Distributed Systems

17a. Distributed Lookup: Amazon Dynamo

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Distributed Hash Table
Case Study

Amazon Dynamo

Amazon Dynamo

- In an infrastructure with millions of components, something is always failing!
  - Failure is the normal case

- A lot of services within Amazon only need primary-key access to data
  - Best seller lists, shopping carts, preferences, session management, sales rank, product catalog
  - No need for complex querying or management offered by an RDBMS
  - Full relational database is overkill: limits scale and availability
    - Still not easy to scale or load balance RDBMS on a large scale

- Dynamo: not exposed as a web service
  - Used to power parts of Amazon's services
  - Highly available, key-value storage system

Core Assumptions & Design Decisions

- Two operations: **get(key)** and **put(key, data)**
  - Binary objects (data) identified by a unique key
  - Objects tend to be small (< 1MB)
- ACID gives poor availability
  - Use weaker consistency (C) for higher availability.
- Apps should be able to configure Dynamo for desired latency & throughput
  - Balance performance, cost, availability, durability guarantees.
- At least 99.9% of read/write operations must be performed within a few hundred milliseconds:
  - Avoid routing requests through multiple nodes
- Dynamo can be thought of as a **zero-hop DHT**

Core Assumptions & Design Decisions

- Incremental scalability
  - System should be able to grow by adding a storage host (node) at a time
- Symmetry
  - Every node has the same set of responsibilities
- Decentralization
  - Favor decentralized techniques over central coordinators
- Heterogeneity (mix of slow and fast systems)
  - Workload partitioning should be proportional to capabilities of servers

Consistency & Availability

- Strong consistency & high availability cannot be achieved simultaneously

- Optimistic replication techniques – **eventually consistent** model
  - propagate changes to replicas in the background
  - can lead to conflicting changes that have to be detected & resolved

- When do you resolve conflicts?
  - During writes: traditional approach – reject write if cannot reach all (or majority) of replicas
  - During reads: Dynamo approach
    - Design for an "always writable" data store - highly available
    - read/write operations can continue even during network partitions
    - Rejecting customer updates won't be a good experience
      - A customer should always be able to add or remove items in a shopping cart

Consistency & Availability

- Who resolves conflicts?
  - Choices: the <u>data store system</u> or the <u>application</u>?
- Data store
  - Application-unaware, so choices limited
  - Simple policy, such as "last write wins”
- Application
  - App is aware of the meaning of the data
  - Can do application-aware conflict resolution
  - E.g., merge shopping cart versions to get a unified shopping cart.
- Fall back on "*last write wins*" if app doesn't want to bother

Reads & Writes

Two operations:

get(key) returns

1. object or list of objects with conflicting versions
2. context (resultant version per object)

put(key, context, value): stores replicas

– key is hashed with MD5 to create a 128-bit identifier that is used to determine the storage nodes that serve the key

hash(key) identifies node

– the nodes that hold replicas are based on the key.

– *context*: ignored by the application but includes version of object

Partitioning

- Break up database into chunks distributed over all nodes
  - Key to scalability

- Relies on consistent hashing
  - Regular hashing: change in # slots requires all keys to be remapped
  - Consistent hashing:
    - K/n keys need to be remapped, K = # keys, n = # slots

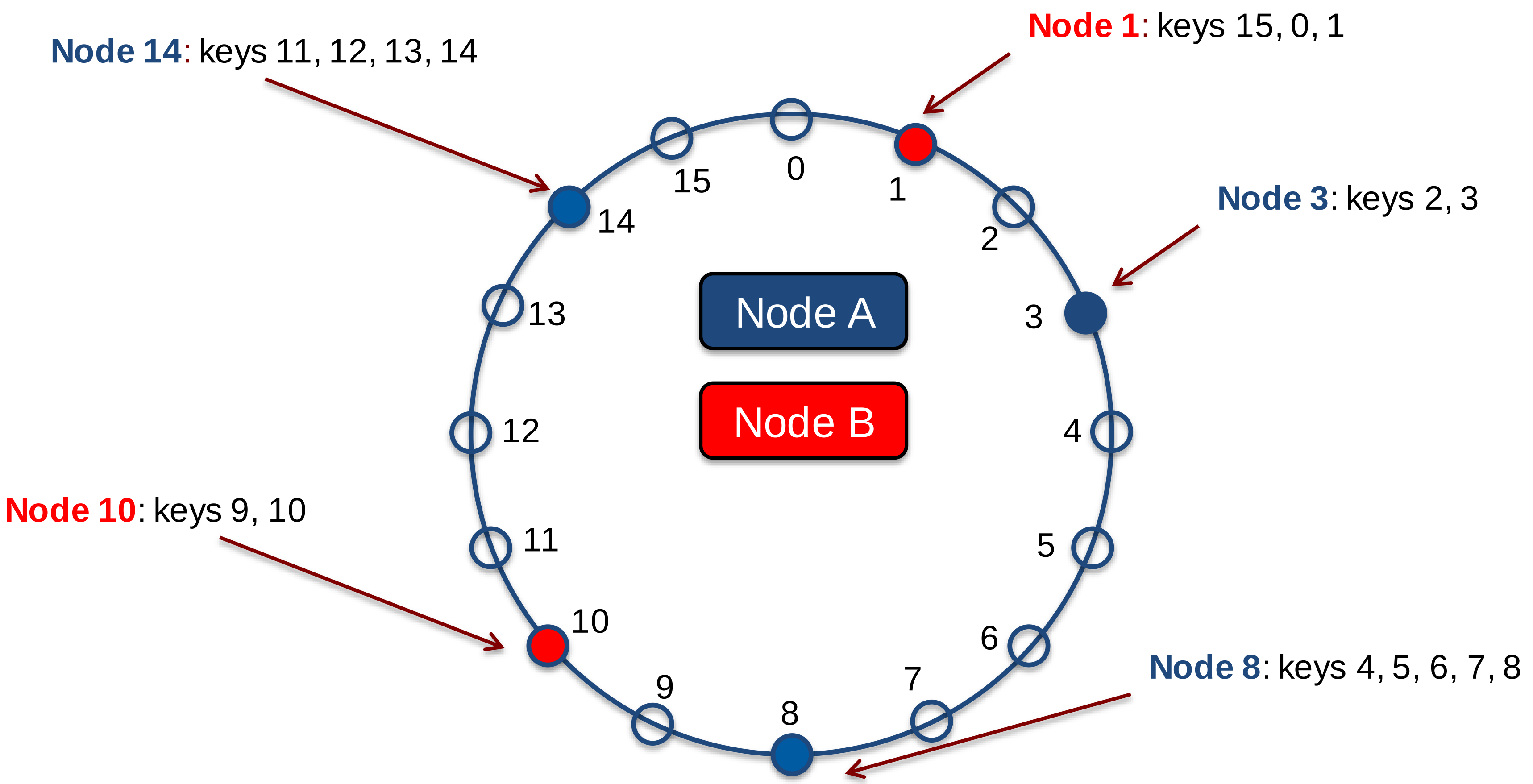
- Logical ring of nodes: just like Chord
  - Each node assigned random value in the hash space: position in ring
  - Responsible for all hash values between its value and predecessor's value
  - Hash(key); then walk ring clockwise to find first node with position>hash
  - Adding/removing nodes affects only immediate neighbors

Partitioning: virtual nodes

- A node is assigned to multiple points in the ring
- Each point is a “virtual node”

Dynamo virtual nodes

- A physical node holds contents of multiple virtual nodes
- In this example: 2 physical nodes, 5 virtual nodes



Partitioning: virtual nodes

Advantages: balanced load distribution

- If a node becomes unavailable, load is evenly dispersed among available nodes
- If a node is added, it accepts an equivalent amount of load from other available nodes
- # of virtual nodes per system can be based on the capacity of that node
  - Makes it easy to support changing technology and addition of new, faster systems

Replication

- Data replicated on *N* hosts (*N* is configurable)
  - Key is assigned a coordinator node (via hashing)
  - Coordinator is in charge of replication

- Coordinator replicates keys at the *N-1* clockwise successor nodes in the ring

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Dynamo Replication

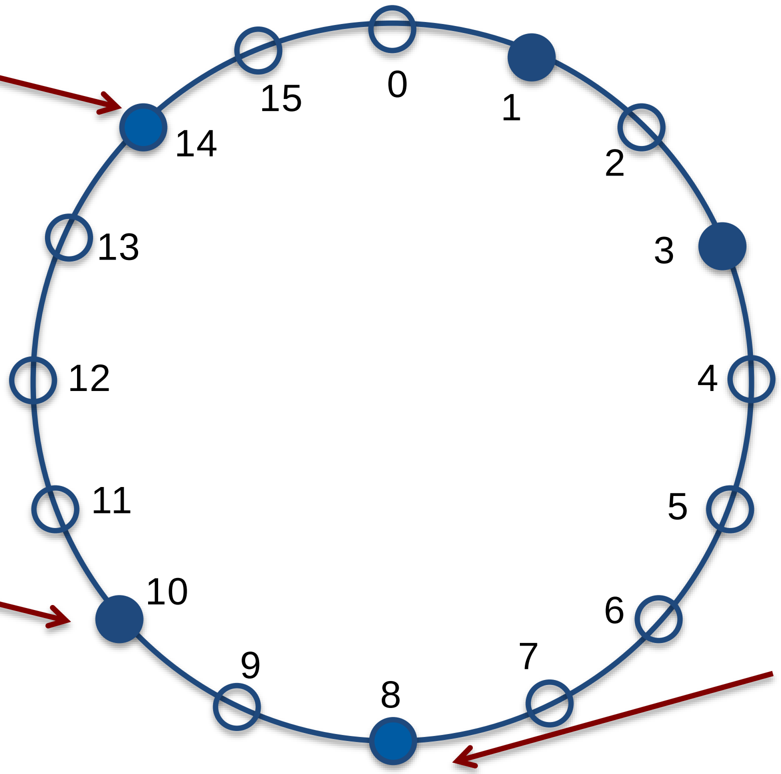
Coordinator replicates keys at the *N-1* clockwise successor nodes in the ring

Example: N=3

Node 14 holds replicas for Nodes 1 and 3

Node 10 holds replicas for Node 14 and 1

Node 8 holds replicas for Nodes 10 and 14



Versioning

- Not all updates may arrive at all replicas

- Application-based reconciliation
  - Each modification of data is treated as a new version

- Vector clocks are used for versioning
  - Capture causality between different versions of the same object
  - Vector clock is a set of (node, counter) pairs
  - Returned as a context from a get() operation

Availability

- Configurable values
  - *R*: minimum # of nodes that must participate in a successful read operation
  - *W*: minimum # of nodes that must participate in a successful write operation
- Metadata hints to remember original destination
  - If a node was unreachable, the replica is sent to another node in the ring
  - Metadata sent with the data contains a hint stating the original desired destination
  - Periodically, a node checks if the originally targeted node is alive
    - if so, it will transfer the object and may delete it locally to keep # of replicas in the system consistent
- Data center failure
  - System must handle the failure of a data center
  - Each object is replicated across multiple data centers

Storage Nodes

Each node has three components

1. *Request* coordination
   - Coordinator executes read/write requests on behalf of requesting clients
   - State machine contains all logic for identifying nodes responsible for a key, sending requests, waiting for responses, retries, processing retries, packaging response
   - Each state machine instance handles one request
2. Membership and failure detection
3. Local persistent storage
   - Different storage engines may be used depending on application needs
     - Berkeley Database (BDB) Transactional Data Store (most popular)
     - BDB Java Edition
     - MySQL (for large objects)
     - in-memory buffer with persistent backing store

Amazon S3 (Simple Storage Service)

Commercial service that implements many of Dynamo's features

- Storage via web services interfaces (REST, SOAP, BitTorrent)
  - Stores more than 449 billion objects
  - 99.9% uptime guarantee (43 minutes downtime per month)
  - Proprietary design
  - Stores arbitrary objects up to 5 TB in size
- Objects organized into buckets and within a bucket identified by a unique user-assigned key
- Buckets & objects can be created, listed, and retrieved via REST or SOAP
  - http://s3.amazonaws/bucket/key
- Objects can be downloaded via HTTP GET or BitTorrent protocol
  - S3 acts as a seed host and any BitTorrent client can retrieve the file
  - reduces bandwidth costs
- S3 can also host static websites

The end