Distributed Systems

20. Spanner

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Spanner
(Google's successor to Bigtable … sort of)

Spanner

Take Bigtable and add:

- Familiar SQL-like multi-table, row-column data model
  - One primary key per table
- Synchronous replication (Bigtable was eventually consistent)
- Transactions across arbitrary rows

Spanner

- **Globally distributed multi-version database**
- ACID (general purpose transactions)
- Schematized tables (Semi-relational)
  - Built on top of a key-value based implementation
  - SQL-like queries
- Lock-free distributed read transactions

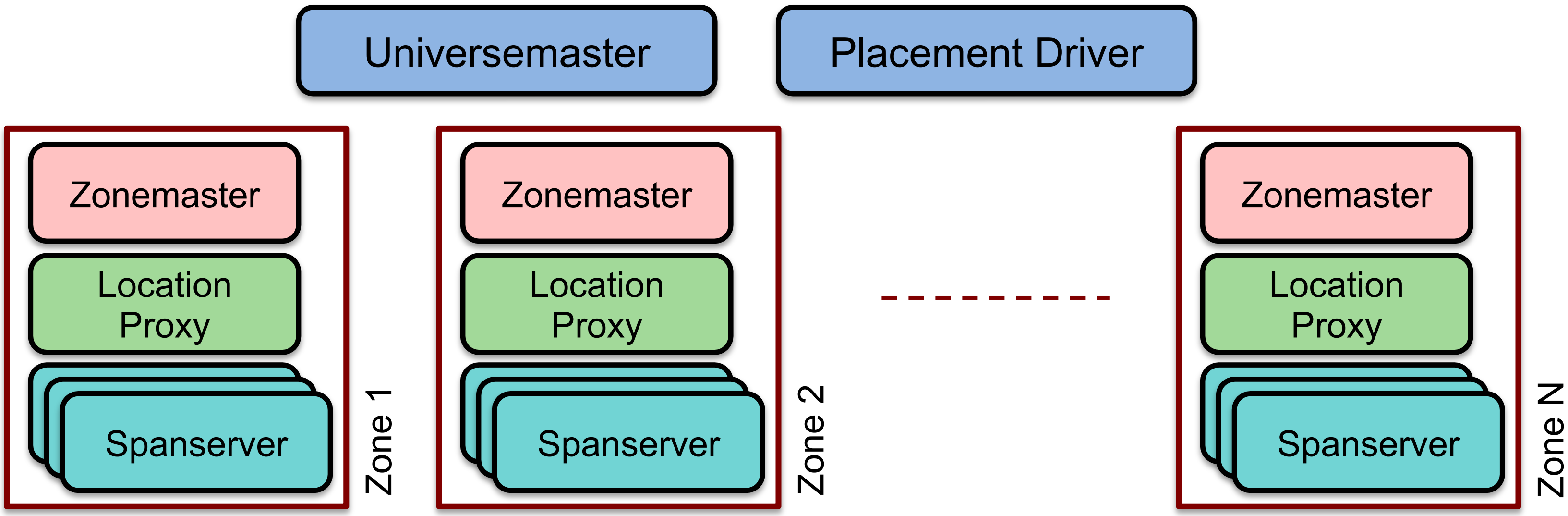
Goal: make it easy for programmers to use

Working with eventual consistency & merging is hard ⇒ don't make developers deal with it

Data Storage

- Tables sharded across rows into *tablets* (like bigtable)
- Tablets stored in spanservers
- 1000s of spanservers per zone
  – Collection of servers – can be run independently

- Zonemaster
  Allocates data to spanservers
- Location proxies
  Locate spanservers with needed data
- Universemaster
  Tracks status of all zones
- Placement driver
  Transfers data between zones



Data Storage

Universe: holds one or more databases

Database: holds one or more tables

Table: rows & columns

Shards (tablets): pieces of tables
Replicated synchronously via Paxos

Data in table is versioned & has a timestamp

Transactions across shards use two-phase commit

Directory: "bucket" – set of contigious keys with a common prefix
Unit of data movement between Paxos groups

Transactions

- ACID properties
- Transactions are serialized: strict 2-phase locking used

1. Acquire all locks
   – do work –
2. **Get a commit timestamp**
3. Log the commit timestamp via Paxos to majority of replicas
4. Do the commit
   - Apply changes locally & to replicas
5. Release locks

2-Phase locking can be slow

We can use *read locks* and *write locks*

But

- *read locks* block behind *write locks*
- *write locks* block behind *read locks*

Multiversion concurrency to the rescue!

- Take a snapshot of the database for transactions up to a point in time
- You can read old data without getting a lock
  - Great for long-running reads (e.g., searches)
- Because you are reading before a specific point in time
  - Results are consistent

We need ***commit timestamps*** that will enable meaningful snapshots

Getting good commit timestamps

- Vector clocks work
  - Pass along current server's notion of time with each message
  - Receiver updates its concept of time (if necessary)
- But not feasible in large systems
  - Pain in HTML (have to embed vector timestamp in HTTP transaction)
  - Doesn't work if you introduce things like phone call logs
- **Spanner: use physical timestamps**
  - If T_1 commits before T_2, T_1 *must* get a smaller timestamp
  - Commit order matches global wall-time order

TrueTime

Remember: we can't know global time across servers!

- **Global wall-clock time** = time + interval of uncertainty
  - TT.now().earliest = time guaranteed to be <= current time
  - TT.now().latest = time guaranteed to be >= current time

- Each data center has a GPS receiver & atomic clock
- Atomic clock synchronized with GPS receivers
  - Validates GPS receivers
- Spanservers periodically synchronize with time servers
  - Know uncertainty based on interval
  - Synchronize ~ every 30 seconds: clock uncertainty < 10 ms

Commit Wait

We don’t know the *exact* time

… but we can wait out the uncertainty

1. Acquire all locks

   – do work –

2. Get a commit timestamp: t = TT.now().latest
3. **Commit wait: wait until TT.now().earliest > t**
4. Commit
5. Release locks

average worst-case wait is ~10 ms

Integrate replication with concurrency control

1. Acquire all locks
   – do work –
2. Get a commit timestamp: t = TT.now().latest
3. (a) Start consensus for replication
   (b) Commit wait (in parallel)

   Make the replicas & wait for all to finish
4. Commit
5. Release locks

Spanner Summary

- Semi-relational database of tables
  - Supports externally consistent distributed transactions
  - No need for users to try deal with eventual consistency
- Multi-version database
- Synchronous replication
- Scales to millions of machines in hundreds of data centers
- SQL-based query language

- Used in F1, the system behind Google's Adwords platform
- May be used in Gmail & Google search and others…

Are we breaking the rules?

- **Global ordering of transactions**
  - *Systems cannot have globally synchronized clocks*
  - But we can synchronize closely enough that we can wait until we are sure a specific time has passed
- **CAP theorem**
  - *We cannot offer Consistency + Availability + Partition tolerance*
  - Spanner is a CP system
  - If there is a partition, Spanner chooses C over A
  - In practice, partitions are rare - ~8% of all failures of Spanner
    - Spanner uses Google's private global network, not the Internet
    - Each data center has at least three independent fiber connections
  - In practice, users can feel they have a CA system

https://storage.googleapis.com/pub-tools-public-publication-data/pdf/45855.pdf

Spanner Conclusion

- ACID semantics not sacrificed
  - Life gets easy for programmers
  - Programmers don't need to deal with eventual consistency
- Wide-area distributed transactions built-in
  - Bigtable did not support distributed transactions
  - Programmers had to write their own
  - Easier if programmers don't have to get 2PC right
- Clock uncertainty is known to programmers
  - You can wait it out

The end