Peer-to-Peer Systems and Distributed Hash Tables

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CS 240: Computing Systems and Concurrency
Lecture 8

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Credits: Michael Freedman and Kyle Jamieson developed much of the original material.
Selected content adapted from B. Karp, R. Morris.

Today

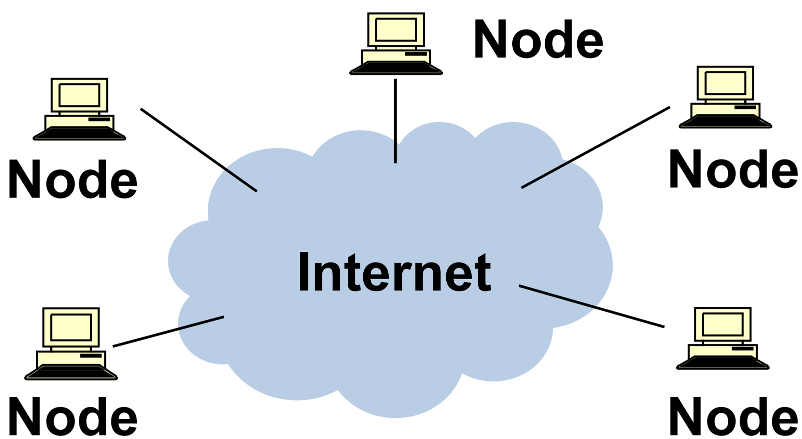
1. **Peer-to-Peer Systems**
   - **Napster, Gnutella, BitTorrent, challenges**

2. Distributed Hash Tables

3. The Chord Lookup Service

4. Concluding thoughts on DHTs, P2P

What is a Peer-to-Peer (P2P) system?



- A **distributed** system architecture:
  - **No centralized control**
  - Nodes are **roughly symmetric** in function

- **Large** number of **unreliable** nodes

Advantages of P2P systems

- **High capacity for services** through resource pooling:
  - Many disks
  - Many network connections
  - Many CPUs

- **No centralized server** or servers may mean:
  - **Less chance** of service overload as load increases
  - A single failure **won't wreck** the whole system
  - System as a whole is **harder to attack**

P2P adoption

- Successful adoption in **some niche areas –**

1. Client-to-client (legal, illegal) **file sharing**
   – Popular data but owning organization has no money

2. **Digital currency:** no natural single owner (Bitcoin)

3. **Voice/video telephony**
   – Skype used to do this…

Example: Classic BitTorrent

1. User clicks on download link
   - Gets ***torrent*** file with content hash, IP addr of ***tracker***

2. User's BitTorrent (BT) client talks to tracker
   - Tracker tells it **list of peers** who have file

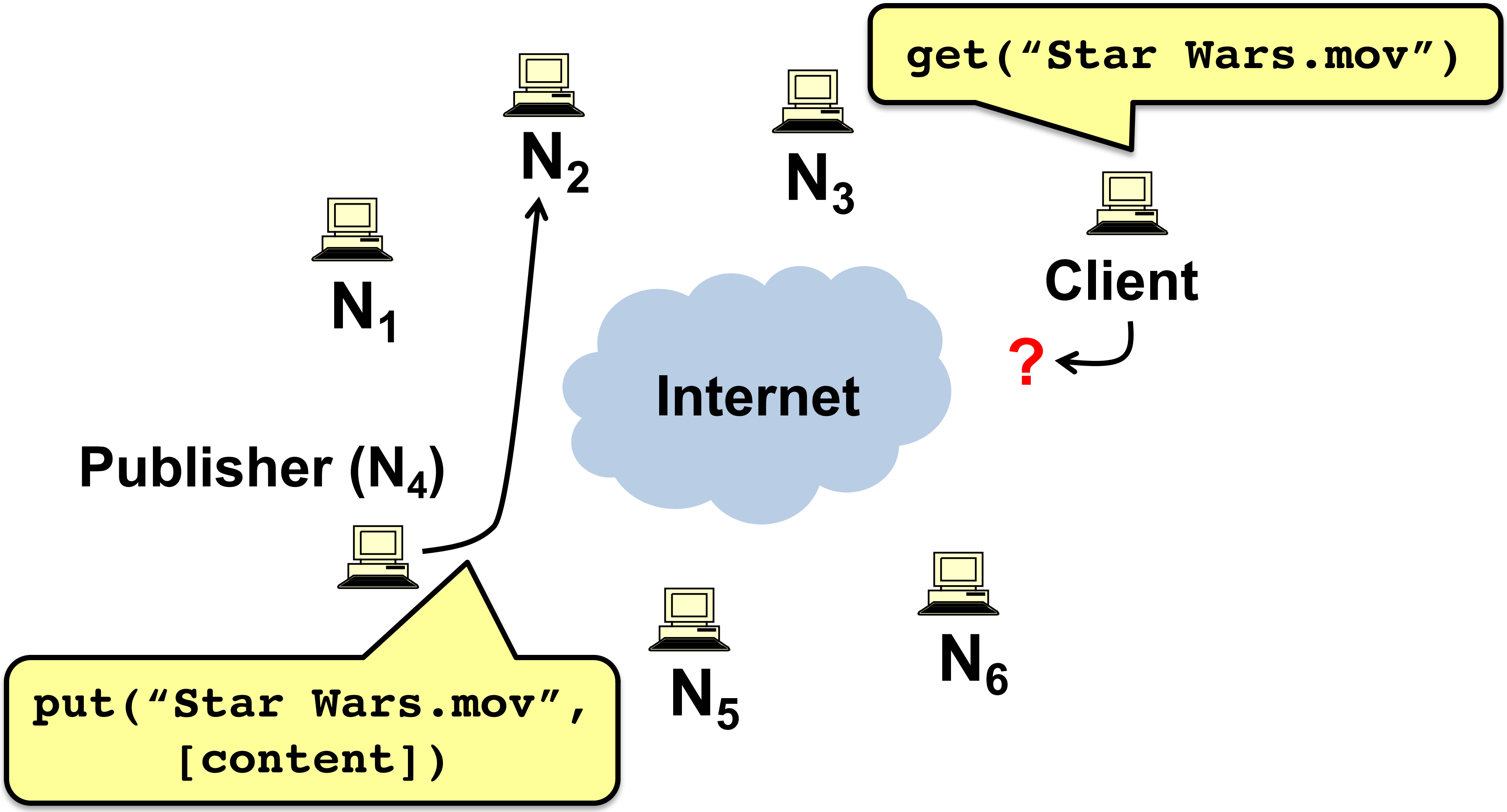
3. User's BT client downloads file from one or more peers

4. User's BT client tells tracker it has a copy now, too

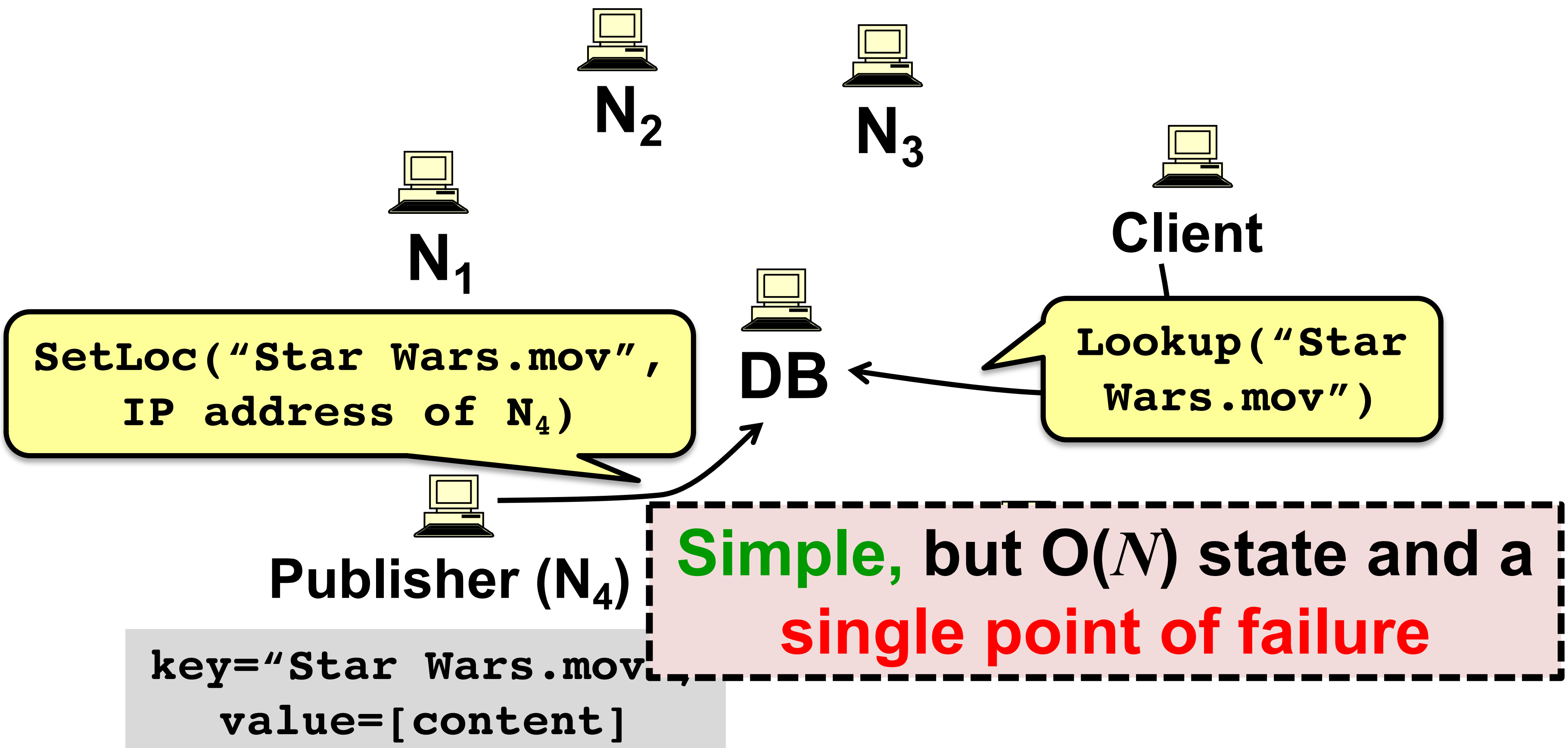
5. User's BT client serves the file to others for a while

Provides huge download bandwidth, **without** expensive server or network links

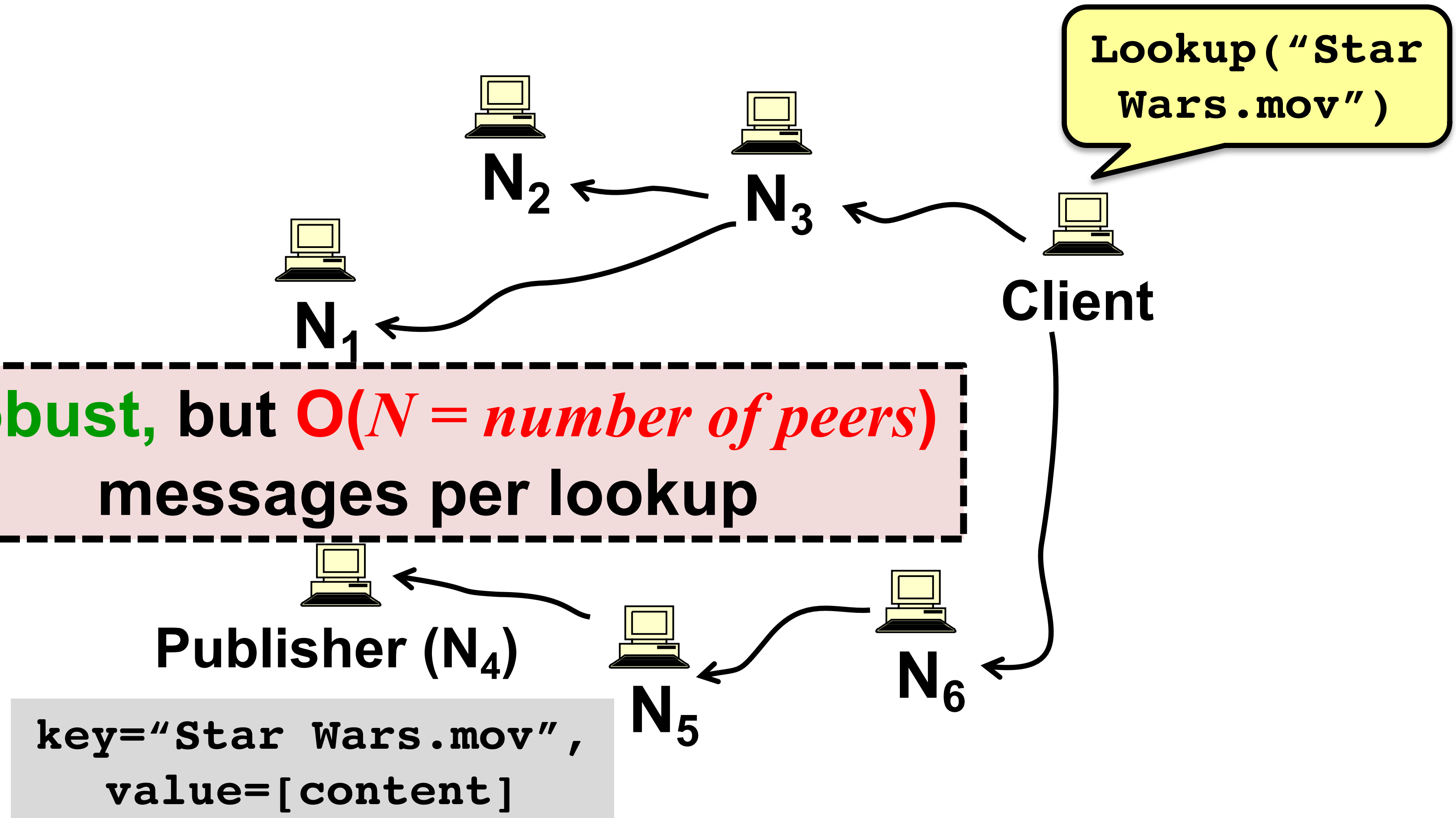
The lookup problem



Centralized lookup (Napster)

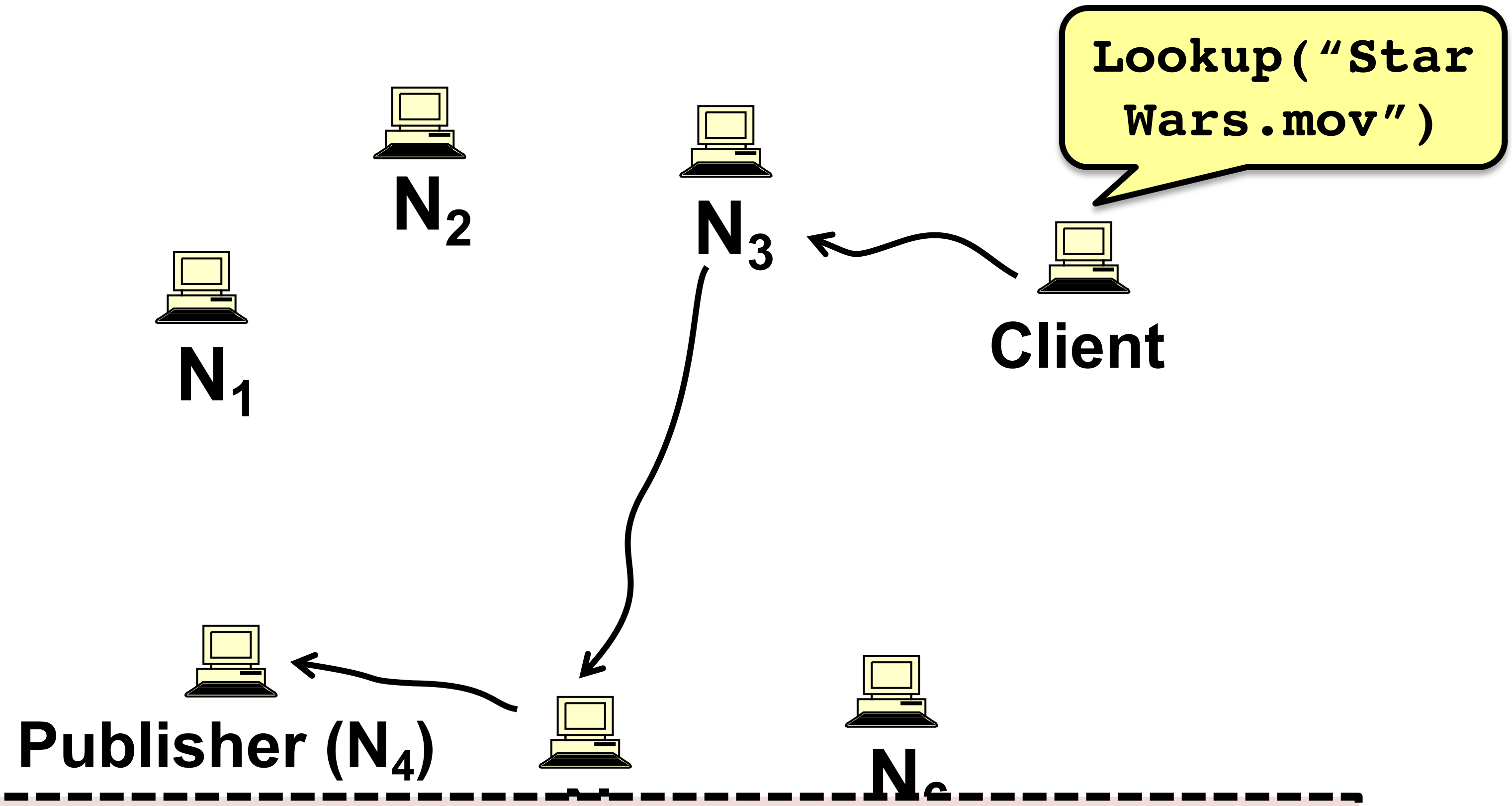


Flooded queries (original Gnutella)



Robust, but **O(*N = number of peers*)** messages per lookup

Routed DHT queries (Chord)



Goal: robust, reasonable state, reasonable number of hops?

Today

1. Peer-to-Peer Systems

2. **Distributed Hash Tables**

3. The Chord Lookup Service

What is a DHT (and why)?

- Local hash table:

```
key = Hash(name)
put(key, value)
get(key) → value
```

- **Service:** Constant-time insertion and lookup

Distributed Hash Table (DHT):
Do (roughly) this across millions of hosts on the Internet!

What is a DHT (and why)?

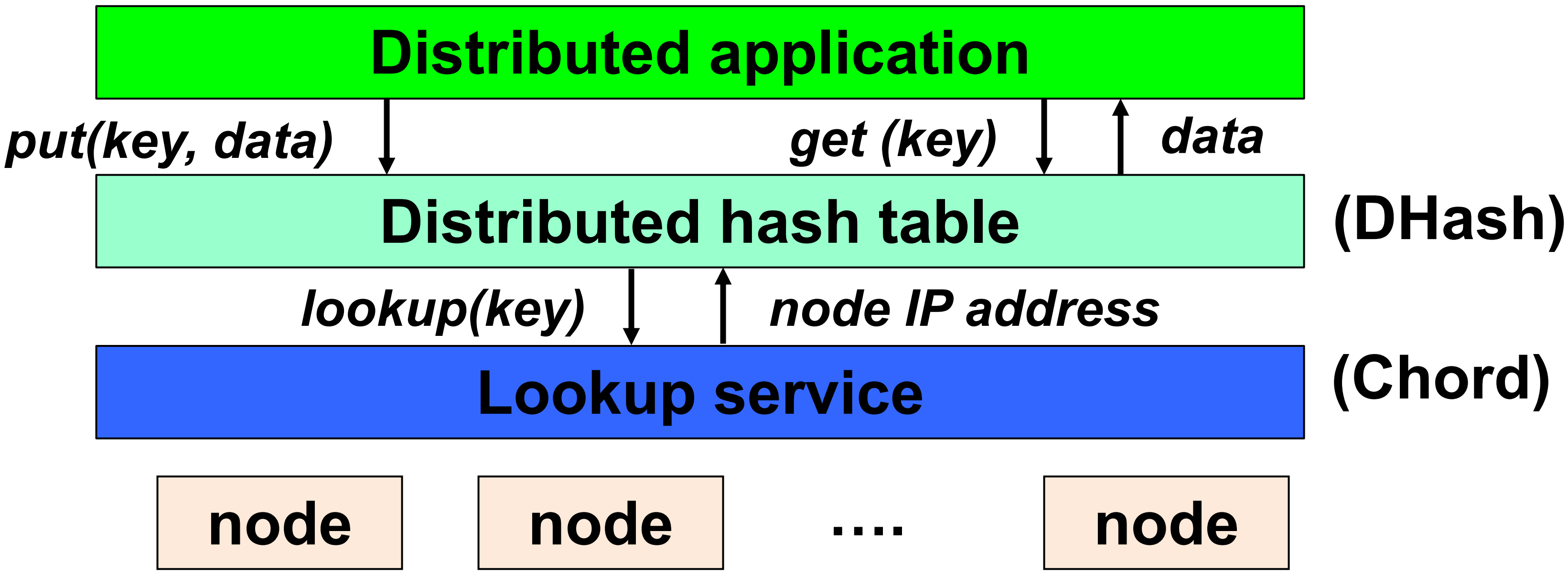
- Distributed Hash Table:

```
key = hash(data)
lookup(key) → IP addr
```
(Chord lookup service)

```
send-RPC(IP address, put, key, data)
send-RPC(IP address, get, key) → data
```

- **Partitioning data** in **large-scale distributed systems**
  - Tuples in a global database engine
  - Data blocks in a global file system
  - Files in a P2P file-sharing system

Cooperative storage with a DHT



- App may be **distributed** over many nodes
- DHT **distributes data storage** over many nodes

BitTorrent over DHT

- BitTorrent can use DHT instead of (or with) a tracker

- BT clients use DHT:
  - Key = **?**
  - Value = **?**

BitTorrent over DHT

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- BT clients use DHT:
  - Key = **file content hash** ("infohash")
  - Value = **?**

BitTorrent over DHT

- BitTorrent can use DHT instead of (or with) a tracker

- BT clients use DHT:
  - Key = **file content hash** ("infohash")
  - Value = **IP address of peer** willing to serve file
    - Can store multiple values (*i.e.* IP addresses) for a key

- Client does:
  - `get(infohash)` to find other clients willing to serve
  - `put(infohash, my-ipaddr)` to identify itself as willing

Why DHT for BitTorrent?

- The DHT comprises a single giant tracker, less fragmented than many trackers
  - So peers more likely to **find each other**

- Classic BitTorrent tracker is a single point of failure
  - Legal attacks
  - Denial-of-Service (DoS) attacks

What is hard in DHT design?

- **Decentralized:** no central authority
- **Scalable:** low network traffic overhead
- **Efficient:** find items quickly (latency)
- **Dynamic:** nodes fail, new nodes join

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1. Peer-to-Peer Systems

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3. **The Chord Lookup Service**

Chord lookup algorithm properties

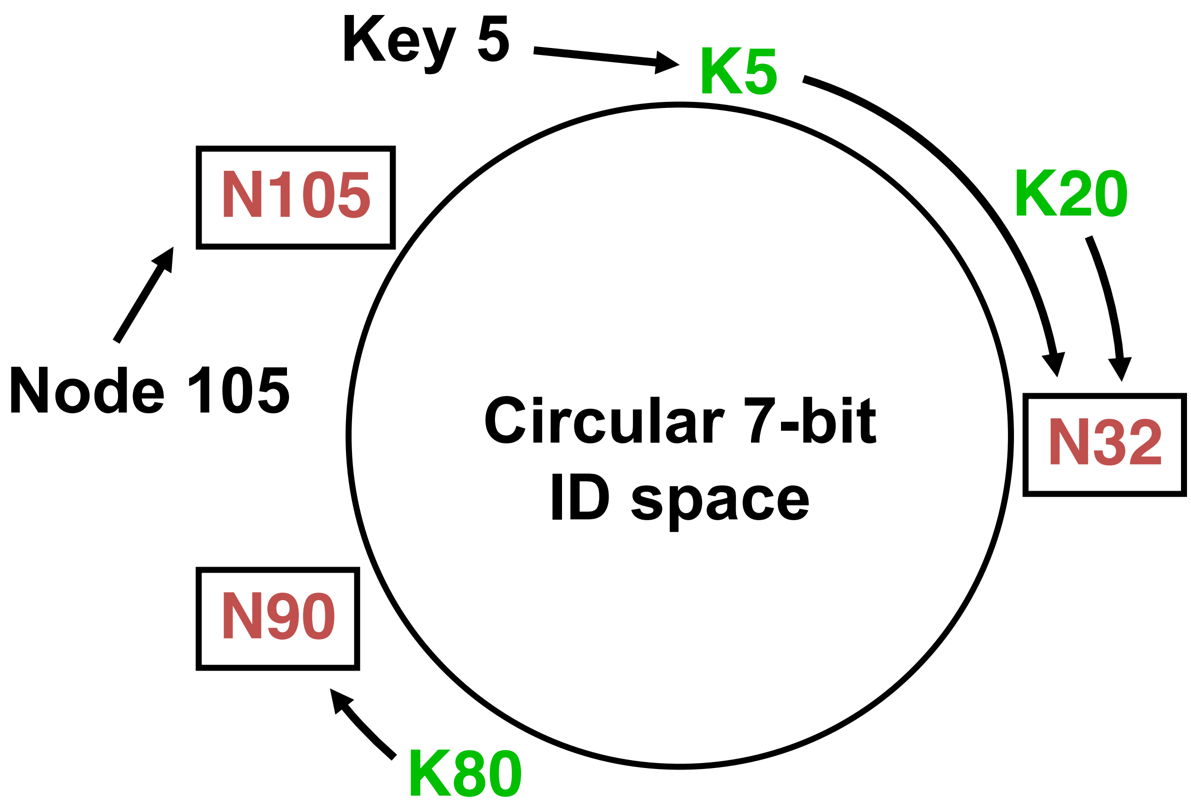
Interface: lookup(key) → IP address

- **Efficient:** O(log *N*) messages per lookup
  - *N* is the total number of nodes
- **Scalable:** O(log *N*) state per node
- **Robust:** survives massive failures
- **Simple to analyze**

Chord identifiers

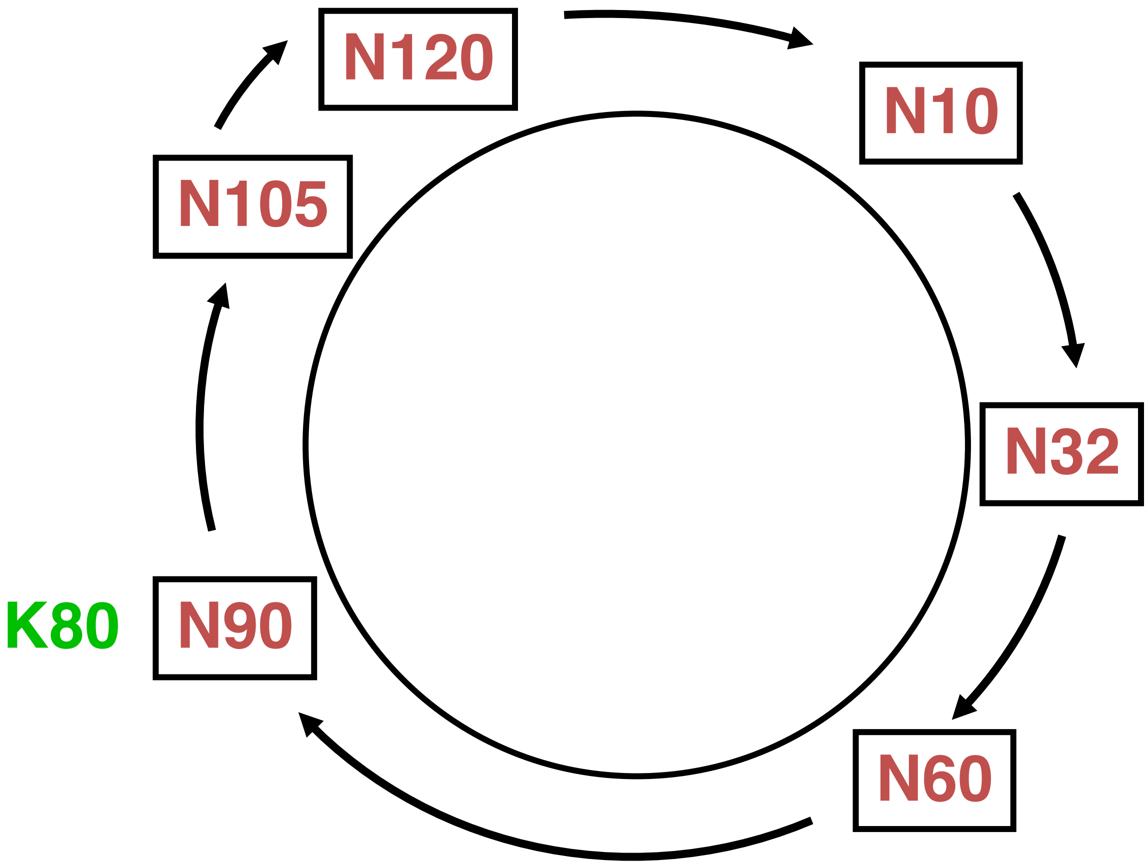
- **Key identifier** = SHA-1(key)
- **Node identifier** = SHA-1(IP address)
- SHA-1 distributes both uniformly
- ***How does Chord partition data?***
  - *i.e.*, map key IDs to node IDs

Consistent hashing

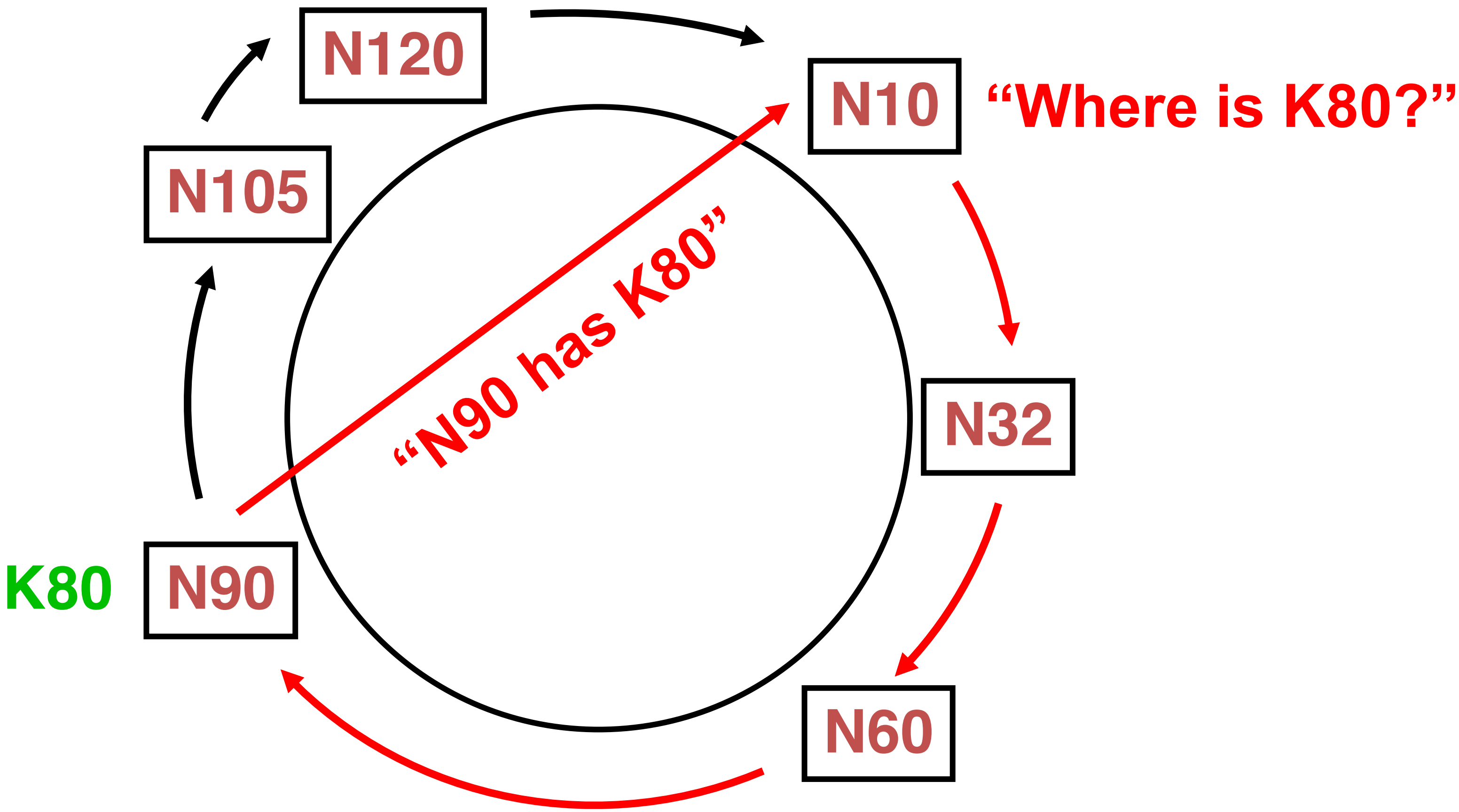


Key is stored at its **successor:** node with next-higher ID

Chord: Successor pointers



Basic lookup



Simple lookup algorithm

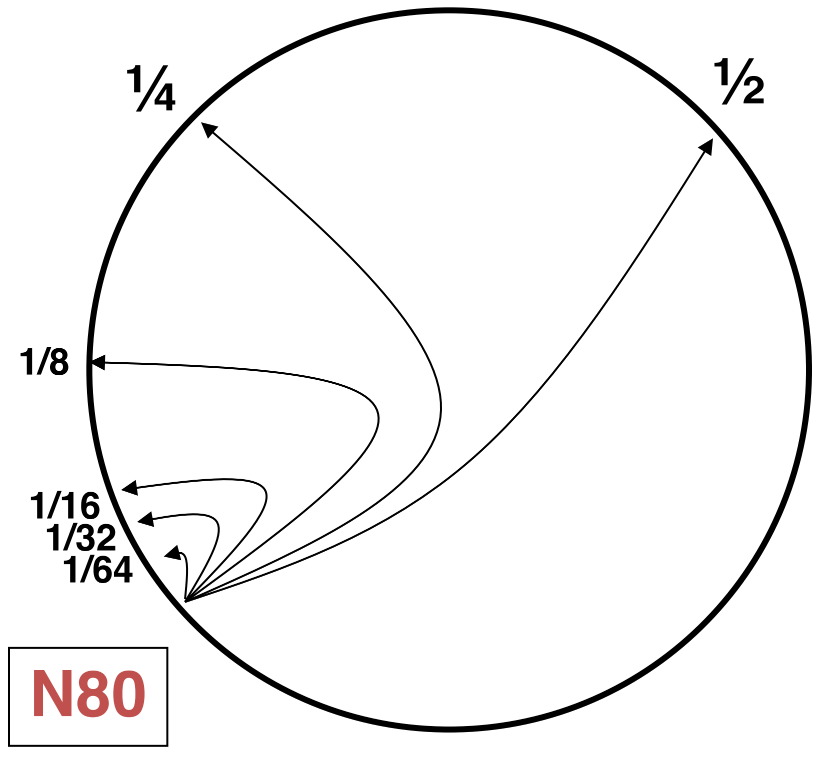
```
Lookup(key-id)
  succ ← my successor
  if my-id < succ < key-id // next hop
    call Lookup(key-id) on succ
  else                      // done
    return succ
```

- **Correctness** depends only on **successors**

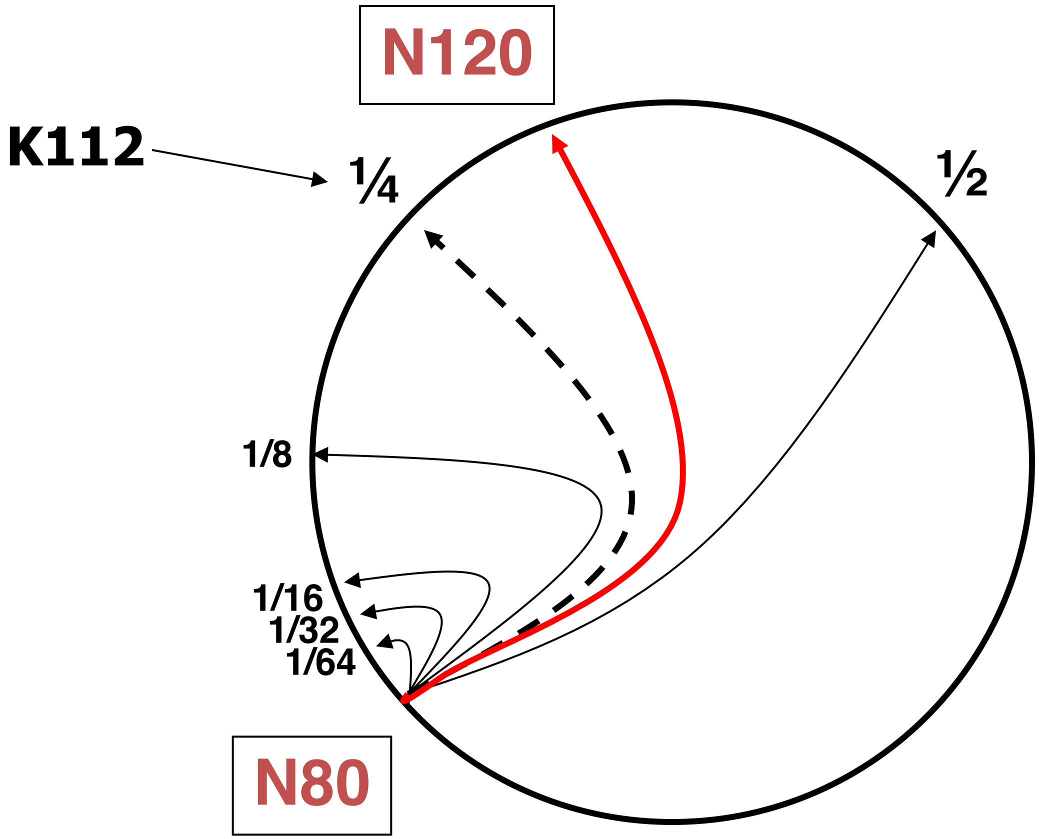
Improving performance

- **Problem:** Forwarding through successor is slow
- Data structure is a linked list: O(n)
- **Idea:** Can we make it more like a binary search?
  - Need to be able to halve distance at each step

“Finger table” allows log N-time lookups



Finger i Points to Successor of $n+2^i$



Implication of finger tables

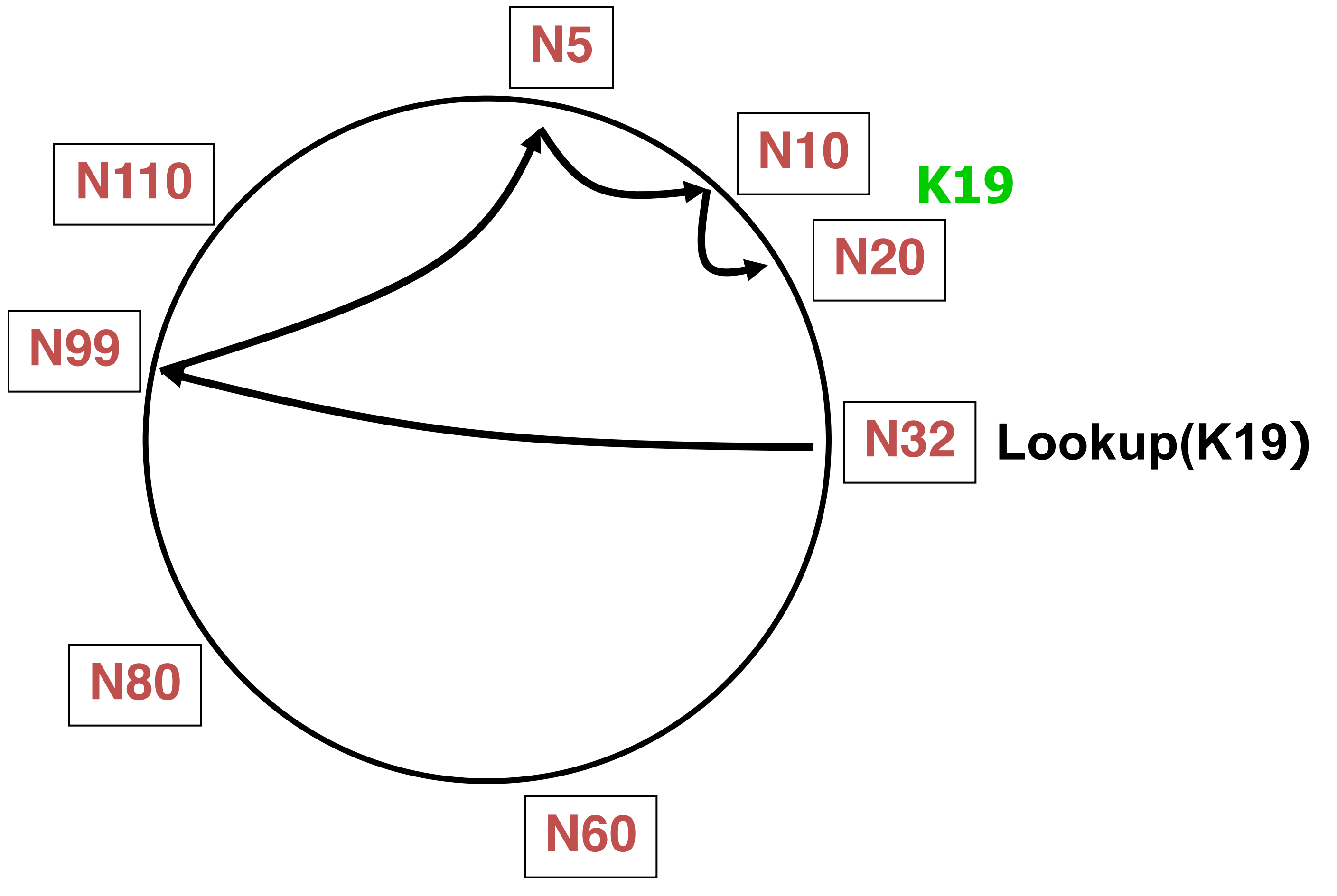
- A **binary lookup tree** rooted at every node
  - Threaded through other nodes' finger tables

- This is **better** than simply arranging the nodes in a single tree
  - Every node acts as a root
    - So there's **no root hotspot**
    - **No single point** of failure
    - But a **lot more state** in total

Lookup with finger table

```
Lookup(key-id)
  look in local finger table for
     highest n: my-id < n < key-id
  if n exists
     call Lookup(key-id) on node n  //next hop
  else
     return my successor  //done
```

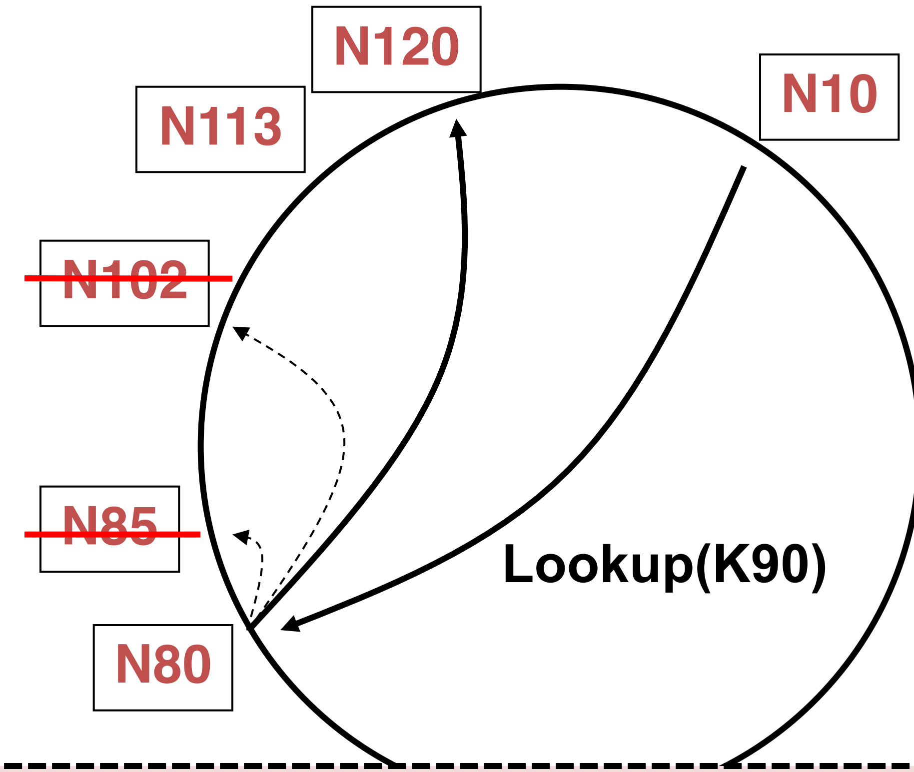
Lookups Take O(log *N*) Hops



An aside: Is log(n) fast or slow?

- For a million nodes, it’s 20 hops
- If each hop takes 50 milliseconds, lookups take **a second**
- If each hop has 10% chance of failure, it’s a couple of timeouts
- So in practice log(n) is better than O(n) but **not great**

Failures may cause incorrect lookup



N80 does not know correct successor, so **incorrect lookup**

Successor lists

- Each node stores a **list** of its r **immediate successors**
  - After failure, will know first live successor
  - **Correct successors** guarantee **correct lookups**
    - Guarantee is with some probability
  - r is often O(log N)
    - E.g., 20 for 1 million nodes

Lookup with fault tolerance

```
Lookup(key-id)
  look in local finger table and successor-list
    for highest n: my-id < n < key-id
  if n exists
    call Lookup(key-id) on node n  // next hop
    if call failed,
      remove n from finger table and/or
        successor list
      return Lookup(key-id)
  else
    return my successor   // done
```

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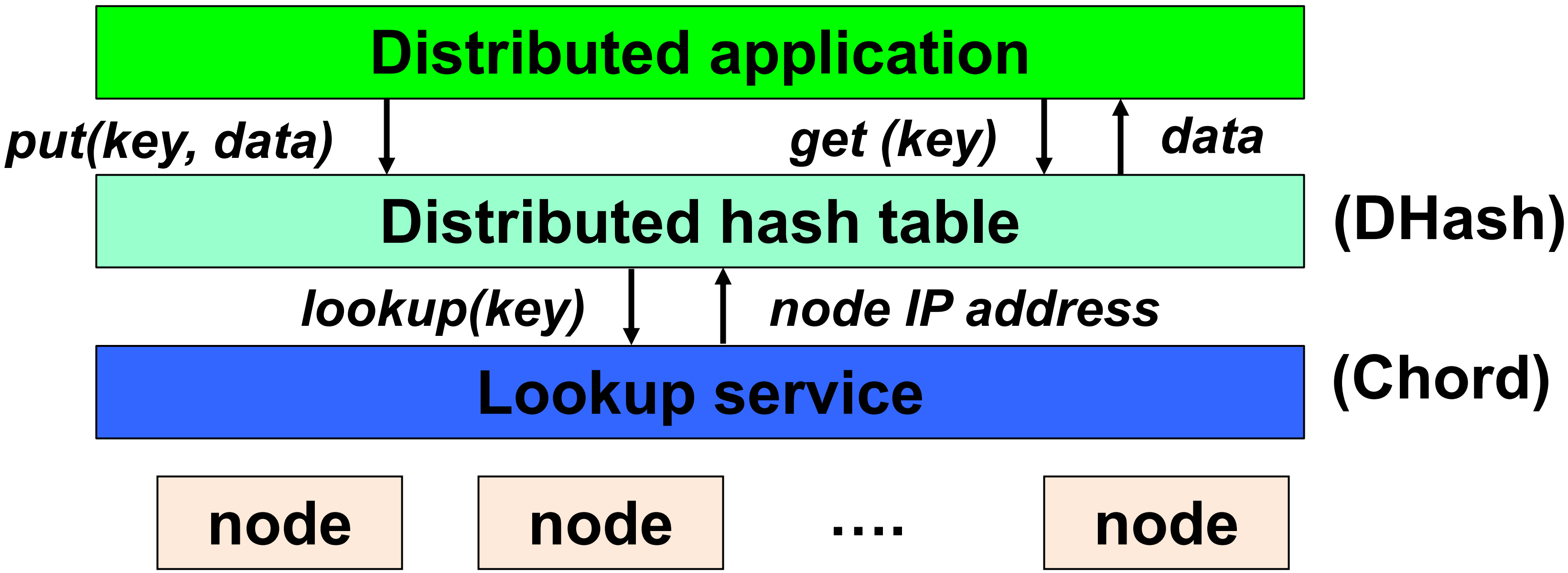
3. **The Chord Lookup Service**
   - **Integration with *DHash* DHT**

Cooperative storage with a DHT



- App may be **distributed** over many nodes
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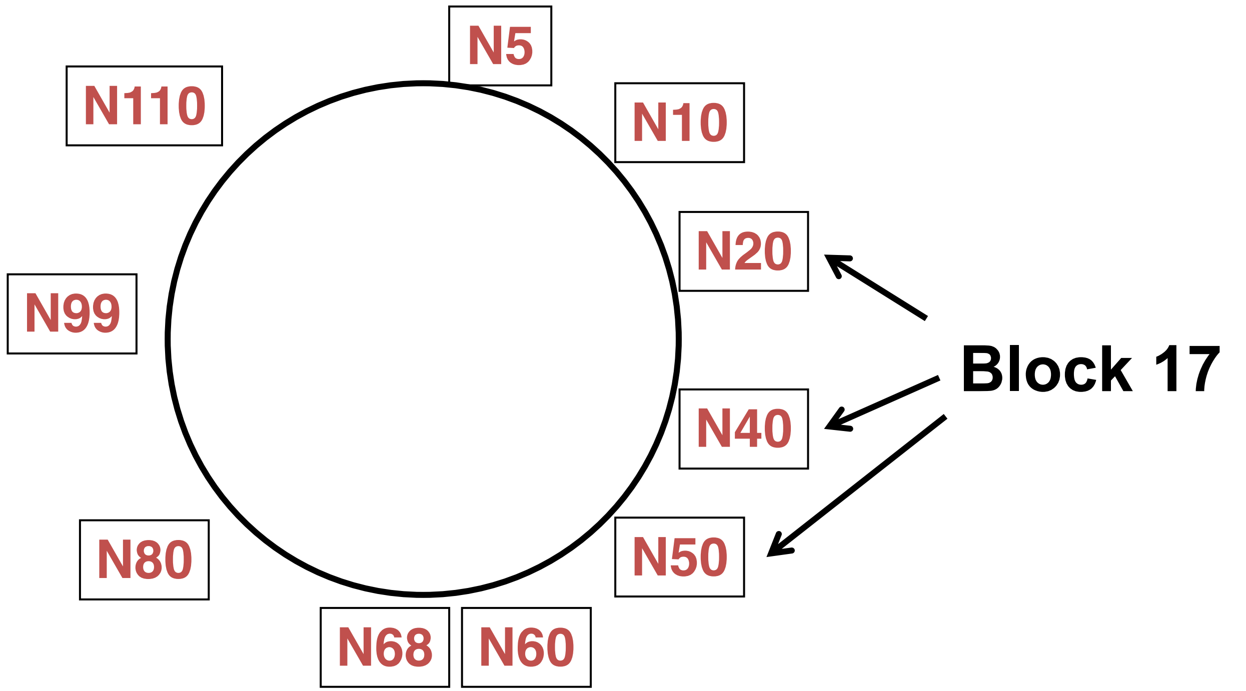
The DHash DHT

- Builds key/value storage on Chord
- **Replicates** blocks for availability
  - Stores k **replicas** at the k **successors** after the block on the Chord ring

DHash replicates blocks at *r* successors



- **Replicas** are **easy to find** if successor fails
- Hashed node IDs ensure **independent failure**

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   - Integration with *DHash* DHT

- **Concluding thoughts on DHTs, P2P**

DHTs: Impact

- Original DHTs (CAN, Chord, Kademlia, Pastry, Tapestry) proposed in 2001-02
- Following 5-6 years saw proliferation of DHT-based applications:
  - Filesystems (e.g., CFS, Ivy, OceanStore, Pond, PAST)
  - Naming systems (e.g., SFR, Beehive)
  - Content distribution systems (e.g., Coral)
  - Distributed databases (e.g., PIER)
- Chord is one of the most cited papers in CS!

Why don’t all services use P2P?

1. **High latency and limited bandwidth** between peers (*vs* servers in a datacenter)

2. User computers are **less reliable** than managed servers

3. **Lack of trust** in peers’ correct behavior
   – Securing DHT routing hard, unsolved in practice

DHTs in retrospective

- Seem promising for finding data in large P2P systems
- Decentralization seems good for load, fault tolerance

- **But:** the **security problems** are difficult
- **But:** **churn** is a problem, particularly if log(n) is big

- So DHTs have not had the impact that many hoped for

Take-away ideas: What DHTs got right

- **Consistent hashing**
  – Elegant way to divide a workload across machines
  – Very useful in clusters: actively used today in Amazon Dynamo, Apache Cassandra and other systems

- **Replication** for high availability, efficient recovery after node failure

- **Incremental scalability:** “add nodes, capacity increases”

- **Self-management:** minimal configuration

- **Unique trait:** no single server to shut down/monitor

Next topic:

Scaling out Key-Value Storage:
Amazon Dynamo