Dynamo

Amazon’s Highly Available Key-value Store
SOSP ’07

Authors

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Motivation

A key-value storage system that provide an **“always-on” experience** at **massive scale**.

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A key-value storage system that provide an “always-on” experience at **massive scale**.

“Over 3 million checkouts in a single day” and “hundreds of thousands of concurrently active sessions.”

Reliability can be a problem: “data center being destroyed by tornados”.

Motivation

A key-value storage system that provide an **“always-on” experience** at massive scale.

Service Level Agreements (SLA): e.g. 99.9th percentile of delay < 300ms

ALL customers have a good experience

Always writeable!

Consequence of “always writeable”

Always writeable ⇒ no master! Decentralization; peer-to-peer.

Always writeable + failures ⇒ conflicts

CAP theorem: A and P

Amazon's solution

Sacrifice consistency!

System design: Overview

- Partitioning
- Replication
- Sloppy quorum
- Versioning
- Interface
- Handling permanent failures
- Membership and Failure Detection

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System design: Partitioning

Consistent hashing

- The output range of the hash function is a fixed circular space
- Each node in the system is assigned a random position
- Lookup: find the first node with a position larger than the item's position
- Node join/leave only affects its immediate neighbors

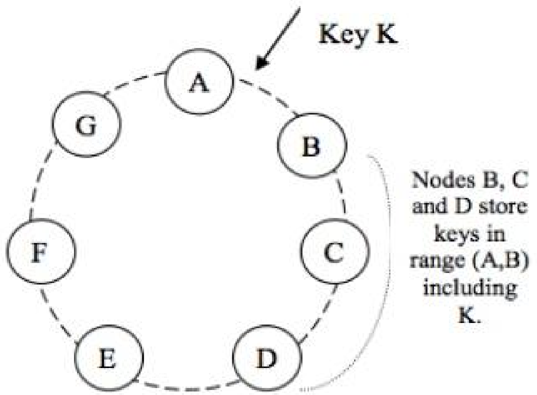
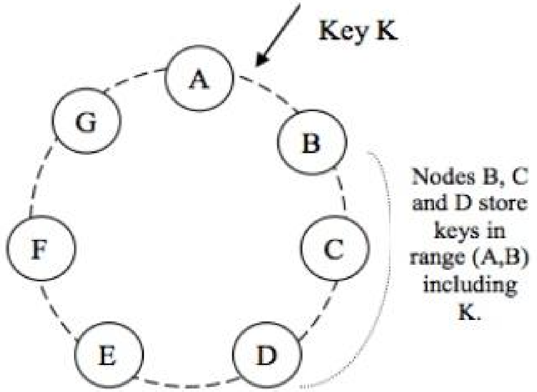


Figure 2: Partitioning and replication of keys in Dynamo ring.

System design: Partitioning

Consistent hashing

- ❑ Advantages:
  - ❑ Naturally somewhat balanced
  - ❑ Decentralized (both lookup and join/leave)



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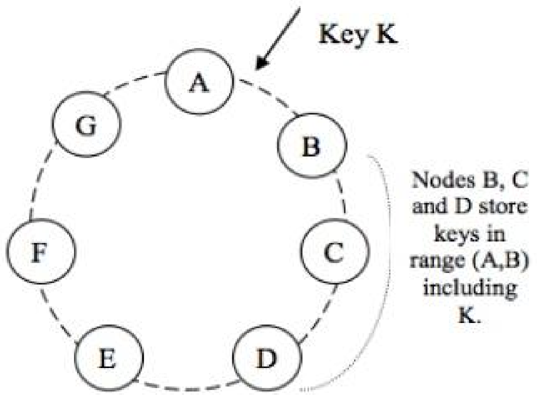
System design: Partitioning

Consistent hashing

- ❑ Problems:
  - ❑ Not really balanced -- random position assignment leads to non-uniform data and load distribution
  - ❑ Solution: use virtual nodes



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System design: Partitioning

Virtual nodes

- ❏ Nodes gets several, smaller key ranges instead of a big one

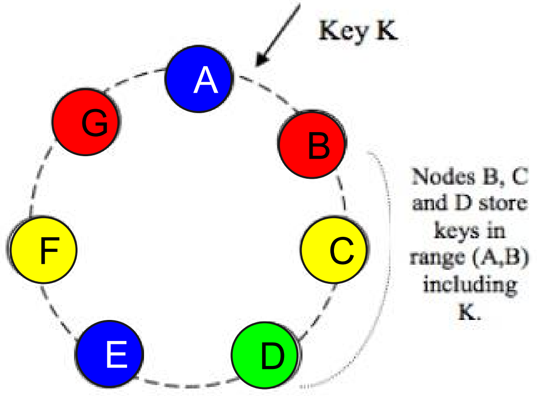
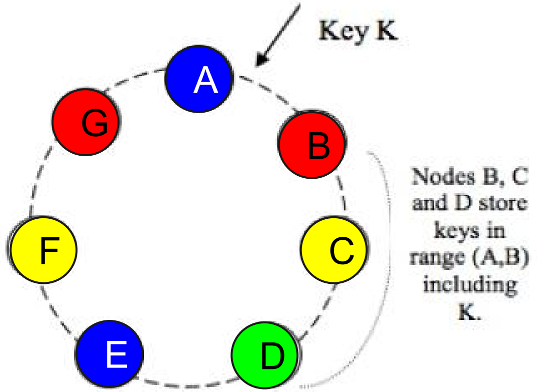


Figure 2: Partitioning and replication of keys in Dynamo ring.

System design: Partitioning

- ❑ Benefits
  - ❑ Incremental scalability
  - ❑ Load balance



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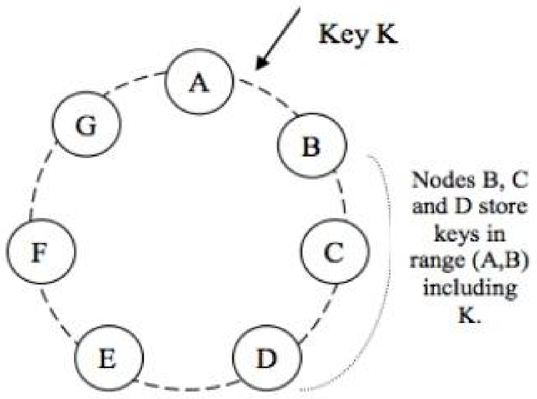
System design: Partitioning

❑ Up to now, we just redefined Chord



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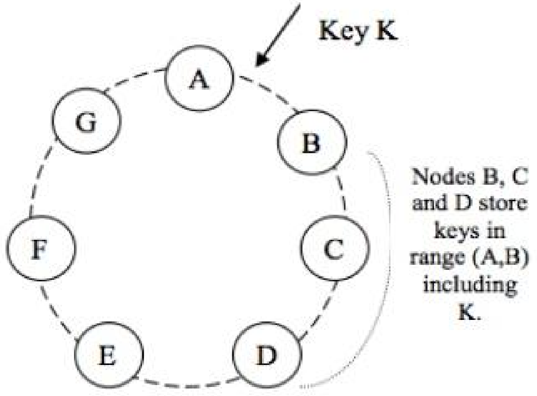
System design: Replication

- Coordinator node
- Replicas at N - 1 successors
    - N: # of replicas
- Preference list
    - List of nodes that is responsible for storing a particular key
    - Contains more than N nodes to account for node failures



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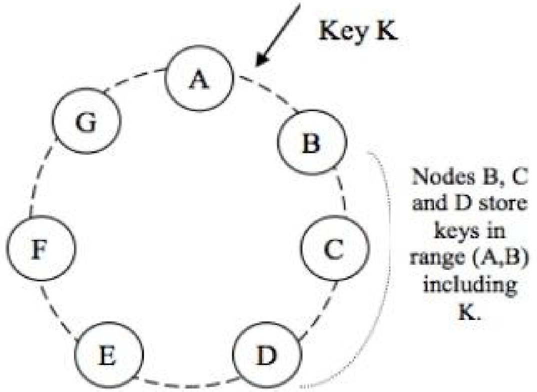
System design: Replication

- Storage system built on top of Chord
- Like Cooperative File System(CFS)



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System design: Sloppy quorum

- Temporary failure handling
- Goals:
  - Do not block waiting for unreachable nodes
  - Put should always succeed
  - Get should have high probability of seeing most recent put(s)
  - CAP

System design: Sloppy quorum

- Quorum: R + W > N
  - N - first N reachable nodes in the preference list
  - R - minimum # of responses for get
  - W - minimum # of responses for put
- Never wait for all N, but R and W will overlap
- “Sloppy” quorum means R/W overlap **is not guaranteed**

Conflict!

Example:
N=3, R=2, W=2
Shopping cart, empty “”
preference list n1, n2, n3, n4
client1 wants to add item X
- get() from n1, n2 yields “”
- n1 and n2 fail
- put(“X”) goes to n3, n4

n1, n2 revive
client2 wants to add item Y
- get() from n1, n2 yields “”
- put(“Y”) to n1, n2

client3 wants to display cart
- get() from n1, n3 yields two values!
- “X” and “Y”
- neither supersedes the other -- conflict!

Eventual consistency

- ❑ Accept writes at any replica
- ❑ Allow divergent replica
- ❑ Allow reads to see stale or conflicting data
- ❑ Resolve multiple versions when failures go away(gossip!)

Conflict resolution

- When?
  - During reads
  - Always writeable: cannot reject updates
- Who?
  - Clients
  - Application can decide the best suited method

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System design: Versioning

- Eventual consistency ⇒ conflicting versions
- Version number? No; it forces total ordering (Lamport clock)
- Vector clock

System design: Versioning

- ❏ Vector clock: version number per key per node.
- ❏ List of [node, counter] pairs

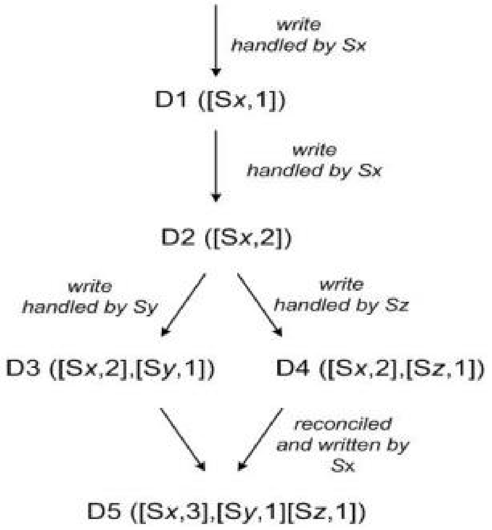

Figure 3: Version evolution of an object over time.

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System design: Interface

- All objects are immutable
- Get(key)
  - may return multiple versions
- Put(key, context, object)
  - Creates a new version of key

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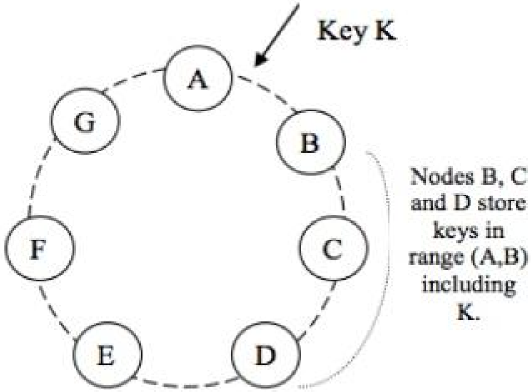
System design: Handling permanent failures

- ❏ Detect inconsistencies between replicas
- ❏ Synchronization



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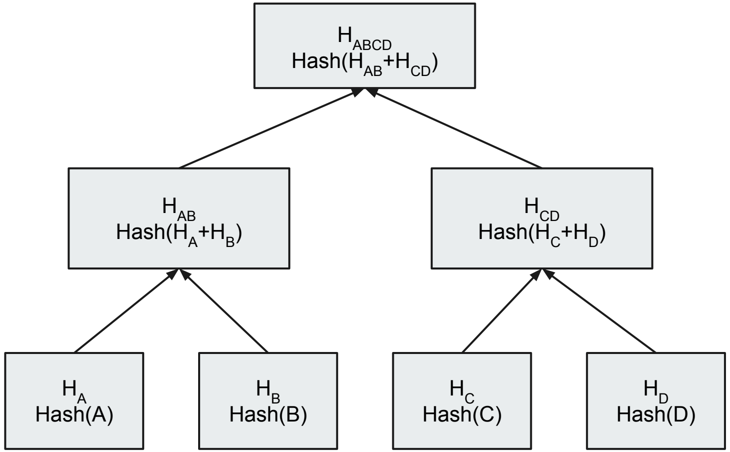
System design: Handling permanent failures

- Anti-entropy replica synchronization protocol
- Merkle trees
  - A hash tree where leaves are hashes of the values of individual keys; nodes are hashes of their children
  - Minimize the amount of data that needs to be transferred for synchronization



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System design: Membership and Failure Detection

- Gossip-based protocol propagates membership changes
- External discovery of seed nodes to prevent logical partitions
- Temporary failures can be detected through timeout

System design: Summary

Table 1: Summary of techniques used in *Dynamo* and their advantages.

Problem	Technique	Advantage
Partitioning	Consistent Hashing	Incremental Scalability
High Availability for writes	Vector clocks with reconciliation during reads	Version size is decoupled from update rates.
Handling temporary failures	Sloppy Quorum and hinted handoff	Provides high availability and durability guarantee when some of the replicas are not available.
Recovering from permanent failures	Anti-entropy using Merkle trees	Synchronizes divergent replicas in the background.
Membership and failure detection	Gossip-based membership protocol and failure detection.	Preserves symmetry and avoids having a centralized registry for storing membership and node liveness information.

Evaluation?

No real evaluation; only experiences

Experiences: Flexible N, R, W and impacts

- They claim "the main advantage of Dynamo" is flexible N, R, W
- What do you get by varying them?
  - (3-2-2) : default; reasonable R/W performance, durability, consistency
  - (3-3-1) : fast W, slow R, not very durable
  - (3-1-3) : fast R, slow W, durable

Experiences: Latency

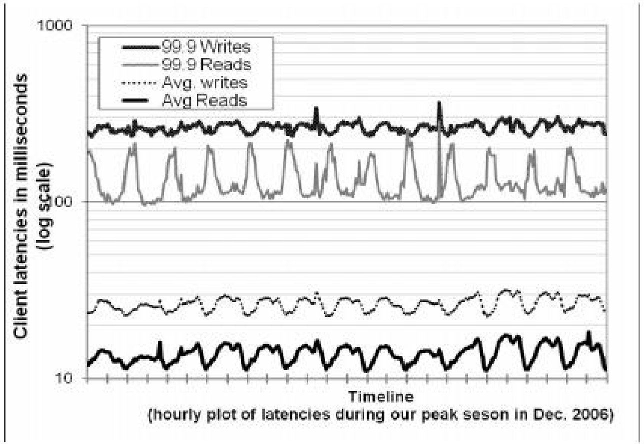

Figure 4: Average and 99.9 percentiles of latencies for read and write requests during our peak request season of December 2006. The intervals between consecutive ticks in the x-axis correspond to 12 hours. Latencies follow a diurnal pattern similar to the request rate and 99.9 percentile latencies are an order of magnitude higher than averages

- 99.9th percentile latency: ~200ms
- Avg latency: ~20ms
- “Always-on” experience!

Experiences: Load balancing

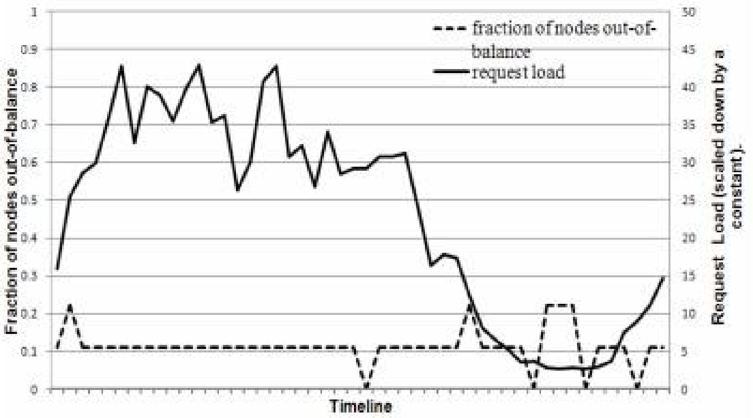

Figure 6: Fraction of nodes that are out-of-balance (i.e., nodes whose request load is above a certain threshold from the average system load) and their corresponding request load. The interval between ticks in x-axis corresponds to a time period of 30 minutes.

- Out-of-balance: 15% away from average load
- High loads: many popular keys; load is evenly distributed; fewer out-of-balance nodes
- Low loads: fewer popular keys; more out-of-balance nodes

Conclusion

- Eventual consistency
- Always writeable despite failures
- Allow conflicting writes, client merges

Questions?