# Overlays and DHTs

Ashish Vulimiri and Liangliang Cao

# Overlays and DHTs

- Discussion on overlay
  - "Resilient Overlay Networks" by D. Andersen, H. Balakrishnan, F. Kaashoek, R. Morris

- Review and compare different DHT algorithms
  - Pastry
  - CAN
  - Kelips

# PART I
# Resilient Overlay Networks

D. Andersen, H. Balakrishnan, F. Kaashoek, R. Morris

# Motivation

- BGP strategy: simplify, summarize, aggregate, propagate
- Great for scalability, but causes problems
  - Loss of policy constraints
  - Performance issues
- Besides, network might not even know what to optimize for
  - Different applications have different priorities

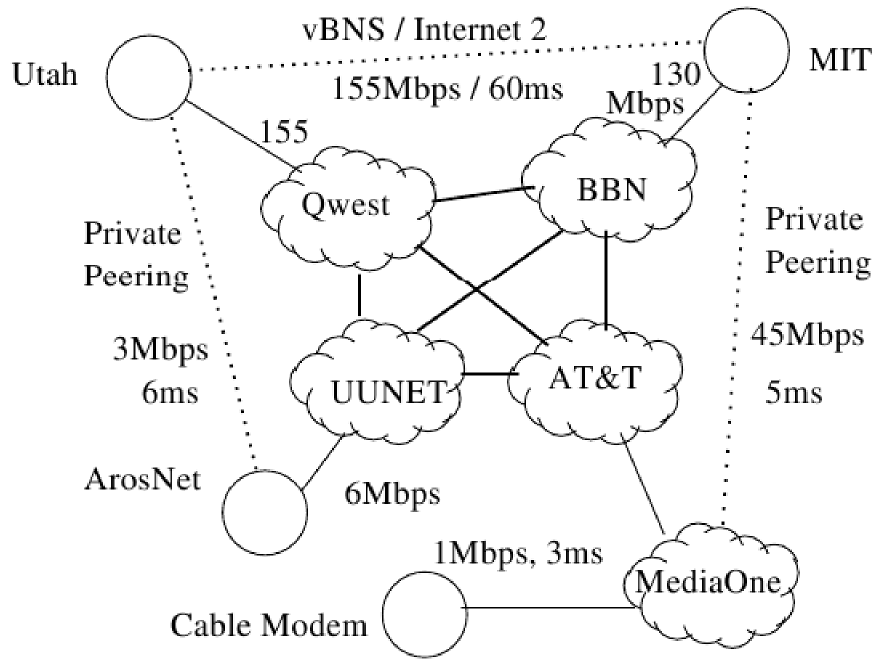
# Goals (as stated)

- Fast failure detection and recovery
  - On the order of seconds instead of minutes
- Tighter integration with applications
  - Let applications choose their performance metrics
- Expressive policy routing
  - Fine grained policy control

# Basic Idea

- Establish overlay over Internet
- Nodes broadcast information, run link state protocol
- Why does this help?
  - Built-in redundancy in Internet paths
    - Not all of it exposed due to policy constraints

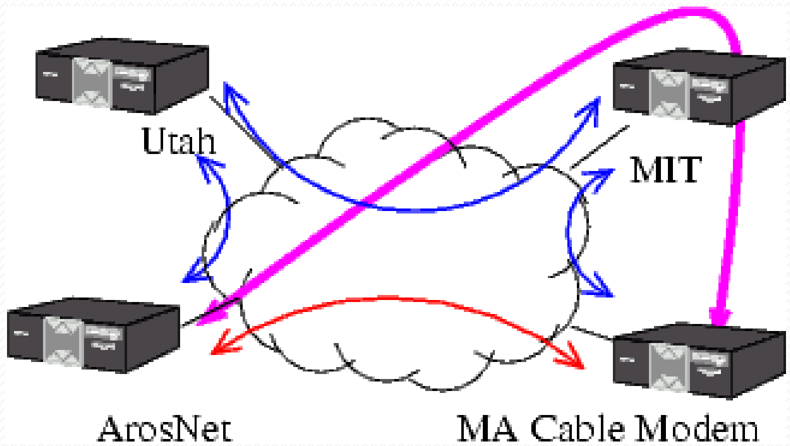
# Basic Idea


vBNS / Internet 2
155Mbps / 60ms
Utah
MIT
130
Mbps
155
Qwest
BBN
Private
Peering
Private
Peering
3Mbps
6ms
UUNET
AT&T
45Mbps
5ms
AroseNet
6Mbps
1Mbps, 3ms
MediaOne
Cable Modem

# Basic Idea

- Establish overlay over Internet
- Nodes broadcast information, run link state protocol
- Why does this help?
  - Built-in redundancy in Internet paths
    - Not all of it exposed due to policy constraints
  - BGP is not purely adaptive in nature; triangle inequality does not hold
    - There may be a node B such that the path AB-BC is actually better than the direct path AC

# Basic Idea



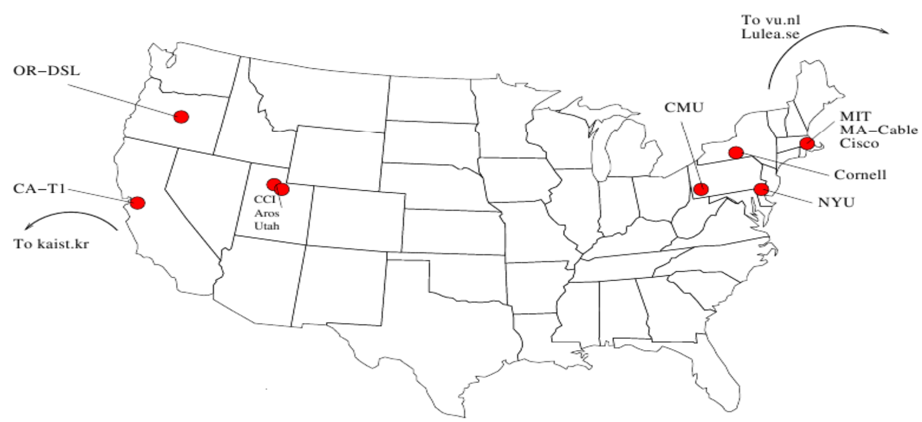
# Details

- Policy
  - Use policy tag on each packet. Policy can depend on value of any part of packet (deep packet inspection)
- Performance – use probe information as input to:
  - Loss rate optimizer
    - p = Loss rate in last 100 samples
  - Latency optimizer
    - lat(i) = (1 – α) lat(i-1) + (α) sample(i) [they take α = 0.9]
  - Throughput optimizer

$$score = \frac{\sqrt{1.5}}{rtt \cdot \sqrt{p}}$$

# Experimental Results

- Two datasets
  - RON1: 12 nodes, 64 hours, Mar 2001
  - RON2: 16 nodes, 85 hours, May 2001



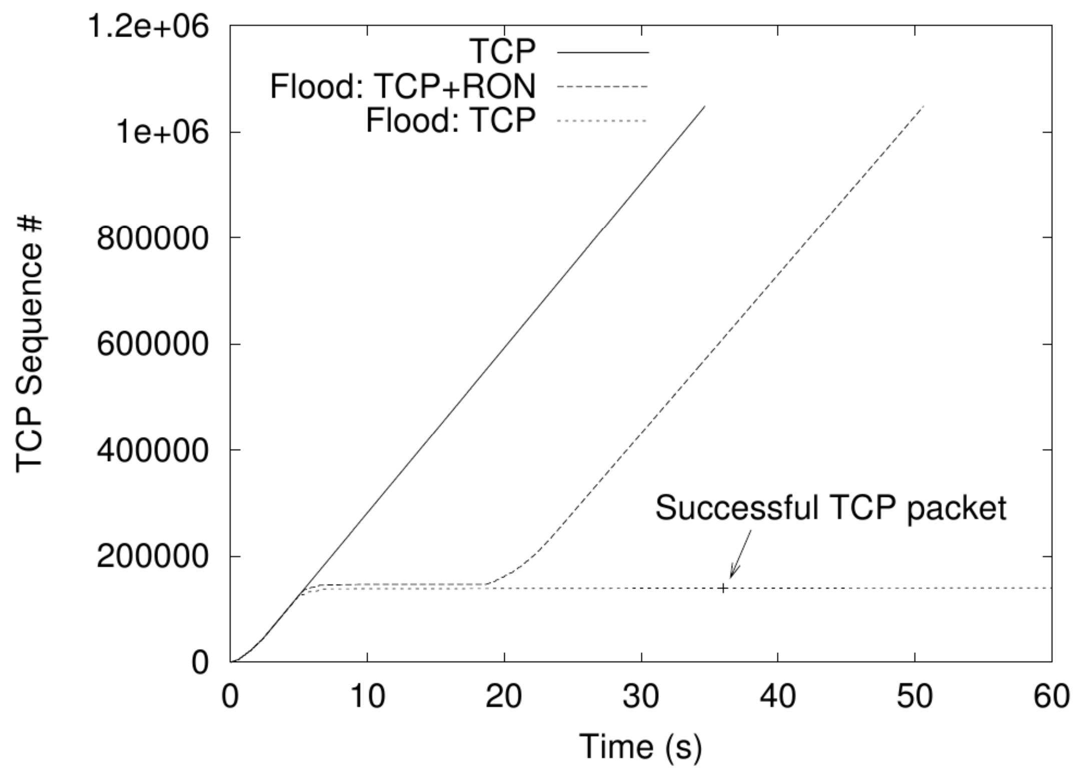

- Loss rate, latency, throughput, convergence time

# Experimental Results: Summary

- Loss rate
  - RON1: Always ensured loss rate was < 30%; Internet did not. For lower loss rates, RON still generally better
  - RON2: RON better, but less dramatic
- Latency:
  - Better by tens/hundreds of ms. Better by >40ms on 11% of paths
  - Worse in some cases due to overhead
- Bandwidth:
  - 1st %ile: 50% degradation
  - 50th %ile: no change
  - 95th %ile: 100% improvement

# Convergence Time

More preferred path is artificially flooded at T=5s. RON switches to alternate path in 15s. BGP: flooding != failure.



# Discussion I

- Authors listed three goals earlier. How well did they do?
- Expressive policy routing
  - Nice solution, but overlay may not be the place for this. Lot of recent research about pushing it into network
- Fast failure detection and recovery
  - Again, …
- Tighter integration with applications
  - This is the key take-away from this paper
- Comments?

# Discussion II

- Why link state? Why not distance vector?
  - SRON [CoNEXT 2009]: $O(n\sqrt{n})$ communication cost instead of $O(n^2)$ – uses a quorum system
- RON is closer to application layer than BGP, yet no congestion control – problem?
- What happens if you have multiple parallel overlays?
  - Routing underlay

# PART II: DHTs

- Overview
- Pastry
- CAN
- Kelips
- Experiments and Discussions

# Overview: Distributed hash tables

- Hash tables
  - essential building block in software systems

- Internet-scale distributed hash tables
  - peer-to-peer systems
    - Napster, Gnutella, FreeNet, …
  - large-scale storage management systems
    - OceanStore (on PlanetLab), PAST, CFS …
  - mirroring on the Web

# Overview: Distributed hash tables

- Idea is to support a simple index with API:
  - Insert(key, value) – saves (key,value) tuple
  - Lookup(key) – looks up key and returns value
  - The (key,value) pairs might tell us *where to look for something* but probably not *the actual thing*
- Comparison with classical hash table:
  - Implement it in a p2p network, not a server
  - Each p2p client has just part of the tuples, hence must route query to the right place

# Recap

- We saw three information location mechanisms:
  - Napster, Gnutella, Chord
- Chord:
  - Hash *node_id* and *key* into same circular keyspace
  - Store *value* for *key* *k* in the node with *node_id* as small as possible while still larger than *k*
- We saw details about how *key*s are actually located, how the network is formed etc

# Summarize

| | Memory | Messages exchanged |
|---|---|---|
| Napster | O(1)<br>(O(N) at server) | O(1) |
| Gnutella | O(N) | O(N) |
| Chord | O(log(N)) | O(log(N)) |
| Pastry | $O(\log(N)/\log(2^b) \times [2^b-1])$ | $O(\log(N)/\log(2^b))$ |
| CAN | O(d) | $O(dn^{1/d})$ |
| Kelips | O(sqrt(N)) | O(1) |

# Pastry: Scalable, decentralized object location and routing for large-scale peer-to-peer systems

A. Rowstron and P. Druschel

# Pastry

- Somewhat similar to Chord – same 128-bit circular keyspace
  - Same hash algorithm (SHA-1) is recommended in both papers
- Differences:
  - Algorithm: Chord uses binary search, Pastry uses radix search
  - Pastry tries to take advantage of locality information

# Routing in Pastry

- All ids are treated as base-$2^b$ numbers (e.g. if b = 4, all ids are treated as hexadecimal numbers)
- Assume network has N nodes
- In each routing step, goal is to forward message to a node whose id is one digit closer to destination's than current node's
- Each node maintains three data structures to help decide where to forward

# Routing in Pastry

- Let D be nodeId of current node
- Two data structures mostly related to routing:
  - **Routing Table (R)**: Each row has $(2^b - 1)$ entries. Each entry in nth row has first n digits same as in D, but (n+1)th digit different from D's.
  - **Leaf Set (L)**: List of nodes with ids closest to D. Half the nodes have id larger than D, other half have smaller id
- Another data structure
  - **Neighbourhood set (M)**: List of nodes closest (most proximate) to D. Mostly used for maintaining locality

# NodeId 10233102

**Leaf set**

| SMALLER | | LARGER | |
|---|---|---|---|
| 10233033 | 10233021 | 10233120 | 10233122 |
| 10233001 | 10233000 | 10233230 | 10233232 |

**Routing table**

| | | | |
|---|---|---|---|
| -0-2212102 | 1 | -2-2301203 | -3-1203203 |
| 0 | 1-1-301233 | 1-2-230203 | 1-3-021022 |
| 10-0-31203 | 10-1-32102 | 2 | 10-3-23302 |
| 102-0-0230 | 102-1-1302 | 102-2-2302 | 3 |
| 1023-0-322 | 1023-1-000 | 1023-2-121 | 3 |
| 10233-0-01 | 1 | 10233-2-32 | |
| 0 | | 102331-2-0 | |
| | | 2 | |

**Neighborhood set**

| | | | |
|---|---|---|---|
| 13021022 | 10200230 | 11301233 | 31301233 |
| 02212102 | 22301203 | 31203203 | 33213321 |

# Routing Algorithm

- Suppose node A receives query with key D
- Case I:
  - If D lies in the range of L, deliver D to the node in L with closest nodeId
- Otherwise: Check R for the entry that is one digit closer to D than A
- Case II:
  - If the entry is not null, forward query to that node
- Case III:
  - Otherwise, find the nodeId in L, R, or M that is closest to D, and forward to that node

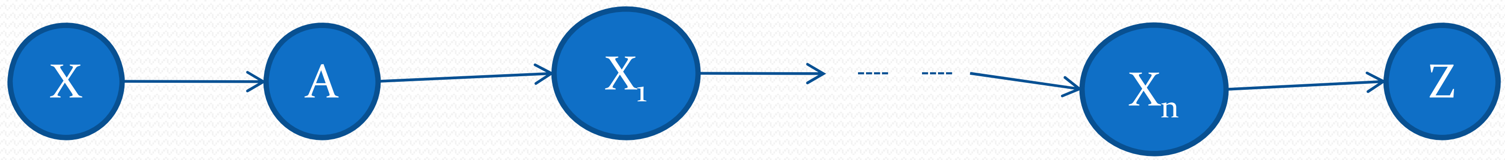
# Analysis

- Case I leads to query termination
- Case II moves the search one digit forward
- Case III is the only problematic one
- Case III is infrequent: probability is 0.6% when $|L| = (2.\ 2^b)$
- Query time is still O(log(N)) when no failures
  - Authors experimentally demonstrate graceful degradation in presence of failures

# Node Arrival

- Assume any node X wanting to join the DHT knows a proximate neighbour A already in the DHT
- X sends a query to A with its own nodeId
- Query returns Z, the node already in the DHT whose id is closest to that of X
- Suppose query path is X-A-X1-X2-…-Xm-Z

# Node Arrival




- X sets:
  - M from M of A (because of proximity)
  - L from L of Z (because nodeIds are close)
  - R values from rows in the Xi nodes (because search process proceeds digit –by –digit, as we saw earlier)
- After constructing all the sets, X sends update notifications to all the nodes in the sets
- Can be shown that this method of joining does not impact locality properties

# Node Departure

- Neighbourhood set is actively kept current
- Node failures are detected in other two sets only when attempt is made to contact them
- Updating the sets in event of a failure:
  - M: Request neighbour lists from the nodes still in M
  - L: Ask node in L with highest (or lowest, as necessary) remaining nodeId for a successor (or predecessor)
  - R: Iterate through the table R, starting from the row containing the failure, and ask the nodes for a replacement until one is found

# Summary

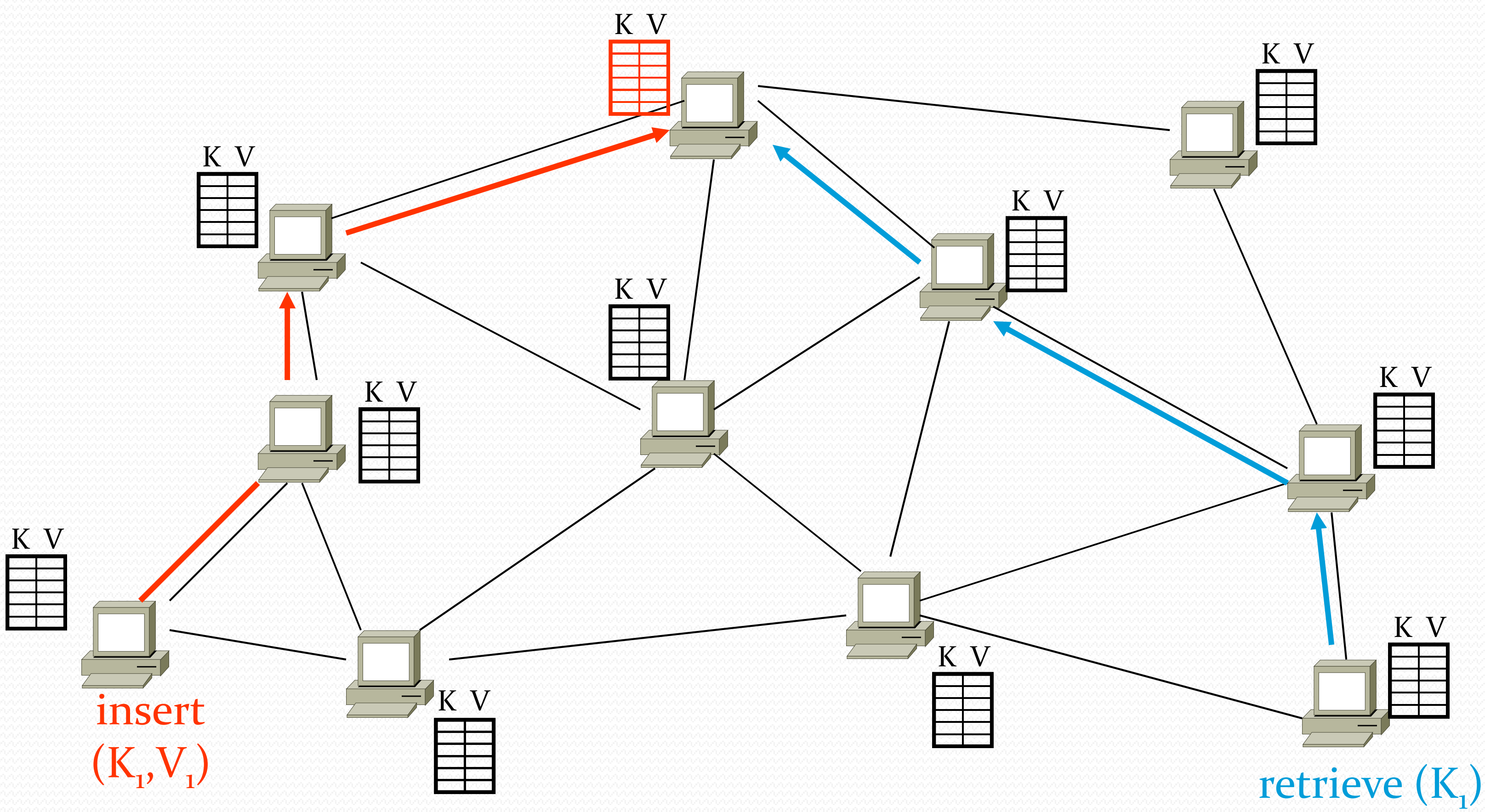
- Pastry: similar to Chord
- Asymptotically similar memory and message complexity
  - But with a potentially smaller constant, depending on b
- Also tries to take advantage of locality information

# A Scalable, Content-Addressable Network

Sylvia Ratnasamy , Paul Francis, Mark Handley , Richard Karp , Scott Shenker
Berkeley, AT&T

Some figures are courtesy to Ratnasamy

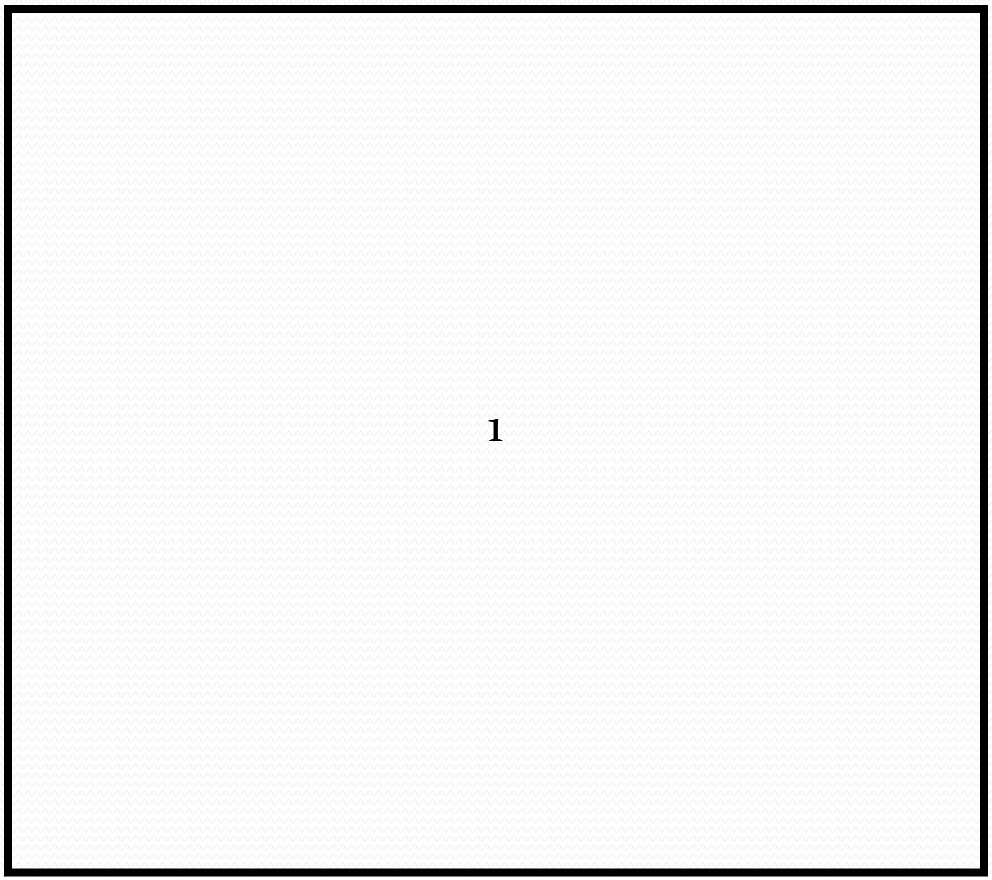
# CAN: basic idea



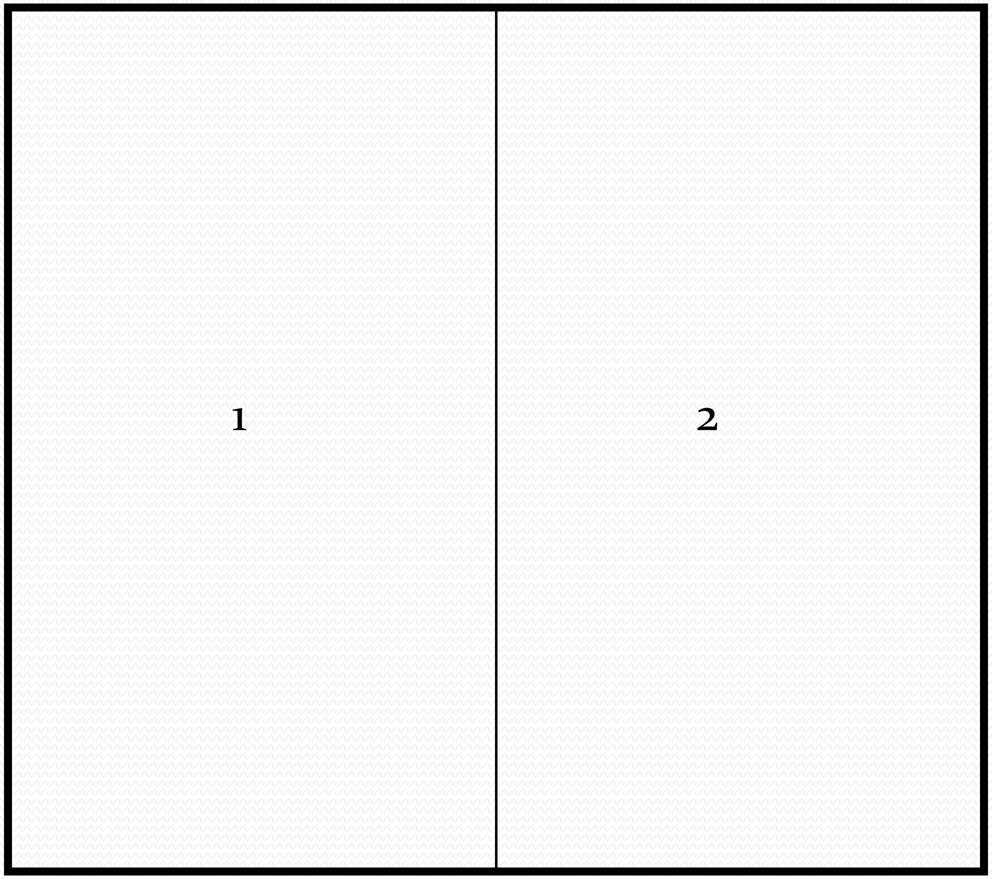
# CAN: basic ideas

- virtual Cartesian coordinate space
- entire space is partitioned amongst all the nodes
  - every node "owns" a zone in the overall space
- nodes only maintain state for their immediate neighbors

# CAN: simple example



# CAN: simple example



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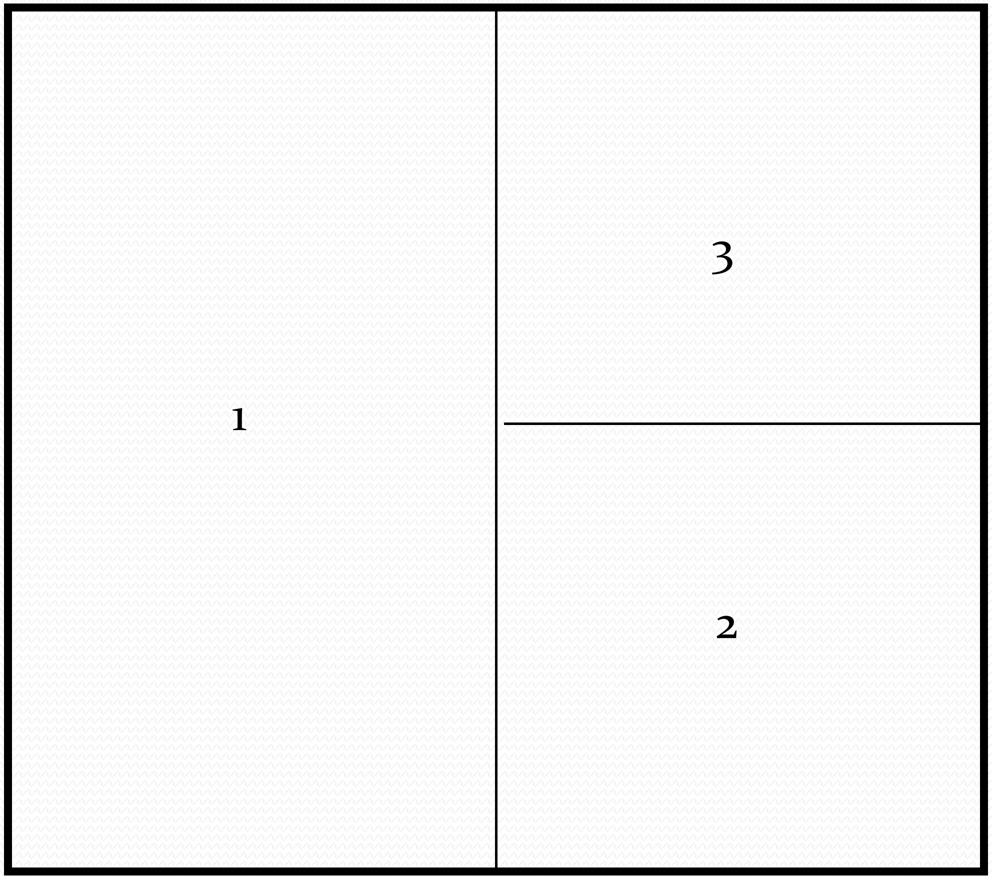

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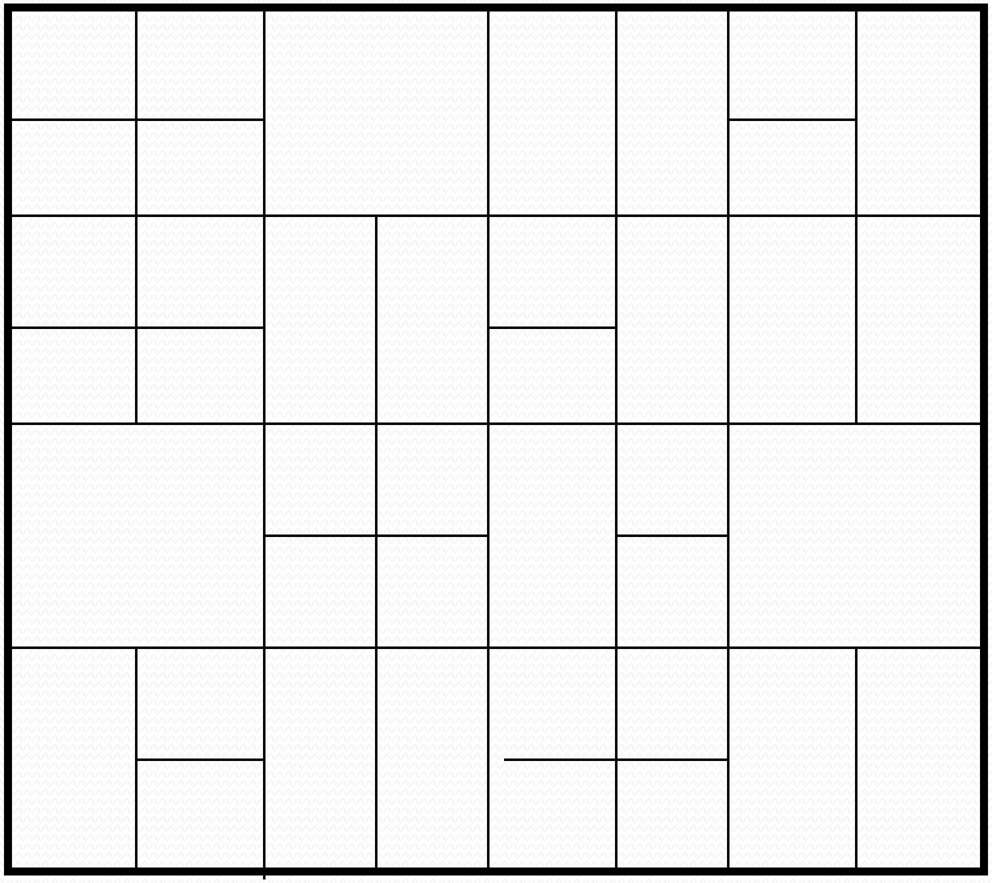

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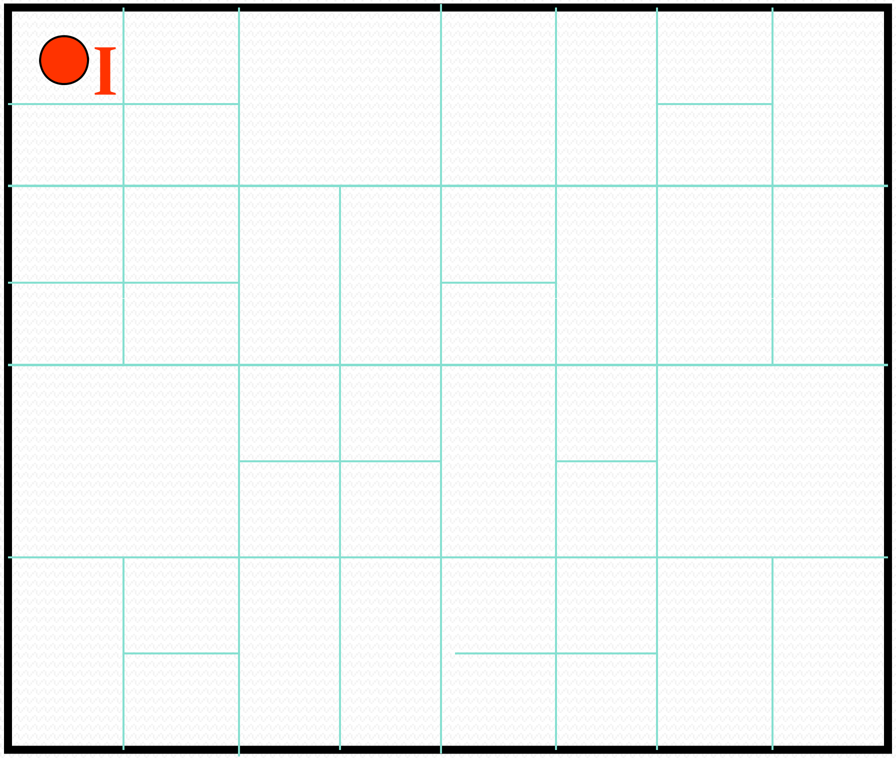
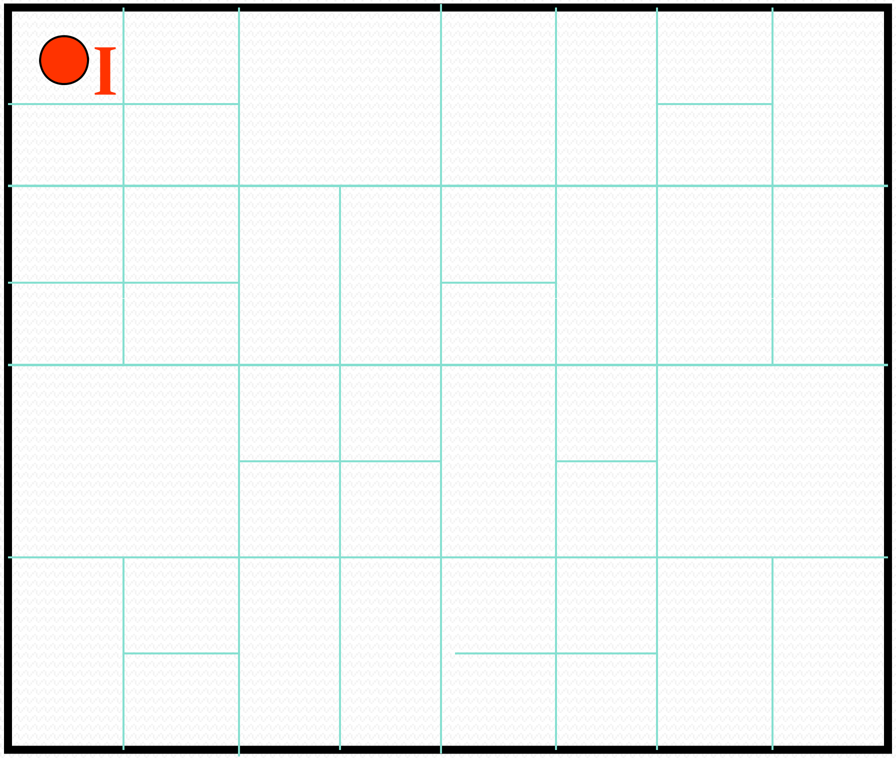


# CAN: simple example

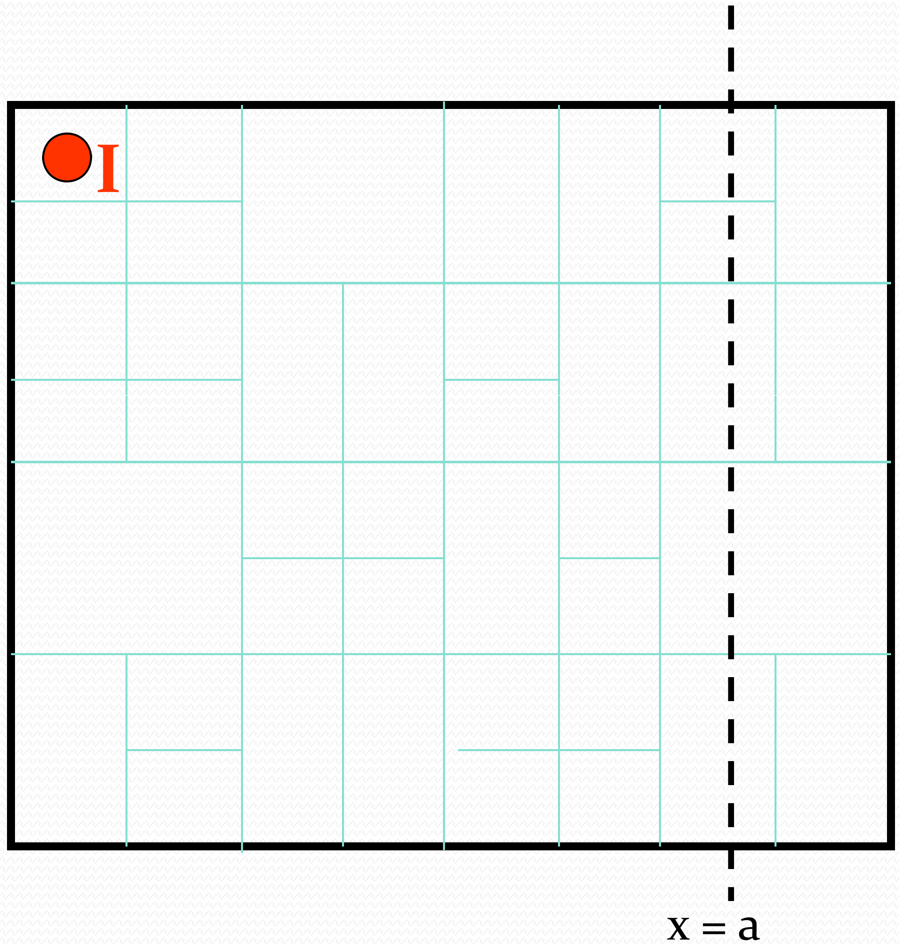
node I::insert(K,V)



# CAN: simple example

node I::insert(K,V)

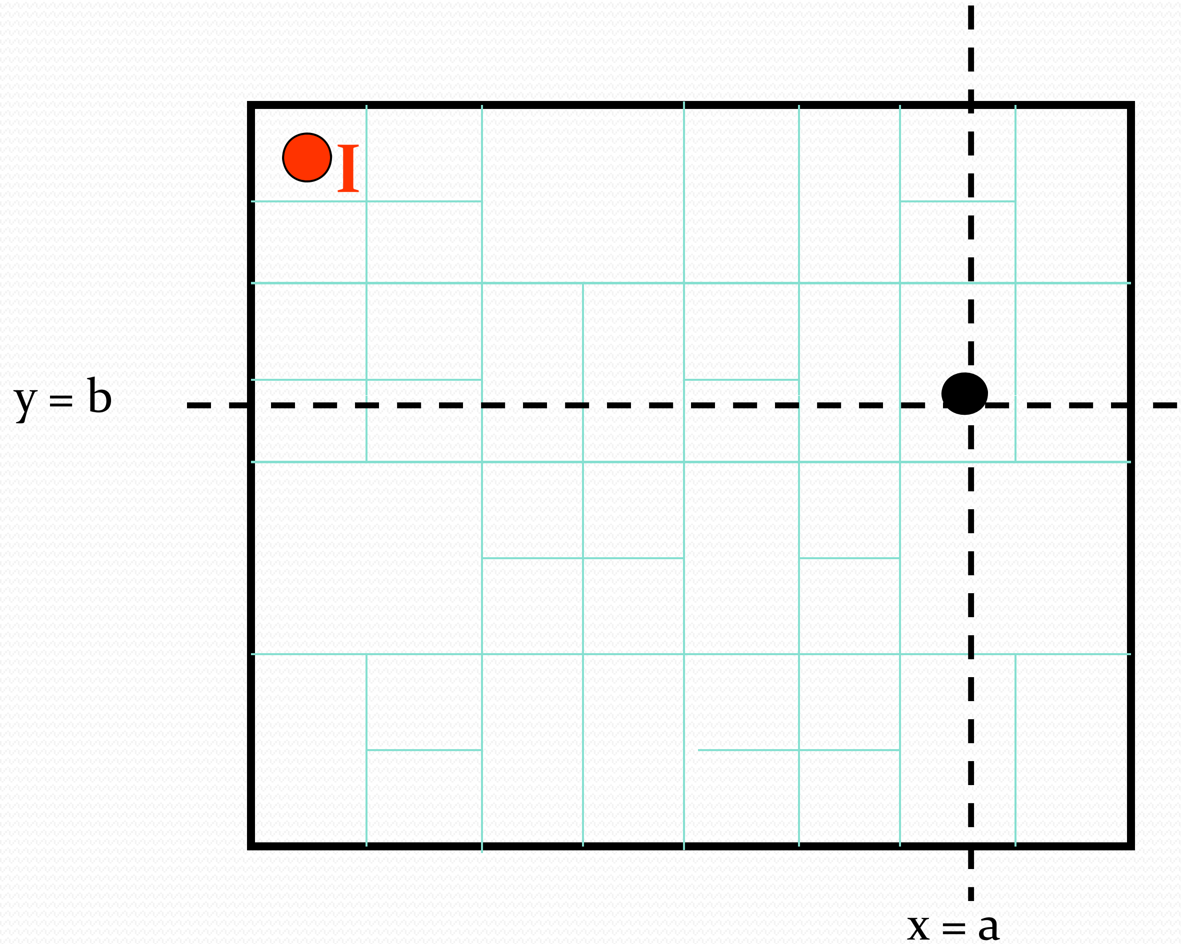
(1) $a = h_x(K)$



# CAN: simple example

node I::insert(K,V)

(1) $a = h_x(K)$
$b = h_y(K)$

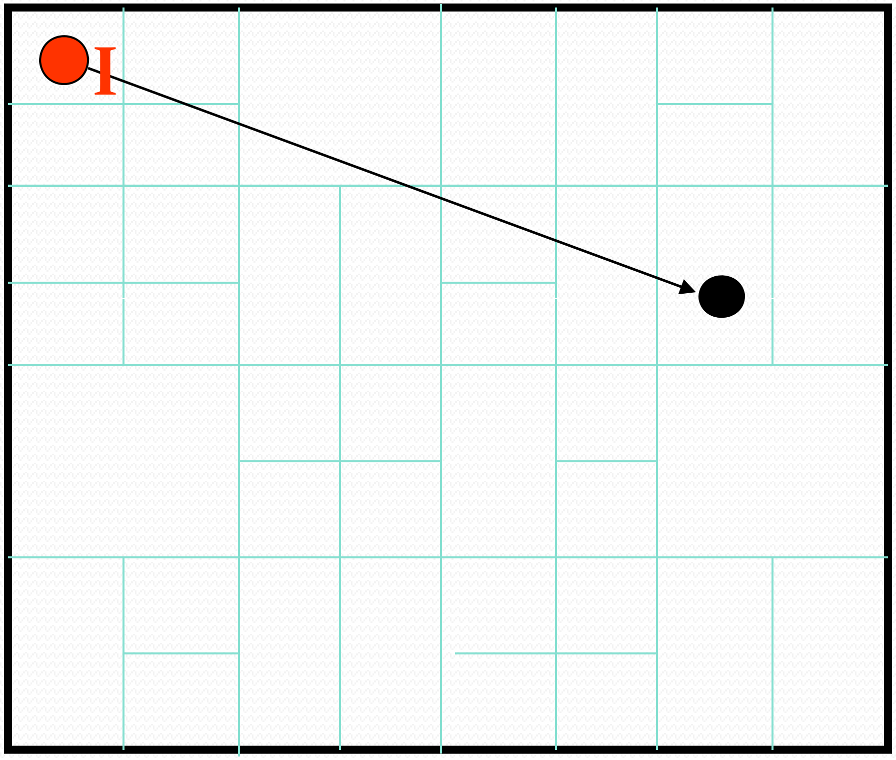


# CAN: simple example

node I::insert(K,V)

(1) $a = h_x(K)$
$b = h_y(K)$

(2) route(K,V) -> (a,b)



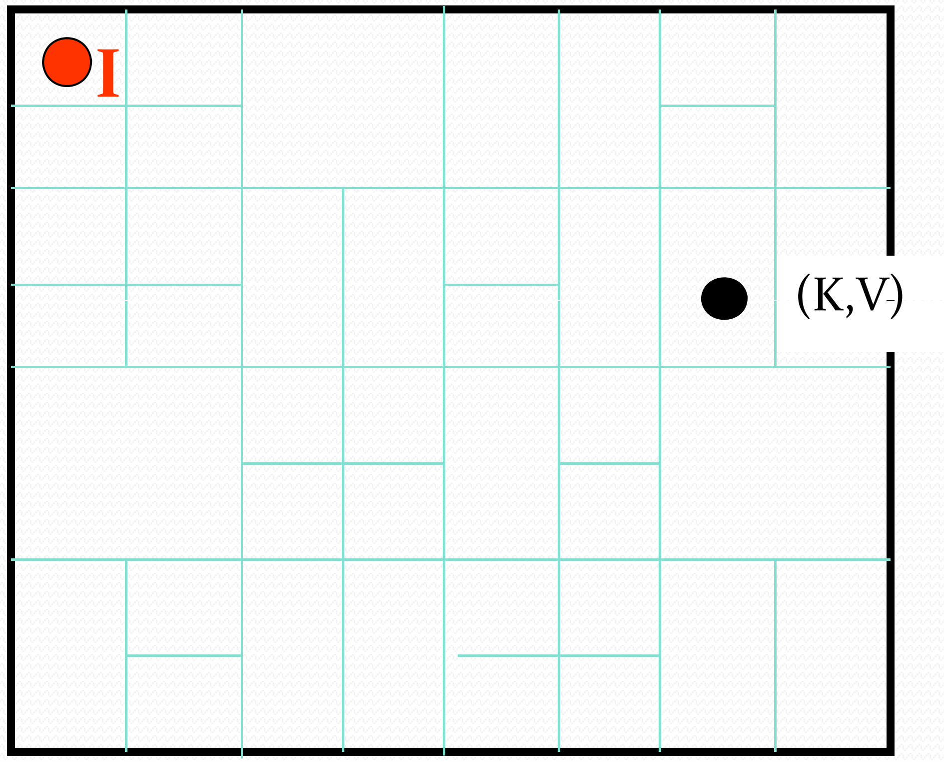
# CAN: simple example

node I::insert(K,V)

(1) $a = h_x(K)$
$b = h_y(K)$

(2) route(K,V) -> (a,b)

(3) (a,b) stores (K,V)

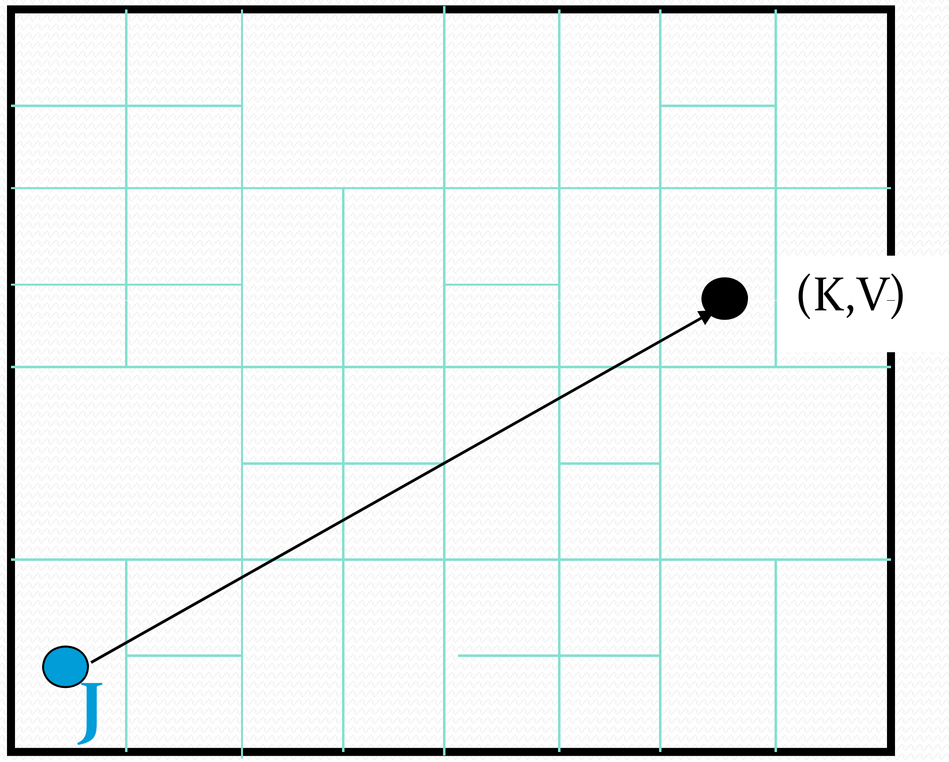


# CAN: simple example

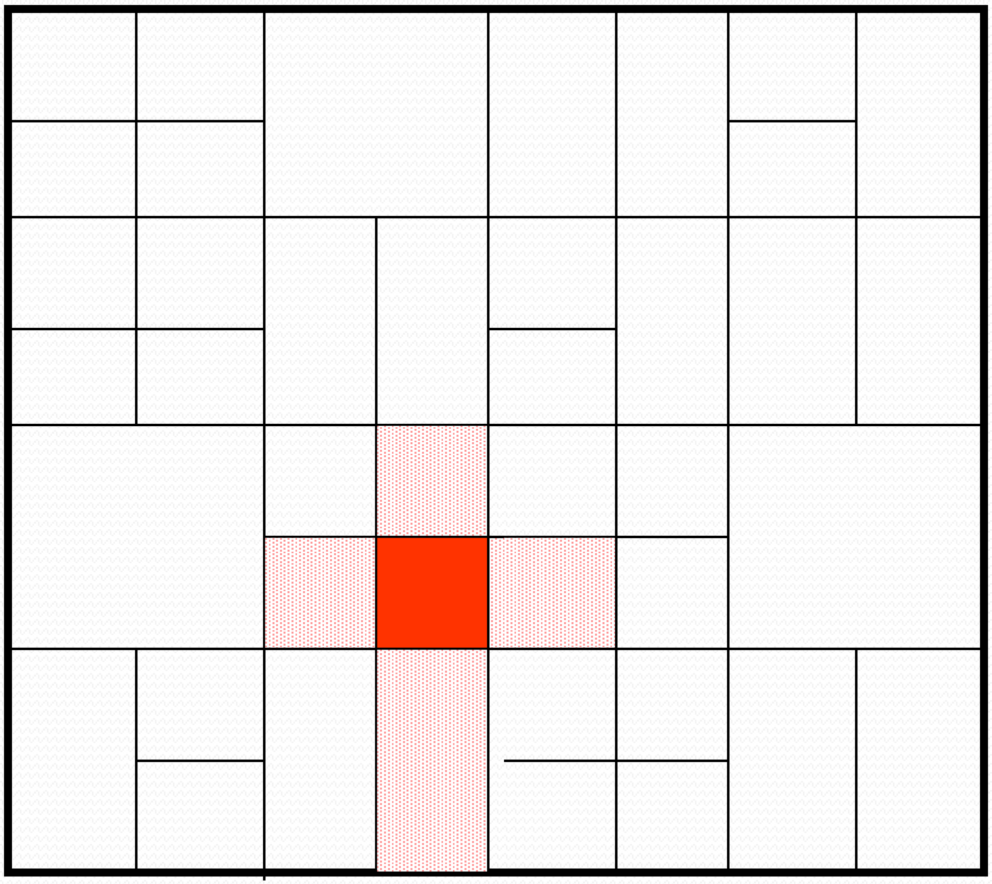
node J::retrieve(K)

(1) $a = h_x(K)$
$b = h_y(K)$

(2) route "retrieve(K)" to (a,b)

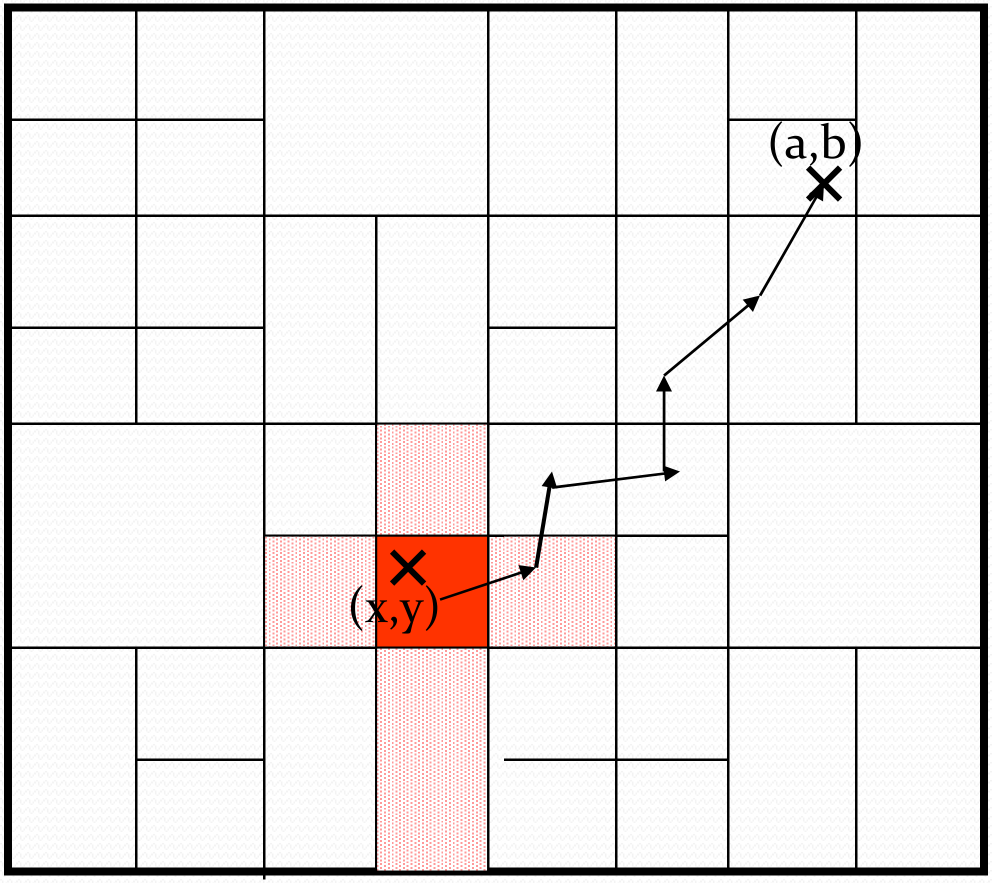


# CAN: routing table

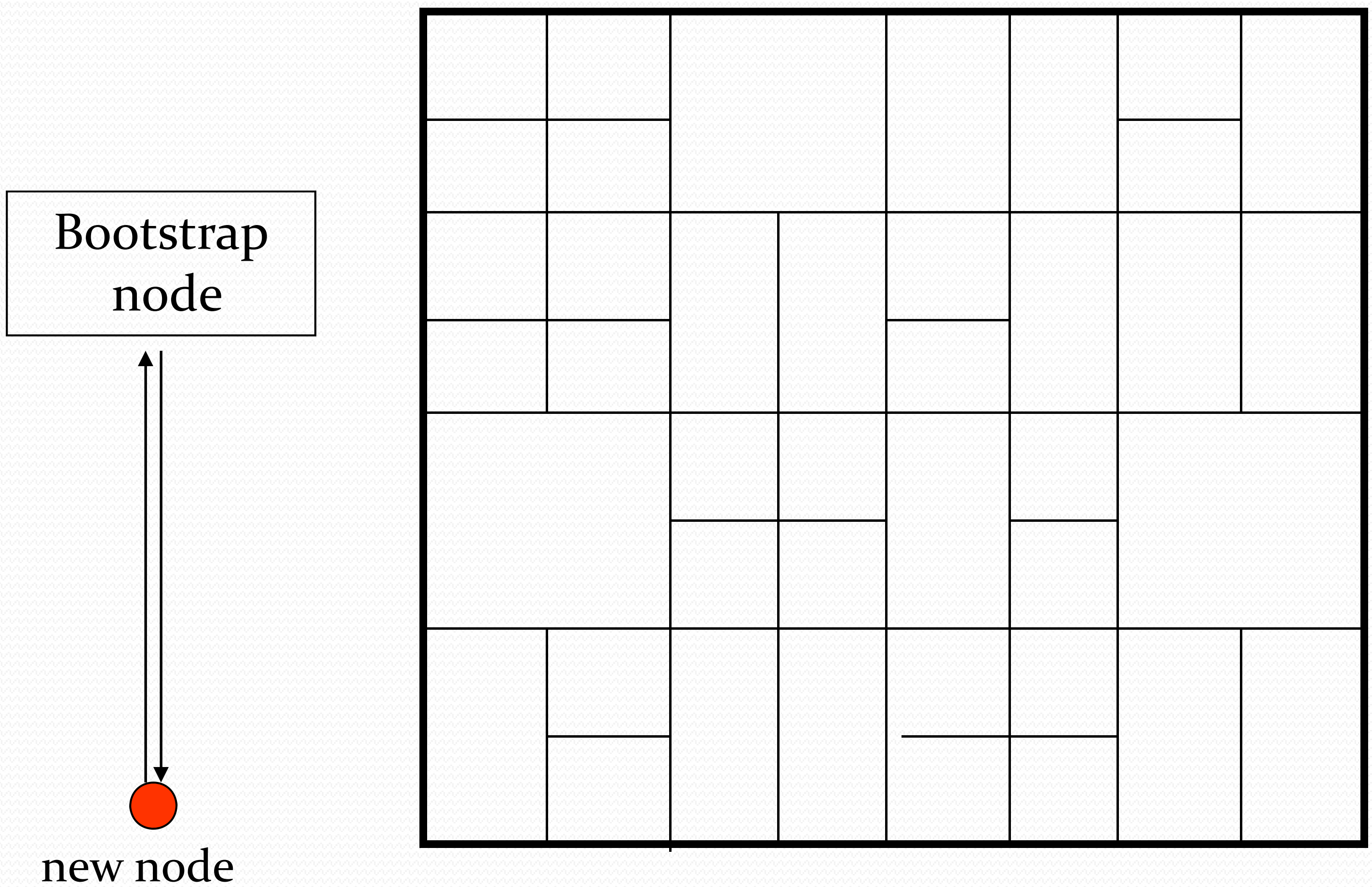


# CAN: routing

A node only maintains state for its immediate neighboring nodes

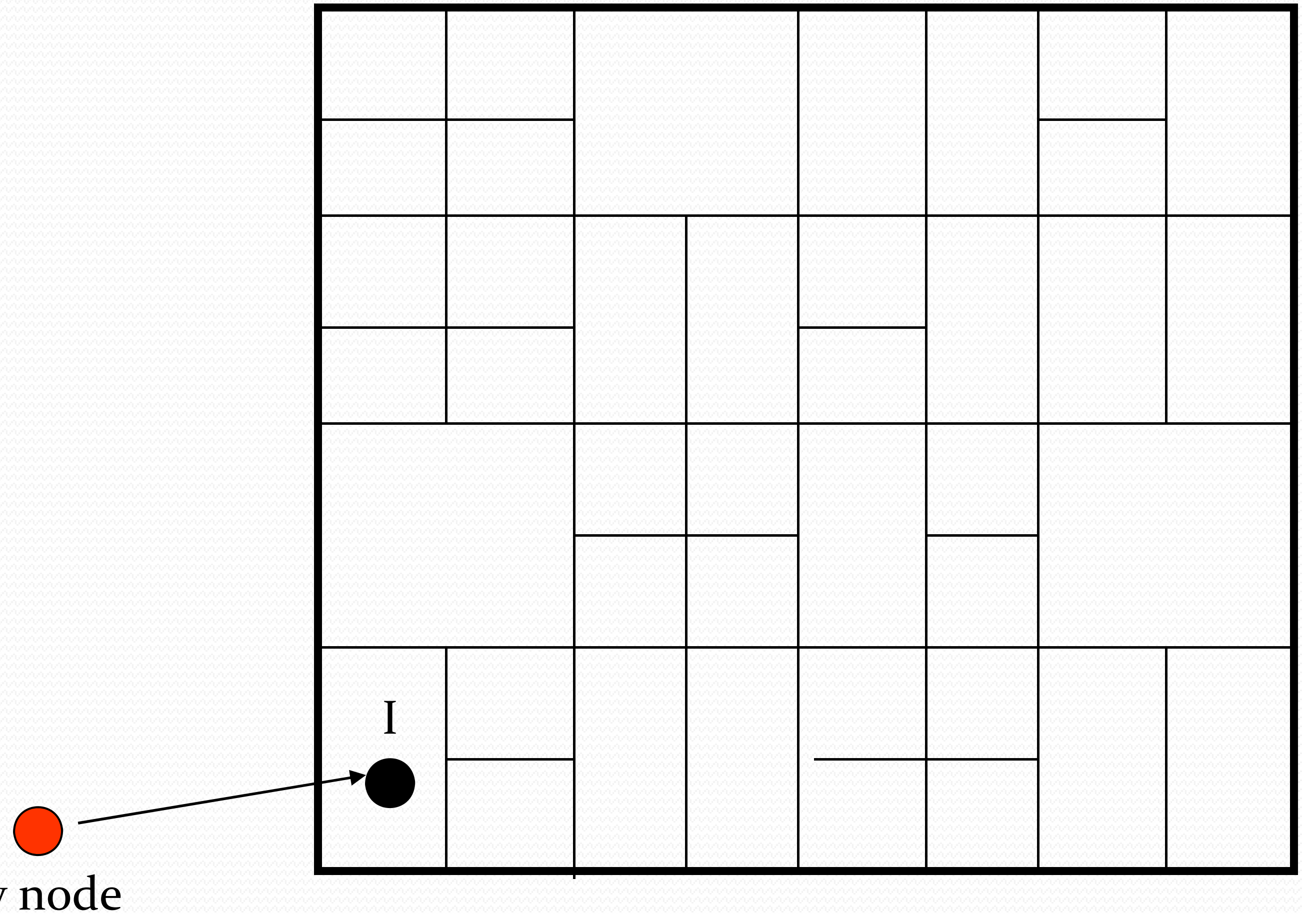


# CAN: node insertion




1) Discover some node "I" already in CAN

# CAN: node insertion

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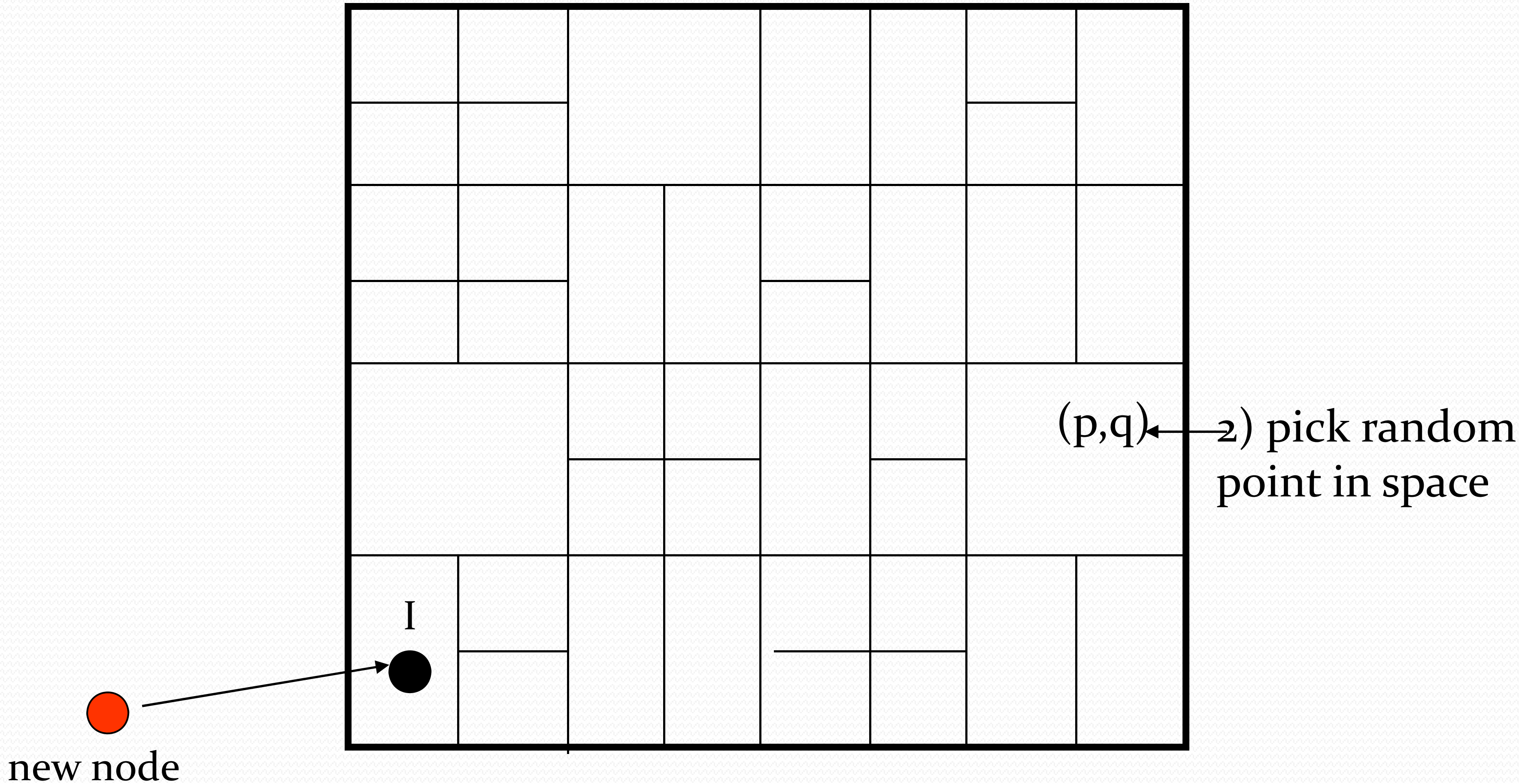
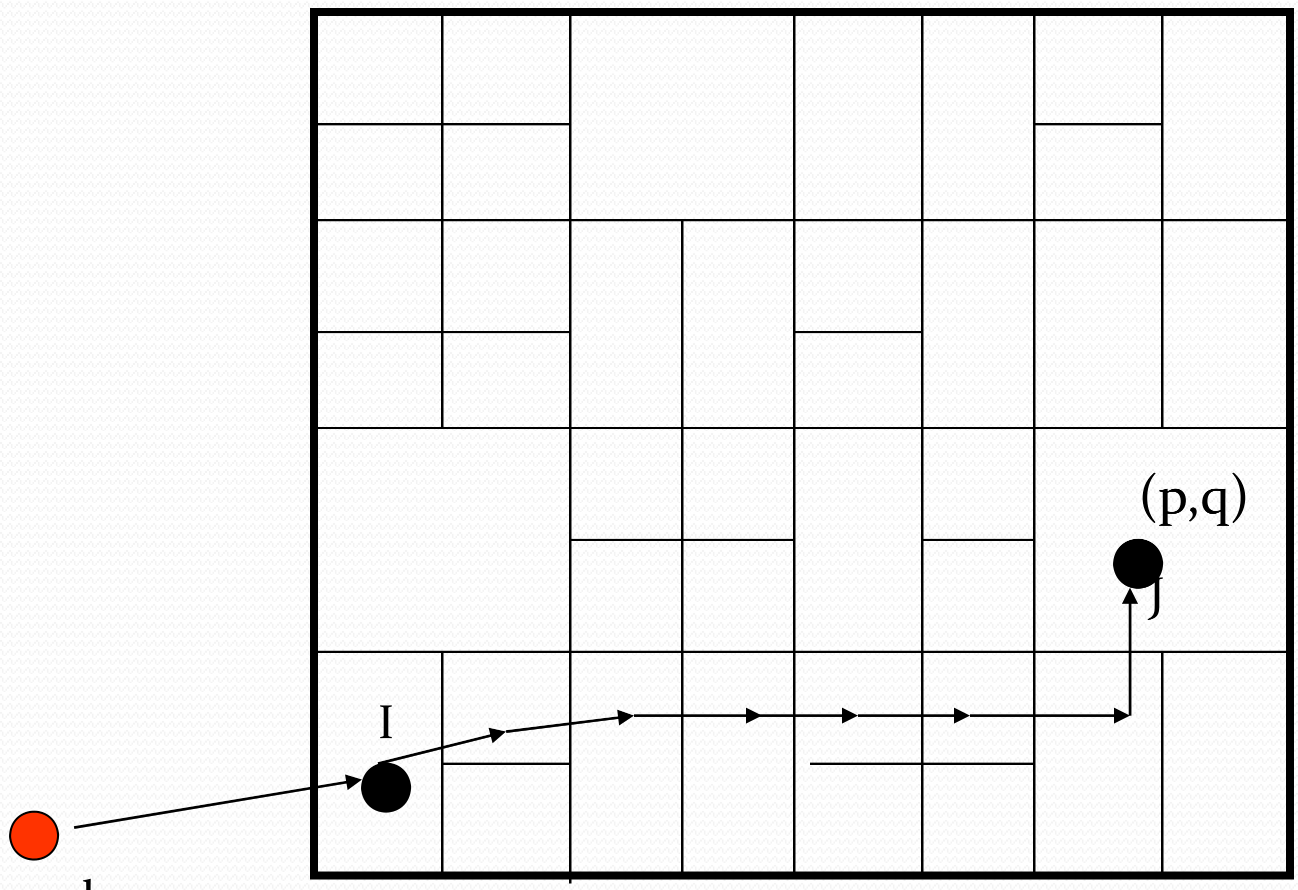
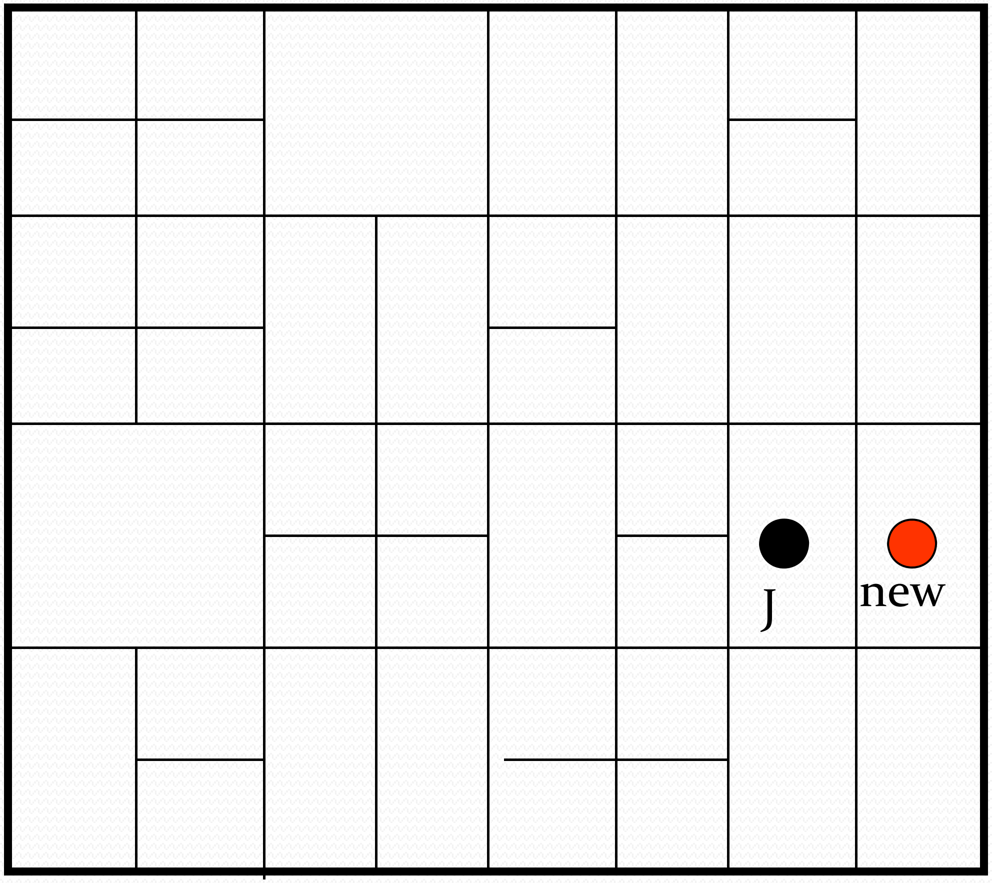


# CAN: node insertion




3) I routes to (p,q), discovers node J

# CAN: node insertion




4) split J's zone in half… new owns one half

# CAN: node insertion

- Inserting a new node affects only a single other node and its immediate neighbors

- Need to repair the space
  - recover database
  - repair routing by takeover algoritm

# CAN: takeover algorithm

- Simple failures
  - know your neighbor's neighbors
  - when a node fails, one of its neighbors takes over its zone

- More complex failure modes
  - simultaneous failure of multiple adjacent nodes
  - scoped flooding to discover neighbors
  - hopefully, a rare event

# Summary

- CAN
  - an Internet-scale hash table
  - potential building block in Internet applications
- Scalability
  - O(d) per-node state
- Low-latency routing
  - simple heuristics help a lot
- Robust
  - decentralized, can route around trouble

# Kelips: Building an efficient and stable P2P DHT through increased memory and background overhead

Indranil Gupta , Ken Birman , Prakash Linga, Al Demers , Robbert van Renesse

IPTPS 2003

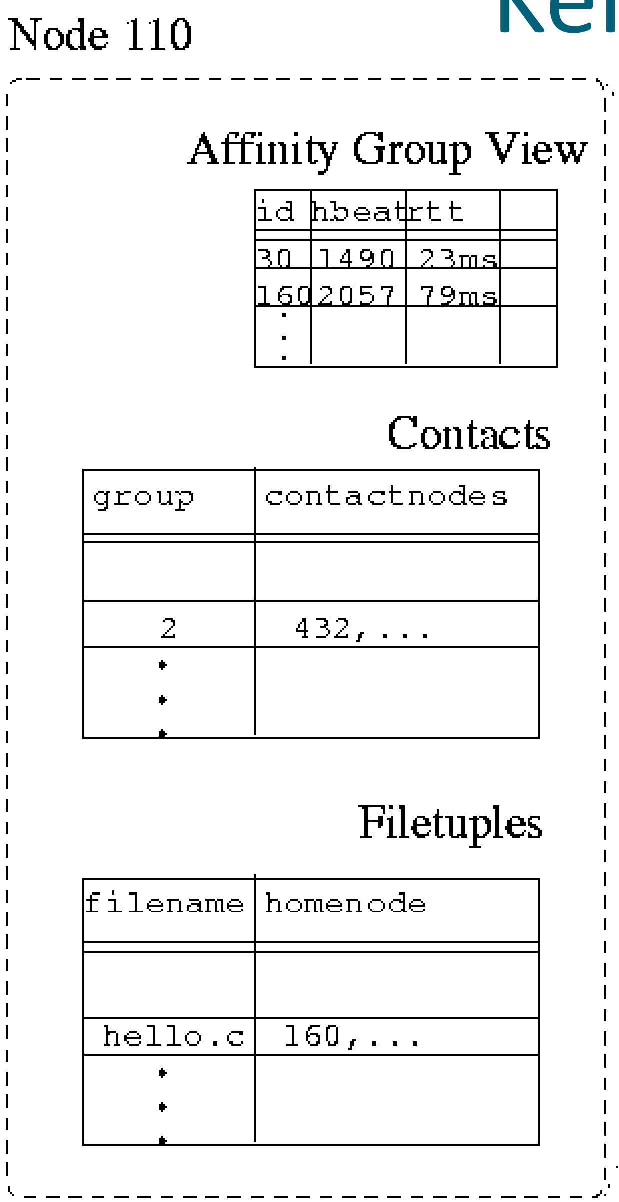
# Kelips: basic idea

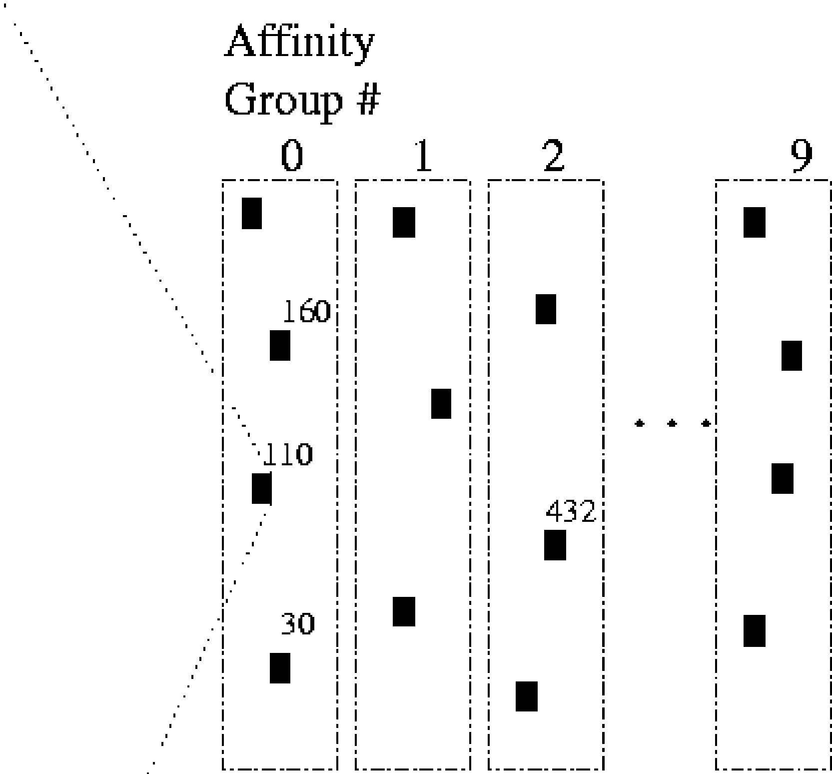
- Two-level hashing with virtual affinity group
  - Hashing of node IP: map to affinity group
  - Hashing of FileName: map to where it is stored
- Kelips: faster lookup, consume more memory
  - O(1) look up cost, O(sqrt(N)) memory
  - Contrast: Chord: O(log(N)) lookup, O(log(N)) memory

# Kelips: Core design

- Three tables stored in each node
  1. Affinity group view:
     - info. of group member: IP, RTT, etc
  2. Contract
     - Info of other groups (small set): IP, RTT, hearbeat count
  3. Filetuples
     - Info of the nodes storing a given file in the affinity group

# Kelips: Core design




Hash function: **SHA-1**
Memory Usage at a node **(n/k) + c(k-1) + (F/k)**
Lookup queries return the location of the file within **O(1) time and message complexity**
Memory utilization is minimized at k = O(√N)
F = O(N), Util = O(√N)

# File Look up

- Querying node maps file name to the appropriate affinity group
- Sends lookup request to the topologically closest '*Contact'node from that group.*
- Receive lookup request resolved by searching among *filetupletable.*
- O(1) time and message complexity

# Discussions: DHT for data center

Several classes of data stores:

- SQL/XML (object-relational) databases
- Distributed hash table (DHT),
- the Hadoop Distributed File System (HDFS)

- Disadvantages of DHT:
  - No full guarantee for data consistency and integrity
  - Limited to simple query: <key, value> mapping
  - No authority, not designed for events/triggers

# Discussions: DHT for data center

- Disadvantages of DHT:
  - No full guarantee for data consistency and integrity
  - Limited to simple query: <key, value> mapping
  - No authority, not designed for events/triggers
- Advantages of DHT:
  - Resilient to network, handle node changes/removal
  - Data is automatically distributed
  - Data is replicated across nodes

# Discussions: DHT for data center

- Conclusion: DHT might not be as competitive as other data center options, however, it is powerful tool to be combined with others
- Examples: add a DTH layer in Hadoop file system
  - Hadoop has different ways for large file replication (blocks of X MB) across a huge cluster.
  - Using a DHT layer to store the locations of each replicated block.
  - Benefits: remove the need for the authoritative and centralized HDFS file directory server and make the network overall more robust and resilient (the HDFS central server is a single point of failure).