TAO: FACEBOOK'S DISTRIBUTED DATA STORE FOR THE SOCIAL GRAPH

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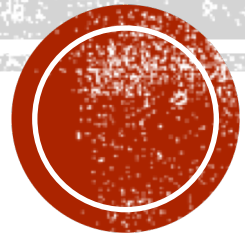


MOTIVATION

- The Facebook graph has more than a billon active users, and trillions of edges.
- Because of complex privacy rules and tailoring of content to individual users, content is generated each time its viewed resulting in a extremely high demand for reads.
- Clients are likely to query similar information as other clients

PREVIOUS APPROACH

- Facebook was built by storing the social graph on MYSQL.
- As facebook scaled, it was necessary to reduce load on the database.
- Memcache, a key value cache system was scaled to work at the size of Facebook.

WHY TAO?

- Memcache which is a key-value system is inefficient at representing graphs.
- Queries must always fetch entire edge list, and change to one edge require edge list reload.
- Decentralized control logic results in more failures and thundering herds.

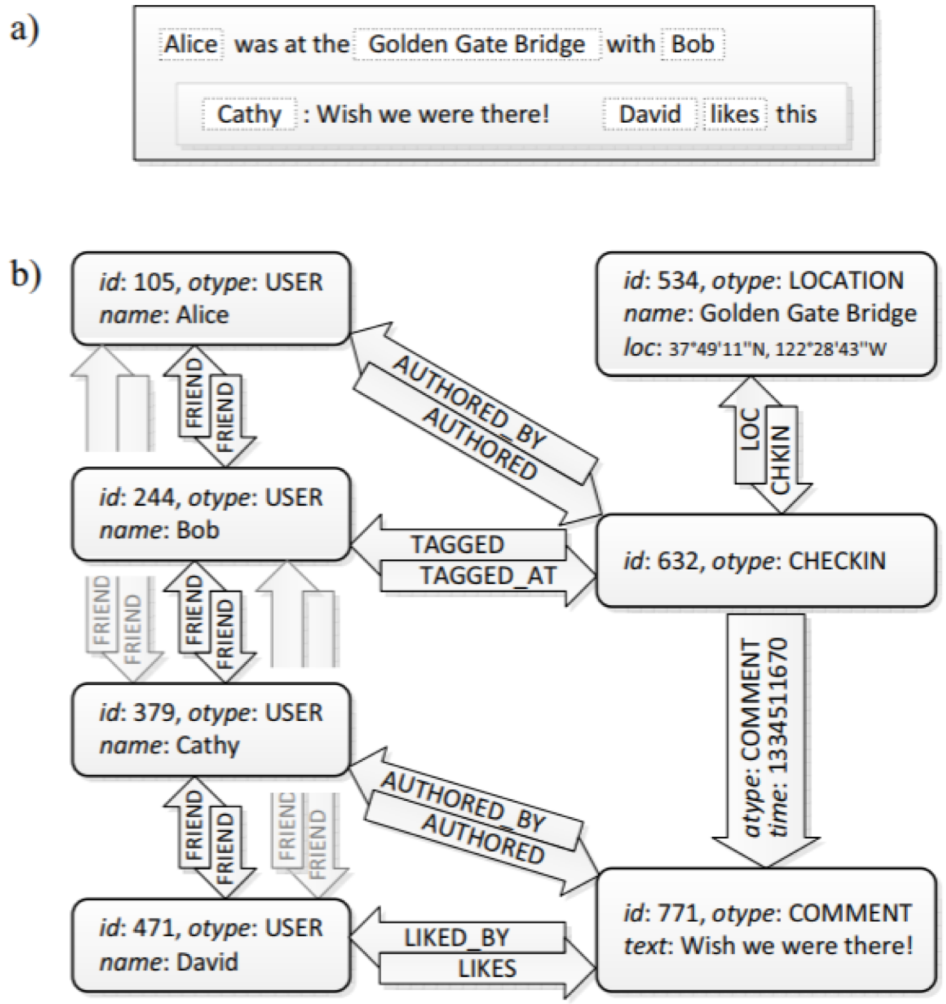
TAO

- A graph-aware caching framework that is geographically distributed over many thousands of machines.
- TAO provides low latency for users, fault tolerance, and eventual consistency.
- Shares many of its design with memcache.

API

- Object: (id) → (otype, (key value)*)
  - Represent Vertices

- Assoc.: (id1, atype, id2) → (time, (key valu
  - Represent edges



API

- Association List: (id1, atype) → [anew …aold]

  - Ordered by timestamp.

- assoc add(id1, atype, id2, time, (k→v)*)

  - Add assocation from id1 to id2 of type atype, and its inverse if exists.

- assoc delete(id1, atype, id2)

  Delete association from id1 to id2

API

- assoc_get(id1, atype, id2set, high?, low?)

- Assoc_count(id1, atype)

  -- "How many checkins at the GG Bridge?" ⇒ assoc count(534, CHECKIN)

- assoc_range(id1, atype, pos, limit)

  -- "50 most recent comments on Alice's checkin" ⇒ assoc range(632, COMMENT, 0, 50)

DATA STORAGE

- TAO's API is mapped to SQL queries.
- Data is divided into shards, and each shard is contained in a logical database and load balancing among different hosts.
- Each object is associated with a unique shard that doesn't change, and the association list is stored with the object.

CACHING LAYER

- TAO's cache implements the complete API for clients, handling all communication with databases.
- A tier consists of multiple cache servers that serve different shards and can collectively serve any TAO request.
- A client issues a request to an appropriate cache, which will be responsible for completing reads and writes.

CACHING LAYER

- Cache misses and writes have to contact database.
- Write operations might involve other shards as inverse id could be on different machine, not guaranteed to be atomic.
- Cache understand semantics of queries.

ALL-TO-ALL CONNECTION

- Common for hundreds of objects and associations to be queried when rendering a Facebook page.
- Results in ALL-TO-ALL connection.
- In theory could scale with a single cache tier, but making shards more fine grained results in quadratic growth of connections and hot spots.

LEADERS AND FOLLOWERS

- Split the cache into two levels: a leader tier and multiple follower tiers.
- Leaders behave as described before, directly communicating with the storage layer.
- Followers forward miss and writes to a leader.
- Eventual Consistency; one leader per shard, and leader notifies followers that are out of date.

SCALING GEOGRAPHICALLY

- Followers can be thousands of miles of apart from leader.
- Master/ slave architecture with slave DB in each region.
- Followers forward write / cache miss requests to local leaders, and leaders forward reads to local db, and writes to master leader.

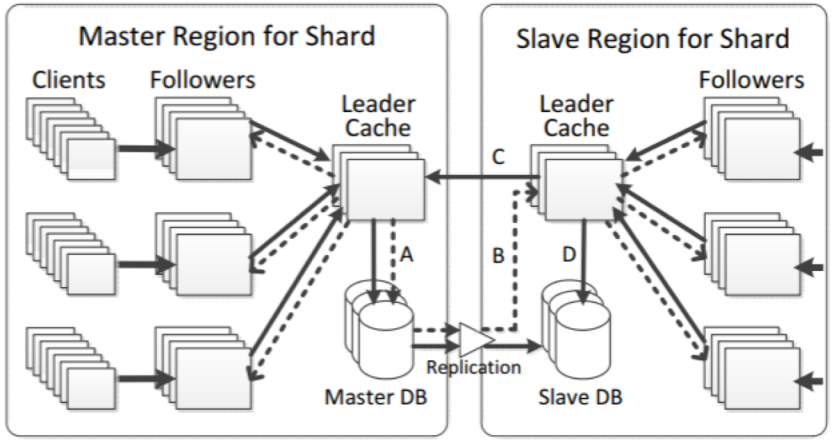


Figure 2: Multi-region TAO configuration. The master region sends read misses, writes, and embedded consistency messages to the master database (A). Consistency messages are delivered to the slave leader (B) as the replication stream updates the slave database. Slave leader sends writes to the master leader (C) and read misses to the replica DB (D). The choice of master and slave is made separately for each shard.

INTERNREGIONAL

- Social graph is tightly connected, meaning each region would have to have a copy of the entire graph.
- Expensive; instead have each region have some of the shards.
- A full copy of the DB can be found across close regions.

CONSITENCY

- Eventual consistency; clients can receive stale data; best effort read after write consistency.
- TAO embeds invalidation and refill messages in the database replication stream.
- If a forwarded write is successful then the local leaders involved (including inverse), will update their cache with the fresh value from a change set before returning.

CONSITENCY

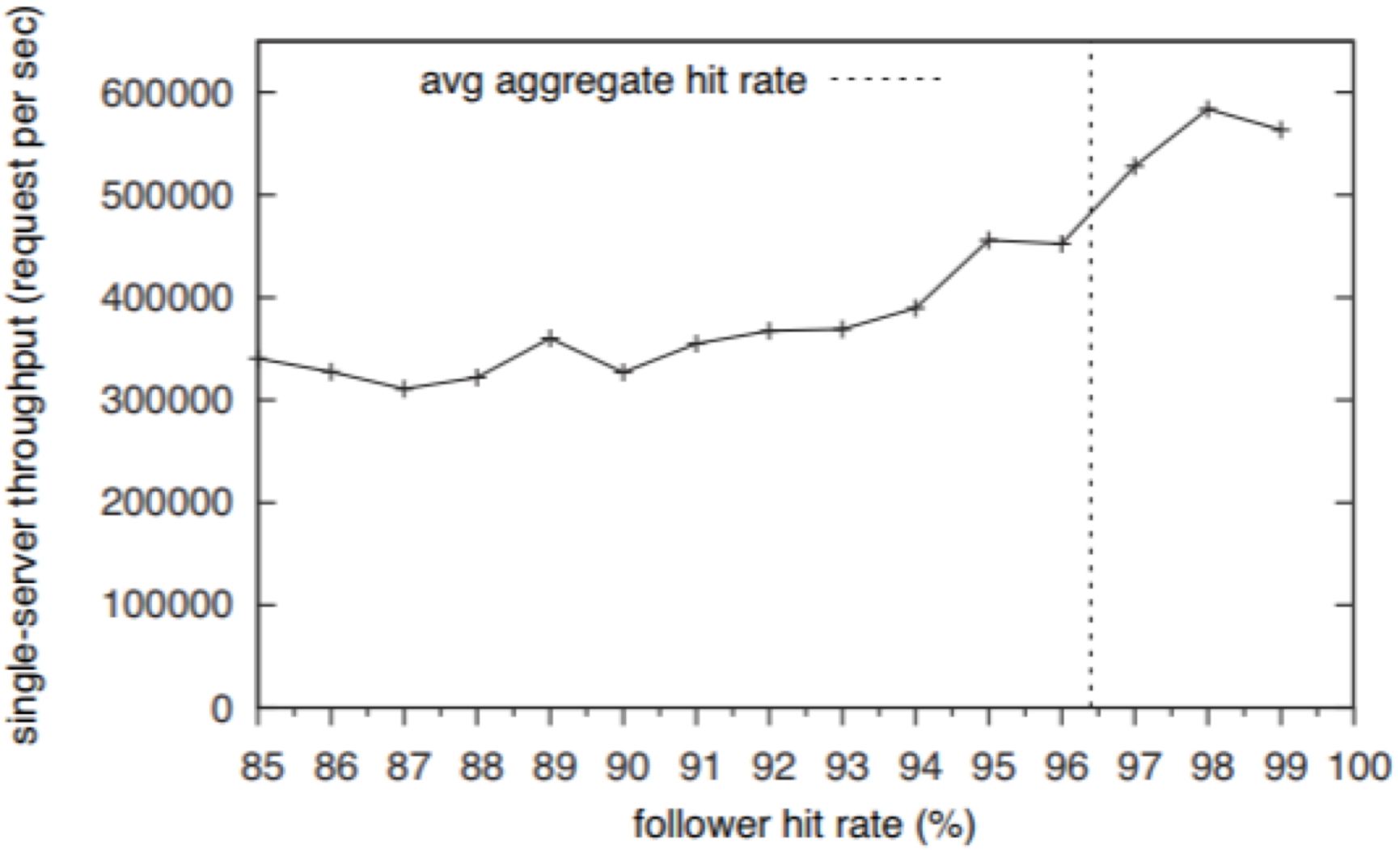
- MYSQL remains a source of truth.
- Version numbers are used to avoid races in updating data.
- Slaves suffer from rare race condition related to evicting elements post change set that are not in local DB.

FAULT TOLERANCE

- Database fail if they crash or are too behind. If master database fails, one of the slaves becomes a master.
- When a leader fails, another leader for different shards takes over until the previous leader comes back.
- Invalidation failures: when a failed leader is replaced, all of the shards of the leader are invalidated.

RESULTS

- Facebook's workload: 99.8% read requests, and 0.2% write requests.
- A single TAO deployment which processes billions of reads and millions of writes per sec.
- Results for randomly sampled 6.5 million requests over a 40 day period.


single-server throughput (request per sec)
avg aggregate hit rate
600000
500000
400000
300000
200000
100000
0
85 86 87 88 89 90 91 92 93 94 95 96 97 98 99 100
follower hit rate (%)

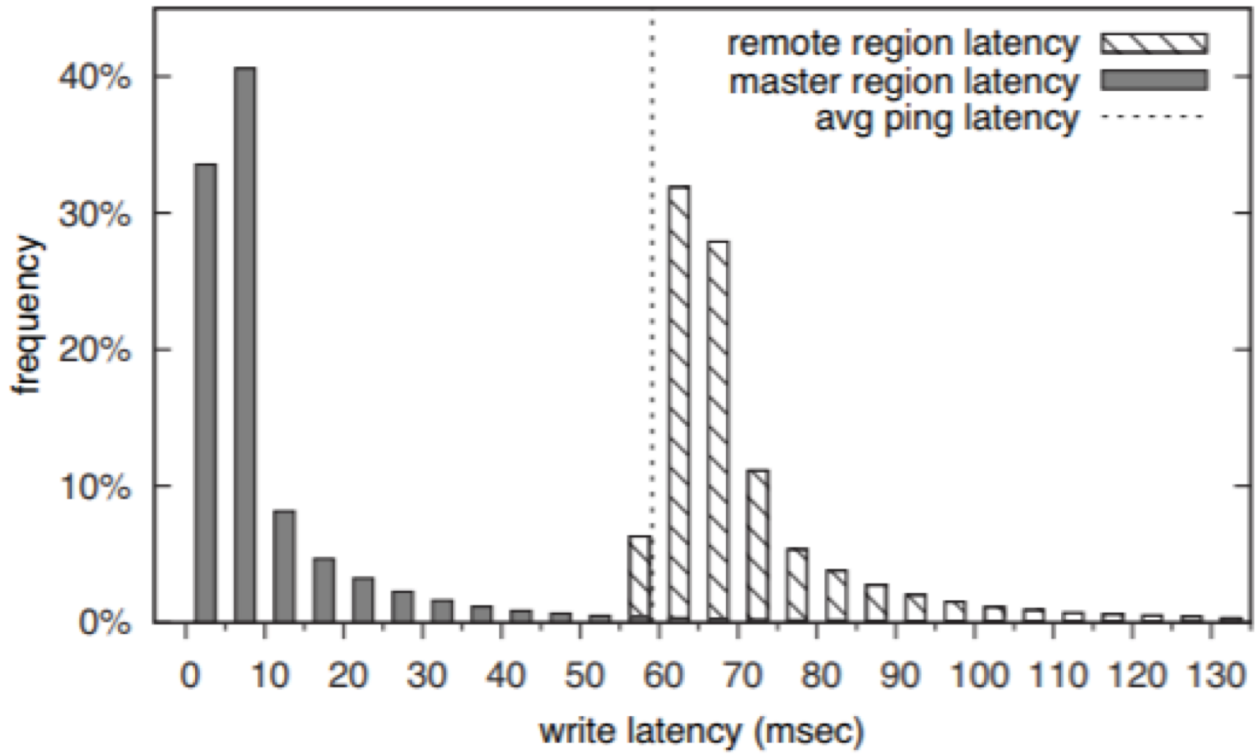


Figure 9: Write latency from clients in the same region as database masters, and from a region 58 msec away.

- Average write latency in same region, 12.1 msec, remote region 74.4 msec

READ PERFORMANCE

	hit lat. (msec)			*miss lat. (msec)*		
operation	*50%*	*avg*	*99%*	*50%*	*avg*	*99%*
assoc_count	1.1	2.5	28.9	5.0	26.2	186.8
assoc_get	1.0	2.4	25.9	5.8	14.5	143.1
assoc_range	1.1	2.3	24.8	5.4	11.2	93.6
assoc_time_range	1.3	3.2	32.8	5.8	11.9	47.2
obj_get	1.0	2.4	27.0	8.2	75.3	186.4

RESULTS

- Replicas lag by 1 second 85% of the time, by utmost 3 secs 99% of the time, and 10 secs for 99.8%.

- Local leader was unavailable 0.15% of the time, and slave databases were promoted 0.25% of the time.

CONCLUSION

- TAO is a graph-aware caching framework that is geographically distributed and has great performance.
- Eventual consistency.
- Future work on guaranteeing bounded consistency, noSQL database, fast writes, and getting rid of "rare" races that result in stale data.