Reliability at Scale

A tale of Amazon Dynamo

Presented by Yunhe Liu @ CS6410 Fall'19
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Dynamo: Amazon’s Highly Available Key-value Store

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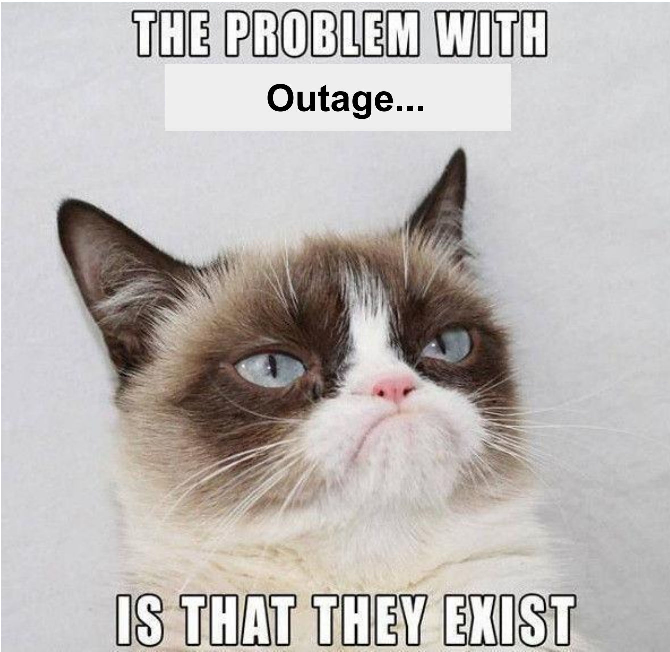
Werner Vogels
Cornell → Amazon

Motivation: No Service Outage

- Amazon.com, one of the largest e-commerce operations
- Slightest outage has:
  - significant financial consequences
  - impacts customer trust



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Challenge: Reliability at Scale

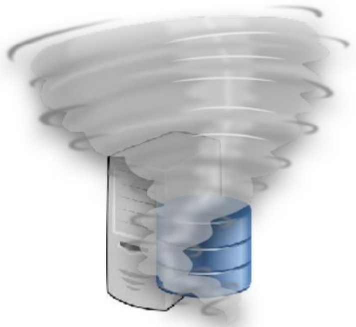
A key-value storage system that provide an **“always-on” experience** at **massive scale**.

Challenge: Reliability at Scale

A key-value storage system that provide an **"always-on" experience** at **<u>massive scale</u>**.

- Tens of thousands of servers and network components
- Small and large components fail continuously (extreme case: tornadoes can striking data centers)

millions of users



thousands of servers

Challenge: Reliability at Scale

A key-value storage system that provide an **<u>"always-on" experience</u>** at **massive scale**.

- Service Level Agreements (SLA): e.g. 99.9th percentile of delay < 300ms
- Users must be able to buy -> always writable!

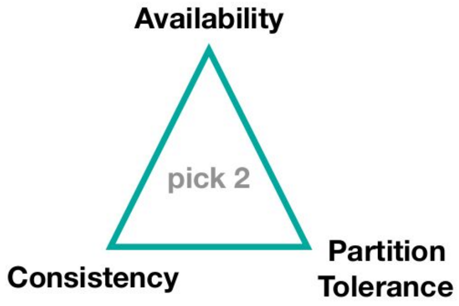
millions of users

thousands of servers

Challenge: Reliability at Scale

A key-value storage system that provide an **<u>"always-on" experience</u>** at **massive scale**.

- Given Partition tolerance: has to pick between A and C.



CAP Theorem

Solution: Sacrifice Consistency

- Eventually consistent
- <u>Always writeable</u>: allow conflicts
- Conflict resolution <u>on reads</u>
  - Defer to applications
  - Defaults to “last write wins”

Design

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

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Interface

```
                             → success
put(key, context, object)
                             → failure

          → success + object + context
get(key)  → success + set of objects + context
          → failure
```

- Key/value treated as opaque array of bytes.
- Context encodes system metadata, for conflict resolution.

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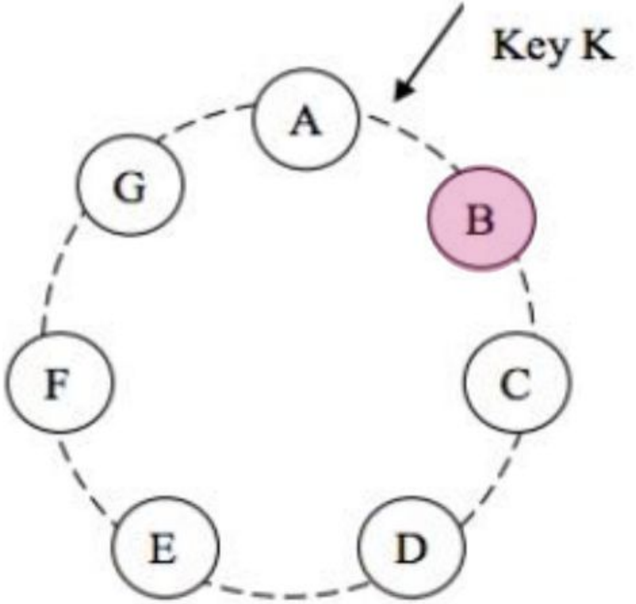
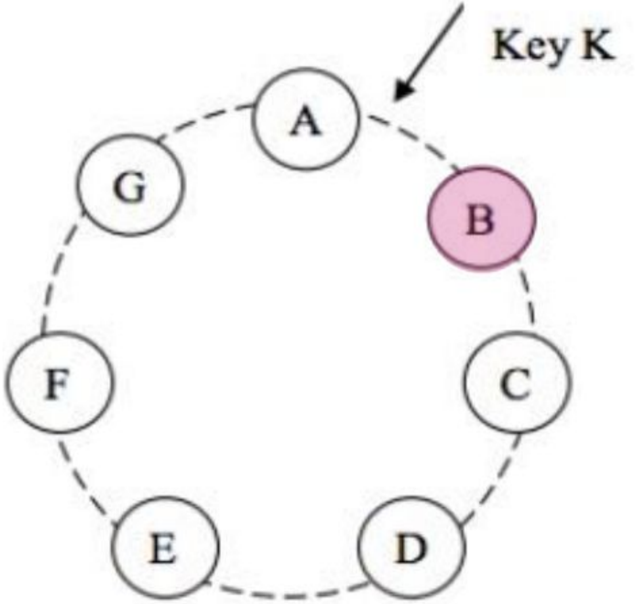
Partitioning

- Goal: load balancing
- Consistent hashing across ring
- Nodes responsible for regions
  - Region: between the node and its processor.
- Unlike Chord: no fingers



Partitioning

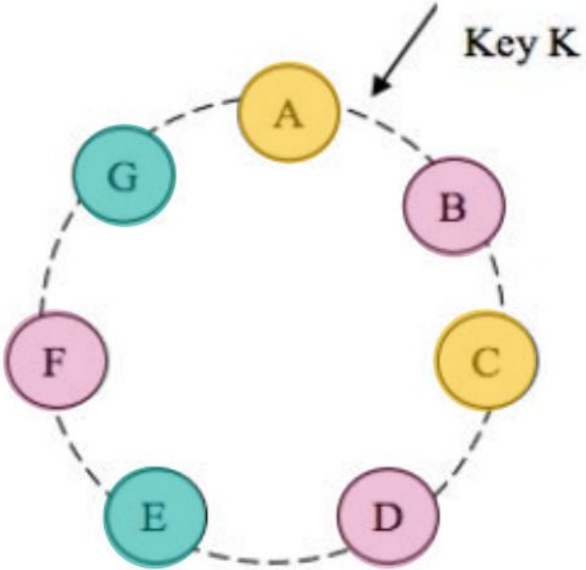
- Advantages:
  - Decentralized find
  - Join, leave have minimum impact (incremental scalability)
- Disadvantages:
  - Random position assignment for (k,v) instead of uniform
  - No server heterogeneity



Partitioning

- To address non-uniform distribution and node heterogeneity: **<u>Virtual Nodes</u>**!

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



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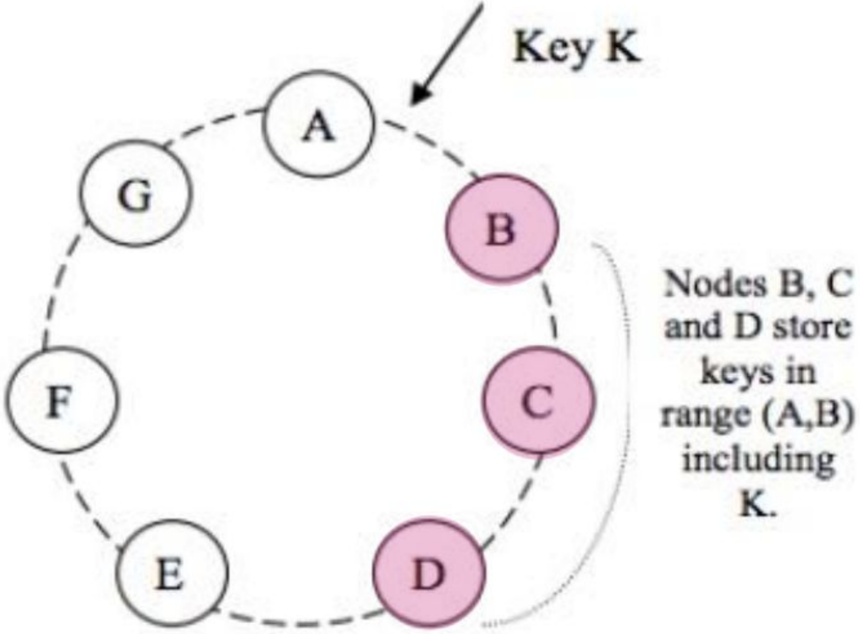
Replication

- Coordinator node replicatess k at N - 1 successors
  - N: # of replicas
  - Skip positions to avoid replicas on the same physical node

- Preference list
  - All nodes that stores k
  - More than N in node preference list for fault tolerance



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Sloppy Quorum

- Quorum-like System: R + W > N
    - N - number of replicas
    - R - minimum # of responses for get
    - W - minimum # of responses for put

- Why require R + W > N?
    - What is the implication of having a larger R?
    - What is the implication of having a larger W?

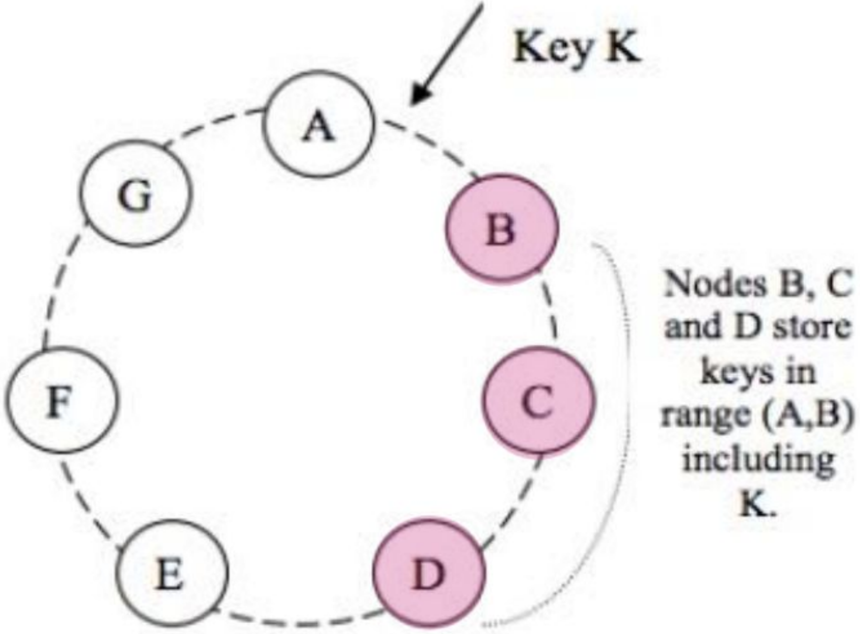
Sloppy Quorum

- “Sloppy quorum”
  - Does not enforce strict quorum membership
  - Ask first N healthy nodes from preference list
  - R and W configurable
- Temporary failure handling
  - Do not block waiting for unreachable nodes
  - Put should always succeed (set W to 1). Again, always writable.
  - Get should have high probability of seeing most recent put(s)

Sloppy Quorum: Conflict Case

Can you come up with a conflict case with the following parameters:

1) N = 3, W = 2, W = 2
2) Preference list: B, C, D, E
3) Client0 performs put(k, v)
4) Client1 performs put(k, v’)



Sloppy Quorum: Eventual Consistency

- Allow divergent replica
    - Allow reads to see stale or conflicting data
    - Application can decide the best way to resolve conflict.
    - Resolve multiple versions when failures go away(gossip!)

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Versioning

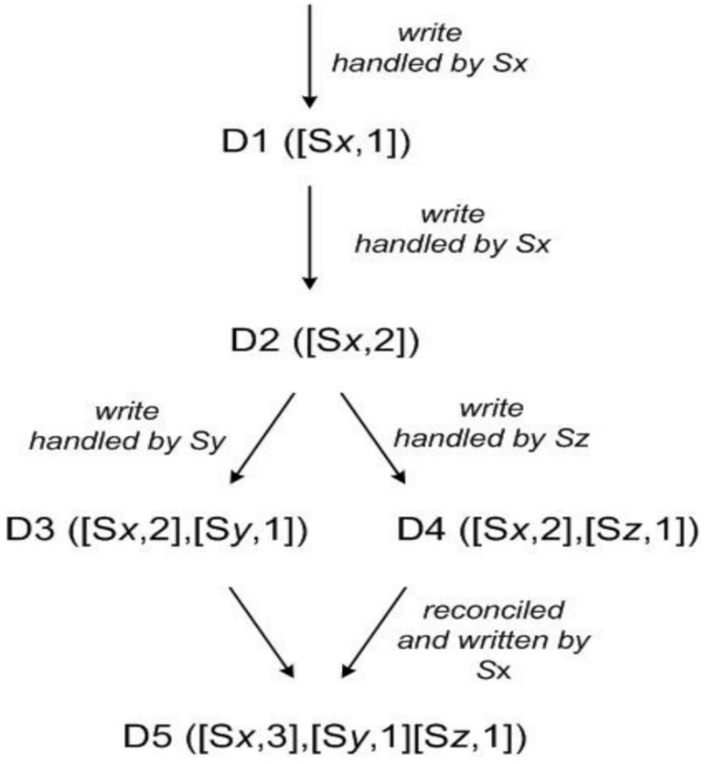
- Eventual Consistency
  - Updates propagates to all replicas asynchronously
  - A put() can return before all replicas update
  - Subsequent get() may return data without latest updates.
- Versioning
  - Most recent state is not available, write to a state without latest updates.
  - Treat each modification as a new and immutable version of the data.
  - Uses vector clocks to capture causality between different versions of same data.

System design: Versioning

- Vector clock (node, counter)

- Syntactic Reconciliation:
    - Versions has causal order
    - Pick later version

- Semantic Reconciliation:
    - Versions does not have casual order
    - Client application perform reconciliation.



Design

- Interface
- Partitioning
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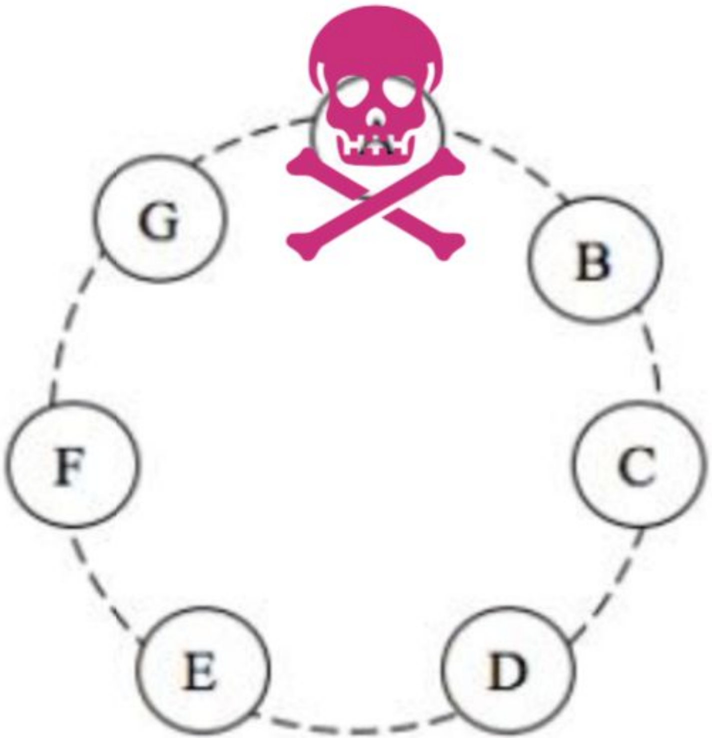
- <u>Handling permanent failures</u>
- Membership and Failure Detection

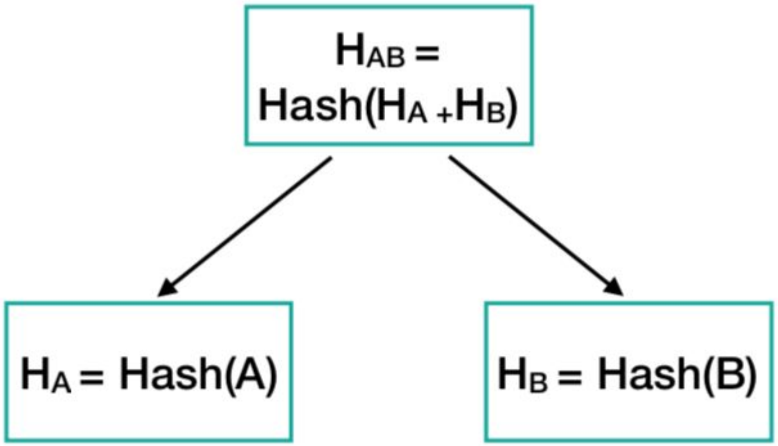
Handling permanent failures

- Replica becomes unavailable.
  - Replica synchronization is needed.



Handling permanent failures

- Anti-entropy (replica synchronization) protocol
  - Using Merkle trees.
- Merkle Tree
  - Leaf node: Hash of data (individual keys)
  - Parent node: hash of children nodes.
  - Efficient data transfer for comparison: Just the root!



Design

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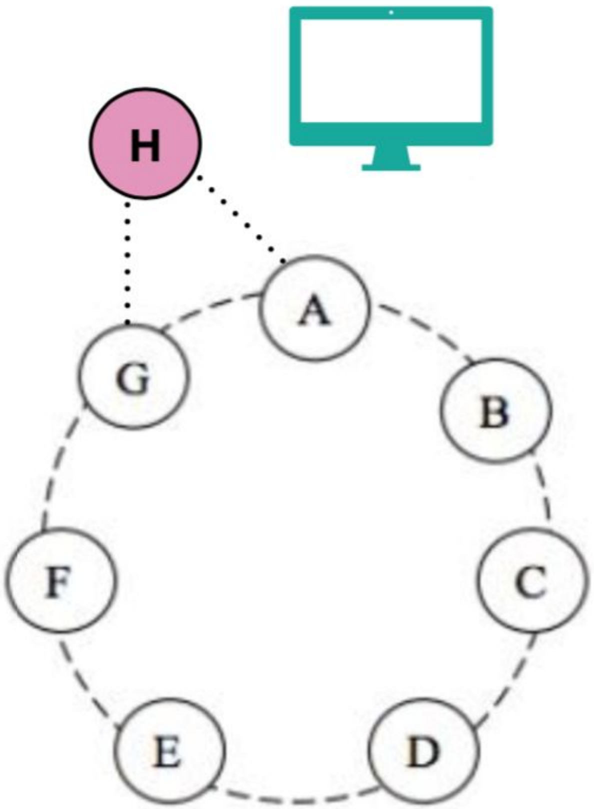
- Membership

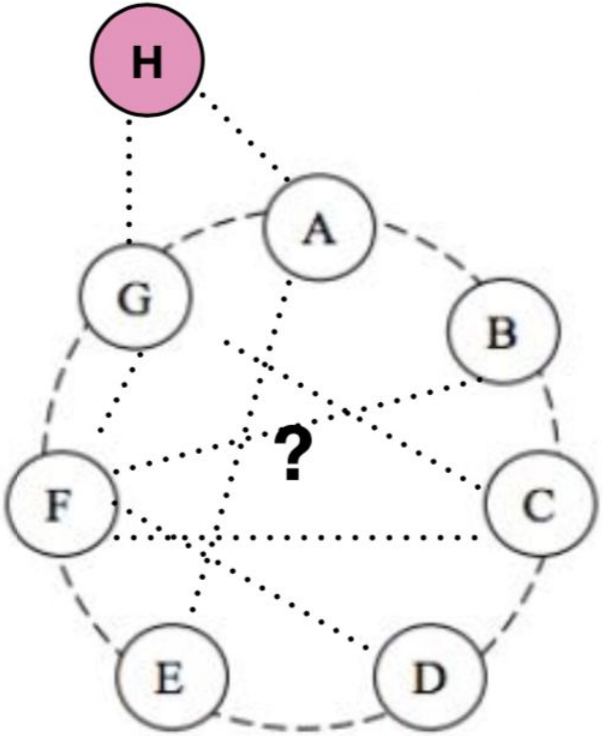
Membership: Adding Node

- Explicit mechanism by admin



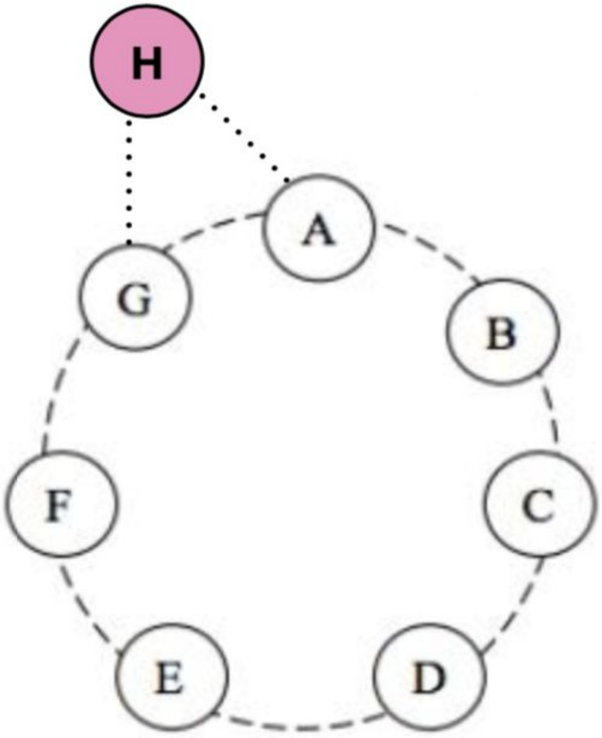
Membership: Adding Node

- Explicit mechanism by admin
- Propagated via gossip
  - Pull random peer every 1s



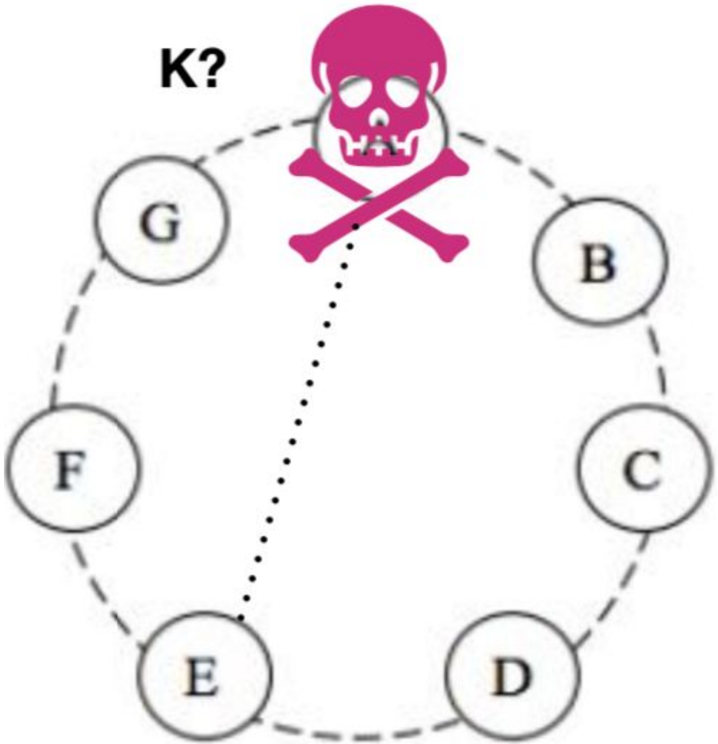
Membership: Adding Node

- Explicit mechanism by admin
- Propagated via gossip
    - Pull random peer every 1s
- “Seeds” to avoid partitions



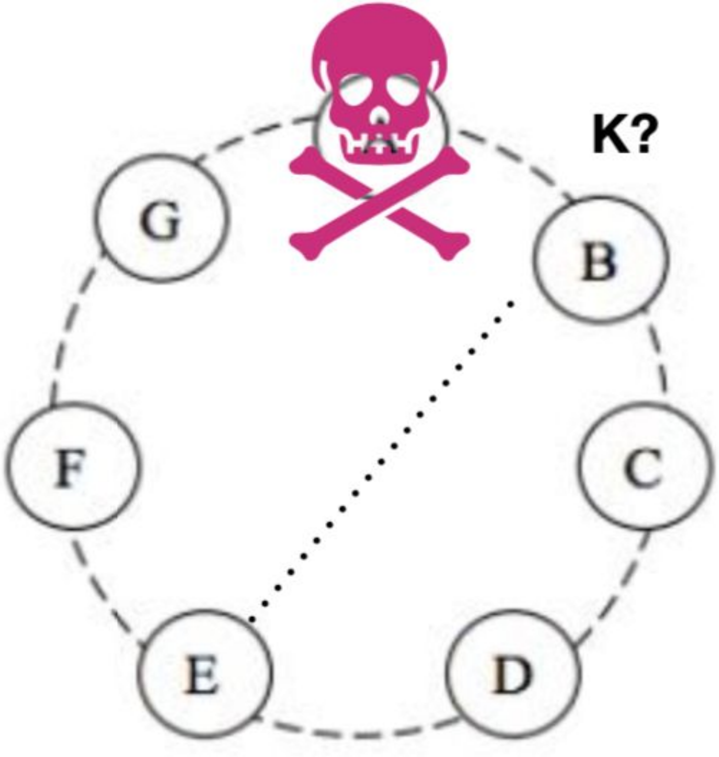
Membership: Detect/Remove Failed Nodes

- Local failure detection



Membership: Detect/Remove Failed Nodes

- Local failure detection
- Use alternative nodes in preference list

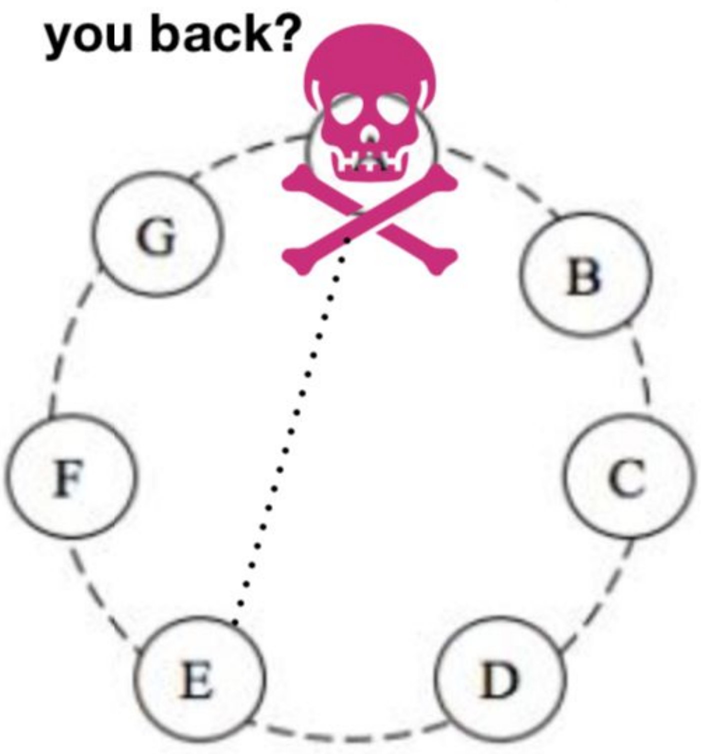


Membership: Detect/Remove Failed Nodes

- Local failure detection

- Use alternative nodes in preference list

- Periodic retry



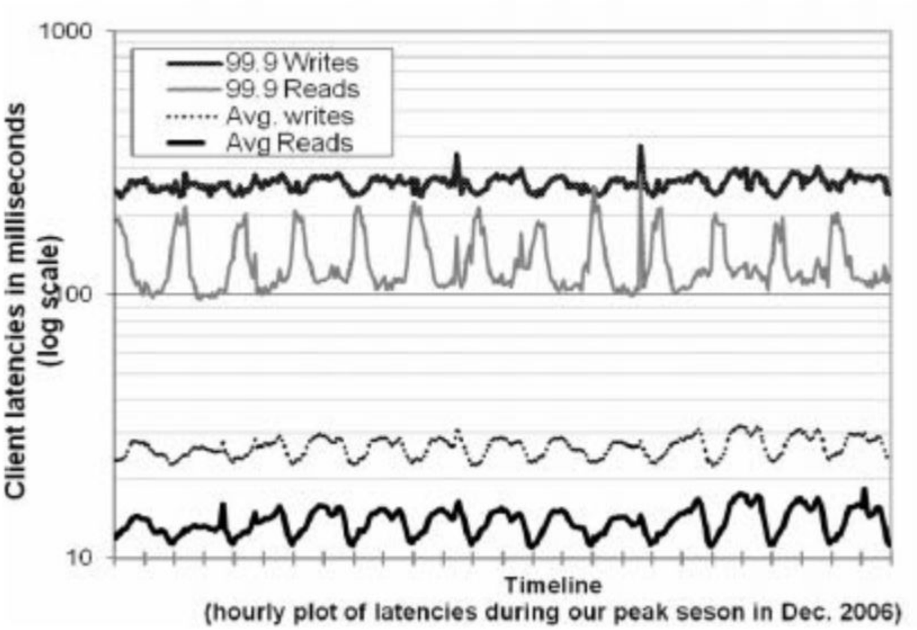
Design Summary

Problem	Solution	Pro
Partitioning	Consistent hashing	Scalability
High availability for writes	Vector clocks; fix conflicts on reads	Users can buy!
Temporary failures	Sloppy quorum	Users can buy!
Permanent failures	Merkle trees for anti-entropy	Sync in background
Membership/failure detection	Gossip	Decentralized

Evaluation

“Experiences & Lessons Learned”

Latency: “Always-on” Experience



Average and 99.9% Latency, December 2006

- Common SLA goal: 99.9th percentile < 300ms
    - Dynamo gets < 200ms!
- Average an order of magnitude less: < 20ms

Flexible N, R, W

- The main advantage of Dynamo” is flexible N, R, W
- Many internal Amazon clients, varying parameters
  - (N-R-W)
  - (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

Balancing

- "Out-of-balance" if load > 15% off from average

Conclusion

1. Combines well-known systems protocols into highly available database.
2. Achieved reliability at massive-scale.
3. Gives client application high configurability.
4. Conflict resolution not an issue in practice.

Acknowledgement

1. Dynamo (DeCandia et al., 2007)
2. P2P Systems: Storage (Max & Zhen, 2017)
3. P2P Systems: Storage (VanHattum, 2018)