

Tapestry & Skip Graphs

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Tapestry

- Distributed data structure:
 - Maps keys to object locations (pointers)
 - Pointers are wide-area pointers (IP address, port number, etc.)
- Keys interpreted as a sequence of digits
 - Randomly generated
- Incremental suffix routing
 - Source to target route is accomplished by correcting one digit at a time
 - For instance: (to route from 0312 → 1643)
 - 0312 → 2173 → 3243 → 2643 → 1643
 - Each node has a routing table

Routing Table

- Size of routing table:
 - Number-levels * digit-range
- Some elements could be missing because of sparse id space
- Assume "n" nodes, octal digits:
 - For level 1, n/8 candidates for each entry
 - For level k, n/8^k candidates for each entry
 - When n=512, there is on average only one candidate for a level 3 neighbor
 - Holes filled with next higher/lower number
 - Degenerate case: self loops

Neighbor Map
For "5712" (Octal)

0712	x012	xx02	xxx0	
1712	x112	5712	xxx2	
2712	x212	xx22	5712	
3712	x312	xx32	xxx3	
4712	x412	xx42	xxx4	
5712	x512	xx52	xxx5	
6712	x612	xx62	xxx6	
7712	5712	xx72	xxx7	
	4	3	2	1

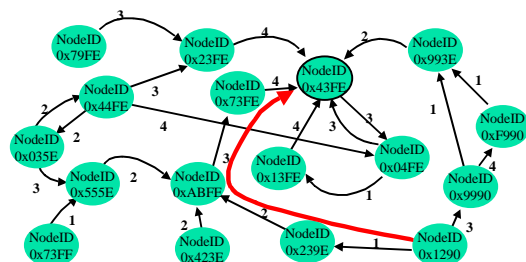
Routing Levels

Publishing

- Node X wants to publish an object O
 - Generates a key for O
 - Routes towards the key in the tapestry system starting with X
 - Deposits a pointer to "X:O" at every routing hop
 - These pointers can be discarded
 - Deposits a permanent pointer at the "root"
 - This pointer cannot be discarded
- Multiple copies of the object could be published at the same time
 - Each deposits pointers along its own trail
 - Trails intersect at the "root"
- Object can be updated without updating the pointers
- Unpublishing objects is hard

Publishing/Locating Objects

Node "1290" wants to publish "53FE"



Surrogate Routing

- In the example:
 - "43FE" is considered as the surrogate of "53FE"
- Surrogate is unique irrespective of which node you start searching from
 - As long as there is a consistent rule for finding the surrogate
 - Such as taking the next lower/higher entry in the routing table if the corresponding entry is missing
- System needs to guarantee that neighbor routing tables are kept consistent
 - If "73FE" is missing an entry at level 4 for digit "5"
 - Then "23FE" should also be missing an entry at level 4 for digit "5"

[illegible]

The graph illustrates the relationships between NodeIDs and NodeFEs. The nodes are labeled as follows:

- NodeID 0x79FE (green)
- NodeID 0x44FE (green)
- NodeID 0x35FE (green)
- NodeID 0x55FE (green)
- NodeID 0x73FE (green)
- NodeID 0x42FE (green)
- NodeID 0x73FE (yellow)
- NodeID 0x43FE (yellow)
- NodeID 0x13FE (yellow)
- NodeID 0xABFE (yellow)
- NodeID 0x239E (yellow)
- NodeID 0x43FE (yellow)
- NodeID 0x993FE (yellow)
- NodeID 0xF990 (yellow)
- NodeID 0x9990 (yellow)
- NodeID 0x1290 (yellow)

Edges are labeled with numbers 1 through 4. A red arrow highlights a specific path from NodeID 0x79FE to NodeID 0x43FE.

Locating Objects

Node *73FF* wants to find *53FE*

The diagram illustrates a network of nodes and their connections. The nodes are represented as circles with labels indicating their NodeID. The connections are represented by arrows, some of which are numbered. A red path highlights the search for NodeID 0x53FE.

Nodes and their connections (indicated by arrows and numbers):

- NodeID 0x79FE (yellow) connects to NodeID 0x43FE (yellow) with weight 4.
- NodeID 0x43FE (yellow) connects to NodeID 0x993F (green) with weight 2.
- NodeID 0x993F (green) connects to NodeID 0x9990 (green) with weight 1.
- NodeID 0x9990 (green) connects to NodeID 0x04FE (green) with weight 4.
- NodeID 0x04FE (green) connects to NodeID 0x13FE (green) with weight 1.
- NodeID 0x13FE (green) connects to NodeID 0xABFE (yellow) with weight 2.
- NodeID 0xABFE (yellow) connects to NodeID 0x239E (yellow) with weight 1.
- NodeID 0x239E (yellow) connects to NodeID 0x1290 (yellow) with weight 3.
- NodeID 0x1290 (yellow) connects to NodeID 0x73FE (green) with weight 1.
- NodeID 0x73FE (green) connects to NodeID 0x555E (yellow) with weight 3.
- NodeID 0x555E (yellow) connects to NodeID 0x43FE (yellow) with weight 4.
- NodeID 0x43FE (yellow) connects to NodeID 0x44FE (green) with weight 3.
- NodeID 0x44FE (green) connects to NodeID 0x035E (green) with weight 2.
- NodeID 0x035E (green) connects to NodeID 0x73FE (green) with weight 2.
- NodeID 0x73FE (green) connects to NodeID 0x53FE (yellow) with weight 4.

The red path highlights the search for NodeID 0x53FE, starting from NodeID 0x73FE (green) and ending at NodeID 0x53FE (yellow).

The graph consists of 12 nodes, each labeled with a NodeID and a hexadecimal value. The nodes are colored either yellow or teal. The edges are directed and labeled with numbers 1 through 4. A red path highlights a specific sequence of nodes: NodeID 0x0335E, NodeID 0x5555E, NodeID 0xABFF, NodeID 0x13FF, and NodeID 0x1290.

```

graph TD
    N1((NodeID 0x79FE)) -- 3 --> N2((NodeID 0x23FE))
    N2 -- 4 --> N3((NodeID 0x43FE))
    N3 -- 2 --> N4((NodeID 0x993E))
    N4 -- 1 --> N5((NodeID 0xF990))
    N5 -- 4 --> N6((NodeID 0x9990))
    N6 -- 3 --> N7((NodeID 0x1290))
    N7 -- 1 --> N8((NodeID 0x239E))
    N8 -- 2 --> N9((NodeID 0x423E))
    N9 -- 1 --> N10((NodeID 0x73FE))
    N10 -- 3 --> N11((NodeID 0x0335E))
    N11 -- 2 --> N12((NodeID 0x5555E))
    N12 -- 4 --> N13((NodeID 0xABFF))
    N13 -- 3 --> N14((NodeID 0x73FE))
    N13 -- 4 --> N15((NodeID 0x13FF))
    N15 -- 1 --> N16((NodeID 0x04FE))
    N16 -- 3 --> N3
    N16 -- 4 --> N17((NodeID 0x73FE))
    N17 -- 3 --> N2
    N17 -- 4 --> N3
  
```

Tapestry Routing Table

- Routing table is optimized to reflect locality
- For instance, consider level 2 for "0234":
 - Let's say we have two candidates for an entry:
1204, 2704
 - Pick the closest one based on round-trip latency
- Also can have backup entries:
 - Improves fault-tolerance

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Node addition


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DHT Wrap-up: Common Properties

- Underlying **metric space**.
- Nodes embedded in metric space.
- Location determined by key.
- **Hashing** to balance load.
- Greedy routing.
- $O(\log n)$ space at each node.
- $O(\log n)$ routing time.

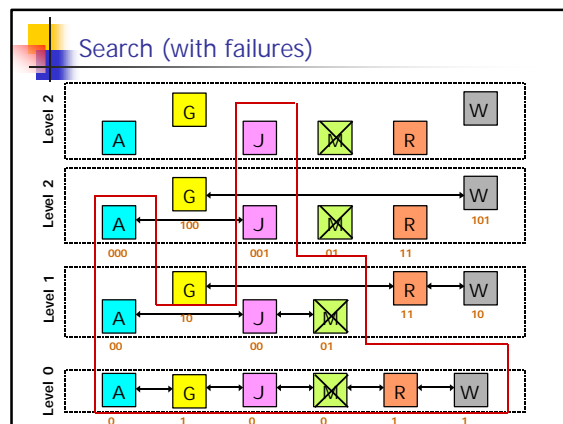
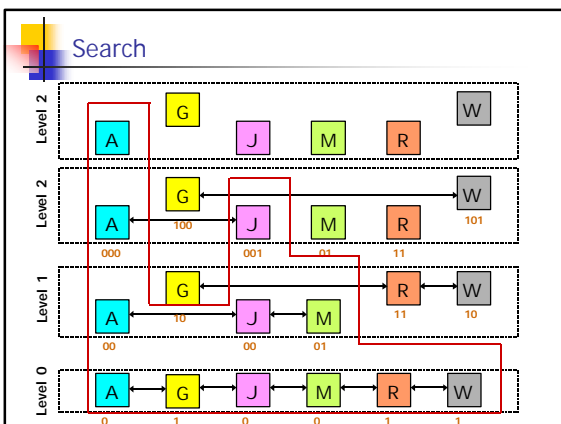
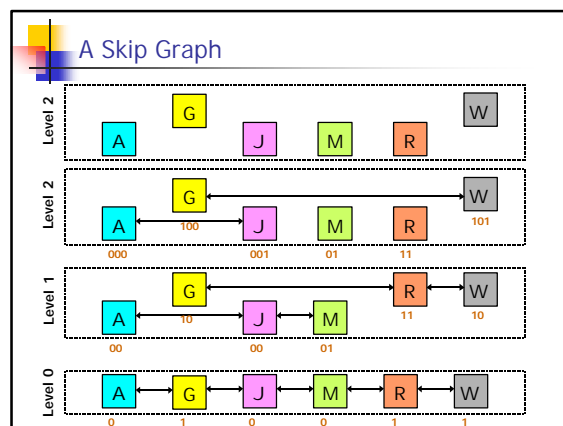
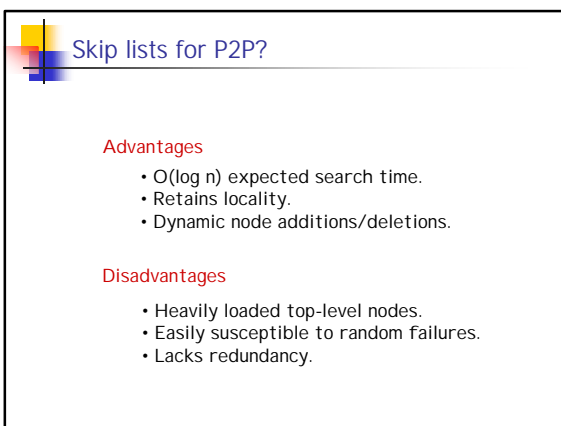
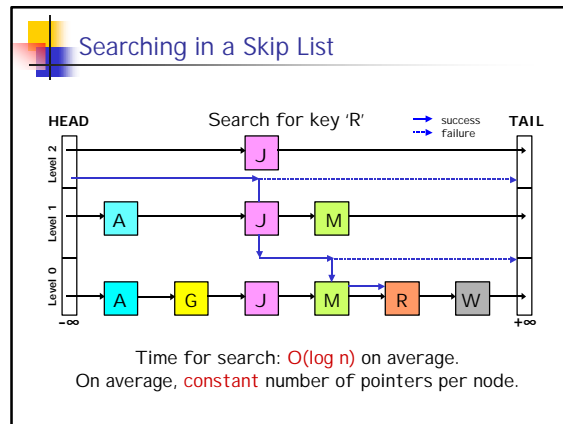
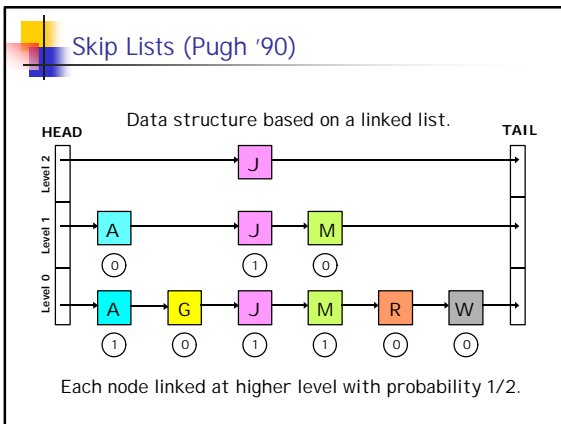
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Announcements

- Begin discussing routing algorithms for Internet/wireless networks on Wednesday
- Friday: guest lecture by Richard Yang
 - Performance of "Selfish routing"

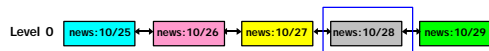
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Locality and range queries

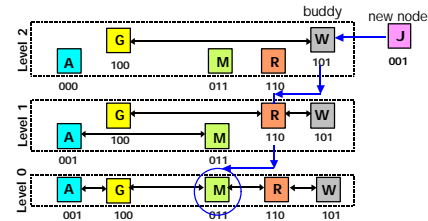
- Find key $< F, > F$.
- Find largest key $< x$.
- Find least key $> x$.
- Find all keys in interval $[D..O]$.

Example: find latest news from yesterday.
 → find largest key $< \text{news:10/29}$.



DHTs cannot do this easily since hashing destroys locality.

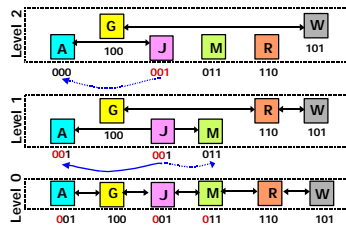
Node Insertion



Starting at buddy node, find nearest key at level 0.
 Basically a range query looking for key closest to new key.
 Takes $O(\log n)$ on average.

Node Insertion (contd.)

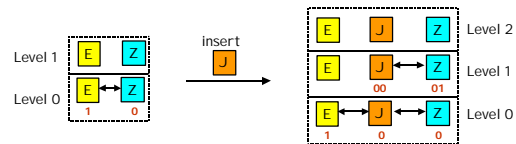
At each level i , find nearest node with matching prefix of membership vector of length $i+1$.



Total time for insertion: $O(\log n)$
 DHTs take: $O(\log^2 n)$

Independent of system size

No need to know size of keyspace or number of nodes.



Old nodes extend membership vector as required with arrivals.
 DHTs require knowledge of keyspace size initially.

Skip Graphs: Discussion

- Virtual to physical node mapping is definitely an issue
- Could use random mapping to guarantee load balance
 - Note that this does not destroy the ability to perform range queries
 - Destroys geographical locality
- State is larger than DHTs:
 - DHT state: $O(\log n)$ per node where n is number of nodes
 - Skip graph state: $O(\log n)$ per virtual node (with n being number of objects)