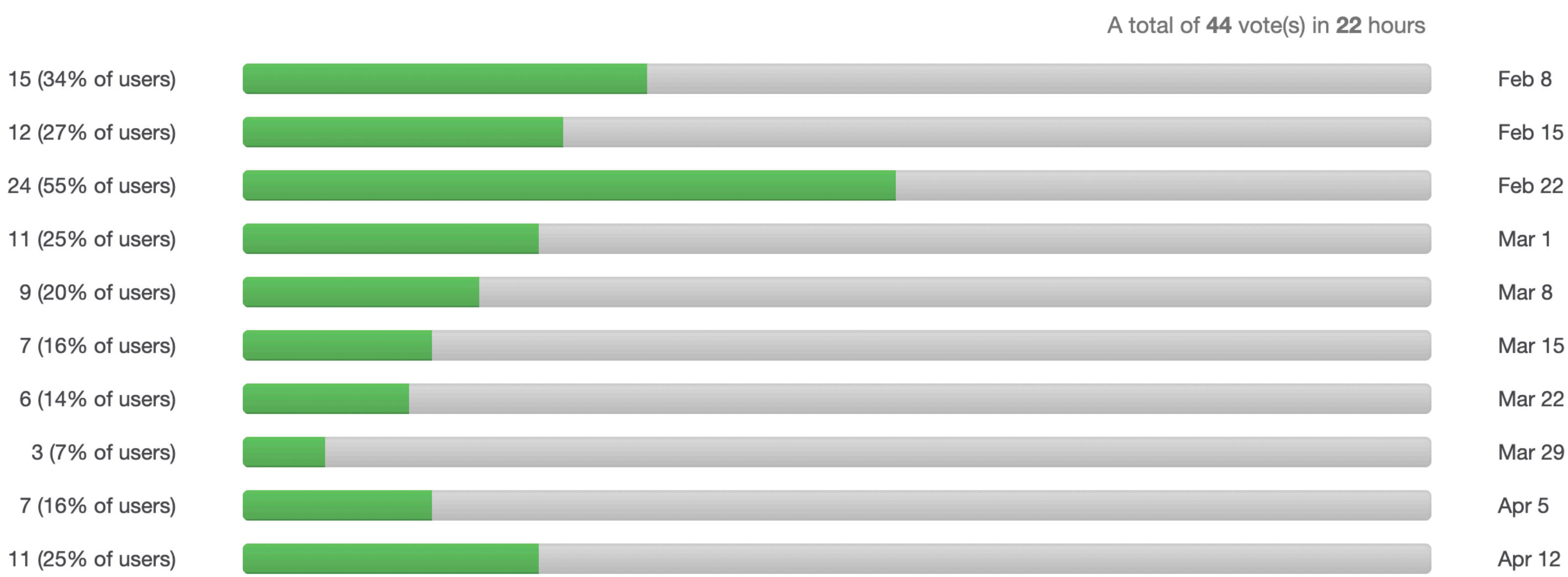
Updates

- A3 due this Sunday
- Don't forget to Piazza vote for your *"worst weeks"*



416 Distributed Systems

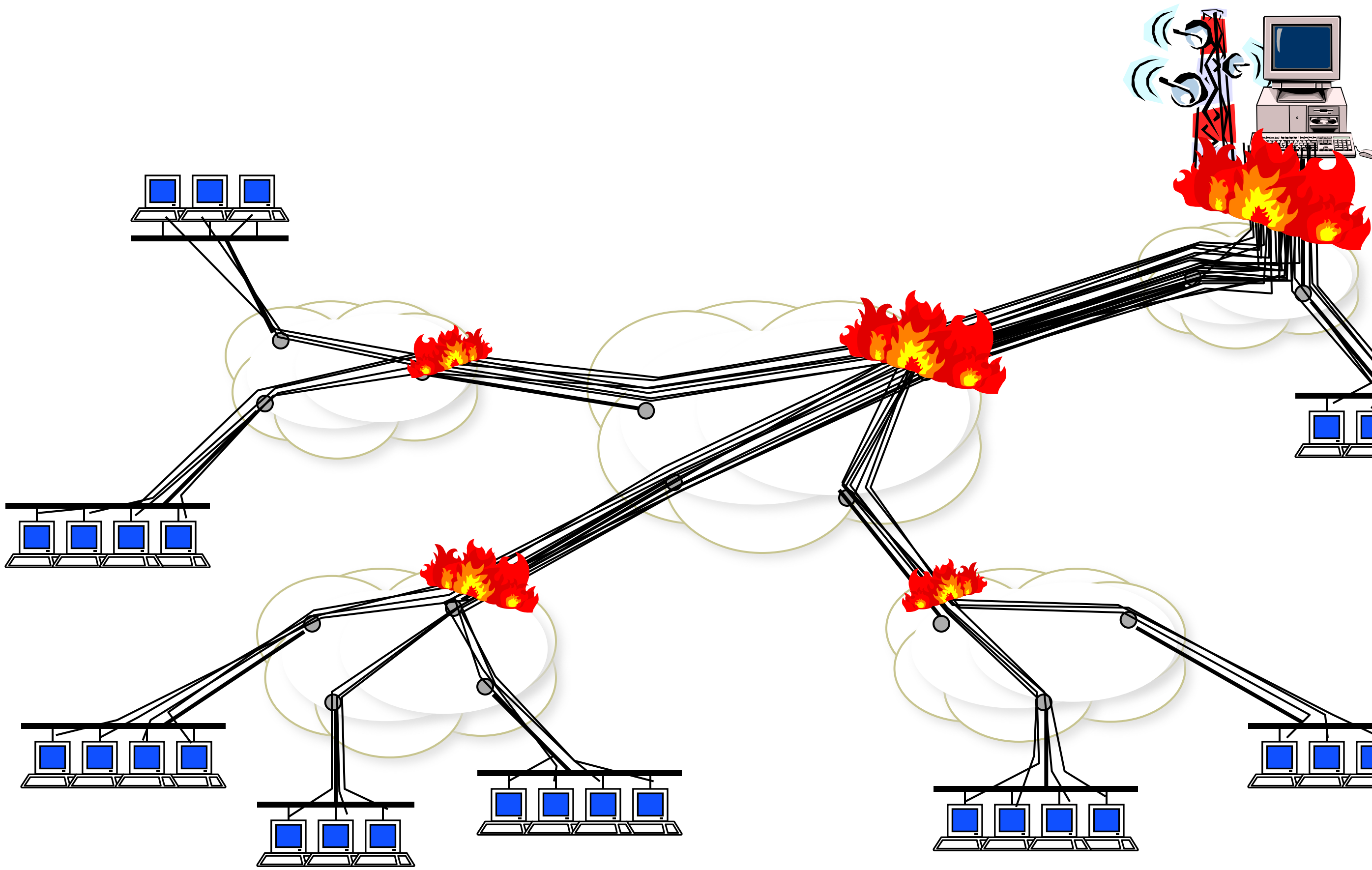
Feb 2, Peer-to-Peer

Outline

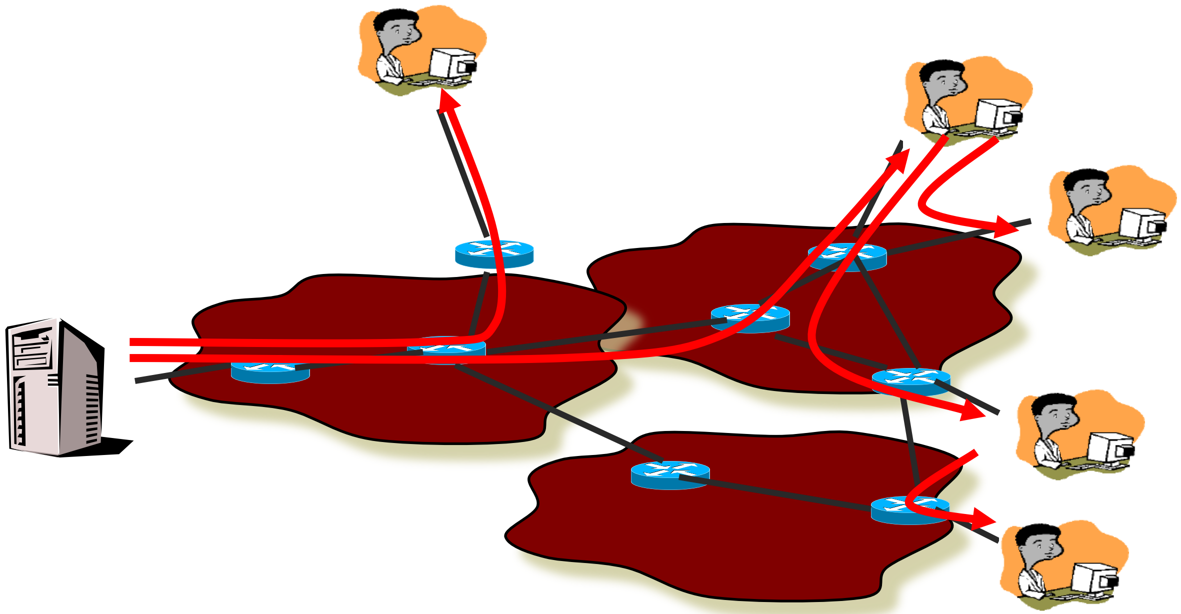
- P2P Lookup Overview
- Centralized/Flooded Lookups
- BitTorrent
- Routed Lookups – Chord

Scaling Problem

- Millions of clients ⇒ server and network meltdown



P2P System

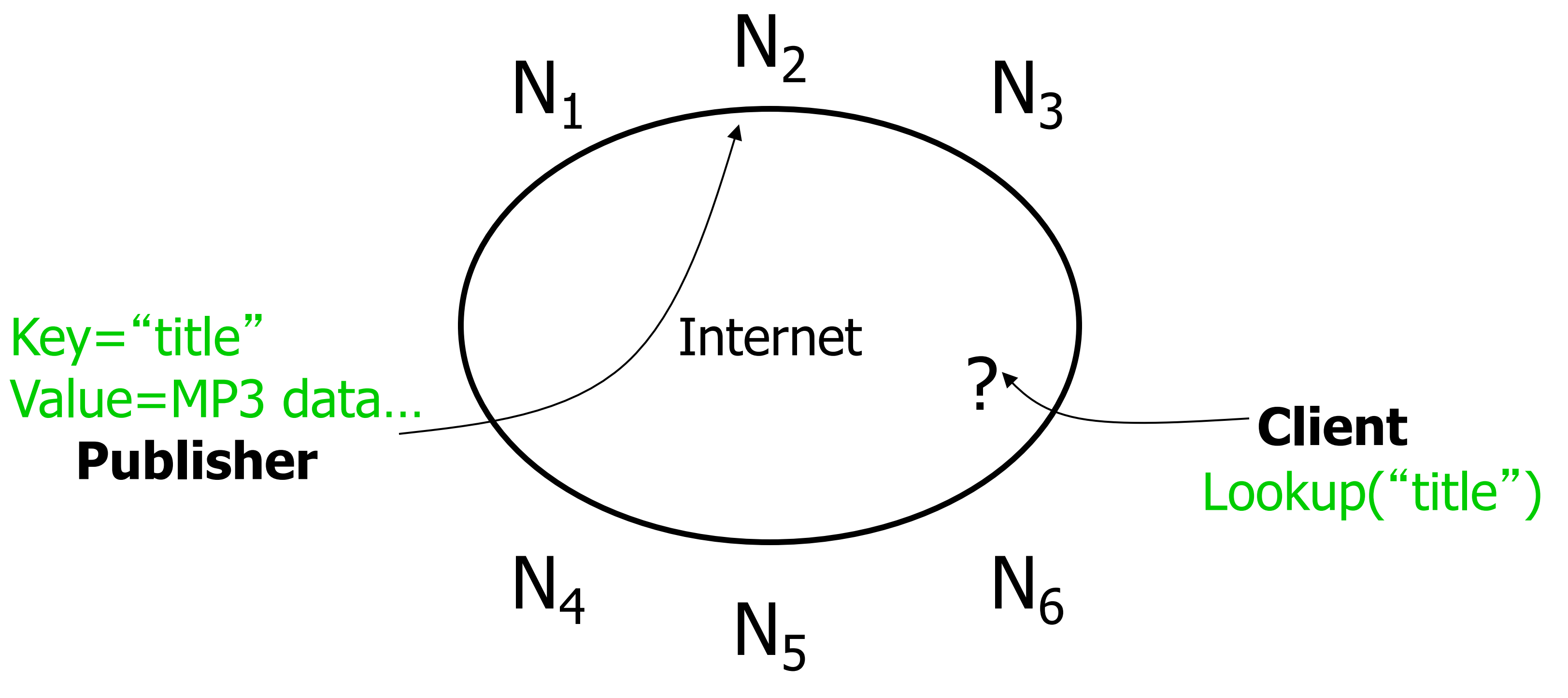


- Leverage the resources of client machines (peers)
  - Traditional: Computation, storage, bandwidth
  - Non-traditional: Geographical diversity, mobility, special token we call coins, sensors!

Peer-to-Peer (storage) Networks

- Typically each member stores/provides access to content
- Basically a replication system for files
  - Always a tradeoff between possible location of files and searching difficulty
  - Peer-to-peer allow files to be anywhere → searching is the challenge
  - Dynamic member list makes it more difficult: **node churn**
- What other systems have similar goals?
  - Routing, CDNs, DNS

The Lookup Problem



Searching

- Needles vs. Haystacks
  - Searching for top 40, or an obscure punk track from 1981 that nobody's heard of?
- Search expressiveness
  - Whole word? Regular expressions? File names? Attributes? Whole-text search?
- Searching for recent versus older content
- Searching for content correlated with your location/time of day/etc versus not

Framework

- Common Primitives:
  - **Join**: how do I begin participating?
  - **Publish**: how do I advertise my file?
  - **Search**: how to I find a file?
  - **Fetch**: how to I retrieve a file?

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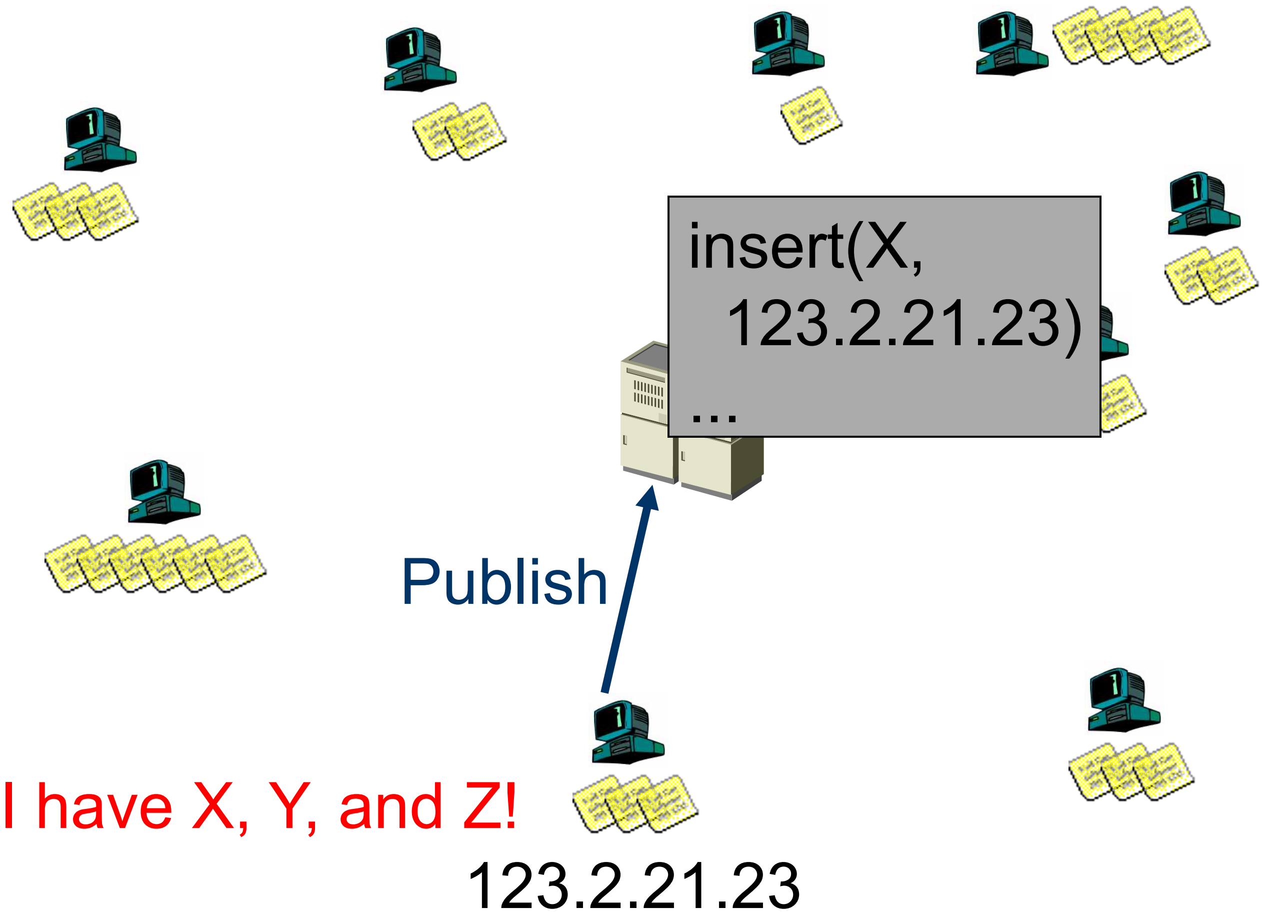
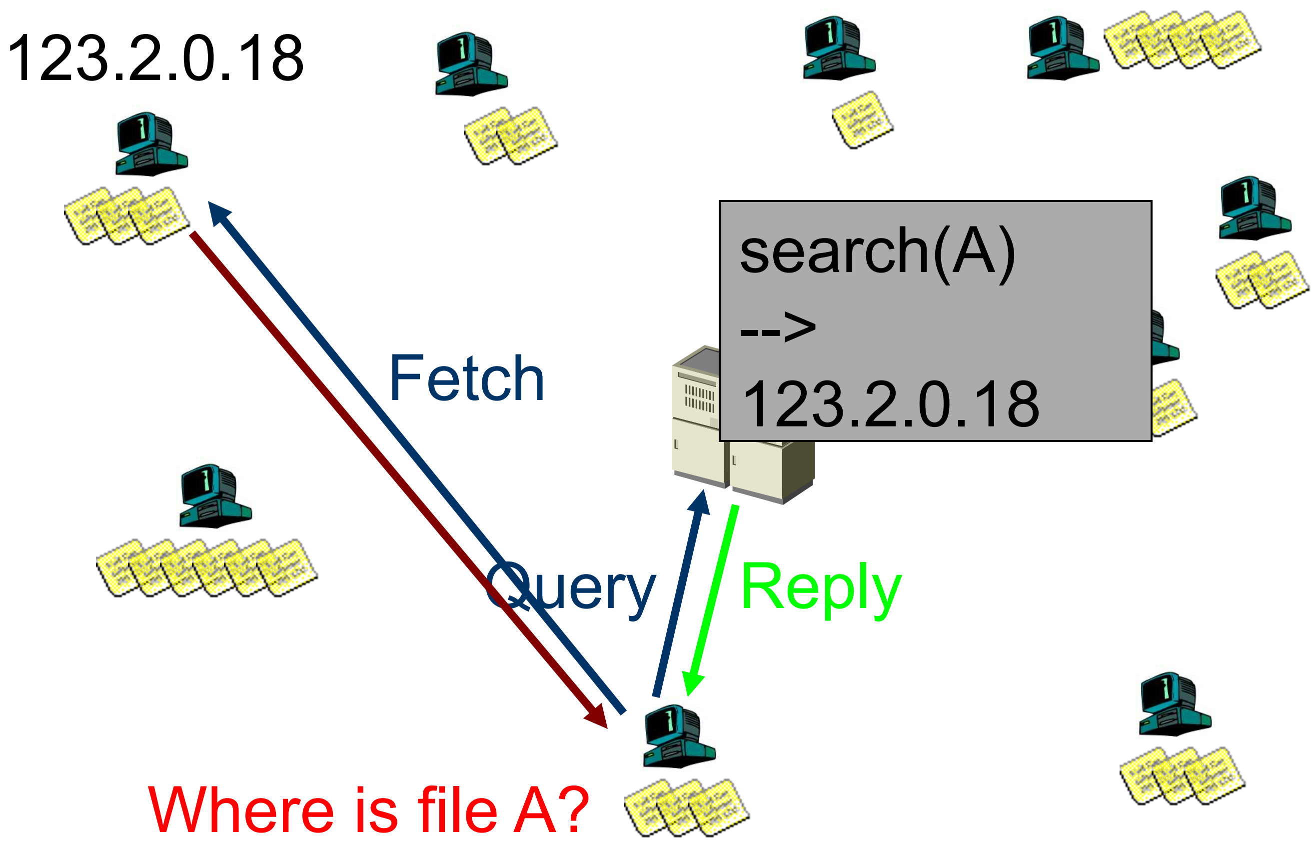
Napster: Overiew

- Centralized Database:
  - **Join:** on startup, client contacts central server
  - **Publish:** reports list of files to central server
  - **Search:** query the server => return someone that stores the requested file
  - **Fetch:** get the file directly from peer

Napster: Publish



Napster: Search



Napster: Discussion

- Pros:
  - Simple
  - Search scope is O(1)
  - Controllable (pro or con?)
- Cons:
  - Server maintains O(N) State
  - Server does all processing
  - Single point of failure

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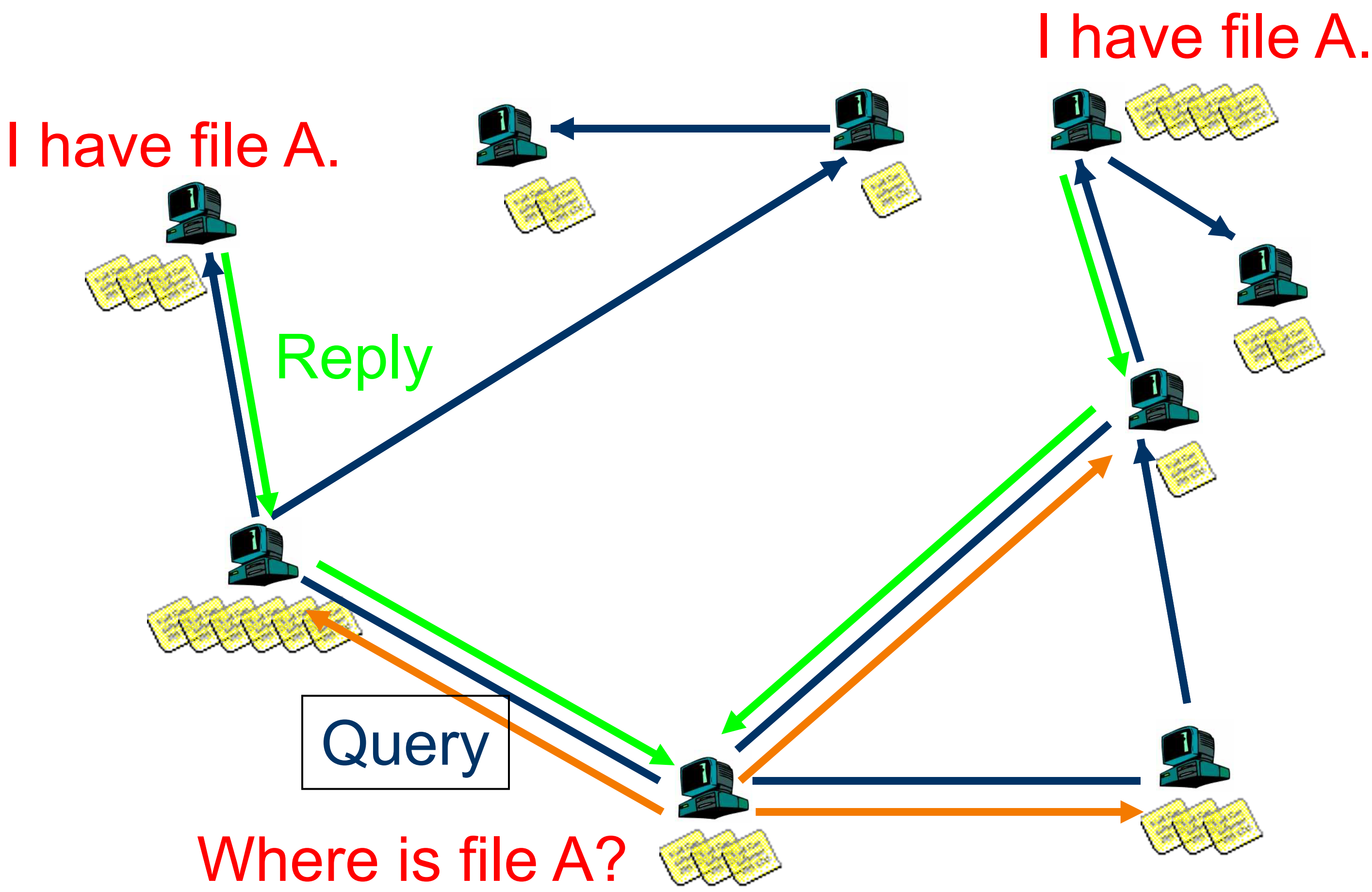
  - Server does all processing
  - **Single point of failure**

"Old" Gnutella: Overview

- Query Flooding:
  - **Join**: on startup, client contacts *a few* other nodes; these become its "neighbors"
    - "unstructured overlay"
  - **Publish**: no need
  - **Search**: ask neighbors, who ask their neighbors, and so on... when/if found, reply to sender.
    - TTL limits propagation
  - **Fetch**: get the file directly from peer

Gnutella: Search

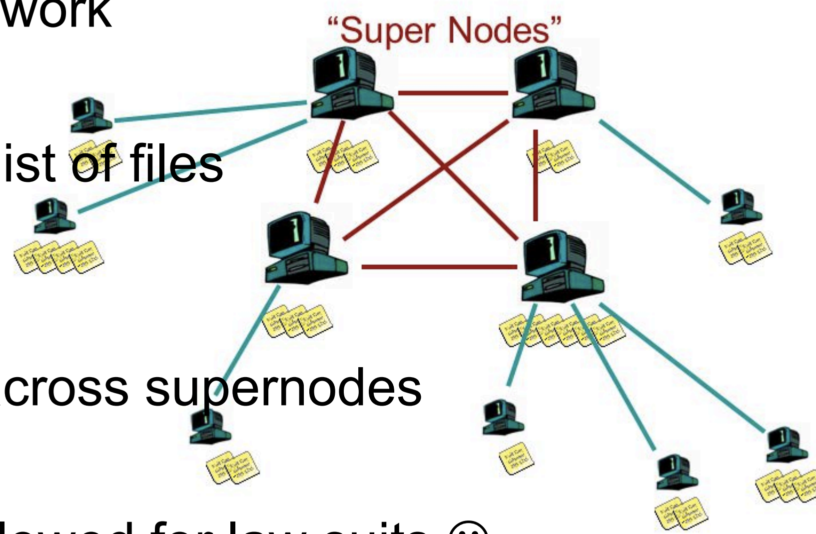


Gnutella: Discussion

- Pros:
  - Fully de-centralized
  - Search cost distributed
  - Processing @ each node permits powerful search semantics
- Cons:
  - Search scope is O(*N*)
  - Search time is O(???)
  - Nodes leave often, network unstable
- TTL-limited search works well for haystacks.
  - For scalability, does NOT search every node. May have to re-issue query later; no guarantee that it will find the file!

Flooding: Gnutella, **Kazaa**

- Modifies the Gnutella protocol into two-level hierarchy
  - Hybrid of Gnutella and Napster
- Supernodes
  - Nodes that have better connection to Internet
  - Act as temporary indexing servers for other nodes
  - Help improve the stability of the network



- Standard nodes
  - Connect to supernodes and report list of files
  - Allows slower nodes to participate
- Search
  - Broadcast (Gnutella-style) search across supernodes
- Disadvantages
  - Kept a centralized registration → allowed for law suits ☹

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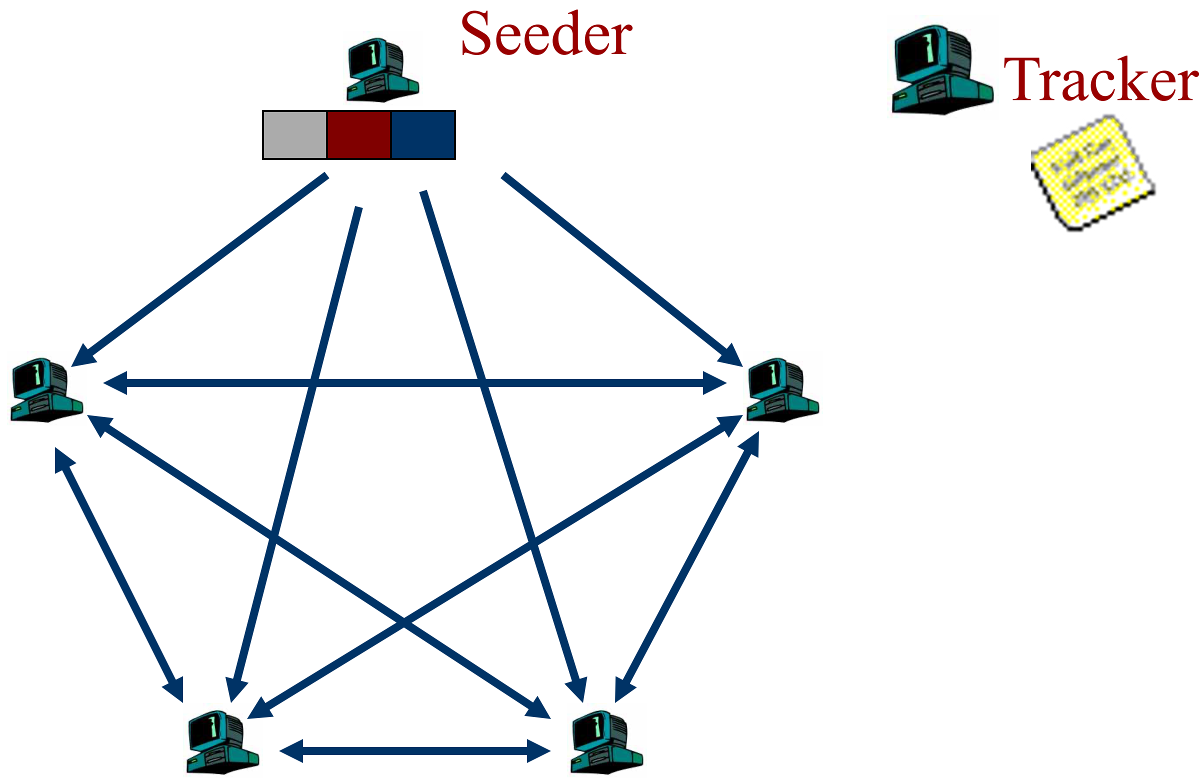
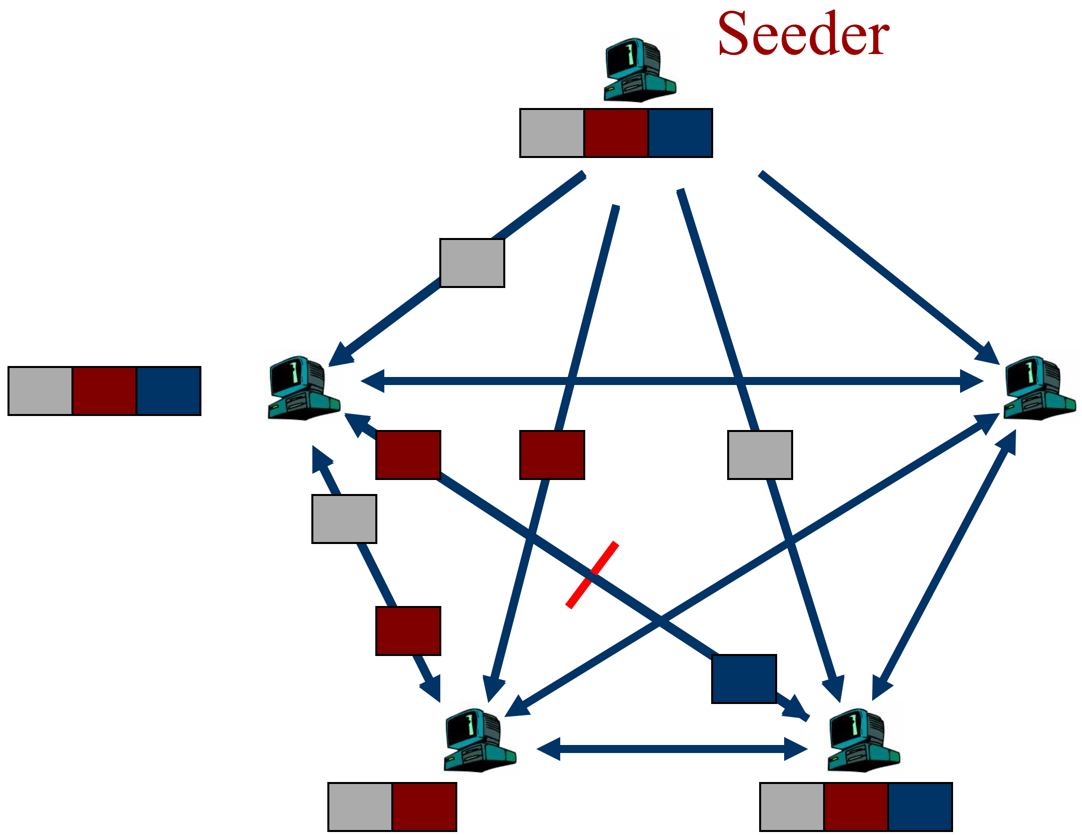
BitTorrent: Overview

- File swarming:
  - **Join**: contact centralized “tracker” server, get a list of peers.
  - **Publish**: Run a tracker server.
  - **Search**: Out-of-band. E.g., use Google to find a tracker for the file you want.
  - **Fetch**: Download chunks of the file from your peers. Upload chunks you have to them.
- Big differences from Napster:
  - Chunk based downloading
  - “few large files” focus
  - Anti-freeloading mechanisms
  - Out-of-band with search engines scalable and resilient

BitTorrent: Publish/Join



BitTorrent: Fetch



BitTorrent: Sharing Strategy

- Employ “Tit-for-tat” sharing strategy
  - A is downloading from some other people
    - A will let the fastest N of those download from it
  - Be optimistic: occasionally let freeloaders download
    - *Optimistic unchoke*
    - Otherwise no one would ever start!
    - Also allows you to discover better peers to download from when they reciprocate
  - Rarest first policy: distribute rare blocks first

- Goal: Pareto Efficiency
  - Game Theory: “No change can make anyone better off without making others worse off”
  - Does it work? How would you cheat?
  - (not perfectly, but perhaps good enough?)

BitTorrent: Summary

- Pros:
  - Works reasonably well in practice
  - Gives peers incentive to share resources; avoids freeloaders
- Cons:
  - Pareto Efficiency claim is not true ... a lie
  - Central tracker server needed to bootstrap swarm
    - Alternate tracker designs exist (e.g., DHT-based trackers)

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- P2P Lookup Overview
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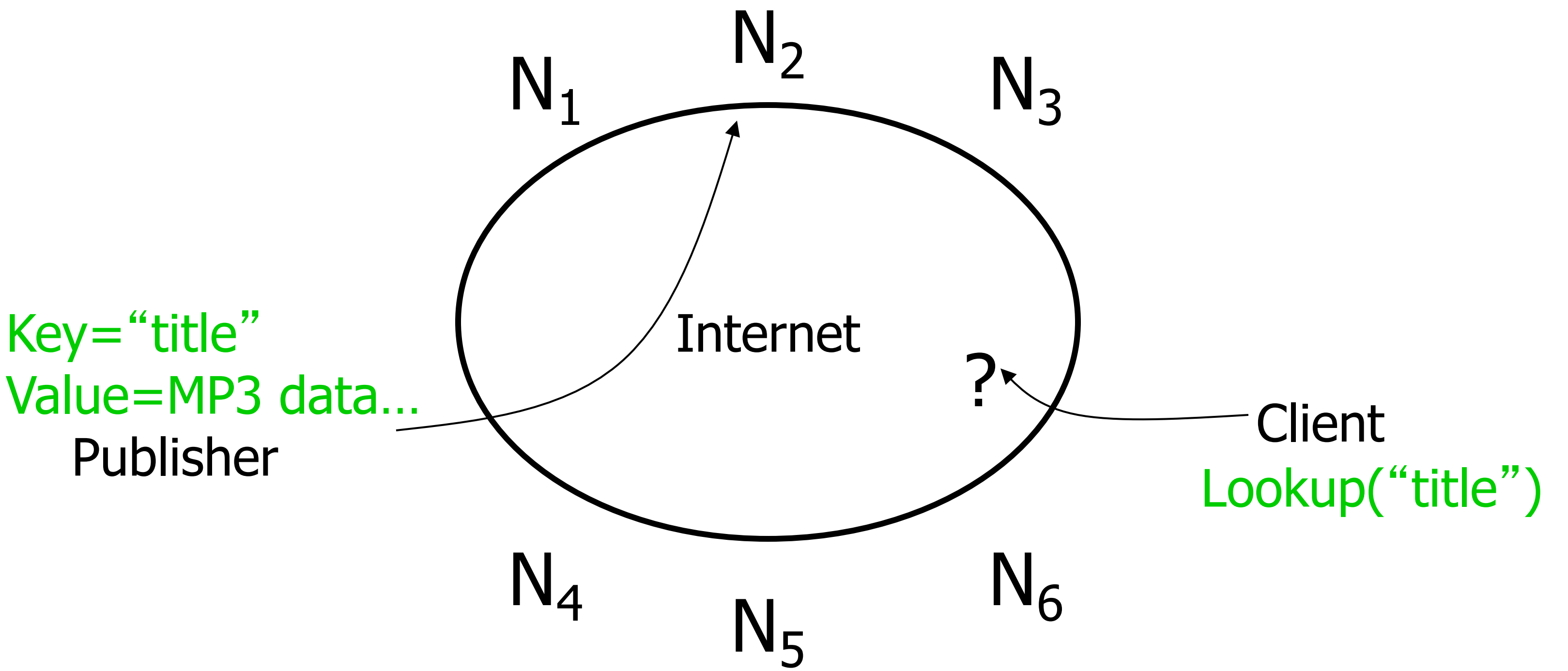
- BitTorent
- Routed Lookups (DHTs) – Chord (another example: Kademlia)

The Lookup Problem



DHT: Overview (1)

- Goal: make sure that an item (file) identified is always found in a reasonable # of steps
- Abstraction: a distributed hash-table (DHT) data structure
  - insert(id, item);
  - item = query(id);
  - Note: item can be anything: a data object, document, file, pointer to a file…
- Implementation: nodes in system form a distributed data structure
  - Can be Ring, Tree, Hypercube, Skip List, Butterfly Network, ...

DHT: Overview (2)

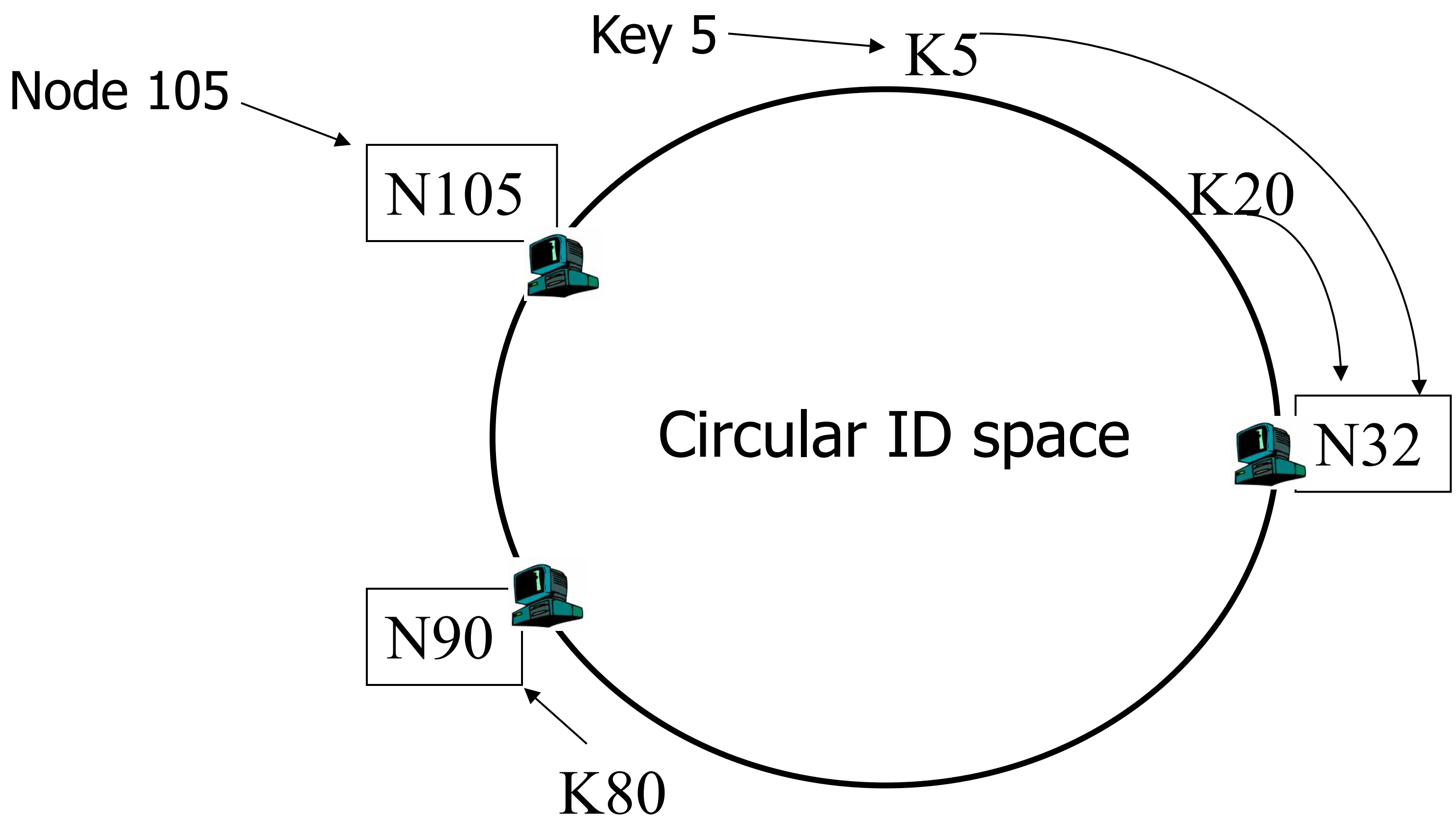
- *Structured* Overlay Routing:
  - Usually builds on *consistent hashing:*
    - *Items and nodes are hased into the same ID space*
  - **Join**: On startup, contact a "bootstrap" node and integrate yourself into the distributed data structure; get a *node id*
  - **Publish**: Route publication for *file id* toward a close *node id* along the data structure
  - **Search**: Route a query for file id toward a close node id. Data structure guarantees that query will meet the publication.
  - **Fetch**: Two options:
    - Publication contains actual file => fetch from where query stops
    - (Indirection) Publication says "I have file X" => query tells you 128.2.1.3 has X, use IP routing to get X from 128.2.1.3

DHT: Example - Chord

- Associate to each node and file a unique *id* in an *uni*-dimensional space (a Ring)
  - E.g., pick from the range $[0...2^m]$
  - Usually the hash of the file or IP address
- Routing properties:
  - Routing table size is O(log *N*) , where *N* is the total number of nodes
  - Guarantees that a file is found in O(log *N*) hops

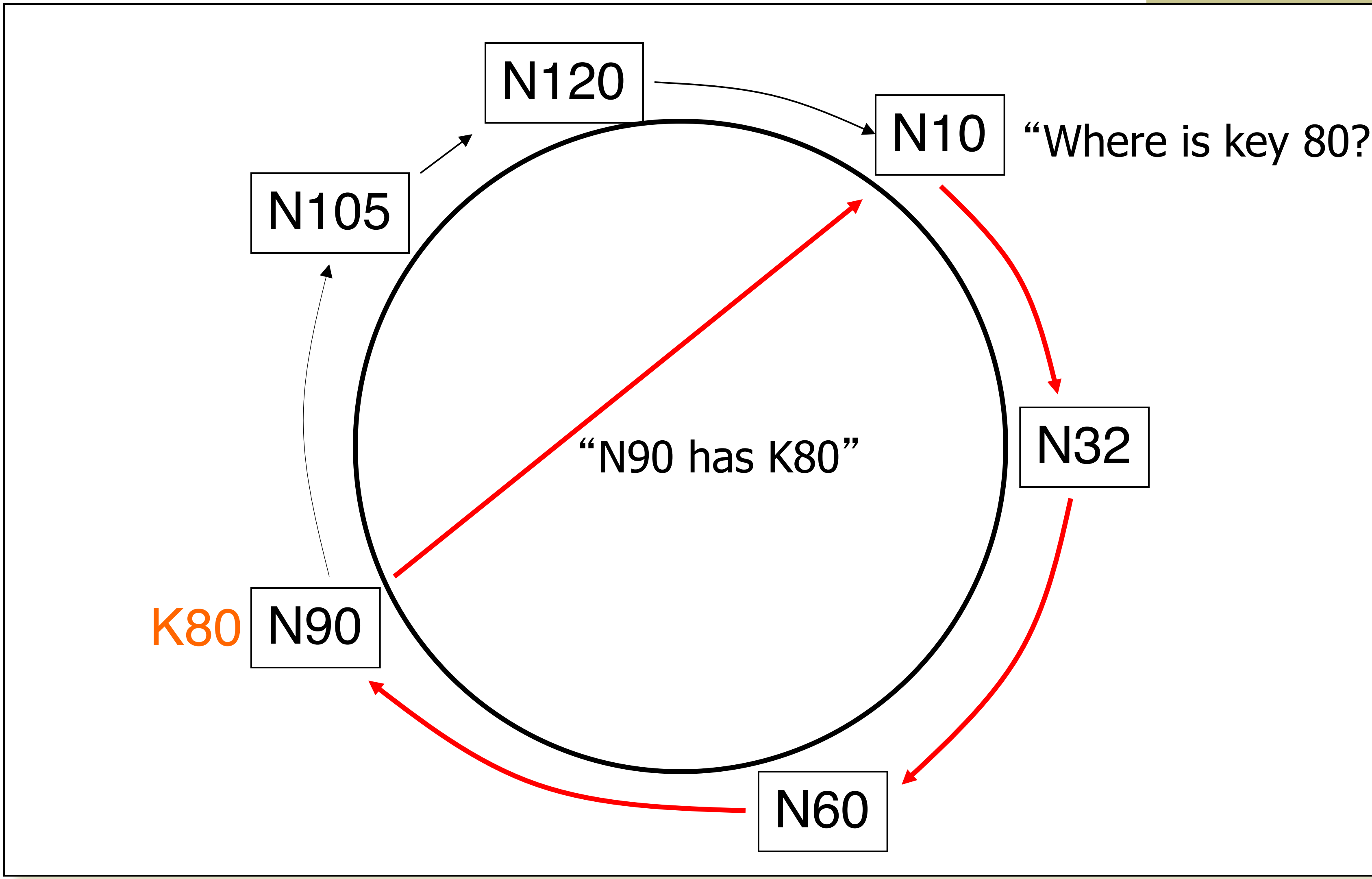
from MIT in 2001

DHT: Consistent Hashing



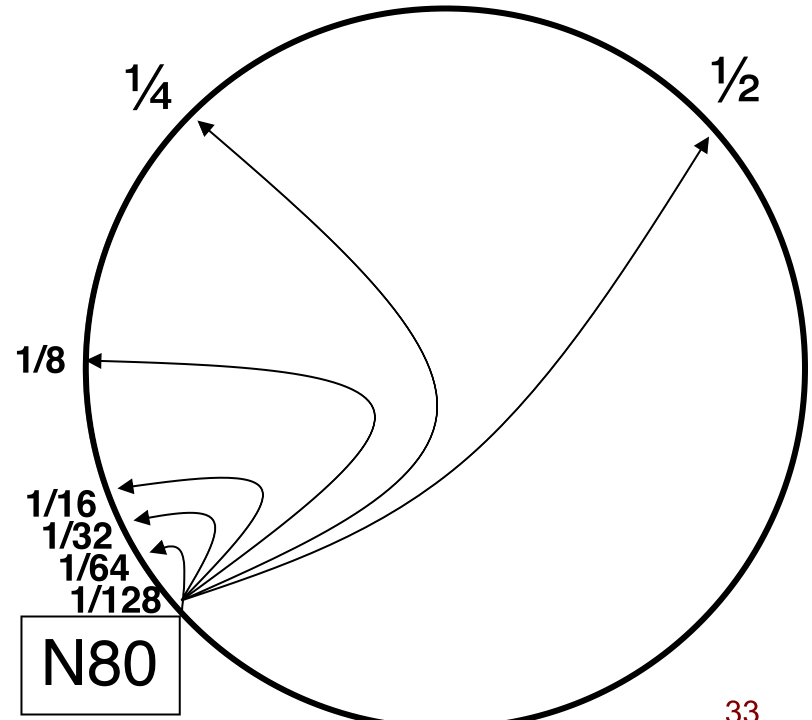
A key is stored at its successor: node with next higher ID

Routing: Chord Basic Lookup



Chord: finger tables (fast lookup)

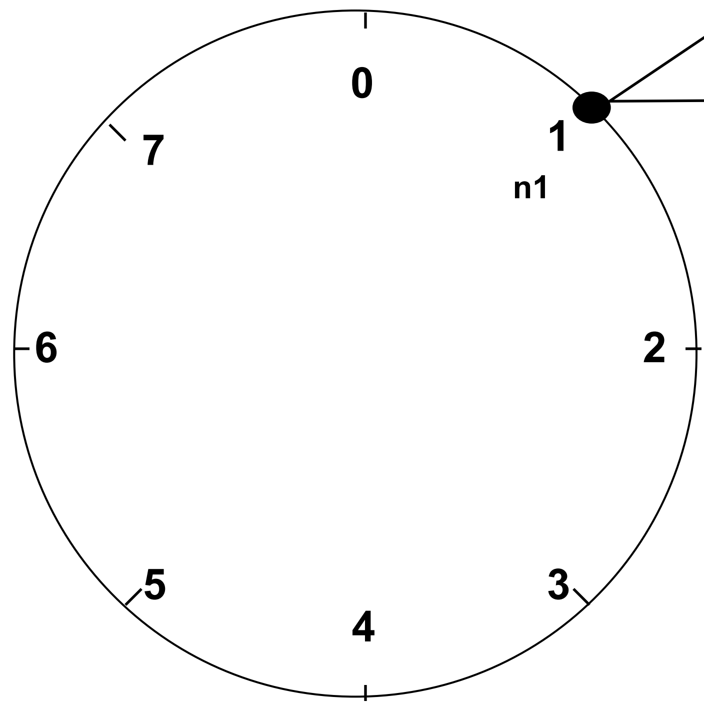
- Assume identifier space is $0 \ldots 2^m$
- Each node maintains
  - Finger table
    - Entry *i* in the finger table of *n* is the first node that succeeds or equals $n + 2^i$
  - Predecessor node
- An item identified by *id* is stored on the successor node of *id*



Routing: Chord Example

- Assume an identifier space 0..7

- Node n1:(1) joins→all entries in its finger table are initialized to itself

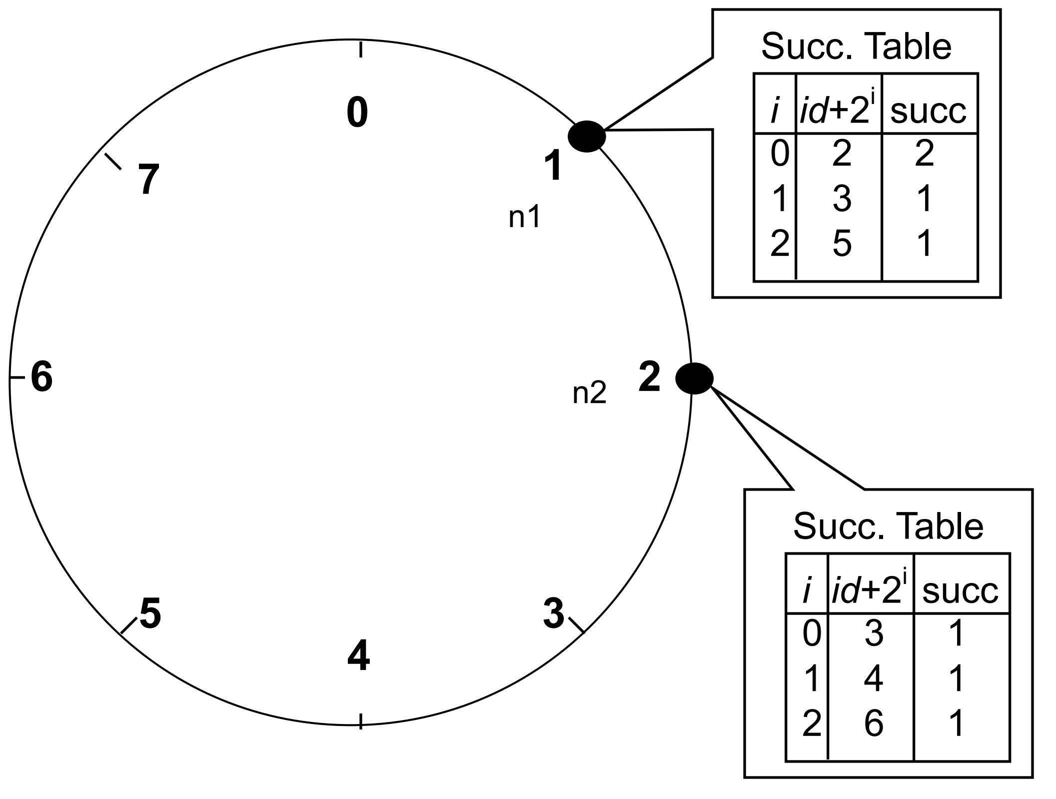


Succ. Table

i	$id+2^i$	succ
0	2	1
1	3	1
2	5	1

Routing: Chord Example

- Node n2(2) joins



Succ. Table (n1)

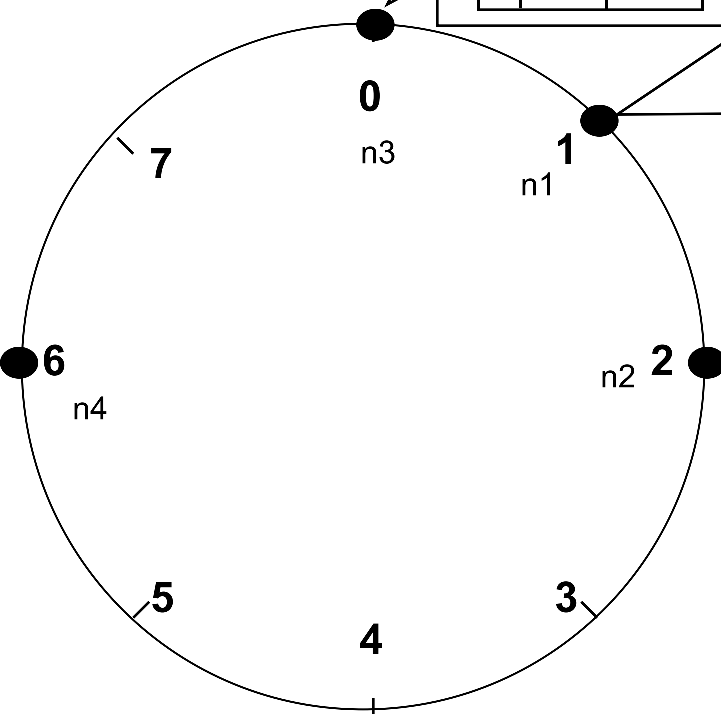
i	$id+2^i$	succ
0	2	2
1	3	1
2	5	1

Succ. Table (n2)

i	$id+2^i$	succ
0	3	1
1	4	1
2	6	1

Routing: Chord Example

- Nodes n3:(0), n4:(6) join



Succ. Table

i	$id+2^i$	succ
0	1	1
1	2	2
2	4	6

Succ. Table

i	$id+2^i$	succ
0	2	2
1	3	6
2	5	6

Succ. Table

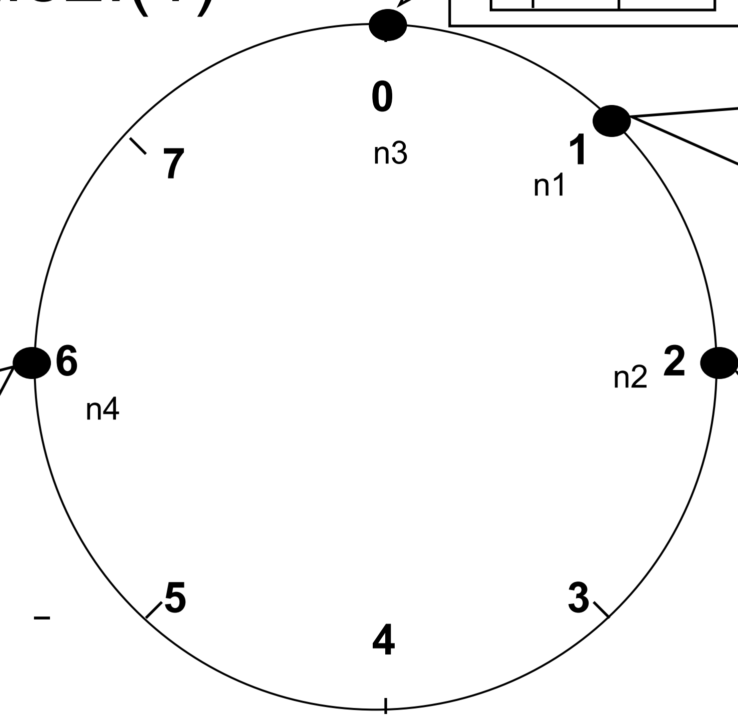
i	$id+2^i$	succ
0	7	0
1	0	0
2	2	2

Succ. Table

i	$id+2^i$	succ
0	3	6
1	4	6
2	6	6

Routing: Chord Examples

- Nodes: n1:(1), n2(2), n3(0), n4(6)
- Items: file1:(7), file2:(1)



Node 0 (n3):

Succ. Table

i	$id+2^i$	succ
0	1	1
1	2	2
2	4	6

Items: 7

Node 1 (n1):

Succ. Table

i	$id+2^i$	succ
0	2	2
1	3	6
2	5	6

Items: 1

Node 2 (n2):

Succ. Table

i	$id+2^i$	succ
0	3	6
1	4	6
2	6	6

Node 6 (n4):

Succ. Table

i	$id+2^i$	succ
0	7	0
1	0	0
2	2	2

Routing: Query

- Upon receiving a query for item *id*, a node
  - Check whether stores the item locally
  - If not, forwards the query to the largest node in its successor table that does not exceed *id*

Node 0:

i	*id*+2^i	succ
0	1	1
1	2	2
2	4	6

Items: 7

Node 1:

i	*id*+2^i	succ
0	2	2
1	3	6
2	5	6

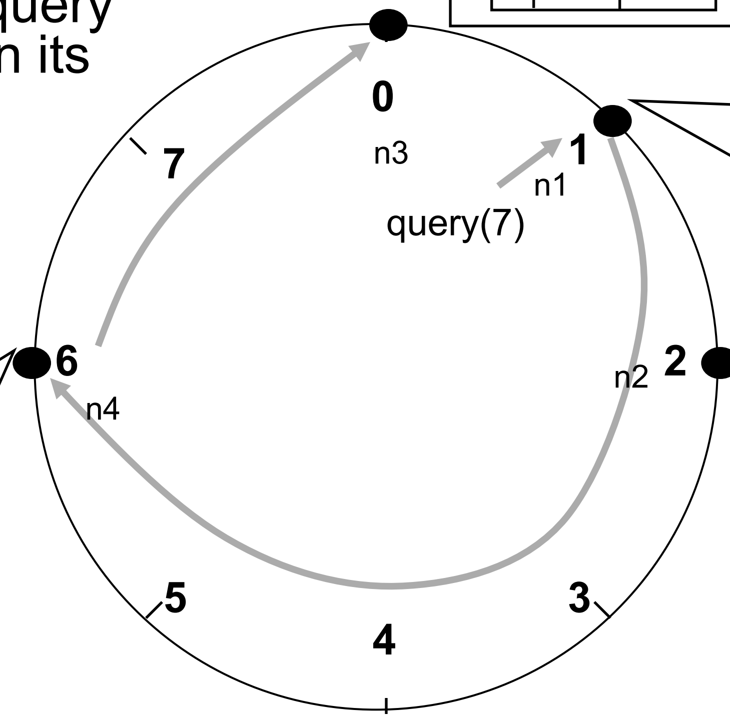
Items: 1

Node 6:

i	*id*+2^i	succ
0	7	0
1	0	0
2	2	2

Node 2:

i	*id*+2^i	succ
0	3	6
1	4	6
2	6	6



DHT: Chord Summary

- Routing table size?
  - Log *N* fingers
- Routing time?
  - Each hop expects to 1/2 the distance to the desired id => expect O(log *N*) hops.
- Pros:
  - Guaranteed Lookup
  - O(log *N*) per node state and search scope
  - Influenced many future systems; esp. key-val stores
- Cons:
  - No one uses them? (BitTorrent somewhat)
  - Supporting non-exact match search is hard

What can DHTs do for us?

- Distributed object lookup
  - Based on object ID
- De-centralized file systems
  - CFS, PAST, Ivy
- Application Layer Multicast
  - Scribe, Bayeux, Splitstream
- Databases
  - PIER

When are p2p / DHTs useful?

- Caching and “soft-state” data
  - Works well! BitTorrent, KaZaA, etc., all use peers as caches for hot *read-only* data
- Finding read-only data
  - Limited flooding finds hay
  - DHTs find needles
- BUT

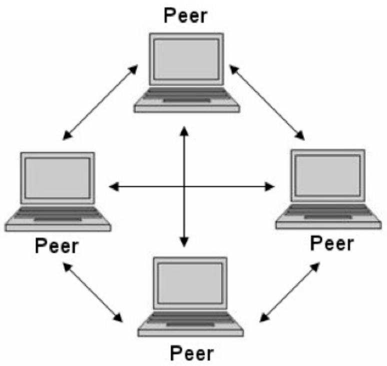
A Peer-to-peer Google ?

- Complex intersection queries (“the” + “who”)
  - Billions of hits for each term alone
- Sophisticated ranking
  - Must compare many results before returning a subset to user
- Very, very hard for a DHT / p2p system
  - Need high inter-node bandwidth
  - (This is exactly what Google does - massive clusters)

Writable, persistent p2p

- Do you trust your data to 100,000 monkeys?
- Node availability hurts
  - Ex: Store 5 copies of data on different nodes
  - When someone goes away, you must replicate the data they held
  - Hard drives are *huge*, but edge network upload bandwidth is tiny
  - May take days to upload contents of a hard drive. P2P replication/fault-tolerance expensive.

P2P: Summary



- Many different styles; remember pros and cons of each
  - centralized, flooding, swarming, and structured routing
- Lessons learned:
  - Single points of failure are very bad
  - Flooding messages to everyone is bad
  - Underlying network topology is important
  - Not all nodes are equal
  - Need incentives to discourage freeloading
  - Privacy and security are important
  - Structure can provide theoretical bounds and guarantees