Consistent Distributed Storage

Megastore System

- Paper is not specific about who is the actual customer of the system
- Guess (supported by Spanner paper): consumer-facing web sites and Google App Engine
  - selling storage as a service
  - not just an internal tool
  - Examples: email, Picasa, calendar, Android Market

What might the customer want?

- 100% available ==> replication, seamless fail-over
- Never lose data ==> don't ack until truly durable
- Replicated at multiple data centers, for low latency and availability
- Consistent for *transactional* operations
- High performance

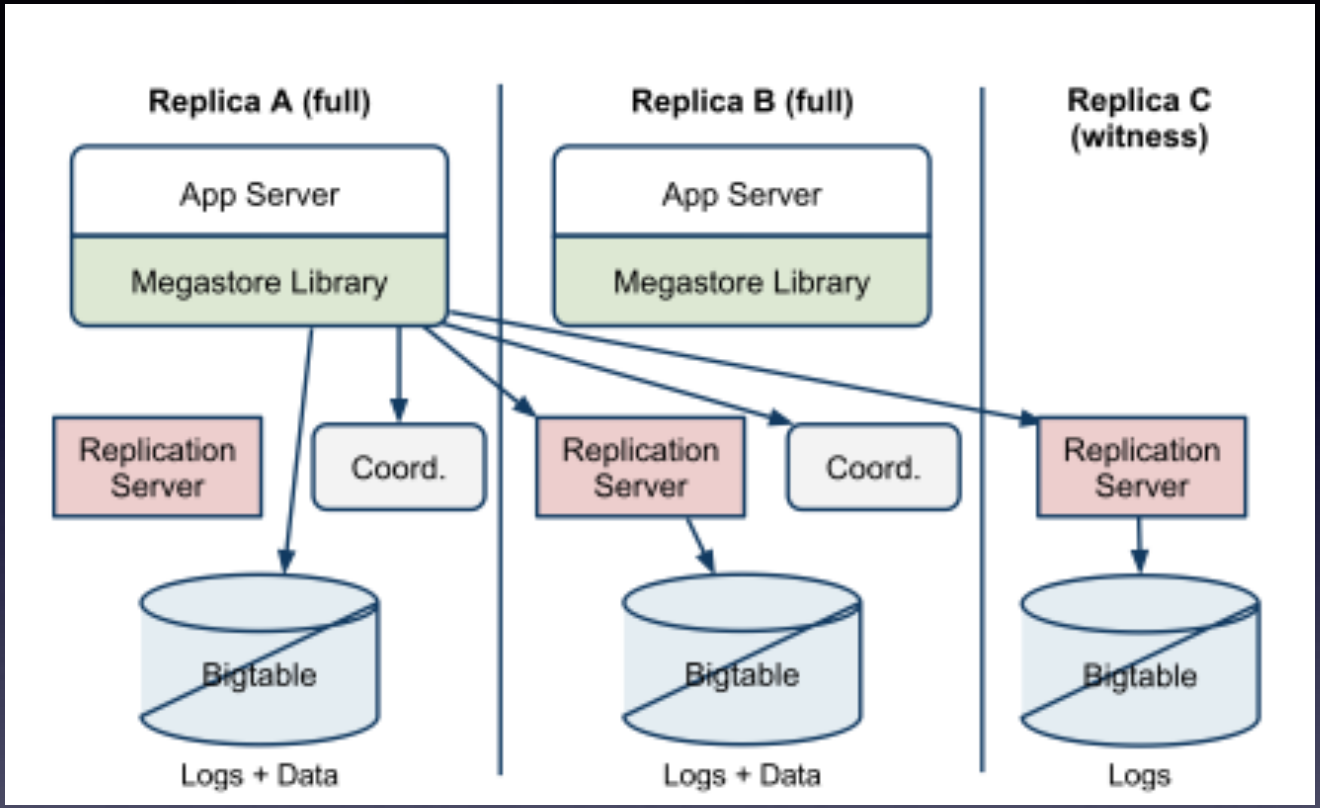
Transaction Semantics

- Transaction: BEGIN reads and writes END
- Serializable:
  - as if executed one at a time, in some order
  - no intermediate state visible
  - no read-modify-write races
  - transaction’s reads see data at just one point in time
- Durable

Conventional Wisdom

- Hard to have both consistency and performance in the wide area (as consistency requires communication)
- Popular solution: relaxed consistency
  - read/write local replica, send writes in background
  - reads may yield stale data, multiple write operations may not be atomic, RMW races may yield lost updates, etc.

Basic Design



- Each data center: BigTable cluster, application server + Megastore library, replication server, coordinator
- Data in BigTable is identical at all replicas

Setting

- Browser web requests may arrive at any replica
  - That is, at the application server at any replica
  - There is no special primary replica
  - So could be concurrent transactions on same data from multiple replicas

Setting

- Transactions can only use data within a single “entity group”
  - An entity group is one row or a set of related rows
  - Defined by application
  - E.g., all my email messages may be in a single entity group; yours will be in a different one
  - Example transaction:
    - Move msg 321 from Inbox to Personal
    - Not a transaction: deliver message to both kaiyuan and paul

Entity Groups Example

```
CREATE SCHEMA PhotoApp;

CREATE TABLE User {
 required int64 user_id;
 required string name;
} PRIMARY KEY(user_id), ENTITY GROUP ROOT;

CREATE TABLE Photo {
 required int64 user_id;
 required int32 photo_id;
 required int64 time;
 required string full_url;
 optional string thumbnail_url;
 repeated string tag;
} PRIMARY KEY(user_id, photo_id),
  IN TABLE User,
  ENTITY GROUP KEY(user_id) REFERENCES User;
```

BigTable Layout

Row key	User. name	Photo. time	Photo. tag	Photo. _url
101	John			
101,500		12:30:01	Dinner, Paris	...
101,502		12:15:22	Betty, Paris	...
102	Mary			

- How would you build a wide-area storage system using Paxos? How do you achieve good performance?

Transactions

- Each entity group has a log of transactions
  - Stored in BigTable, a copy at each replica
- Data in BigTable should be a result of playing log
- Transaction code in application server:
  - Find highest log entry # (n)
  - Read data from local BigTable
  - Accumulate writes in temporary storage
  - Create log entry: the set of writes
  - Use Paxos to agree that log entry n+1 is new entry
  - Apply writes in log entry to BigTable data

Notes

- Commit requires waiting for inter-datacenter messages
- Only a majority of replicas need to respond
- Non-responders may miss some log entries
  - Later transactions will need to repair this
- There might be conflicting transactions

Concurrent Transactions

- Data race: e.g., two clients doing “x = x+1”
- Megastore allows one to commit, aborts the others
  - Conservatively prohibits concurrency within an entity group
  - So does not use traditional DB locking; which would allow concurrency if non-overlapping data
- Conflicts are caught during Paxos agreement
  - Application server will find that some other transaction got log entry n+1
  - Application must retry the whole transaction

Reads

- Must get latest data
- Would like to avoid inter-replica communication
- Ideally would read from local BigTable w/o talking to any other replicas
- Problems?
- Solutions?

Rotating Leader

- Each accepted log entry indicates a "leader" for next entry
  - Leader gets to choose who submits proposal #0 for next log entry
  - First replica to ask wins that right
  - All replicas act as if they had already received the prepare for #0
- Why and when does this help?

Log Format

What if concurrent commits?

- Leader will give one the right to send accepts for proposal #0
- The other will send prepares for higher proposal #
- The higher proposal may still win!
- So proposal #0 is not a guarantee of winning
  - Just eliminates one round in the common case

“Write” Details

- Ask leader for permission to use proposal #0
- If “no”, send Paxos prepare messages
- Send accepts, repeat prepares if no majority
- Send invalidate to coordinator of ANY replica that did not accept
- Apply transaction’s writes to as many replicas as possible
- If you don’t win, return an error; caller will rerun transaction

Failure: Overloaded replica (R1)

- R1 won't respond
- Transactions can still commit as long as majority respond
- Need to talk to R1 coordinator to clear the flag it maintains for being up-to-date
  - Reads at R1 will use a different replica

Failure: replica disconnection

- Designers view this as rare
- Replica won't respond to Paxos (OK), but coordinator not responding is a problem
  - Write will block
- Paper implies that coordinators have leases
  - Each must renew lease at every replica periodically
  - If it doesn't/can't
    - Commits can ignore the replica
    - Replica marks all entity groups as "not up to date"

MegaStore Summary

- High availability through replication, seamless fail-over
- Replicated at multiple data centers, for low latency and availability
- Ack only when truly durable
- Consistency for *transactional* operations
- Performance improvements

Spanner

- Picks up from where MegaStore left off
- Some commonality in terms of mechanisms but a different implementation
- Key additions:
    - general-purpose transactions across entity groups
    - higher performance
    - "TrueTime" API and "external consistency"
    - multi-version data store

Example: Social Network

- Consider a simple schema:
  - User posts
  - Friend lists
- Looks like a database, but:
  - shard data across multiple continents
  - shard data across 1000s of machines
  - replicated data within a continent/country
- Lock-free read only transactions

Read Transactions

- Example: Generate a page of friends' recent posts
    - Consistent view of friend list and their posts
    - Want to support:
        - remove friend X
        - post something about friend X

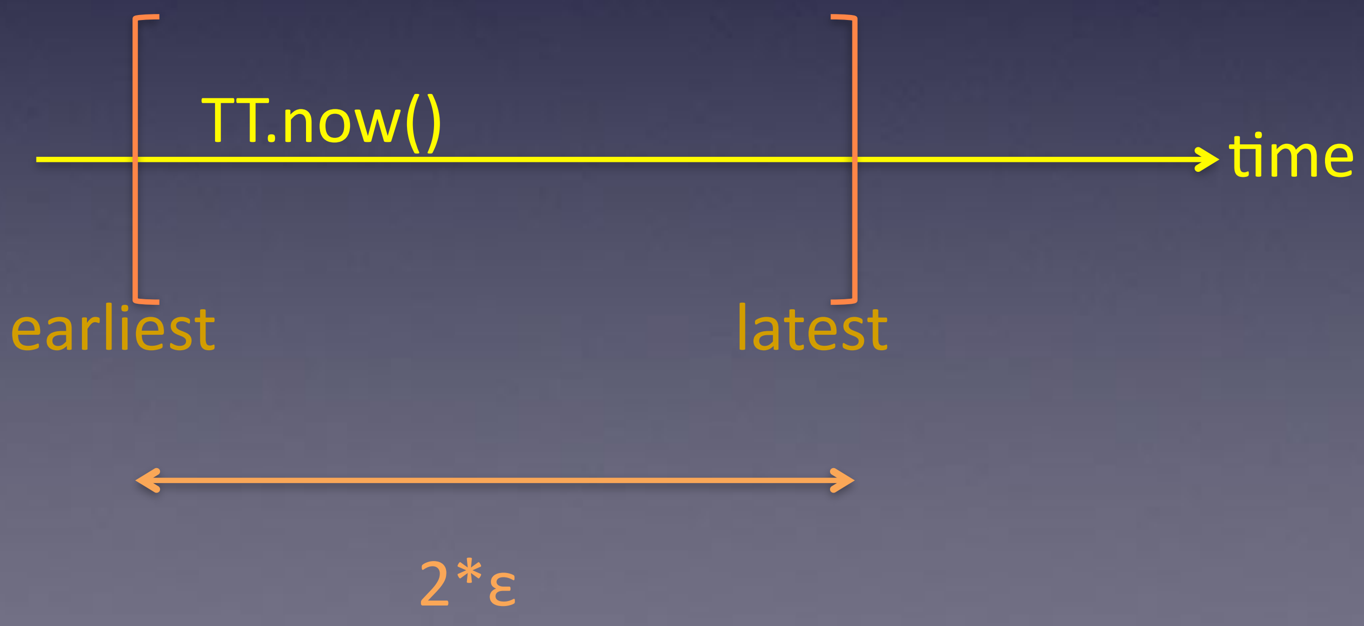
- MegaStore: transactions within entity groups
- Spanner: transactions across entity groups
    - How can you support transactions across entity groups, where each entity group is replicated across datacenters?

Spanner Transaction

- Two-phase commit layered on top of Paxos
  - Paxos provides reliability and replication
  - 2PC allows coordination of different groups responsible for different datasets
  - Layering provides non-blocking 2PC
- Uses 2-phase locking to deal with concurrency

Spanner’s TimeStamps

- TrueTime: “Global wall-clock time” with bounded uncertainty
- Returns a lower-bound and upper-bound on wall-clock time



Spanner Transaction

- Each participant selects a proposed timestamp for the transaction greater than what it has committed earlier
- Coordinator assigns the transaction a timestamp that is greater than these timestamps
- Coordinator waits until the chosen timestamp is definitely in the past
- Then notifies the client and the participants of the transaction's timestamp
- Participants release the locks

Read Transactions

- Currently handled at the group leaders
- Two forms: read transactions across multiple groups, read transaction across a single group
- In both cases:
  - check whether there is an ongoing transaction
  - attribute the earliest possible timestamp that is safe
  - wait for a certain period before responding

Summary

- GFS: blob store abstraction
- BigTable: semistructured table abstraction within a datacenter
- MegaStore: limited transactions across multiple datacenters
- Spanner: more general transactions across multiple datacenters