CS417: Distributed Systems

Large Scale Data Stores

Department of Computer Science The Johns Hopkins University

Key Value Stores:

key → Value

Requirements: Scalability and Reliability

- Sharding – distribute keys/indexes
- Replication- same key/index on multiple machines

Example – DNS

Domain Name Service: maps URLs to IP adresses

Distributed Indexing

Distributed systems have two engineering aspects:

- A highly efficient sharding mechanism.
- A lookup mechanism that tracks down the node holding the object.

These can be used to implement a higher-level services.

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Simple Sharding Mechanism

Let us consider doing it by simple hashing -

store = hash(key) % stores.count

Issues-

- What if stores.count changes ?
- What if keys are non-uniformly distributed ?

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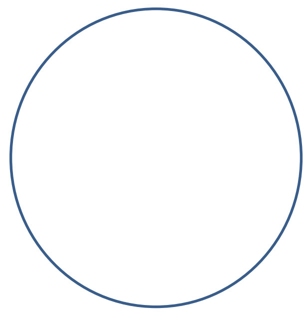
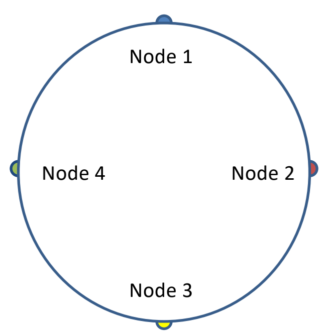
Consistent hashing

1. Imagine the hash space as a ring.



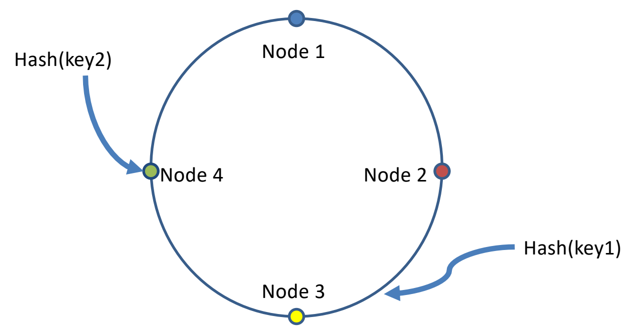
Consistent hashing

2. Take server/DB’s IP, hash it and place them on hash ring



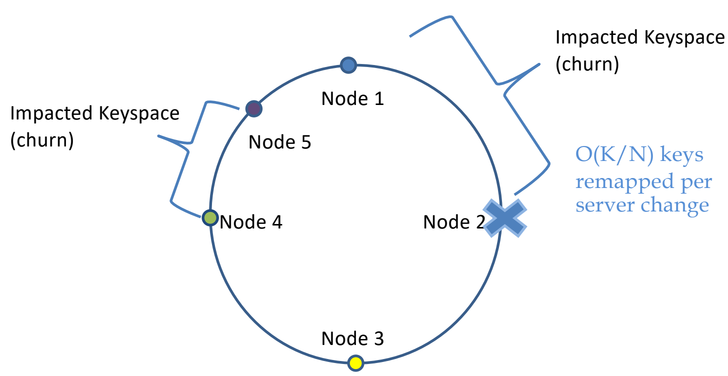
Consistent hashing

3. Distribute keys – hash(key) and map it onto the ring
- The key resides on the first server in clockwise direction



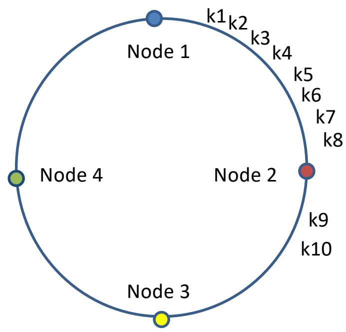
Consistent hashing

Q1. What happens if stores.count changes ?



Consistent hashing

Q2. How to achieve uniform distribution ?



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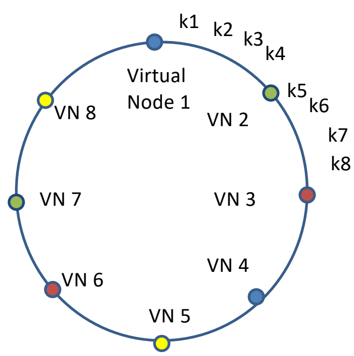
Consistent hashing

Virtual Nodes-



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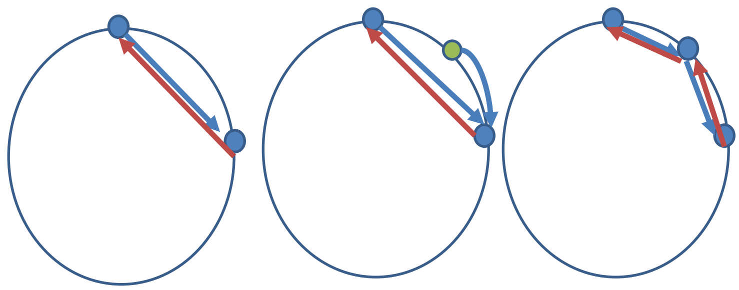
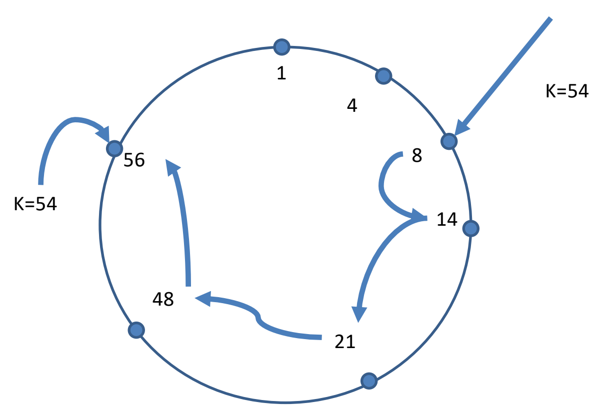
Lookup

A lookup mechanism that tracks down the node holding the object for the client efficiently.

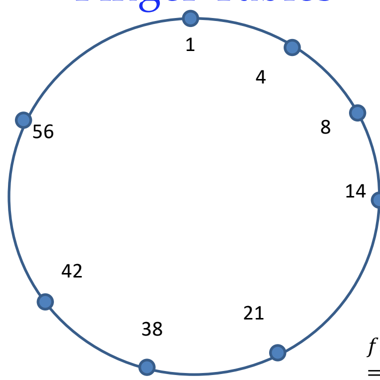
Let us look at Chord's node join and startup mechanism



Naive Approach



Chord's Approach with Finger Tables



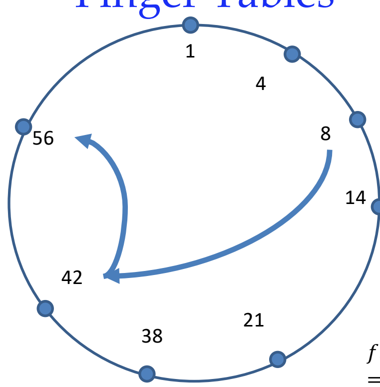
Finger Table : 8	
N8+1	14
N8+2	14
N8+4	14
N8+8	21
N8+16	38
N8+32	42

Finger Table:42	
N42+1	56
N42+2	56
N42+4	56
N42+8	56
N42+16	1
N42+32	14

$$finger[k] = [n + 2^{k-1}]\ mod\ 2^m$$

$1 \le k \le m$

Chord's Approach with Finger Tables



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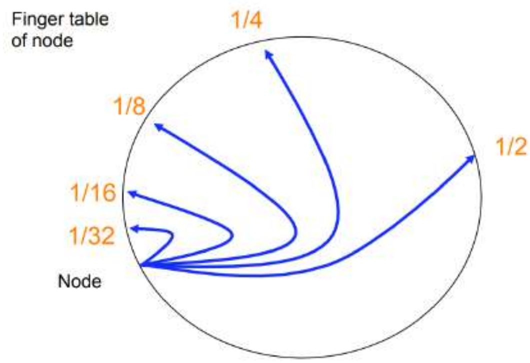
Efficiency of Chord's Lookup



Chord Issues to consider

Overall, log(n) hops for lookup in the worst case! – very good.

- What is a hop? Where are the nodes? Is log(n) really good ?
- What about churn ?
- Is it really log(n) worst case over time?
- How to maintain robustness?

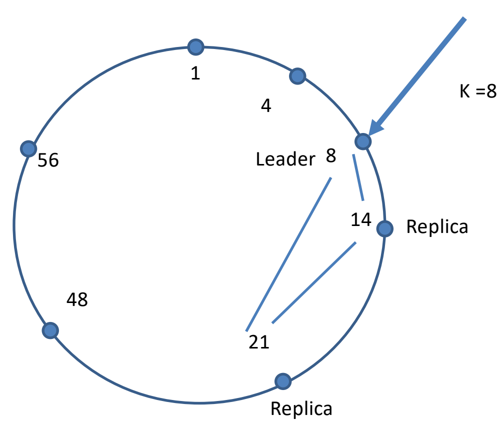
Replication

How to fit replication into this ?

The key is stored on first N servers in the ring.

Consensus Protocols.

Replication



Kelips

- Developed at Cornell (2003).
- Uses more storage (sqrt(n) instead of log(n)) at each node. – Replicating each item at sqrt(n) nodes.
- Aims to achieve O(1) for lookups.
- Copes with churn by imposing a constant communication overhead.
  - Although data quality may lag if updates occur too rapidly.
- How would you do that? .

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Kelips Lookup

- N is approximate number for the number of nodes.
- Each node id is hashed into one of sqrt(N) affinity groups.
- Each key from (**key,value**) pair is hashed into one of the sqrt(N) groups.
- Approximately sqrt(N) replicas in each affinity group.
- Pointers are maintained to a small number of members of each affinity group. Lookup is O(1).
- Weak consistency between the replicas is maintained using a reliable multicast protocol based on gossip.

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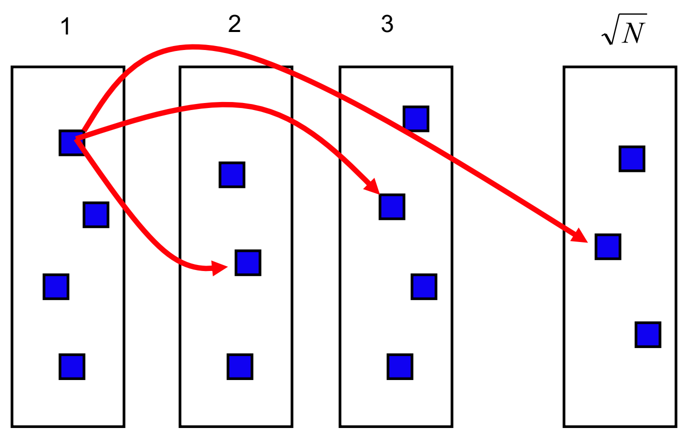
Kelips Lookup (cont.)



Operations in Replicated DHTs

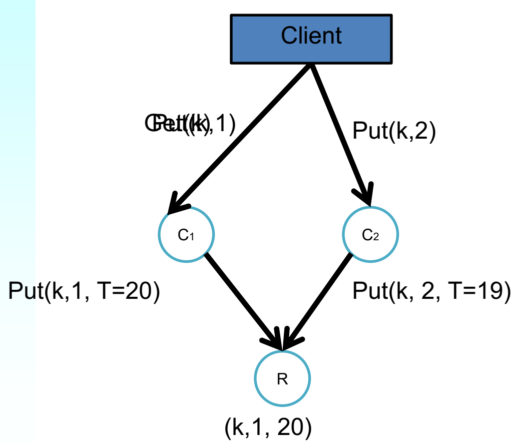
How is the most recent version determined?

Leader/Coordinators give each write update a timestamp, based on its local clock

Clock-based Timestamps

- Each put is given a timestamp by the coordinator responsible for that update
- If a replica receives an update with a lower timestamp than its current version, it ignores the update, but acknowledges that the write was successful
- If the clocks on different coordinators drift, this can cause unexpected behavior

Example: Losing an update



Let's say C_2 has a slower clock

Resolution

- Applications need to handle
- How does you application want to handle these?

Operations in Replicated DHTs

Setting –

- A key is in N stores.
- When a request reaches one of them, that store becomes leader/co-ordinator for that operation.

Reads / Get(k)

- Coordinator requests the object from the relevant N nodes
- After R of those replicas respond, the coordinator returns the most recent version held by any of the replicas

Writes / Put(k,v)

- Coordinator forwards the update to the relevant N replicas.
- After W of those replicas have acknowledged the update, the coordinator can tell the client that the write was successful.

Quorum Flavors

Choice 1: R+W > N (Strong Consistency)
Every read quorum will contain a node with the latest write.

Further Choices: For N=5, R(2)+W(4), R(3)+W(3), R(4)+W(2)

Choice 1: R+W <N (Weak Consistency)
Staleness

Crashes and recovery

To address this, nodes participate in anti-entropy with nodes that share a key-range by exchanging Merkle hash trees

Some existing distributed systems for mega services

To state some –

Amazon's Dynamo
Facebook's Cassandra
Google's Slicer is alternative to Consistent hashing used by above two

Each with their own design considerations specific to their application

Hyperdex

Limited API for KV Stores – search based on only key

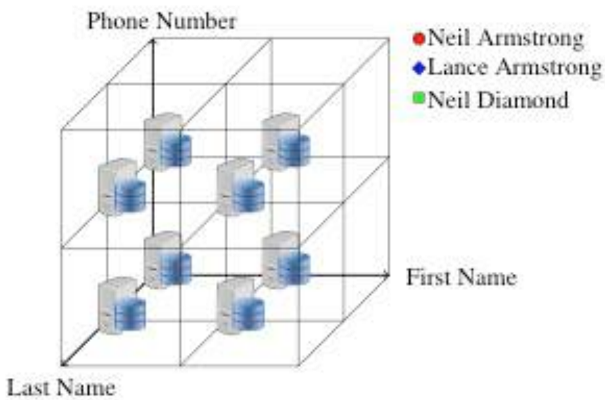
Want richer service –

High Performance, Scalable, Consistent, Fault-tolerant Data Stores
\+
Supports efficient search on secondary attributes

Hyperdex

Hyperspace Hashing

Each server is responsible for a region of the hyperspace



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Hyperdex Search

- In addition to partitioning based on the key, each object is stored on additional servers based on its secondary attributes
- Combining the hashes of a set of secondary attributes forms a hyperspace which can be partitioned
- This enables efficient search by limiting the number of servers that need to be contacted
- This can be done for multiple sets of attributes

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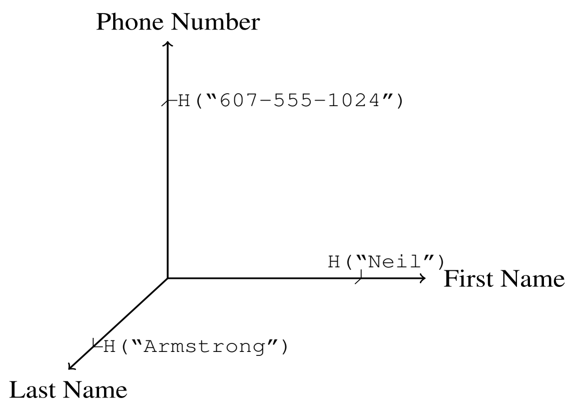
Hyperspace Hashing

Attribute values are hashed independently
Any hash function may be used



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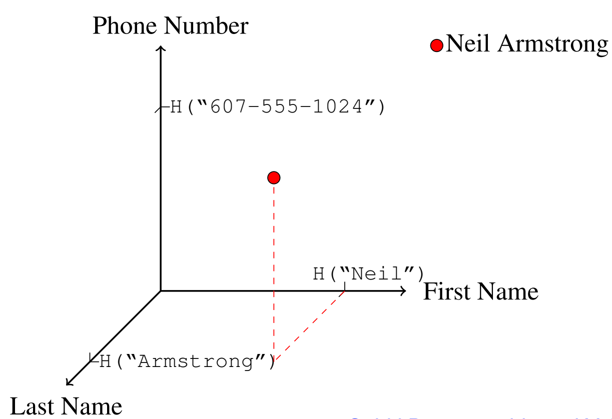
Hyperspace Hashing

Objects reside at the coordinate specified by the hashes



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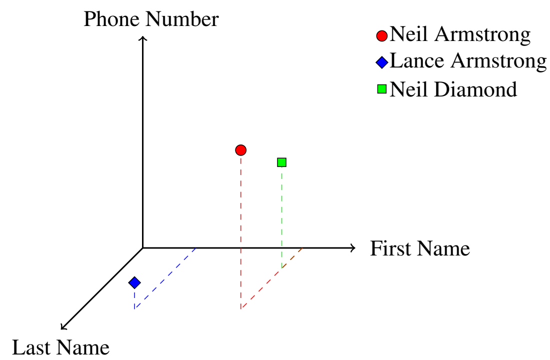
Hyperspace Hashing

Different objects reside at different coordinates



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Hyperspace Hashing

- Every object is placed on a server based on its primary key (like Cassandra and Chord)
- For each set of attributes (subspace) we would like to search by, we will place each object on an additional server
- For each object, its attributes are hashed into a point in the hyperspace, and object is placed on the server responsible for that point

Hyperspace Hashing

- By specifying more of the secondary attributes, we can reduce the number of servers that need to be searched
- If all of the subspace attributes are specified, the search is equally efficient as searching by key
- What if the secondary attributes are updated?

Answer : Value dependent Chaning

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Value-Dependent Chaining

- Initially, let's assume there are no faults
- To perform an update, all of the servers involved are organized in a chain
  - The server responsible for the primary key is at the head of the chain
  - Any server holding the current version of the object is in the chain
  - Any server that will hold the updated version of the object is also in the chain
- The update is ordered at the head and passed through the chain
- Once it reaches the end of the chain, the tail server can commit the update, and pass an acknowledgment back through the chain
- Updates are not committed until an acknowledgement is received from the next server in the chain

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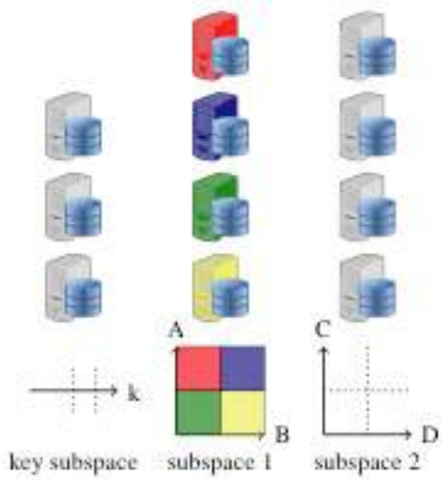
Value-Dependent Chaining



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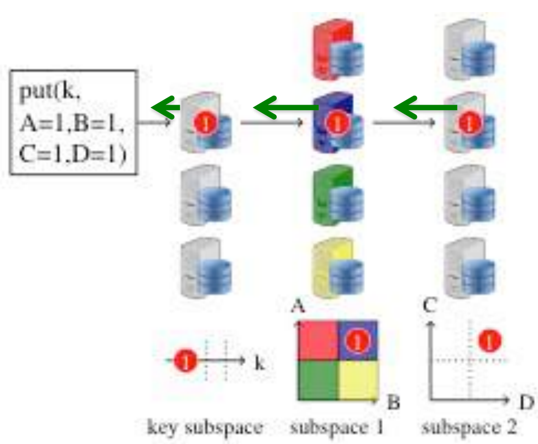
Value-Dependent Chaining



A put includes one node from each subspace

Each put takes a forward pass down the chain and is committed during the backward pass

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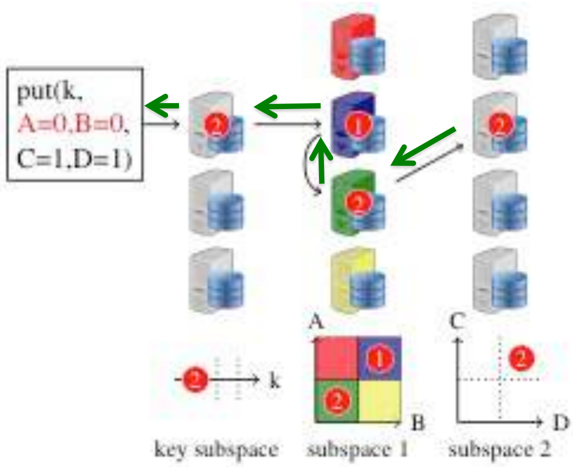
Value-Dependent Chaining



When updating an object, the value-dependent chain includes the servers which hold the old and new versions of the object

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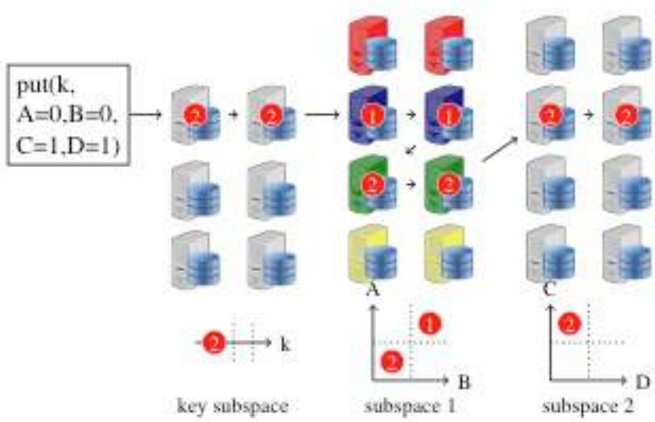
Consistency Guarantees

- Any operation that was committed before a search will be reflected in its results
- In the presence of concurrent updates, either version may be returned, but at least one version of every object will be seen
- Because an update can be reflected in a search before it is committed, search results may be inconsistent with get calls

Fault Tolerance

- Each server in the chain can be replicated
- Hyperdex uses chain replication, but any consistent replication protocol could be used
- If every block of replicas remains available, the system remains available

Fault Tolerance



The value-dependent chain includes all replicas

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Hyperdex: Conclusions

- Search can scale by partitioning on attributes other than the primary key
- What is the cost?

Hyperdex: Conclusions

- What is the cost?
  - More servers
  - Higher latency
  - Lower resiliency

Geo-replicated Key Value Stores

Build it for the Globe !

So think of replication across data centers.

Some such systems-
- Google's Spanner
- Consus, logical successor to HyperDex

References

- https://en.wikipedia.org/wiki/Consistent_hashing
- https://pdos.csail.mit.edu/papers/chord:sigcomm01/chord_sigcomm.pdf
- https://www.cs.cornell.edu/home/rvr/papers/Kelips.pdf
- https://dl.acm.org/citation.cfm?id=1773922
- https://dl.acm.org/citation.cfm?id=1294281
- https://arxiv.org/abs/1612.03457