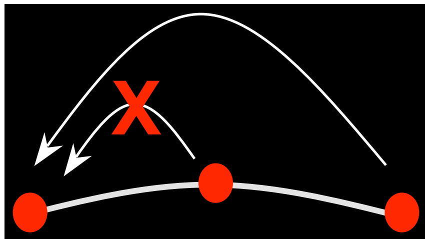


Non-Transitive Connectivity and DHTs

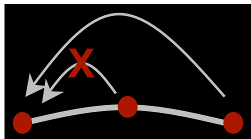
Mike Freedman

Karthik Lakshminarayanan

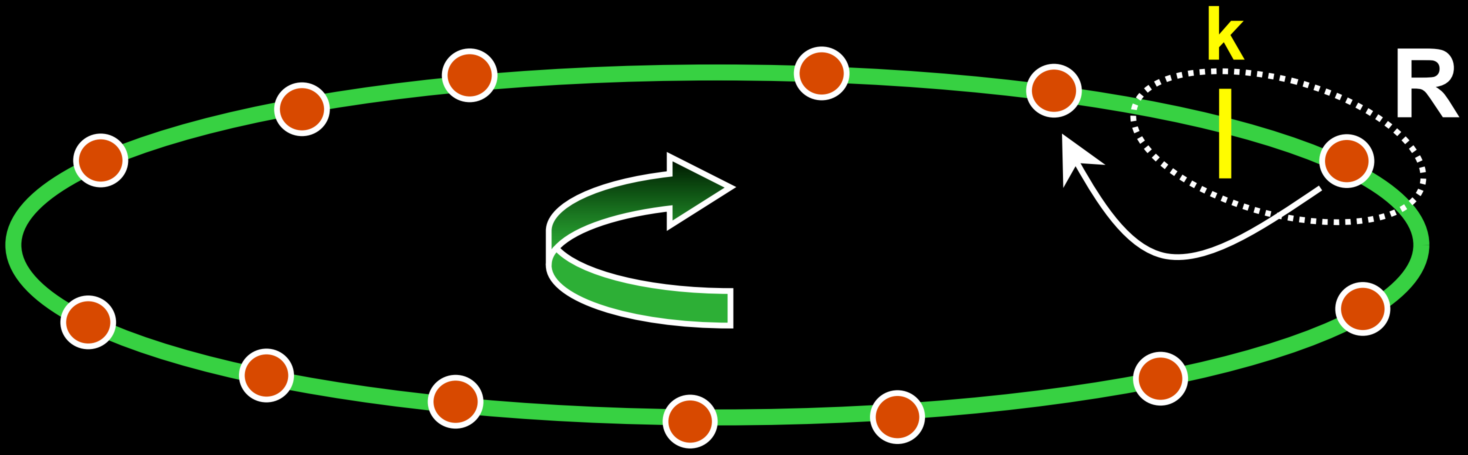
Sean Rhea

Ion Stoica

WORLDS 2005

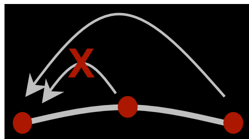


Distributed Hash Tables…

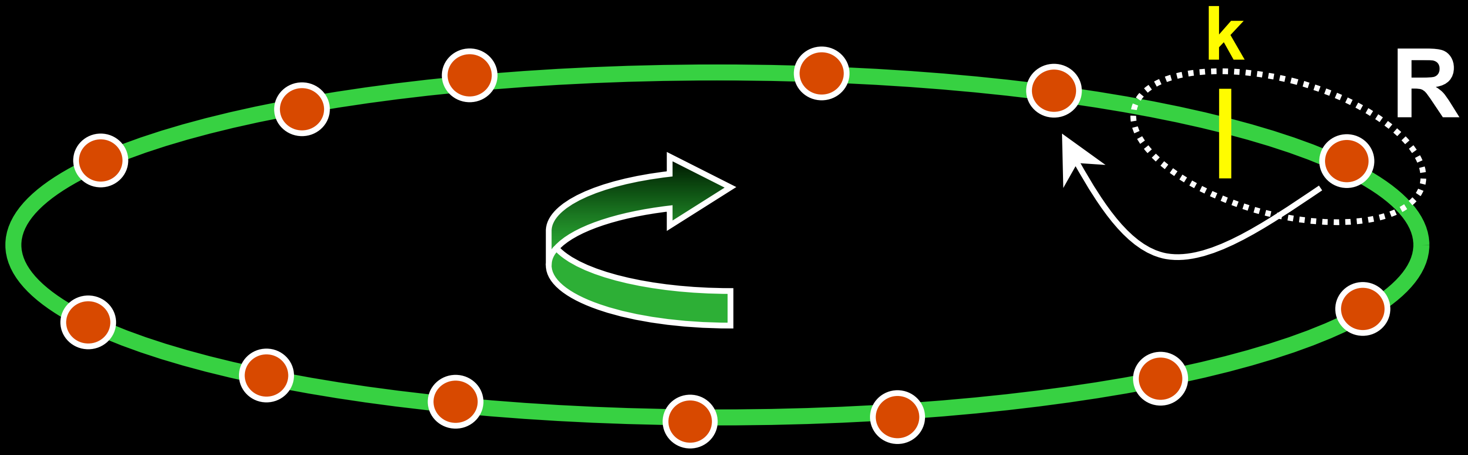


- System assigns keys to nodes
- All nodes agree on assignment

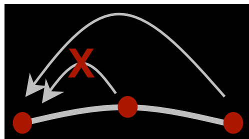
- Chord assigns keys as integers modulo 2^{160}
- Assigns keys via successor relationship
- Each node must know predecessor



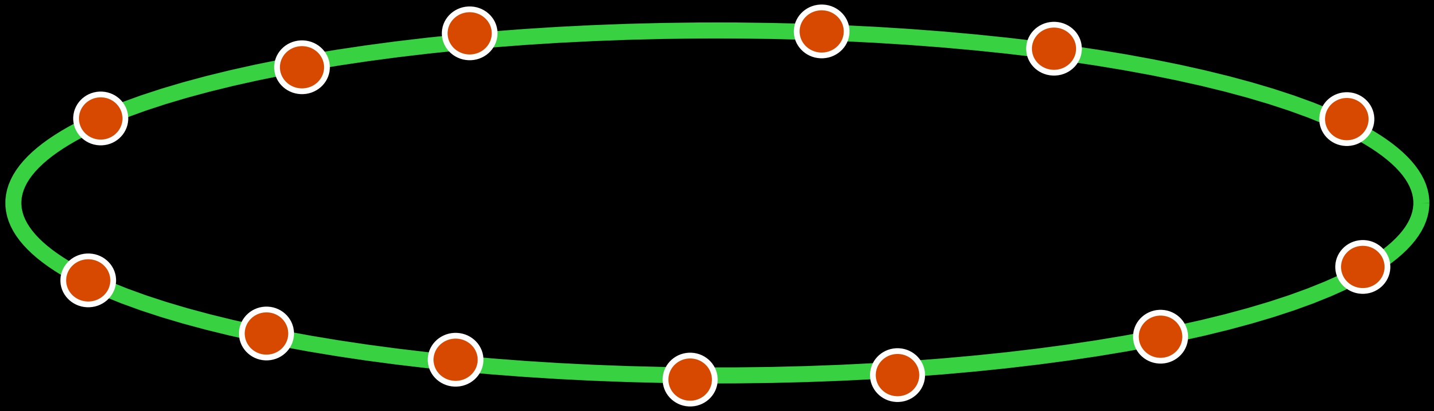
Distributed Hash Tables…



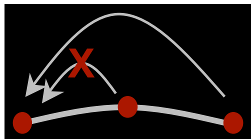
- Used to store and retrieve (key, value) pairs
- Any node can discover key's successor, yet without full knowledge of network
  - Implies some form of routing



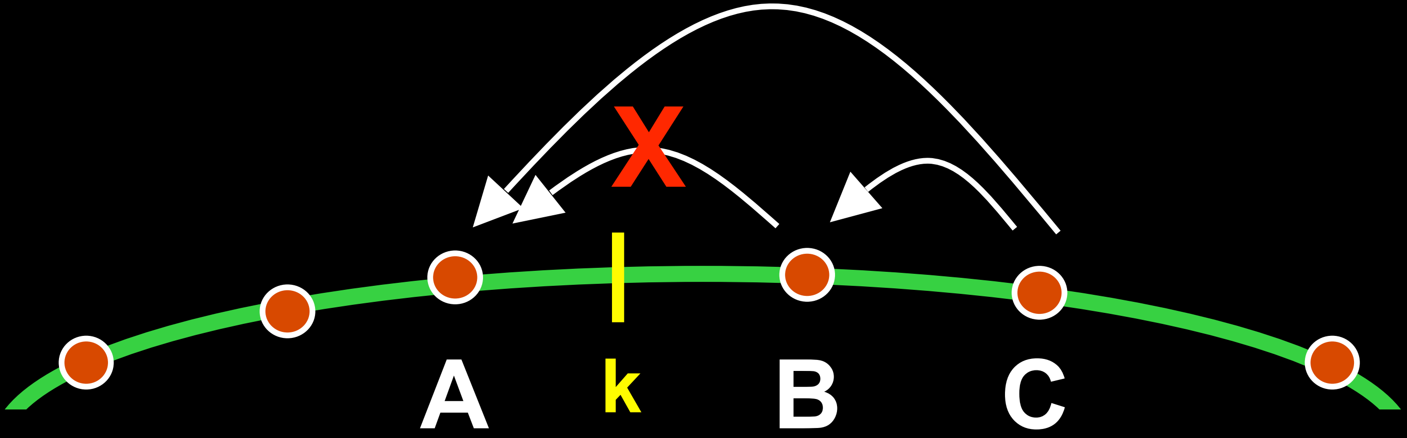
Distributed Hash Tables…



- All have implicit assumption: full connectivity



Distributed Hash Tables…



- All have implicit assumption: full connectivity
- *Non-transitive connectivity (NTC)* not uncommon

$$B \leftrightarrow C \;,\; C \leftrightarrow A \;,\; A \not\leftrightarrow B$$

- A thinks C is its successor!

Does non-transitivity exist?

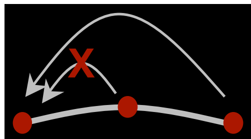
- Gerding/Stribling PlanetLab study
  - 9% of all node triples exhibit NTC
  - Attributed high extent to Internet-2
- Yet NTC is also transient
  - One 3 hour PlanetLab all-pair-pings trace
  - 2.9% have persistent NTC
  - 2.3% have intermittent NTC
  - 1.3% fail only for a single 15-minute snapshot
- Level3 $\nleftrightarrow$ *Cogent, but Level3* $\leftrightarrow$ *X* $\leftrightarrow$ *Cogent*
- NTC motivates RON, Detour, and SOSR!

Our contributions

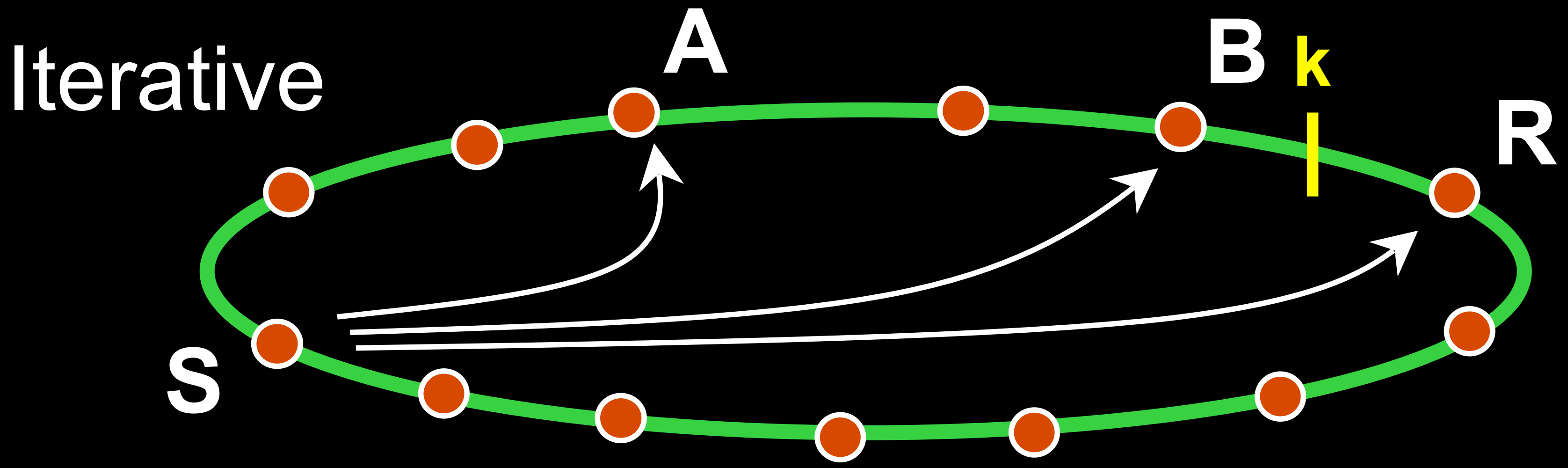
- We have built and run Bamboo (OpenDHT), Chord (i3), Kademlia (Coral) for > 1 year
- Vanilla DHT algorithms break under NTC
- Identify four main algorithmic problems and present our solutions

Our goals

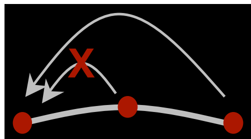
- Short-term
  - Inform other developers about NTC solutions
  - Important: DHTs are being widely deployed in Overnet, Morpheus, and BitTorrent
- Long-term
  - Encourage new designs to directly handle NTC
  - (This topic is far from solved)



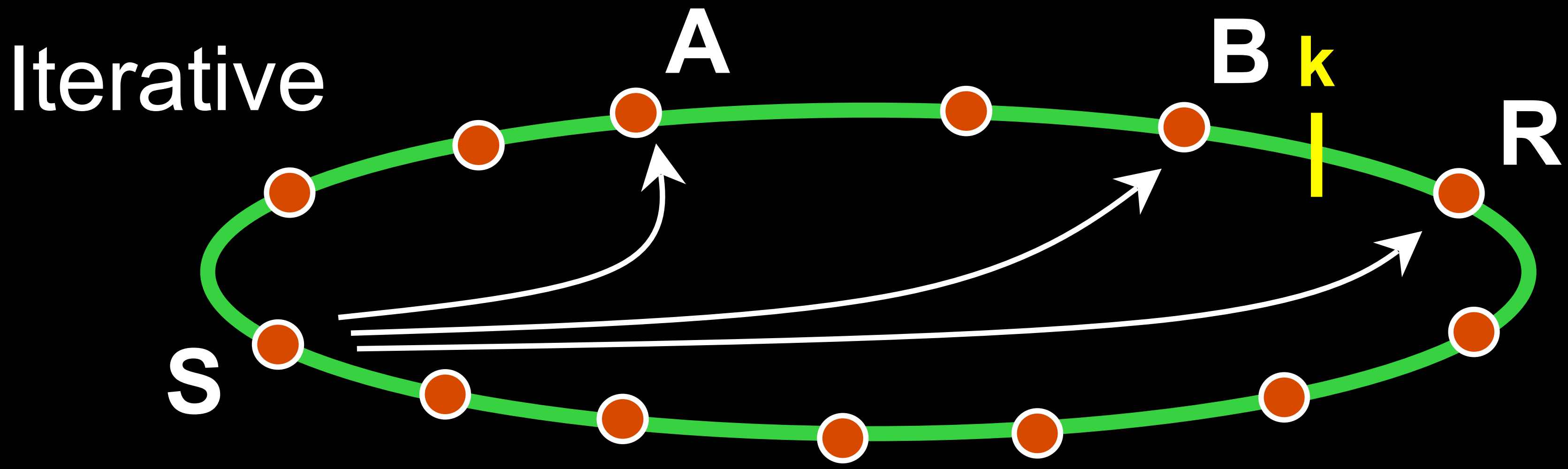
DHTs 101: Routing

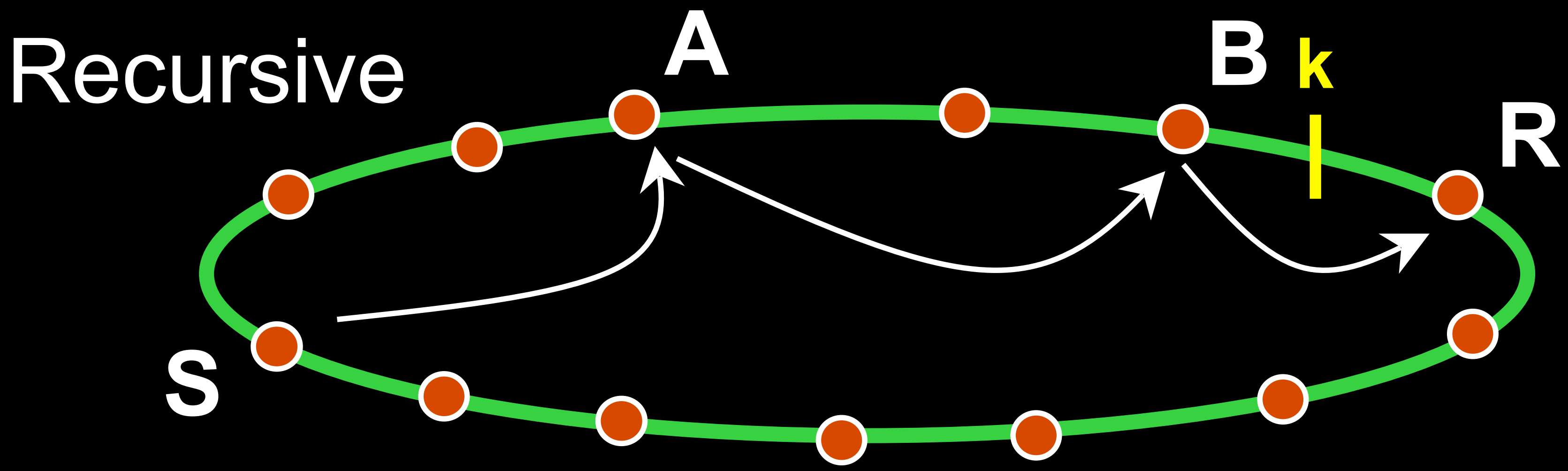


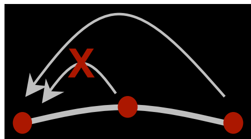
- Key space defines an identifier distance
- Routing ideally proceeds by halving distance to destination per overlay hop



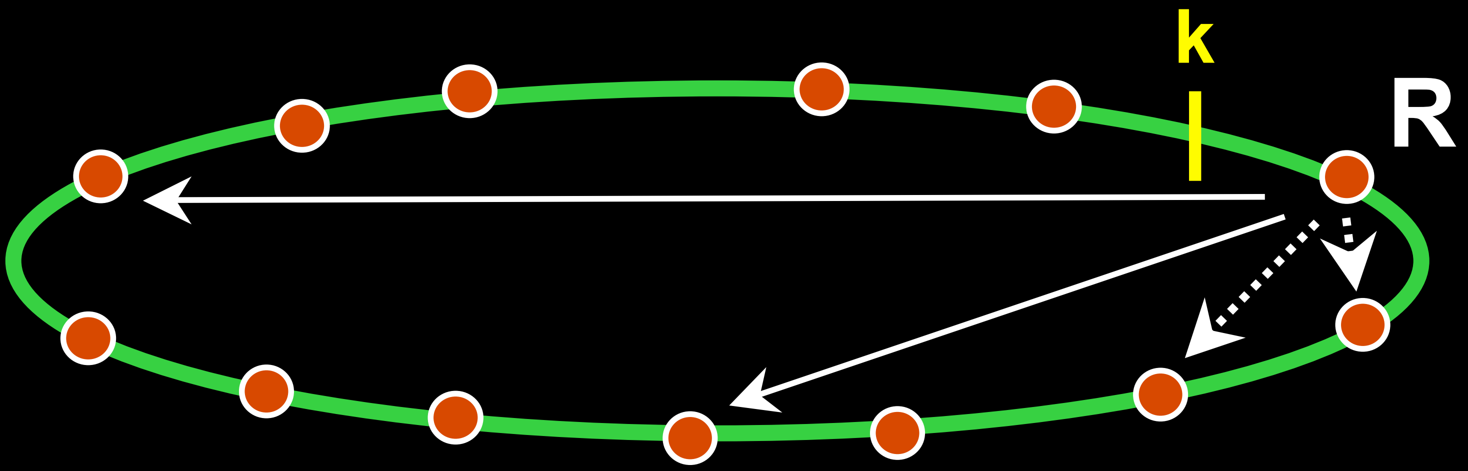
DHTs 101: Routing







DHTs 101: Routing tables

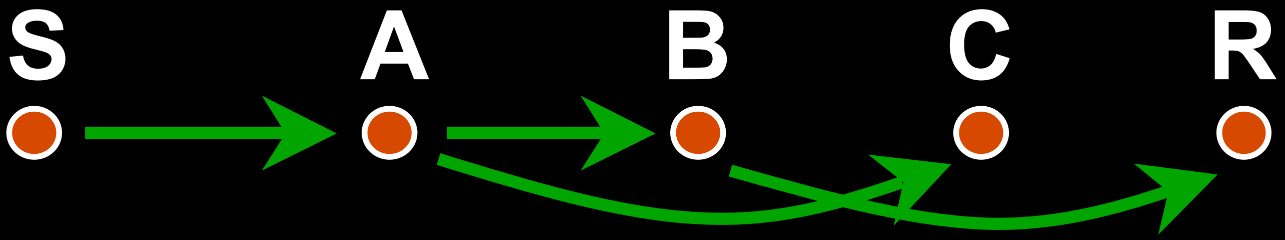


- successors / leaf set: ensure correctness
- fingers / routing table: efficient routing
  - O (log (n)) hops, generally

Problems we identify

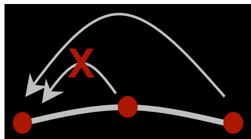
- Invisible nodes
- Routing loops
- Broken return paths
- Inconsistent roots

NTC problem fundamental?

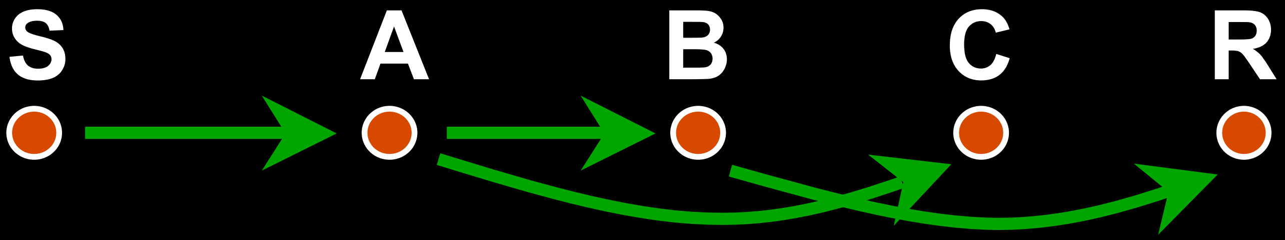


Traditional routing

S → R	A
A → R	B
B → R	R



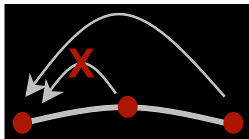
NTC problem fundamental?



Traditional routing	
S → R	A
A → R	B
B → R	R

Greedy routing	
S → R	A
A → R	C
C → R	X

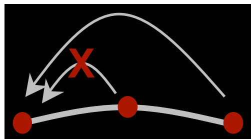
- DHTs implement greedy routing for scalability
- Sender might not use path, even though exists: finds local minima when id-distance routing



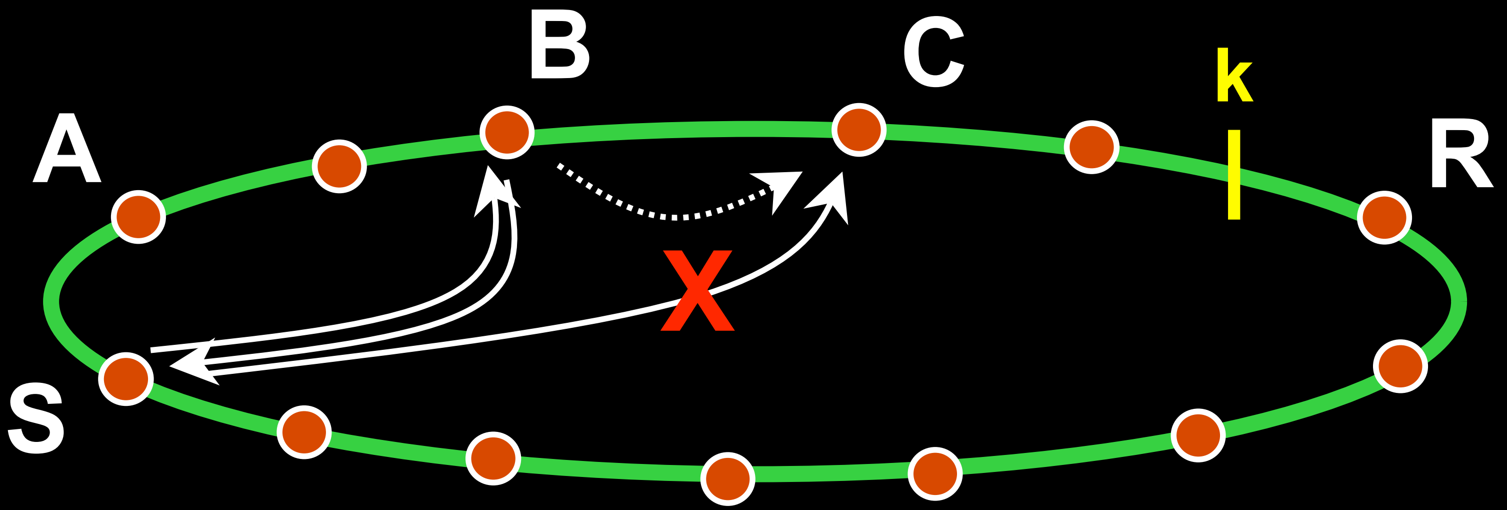
Problems we identify

- Invisible nodes
- Routing loops
- Broken return paths
- Inconsistent roots

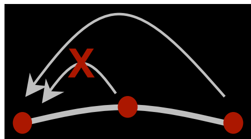
(First discuss how problems apply to iterative routing, then consider recursive routing.)



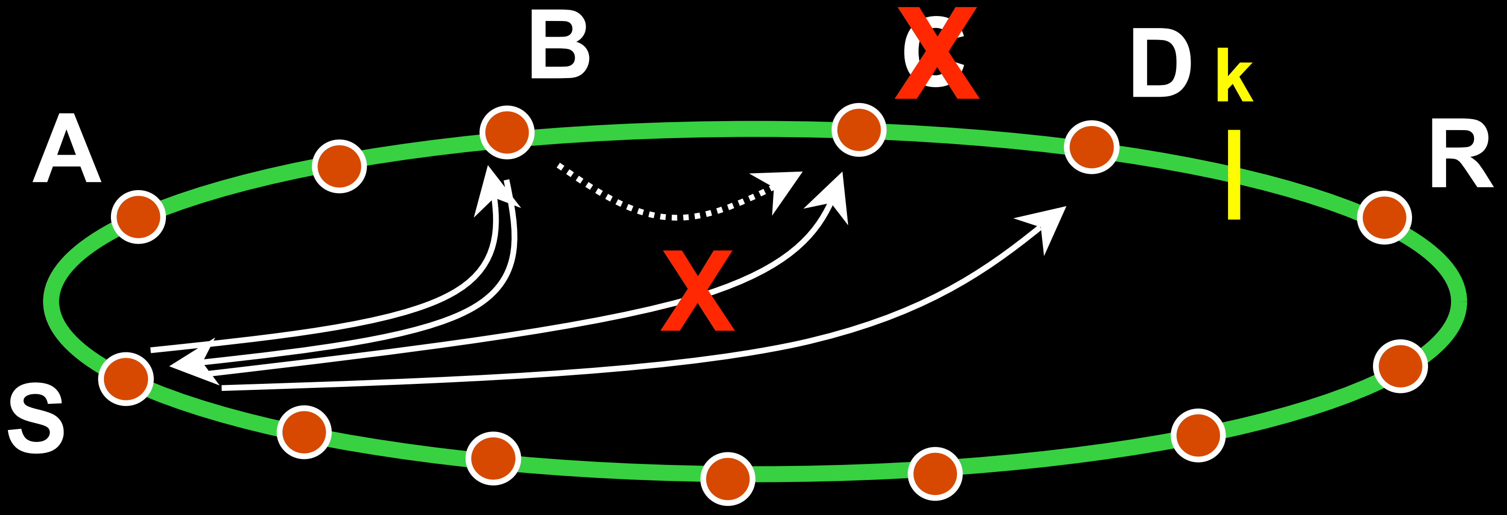
Iterative routing: Invisible nodes



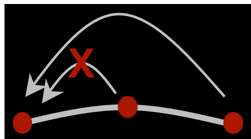
- Invisible nodes cause lookup to halt



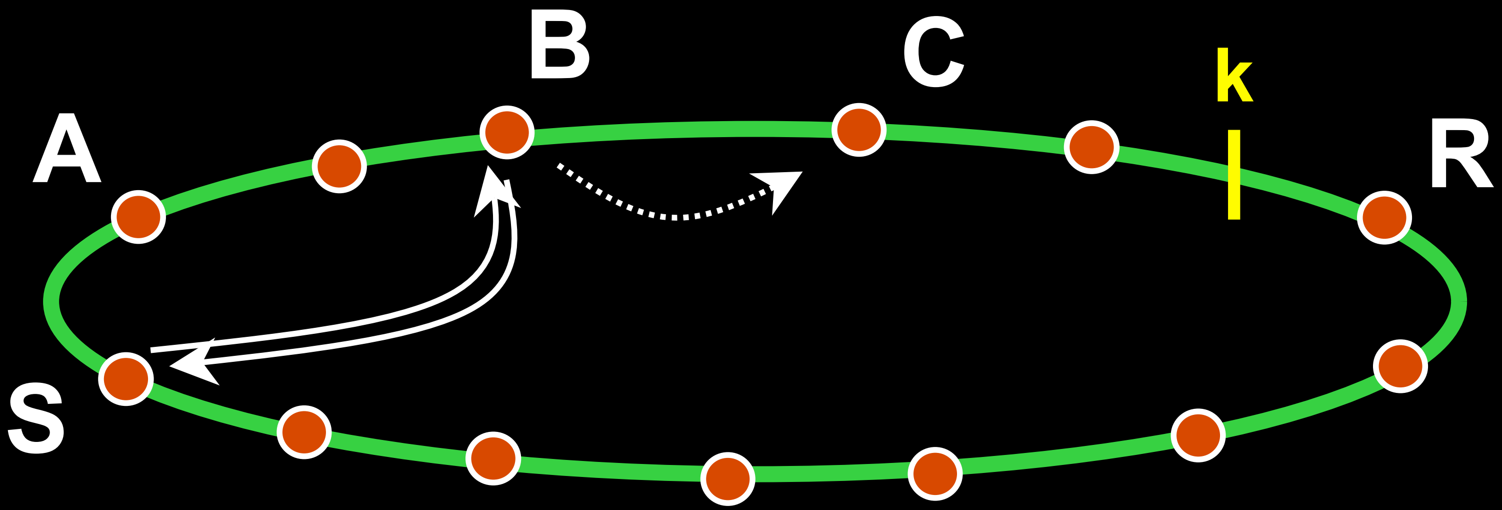
Iterative routing: Invisible nodes



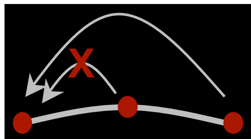
- Invisible nodes cause lookup to halt
- Enable lookup to continue
  - Tighter timeouts via network coordinates
  - Lookup RPCs in parallel
  - Unreachable node cache



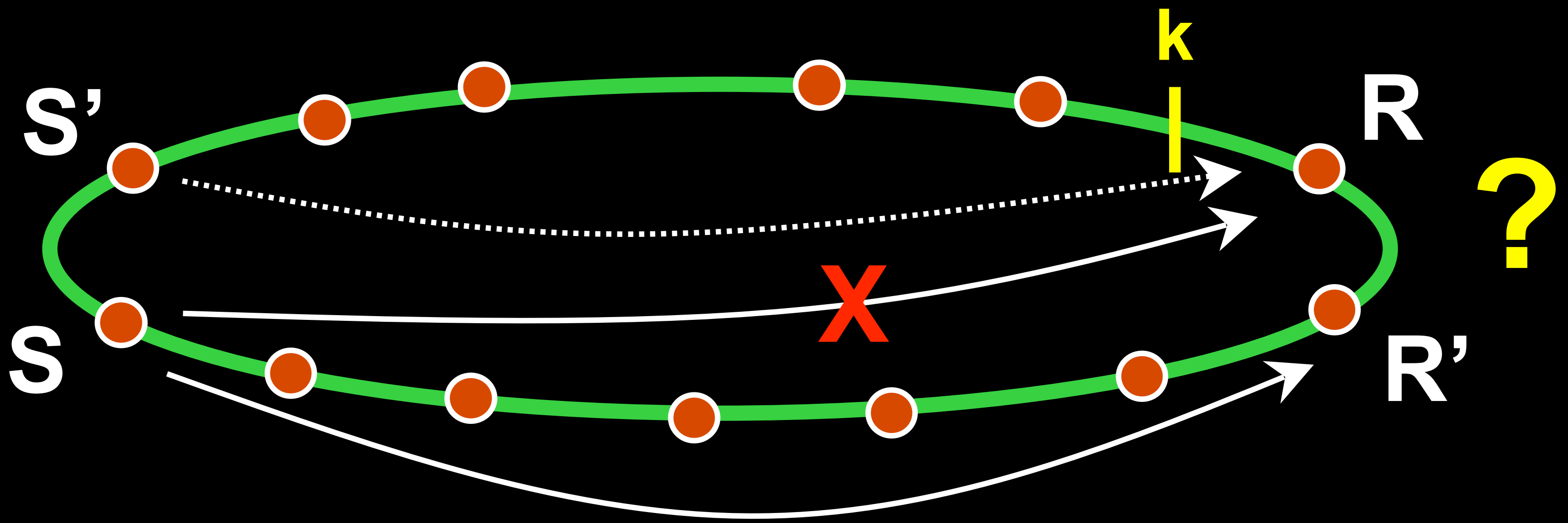
Routing table pollution



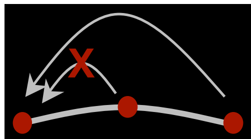
- Many proposals for maintaining routing tables
  - E.g., replace nodes with larger RTT
- Must first prevent routing table pollution
  - Only add new nodes upon contacting *directly*
  - Do not immediately remove nodes from hearsay



Inconsistent roots

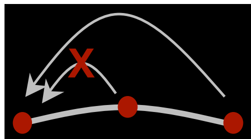


- Nodes do not agree where key is assigned: inconsistent views of root
  - Can be caused by membership changes
  - Also due to non-transitive connectivity
    - May persist indefinitely

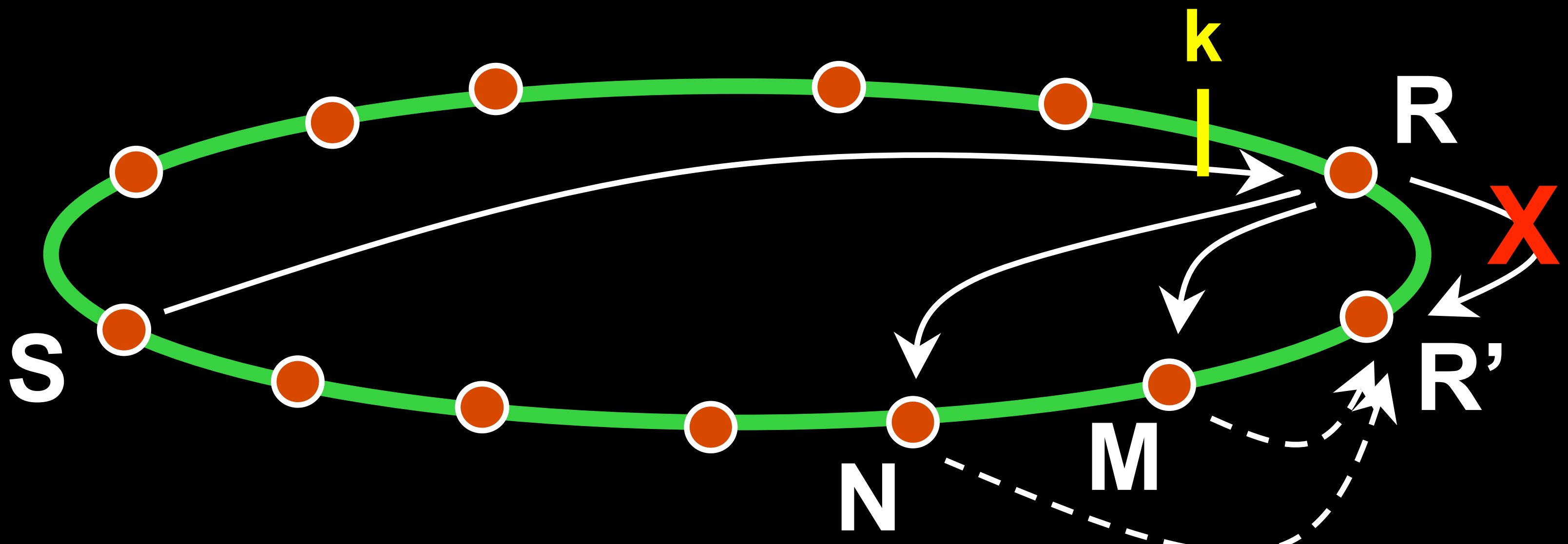


Inconsistent roots

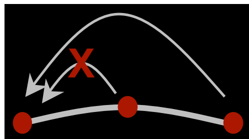
- No solution when network partitions
- If non-transitivity is limited:
  - Consensus among leaf set?
    - [Etna, Rosebud]
    - Expensive in messages and bandwidth
  - Link-state routing among leaf set?
    - [Pastry 1.4.1]
- Can use application-level solutions!



Inconsistent roots

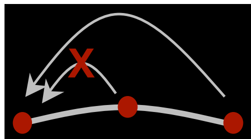


- Root replicates (key,value) among leaf set
  - Leafs periodically synchronize
  - Get gathers results from multiple leafs
  - [OpenDHT, DHash]
- Not applicable when require fast update (i3)

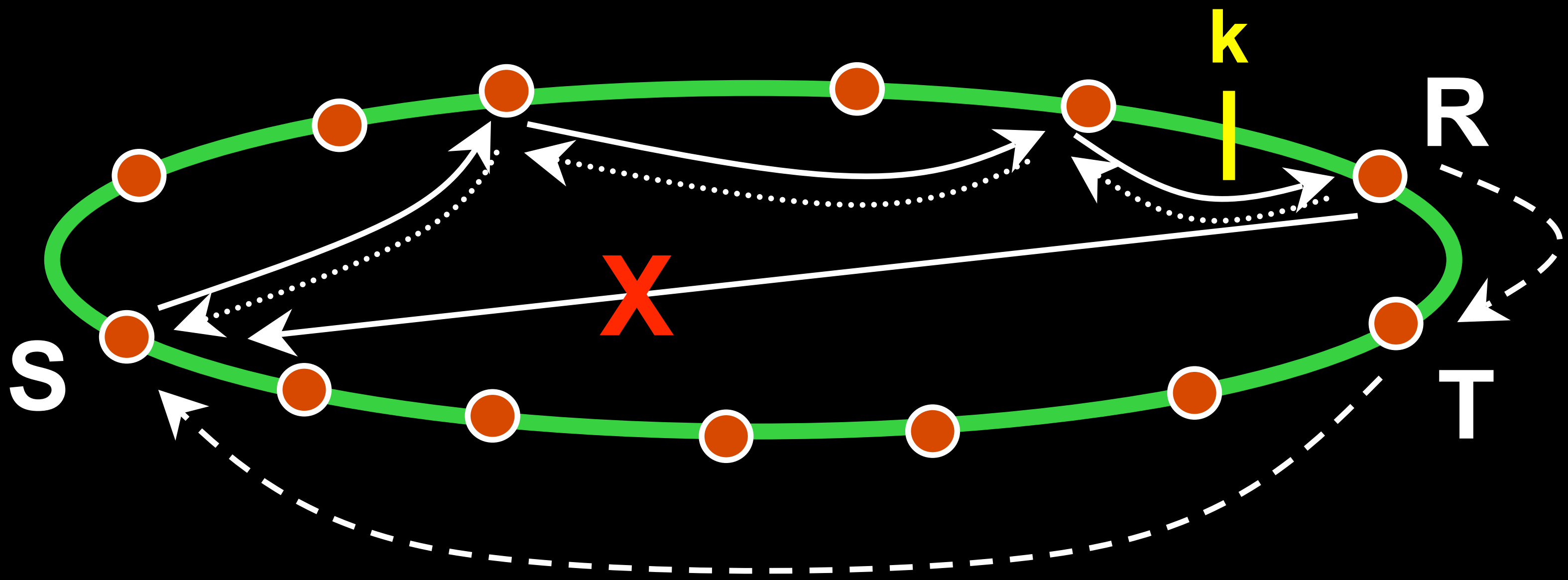


Recursive routing

- Invisible nodes
  - Must also prevent routing table pollution
  - Easier to achieve accurate timeouts
  - Harder to perform concurrent RPCs
- Inconsistent Roots
  - Similar solutions
- (Routing Loops)
- One new problem…



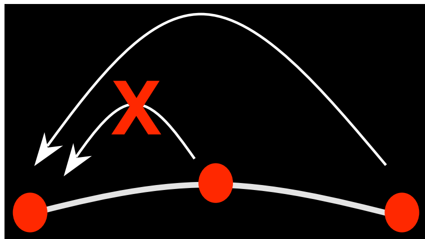
Broken return paths



- Direct path back from R to S fails
  - Source-route reverse path ....
  - Use single intermediate hop - - - -
    - RON, Detour, SOSR…

Summary

- Non-transitive connectivity exists
  - DHTs must deal with it
- Discovered problems the “hard way”
  - OpenDHT / Bamboo,   i3 / Chord,   Coral / Kademlia
  - Presented our “from the trenches” fixes
- NTC should be considered during design phase



Thanks…

Watch **O**ur **R**eal, **L**arge **D**istributed **S**ystems…

coralcdn.org

opendht.org

i3.cs.berkeley.edu