Dynamo

Context

Dynamo observes that the storage layer sets a bound on the reliability and scalability of a scalable system. Therefore, they try hard to provide the usual properties:

- scalability: incremental; add a node at a time

- symmetry: no "special roles" – all features exist in each node. Simplifies management? An extension of this is decentralization: no centralized control. Avoids outages caused by failure of the centralized control nodes.

- availability: reads and writes must succeed even if nodes have failed. Leads dynamo to pick a relaxed eventual consistency model, implying conflict resolution is needed.

- SLAs: focus in 99.9th percentile of latency (1 in a 1000). They don't describe any particular technique to lower this tail latency, however; they just measure it.

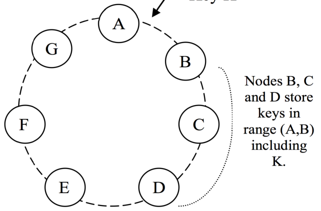
Design

Data partitioning

- consistent hashing
    - circular ID space
        - map both the key (hash) and the node (random ID) to it
        - key is stored on first node that is a successor
    - virtual nodes
        - each physical node is stored as many virtual nodes
        - lets you adapt to node heterogeneity (# virtual nodes ∝ capacity)
        - if many virtual nodes, then on failure, load spread out evenly across ring
- advantages
    - automatically adapts data partitioning as node membership changes, with minimal "reshuffling" of data during repartitioning
    - random node and key assignment gives an approximation to load balance
- disadvantage
    - uneven distribution of key storage is a natural consequence of random node names; leads to uneven query load
    - key management can be expensive when nodes transiently fail
        - as must transfer state on failure, then transfer back on recovery
- need a routing algorithm
    - given a key, how do you know which node is responsible?
    - Dynamo: O(1) routing by having all nodes know about all nodes; flat, complete routing table

Replication

- each data item is replicated at N hosts (usually N=3)
- "preference list": the set of nodes that is responsible for storing a particular key
    - the node the key is assigned to, followed by its N-1 physically distinct successors



- when new replica is created (e.g., in response to permanent failure), or when doing pairwise anti-entropy, data transfer is coordinated using “merkle tree”
    - hash tree
    - lets you quickly “zoom in” on parts of the data that differ, and minimize the data that has to be transferred to check for inconsistencies

Data versioning

- dynamo provides “eventual consistency” – updates propagate asynchronously, i.e., a put() call will return to its caller before the update is applied at all the replicas
    - implies get() operations may return an object that does not have the latest updates
    - also implies that concurrent put()’s to the same key can result in replica divergence – why?
    - also implies that failures can result in replica divergence – why? (nodes partitioned off won’t get update; update propagates only within the partition)
- idea: each modification creates a new, immutable version of the data
    - multiple versions can be present at the same time
    - most of the time, the system will be able to determine which version is authoritative (“syntactic reconciliation”)
    - sometimes, the client needs to step in to reconcile multiple branches (“semantic reconciliation”)
- idea: name versions using vector clocks to capture causality
    - clock stores list of (coordination server, version at that server) pairs
    - can examine clocks to understand causal history; helpful for clients during semantic reconciliation
    - issue: need to store vector clocks, and those clocks may grow in size if many servers act as coordination server for a key. truncate this list over time.

How get() and put() work

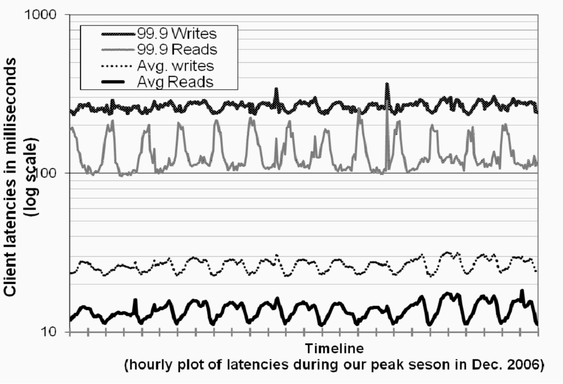
- Dynamo uses a (sloppy) quorum based consistency protocol
    - R: minimum number of nodes that must participate in a read
    - W: minimum number of nodes that must participate in a write
    - if R+W > N, you get a quorum, and per-key sequential consistency
        - dynamo typically operates with N=3, R=2, W=2
        - but, applications can override to choose their own settings

- reads and writes go to the first N healthy nodes in the preference list, skipping those that are down or inaccessible
    - for a put(), the coordinator (the first node in the list) generates a vector timestamp, writes the new version locally, then sends the new version to the N highest-ranked reachable nodes. If at least W-1 respond, the write is successful.
    - for a get(), coordinator requests all versions of the key from the N highest-ranked reachable nodes, waits for R responses, and returns gathered results to the client.
        - implies client may get multiple causally distinct versions of the data, in which case its up to the client to reconcile.
        - nice side-effect: since R < N, waiting for first R helps deals with stragglers!

Evaluation

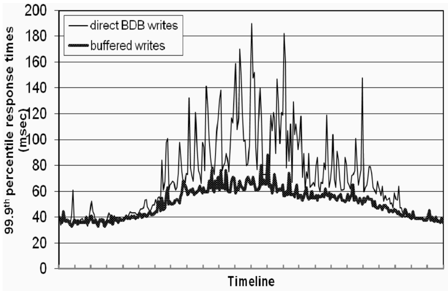
Latency as a function of time:

- writes 2x slower than reads – why? (disk access)
- 99.9th percentile 10x of average – why? is this good? how do they achieve it?
    - "99th percentile affected by factors such as variability in request load, object sizes, and locality patterns" -- bursts in load, large objects, cold objects
- note that latency $\propto$ load. why?



Write latency can be reduced by using "buffered write" – write into an in-memory buffer, slowly drain that buffer to disk.

- sacrifices durability under some failure modes for performance in the common case
- what do you think of relying on "store in multiple nodes' memory" as a durability guarantee?



Divergent version frequency

- 99.94% of requests saw one version
- 0.00057% saw two versions
- 0.00047% saw three versions
- 0.00009% saw four versions

- "experience shows that the increase in number of divergent versions is contributed not by failures but due to the increase in the number of concurrent writers."
    - concurrent write sharing is rare, so divergence is rare
    - "triggered by busy robots – sensitive nature of the story" ☺