Distributed Systems

20. Spanner

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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

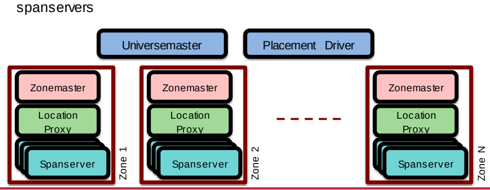
Spanner

- **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 – Used by clients to locate spanservers that hold the data they need
- Universemaster – status of all zones
- Placement driver – transfers data between zones



Data Storage

- Universe holds 1 or more databases
  – Database holds 1 or more tables
  – Table = arbitrary number of rows and columns
    - Table storage may be interleaved
    - All data in a table has version information (timestamp)
- Shards (tablets) are replicated
  – Synchronous replication via Paxos
- Transactions across shards use 2-phase commit
- Directory = set of contiguous keys
  – Unit of data allocation
  – Granularity for data movement between Paxos groups
    - Done in background

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 <u>*must*</u> get a smaller timestamp
  - Commit order matches global wall-time order

TrueTime

- <u>Remember: we can't know global time across servers!</u>
- **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 <u>wait out the uncertainty</u>

average worst-case wait is ~10 ms

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

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)
4. Commit
5. Release locks

Integrate commit wait with 2-phase commit

- 2-phase commit used across shards

1. Acquire all locks
   – do work –
2. 2PC coordinator gets a commit timestamp: t = TT.now().latest
3. Use Paxos protocol to commit
   – timestamp included in the Paxos proposal
   – timetamp conveyed to all participants
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

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