# Distributed Software Development

## Distributed Hash Tables

Chris Brooks

Department of Computer Science
University of San Francisco



## Network Characteristics

- What are some qualities of unstructured P2P networks?



## Network Characteristics

- What are some qualities of unstructured P2P networks?
- Peers can connect to any other peer
- Peers can choose what data to store
- No fixed peer addressing scheme
- Peers can easily come and go



## Network Characteristics

- What are the implications of this?



## Network Characteristics

- What are the implications of this?
- Search may be slow or incomplete
- Data may not always be available
- Data may be difficult to locate
- It may be difficult to find a particular peer



## Applications

- What sorts of applications are a good fit for this sort of network?
- What sorts of applications are a poor fit?

# Structured P2P networks

- So far, we've focused on P2P apps in which users may join the network at any point, and may store whatever data they want.
  - Network has no particular topology.
  - No guarantees that all nodes in the network can reach each other.
- These are referred to as *unstructured* P2P networks.
- We can also talk about *structured P2P* networks
  - Topology, number of connections, file placement is fixed.



# Distributed Hash Tables

- The most common structured P2P application is the *distributed hash table*
  - We can build a file system or storage scheme on top of this.
- Supports a single operation: map keys to node IDs.
- Key is a unique data identifier.



# DHT - design goals

- We would like for DHTs to have the following properties:
  - Data can always be found if it is in the network.
  - Each node only has to know about a small number of other nodes.
  - Number of messages needed to find data is small
  - Can tolerate crash failure
  - Can handle nodes entering and leaving



# Hash tables - review

- Hash tables provide a mapping from keys to values.
- They do this by means of a *hash function*
  - For example, modulo can be used as a hash function
- Good hash functions distribute hashed values evenly.
- Problem: What if we add buckets to our hash table?
  - Might need to re-hash all our data!
- How can we avoid this?



# Consistent Hashing

- Consistent hashing is a particular type of hash function.
- It has the property that when the number of buckets (or nodes in the network) is changed, at most $O(lgN)$ items will need to be re-hashed.
- This means that, in a distributed hash table, we can efficiently add or subtract nodes without large-scale updating.



# Chord

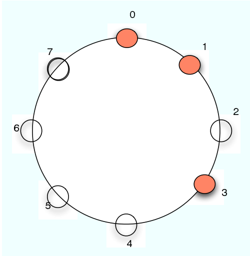
- Our discussion of DHTs will focus on Chord.
  - Developed at MIT
  - One of four DHT schemes (Can, Pastry, Tapestry are the others) developed contemperaneously.
- Designed to serve as the basis of a cooperative file system.

# Chord nodes

- Each Chord node begins with an $m$ bit identifer obtained by hashing its IP address.
- Nodes are arranged in a circle modulo $2^m$.
- Data is hashed with the same function (SHA-1) to produce a $key$
- A node is responsible for storing all data whose key is between its identifier and its successor's identifier.



# Example




- Three nodes in this example, with identifiers 0,1,3.
- 0 is responsible for data that hashes to 0.
- 1 is responsible for data that hashes to 1 or 2.
- 3 is responsible for data that hashes to 3-7.



# Simple Routing

- The simplest way to routing in Chord is as follows:
  - Each node keeps track of one other node: its successor.
  - To find a piece of data with key $k$, if a node does not have $k$, it asks its successor.
  - Eventually, all nodes in the ring are queried.
- Very simple, but requires $N$ messages.

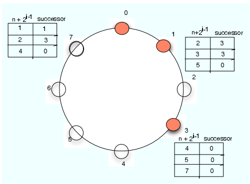


# Actual Chord Routing

- What Chord really does is have each node keep a *finger table*
- $m$ entries in the table.
- For node $n$, the $i$th entry is the first node that succeeds $n$ by $2^{i-1}$ modulo $n$.
- Contains the Chord identifier and the actual IP address of the node.



# Example




- In this case, each finger table has three entries.
- Indexes the nodes storing data 1,2 and 4 keys away.
- Each node only needs to contain $O(logN)$ entries.



# Routing

- To find a piece of data, a node computes the data's hash, yielding its key.
- Three possibilities:
  - The node is storing the data itself.
  - The key is in the seeking node's finger table.
  - The key is not in the seeking node's finger table.
- If the key is not in the seeking node's finger table, we execute find-predecessor.

# Routing

- Find-predecessor is meant to find the node that is before the data we are trying to find.
  - In the example, the predecessor of 5 is 3.
- Each node sends a message to the node in its finger table who is closest to the data being sought without going over.
- If a message is received by a node $n$ to find data with key $k$, and $successor(n) > k$, then $n$ has the data.
- Otherwise, call find-predecessor on the successor on $n$.
- Example: At node 3, want to find 2.
- We know that successor(7) is 0. We then query 0 to find that 2 is stored by node 1.



# Routing

- Chord is guaranteed to find data in $O(logN)$ messages.
  - Assuming that SHA-1 is a fair hashing function.
- In this way, the network can grow to large numbers of nodes while still retaining fast search.
- How is this different from the way Gnutella handles network structure and routing?



# Node Joining

- One of the hallmarks of P2P networks is the ability for nodes to join and leave dynamically.
- Goals:
  - No data is lost. This requires:
    - Each node's successor is correctly maintained.
    - For each key $k$, $successor(k)$ is responsible for $k$.
  - For the network to be efficient, finger tables must also be updated.



# Node Joining

- To simplify things, let's assume that every node knows the node before it (its predecessor) in the ring.
  - (It can find this by searching for the next smallest key with $O(logN)$ messages)
- When a new node $n^*$ joins the network, the following things must happen:
  - Its predecessor pointer and finger table are initialized.
  - Other nodes' predecessor pointers and finger tables are updated as necessary.



# Node Joining

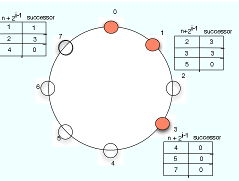
- When node $n^*$ wants to join the network, it contacts some other node $j$ that it already knows about.
- It asks $j$ to find its predecessor and fill in its finger table by looking up each of the values.
- As a practical optimization, start with the finger table of $n^*$'s immediate successor.



# Node joining

- We may also need to update the finger tables of other nodes.
  - Example: If we added a node 6 in our example, we would need to update the finger tables of nodes 2 and 3.
- For each node $a$ in the network, our new node $n^*$ will become the $i$th finger of $a$ if:
  - $a + 2^{i-1} < n^*$
  - the $i$th finger of $a$ succeeds $n^*$
- Start with the predecessor of $n^*$ and works "backwards"

## Example




- for i = 1 to 3 :
  - find the predecessor of $n^* - 2^{i-1}$
  - update finger table - recurse if necessary.
- Add 6.
  - Update entry 1 of 3.
  - Update entry 2 of 3.
  - Update entry 3 of 0 and 1.



## Node Joining

- Updating all finger tables takes $O(log^2 n)$ messages.
- Lastly, all data for which node $n^*$ is the successor must be transferred to $n^*$.
  - What this means may depend on the application.
- Note that this means that nodes do not have complete control over what they store.



## Stabilizing

- While the network is being updated, other nodes may also be joining or issuing queries.
- The basic Chord algorithm may fail if a query is done before successors are updated or keys are transferred.
- This can be corrected by occasionally having each node run a stabilize algorithm.



## Stabilizing

- On joining:
  - Find your successor and stop.
- Periodically, each node runs stabilize:
  - Find successor.
  - Find successor's predecessor - should we be that node's successor?
  - If so, update its finger table.
- This will allow the network to survive simultaneous joins.



## Failure

- To deal with failure, have each node keep a list of its $r$ first successors.
- If you notice your successor has failed, replace it with the first live successor in the list.
- We can also use this to replicate data by storing a copy of each key at each of the $r$ successors.



## Discussion

- DHTs provide a way to store and retrieve data in a P2P setting.
- Assumptions are different than in unstructured file-sharing networks:
  - Node may only join in specific places in the network
  - Nodes agree to allow foreign data to be stored on them.
  - All nodes have the same functionality and requirements.

# Summary

- DHTs provide a P2P-like abstraction
- Chord uses a 1D keyspace to connect peers in a logical ring.
- Finger tables provide efficient routing.
- Can tolerate dynamic join/leave and failure.



# Next Time

- CAN vs Chord
- Coral
- Overlay networks - routing based on content.