Distributed Data Management

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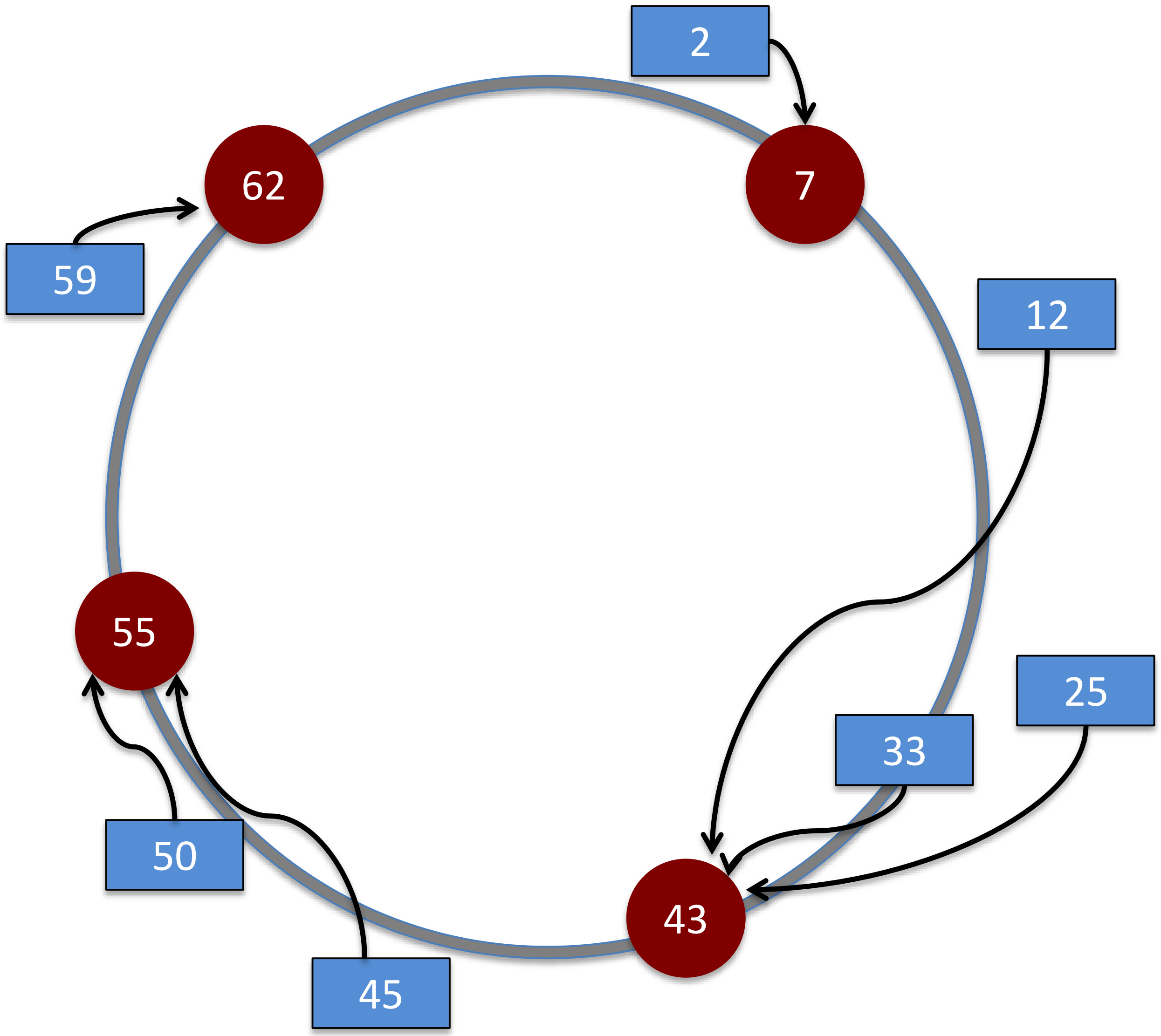
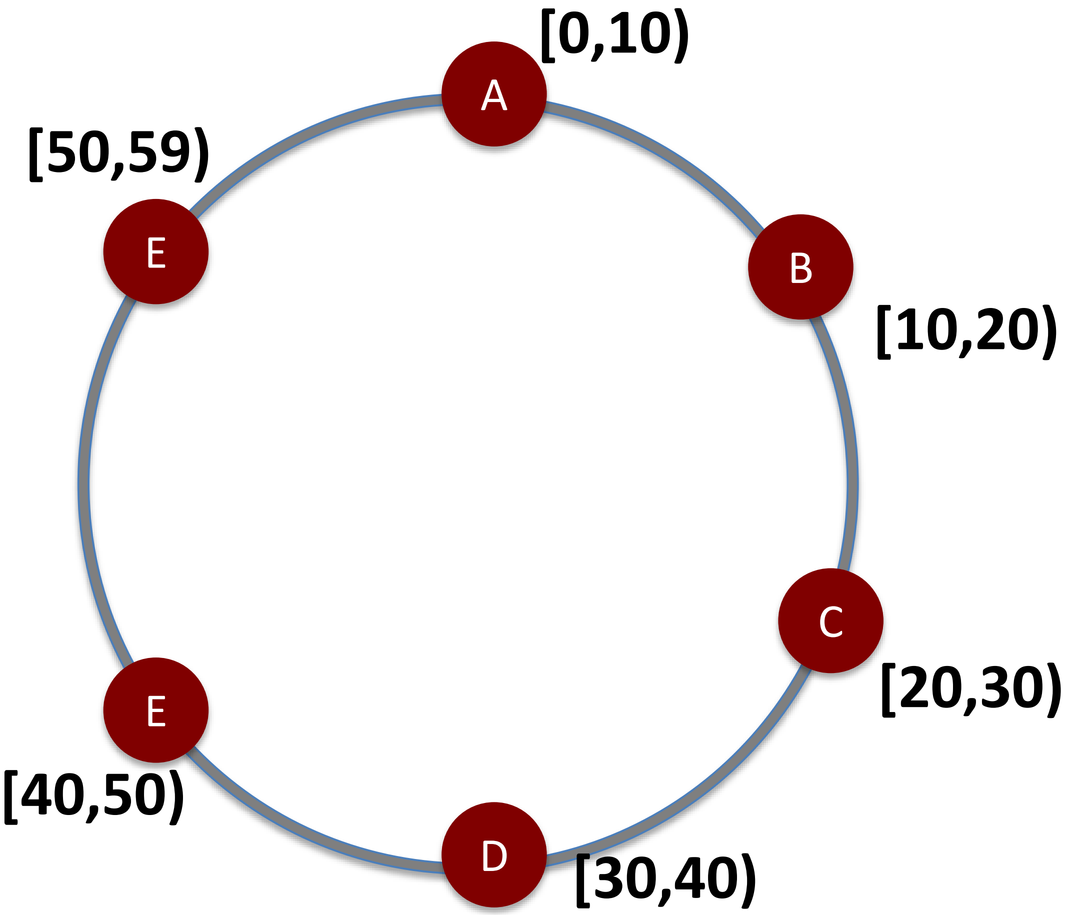
Recap: Consistent Hashing



“Consistent Hashing” in **Amazon Dynamo**

- **Global view of partitioning following the principles of consistent hashing**
- **No routing tables**, **no multi-hop routing** (reason, network #roundtrips is too expensive for low latency) (check SLA=Service Level Agreements, e.g., 300ms for 99.9%)
- **Instead:** dissemination of full network information, using gossiping as information dissemination (will see later) => then O(1) lookup cost

Replication in Amazon's Dynamo



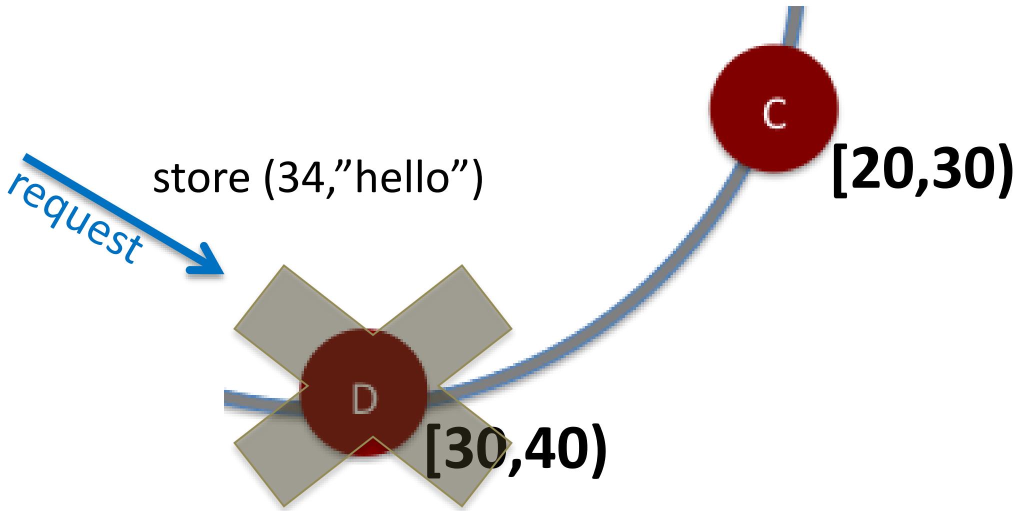
Key	Node	Replica
3	A	B, C
12	B	C, D
19	B	C, D
20	C	D, E
37	D	E, F
40	E	F, A
54	F	A, B

Replicas are stored at X (here 2) successors of node that "owns" the key.

Replica holders are **physically distinct nodes** (because of virtual nodes).

Hinted Handoff

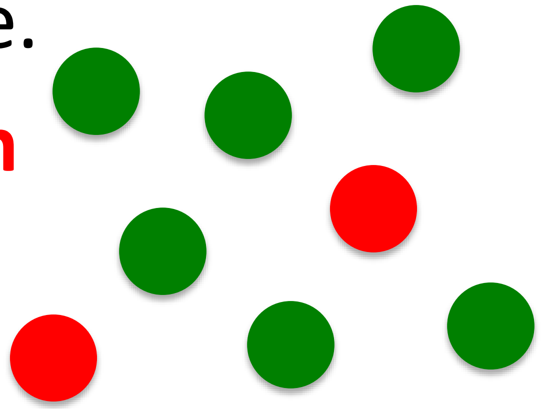
- **What if a node for a key is not available?**



- Store data at other node, coordinator, or neighbor. With hint that it is for the (currently) unavailable node.

Hinted Handoff (Cont'd)

- **Problem:** Hinted Handoff information can get lost if holding node is unavailable.
- **Requires protocol that fixes such inconsistencies.**



- Each node stores a set of entries of the form
  <key, value, version>
- According to, here, ranges on the "ring", but protocols we see now are independent on that.

Synchronization Process

- Given N nodes (replicas)
- Each of them **might or might** not have the recent value of an object
- Communication between nodes has to ensure consistent view on data (replicas)

Deterministic Solution

- Node that gets new information sends the information to the N-1 other nodes. *(Also called **direct mail**).*

- **Pros and Cons?**

Deterministic Solution

- Node that gets new information sends the information to the N-1 other nodes. *(Also called **direct mail**).*

- **Pros and Cons?**
- **Very efficient**, **no duplicate messages** that waste network bandwidth or CPU time.
- But **what if a nodes fails?**

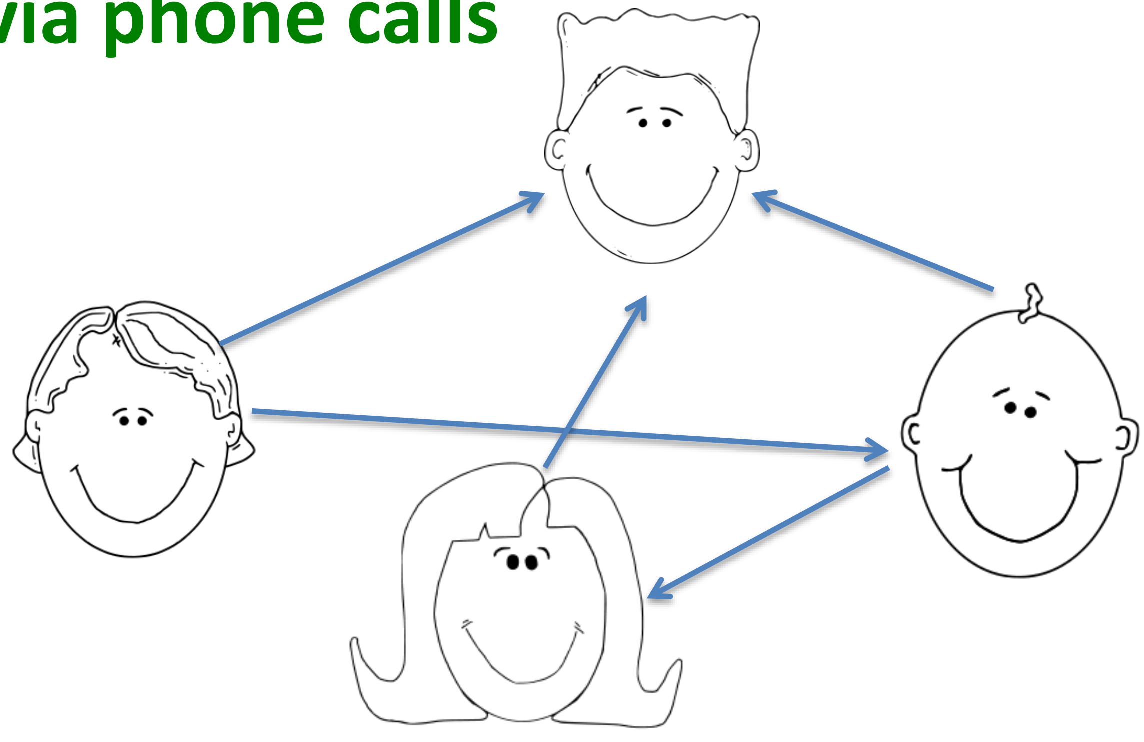
Epidemic Algorithms

- **Anti-entropy: Information is constantly exchanged with randomly selected node**. Items to be exchanged are always the current versions items stored in the nodes. **Do that continuously**.

- **Rumor spreading: Information is exchanged with randomly chosen nodes**, **multiple rounds, then stop**. With high probability, data is consistently replicated afterwards.

Rumor Spreading

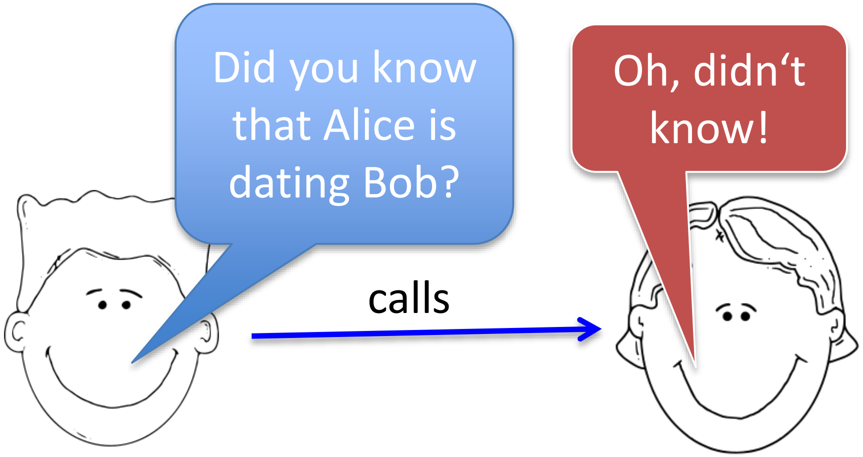
- **Think: Spreading rumors between people, say, via phone calls**



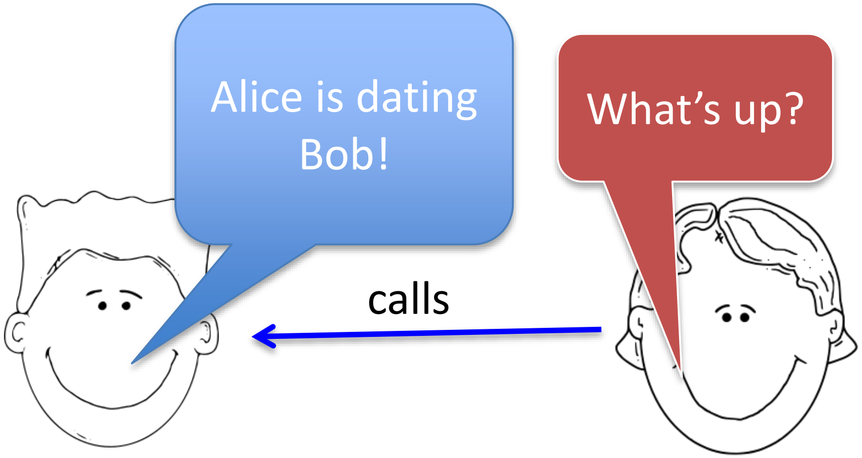
- Two issues: Understanding how rumor spreads (in social networks, e.g.,) or how to devise algorithms that behave similarly (we, here, will look at algorithms)

Variants of Gossiping

- **Push:** Holder of new information actively distributes it.

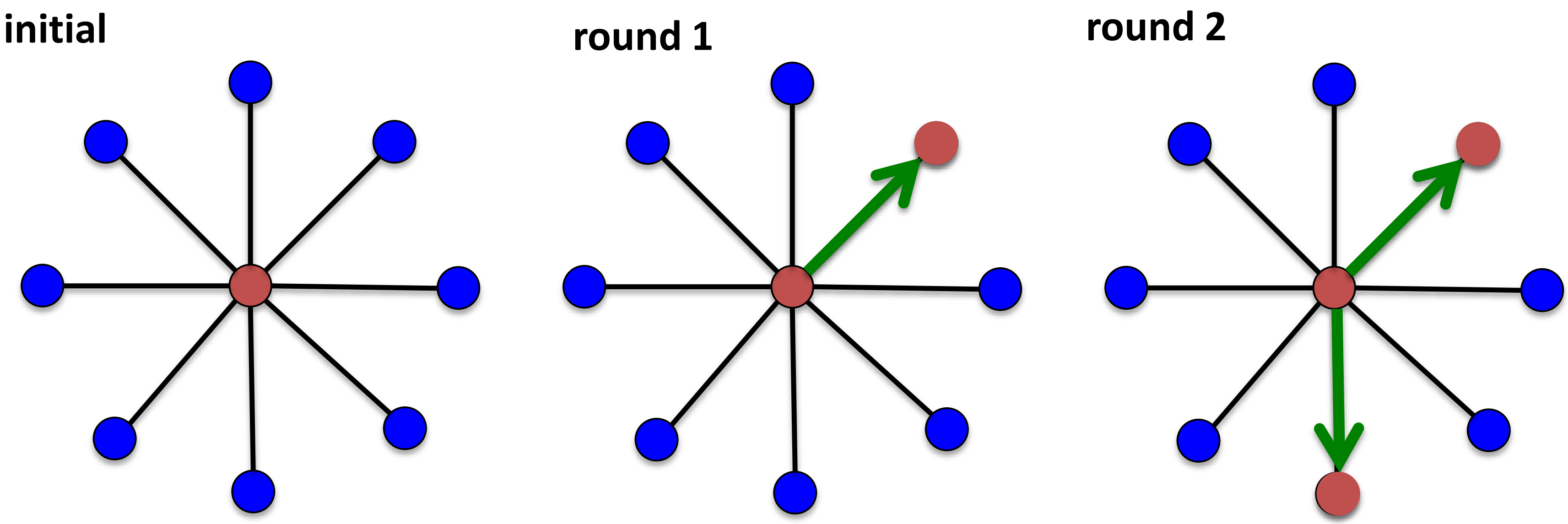


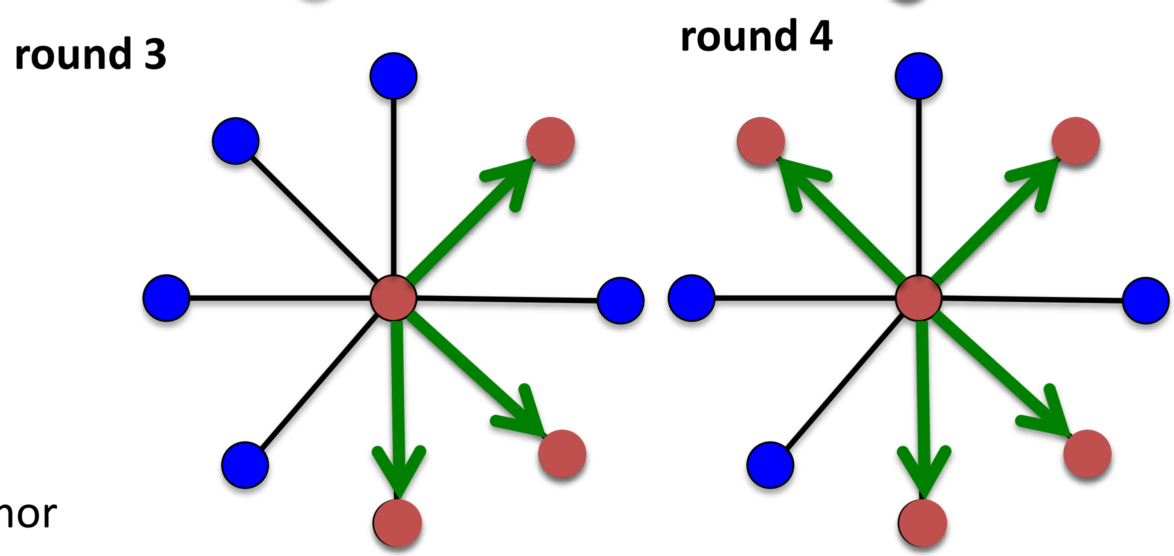
- **Pull:** People actively call to obtain news.



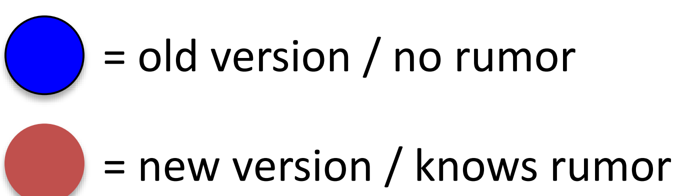
What are the strong and weak characteristics of both strategies?

Push



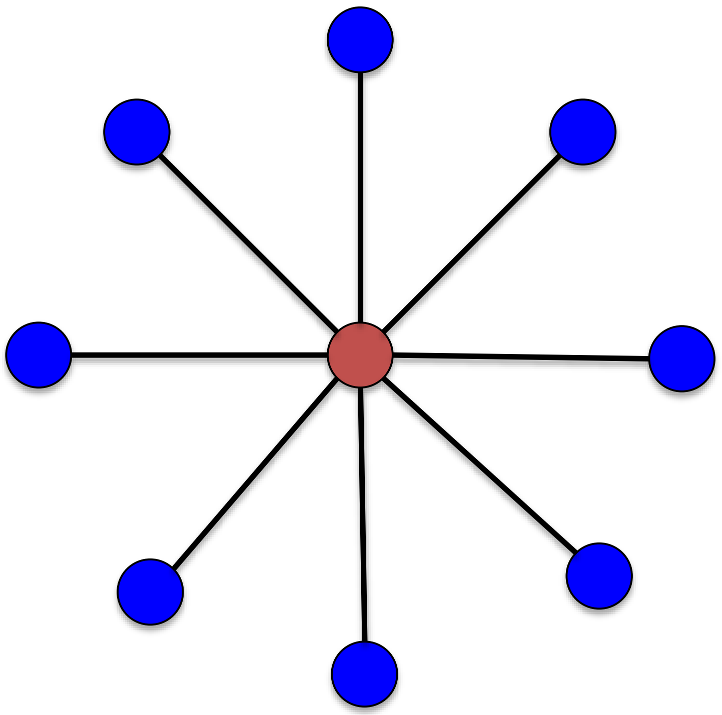


Shown only relevant push operations for illustration.

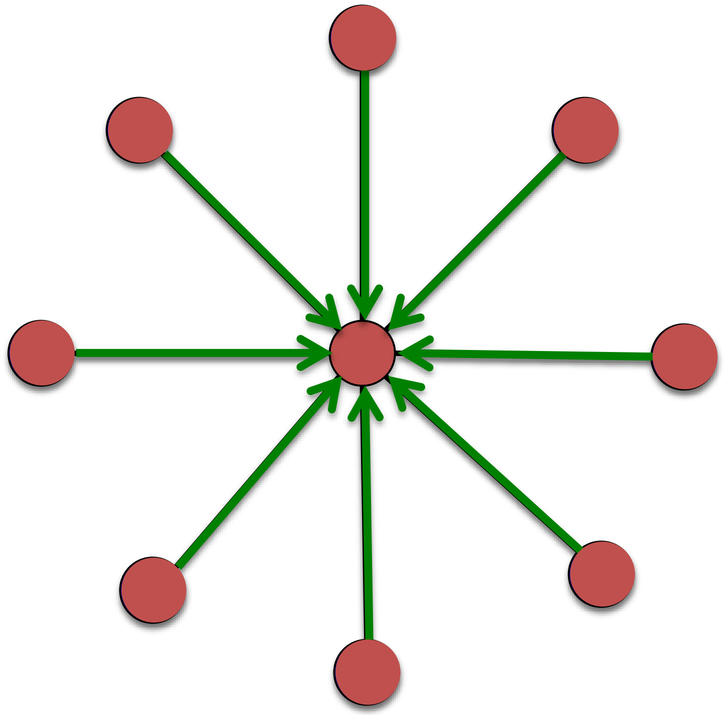


Pull

initial

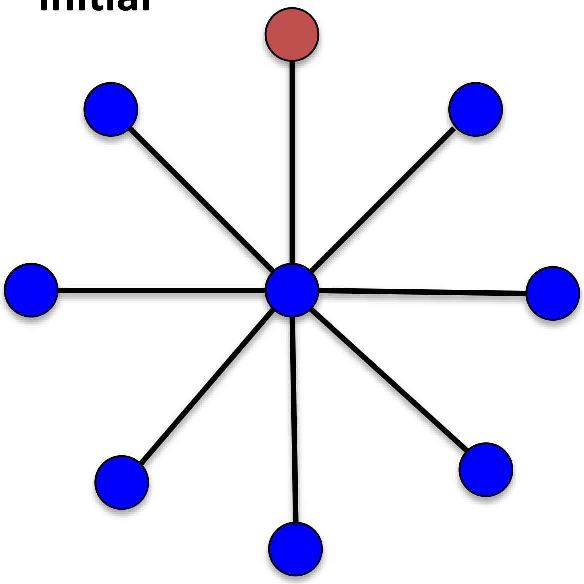


round 1

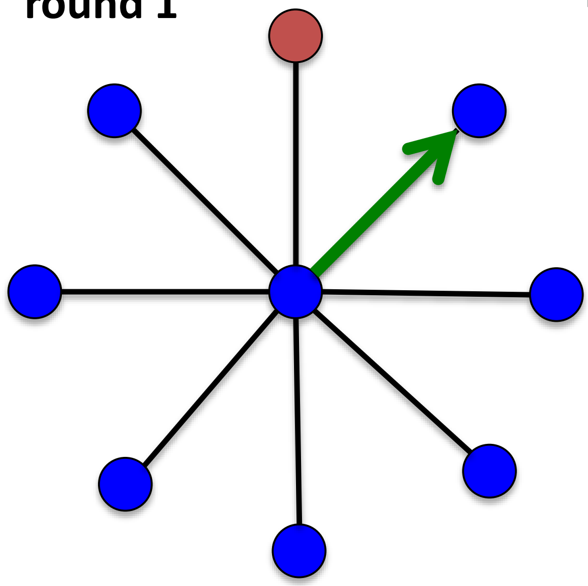


Pull

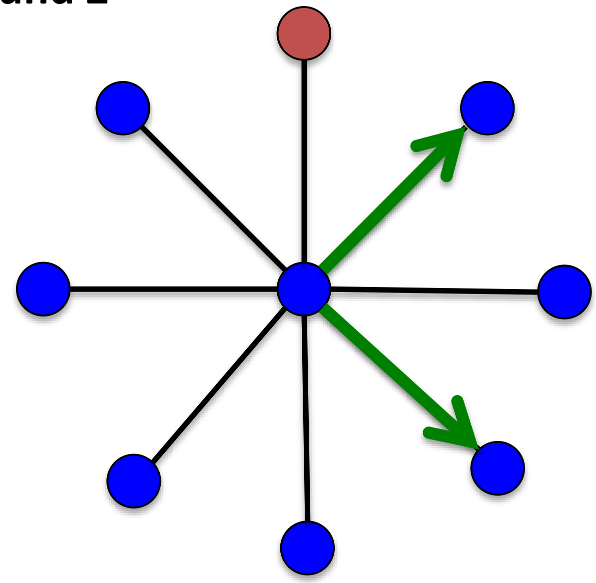
initial



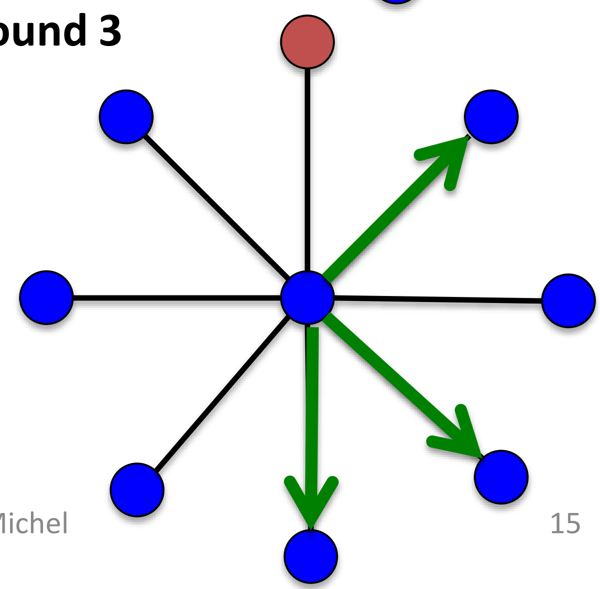
round 1



round 2



round 3



Shown only relevant pulls for illustration.

Push-Pull

- **Combination of push and pull**
- Also works in rounds.

- **In each round:**
  - **each node contacts a random neighbor**
  - **if one of the two has the rumor it tells the other**
    - push: caller sends rumor
    - pull: caller receives (learns) rumor

Behavior

- Rumor spreading in case of complete graphs, random graphs or hypercube graphs:

  in **O(log n) rounds** all nodes know the rumor with **high probability (w.h.p.)**

  Also **robust to failures:** if communication links fail with certain probability $f<1$ then, e.g., $O(1/(1-f))$ more time needed

Robert Elsässer, Thomas Sauerwald: On the runtime and robustness of randomized broadcasting. Theor. Comput. Sci. 410(36): 3414-3427 (2009)

Anti-Entropy as Secondary Protocol

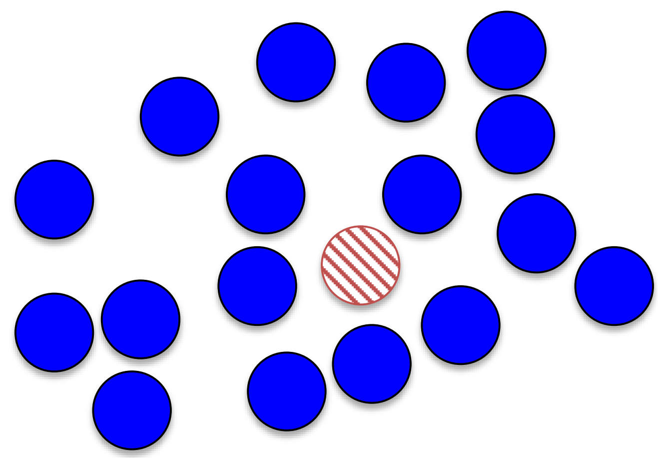
- Demers et al.* put **Anti-Entropy** in the role of being used **after "direct mail" or rumor spreading protocols**.
- To **fix missing information** due to unavailable nodes or
- **in case rumor spreading did not receive 100% of all nodes** (as it comes with *only* a "with high probability" guarantee)

*Alan J. Demers et al. : Epidemic Algorithms for Replicated Database Maintenance. PODC 1987: 1-12

Anti-Entropy as Secondary Protocol (2)

- Assume case of having majority of nodes that are in sync already and have the same latest version

- What is the method of choice, push or pull?

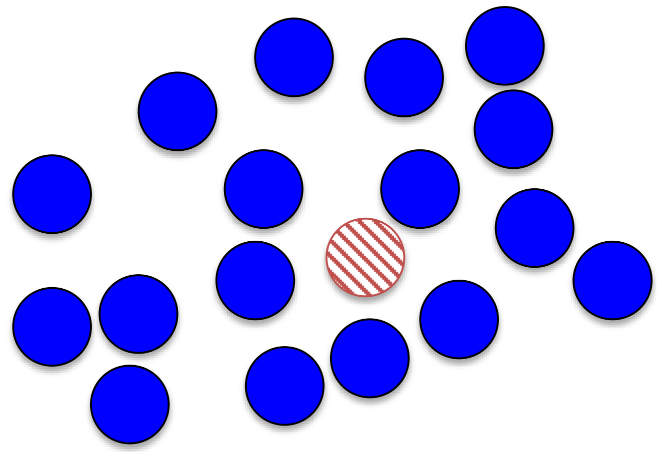


Latest version (="knows rumor")

Not latest version (="does not know rumor")

Anti-Entropy as Secondary Protocol (3)

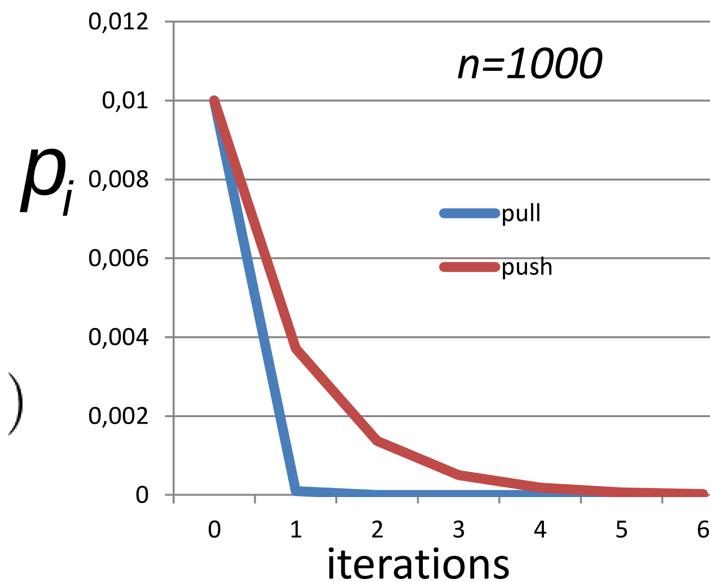
- **Then: Pull or pull-push is much better suitable then push only.**



Say p_i is **probability that a node is not informed, then in next round**

for pull: $$p_{i+1} = (p_i)^2$$

for push: $$p_{i+1} = p_i \times (1 - \frac{1}{n})^{n(1-p_i)}$$



source: Demers et al.

Optimizing Data Exchange/Comparison

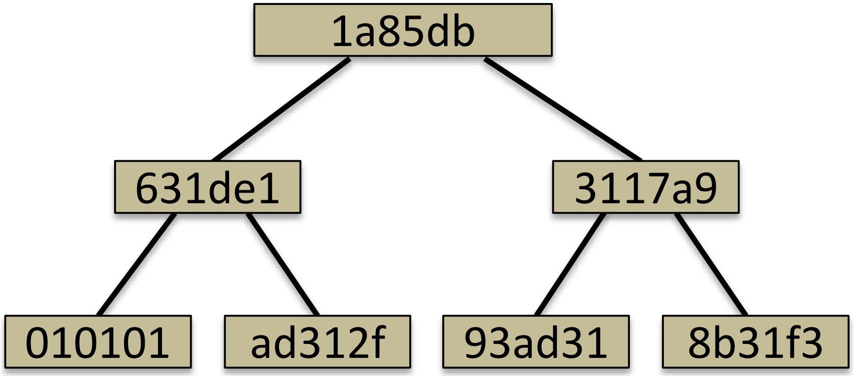
- Points before addresses the protocols for **data exchange** between two nodes.
- In each such process, potentially **lots of data** is required to be sent/processed.

- Large potential for **optimization through compression** (signatures).

- **First shot:** use **checksums** (e.g., MD5 or SHA-1) of data
- If checksum is the same, data is precisely the same (almost certainly)

Merkle Trees

- Hash Trees (invented 1979 by R. Merkle)
- Parent node is hash of its children

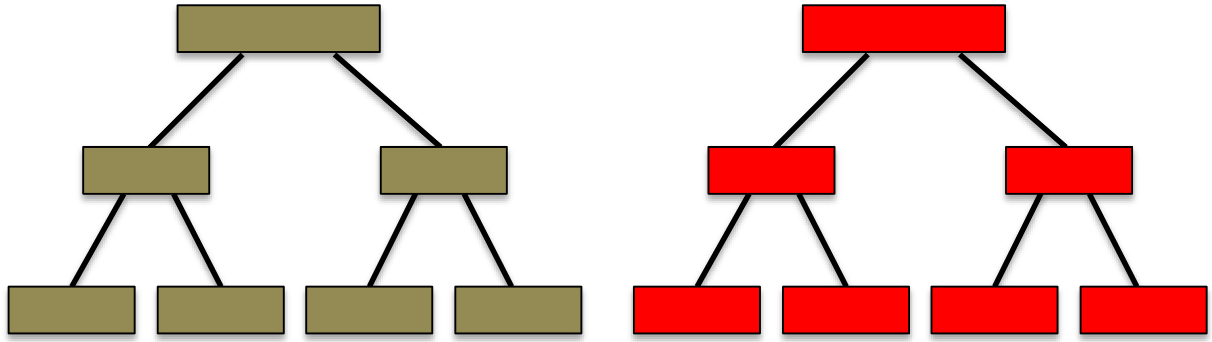


- Used in distributed systems for checking consistency of data
- **Allows hierarchical checking**

Comparing Merkle Trees

- **Start at root.**
- **If the same hash, then stop.**
- **Otherwise:** compare corresponding nodes in levels. **For nodes with different hash: go down to children**, etc.
- Eventually: Found different data (leaves)

  => exchange them



Merkle Trees in Dynamo

- **Each node maintains a separate Merkle tree for each key range** (as we have multiple due to virtual nodes!)

- Two nodes compare Merkle trees of the ranges they have in common, as described before.

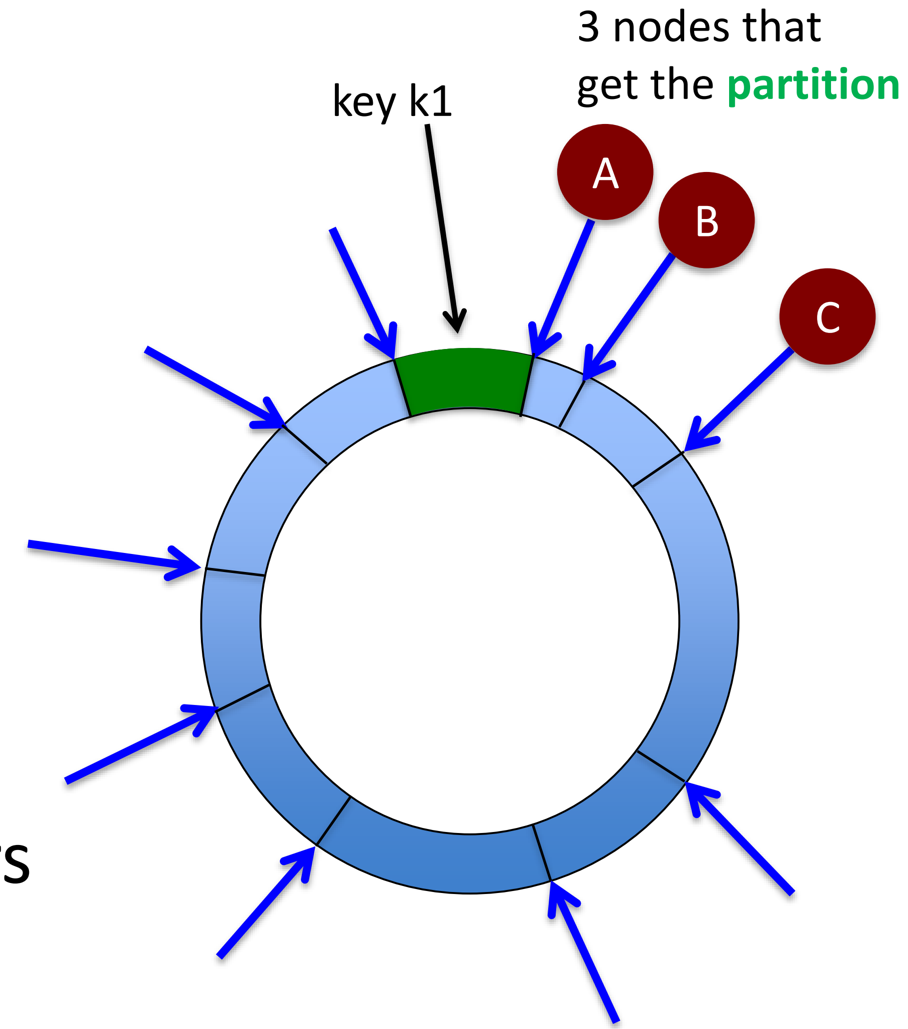
Partitioning / Replication & Dynamics

- Have seen **consistent hashing**
- Now, **slight variations for (said) better performance (again, in Dynamo)**

- Dynamics: new nodes cause key ranges of nodes to change.
- Merkle trees need to be recomputed
- Data for "moving" ranges gathered and transferred.

Traditional Consistent Hashing

- S*T nodes are placed randomly (S=number of real nodes, T=virtual instances per node, called also Tokens in*)
- Range between them defines partitions
- N (here =3) copies of partitions in N-1 successors of node that hashing tells to be responsible

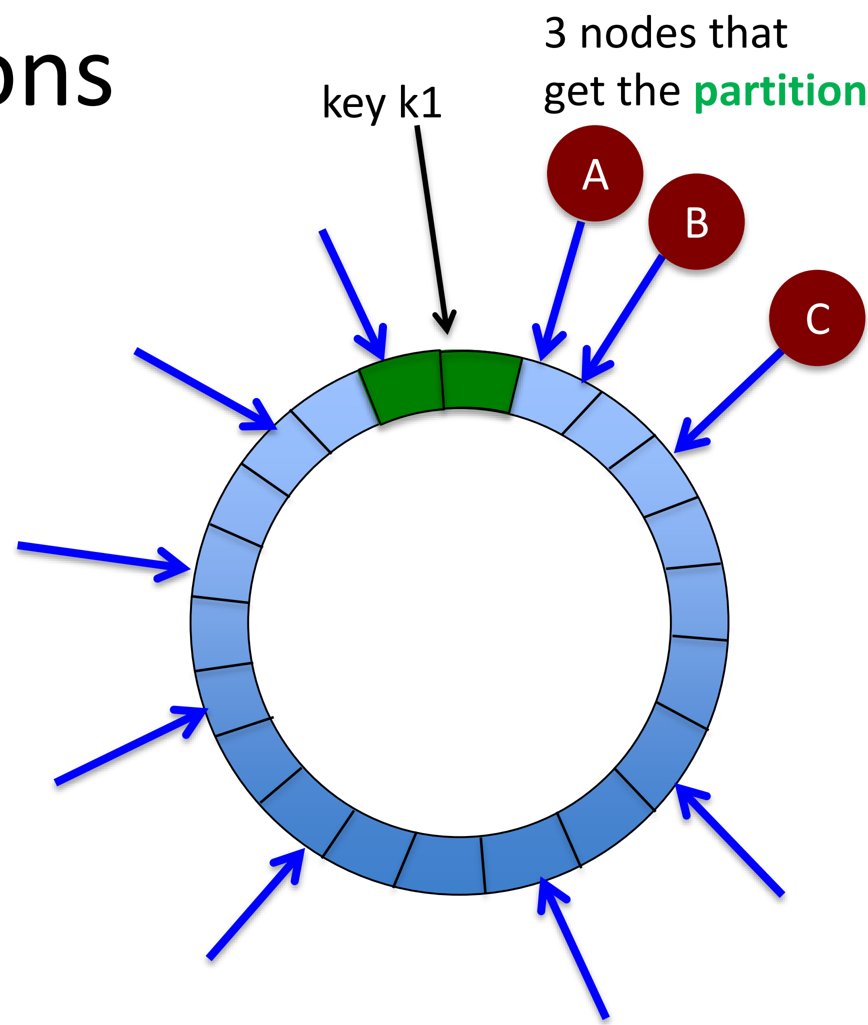


not possible to add nodes without affecting data partitioning

*) http://www.allthingsdistributed.com/2007/10/amazons_dynamo.html

Random Placement with Equal-Sized Partitions

- Have **Q equal sized partitions** (Q >> T*S), where
- Nodes are (as before) placed randomly.
- Partition is assigned to N nodes that follow (successors) the end of the partition.



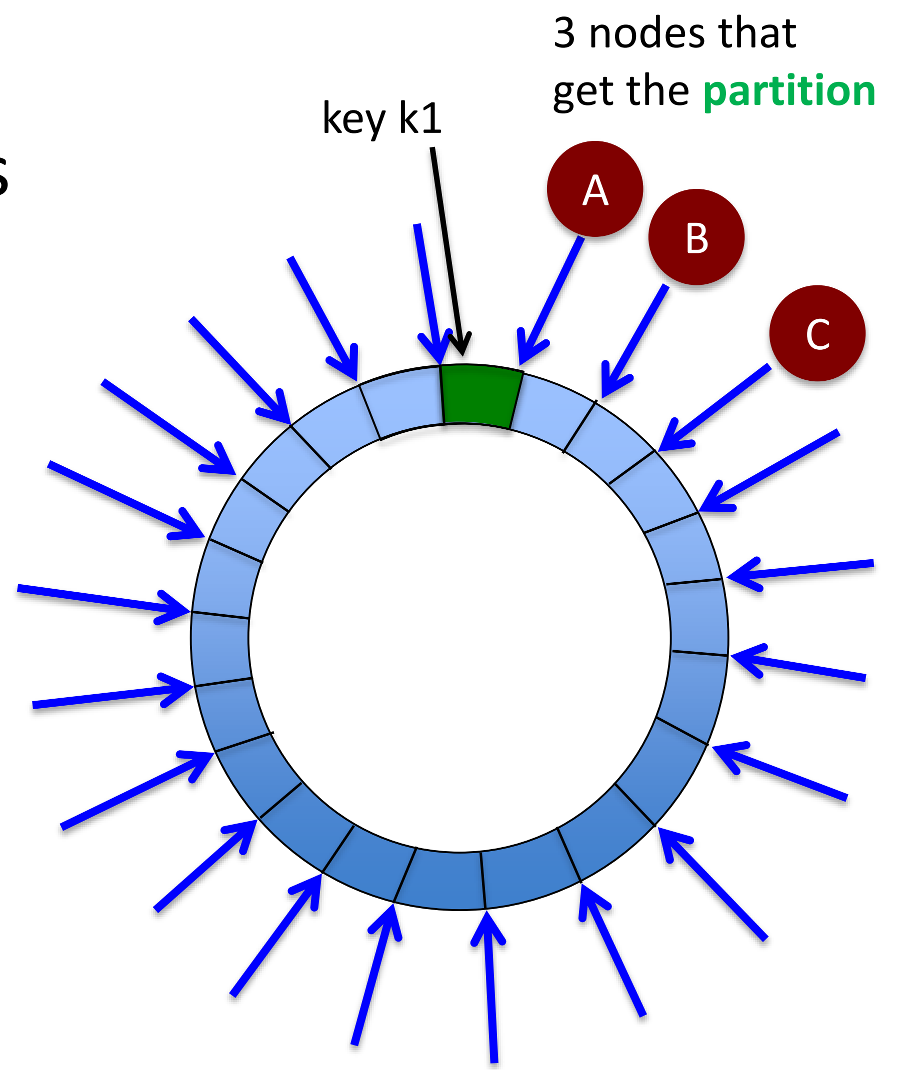
Decoupling of partitioning and partition placement

Partition bounds don’t change. Efficient maintenance.

Q/S Virtual Nodes for each Node

Q=number of partitions (as before)

- Q/S **virtual nodes per node** (S=number of nodes in system)
- i.e., **one partition per virtual node + replication**
- When node enters: steals positions from existing ones
- At leave: gives back
- Such that property remains (means: extra work to do!)



Best load balancing among discussed schemes.

Literature

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Summary NoSQL Part

- Walked through core **characteristics of fault-tolerant (replicated) distributed data stores**.
- Started with **simple replica management and state machine replication**. **t-fault tolerance**. Different **failure models**.
- **Paxos** for consensus. **Logical clocks and vector clocks** for bringing order to "events" in a distributed system.
- **CAP theorem**, **BASE**, consistency models.
- **Data placement (consistent hashing)** and **synchronization methods (rumor spreading)**.