Leader or Majority: Why Have One When You Can Have Both? Improving Read Scalability in Raft-like Consensus Protocols

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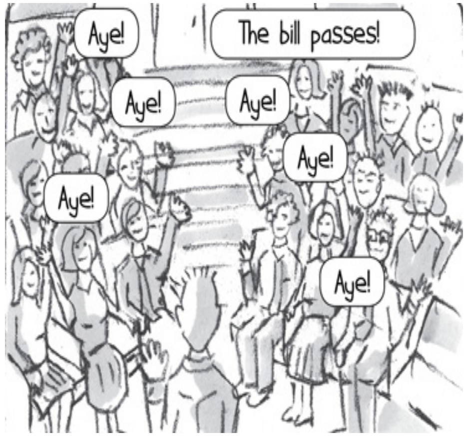
Large-Scale Distributed Systems

- Large-scale distributed systems are now ubiquitous
- Advent of the cloud have made them more accessible
- Failures are now the norm, and have to be dealt with

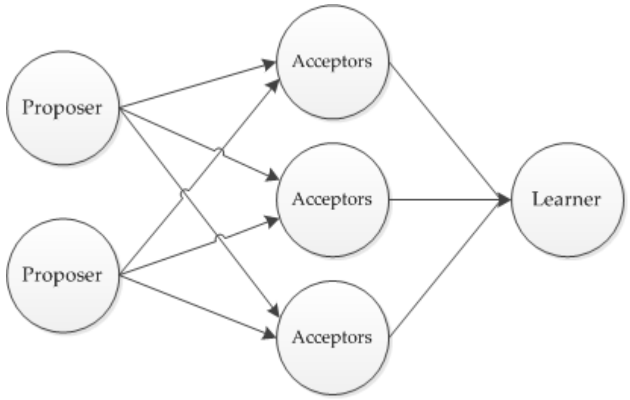
Replication and Consensus

- Large-scale distributed systems need to be fault tolerant
- Replication is a technique to achieve fault tolerance
- Replication brings in added complexity in synchronizing multiple data copies
- **Consensus Protocols**
  - Allows set of Replicas to act as a coherent group
  - Goal is to have multiple processes agree on a common value
  - Quorums – Minimum number of votes to make a decision for a collection of processes

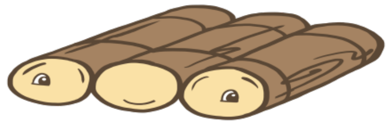


Consensus Protocols

- **Paxos** and variants
  - Classic Paxos, Multi Paxos, Fast Paxos
  - Widely used in recent large-scale distributed systems
    - GFS, Megastore, Spanner, Ceph etc



- **Raft**
  - Designed with the goal of understandability
  - Separates Leader election and Log replication



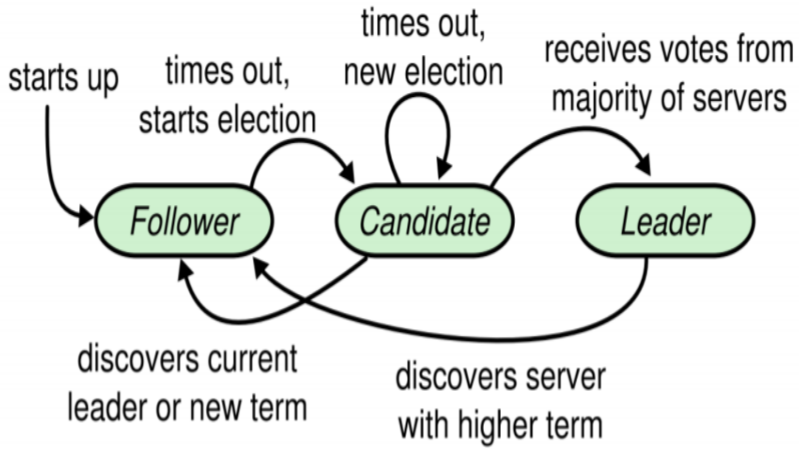
Consensus Protocols – Read Optimization

- Many applications need **Linearizable** reads.
  - Our industrial partners, Huawei, have these demands too
  - Consensus protocols can help provide these guarantees

- Variants for read-optimized settings
  - Master Leases – Multi-Paxos
  - Quorum Leases – SOCC 2014
  - Read-Optimization in Megastore – Read-any, write all

Raft

Leader Election



Log Replication

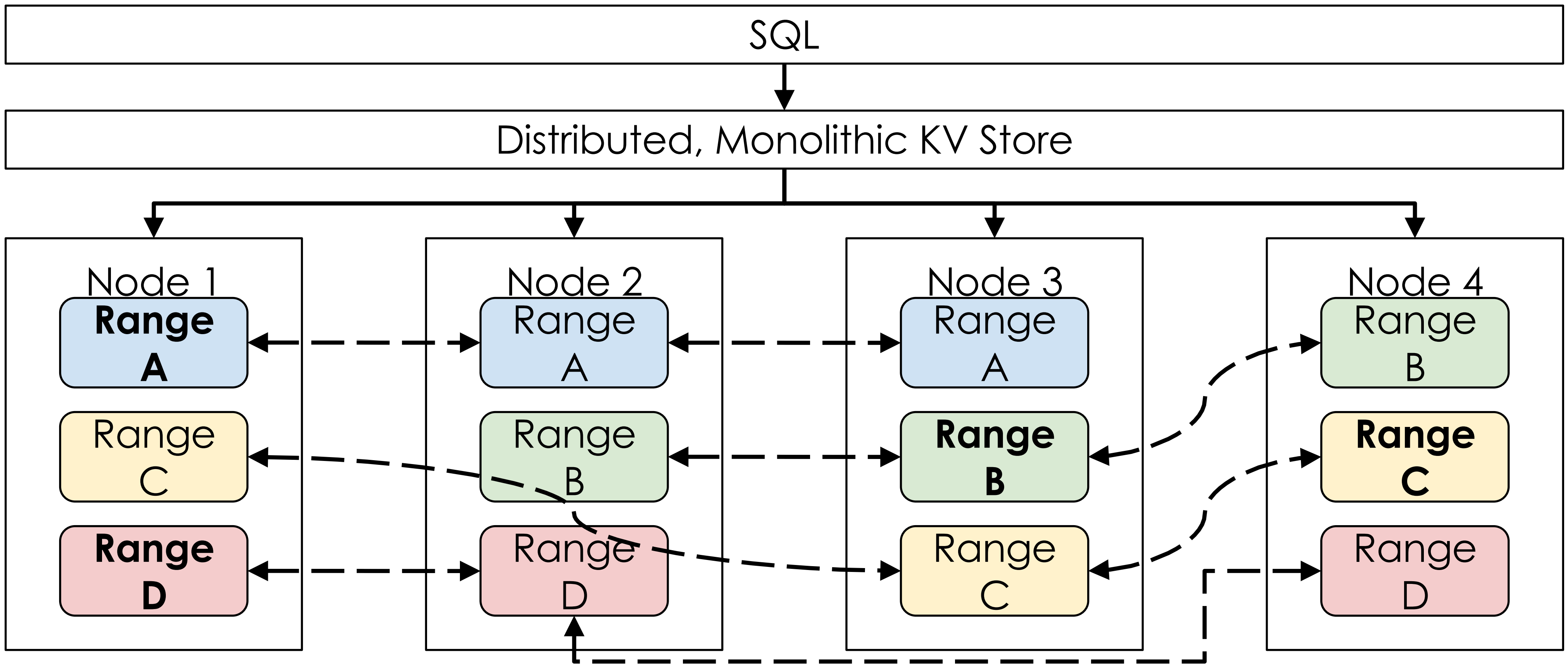
- Leader proposes a value to the cluster
- Followers accept the proposal and reply
- Leader waits to hear from a majority, commits the value locally and notifies the cluster
- Followers also commit the value

Linearizable reads at the leader – wait a round of heartbeats

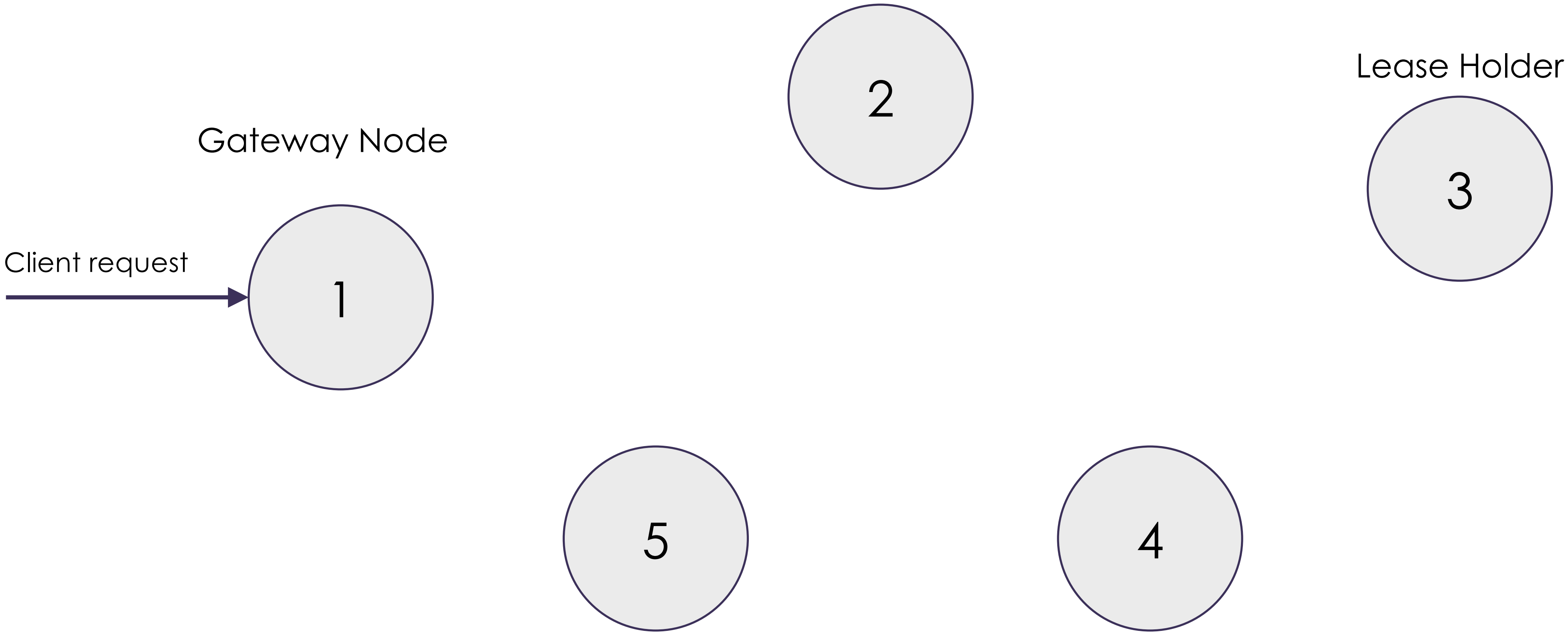
CockroachDB

- An open-source, fault-tolerant, strongly consistent, scale-out SQL database
- Inspired by Spanner
- Storage
  - Data sorted as single monolithic key-value map
  - Divided into partitions / ranges replicated by Raft
- Lease-Holder – Non-overlapping leases

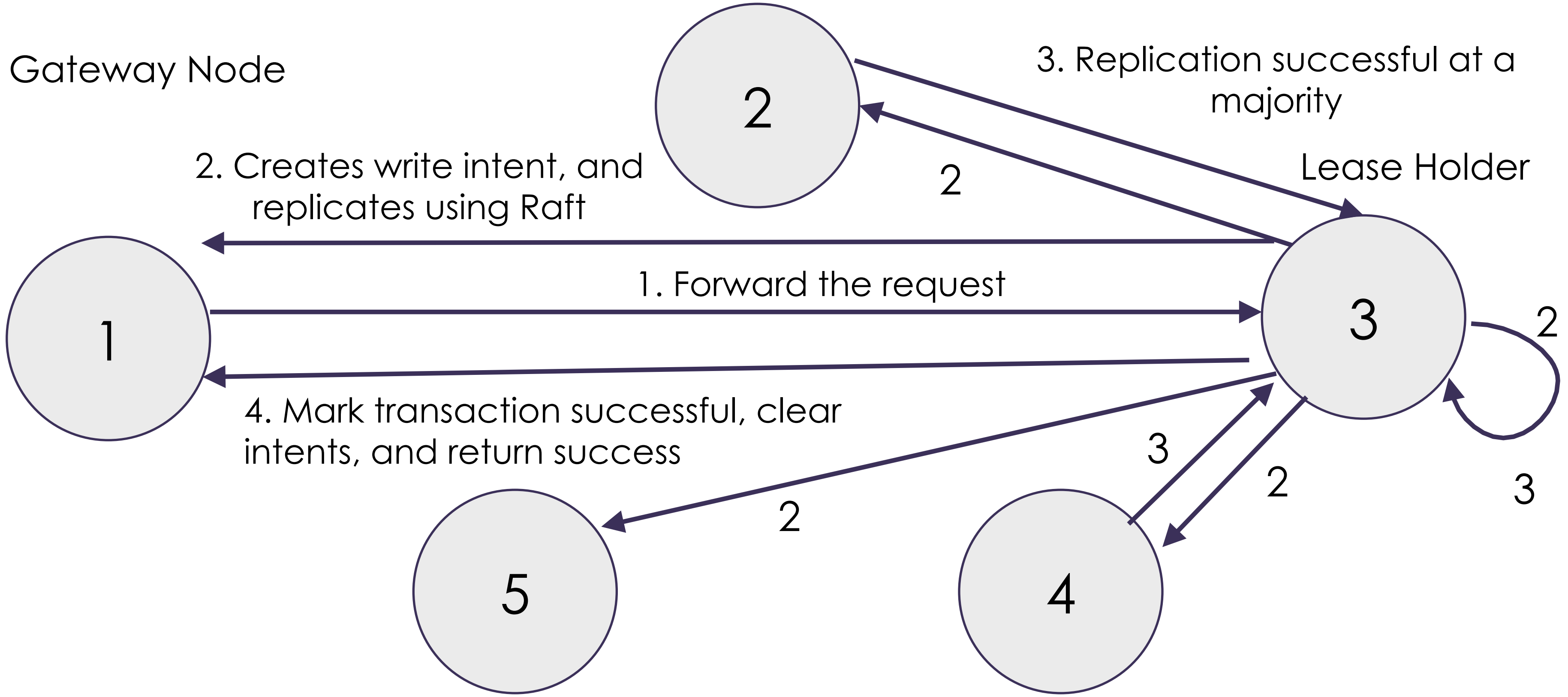
Logical Overview of CockroachDB



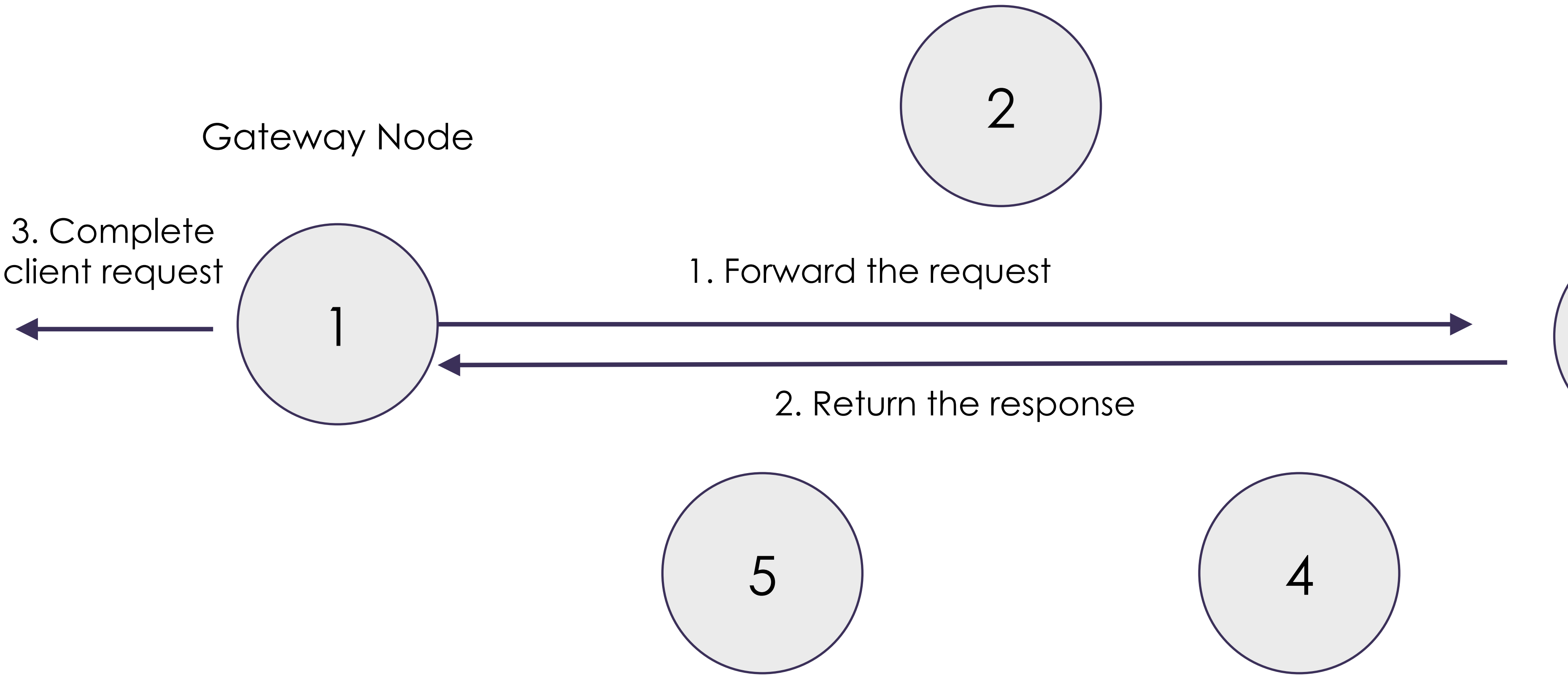
Journey of a Request



Write Request



Read Request



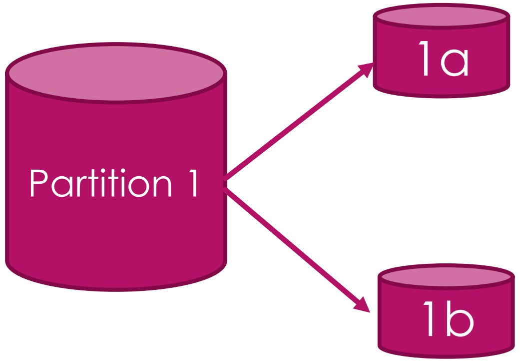
If there is write intent, based on priority:

- Abort
- Wait until intent is cleared

Bottleneck to Read Performance

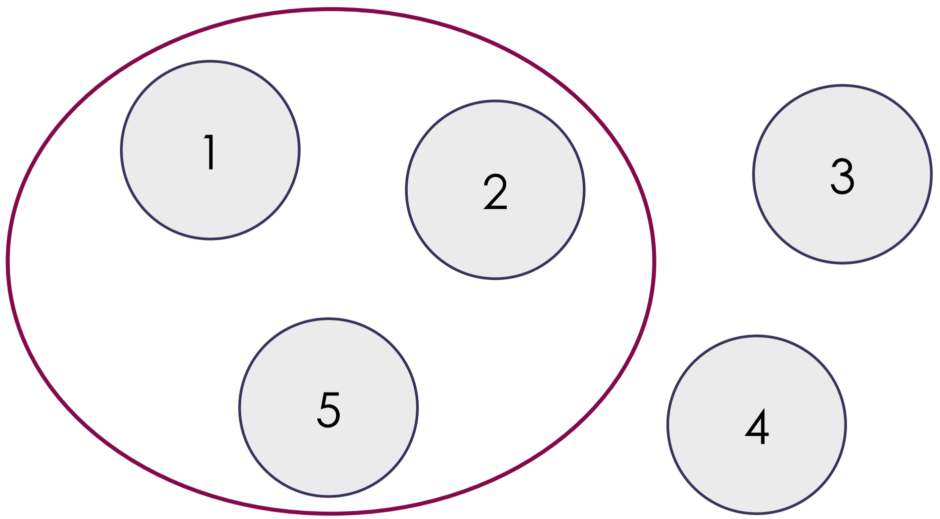
- Reads are executed at the Lease-holder
- Overloads Lease-holder
  - Can be reduced by partition / range splitting – but this has many challenges - percentage of distributed transactions across ranges increases, find the right partitioning strategy is hard, hotspot partitions will still cause read bottlenecks
  - Followers are cold standbys during failure-free scenarios
- Can we use the follower nodes for Linearizable reads ?

And optimize for read-heavy workloads ?



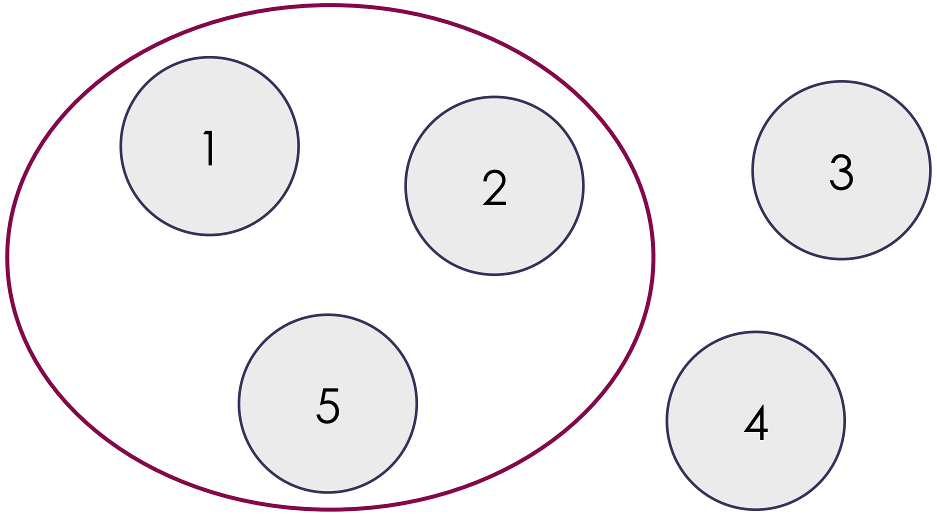
Improving Read Scalability

- Raft uses Majority Quorums to **commit writes**
- We exploit this fact to read from **a majority quorum**
- Combine with Lease-holder reads

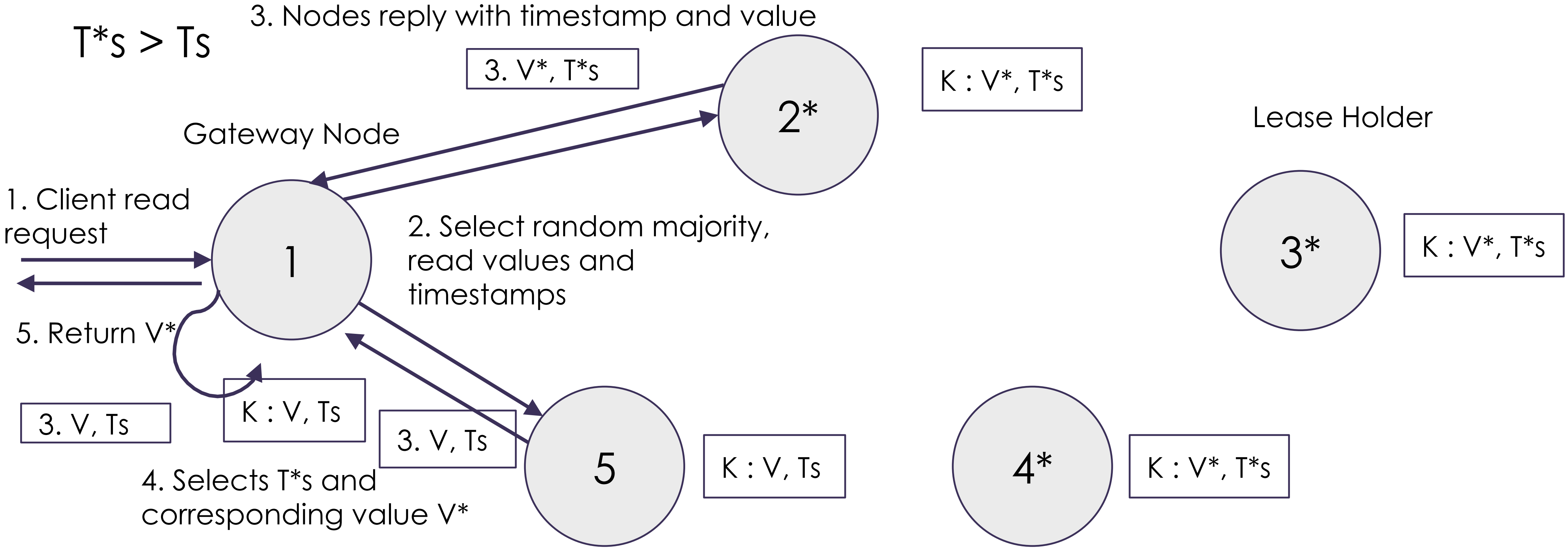


Quorum Reads

- Send read requests to a majority of nodes
- Every node replies with latest stable value with corresponding timestamp
- Choose the value with latest timestamp



Quorum Reads



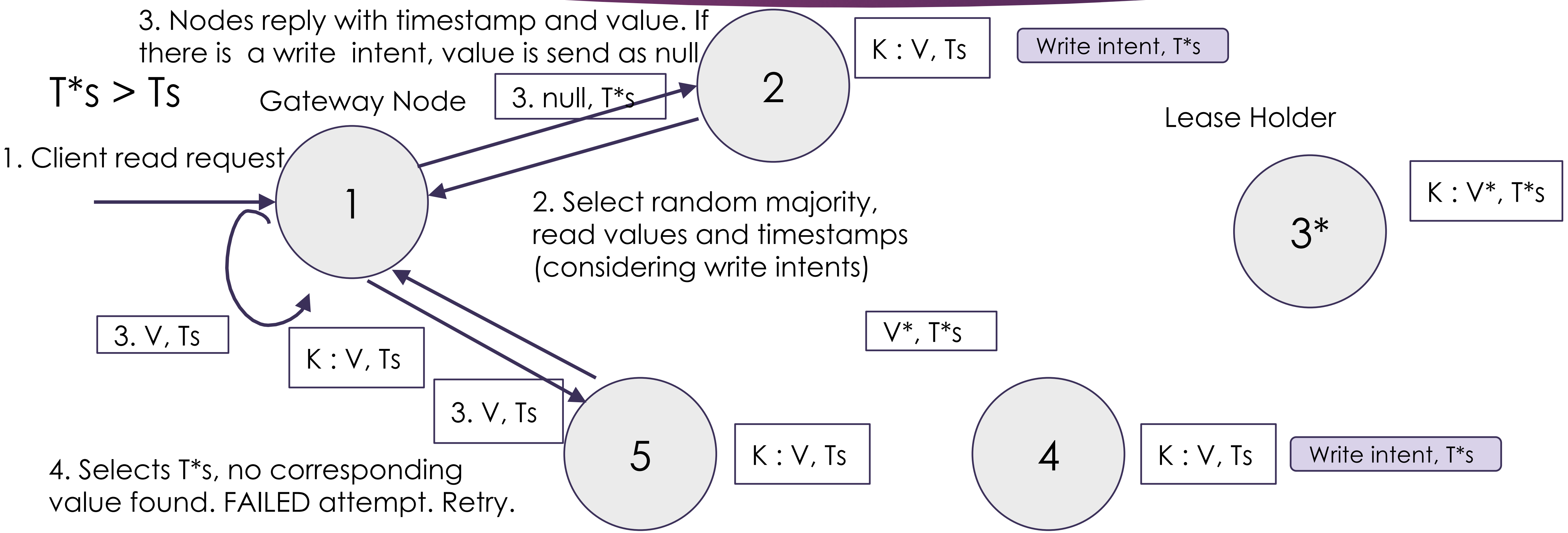
Strongly Consistent Quorum Reads

- **What if there is an ongoing request committed at the Lease-holder ?**

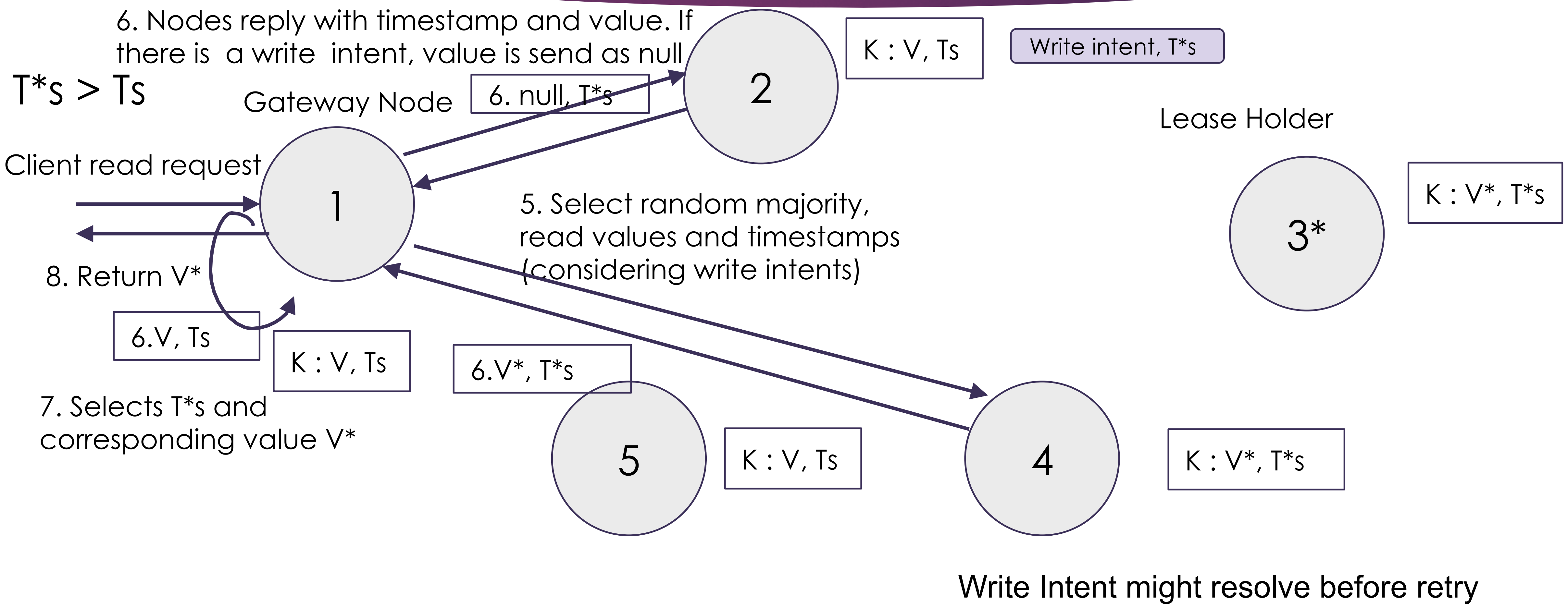
- **Strongly Quorum Reads**
  - Use Write intents to detect ongoing writes
  - In case of conflicting writes, every node replies with timestamp and no value
  - At gateway node, if there's no value corresponding to latest timestamp, retry with a backoff

- This approach can serve linearizable / strongly consistent reads

Strongly Consistent Quorum Reads



Strongly Consistent Quorum Reads



Combining Lease-holder Reads and Quorum Reads

- Lease-holder can always read from local store
- Non lease-holders can read from:
  - Lease-holder, or
  - Majority
- To uniformly distribute read requests over all nodes, assuming:
  - a cluster of ***n*** fully replicated nodes
  - every node gets equal no. of read requests
  - a node always includes itself for majority

A gateway node can use lease-holder for ***x%*** of total reads, and quorums for others

$$x = \frac{P*(n-2)}{n+P*(n-2)} \times 100$$

where ***P*** is probability of a non lease-holder node being included in a majority by other non lease-holder nodes

$$P = \begin{cases} 1 & n = 3 \\ \frac{\binom{n-3}{\lfloor n/2 \rfloor - 1}}{\binom{n-2}{\lfloor n/2 \rfloor}} & n > 3 \end{cases}$$

Provides ability to trade-off read & write latencies

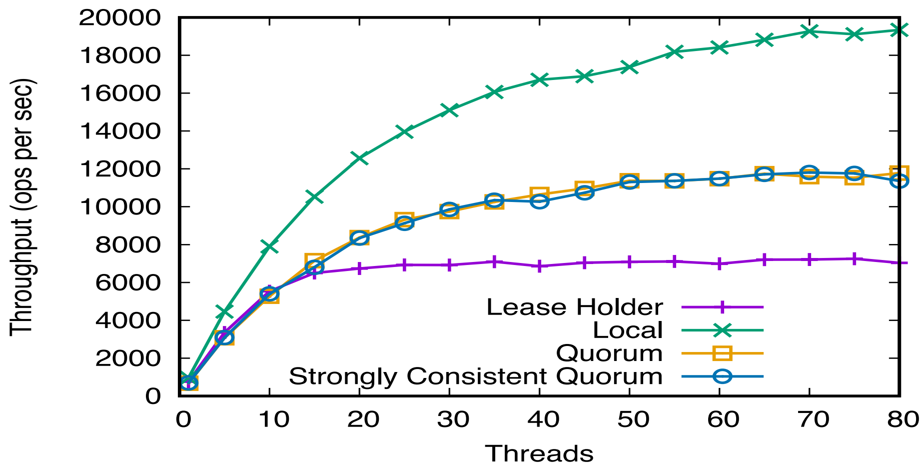
Evaluation

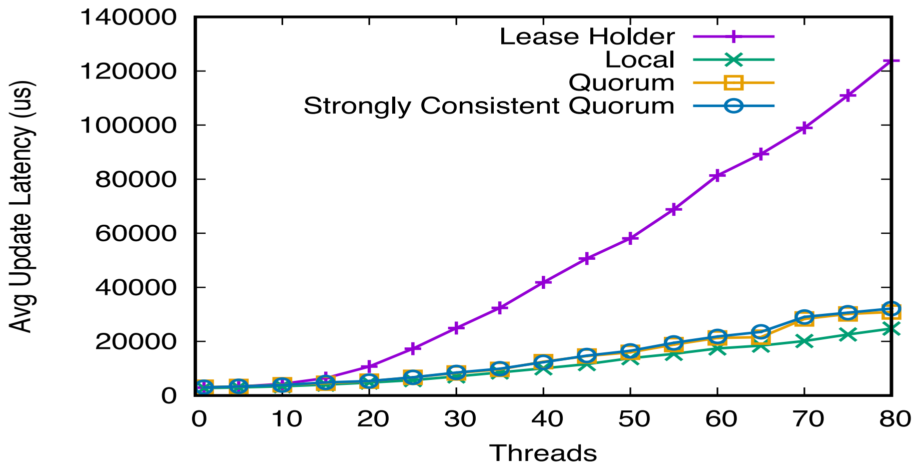
- The proposed approaches are integrated within CockroachDB. Available on GitHub.
  https://github.com/vaibhavarora/cockroach/tree/raft-read-scalability
- YCSB Workload. Dataset of 100K items with (key, value)
- CockroachDB cluster of 5 AWS EC2 machines (m3.2xlarge instance type). 1 machine for YCSB clients
- 4 different read strategies
  - **Lease-holder reads**
  - **Local reads** – an upper bound on performance
  - **Quorum reads**
  - **Strongly consistent Quorum reads**

Uniform read distribution throughout the cluster – **28% lease-holder reads** for both proposed quorum read approaches

Scaling Clients

Uniform workload (95% reads, 5% writes)





Improvements with Quorum reads :

~4x write latency

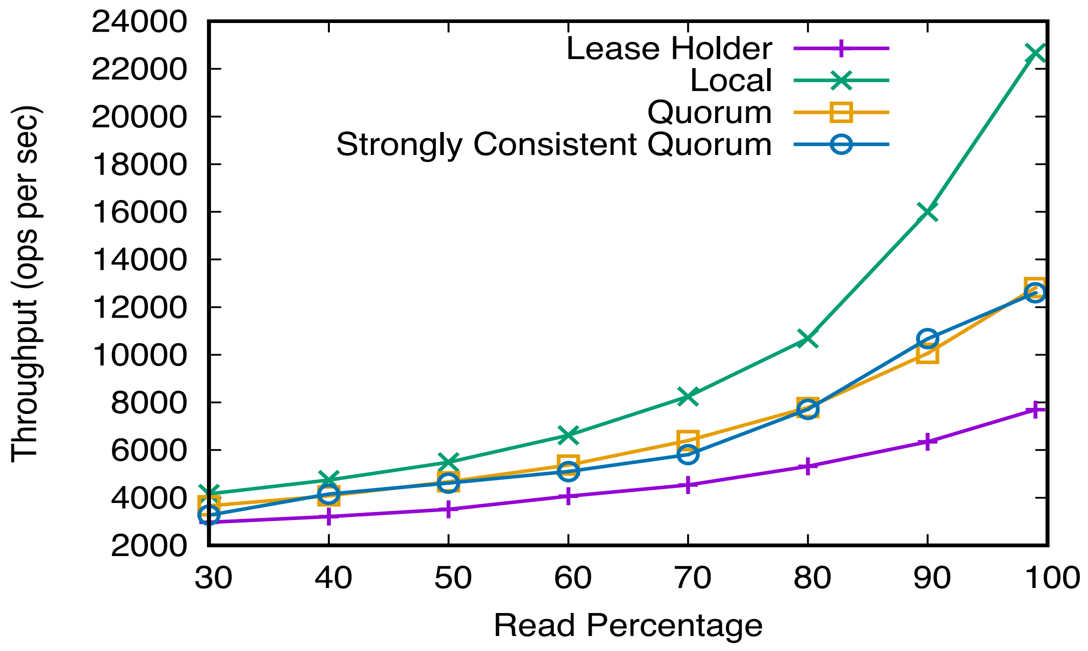
~60% throughput

Varying Read-Write Ratio

- Uniform workload
- **Varying read requests** (30% to 99%)
- 70 client threads

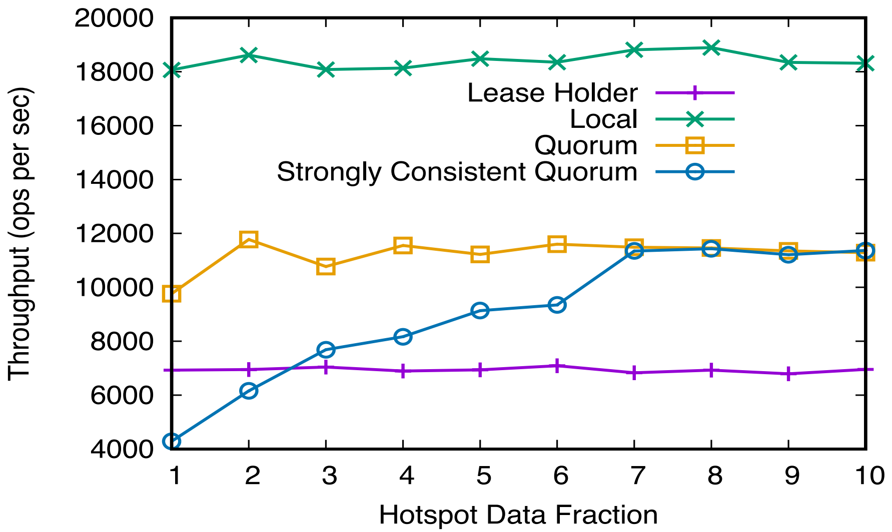
Higher the read %, higher is the benefit of using the quorum read approaches

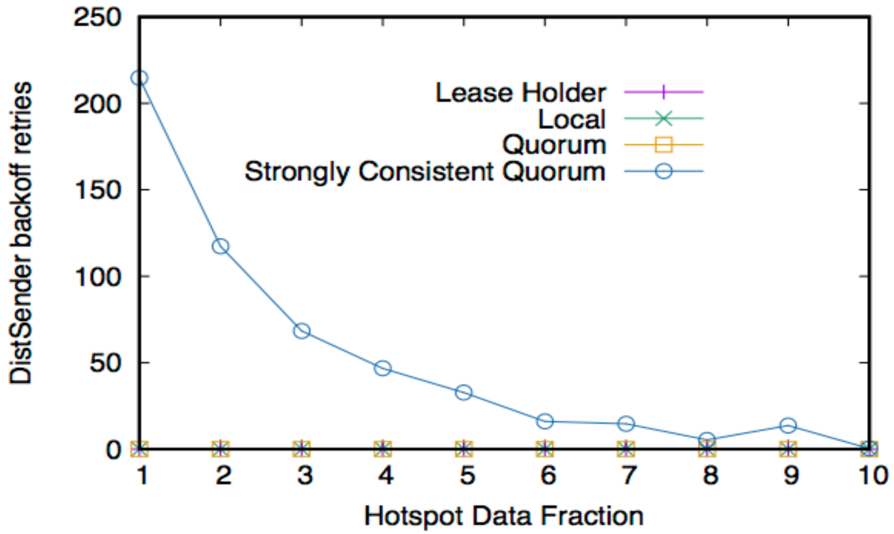
Up to **~85% improvement** in throughout using Quorum read approaches



HotSpots

Hotspot workload - 80% requests access varying data (1% to 10%)
(95% reads, 5% writes)

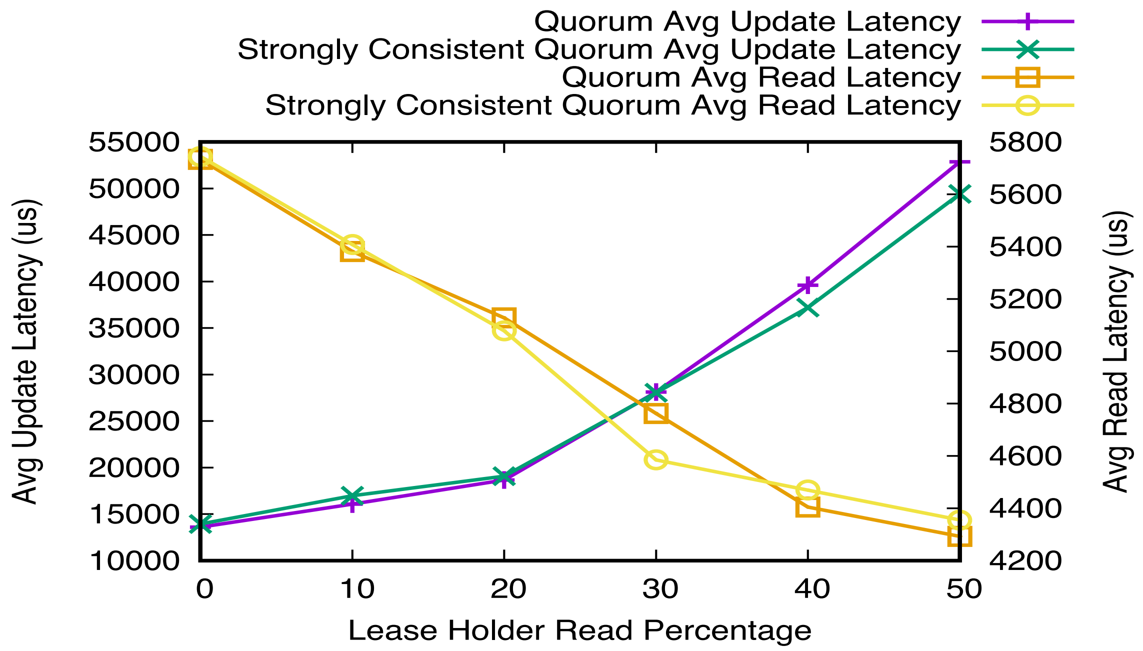




At **high contention**, strongly consistent quorum reads have a large number of **retries** because of frequent conflicts.

Read-write latency tradeoff

Varying lease-holder reads (0% to 50%)
Uniform workload (95% reads, 5% writes)
70 client threads



- **Quorum read approaches** reduce load on lease-holder, leading to **improved write latencies**
- Lease-holder reads reduce **read latency**

Read and write latencies curves Intersect near the point of **Uniform read distribution**

Future Considerations / Discussion

- Can we choose majority in a more intelligent way?
  - Use resource utilization & network latencies
- How well can quorum reads perform in failure-prone scenarios?
- Look into using strongly consistent quorum reads as part of transactional mechanisms
- Further improving read latencies – maybe for a subset of keys

Conclusion

- Proposed **Quorum read** approaches for Raft-like consensus protocols
- **Combine** them with traditional lease-holder reads
- Provide a way to trade-off between **read & write latencies**
- For failure-free scenarios with read-heavy workloads:
  - Improved throughput
  - Highly Improved **write latencies**

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