DISTRIBUTED HASH TABLES: simplifying building robust Internet-scale applications

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PROJECT IRIS
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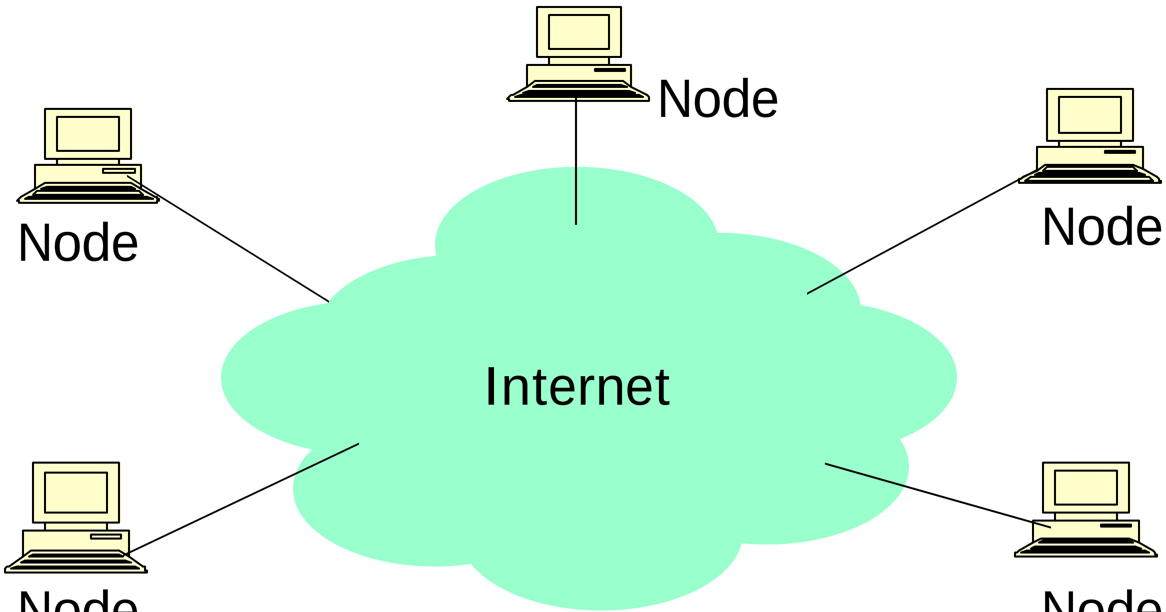
What is a P2P system?



- A distributed system architecture:
  - No centralized control
  - Nodes are symmetric in function
- Larger number of unreliable nodes
- Enabled by technology improvements

P2P: an exciting social development

- Internet users cooperating to share, for example, music files
  - Napster, Gnutella, Morpheus, KaZaA, etc.
- Lots of attention from the popular press

  “The ultimate form of democracy on the Internet”

  “The ultimate threat to copy-right protection on the Internet”

How to build critical services?

- Many critical services use Internet
  - Hospitals, government agencies, etc.
- These services need to be robust
  - Node and communication failures
  - Load fluctuations (e.g., flash crowds)
  - Attacks (including DDoS)

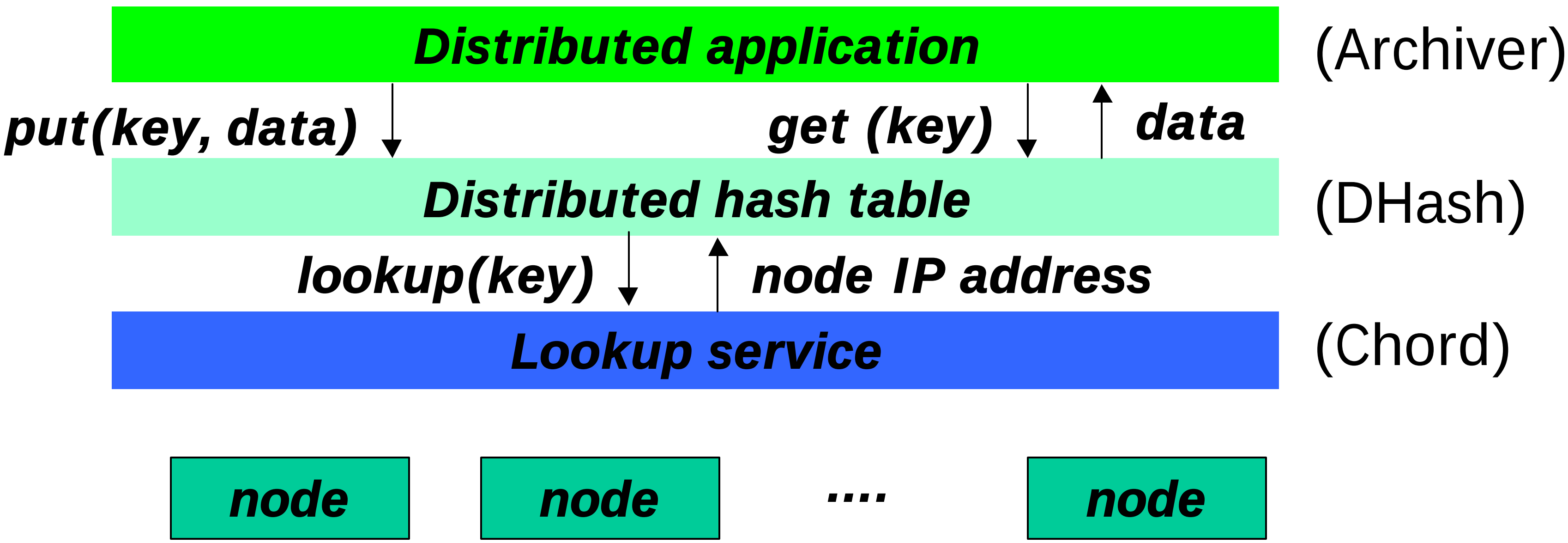
Example: robust data archiver

- Idea: archive on other user's machines
- Why?
  - Many user machines are not backed up
  - Archiving requires significant manual effort now
  - Many machines have lots of spare disk space
- Requirements for cooperative backup:
  - Don't lose *any* data
  - Make data highly available
  - Validate integrity of data
  - Store shared files once
- More challenging than sharing music!

The promise of P2P computing

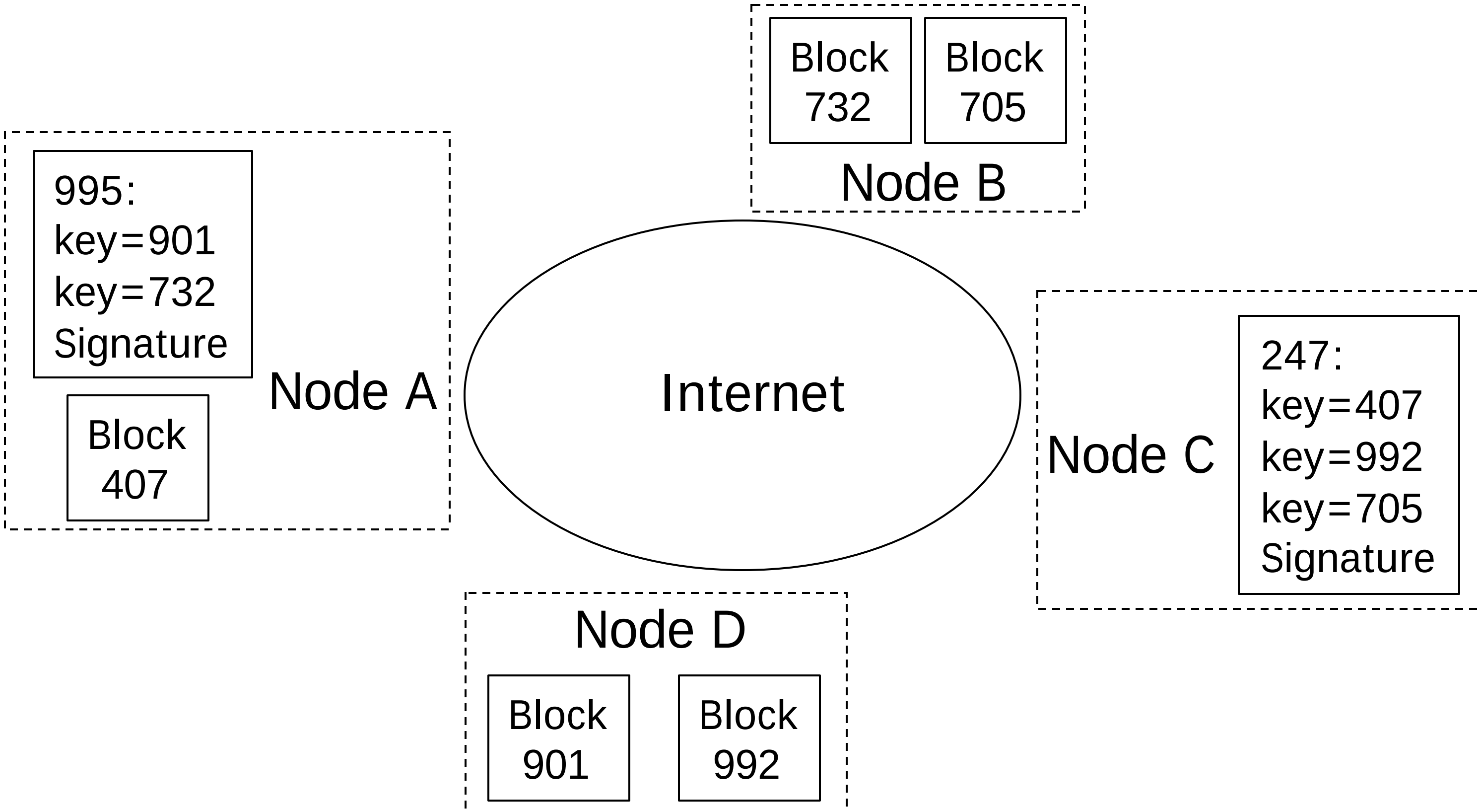
- Reliability: no central point of failure
  - Many replicas
  - Geographic distribution
- High capacity through parallelism:
  - Many disks
  - Many network connections
  - Many CPUs
- Automatic configuration
- Useful in public and proprietary settings

Distributed hash table (DHT)



- DHT distributes data storage over perhaps millions of nodes

DHT distributes blocks by hashing



- DHT replicates blocks for fault tolerance
- DHT balances load of storing and serving

A DHT has a good interface

- Put(key, value) and get(key) $\rightarrow$ value
  - Simple interface!
- API supports a wide range of applications
  - DHT imposes no structure/meaning on keys
- Key/value pairs are persistent and global
  - Can store keys in other DHT values
  - And thus build complex data structures

A DHT makes a good *shared* infrastructure

- Many applications can share one DHT service
  - Much as applications share the Internet
- Eases deployment of new applications
- Pools resources from many participants
  - Efficient due to statistical multiplexing
  - Fault-tolerant due to geographic distribution

Many applications for DHTs

- File sharing [CFS, OceanStore, PAST, Ivy, ...]
- Web cache [Squirrel, ..]
- Archival/Backup store [HiveNet,Mojo,Pastiche]
- Censor-resistant stores [Eternity, FreeNet,..]
- DB query and indexing [PIER, ...]
- Event notification [Scribe]
- Naming systems [ChordDNS, Twine, ..]
- Communication primitives [I3, ...]

Common thread: data is location-independent

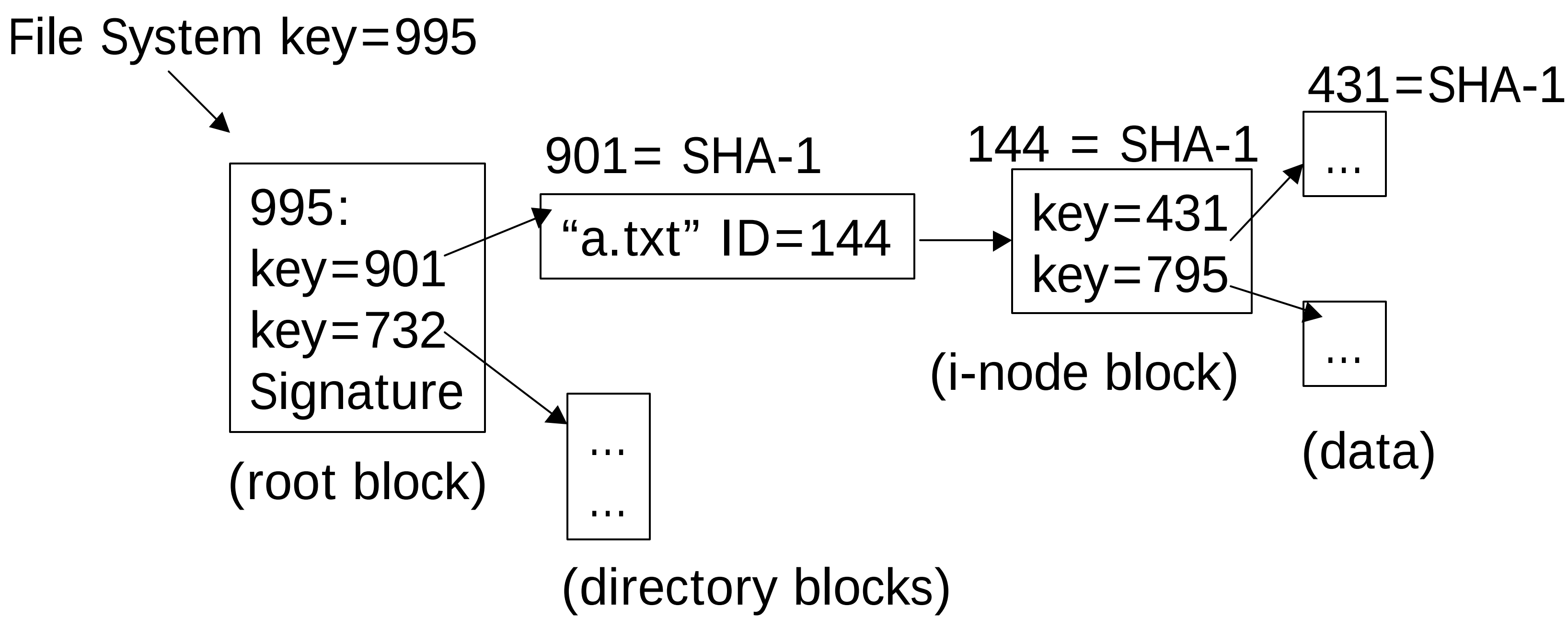
DHT implementation challenges

- Data integrity
- Scalable lookup
- Handling failures
- Network-awareness for performance
- Coping with systems in flux
- Balance load (flash crowds)
- Robustness with untrusted participants
- Heterogeneity
- Anonymity
- Indexing

} this talk (first four items)

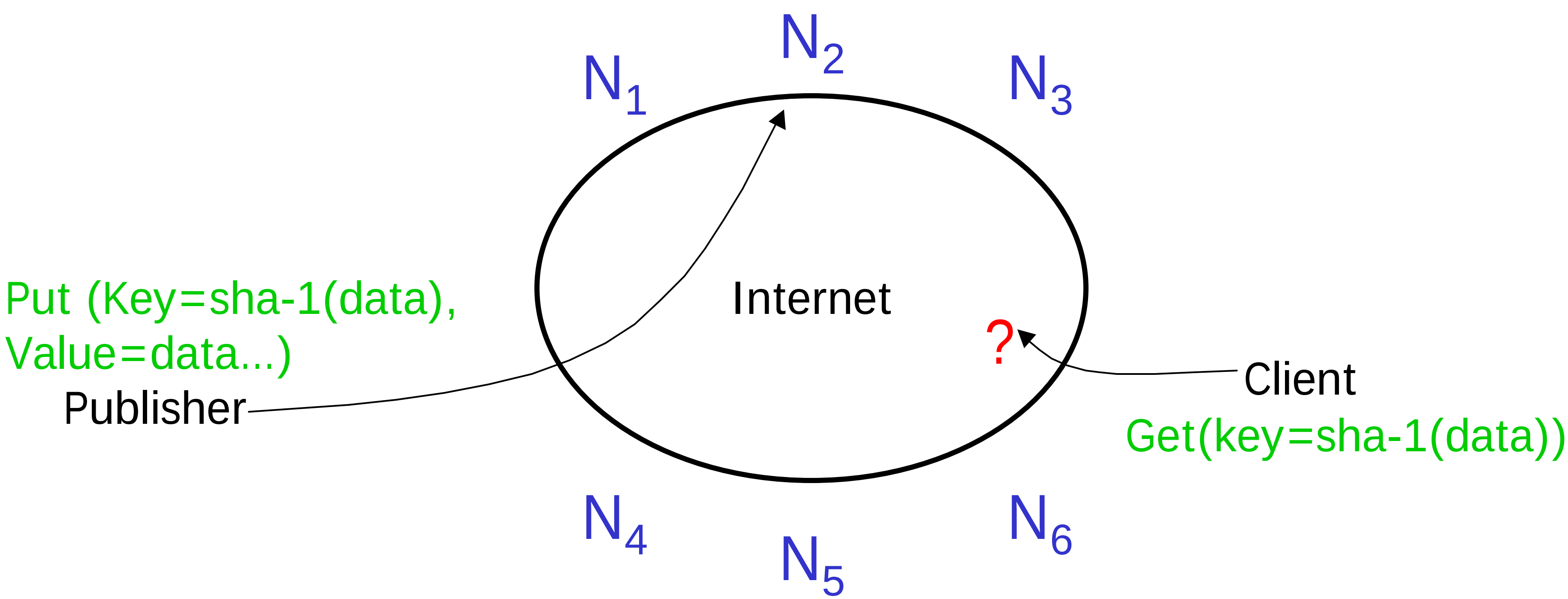
Goal: simple, provably-good algorithms

1. Data integrity: self-authenticating data



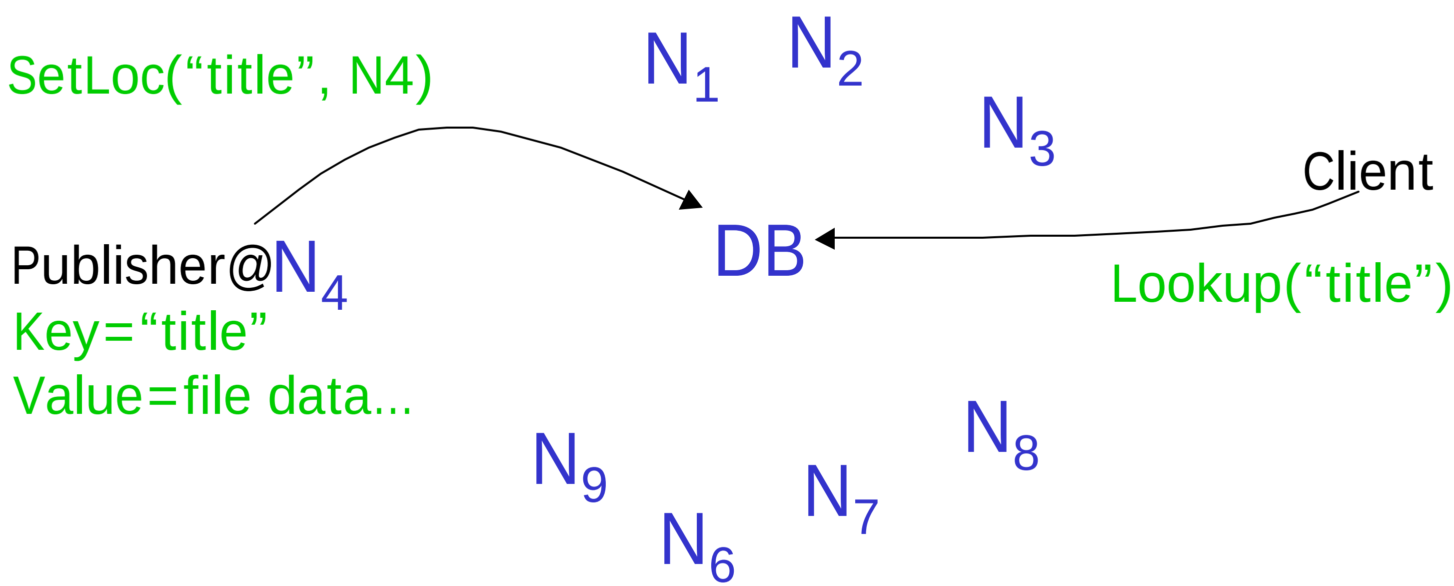
- Key = SHA-1(content block)
- File and file systems form Merkle hash trees

2. The lookup problem



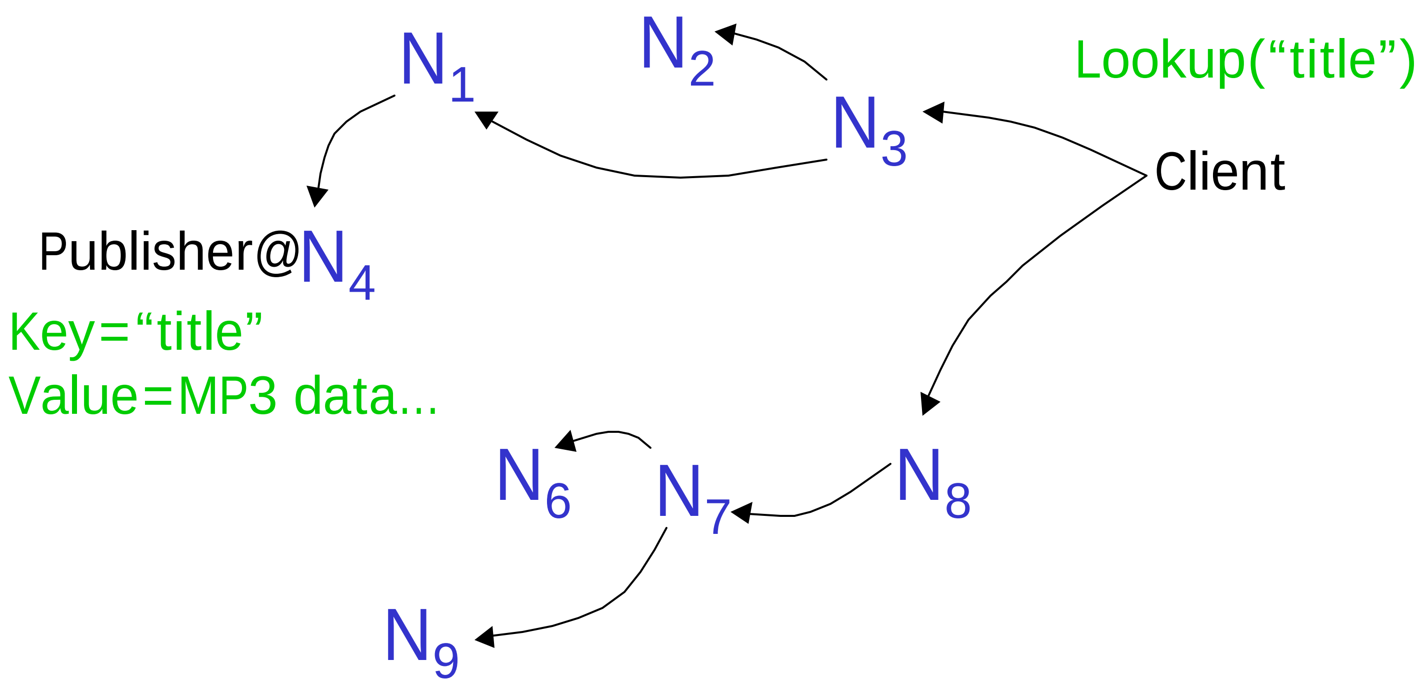
- Get() is a lookup followed by check
- Put() is a lookup followed by a store

Centralized lookup (Napster)



Simple, but O(N) state and a single point of failure

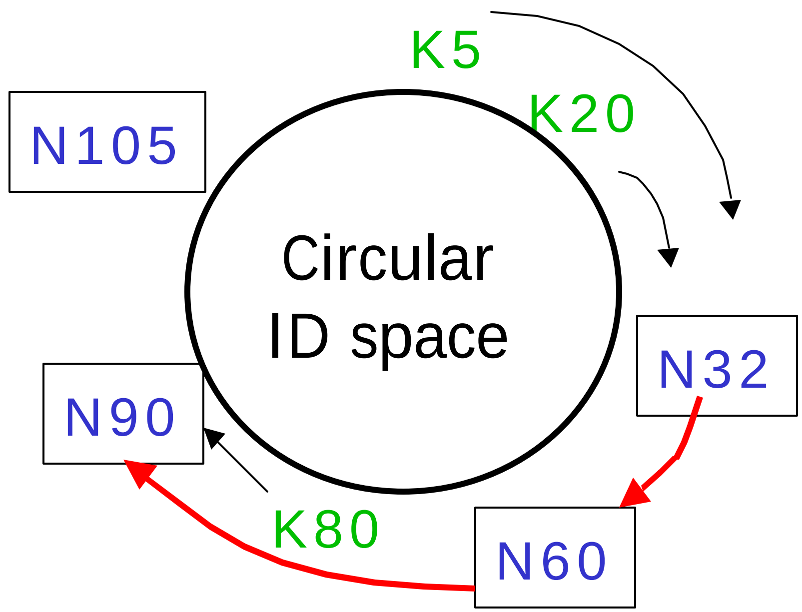
Flooded queries (Gnutella)



Robust, but worst case O(N) messages per lookup

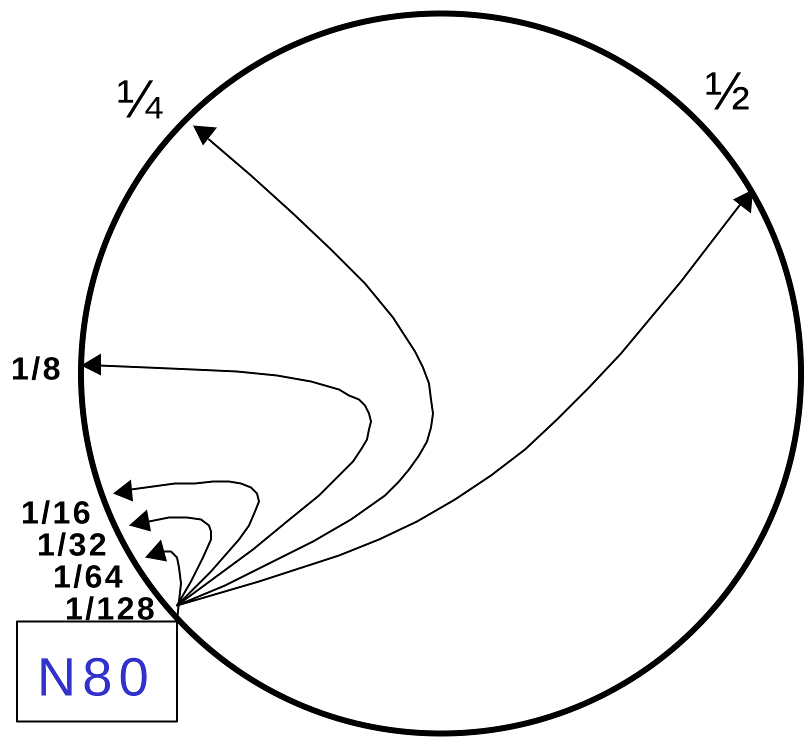
Algorithms based on routing

- Map keys to nodes in a load-balanced way
  - Hash keys and nodes into a string of digit
  - Assign key to “closest” node
- Forward a lookup for a key to a closer node
- Join: insert node in ring

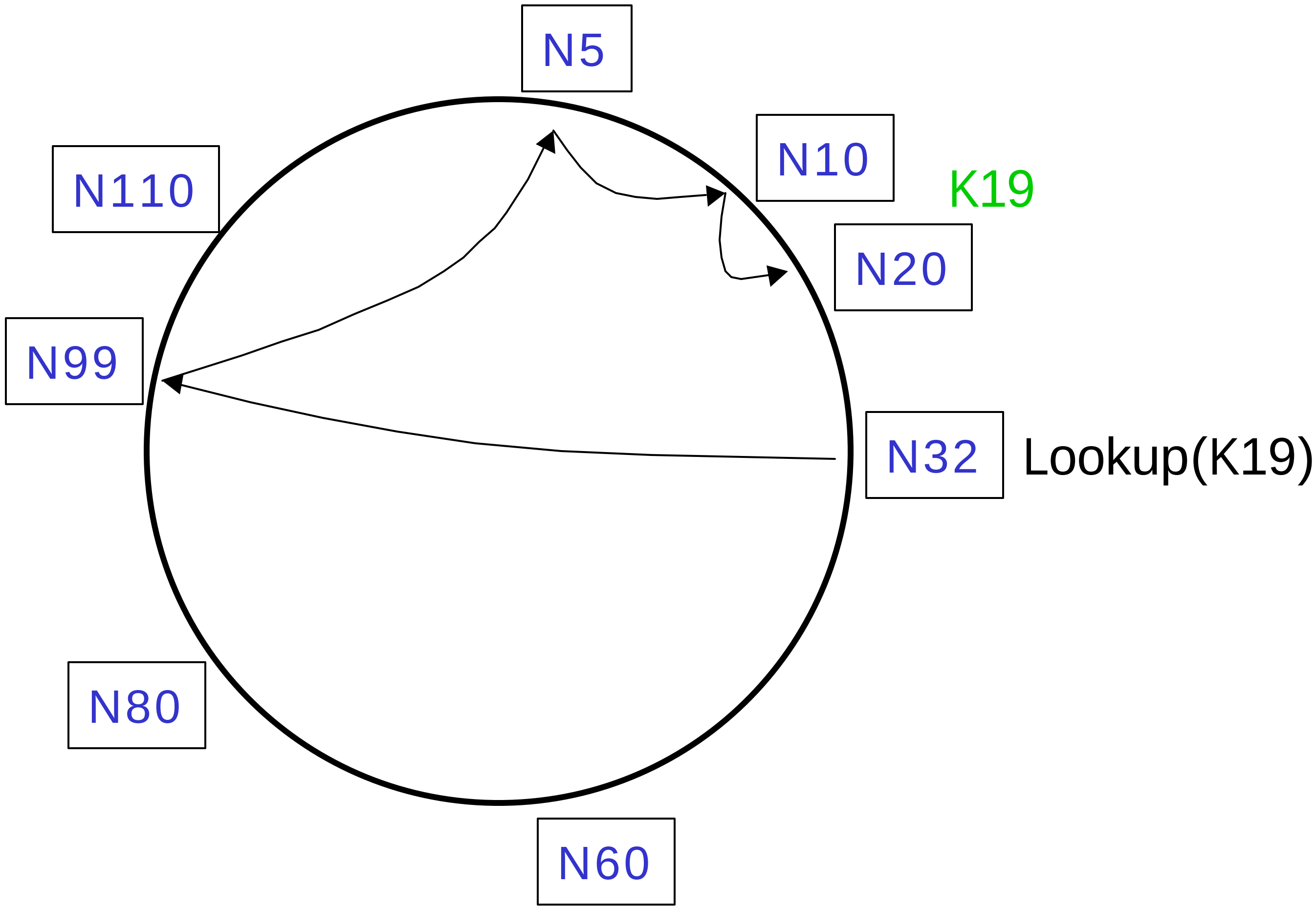


Examples: CAN, Chord, Kademlia, Pastry, Tapestry, Viceroy, Koorde, ..

Chord's routing table: fingers

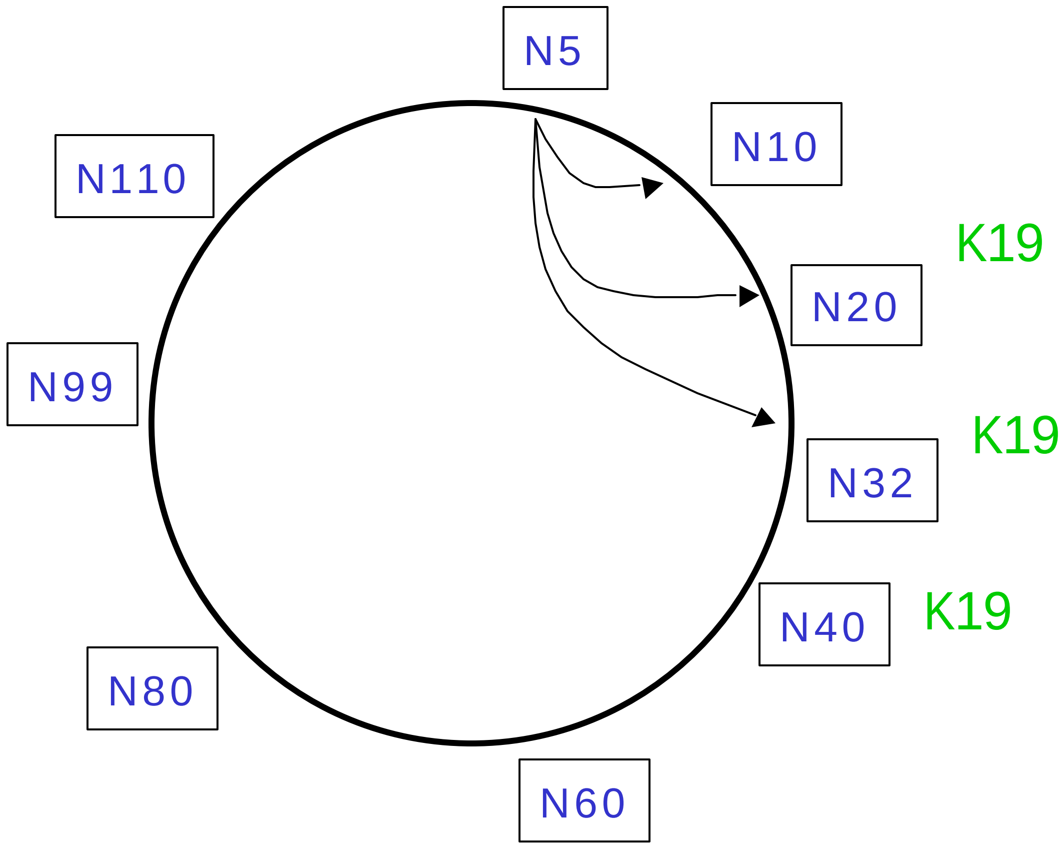


Lookups take O(*log(N)*) hops



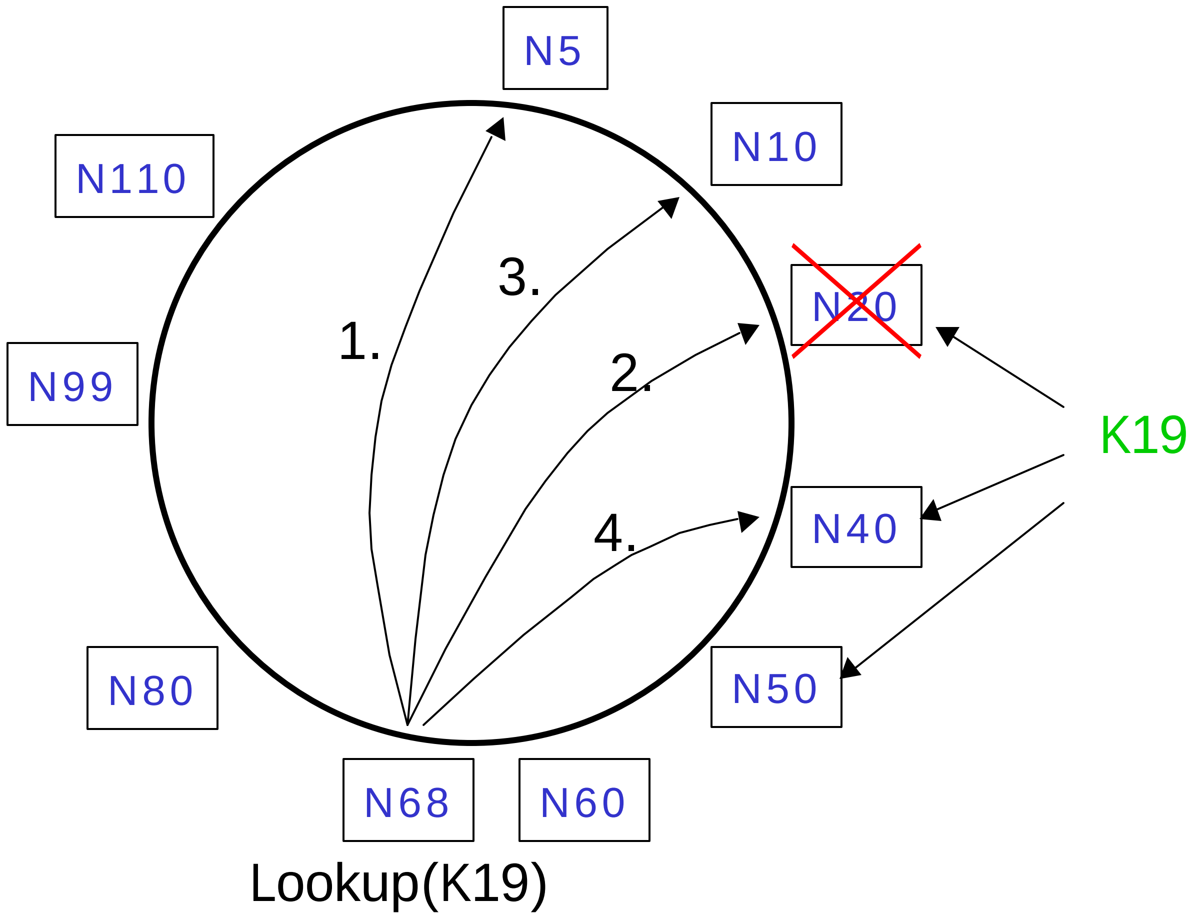
- Lookup: route to closest predecessor

3. Handling failures: redundancy



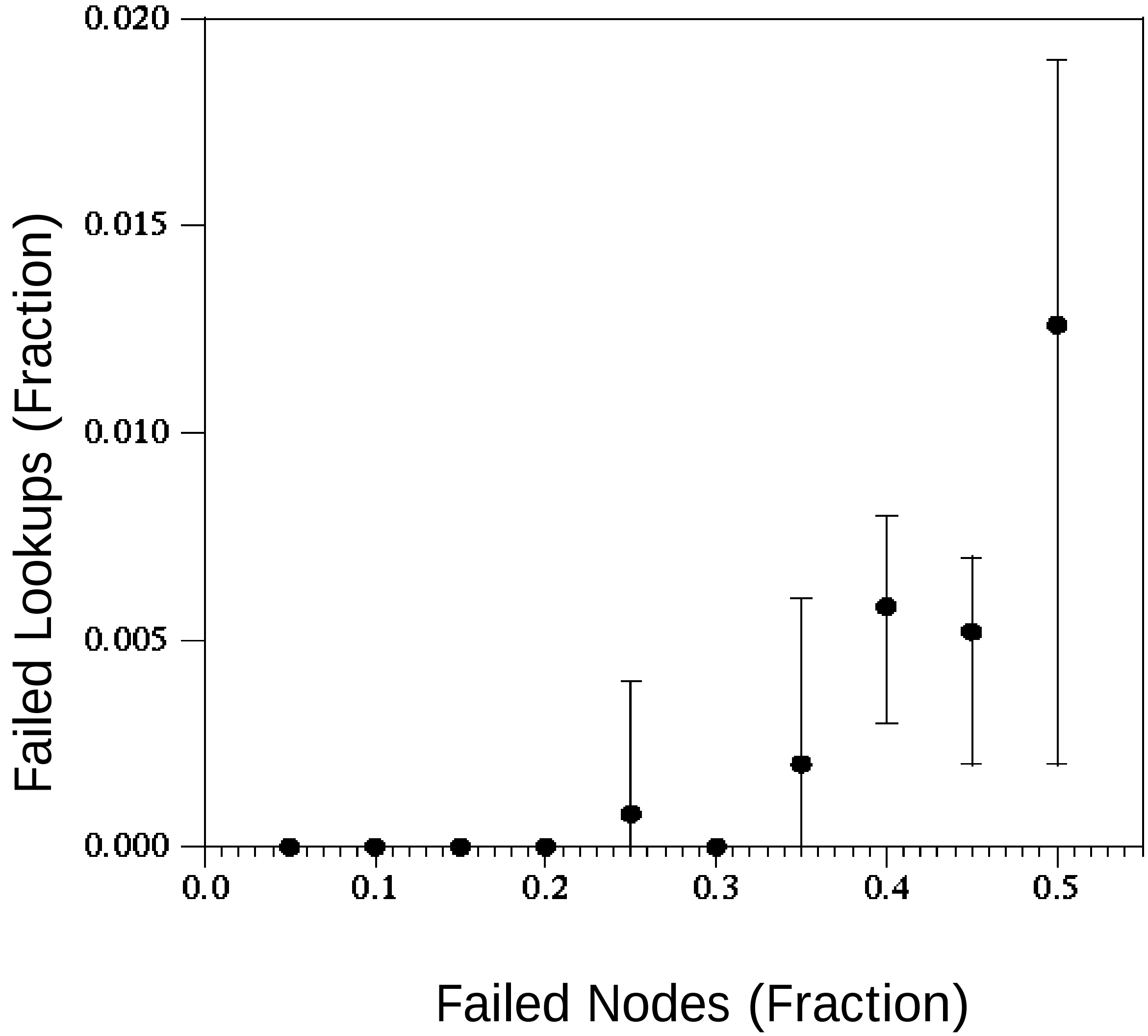
- Each node knows IP addresses of next *r* nodes
- Each key is replicated at next *r* nodes

Lookups find replicas



- Opportunity to serve data from nearby node
- Use erasure codes to reduce storage and comm overhead

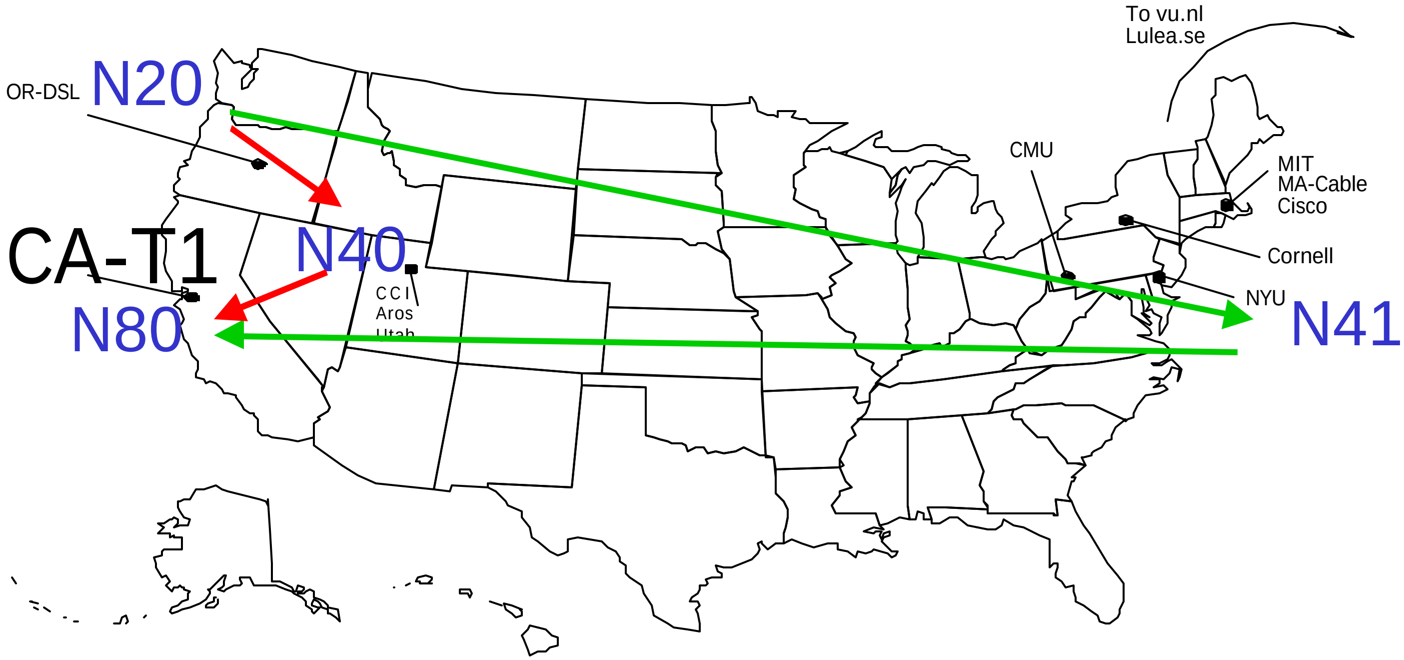
Robustness Against Failures



1000 DHT servers
Average of 5 runs
Run *before* stabilization
All failures due to replica failing

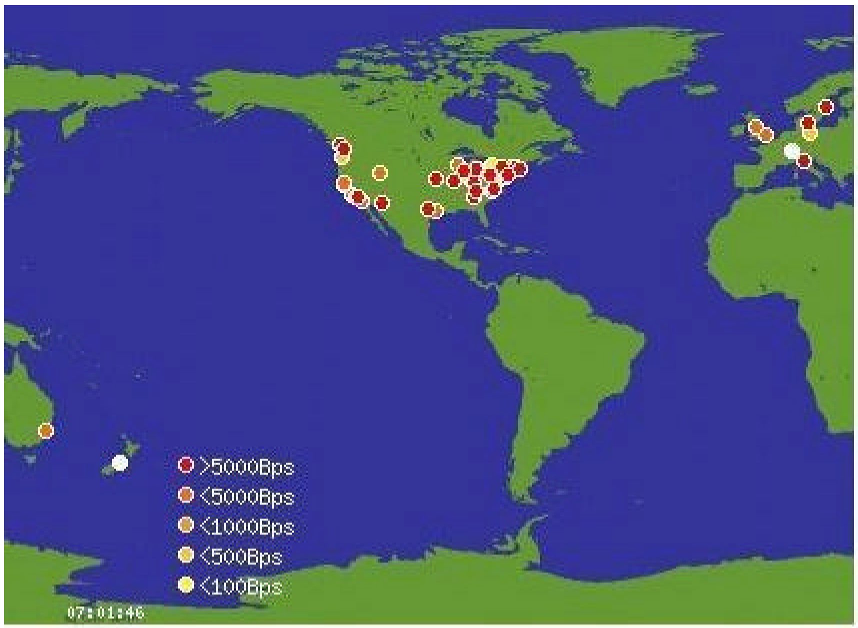
50% of nodes disappear but only less than 1.6% of lookups fail

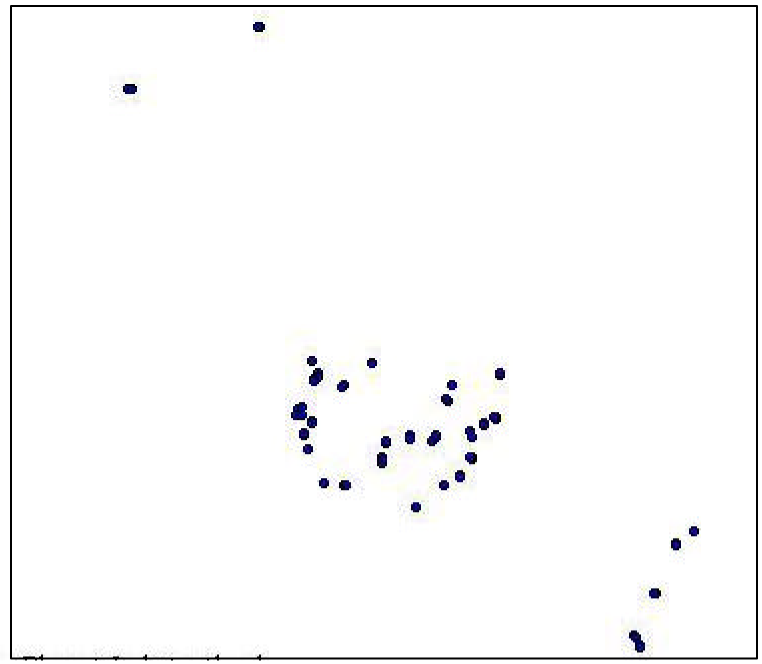
4. Exploiting proximity



- Nodes <u>close</u> on ring, but <u>far away</u> in Internet
- Goal: put nodes in routing table that result in few hops <u>and</u> low latency
- Problem: how do you know a node is nearby? How do you find nearby nodes?

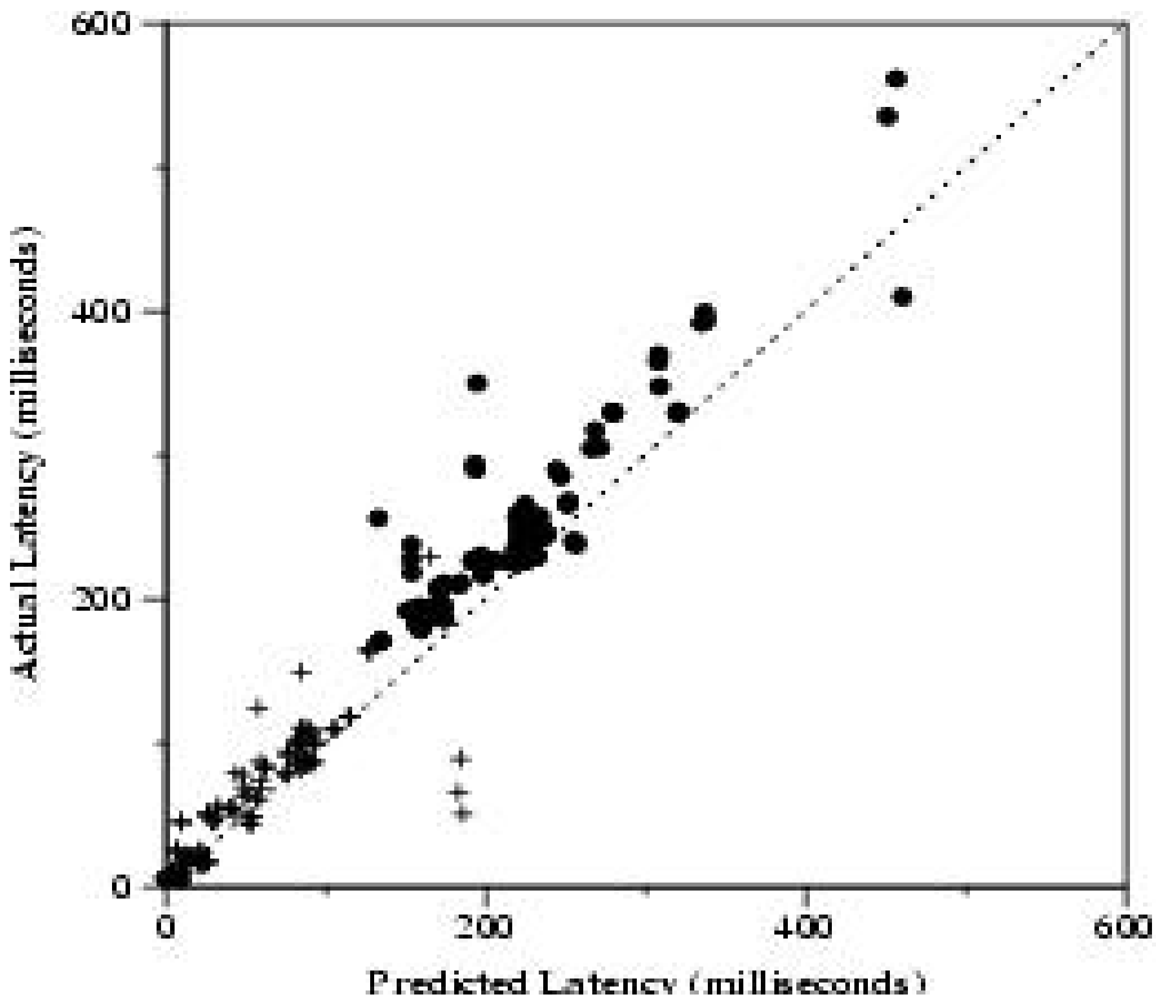
Vivaldi: synthetic coordinates





- Model the network as network of springs
- Distributed machine learning algorithm
- Converges fast and is accurate ....

Vivaldi predicts latency well



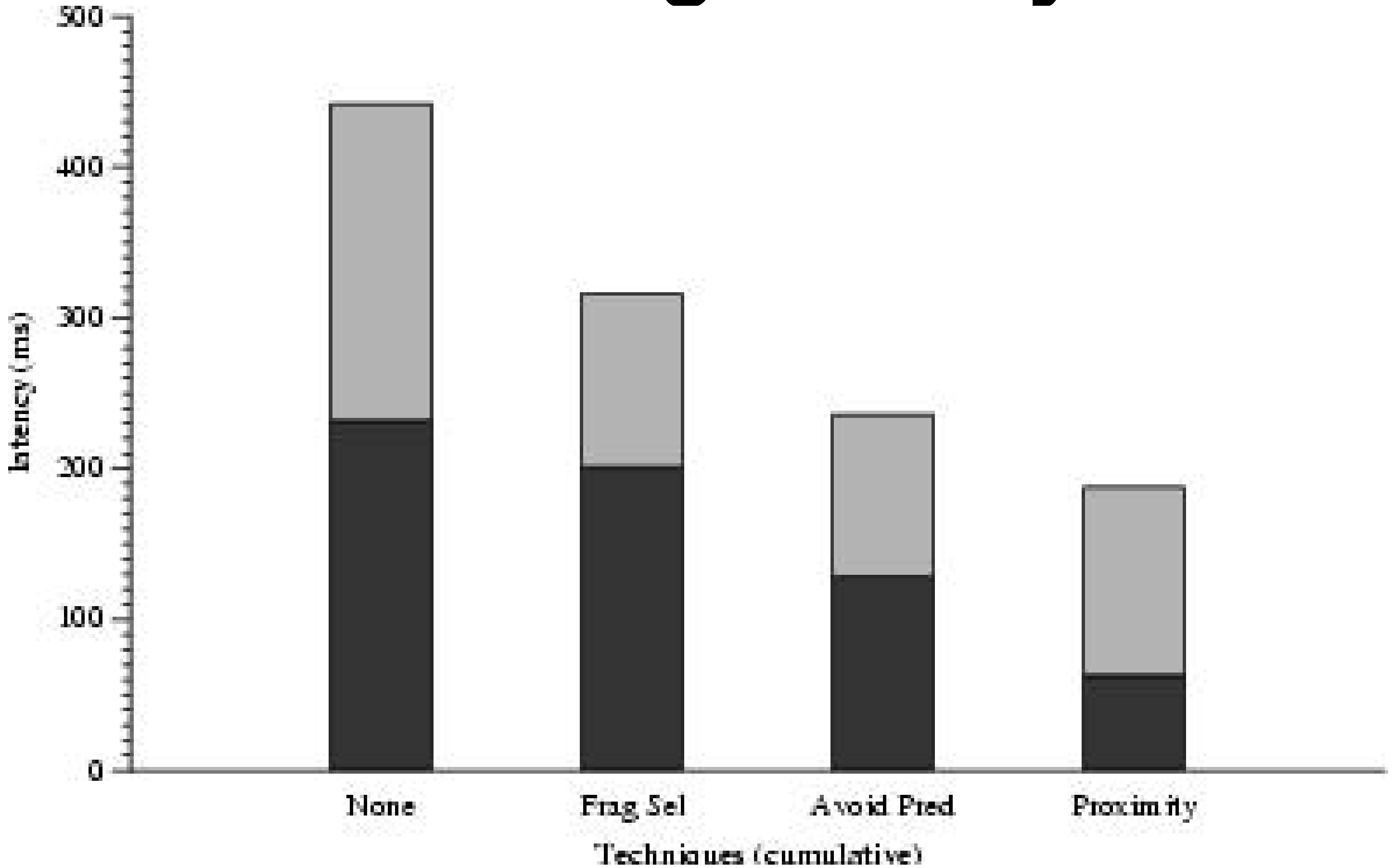
- PlanetLab
- RON

- NYC (+)
- Australia (•)

Finding nearby nodes

- Swap neighbor sets with random neighbors
  - Combine with random probes to explore
- Provably-good algorithm to find nearby neighbors based on sampling [Karger and Ruhl 02]

Reducing latency



- Latency = lookup + download

DHT implementation summary

- Chord for looking up keys
- Replication at successors for fault tolerance
- Vivaldi synthetic coordinate system for
  - Proximity routing
  - Server selection

Conclusions

- Once we have DHTs, building large-scale, distributed applications is easy
  - Single, shared infrastructure for many applications
  - Robust in the face of failures and attacks
  - Scalable to large number of servers
  - Self configuring across administrative domains
  - Easy to program
- Let’s build DHTs .... stay tuned ....

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