# Internet Technology

05r. Distributed Hash Tables

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## Locating content

- Our discussion on peer-to-peer applications focused on content distribution
  – Content was fully distributed
- How do we find the content?

| | |
|---|---|
| Napster | Central server (hybrid architecture) |
| Gnutella & Kazaa | Network flooding<br>Optimized to flood supernodes … but it's still flooding |
| BitTorrent | Nothing!<br>It's somebody else's problem |

- Can we do better?



## What's wrong with flooding?

- Some nodes are not always up and some are slower than others
  – Gnutella & Kazaa dealt with this by classifying some nodes as "supernodes" (called "ultrapeers" in Gnutella)
- Poor use of network resources
- Potentially high latency
  – Requests get forwarded from one machine to another
  – Back propagation (e.g., Gnutella design), where the replies go through the same chain of machines used in the query, increases latency even more



## Hash tables

- Remember hash functions & hash tables?
  – Linear search: O(*N*)
  – Tree: O(log*N*)
  – Hash table: O(1)



## What's a hash function? (refresher)

- Hash function
  – A function that takes a variable length input (e.g., a string) and generates a (usually smaller) fixed length result (e.g., an integer)
  – Example: hash strings to a range 0-6:
    - *hash("Newark") → 1*
    - *hash("Jersey City") → 6*
    - *hash("Paterson") → 2*
- Hash table
  – Table of *(key, value)* tuples
  – Look up a key:
    - Hash function maps *keys* to a range *0 … N-1*
      table of *N* elements
      `i = hash(key)`
      `table[i]` contains the item
  – No need to search through the table!



## Considerations with hash tables (refresher)

- Picking a good hash function
  – We want uniform distribution of all values of *key* over the space *0 … N-1*
- Collisions
  – Multiple keys may hash to the same value
    - hash("Paterson") → 2
    - hash("Edison") → 2
  – `table[i]` is a bucket (slot) for all such *(key, value)* sets
  – Within `table[i]`, use a linked list or another layer of hashing
- Think about a hash table that grows or shrinks
  – If we add or remove buckets → need to rehash keys and move items

## Distributed Hash Tables (DHT)

- Create a peer-to-peer version of a (*key, value*) database
- How we want it to work
  1. A peer queries the database with a key
  2. The database finds the peer that has the value
  3. That peer returns the (key, value) pair to the querying peer
- Make it efficient!
  - A query should not generate a flood!
- We'll look at one DHT implementation called **Chord**

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## The basic idea

- Each node (peer) is identified by an integer in the range $[0, 2^n-1]$
- Each key is hashed into the range $[0, 2^n-1]$
- Each peer will be responsible for specific keys
  - A key is stored at the closest successor node
  - This is the first node whose ID ≥ hash(key)
- If we arrange the peers in a logical ring (incrementing IDs) then a peer needs to know only of its successor and predecessor
  - This limited knowledge of peers makes it an **overlay network**

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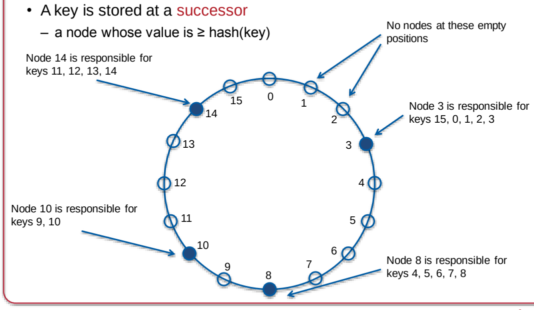
## Key assignment

- Example: *n=16;* system with 4 nodes (so far)
- A key is stored at a successor
  - a node whose value is ≥ hash(key)

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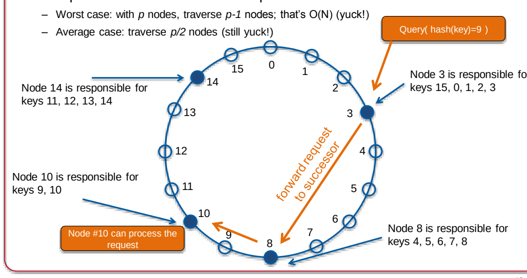
## Handling requests

- Any peer can get a request (*insert* or *query*). If the hash(key) is not for its ranges of keys, it forwards the request to a successor.
- The process continues until the responsible node is found
  - Worst case: with *p* nodes, traverse *p-1* nodes; that's O(N) (yuck!)
  - Average case: traverse *p/2* nodes (still yuck!)

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## Let's figure out three more things

1. Adding/removing nodes
2. Improving lookup time
3. Fault tolerance

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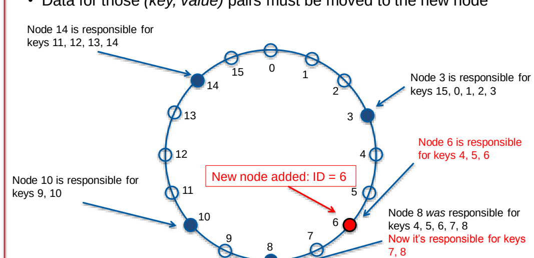
## Adding a node

- Some keys that were assigned to a node's successor now get assigned to the new node
- Data for those *(key, value)* pairs must be moved to the new node

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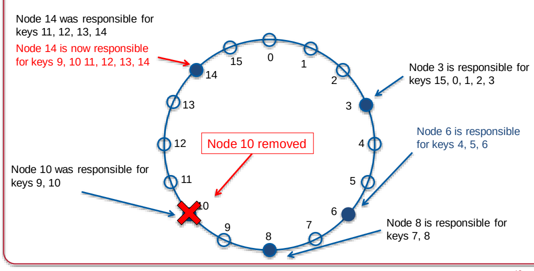
## Removing a node

- Keys are reassigned to the node's successor
- Data for those *(key, value)* pairs must be moved to the successor

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## Performance

- We're not thrilled about *O(N)* lookup
- Simple approach for great performance
  - Have all nodes know about each other
  - When a peer gets a node, it searches its table of nodes for the node that owns those values
  - Gives us *O(1)* performance
  - Add/remove node operations must inform everyone
  - Not a good solution if we have millions of peers (huge tables)

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## Finger tables

- Compromise to avoid huge per-node tables
  - Use finger tables to place an upper bound on the table size
- Finger table = partial list of nodes
- At each node, $i^{th}$ entry in finger table identifies node that succeeds it by at least $2^{i-1}$ in the circle
  - finger_table[0]: immediate ($1^{st}$) successor
  - finger_table[1]: successor after that ($2^{nd}$)
  - finger_table[2]: $4^{th}$ successor
  - finger_table[3]: $8^{th}$ successor
  - …
- *O(log N)* nodes need to be contacted to find the node that owns a key
  … not as cool as O(1) but way better than O(N)

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## Fault tolerance

- Nodes might die
  - (key, value) data would need to be replicated
  - Create R replicas, storing each one at *R-1* successor nodes in the ring
- It gets a bit complex
  - A node needs to know how to find its successor's successor (or more)
    - Easy if it knows all nodes!
  - When a node is back up, it needs to check with successors for updates
  - Any changes need to be propagated to all replicas

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The end

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