An Overview of Peer-to-Peer

Sami Rollins

Outline

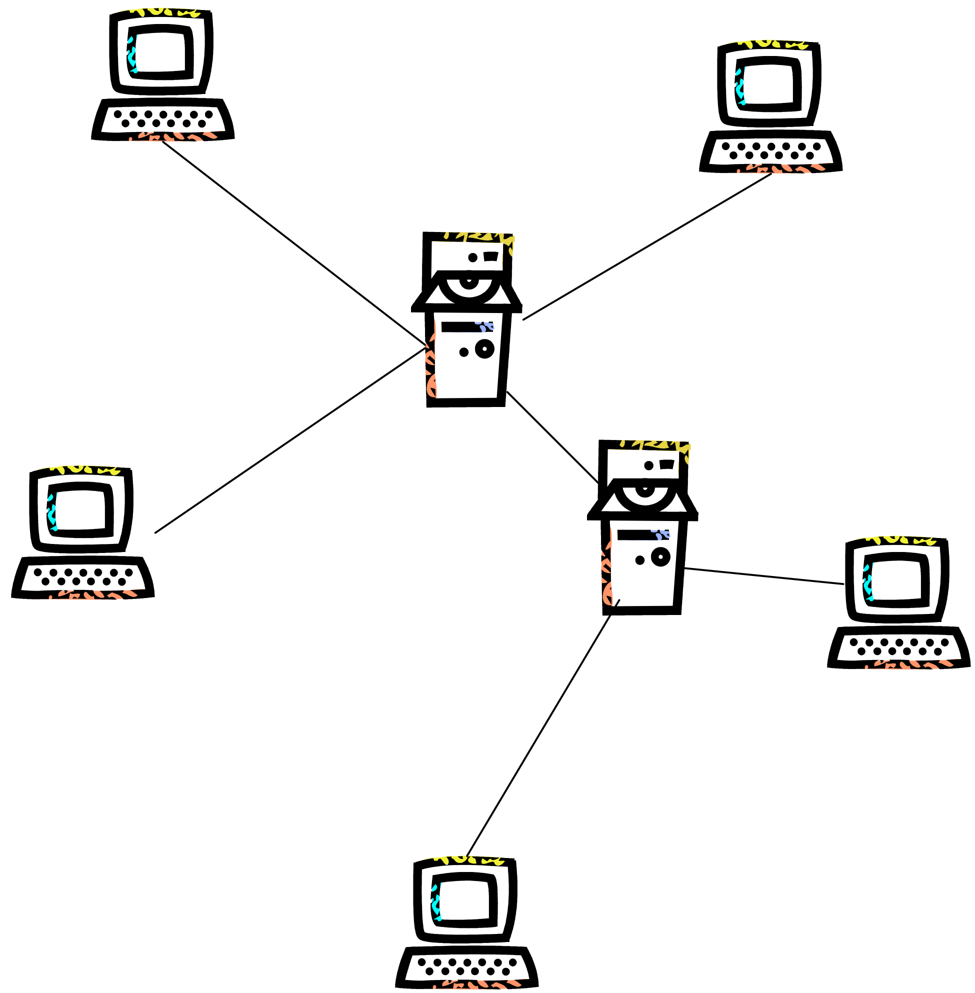
- P2P Overview
  - What is a peer?
  - Example applications
  - Benefits of P2P
  - Is this just distributed computing?
- P2P Challenges
- Distributed Hash Tables (DHTs)

What is Peer-to-Peer (P2P)?

- Napster?
- Gnutella?
- Most people think of P2P as music sharing

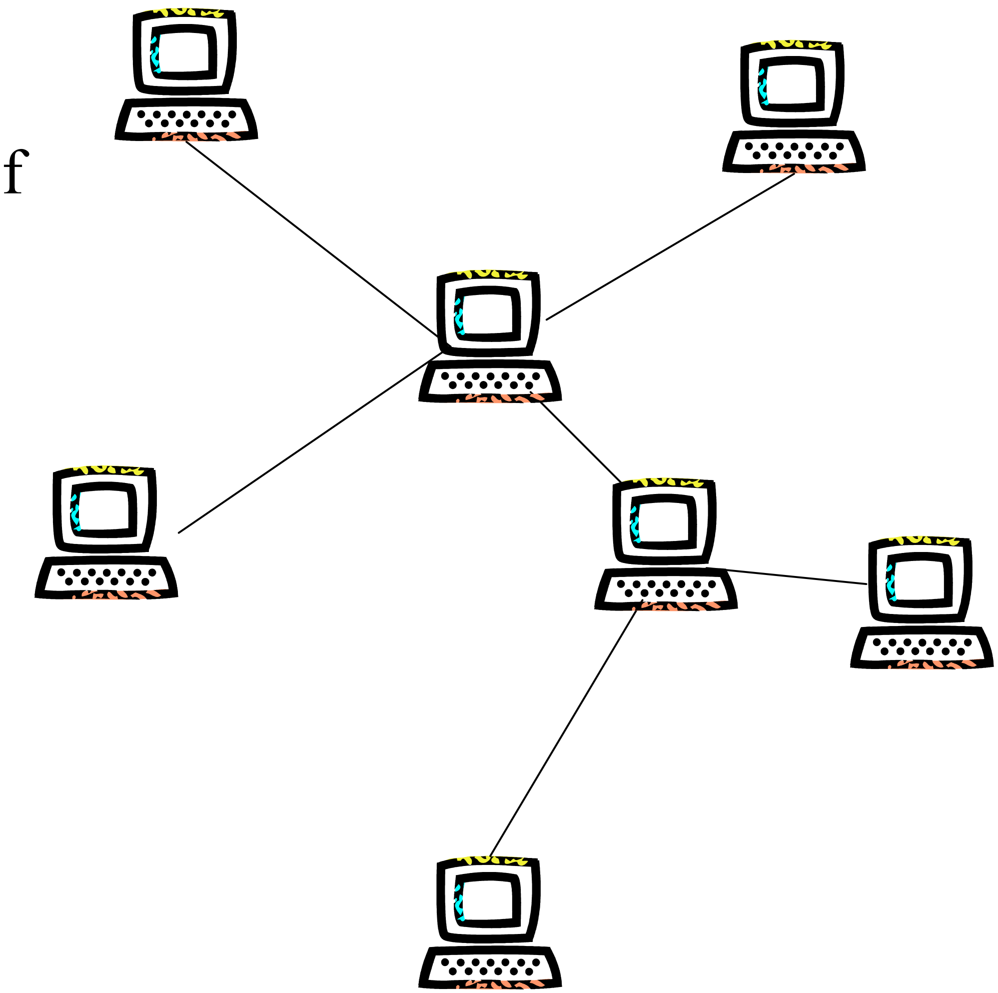
What is a *peer*?

- Contrasted with Client-Server model
- Servers are centrally maintained and administered
- Client has fewer *resources* than a server

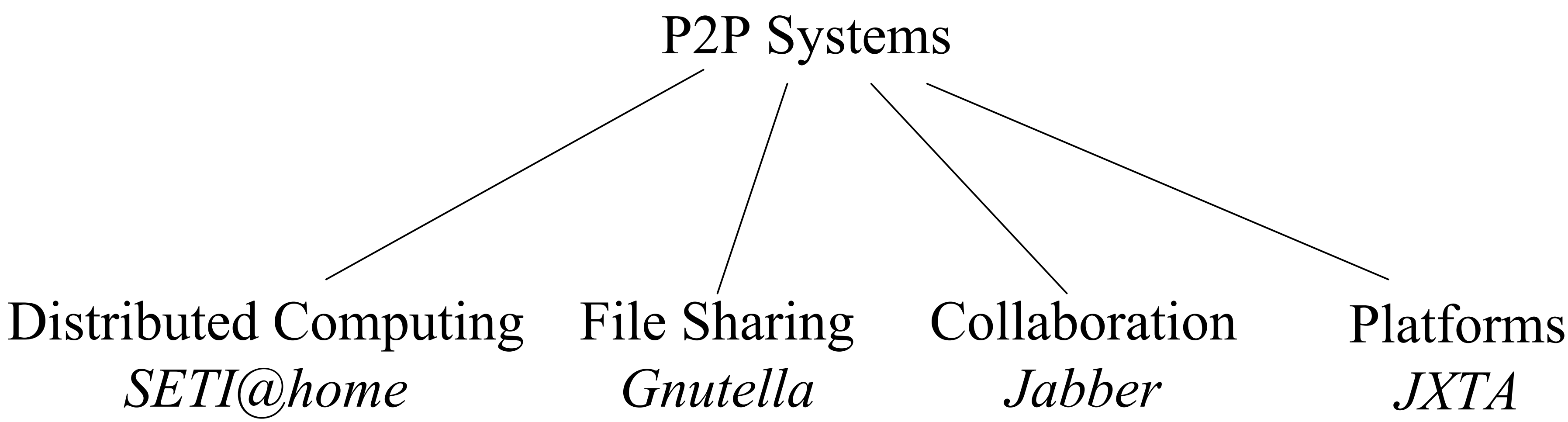


What is a *peer*?

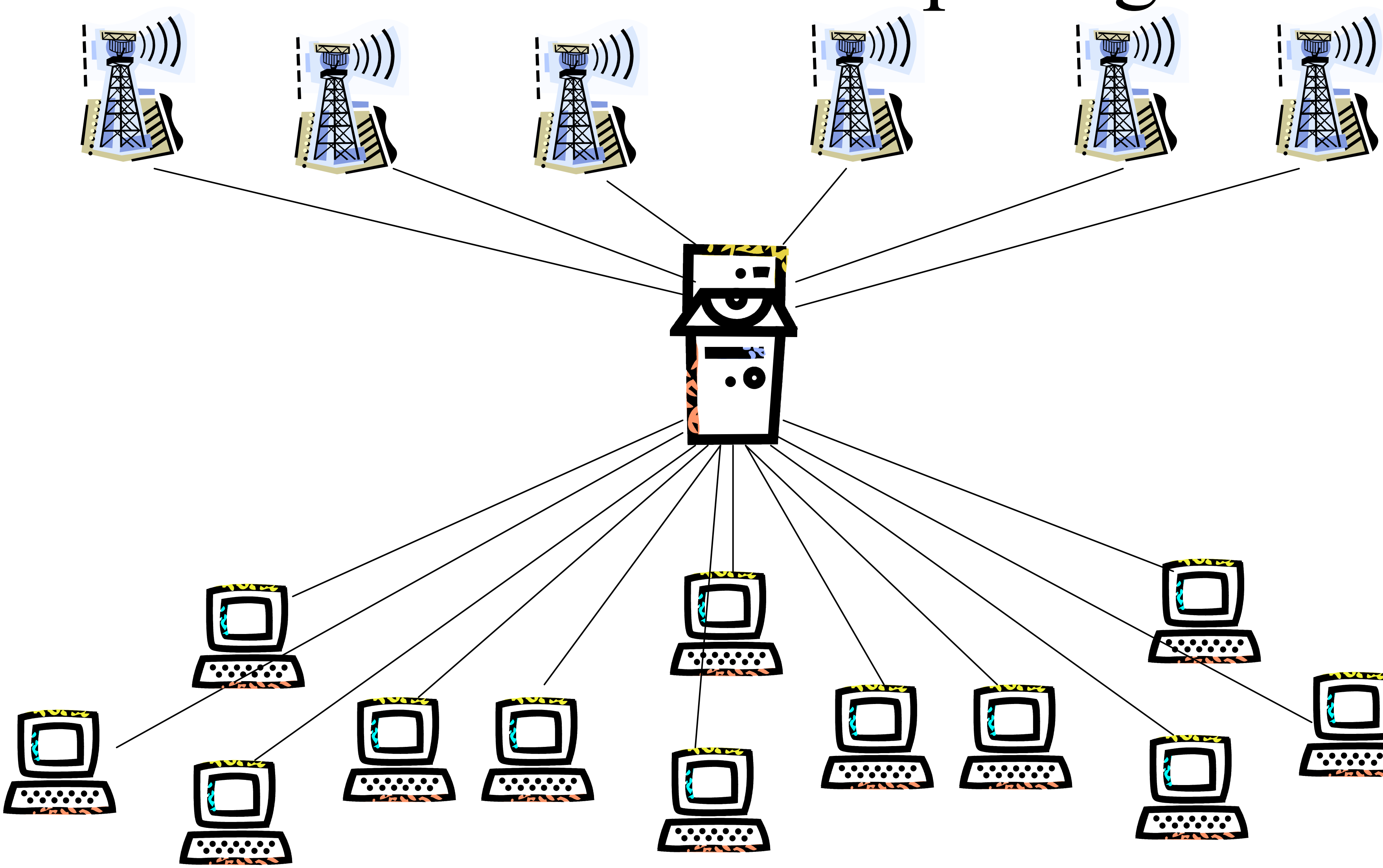
- A peer’s resources are similar to the resources of the other participants
- P2P – peers communicating directly with other peers and sharing resources
- Often administered by different entities
  - Compare with DNS



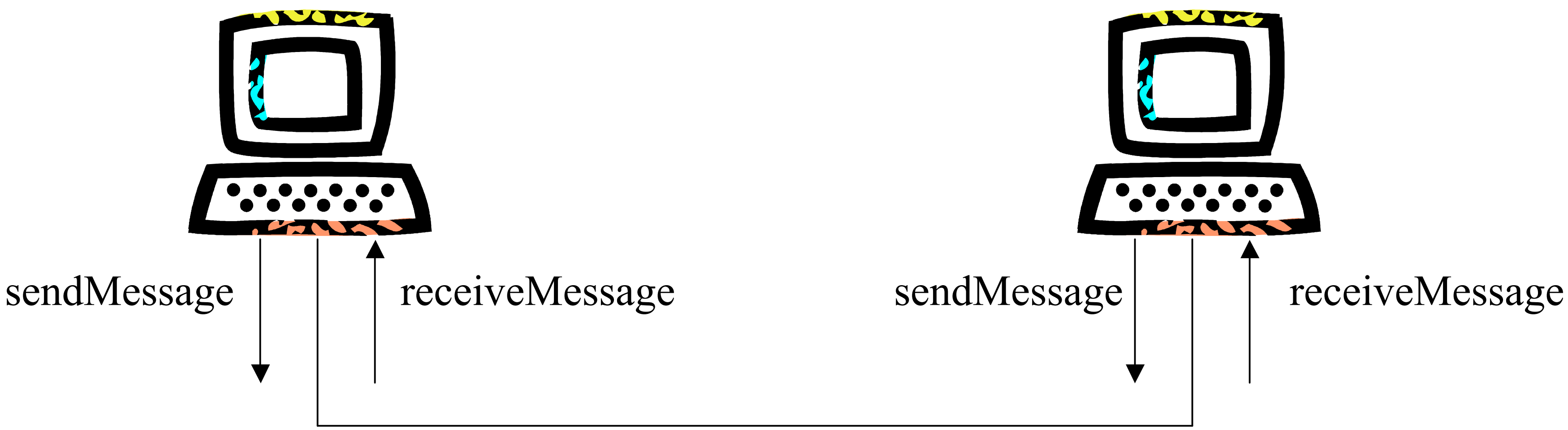
P2P Application Taxonomy



Distributed Computing



Collaboration



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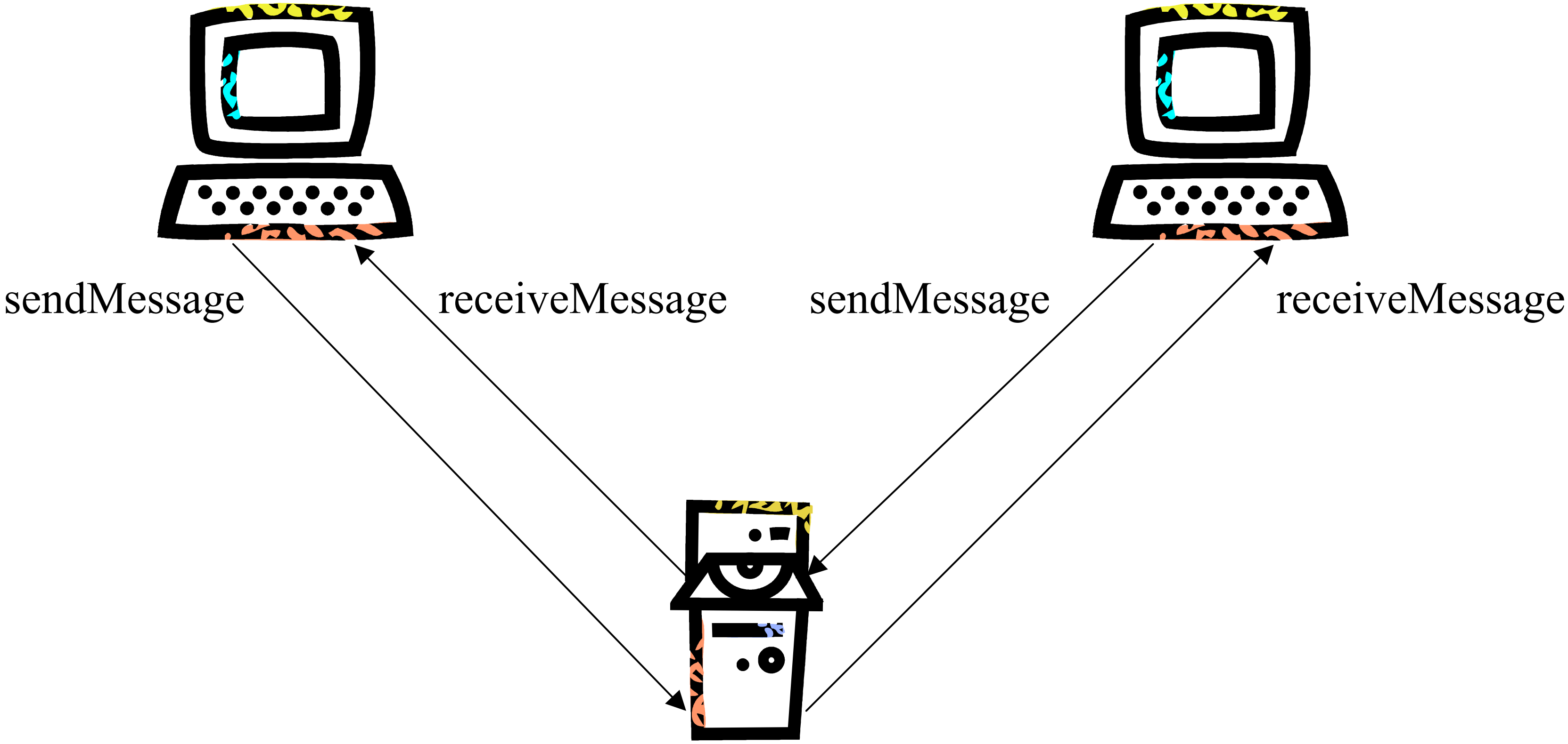


Platforms

Gnutella	Instant Messaging

Find Peers	…	Send Messages

P2P Goals/Benefits

- Cost sharing
- Resource aggregation
- Improved scalability/reliability
- Increased autonomy
- Anonymity/privacy
- Dynamism
- Ad-hoc communication

P2P File Sharing

- Centralized
  - Napster
- Decentralized
  - Gnutella
- Hierarchical
  - Kazaa
- Incentivized
  - BitTorrent
- Distributed Hash Tables
  - Chord, CAN, Tapestry, Pastry

Challenges

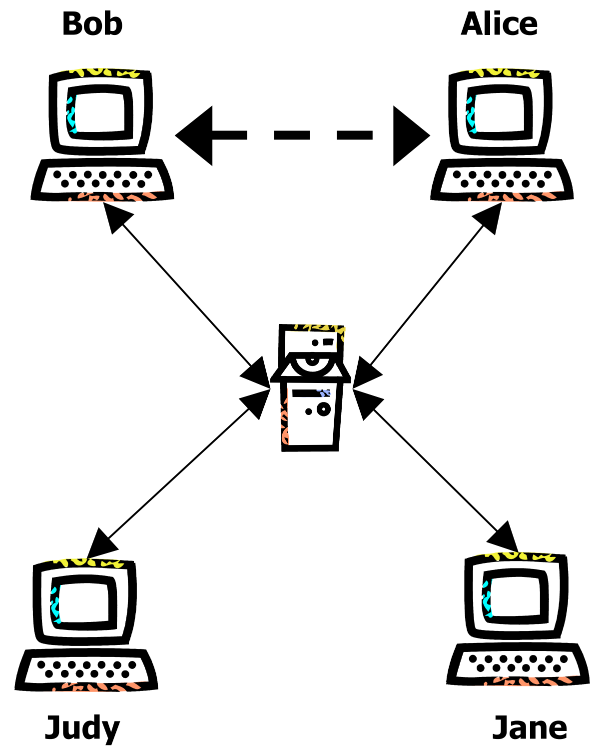
- Peer discovery
- Group management
- Search
- Download
- Incentives

Metrics

- Per-node state
- Bandwidth usage
- Search time
- Fault tolerance/resiliency

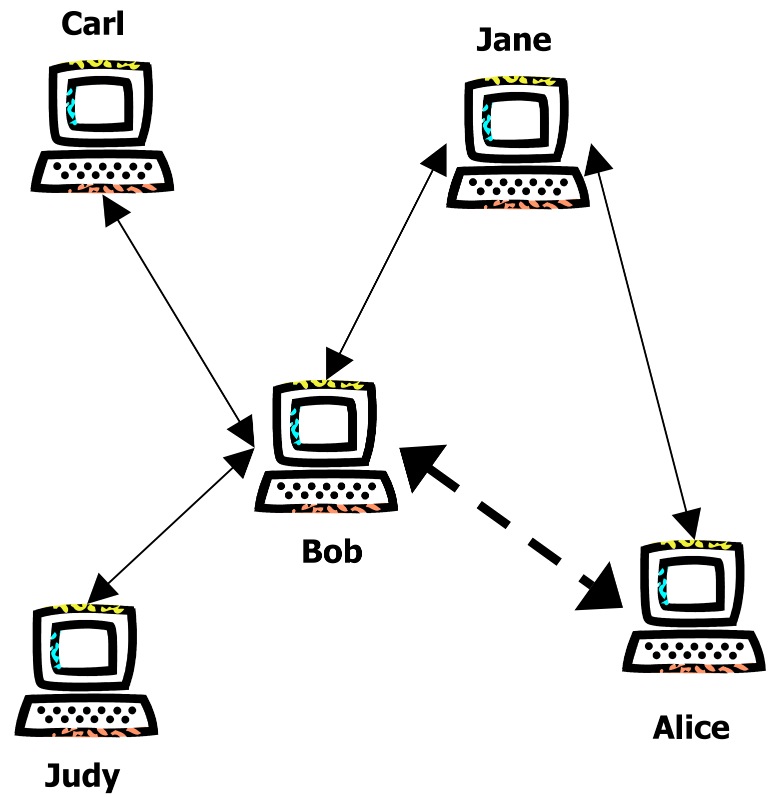
Centralized

- Napster model
  - Server contacted during search
  - Peers directly exchange content
- Benefits:
  - Efficient search
  - Limited bandwidth usage
  - No per-node state
- Drawbacks:
  - Central point of failure
  - Limited scale



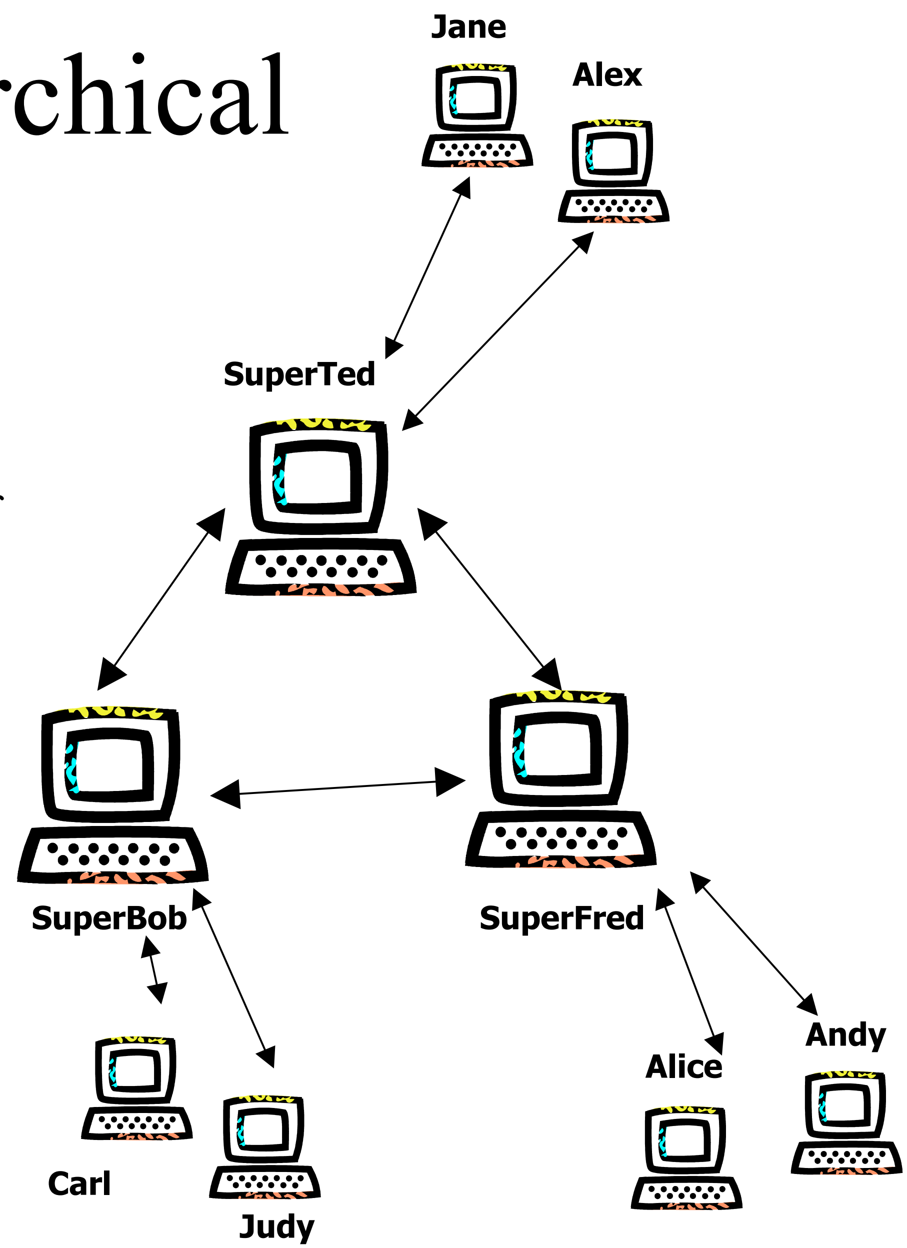
Decentralized (Flooding)

- Gnutella model
  - Search is flooded to neighbors
  - Neighbors are determined *randomly*
- Benefits:
  - No central point of failure
  - Limited per-node state
- Drawbacks:
  - Slow searches
  - Bandwidth intensive

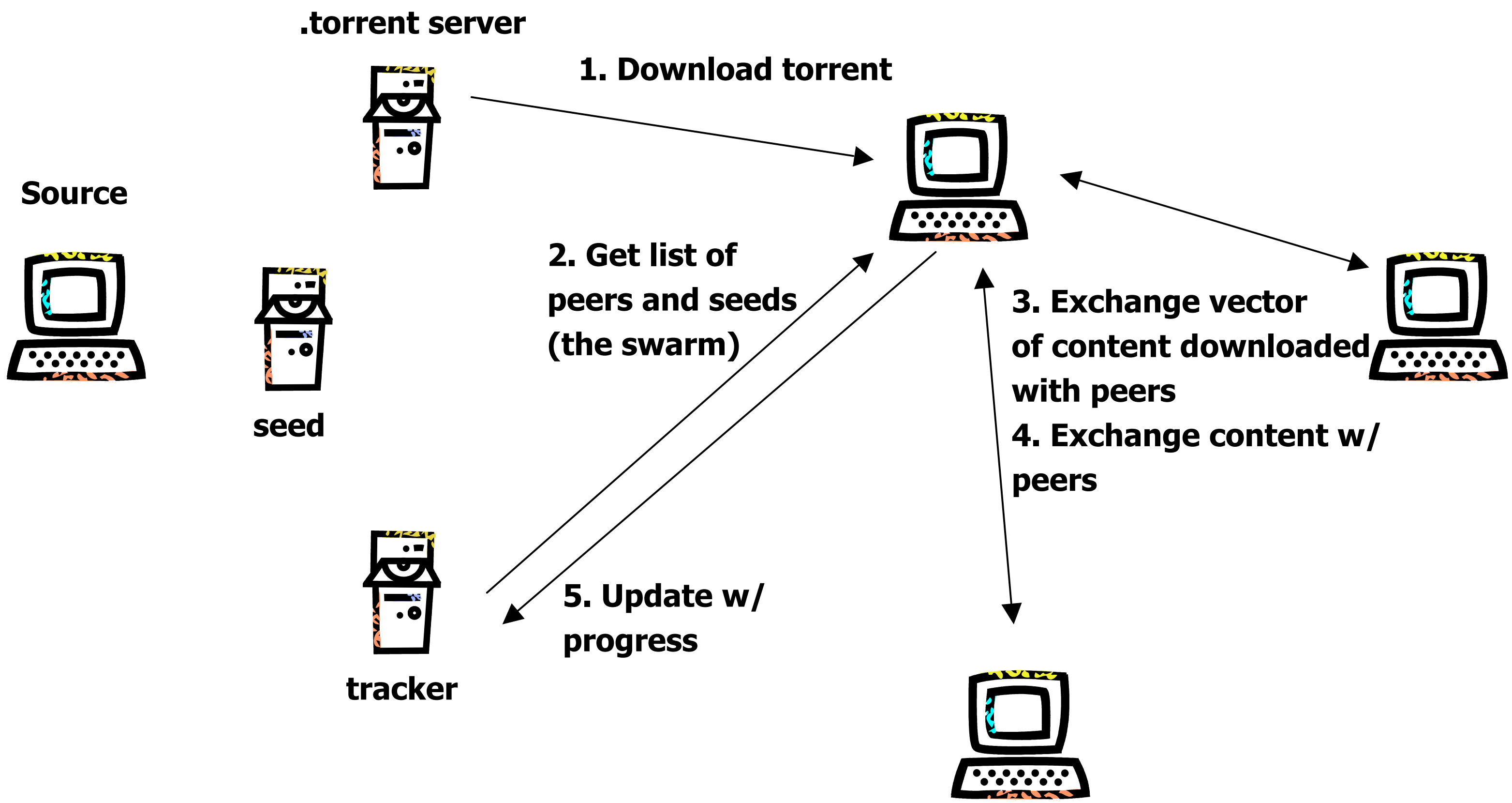


Hierarchical

- Kazaa/new Gnutella model
  - Nodes with high bandwidth/long uptime become *supernodes/ultrapeers*
  - Search requests sent to supernode
  - Supernode caches info about attached leaf nodes
  - Supernodes connect to eachother (32 in Limewire)
- Benefits:
  - Search faster than flooding
- Drawbacks:
  - Many of the same problems as decentralized
  - Reconfiguration when supernode fails



BitTorrent

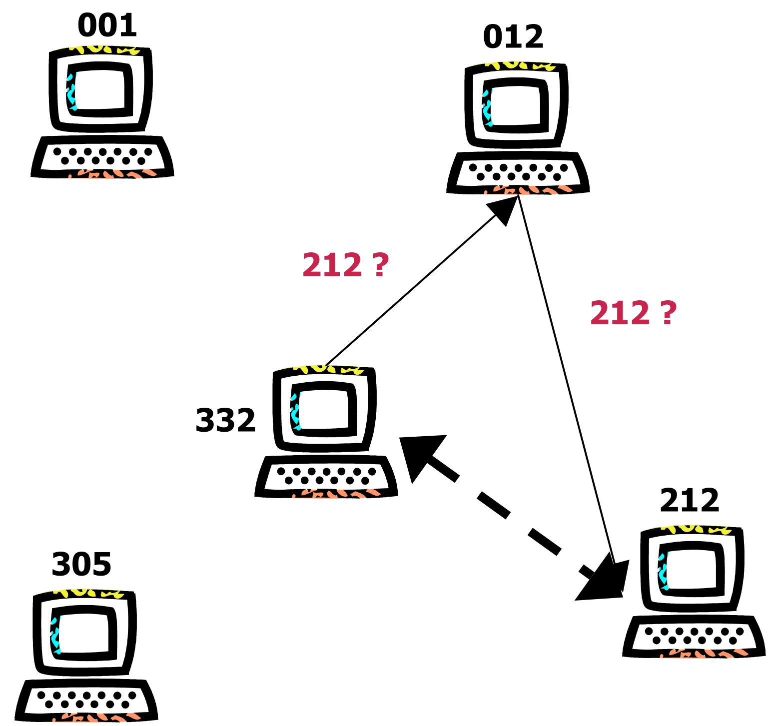

.torrent server
1. Download torrent
Source
seed
2. Get list of
peers and seeds
(the swarm)
3. Exchange vector
of content downloaded
with peers
4. Exchange content w/
peers
5. Update w/
progress
tracker

BitTorrent

- Key Ideas
  - Break large files into small blocks and download blocks individually
  - Provide incentives for uploading content
    - Allow download from peers that provide best upload rate
- Benefits
  - Incentives
  - Centralized search
  - No neighbor state (except the peers in your swarm)
- Drawbacks
  - "Centralized" search
    - No central repository

Distributed Hash Tables (DHT)

- Chord, CAN, Tapestry, Pastry model
  - AKA Structured P2P networks
  - Provide performance guarantees
  - If content exists, it will be found
- Benefits:
  - More efficient searching
  - Limited per-node state
- Drawbacks:
  - Limited fault-tolerance vs redundancy



DHTs: Overview

- Goal: Map key to value
- Decentralized with bounded number of neighbors
- Provide guaranteed performance for search
  - If content is in network, it will be found
  - Number of messages required for search is bounded
- Provide guaranteed performance for join/leave
  - Minimal number of nodes affected
- Suitable for applications like file systems that require guaranteed performance

Comparing DHTs

- Neighbor state
- Search performance
- Join algorithm
- Failure recovery

CAN

- Associate to each node and item a unique *id* in an *d*-dimensional space
- Goals
  - Scales to hundreds of thousands of nodes
  - Handles rapid arrival and failure of nodes
- Properties
  - Routing table size O(*d*)
  - Guarantees that a file is found in at most $d*n^{1/d}$ steps, where *n* is the total number of nodes

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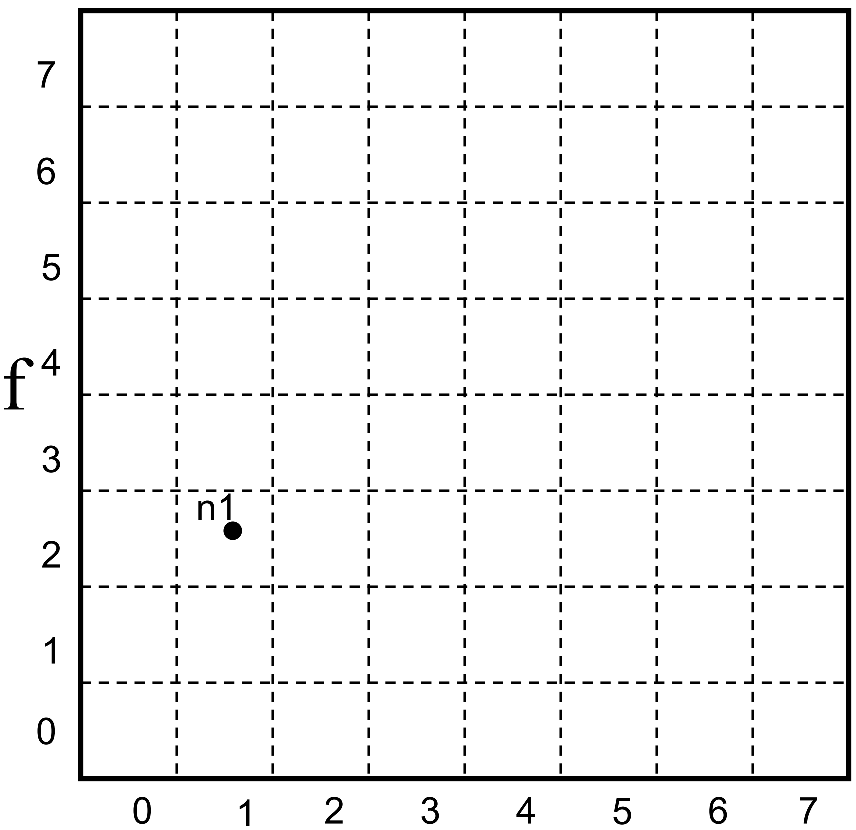
CAN Example: Two Dimensional Space

- Space divided between nodes
- All nodes cover the entire space
- Each node covers either a square or a rectangular area of ratios 1:2 or 2:1
- Example:
  – Node n1:(1, 2) first node that joins → cover the entire space



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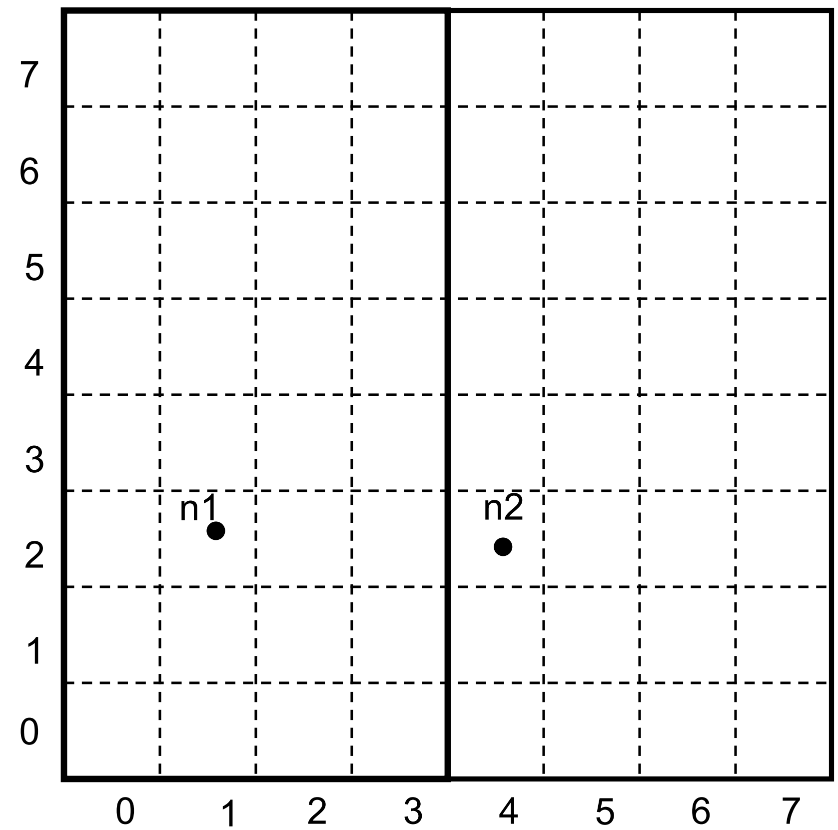
CAN Example: Two Dimensional Space

- Node n2:(4, 2) joins
- n2 contacts n1
- n1 splits its area and assigns half to n2



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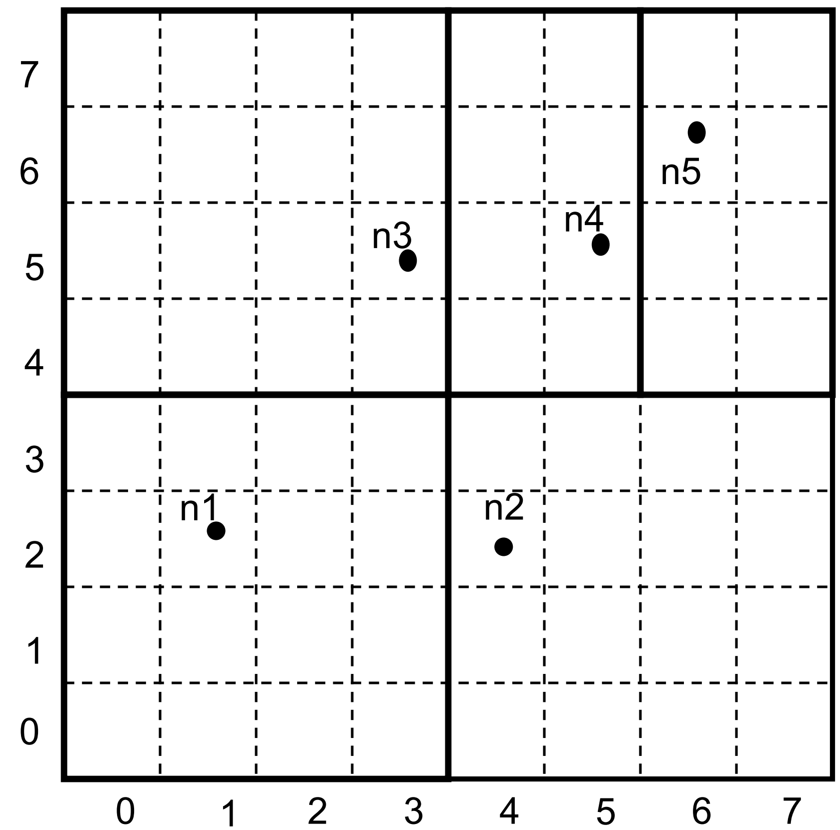
CAN Example: Two Dimensional Space

- Nodes n3:(3, 5) n4:(5, 5) and n5:(6,6) join
- Each new node sends JOIN request to an existing node chosen randomly
- New node gets neighbor table from existing node
- New and existing nodes update neighbor tables and neighbors accordingly
  - before n5 joins, n4 has neighbors n2 and n3
  - n5 adds n4 and n2 to neighborlist
  - n2 updated to include n5 in neighborlist
- Only O(2d) nodes are affected



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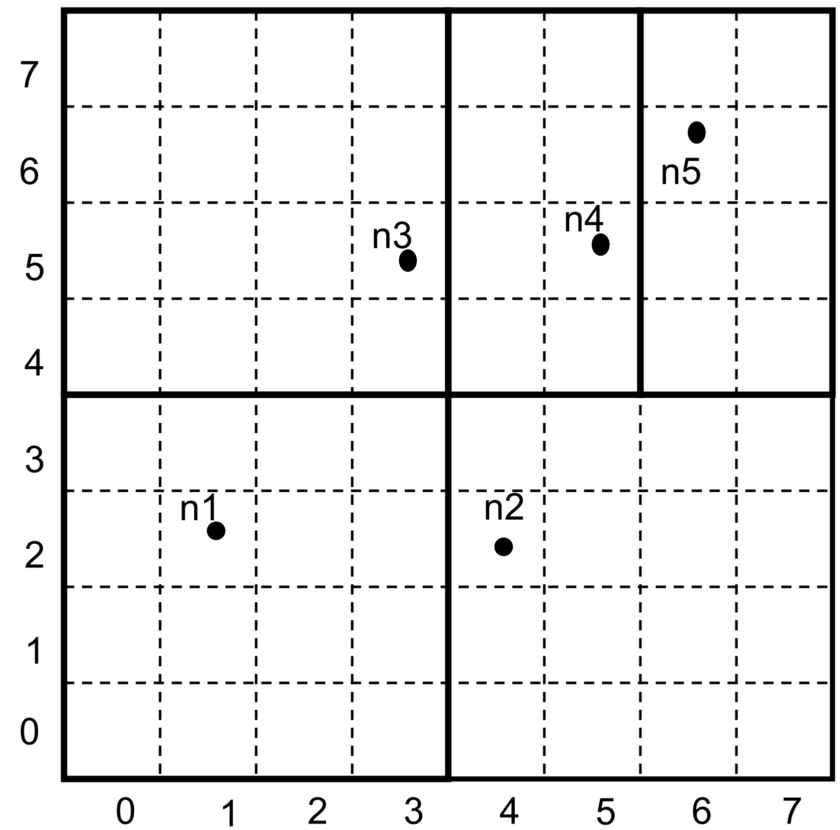
CAN Example: Two Dimensional Space

- Bootstrapping - assume CAN has an associated DNS domain and domain resolves to IP of one or more bootstrap nodes
- Optimizations - landmark routing
  - Ping a landmark server(s) and choose an existing node based on distance to landmark



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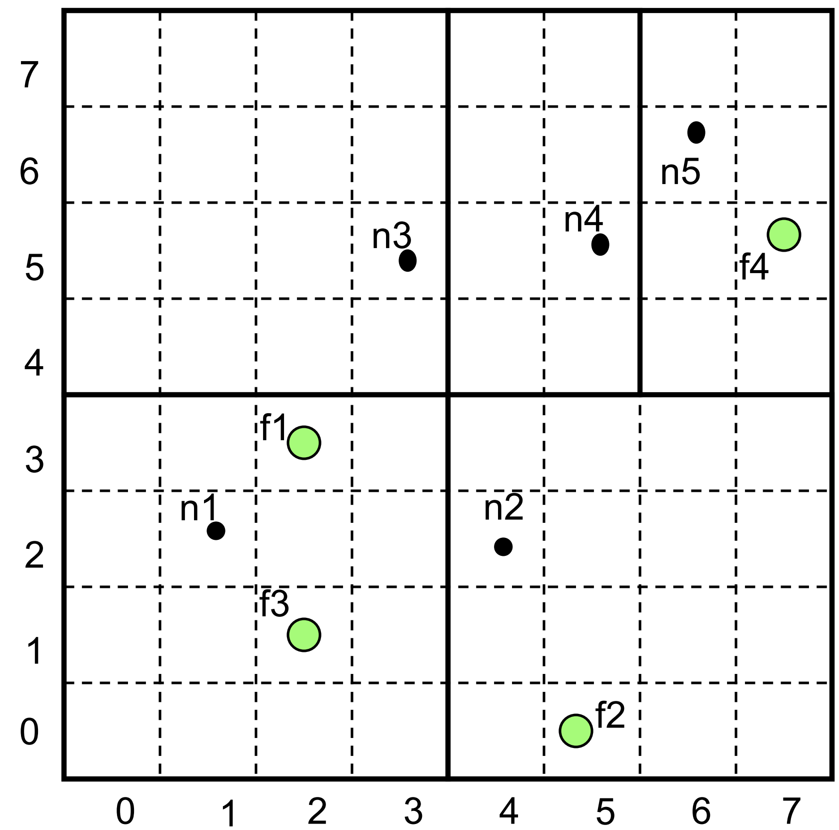
CAN Example: Two Dimensional Space

- Nodes: n1:(1, 2); n2:(4,2); n3:(3, 5); n4:(5,5);n5:(6,6)
- Items: f1:(2,3); f2:(5,1); f3:(2,1); f4:(7,5);



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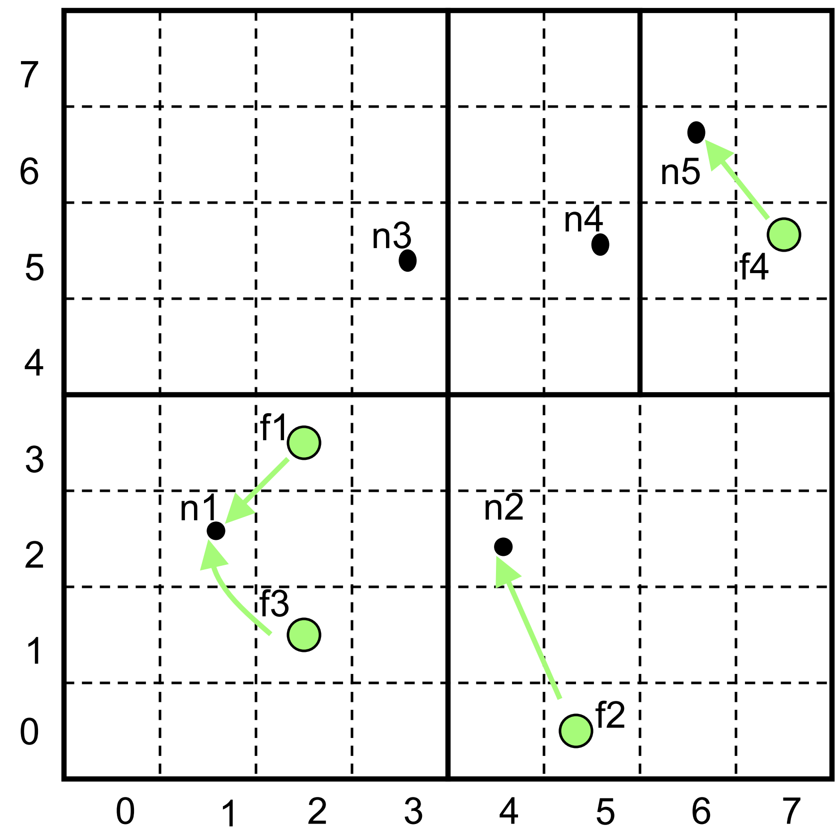
CAN Example: Two Dimensional Space

- Each item is stored by the node who owns its mapping in the space



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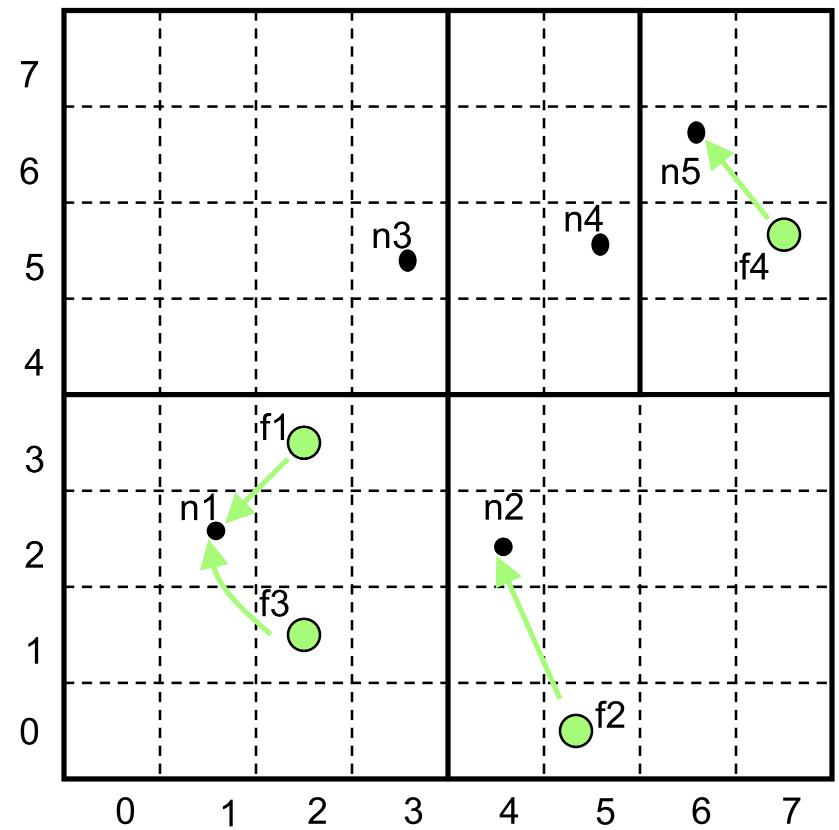
CAN: Query Example

- Forward query to the neighbor that is closest to the query *id* (Euclidean distance)
- Example: assume n1 queries f4



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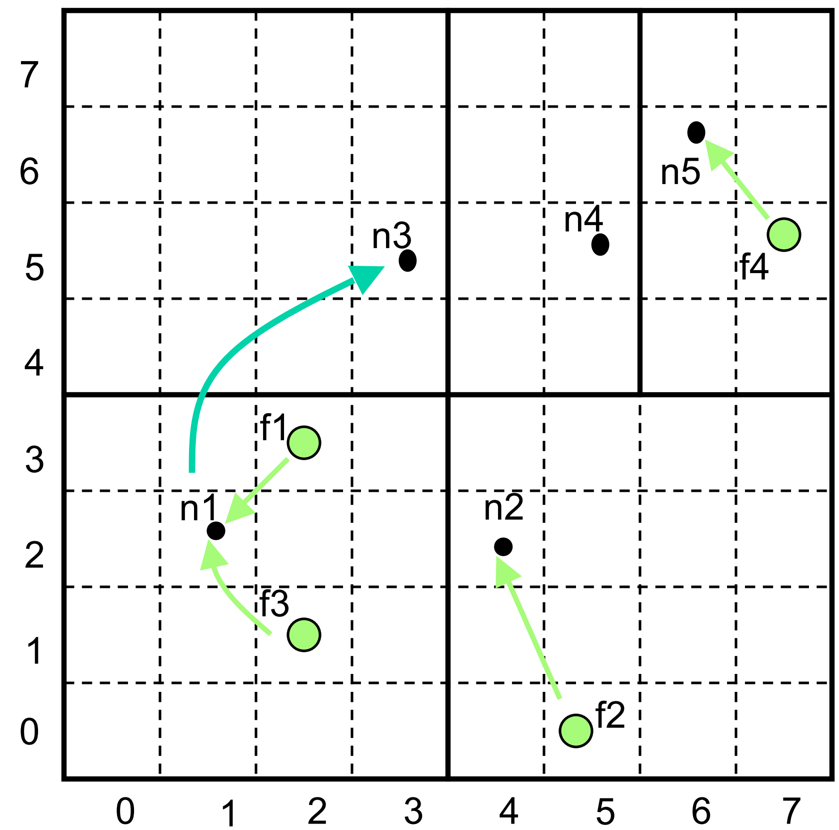

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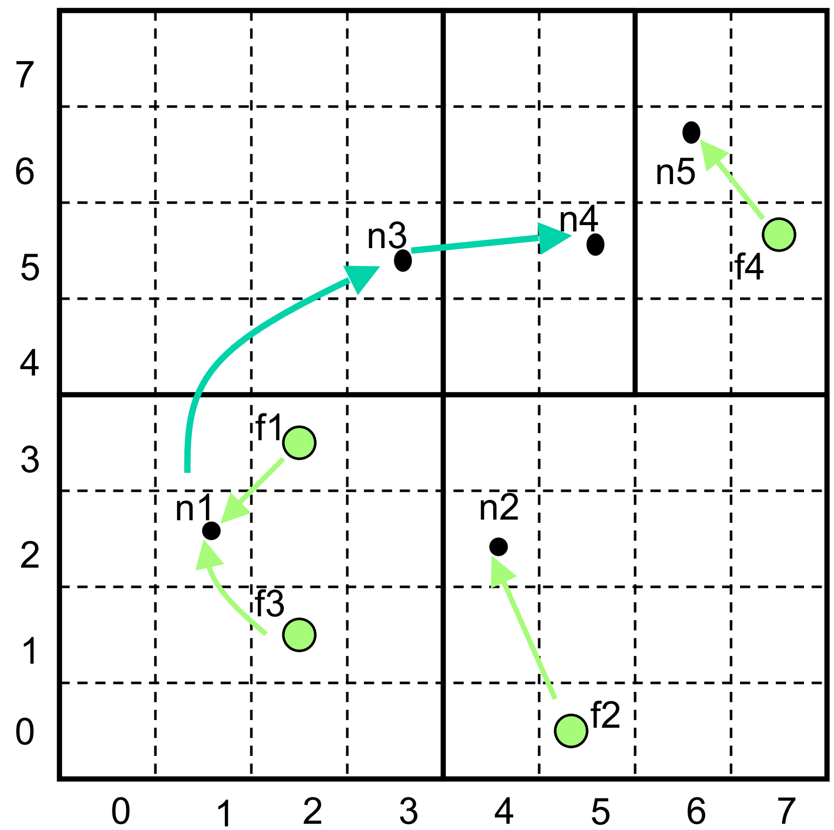

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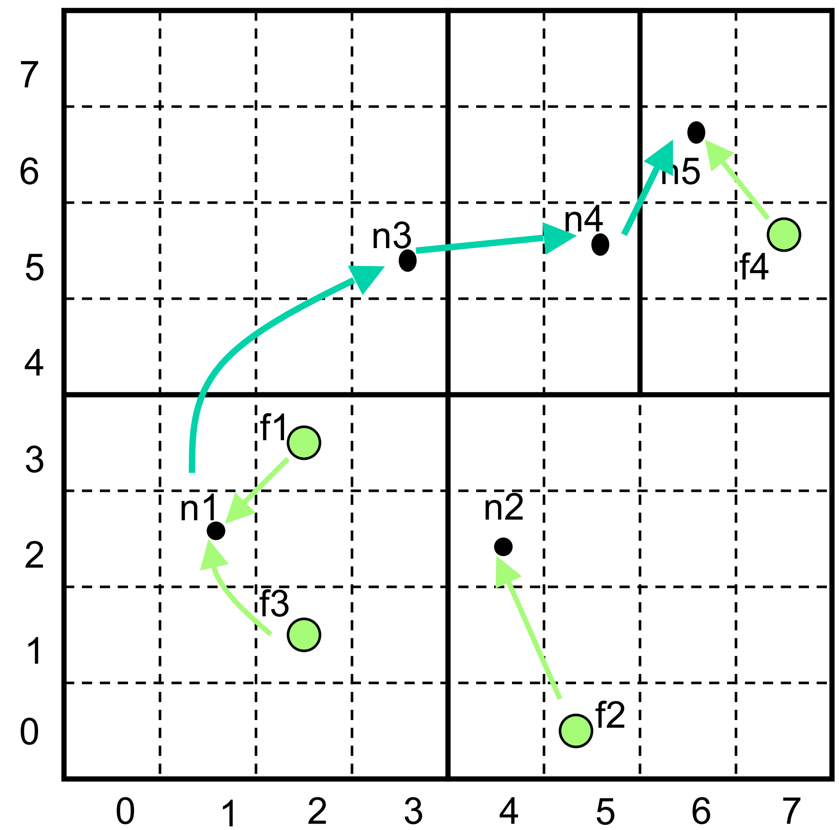
CAN: Query Example

- Content guaranteed to be found in $d*n^{1/d}$ hops
  - Each dimension has $n^{1/d}$ nodes
- Increasing the number of dimensions reduces path length but increases number of neighbors



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Node Failure Recovery

- Detection
  - Nodes periodically send refresh messages to neighbors
- Simple failures
  - neighbor's neighbors are cached
  - when a node fails, one of its neighbors takes over its zone
    - when a node fails to receive a refresh from neighbor, it sets a timer
    - many neighbors may simultaneously set their timers
    - when a node's timer goes off, it sends a TAKEOVER to the failed node's neighbors
    - when a node receives a TAKEOVER it either (a) cancels its timer if the zone volume of the sender is smaller than its own or (b) replies with a TAKEOVER

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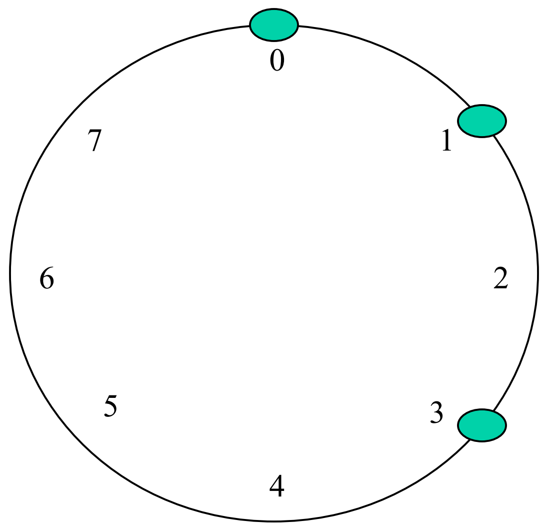
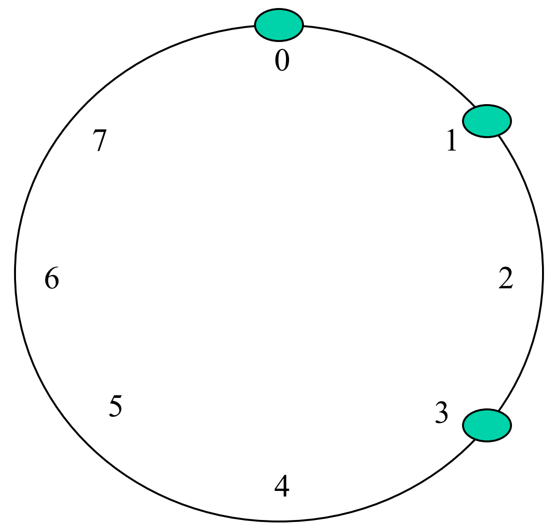
Chord

- Each node has m-bit id that is a SHA-1 hash of its IP address
- Nodes are arranged in a circle modulo m
- Data is hashed to an id in the same id space
- Node *n* stores data with id between *n* and *n*'s *predecessor*
  - 0 stores 4-0
  - 1 stores 1
  - 3 stores 2-3



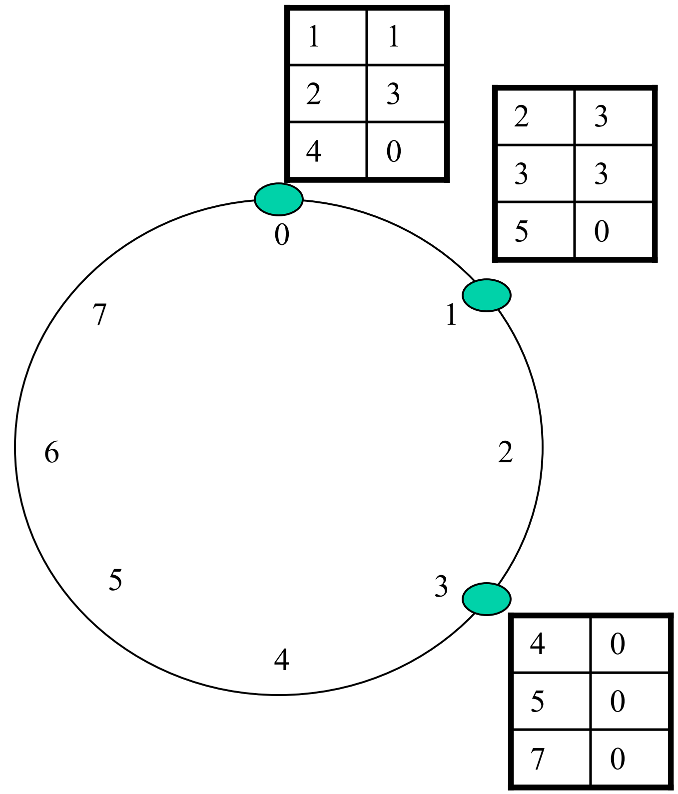
Chord

- Simple query algorithm:
  - Node maintains successor
  - To find data with id *i,* query successor until successor > *i* found
- Running time?



Chord

- In reality, nodes maintain a *finger table* with more routing information
  - For a node *n*, the i^{th} entry in its finger table is the first node that succeeds *n* by at least 2^{i-1}
- Size of finger table?



Chord

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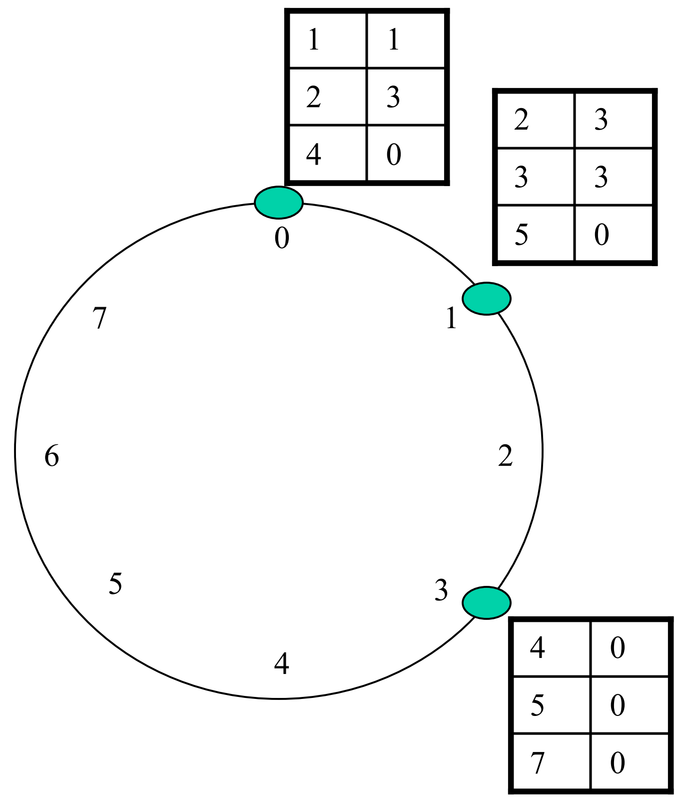
  - For a node *n*, the i^{th} entry in its finger table is the first node that succeeds *n* by at least 2^{i-1}
- Size of finger table?
- O(log N)



Chord

query:

hash key to get id

if id == node id - data found

else if id in finger table - data found

else

    p = find_predecessor(id)

    n = find_successor(p)

find_predecessor(id):

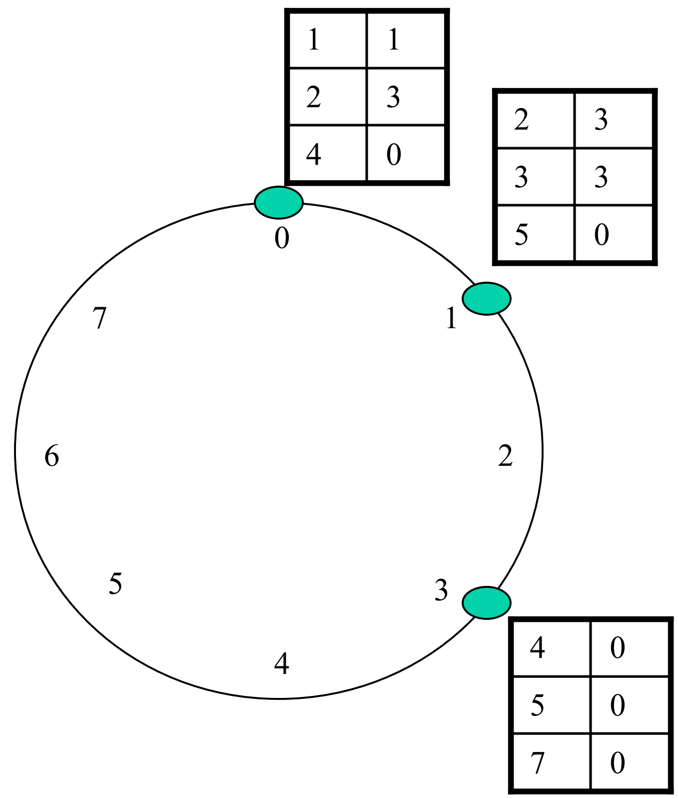
choose n in finger table closest to id

if n < id < find_successor(n)

    return n

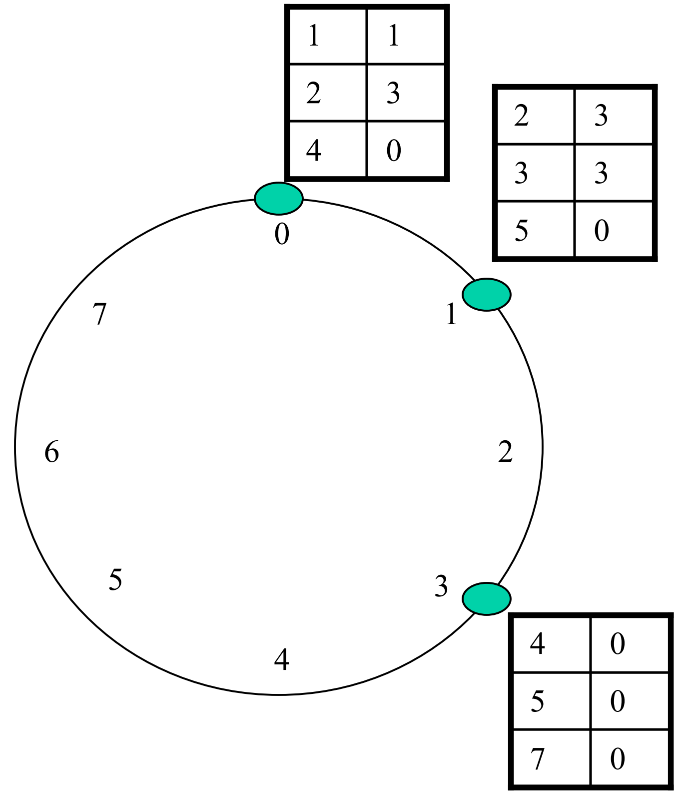
else

    ask n for finger entry closest to id and recurse



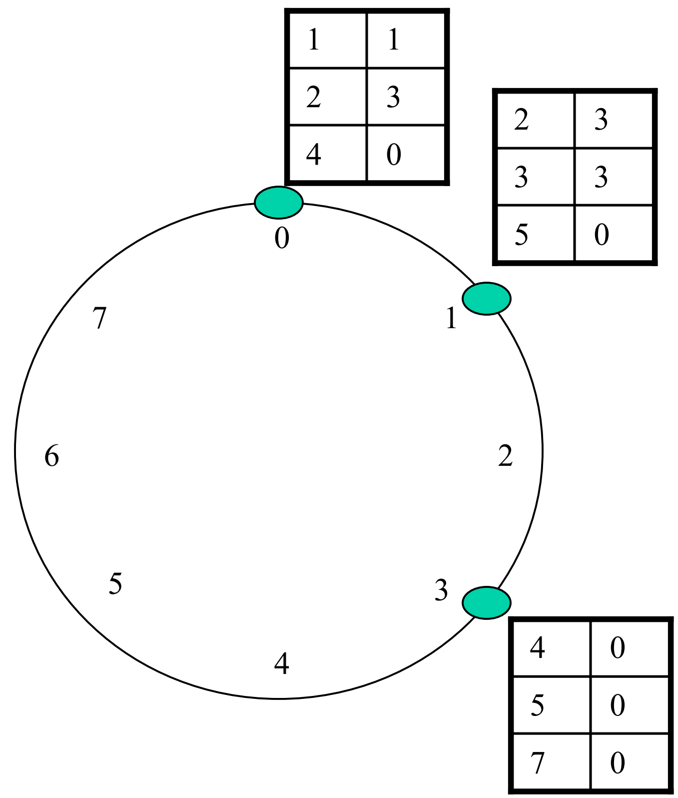
Chord

- Running time of query algorithm?
  - Problem size is halved at each iteration



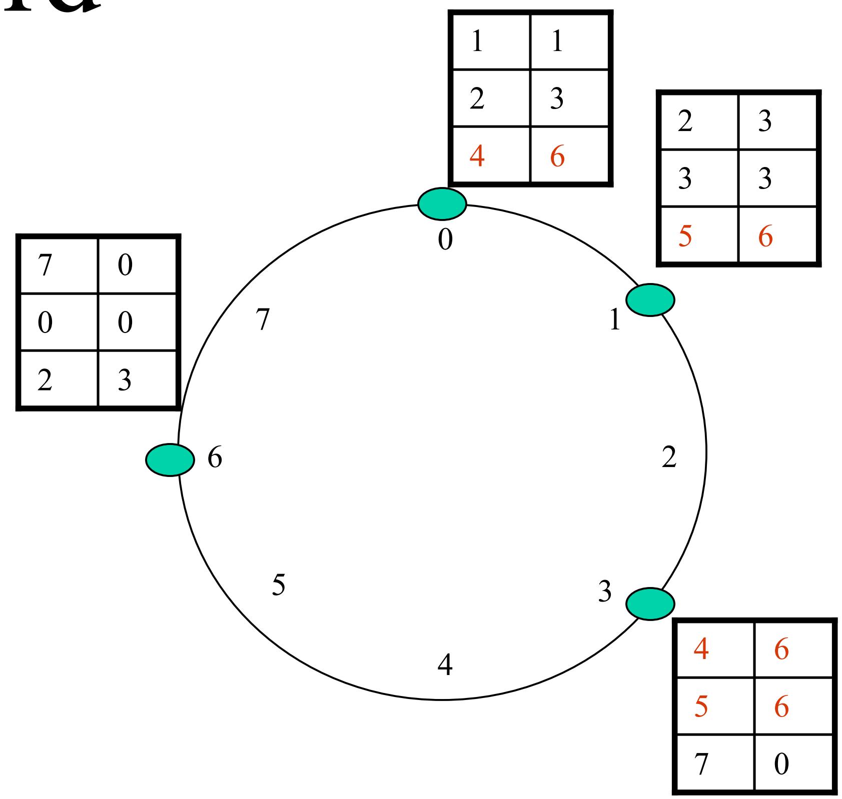
Chord

- Running time of query algorithm?
  - O(log N)



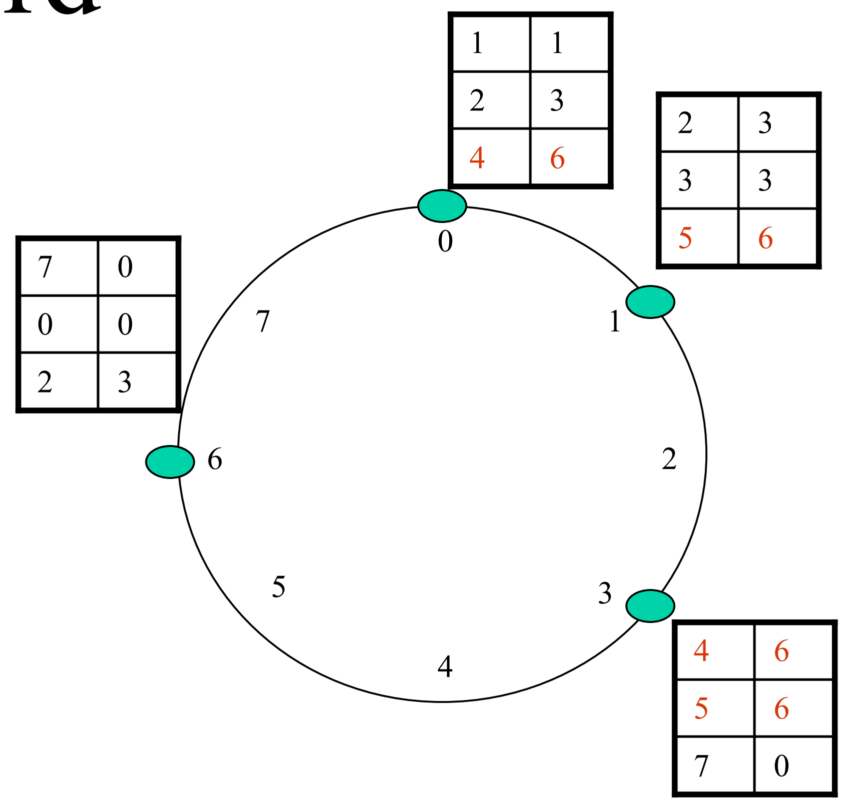
Chord

- Join
  - initialize predecessor and fingers
  - update fingers and predecessors of existing nodes
  - transfer data



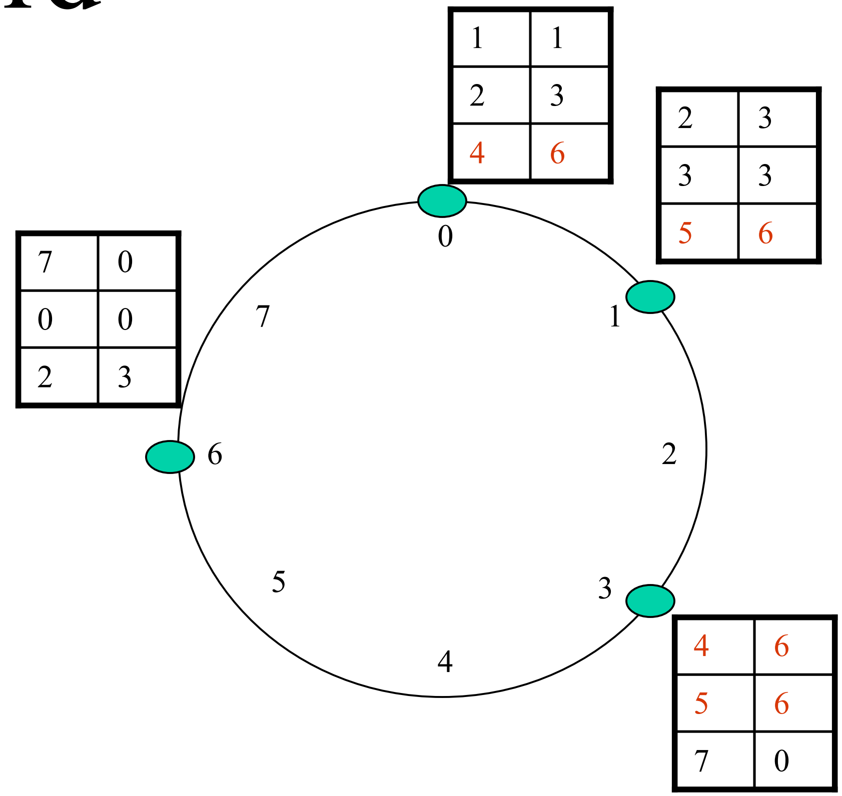
Chord

- Initialize predecessor and finger of new node *n**
  - *n** contacts existing node in network *n*
  - *n* does a lookup of predecessor of n*
  - for each entry in finger table, look up successor
- Running time - O(mlogN)
- Optimization - initialize *n** with finger table of successor
  - with high probability, reduces running time to O(log N)



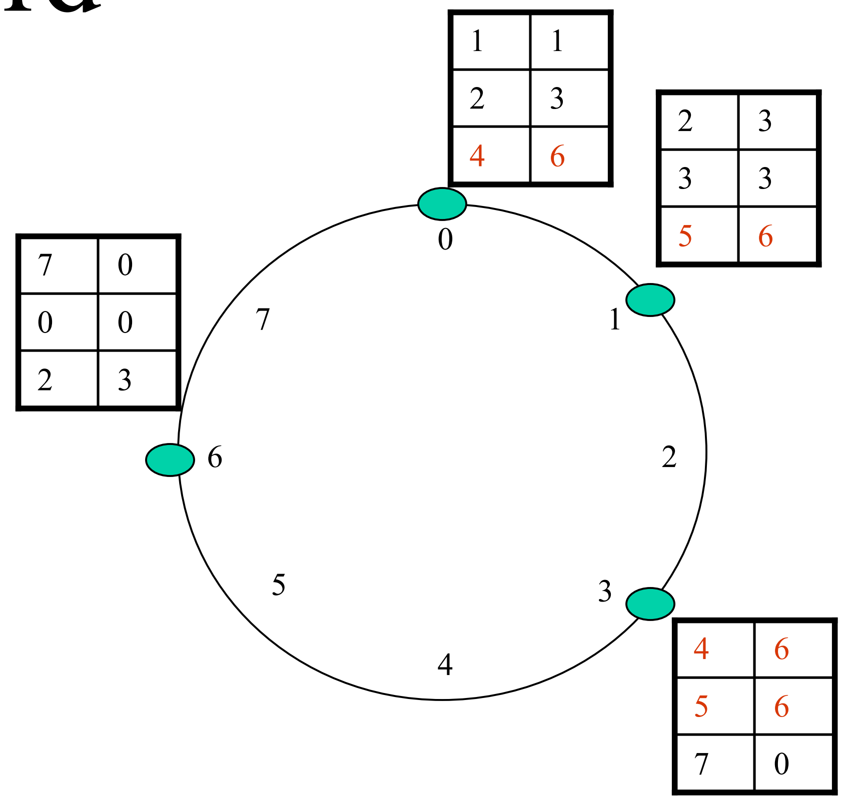
Chord

- Update existing nodes
  - n* becomes ith finger of a node p if
    - p precedes n by at least 2^{i-1}
    - the ith finger of p succeeds n
  - start at predecessor of n* and walk backwards
  - for i=1 to 3:
    - find predecessor of n^*-2^{i-1}
    - update table and recurse
- Running time $O(\log^2 N)$



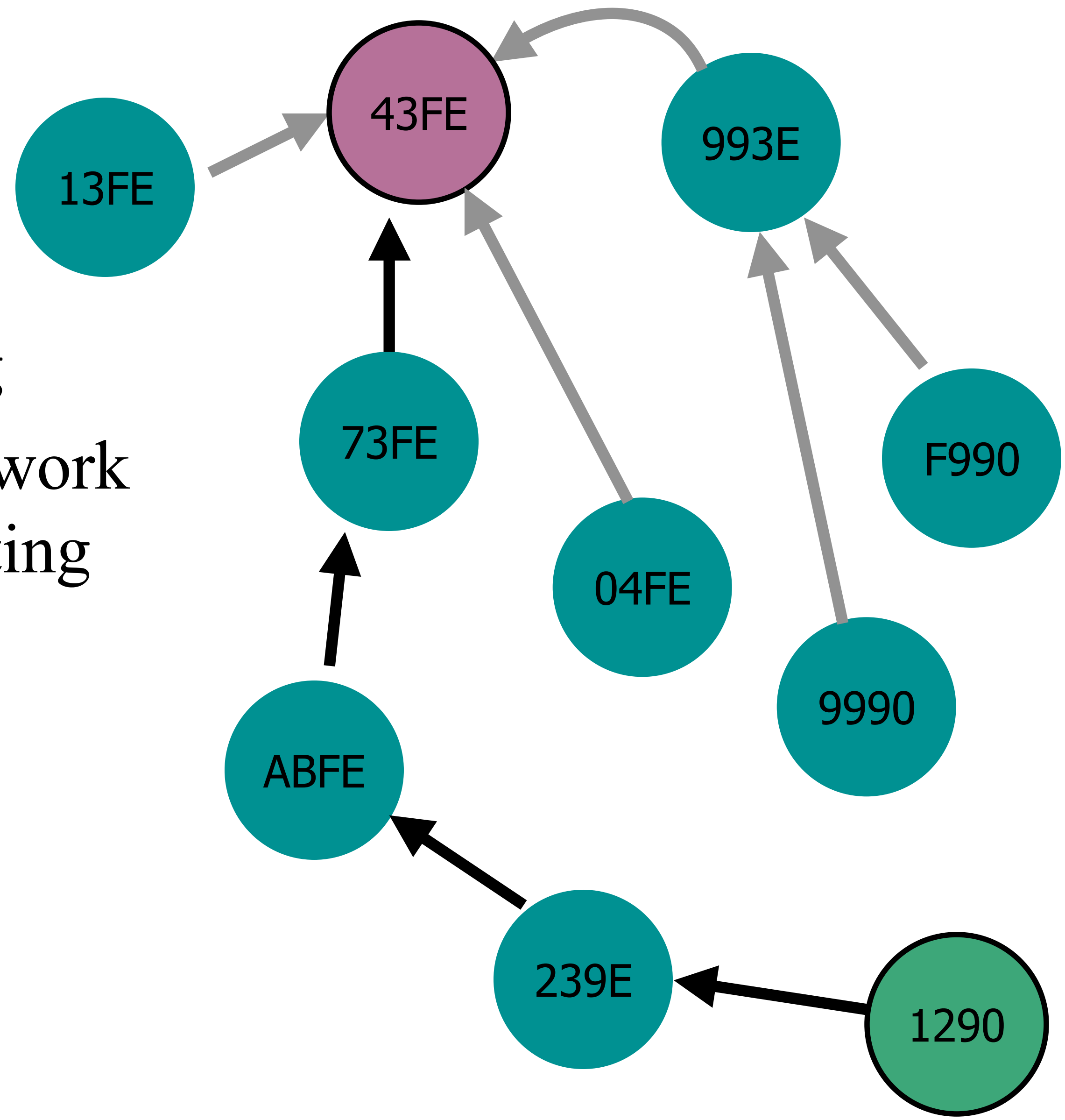
Chord

- Stabilization
  - Goal: handle concurrent joins
  - Periodically, ask successor for its predecessor
  - If your successor's predecessor isn't you, update
  - Periodically, refresh finger tables
- Failures
  - keep list of *r* successors
  - if successor fails, replace with next in the list
  - finger tables will be corrected by stabilization algorithm



DHTs – Tapestry/Pastry

- Global mesh
- Suffix-based routing
- Uses underlying network distance in constructing mesh



Comparing Guarantees

	Model	**Search**	**State**
Chord	Uni-dimensional	log N	log N
CAN	Multi-dimensional	$dN^{1/d}$	2d
Tapestry	Global Mesh	$\log_b N$	$b \log_b N$
Pastry	Neighbor map	$\log_b N$	$b \log_b N + b$

Remaining Problems?

- Hard to handle highly dynamic environments
- Usable services
- Methods don’t consider peer characteristics

Measurement Studies

- “Free Riding on Gnutella”
- Most studies focus on Gnutella
- Want to determine how users behave
- Recommendations for the best way to design systems

Free Riding Results

- Who is sharing what?
- August 2000

The top	Share	As percent of whole
333 hosts (1%)	1,142,645	37%
1,667 hosts (5%)	2,182,087	70%
3,334 hosts (10%)	2,692,082	87%
5,000 hosts (15%)	2,928,905	94%
6,667 hosts (20%)	3,037,232	98%
8,333 hosts (25%)	3,082,572	99%

Saroiu et al Study

- How many peers are server-like…client-like?
  – Bandwidth, latency
- Connectivity
- Who is sharing what?

Saroiu et al Study

- May 2001
- Napster crawl
  - query index server and keep track of results
  - query about returned peers
  - don’t capture users sharing unpopular content
- Gnutella crawl
  - send out ping messages with large TTL

Results Overview

- Lots of heterogeneity between *peers*
  - Systems should consider peer capabilities
- Peers lie
  - Systems must be able to verify reported peer capabilities or measure true capabilities

Measured Bandwidth

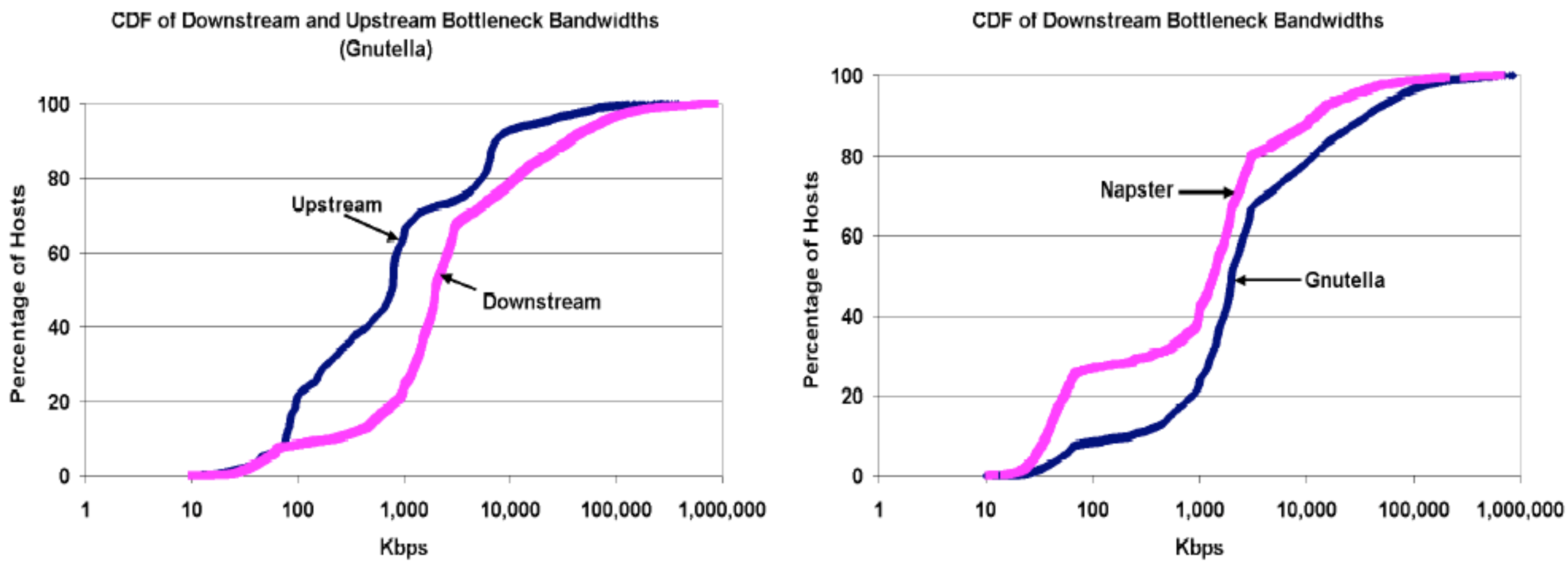
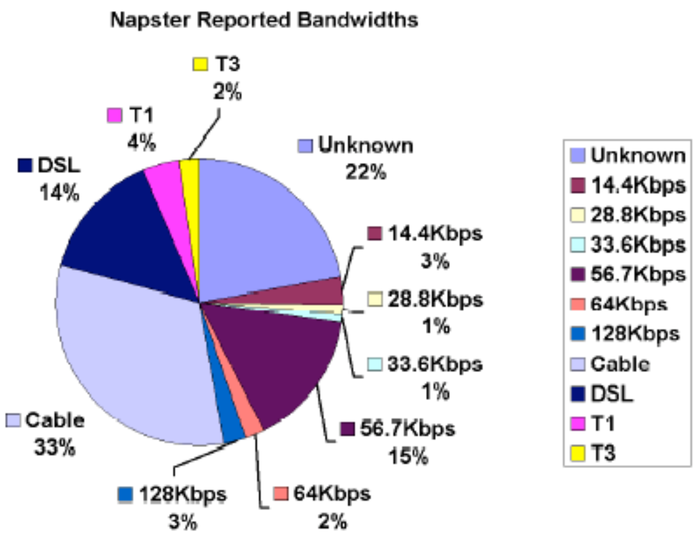


Figure 3. Left: CDFs of upstream and downstream bottleneck bandwidths for Gnutella peers; Right: CDFs of downstream bottleneck bandwidths for Napster and Gnutella peers.

Reported Bandwidth



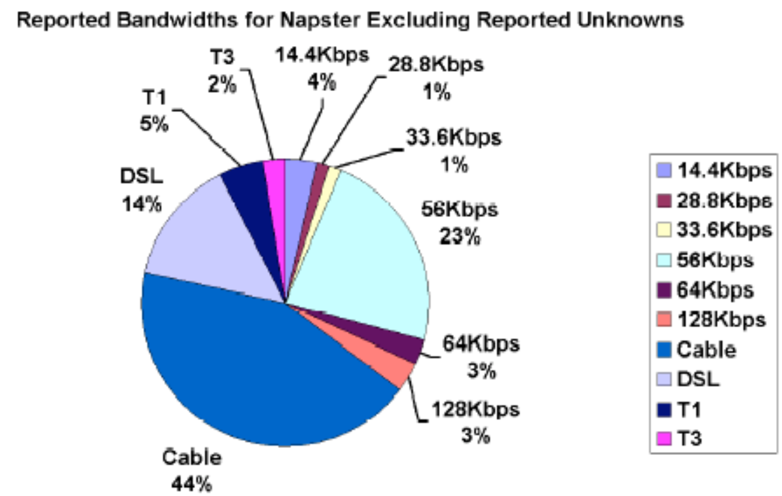


Figure 4. Left: Reported bandwidths For Napster peers; Right: Reported bandwidths for Napster peers, excluding peers that reported "unknown".

Measured Latency

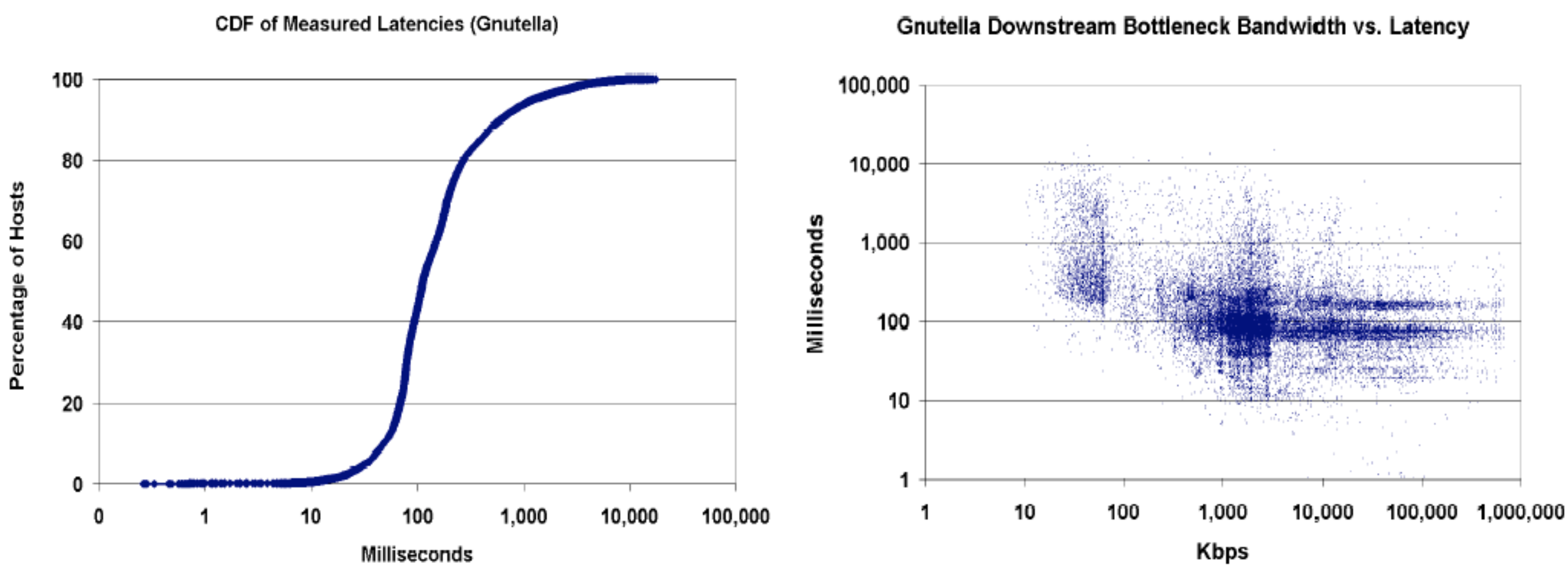


Figure 5. Left: Measured latencies to Gnutella peers; Right: Correlation between Gnutella peers' downstream bottleneck bandwidth and latency.

Measured Uptime

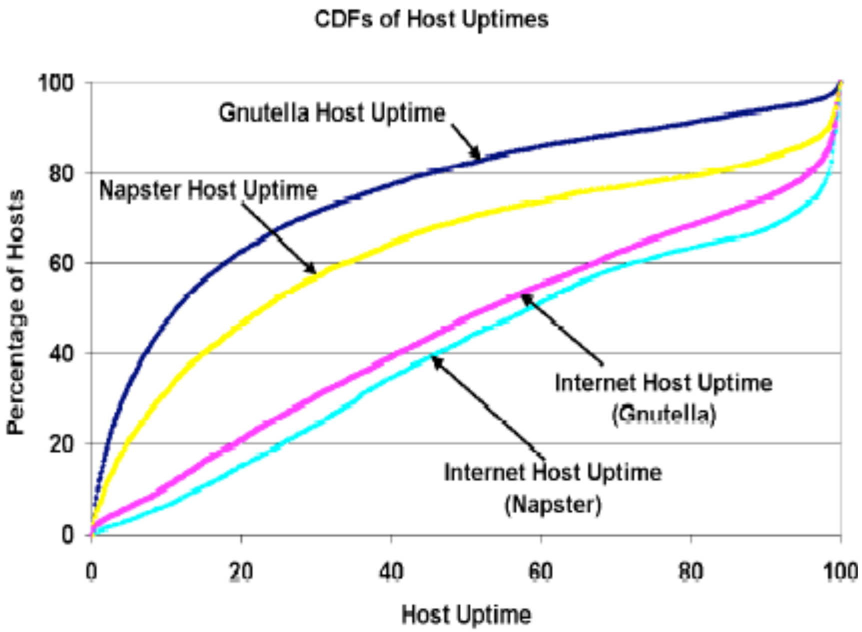


Figure 6. IP-level uptime of peers ("Internet Host Uptime"), and application-level uptime of peers ("Gnutella/Napster Host Uptime") in both Napster and Gnutella, as measured by the percentage of time the peers are reachable.

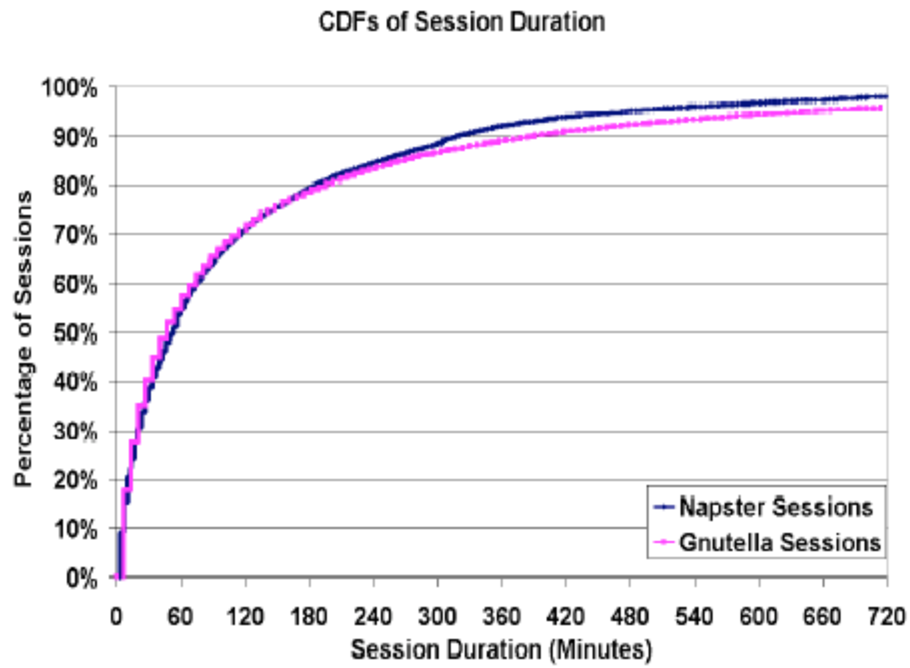


Figure 7. The distribution of Napster/Gnutella session durations.

Number of Shared Files

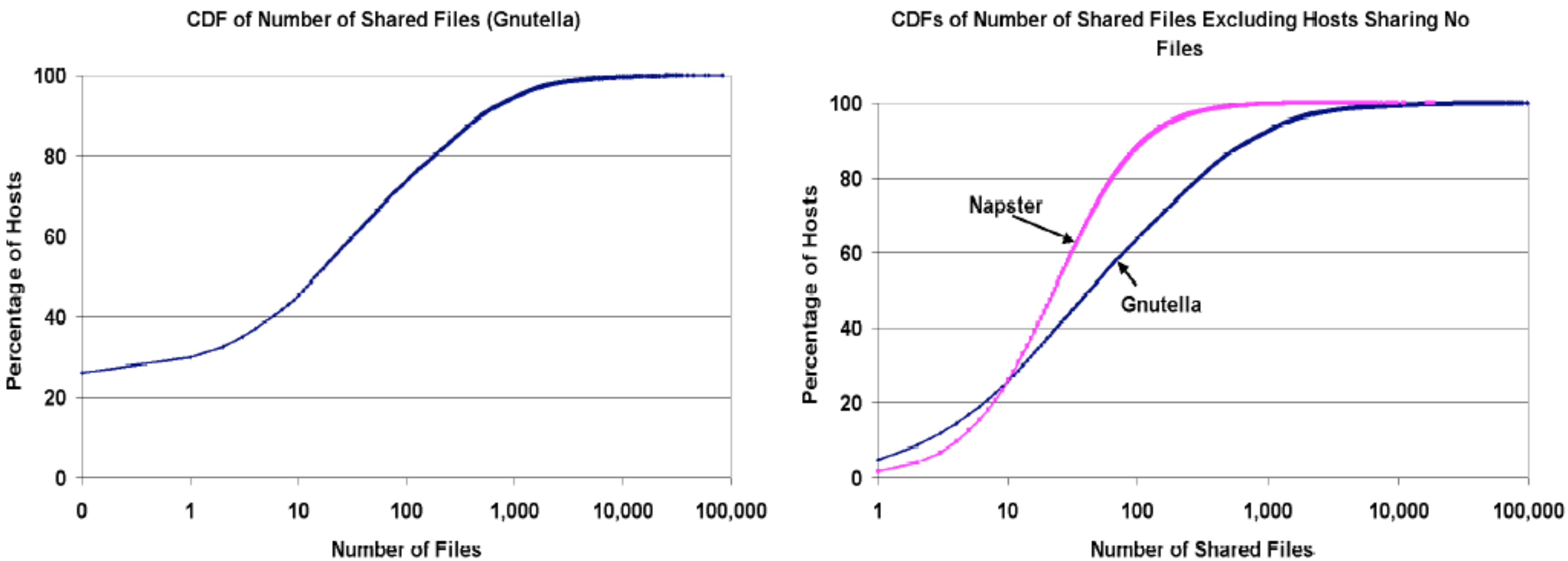


Figure 8. Left: The number of shared files for Gnutella peers; Right: The number of shared files for Napster and Gnutella peers (peers with no files to share are excluded).

Connectivity

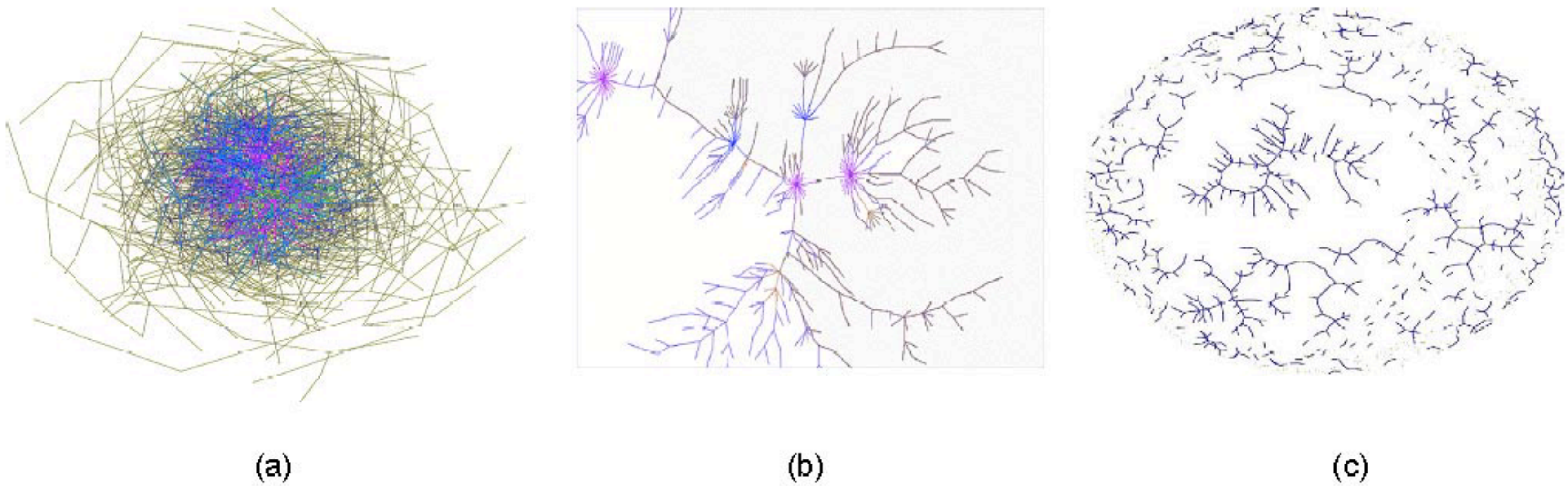


Figure 15. Left: Topology of the Gnutella network as of February 16, 2001 (1771 peers); Middle: Topology of the Gnutella network after a random 30% of the nodes are removed; Right: Topology of the Gnutella network after the highest-degree 4% of the nodes are removed.

Points of Discussion

- Is it all hype?
- Should P2P be a research area?
- Do P2P applications/systems have common research questions?
- What are the “killer apps” for P2P systems?

Conclusion

- P2P is an interesting and useful model
- There are lots of technical challenges to be solved