Distributed Systems

CS425/ECE428

Lecture 22

Adopted from Spring 2021

Our agenda for the next 2-3 classes

- Brief overview of key-value stores

- Distributed Hash Tables
  - Peer-to-peer protocol for efficient insertion and retrieval of key-value pairs.

- Key-value stores in the cloud
  - How to run large-scale distributed computations over key-value stores?
    - Map-Reduce Programming Abstraction
  - How to design a large-scale distributed key-value store?
    - Case-study: Facebook's Cassandra

Quick Recap

- Distributed Hash Tables
  - Peer-to-peer protocol for efficient insertion and retrieval of key-value pairs.
  - Other required properties: load balancing, fault tolerance.
- Case-study: Chord

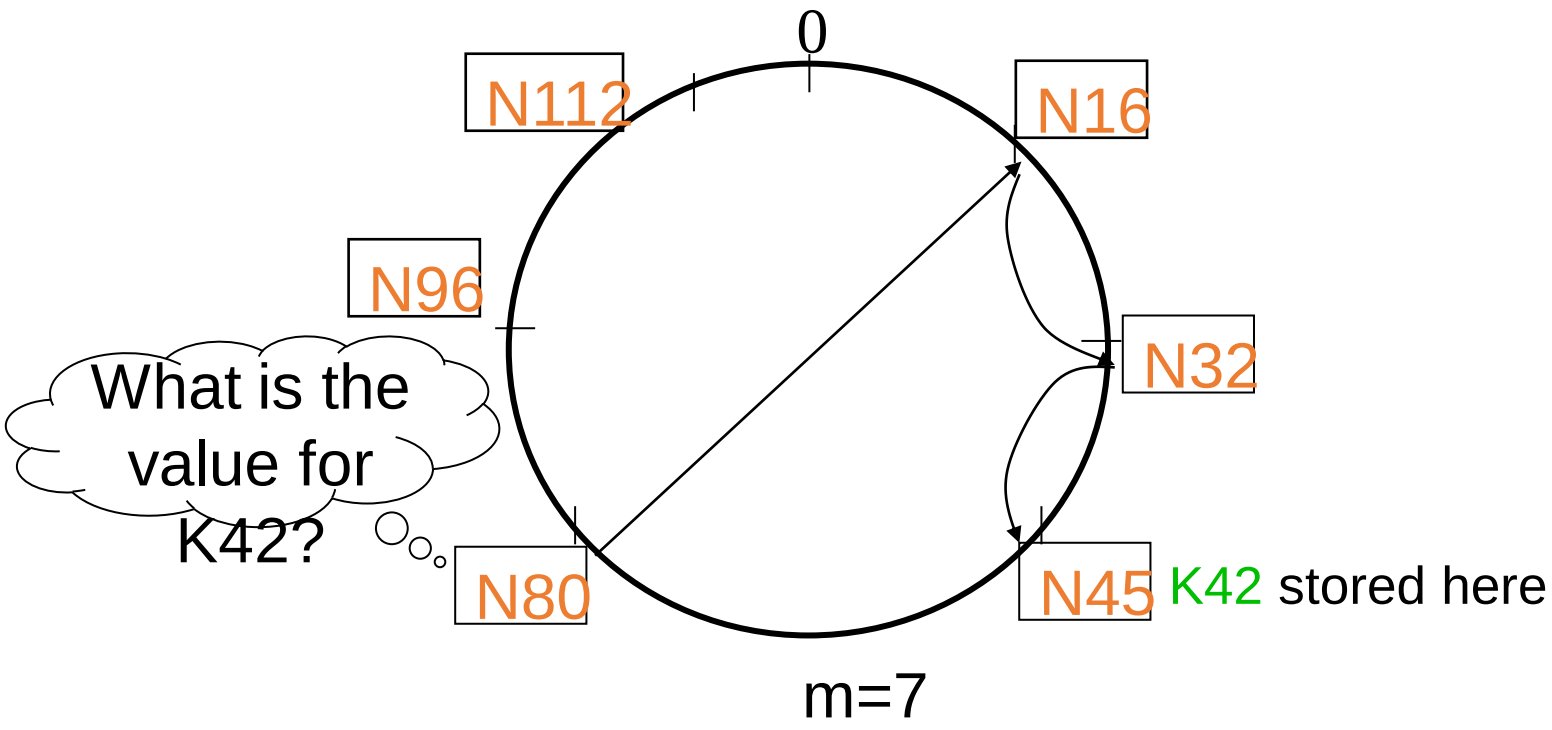
Quick Recap: Chord

- Uses consistent hashing to map nodes on a ring with m-bits identifiers.

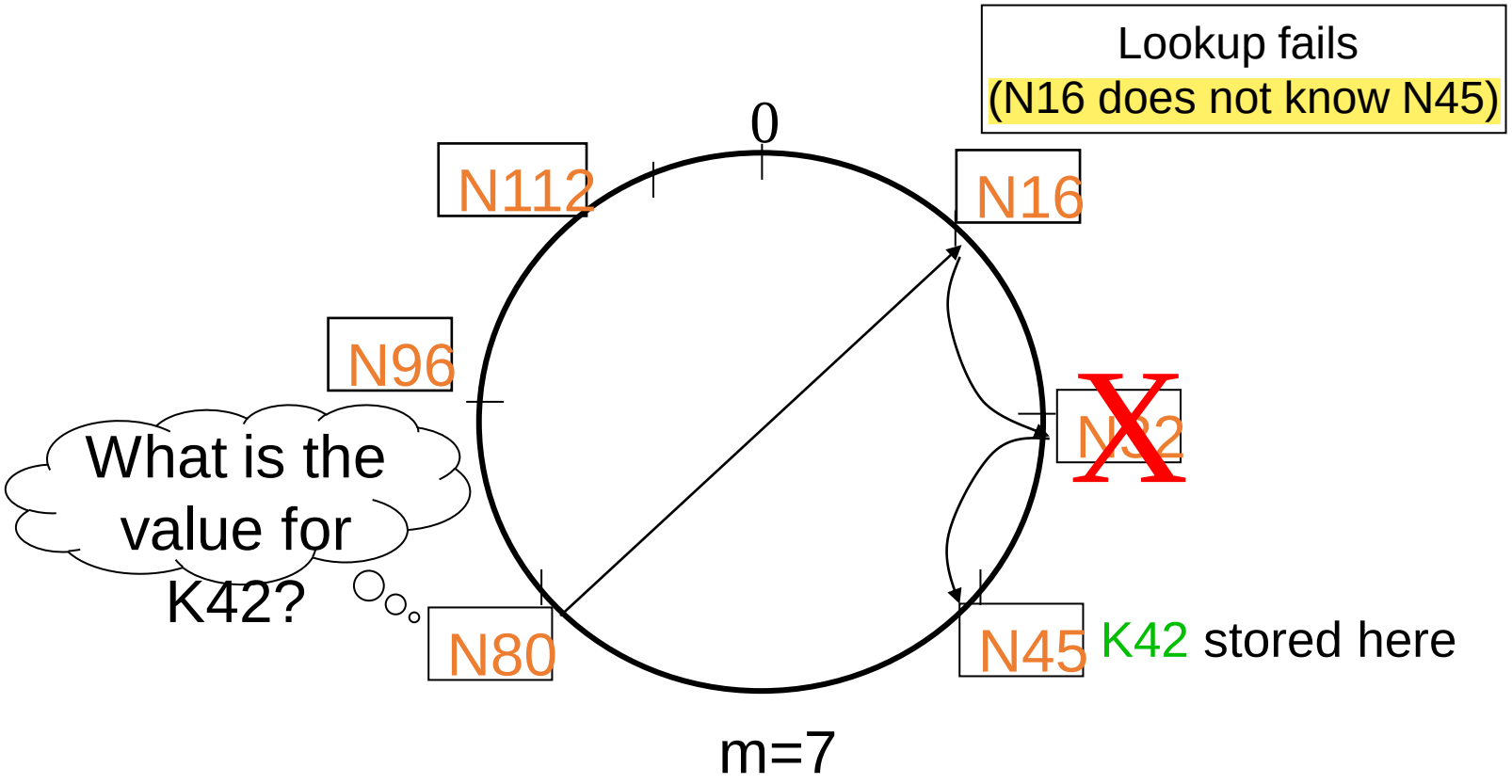
- Uses consistent hashing to map a key to a node.
  - Data stored at successor(key)

- Each node maintains a finger table with m fingers.
  - With high probability, results in O(logN) hops for a look-up.
  - O(log(N)) true only if finger and successor entries correct.
    - What happens when nodes fails or new nodes join in?
      - Our focus today.

Search for key k at node n



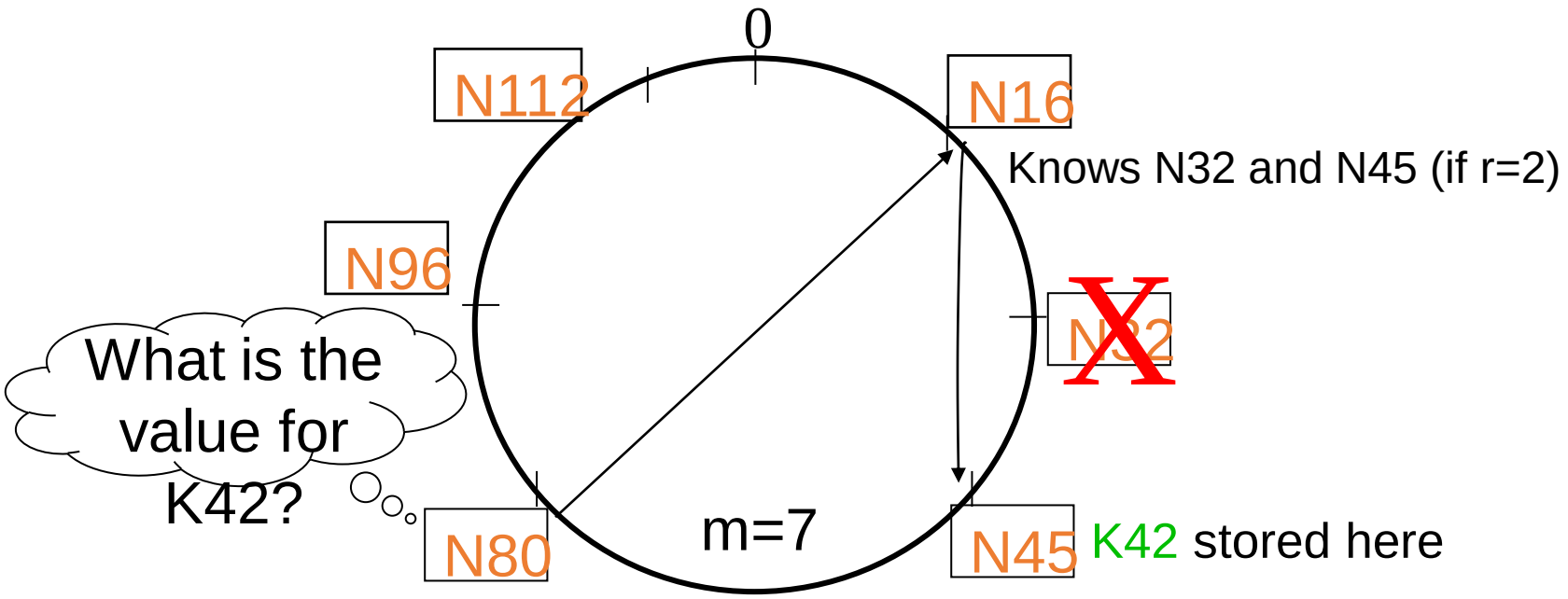
If a node fails



How do we handle this?

If a node fails

One solution: maintain r multiple successor entries.
In case of failure, use another successor entry.



Search under node failures

- If every node fails with probability 0.5, choosing r=2log(N) suffices to maintain lookup correctness (i.e. keep the ring connected) with a high probability.
  - Intuition:

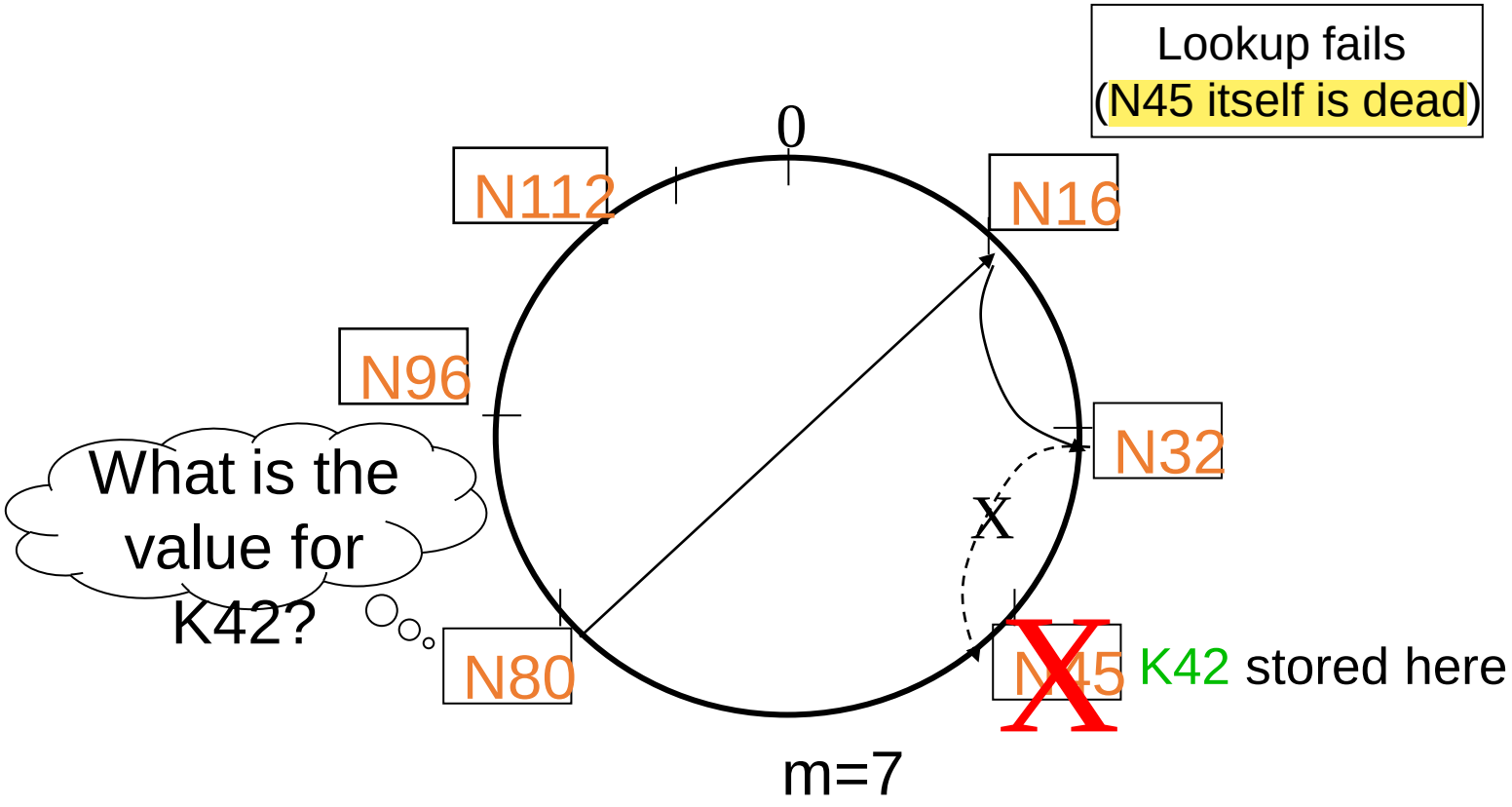
    Pr(at given node, at least one successor alive)=

$$1-(\frac{1}{2})^{2\log N}=1-\frac{1}{N^2}$$

    Pr(the above is true at all alive nodes)=

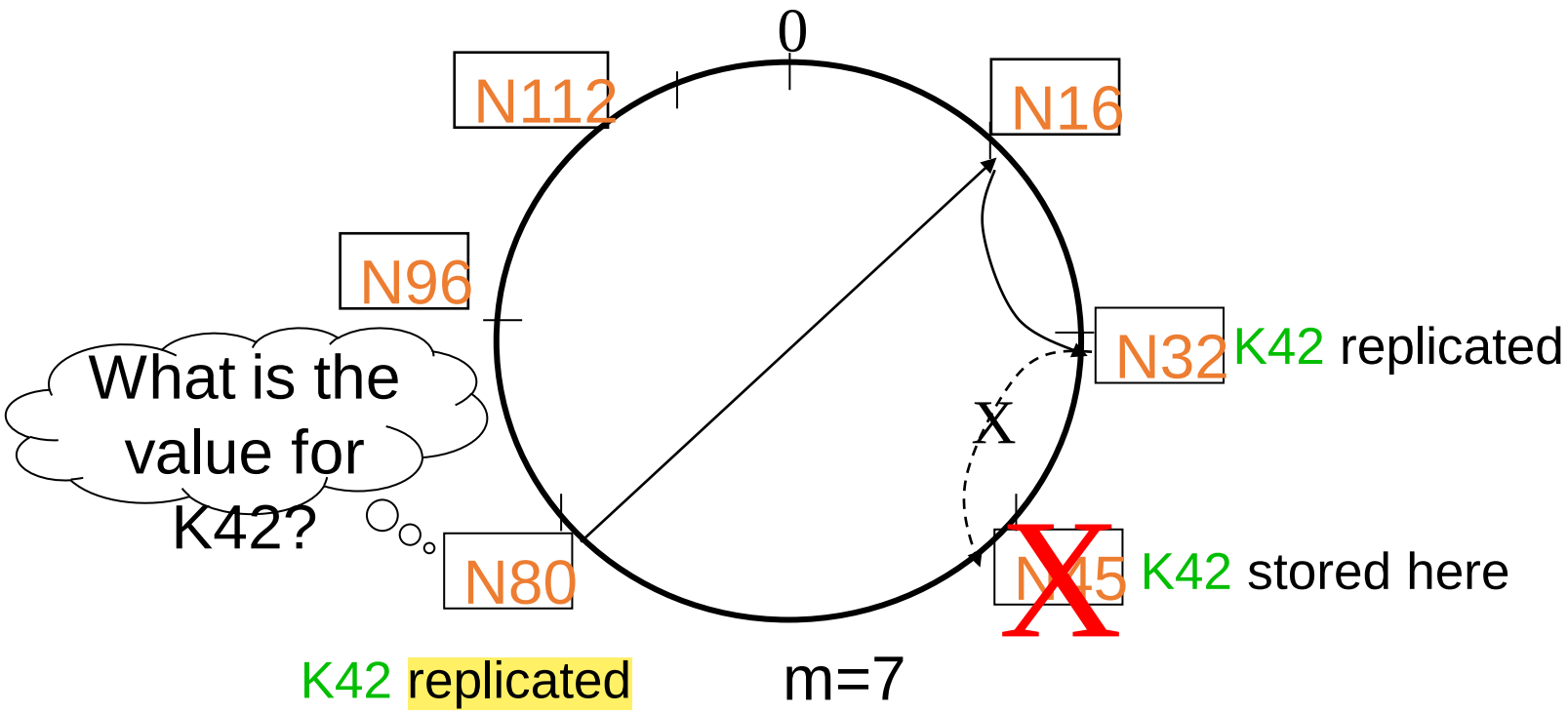
$$(1-\frac{1}{N^2})^{N/2}=e^{-\frac{1}{2N}}\approx 1$$

If a node fails



If a node fails

One solution: replicate key-value at r successors



Need to deal with dynamic changes

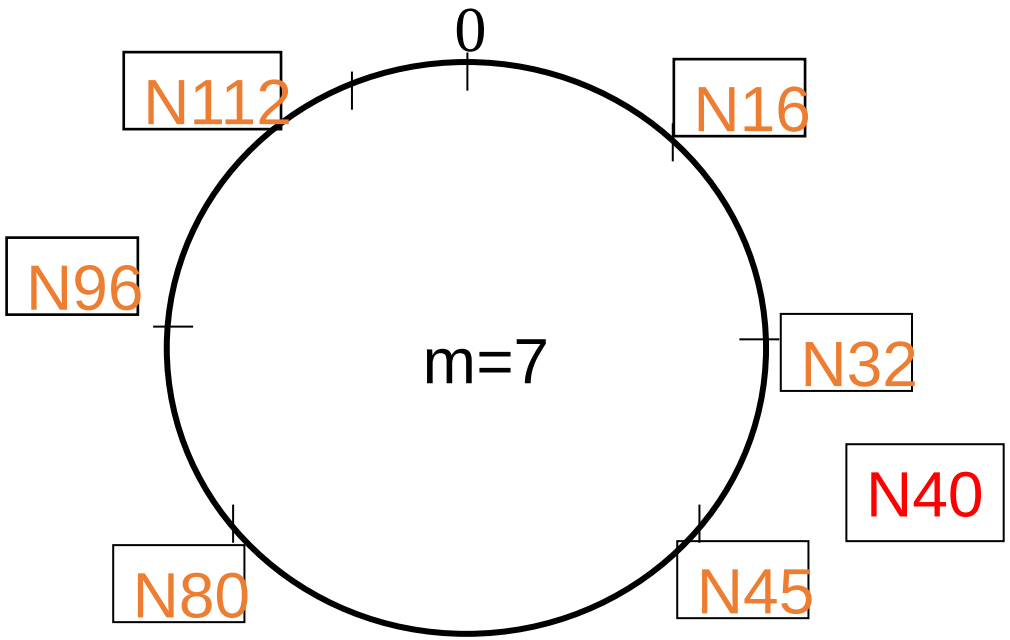
- ✓ Nodes fail
- New nodes join
- Nodes leave

So, all the time, need to:

→ update successors and fingers, and copy keys

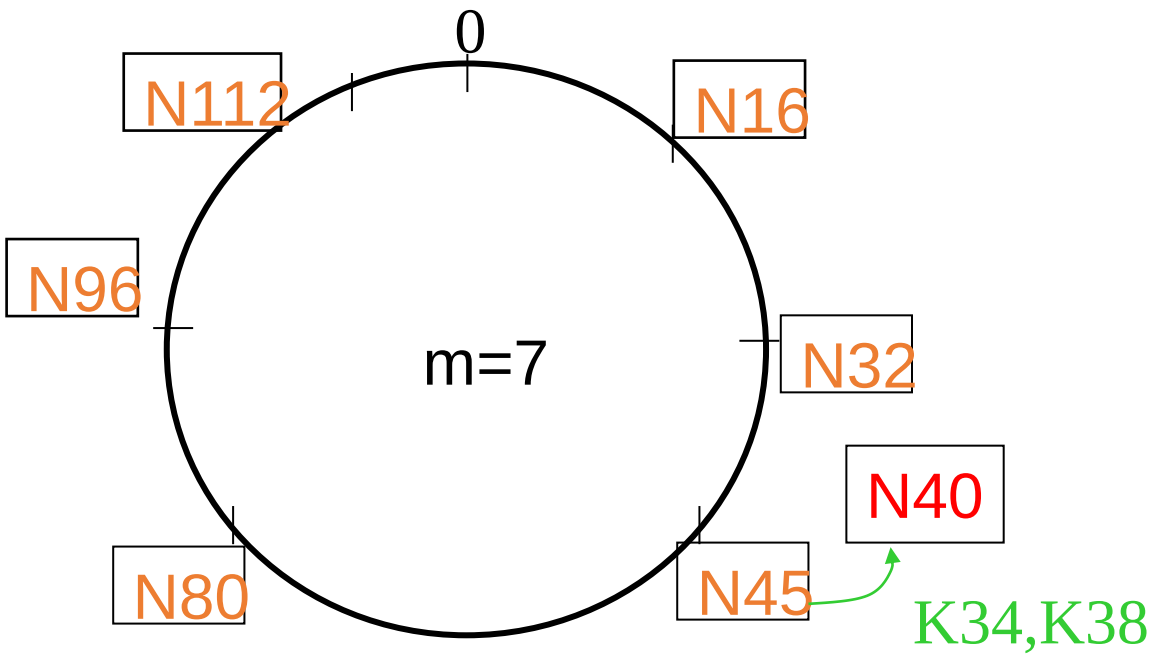
New node joins

New node contacts an existing Chord node (introducer).
Introducer directs N40 to N45 (and N32).
N32 updates its ring successor to N40.
N40 initializes its finger table and ring successor to N45.
Then other nodes also update their finger table.



New node joins

N40 may need to copy some files/keys from N45 (files with keys between 32 and 40)



New node joins

- A new peer affects O(log(N)) other finger entries in the system, on average.
- Number of messages per a node join (to initialize the new node's finger table) = O(log(N)*log(N))
- Proof in Chord's extended TechReport.

Concurrent Joins

- Aggressively maintaining and updating finger tables each time a node join can be difficult under high *churn*.
  - E.g. when new nodes are concurrently added.
- Correctness of lookup does not require all nodes to have fully "correct" finger table entries.
- Need two invariants:
  - Each node, n, correctly maintains its ring successor (*next(n)*)
    - First entry in the finger table.
  - The node, successor(k), is responsible for key k.

Stabilization Protocol

- When a node n joins (via an introducer)
  - initialize next(n), i.e. the ring successor
  - notify next(n).

- When node n gets notified by another node n’:
  - update prev(n), i.e. the ring predecessor of n
  - if (prev(n) == nil or n’ is in (prev(n), n)), then prev(n) = n’

Stabilization Protocol (contd)

- Each node n will periodically run stabilization:
  - x = prev(next(n))
  - if x in (n, next(n)), then next(n) = x
  - notify next(n)
- Each node n periodically updates random finger entry:
  - Pick a random i in [0, m-1]
  - Lookup successor($n + 2^i$)

New node joins

New node contacts an existing Chord node (introducer).

Introducer informs N40 of N45.

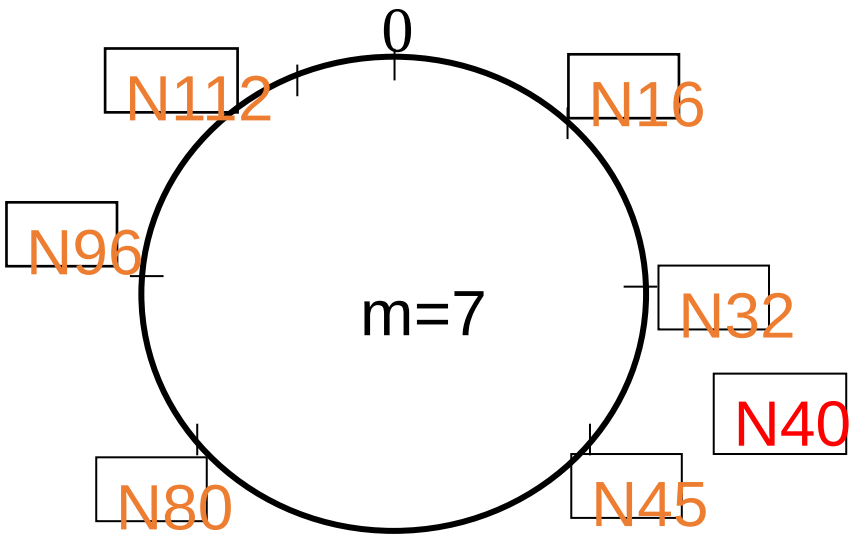
N40 initializes its ring successor to N45.

N40 notifies N45, and N45 initializes its ring predecessor to N40.

N32 realizes its new successor is N40 when it runs stabilization.

N32 notifies N40, and N40 initializes its ring predecessor to N32.

Periodically and eventually, each node update their finger table entries.



Stabilization Protocol (contd)

- Failures can be handled in a similar way.
  - *Need failure detectors (you've seen them!)*
  - Maintain knowledge of r ring successors.
  - Update ring successor when it fails, and notify others.

Stabilization Protocol (contd)

- Look-ups may fail while the Chord system is getting stabilized.
  - Such failures are transient (temporary).
    - Eventually ring successors and finger-table entries will get updated.
    - Application can then try again after a timeout.
  - Such failures are also unlikely in practice
    - Multiple key-value replicas and ring successors.

Chord Summary

- Consistent hashing for load balancing.
- O(log N) lookups via correct finger tables.
- *Correctness* of lookups requires correctly maintaining ring successors.
- As nodes join and leave a Chord network, runs stabilization protocol to periodically update ring successors and finger table entries.
- Fault tolerance: Maintain r ring successors and r key replicas.