TRƯỜNG ĐẠI HỌC BÁCH KHOA HÀ NỘI
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Distributed hash table (DHT)

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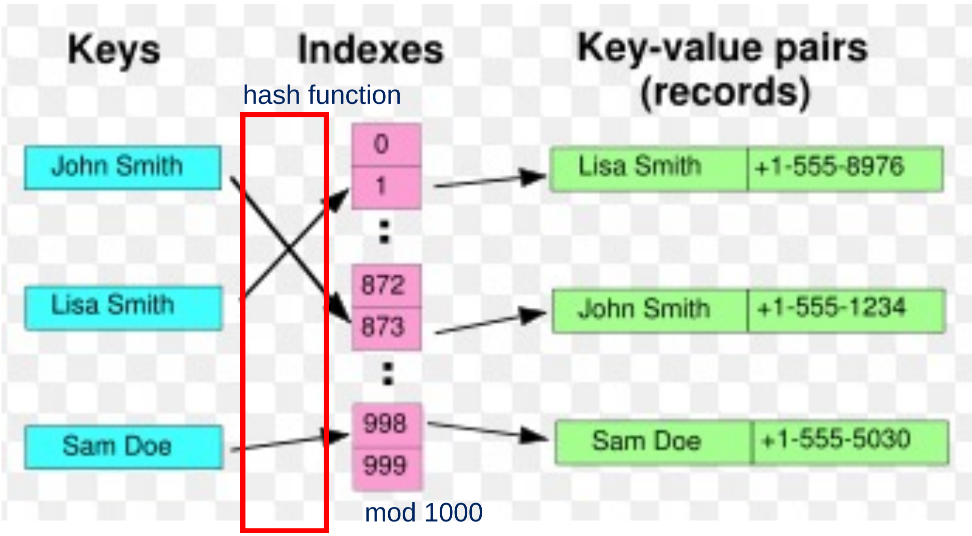
Outline

- Hashing
- Distributed Hash Table
- Chord

A Hash Table (hash map)

- A data structure implements an associative array that can map keys to values.
  - searching and insertions are 0(1) in the worse case
- Uses a hash function to compute an index into an array of buckets or slots from which the correct value can be found.
  - index = f(key, array_size)



Hash functions

- Crucial for good hash table performance
- Can be difficult to achieve
  - WANTED: uniform distribution of hash values
  - A non-uniform distribution increases the number of collisions and the cost of resolving them

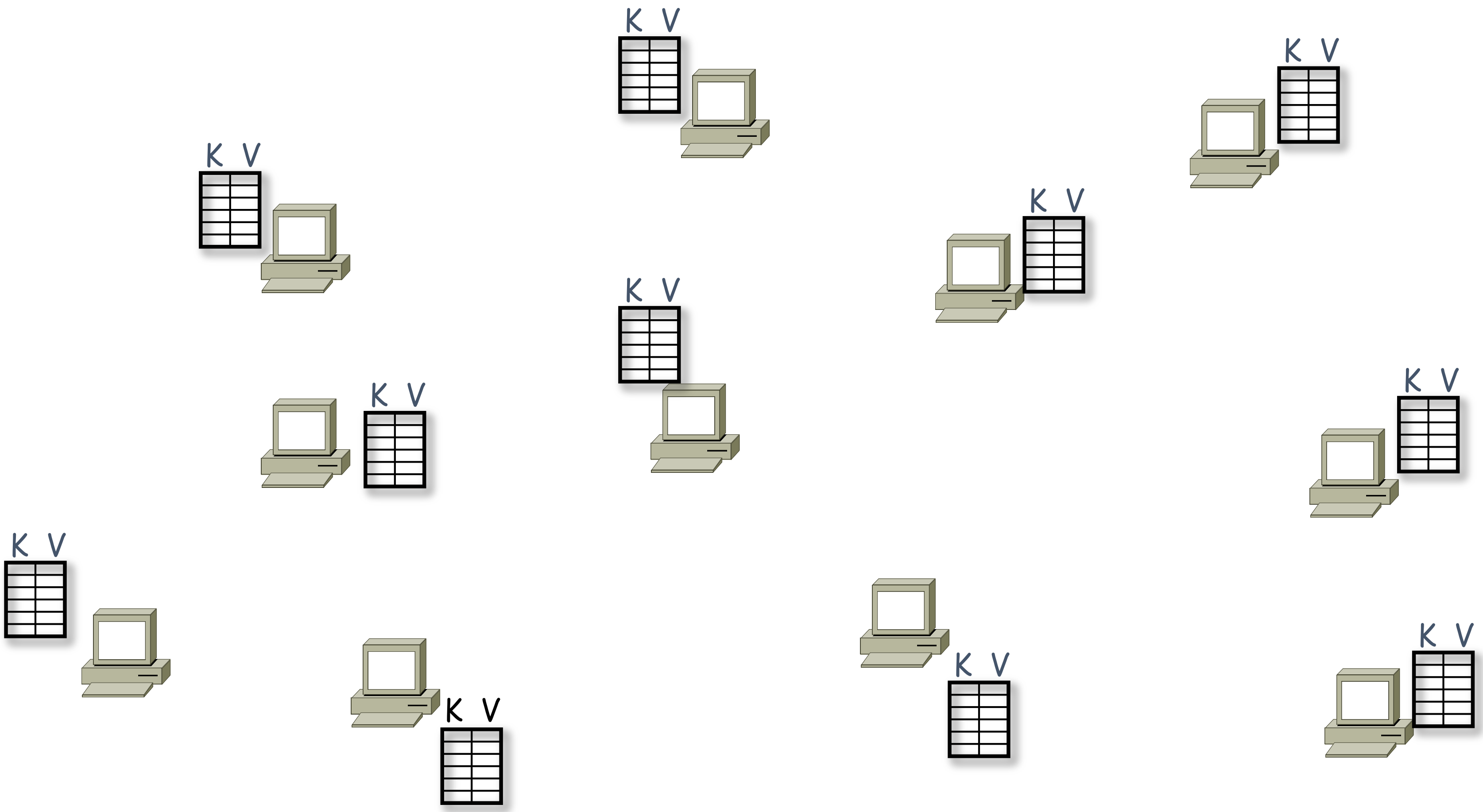
Hashing for partitioning usecase

- Objective
  - Given document X, choose one of k servers to use
- Eg. using modulo hashing
  - Number servers 1..k
  - Place X on server i = (X mod k)
    - Problem? Data may not be uniformly distributed
  - Place X on server i = hash (X) mod k
- Problem?
  - What happens if a server fails or joins (k → k±1)?
  - What is different clients has different estimate of k?
  - Answer: All entries get remapped to new nodes!

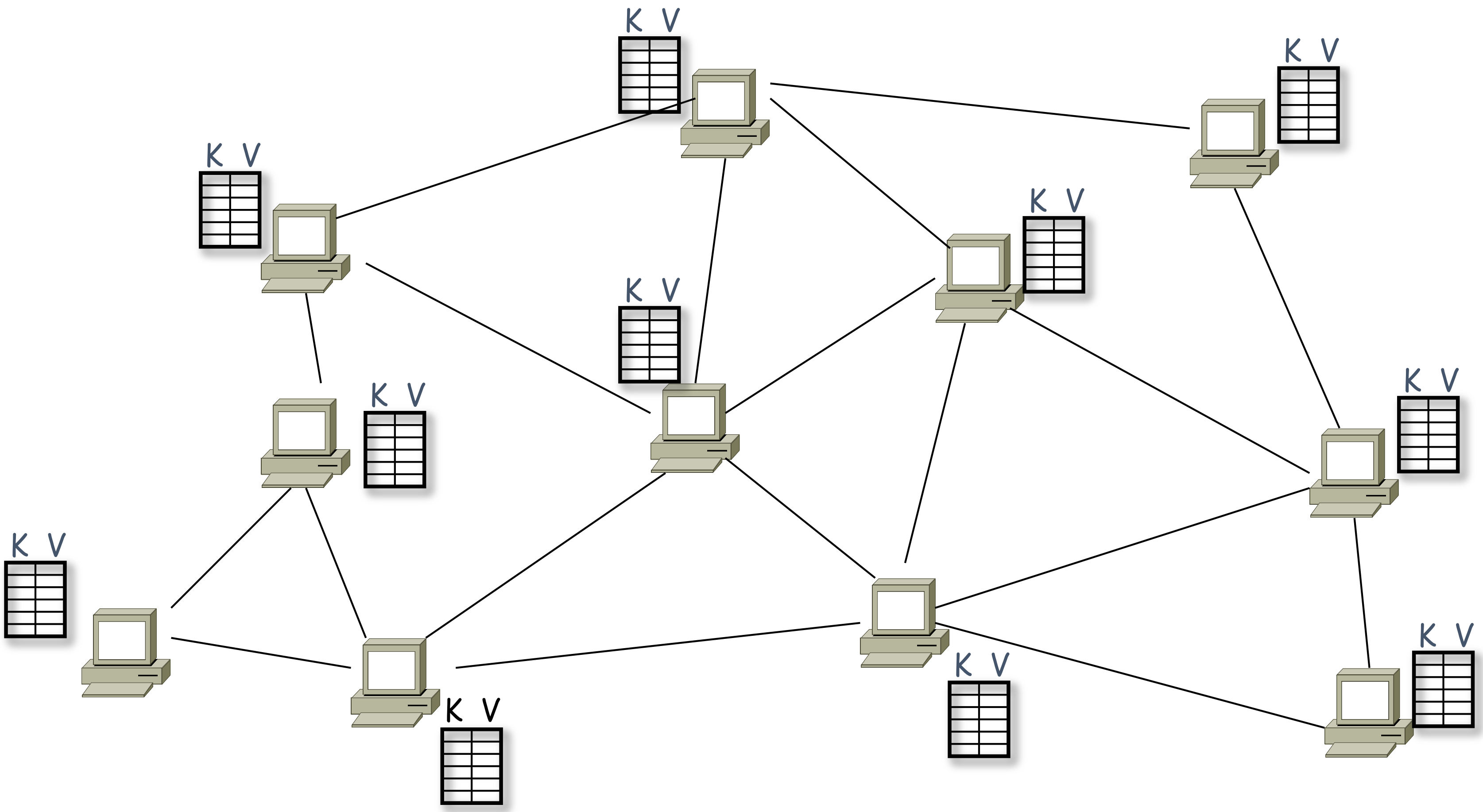
Distributed hash table (DHT)

- Distributed Hash Table (DHT) is similar to hash table but spread across many hosts
- Interface
  - insert(key, value)
  - lookup(key)
- Every DHT node supports a single operation:
  - Given key as input; route messages to node holding key

DHT: basic idea

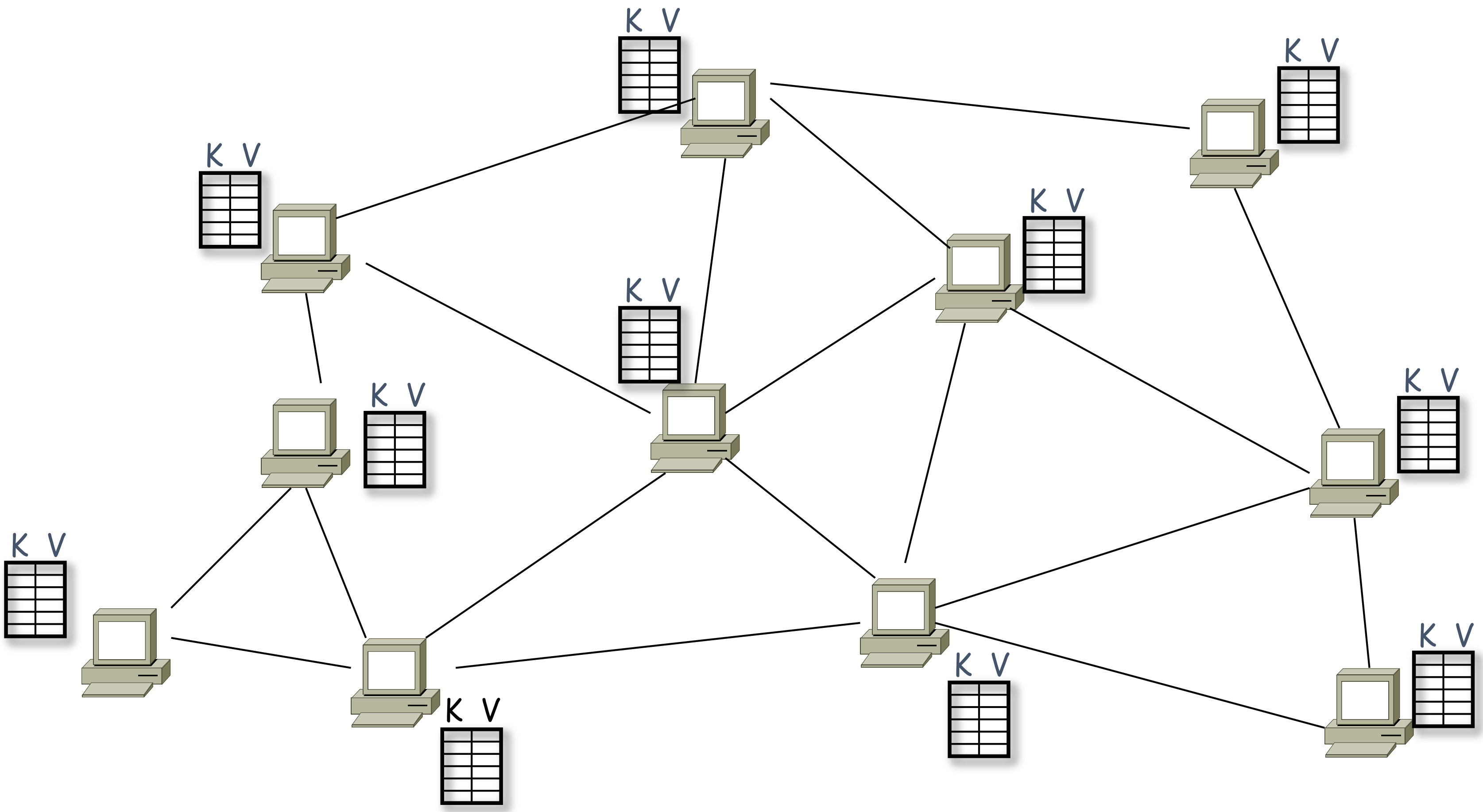


DHT: basic idea



Neighboring nodes are "connected" at the application-level

DHT: basic idea



<u>Operation: take *key* as input; route messages to node holding *key*</u>

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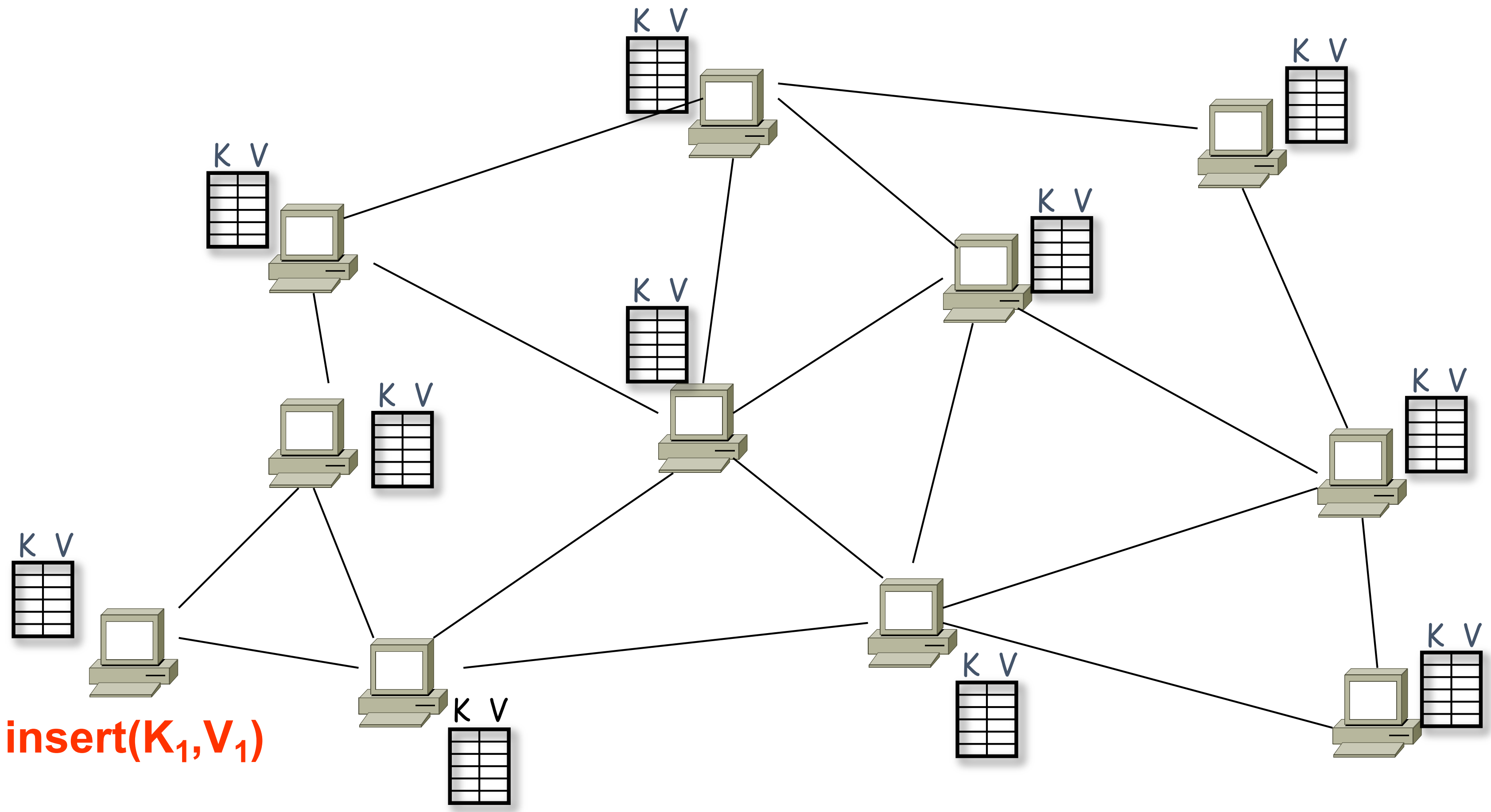

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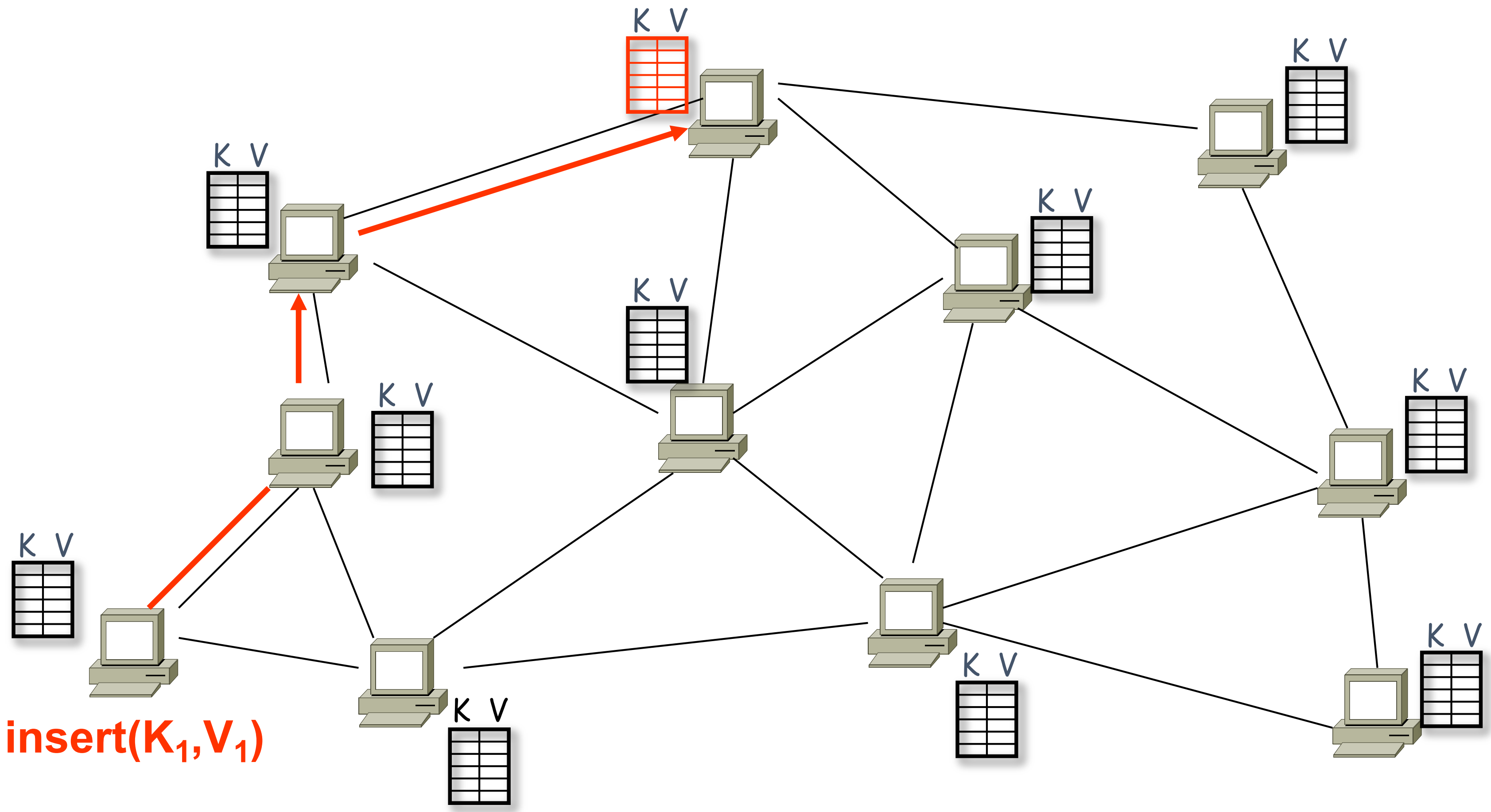

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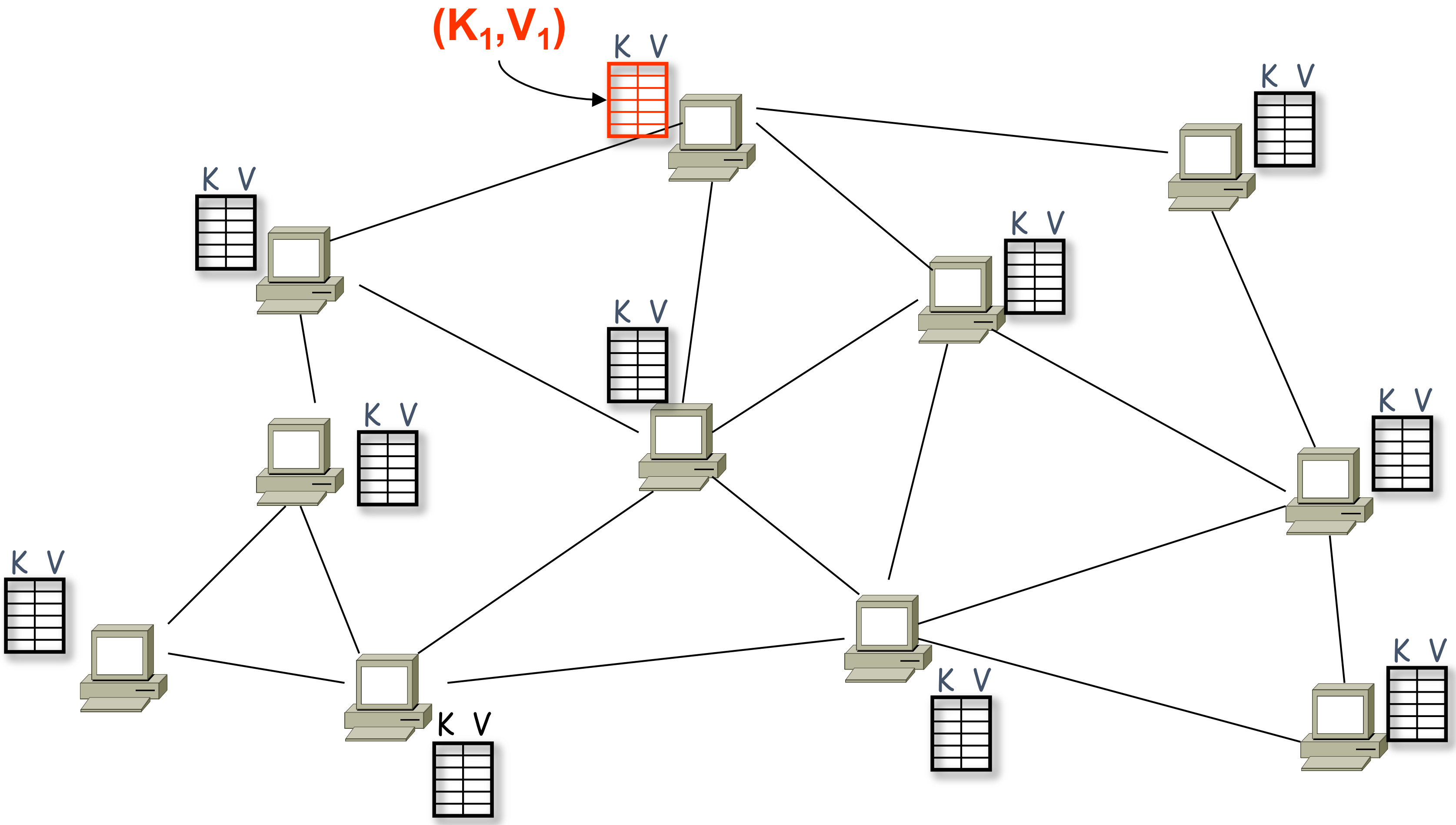

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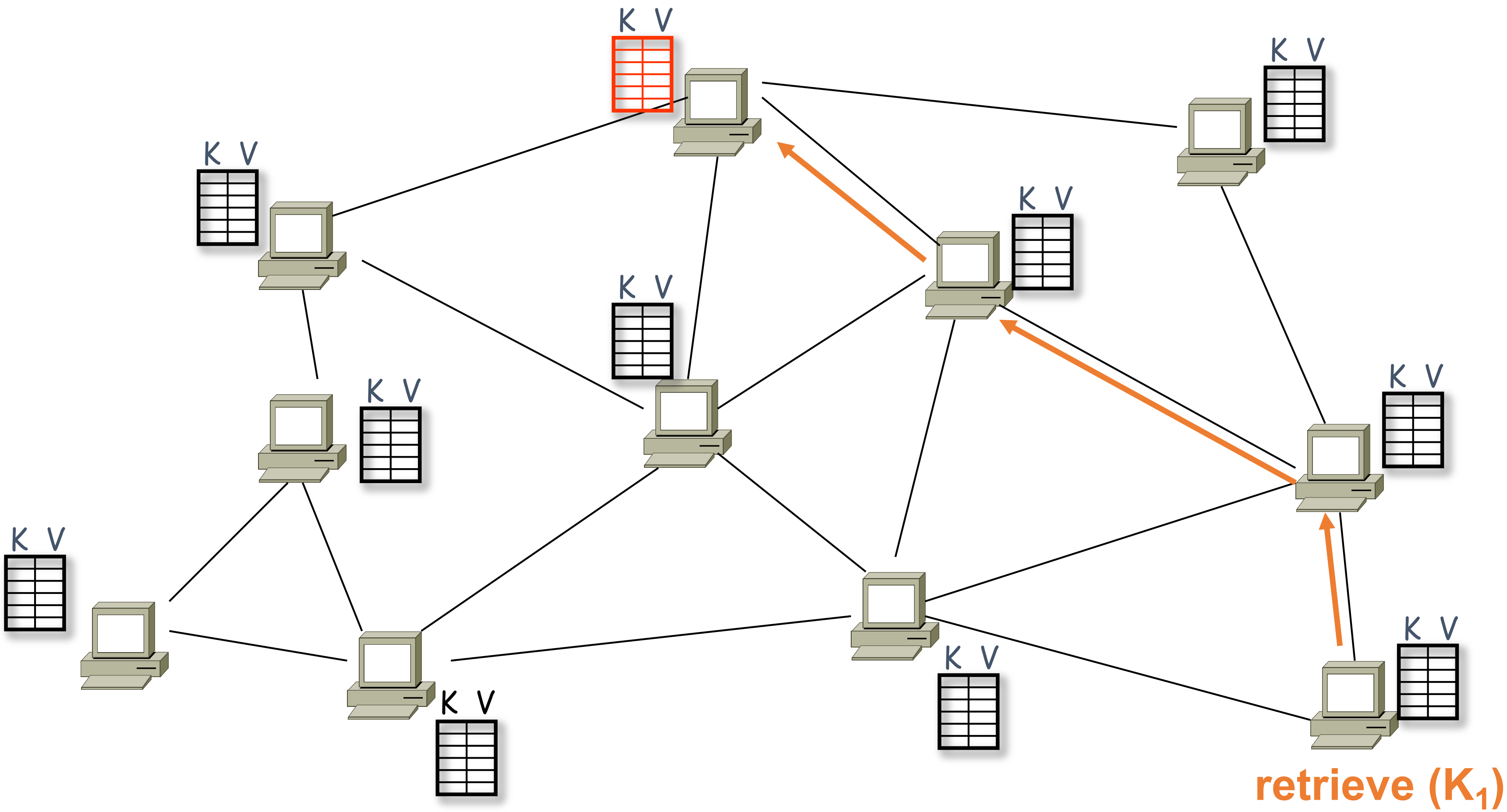


Operation: take *key* as input; route messages to node holding *key*

How to design a DHT?

- State Assignment
  - What "(key, value) tables" does a node store?
- Network Topology
  - How does a node select its neighbors?
- Routing Algorithm:
  - Which neighbor to pick while routing to a destination?
- Various DHT algorithms make different choices
  - CAN, Chord, Pastry, Tapestry, Plaxton, Viceroy, Kademlia, Skipnet, Symphony, Koorde, Apocrypha, Land, ORDI …

Chord: A scalable peer-to-peer look-up protocol for internet applications

Credit: University of California, berkely and Max planck institute

Outline

- What is Chord?
- Consistent Hashing
- A Simple Key Lookup Algorithm
- Scalable Key Lookup Algorithm
- Node Joins and Stabilization
- Node Failures

What is Chord?

- In short: a peer-to-peer lookup system
- Given a key (data item), it maps the key onto a node (peer).

map key vào trong một node trong hệ thống cluster

- Uses consistent hashing to assign keys to nodes .

sử dụng hàm băm để gán 1 key vào trong 1 node

- Solves the problem of locating key in a collection of distributed nodes.
- Maintains routing information with frequent node arrivals and departures

Consistent hashing

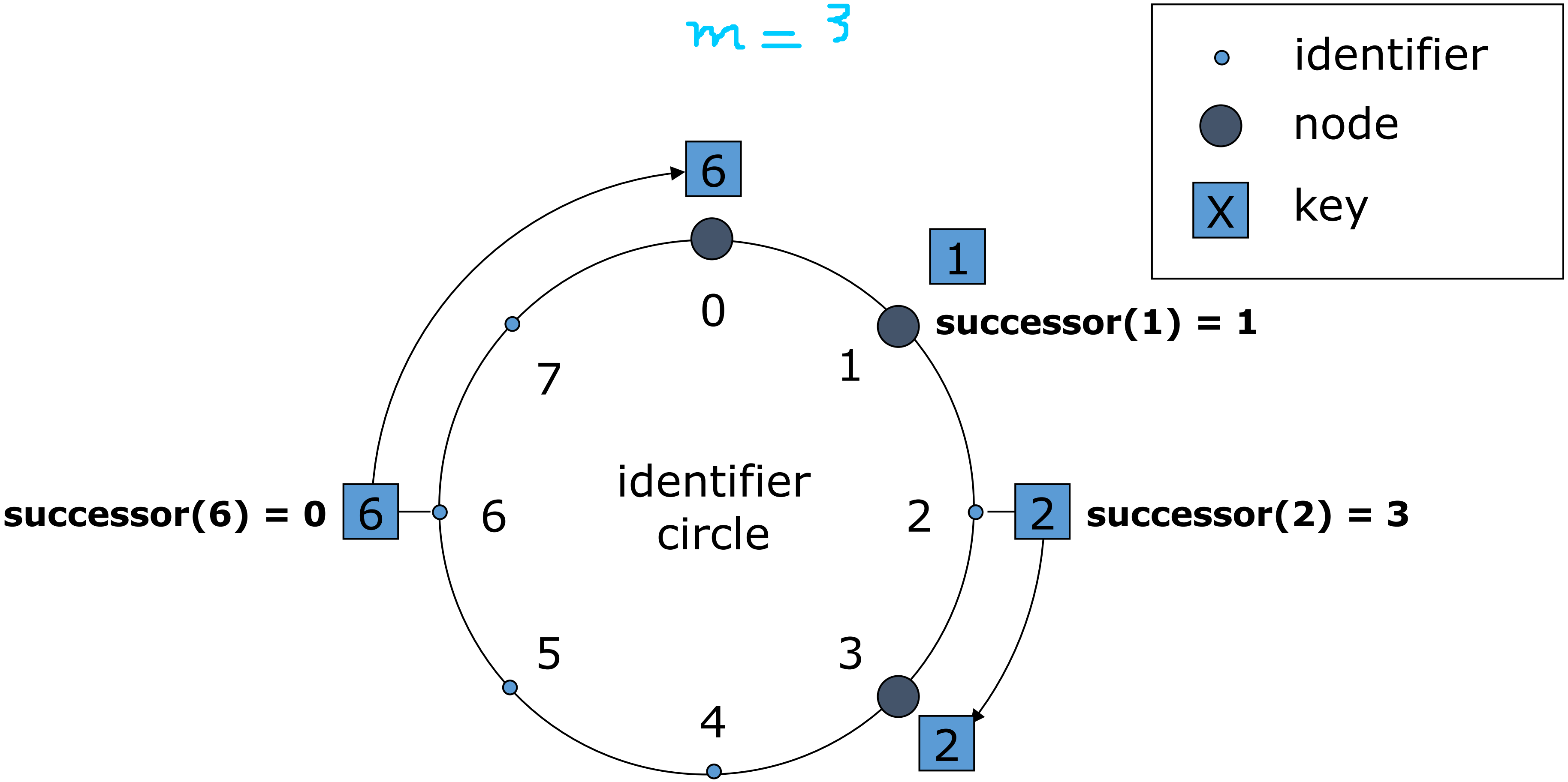
- Consistent hash function assigns each node and key an m-bit identifier. đinh danh m-bit 2^m identifier
- SHA-1 is used as a base hash function.
- A node's identifier is defined by hashing the node's IP address.
- A key identifier is produced by hashing the key (chord doesn't define this. Depends on the application).
  - ID(node) = hash(IP, Port)
  - ID(key) = hash(key)

Consistent hashing

- In an m-bit identifier space, there are 2^m identifiers.
- Identifiers are ordered on an identifier circle modulo 2^m.
- The identifier ring is called Chord ring.
- Key k is assigned to the first node whose identifier is equal to or follows (the identifier of) k in the identifier space.
- This node is the successor node of key k, denoted by successor(k).

Consistent hashing – Successor nodes

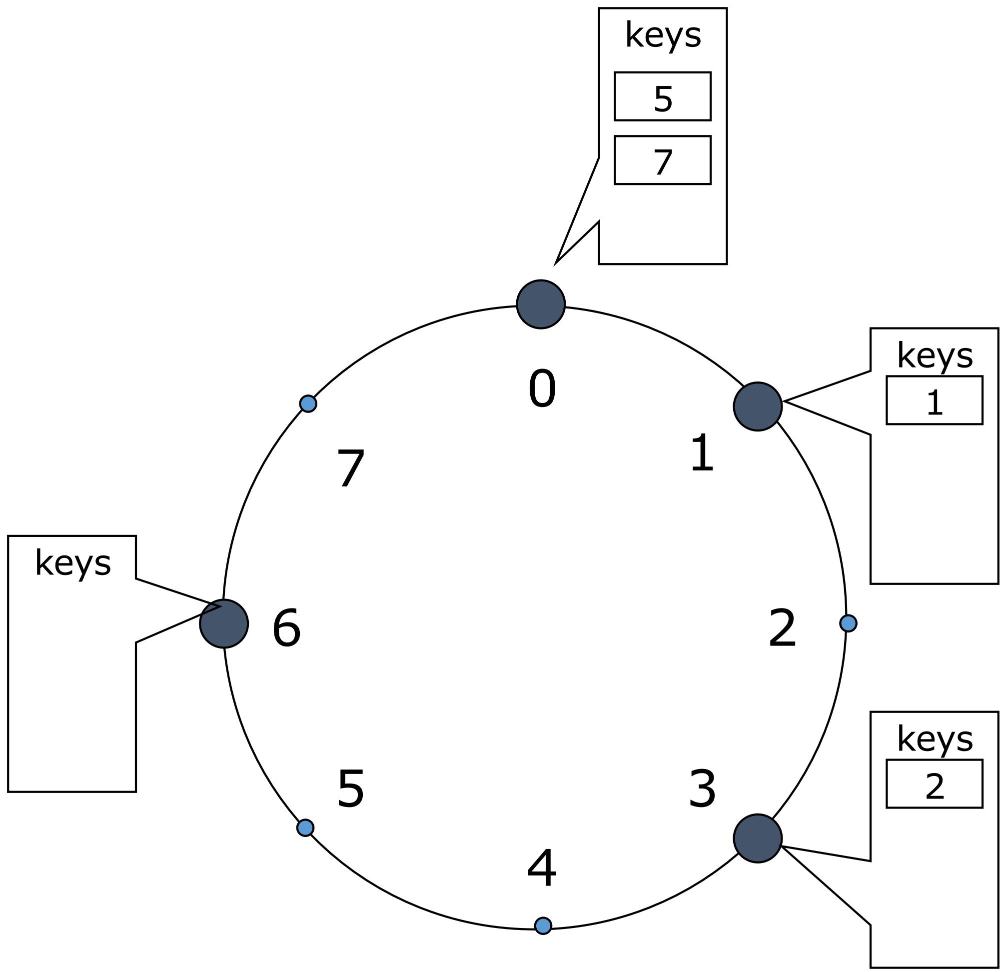
$m = 3$



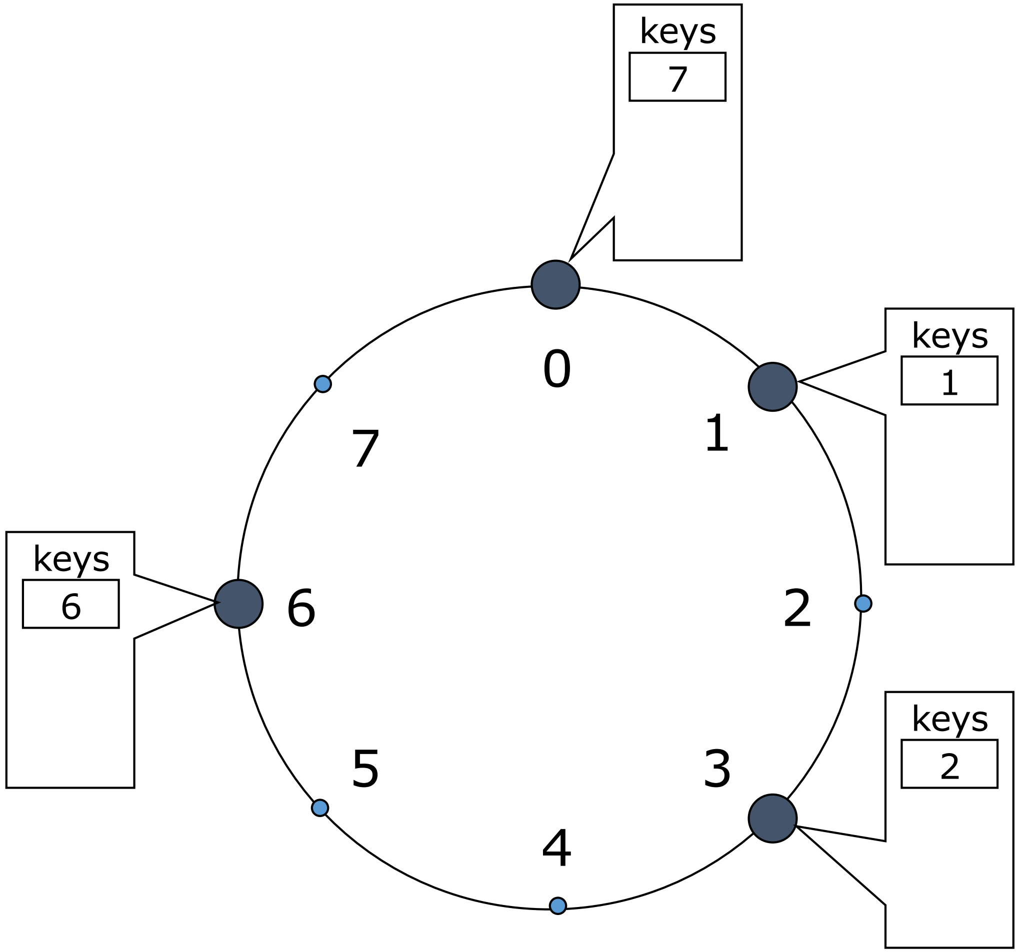
Consistent hashing – Join and departure

- When a node n joins the network, certain keys previously assigned to n's successor now become assigned to n.
- When node n leaves the network, all of its assigned keys are reassigned to n's successor.

Consistent hashing – Node join



Consistent hashing – Node departure



A Simple key lookup

- If each node knows only how to contact its current successor node on the identifier circle, all node can be visited in linear order.
- Queries for a given identifier could be passed around the circle via these successor pointers until they encounter the node that contains the key.

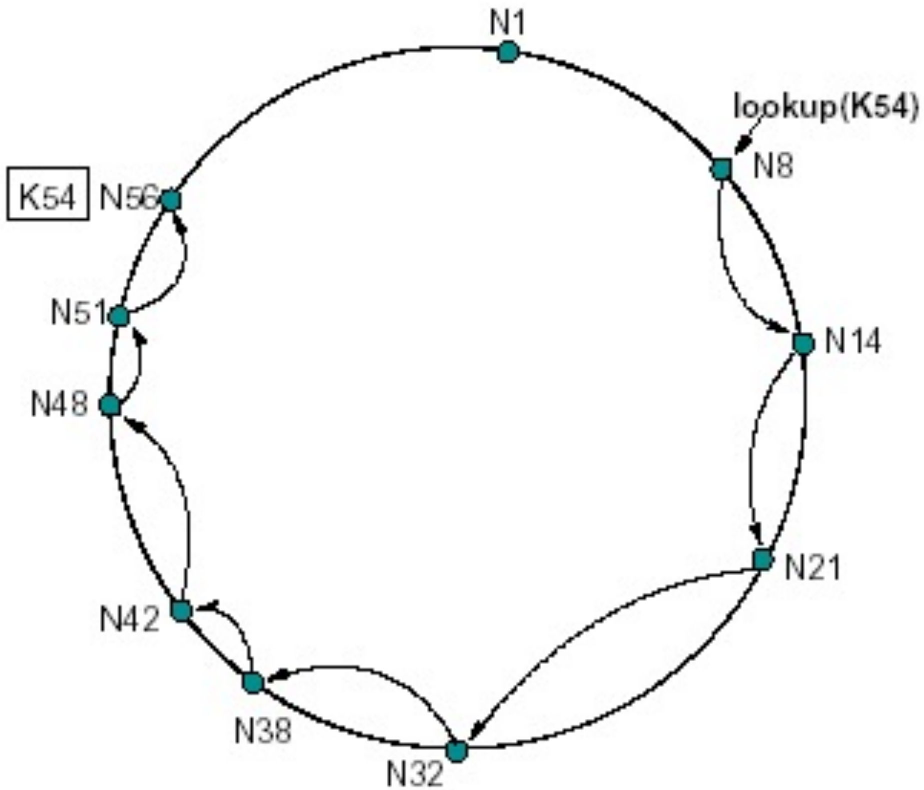
A Simple key lookup

- Pseudo code for finding successor:

```
// ask node n to find the successor of id
n.find_successor(id)
    if (id ∈ (n, successor])
        return successor;
    else
        // forward the query around the circle
        return successor.find_successor(id);
```

A Simple key lookup

- The path taken by a query from node 8 for key 54:



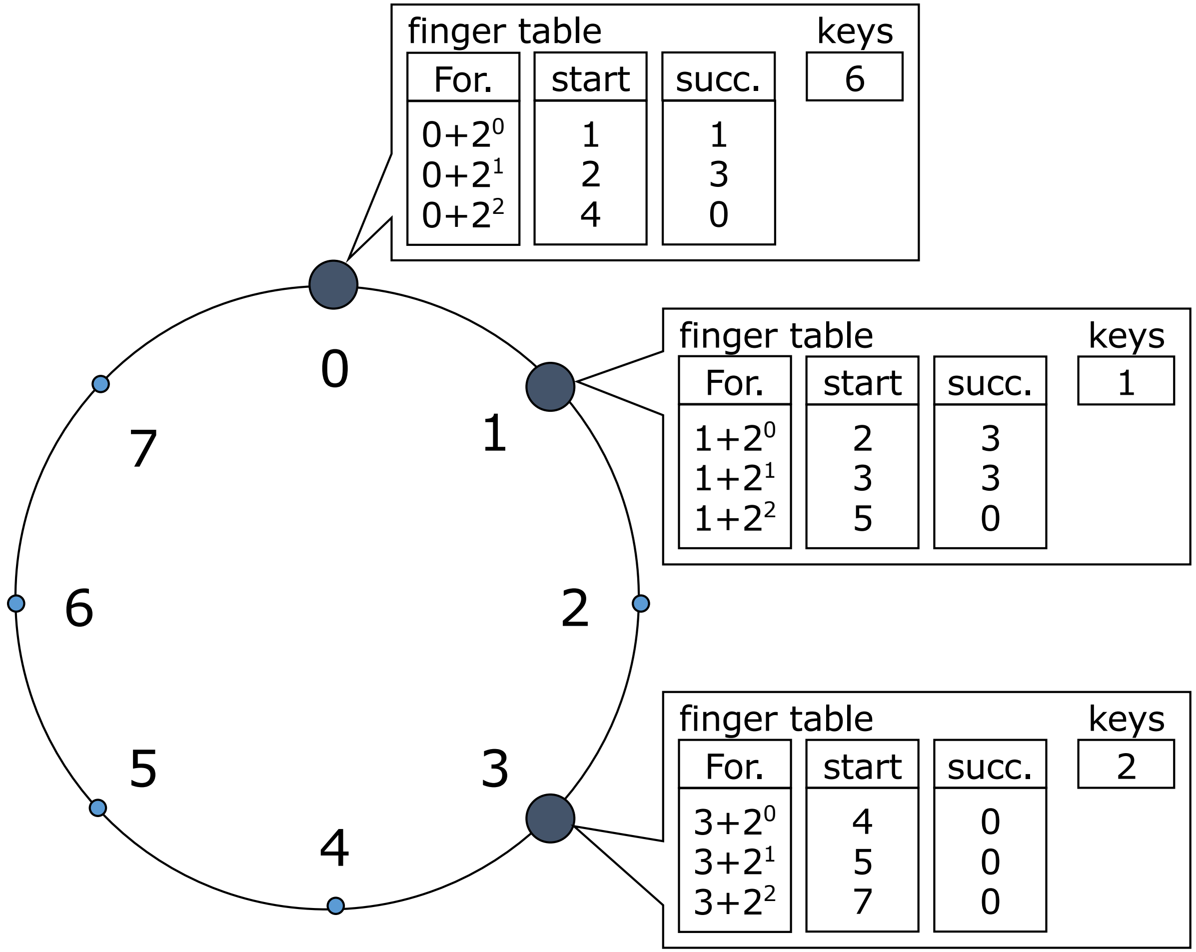
Scalable key location

- To accelerate lookups, Chord maintains additional routing information.
- This additional information is not essential for correctness, which is achieved as long as each node knows its correct successor.

Scalable key location – Finger tables

- Each node n' maintains a routing table with up to m entries (which is in fact the number of bits in identifiers), called finger table.
- The ith entry in the table at node n contains the identity of the first node s that succeeds n by at least 2^i-1 on the identifier circle.
- s = successor(n+2^i-1). i = 1-> m
- s is called the ith finger of node n, denoted by n.finger(i)

Scalable key location – Finger tables

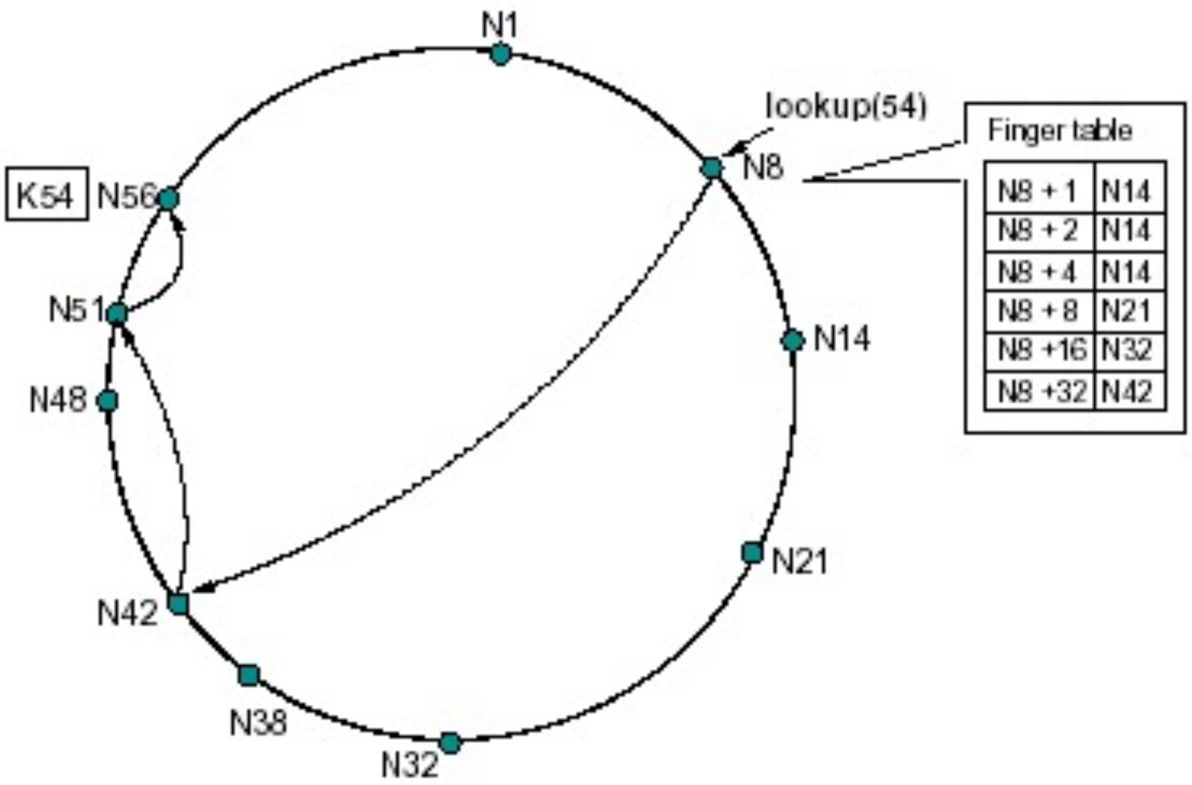


Scalable key location – Finger tables

- A finger table entry includes both the Chord identifier and the IP address (and port number) of the relevant node.
- The first finger of n is the immediate successor of n on the circle.

Scalable key location – Example query

- The path a query for key 54 starting at node 8:



Scalable key location – A characteristic

- Since each node has finger entries at power of two intervals around the identifier circle, each node can forward a query at least halfway along the remaining distance between the node and the target identifier. From this intuition follows a theorem:
  - Theorem: With high probability, the number of nodes that must be contacted to find a successor in an N-node network is O(logN).

Node joins and stabilizations

- The most important thing is the successor pointer.
- If the successor pointer is ensured to be up to date, which is sufficient to guarantee correctness of lookups, then finger table can always be verified.
- Each node runs a “stabilization” protocol periodically in the background to update successor pointer and finger table.

Node joins and stabilizations

- "Stabilization" protocol contains 6 functions:
  - create()
  - join()
  - stabilize()
  - notify()
  - fix_fingers()
  - check_predecessor()

Node Joins – join()

- When node n first starts, it calls n.join(n'), where n' is any known Chord node.
- The join() function asks n' to find the immediate successor of n.
- join() does not make the rest of the network aware of n.

Node Joins – join()

```
// create a new Chord ring.
n.create()
  predecessor = nil;
  successor = n;

// join a Chord ring containing node n'.
n.join(n')
  predecessor = nil;
  successor = n'.find_successor(n);
```

Node joins – stabilize()

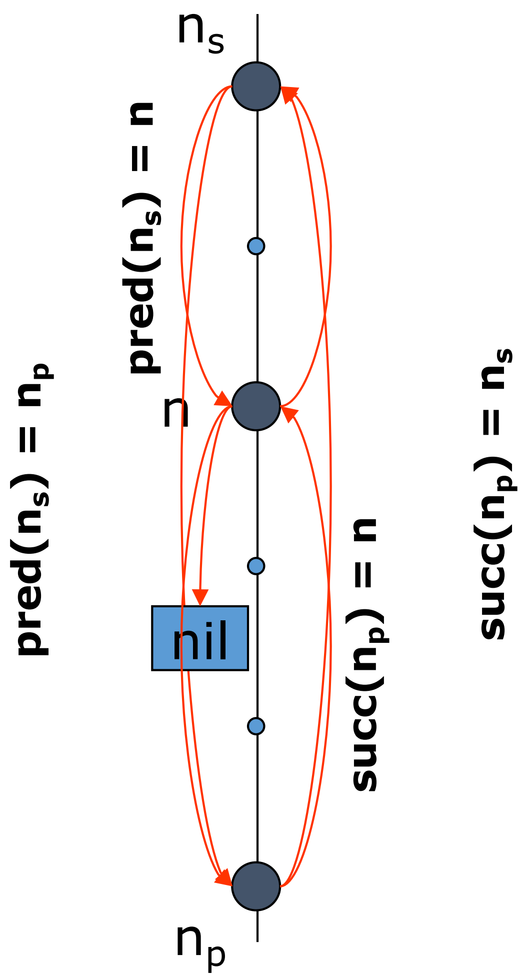
- Each time node n runs stabilize(), it asks its successor for it's predecessor p, and decides whether p should be n's successor instead.
- stabilize() notifies node n's successor of n's existence, giving the successor the chance to change its predecessor to n.
- The successor does this only if it knows of no closer predecessor than n.

Node joins – stabilize()

```
// called periodically. verifies n's immediate
// successor, and tells the successor about n.
n.stabilize()
  x = successor.predecessor;
  if (x ∈ (n, successor))
        successor = x;
  successor.notify(n);

// n' thinks it might be our predecessor.
n.notify(n')
if (predecessor is nil or n' ∈ (predecessor, n))
  predecessor = n';
```

Node joins – Join and stabilization



- **n joins**
  - predecessor = nil
  - n acquires n_s as successor via some n'
- **n runs stabilize**
  - n notifies n_s being the new predecessor
  - n_s acquires n as its predecessor
- **n_p runs stabilize**
  - n_p asks n_s for its predecessor (now n)
  - n_p acquires n as its successor
  - n_p notifies n
  - n will acquire n_p as its predecessor
- **all predecessor and successor pointers are now correct**
- **fingers still need to be fixed, but old fingers will still work**

Node Joins – fix_fingers()

- Each node periodically calls fix fingers to make sure its finger table entries are correct.
- It is how new nodes initialize their finger tables
- It is how existing nodes incorporate new nodes into their finger tables.

Node Joins – fix_fingers()

```
// called periodically. refreshes finger table entries.
n.fix_fingers()
  next = next + 1 ;
  if (next > m)
        next = 1 ;
  finger[next] = find_successor(n + 2^(next-1));

// checks whether predecessor has failed.
n.check_predecessor()
  if (predecessor has failed)
        predecessor = nil;
```

Node failures

- Key step in failure recovery is maintaining correct successor pointers
- To help achieve this, each node maintains a successor-list of its r nearest successors on the ring. Hence, all r successors would have to simultaneously fail in order to disrupt the Chord ring.
- If node n notices that its successor has failed, it replaces it with the first live entry in the list
- Successor lists are stabilized as follows:
  - node n reconciles its list with its successor s by copying s's successor list, removing its last entry, and prepending s to it.
  - If node n notices that its successor has failed, it replaces it with the first live entry in its successor list and reconciles its successor list with its new successor.

Chord – The math

- Each node maintains O(logN) state information and lookups needs O(logN) messages
- Every node is responsible for about K/N keys (N nodes, K keys)
- When a node joins or leaves an N-node network, only O(K/N) keys change hands (and only to and from joining or leaving node)

Interesting simulation results

- Adding virtual nodes as an indirection layer can significantly improve load balance.
- The average path length is about ½(logN).
- Maintaining a set of alternate nodes for each finger and route the queries by selecting the closest node according to network proximity metric improves routing latency effectively.
- Recursive lookup style is faster iterative style

Applications: Time-shared storage

- For nodes with intermittent connectivity (server only occasionally available)
- Store others‘ data while connected, in return having their data stored while disconnected
- Data‘s name can be used to identify the live Chord node (content-based routing)

Applications: Chord-based DNS

- DNS provides a lookup service
  - keys: host names values: IP adresses
- Chord could hash each host name to a key
- Chord-based DNS:
  - no special root servers
  - no manual management of routing information
  - no naming structure
  - can find objects not tied to particular machines

What is Chord? – Addressed problems

- **Load balance**: chord acts as a distributed hash function, spreading keys evenly over nodes
- **Decentralization**: chord is fully distributed, no node is more important than any other, improves robustness
- **Scalability**: logarithmic growth of lookup costs with the number of nodes in the network, even very large systems are feasible
- **Availability**: chord automatically adjusts its internal tables to ensure that the node responsible for a key can always be found
- **Flexible naming**: chord places no constraints on the structure of the keys it looks up.

Summary

- Simple, powerful protocol
- Only operation: map a key to the responsible node
- Each node maintains information about O(log N) other nodes
- Lookups via O(log N) messages
- Scales well with number of nodes
- Continues to function correctly despite even major changes of the system

Thanks for your attention!