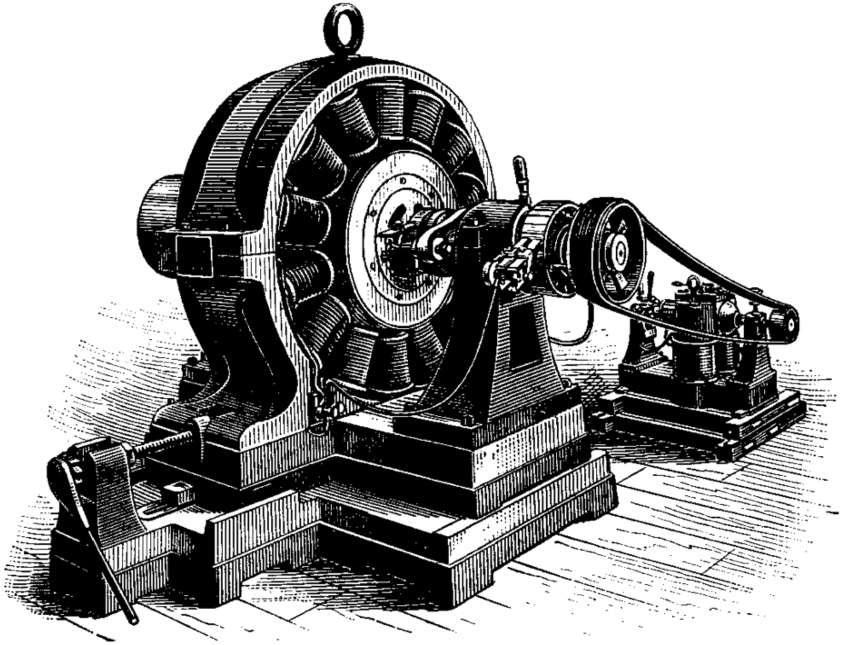
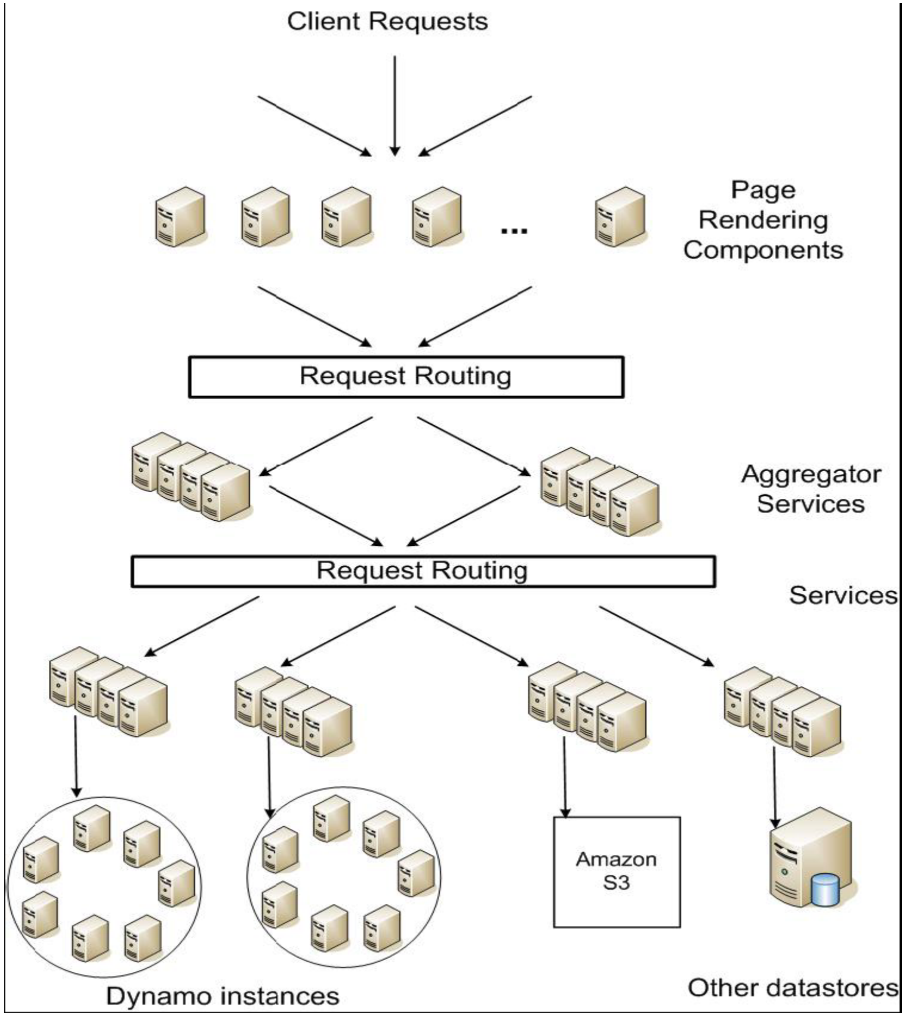
CS 5450

Amazon Dynamo



Amazon’s Architecture



Dynamo

- The platform for Amazon's e-commerce services: shopping cart, best seller list, product catalog, promotional items etc.
- A highly available, distributed key-value storage system: put() & get() interfaces
- Aims to provide "always on" guarantee at the cost of losing some consistency

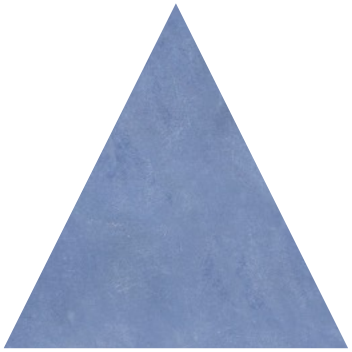
Design Considerations

- Incremental scalability
  - Minimal management overhead
- Symmetry
  - For ease of maintenance, no master/slave nodes
- Decentralized control
  - Centralized approach leads to outages
- Heterogeneity
  - Exploit capabilities of different nodes

CAP Theorem

Consistency

single up-to-date copy



Availability

for updates

Partition Tolerance

Pick 2 out of 3

What Does CAP Really Mean?

“No system where P is possible can
at all times guarantee both C and A”

if your network is highly reliable (and fast), so that P is extremely rare, you can aim for both C and A

Google Spanner

Requirements

Reliability

customers should be able to edit their shopping cart even when there are:

- disk failures
- network failures
- tornados!

Efficiency

latency measurement is done at 99.9th percentile of the distribution

ACID Properties

- Atomicity
- Consistency
- Isolation
- Durability

Requirements

Query model:

only simple read/write to small data (less than 1MB), uniquely identified by a key

ACID properties:

- atomicity: important!
- consistency: weak is sufficient
- isolation: not at all
- durability: important!

Consistency

- BASE
  - Basically Available, Soft State, Eventually Consistent
- Always writable
  - Can always write to shopping cart
  - Conflict resolution on reads
- Application-driven conflict resolution
  - Merge conflicting shopping carts to never lose "Add Cart"
  - Push inconsistencies to customer service

Requirements

Service Level Agreement (SLA):

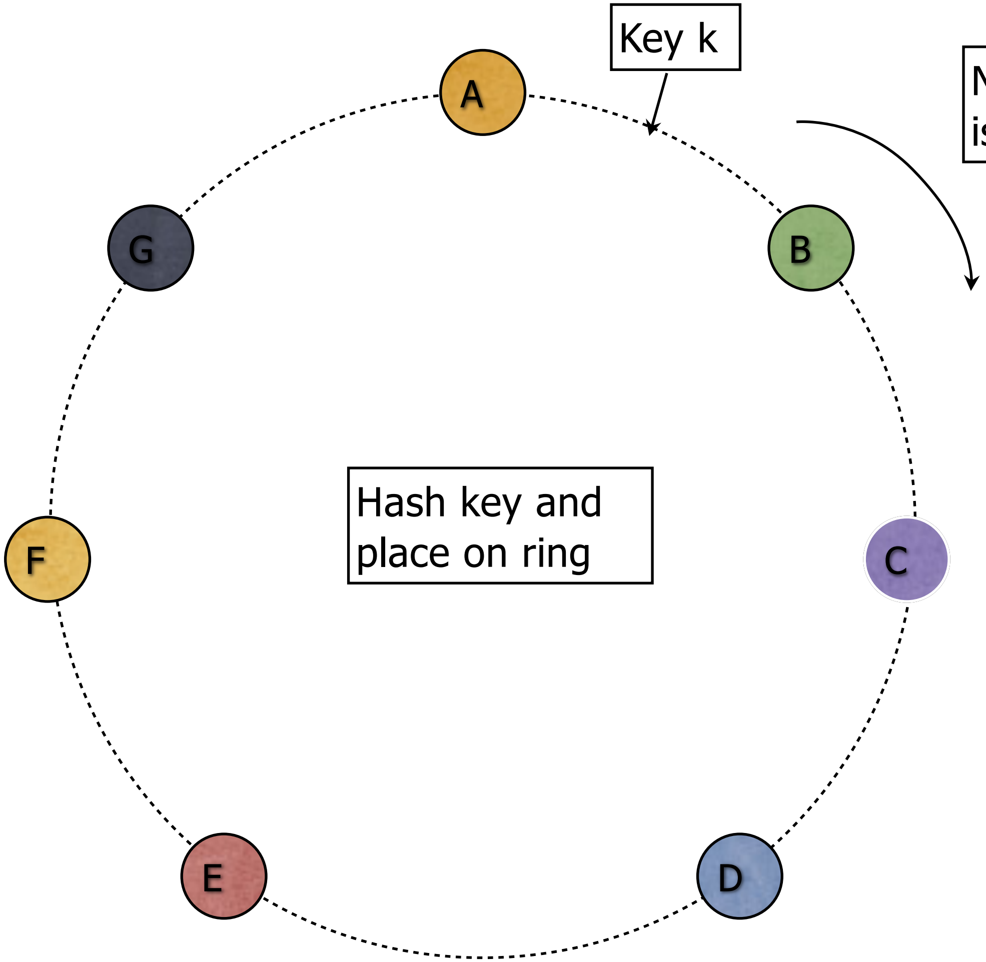
- client and server agree on several characteristics related to the system
  - e.g., 300 ms response time for peak load of 500 requests/second

- putting together a single webpage can require responses from 150 services for typical request

Techniques Used by Dynamo

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

Consistent Hashing



Key k

Hash key and place on ring

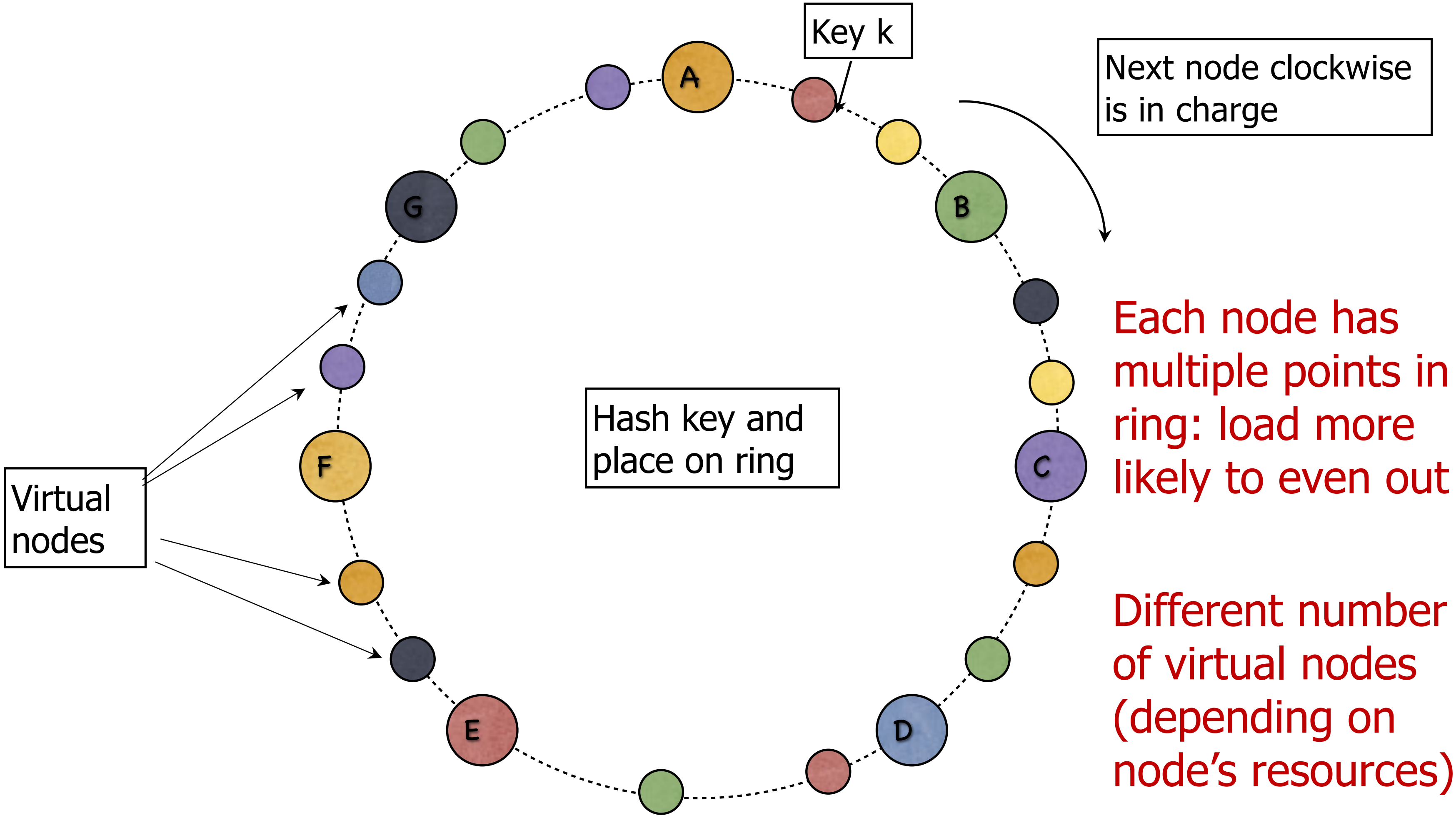
Next node clockwise is in charge

Issues

Unbalanced load distribution

Nodes are heterogenous, uneven resources per node

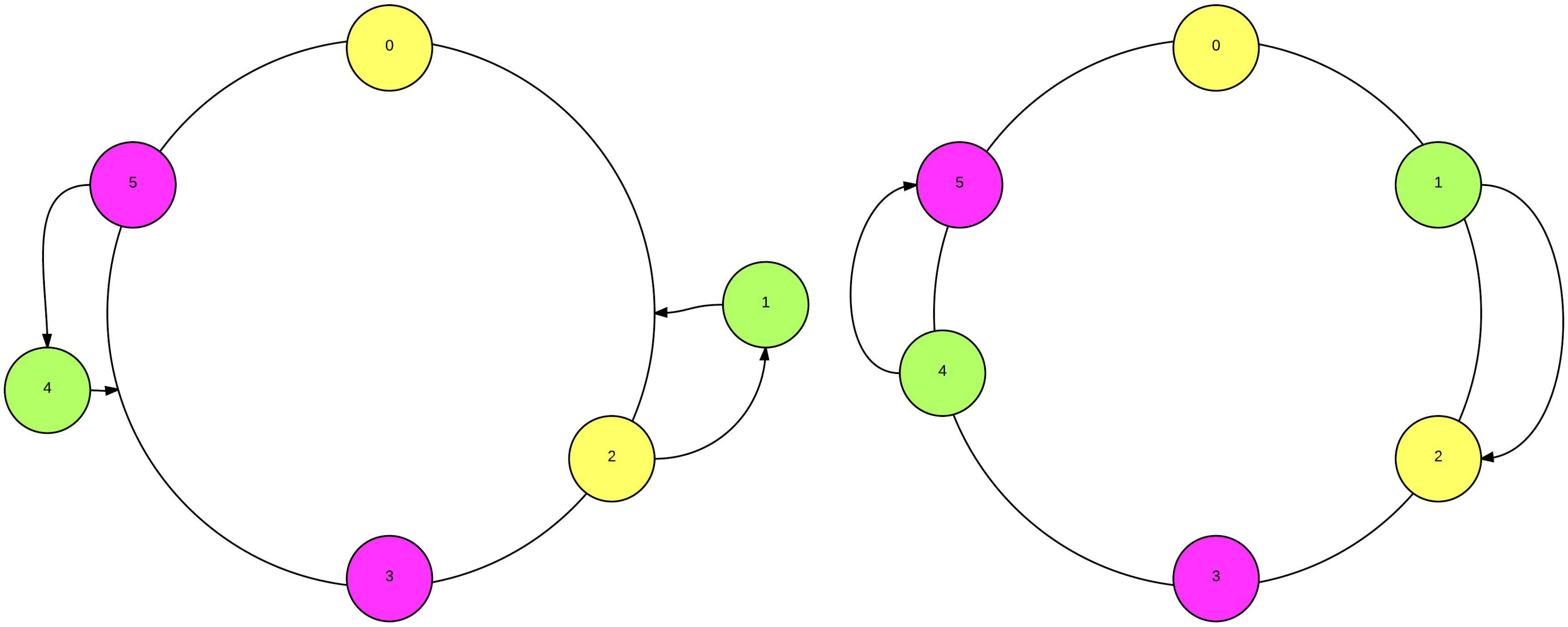
Virtual Nodes



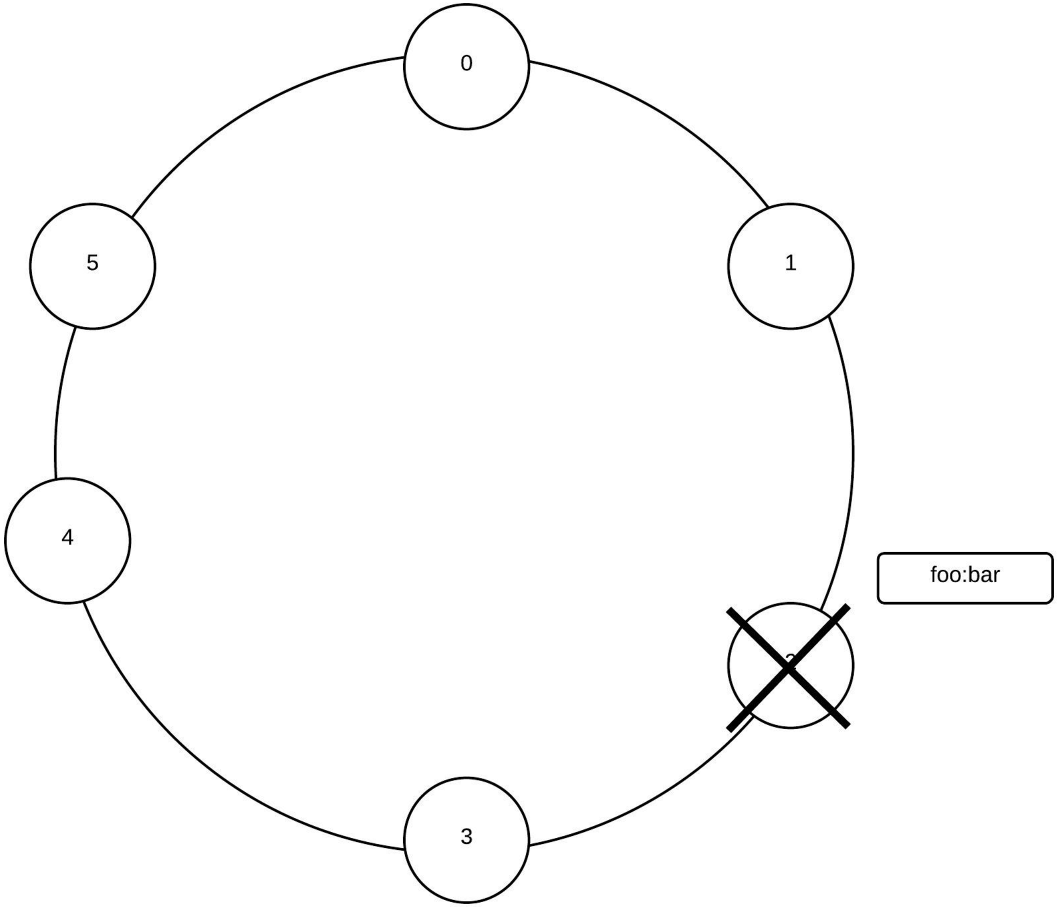
Each node has multiple points in ring: load more likely to even out

Different number of virtual nodes (depending on node's resources)

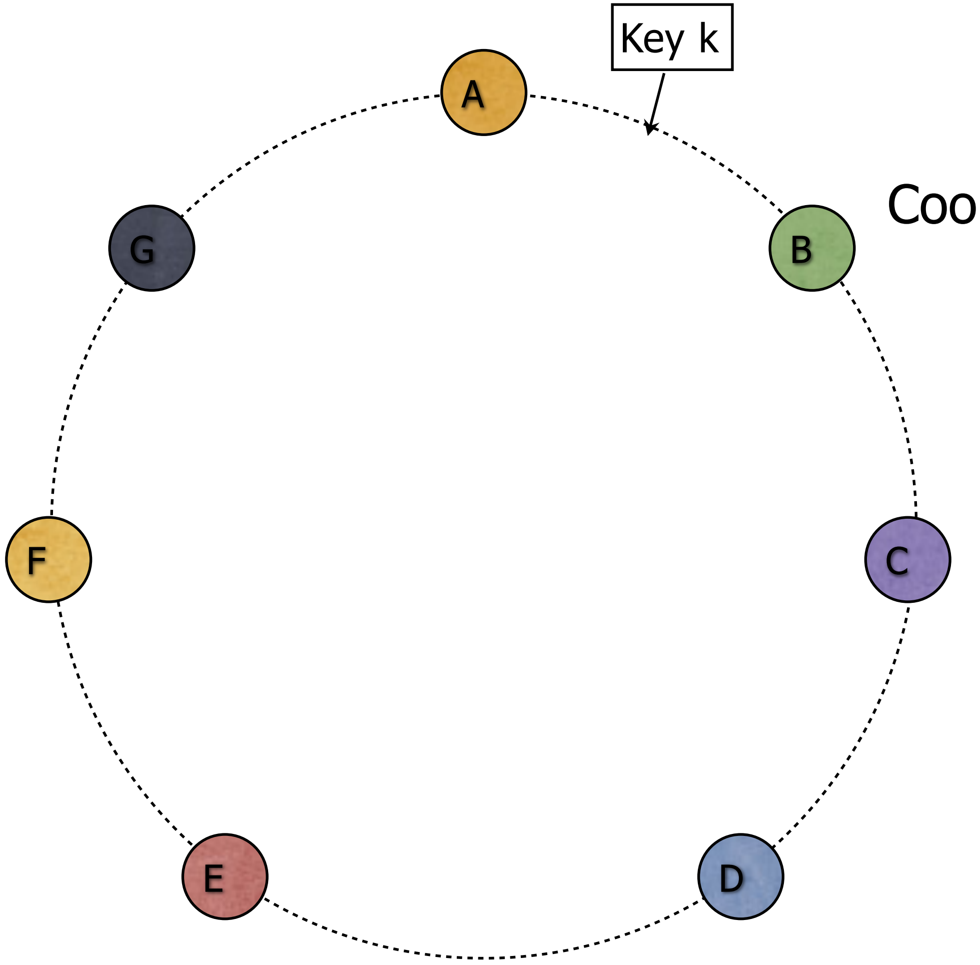
Node Joining or Leaving



What If



Replication



Coordinator

Replicates data in a list of N nodes

N is per key

Part of longer preference list

Mindful of virtual nodes

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Quorums

put()

- coordinator writes new data locally
- sends to next n-1 nodes
- when w-1 respond, considered successful

get()

- coordinator requests next n-1 nodes
- when r-1 respond, considered successful

- $r + w > n$

Data Versioning

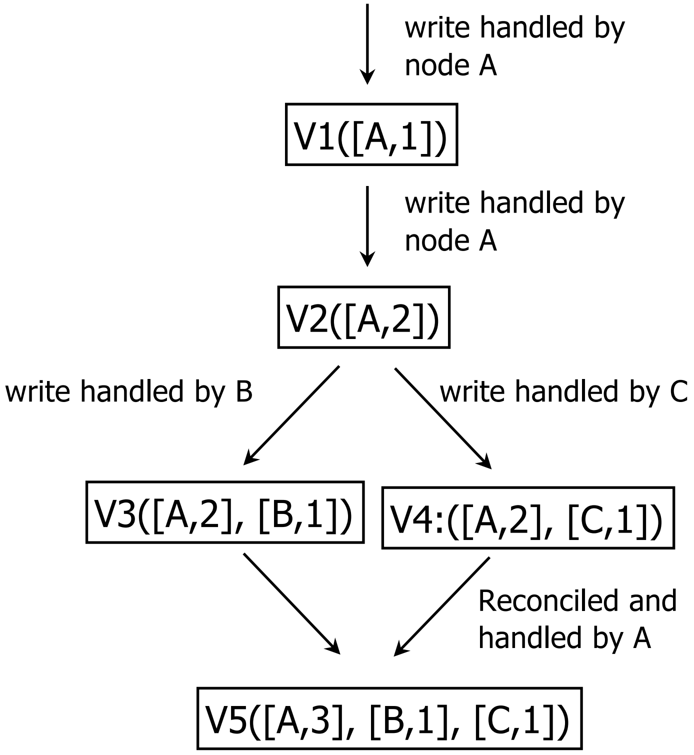
- A put() call may return successfully to caller before the update has been applied to all replicas
  - If latest object version unavailable, apply put to earlier version, merge later
- A get() call may return many versions of the same object
- An object may have distinct version sub-histories that need to be reconciled

Delayed Reconciliation

The goal: "add to cart" operation should never be forgotten or rejected

- When a customer wants to add an item to (or remove from) a shopping cart and the latest version is not available, the item is added to (or removed from) the older version
- The divergent versions are reconciled later

Vector Clocks in Dynamo



- List of (node, counter) pairs

  Counters are logical integer timestamps assigned by coordinator

- Each object version has one vector clock

- Used to determine whether a version is subsumed

- Stored in “context” in get(), put()

Vector Clocks in Dynamo

Size of vector clock can get arbitrarily long

- bounded by N in practice
- drop oldest one when beyond certain threshold

Reconciliation

- Easy if values are causally ordered
- Otherwise, applications will handle

Reconciliation (Summary)

- An "add to cart" operation will never be lost

  … but removed items may reappear

Reconciliation in Practice

- In one 24 hour period, 99.94% of requests saw exactly one version

- Divergent version usually not caused by failure but concurrent writers....(rarely human beings, usually automated client programs)

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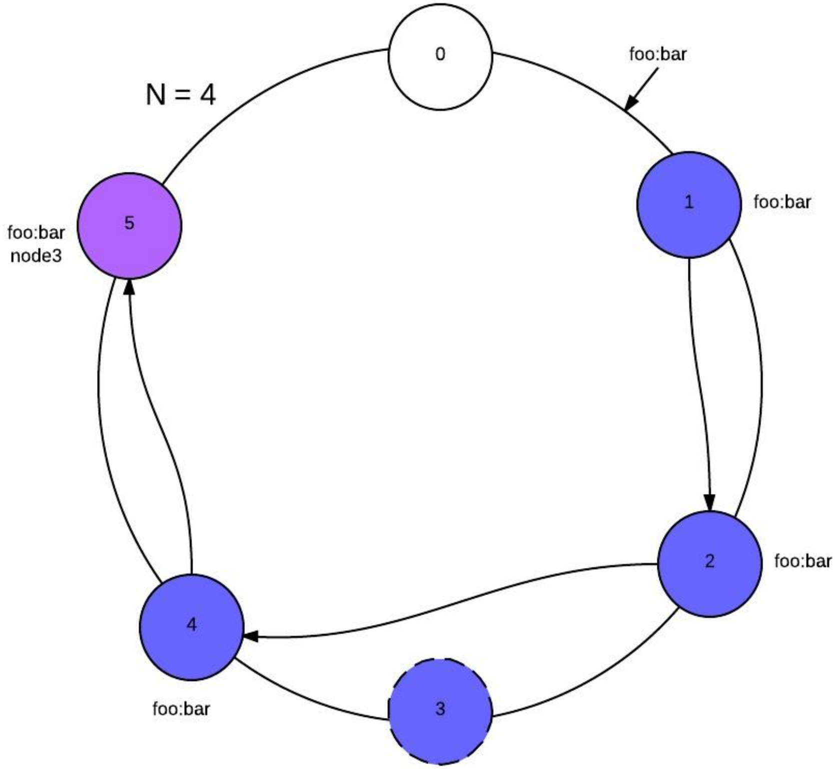
Quasi-Quorums

- get() and put() driven by two parameters
  - R: minimum number of replicas to read from
  - W: minimum number of replicas to write to
- if R+W > N, we have a quorum system!

  … but latency dictated by slowest replica

- What if we want to execute a put() but the number of available replicas in the next node is less than w-1?

Sloppy Quorum and Hinted Handoff



- Use next N healthy nodes for read/write
- Data tagged with the node it should go to

  (notified later if temporarily unavailable)
- Transfer the data to the node when it becomes available
- Always writeable!

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Handling Permanent Failures

Replica synchronization:

- Node synchronizes with another node
- A Merkle Tree is used to detect inconsistency and minimize the data that needs to be transferred
  - leaves are hash of objects
  - parents are hash of children

Membership and Failure Detection

- Gossip-based protocol propagates membership change and maintains an eventually consistent view
- Seeds are used to prevent parititioned ring
- Use timeout to for failure discovery