Spanner

Part II

COS 418: Distributed Systems
Lecture 18

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Slides adapted from Haonan Lu, Wyatt Lloyd, and Mike Freedman's, which are adapted from the Spanner OSDI talk

Recap: Spanner is Strictly Serializable

- Efficient read-only transactions in strictly serializable systems
  - Strict serializability is desirable but costly!
  - Reads are prevalent! (340x more than write txns)
  - Efficient RO txns → good system overall performance

Recap: Ideas Behind Read-Only Txns

- Tag writes with physical timestamps upon commit
  - Write txns are strictly serializable, e.g., 2PL

- Read-only txns return the writes whose commit timestamps precede its timestamp
  - RO txns are one-round, lock-free, and never abort

Recap: TrueTime

- Timestamping writes must enforce the invariant
  - If T2 starts after T1 commits (finishes), then T2 must have a larger timestamp

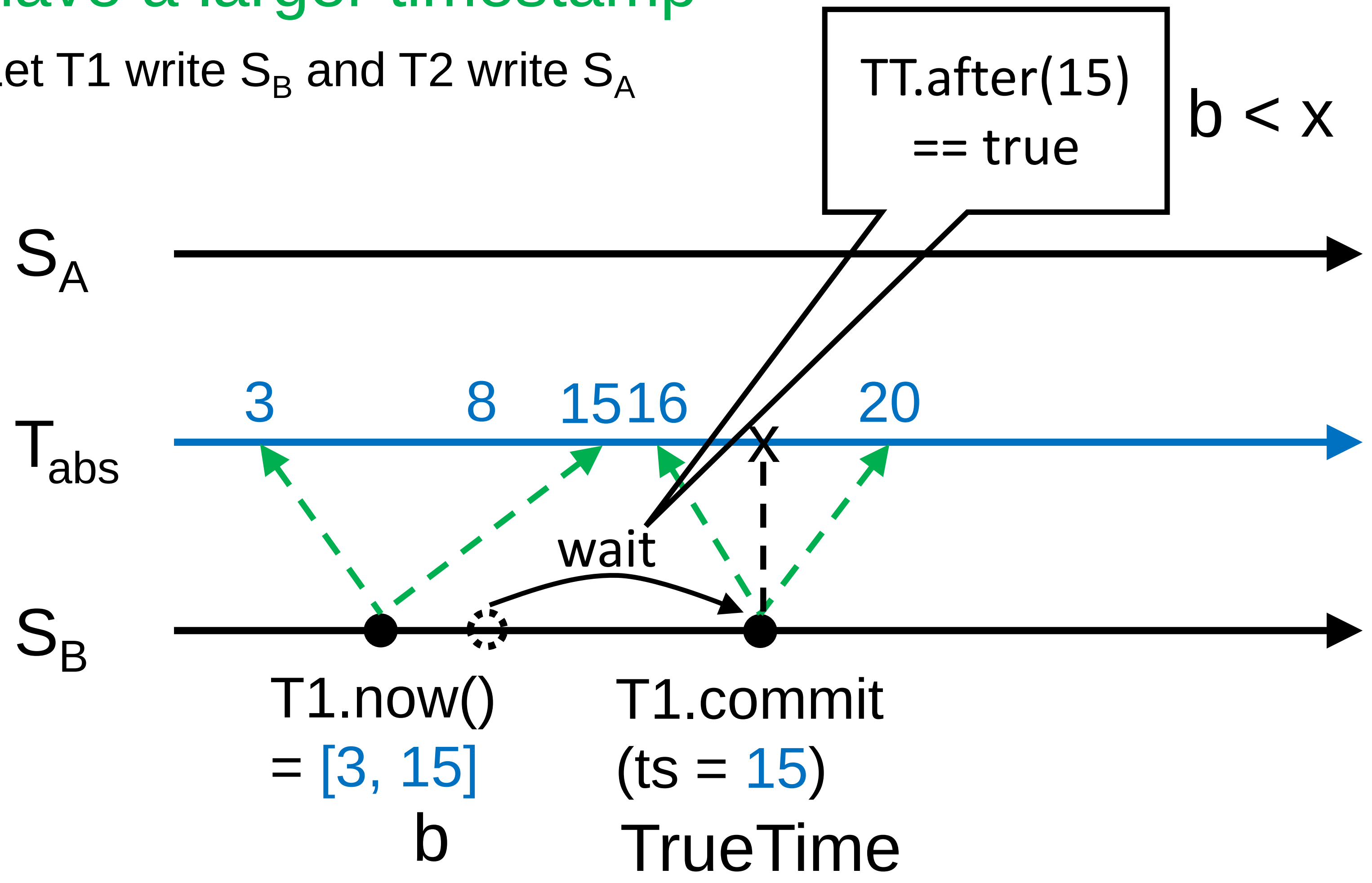
- TrueTime: partially-synchronized clock abstraction
  - Bounded clock skew (uncertainty)
  - TT.now() → [earliest, latest]; earliest <= T_{abs} <= latest
  - Uncertainty (ε) is kept short

- TrueTime enforces the invariant by
  - Use at least TT.now().latest for timestamps
  - Commit wait

Enforcing the Invariant with TT

If T2 starts after T1 commits (finishes), then T2 must have a larger timestamp

Let T1 write S_B and T2 write S_A



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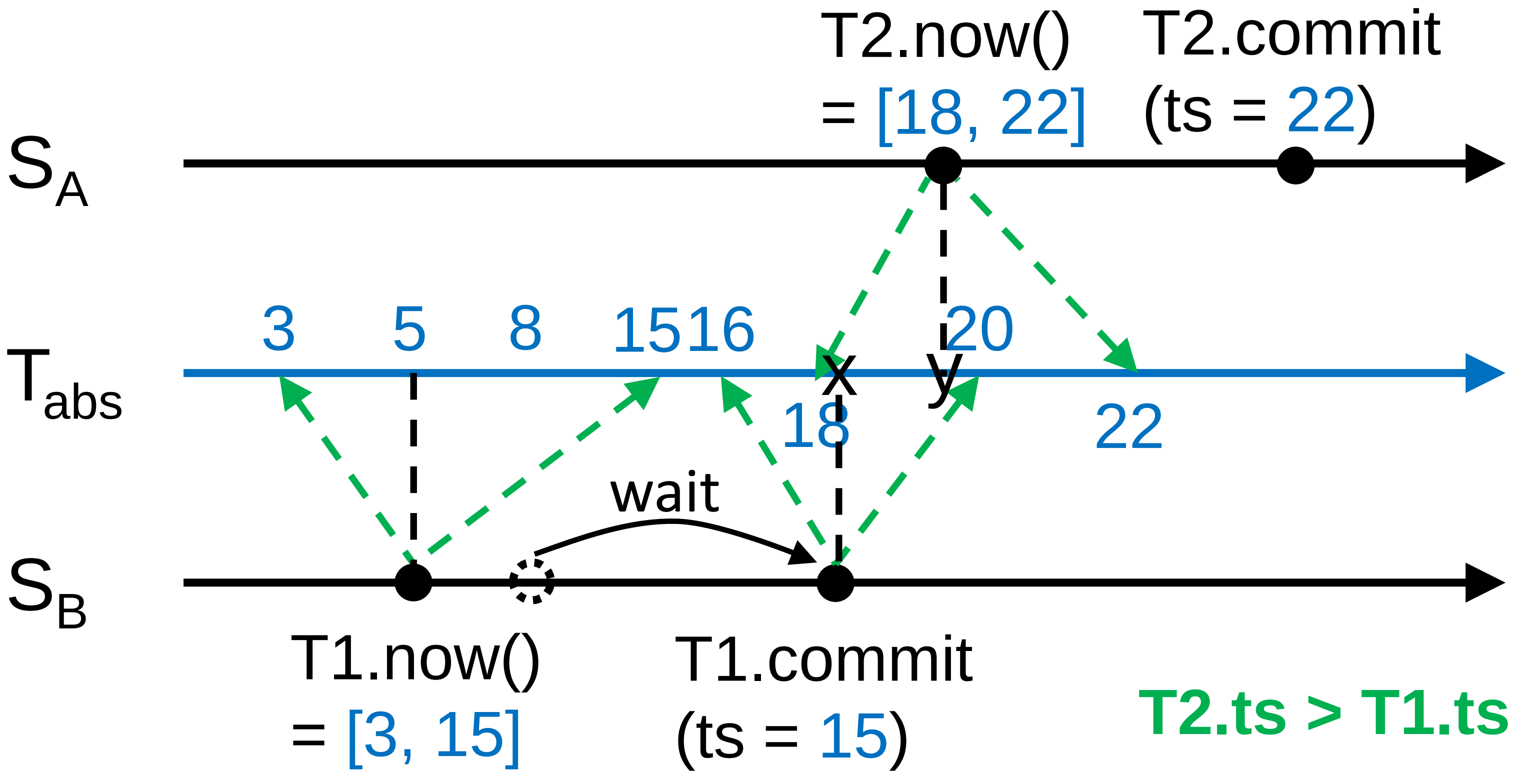


TrueTime

After-class Puzzles

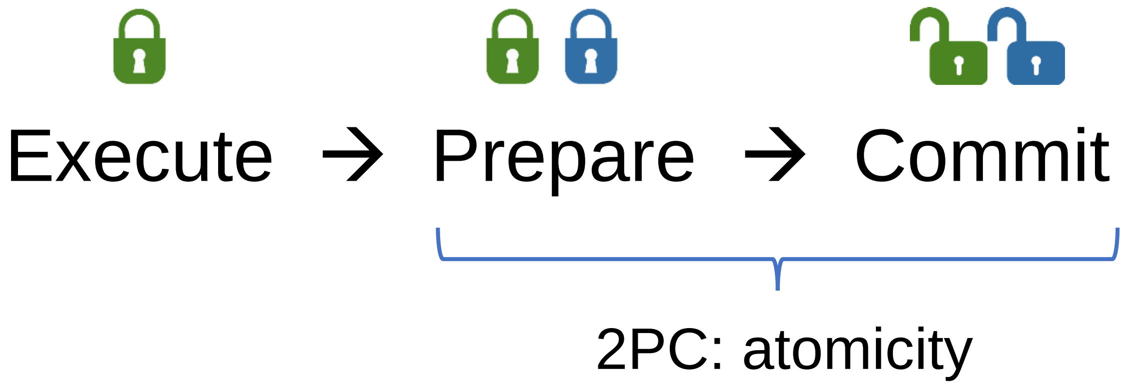
- What’s the rule of thumb for choosing ts?
  - At least T_{abs}, then at least TT.now().latest
- Can we use TT.now().earliest for ts?
- Can we use TT.now().latest – 1 for ts?
- Can we use TT.now().latest + 1 for ts?

This Lecture

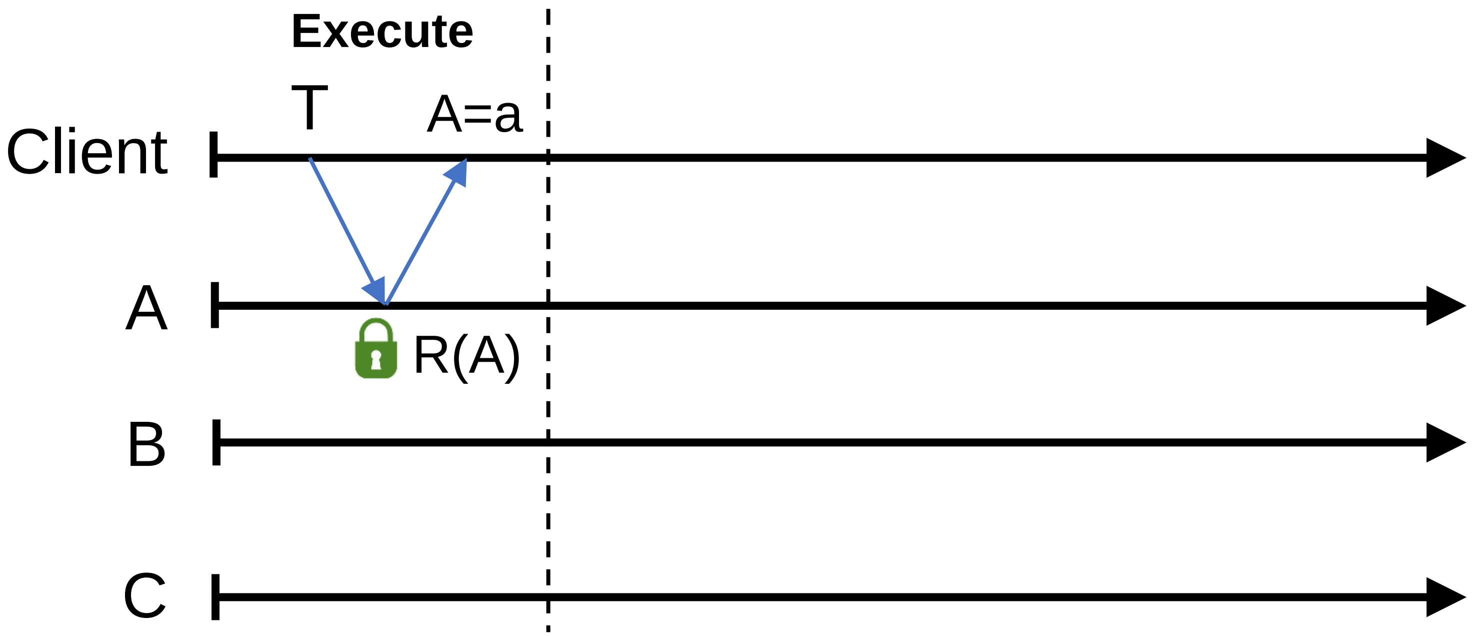
- What is the read-write transaction protocol?
  - 2PL + 2PC
  - How are they timestamped?
- What is the read-only transaction protocol?
  - How are read timestamps chosen?
  - How are reads executed?

Read-Write Transactions (2PL)

- Three phases



Read-Write Transactions (2PL)

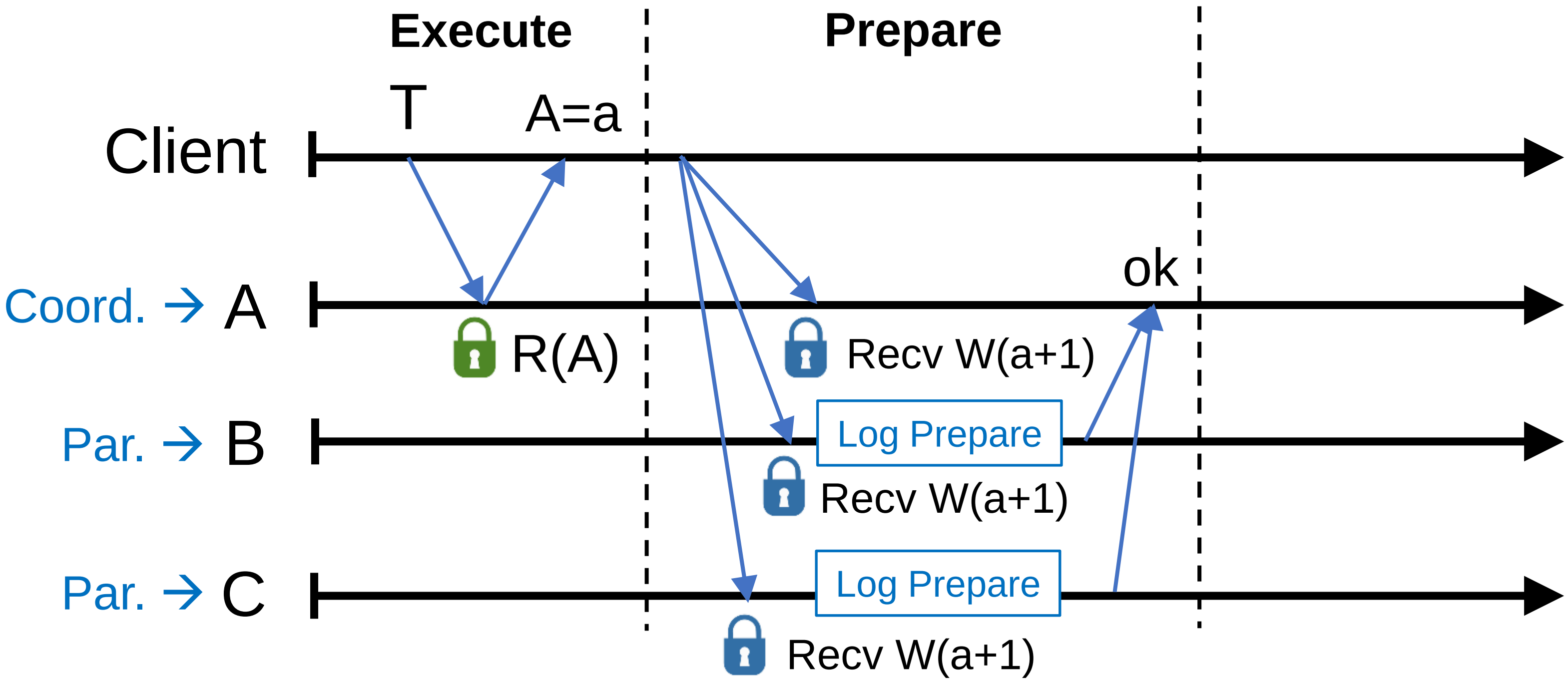


Txn T = {R(A=?), W(A=?+1), W(B=?+1), W(C=?+1)}

Execute:

- Does reads: grab read locks and return the most recent data, e.g., R(A=a)
- Client computes and buffers writes locally, e.g., A = a+1, B = a+1, C = a+1

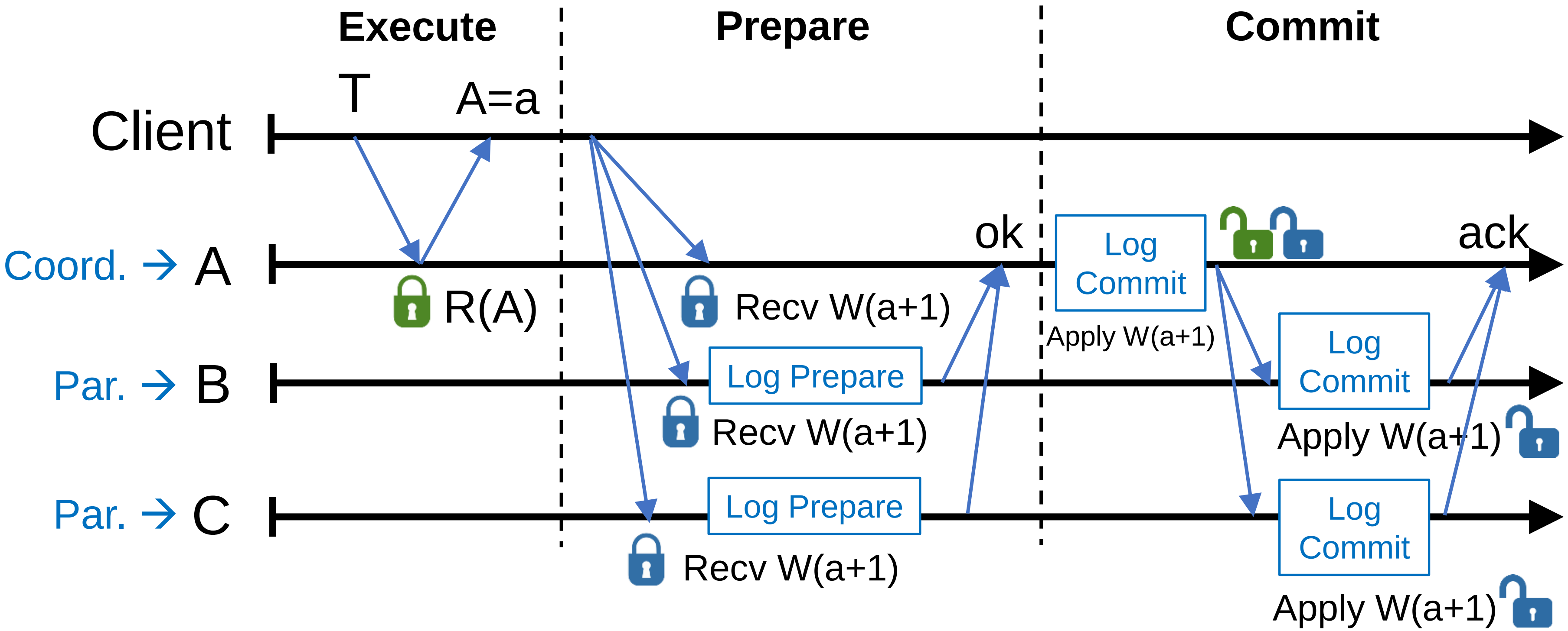
Read-Write Transactions (2PL)



Prepare:

- Choose a coordinator, e.g., A, others are participants
- Send buffered writes and the identity of the coordinator; grab write locks
- Each participant prepares T by logging a prepare record via Paxos with its replicas. Coord skips prepare (Paxos Logging)
- Participants send OK to the coord if lock grabbed and after Paxos logging is done

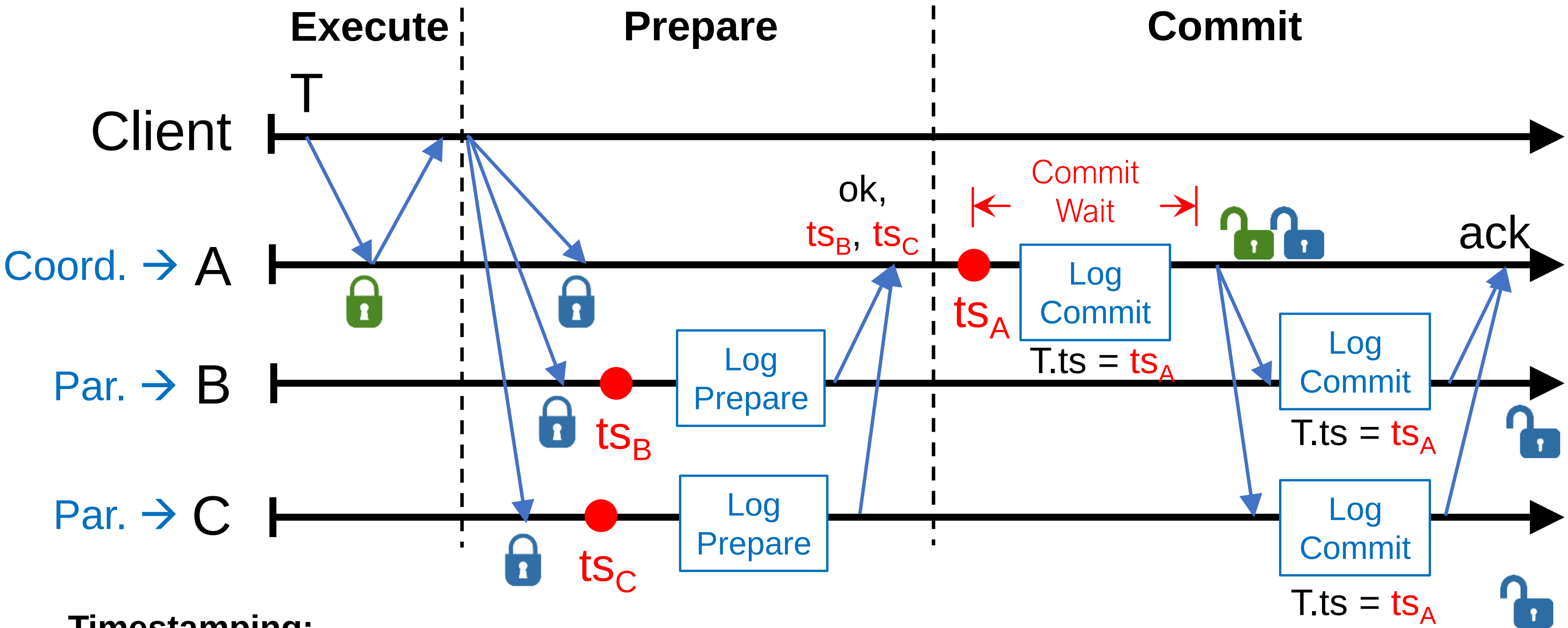
Read-Write Transactions (2PL)



Commit:

- After hearing from all participants, coord commits T if all OK; otherwise, abort T
- Coord logs a commit/abort record via Paxos, applies writes if commit, release all locks
- Coord sends commit/abort messages to participants
- Participants log commit/abort via Paxos, apply writes if commit, release locks
- Coord sends result to client either after its "log commit" or after ack

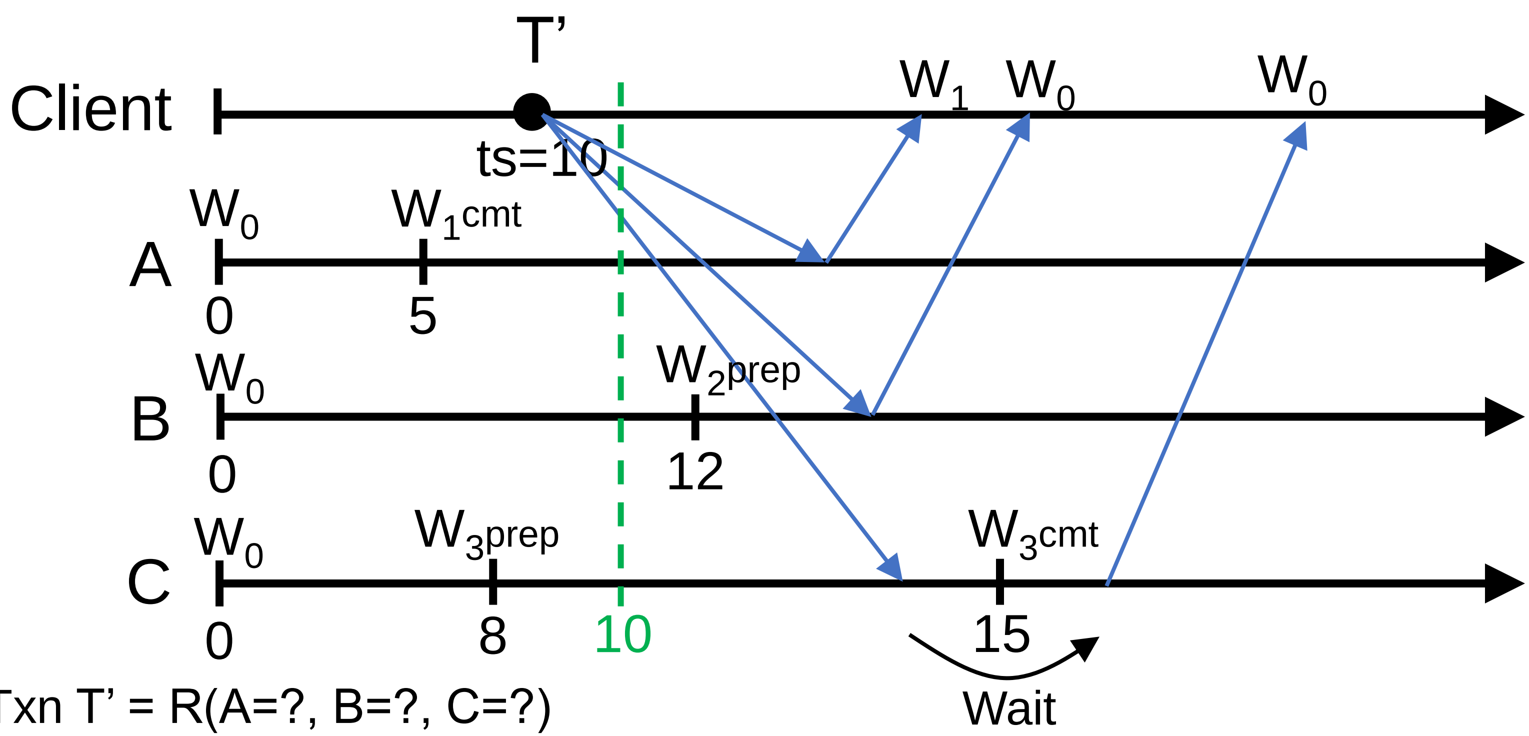
Timestamping Read-Write Transactions



Timestamping:

- Participant: choose a timestamp, e.g., ts_B and ts_C, larger than any writes it has applied
- Coordinator: choose a timestamp, e.g., ts_A, larger than
  - Any writes it has applied
  - Any timestamps proposed by the participants, e.g., ts_B and ts_C
  - Its current TT.now().latest
- Coord commit-waits: TT.after(ts_A) == true. Commit-wait overlaps with Paxos logging
- ts_A is T's commit timestamp

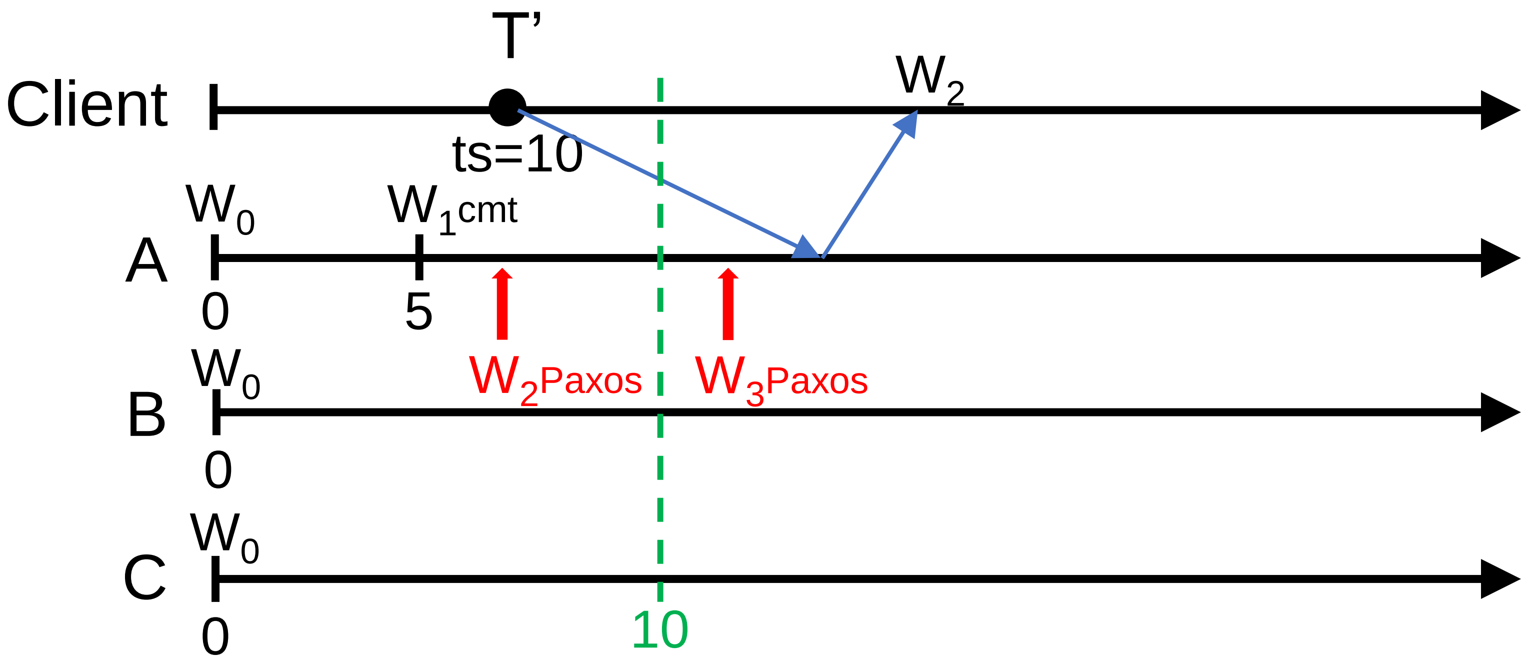
Read-Only Transactions (TM part)



Txn T' = R(A=?, B=?, C=?)

- Client chooses a read timestamp ts = TT.now().latest
- If no prepared write, return the preceding write, e.g., on shard A
- If write prepared with ts' > ts, don't wait, proceed with read, e.g., B
- If write prepared with ts' < ts, wait until write commits, e.g., C

Read-Only Transactions (Paxos part)

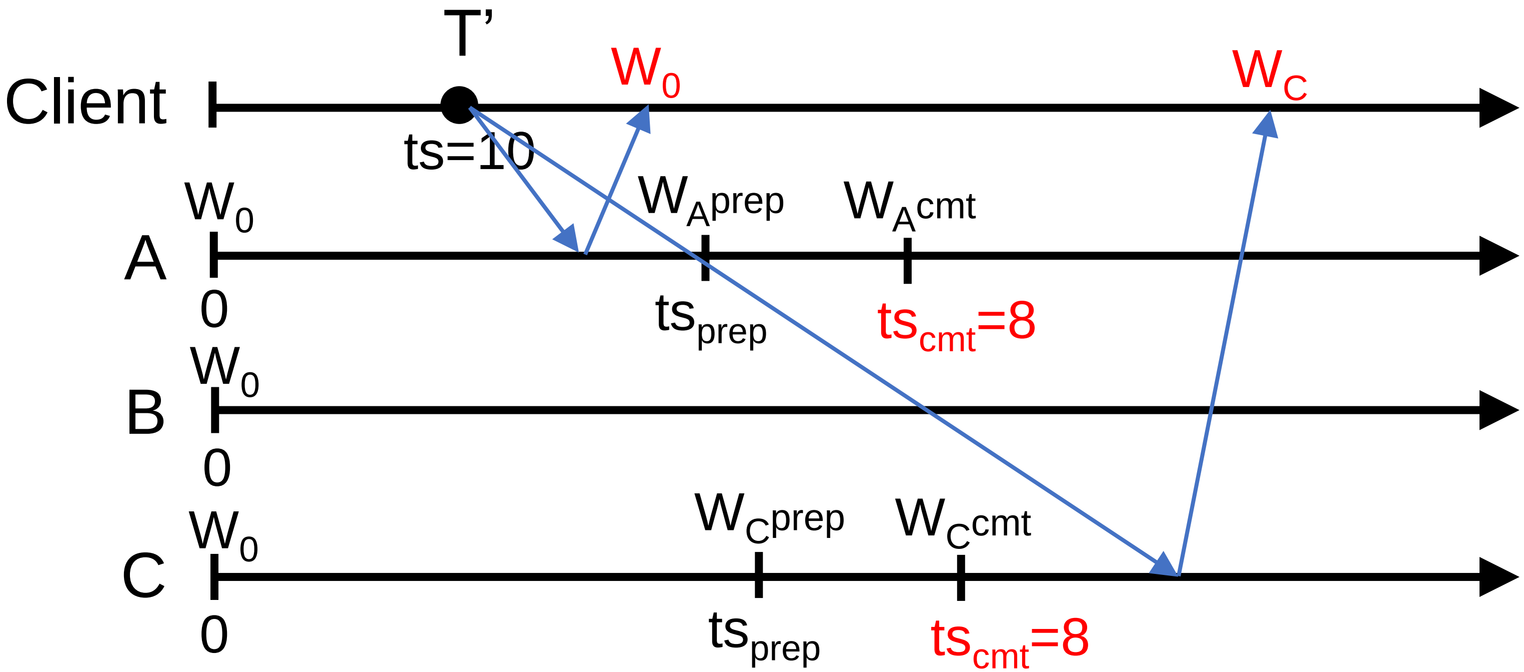


- Paxos writes are monotonic, e.g., writes with smaller timestamp must be applied earlier, W_2 is applied before W_3
- T' needs to wait until there exists a Paxos write with ts >= 10, e.g., W_3, so all writes before 10 are finalized
- **Put it together:** a shard can process a read at ts if ts <= t_{safe}
- $t_{safe} = \min(t_{safe}^{Paxos}, t_{safe}^{TM})$; all writes with timestamps <= t_{safe} have been applied

A Puzzle to Help With Understanding

- Assume no replication, only transaction managers

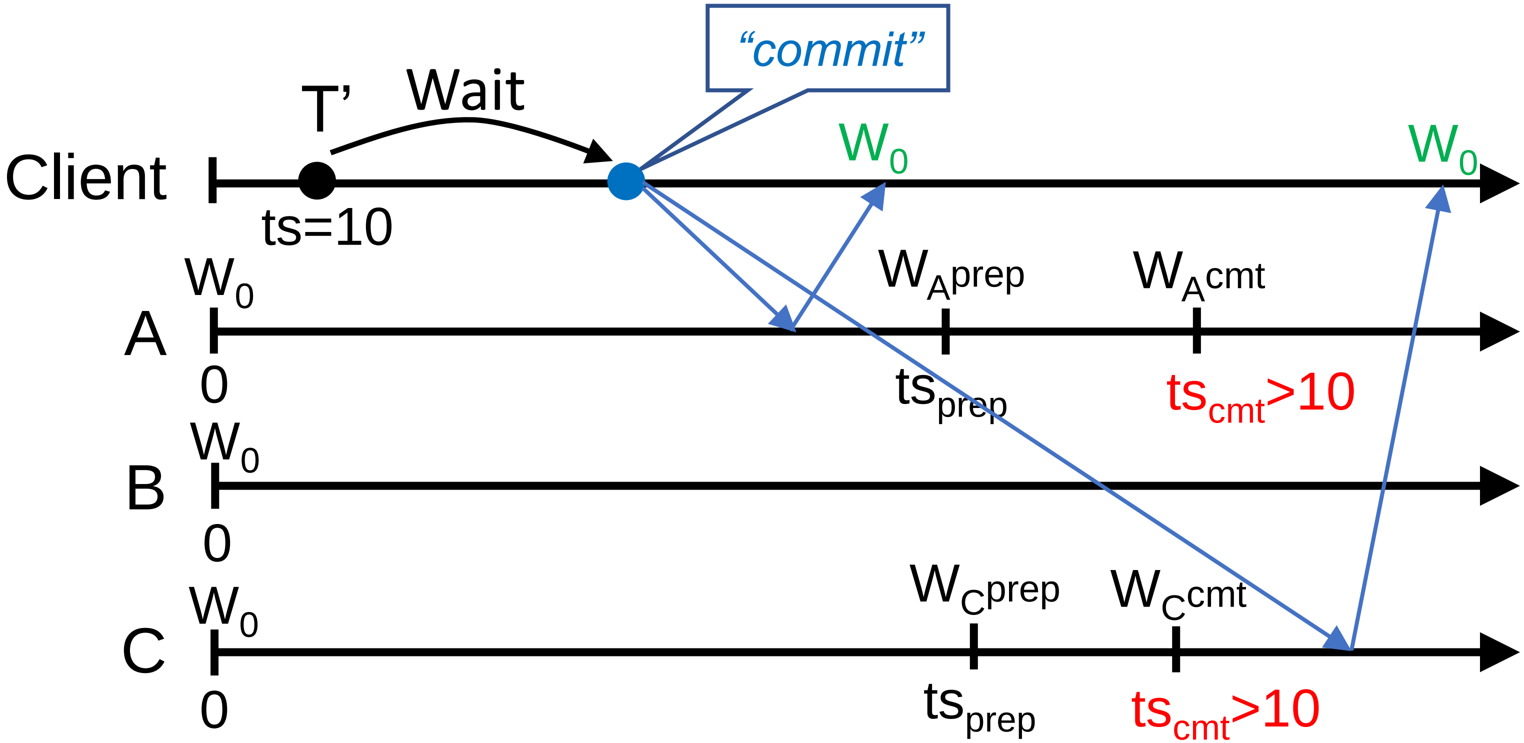
Txn T = {W_A, W_C}, T’ = R (A, C)



T’ sees partial effect of T! Sees W_C but not W_A so violates atomicity!

A Puzzle to Help With Understanding

- **Solution 1:** uncertainty-wait

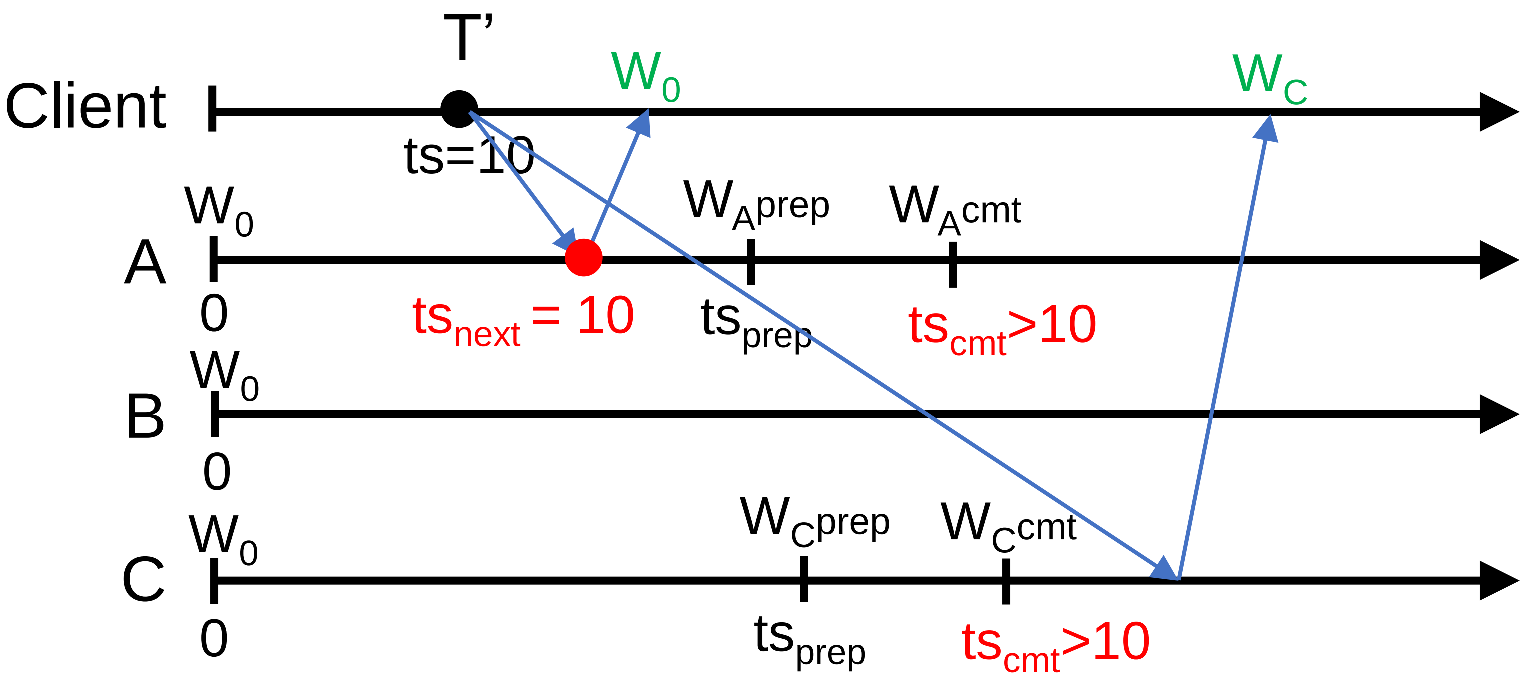


Uncertainty-wait ensures that ts_{cmt} must > T' ts because

- T prepares after T' "commits," and
- T' waits out uncertainty before "commit", e.g., TT.after(10) == true

A Puzzle to Help With Understanding

- **Solution 2:** RO advances next RW prepare ts



Ensures that ts_{cmt} must > T' ts because

- T prepares after T' reads at A and
- Shard A will choose ts_{prep} > ts_{next} for T

Less blocking for RO txns!
This is what Spanner does!

Serializable Snapshot Reads

- Client specifies a read timestamp way in the past
  - e.g., one hour ago
- Read shards at the stale timestamp
- Serializable
  - Old timestamp cannot ensure real-time order
- Better performance
  - Always non-blocking, not just lock-free
- Can we have this performance but still strictly serializable?
  - e.g., one-round, non-blocking, and strictly serializable
  - Coming in next lecture!

Takeaways

- Strictly serializable (externally consistent)
  - Make it easy for developers to build apps!
- Reads dominant, make them efficient
  - One-round, lock-free
  - Must block in some cases
- TrueTime exposes clock uncertainty
  - Commit wait and at least TT.now.latest() for timestamps ensure real-time ordering
- Globally-distributed database
  - 2PL w/ 2PC over Paxos!