Chord : A Scalable Peer-to-Peer Lookup Protocol for Internet Applications

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One slide Summary

Problem

In a *peer-to-peer* network, how does one *efficiently* locate a node which is storing a desired data item?

Solution

Chord: A *scalable*, *distributed* protocol which efficiently locates the desired node in such a *dynamic* network.

Other efforts in the same direction

DNS

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2. DNS requires manual management of NS records. Chord auto-corrects routing information.
3. DNS works best when hostnames are structured to reflect administrative boundaries. Chord imposes no naming structure.

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Napster, Gnutella, DC++

1. Napster & DC++ use a central index. This leads to a single point of failure.
2. Gnutella floods the entire network with each query.
3. No *keyword* search in Chord. Only unique Ids.

Content Addressable Network (CAN)

Problem Identification

Scalability Bottleneck :- Centralized hash table

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Key Facts

- Info maintained by each node is indepedent of N
- How does one fix *d*?

CHORD : Design Requirements

Network Assumptions

1. **Symmetric:-** If $A \rightarrow B$, then $B \rightarrow A$
2. **Trasitive:-** If $A \rightarrow B$ and $B \rightarrow C$ then $A \rightarrow C$

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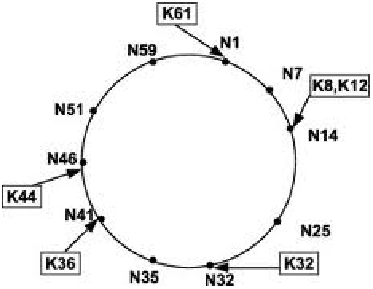
4. **Availibility :-** Handles most network failures.
5. **Flexible naming :-** Flat and unstructured key space.

The big picture

Consistent Hashing

How do you do it?

1. Assign an *m bit identifier* to each node and key separately.
2. Use SHA-1 to ensure keys are evenly distributed.
3. **Chord ring:-** a 2^m identifier circle.



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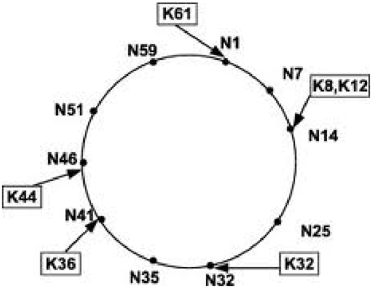

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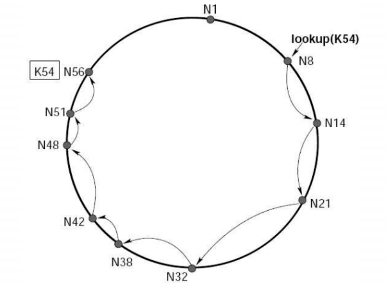
Theorem

1. Each node responsible for $(1+\epsilon)K/N$ keys
2. Only $O(K/N)$ keys change hands when $(N+1)^{st}$ node joins/leaves.

Naive Key Lookup

Naive



Algorithm

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

Performance

$O(N)$

Scalable Key Lookup

- **Finger Table :-** m entries, only $O(log(N))$ are distinct
- i^{th} entry $=$ *first* node that succeeds the current node by atleast 2^{i-1} on the identifier circle.
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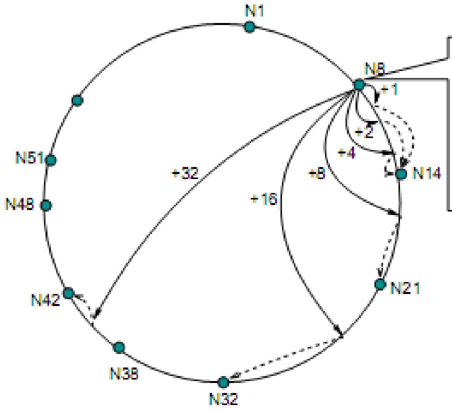
Important Observations

1. Each nodes stores a small amount of info.
2. Each node, knows more about closer nodes than far off ones.
3. A node's finger table does not contain enough info to directly find the successor of any arbitrary node k.

Sample Finger Table

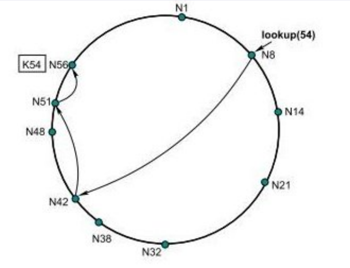


Finger table

N8 + 1	N14
N8 + 2	N14
N8 + 4	N14
N8 + 8	N21
N8 +16	N32
N8 +32	N42

The Lookup Algorithm

N8 looks up K54



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if(id \belongs (n,successor] )
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else
     n'=closest_preceding_node(id);
     return n'.find_successor(id);

//search the local table for the highest
//predecessor of id
n.closest_preceding_node(id)
     for i= m down to 1
     if (finger[i] \belongs (n,id))
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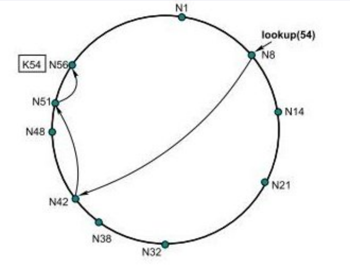

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Theorem

The no. of nodes which need to be contacted are $O(log(N))$

Node Join and Stabilization

- Every node periodically runs the *stabilize* algo to learn about newly joined nodes.
- The algo is, basically ask the successor for its predecessor p. Decide if p should be its successor.
- Thereby, the successor also gets a chance to check its predecessor.
- Each node periodically fixes its finger table by essentially reconstructing it.
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Theorem

If any sequence of join operations are interleaved with stabilize, *eventually*, the successor pointers will form a cycle on all nodes in the network.

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Case 1: Finger table entries are reasonably correct : Theorem

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Case 3: Successor pointers incorrect

Lookup will fail. The high level application can try again after a small pause. It will not take time for the successor pointers to get fixed.

Failure and Replication

- Invariant Assumed so far :- Each node knows its successor.
- To increase Robustness, maintain a *successor list* containing r successors.
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Modified closest preceding node

Search not just the finger table, but also the successor list for the most immediate successor of *id*

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Theorem

If we use a successor list of length $r = \Omega(log(N))$, in a network which is initially stable, and every node fails with probability 0.5, then with high probability *find_successor* returns the closes living successor to the query key.

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In a network which is initially stable, if every node fails with probability .5, then the expected time to execute *find_successor* is $O(log(N))$

Voluntary Node Departures

- Treating a departure as a node failure is rather wasteful.
- A node which is about to leave may transfer its keys to its successor as it departs.
- It can also notify its predecessor and successor before departing.
- The predecessor can remove the node from its successor list and add the last node in the *new* successor list to its own successor list.
- Similarly, the departing nodes successor can update its predecessor to reflect the departure.

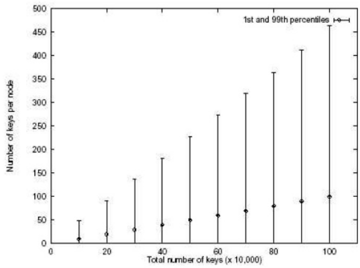
Simulation

Environment

- successor list size $= 1$
- when the predecessor of a node changes, it notifies its old predecessor about its new predecessor
- packet delay modelled with exponential distribution with meain 50ms.
- node declared dead if it does not respond within 500ms.
- not concerned with actual data. Lookup is considered successful if current successor has the desired key.

Load Balance

Without virtual nodes



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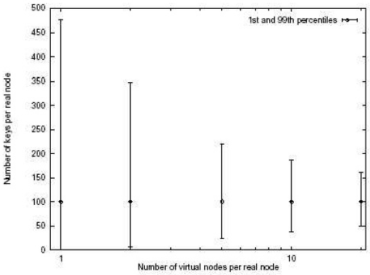
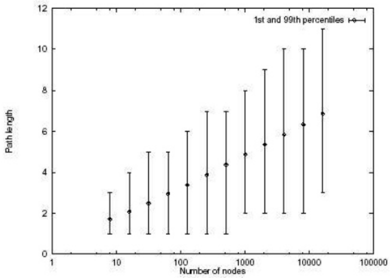


Parameter Settings

- No. of nodes $= 10^4$
- $10^5 \leq$ No. of keys $\leq 10^6$
- Increments of 10^5
- 20 runs per No. of keys

Path Length

- Node coount $= 2^k$
- Key count $= 100 * 2^k$
- $3 \leq k \leq 14$
- Picked a random set of keys
- Find query length



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Topologies

1. **3-d space:** The network distance is modeled as geometric distance in a 3-d space
2. **Transit stub:** A transit-stub topology with 5000 nodes. 50ms link latency for intra-transit domain links. 20ms, for transit-stub links and 1ms for intra-stub links

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Possible extensions

- Deal with network partitions
- Deal with adverserial/faulty nodes

Questions?