Peer-to-Peer Systems and Distributed Hash Tables

COS 418: Distributed Systems
Lecture 9

Mike Freedman, Wyatt Lloyd

1

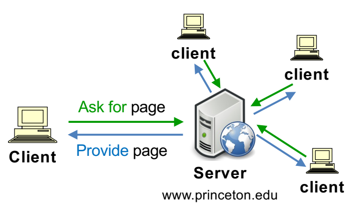
Today

1. Peer-to-Peer Systems
2. Distributed Hash Tables (DHT)
3. The Chord Lookup Service

2

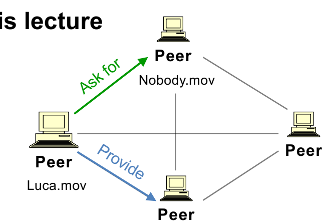
2

Distributed Application Architecture



Client-Server

This lecture

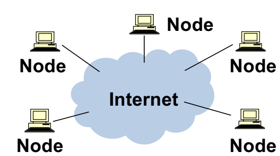


Peer-to-Peer

3

3

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

4

4

P2P adoption

Successful adoption in **some niche areas**

1. Client-to-client (legal, illegal) **file sharing**
   1. Napster (1990s), Gnutella, BitTorrent, etc.

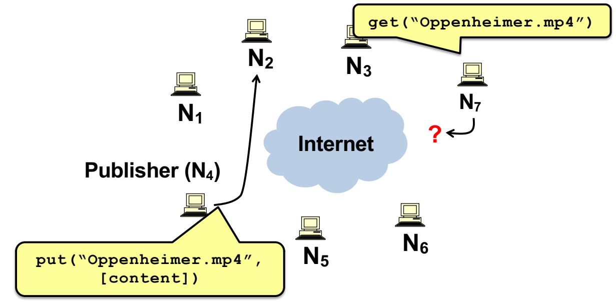
2. **Digital currency:** no natural single owner (Bitcoin)

3. **Voice/video telephony:** user to user anyway (Skype in old days)
   – Issues: Privacy and control

5

5

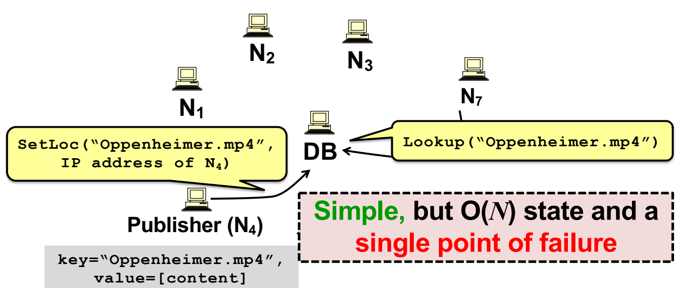
The lookup problem: locate the data



6

6

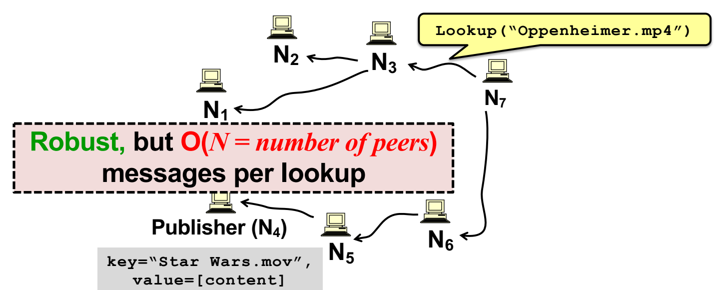
Centralized lookup (Napster)



7

7

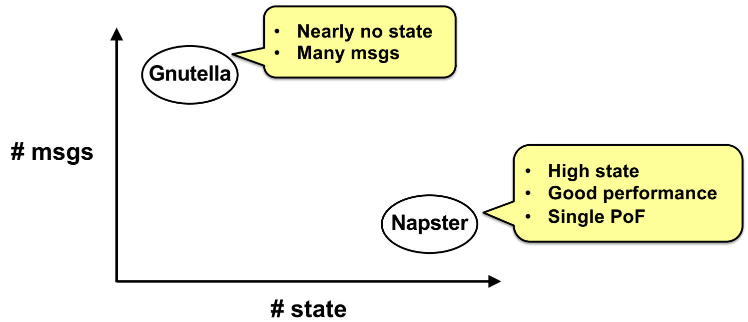
Flooded queries (original Gnutella)



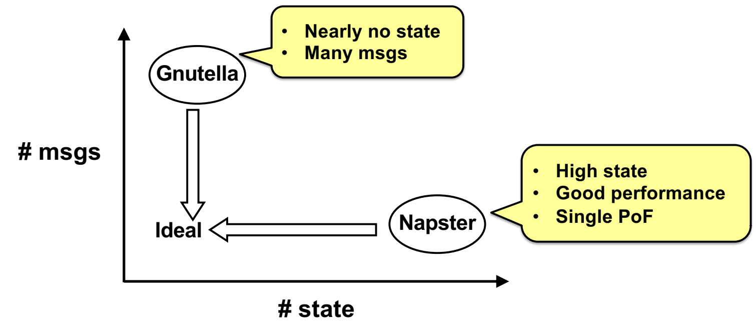
8

8

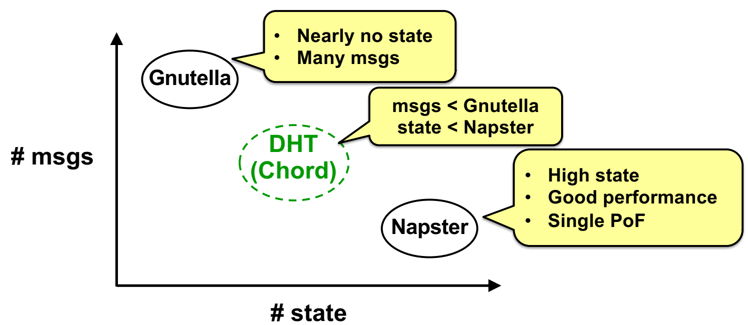
Tradeoffs in distributed systems



Tradeoffs in distributed systems



Tradeoffs in distributed systems



What is a DHT (and why)?

- Distributed Hash Table: an abstraction of hash table in a distributed setting

  `key = hash(data)`

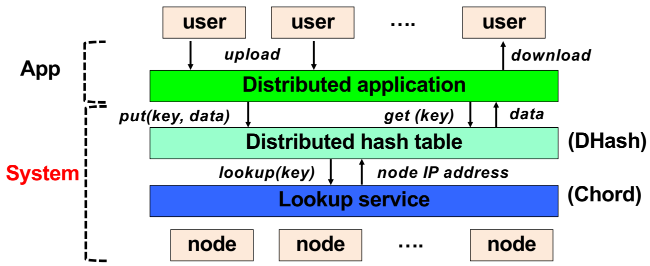
  `lookup(key)` → **`IP addr`** (Chord lookup service)

  `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



13

13

DHT is expected to be

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

14

14

Today

1. Peer-to-Peer Systems
2. Distributed Hash Tables (DHT)
3. **The Chord Lookup Service**

15

15

Chord identifiers

- **Hashed values (integers) using the same hash function**
  - **Key identifier** = SHA-1(key) mod 2^{160}
  - **Node identifier** = SHA-1(IP address) mod 2^{160}
- **How does Chord partition data?**
  - i.e., map key IDs to node IDs
- **Why hash key and address?**
  - Uniformly distributed in the ID space
  - Hashed key → load balancing; hashed address → independent failure

16

16

Alternative: mod (n) hashing

- **System of n nodes: 1…n**
  - Node that owns key is assigned via *hash(key) mod n*
  - Good load balancing
- **What if a node fails?**
  - Instead of n nodes, now *n -1* nodes
  - Mapping of all keys change, as now *hash(key) mod (n-1)*

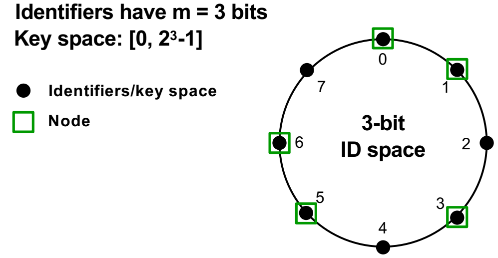
- **N = 5**
  - 12594 mod 5 = 4
  - 28527 mod 5 = 2
  - 816 mod 5 = 1
  - 716565 mod 5 = 0
- **N = 4**
  - 12594 mod 4 = 2
  - 28527 mod 4 = 3
  - 816 mod 4 = 0
  - 716565 mod 4 = 1

17

17

Consistent hashing [Karger '97] – data partition

Identifiers have m = 3 bits
Key space: [0, 2^3-1]

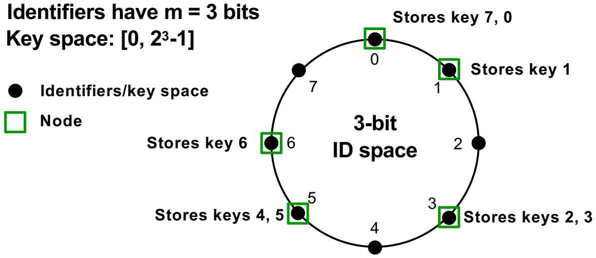


18

18

Consistent hashing [Karger '97] – data partition

Identifiers have m = 3 bits
Key space: [0, 2^3-1]



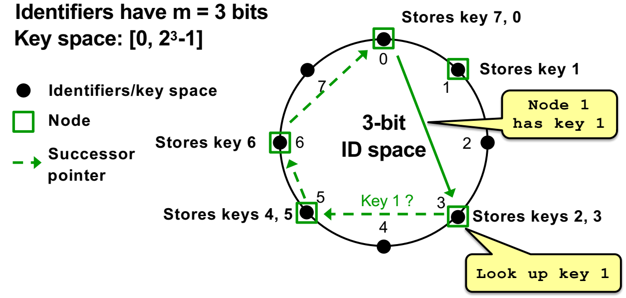
Key is stored at its **successor:** node with next-higher ID

19

19

Consistent hashing [Karger '97] – basic lookup

Identifiers have m = 3 bits
Key space: [0, 2^3-1]



O(N) messages and hops!

20

20

Chord – finger tables

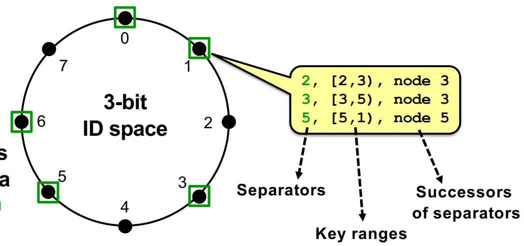
Identifiers have **m** = 3 bits
Key space: [0, 2^3-1]

● Identifiers/key space
□ Node

Each node keeps **m** states
Key space → **m** ranges via
$(N+2^{k-1}) \bmod 2^m$, $1 \le k \le m$

Example for node N = 1:

- 1 + 1 => 2
- 1 + 2 => 3
- 1 + 4 => 5



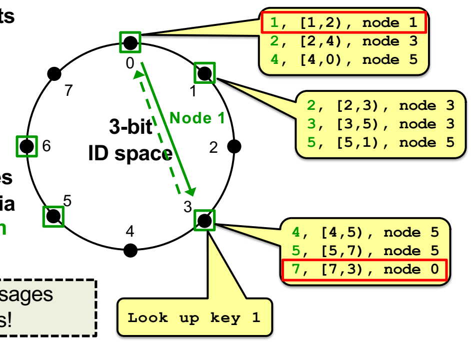
22

Chord – finger tables

Identifiers have **m** = 3 bits
Key space: [0, 2^3-1]

● Identifiers/key space
□ Node

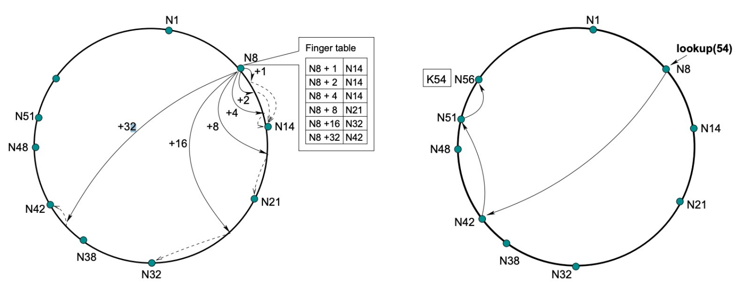
Each node keeps **m** states
Key space → **m** ranges via
$(N+2^{k-1}) \bmod 2^m$, $1 \le k \le m$



O(logN) messages
and hops!

23

Chord – finger tables



From Chord ToN paper

24

Implication of finger tables

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

26

Chord lookup algorithm properties

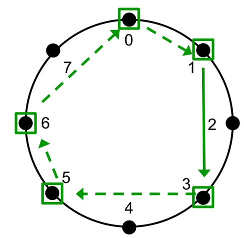
- **Interface:** lookup(key) → IP address
- **Efficient:** O(log N) messages per lookup
  - – N is the total number of nodes (peers)
- **Scalable:** O(log N) state per node
- **Robust:** survives massive failures

27

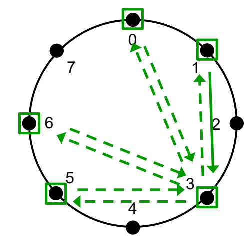
27

Chord – Recursive vs. Iterative Lookup

get(key 1)



Recursive Lookup



Iterative Lookup

28

28

System Dynamics

- Handling node joins
- Handling node failures
  - –Rebuilding lookup structures
  - –Ensure data durability

29

29

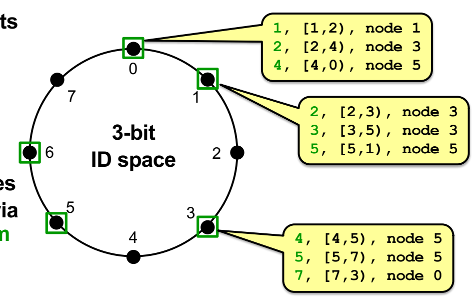
Chord – finger tables

Identifiers have m = 3 bits
Key space: [0, 2^3-1]

● **Identifiers/key space**
□ **Node**

Each node keeps m states
Key space → m ranges via
$(N+2^{k-1}) \bmod 2^m$, 1<=k<=m

Example for node N = 1:
- 1 + 1 => 2
- 1 + 2 => 3
- 1 + 4 => 5



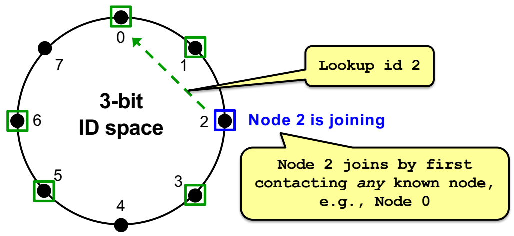
30

30

Chord – node joining

Identifiers have m = 3 bits
Key space: [0, 2^3-1]

● Identifiers/key space
□ Node



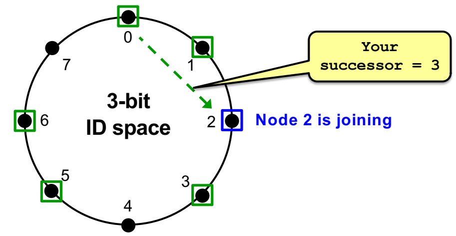
31

31

Chord – node joining

Identifiers have m = 3 bits
Key space: [0, 2^3-1]

● Identifiers/key space
□ Node



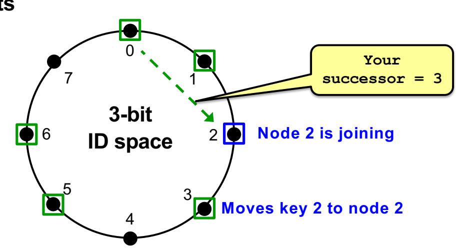
32

32

Chord – node joining

Identifiers have m = 3 bits
Key space: [0, 2^3-1]

● Identifiers/key space
□ Node



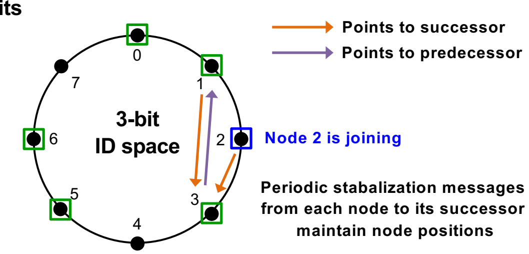
33

33

Chord – node joining

Identifiers have m = 3 bits
Key space: [0, 2^3-1]

● Identifiers/key space
□ Node



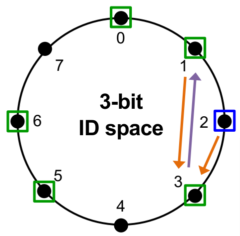
34

34

Chord – node joining

Identifiers have m = 3 bits
Key space: [0, 2^3-1]

● Identifiers/key space
□ Node



Points to successor
Points to predecessor

Node 2 is joining

```
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
```

Pseudocode from Rodrigo Fonseca's lecture notes

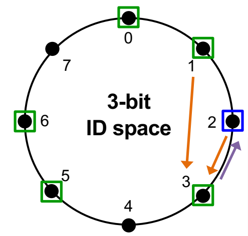
35

35

Chord – node joining

Identifiers have m = 3 bits
Key space: [0, 2^3-1]

● Identifiers/key space
□ Node



Points to successor
Points to predecessor

Node 2 is joining

```
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
```

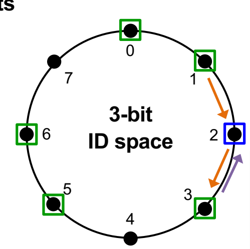
36

36

Chord – node joining

Identifiers have m = 3 bits
Key space: [0, 2^3-1]

● Identifiers/key space
□ Node



Points to successor
Points to predecessor

Node 2 is joining

```
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
```

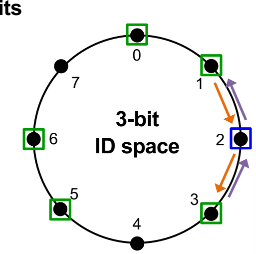
37

37

Chord – node joining

Identifiers have m = 3 bits
Key space: [0, 2^3-1]

● Identifiers/key space
□ Node



Points to successor
Points to predecessor

Node 2 is joining

```
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
```

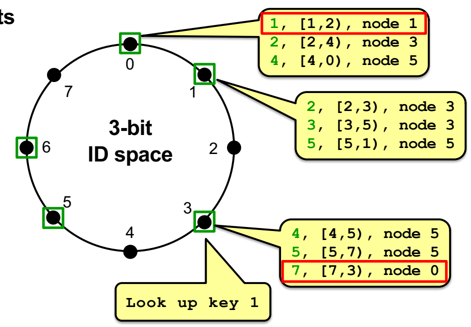
38

38

Chord – failures and successor list

Identifiers have m = 3 bits
Key space: [0, 2^3-1]

● Identifiers/key space
□ Node



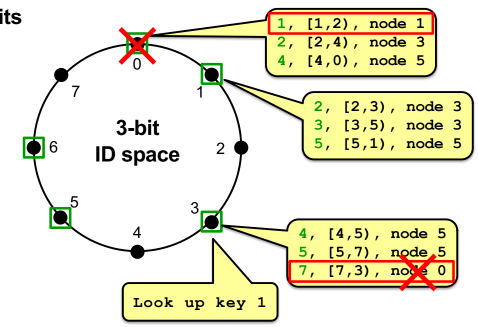
39

39

Chord – failures and successor list

Identifiers have m = 3 bits
Key space: [0, 2^3-1]

● Identifiers/key space
□ Node



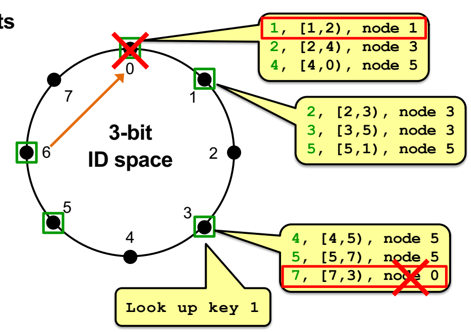
40

40

Chord – failures and successor list

Identifiers have m = 3 bits
Key space: [0, 2^3-1]

● Identifiers/key space
□ Node
→ Points to successor



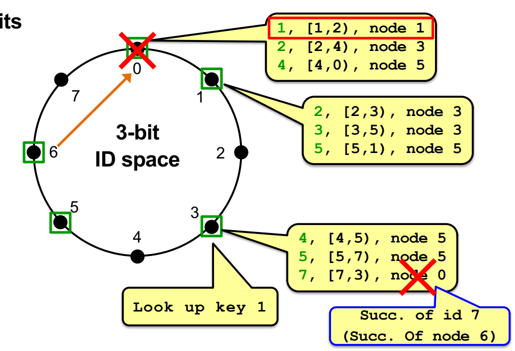
41

41

Chord – failures and successor list

Identifiers have m = 3 bits
Key space: [0, 2^3-1]

● Identifiers/key space
□ Node
→ Points to successor



42

42

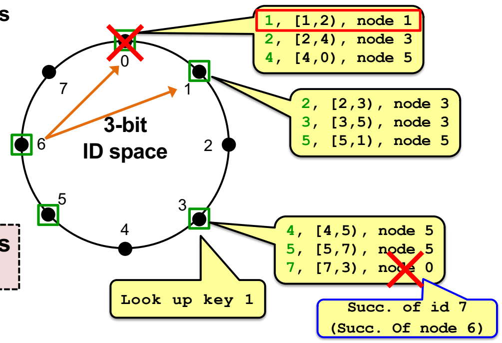
Chord – failures and successor list

Identifiers have m = 3 bits
Key space: [0, 2^3-1]

● Identifiers/key space
□ Node

→ Points to successor

r-nearest successors
(r = logN)



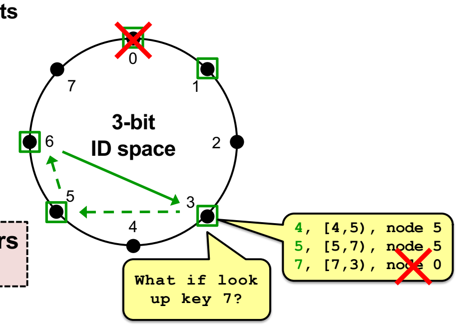
43

Chord – failures and successor list

Identifiers have m = 3 bits
Key space: [0, 2^3-1]

● Identifiers/key space
□ Node

r-nearest successors
(r = logN)



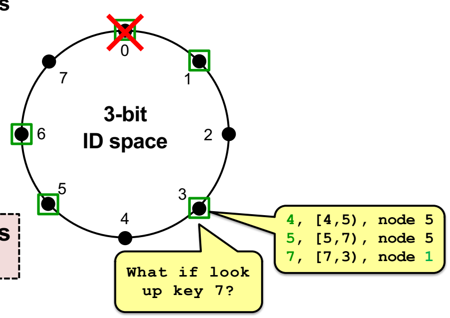
44

Chord – failures and successor list

Identifiers have m = 3 bits
Key space: [0, 2^3-1]

● Identifiers/key space
□ Node

r-nearest successors
(r = logN)



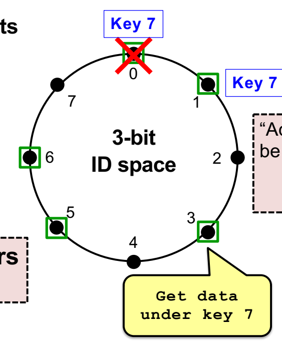
45

DHash replicates data blocks at *r* successors

Identifiers have m = 3 bits
Key space: [0, 2^3-1]

● Identifiers/key space
□ Node

r-nearest successors
(r = logN)



"Adjacent" nodes in the ring may be far away in the network

→ Independent failures

46

Today

1. Peer-to-Peer Systems
2. Distributed Hash Tables
3. The Chord Lookup Service
4. **Concluding thoughts on DHT, P2P**

Why don't all services use P2P?

- **High latency and limited bandwidth** between peers (vs. intra/inter-datacenter, client-server model)
  - 1 M nodes = 20 hops; 50 ms / hop gives 1 sec lookup latency (assuming no failures / slow connections…)
- User computers are **less reliable** than managed servers
- **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
- DHTs have not had the hoped-for impact

What DHTs got right

- **Consistent hashing**
  - Elegant way to divide a workload across machines
  - Very useful in clusters: actively used today in Amazon Dynamo and other systems
- **Replication** for high availability, efficient recovery
- **Incremental scalability**
  - Peers join with capacity, CPU, network, etc.
- **Self-management:** minimal configuration