Fast Transaction Commit in Sharded Data Stores*

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- Social issues in online social networks
- Theory and practice for integrated cloud, fog and edge computing paradigms
- Blockchain technology and theory
- Large-scale distributed systems and middleware
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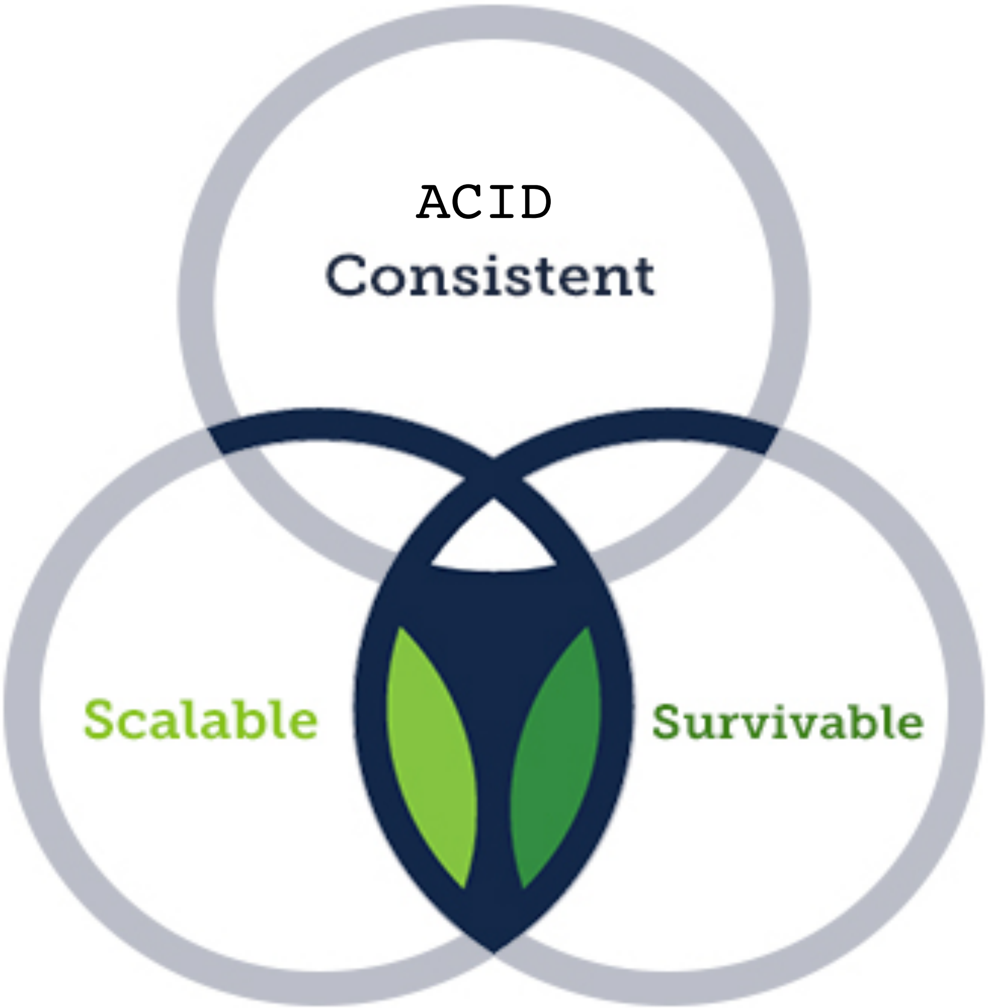
Not Only SQL

No More

Not **O**nly SQL

Modern Data Stores



Modern Data Stores

Google Cloud Spanner

Clustrix

Cockroach DB

apache Ignite™

VOLTDB

Azure Cosmos DB

Blockchain

- Transactional semantics and fault-tolerance are non-negotiable

- Proof-of-Work (PoW): slow
  - Mining rate bounded by block propagation and validation delays

- Committee Consensus (PBFT)
  - Fast but bandwidth bound

Scaling Blockchains

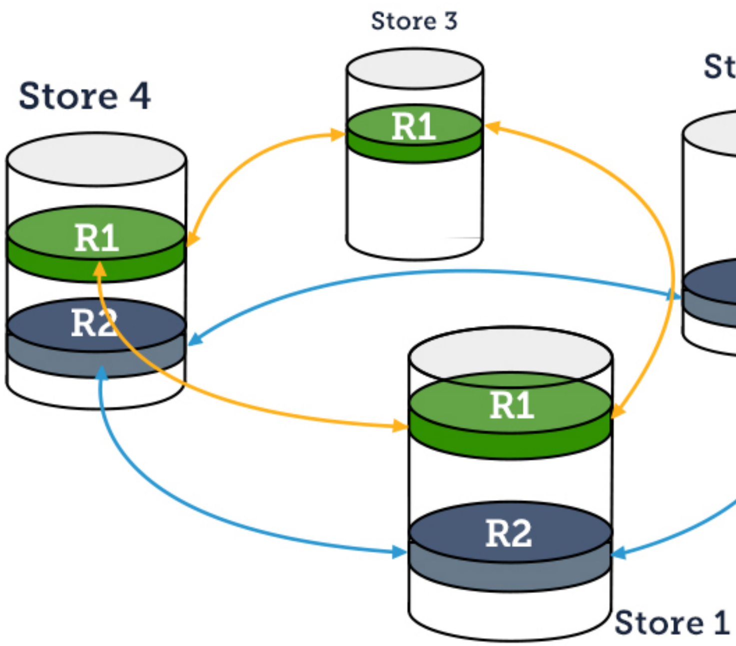
- Hybrid blockchains
  - PoW to elect and maintain a committee
  - Algorand, etc.

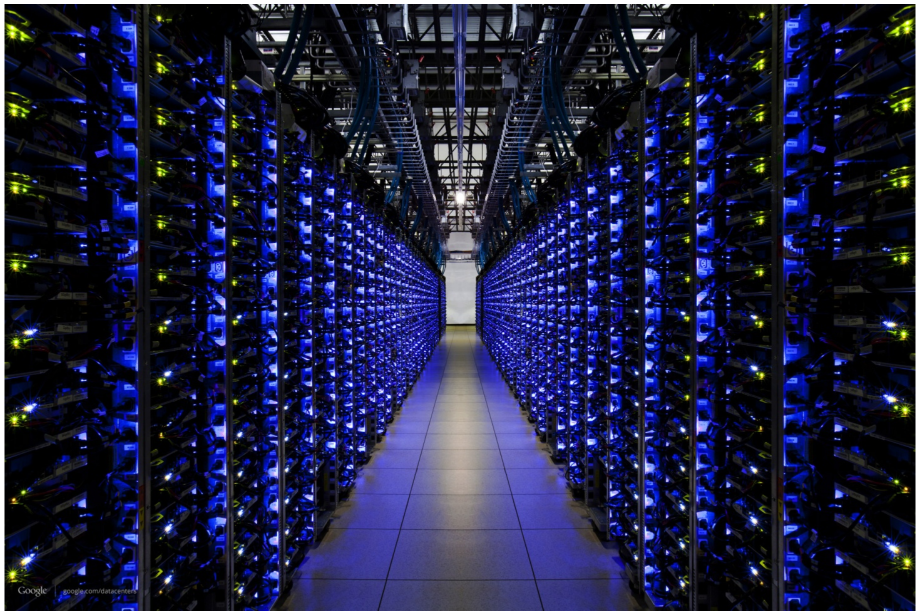
- Permissioned blockchains
  - Separate tx execution, ordering and state
  - Delegate ordering to the committee

- How to scale the committee?

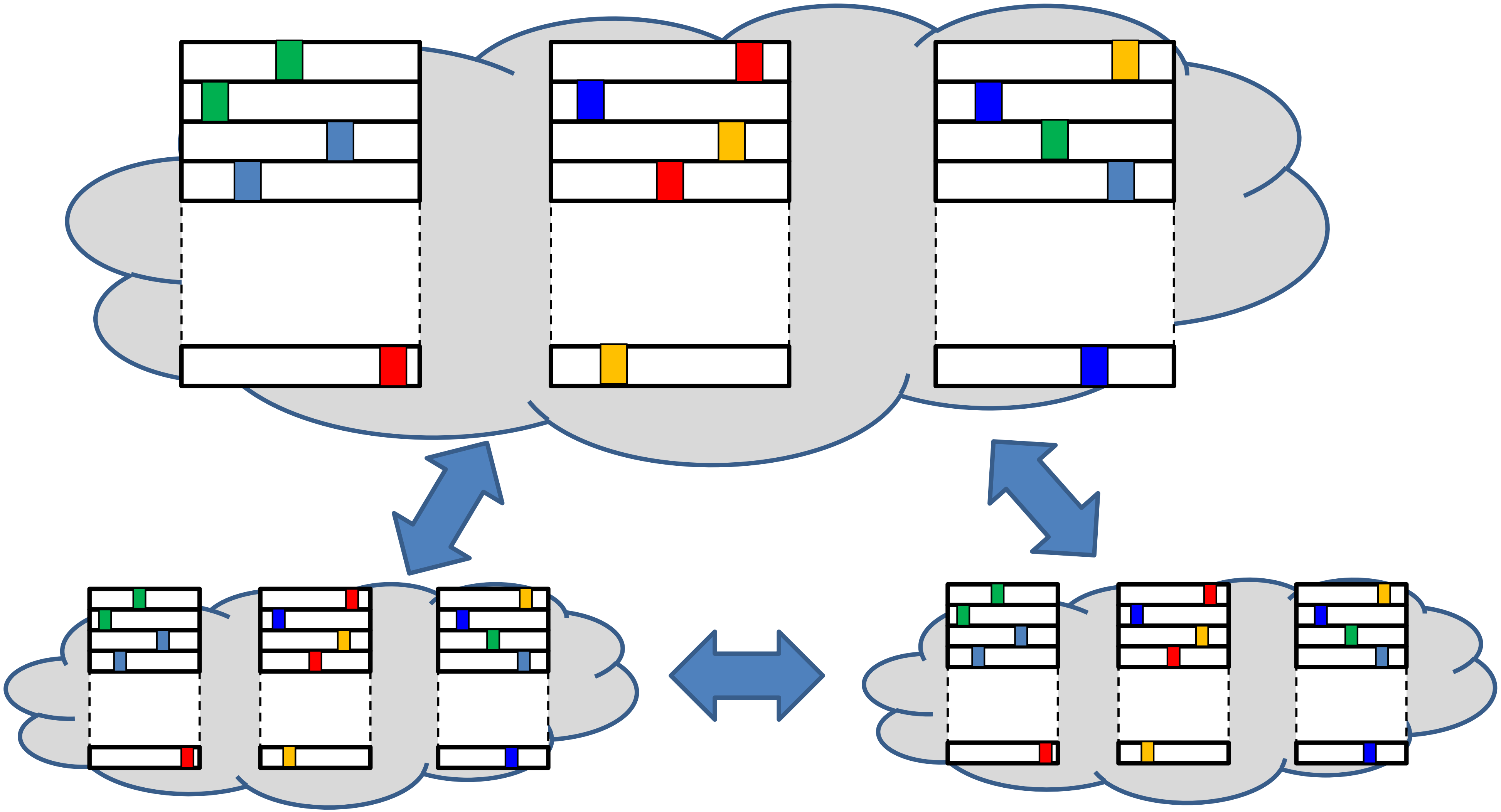
Horizontal Scaling

- Data sharding and replication

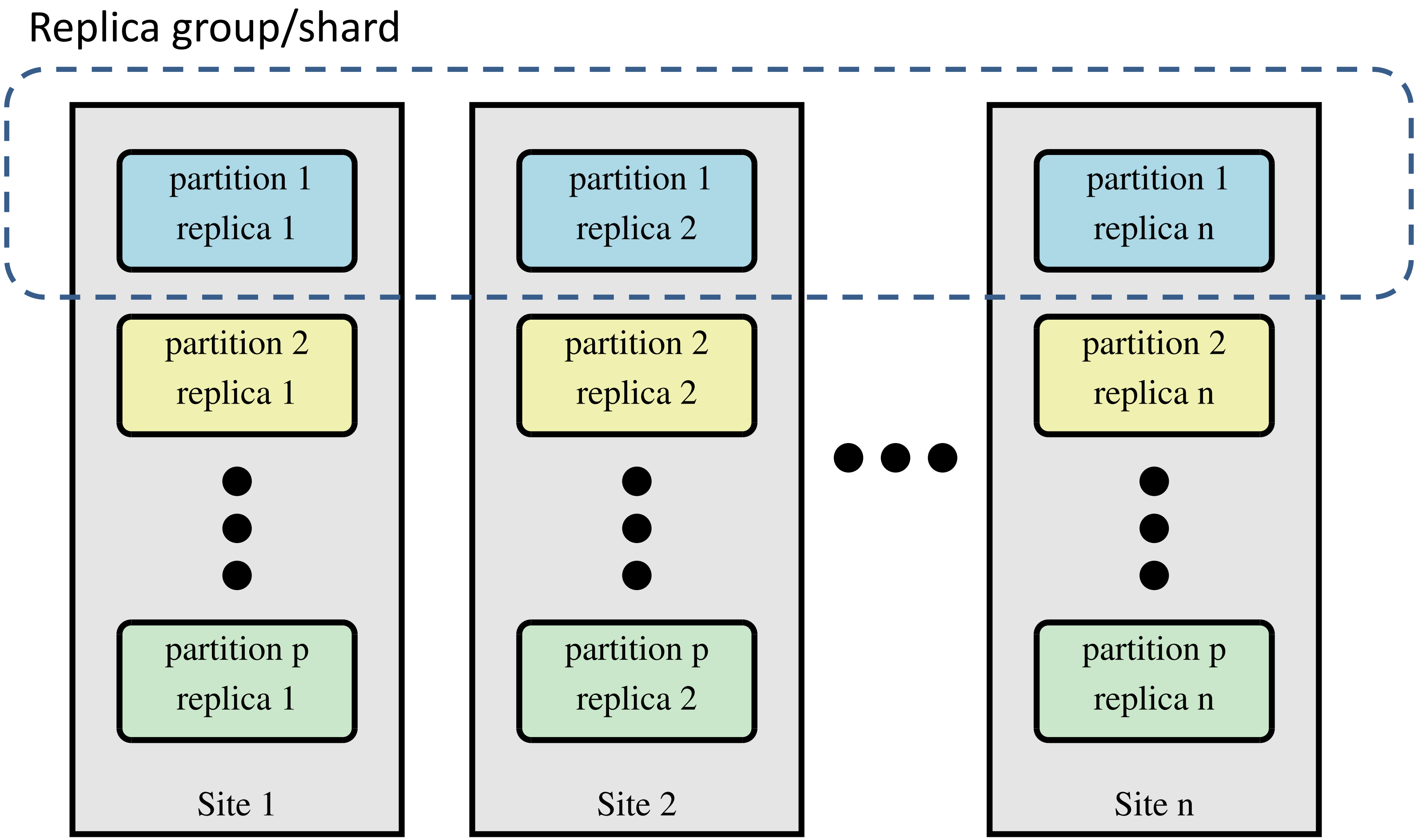




Replicated Sharded Data Store



Abstract View



Agrawal, El Abbadi, Salem, A Taxonomy of Partitioned Replicated Cloud-Based Database Systems

Sharded Transactional Store

- Full ACID semantics for transactions
- Transactions can span multiple shards
- Servers should only process transactions involving the shards they store
- Unlimited concurrency
- Up to f servers can fail in every shard

How to commit a transaction?

- In a sharded (partitioned) datastore
- Touching objects in multiple shards
- Assuming reliable shards (for now)
- ACID guarantees

How to commit a transaction?

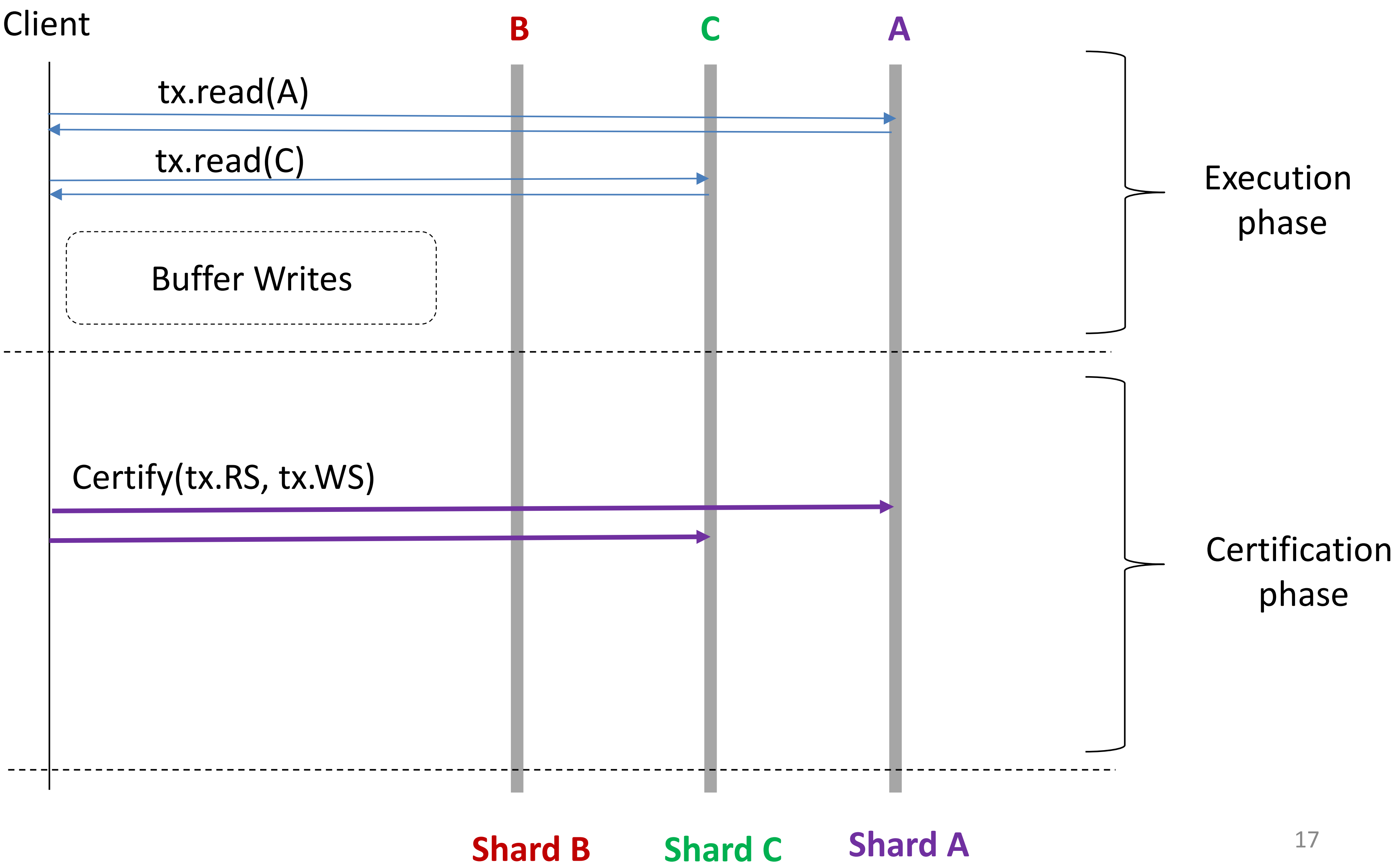
- Two-Phase Commit (2PC)
  - Coordinate distributed decision
- Concurrency control (CC)
  - Ensure a suitable isolation level

How to commit a transaction?

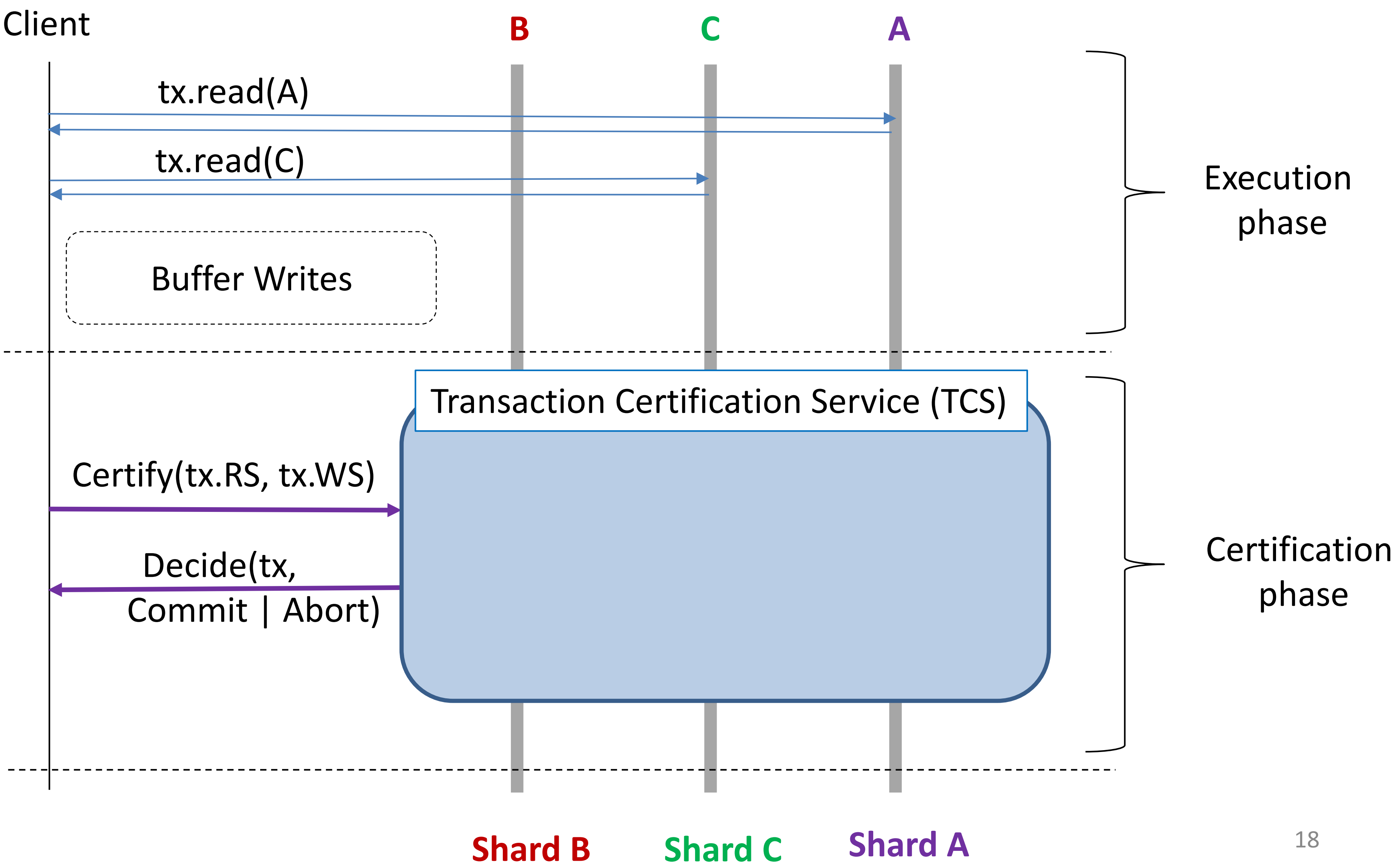
- Traditionally studied in isolation
- In reality, tightly intertwined

- We introduce a unified framework that captures both

Reliable Shards



Reliable Shards



Optimistic Concurrency Control (OCC)

- Reads can be served in any order by any replica
- Writes are buffered ("deferred")
- Certification requests carry read-set and write-set

Certification Functions

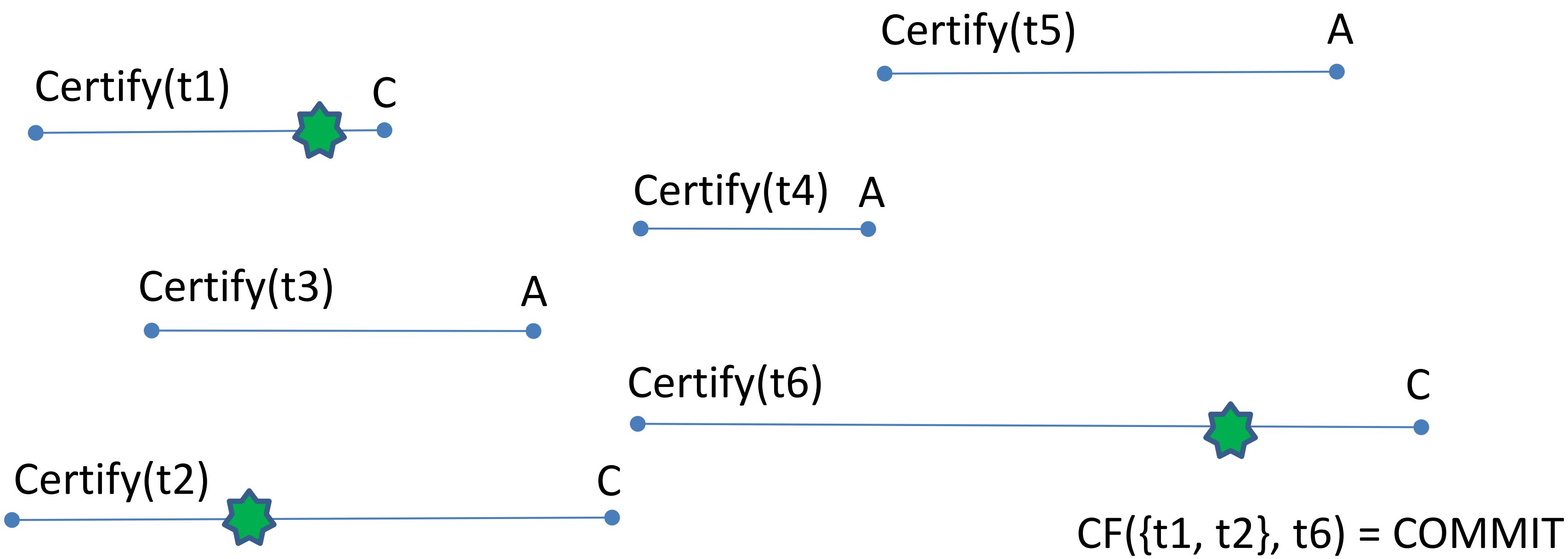
- Models conflict checks
- Determines if a transaction should COMMIT or ABORT given its context (prior committed transactions)

Serializability: $f(T, t) = \text{COMMIT}$ *iff*

$$\forall x, v.\, (x, v) \in R(t) \implies (\forall t' \in T.\, (x, \_) \in W(t') \implies V_c(t') \leq v).$$

Multi-Shot Transaction Commit

- Certify(tx), Decide(tx, COMMIT | ABORT)
- Correctness: CF-consistent linearization of committed Certify requests



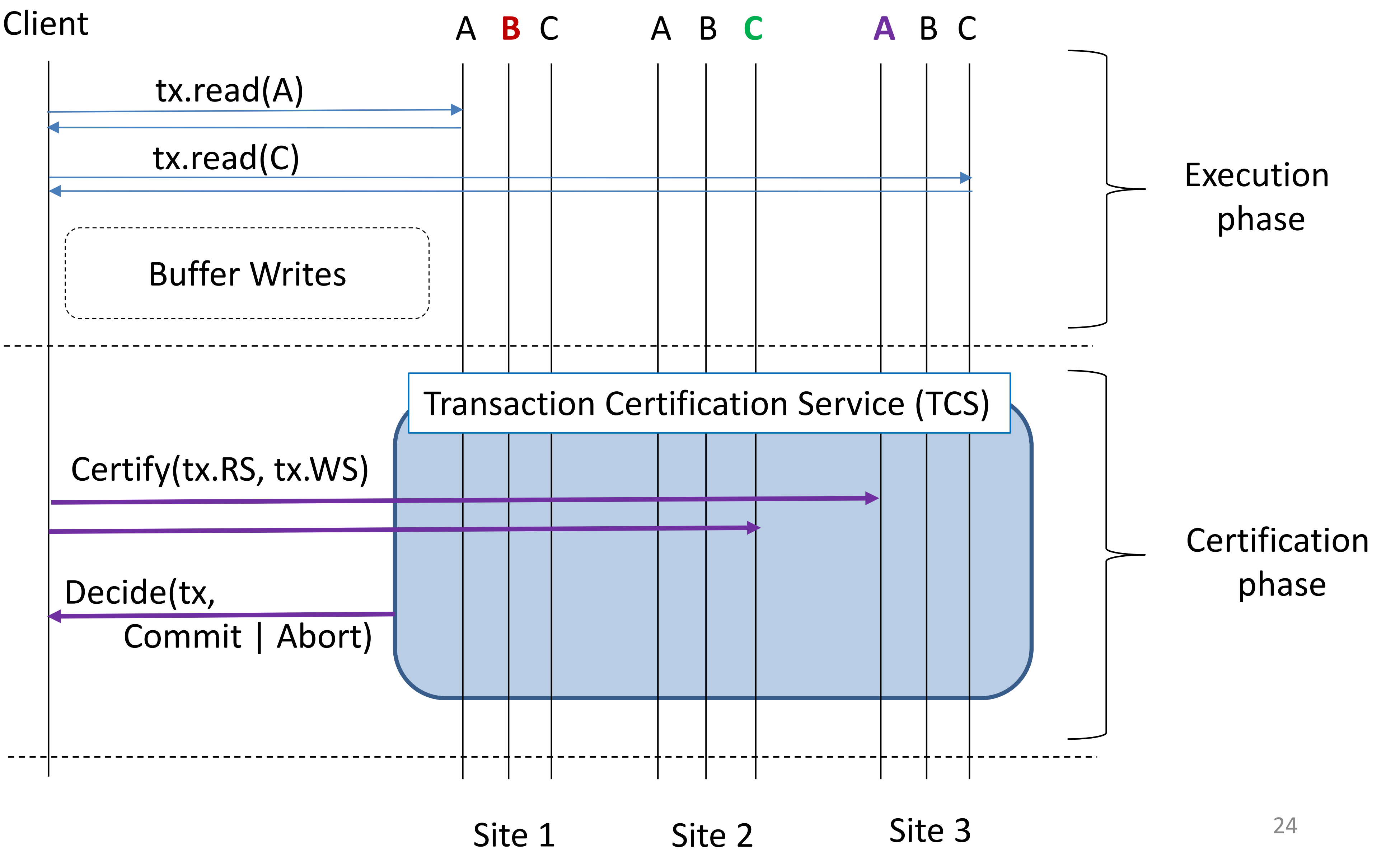
Problem Statement

- Implement a resilient TCS with a given CF
  - ≤ f servers can fail in every shard
  - Transactions can span multiple shards
  - Servers must only process transactions involving the shards they store
  - Unlimited concurrency
  - Eventual synchrony (or eventual leader)

Our Contribution

- Family of resilient cross-shard TCS protocols
- Crash fault-tolerant (CFT): 2f+1 replicas/group
  - Optimal latency, unbounded pipelining
- Byzantine fault-tolerant (BFT): 3f+1 replica/group
  - Latency matching PBFT, unbounded pipelining
  - First of a kind?
- Formal framework for multi-shot transaction commit

Setting



Client
A B C
A B C
A B C
tx.read(A)
tx.read(C)
Buffer Writes
Execution phase
Transaction Certification Service (TCS)
Certify(tx.RS, tx.WS)
Decide(tx,
Commit | Abort)
Certification phase
Site 1
Site 2
Site 3

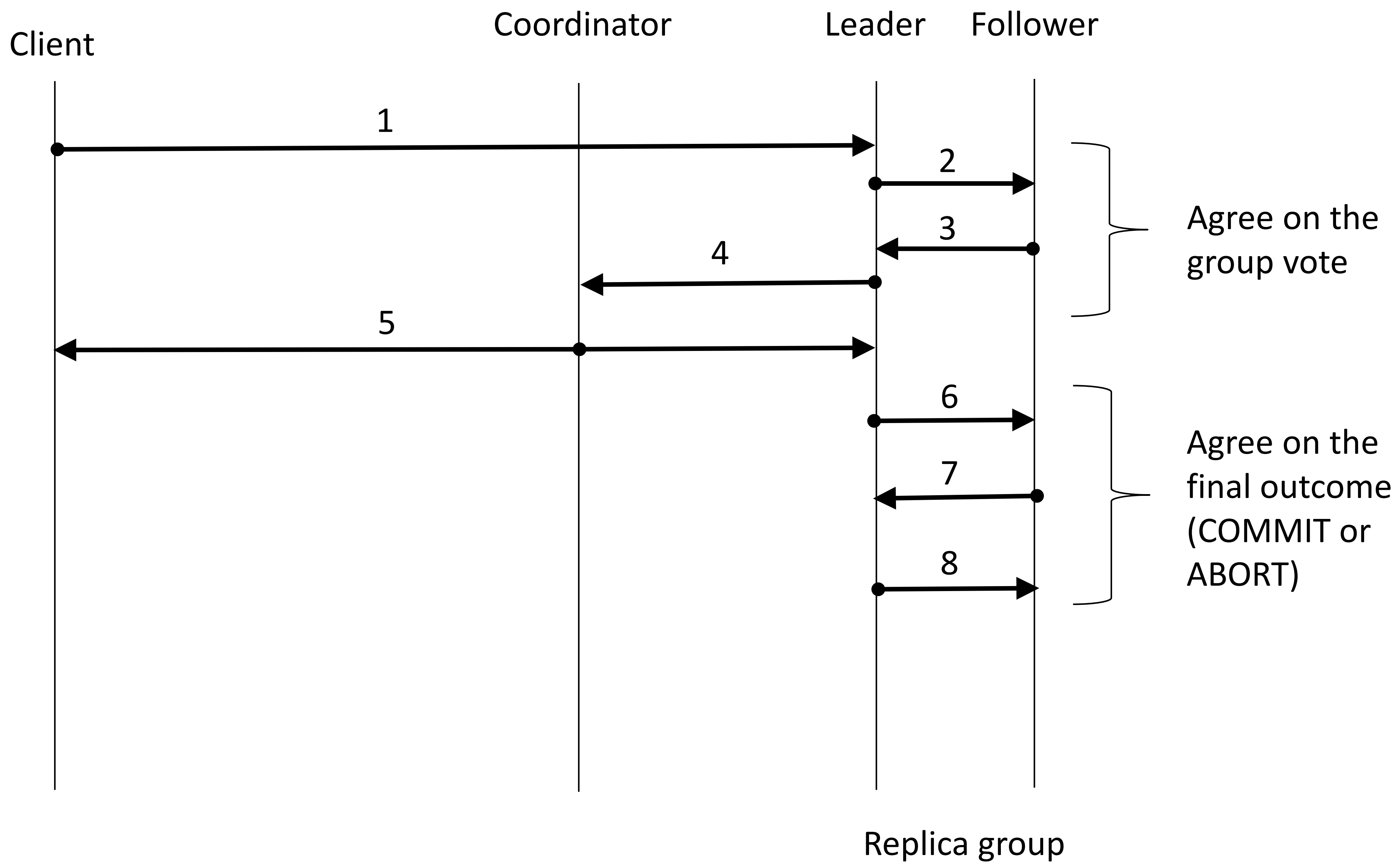
"Black-box" Solution

- Two-Phase Commit (2PC) to coordinate cross-shard transaction commit

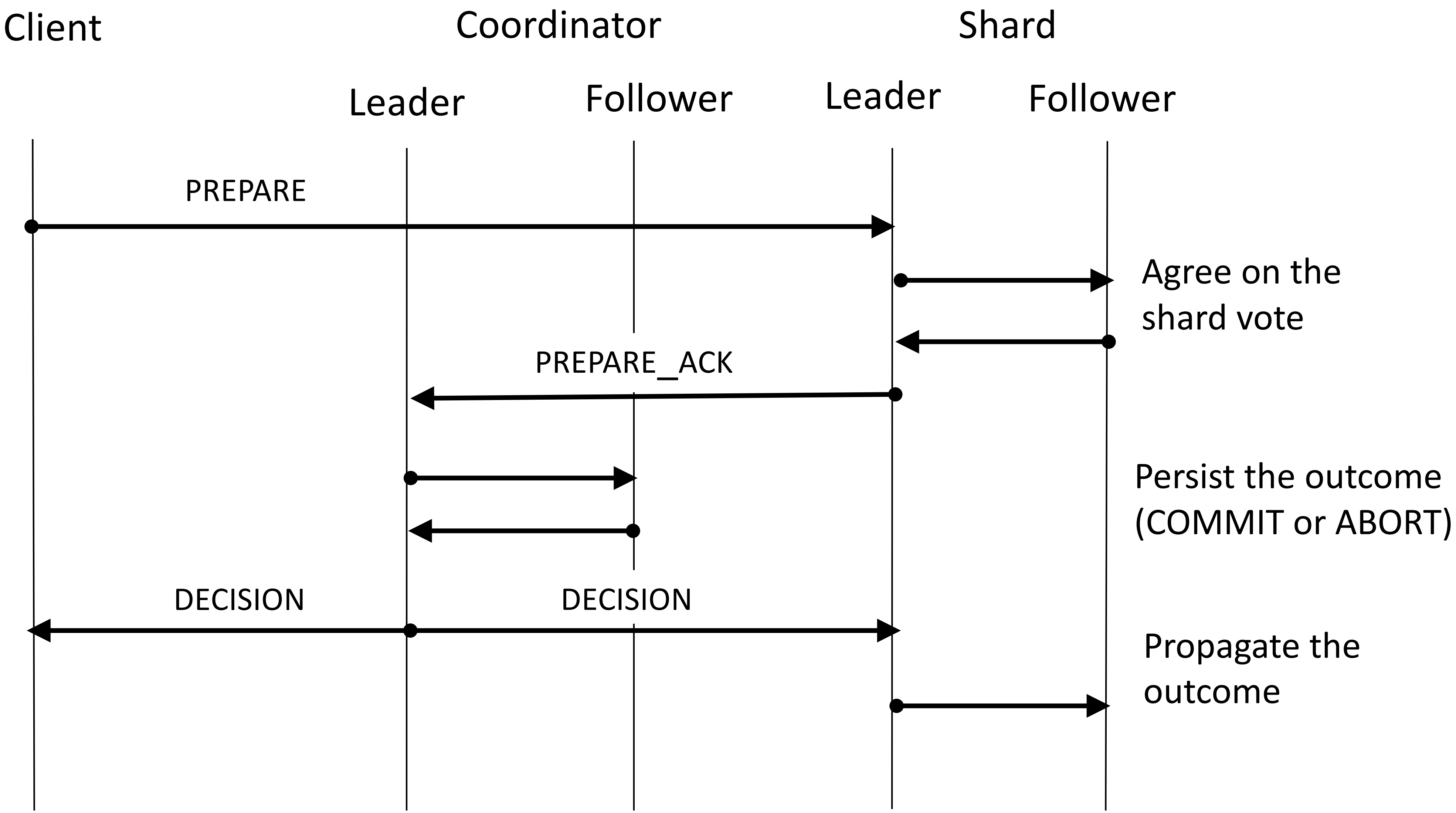
- Paxos in every replica group
  - Ordered transaction log for concurrency control
  - 2PC state for each transaction (prepared/committed/aborted)

- Examples: Spanner, Scatter, Granola, etc.

“Black-Box”: Failure-Free Case



“Black-Box”: Failure-Free Case



Goals

- Eliminate black-box abstractions
- Design single coherent protocol
- Identify optimization opportunities
  - For failure-free case

Recipe

- Abstract protocol to solve multi-shot transaction commit with reliable shards
- Refine to obtain a resilient solution for a desired failure model
  - CFT or BFT

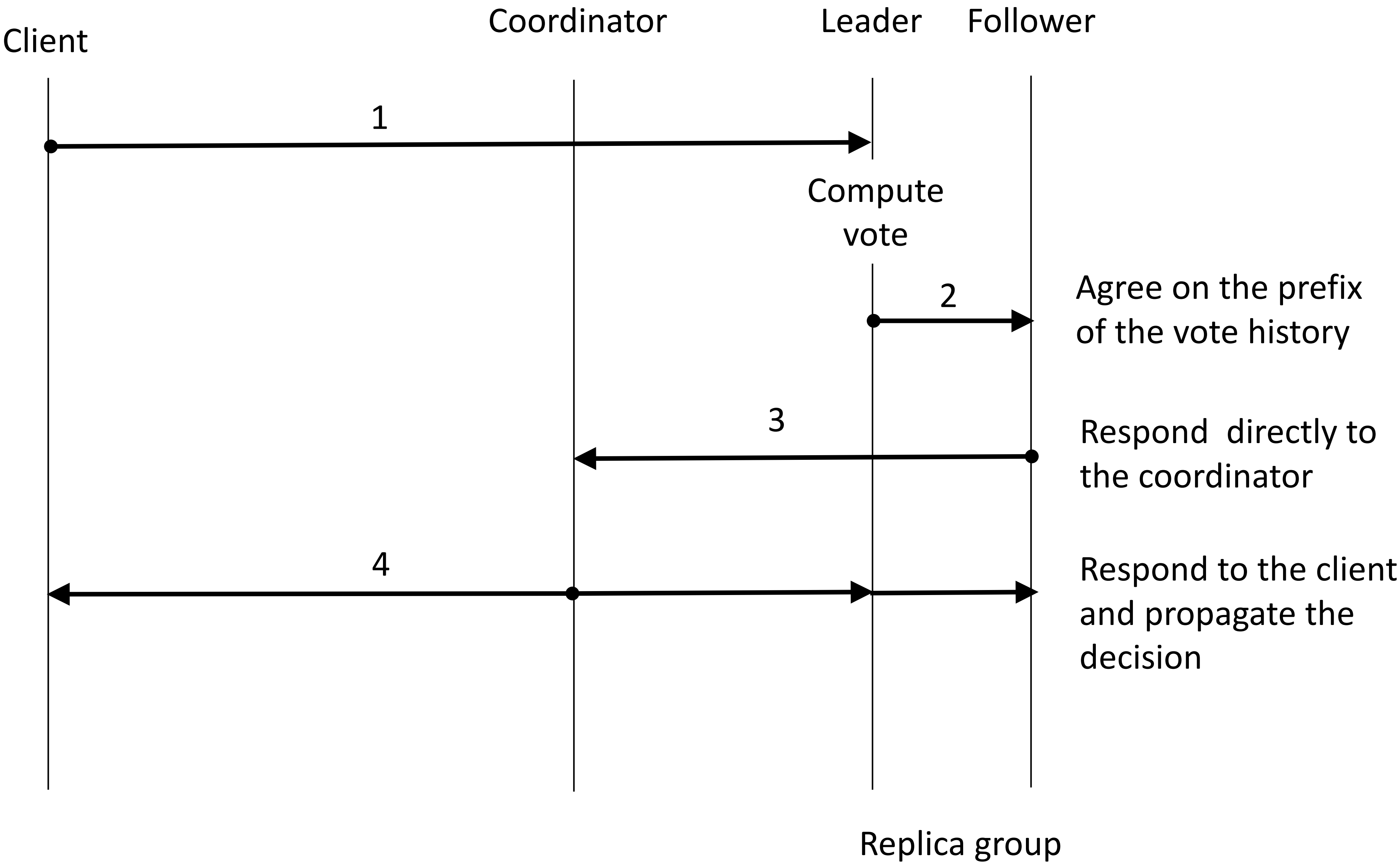
Abstract Multi-Shot 2PC

```
function certify(t)
    send PREPARE(t) to proc(shards(t));

when received PREPARE(t)
    next ← next + 1;
    txn[next] ← t;
    vote[next] ← f_{s_0}({txn[k] | k < next ∧ phase[k] = DECIDED ∧ dec[k] = COMMIT}, t) ⊓
                 g_{s_0}({txn[k] | k < next ∧ phase[k] = PREPARED ∧ vote[k] = COMMIT}, t);
    phase[next] ← PREPARED;
    send PREPARE_ACK(s_0, next, t, vote[next]) to coord(t);

when received PREPARE_ACK(s, pos_s, t, d_s) for every s ∈ shards(t)
    send DECISION(t, ⨅_{s∈shards(t)} d_s) to client(t);
    forall s ∈ shards(t) do send DECISION(pos_s, ⨅_{s∈shards(t)} d_s) to proc(s);

when received DECISION(k, d)
    dec[k] ← d;
    phase[k] ← DECIDED;
```

CFT Protocol Overview

- Maintain a contiguous prefix of the vote history (certification order) in every replica group
- Leaders can compute votes locally and persist at a majority through a consensus round
  - No need in 2nd consensus to persist the decision!
- Coordinator is stateless
  - Can learn of the votes directly from replicas
  - Can also drive a new decision without risking conflicts

CFT Protocol: Failure-Free Case



BFT Protocol Overview

- Reduce to a single consensus via certification order agreement in every replica group
- Extra message delay to verify the leader's vote
  - Vote computation verification to prevent spurious aborts
- Many-to-many exchange pattern for independent verification
- Failure-free latency is the same as PBFT

Failure-Free Case Latency

	CFT	BFT
"Black-box" TCS protocols	5 (client) 8 (decision)	N/A
Our TCS protocols	4 (client) 4 (decision)	5 (client and decision)

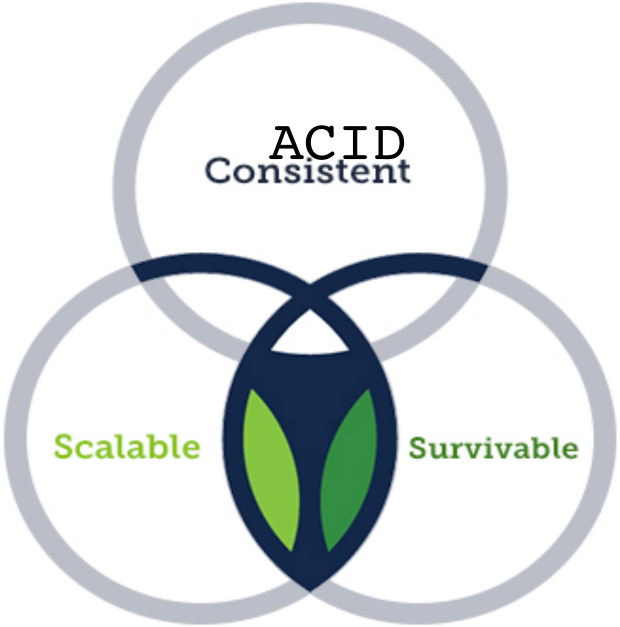
- Match latency of consensus
- Known to be optimal for CFT
  - Collocated coordinator and client
  - Use many-to-many exchange instead of leader-based protocol

Future Work

- Study complexity for different sharding strategies

- Support pessimistic concurrency control

- TCS BFT protocol for blockchain scaling
  - E.g., cross-channel transactions in Hyperledger



Thank You!