Dynamo: Amazon’s Highly Available Key-Value Store

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Amazon.com

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Motivation

- A storage system that attains high availability, performance and durability
- Decentralized techniques
  - Data partitioning
  - Replica synchronization
  - Membership

Agenda

- Introduction
- System Architecture
- Implementation
- Experiments
- Conclusion

Amazon.com

- One of the largest e-business platform
  - 3 million checkouts on a peak day
- Also a major cloud hosting service
  - Customer trust
- Hundreds of thousands of machines
- Network failures/ disk failures is a norm

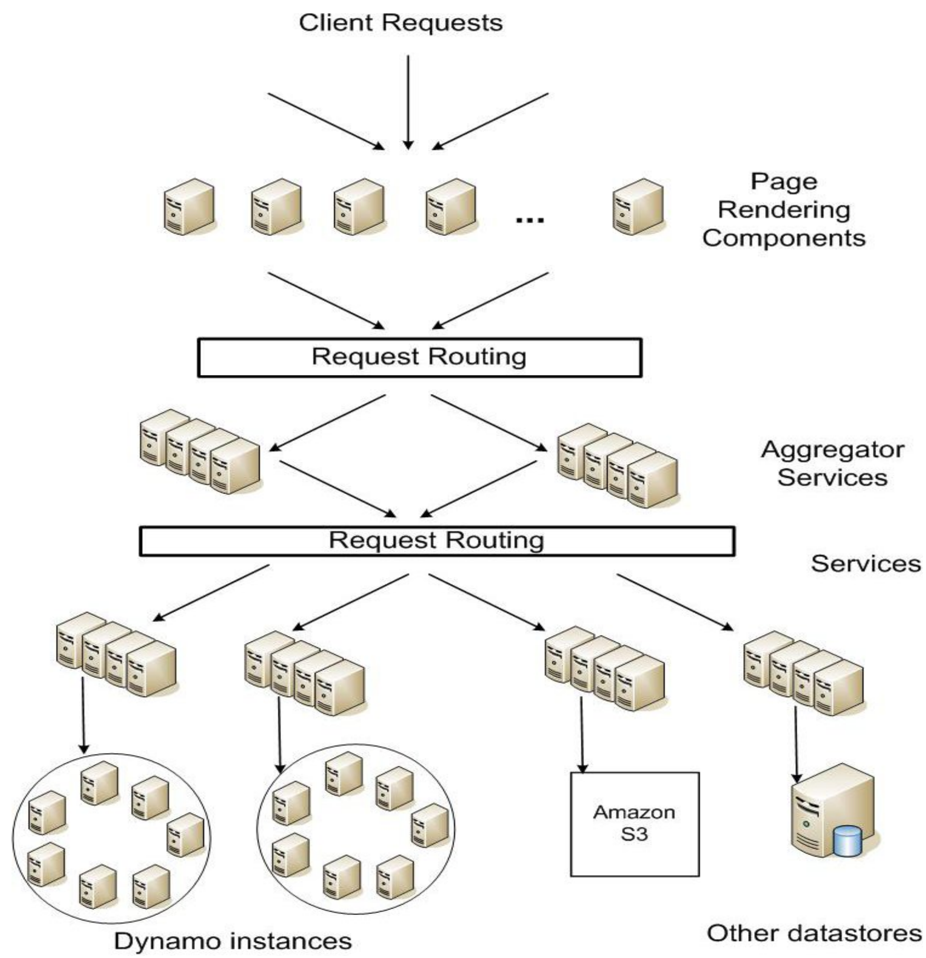
Availablility?

Service Oriented Architecture

- Loosely coupled replicated services
- Stateless
- Persistent store

- Services e.g

  - Recommendation, top selling, catalog, etc



Service Requirements

- Query Model – key, value
  - Code versioning systems
- Must be able to make tradeoffs between availability, consistency, durability
- 99.99 percentile SLA
- Example – Shopping Cart service

- why not relational database?

Design Considerations

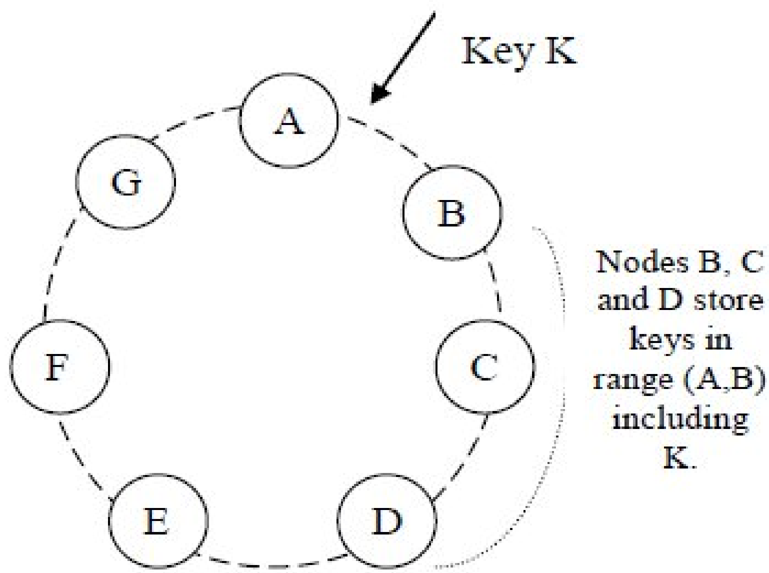
- Highly available (writes)
  - Eventually consistent
  - Merge during read
  - Handled by applications
- Less manual interaction
- Incrementally scalable
- Completely decentralized
  - Contrast Bigtable?

Challenges

- Partitioning
- Availability (writes)
- Handling Failures
  - Temporary
  - Permanent
- Membership

Partitioning

- Consistent Hashing
  - Contrast linear hashing?
  - MD5 hash
- Replication – N nodes
  - Preference list
    - Multiple data centers
  - Coordinator
- Is this a global view?
  - Hierarchical namespace?



Ring partitioning

- Problems
  - Non uniform data
  - Heterogeneity

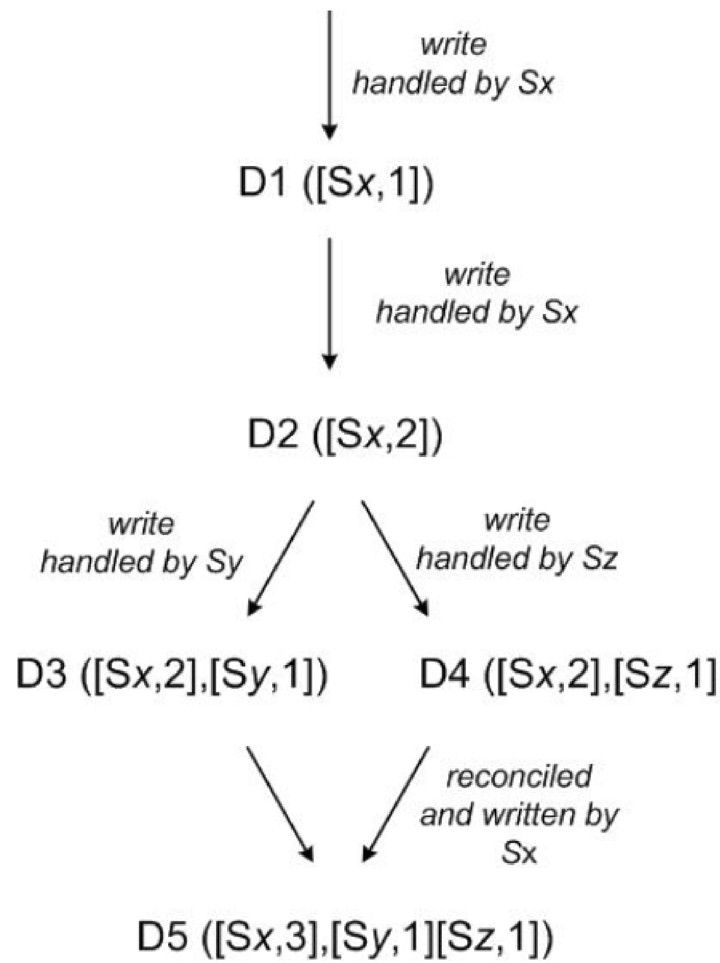
- Use virtual nodes
  - Multiple tokens per node
  - Add/remove node keeps system load steady
  - Incorrect buckets are bounded.

Data Versioning

- Asynchronous updates
- Merging – maintain new immutable version
  - Objects as blobs
  - Syntactic and semantic
  - Associative and commutative?
- Multiple branches
- Reconcile versions – during read
  - Last write wins
- Vector clocks

Vector clocks

- list (node, counter)
- Partial ordering
- Merged during read

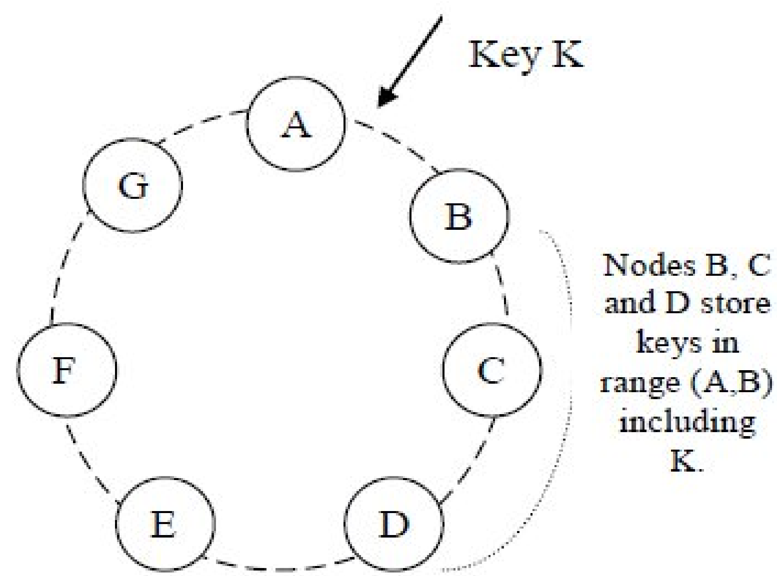


Get and Put

- API
  - get(key) returns list<object>
  - put(key, context, object)
- Context – contains metadata & version
- Load balancer or client library
- Request forwarding to coordinator
- Quorum – durability and anti-entropy
  - R nodes for read
  - W nodes for write

Hinted Handoff

- Sloppy quorum
  - Use first N healthy nodes
  - N=3, B unresponsive
  - Sent to E, metadata hints B



Replica Synchronization

- Anti-entropy
- Merkle trees
  - Leaf – hash value of key
  - Parents - hash of childs
  - One tree per key range/virtual node
  - Peers compare merkle trees
- Advantages
  - Less reads

Gossip

- Admin issue command to join/remove node
- Serving node records in its local membership history
- Gossip based protocol used to agree on the memberships
- Partition and Placement information sent during gossip

Failure detection

Integer pr; /* Local period number */

Every T' time units at M_i:

0. $pr := pr + 1$
1. Select random member M_j from view
   Send a ping(M_i, M_j, pr) message to M_j
   Wait for the worst-case message round-trip time for
   an ack(M_i, M_j, pr) message
2. If have not received an ack(M_i, M_j, pr) message yet
   Select k members randomly from view
   Send each of them a ping-req(M_i, M_j, pr) message
   Wait for an ack(M_i, M_j, pr) message until
   the end of period pr
3. If have not received an ack(M_i, M_j, pr) message yet
   Declare M_j as failed

Anytime at M_i:

4. On receipt of a ping-req(M_m, M_j, pr) ($M_j \neq M_i$)
   Send a ping(M_i, M_j, M_m, pr) message to M_j
   On receipt of an ack(M_i, M_j, M_m, pr) message from M_j
   Send an ack(M_m, M_j, pr) message to received to M_m

Anytime at M_i:

5. On receipt of a ping(M_m, M_i, M_l, pr) message from member M_m
   Reply with an ack(M_m, M_i, M_l, pr) message to M_m

Anytime at M_i:

6. On receipt of a ping(M_m, M_i, pr) message from member M_m
   Reply with an ack(M_m, M_i, pr) message to M_m

Implementation

- Local persistence
  - BerkleyDataBase Transactional Data Store
- Request Coordination
  - SEDA architecture

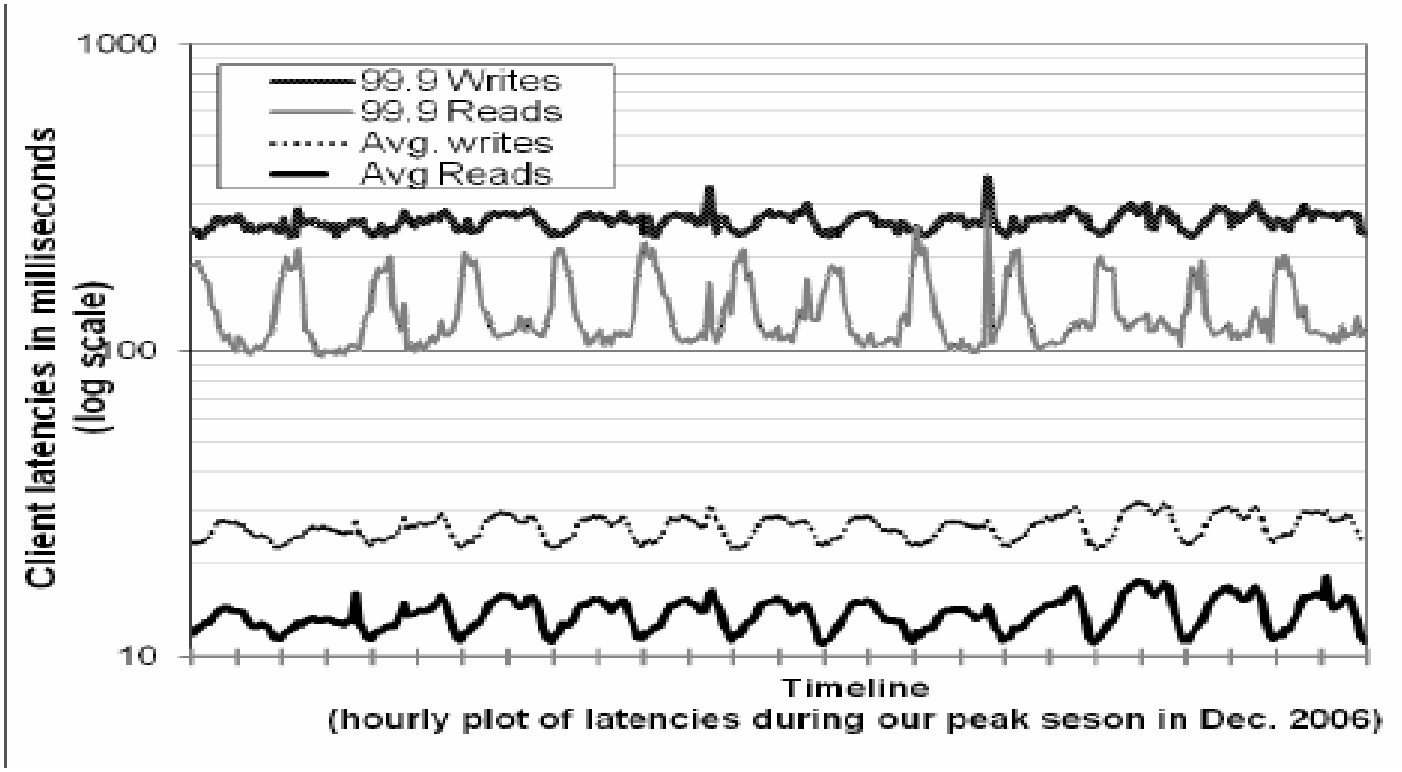
Read Operation

- Send read requests to nodes
- Wait for minimum no of responses (R)
- Too few replies fail within time bound
- Gather and find conflicting versions
- Create context (opaque to caller)
- Read repair

Values of N, R and W

- N represents durability
  - Typical value 3
- W and R affect durability, availability, consistency
  - What if W is low?
- Durability and Availability go hand-in-hand?

Results



1000
100
10
99.9 Writes
99.9 Reads
Avg. writes
Avg Reads
Client latencies in milliseconds
(log scale)
Timeline
(hourly plot of latencies during our peak seson in Dec. 2006)

Out of balance nodes

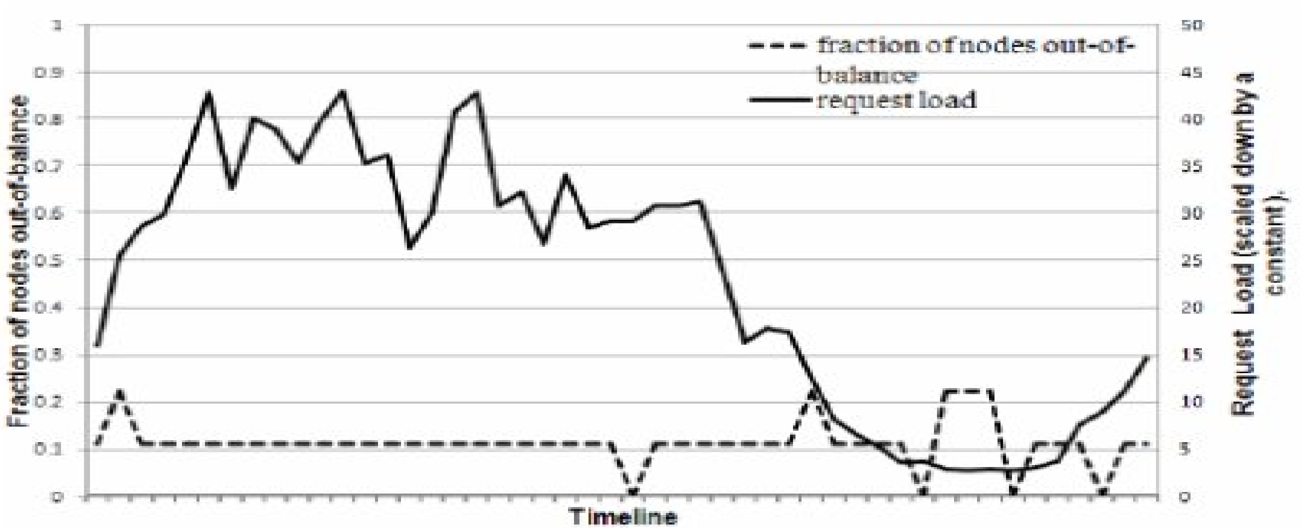


Figure 6: Fraction of nodes that are out-of-balance (i.e., nodes whose request load is above a certain threshold from the average system load) and their corresponding request load. The interval between ticks in x-axis corresponds to a time period of 30 minutes.

Partition Strategies

- T random tokens per node and partition by token value
  - Scan a range
  - Updating merkle trees
- T random tokens per node and equal partitions
  - Decoupling partition and placement
  - Changing the placement scheme at runtime
- Q/S tokens per node, equal partitions

Conclusion

- Dynamo has provided high availability and fault tolerance
- Provides owners to customize according to their SLA requirements
- Decentralized techniques can provide highly available system

Current State

- Some of the principles used by S3
- Open source implementation
  - Cassandra
  - Voldemort