CSE 544
Principles of Database Management Systems

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Fall 2015

Finale – NoSQL

Poster Session Information

- Time: 12/15 (next Tuesday!), 2-4:30pm
- Place: CSE first floor atrium

- Easels: will be provided, please set up in the atrium
- Poster boards: poster printer room (CSE 415) or 1st floor copy room (next to CSE main office)
- Anyone planning to do demos?

- Format: please prepare an 8 min talk-through of your poster
  - We have 14 groups to go through

- There will be a best poster award !!!

Final Reports

- Final report due on 12/18, 11:45 pm
  - Turn in on dropbox
  - Instructions and format on website

- No class on Thursday
  - This will be the last 544 lecture ☹

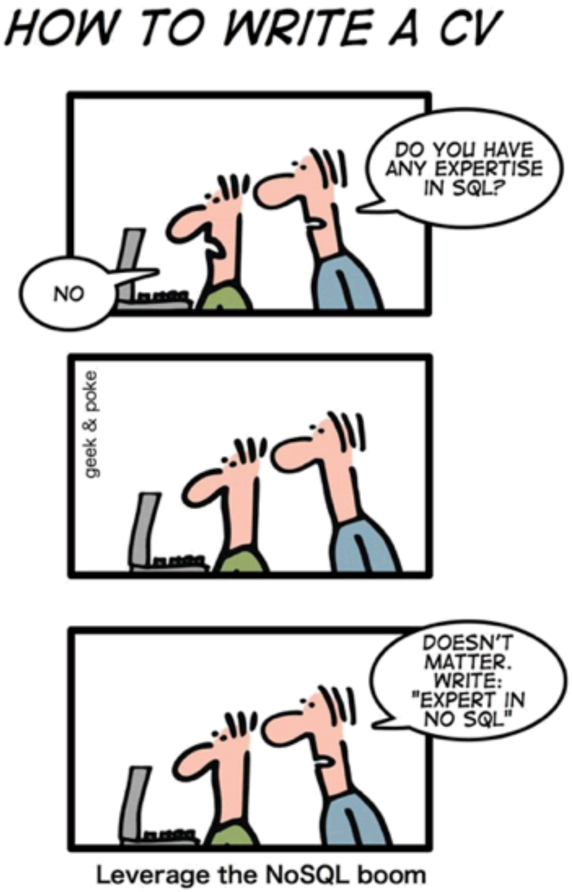
References

- **Scalable SQL and NoSQL Data Stores**, Rick Cattell, SIGMOD Record, December 2010 (Vol. 39, No. 4)
- **Dynamo: Amazon's Highly Available Key-value Store**. By Giuseppe DeCandia et. al. SOSP 2007.
- Online documentation: Amazon DynamoDB.
- Online documentation: MongoDB.

Outline

- NoSQL overview

- Two example systems
  - Amazon Dynamo
  - MongoDB



NoSQL Overview

NoSQL Motivation

- Originally motivated by Web 2.0 applications
  - Examples?
- Goal is to scale simple OLTP-style workloads to thousands or millions of users
- Users are doing both updates and reads

Why NoSQL as the Solution?

- Hard to scale ***transactions***
  - Need to partition the database across multiple machines
  - If a transaction touches one machine, life is good
  - If a transaction touches multiple machines, ACID becomes extremely expensive! Need two-phase commit as we saw
- Replication
  - Replication can help increase throughput and lower latency
  - Create multiple copies of each database partition
  - Spread queries across these replicas
  - Easy for reads
  - But writes are expensive! (remember all the log shipping business)

NoSQL Key Feature Decisions

- Want a data management system that is
  - Elastic and highly scalable
  - Flexible (different records have different schemas)

- To achieve above goals, willing to give up
  - Complex queries: e.g., give up on joins
  - Multi-object transactions
  - ACID guarantees: e.g., *eventual consistency* is OK
    - Eventual consistency: If updates stop, all replicas will *converge* to the same state and all reads will return the same value
  - *Not all NoSQL systems give up all these properties*

All updates *eventually* reach all replicas

Cattell, SIGMOD Record 2010

“Not Only SQL” or “Not Relational”

Six key features:

1. Scale horizontally “simple operations”
   - key lookups, reads and writes of one record or a small number of records, simple selections
2. Replicate/distribute data over many servers
3. Simple call level interface (contrast w/ SQL)
4. Weaker concurrency model than ACID
5. Efficient use of distributed indexes and RAM
6. Flexible schema

ACID vs BASE

- ACID = Atomicity, Consistency, Isolation, and Durability
- BASE = Basically Available, Soft state, Eventually consistent

NoSQL Data Models

- Tuple = row in a relational db
- Extensible record = families of attributes have a schema, but new attributes may be added
- Document = nested values, extensible records (think XML, JSON, attribute-value pairs)
- Object = like in a programming language, but without methods

Cattell, SIGMOD Record 2010

Different Types of NoSQL

Taxonomy based on data models:

- Key-value stores
  - e.g., Project Voldemort, Memcached
- Extensible Record Stores
  - e.g., HBase, Cassandra, PNUTS
- Document stores
  - e.g., CouchDB, MongoDB
- New types of RDBMSs.. not really NoSQL, not just SQL
  - (not exactly sure what they are..)

Key-Value Stores: Dynamo

Key-Value Store: Dynamo

- **Dynamo: Amazon’s Highly Available Key-value Store**. By Giuseppe DeCandia et. al. SOSP 2007.

- Main observation:
  - “There are many services on Amazon’s platform that only need **primary-key access** to a data store.”
  - Best seller lists, shopping carts, customer preferences, session management, sales rank, product catalog

Basic Features

- **Data model**: (key,value) pairs
  - Values are binary objects (blobs)
  - No further schema
- **Operations**
  - Insert, delete, and lookup operations on keys
  - No operations across multiple data items
- **Consistency**
  - Replication with eventual consistency
  - Goal is to NEVER reject any writes (bad for business)
    - That’s why conflict resolution is pushed to reads
  - Multiple versions with conflict resolution during reads

Operations

- **get(key)**
  - Locates object replicas associated with *key*
  - Returns a single *object*
  - Or a list of objects with conflicting versions
  - Also returns a *context*
    - Context holds metadata including version
    - Context is opaque to caller
- **put(key, context, object)**
  - Determines where replicas of object should be placed
  - Location depends on key value
  - Data stored persistently including context

Storage: Distributed Hash Table

Implements a distributed storage engine:

- Each key-value pair (k,v) is stored at some server h(k)
- API: write(k,v); read(k)

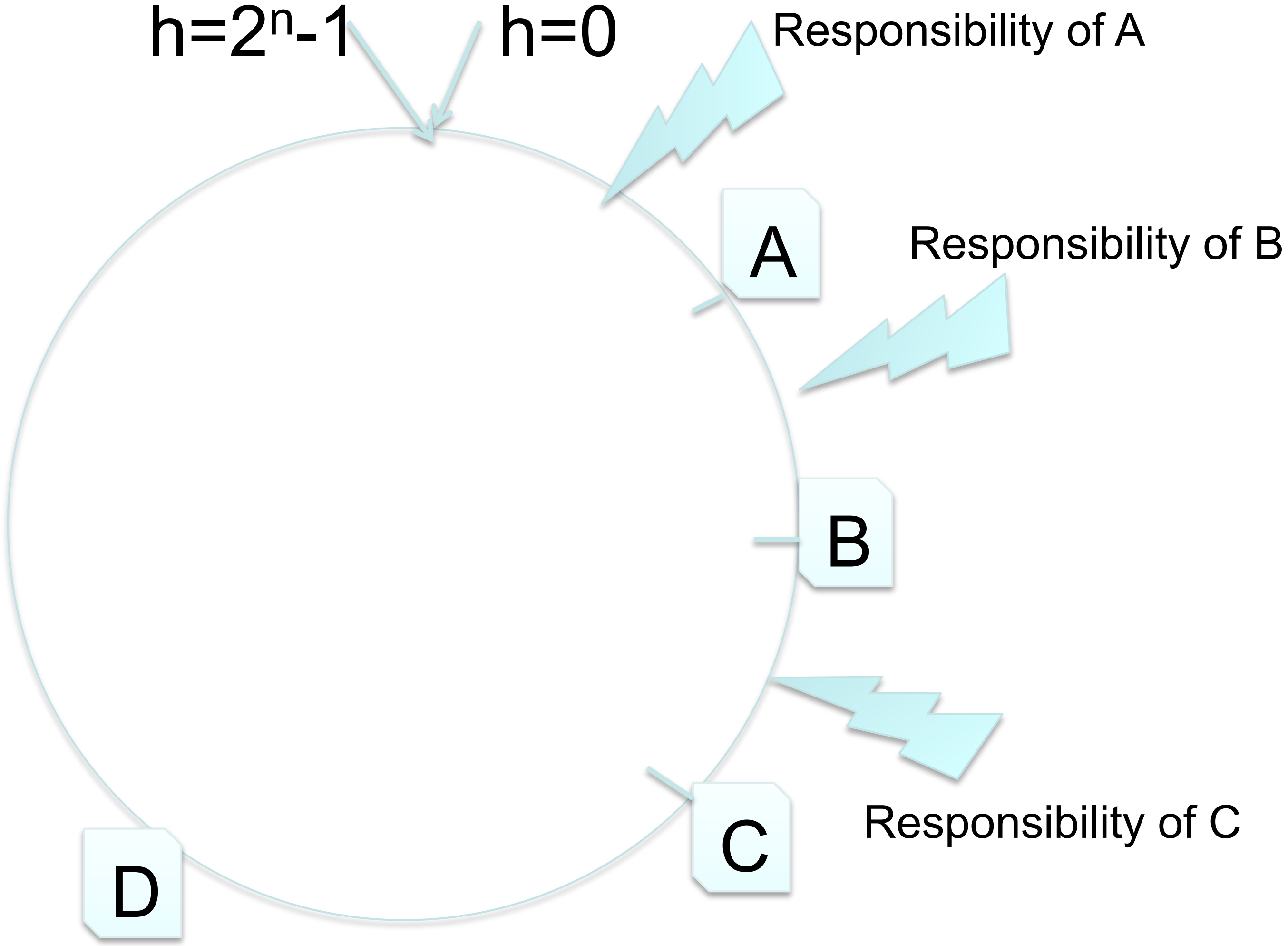
Use standard hash function: service key k by server h(k)

- Problem 1: a client knows only one server, doesn't know how to access h(k)

- Problem 2. if new server joins, then N → N+1, and the entire hash table needs to be reorganized

- Problem 3: we want replication, i.e., store the object at more than one server

Distributed Hash Table



Distributed Hash Table Details

- This type of hashing called "**consistent hashing**"
- Basic approach leads to load imbalance
  - Why?
  - Solution: Use V virtual nodes for each physical node
  - Virtual nodes provide better load balance
  - Number of virtual nodes can vary based on capacity

Problem 1: Routing

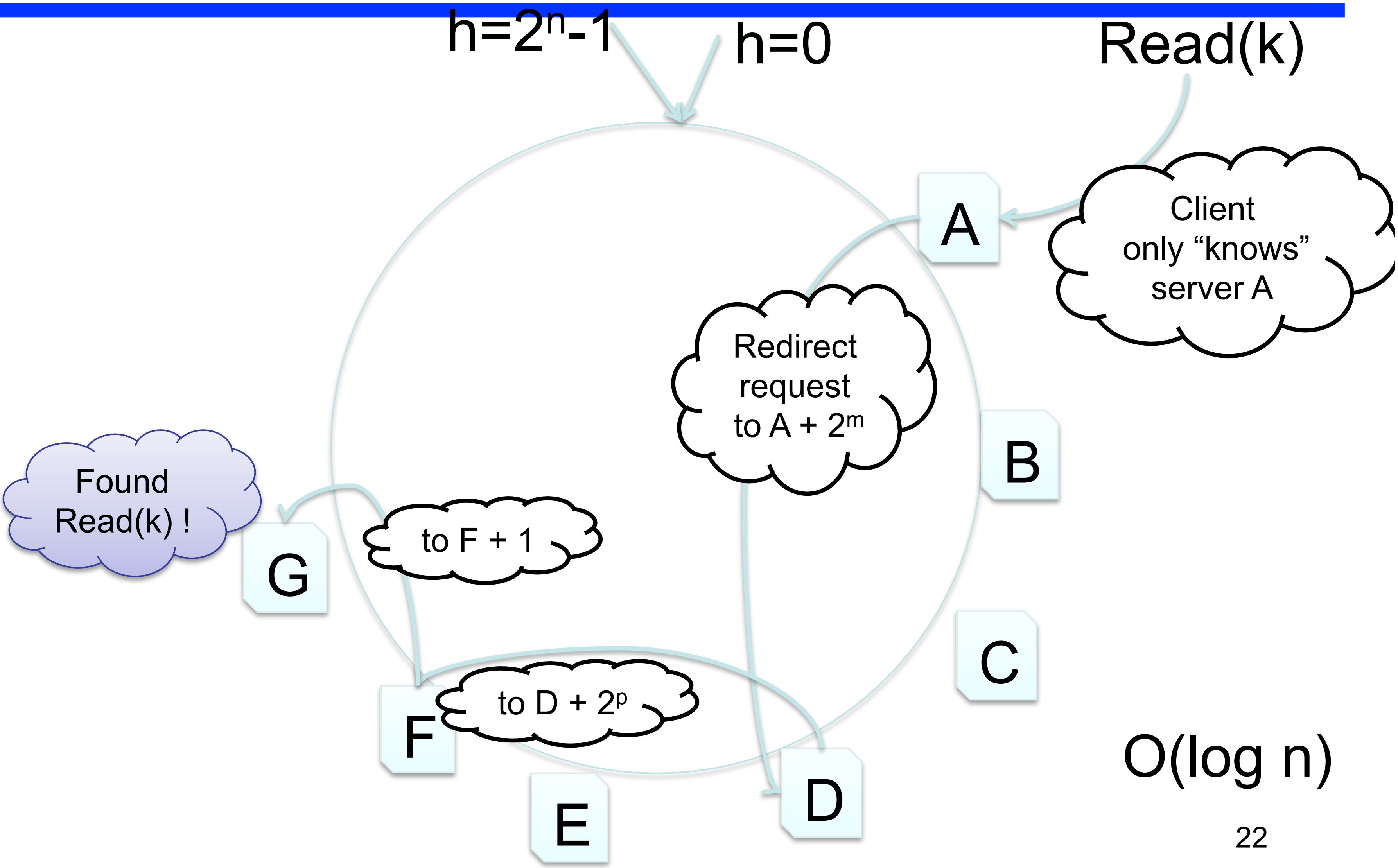
A client doesn’t know server h(k), but some other server

- Naive routing algorithm:
  - Each node knows its neighbors
  - Send message to nearest neighbor
  - Hop-by-hop from there
  - Obviously this is O(n), so no good

- Better algorithm: “finger table”
  - Memorize locations of other nodes in the ring
  - a, a + 2, a + 4, a + 8, a + 16, ... a + 2^n – 1
  - Send message to closest node to destination
  - Hop-by-hop again: this is log(n)

Problem 1: Routing

h(k) handled by server G



$h=2^n-1$

$h=0$

Read(k)

Client only “knows” server A

Redirect request to $A + 2^m$

to $D + 2^p$

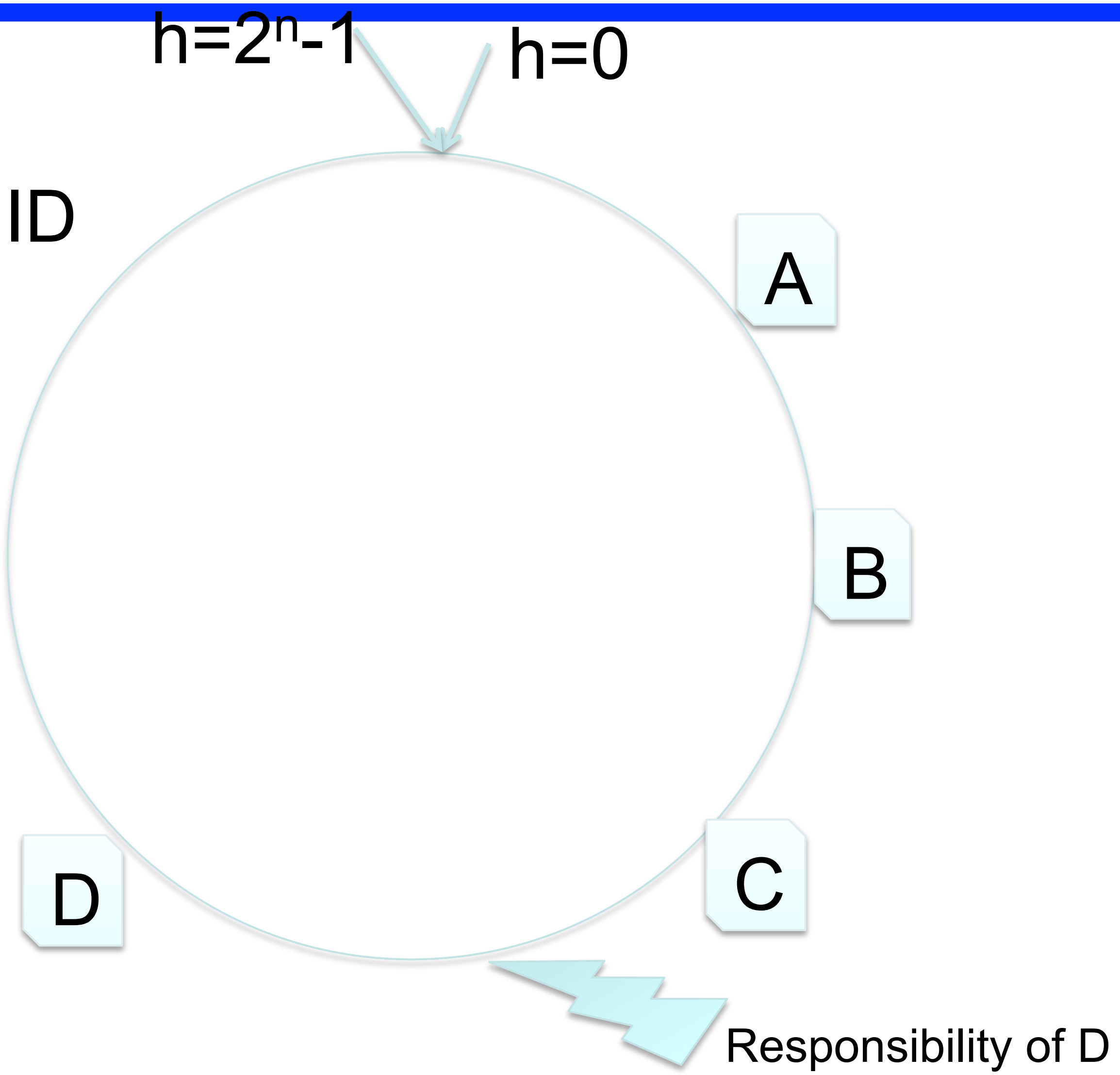
to F + 1

Found Read(k) !

O(log n)

Problem 2: Joining

When X joins:
select random ID



Problem 2: Joining

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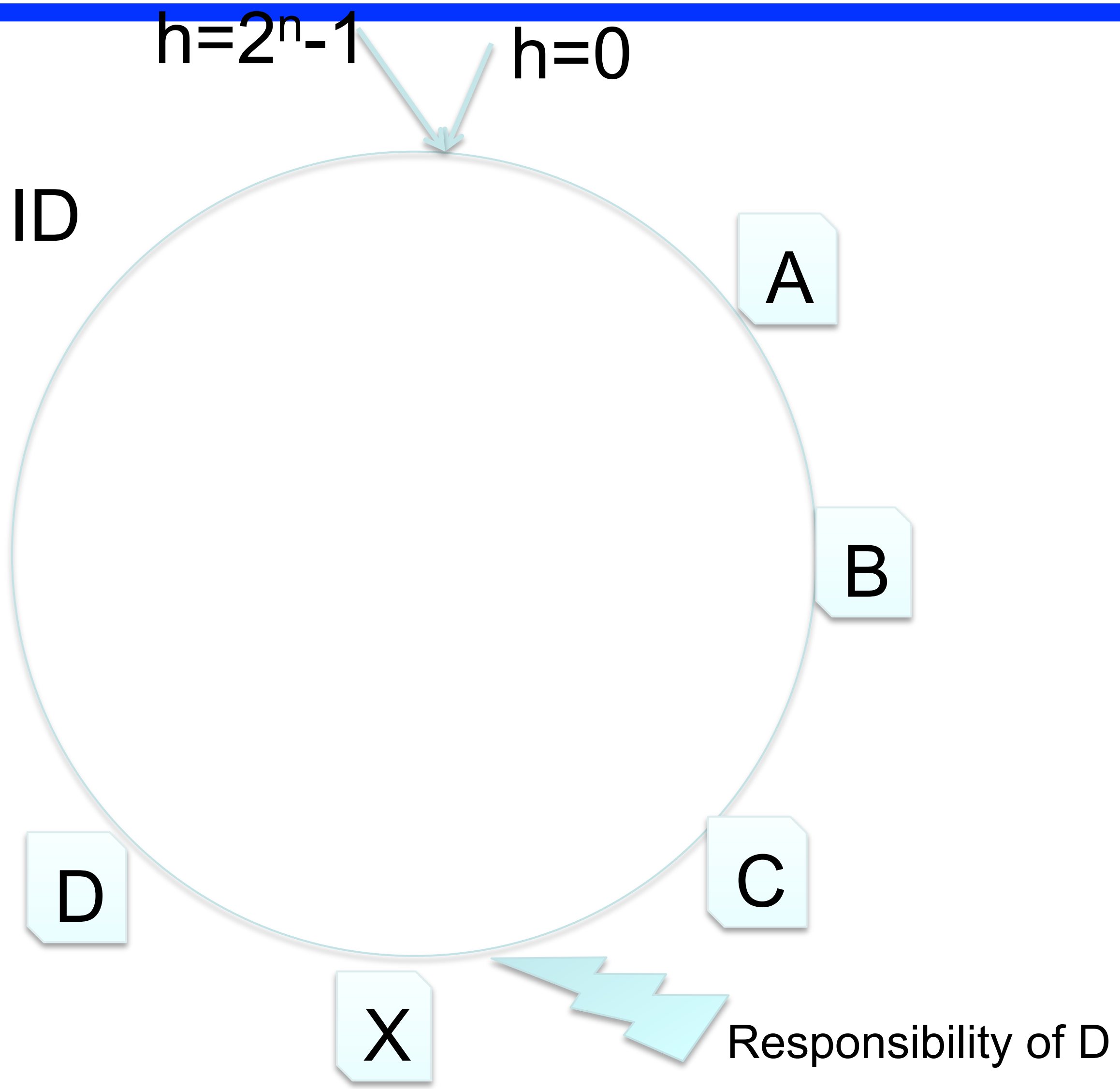
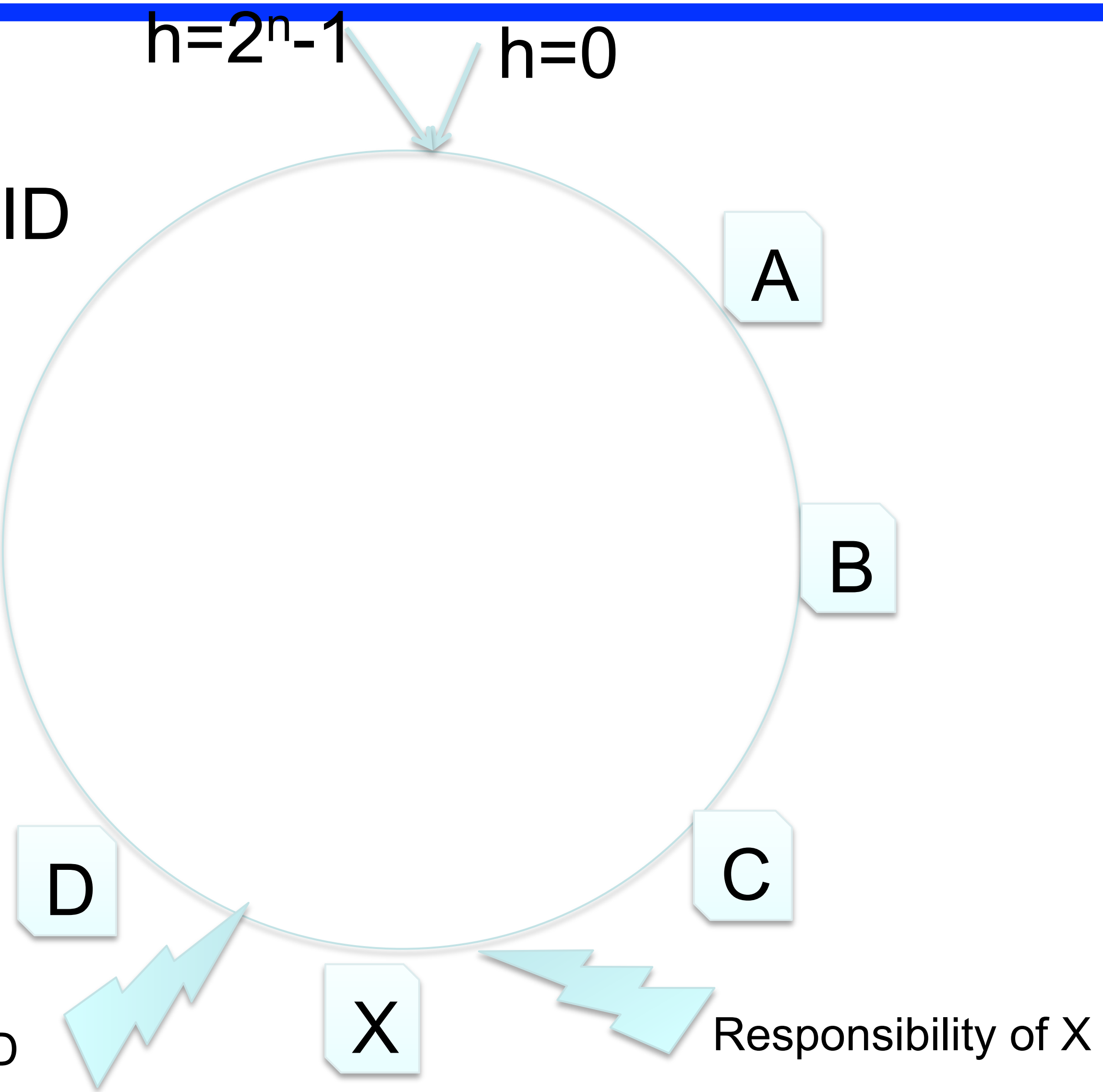


Problem 2: Joining

When X joins:
select random ID

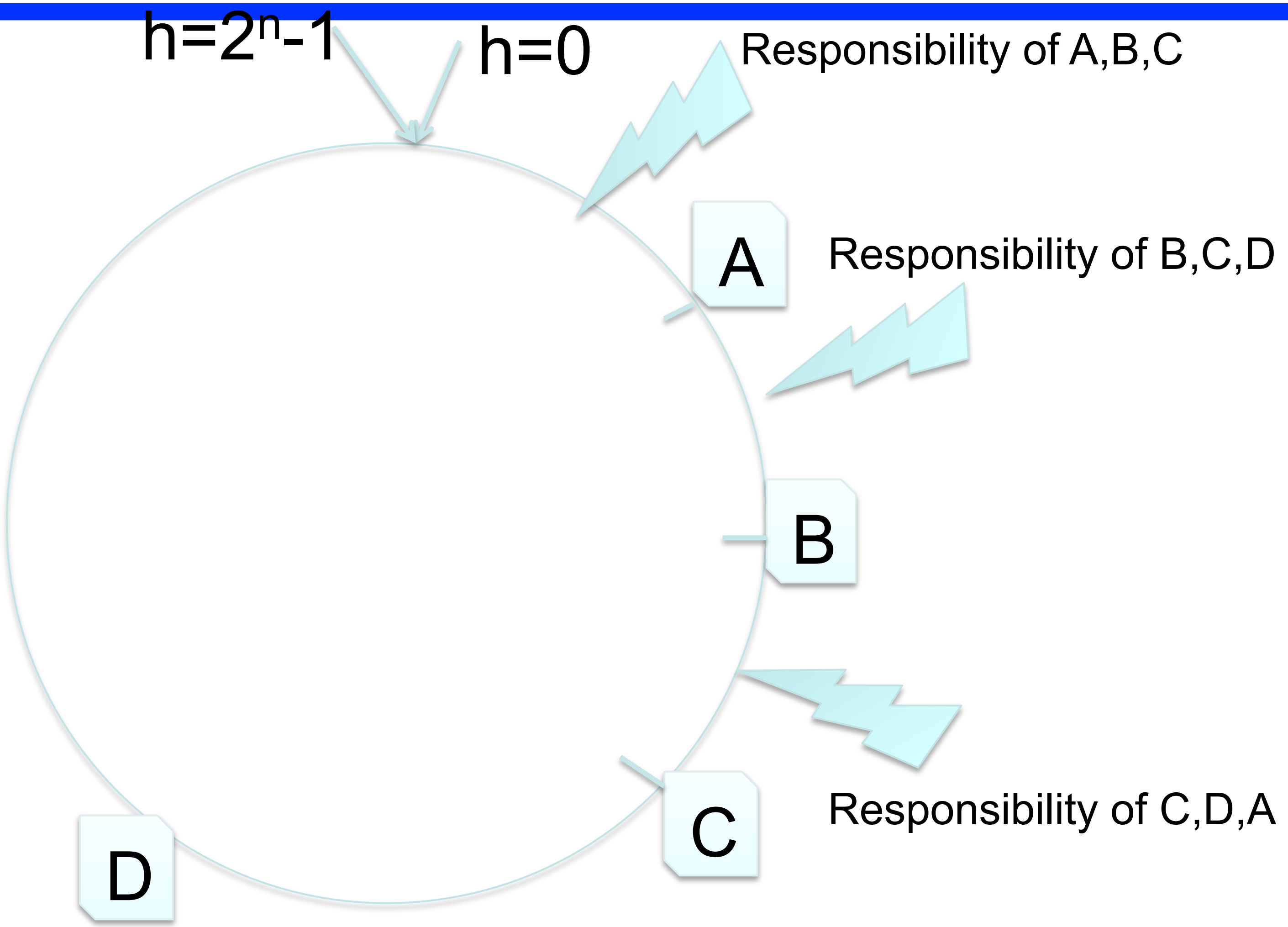
Redistribute
the load at D



Problem 3: Replication

- Need to have some degree of replication to cope with node failures
- Let N=degree of replication
- Assign key k to h(k), h(k)+1, …, h(k)+N-1

Problem 3: Replication



h=2^n-1

h=0

Responsibility of A,B,C

A

Responsibility of B,C,D

B

C

Responsibility of C,D,A

D

Additional Dynamo Details

- Each key assigned to a *coordinator*
- Coordinator responsible for replication
  - Replication skips virtual nodes that are not distinct physical nodes
- Set of replicas for a key is its *preference list*
- One-hope routing:
  - Each node knows preference list of each key
- "Sloppy quorum" replication
  - Each update creates a new version of an object
  - Vector clocks track causality between versions

Vector Clocks

- An extension of Multiversion Concurrency Control (MVCC) to multiple servers
- Standard MVCC:
  each data item X has a timestamp t:
  $X_4, X_9, X_{10}, X_{14}, \ldots, X_t$
- Vector Clocks:
  X has set of [server, timestamp] pairs
  X([s1,t1], [s2,t2],…)

Dynamo:2007

Vector Clocks

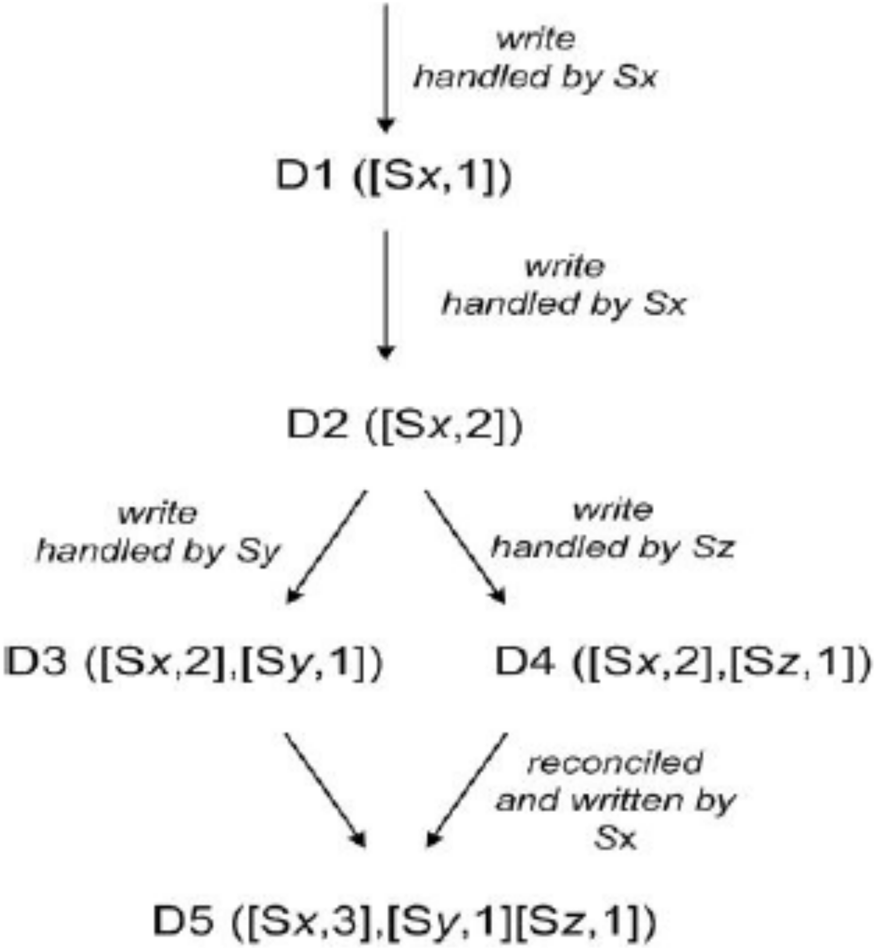


Figure 3: Version evolution of an object over time.

Vector Clocks: Example

- A client writes D1 at server SX:
  D1 ([SX,1])
- Another client reads D1, writes back D2; also handled by server SX:
  D2 ([SX,2]) (D1 garbage collected)
- Another client reads D2, writes back D3; handled by server SY:
  D3 ([SX,2], [SY,1])
- Another client reads D2, writes back D4; handled by server SZ:
  D4 ([SX,2], [SZ,1])
- Another client reads D3, D4: CONFLICT !

Vector Clocks: Conflict or not?

Data 1	Data 2	Conflict ?
([SX,3],[SY,6])	([SX,3],[SZ,2])	

Vector Clocks: Conflict or not?

Data 1	Data 2	Conflict ?
([SX,3],[SY,6])	([SX,3],[SZ,2])	Yes

Vector Clocks: Conflict or not?

Data 1	Data 2	Conflict ?
([SX,3],[SY,6])	([SX,3],[SZ,2])	Yes
([SX,3])	([SX,5])	

Vector Clocks: Conflict or not?

Data 1	Data 2	Conflict ?
([SX,3],[SY,6])	([SX,3],[SZ,2])	Yes
([SX,3])	([SX,5])	No

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([SX,3])	([SX,5])	No
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([SX,3])	([SX,5])	No
([SX,3],[SY,6])	([SX,3],[SY,6],[SZ,2])	No
([SX,3],[SY,10])	([SX,3],[SY,6],[SZ,2])	

Vector Clocks: Conflict or not?

Data 1	Data 2	Conflict ?
([SX,3],[SY,6])	([SX,3],[SZ,2])	Yes
([SX,3])	([SX,5])	No
([SX,3],[SY,6])	([SX,3],[SY,6],[SZ,2])	No
([SX,3],[SY,10])	([SX,3],[SY,6],[SZ,2])	Yes

Vector Clocks: Conflict or not?

Data 1	Data 2	Conflict ?
([SX,3],[SY,6])	([SX,3],[SZ,2])	Yes
([SX,3])	([SX,5])	No
([SX,3],[SY,6])	([SX,3],[SY,6],[SZ,2])	No
([SX,3],[SY,10])	([SX,3],[SY,6],[SZ,2])	Yes
([SX,3],[SY,10])	([SX,3],[SY,20],[SZ,2])	

Vector Clocks: Conflict or not?

Data 1	Data 2	Conflict ?
([SX,3],[SY,6])	([SX,3],[SZ,2])	Yes
([SX,3])	([SX,5])	No
([SX,3],[SY,6])	([SX,3],[SY,6],[SZ,2])	No
([SX,3],[SY,10])	([SX,3],[SY,6],[SZ,2])	Yes
([SX,3],[SY,10])	([SX,3],[SY,20],[SZ,2])	No

Executing Writes and Reads

- Write operations
  - Initial request sent to coordinator
  - Coordinator generates vector clock & stores locally
  - Coordinator forwards new version to all N replicas
  - If at least W-1 < N-1 nodes respond then success!
- Read operations
  - Initial request sent to coordinator
  - Coordinator requests data from all N replicas
  - Once gets R responses, returns data
- Sloppy quorum: Involve first N *healthy* nodes

Amazon DynamoDB

Additional functionality:

- Offers choice of eventual consistent vs strongly consistent read
- Offers secondary indexes to enable queries over non-key attributes
  - So can support selection queries

When would you want to use DynamoDB?

Try it at: http://aws.amazon.com/dynamodb/

Document Stores: MongoDB

Popular NoSQL System

From Wikipedia:

- Used by: Craigslist, eBay, Foursquare, SourceForge, Viacom, and the *New York Times*

- As of February 2015, MongoDB is the fourth most popular type of database management system, and the most popular for document stores.

Data Model

http://docs.mongodb.org

- Data model
  - Collections of documents (analogue of a table)
  - BSON documents (attribute-value pairs with nesting and arrays)
  - Documents can reference each other
    - Apps must issue follow-up queries to resolve the references
  - Documents can be embedded in each other (i.e., nested)
    - But then have to worry about documents getting very large

Consistency and Replication

- Consistency
  - Write operations are atomic at the document level
  - Operations that modify more than a single document in a collection still operate on one document at a time

- Replication
  - Master scheme with master performing all reads & writes by default
    - Achieves strong consistency by always going through the master
  - Eventual consistency by default when reading from replicas
    - Updates propagate to replicas asynchronously
    - But can be configured to use synchronous replication

Programming Model

- Javascript API and Javascript shell
- Querying: Selection
  - A query targets a collection of documents
  - Selection queries on attribute values (including arrays)

```
db.inventory.find( { type: "snacks" } )
```

  - Can also have conditions on embedded documents
  - Can also do projections, sort, limit and skip
- Querying: Aggregation
  - Aggregation pipelines

```
db.orders.distinct(“cust_id”)
```

  - MapReduce API (JavaScript map/reduce functions)

Query Optimization

- Sharding
  - Horizontal partitioning
  - User selects the “shard key”
- Indexing
  - MongoDB automatically indexes the ID field
  - Users can add indexes on other attributes

- Other interesting features
  - Can insert data and specify a “time to live” to expire docs
    - Why is that useful?

Takeaway

- Claim: NoSQL is really no SQL
- We have seen noSQL systems with:
  - Relational data models
  - Consistency support
  - Replication support
  - Querying interface
  - Optimization engine
- We have encountered all these during this quarter

That’s it!

- What you achieved in 10 weeks:
  - Various data models
  - Processing and optimizing SQL queries
  - Data analytics
  - Transactions
  - Replication and recovery
  - DaaS and real-world DBMS

- Thanks for everything
  - Have fun finishing your projects
  - Have a great winter break!