CSCI-1680
Some Alternatives

Rodrigo Fonseca

Based partly on lecture notes by Scott Shenker and John Jannotti

Alternatives

- **P2P**
  - Focus on scalable routing on flat names
- **Erasure Coding**
  - Alternative to ACK-based reliability
- **Information-Centric Networking**
  - Alternative to pair-based communication

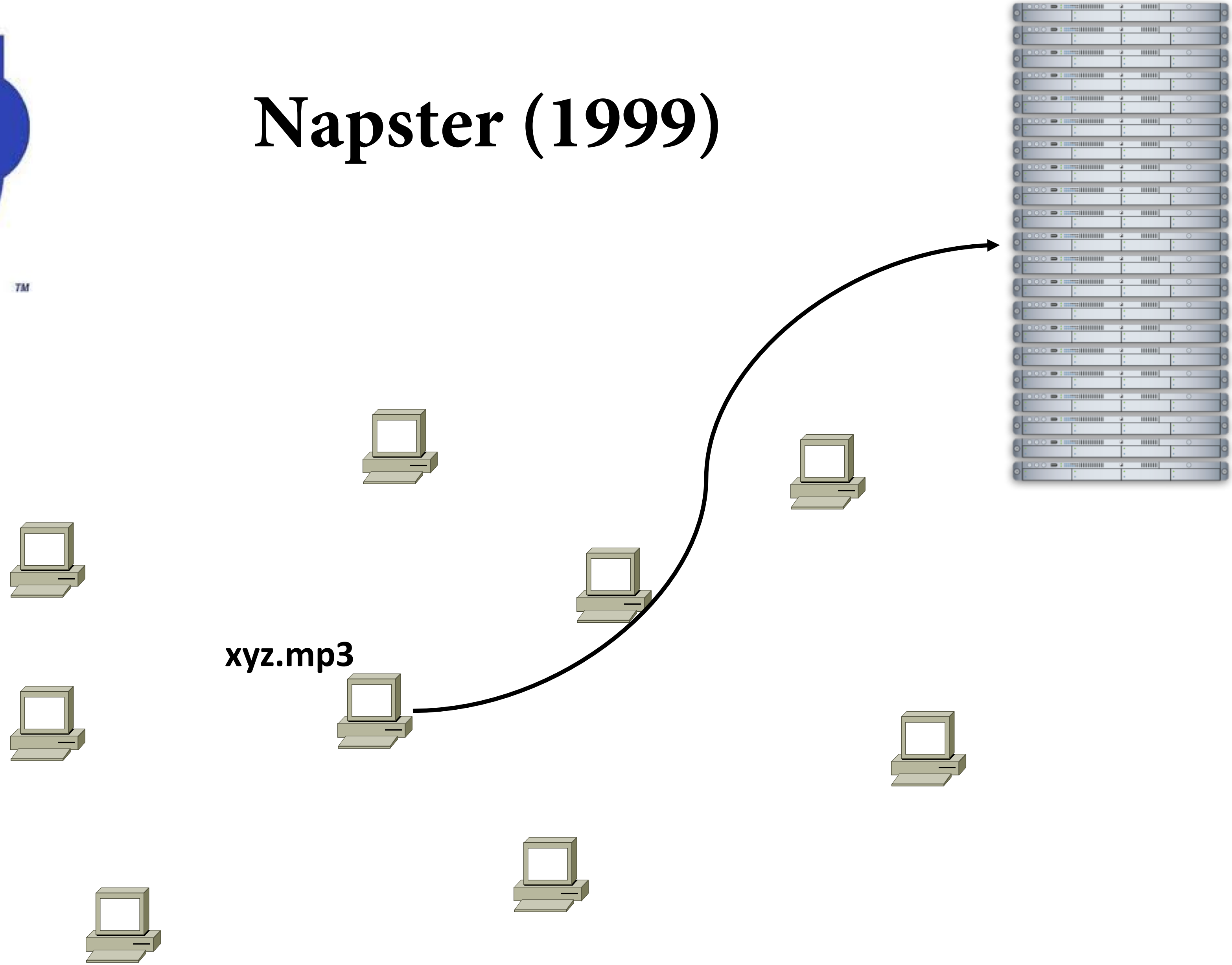
Peer-to-Peer Systems

- **How did it start?**
  - A killer application: file distribution
  - Free music over the Internet! (*not exactly legal…*)
- **Key idea: share storage, content, and bandwidth of individual users**
  - Lots of them
- **Big challenge: coordinate all of these users**
  - In a scalable way (not NxN!)
  - With changing population (aka *churn*)
  - With no central administration
  - With no trust
  - With large heterogeneity (content, storage, bandwidth,…)

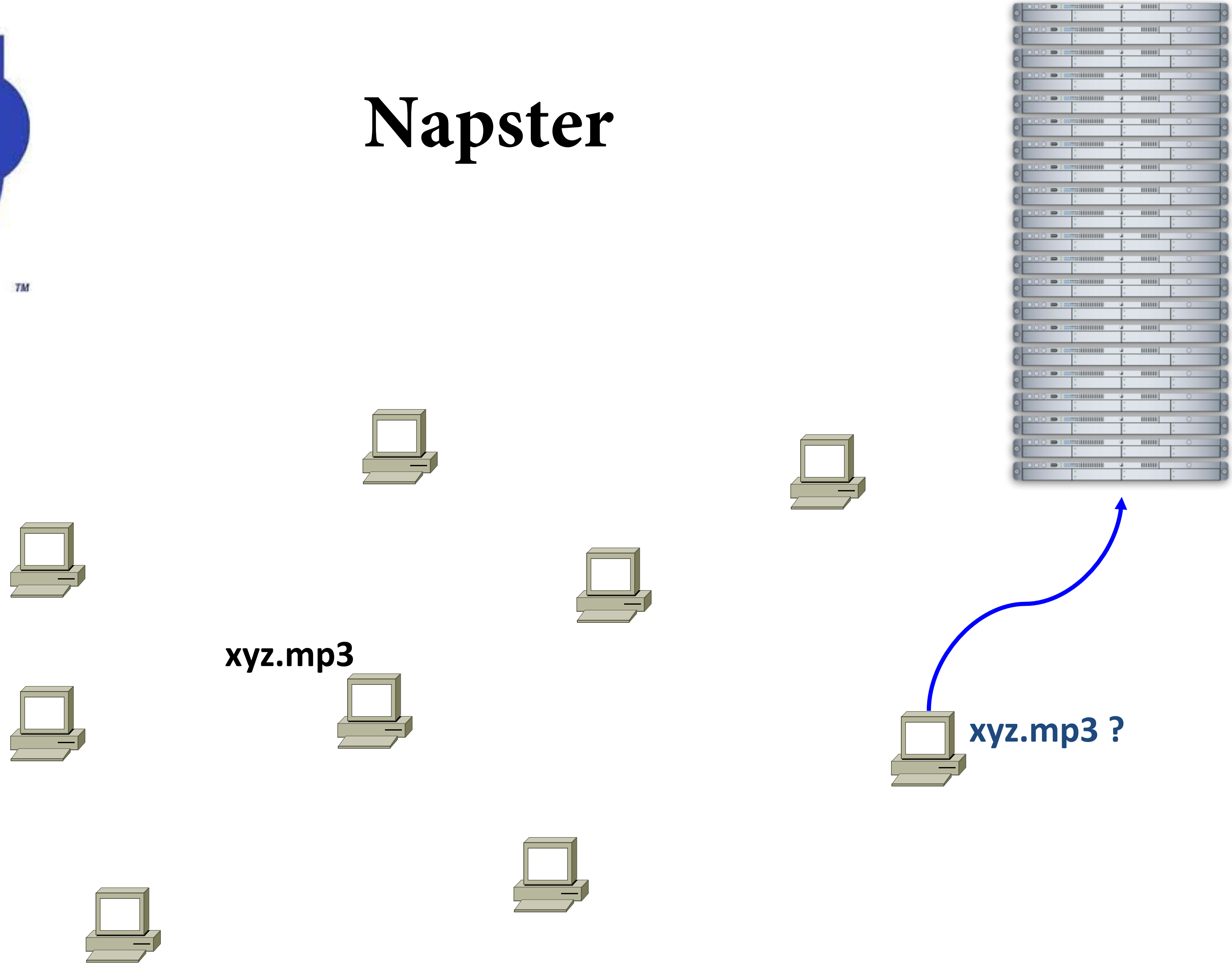
3 Key Requirements

- **P2P Systems do three things:**
- **Help users determine what they want**
  - Some form of search
  - P2P version of Google
- **Locate that content**
  - Which node(s) hold the content?
  - P2P version of DNS (map name to location)
- **Download the content**
  - Should be efficient
  - P2P form of Akamai

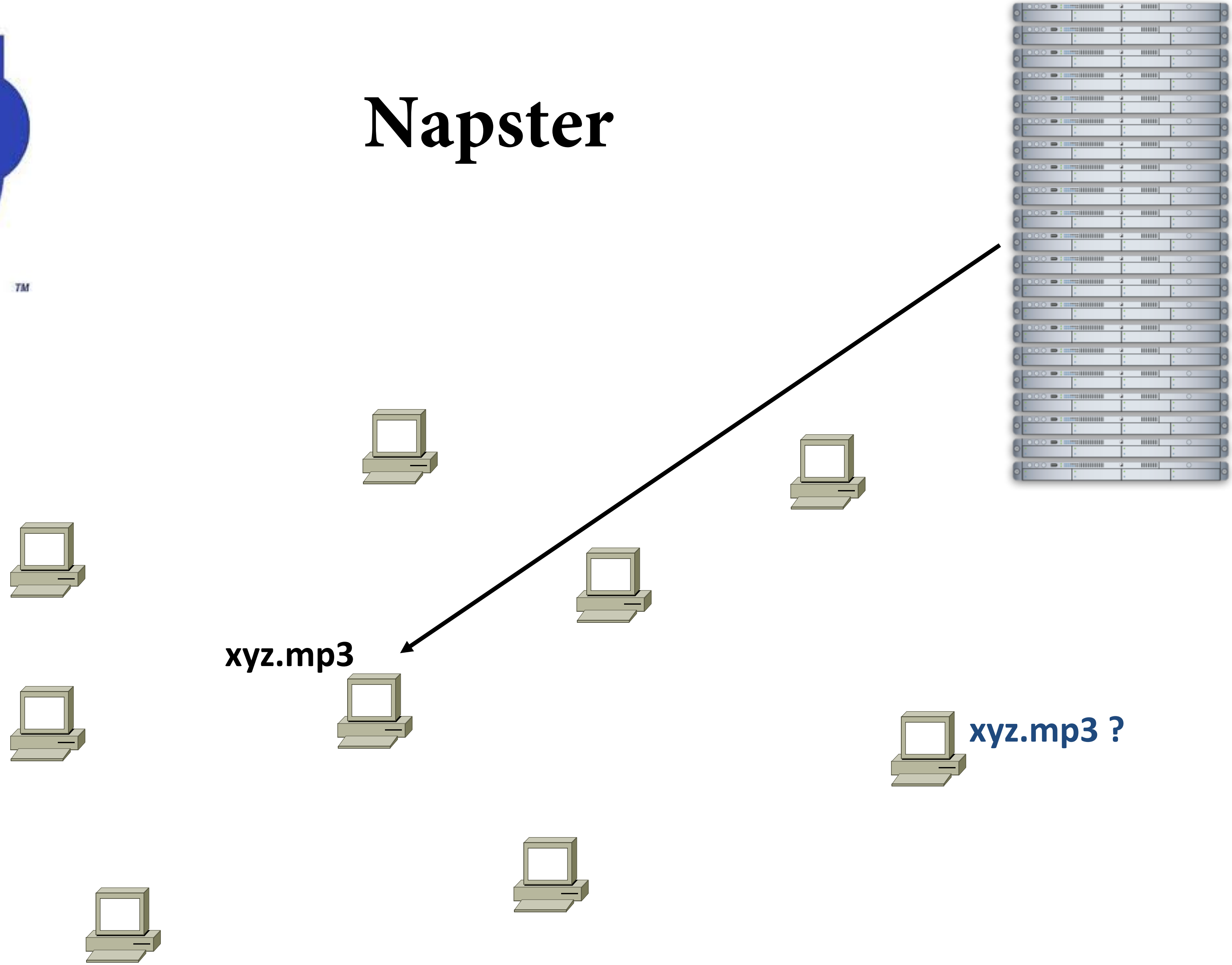
Napster (1999)



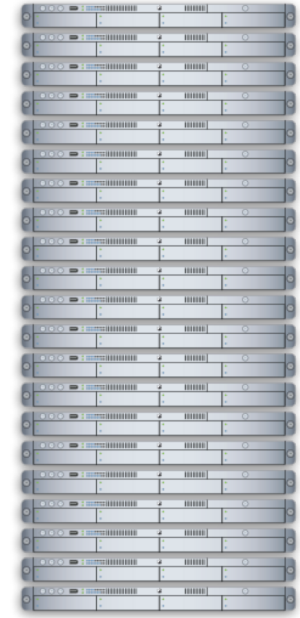
Napster

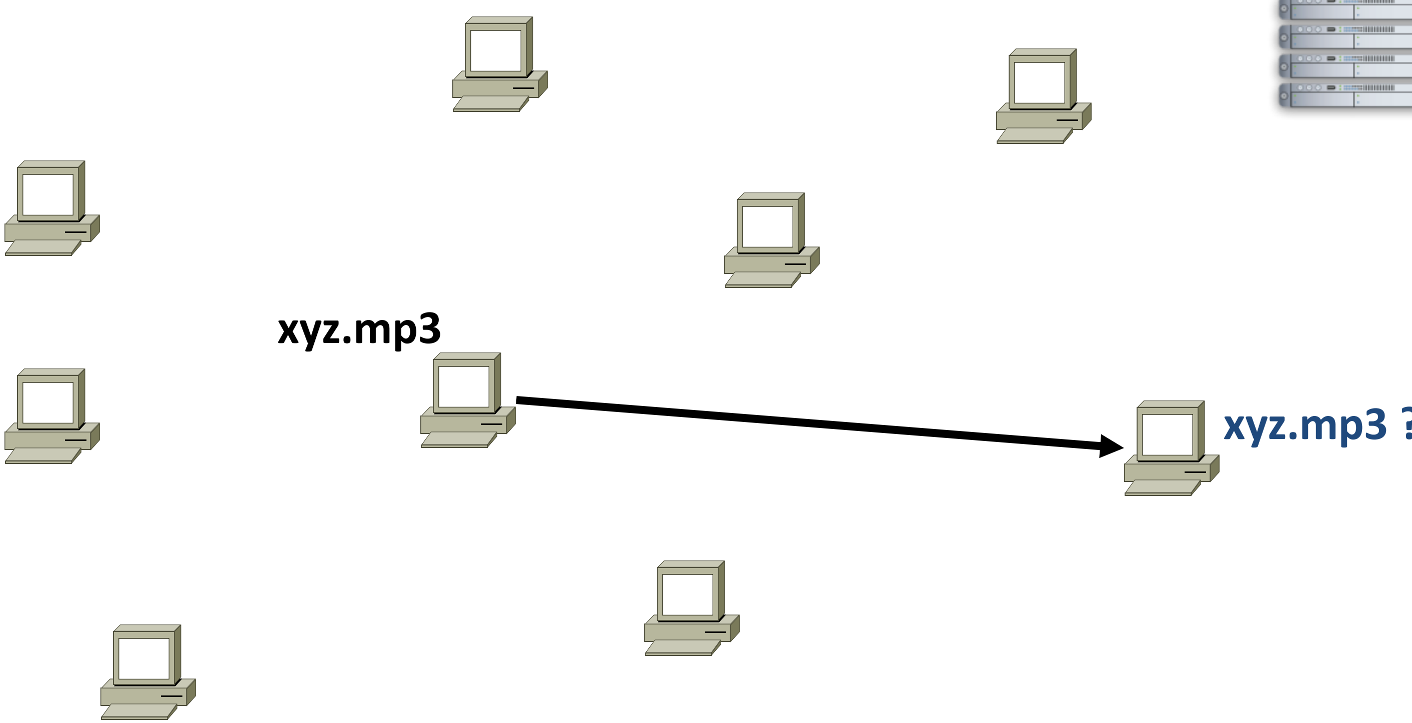


Napster



Napster



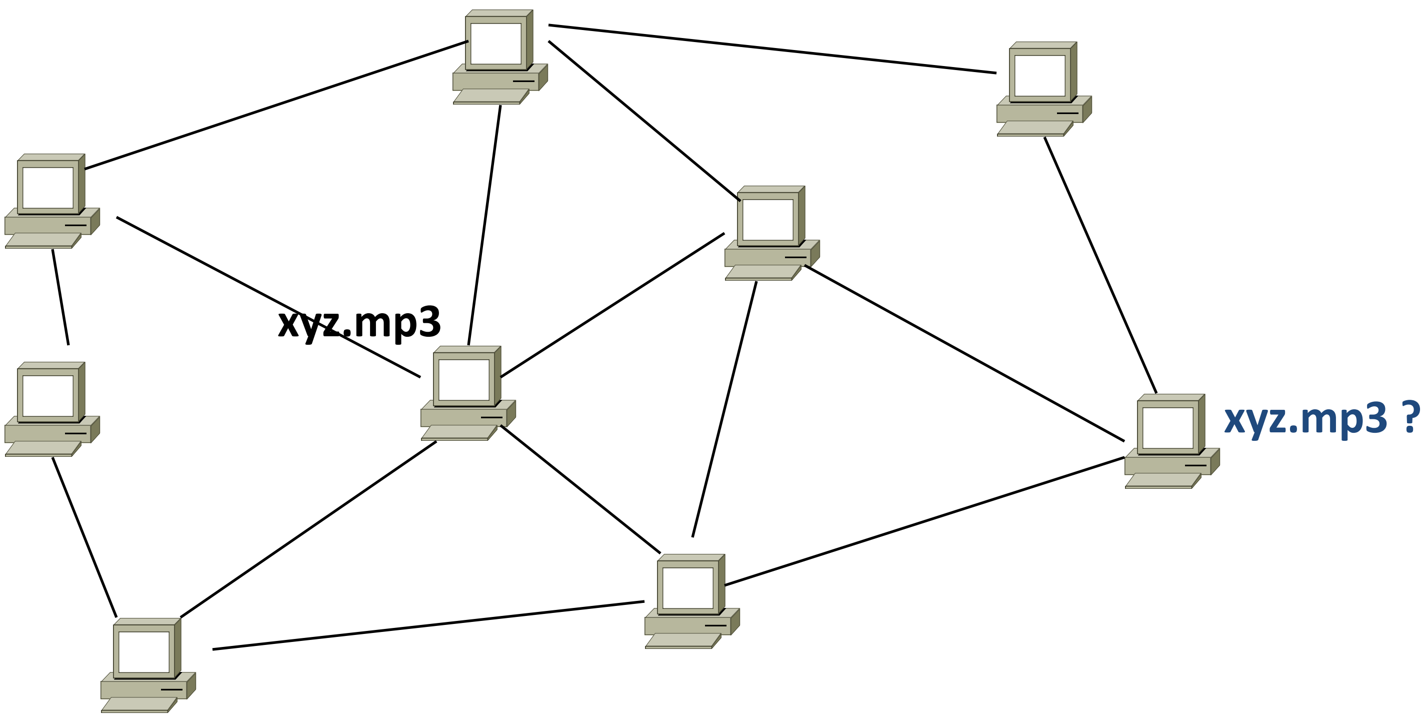


Napster

- **Search & Location: central server**
- **Download: contact a peer, transfer directly**
- **Advantages:**
  - Simple, advanced search possible
- **Disadvantages:**
  - Single point of failure (technical and … legal!)
  - The latter is what got Napster killed

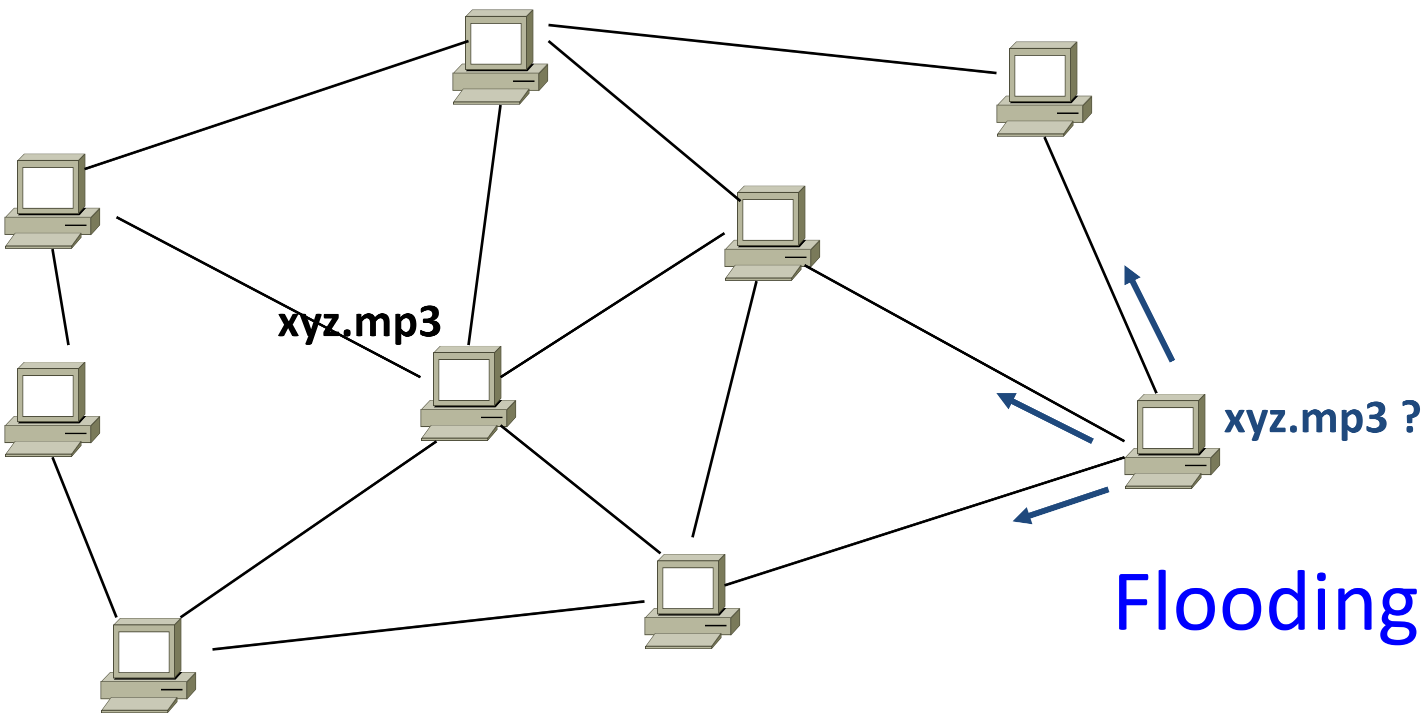
Gnutella: Flooding on Overlays (2000)

- **Search & Location: flooding (with TTL)**
- **Download: direct**

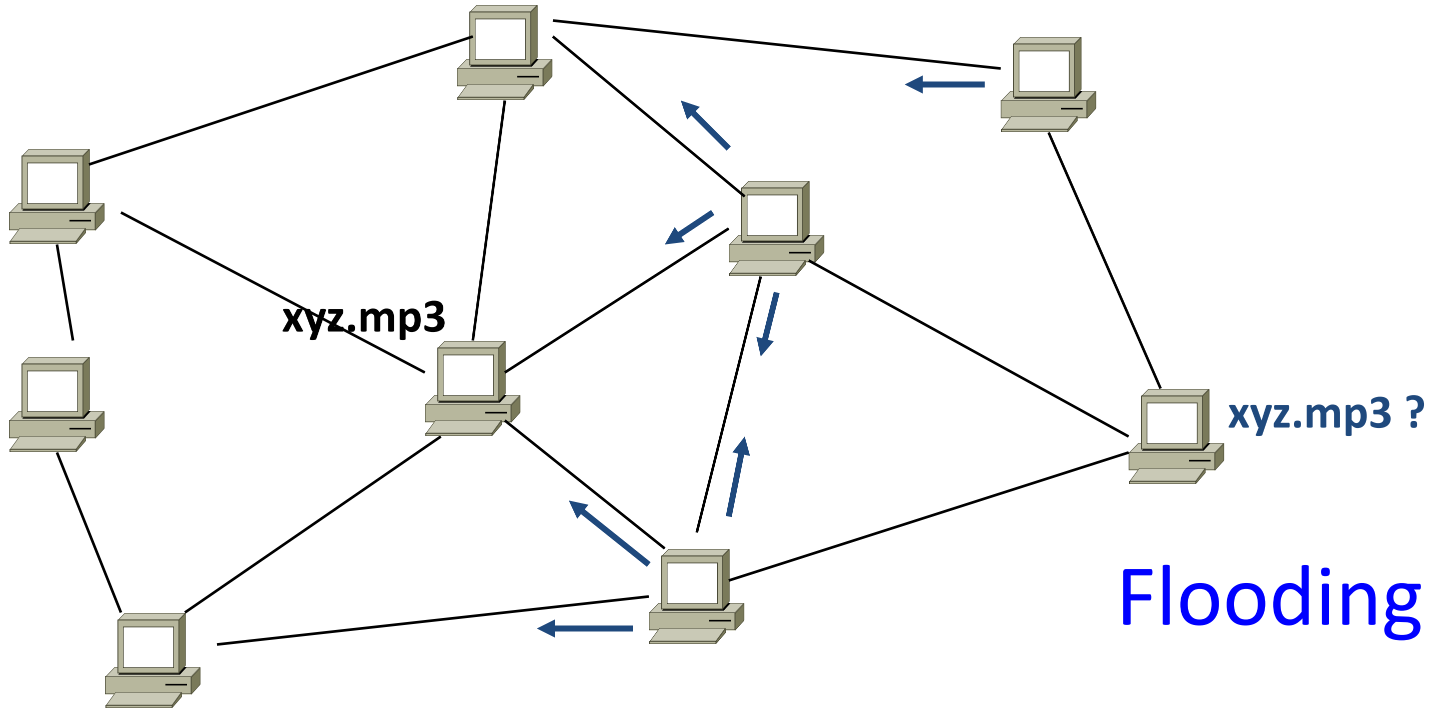


An "unstructured" *overlay network*

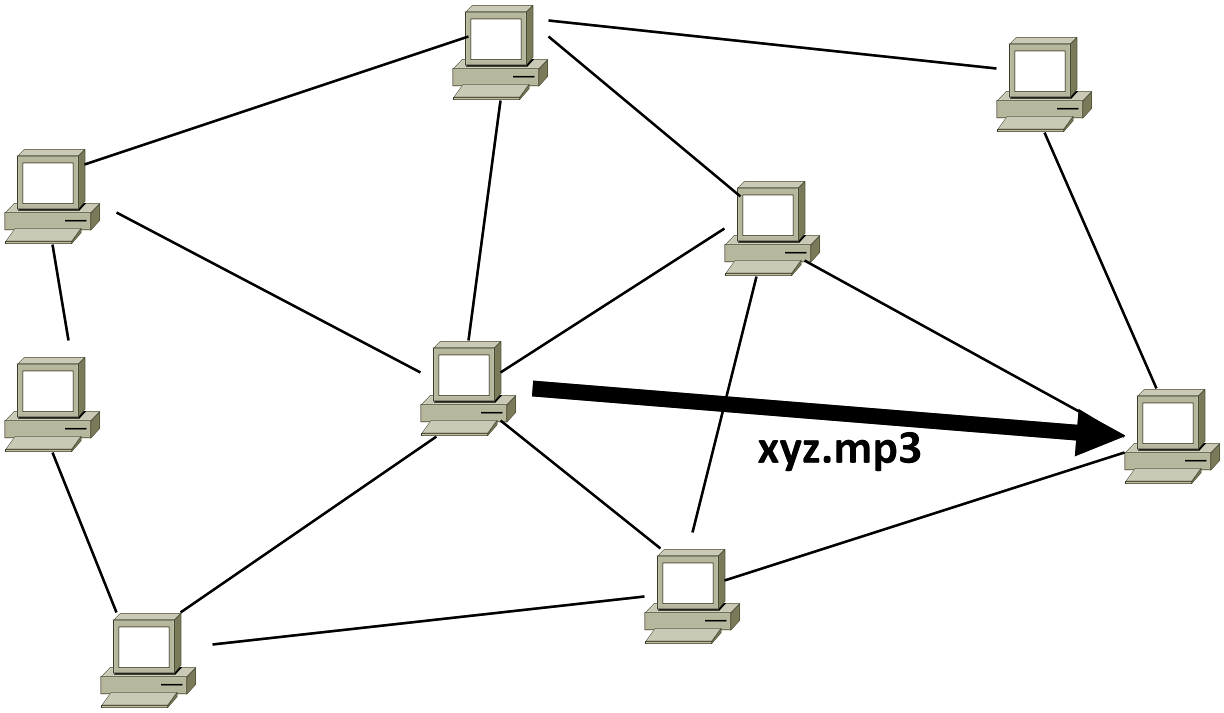
Gnutella: Flooding on Overlays



Gnutella: Flooding on Overlays

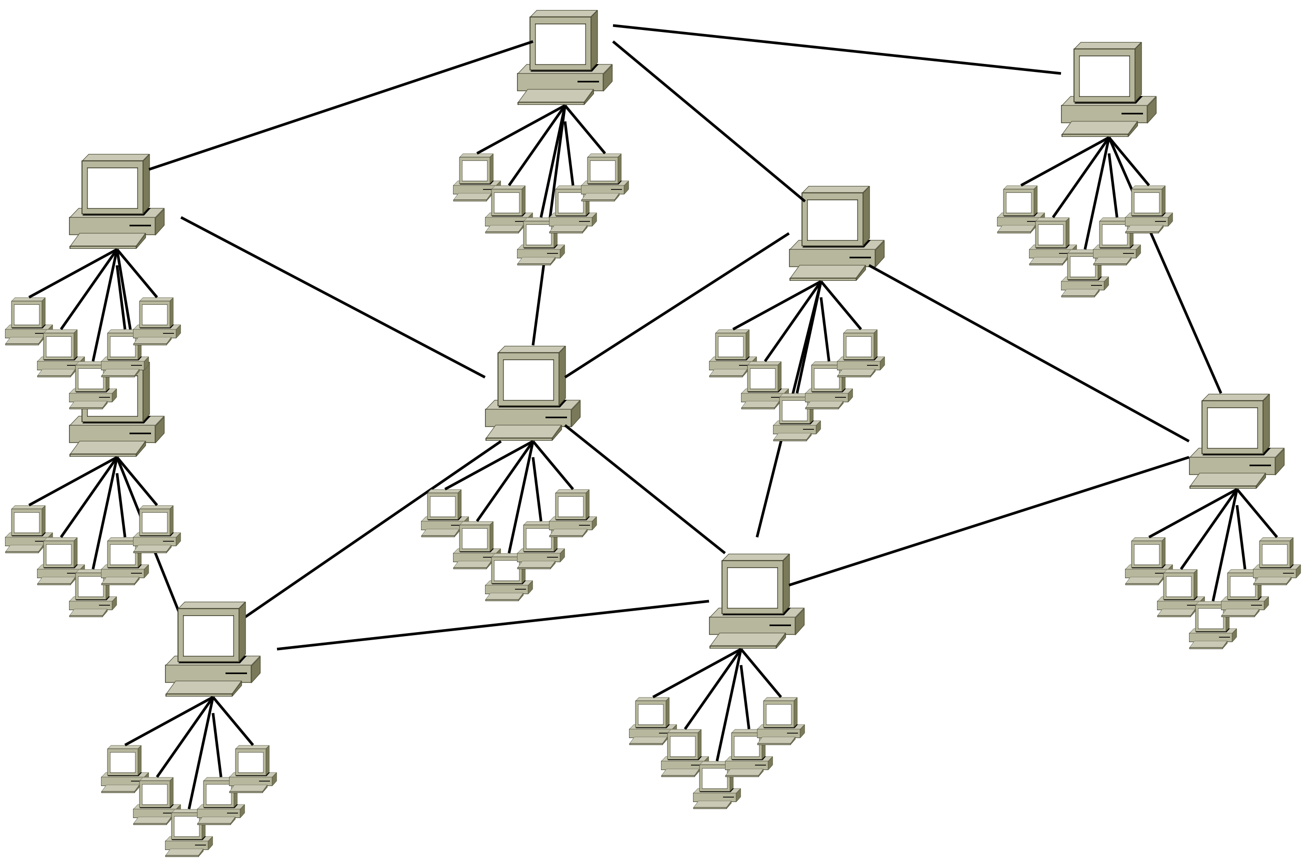


Gnutella: Flooding on Overlays



KaZaA: Flooding w/ Super Peers (2001)

- **Well connected nodes can be installed (KaZaA) or self-promoted (Gnutella)**



Say you want to make calls among peers

- **You need to find who to call**
  - Centralized server for authentication, billing
- **You need to find where they are**
  - Can use central server, or a decentralized search, such as in KaZaA
- **You need to call them**
  - What if both of you are behind NATs? (only allow outgoing connections)
  - You could use another peer as a relay…

Skype

- **Built by the founders of KaZaA!**
- **Uses Superpeers for registering presence, searching for where you are**
- **Uses regular nodes, outside of NATs, as decentralized relays**
  - This is their killer feature
- **This morning, from my computer:**
  - 29,565,560 people online

Lessons and Limitations

- **Client-server performs well**
  - But not always feasible
- **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.)

BitTorrent (2001)

- **One big problem with the previous approaches**
  - Asymmetric bandwidth
- **BitTorrent (original design)**
  - Search: independent search engines (e.g. PirateBay, isoHunt)
    - Maps keywords -> .torrent file
  - Location: centralized *tracker* node per file
  - Download: chunked
    - File split into many pieces
    - Can download from many peers

BitTorrent

- **How does it work?**
  - Split files into large pieces (256KB ~ 1MB)
  - Split pieces into subpieces
  - Get peers from tracker, exchange info on pieces
- **Three-phases in download**
  - Start: get a piece as soon as possible (random)
  - Middle: spread pieces fast (rarest piece)
  - End: don't get stuck (parallel downloads of last pieces)

BitTorrent

- **Self-scaling: incentivize sharing**
  - If people upload as much as they download, system scales with number of users (no free-loading)
- **Uses *tit-for-tat*: only upload to those who give you data**
  - *Choke* most of your peers (don’t upload to them)
  - Order peers by download rate, choke all but P best
  - Occasionally unchoke a random peer (might become a nice uploader)
- **Optional reading:**

  [*Do Incentives Build Robustness in BitTorrent?* Piatek et al, NSDI’07]

Structured Overlays: DHTs

- **Academia came (a little later)…**
- **Goal: Solve efficient decentralized location**
  - Remember the second key challenge?
  - Given ID, map to host
- **Remember the challenges?**
  - Scale to millions of nodes
  - Churn
  - Heterogeneity
  - Trust (or lack thereof)
    - Selfish and malicious users

DHTs

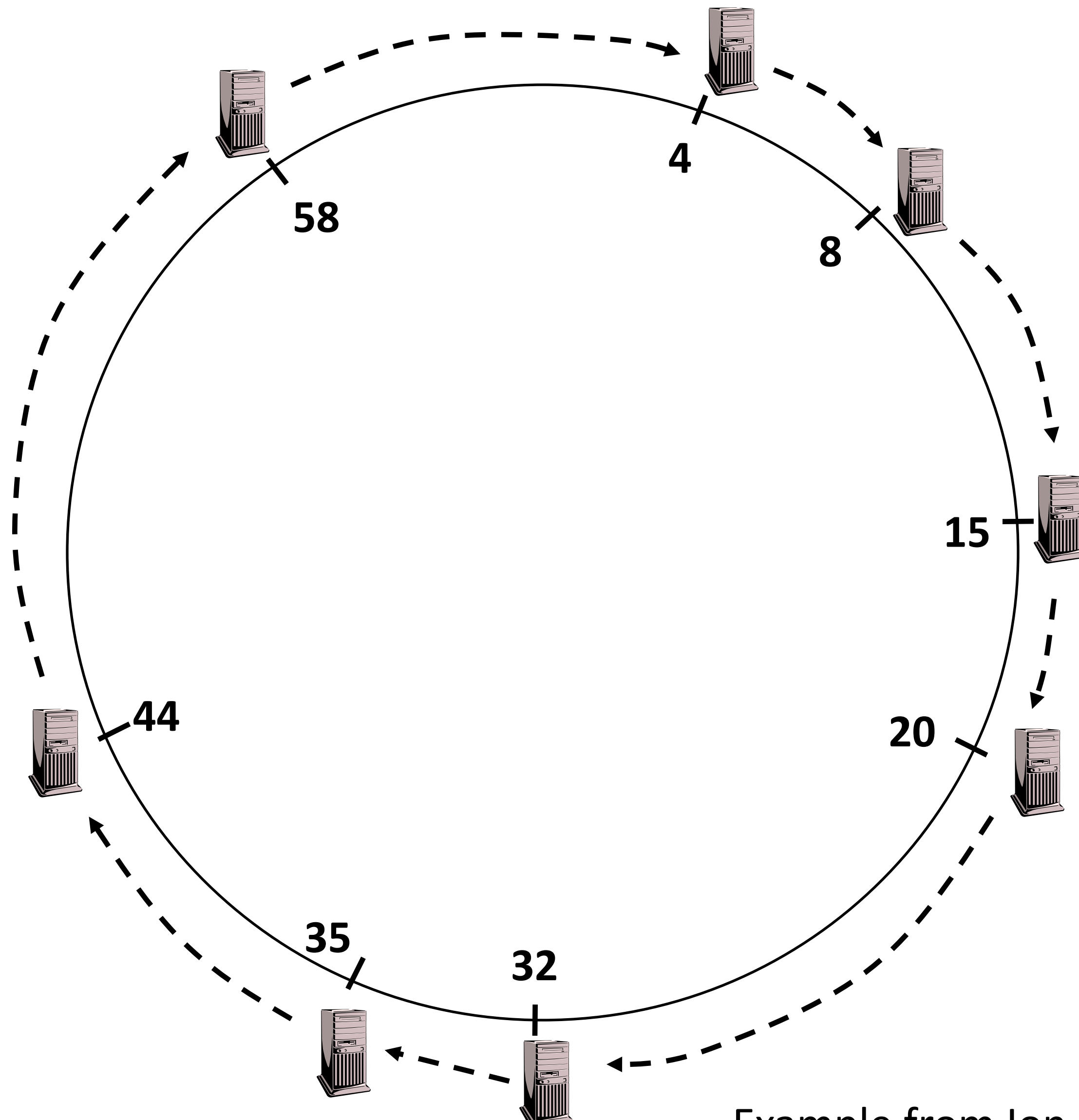
- **IDs from a *flat* namespace**
  - Contrast with hierarchical IP, DNS
- **Metaphor: hash table, but distributed**
- **Interface**
  - Get(key)
  - Put(key, value)
- **How?**
  - Every node supports a single operation:

    Given a *key*, route messages to node holding *key*

Identifier to Node Mapping Example

- Node 8 maps [5,8]
- Node 15 maps [9,15]
- Node 20 maps [16, 20]
- …
- Node 4 maps [59, 4]

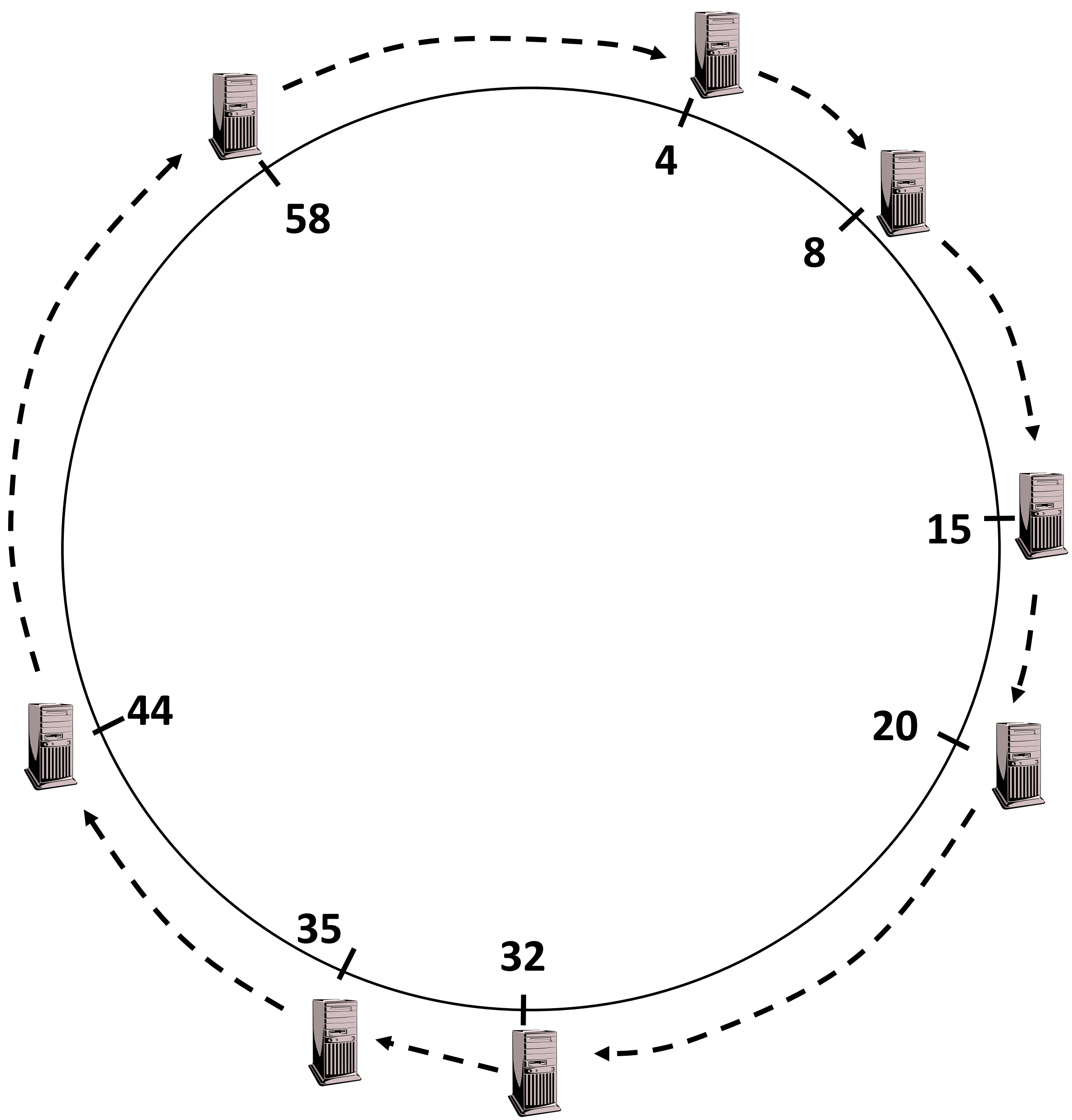
- Each node maintains a pointer to its successor



Example from Ion Stoica

Consistent Hashing-like

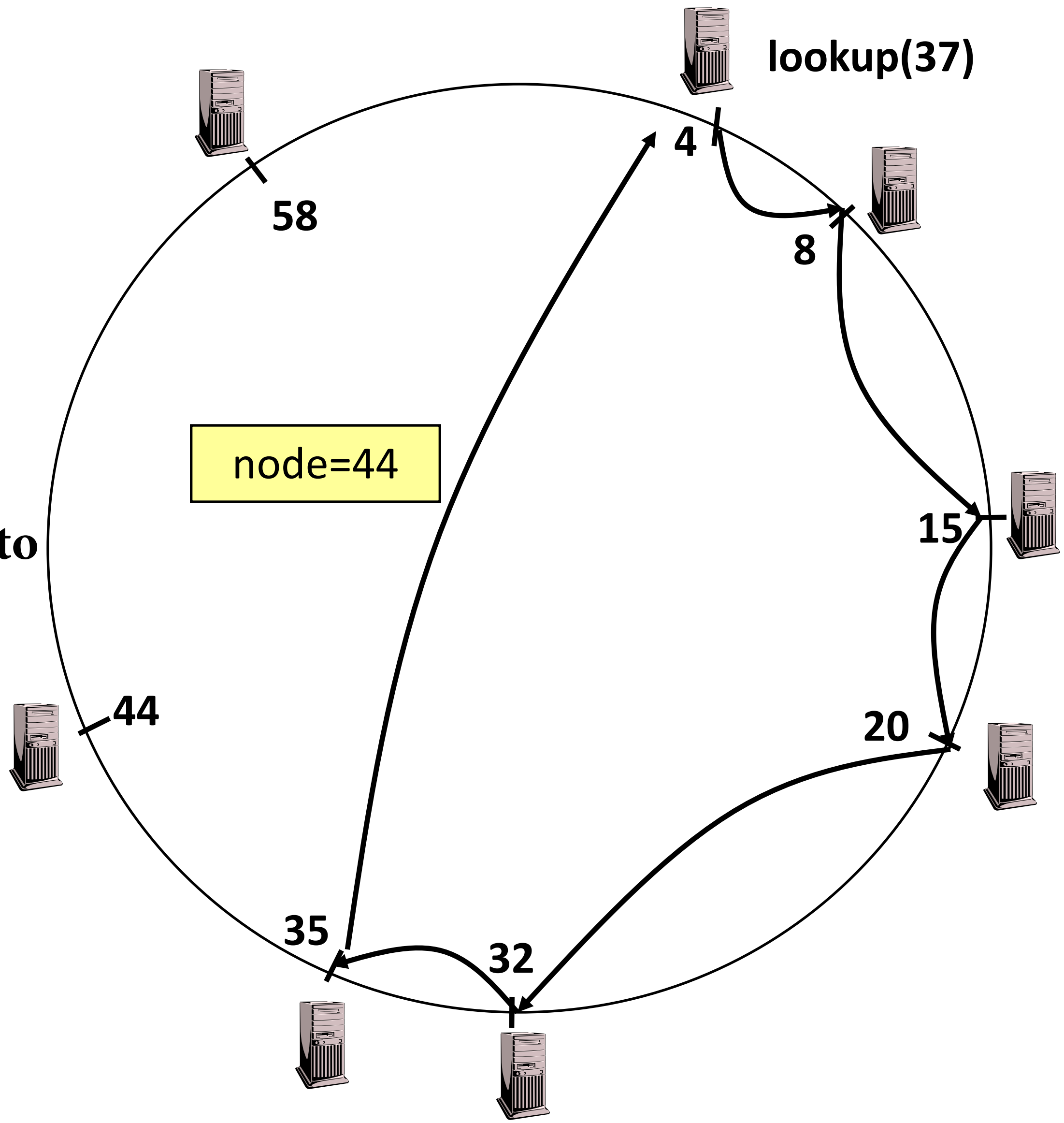
- **But each node only knows about a small number of other nodes (so far only their successors)**



Lookup

- Each node maintains its successor

- Route packet (ID, data) to the node responsible for ID using successor pointers



Optional: DHT Maintenance

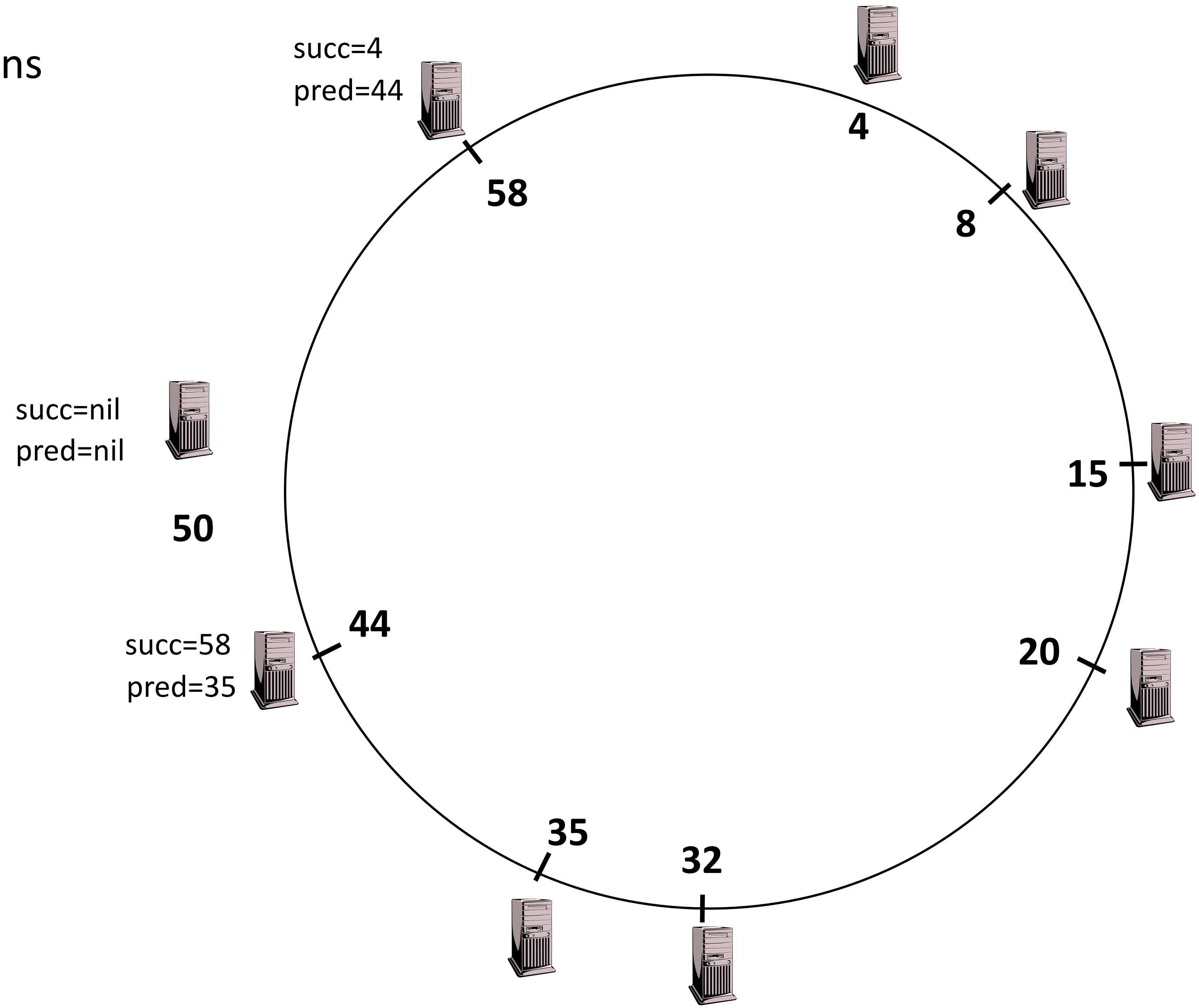
Stabilization Procedure

- **Periodic operations performed by each node N to maintain the ring:**

```
STABILIZE() [N.successor = M]
   N->M: "What is your predecessor?"
   M->N: "x is my predecessor"
   if x between (N,M), N.successor = x
   N->N.successor: NOTIFY()
NOTIFY()
    N->N.successor: "I think you are my successor"
M: upon receiving NOTIFY from N:
    If (N between (M.predecessor, M))
        M.predecessor = N
```

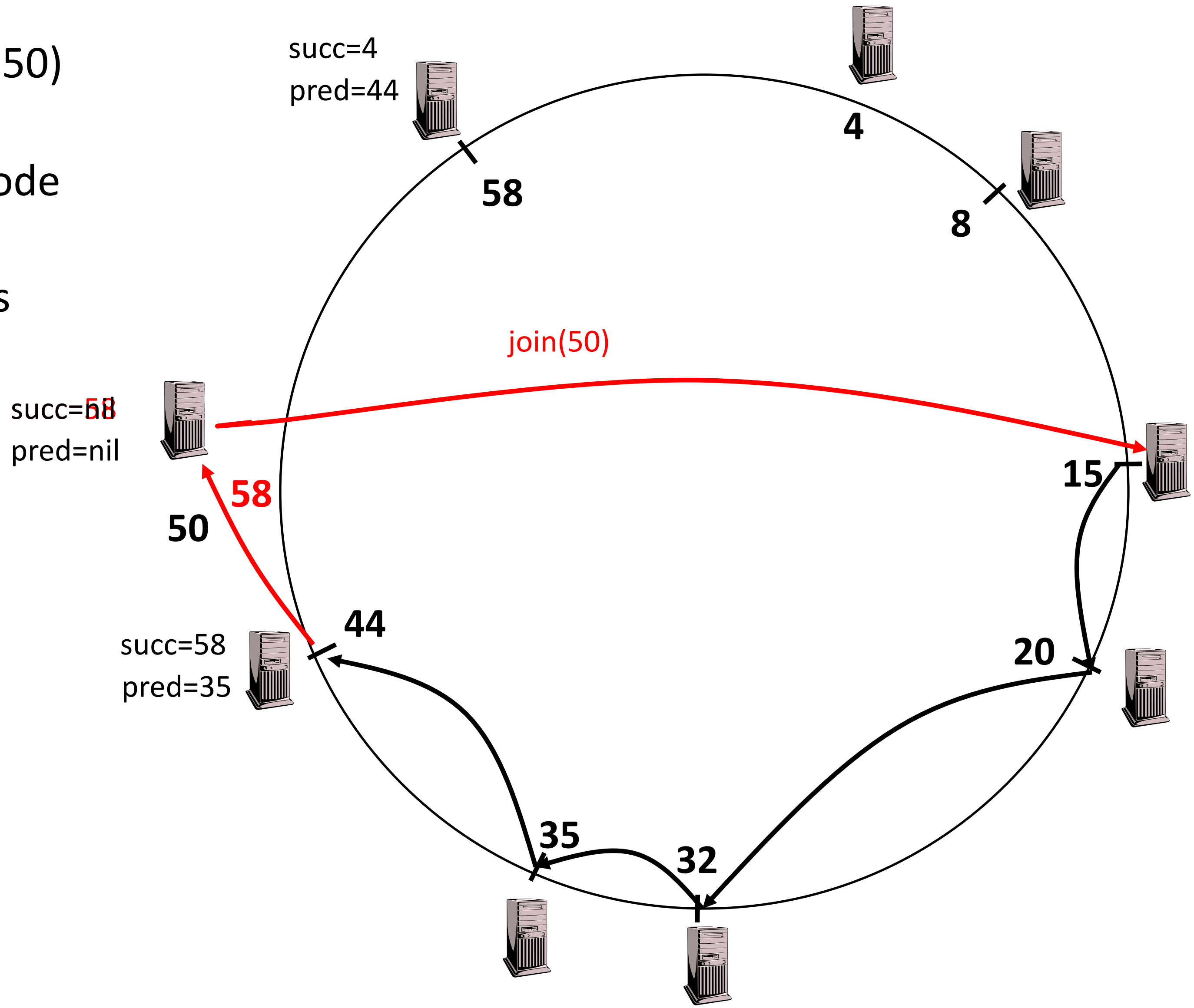
Joining Operation

- Node with id=50 joins the ring
- Node 50 needs to know at least one node already in the system
  - Assume known node is 15



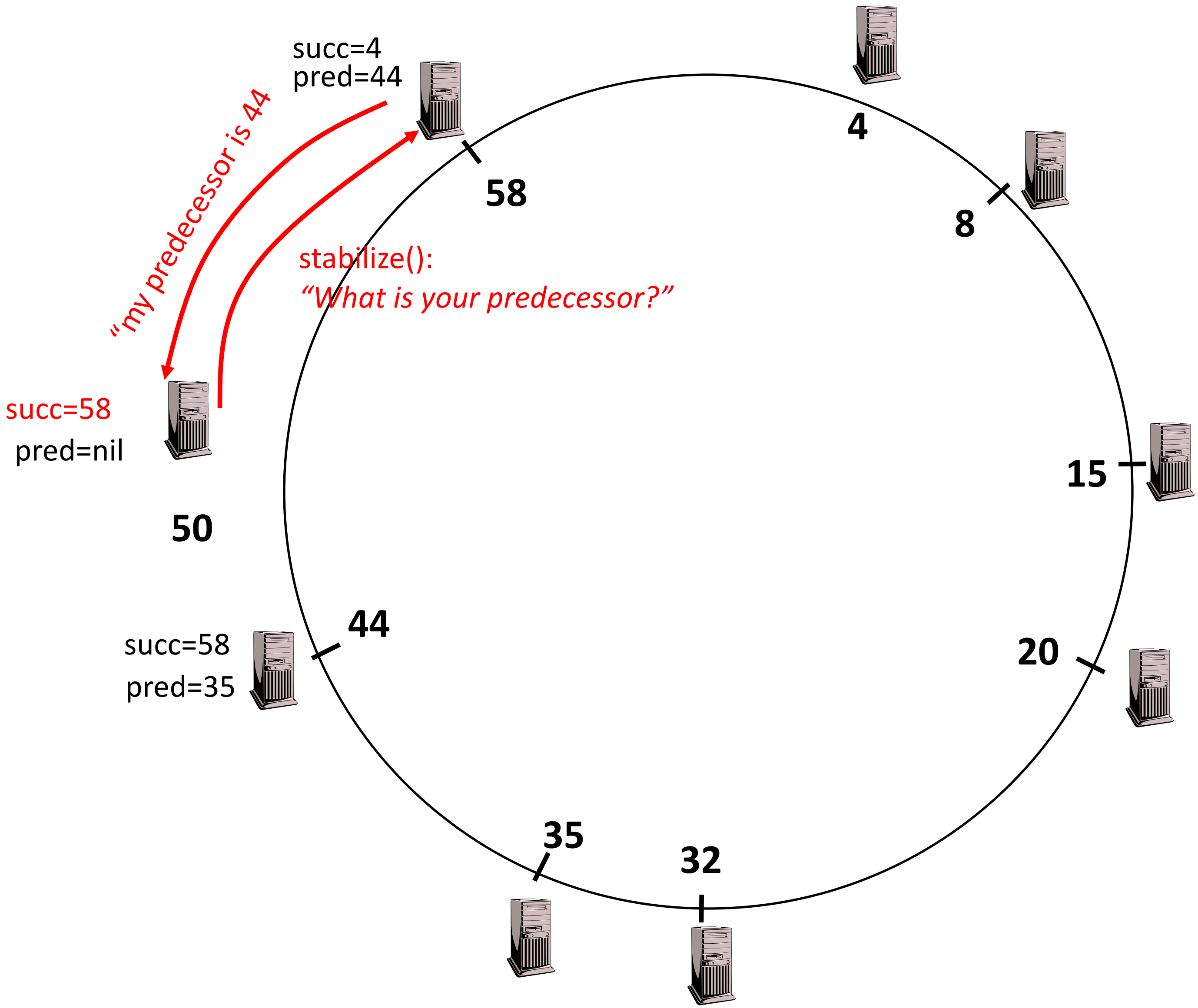
Joining Operation

- Node 50: send join(50) to node 15
- Node 44: returns node 58
- Node 50 updates its successor to 58



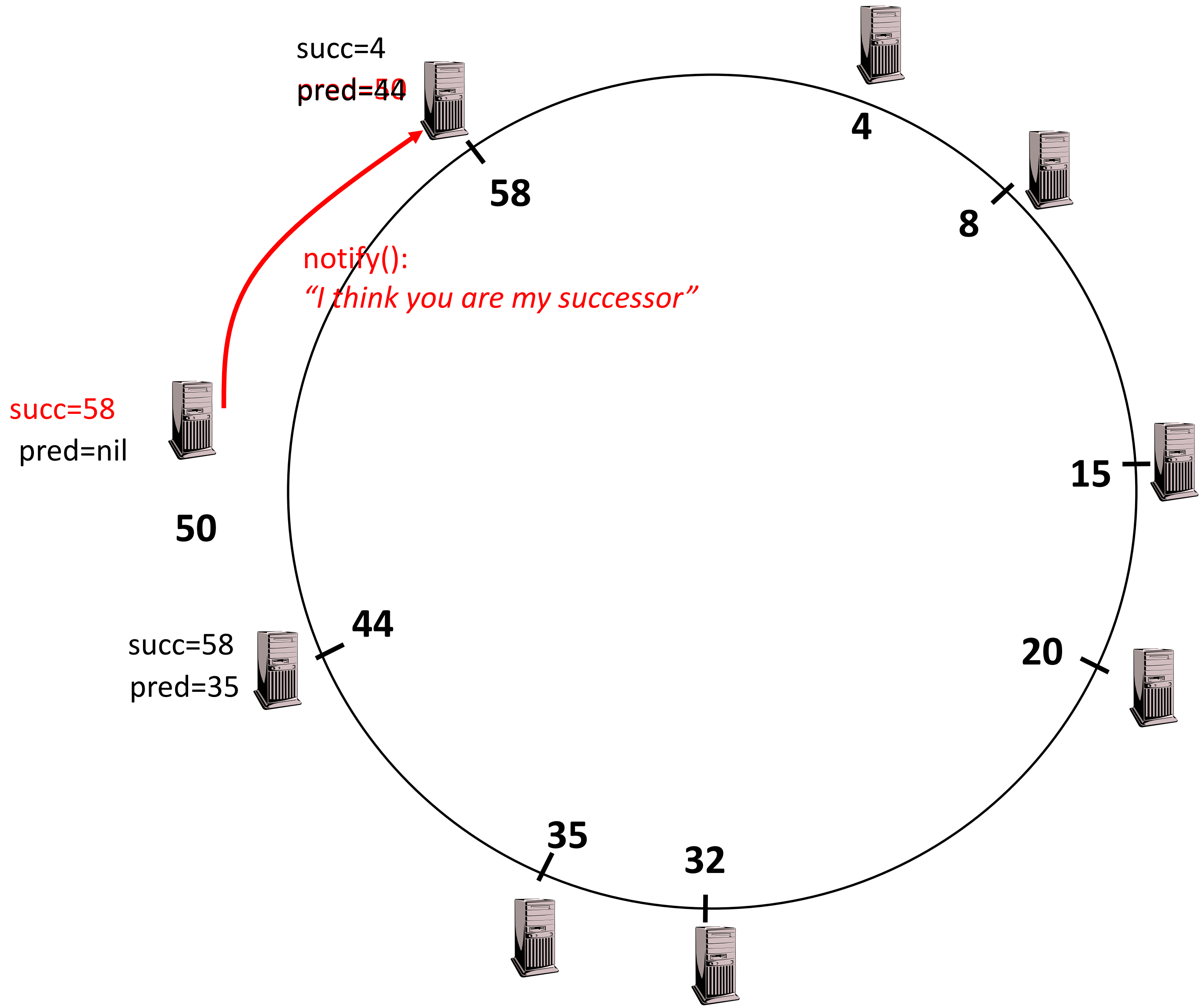
Joining Operation

- Node 50: send stabilize() to node 58
- Node 58:
  - Replies with 44
  - 50 determines it is the right predecessor



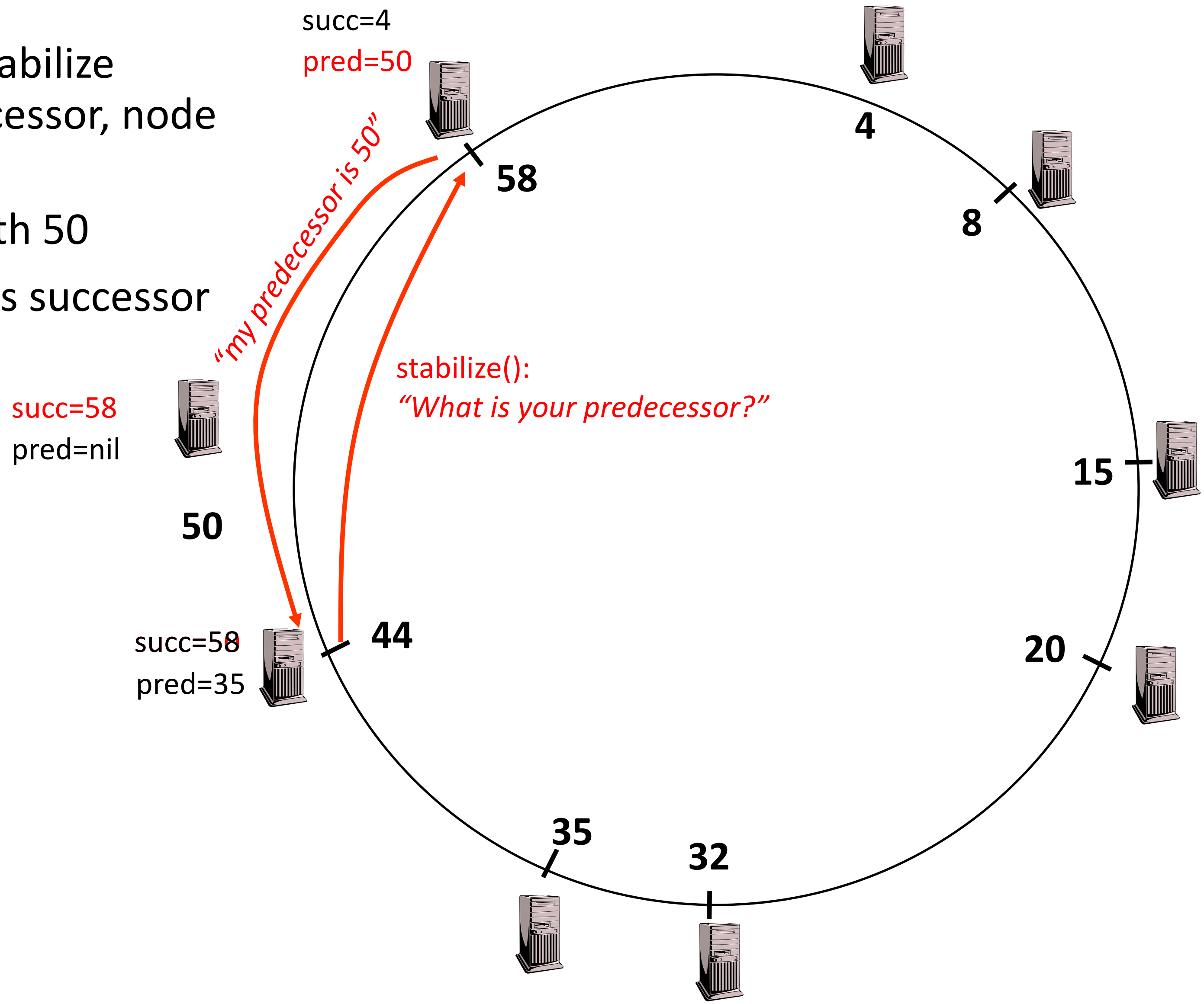
Joining Operation

- Node 50: send notify() to node 58
- Node 58:
  - update predecessor to 50



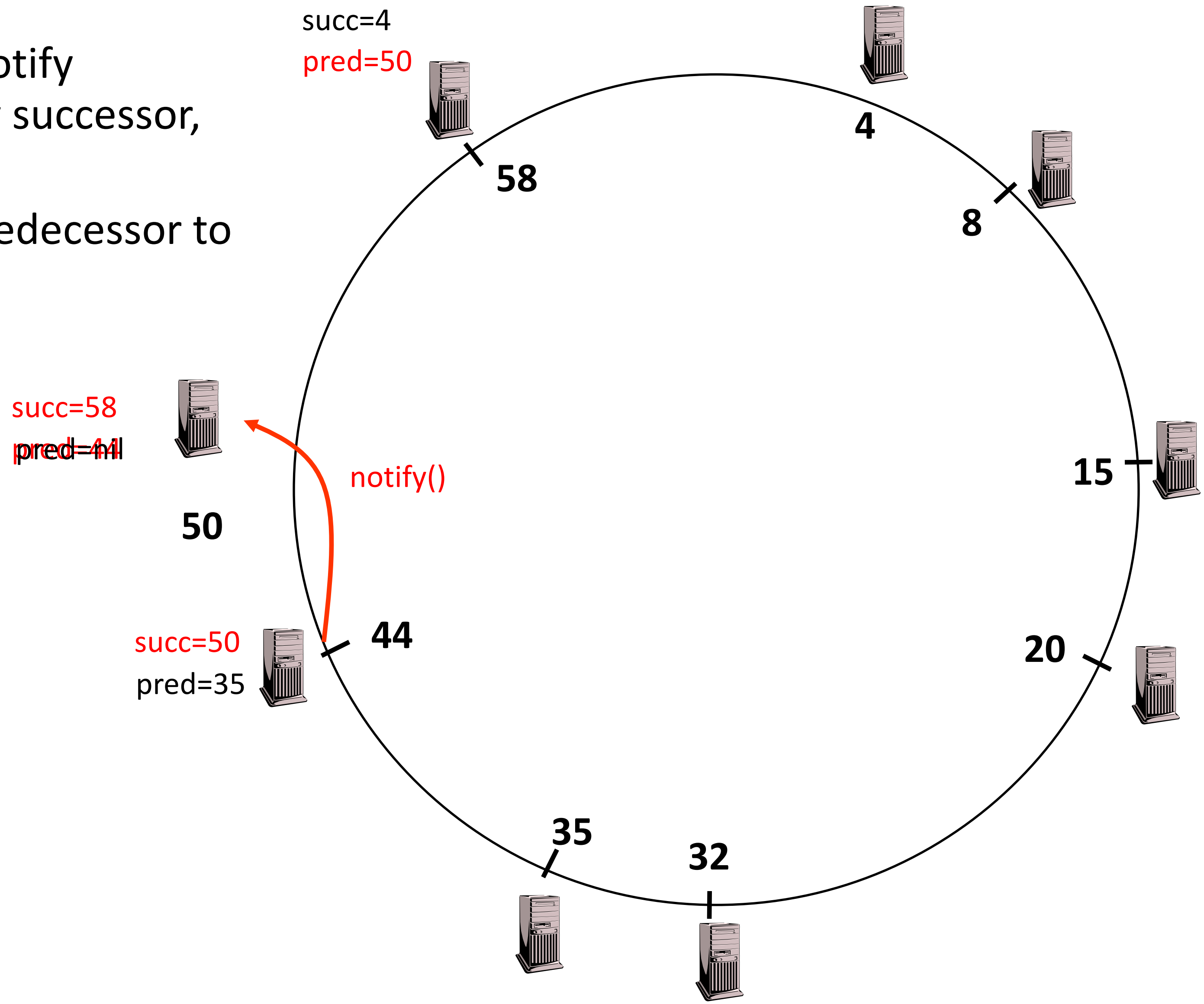
Joining Operation

- Node 44 sends a stabilize message to its successor, node 58
- Node 58 replies with 50
- Node 44 updates its successor to 50



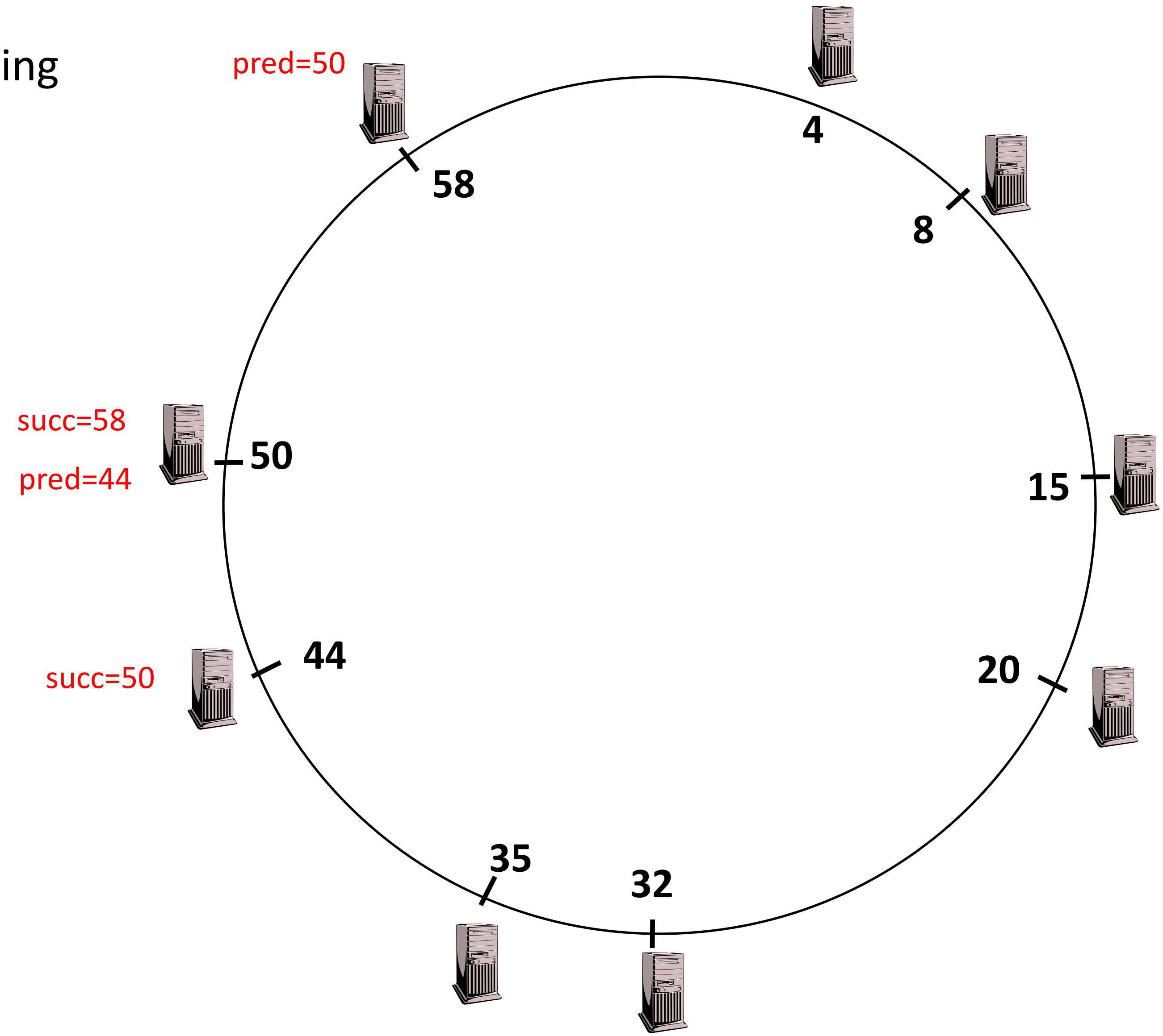
Joining Operation

- Node 44 sends a notify message to its new successor, node 50
- Node 50 sets its predecessor to node 44



Joining Operation (cont'd)

- This completes the joining operation!

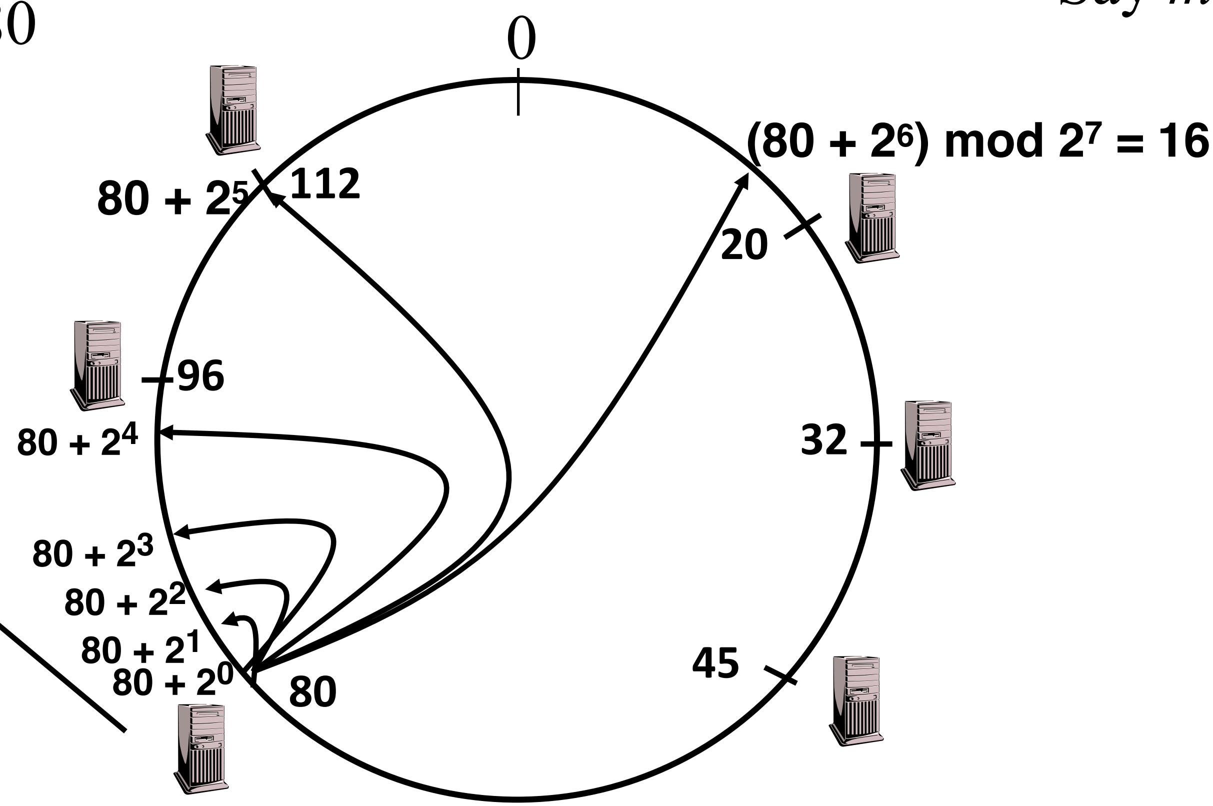


Achieving Efficiency: *finger tables*

Say $m=7$

Finger Table at 80

i	$ft[i]$
0	96
1	96
2	96
3	96
4	96
5	112
6	20



ith entry at peer with id n is first peer with id >= $n+2^i \pmod{2^m}$

Chord

- **There is a tradeoff between routing table size and diameter of the network**
  - You can achieve diameter O(1) with O(n)-entry routing tables
  - Max diameter with O(1) routing tables (random walks)
- **Chord achieves diameter O(log n) with O(log n)-entry routing tables**

Many other DHTs

- **CAN**
  - Routing in n-dimensional space
- **Pastry/Tapestry/Bamboo**
  - (Book describes Pastry)
  - Names are fixed bit strings
  - Topology: hypercube (plus a ring for fallback)
- **Kademlia**
  - Similar to Pastry/Tapestry
  - But the ring is ordered by the XOR metric
  - Used by BitTorrent for distributed tracker
- **Viceroy**
  - Emulated butterfly network
- **Koorde**
  - DeBruijn Graph
  - Each node connects to 2n, 2n+1
  - Degree 2, diameter log(n)
- …

Discussion

- **Query can be implemented**
  - Iteratively: easier to debug
  - Recursively: easier to maintain timeout values
- **Robustness**
  - Nodes can maintain (k>1) successors
  - Change notify() messages to take that into account
- **Performance**
  - Routing in overlay can be worse than in the underlay
  - Solution: flexibility in neighbor selection
    - Tapestry handles this implicitly (multiple possible next hops)
    - Chord can select any peer between $[2^n, 2^{n+1})$ for finger, choose the closest in latency to route through

Where are they now?

- **Many P2P networks shut down**
  - Not for technical reasons!
  - Centralized systems work well (or better) sometimes
- **But…**
  - Vuze network: Kademlia DHT, millions of users
  - Concepts incorporated into many systems (e.g., Amazon's DynamoDB)
  - Skype used to use a P2P network similar to KaZaA
- **Shown that you can have scalable routing *without* hierarchy**

Where are they now?

- **DHTs allow coordination of MANY nodes**
  - Efficient *flat* namespace for routing and lookup
  - Robust, scalable, fault-tolerant
- **If you can do that**
  - You can also coordinate co-located peers
  - Now dominant design style in datacenters
    - E.g., Amazon's Dynamo storage system
  - DHT-style systems everywhere
- **Similar to Google's philosophy**
  - Design with failure as the common case
  - Recover from failure only at the highest layer
  - Use low cost components
  - Scale out, not up

An alternative for reliability

- **Erasure coding**
  - Assume you can detect errors
  - Code is designed to tolerate entire missing packets
    - Collisions, noise, drops because of bit errors
  - Forward error correction
- **Examples: Reed-Solomon codes, LT Codes, Raptor Codes**
- **Property:**
  - From K source frames, produce B > K encoded frames
  - Receiver can reconstruct source with *any* K’ frames, with K’ *slightly* larger than K
  - Some codes can make B as large as needed, on the fly

Erasure Codes

- **Motivation: scalability of reliable multicast**
  - Problem: in large multicast groups, where each receiver misses specific packets, how to coordinate retransmissions?
- **Erasure codes:**
  - Any K out of N messages reconstruct original content
- **Initially:**
  - Fixed-rate codes (e.g. Reed-Solomon ~ 1960)
    - Solve for polynomial of degree K with N linearly independent equations

LT Codes

- **Luby Transform Codes**
  - Michael Luby, circa 1998
- **Encoder: repeat B times**
  1. Pick a degree *d (*)*
  2. Randomly select *d* source blocks. Encoded block t_n= XOR or selected blocks

* The degree is picked from a distribution, *robust soliton distribution*, that guarantees that the decoding process will succeed with high probability

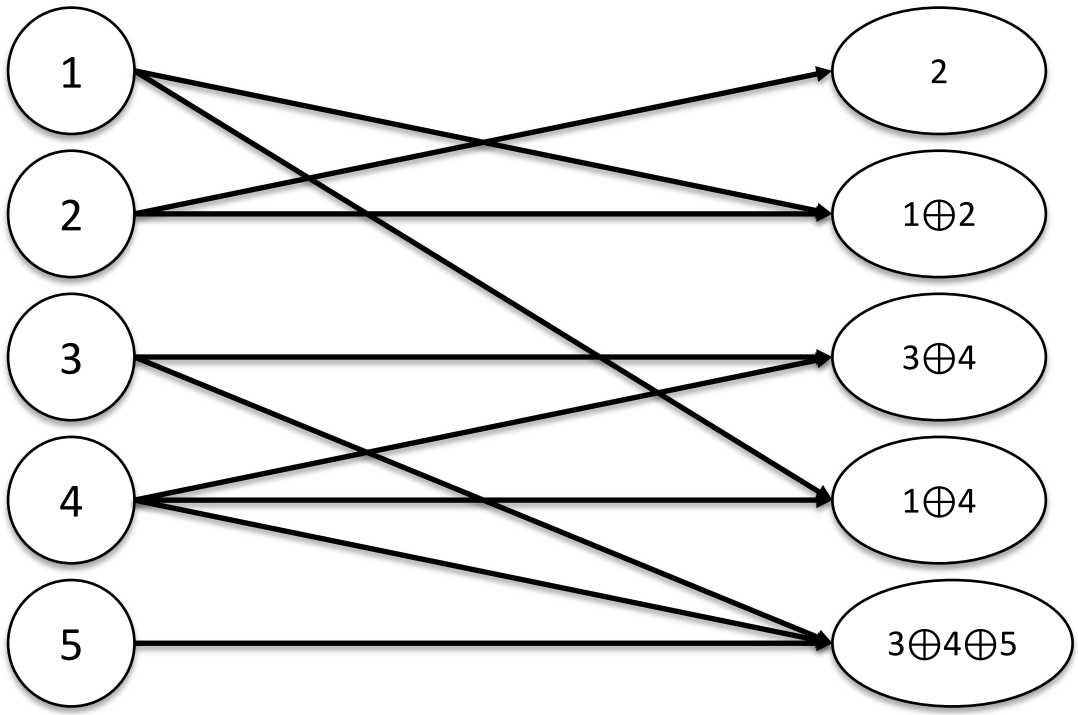
More on encoding

- **Picking the degree d of encoded blocks**
  - Robust Soliton Distribution
  - Balances the probability that there is at least one block of degree 1 in each decoding iteration
  - While trying to minimize the probability of decoding failing
- **In practice, you don't encode the list of source blocks on each block, but the state of a pseudo-random number generator**
  - From this you can generate the next numbers in the sequence: degree d, and the next ids of the d source blocks in the encoded block

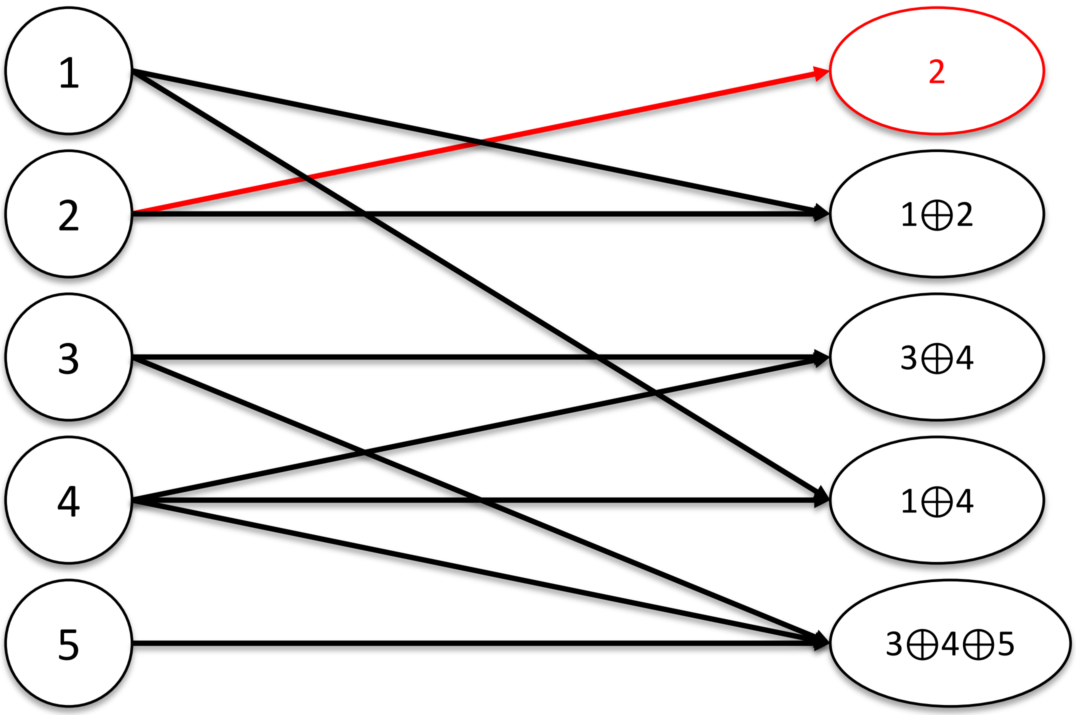
LT Decoder

- **Find an encoded block t_n with d=1**
- **Set $s_n = t_n$**
- **For all other blocks $t_{n'}$ that include s_n ,**
  set $t_{n'}=t_{n'}$ XOR s_n
- **Delete s_n from all encoding lists**
- **Finish if**
  1. You decode all source blocks, or
  2. You run out out blocks of degree 1

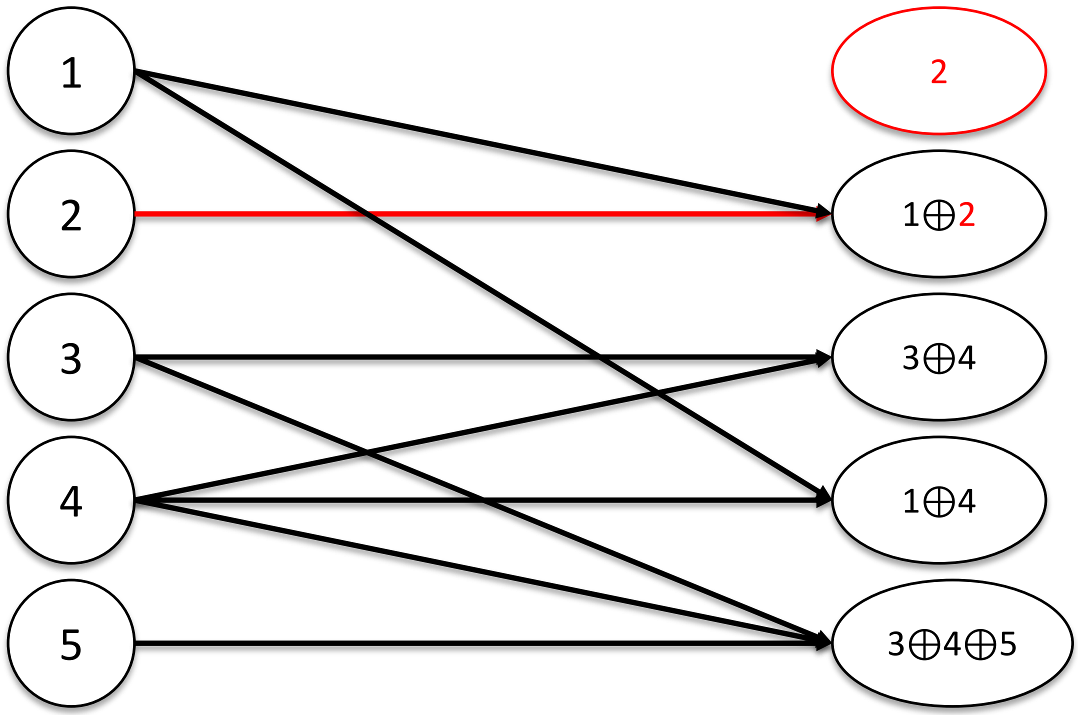
Decoding Example



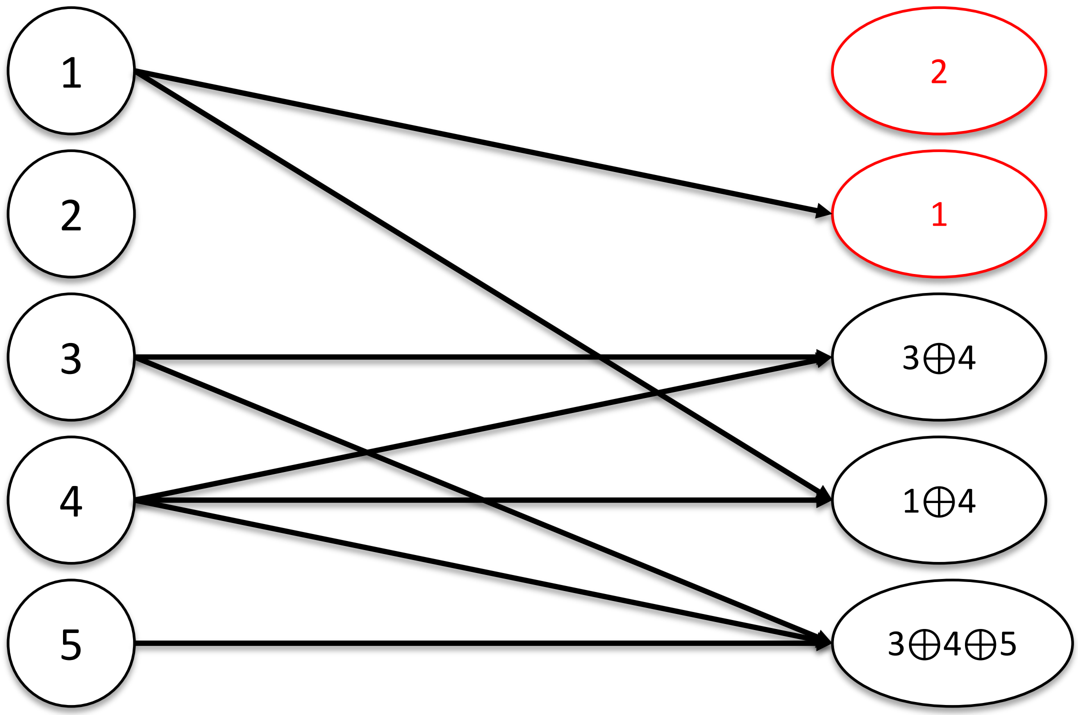
Decoding Example



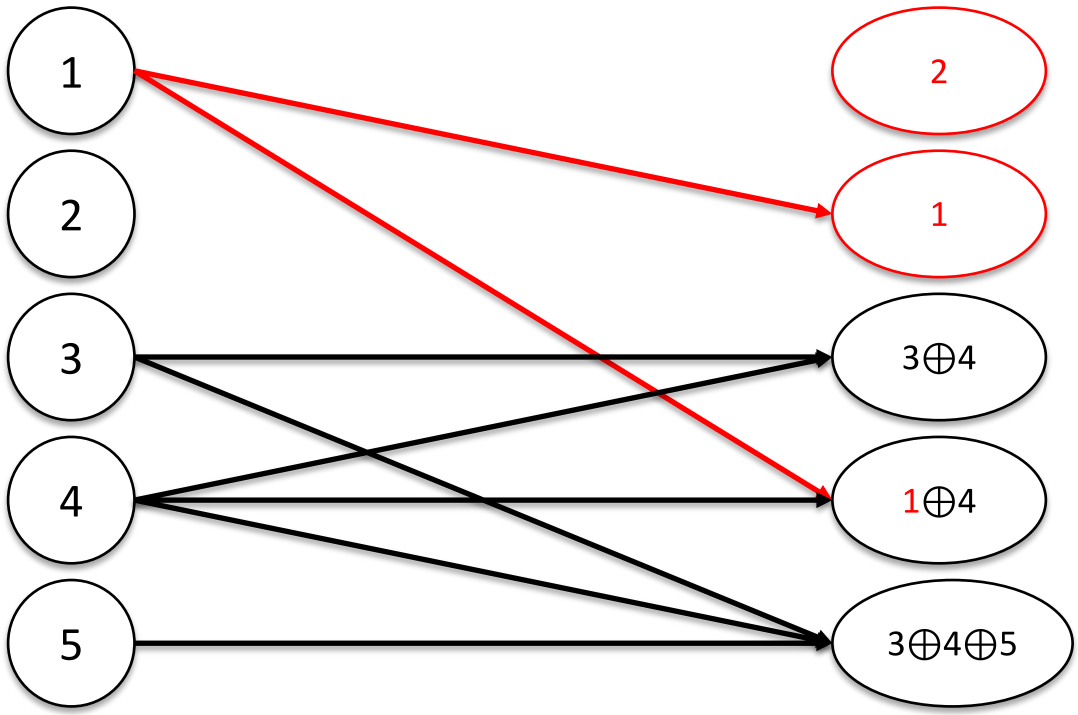
Decoding Example



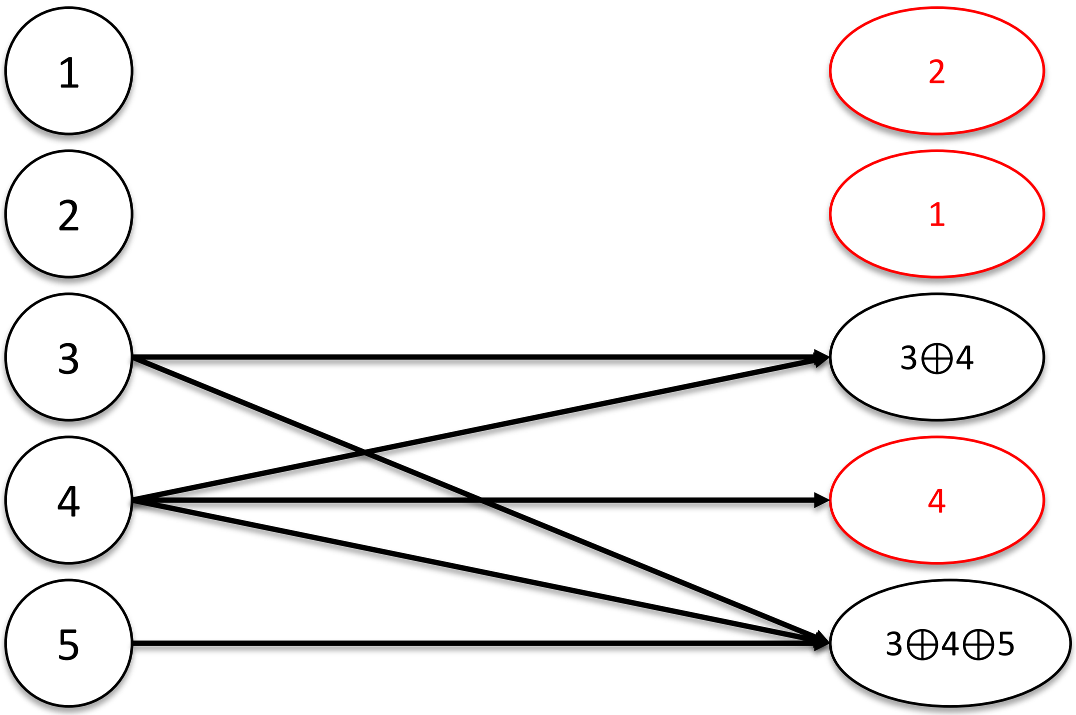
Decoding Example



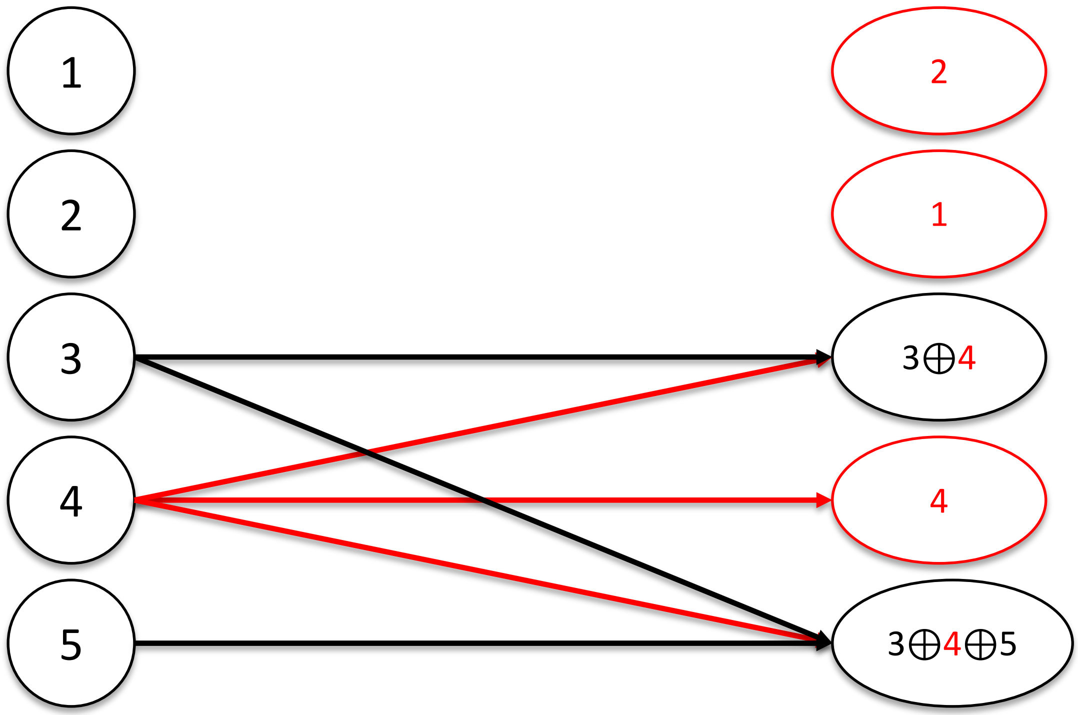
Decoding Example



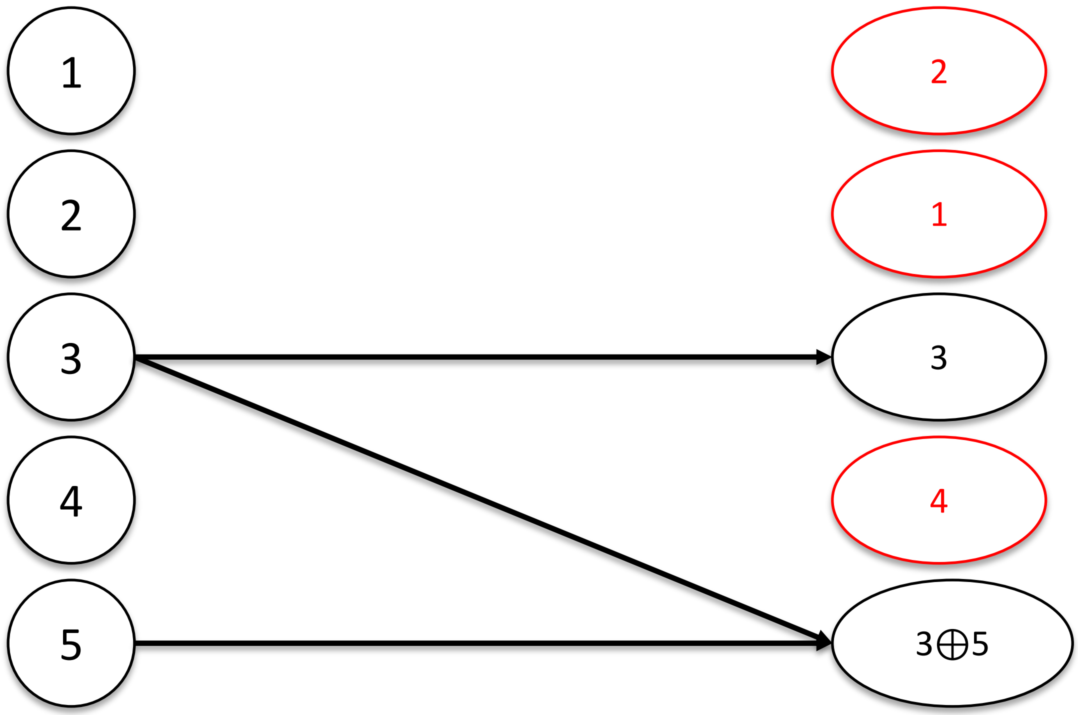
Decoding Example



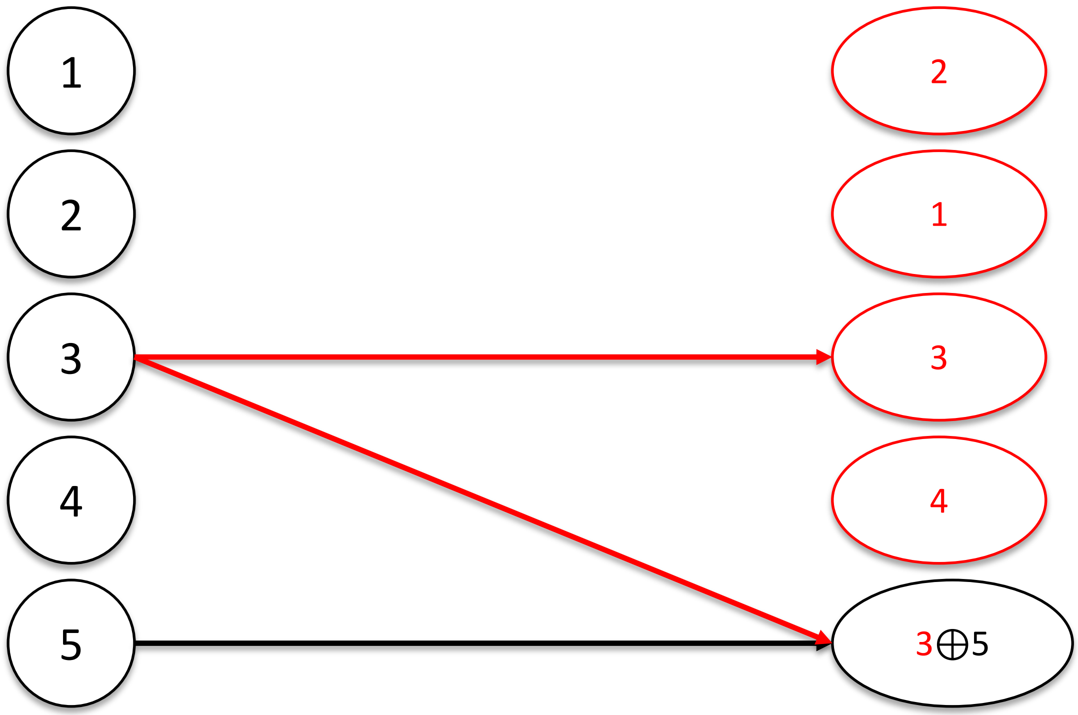
Decoding Example



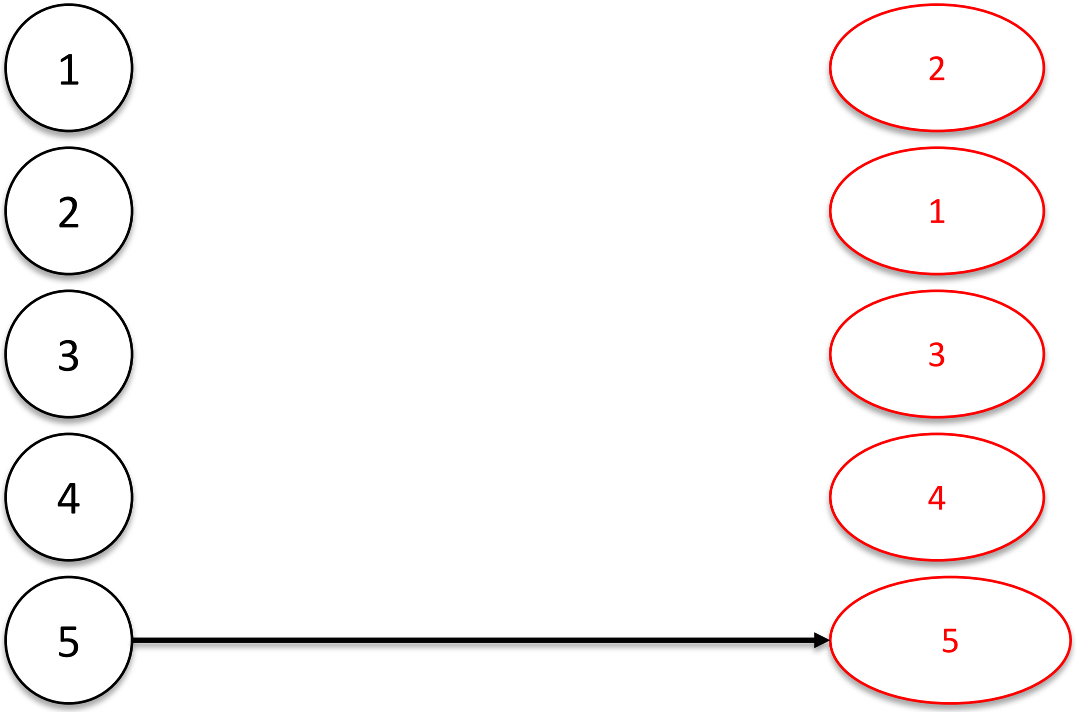
Decoding Example



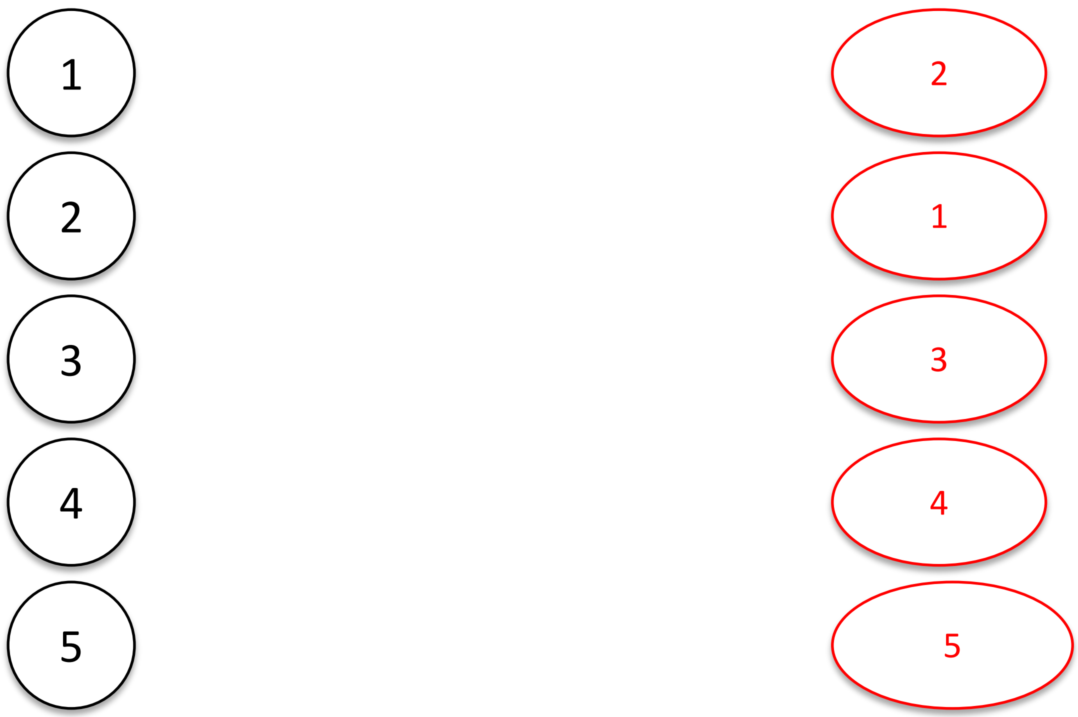
Decoding Example



Decoding Example



Decoding Example



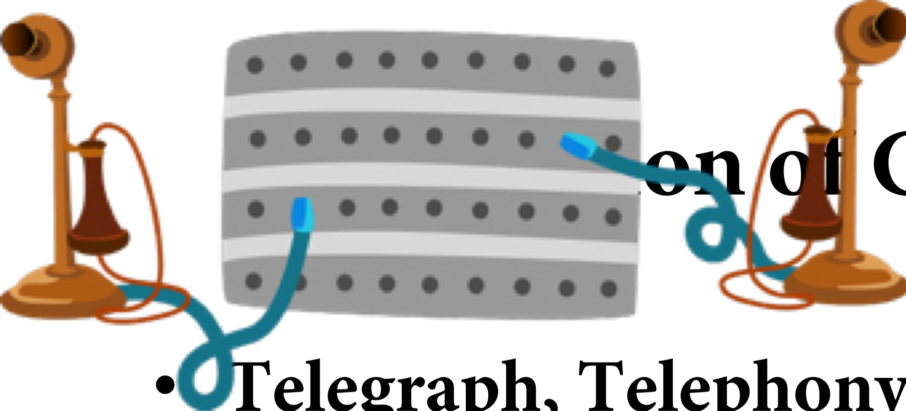
Uses

- IPTV, defense, postal service, satellite systems
- 3G/4G/5G Multicast service (Qualcomm)
- Storage systems
- …

Byers, Luby, Mitzenmacher, CCR 2019. A Digital Fountain Retrospective
https://ccronline.sigcomm.org/wp-content/uploads/2019/10/acmdl19-354.pdf

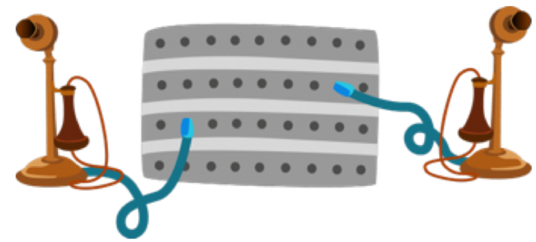
Information-Centric Networking (ICN)
(a vision)
Named-Data Networking (NDN)
(a specific architecture proposal)
Content-Centric Networking (CCN)
(an earlier project)

Some content from kc klaffy, CAIDA

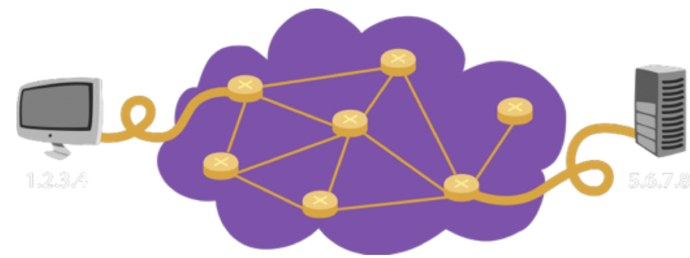


on of Communications

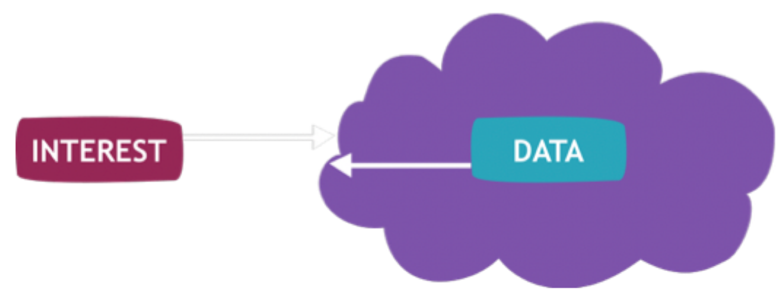
- Telegraph, Telephony: pairwise communication



- IP Networking: node-to-node communication



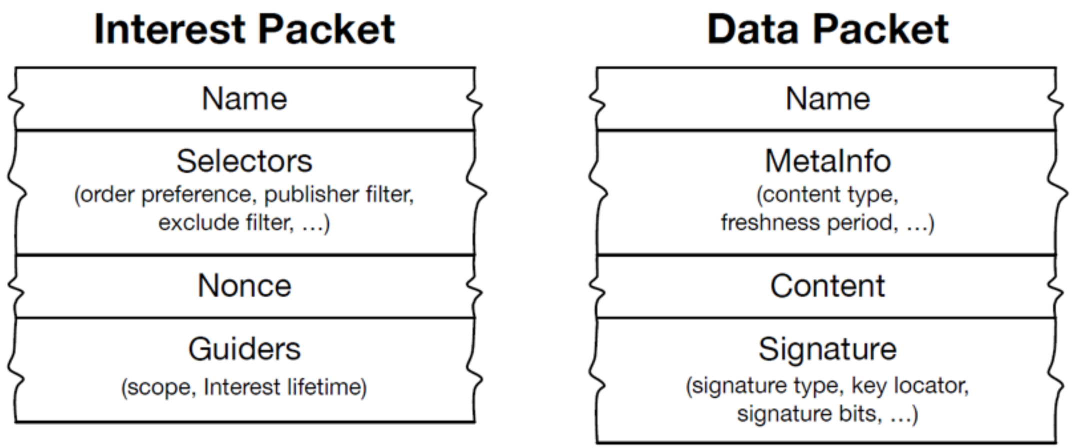
- Today: most uses retrieve objects, don’t care which server they come from

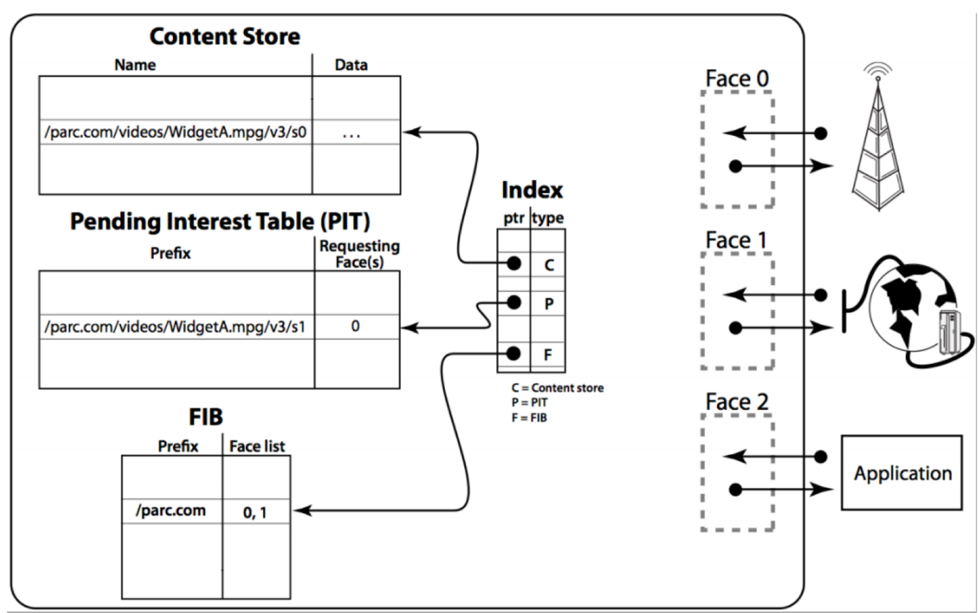


-Data Networking

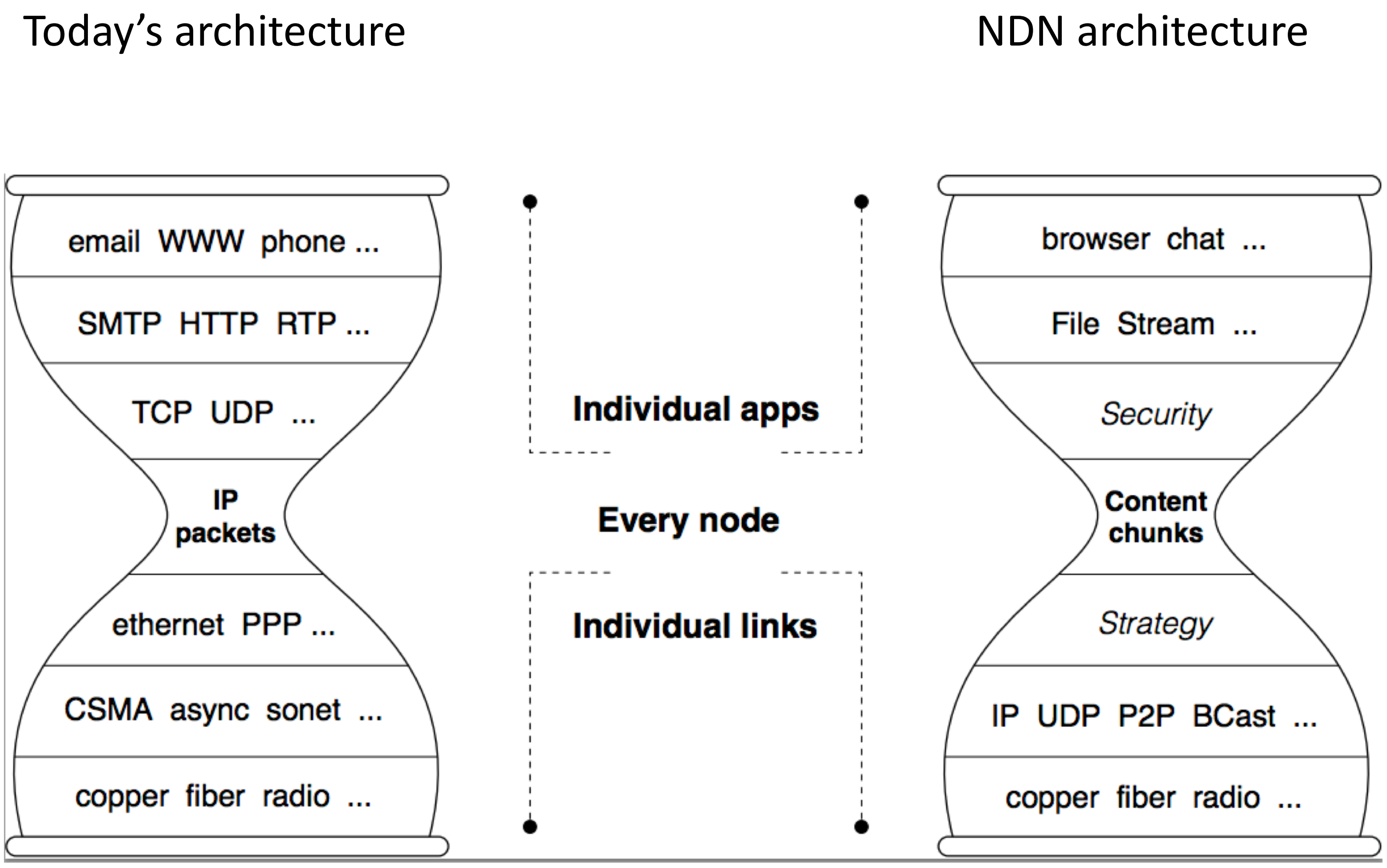
- **Focus on *data* rather than on *endpoints***
- **All content is named**
- **In-network storage and multicast arise naturally**
- **Secure the data rather than the process**
  - Each data packet is immutable and signed

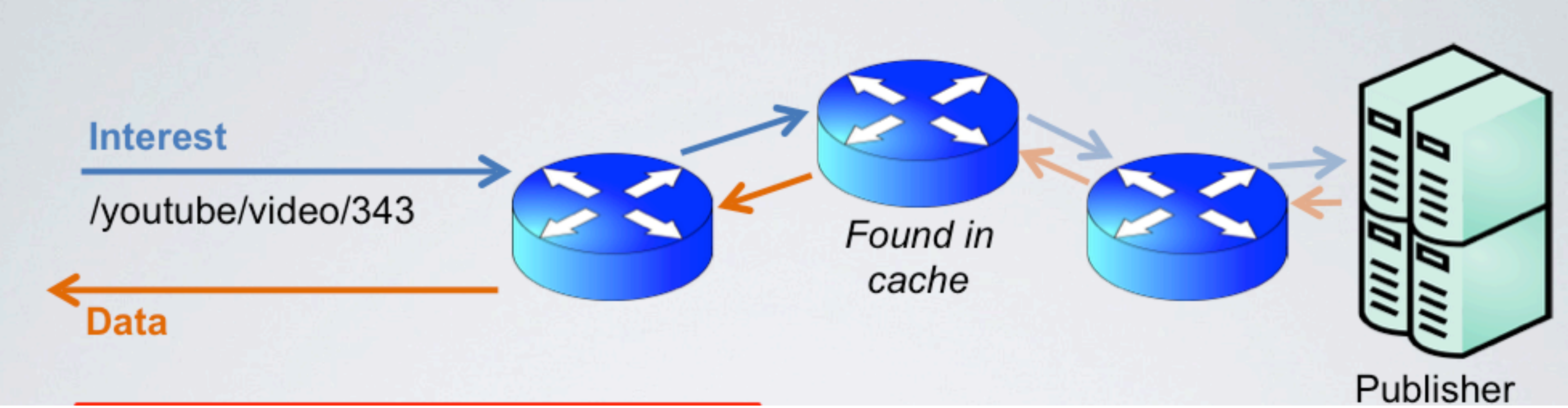
How does this work?





A new architecture




Interest
/youtube/video/343
Data
Found in
cache
Publisher

Some details (and questions)

- **Names are hierarchical**
  - e.g. /brown.edu/courses/cs168/f19/videos/l25.mpg/5
  - Can name anything (including endpoints)
- **Routing can work similarly to IP prefix-based routing**
  - Aggregation on prefixes, longest-prefix matching
- **Signatures enable caching anywhere**
  - Hierarchical names provide context for trust management
- **Pull-based model**
  - Not "always on", no unsolicited packets
  - Eliminates some types of DDoS attackes

Will this work?

- **Many challenges**
  - Does the current architecture work "well enough"?
  - Can we route efficiently on names of unbounded length?
  - How does trust management work? Yet another PKI?
  - What is the role of CDNs?
- **Proponents view this as the underlying architecture in 20 years, with IP-like communications as a special case**
  - Much like telephony today is a special case of IP communications