Peer-to-Peer Systems and Distributed Hash Tables

جامعة الملك عبدالله للعلوم والتقنية
King Abdullah University of Science and Technology

CS 240: Computing Systems and Concurrency
Lecture 11

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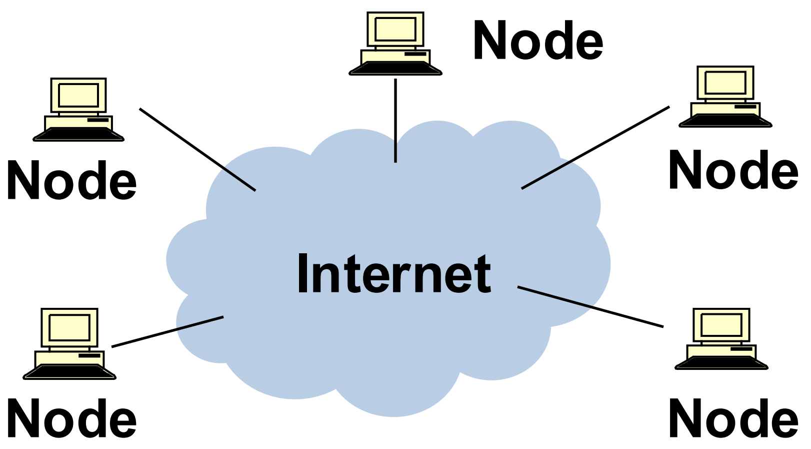
Today

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

2. Distributed Hash Tables

3. The Chord Lookup Service

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

P2P adoption

- Successful adoption in **some niche areas**

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

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

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

Why might P2P be a win?

- **High capacity for services** through resource pooling:
  - Many disks, network connections, CPUs, as peers join
  - Data are divided and duplicated, accessible from multiple peers concurrently

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

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

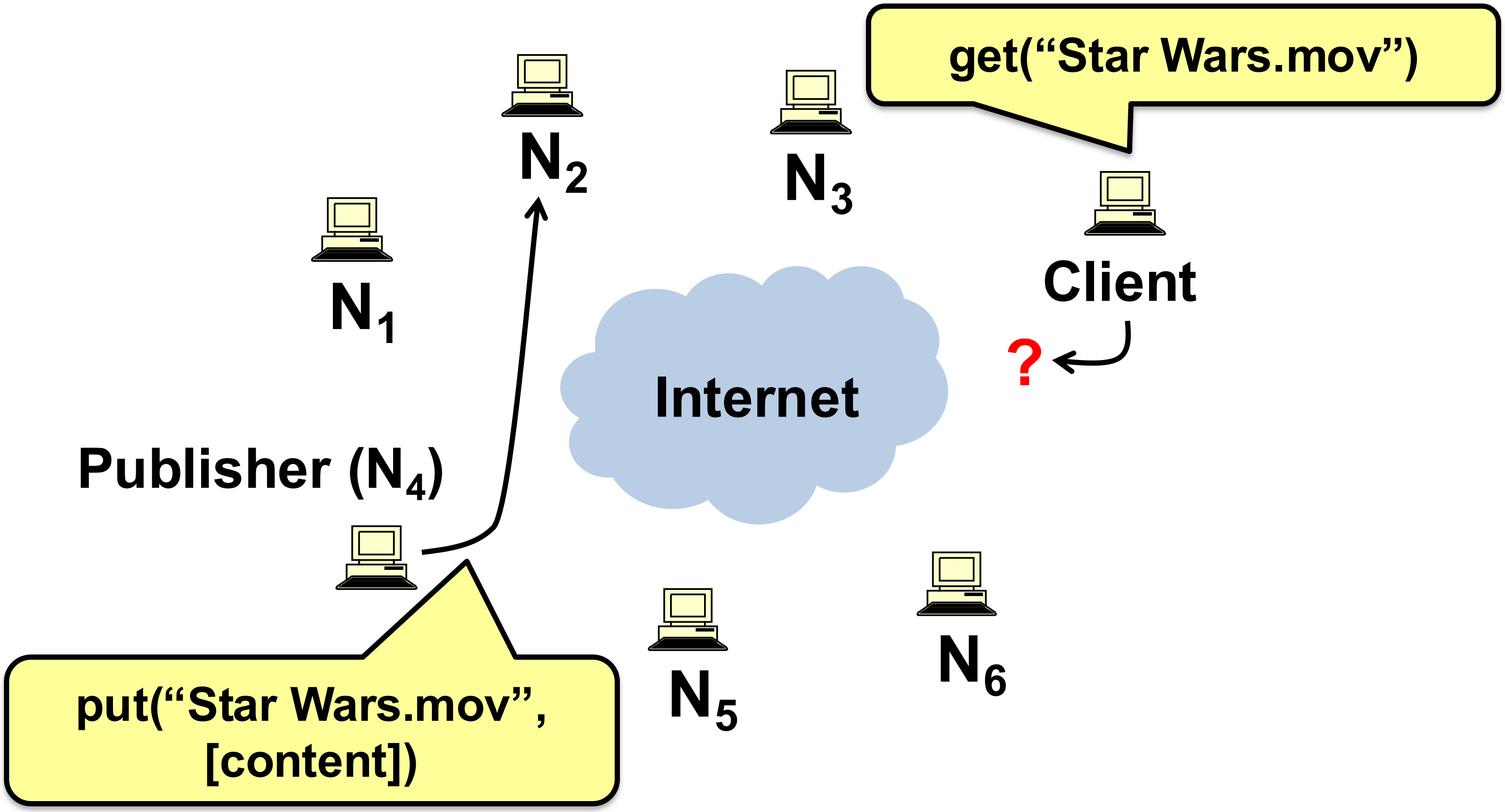
3. User's BT client downloads file from one or more peers

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

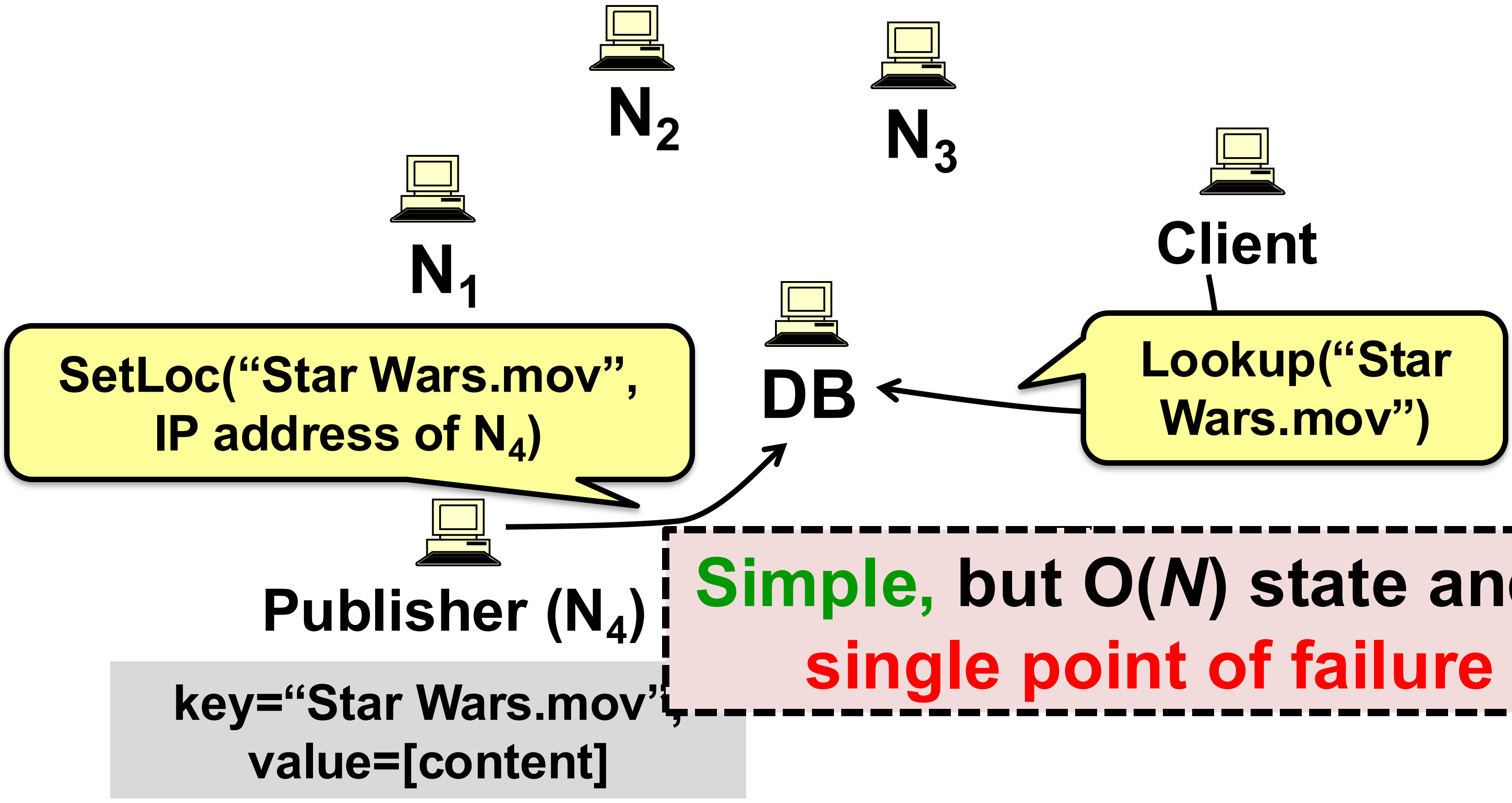
5. User's BT client serves the file to others for a while

Provides huge download bandwidth,
without expensive server or network links

The lookup problem

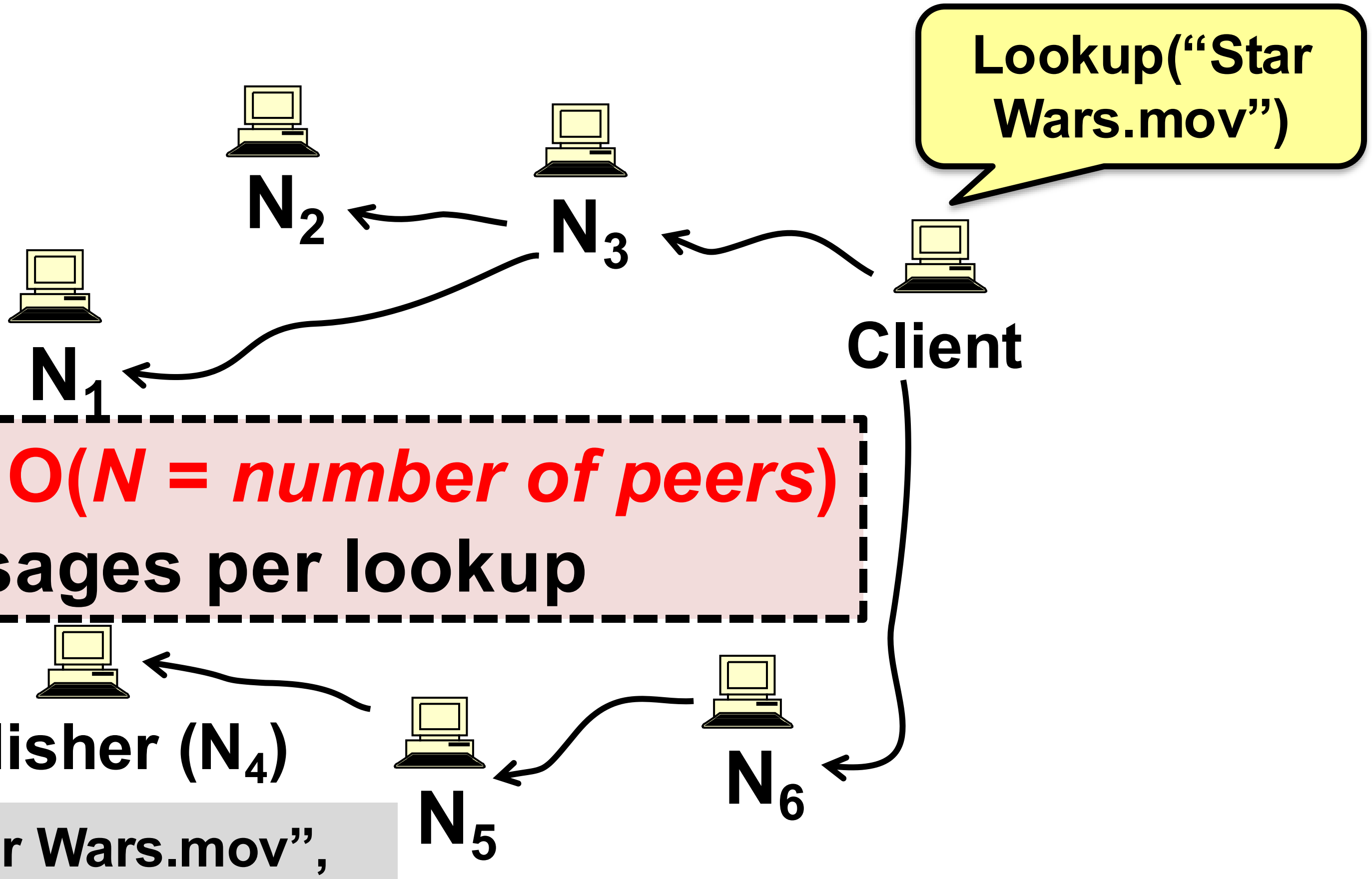


Centralized lookup (Napster)


N_2
N_3
N_1
Client
DB
SetLoc("Star Wars.mov", IP address of N_4)
Lookup("Star Wars.mov")
Publisher (N_4)
key="Star Wars.mov", value=[content]

Simple, but O(*N*) state and a **single point of failure**

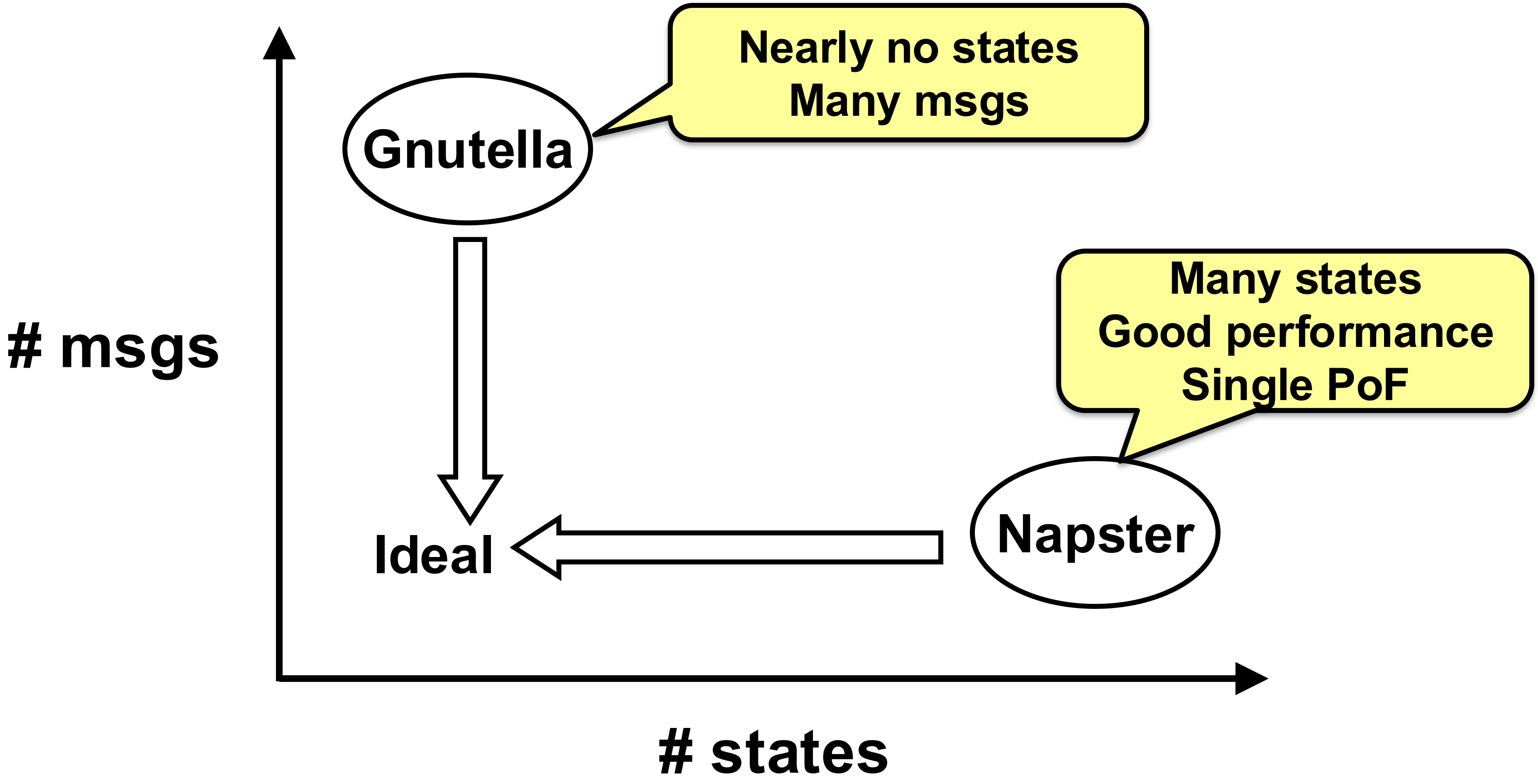
Flooded queries (original Gnutella)



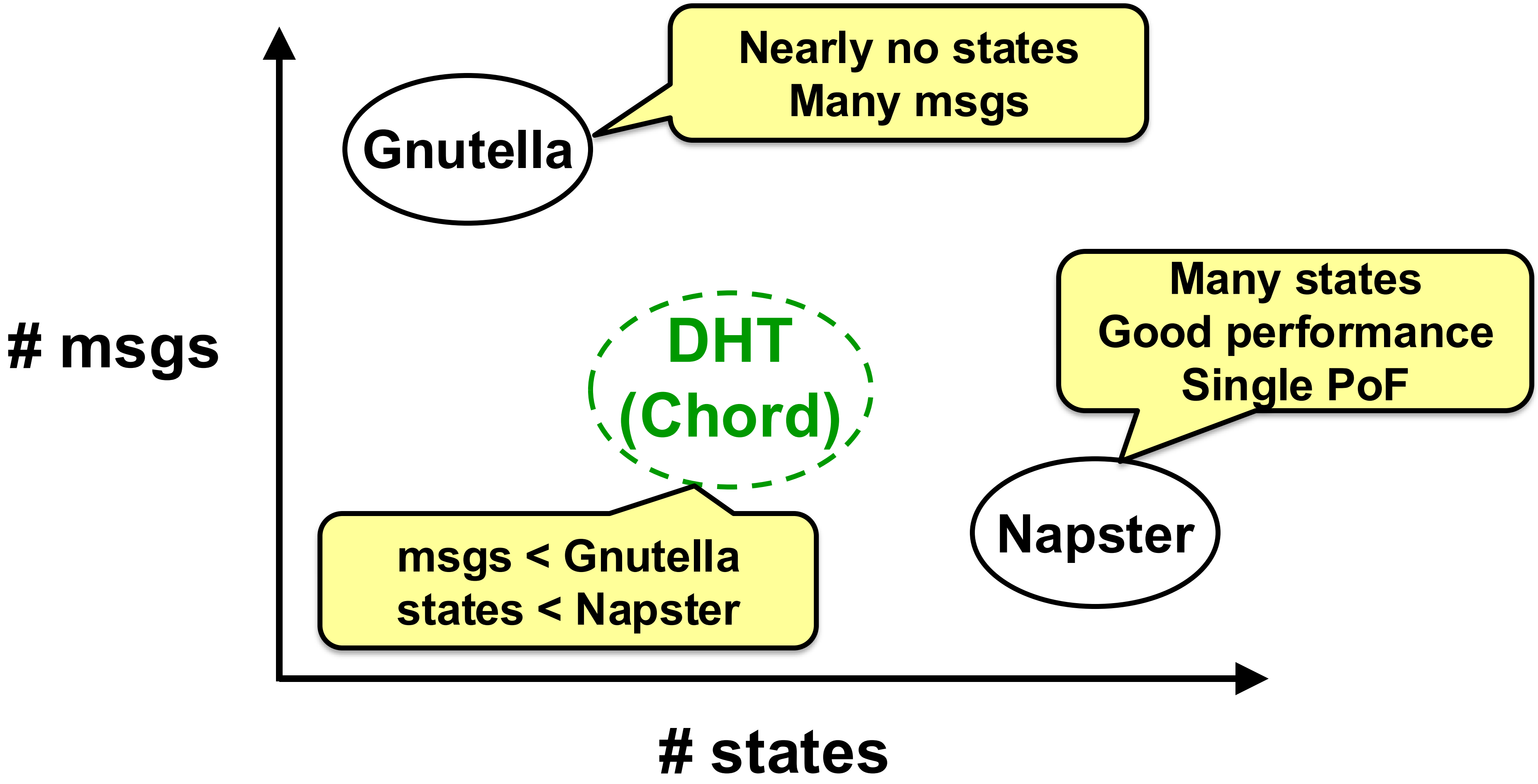
Robust, but **O(*N* = *number of peers*)** messages per lookup

key="Star Wars.mov", value=[content]

Tradeoffs in distributed systems



Tradeoffs in distributed systems



Today

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

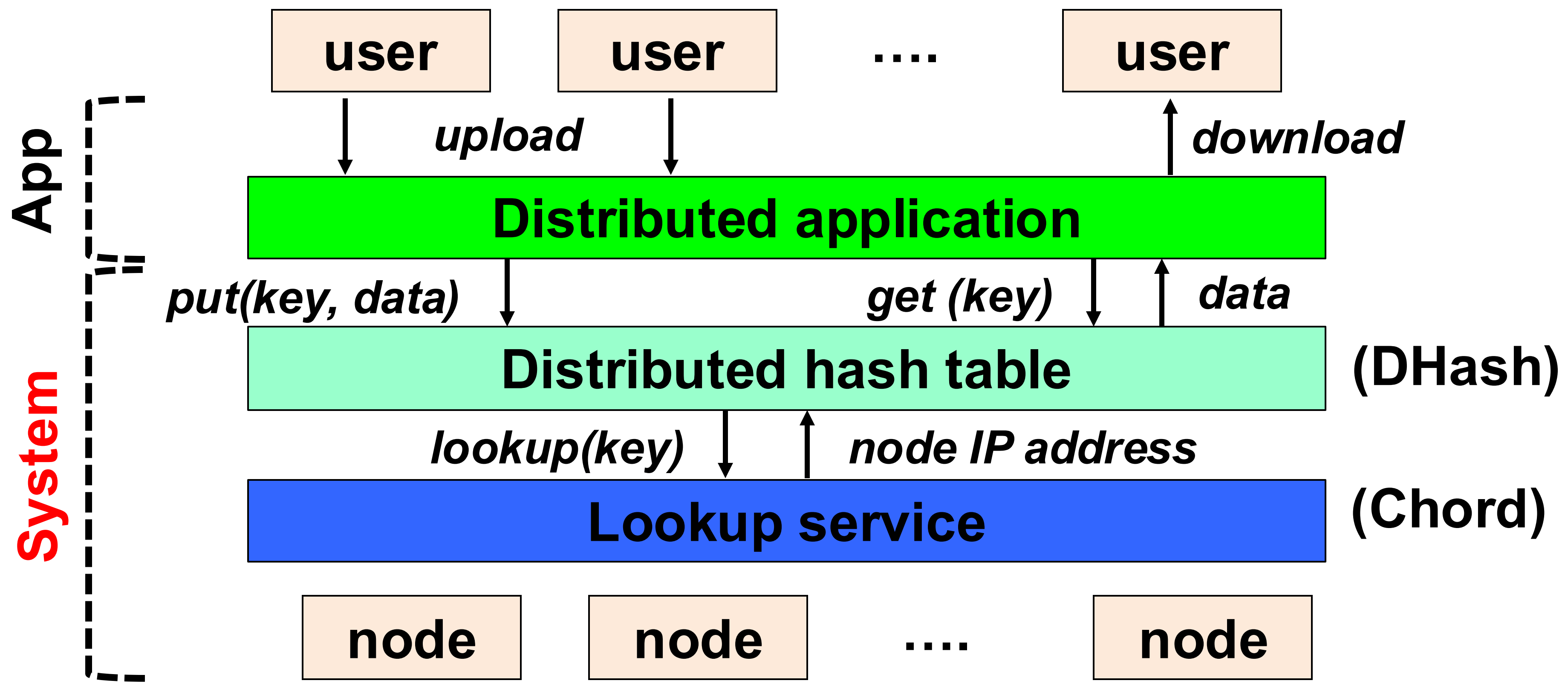
What is a DHT (and why)?

- 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



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

Today

1. Peer-to-Peer Systems

2. Distributed Hash Tables

3. **The Chord Lookup Service**

Chord identifiers

- **Hashed values (int) using the same hash function**
  - **Key identifier** = SHA-1(key)
  - **Node identifier** = SHA-1(IP address)

- ***How does Chord partition data?***
  - *i.e.*, map key IDs to node IDs

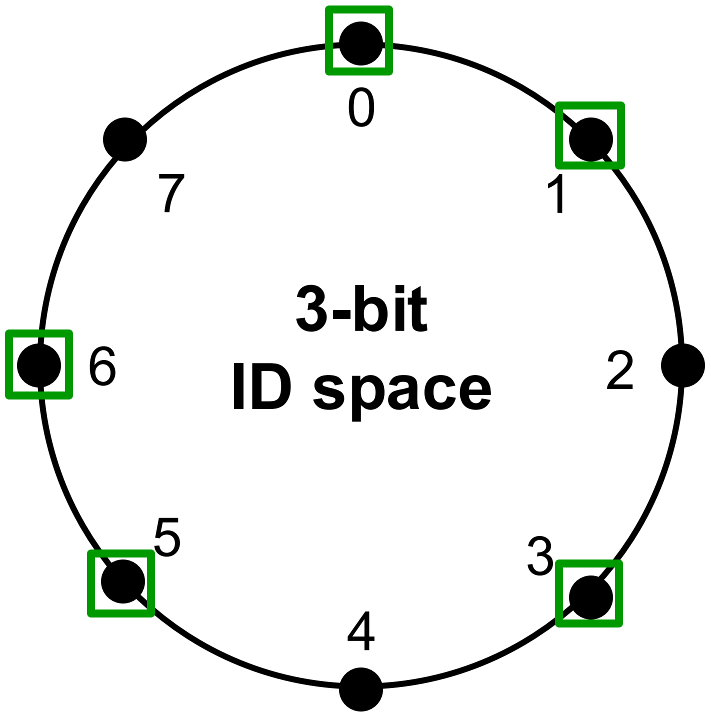
- **Why hash key and address?**
  - Uniformly distributed in the ID space
  - Hashed key → load balancing
  - Hashed IP address → independent failure

Consistent hashing: data partition

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

● Identifiers/key space

□ Node



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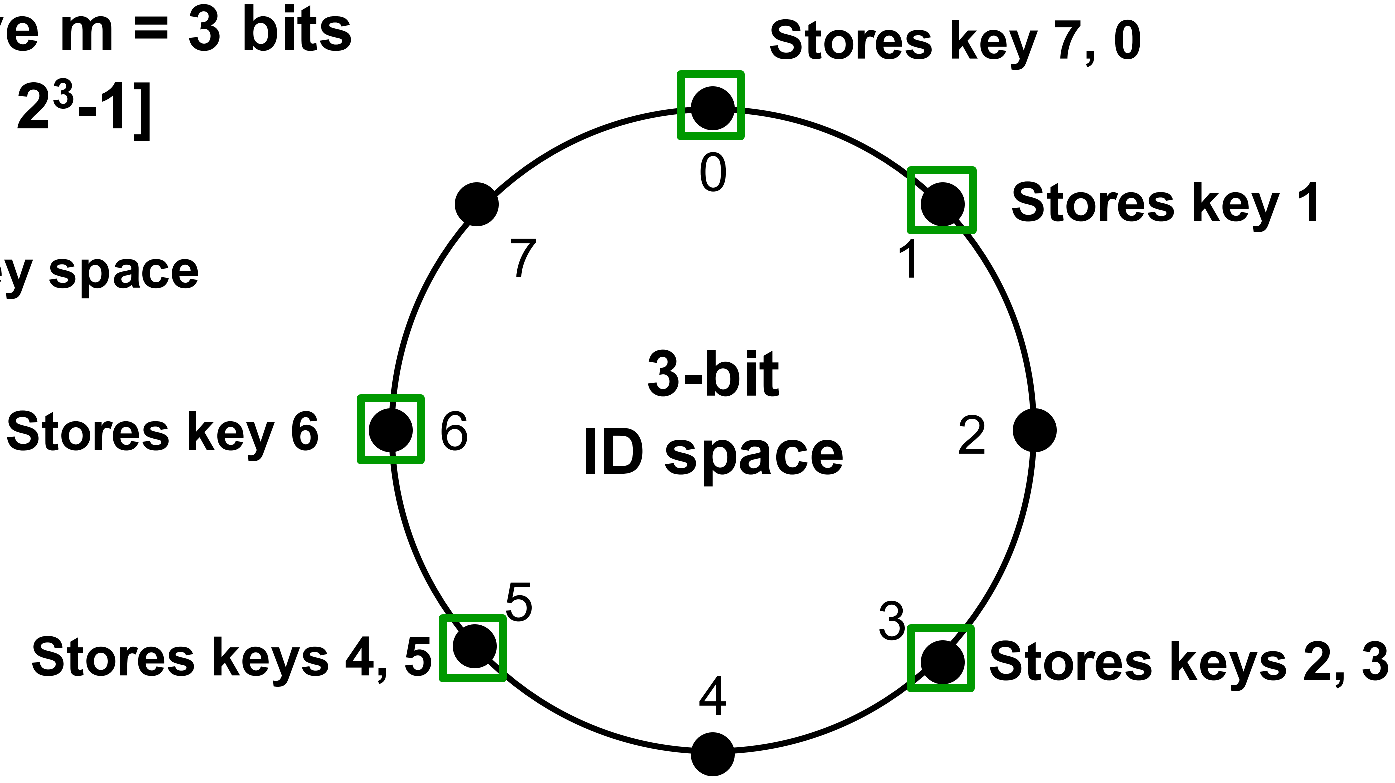


Key is stored at its **successor:** node with next-higher ID

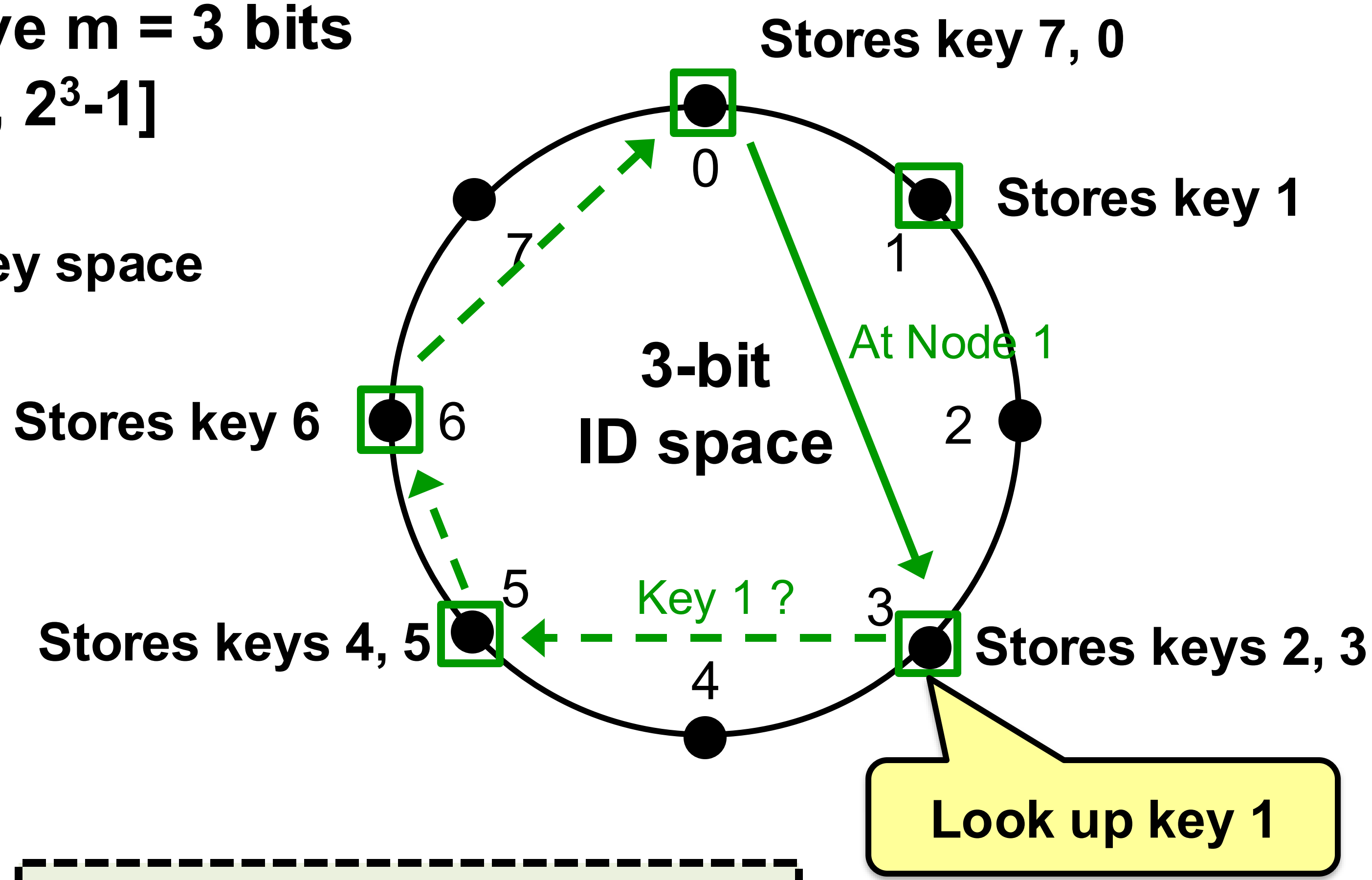
Consistent hashing: basic lookup

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

● **Identifiers/key space**

□ **Node**

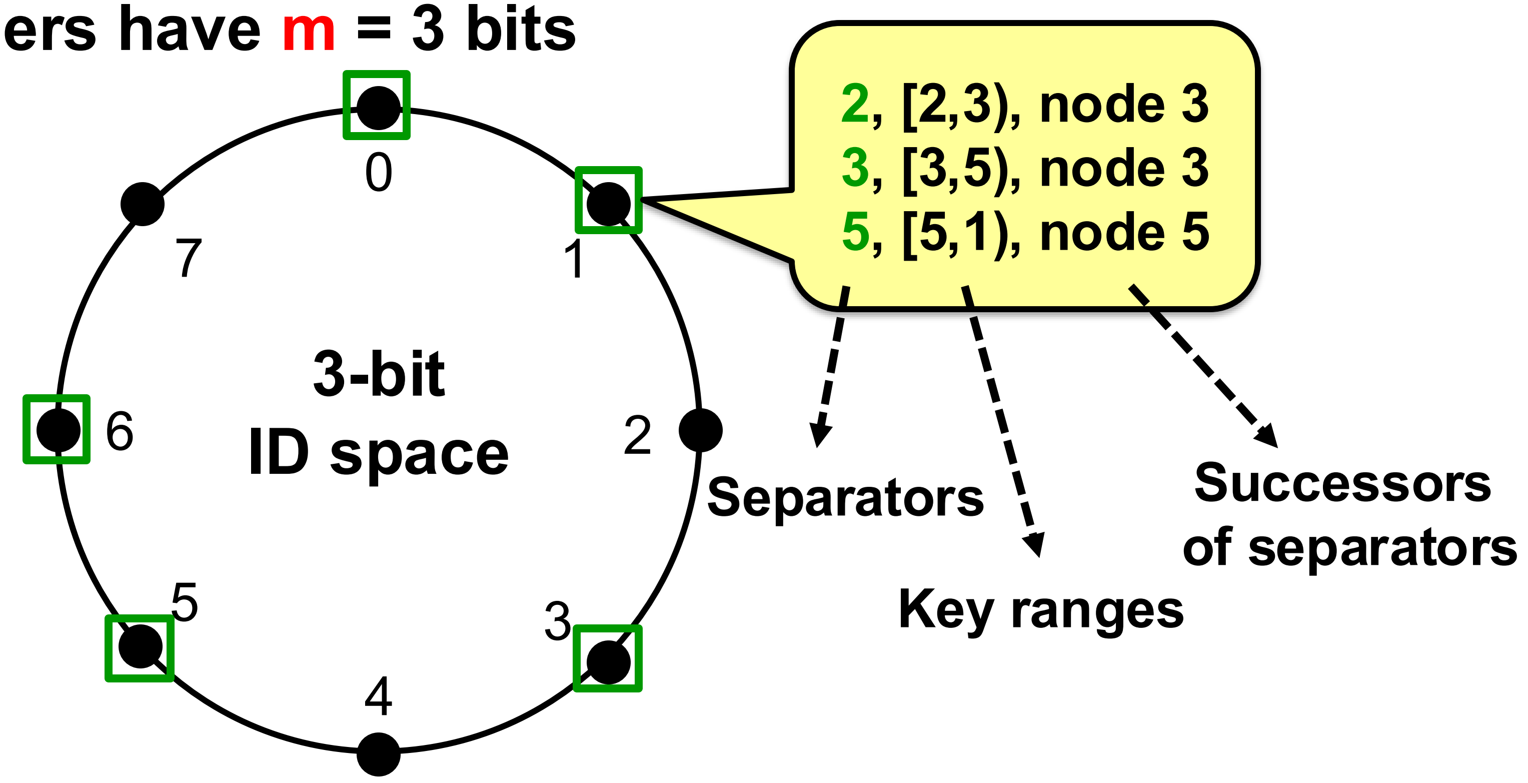
- - ➜ Successor pointer



O(N) messages and hops!

Chord: finger tables

Identifiers have m = 3 bits

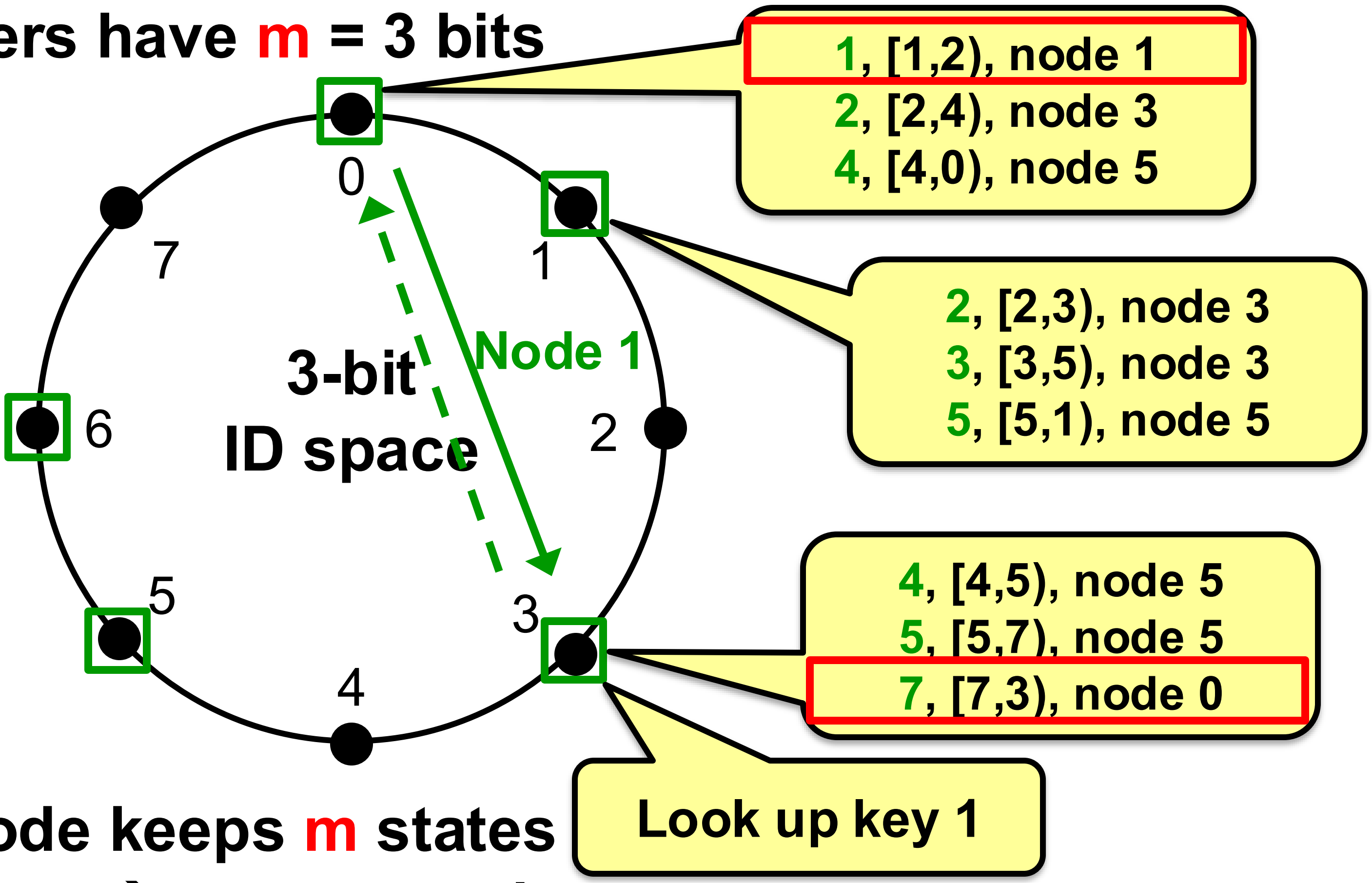


Each node keeps m states
Key space → m ranges via
$(N+2^{k-1}) \bmod 2^m$, $1 \le k \le m$

k=1 → range size 1
k=2 → range size 2
k=3 → range size 4

Chord: finger tables

Identifiers have m = 3 bits



Each node keeps m states

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

O(log N) messages and hops!

Implication of finger tables

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

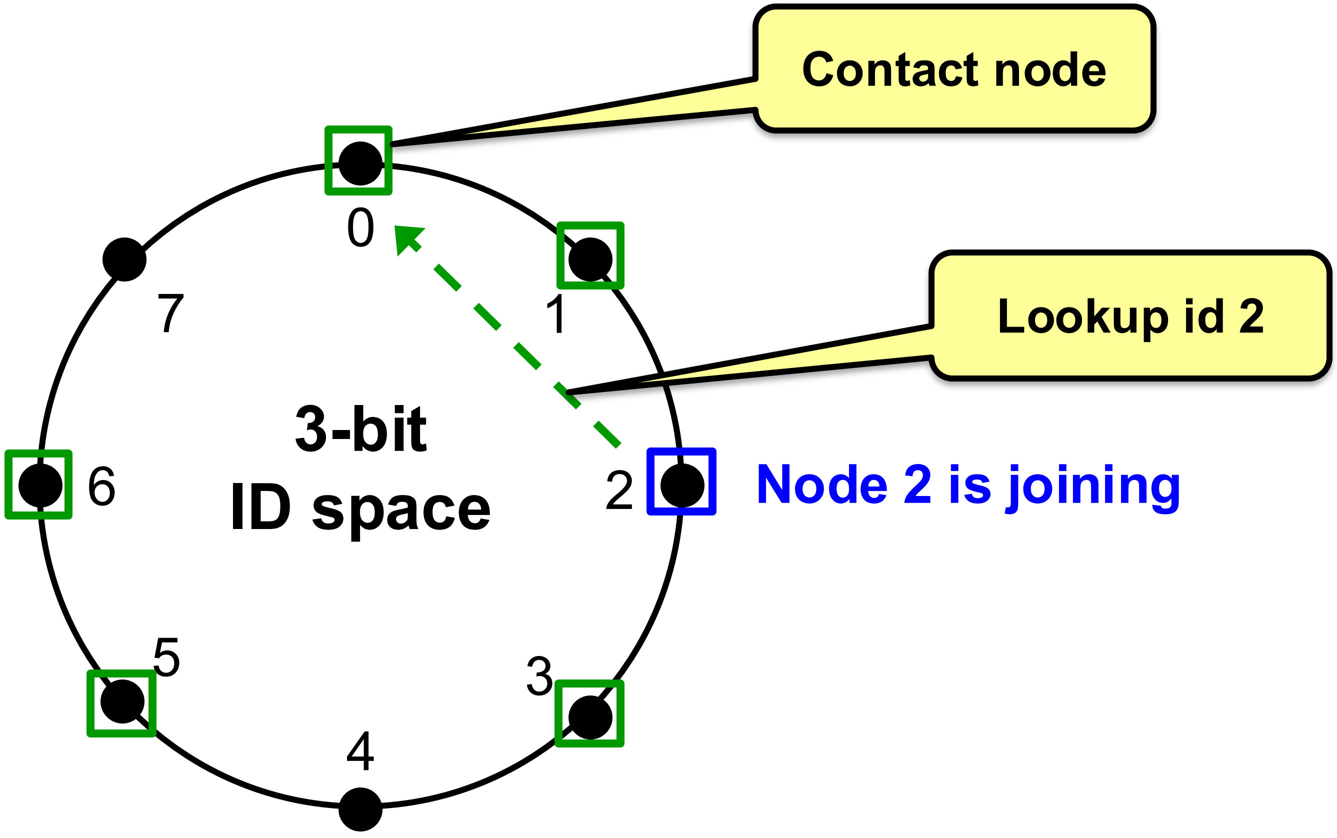
- This is **better** than simply arranging the nodes in a single tree
  - Every node acts as a root
    - So there's **no root hotspot**
    - **No single point** of failure
    - But a **lot more state** in total

Chord lookup algorithm properties

Interface: lookup(key) $\rightarrow$ 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

Chord – node joining



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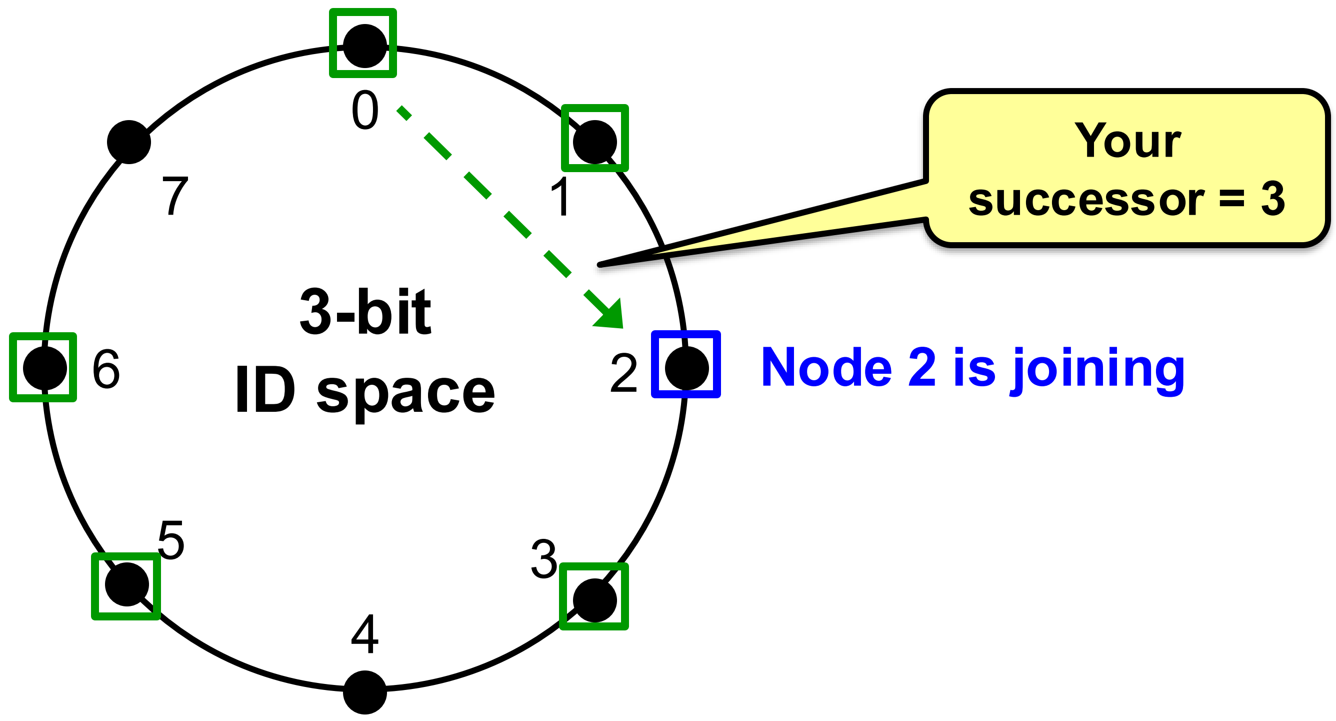

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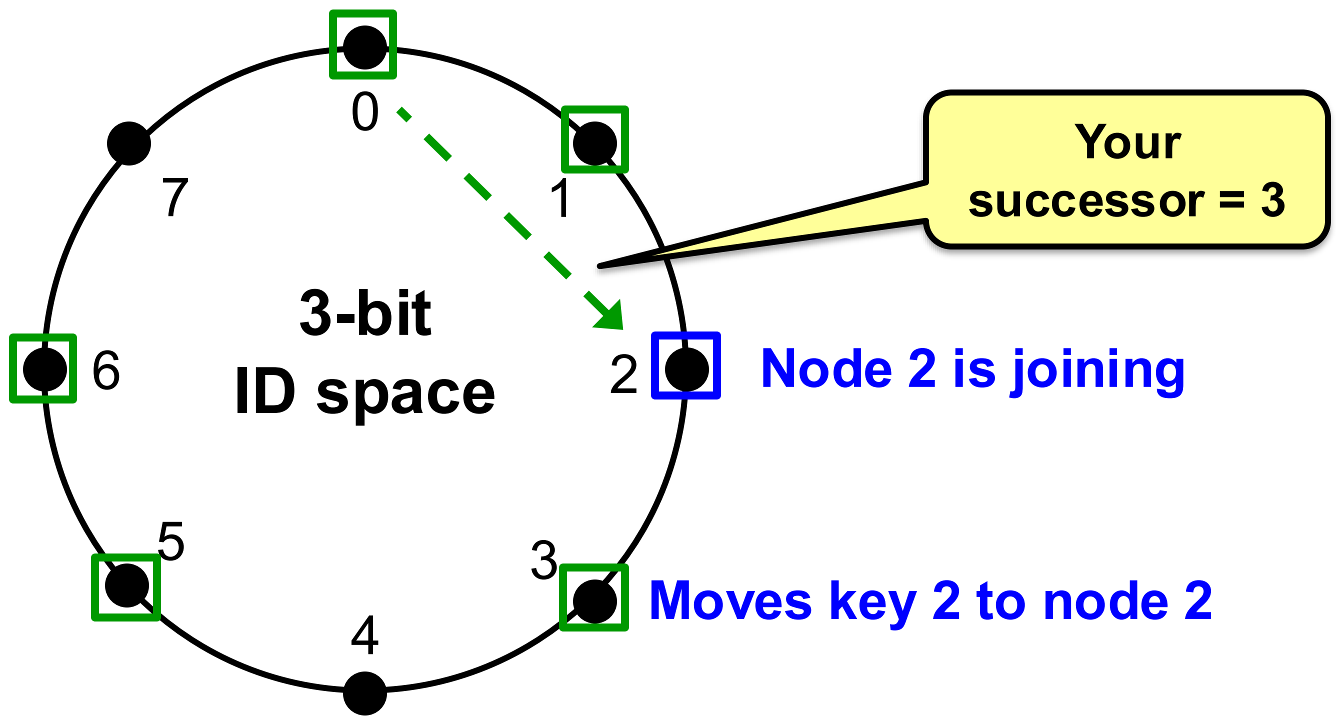

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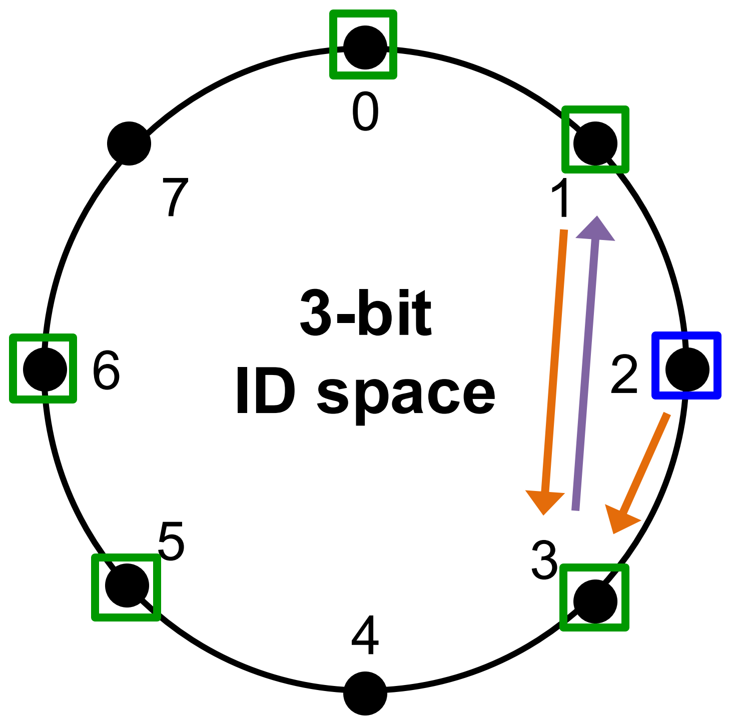


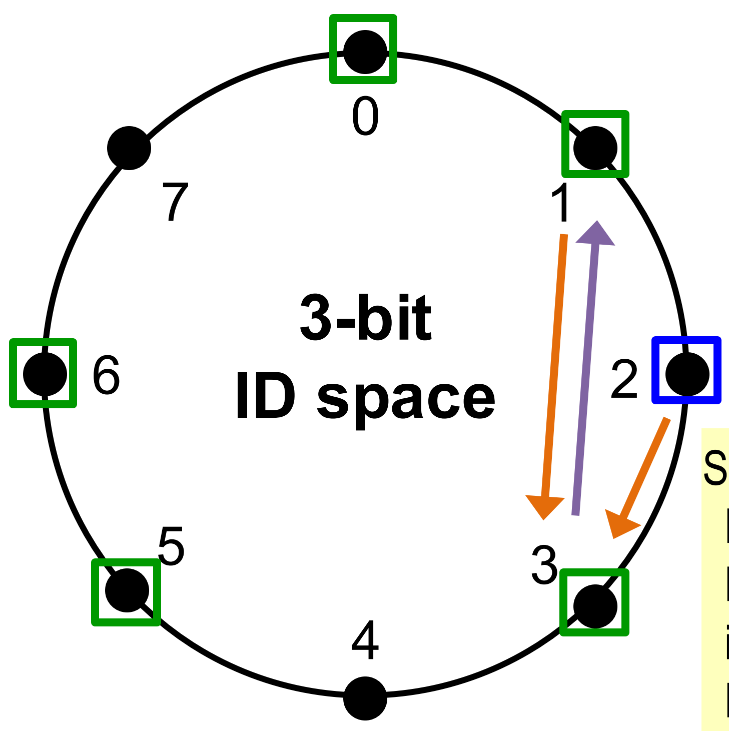
Points to successor

Points to predecessor

Node 2 is joining

Periodic stabilization messages from each node to its successor maintain node positions

Chord – node joining



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
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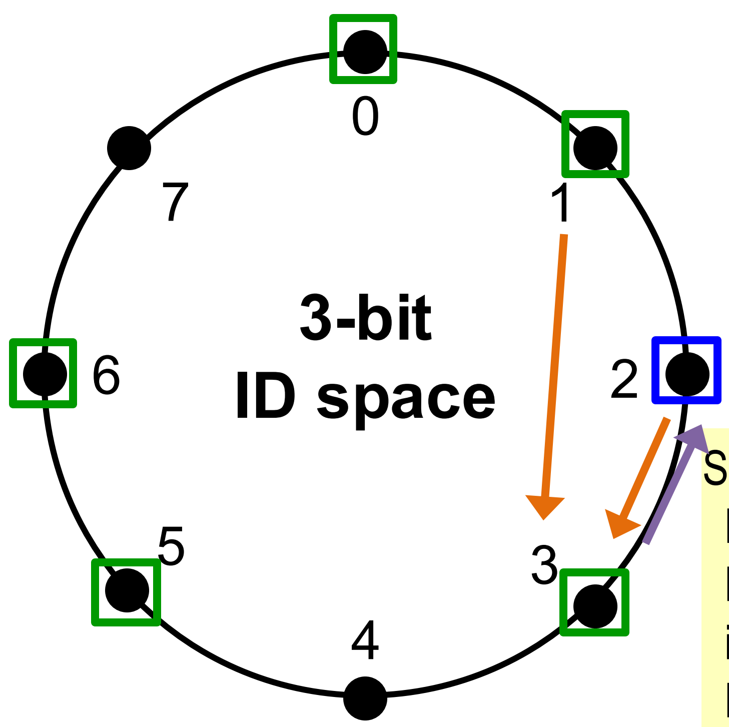
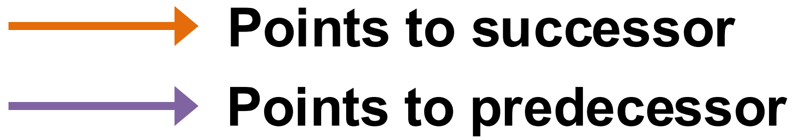
Chord – node joining





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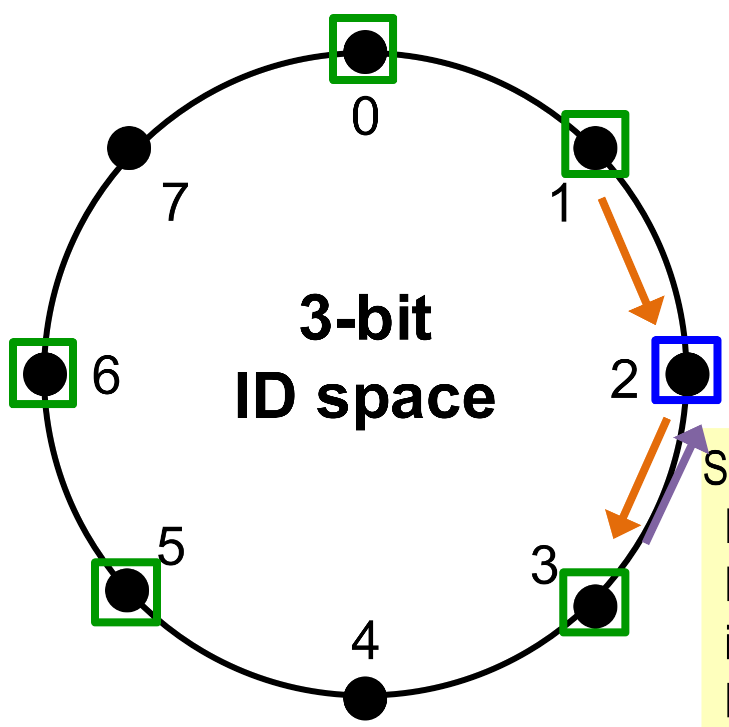

→ **Points to successor**

→ **Points to predecessor**

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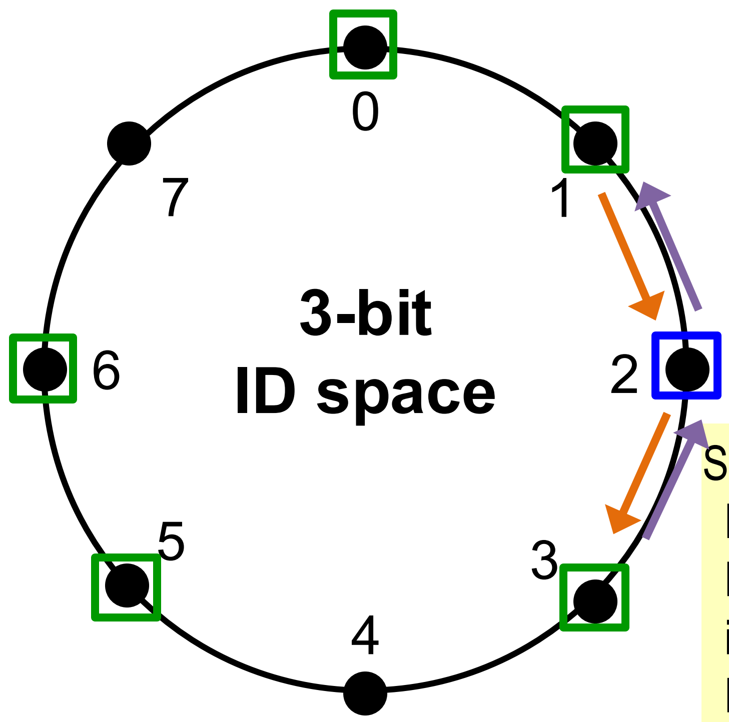

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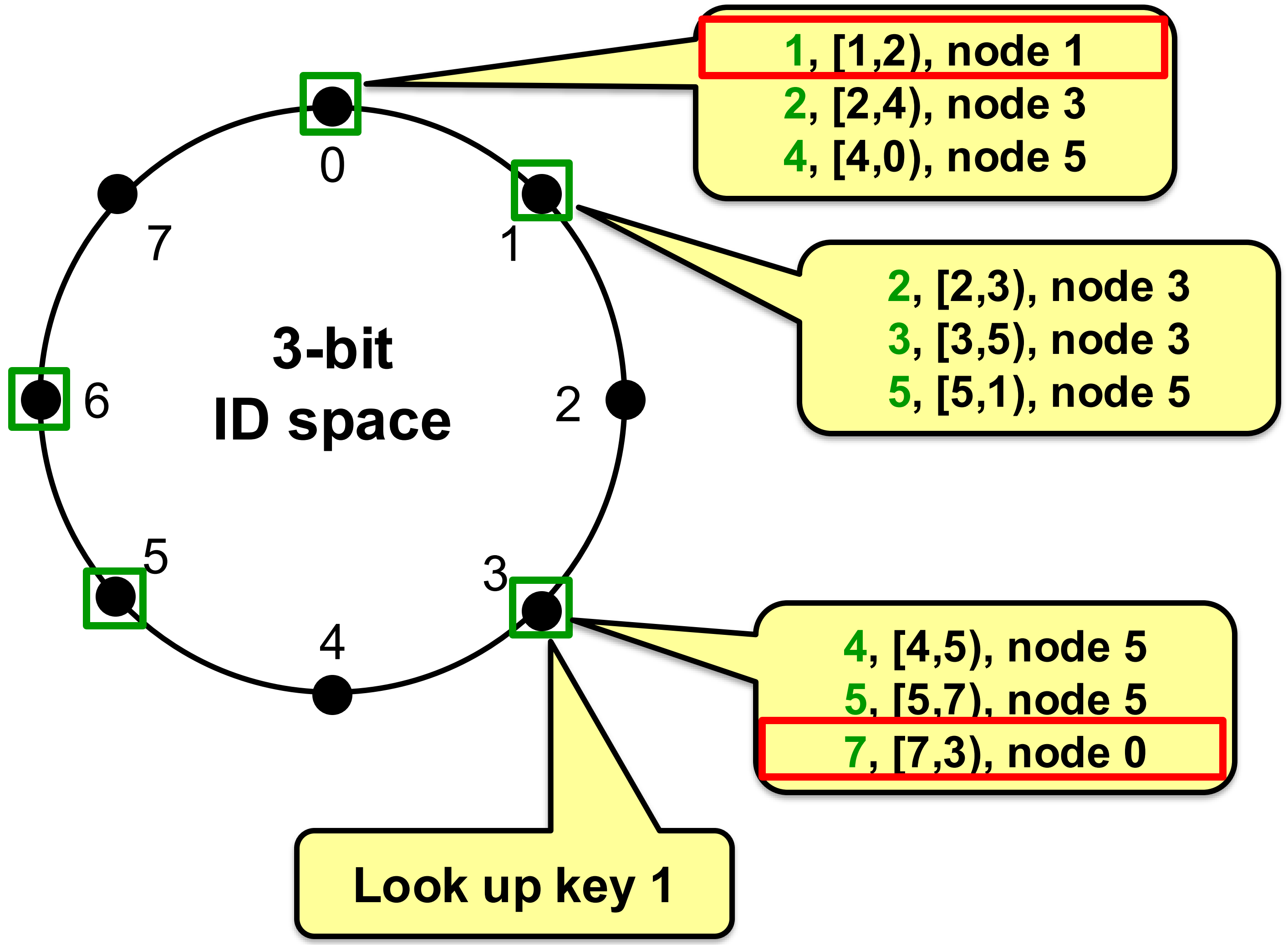
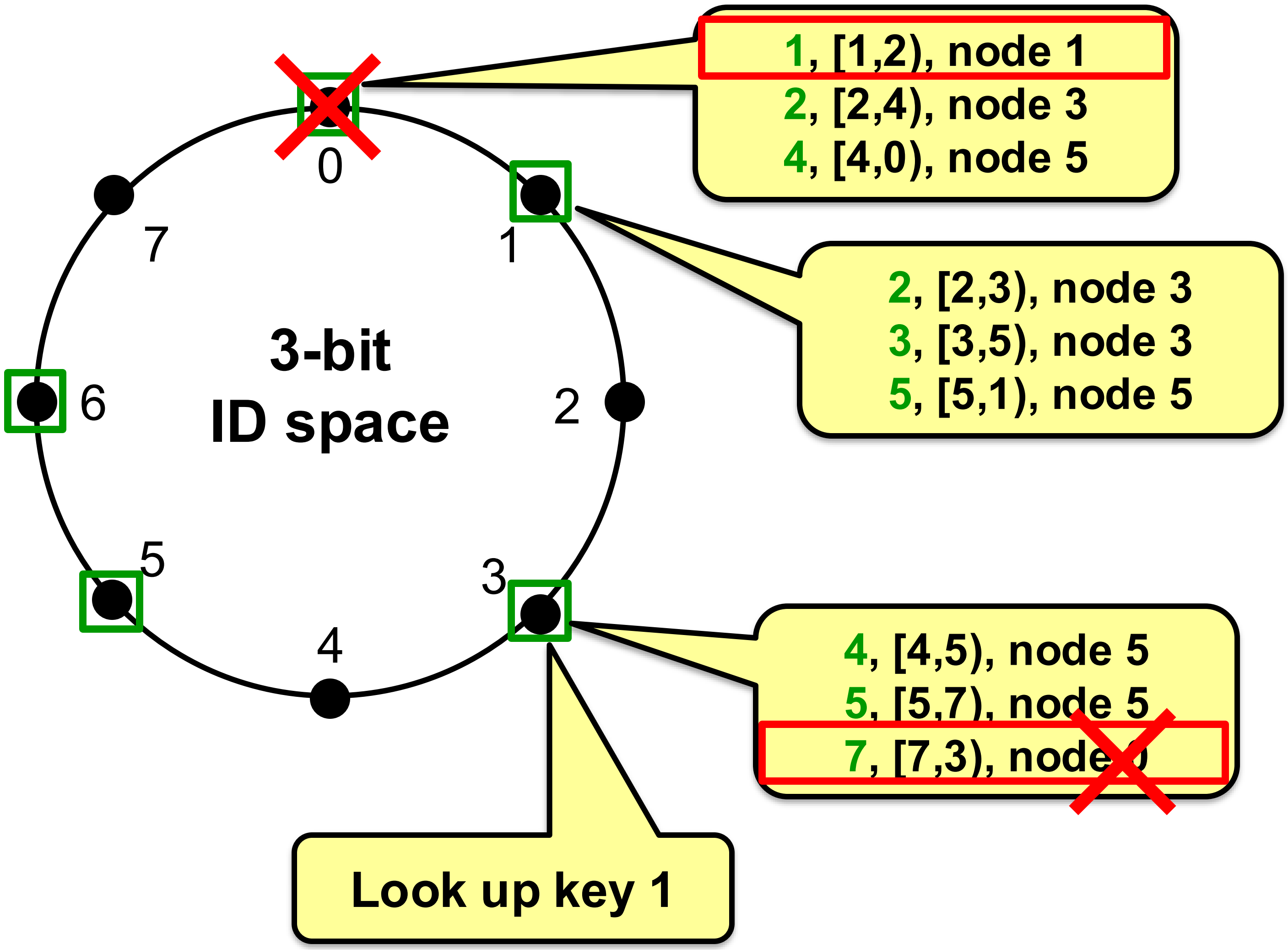
Chord – failures and successor list



Chord – failures and successor list



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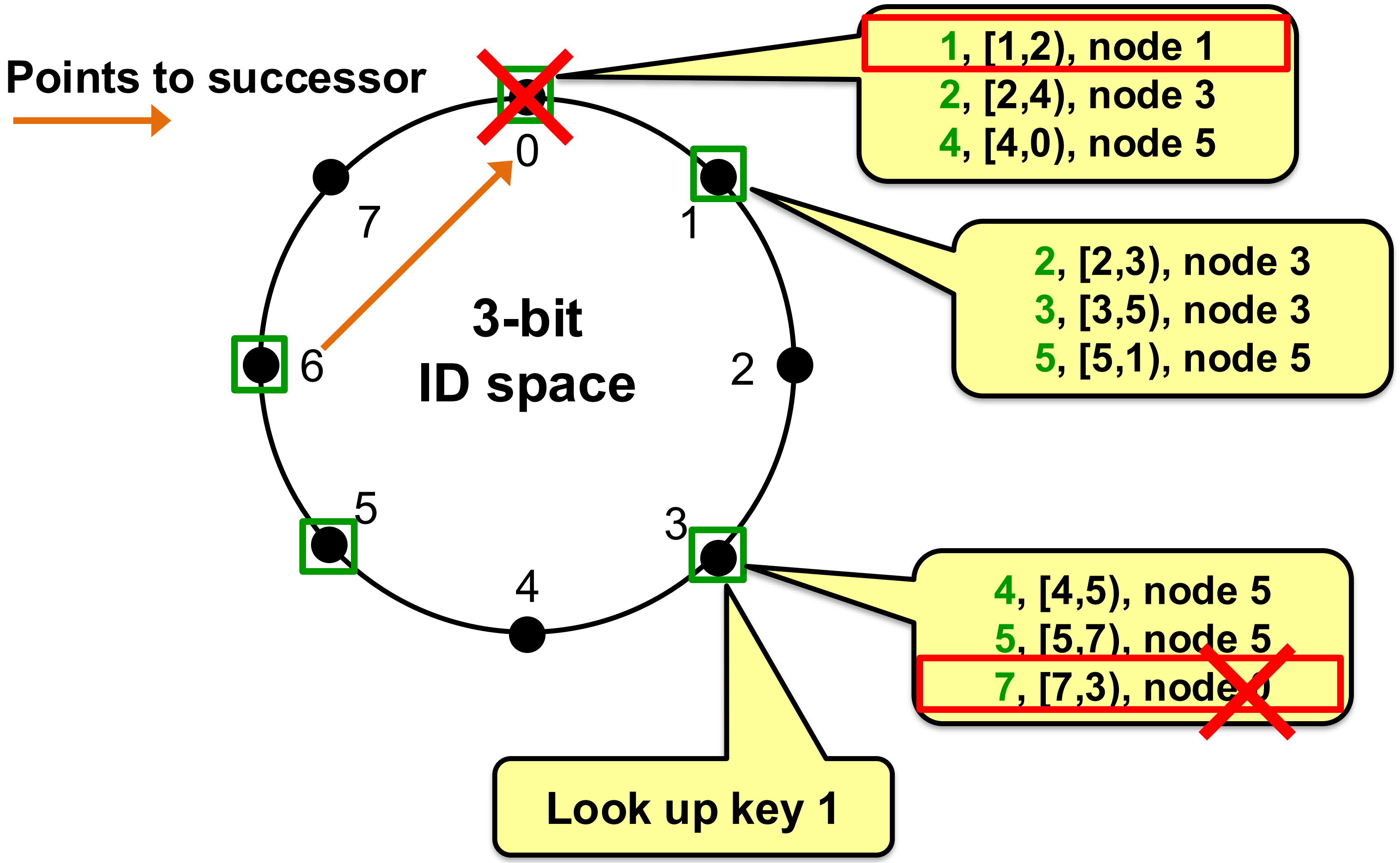

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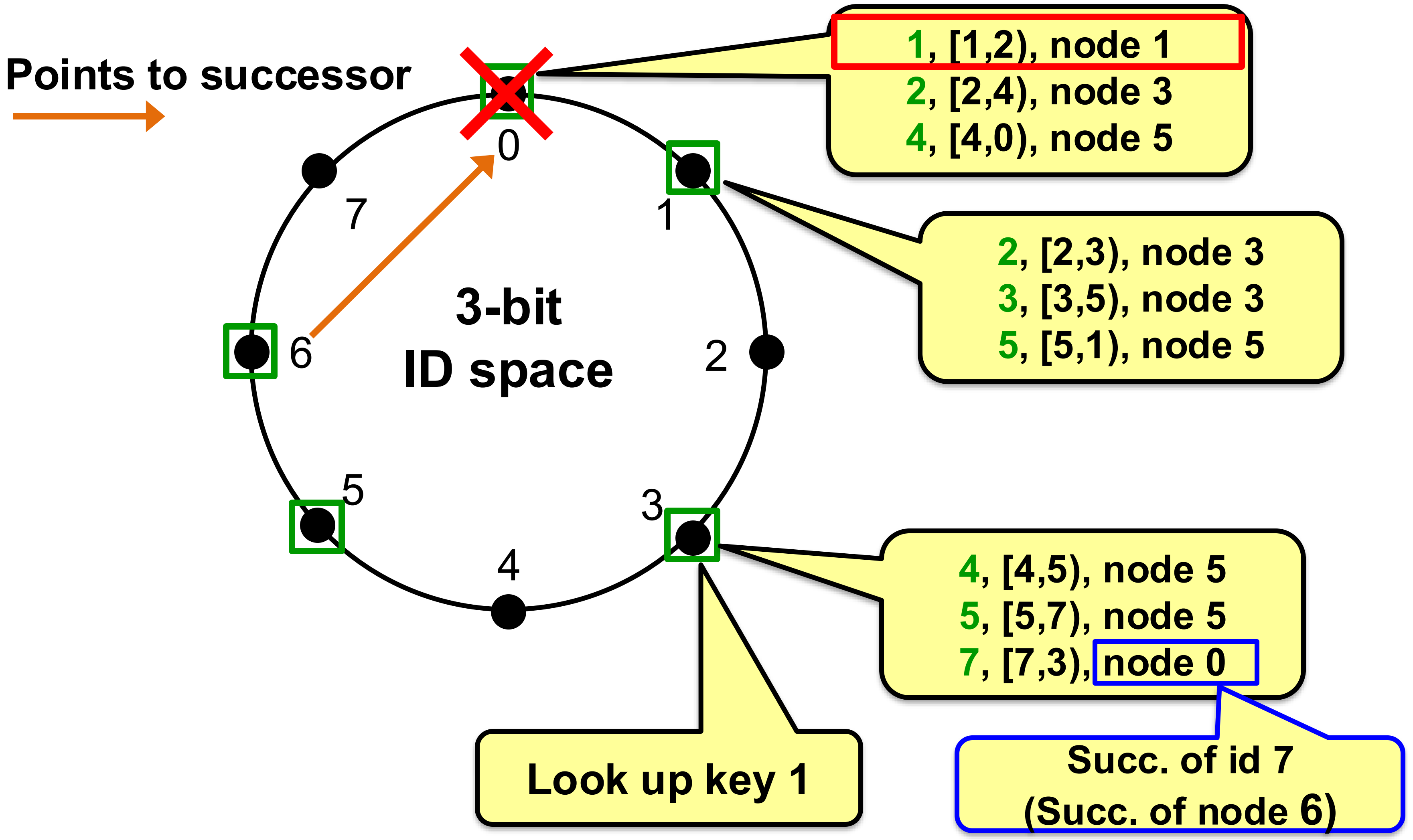
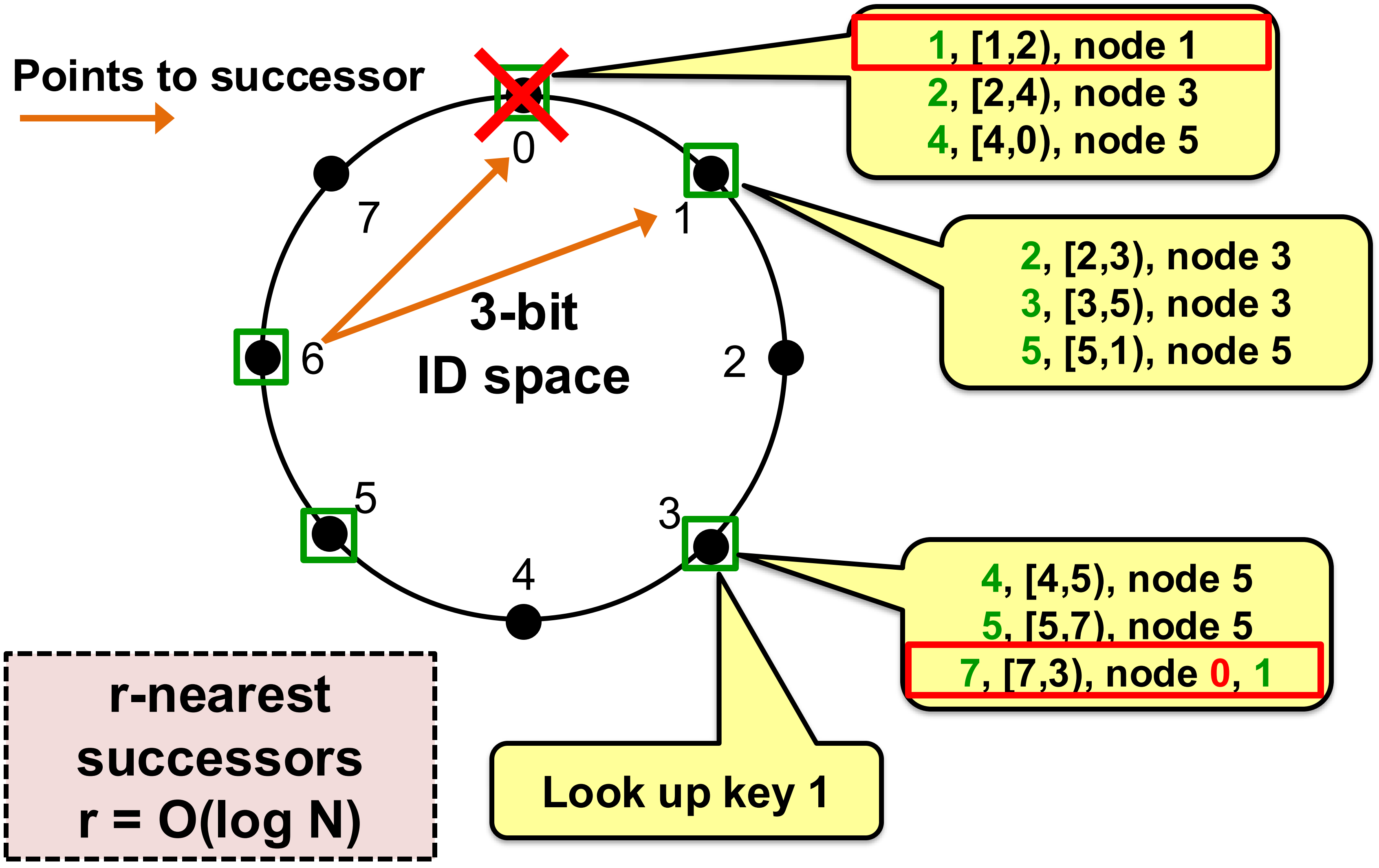
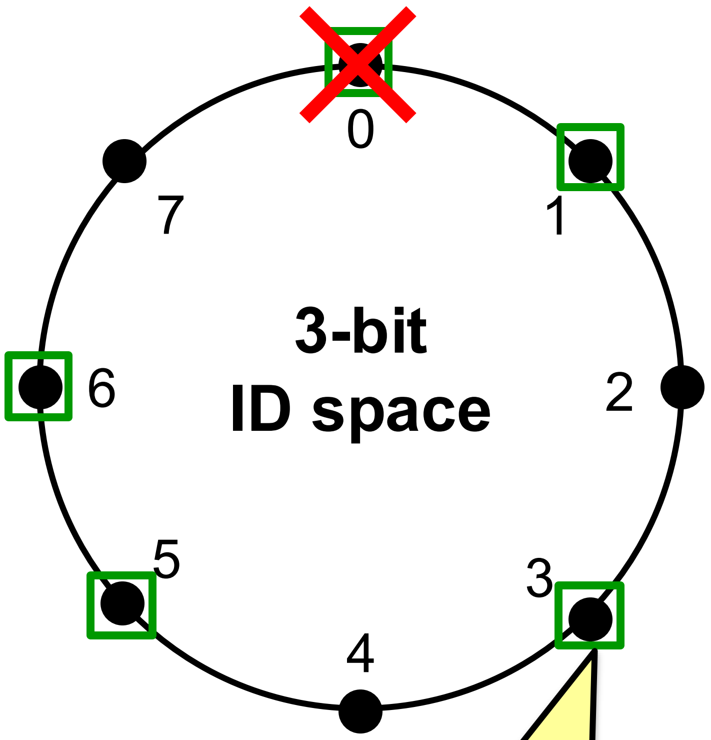


Chord – failures and successor list



r-nearest successors
r = O(log N)

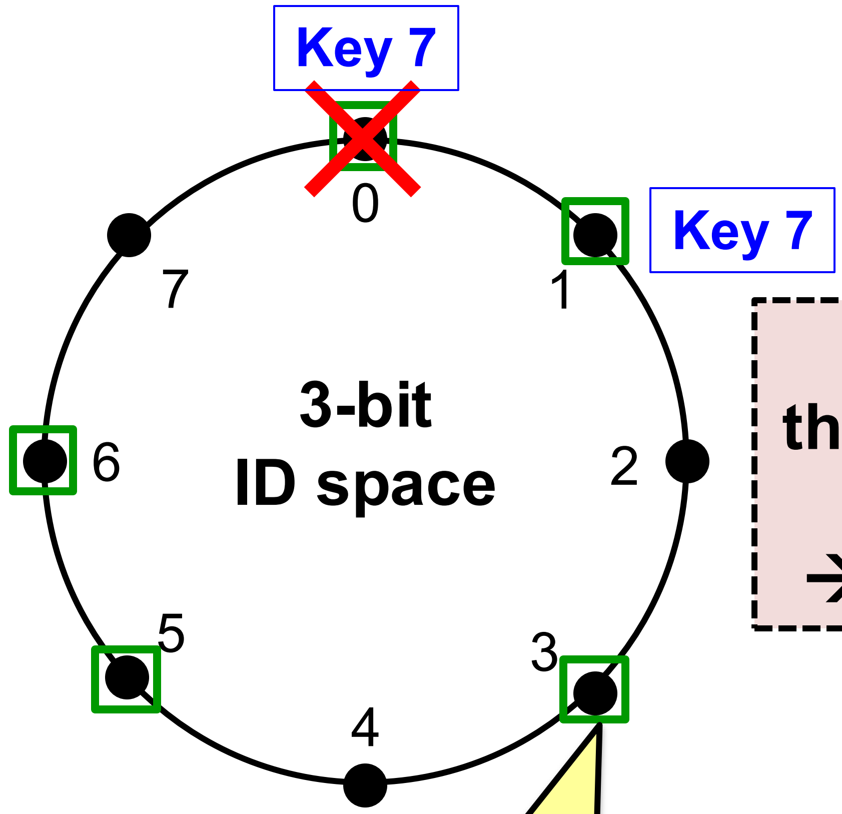
Chord – failures and successor list



r-nearest successors
r = O(log N)

What if look up key 7?

DHash replicates blocks at *r* successors



“Adjacent” nodes in the ring may be far away in the network
→ Independent failures

r-nearest successors
r = O(log N)

What if look up key 7?

Today

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- **Concluding thoughts on DHTs, P2P**

Why don’t all services use P2P?

1. **High latency and limited bandwidth** between peers (*vs.* intra/inter-datacenter, client-server model)
   – 1M nodes = 20 hops; 50ms/hop → 1s lookup latency

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 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, 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