Chord

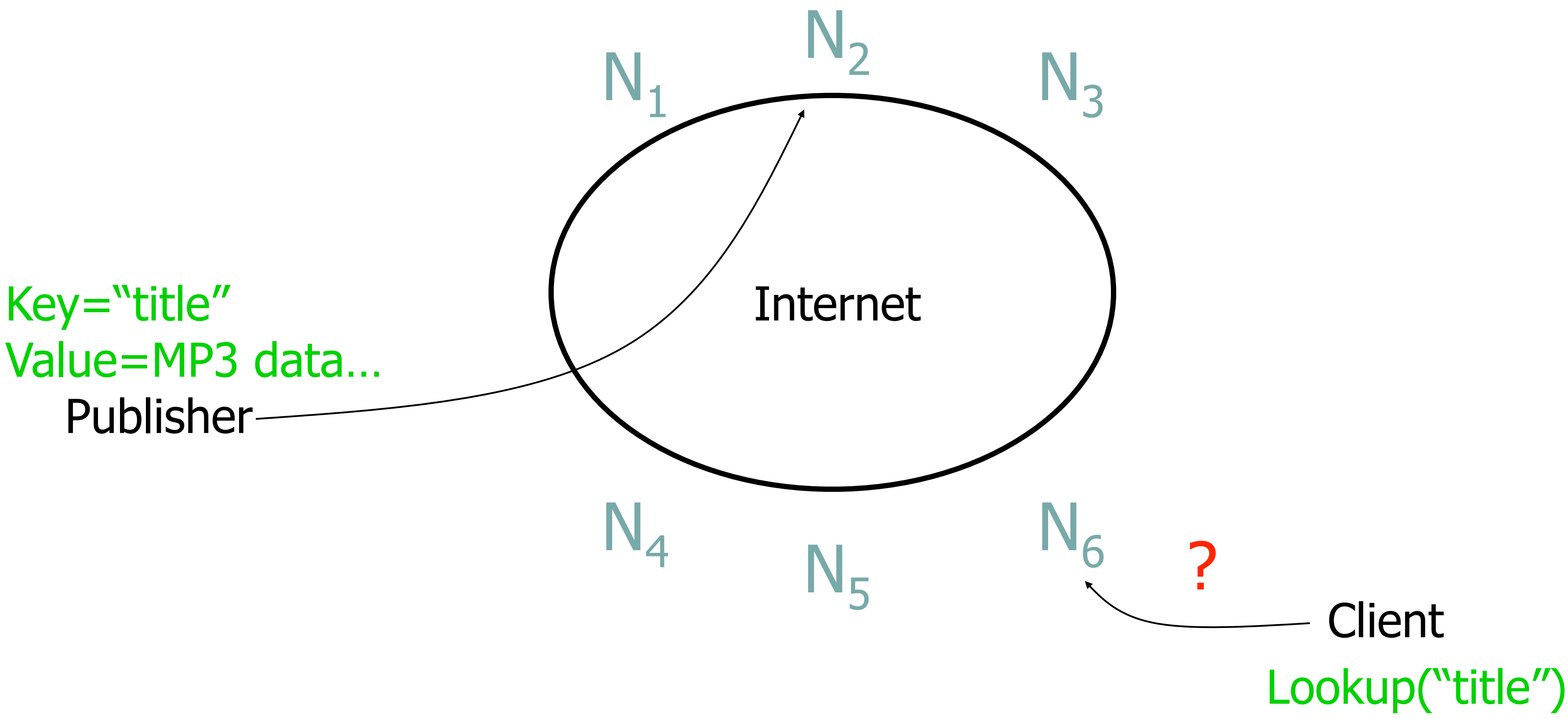
A scalable peer-to-peer look-up protocol for internet applications

by Ion Stoica, Robert Morris, David Karger,
M. Frans Kaashoek, Hari Balakrishnan

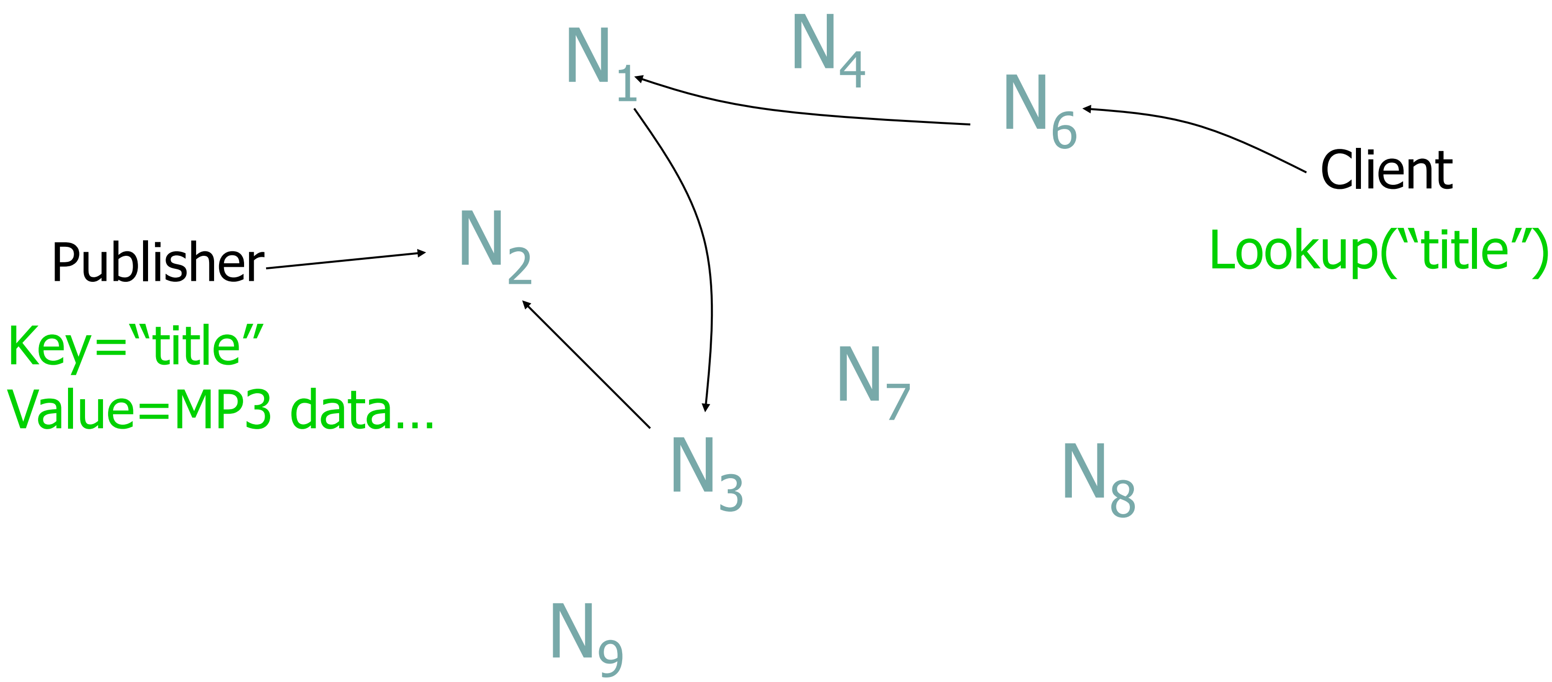
Overview

- Introduction
- The Chord Algorithm
  - Construction of the Chord ring
  - Localization of nodes
  - Node joins and stabilization
  - Failure of nodes
- Applications
- Summary
- Questions

The lookup problem



Routed queries (Freenet, Chord, etc.)



What is Chord?

- Problem addressed: efficient node localization
- Distributed lookup protocol
- Simplicity, provable performance, proven correctness
- Support of just one operation: given a key, Chord maps the key onto a node

Chord software

- 3000 lines of C++ code
- Library to be linked with the application
- provides a lookup(key) – function: yields the IP address of the node responsible for the key
- Notifies the node of changes in the set of keys the node is responsible for

Overview

- Introduction
- The Chord Algorithm
  - Construction of the Chord ring
  - Localization of nodes
  - Node joins and Stabilization
  - Failure/Departure of nodes
- Applications
- Summary
- Questions

The Chord algorithm – Construction of the Chord ring

- use Consistent Hash Function assigns each <u>node</u> and each <u>key</u> an m-bit identifier using SHA 1 (Secure Hash Standard).

  m = any number <u>big enough</u> to make collisions improbable

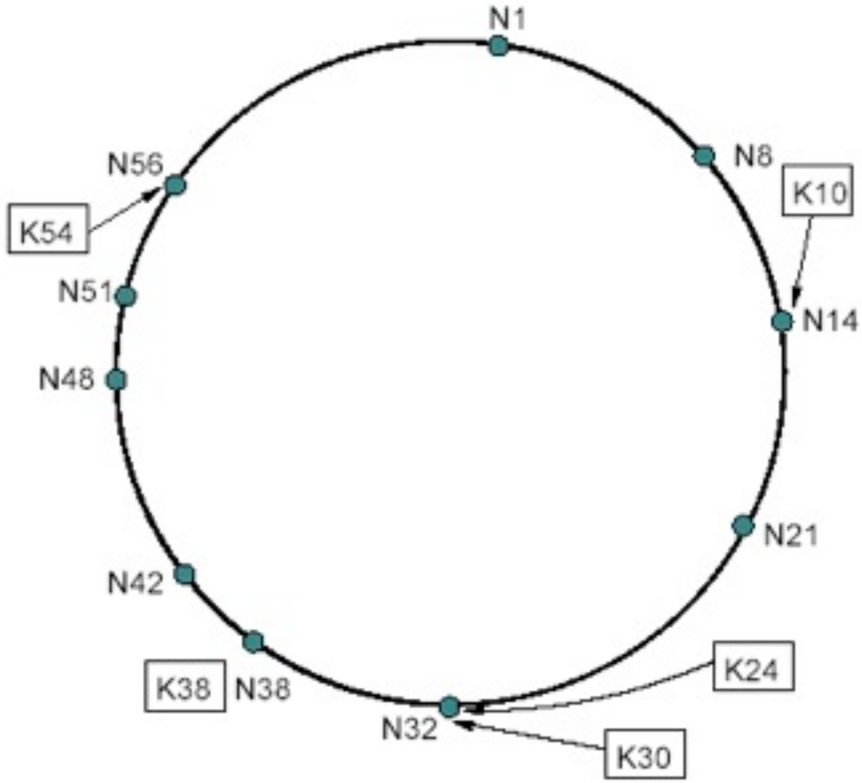
  Key identifier = SHA-1(key)

  Node identifier = SHA-1(IP address)

- Both are uniformly distributed
- Both exist in the same ID space

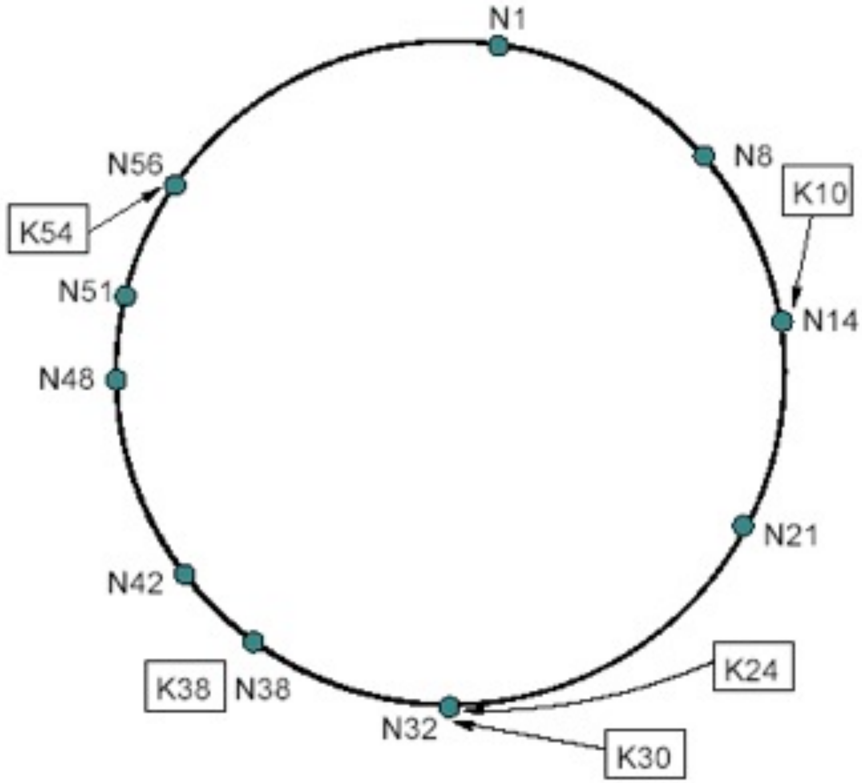
The Chord algorithm – Construction of the Chord ring

- identifiers are arranged on a identifier circle modulo 2^m => **Chord ring**



The Chord algorithm – Construction of the Chord ring

- a key k is assigned to the node whose identifier is equal to or greater than the key's identifier
- this node is called successor(k) and is the first node clockwise from k.



The Chord algorithm – Simple node localization

// ask node n *to find the successor of* id

n.find_successor(id)

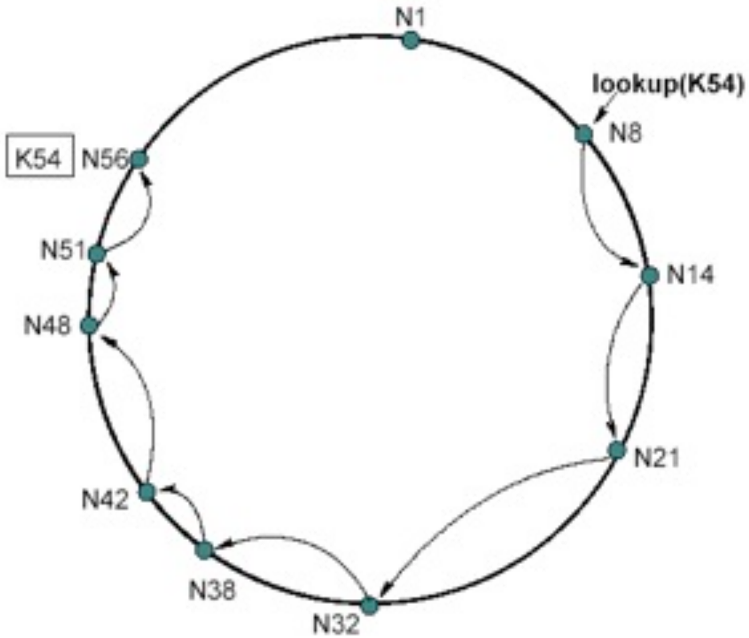
if (id ∈ (n; *successor*])

return *successor*;

else

// forward the query around the circle

return *successor.find_successor*(id);



=> Number of messages linear in the number of nodes !

The Chord algorithm – Scalable node localization

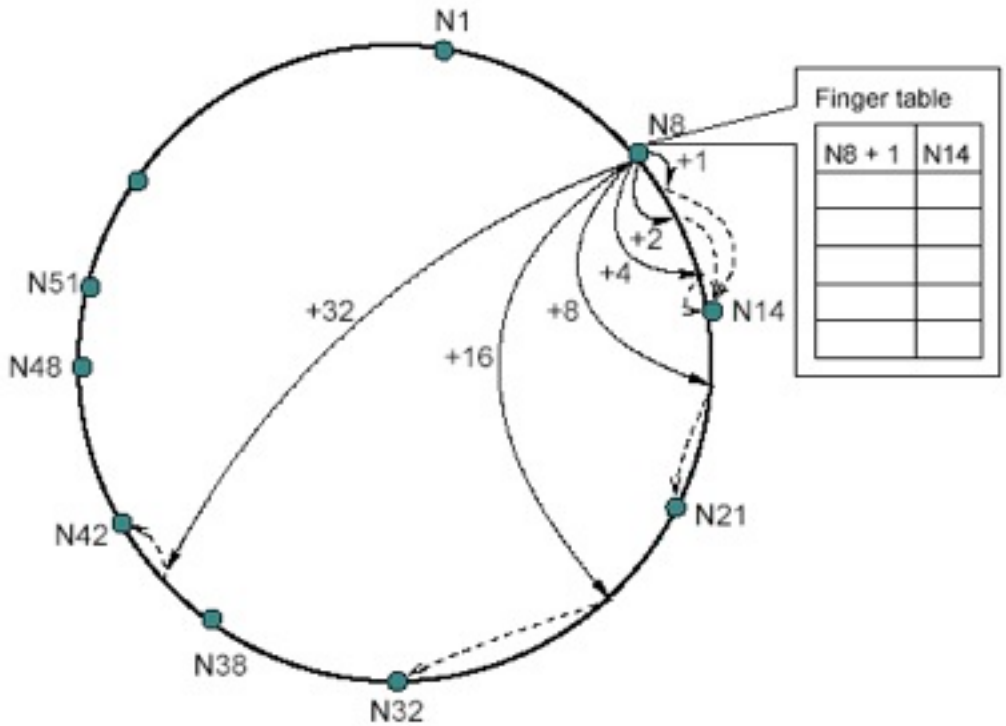
- Additional routing information to accelerate lookups
- Each node n contains a routing table with up to m entries (m: number of bits of the identifiers) => finger table
- i^{th} entry in the table at node n contains the first node s that succeeds n by at least 2^{i-1}
- s = successor $(n + 2^{i-1})$
- s is called the i^{th} finger of node n

The Chord algorithm – Scalable node localization

Finger table:

finger[i] =

successor $(n + 2^{i-1})$

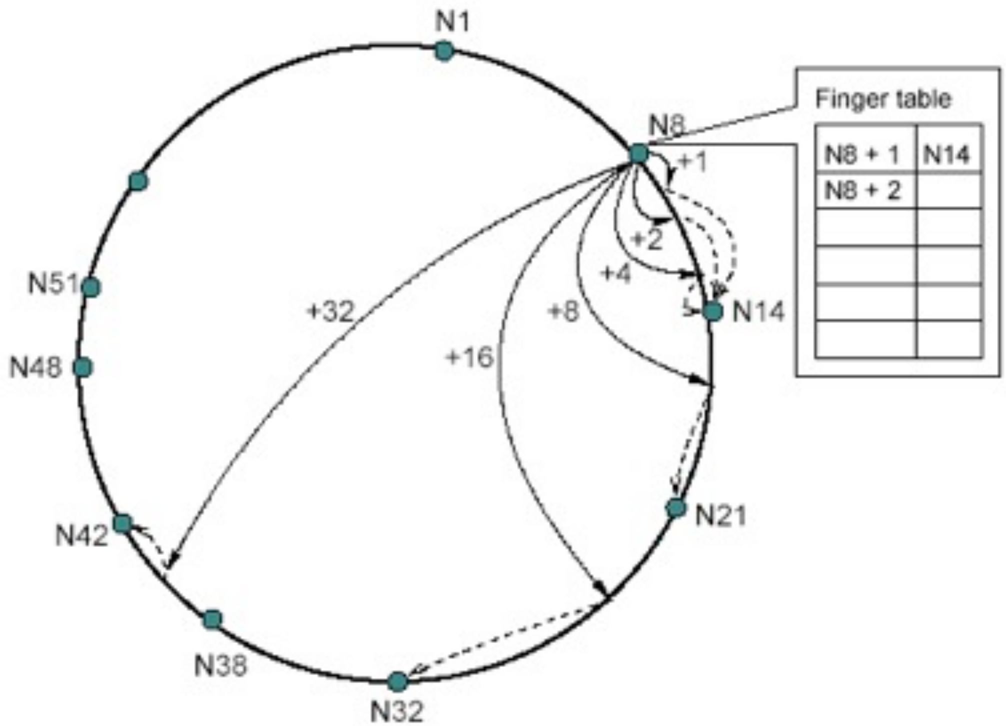


The Chord algorithm – Scalable node localization

Finger table:

finger[i] =

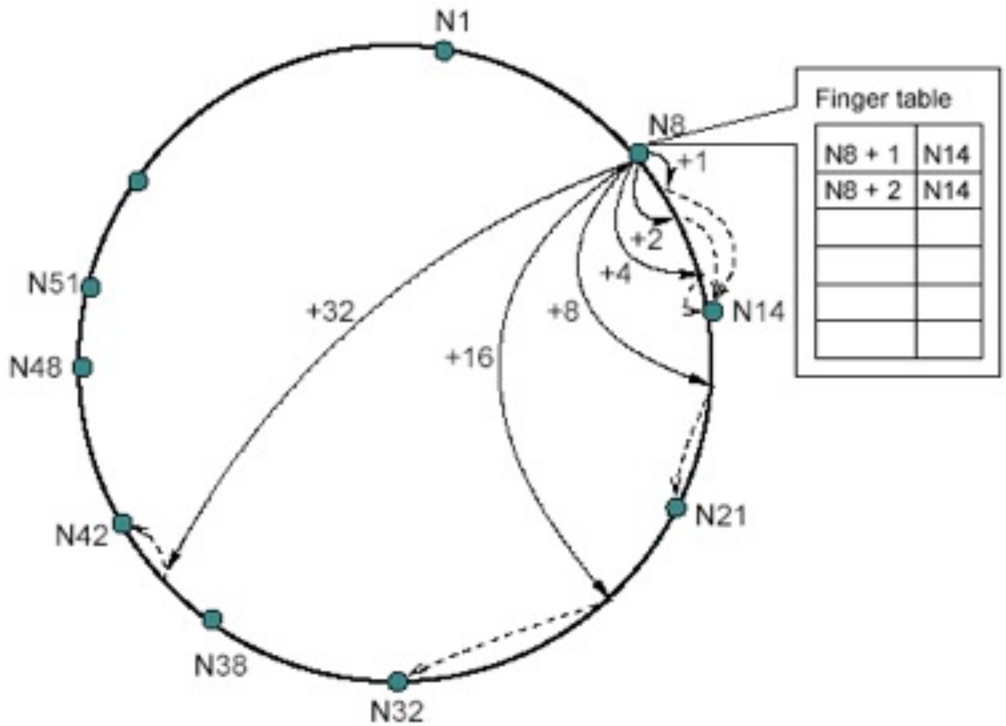
successor $(n + 2^{i-1})$



The Chord algorithm – Scalable node localization

Finger table:

finger[i] = *successor* $(n + 2^{i-1})$

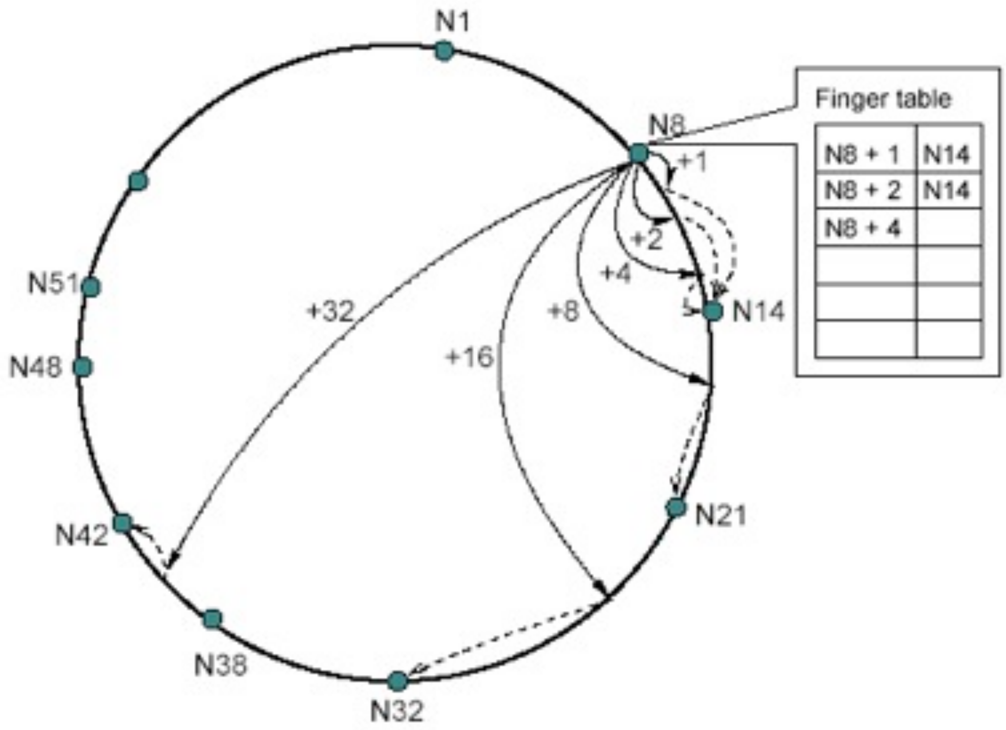


The Chord algorithm – Scalable node localization

Finger table:

finger[i] =

successor $(n + 2^{i-1})$

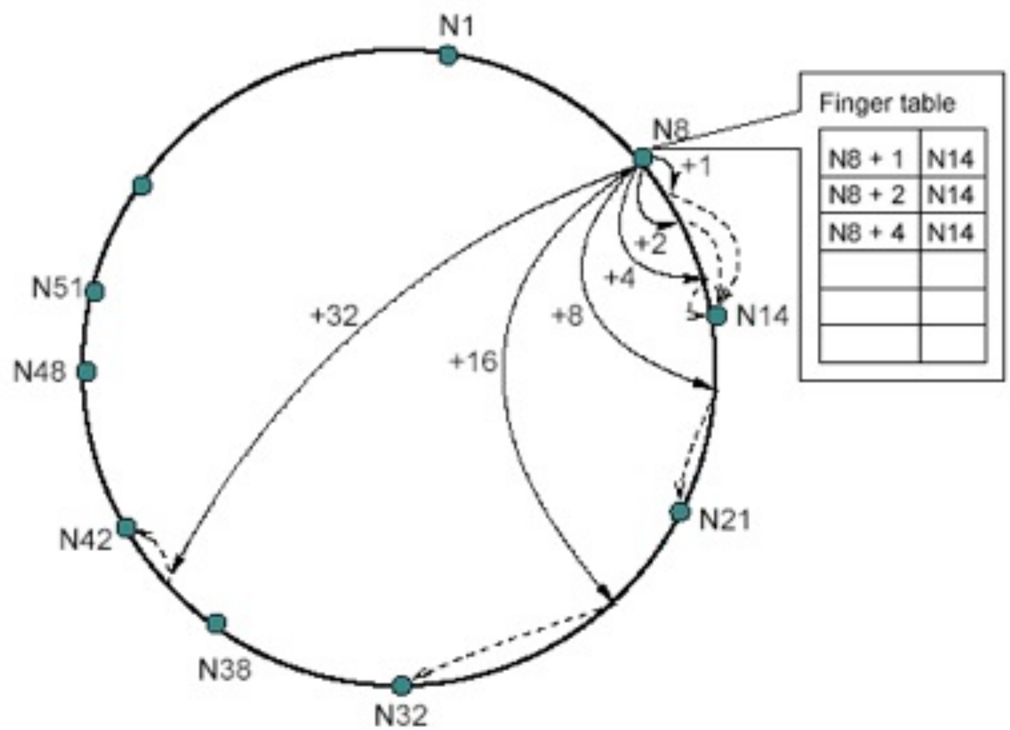


The Chord algorithm – Scalable node localization

Finger table:

finger[i] =

successor $(n + 2^{i-1})$

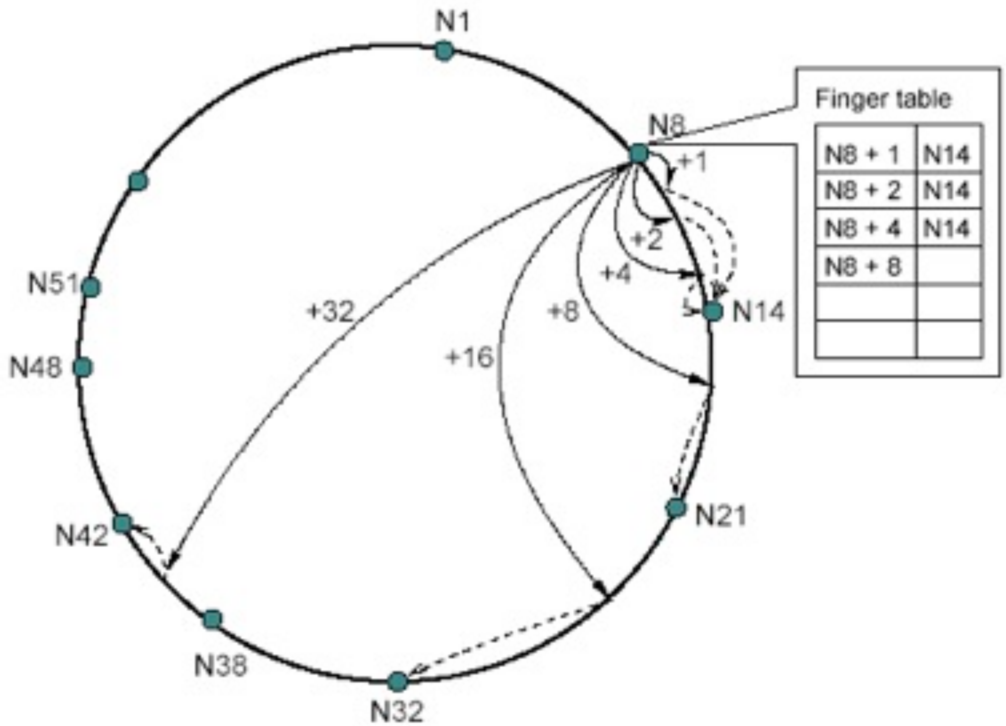


The Chord algorithm – Scalable node localization

Finger table:

finger[i] =

successor (n + 2^{i-1}*)*

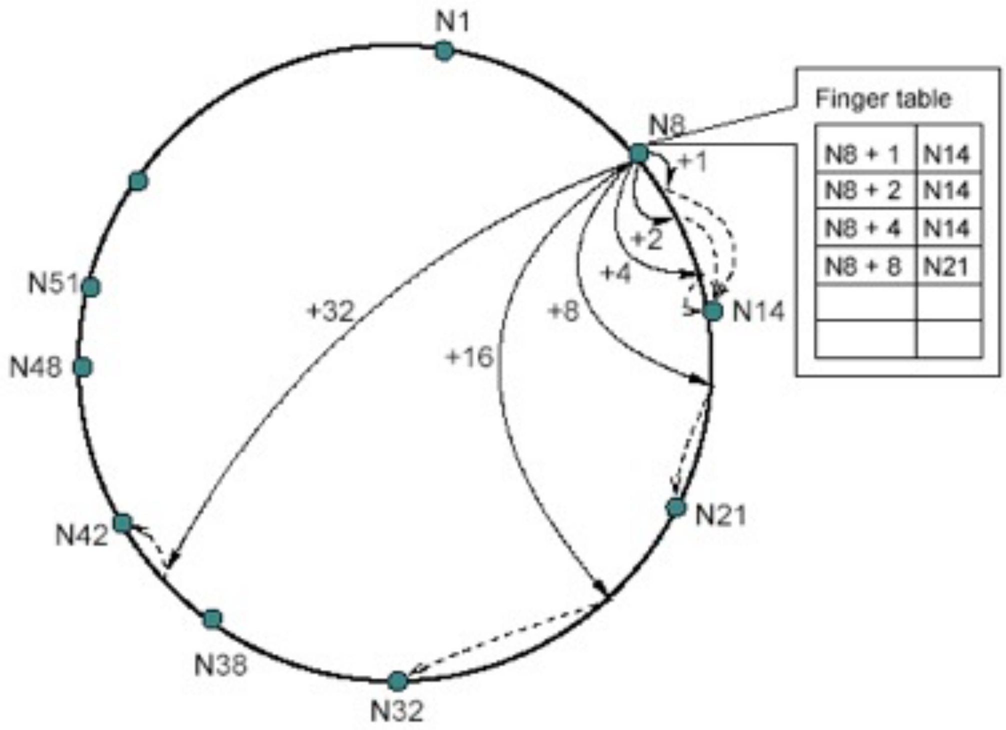


The Chord algorithm – Scalable node localization

Finger table:

finger[i] =

successor $(n + 2^{i-1})$

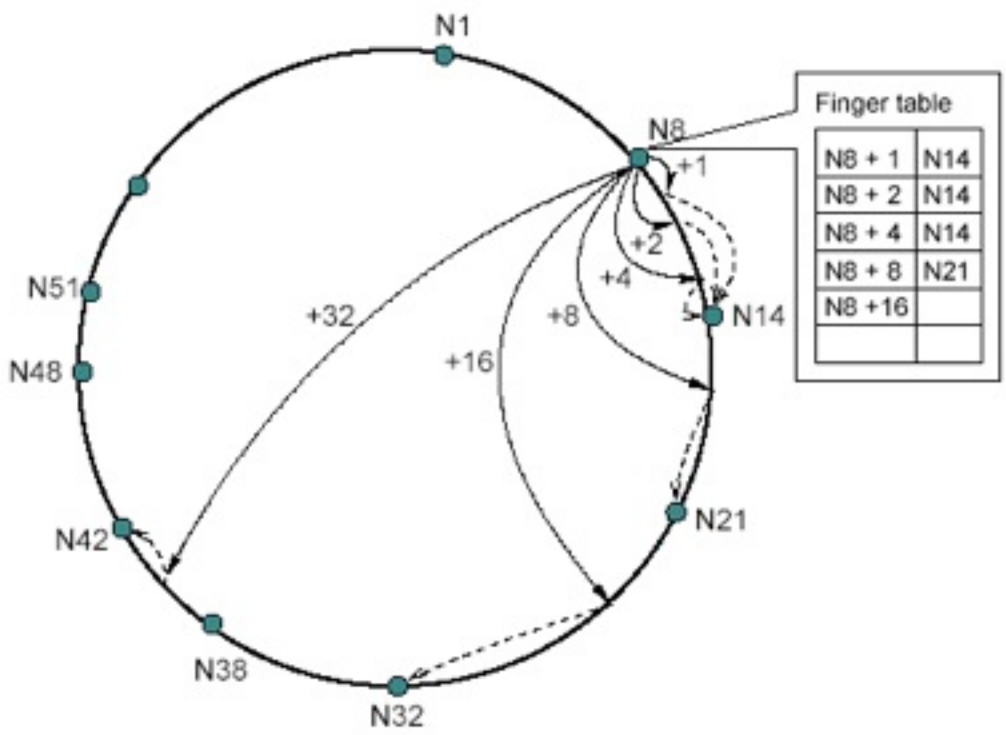


The Chord algorithm – Scalable node localization

Finger table:

finger[i] =

successor $(n + 2^{i-1})$

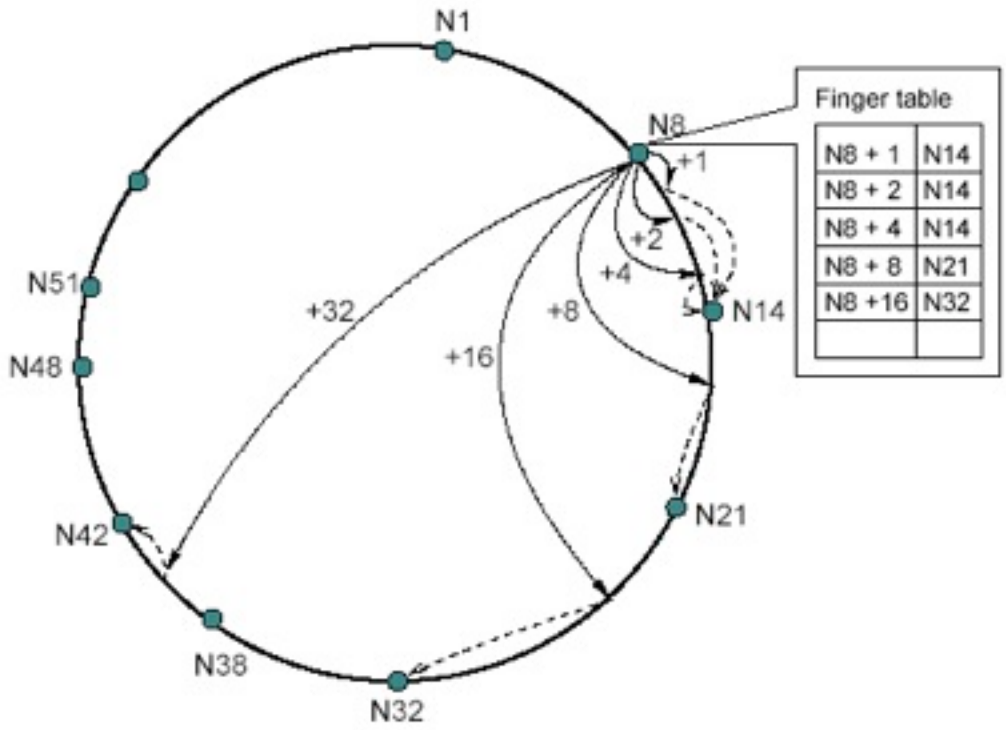


The Chord algorithm – Scalable node localization

Finger table:

finger[i] =

successor $(n + 2^{i-1})$

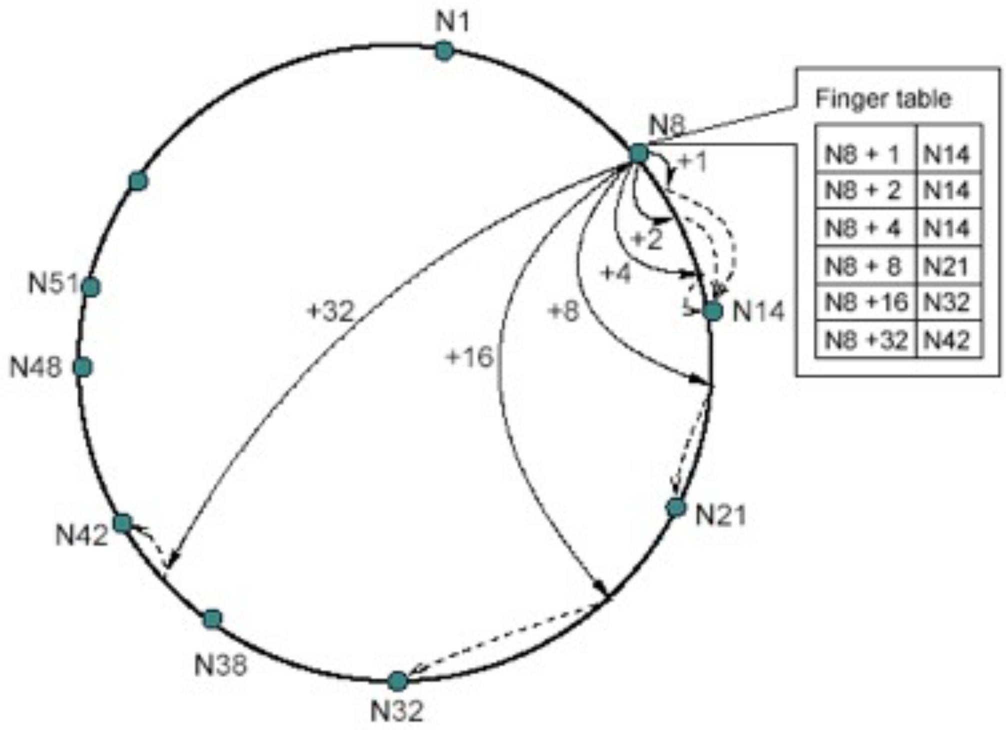


The Chord algorithm – Scalable node localization

Finger table:

finger[i] =

successor $(n + 2^{i-1})$



The Chord algorithm – Scalable node localization

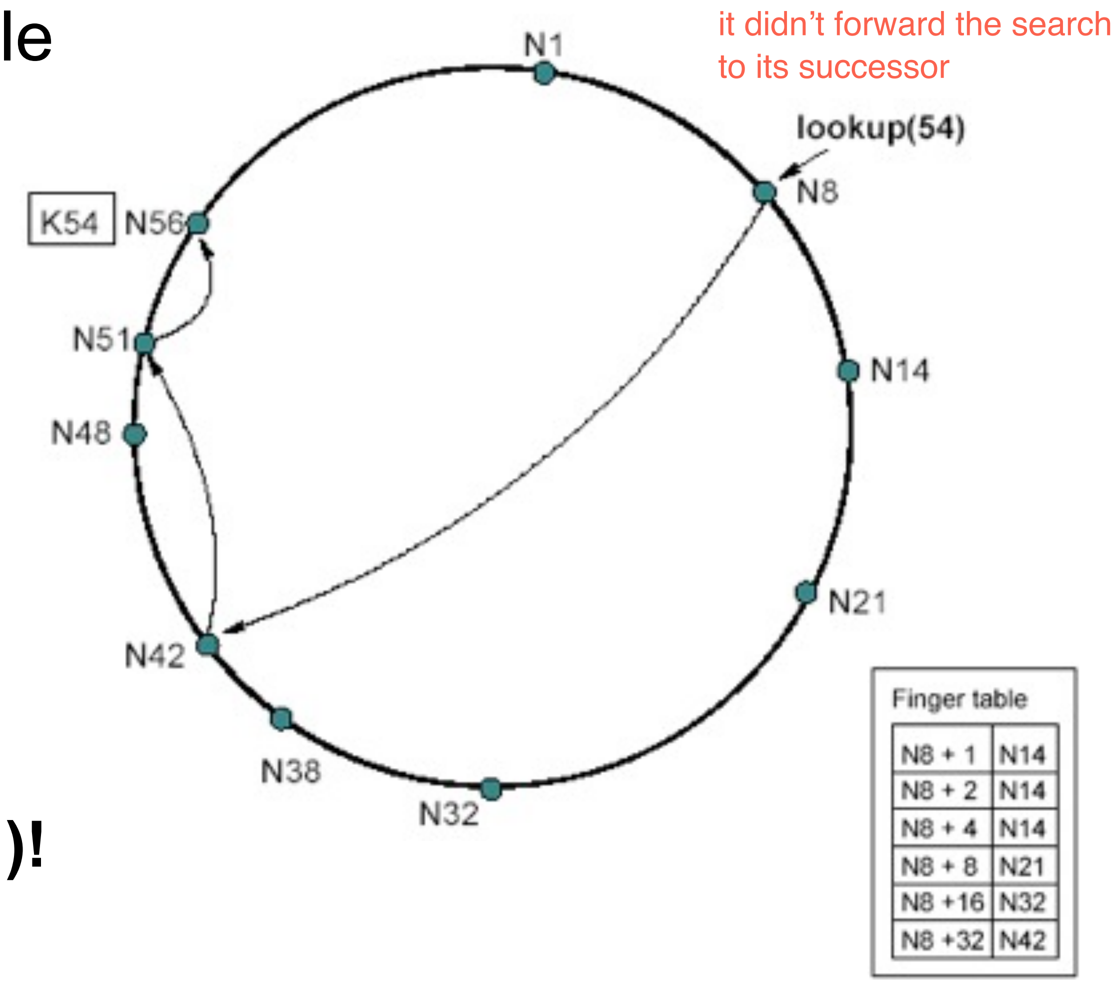
Important characteristics of this scheme:

- Each node stores information about only a small number of nodes (m)
- Each nodes knows more about nodes closely following it than about nodes further away
- A finger table generally does not contain enough information to directly determine the successor of an arbitrary key k

The Chord algorithm – Scalable node localization

- Search in finger table for the nodes which most immediately precedes id
- Invoke find_successor from that node

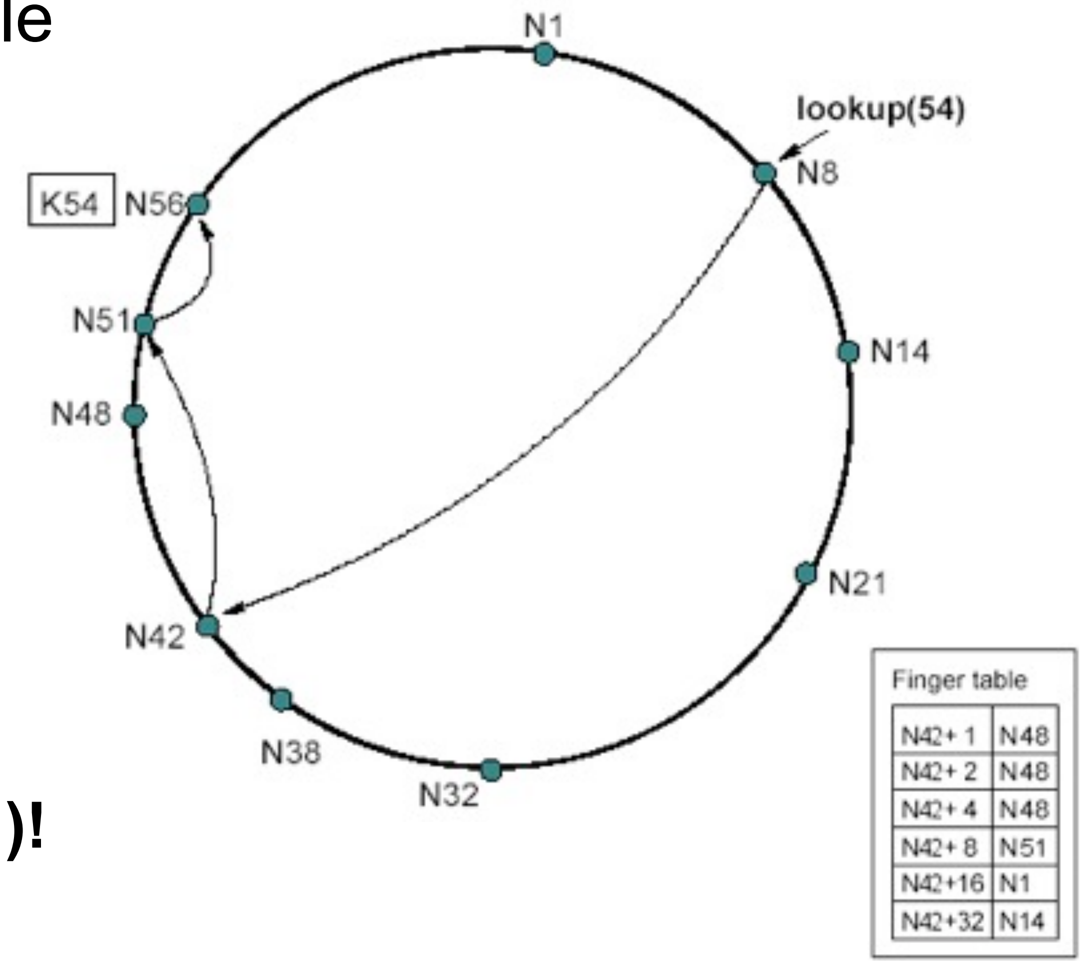
=> Number of messages O(log N)!



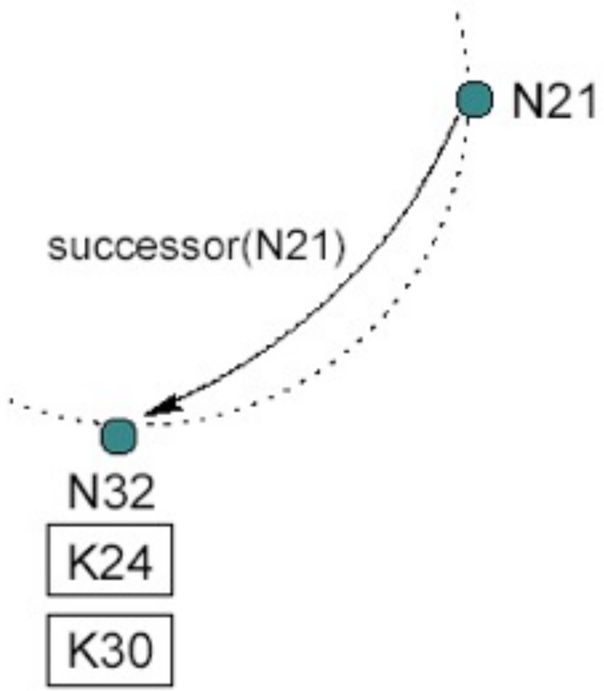
The Chord algorithm – Scalable node localization

- Search in finger table for the nodes which most immediately precedes id
- Invoke find_successor from that node

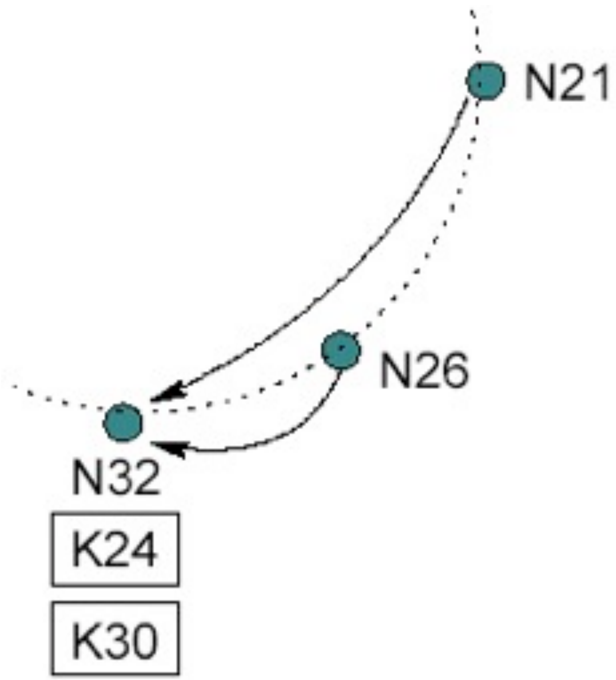
=> Number of messages O(log N)!



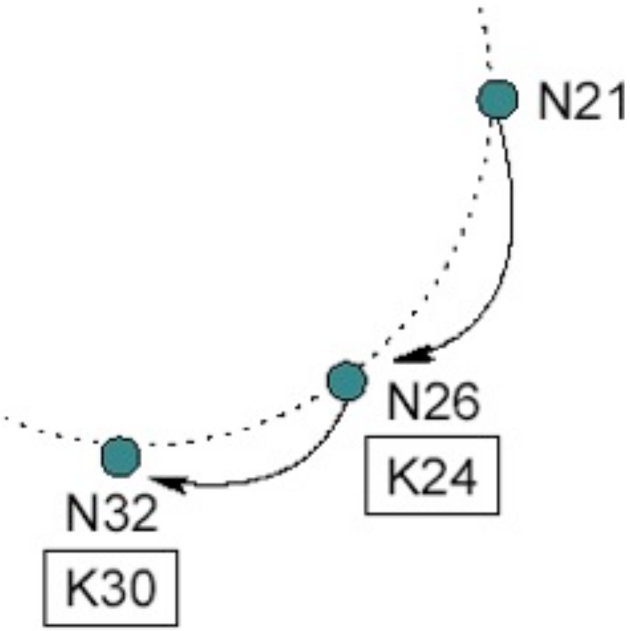
The Chord algorithm – Node joins and stabilization



The Chord algorithm – Node joins and stabilization



The Chord algorithm – Node joins and stabilization



The Chord algorithm – Node joins and stabilization

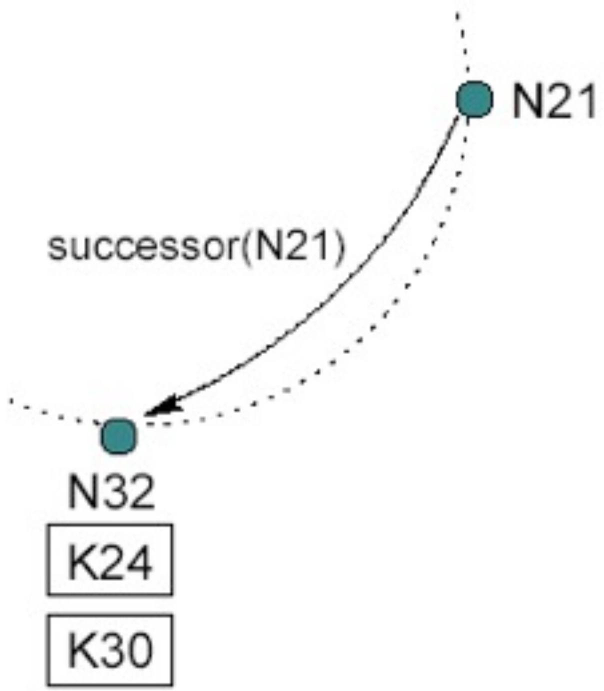
- To ensure correct lookups, all successor pointers must be up to date
- => stabilization protocol running periodically in the background
- Updates finger tables and successor pointers

The Chord algorithm – Node joins and stabilization

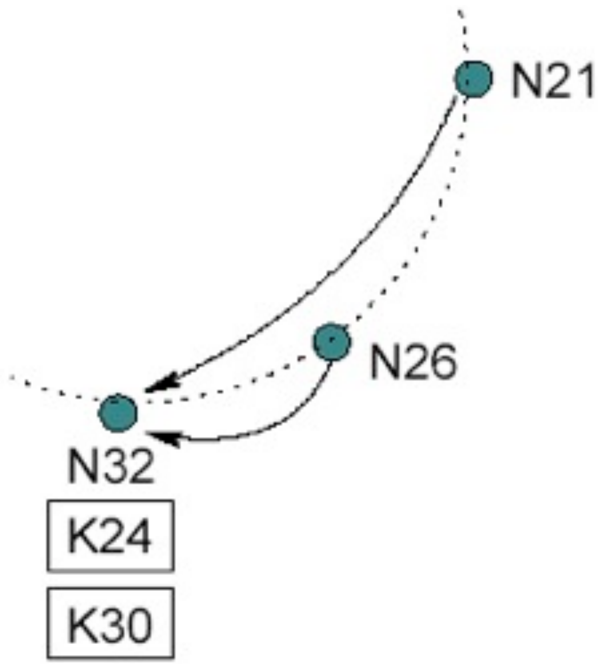
Stabilization protocol:

- Stabilize(): n asks its successor for its predecessor p and decides whether p should be n‘s successor instead (this is the case if p recently joined the system).
- Notify(): notifies n‘s successor of its existence, so it can change its predecessor to n
- Fix_fingers(): updates finger tables

The Chord algorithm – Node joins and stabilization

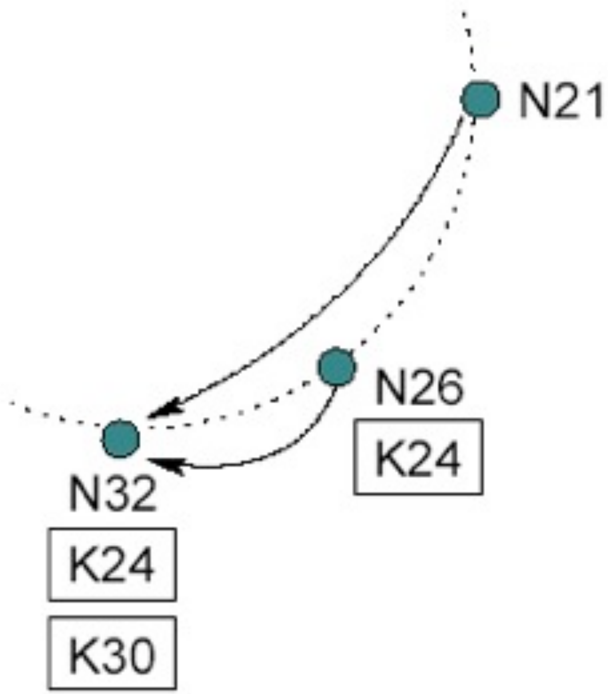


The Chord algorithm – Node joins and stabilization



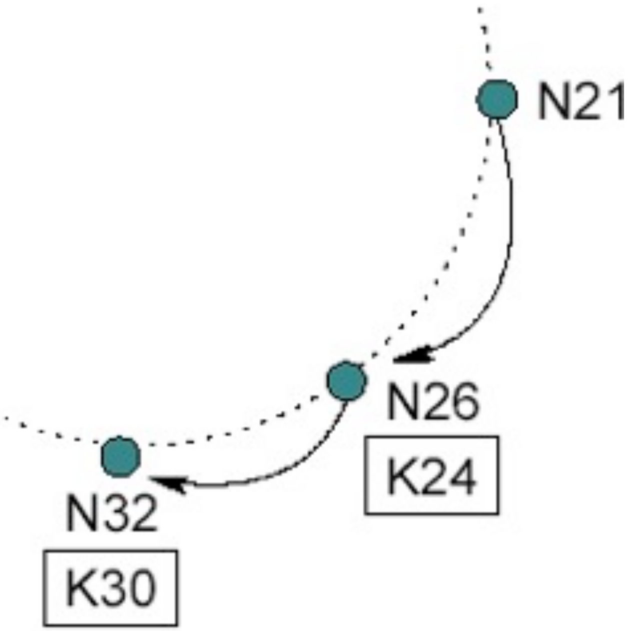
- N26 joins the system
- N26 acquires N32 as its successor
- N26 notifies N32
- N32 acquires N26 as its predecessor

The Chord algorithm – Node joins and stabilization



- N26 copies keys
- N21 runs stabilize() and asks its successor N32 for its predecessor which is N26.

The Chord algorithm – Node joins and stabilization



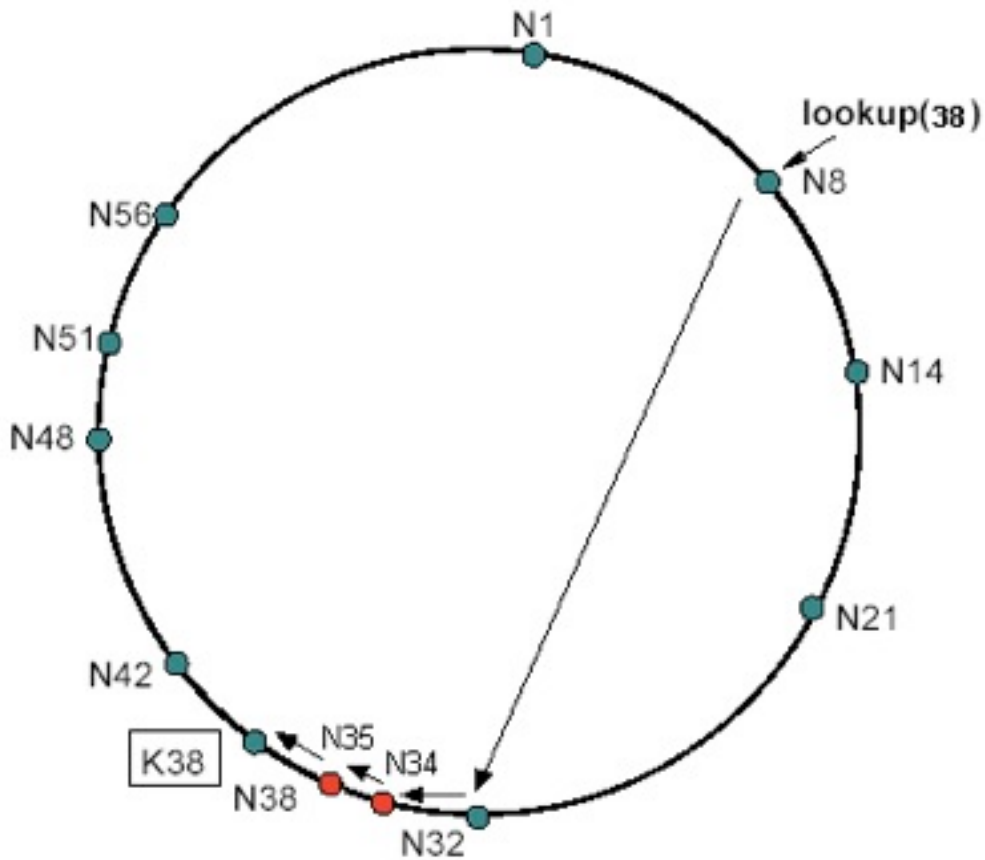
- N21 acquires N26 as its successor
- N21 notifies N26 of its existence
- N26 acquires N21 as predecessor

The Chord algorithm – Impact of node joins on lookups

- All finger table entries are correct => O(log N) lookups
- Successor pointers correct, but fingers inaccurate => correct but slower lookups

Finger table

N8 + 1	N14
N8 + 2	N14
N8 + 4	N14
N8 + 8	N21
N8 +16	N32
N8 +32	N42



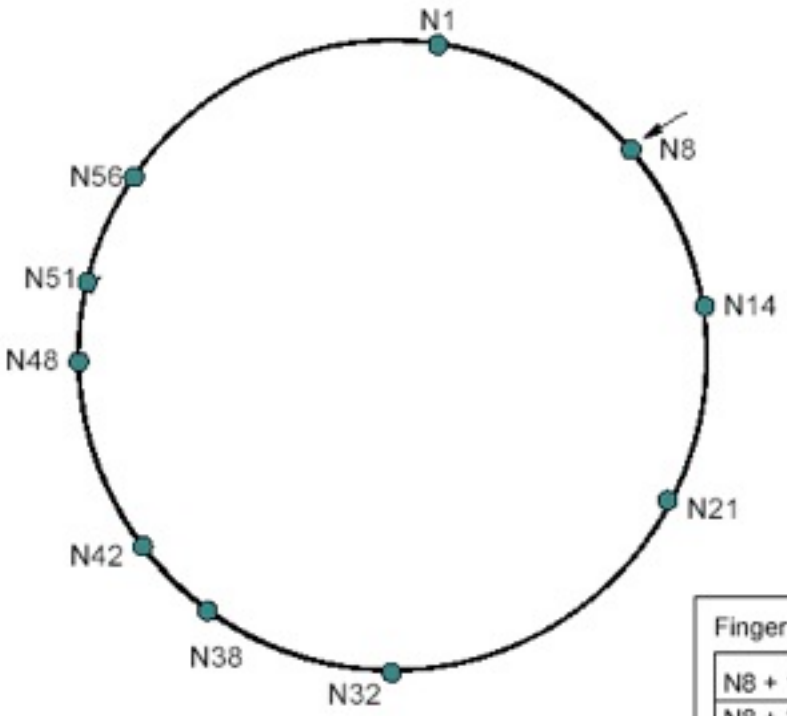
The Chord algorithm – Impact of node joins on lookups

- Incorrect successor pointers => lookup might fail, retry after a pause
- But still correctness!

The Chord algorithm – Impact of node joins on lookups

- Stabilization completed => no influence on performance
- Only for the negligible case that a large number of nodes joins between the target's predecessor and the target, the lookup is slightly slower
- No influence on performance as long as fingers are adjusted faster than the network doubles in size

The Chord algorithm – Failure of nodes

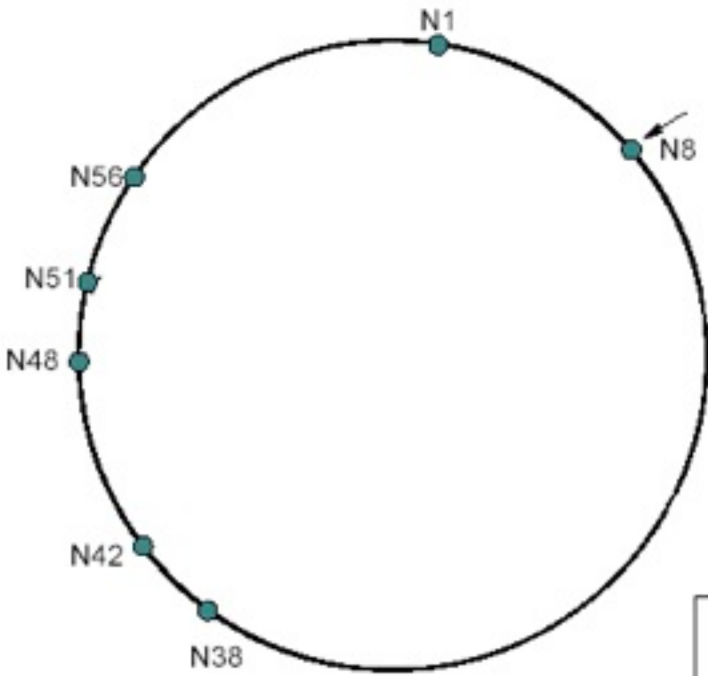


Finger table

N8 + 1	N14
N8 + 2	N14
N8 + 4	N14
N8 + 8	N21
N8 +16	N32
N8 +32	N42

- Correctness relies on correct successor pointers
- What happens, if N14, N21, N32 fail simultaneously?
- How can N8 acquire N38 as successor?

The Chord algorithm – Failure of nodes



Finger table

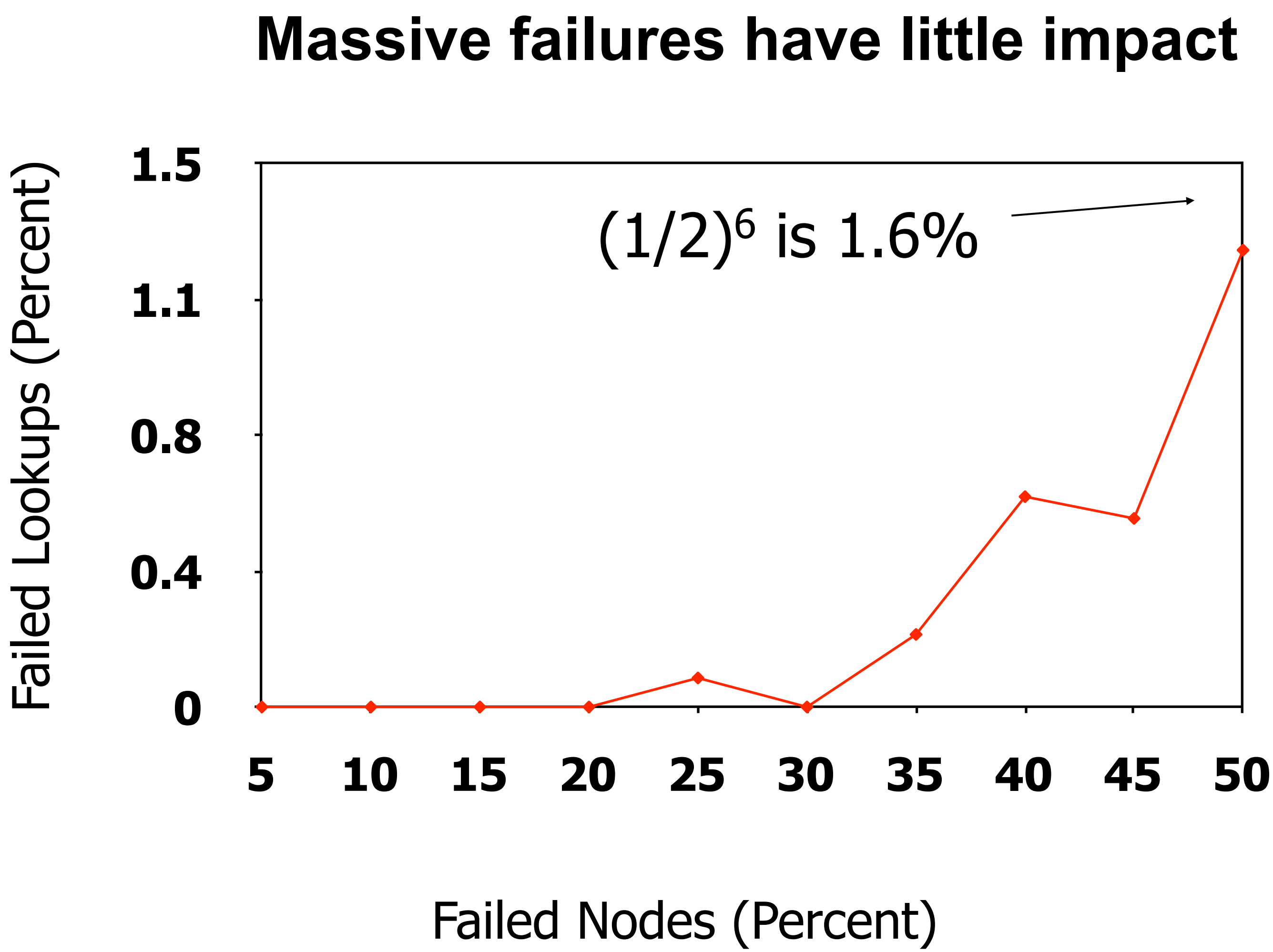
N8 + 1	N14
N8 + 2	N14
N8 + 4	N14
N8 + 8	N21
N8 +16	N32
N8 +32	N42

- Correctness relies on correct successor pointers
- What happens, if N14, N21, N32 fail simultaneously?
- How can N8 acquire N38 as successor?

The Chord algorithm – Failure of nodes

- Each node maintains a successor list of size r
- If the network is initially stable,
  and every node fails with probability ½,
  find_successor still finds the closest living successor to the query key and
  the expected time to execute find_succesor is $O(\log N)$
- Proofs are in the paper

The Chord algorithm – Failure of nodes



Overview

- Introduction
- The Chord Algorithm
  - Construction of the Chord ring
  - Localization of nodes
  - Node joins and stabilization
  - Failure/Departure of nodes
- Applications
- Summary
- Questions

Applications: Chord-based DNS

- DNS provides a lookup service
  keys: host names values: IP addresses
  Chord could hash each host name to a key
- Chord-based DNS:
  - no special root servers
  - no manual management of routing information
  - no naming structure
  - can find objects not tied to particular machines

Summary

- Simple, powerful protocol
- Only operation: map a key to the responsible node
- Each node maintains information about O(log N) other nodes
- Lookups via O(log N) messages
- Scales well with number of nodes
- Continues to function correctly despite even major changes of the system

Questions?

Thanks!