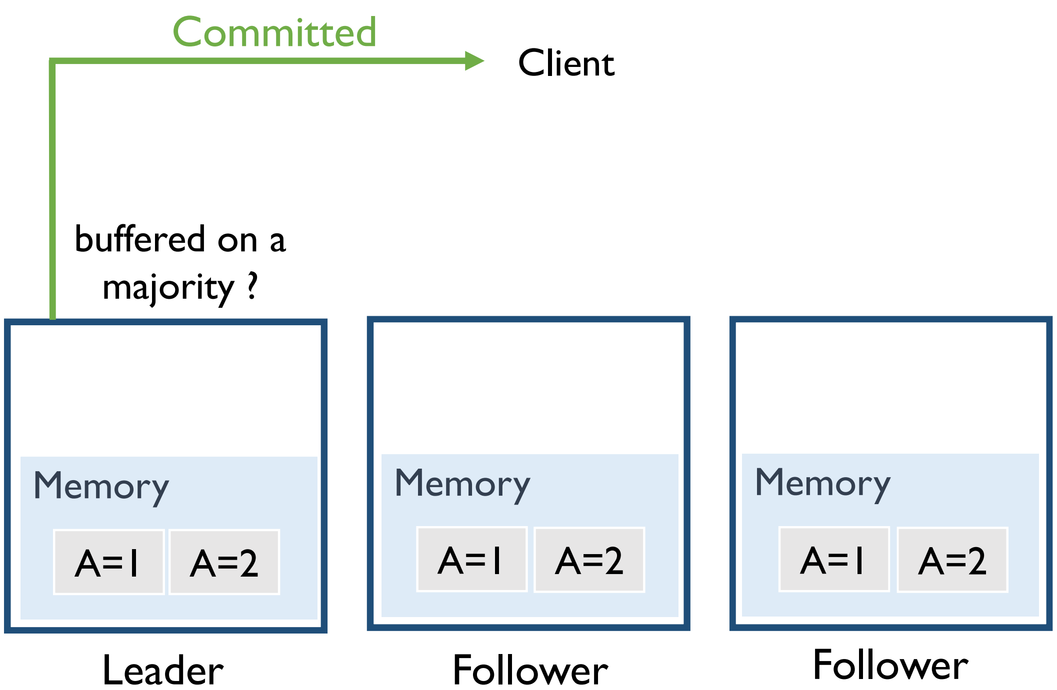

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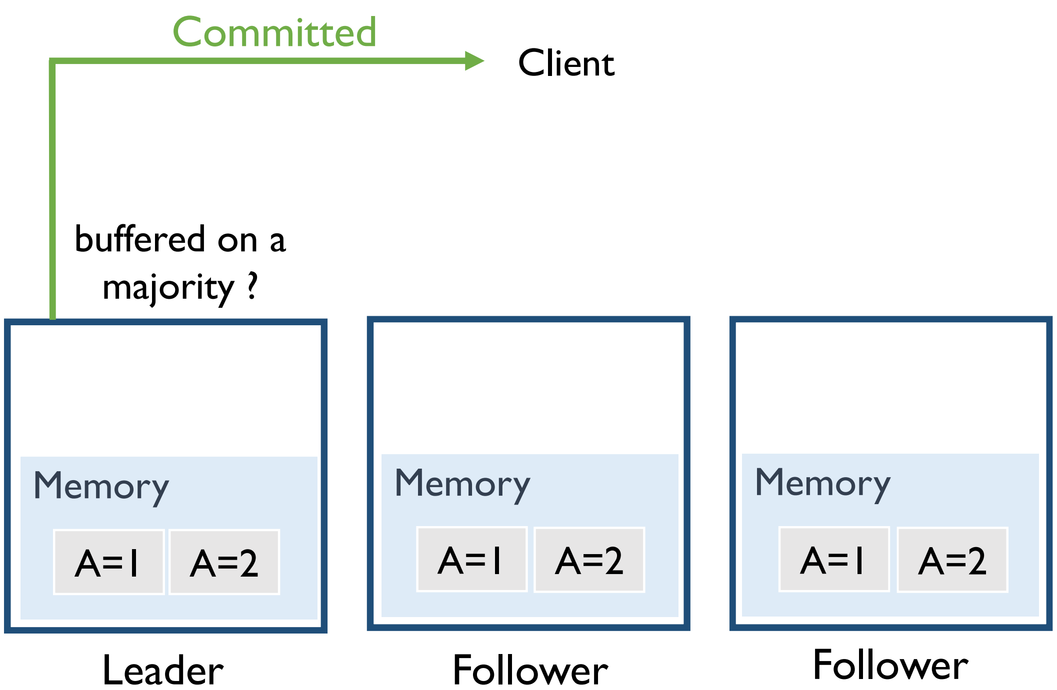

Recovery

Loss-aware: realizes loss, waits for majority

e.g., Viewstamped replication

Avoids loss (unlike oblivious) but can lead to unavailability

Unavailability Example in Loss-Aware Approach

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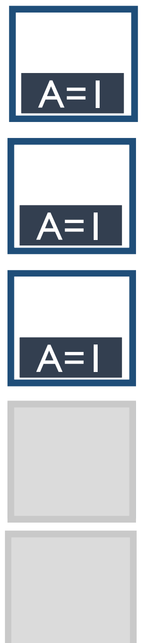

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two nodes crashed

Unavailability Example in Loss-Aware Approach

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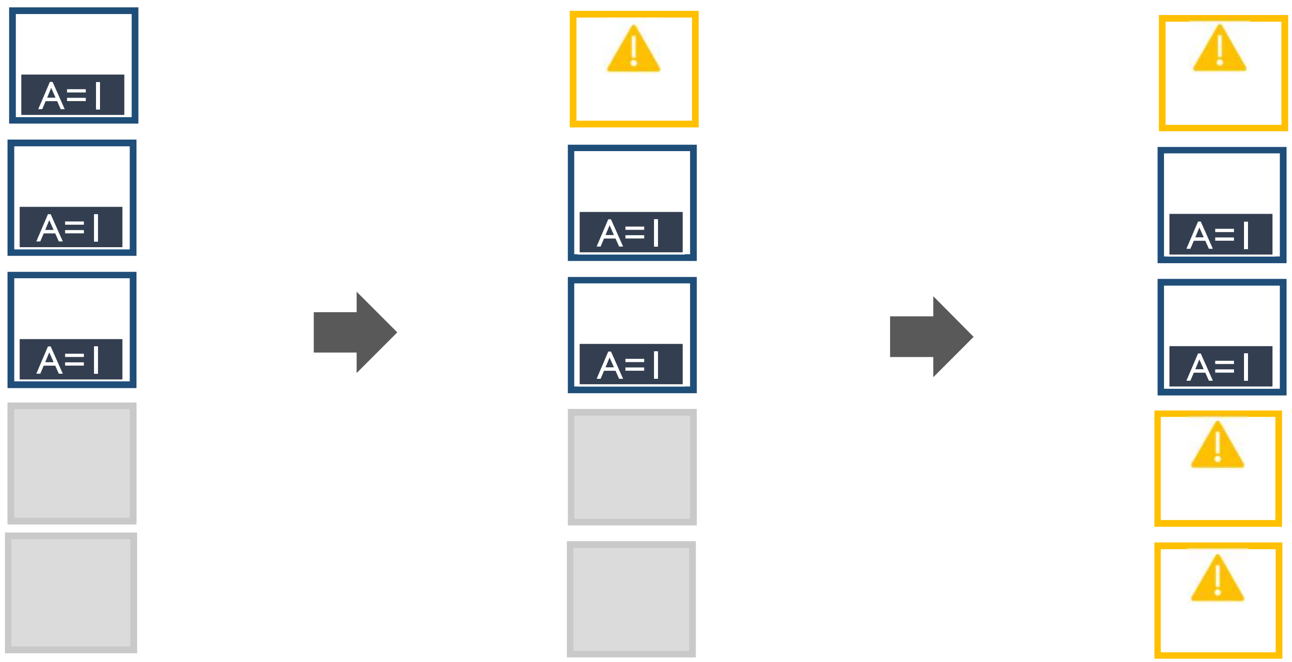

A=1 committed
two nodes crashed

crashes, recovers
cannot collect
majority responses
although majority up – unavailable

failed nodes recover
stay in recovering
unavailable even after
all nodes recover

Outline

Introduction

Distributed updates and crash recovery

Situation-aware updates and crash recovery

- SAUCR insights, guarantees, and overview
- situation-aware updates
- situation-aware crash recovery

Results

Summary and conclusion

SAUCR Intuition and Insight

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Existing protocols are static in nature: do not adapt to failures

SAUCR Intuition and Insight

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buffer even with many failures

poor reliability

SAUCR Intuition and Insight

Existing protocols are **static in nature**: do not adapt to failures

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Memory-durable	**Disk-durable**
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SAUCR Intuition and Insight

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Insight: reacting to failures and adapting to situation can achieve reliability and performance

SAUCR Intuition and Insight

Existing protocols are static in nature: do not adapt to failures

always	always	***common case*** when many or all up
Memory-durable	Disk-durable	Memory-durable
buffer even with many failures	persist even when no failures	buffer in memory
poor reliability	poor performance	

Insight: reacting to failures and adapting to situation can achieve reliability and performance

- ➡ when no or few failures could buffer in memory

SAUCR Intuition and Insight

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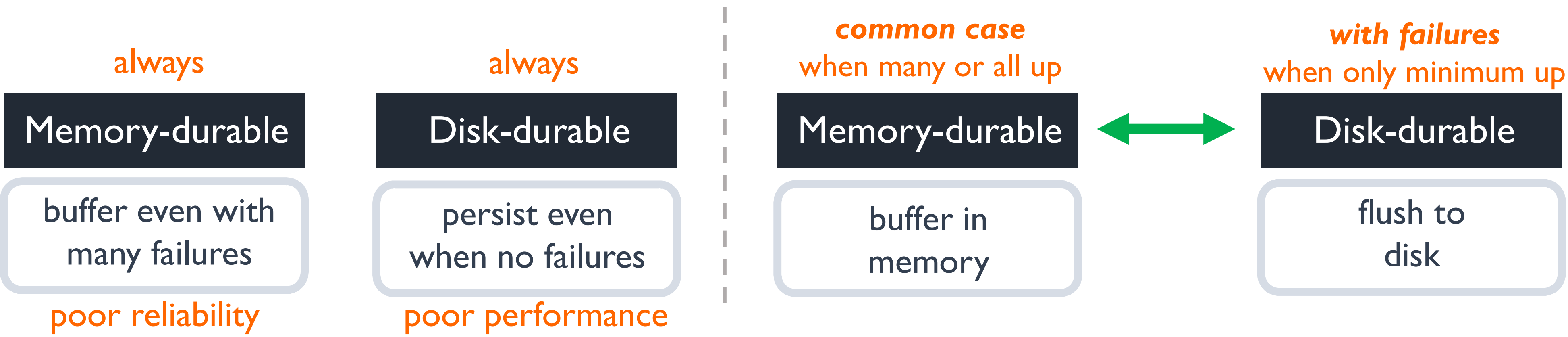

Insight: reacting to failures and adapting to situation can achieve reliability and performance

➡ when no or few failures could buffer in memory

➡ when failure arise, flush

Guarantees Depend upon Simultaneity of Failures

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- correlated but a few seconds apart [Ford et al., OSDI '10]
- analysis reveals a gap of 50 ms or more almost always

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We conjecture they are extremely rare: a gap exists between failures

- correlated but a few seconds apart [Ford et al., OSDI '10]
- analysis reveals a gap of 50 ms or more almost always

Most cases: any no. of independent and non-simultaneous correlated – same as disk-durable
Rare cases: more than a majority crash truly simultaneously – remain unavailable

SAUCR Overview

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- when more than a majority up, buffer updates in memory – fast mode
  - e.g., 4 or 5 nodes up in a 5-node cluster

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Crash Recovery

- when a node recovers from a crash, it recovers its data
  - either from its disk (if crashed in slow mode)
  - or from other nodes (if crashed in fast mode)

Situation-Aware Updates

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all nodes up

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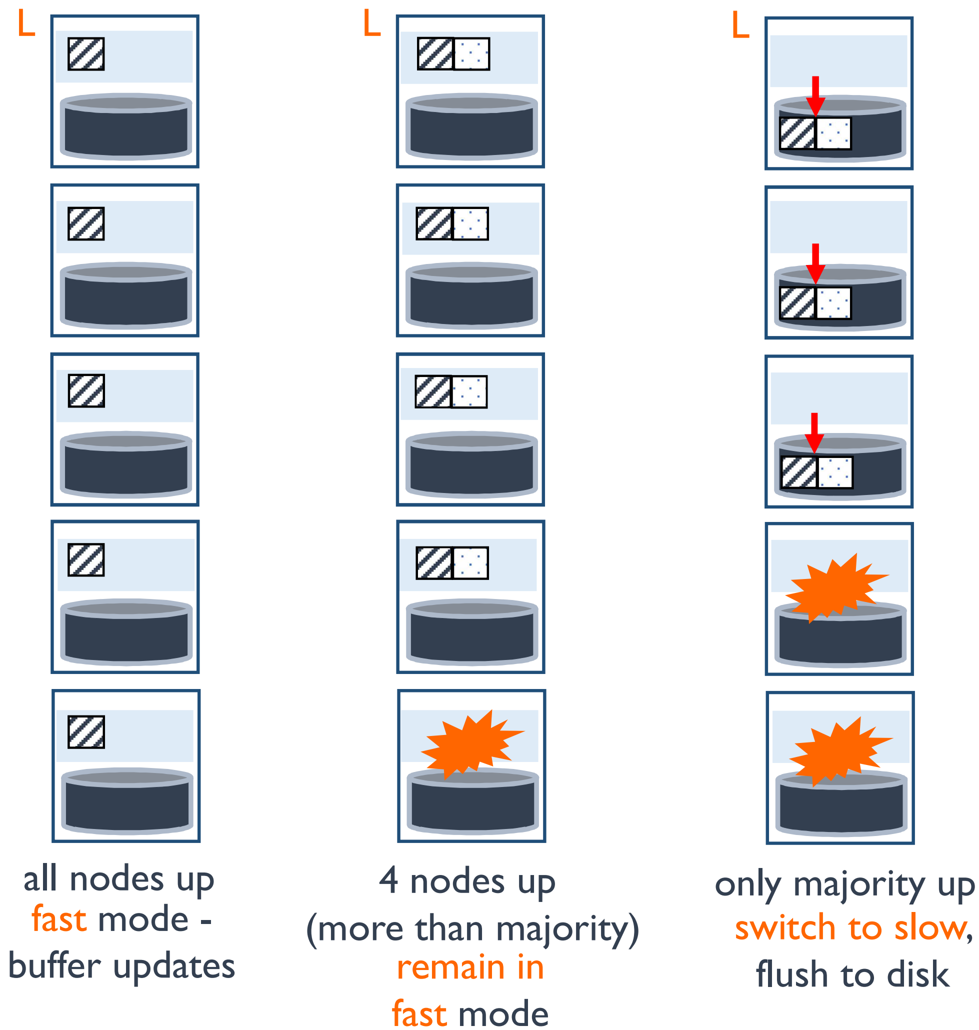

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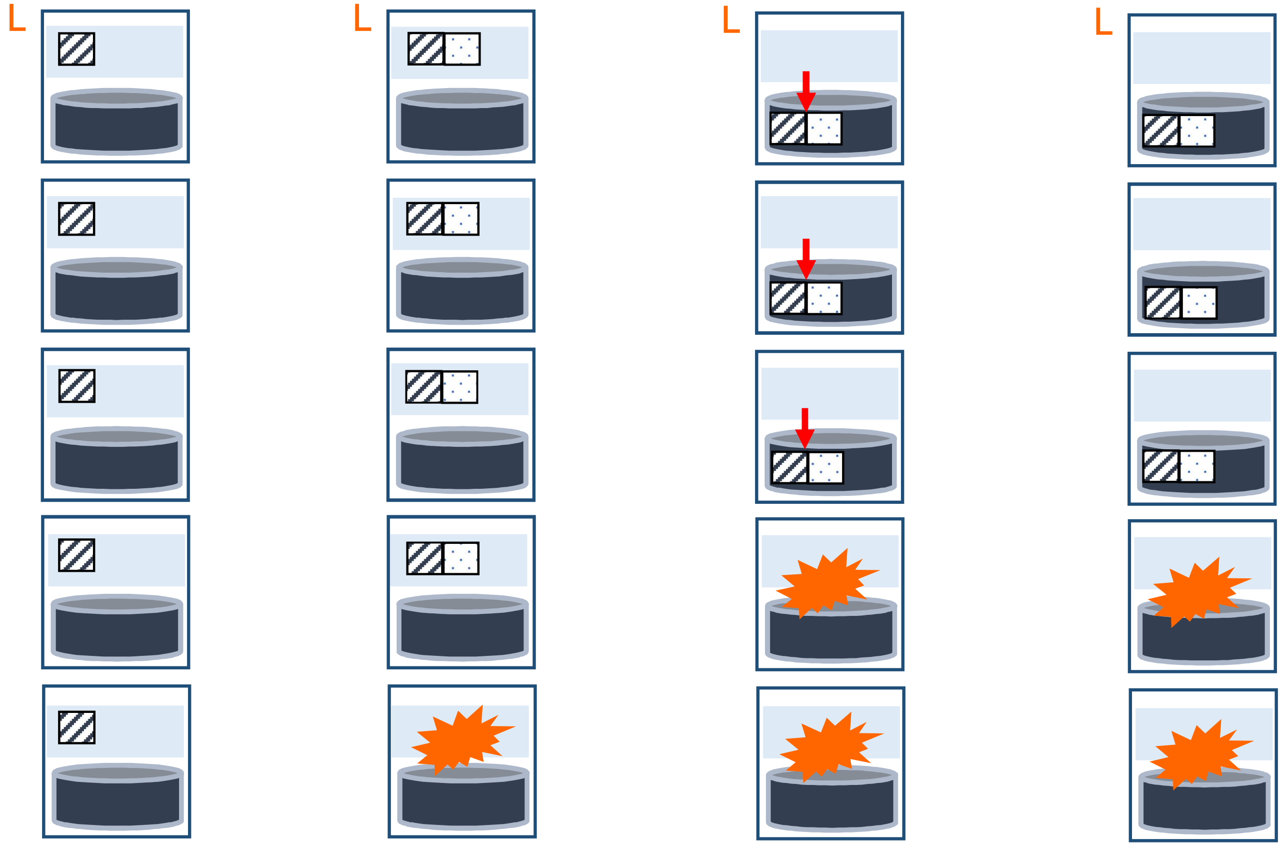

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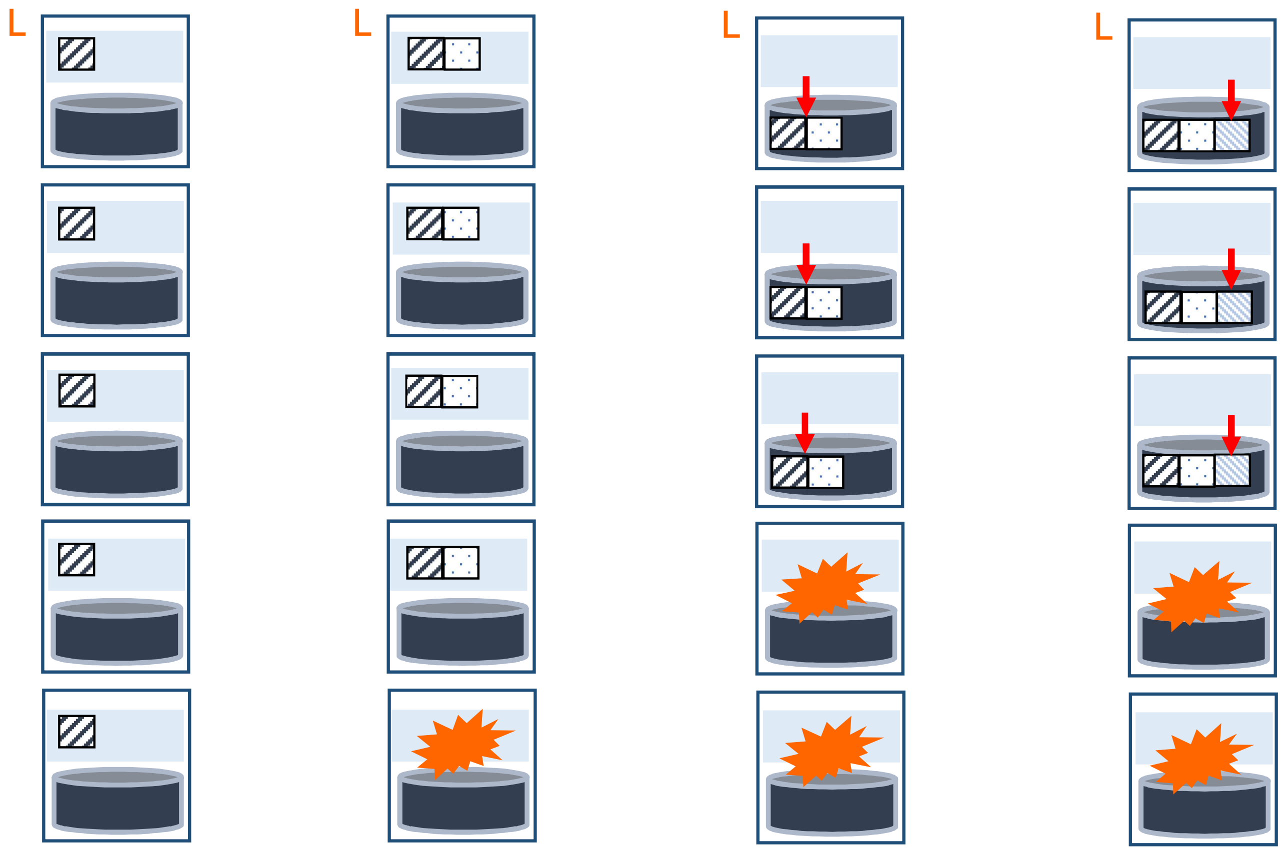

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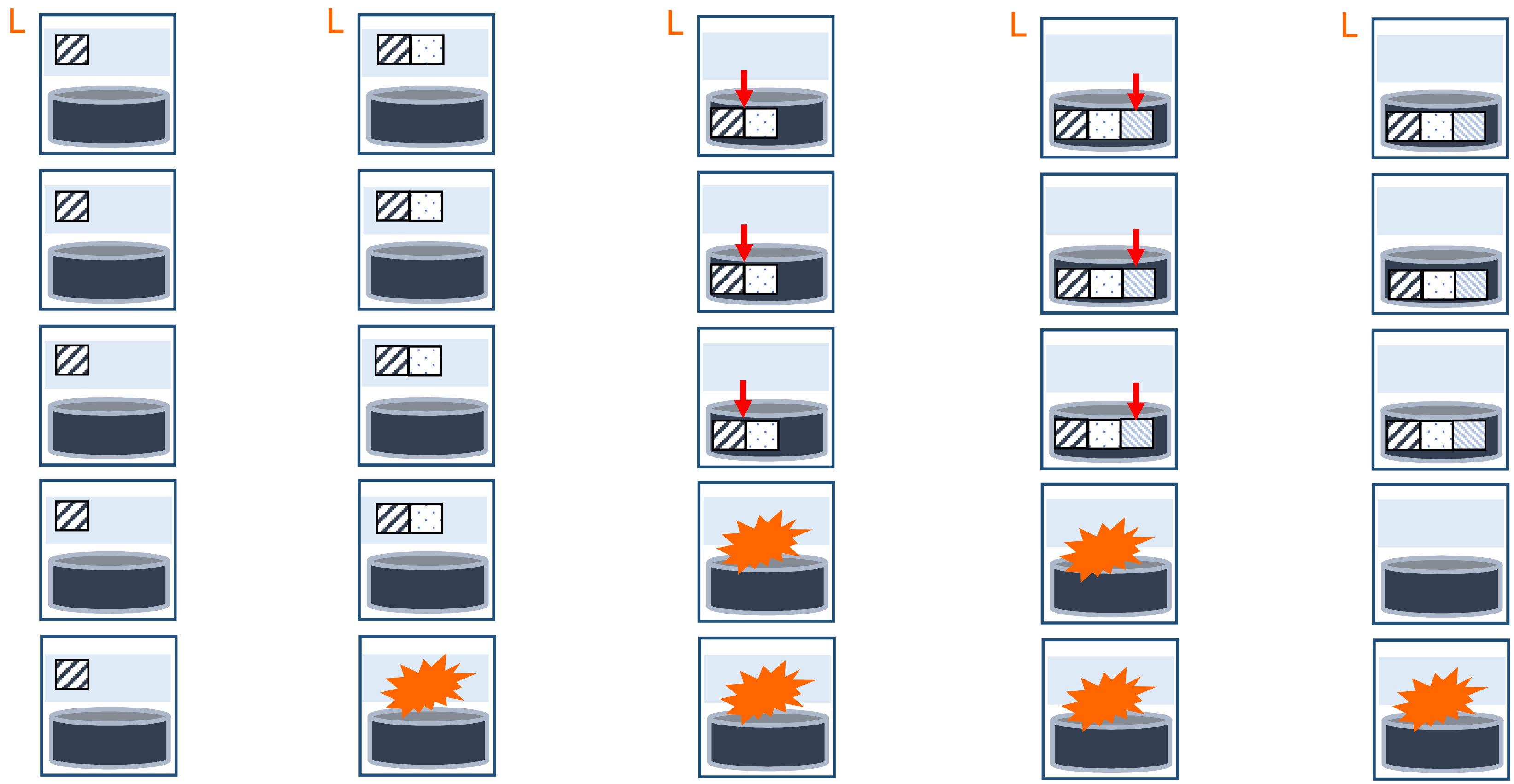

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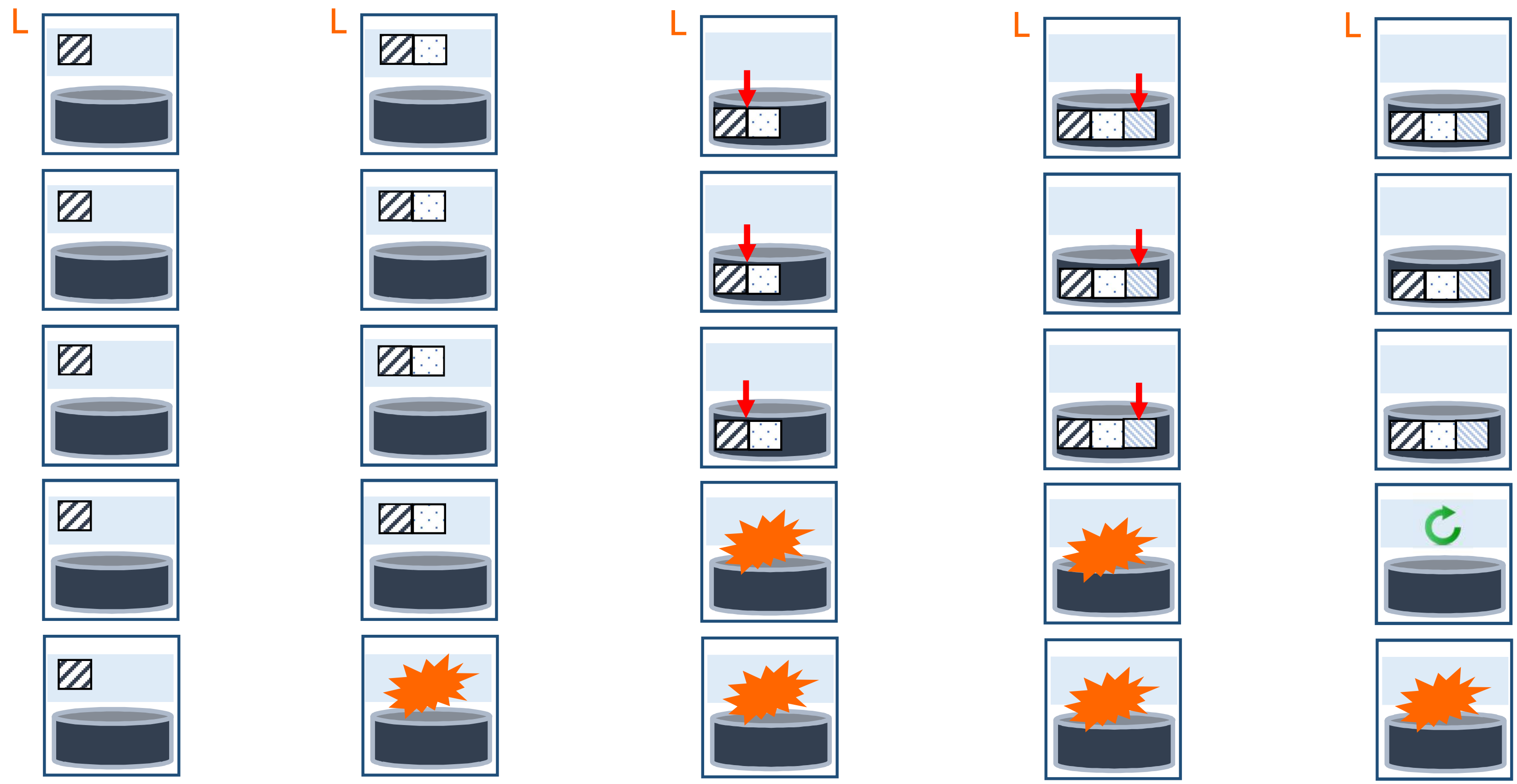

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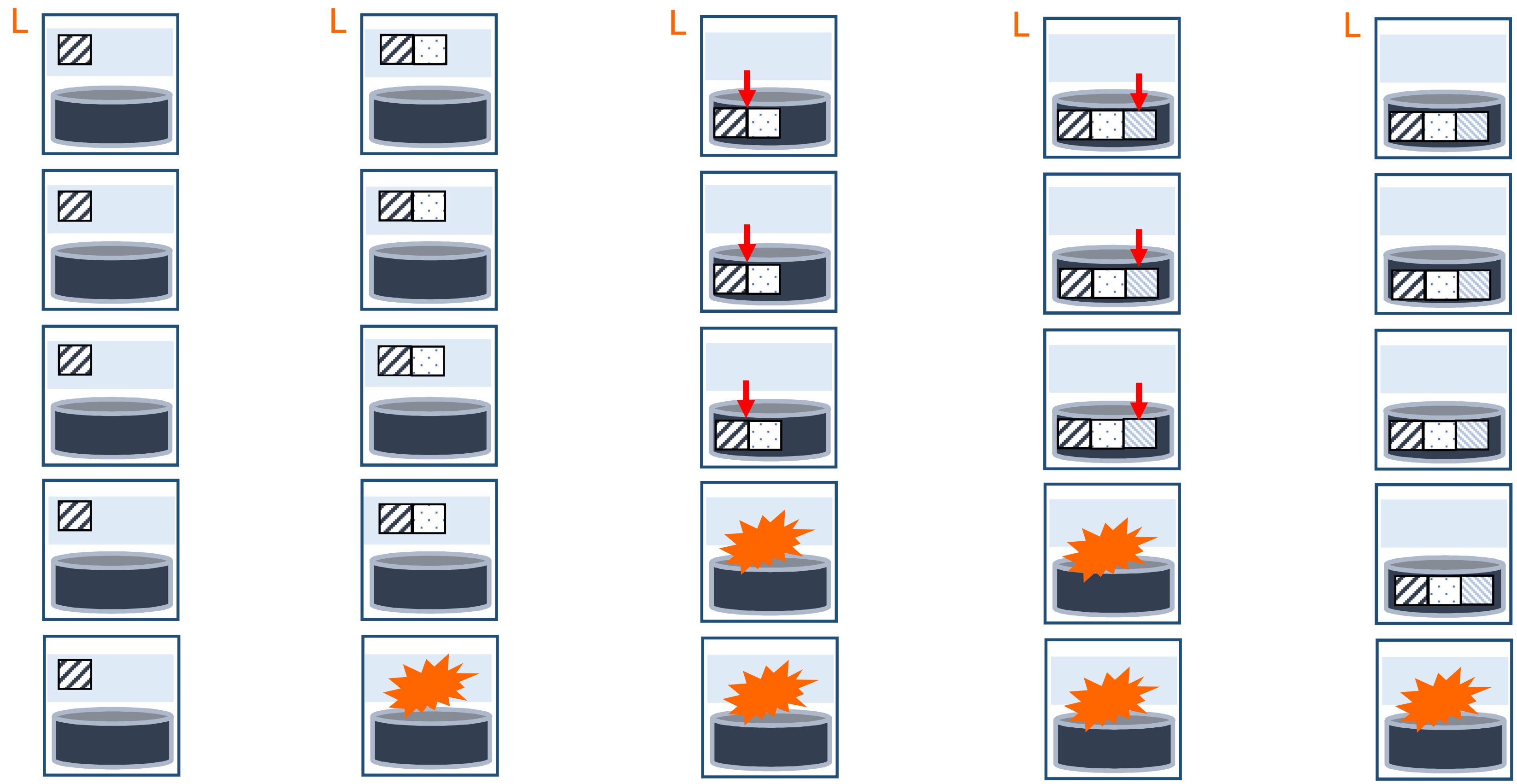

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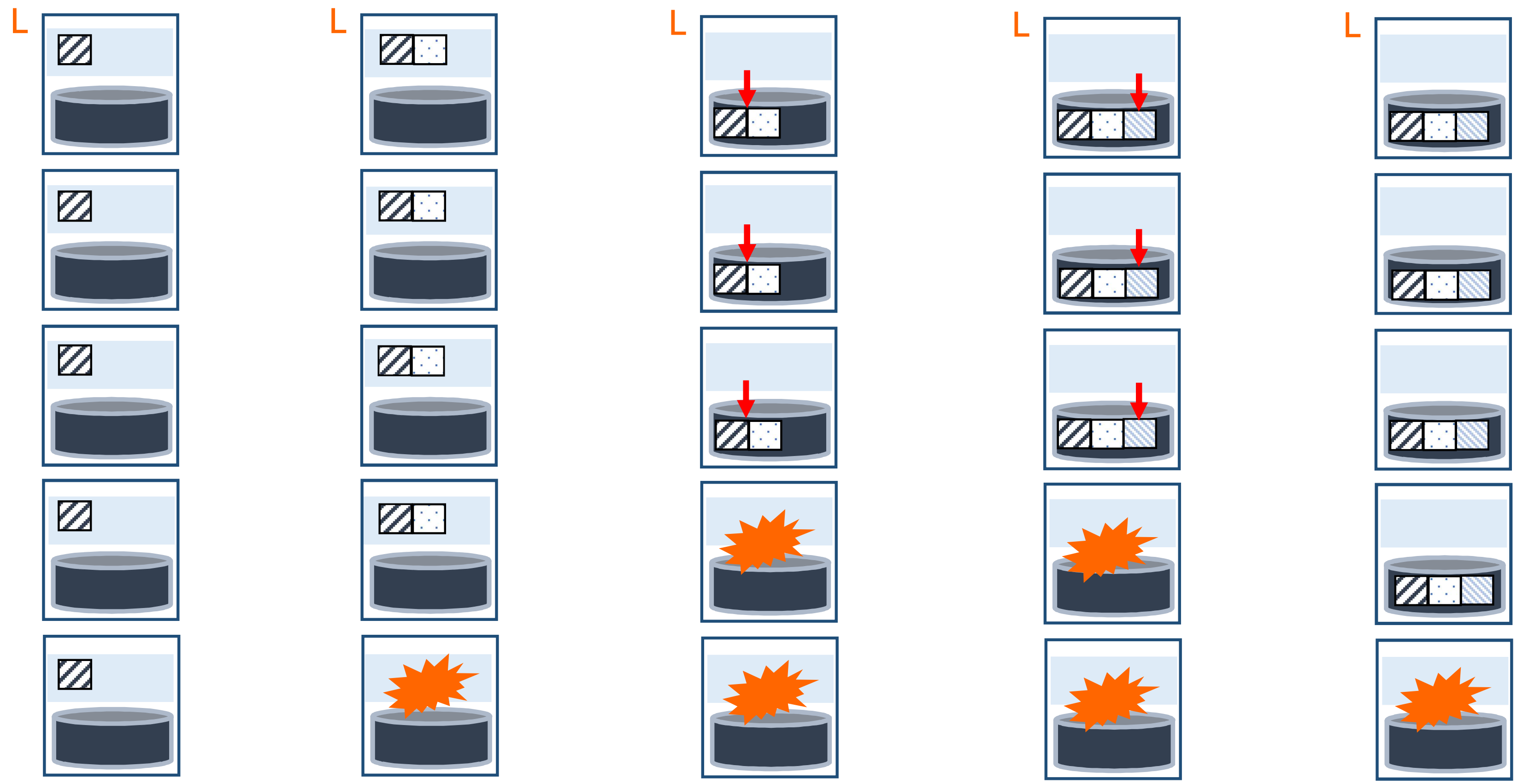

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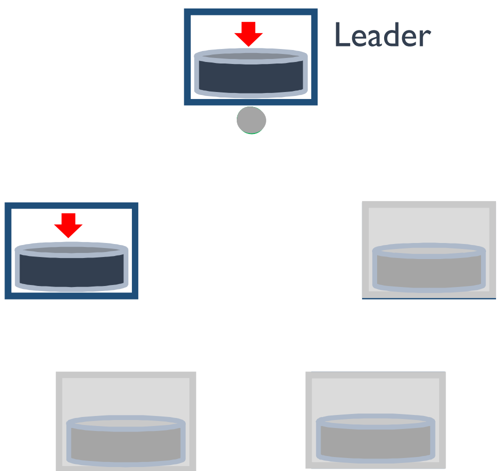
switch to fast

Failure Reaction

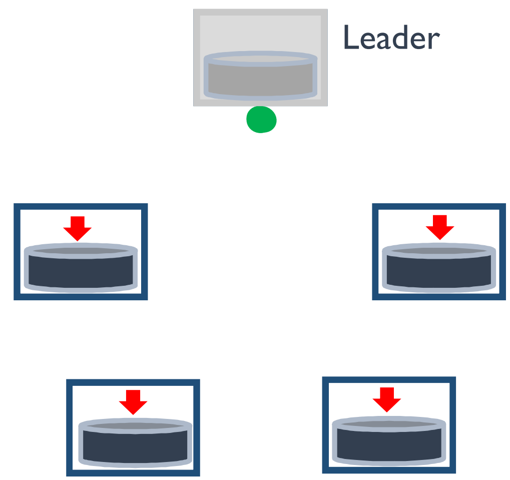
Basic failure-detection mechanism: heartbeats

Follower failures



remain in fast mode
switch to slow mode
steps down

Leader failures



on a missing heartbeat, followers flush to disk

Challenges: too many packets, spurious elections, too much data to flush

Techniques in the paper …

Result: can react to failures even when they are only a few milliseconds apart, preserving durability and availability

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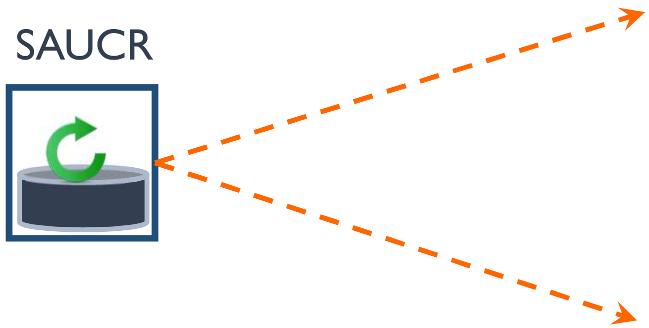

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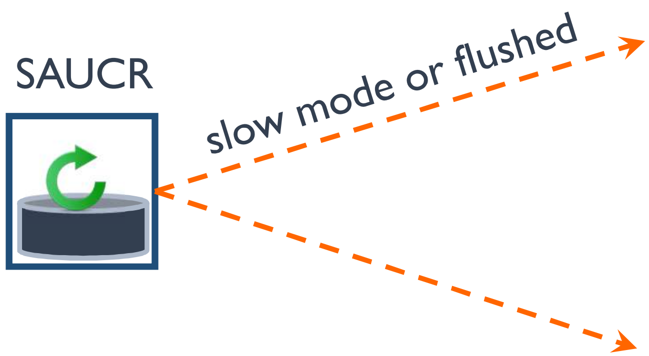

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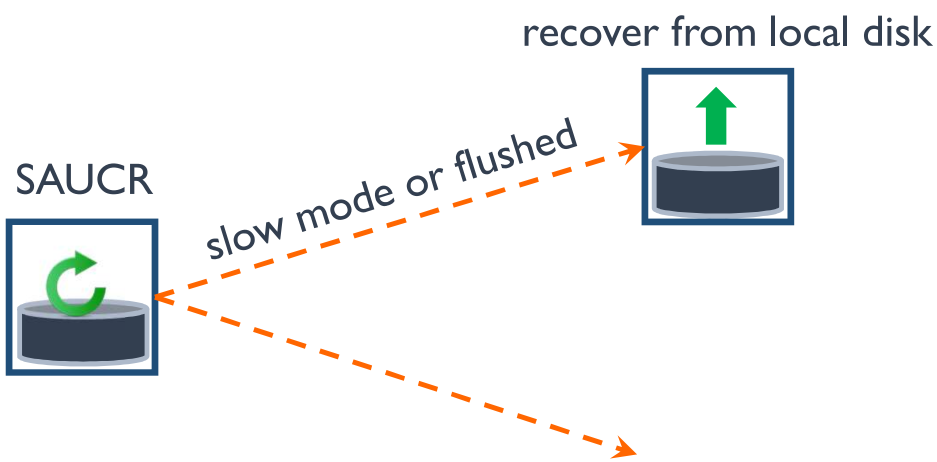

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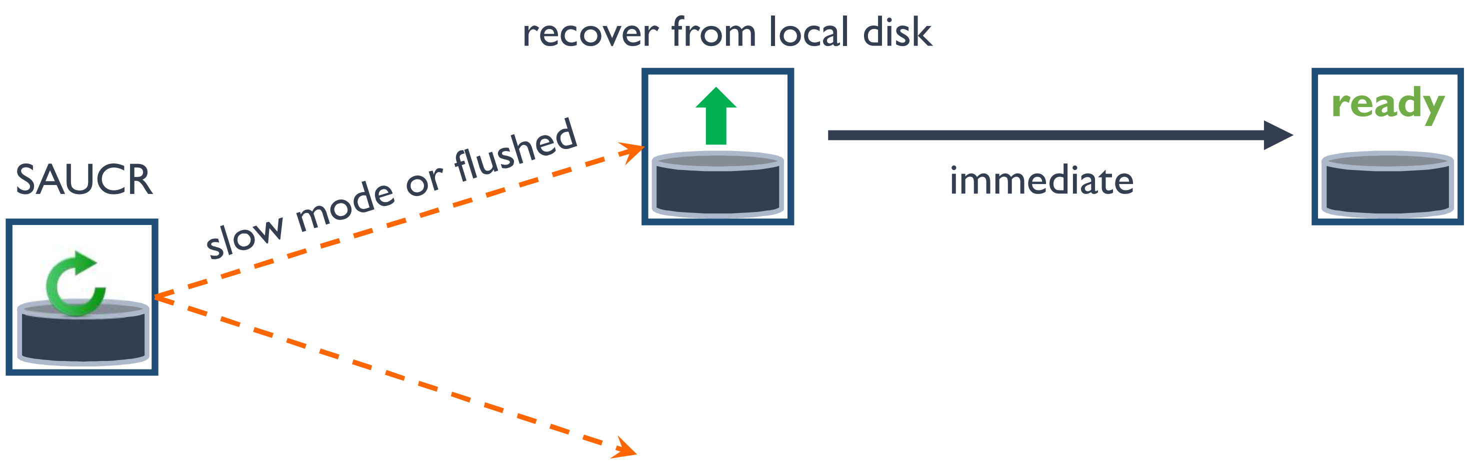

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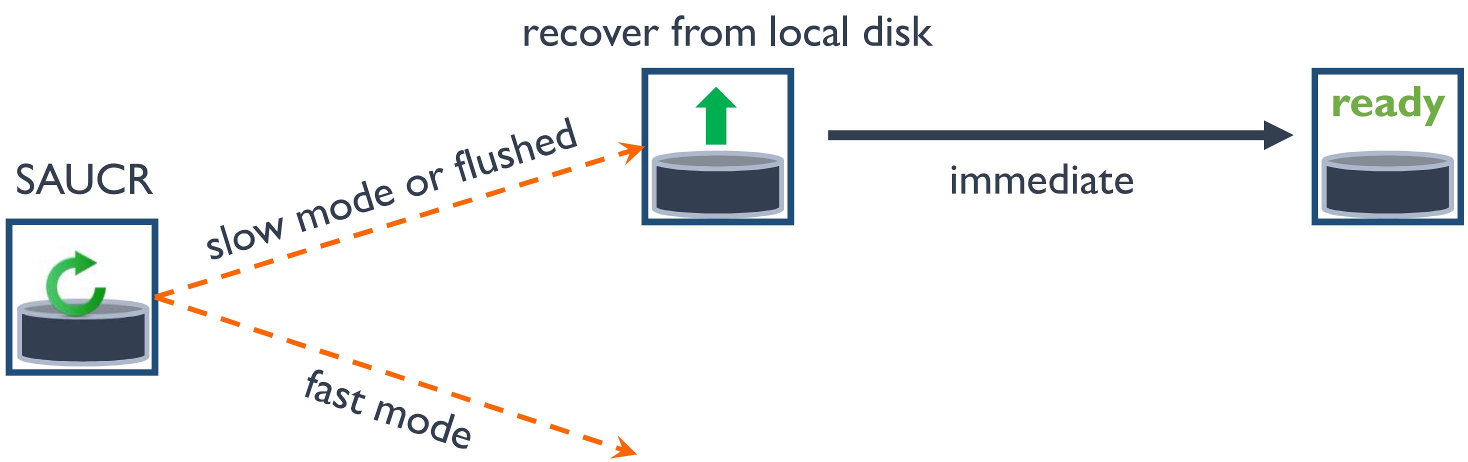

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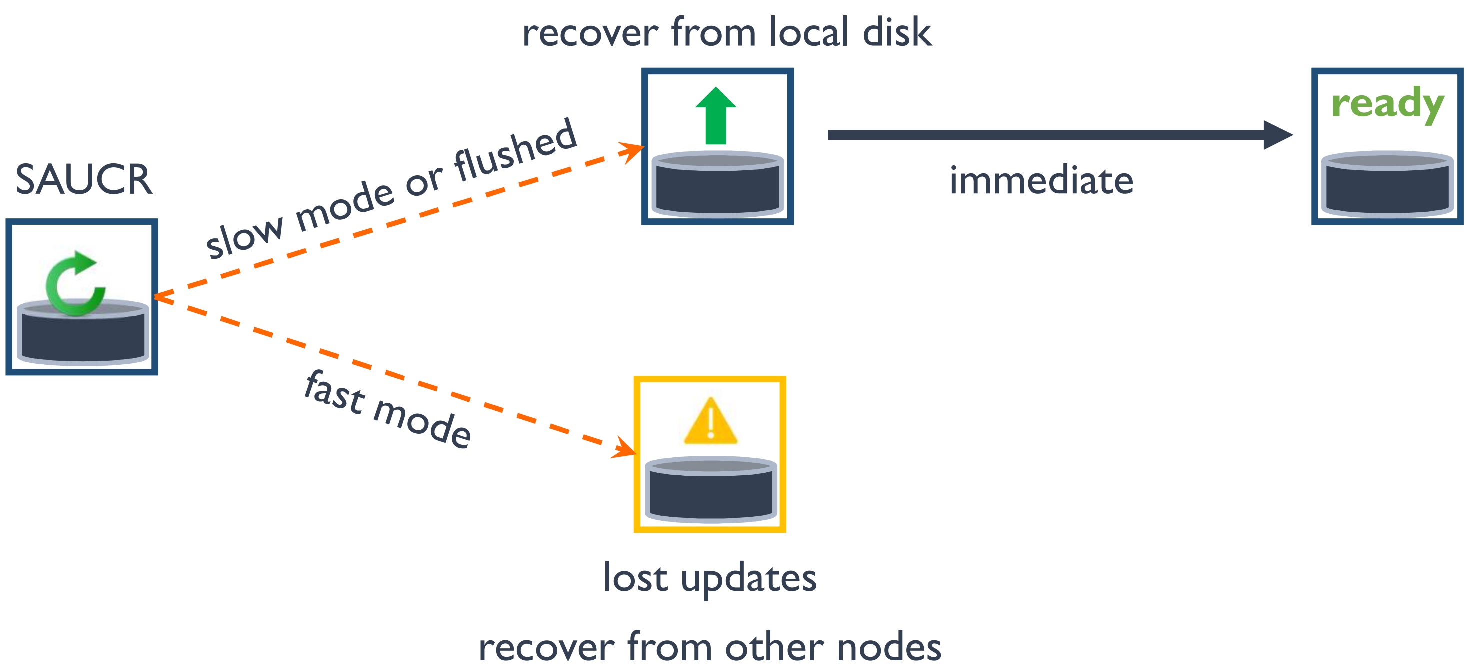

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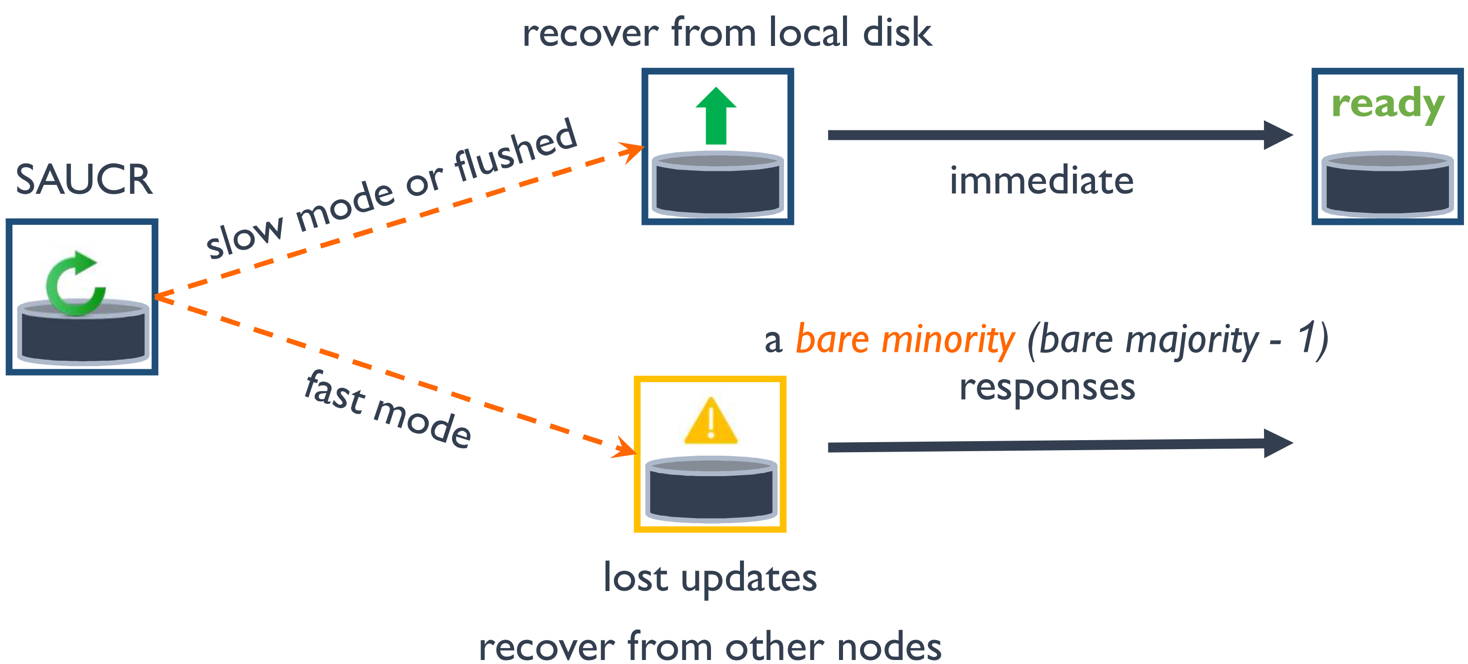

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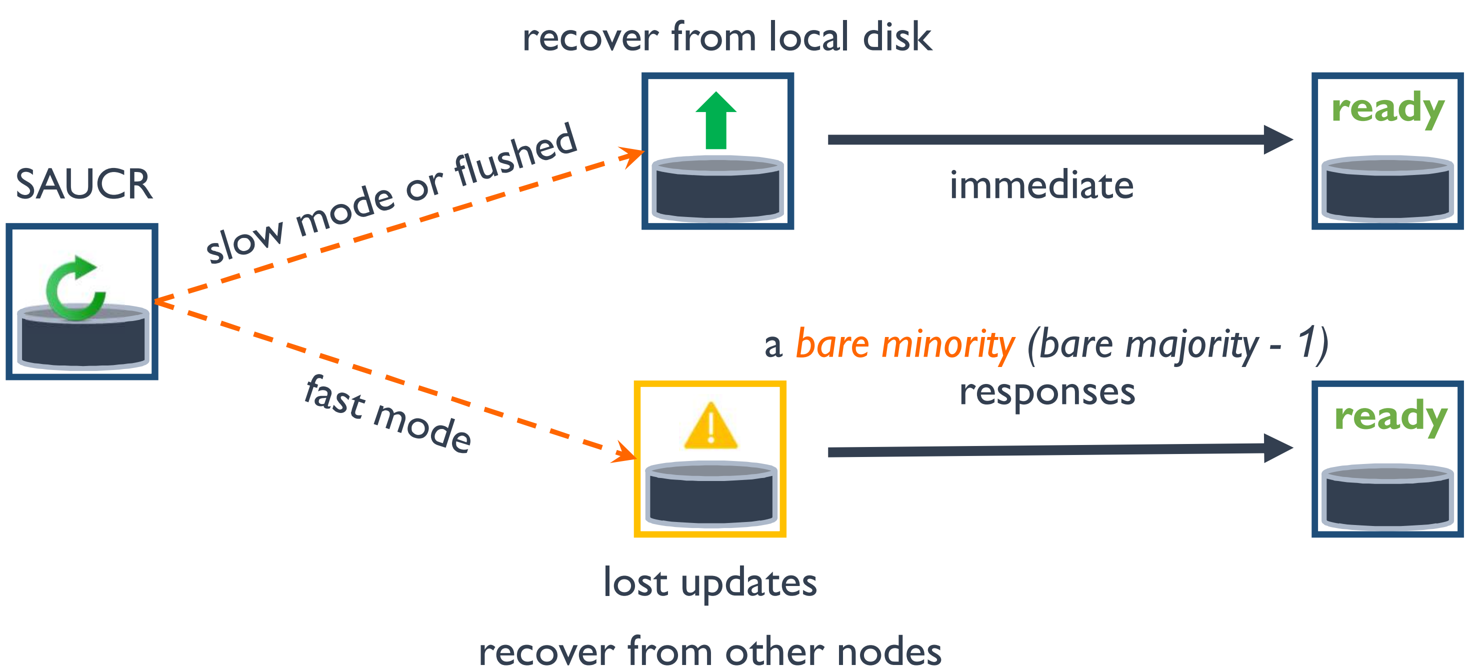

Intuition for why SAUCR's recovery is safe

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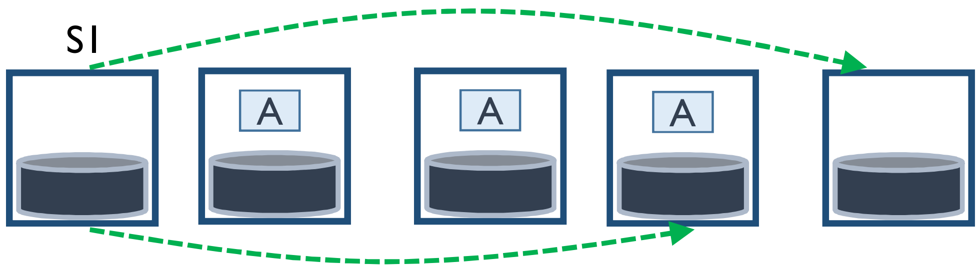

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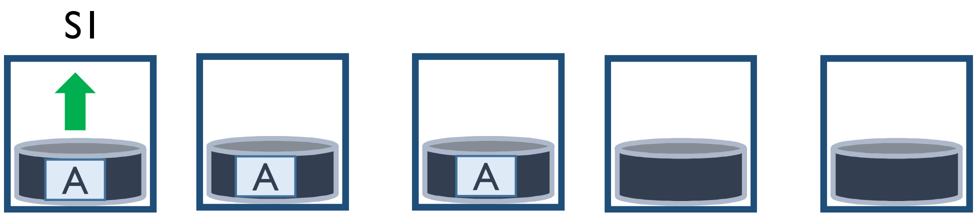

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Proof sketch in the paper …

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Results

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Evaluation

We implement in SAUCR in ZooKeeper

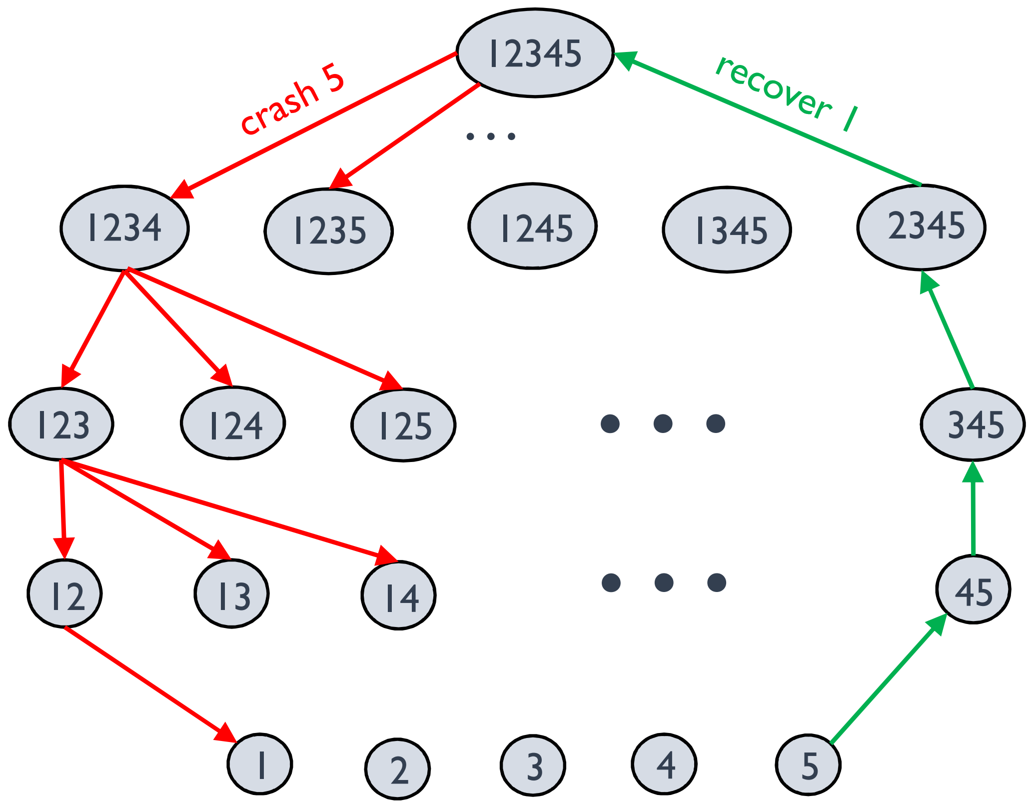
Compare SAUCR's reliability and performance against

- ➡ disk-durable ZooKeeper (forceSync = true)
- ➡ memory-durable ZooKeeper (forceSync = false)
- ➡ viewstamped replication (ideal model)

Reliability Testing

Cluster crash-testing framework
Generates cluster-state sequences

How it works?
Please see our paper…

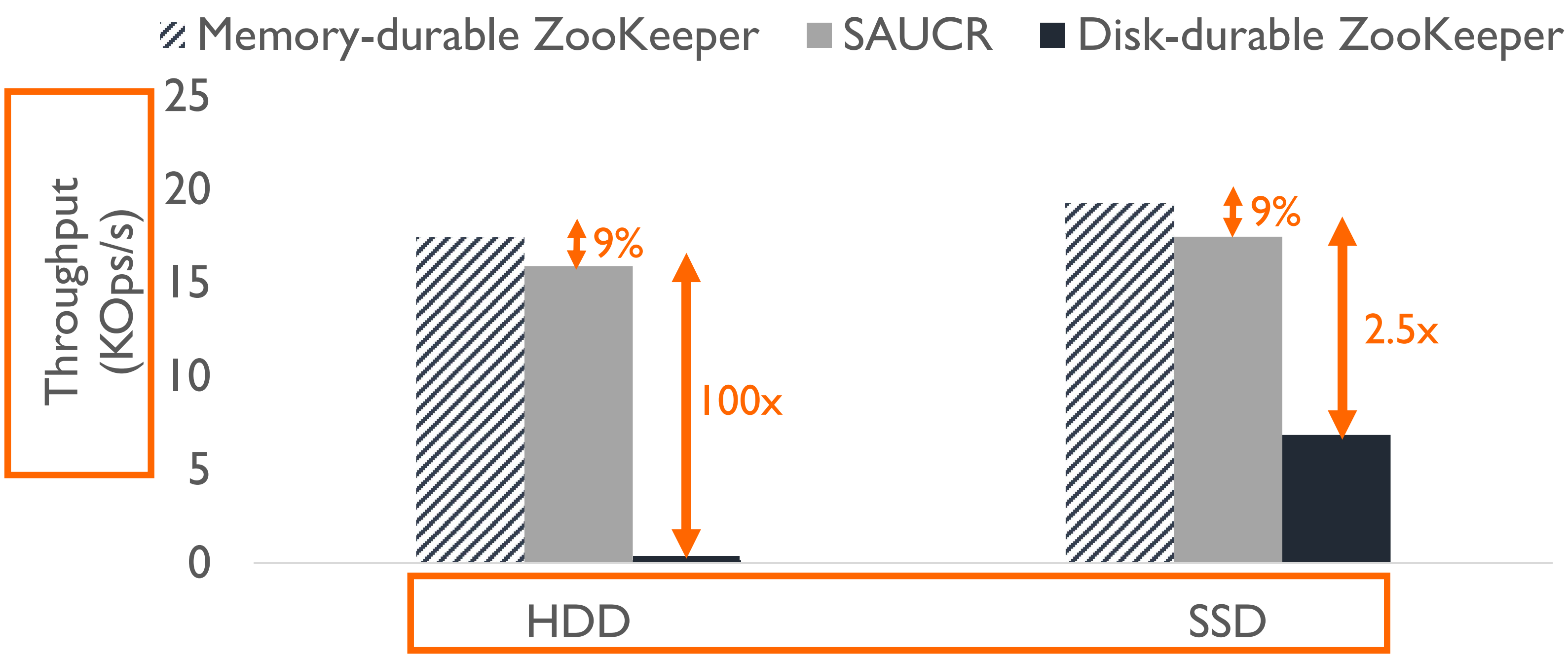


Reliability Results

	Non-Simultaneous			Simultaneous		
Systems	**Correct**	**Unavailable**	**Data loss**	**Correct**	**Unavailable**	**Data loss**
memory-durable zookeeper	703	0	561	703	0	561
viewstamped replication	217	1047	0	217	1047	0
disk-durable zookeeper	1264	0	0	1264	0	0
SAUCR	1264	0	0	1200	64	0

non-simultaneous: gap of 50 ms, simultaneous: no gap
memory-durable zookeeper silently loses data
viewstamped replication leads to permanent unavailability
SAUCR reacts to non-simultaneous – durable and available
other systems behave the same as non-simultaneous cases
simultaneous: SAUCR by design remains unavailable in some cases

Macro-benchmark Performance: YCSB-load



Compared to disk-durable, both memory-durable and SAUCR are faster

SAUCR's performance matches memory-durable ZooKeeper

- within 9% of memory-durable Zookeeper even for write-intensive workloads
- overheads because SAUCR writes to one additional node

Summary

Replication protocols are an important foundation

- need to be performant, yet also provide high reliability

Dichotomy: disk-durable vs. memory-durable protocols

- unsavory choices: either performant or reliable

SAUCR – situation-aware updates and crash recovery

- provides both high performance and reliability

Conclusions

Paying careful attention to how failures occur

- ➡ can find approaches that provide both performance and reliability
- ➡ more data from real-world deployments?

Hybrid approach – an effective systems-design technique – applicable to distributed updates and recovery too

- ➡ worthwhile to look at other important protocols/systems where we make similar two-ends-of-the-spectrum tradeoffs?

Thank you!

Poster #6