Bring Consensus to Data Replication

QCon 2017

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UBER

DISTRIBUTED SYSTEM

- Resource sharing
- Openness
- Concurrency
- Scalability
- Fault Tolerance
- Transparency

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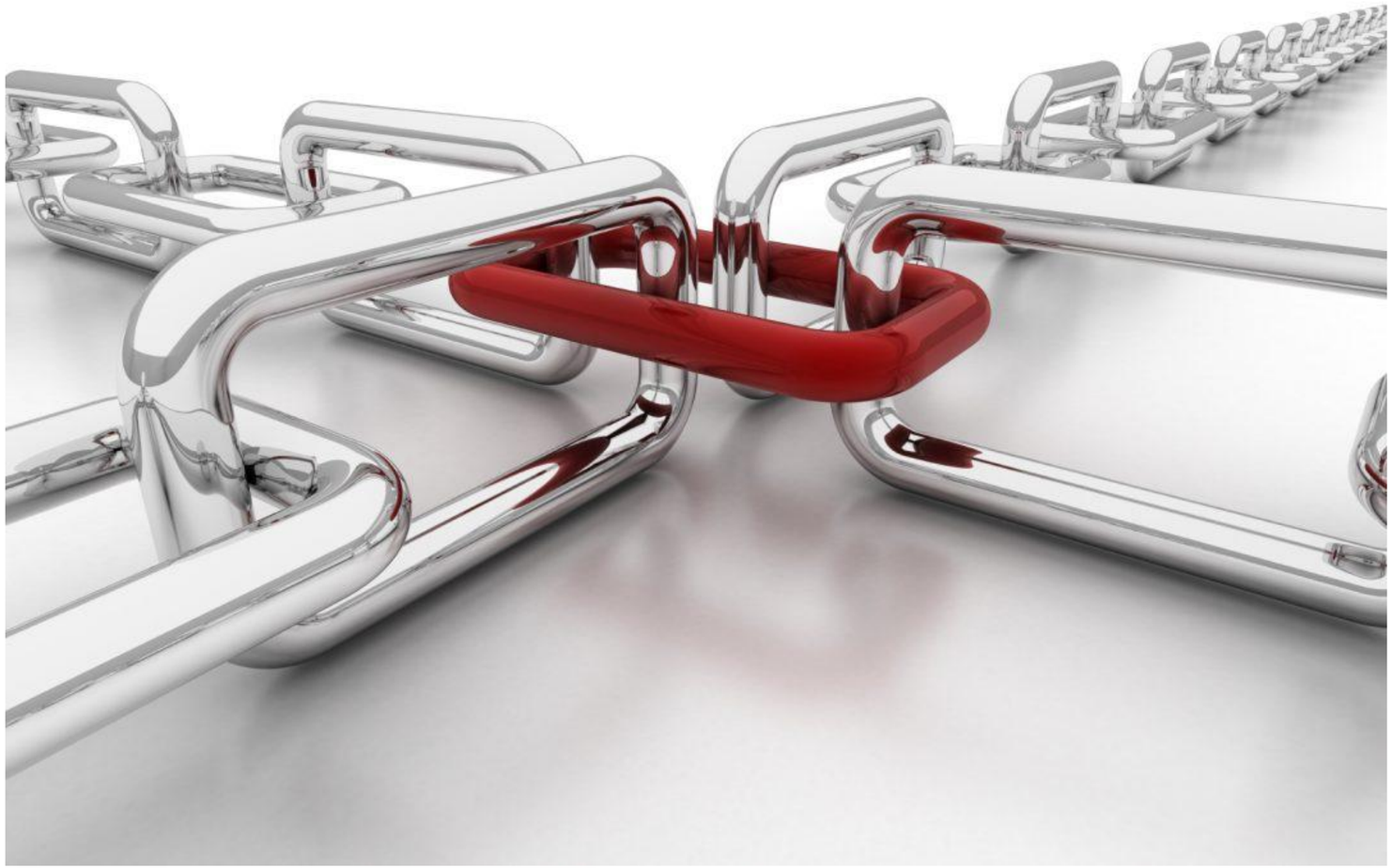
SINGLE POINT OF FAILURE



REDUNDANCY

Adding more replicas

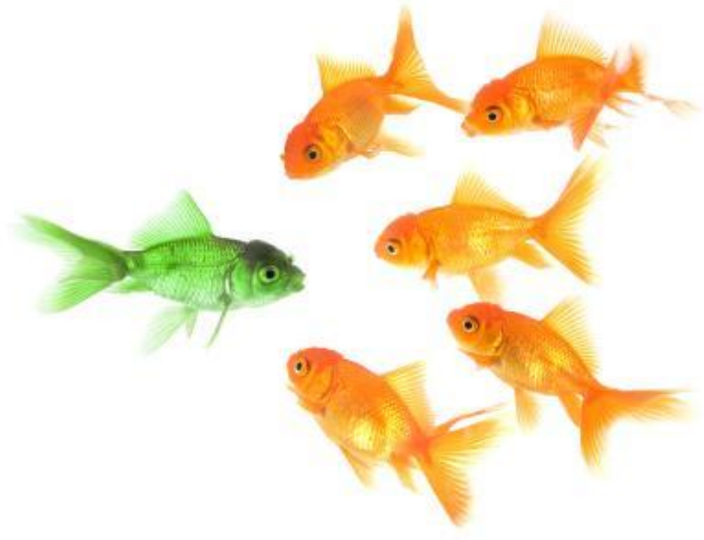
- scale out the reads
- resilient to machine crashes
- more concurrency

CHALLENGES

consistency

synchronization

fence off stale write



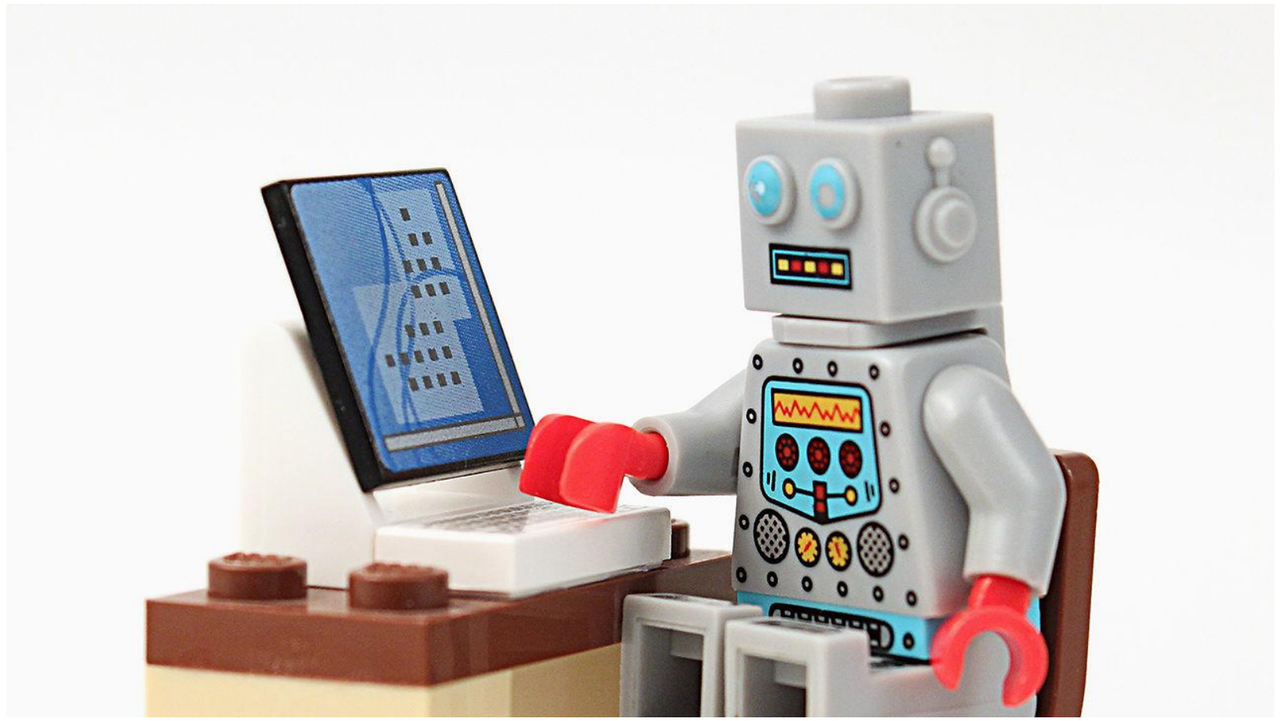
OUR FOCUS

Focusing on our four 9s’ availability

Availability %	Downtime per year	Downtime per month	Downtime per week	Downtime per day
99% (“two nines”)	3.65 days	7.20 hours	1.68 hours	14.4 minutes
99.9% (“three nines”)	8.76 hours	43.8 minutes	10.1 minutes	1.44 minutes
99.99% (”four nines”)	52.56 minutes	4.38 minutes	1.01 minutes	8.66 seconds

OUR FOCUS

Take human out of the equation



OUR FOCUS

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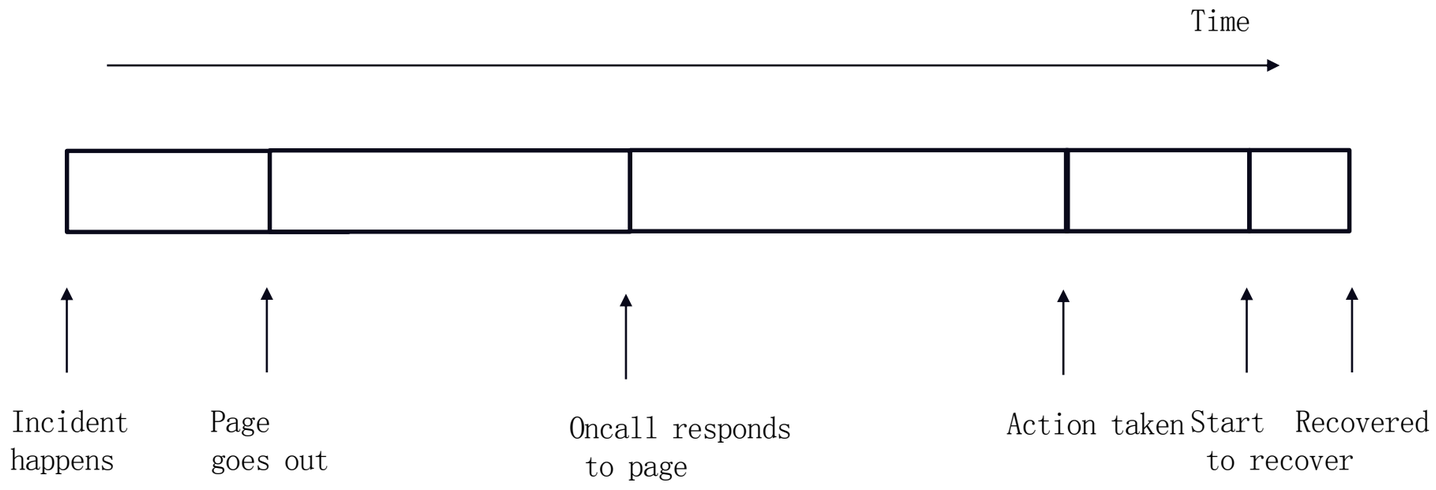


OUR FOCUS

Take human out of the equation

- System reacts to a subset of failure modes CORRECTLY
- Human makes judgement call in the disastrous scenarios.

OUR FOCUS

Linearizability

- If a write to a key (which identifies a piece of data) is successfully applied, all the subsequent reads via the same key must return the same data written by this particular write or some later write;
- If a read of a key returns some data, all subsequent reads via the same key must return the same data or some data from some later write.

METHODOLGY

- Replicated state machine
  - A type of active replication
  - All replicas receive and process the same sequence of client requests

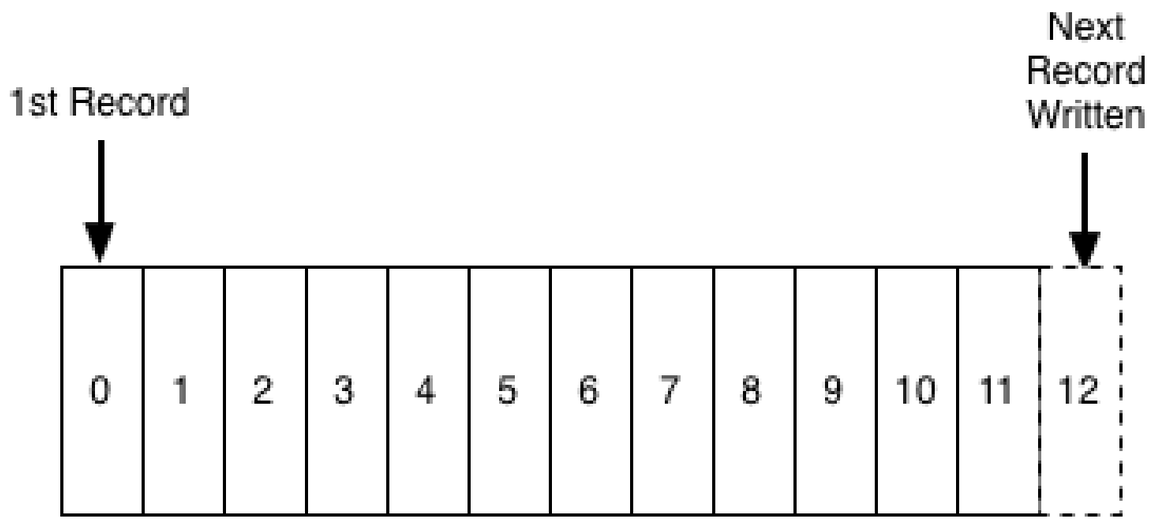
- Consensus protocol to maintain the replicated log consumed by replicas
  - Elect leader automatically
  - Tolerate node failure (non-Byzantine failures)
  - Maintain consistency among nodes

REPLICATED STATE MACHINE

- Deterministic state machines running on a collection of servers.
- Each state machine computes identical copies of the same data.
- The system can continue to operate even if some servers are down.

REPLICATED LOG

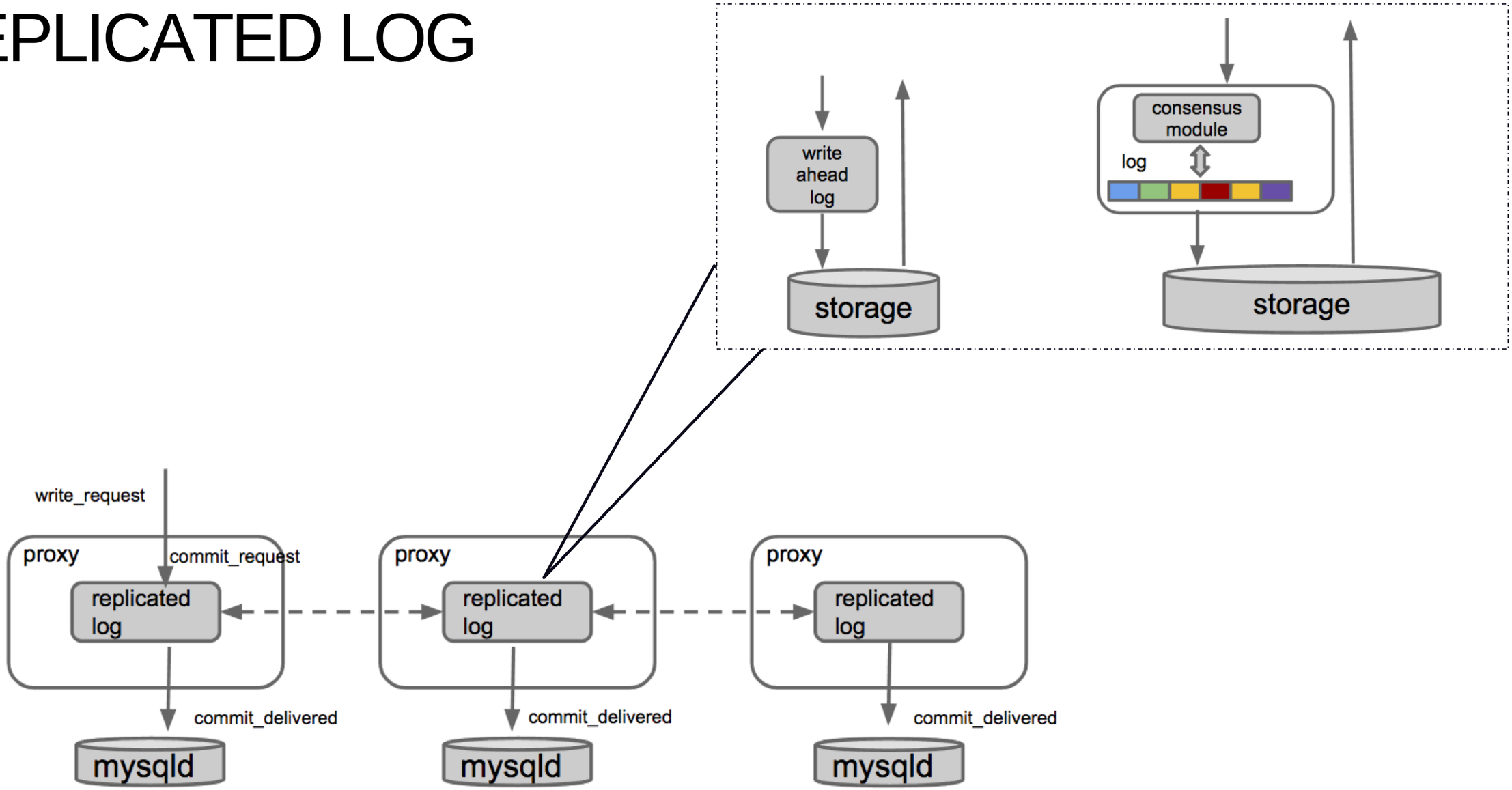
- Log is an append-only and totally ordered abstraction.
- Log replication makes every replica see the exact order of entries.
- If we treat every write to DB as an entry in the log, applying these entries on the same starting snapshot in the same order will yield same ending snapshot.
- Replicated log is maintained by consensus protocol.



Replicated State Machine

- Each server stores a log containing a series of commands which are executed in order by the state machine.
- Each log contains the same commands in the same order.
- State machine is deterministic so each computes the same state and has the same sequence of outputs.

REPLICATED LOG

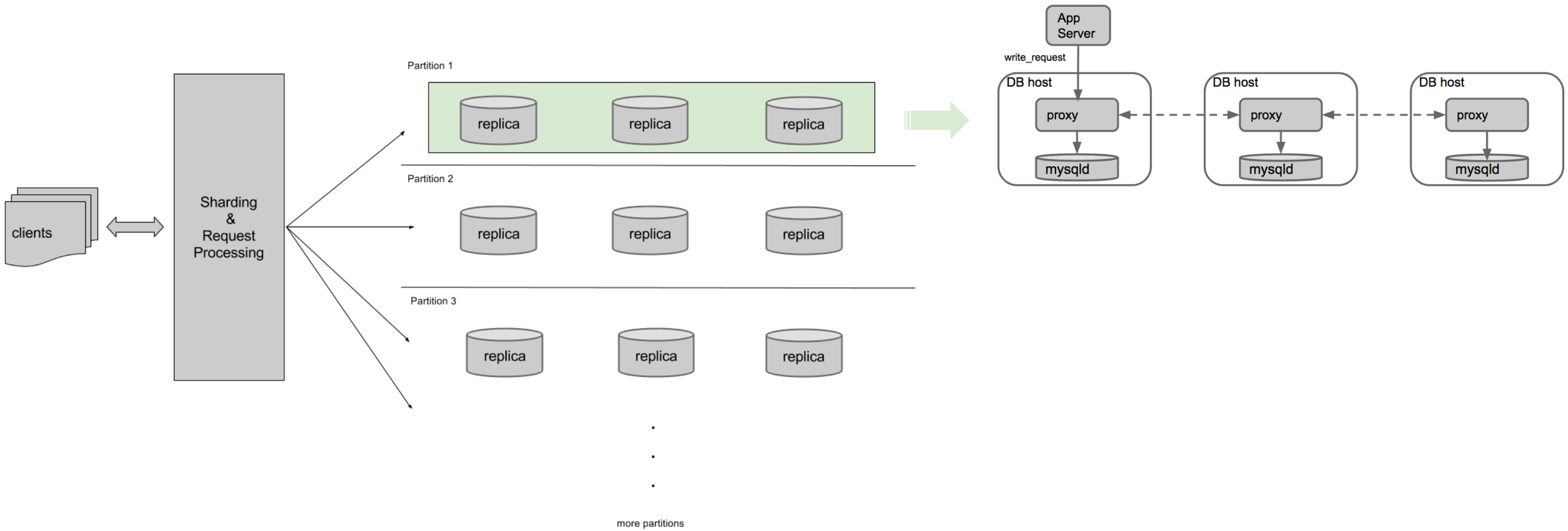


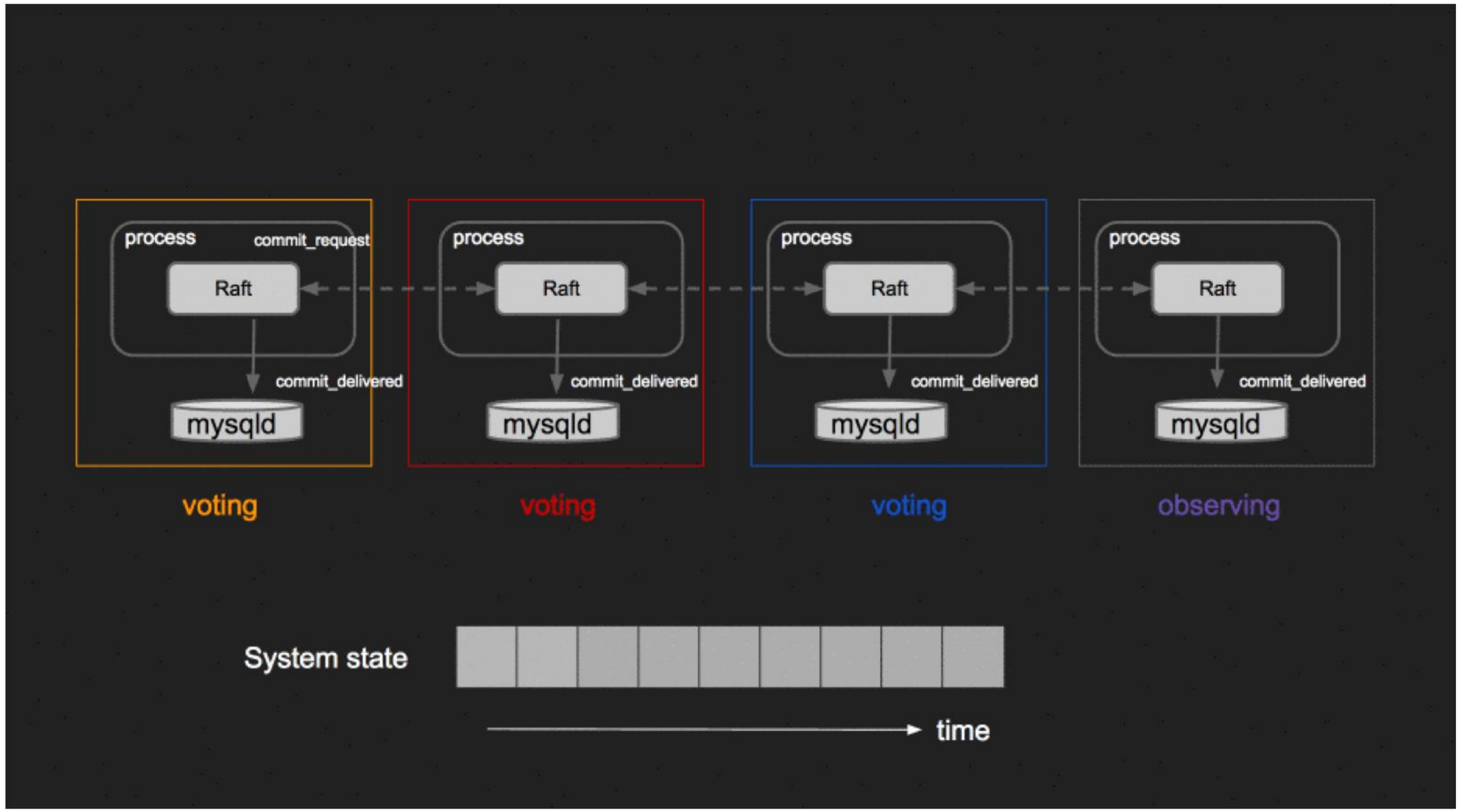
RAFT

- Election Safety
  At most one leader can be elected in a given term.
- Leader Append-Only
  A leader never overwrites or deletes entries in its log; it only appends new entries.
- Log Matching
  If two logs contain an entry with the same index and term, then the logs are identical in all entries up through the given index.
- Leader Completeness
  If a log entry is committed in a given term, then that entry will be present in the logs of the leaders for all higher-numbered terms.
- State Machine Safety
  If a server has applied a log entry at a given index to its state machine, no other server will ever apply a different log entry for the same index.

SYSTEM SET-UP

Note that we don't have a 'global' Raft set-up for the entire system; rather the data is partitioned into multiple partitions each of which has its own Raft set-up. Sharding is out of scope of this talk but the overall system architecture looks like the following.

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observing
System state
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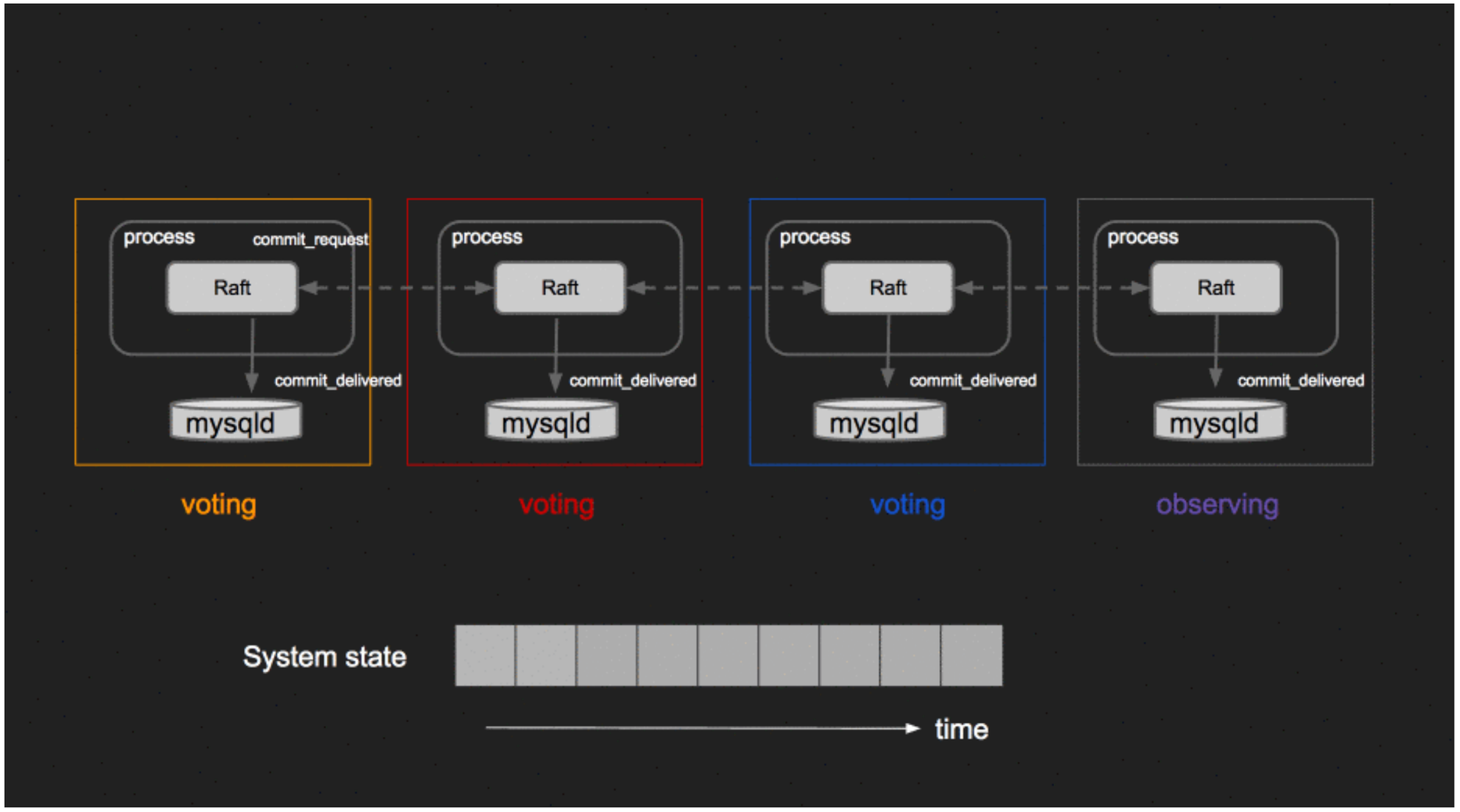
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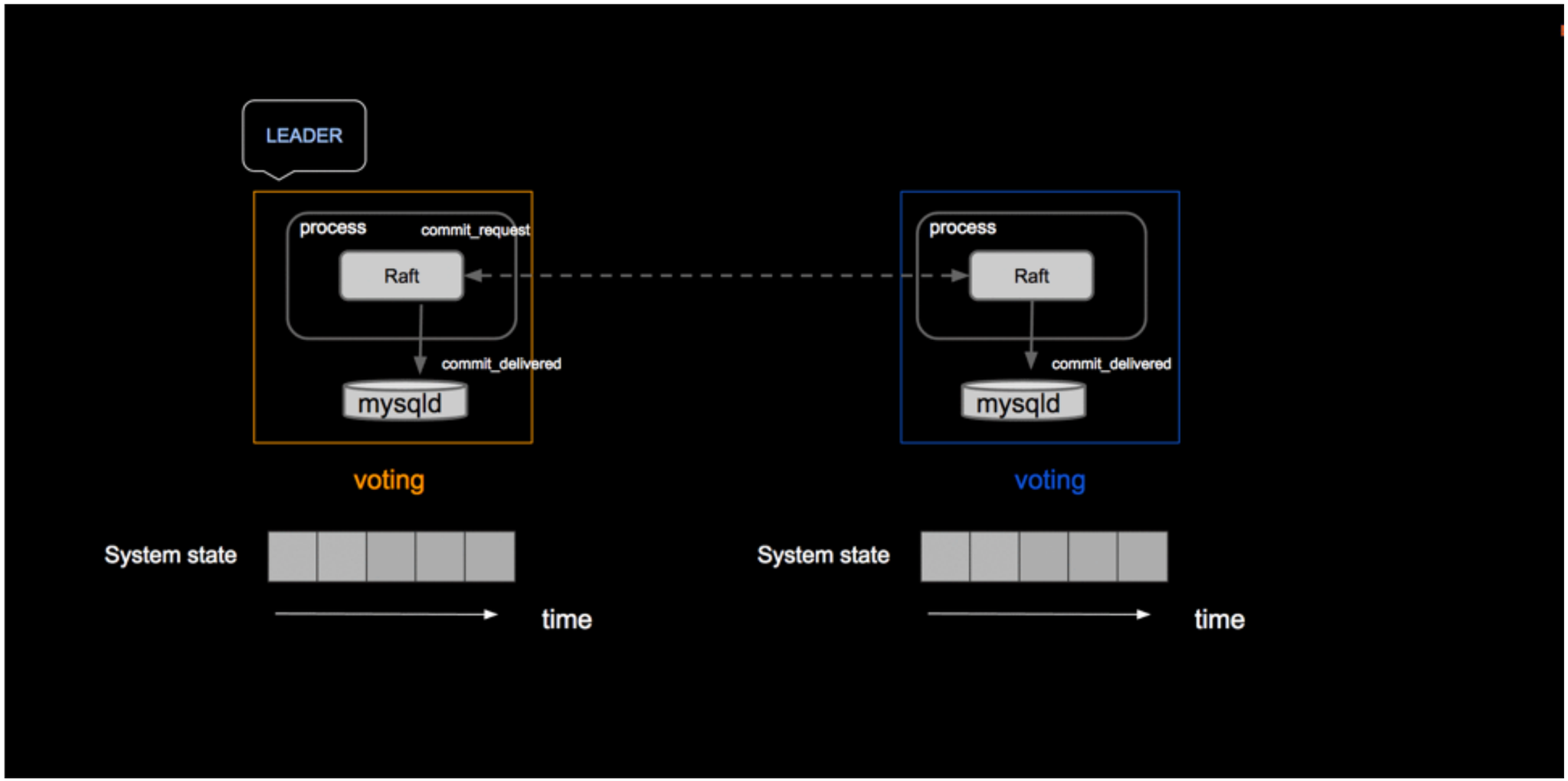
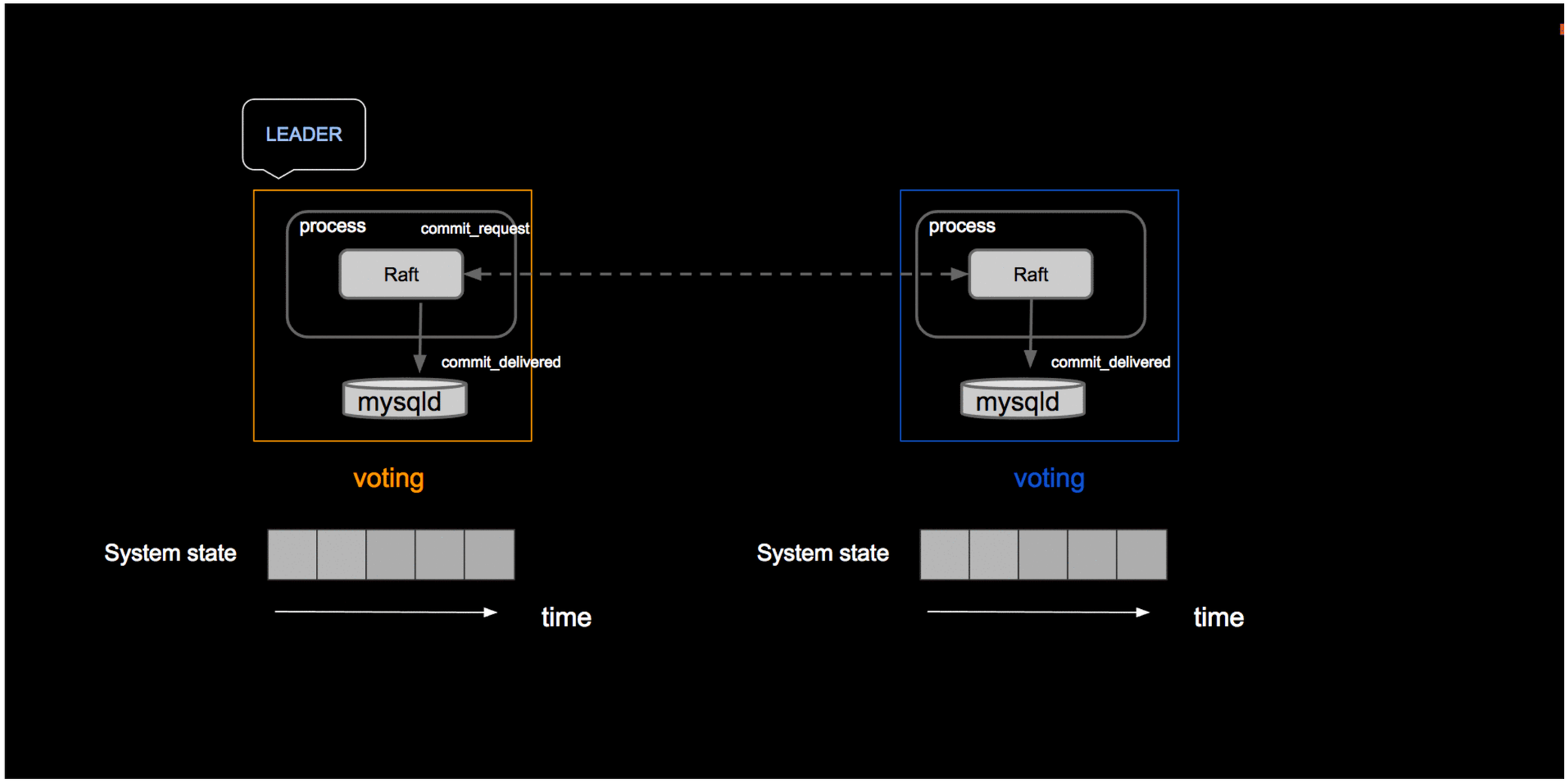
STRONGLY CONSISTENT READ



STRONGLY CONSISTENT READ



INTEGRATION WITH MYSQL

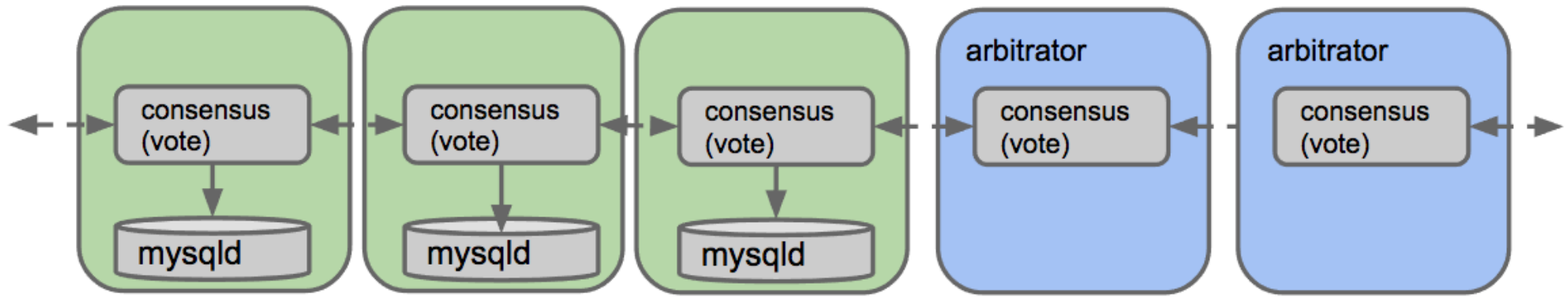
- Statement Idempotency
  - There may be non-idempotent SQL statements. Even if the replicated log is consistent we cannot allow same statement to apply twice.
  - Our solution: using Raft entry index to construct the GTID
- Parallel Execution
  - Raft essentially sequentializes everything which compromises the the parallelism if we would use Mysql directly.
  - Our solution: parallel execution SQL statements based on the shard that the statement targets at.
- Auto Increment ID
  - Mysql's auto increment ID is NOT transactional so we can NOT have individual replica use its own auto increment ids.
  - Our solution: use Raft to maintain the cluster-wide auto increment ID.

RAFT EXTENSIONS

- Observer
  A participant which doesn’t vote nor solicit a vote
- Arbitrator
  A participant which acts as a voter but will relinquish leadership (if allowed by the consensus protocol) if it itself is elected as the leader.
- Leader Lease
- DC awareness/Efficient cross DC data streaming

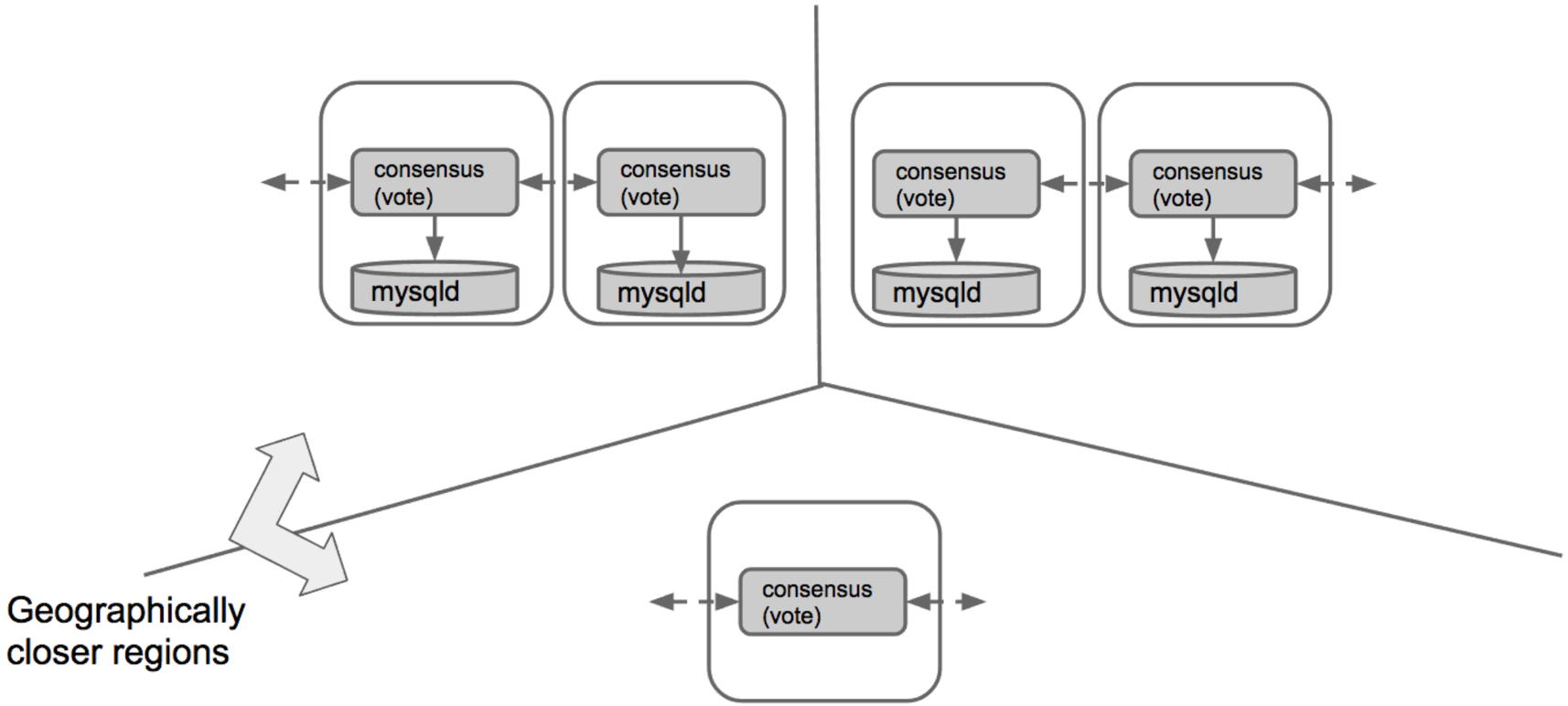
ARBITRATOR

Within one DC we can achieve tolerance of two nodes being down with the cost of 3 copies of data, which is not possible with the vanilla 3-voter set-up.

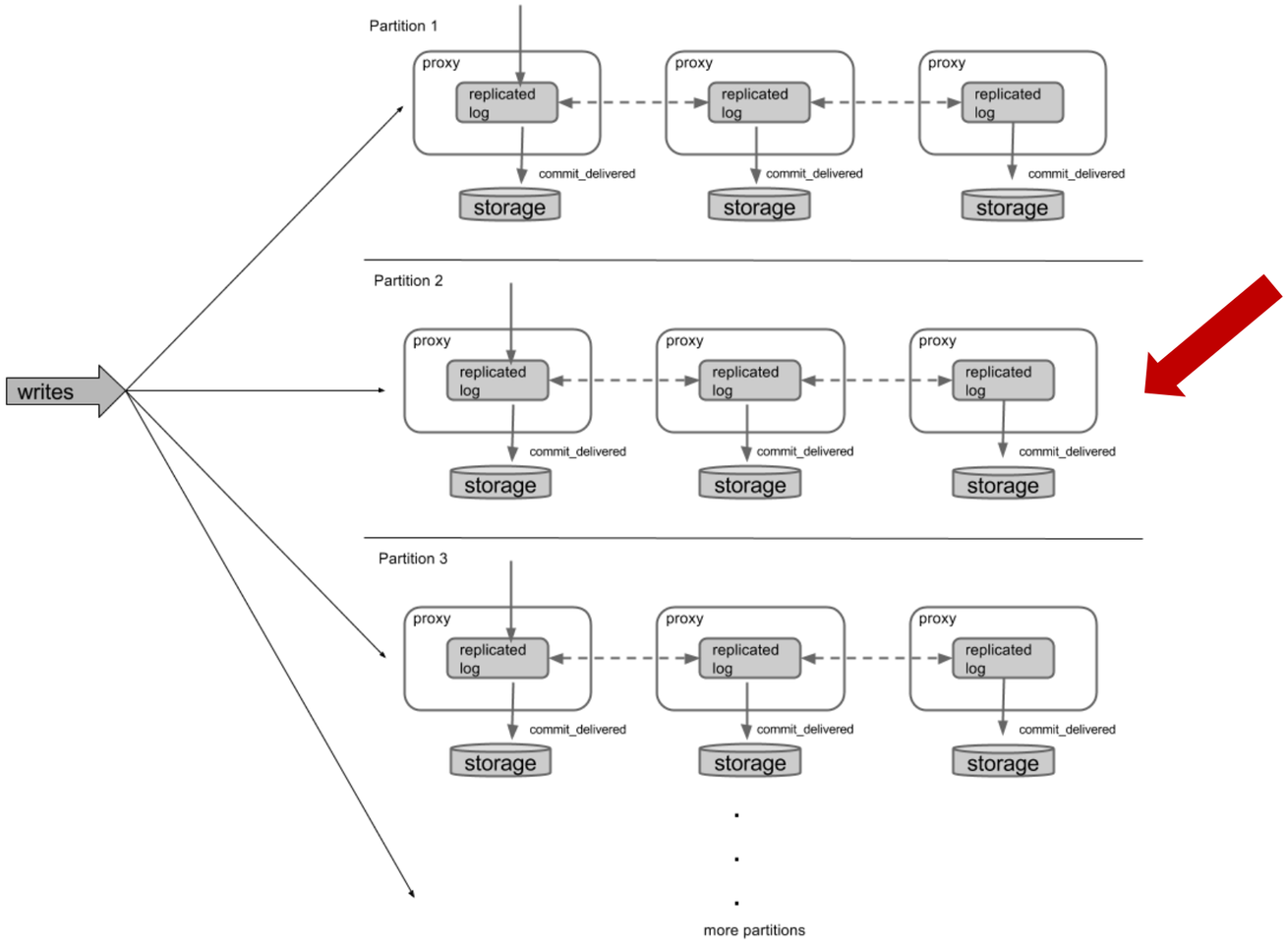


CROSS DC SET-UP

	Leader and its majority are in the same DC	**Leader and its majority are in DIFFERENT DCs.**
Requester and leader are in the same DC	Intra-dc latency	one xdc roundtrip
Requester and leader are in DIFFERENT DCs	one xdc roundtrip	two xdc roundtrips



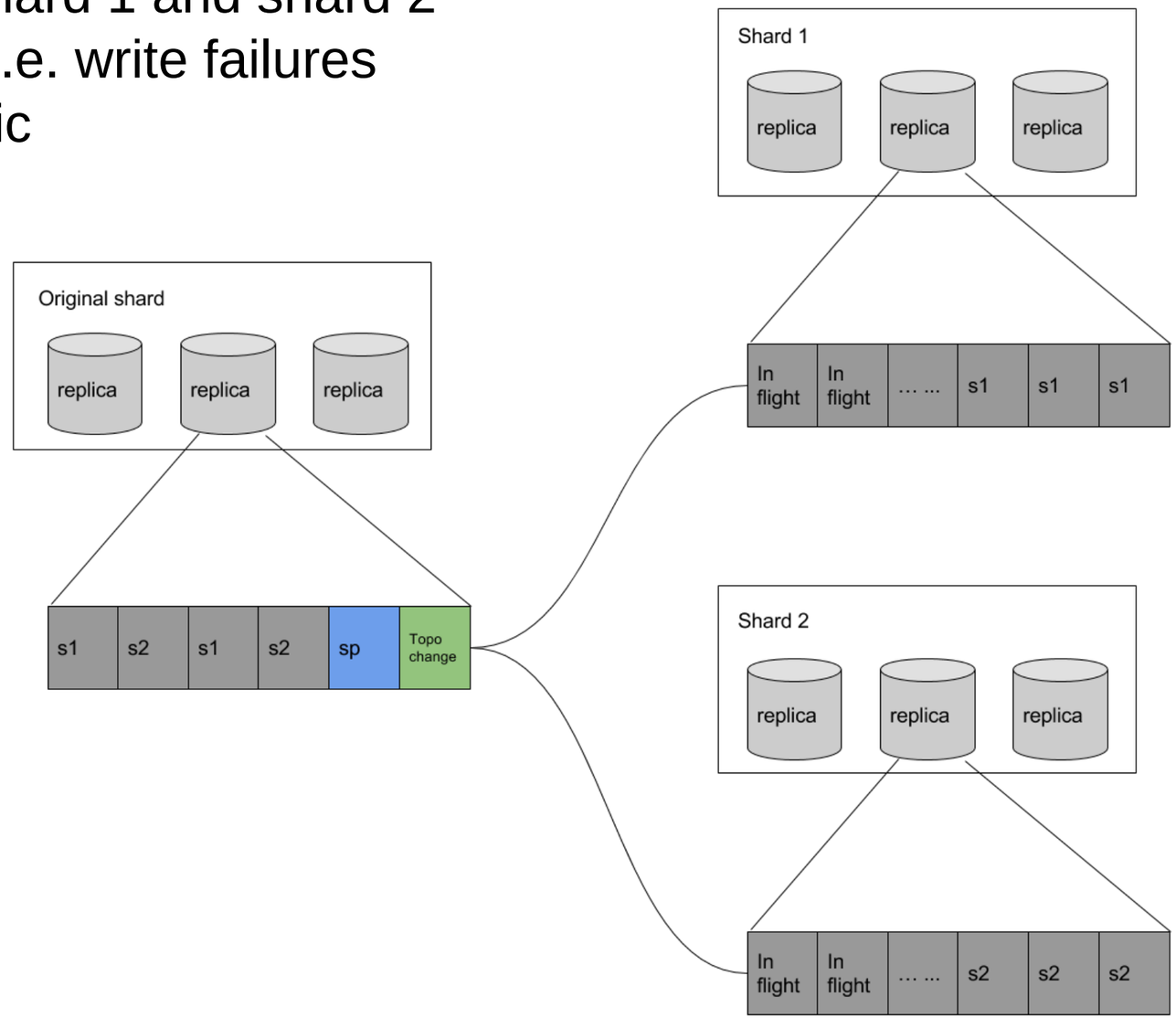
SHARD SPLITTING



Extending capacity??

SHARD SPLITTING

Split original shard into shard 1 and shard 2
- Very short ‘downtime’, i.e. write failures
- No need to stop the traffic
- Split is idempotent



FUTURE WORK

Coordinated Transaction among Replicas

- Cross-shard transactional update

Multiplexing Raft

- Move shard around Raft clusters

THE TEAM

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https://www.uber.com/careers/

THANK YOU

On behalf of Uber Storage Platform