TAO: Facebook's Distributed Data Store for the Social Graph

Nathan Bronson et al.
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About Me

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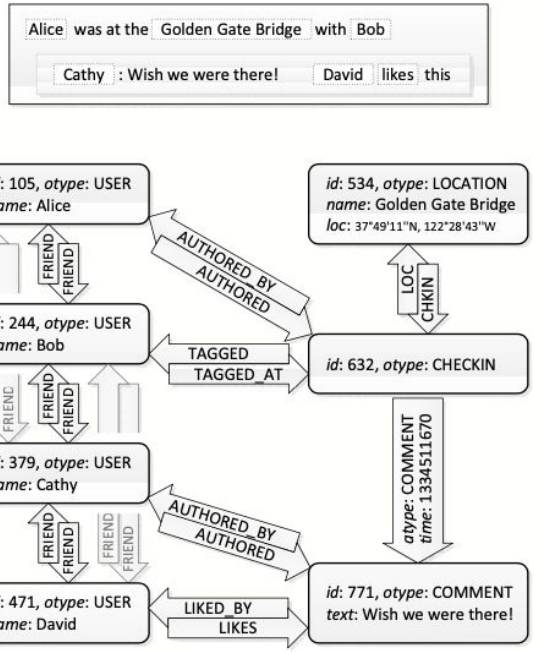
The Social Graph

- A flexible representation that **directly models real-life objects** and relationships
- **Objects** (Typed Nodes) connected by **Associations** (Typed Edges) form the Graph
- **Objects** model People, Places, Posts etc and repeatable Actions
- **Associations** model relationships, non-repeatable Actions and State Transitions
- **Associations** are directed, and often are tightly coupled with an inverse Edge

The Social Graph



The Social Graph

- Both Objects and Associations encode **data as Key Value pairs**; Associations have a time field
- The possible keys are defined by per-type schema
- The graph is **read-heavy**; Each page view involves fetching hundreds of items
- **Recent items** are often read the most
- **Read after Write consistency** is critical; **Eventual consistency** is acceptable

The Pre-TAO Architecture

- The Social Graph is **stored in MySQL**, with masters and slaves distributed across “Regions”
- Memcached pools per “Region” function as a **lookaside cache** for Objects and Associations
- A **PHP abstraction** provides an Object-Association API without direct MySQL access for applications
- Data mapping, Cache invalidations and Control logic are implemented in the PHP client

The Pre-TAO Architecture: Challenges

- Lookaside caches require a distributed control logic to avoid "**Thundering Herds**" *(Leases, Nishtala et al.)*
- Edge Lists cached in a Key-Value store **have to be invalidated completely** on updates.
- **Harder Read After Write consistency** *(Remote markers, Nishtala et al.)*
- Accessing the Graph data from **non-PHP services**

TAO: The Objectives

- A **geographically distributed** graph storage system
- Serve **read queries from a "Region" local** to the requesting web server efficiently
- **Read and Write through** data access pattern, avoiding any storage layer access from clients
- Support **logic specific to the Social Graph** Eg. Adding inverse edges
- Favour **efficiency and availability over strong consistency**
- Ensure **Read-After-Write consistency** in the region where the write originated

TAO: The API Characteristics

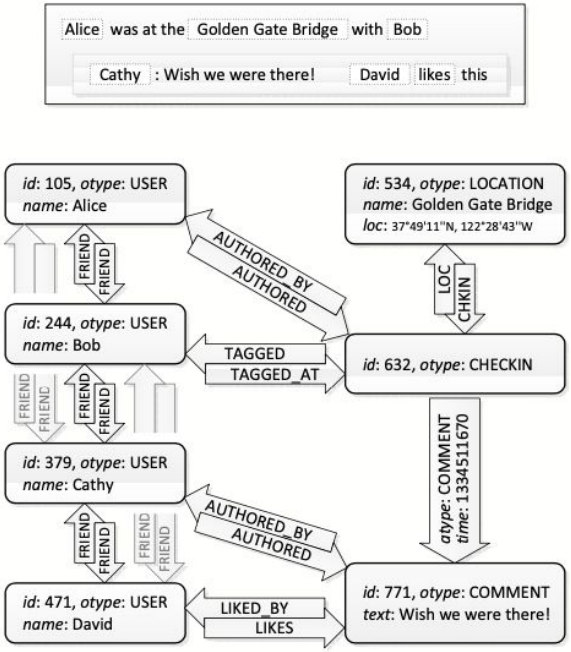
- Does not support a complete set of graph queries, but sufficient to **serve the Social Graph use cases** efficiently

- The creation-time locality of Social Graph associations allows an **association list to be always ordered by the time field**. For example: Recent posts and comments are more often fetched than older ones

- Enforces a **maximum number of associations per-association type** to be returned for a query

TAO: The API

- CRUD Operations on Objects
- A Restricted set of Association Operations
  - `assoc_add(id1, atype, id2, time, (k→v)*)`
  - `assoc_delete(id1, atype, id2)`
  - `assoc_change_type(id1, atype, id2, newtype)`
  - `assoc_get(id1, atype, id2set, high?, low?)`
  - `assoc_count(id1, atype)`
  - `assoc_range(id1, atype, pos, limit)`
  - `assoc_time_range(id1, atype, high, low, limit)`



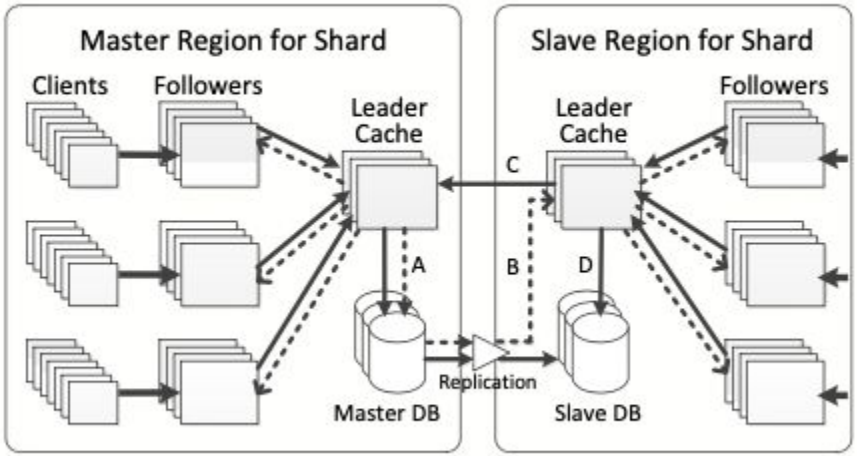
TAO: The Storage Layer

- Objects and Associations are **persisted in logically sharded MySQL databases**
- Associations **reside in the same shard as the source `Object(id1)`**
- Each MySQL Server is responsible for **one or more shards**
- Each shard **manifests as a logical database** within a MySQL server
- Physical servers are henced **decoupled from the sharding technique**

TAO: The Storage Layer

- Shard to server mappings are **modifiable to balance load** across servers
- *Object Ids* contain an **embedded *shard id*** and are bound for its lifetime avoiding the need for a lookup
- Object attributes are serialized into **a single `data` column**. Access patterns involving filtering/searches do not get served by the Social Graph subsystem
- Database **servers in a Region together have a full copy of the complete data**, either in a master or slave role

TAO: The Caching Layer



TAO: The Caching Layer

- The caching layer **implements the TAO API**
- Multiple caching servers form a ***Cache Tier*** that is capable of serving any TAO request
- Storage layer shards are mapped to cache servers using **consistent hashing**
- A single **Leader Tier** is responsible for all storage layer reads and writes

TAO: The Caching Layer

- A region can have several ***Follower Tiers*** that serve the client requests
- On cache misses and write requests, **followers contact the Leader** tier
- Leader tier issues **asynchronous invalidation/refill messages** to its followers
- Cache servers evict items using a **least recently used (LRU) policy**
- Writes **create inverse associations** as it is type-aware, but **without any atomicity guarantees**

TAO: The Leader Tier

- Leaders **perform all the reads** from the local Storage Layer
- Leaders in master regions handle the **writes to the storage layer**, issues invalidation/refill messages to its followers
- Leaders in master regions handling a cross-region write requests, additionally **return change sets** to the requesting leader to propagate to the requesting follower
- Leaders in master regions **embed invalidation/refill messages as writes to a black-hole table** in the storage layer (referred to as embedded messages)
- Leaders in slave regions for a storage layer shard, **delegates the write requests to the Leader tier of the master region**

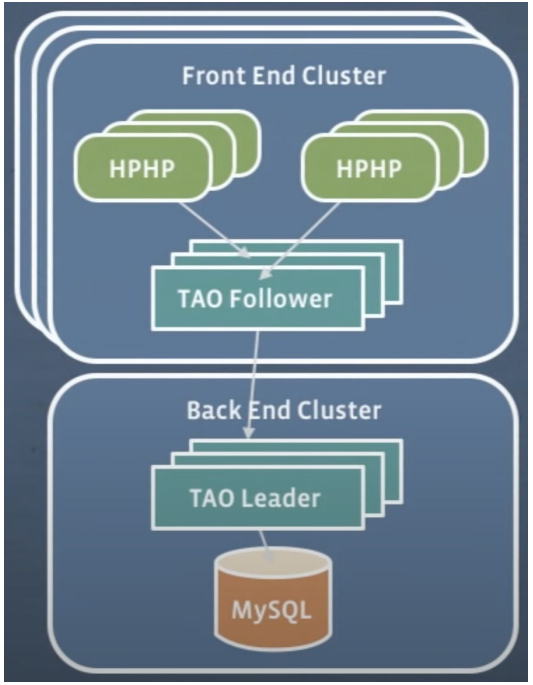
TAO: The Leader Tier

- Leaders in slave regions **subscribe to embedded invalidation/refill messages** from the replication logs and in turn deliver them to the local followers
- In case of failure to deliver invalidation/refill messages to the followers, leader **queues them into disk**
- Leaders acting as the central cache coordinator **prevents Thundering Herds by serializing concurrent writes** for the same key
- Leaders optimize the cross-region communications by bu**ndling multiple requests into a single RPC call**

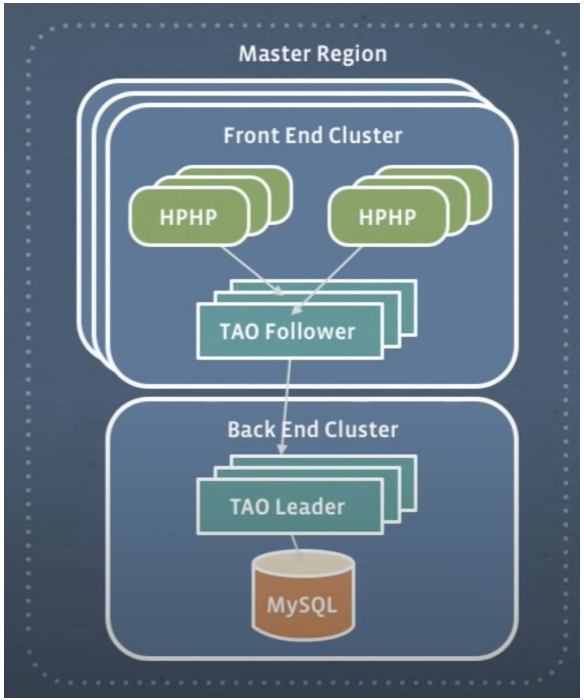
TAO: Follower Tier

- Followers **serve the clients** via the TAO API
- Followers **delegate cache misses and writes to the leader**
- In case of writes, the follower tier **applies the changeset returned** by the leader synchronously to achieve Read-After-Write consistency in the same tier
- Followers **process invalidation/refill messages** from the Leader
- Followers **perform shard cloning** to avoid hot spots i.e overloading specific cache servers housing a “popular” key

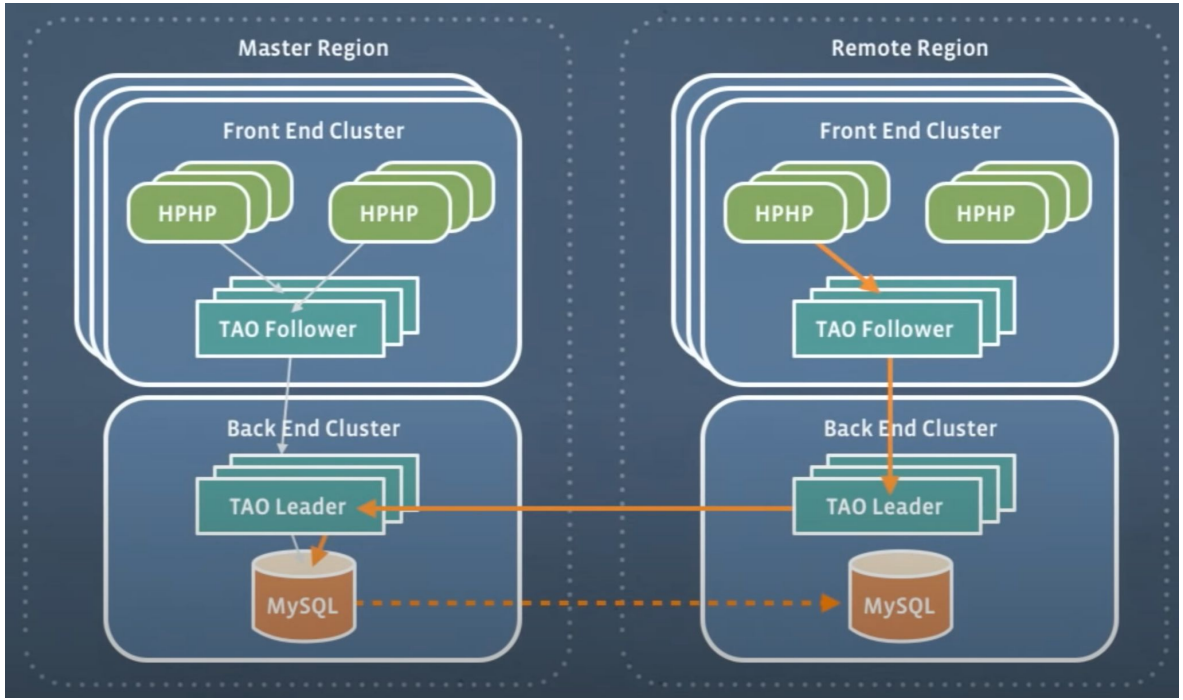
Tao: The Read Path



TAO: The Write Path (Master Region)



TAO: Write Path (The Slave Region)



TAO: Consistency Model

- TAO is **eventually consistent** owing to the asynchronous replication behaviour across regions and across followers
- **Read-After-Write consistency** is assured in the same tier owing to the synchronous delivery of the changeset applied. Changesets are only applied after verifying that current “version” of the data in the cache matches the pre update value in the changeset.
- Inconsistencies may arise in case of **partial leader failure or follower failures during writes** which resolve themselves on receiving the invalidation/refill messages
- In case of a cache eviction due to indications in changeset data version, **clients may observe a go back in time** if the storage layer replication takes longer than the cache eviction

TAO: Failure Handling

- A **storage layer master failure** is handled by auto promoting an existing slave
- A **storage layer slave failure** is handled by redirecting follower reads to the leader in the shard's master region. Invalidation/refill messages are delivered from the master region
- On **slave promotion**, the embedded invalidation/refill messages may be replayed in all regions to ensure data consistency

TAO: Failure Handling

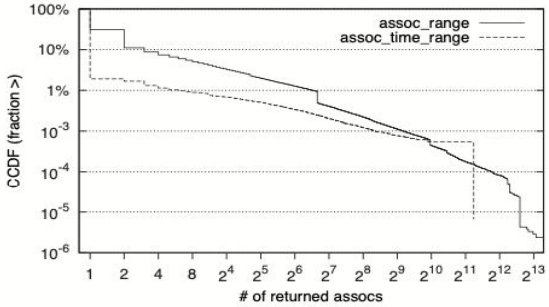
- On a **leader cache server failure**, followers handle cache misses by reading directly off the storage layer
- On a **leader cache server failure**, writes are sent to a replacement leader chosen at random, which queues up embedded invalidation/refill messages for the original leader until it is back in service
- **Refill and invalidation failures** are handled by queuing the messages to the disk to be delivered later
- **Follower server failures** are handled by the client by routing requests to a backup follower tier

TAO: Workload and Performance

- Only **0.2%** of the requests are writes

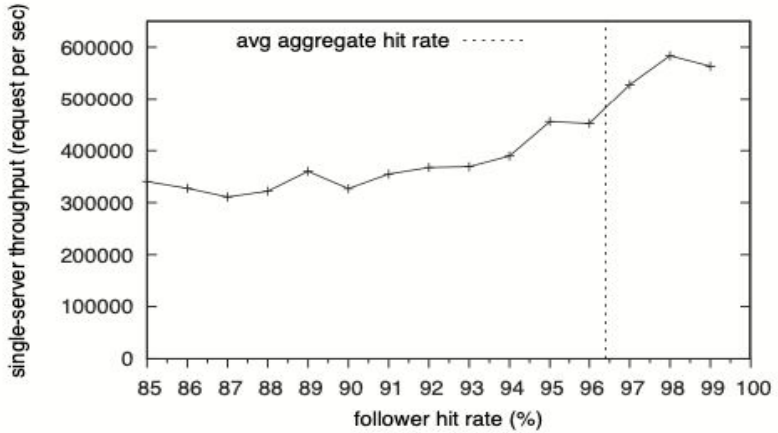
read requests	**99.8 %**	**write requests**	**0.2 %**
assoc_get	15.7 %	assoc_add	52.5 %
assoc_range	40.9 %	assoc_del	8.3 %
assoc_time_range	2.8 %	assoc_change_type	0.9 %
assoc_count	11.7 %	obj_add	16.5 %
obj_get	28.9 %	obj_update	20.7 %
		obj_delete	2.0 %

- Association lists are **very often empty or small**



TAO: Workload and Performance

- Throughput: **Half a million rps** single-server throughput at maximum hit rate



- Availability: Failed queries account for **0.00049%** of total received requests

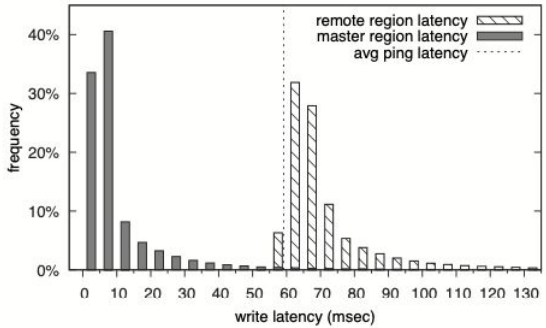
TAO: Workload and Performance

- Overall hit rate of **96.4%**
- Read Latencies

	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

TAO: Workload and Performance

- Write Latency



- Slave storage servers lag their master by less than 1 second during 85% of the sampling window, by less than 3 seconds 99% of the time, and **by less than 10 seconds 99.8% of the time**

Related Work

- Eventual consistency & read-after-write consistency variants as presented by **Terry et al (SOSP, 1995) and Vogels (ACM Queue, 08)**
- Geographically distributed data stores like **Google's Spanner** that distributes data across geographies ensuring one leader shard using the Paxos algorithm
- Distributed hash tables and key-value systems like **Amazon DynamoDB**
- Hierarchical connectivity like **Akamai content cache systems** that minimises latencies by avoiding cross-region requests
- Structured storage systems like **SimpleDB** with weaker guarantees than traditional RDBMS
- Modern Graph databases like **Neo4j**

Summary

- The **Social Graph** data model and its characteristics are presented
- TAO introduces **hierarchical data layers** to optimize for latencies
- TAO introduces an **asynchronous model to optimally ensure data consistency** across geographies

References

- TAO: Facebook's Distributed Data Store for the Social Graph
- Scaling Memcache at Facebook
- USENIX ATC '13 - TAO: Facebook’s Distributed Data Store for the Social Graph
- Large-Scale Low-Latency Storage for the Social Network - Data@Scale
- Eventually Consistent - Revisited

Leases

- Addresses the issues of “**Thundering Herds**” and “**Stale Sets**”
- **Thundering Herds** occur when a specific key undergoes heavy read and write activity. Repeated invalidations cause several reads to default to costly reads from the storage layer
- **Stale Sets** occur when a client sets an older value in to cache due to concurrent writes
- Cache server issues a lease (a token bound to the key) when client initiates a set request
- Cache server invalidates a lease when a key is deleted (Update is a delete and set for simple caches)
- A set request is validated against the lease issued to prevent **Stale Sets**
- For a short duration after issual of a lease for a key, reads to the key are sent a special message instructing retrial after a small time window (few milliseconds). This mitigates **Thundering Herds**

Remote Markers

- Storage layer replication of data needs to be ensured before invalidating caches in a slave region to prevent stale sets
- When a client writes to a key K, it **sets a marker Rk in the local storage** layer
- The write in the master region embeds the **deletion of Rk alongside the write query**
- On reads in the slave region, **requests are routed to the master region as long as an Rk is present**