Spanner and SNOW

Spring 2024

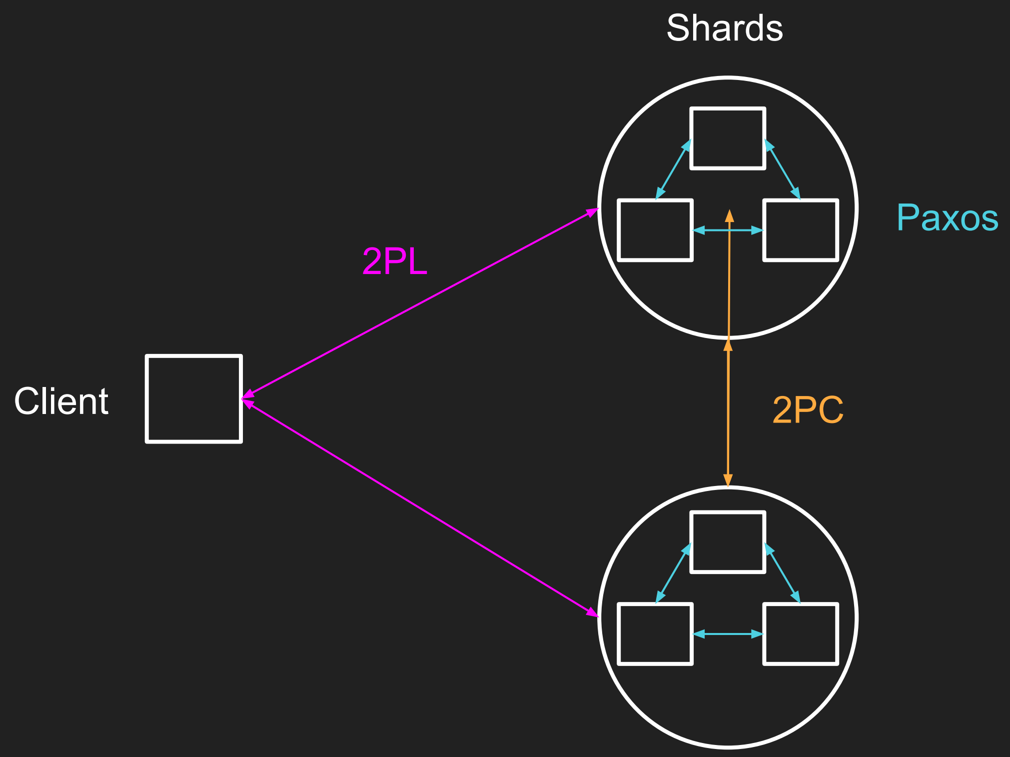
Concurrency Control Recap

- Last precept: 2-phase locking (2PL) ~~and optimistic concurrency control (OCC)~~
- 2PL:
  - Rule: Do not acquire a lock once any lock has been released
  - Growing Phase: acquire shared (read) locks and exclusive (write) locks
  - Shrinking Phase: release locks

How can we achieve strict serializability and scalability?

- Shard the keyspace: servers maintain a subset of the keyspace
- Use 2PL to handle concurrent transactions
- Use 2-phase commit (2PC) to achieve atomic commit of transactions
- How does 2PC handle server failures?
    - It doesn’t!
- Replicate each shard using Paxos!

Toy example:



Putting it together in a real system: Spanner

- Observation: reads are much more frequent than writes
  - Facebook’s TAO sees 500 reads per 1 write.
  - Google Ads (F1) on Spanner from 1 DC saw 51.5B reads in a 24 hour period
  - Many reads are across shards
- Takeaway: Make read-only transactions very efficient
- Two goals:
  - Lock-free read-only transactions
  - Non-blocking, but stale (not strictly serializable), read-only transactions

Spanner

- Main idea: use real-time for ordering transactions by finding a maximum clock skew
- TrueTime
  - TrueTime.now()
    - Returns a range [a,b] where a is the earliest possible time, and b is latest
  - TrueTime.after(t)
    - True if the current time is definitely after t
  - TrueTime.before(t)
    - True if the current time is definitely before t

General transactions

- General transactions are transactions that can contain reads and writes
- Similar to 2PL+2PC+Paxos scheme above, but use TrueTime to determine commit timestamps for transactions
- Each server maintains t_{safe} where all transactions with commit timestamp $s_i < t_{safe}$ are committed and can be read.

General transactions (steps)

General transactions are driven by the client:

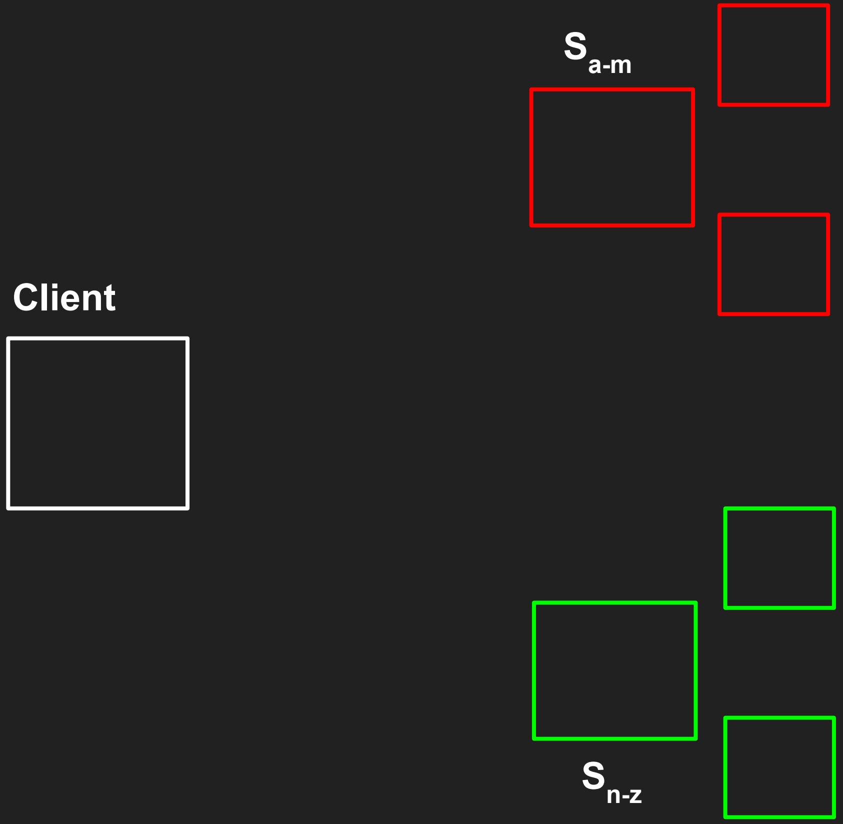
1. Client issues reads to the leader of each shard group
2. Leader acquires read locks and returns the most recent value to the client
3. Client locally performs the writes
4. Client chooses a coordinator from the shard leaders
5. Client initiates the commit protocol by sending a commit message to each leader with the buffered writes and the coordinator ID
6. Leaders execute the commit protocol
7. Client waits for the commit message from the coordinator

General transaction (commit protocol)

1. All shard leaders acquire write locks
2. Non-coordinators
   a. Choose a prepare timestamp > all previous local timestamps
   b. Log the prepare record via Paxos
   c. Notify the coordinator of the prepare timestamp
3. Coordinator
   a. Waits for all prepare timestamps
   b. Chooses a commit timestamp that is
      i. >= prepare timestamps of all other non-coordinators
      ii. > any write timestamps it has applied
      iii. > its current TT.now().latest
   c. Logs commit record via Paxos
   d. Wait until TrueTime.after(commit timestamp)
   e. Sends commit timestamp to replicas, non-coordinators, and the client
4. All apply the transaction at commit timestamp and release the locks

Example

txn 1:
- x = r(a)
- y = r(z)
- x = x + y
- w(z = x)



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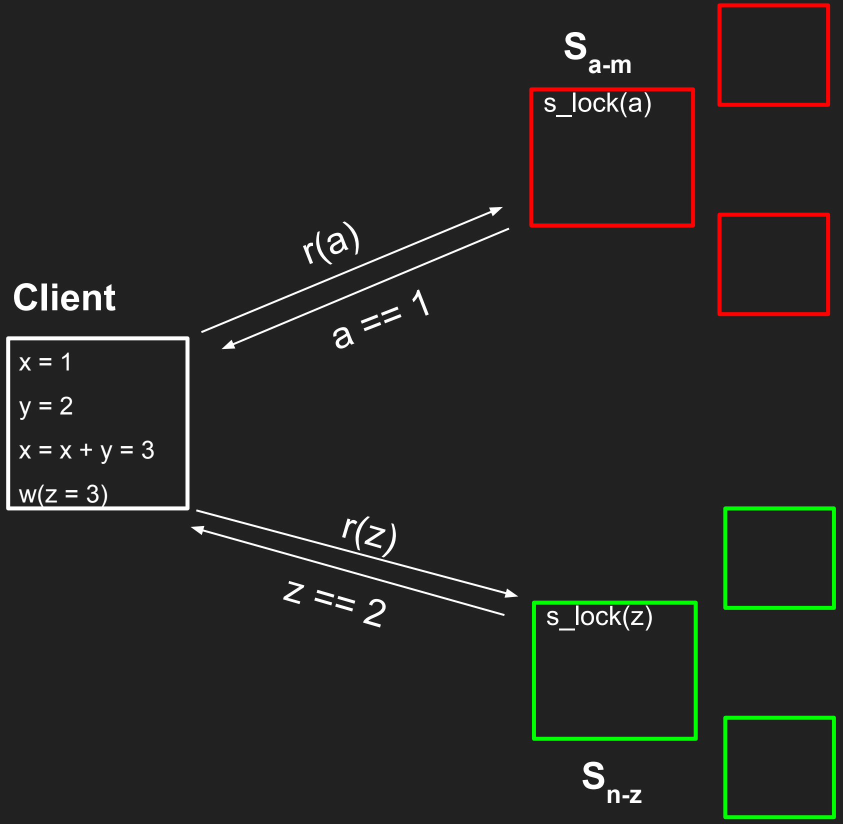

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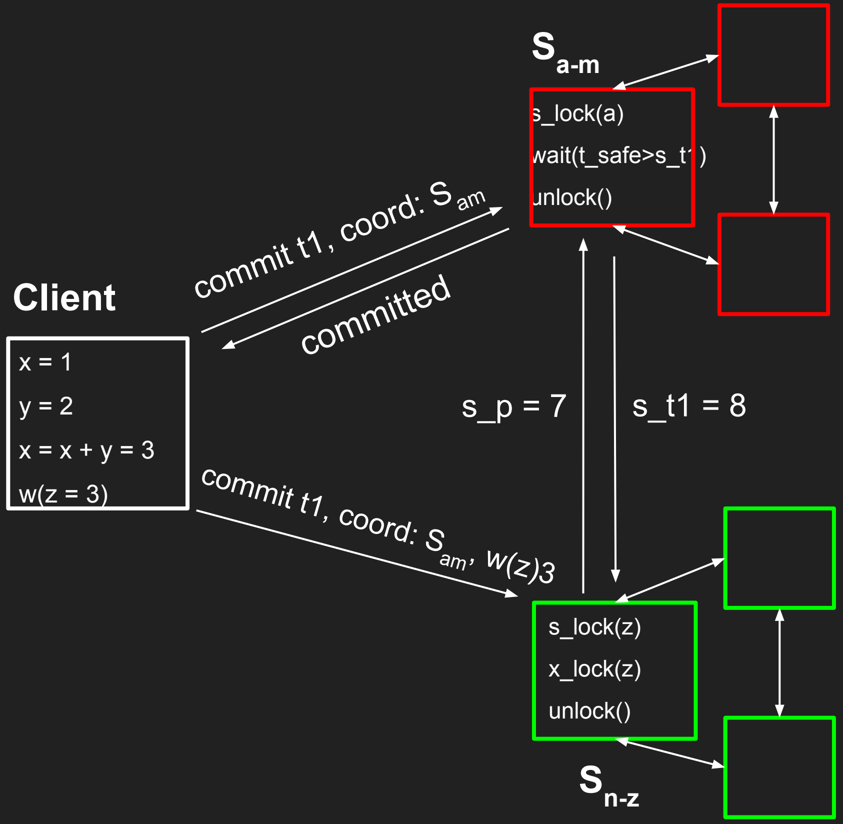
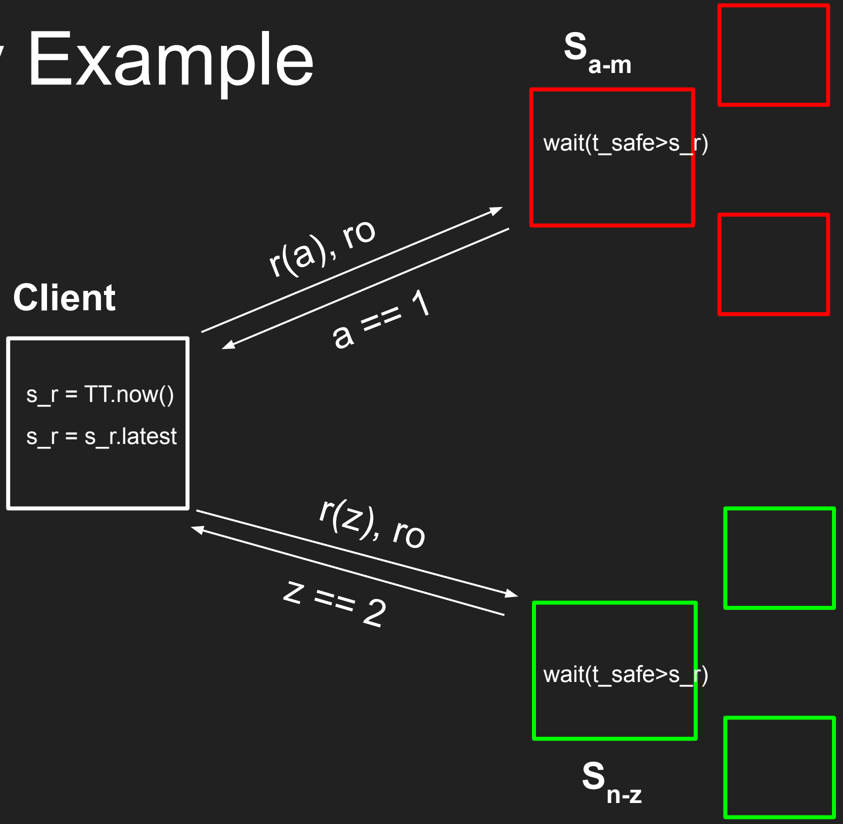


Lock-free read-only transactions

1. Client chooses the commit timestamp (s_{read}) to be TrueTime.now.latest()
2. Shard leaders wait until $s_{read} < t_{safe}$
3. Read data as of the time s_{read}
4. Return data.

Read-Only Example

txn 1:
  x = r(a)
  y = r(z)



Better read-only transaction algorithm?

- Can we make it non-blocking and strictly serializable without adding extra round-trips?
- The SNOW Theorem says no!

The SNOW Theorem

Read-only transaction algorithms can not achieve all of the SNOW properties

- Strict Serializability
- Non-blocking: Servers return a value immediately without waiting
- One Response:
  - Read-only transactions take a single round of communication
  - Read operations return only one value (cannot send multiple versions of the data)
- Write transactions that conflict: Can handle concurrent write transactions
- Latency-optimal: NO
- SNOW-optimal: any three of the four properties

SNOW and Spanner

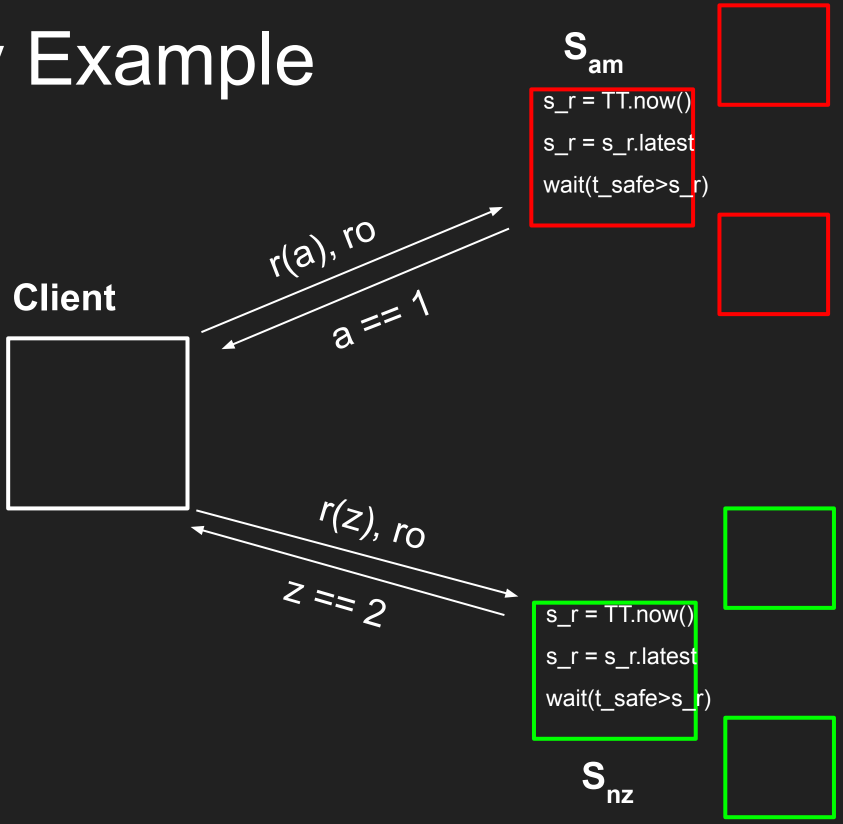
- What properties does the Spanner RO-txn have?
  - SOW: Must block waiting for TrueTime.after(s_{safe})
- SNOW-optimal?
  - Yes.
- Latency-optimal?
  - Nope! Can we get latency-optimal?
    - Must give up something.

Spanner snapshot read-only transactions

- Return a stale read result by explicitly reading at a time before t_{safe}
- Which SNOW properties?
  - NOW

Read-Only Example

txn 1:
  x = r(a)
  y = r(z)



Read-Only Example

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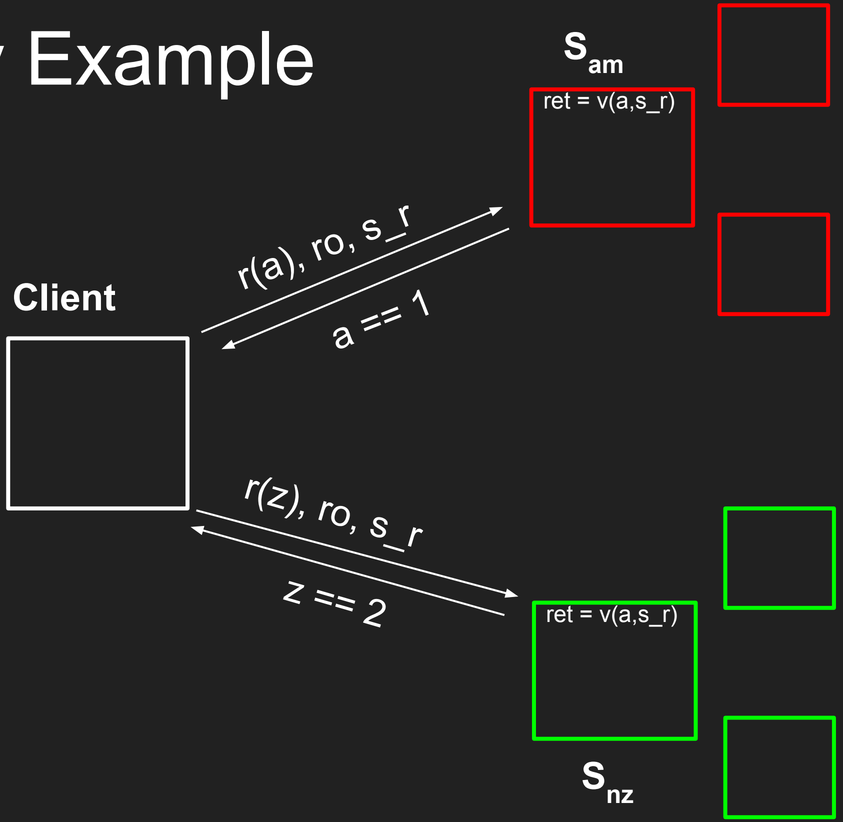

Summary

- Spanner
  - Sharded datastore where shards are Paxos groups
  - Transactions use Client-driven 2PL
  - Commit Wait
    - 2PC with waiting for the commit time to have passed and be safe to read
- SNOW
  - Read-only transaction algorithms cannot achieve strict serializability, non-blocking, one response, and write transactions that conflict, at the same time
  - Spanner RO txns are one of:
    - SOW (best consistency)
    - NOW (best latency)

Q&A