DYNAMO: AMAZON'S HIGHLY AVAILABLE KEY VALUE STORE

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OUTLINE

- Introduction
- Motivation
- Design Overview
- System Objectives
- System Architecture
- Implementations
- Optimizations
- Conclusions

INTRODUCTION

- Two major challenges faced at Amazon
  - Reliability: slight outage results in huge financial loss
  - Scalability
- Amazon architecture is Highly Decentralized, Loosely Coupled and Service Oriented
- Need for always available storage technologies
  - Shopping Cart example
- Dynamo is highly available and scalable data store which can be configured as per application needs

MOTIVATION

- Traditional systems use relational databases
- Implementing RDBMS functionality requires expensive hardware, skilled personnel.
- Replication technologies limited
- Consistency chosen over availability
- Scaling and load balancing is difficult
- Dynamo addresses all the above problems efficiently!

DESIGN OVERVIEW

- Query Model
  - Simple read/write operations on data item identified by key
  - Targets application that store objects < 1 MB
- ACID
  - Relaxed ACID properties
  - Tradeoff on consistency to achieve availability
  - No isolation guarantees

DESIGN OVERVIEW (cont'd)

- Efficiency
  - System must be able to meet 99.9 percentile of reads and write to complete within a few ms
  - Services must be able to configure Dynamo to achieve desired latency and throughput
- Trusted Environment
  - No security related requirements
- Heterogeneity and Load distribution
- Symmetry
- Decentralization
- Incremental scalability

SYSTEM OBJECTIVES

- Guarantee eventual consistency
- Allow reads and writes even during node failures
- Target applications requiring key/value access with primary focus on high availability
- Target the storage space of an ‘always writeable’ data store by pushing conflict resolution to the reads.

SYSTEM ARCHITECTURE

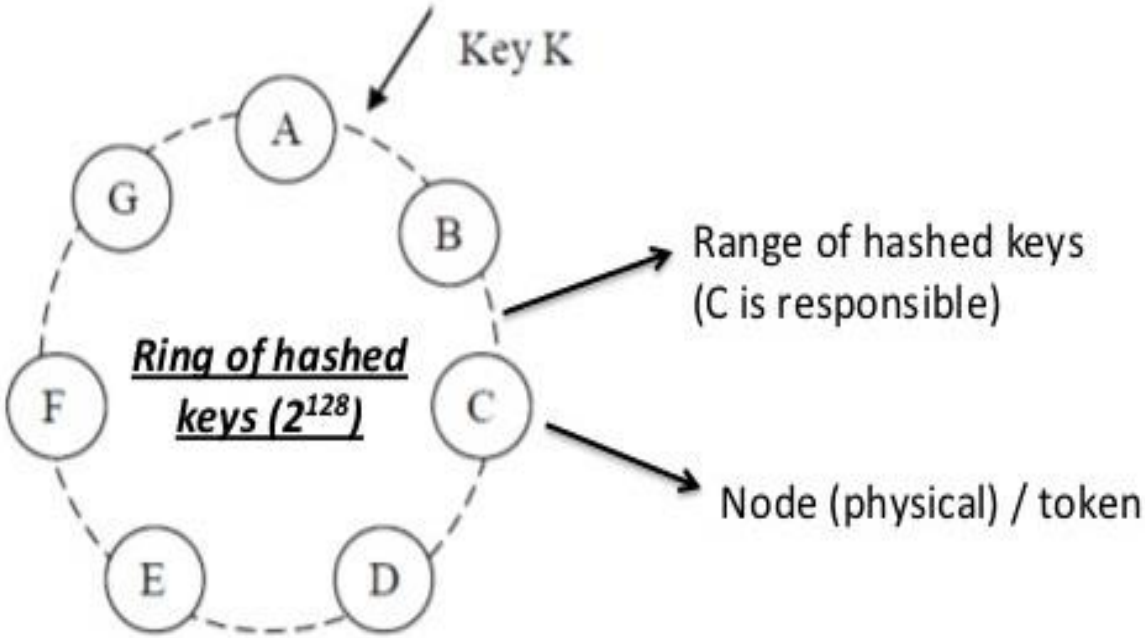
- Core distributed system techniques in Dynamo
  - Partitioning
  - Replication
  - Versioning
  - Execution
  - Consistency
  - Handling failures
  - Membership and failure detection
  - Scaling

PARTITIONING

- Uses Consistent Hashing
  - MD5 hash on key to generate identifier

New nodes are randomly assigned "tokens".

All nodes have full membership info.



PARTITIONING (cont'd)

- Challenges faced :
  - Non uniform data and load distribution
  - Heterogeneity in node performance

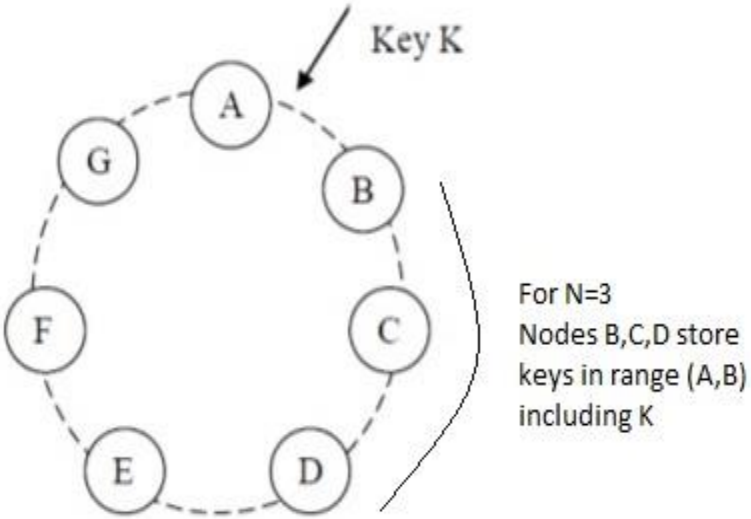
- Solution
  - Consistent hashing using VIRTUAL NODES

Consistent Hashing → Incremental Scalability

REPLICATION

- N = Number of Replicated machines
  - Coordinator Node: In charge of replication
  - Preference List: Nodes where object is replicated
- Coordinator replicates keys at N-1 clockwise successor nodes

Replication → availability,
durability

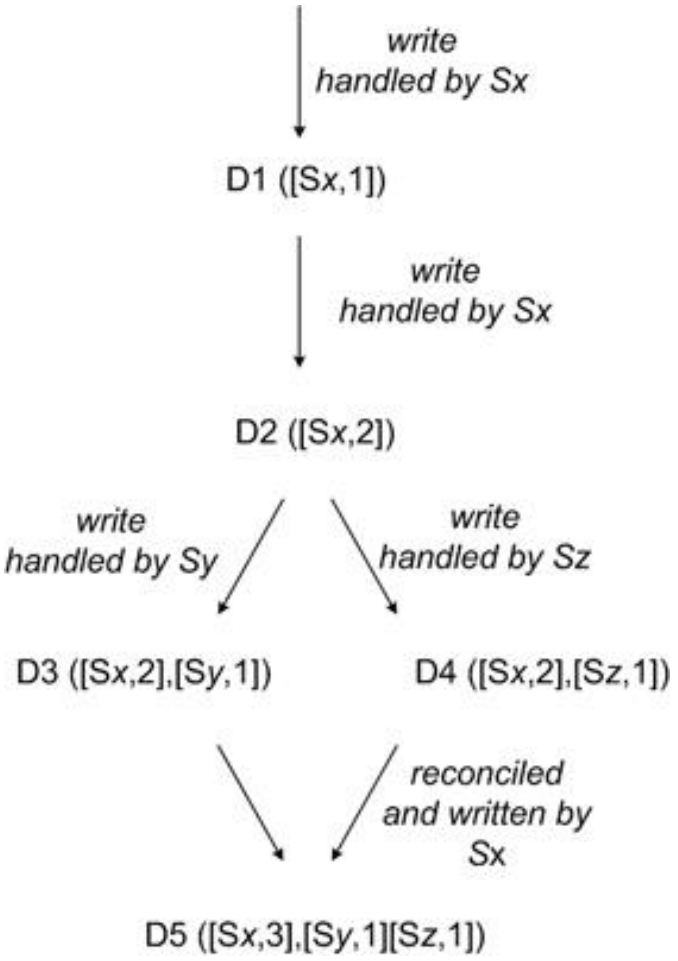


VERSIONING

- Eventual Consistency: asynchronous propagation of updates
- Each version is treated as new and immutable
- Allows multiple versions to be present
- Data reconciliation
  - Syntactic : performed by the system
  - Semantic :performed by some business logic at the client side

VERSIONING (cont'd)

- Vector clocks : to capture causality between different versions
  - (node, counter) pair
  - One clock per version per object
- Problem: increasing size of vector clocks
  - Solution: vector clock with timestamps



EXECUTION

- Any node can receive get() and put()
- Client selects node routing request through
  - Generic load balancer (max one hop)
  - Partition aware client library(zero hop)
- Coordinator for the request
  - Typically first node in preference list

EXECUTION (cont'd)

- To maintain consistencies among replicas:
  - Quorum like protocol
- Three configurable parameters:
  - N: number of replicas
  - R: min number of nodes that must read a key
  - W: min number of nodes that must write a key
- Setting R+W>N → Quorum like system
- R and W usually set less than N for better latency

HANDLING FAILURES

Temporary failures

- "Sloppy Quorum" so that reads/writes requests sent to first N healthy nodes
- Hinted handoff
  - When a intended node is down, hinted object is sent to another node
  - Object returned back to node once node is functionality
- Thus writes rejected only if all nodes are down

Permanent Failures

- Replica synchronization
  - Synchronize each replica periodically using Anti-entropy mechanism
  - Merkle trees used for faster, efficient detection of inconsistencies
  - Each node maintains separate Merkle trees for each key range

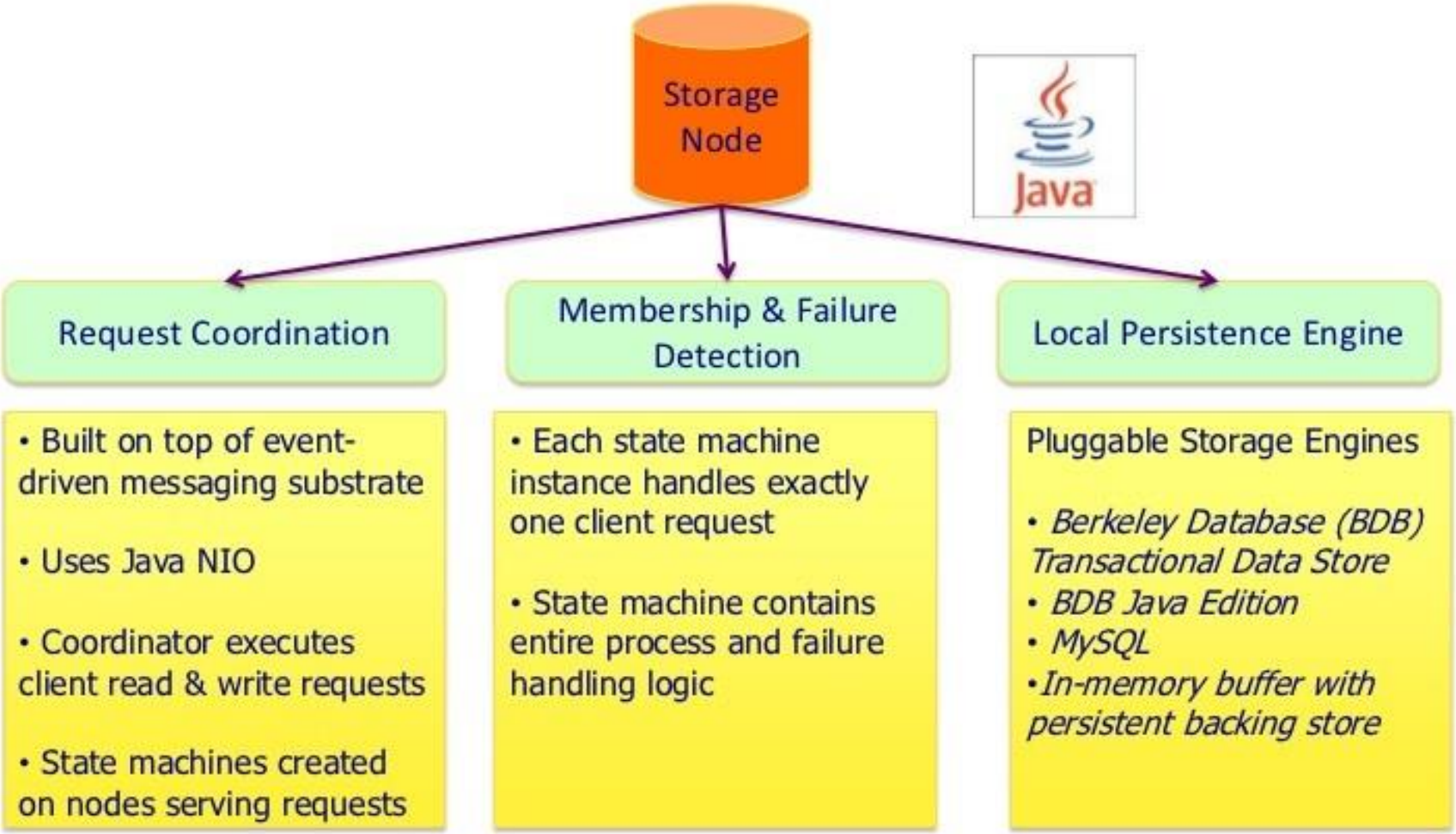
MEMBERSHIP AND FAILURE DETECTION

- Membership
  - Explicit addition/removal of nodes
  - Gossip based protocol propagates membership changes
  - Seed nodes: to prevent logical partitioning
- Failure detection
  - Purely local view of failure detection
  - If A cannot contact B, it considers B failed
  - Periodically retries communication

SUMMARY OF TECHNIQUES

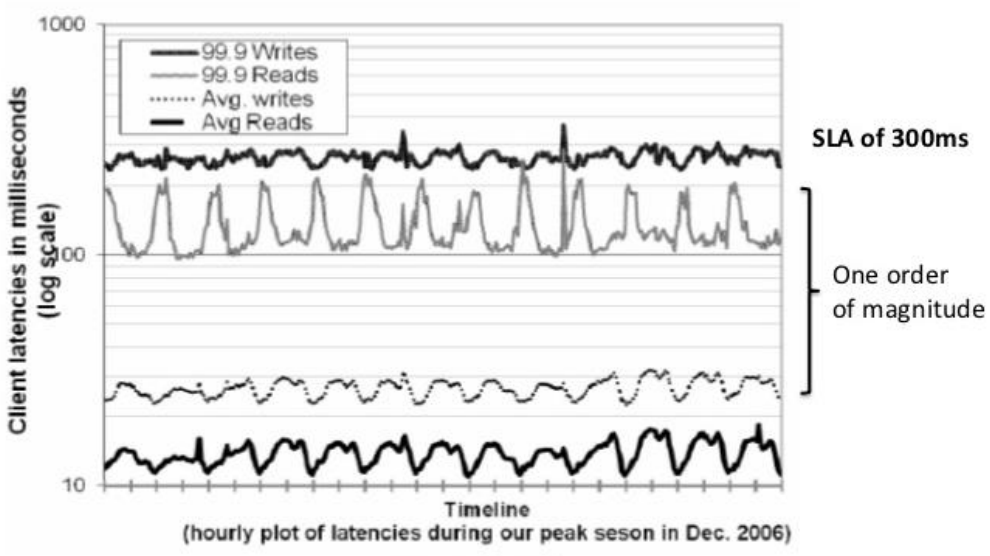
PROBLEM	TECHNIQUE	ADVANTAGE
PARTITIONING	CONSISTENT HASHING	INCREMENTAL SCALABILTIY
HIGH AVAILABILITY	VECTOR CLOCKS WITH RECONCILATION DURING READS	VERSION SIZE IS DECOUPLED FROM UPDATE RATES
HANDLING TEMPORARY FAILURES	SLOPPY QUORAM HINTED HANDOFF	HIGH AVAILABILITY AND DURABILITY GUARANTEE
RECOVERING FROM PERMANENT FAILURES	ANTI ENTROPY USING MERKLE TREES	SYNCHRONIZES DIVERGENT REPLICAS
MEMBERSHIP AND FAILURE DETECTION	GOSSIP BASED PROTOCOL	PRESERVES SYMMETRY AVOIDS CENTRALIZED REGISTRY

Implementation



OPTIMIZATIONS

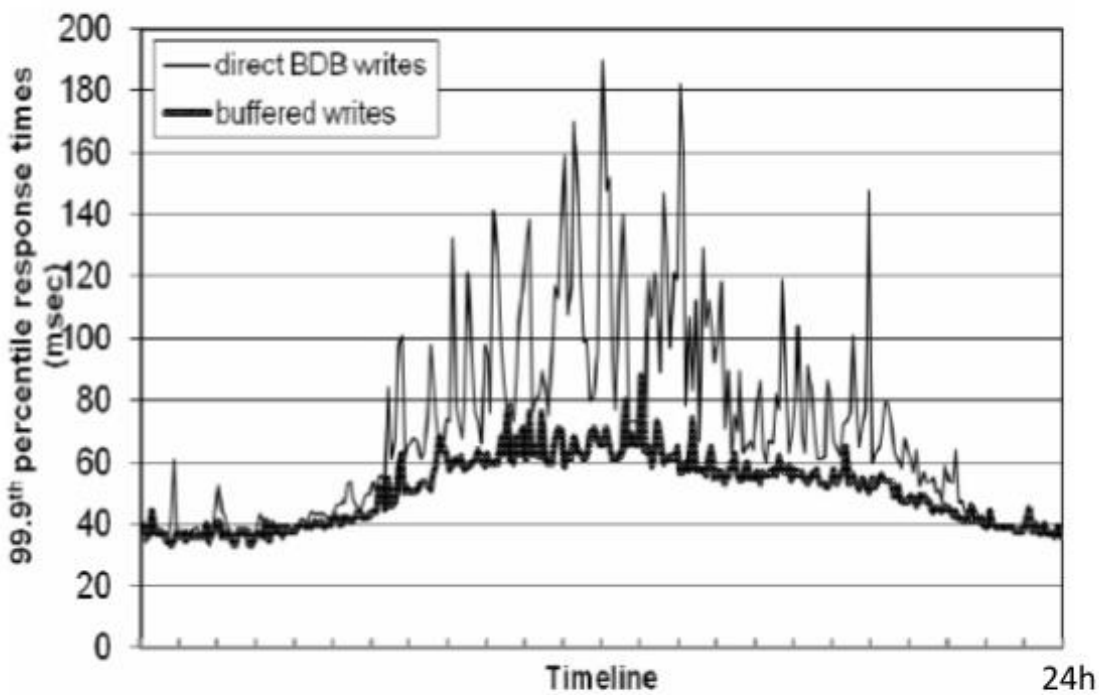
- Comparison between average and 99.9th latencies exhibit diurnal pattern
- Write latencies higher than read
- 99.9th percentile latencies higher than the average



1 interval = 12h

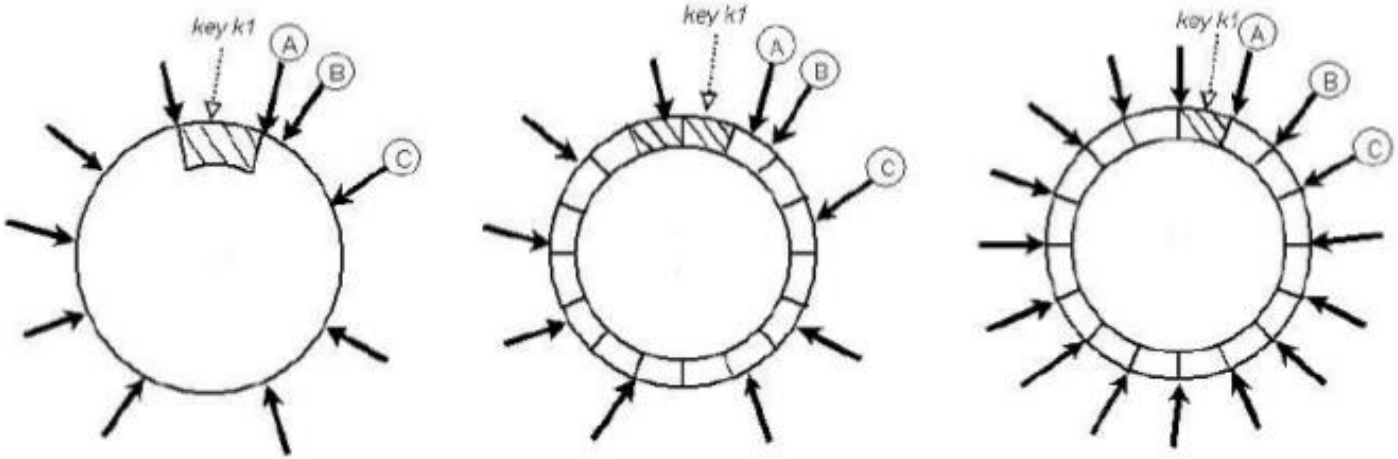
OPTIMIZATIONS (cont'd)

- Optimization solution : Buffered writes
- Result→ Reduction in 99.9th percentile latency by factor of 5 during peak traffic
- Durability tradeoff for performance hence, use Durable Writes



1 interval = 1h

PARTIONING STRATEGIES



Strategy 1

T random tokens per node and partition by token value

Strategy 2

T random tokens per node and Q equal-sized partitions (Q is large)

Strategy 3

Q/S tokens per node, equal-sized partitions (S machines)

In terms of load distribution efficiency,
Stategy 3 > Strategy 1 > Strategy 2

CONCLUSIONS

- Dynamo has provided the desired level of availability
- Successful in handling failures
- Incrementally scalable
- Dynamo allows service owners to customize their storage systems using tunable parameters
- Successfully combines various decentralization technologies to build single system

Dynamo vs. BigTable

- Two different approaches to storage systems
  - BigTable is more tuned for scalability, consistency and Google's specific needs
  - Dynamo is more tuned for SLA's.
- Dynamo scales to only a couple hundred machines whereas BigTable is built to store petabytes of data across thousands of servers
- Dynamo is more flexible due to tune-able parameters and correlates to academic research

SIMILAR WORK

- DynamoDB
  - Similar data model but different underlying implementation
- Apache Cassandra
  - Combination of Dynamo and BigTable
- RIAK
  - Open source implementation of Dynamo paper
- Project Voldemort
  - Key value store used at LinkedIn

LET'S DISCUSS!

- Problems with scalability
  - Nodes need to maintain complete routing information for active gossip
- Amazon's quality metric
  - Interesting that they measure latency at 99.9^{th} percentile!
- Semantic reconciliation increases complexity at client side

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