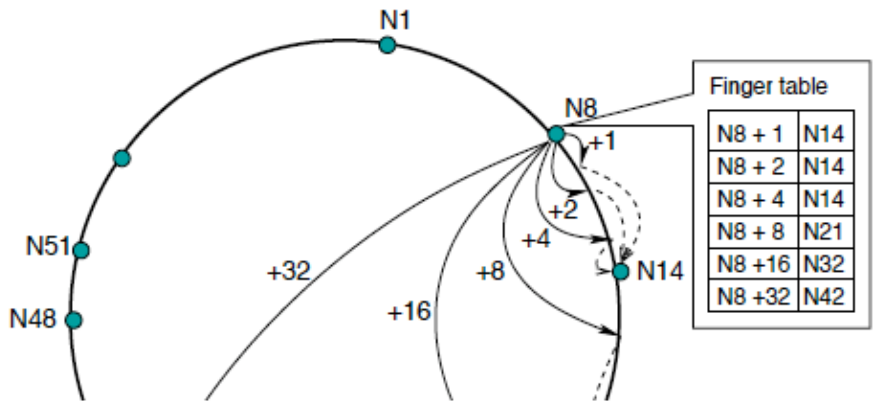


P2P Systems and Distributed Hash Tables

Section 9.4.2

COS 461: Computer Networks

Spring 2011

Mike Freedman

http://www.cs.princeton.edu/courses/archive/spring11/cos461/

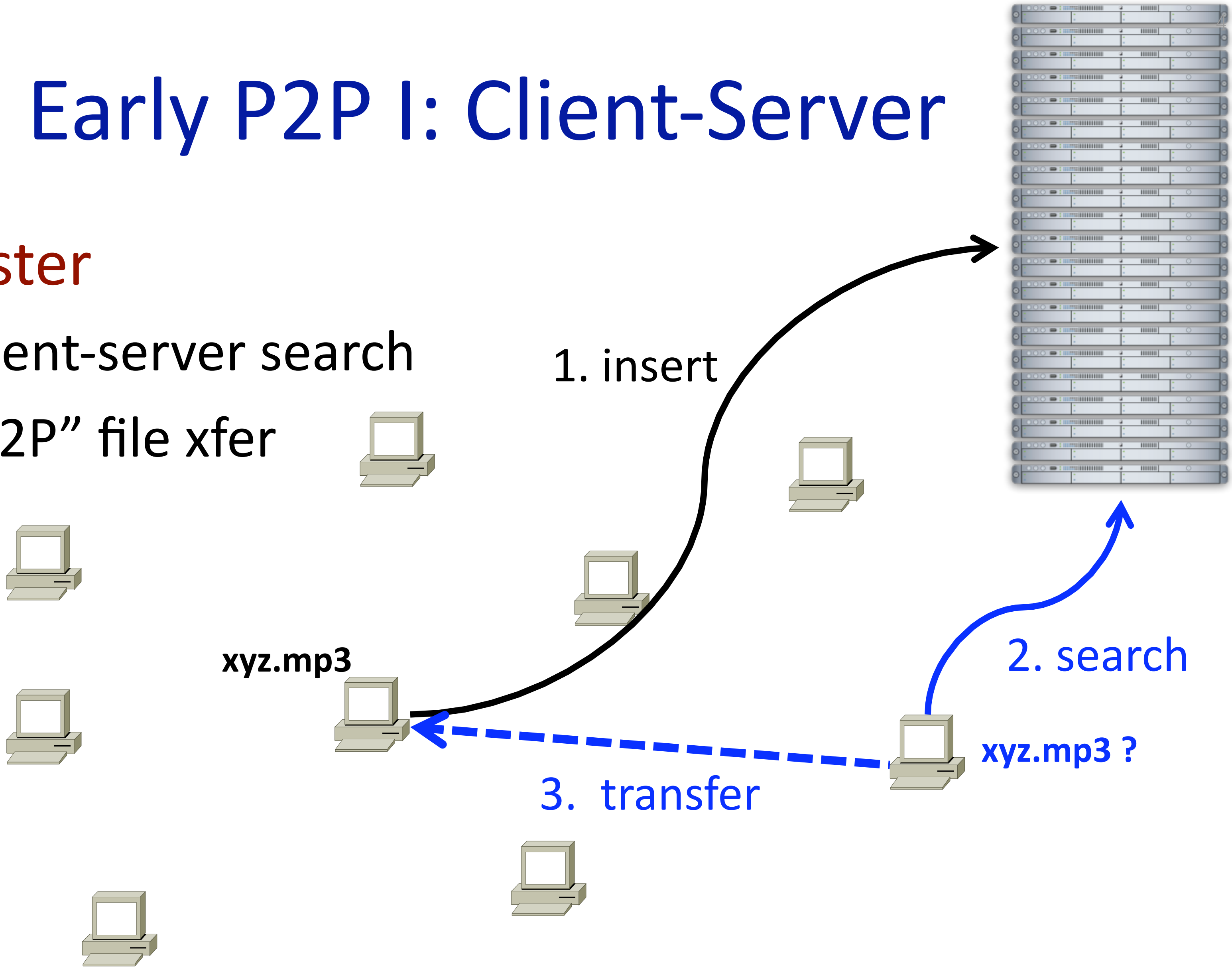
P2P as Overlay Networking

- P2P applications need to:
  - Track identities & IP addresses of peers
    - May be many and may have significant churn
  - Route messages among peers
    - If you don't keep track of all peers, this is "multi-hop"
- *Overlay network*
  - Peers doing both naming and routing
  - IP becomes "just" the low-level transport

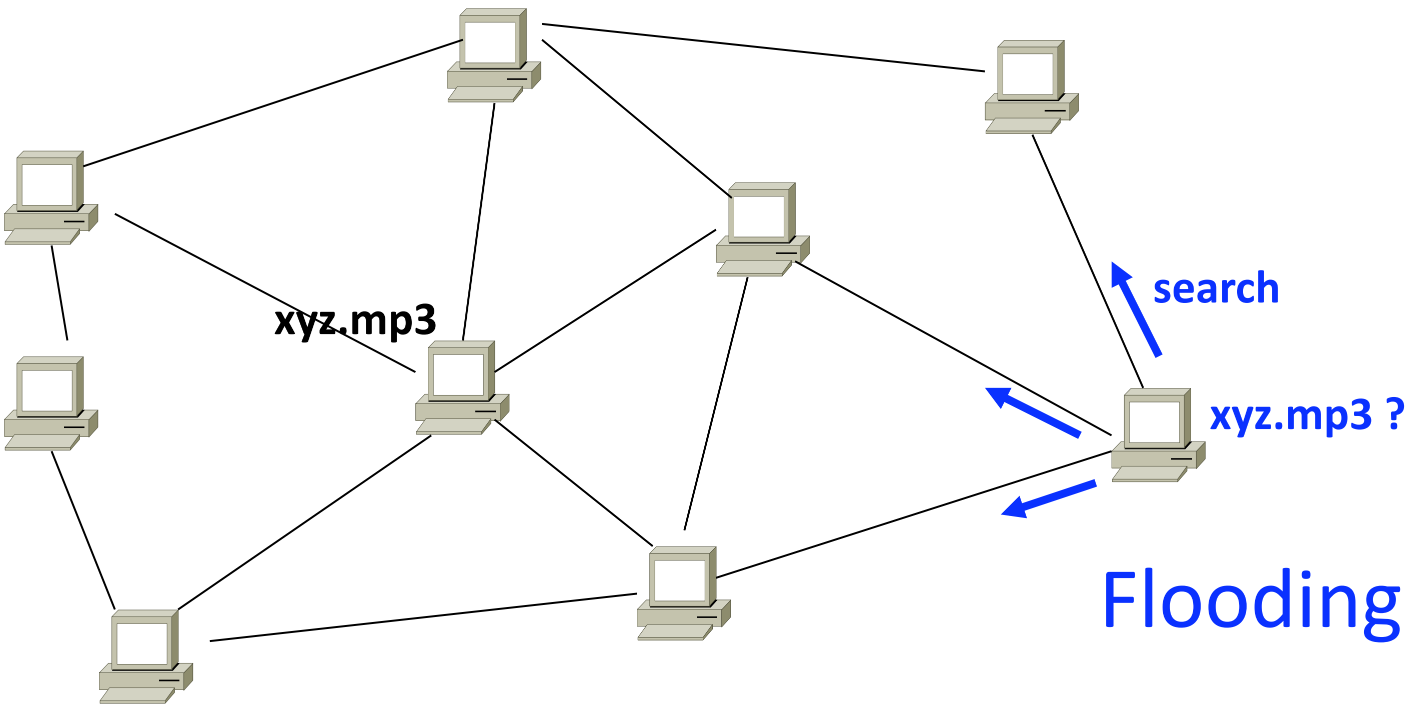
Early P2P

Early P2P I: Client-Server

- Napster
  - Client-server search
  - "P2P" file xfer

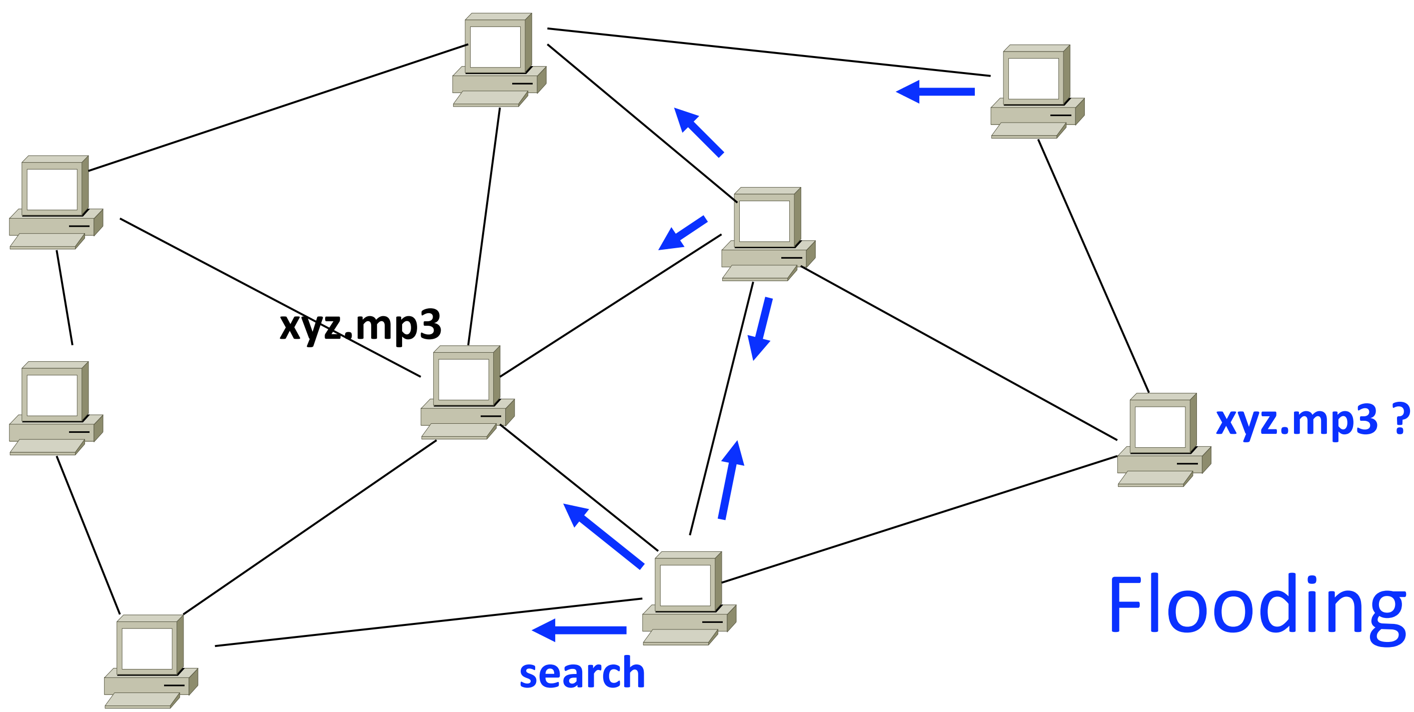


Early P2P II: Flooding on Overlays

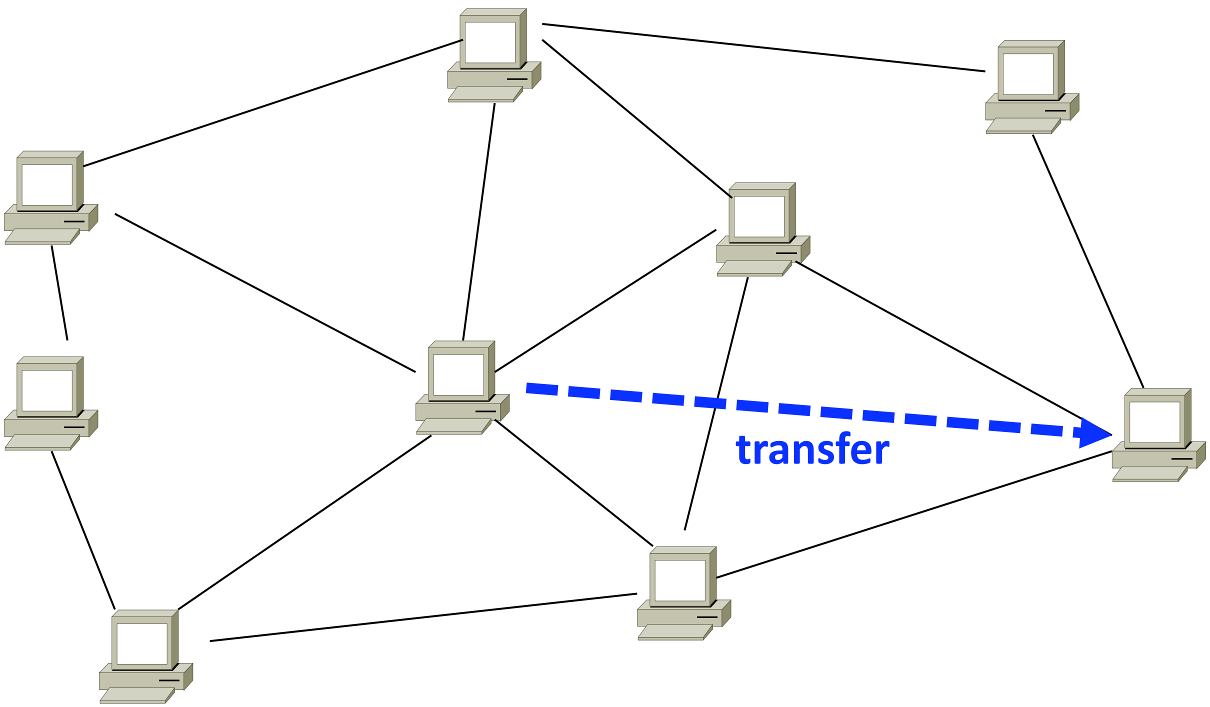


Flooding

Early P2P II: Flooding on Overlays

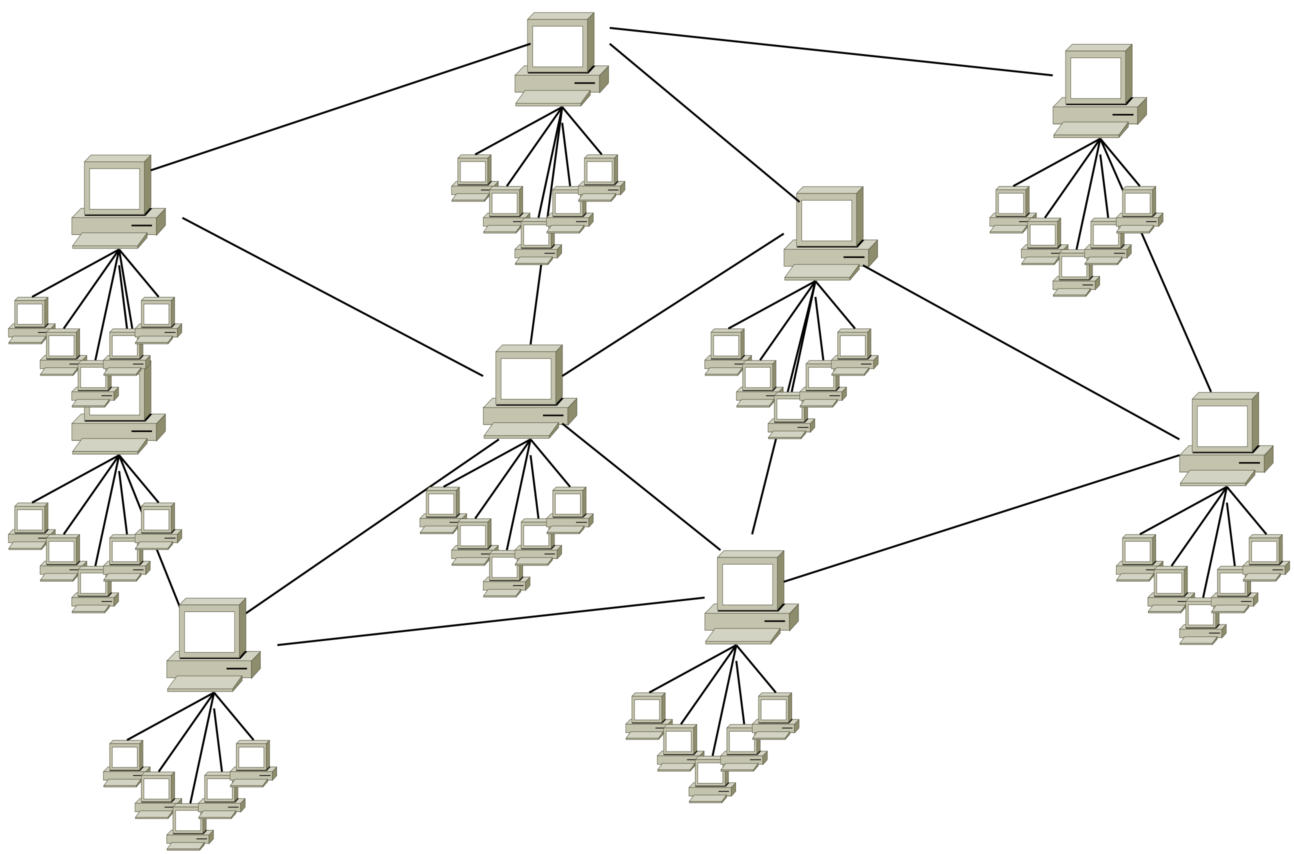


Early P2P II: Flooding on Overlays



Early P2P II: "Ultra/super peers"

- Ultra-peers can be installed (KaZaA) or self-promoted (Gnutella)
  - Also useful for NAT circumvention, e.g., in Skype



Lessons and Limitations

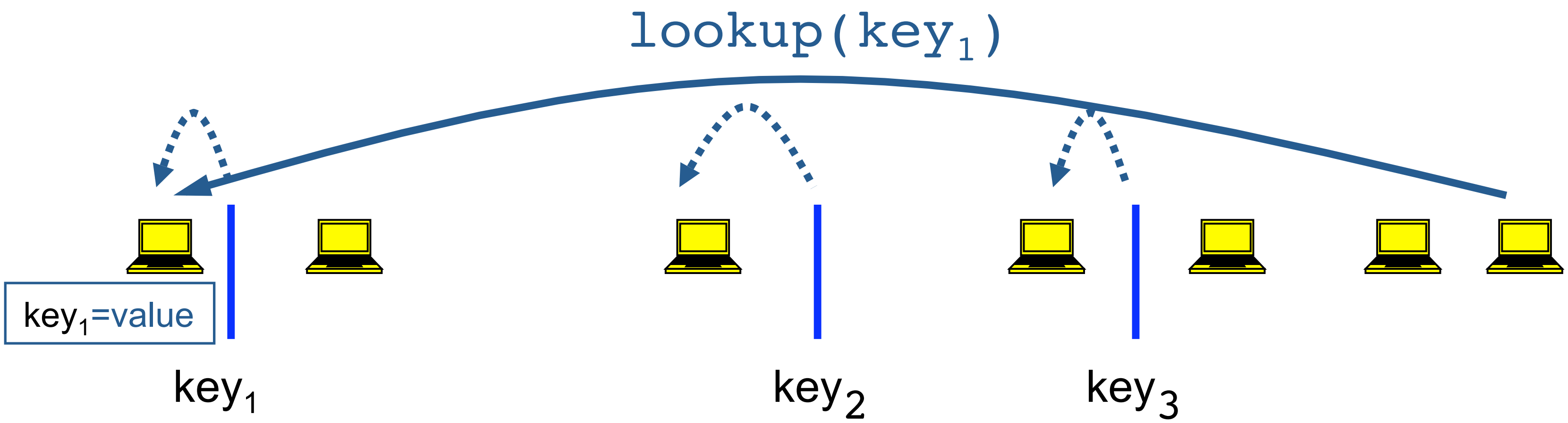
- Client-Server performs well
  - But not always feasible: Performance not often key issue!
- Things that flood-based systems do well
  - Organic scaling
  - Decentralization of visibility and liability
  - Finding popular stuff
  - Fancy *local* queries
- Things that flood-based systems do poorly
  - Finding unpopular stuff
  - Fancy *distributed* queries
  - Vulnerabilities: data poisoning, tracking, etc.
  - Guarantees about anything (answer quality, privacy, etc.)

Structured Overlays:
Distributed Hash Tables

Basic Hashing for Partitioning?

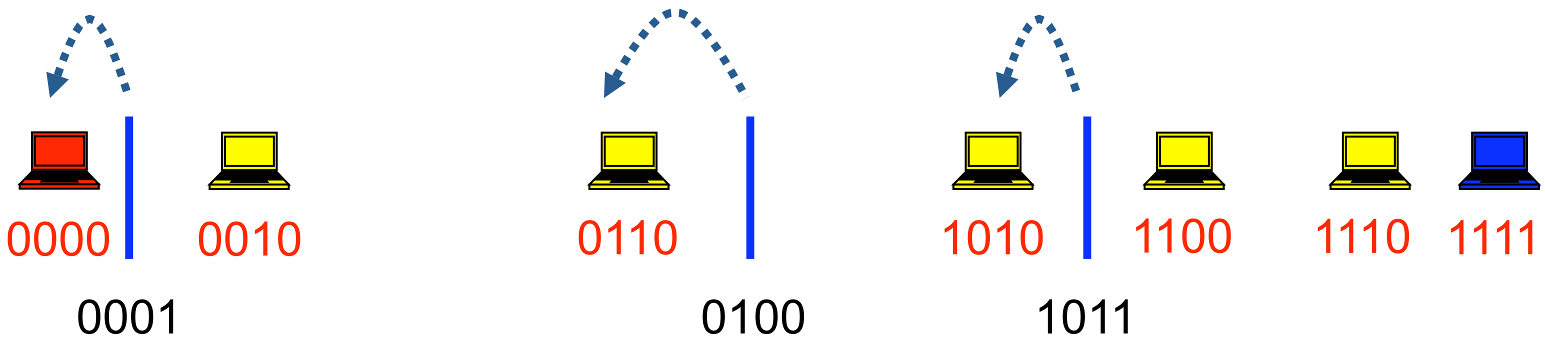
- Consider problem of data partition:
  - Given document X, choose one of k servers to use
- Suppose we use modulo hashing
  - Number servers 1..k
  - Place X on server *i = (X mod k)*
    - Problem? Data may not be uniformly distributed
  - Place X on server *i = hash (X) mod k*
    - Problem?
      - What happens if a server fails or joins (k → k±1)?
      - What is different clients has different estimate of k?
      - Answer: All entries get remapped to new nodes!

Consistent Hashing



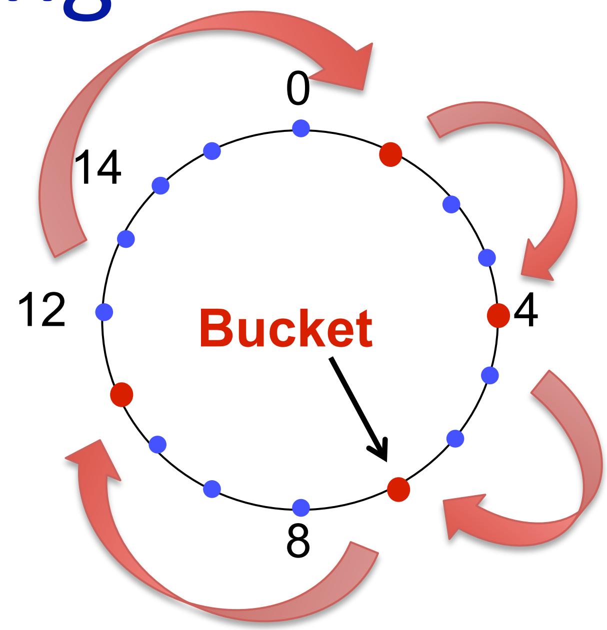
- Consistent hashing partitions key-space among nodes
- Contact appropriate node to lookup/store key
  - Blue node determines red node is responsible for key_1
  - Blue node sends lookup or insert to red node

Consistent Hashing



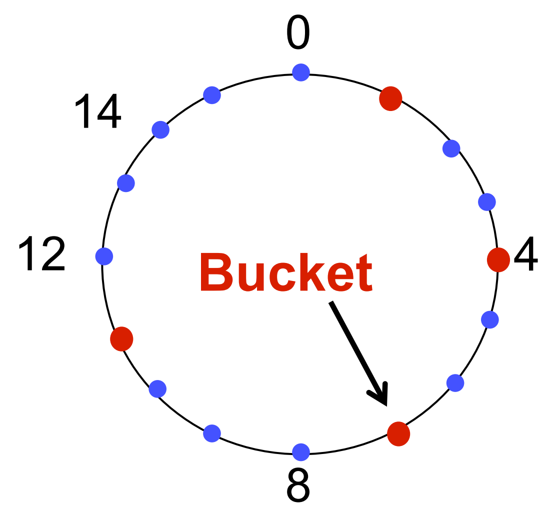
- Partitioning key-space among nodes
  - Nodes choose random identifiers: e.g., hash(IP)
  - Keys randomly distributed in ID-space: e.g., hash(URL)
  - Keys assigned to node “nearest” in ID-space
  - Spreads ownership of keys evenly across nodes

Consistent Hashing



- Construction
  - Assign *n* hash buckets to random points on mod 2^k circle; hash key size = *k*
  - Map object to random position on circle
  - Hash of object = closest clockwise bucket
    - *successor* (key) → bucket
- Desired features
  - Balanced: No bucket has disproportionate number of objects
  - Smoothness: Addition/removal of bucket does not cause movement among existing buckets (only immediate buckets)
  - Spread and load: Small set of buckets that lie near object

Consistent hashing and failures

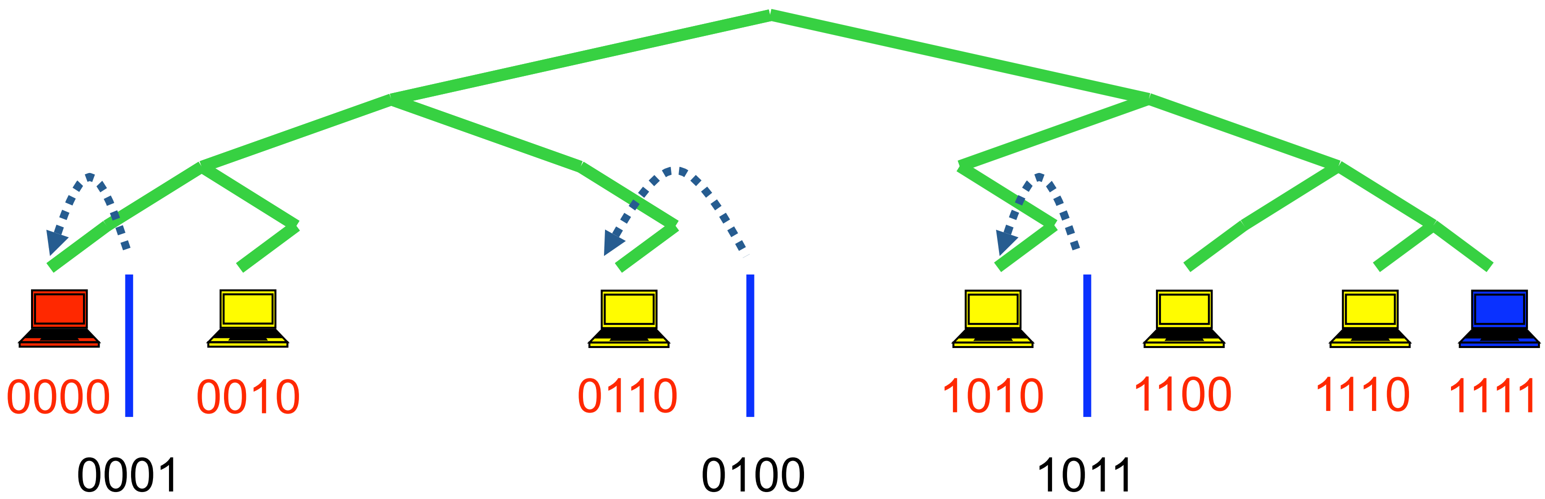


- Consider network of n nodes
- If each node has 1 bucket
  - Owns 1/nth of keyspace *in expectation*
  - Says nothing of request load per bucket
- If a node fails:
  - Its *successor* takes over bucket
  - Achieves smoothness goal: Only localized shift, not O(n)
  - But now successor owns 2 buckets: keyspace of size *2/n*
- Instead, if each node maintains *v* random nodeIDs, not 1
  - "Virtual" nodes spread over ID space, each of size *1 / vn*
  - Upon failure, v successors take over, each now stores *(v+1) / vn*

Consistent hashing vs. DHTs

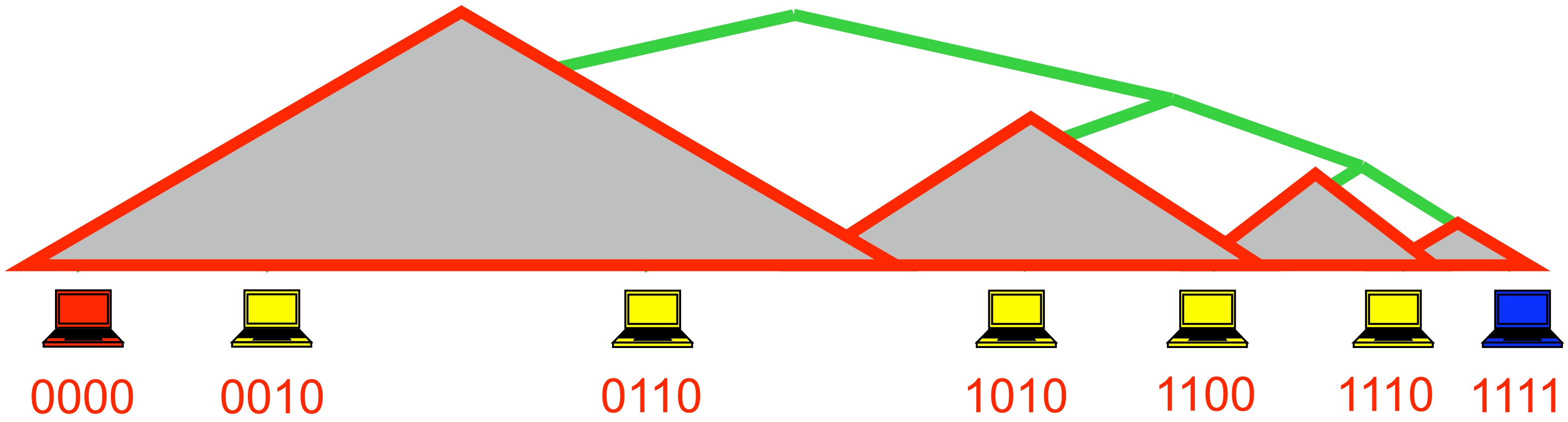
	Consistent Hashing	Distributed Hash Tables
Routing table size	O(n)	O(log n)
Lookup / Routing	O(1)	O(log n)
Join/leave: Routing updates	O(n)	O(log n)
Join/leave: Key Movement	O(1)	O(1)

Distributed Hash Table



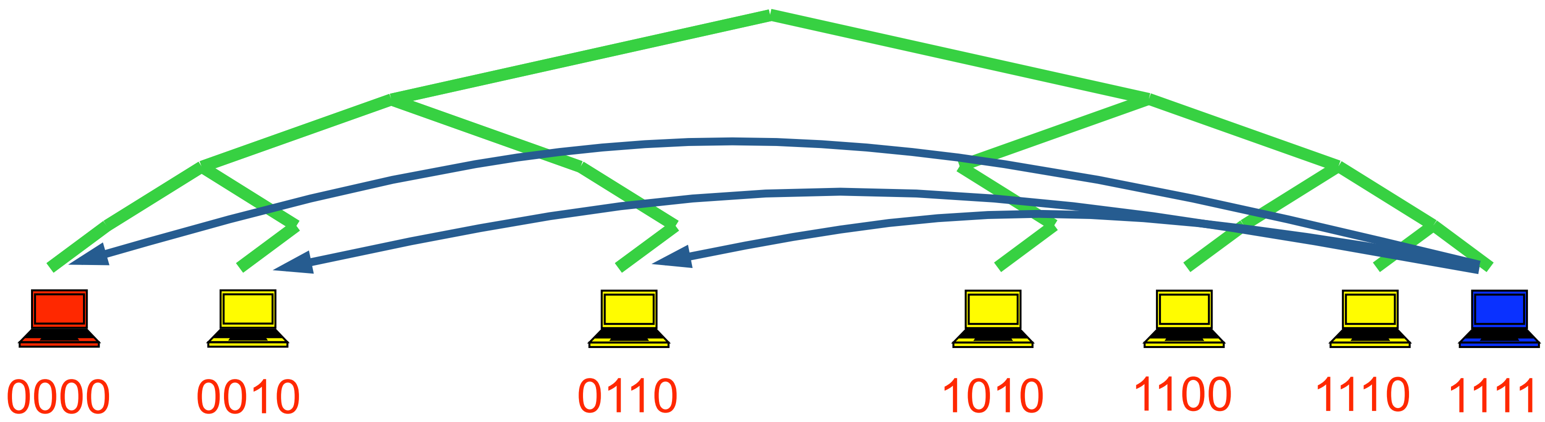
- Nodes' neighbors selected from particular distribution
  - Visual keyspace as a tree in distance from a node

Distributed Hash Table



- Nodes' neighbors selected from particular distribution
  - Visual keyspace as a tree in distance from a node
  - At least one neighbor known per subtree of increasing size / distance from node

Distributed Hash Table



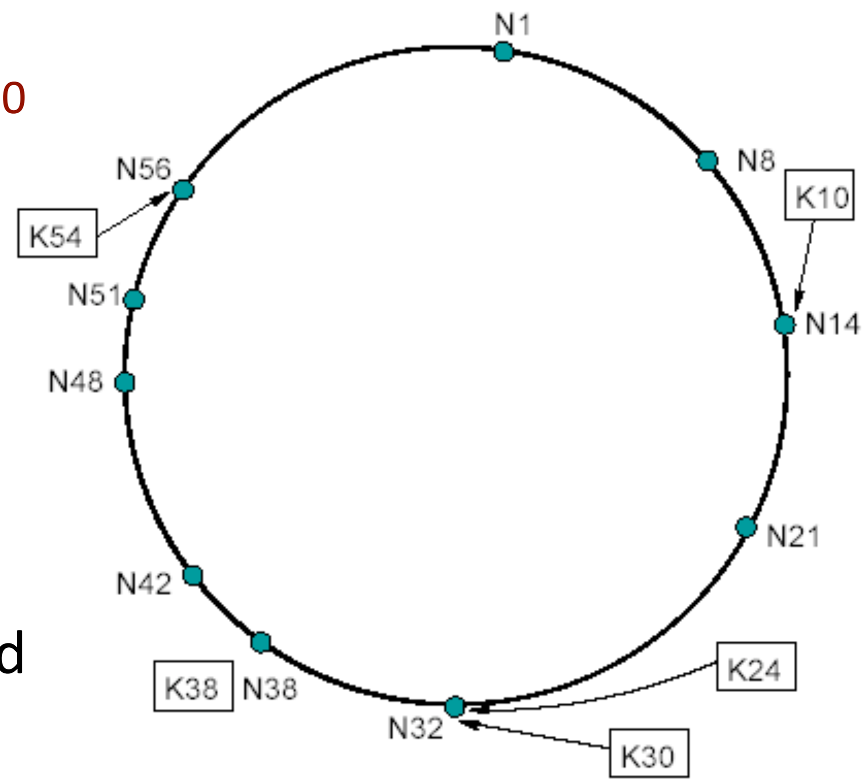
- Nodes' neighbors selected from particular distribution
  - Visual keyspace as a tree in distance from a node
  - At least one neighbor known per subtree of increasing size / distance from node
- Route greedily towards desired key via overlay hops

The Chord DHT

- Chord ring: ID space mod 2^{160}
  - *nodeid = SHA1 (IP address, i)*
    for i=1..v virtual IDs
  - *keyid = SHA1 (name)*

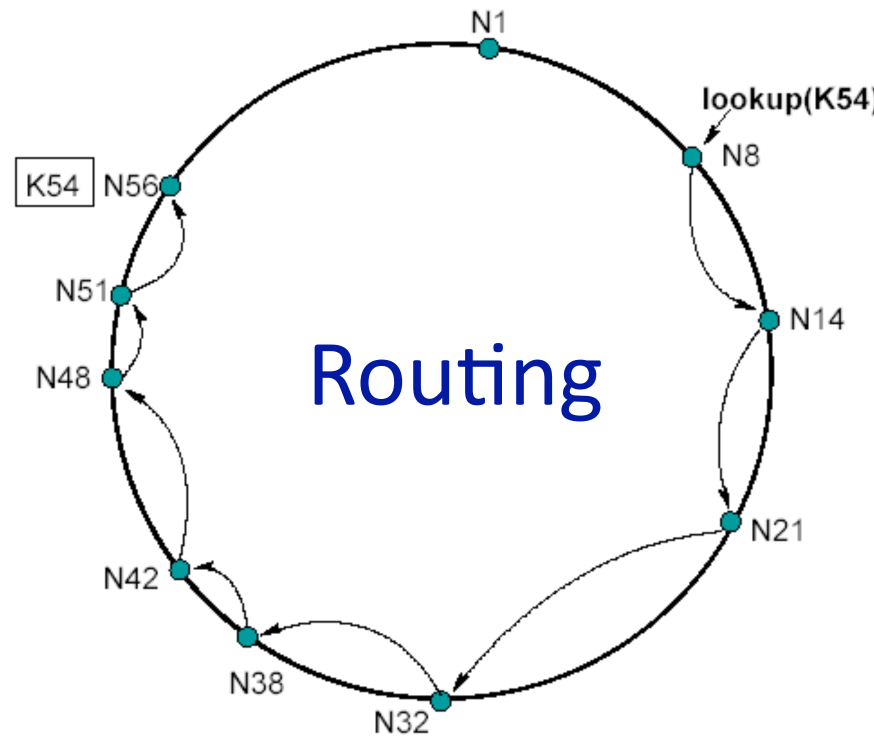
- Routing correctness:
  - Each node knows successor and predecessor on ring

- Routing efficiency:
  - Each node knows O(log n) well-distributed neighbors



Basic lookup in Chord

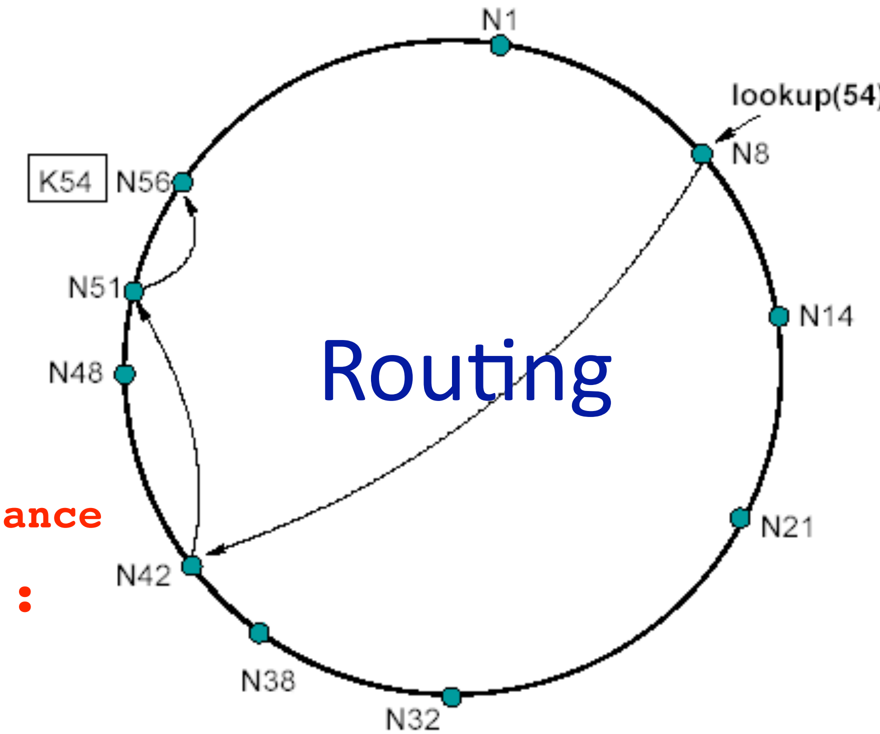
```
lookup (id):
  if ( id > pred.id &&
       id <= my.id )
    return my.id;
  else
    return succ.lookup(id);
```



- Route hop by hop via successors
  - O(n) hops to find destination id

Efficient lookup in Chord

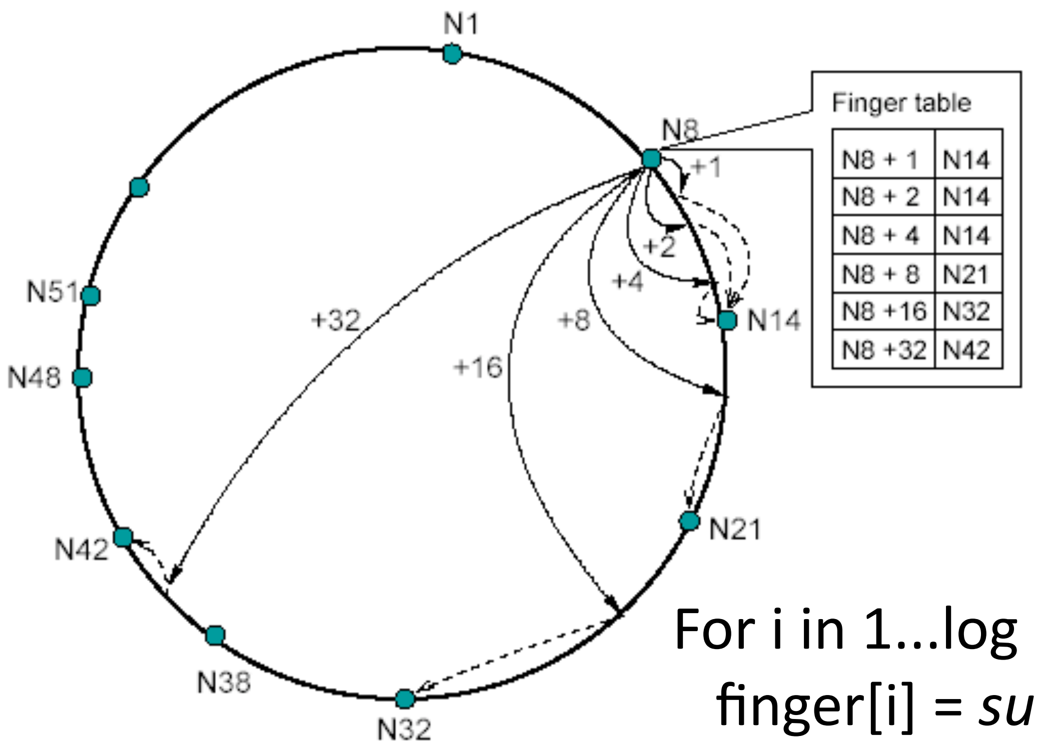
```
lookup (id):
  if ( id > pred.id &&
       id <= my.id )
    return my.id;
  else
    // fingers() by decreasing distance
    for finger in fingers():
      if id <= finger.id
        return finger.lookup(id);
    return succ.lookup(id);
```



- Route greedily via distant "finger" nodes
  - O(log n) hops to find destination id

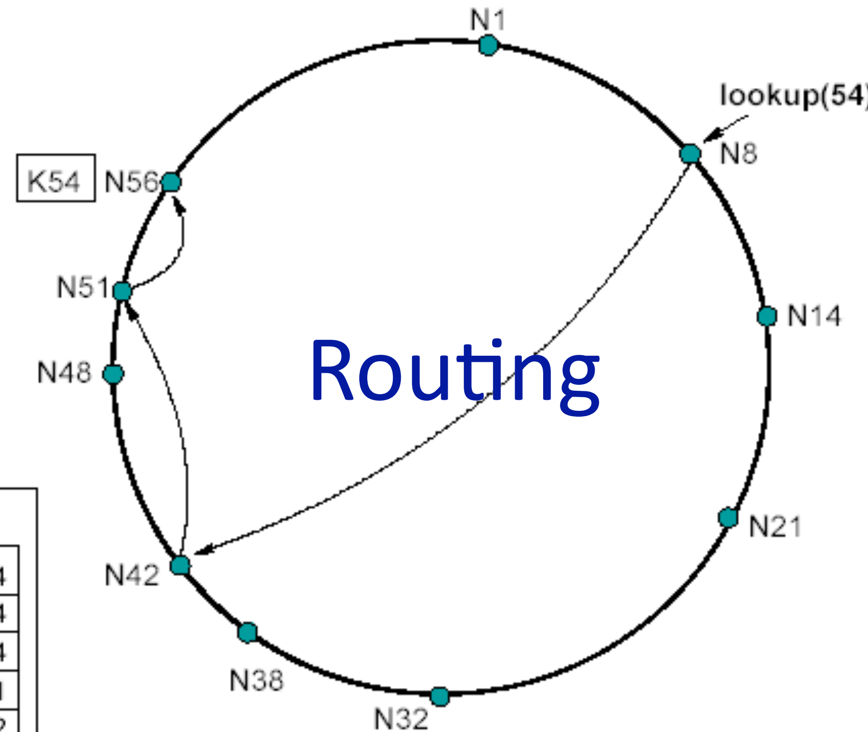
Building routing tables

Routing Tables



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

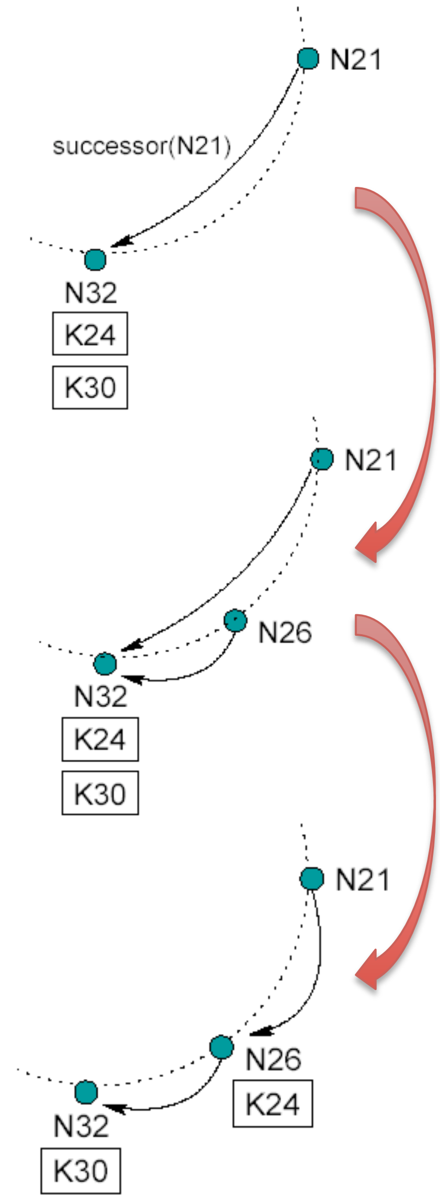
Routing



For i in 1...log n:
  finger[i] = *successor* ($(my.id + 2^{i}) \bmod 2^{160}$)

Joining and managing routing

- Join:
  - Choose nodeid
  - *Lookup (my.id)* to find place on ring
  - During lookup, discover future successor
  - Learn predecessor from successor
  - Update succ and pred that you joined
  - Find fingers by *lookup* (($my.id + 2^i$) mod 2^{160})
- Monitor:
  - If doesn't respond for some time, find new
- Leave: Just go, already!
  - (Warn your neighbors if you feel like it)



DHT Design Goals

- An “overlay” network with:
  - Flexible mapping of keys to physical nodes
  - Small network diameter
  - Small degree (fanout)
  - Local routing decisions
  - Robustness to churn
  - Routing flexibility
  - Decent locality (low “stretch”)
- Different “storage” mechanisms considered:
  - Persistence w/ additional mechanisms for fault recovery
  - Best effort caching and maintenance via soft state

Storage models

- Store *only* on key's immediate successor
  - Churn, routing issues, packet loss make lookup failure more likely
- Store on *k* successors
  - When nodes detect succ/pred fail, re-replicate
- Cache along reverse lookup path
  - Provided data is immutable
  - …and performing recursive responses

Summary

- Peer-to-peer systems
  - Unstructured systems
    - Finding hay, performing keyword search
  - Structured systems (DHTs)
    - Finding needles, exact match
- Distributed hash tables
  - Based around consistent hashing with views of O(log n)
  - Chord, Pastry, CAN, Koorde, Kademlia, Tapestry, Viceroy, …
- Lots of systems issues
  - Heterogeneity, storage models, locality, churn management, underlay issues, …
  - DHTs deployed in wild: Vuze (Kademlia) has 1M+ active users