CS5412: OVERLAY NETWORKS

Lecture IV

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Overlay Networks

- We use the term *overlay network* when one network (or a network-like data structure) is superimposed upon an underlying network
- We saw this idea at the end of lecture III
- Today we'll explore some examples
  - The MIT "Resilient Overlay Network" (RON)
  - Content-sharing overlays (Napster, Gnutella, dc++)
  - Chord: An overlay for managing (key,value) pairs. Also known as a *distributed hash table* or DHT.

Why create a overlay?

- Typically, we're trying to superimpose some form of routed behavior on a set of nodes
- The underlying network gives the nodes a way to talk to each other, e.g. over TCP or with IP packets
- But we may want a behavior that goes beyond just being able to send packets and reflects some kind of end-user "behavior" that we want to implement

VPN overlays

- Many CS5412 students have experience with VPNs
  - A kind of remote login to your company or University
  - Allows you to access site securely through a firewall

- A VPN usually works by
  - Negotiating a security key (using saved credentials plus some form of password)
  - Making a TCP SSL (TLS) connection to a server
  - "Tunneling" traffic over that link; the IP address space of the VPN is available via this route

Next example: RON

- Developed at MIT by a research group that
  - Noticed that Internet routing was surprisingly slow to adapt during overloads and other problems
  - Wanted to move data and files within a set of nodes
  - Realized that "indirect" routes often outperformed direct ones
- What do we mean by an indirect route?
  - Rather than send file F from A to B, A sends to C and C relays the file to B
  - If the A-B route is slow, perhaps A-C-B will be faster

But doesn't Internet "route around" congestion?

- Early Internet adapted routing very frequently
  - Circumvent failed links or crashed routers
  - Cope with periodic connectivity, like dialup modems that are only connected now and then
  - Spread network traffic evenly by changing routing when loads change
- By 1979 a problem was noticed
  - Routing messages were creating a LOT of overhead
  - In fact the rate of growth of this overhead was faster than the rate of growth of the network size & load!

How can overheads grow so fast?

- Think about the idea of algorithmic complexity
  - Like for sorting

- In a single machine, we know that sorting takes time O(n log n) but that bubble sort is slow and takes time $O(n^2)$.
  - Both do the same thing
  - But bubble sort is just an inefficient way to do it
  - Leads to notion of asymptotic complexity

Protocols have complexity too!

- Can be measured in many ways
  - How many messages are sent in total on the network?
  - How many do individual nodes send or receive?
  - How many "rounds" of the protocol are required
  - How many bytes of data are exchanged?
    - Of this how much is legitimate data and how much was added by the protocol?
    - Of the legitimate data, how many bytes are ones the receiver has never seen, and how many are duplicates?
  - How directly does data go from source to destination?

Complexity of routing protocols

- Routing protocols vary widely in network complexity
- BGP, for example, is defined in terms of dialog between a BGP instance and its peers
  - At start, sends initialization messages that inform peers of the full routing table.
  - Subsequently, sends "incremental" update messages that announce new routes and withdraw old ones
- To understand the complexity of BGP we need to understand relationship between frequency of these packets size of network, and rate of network "events"

BGP complexity study

- Can be evaluated using theory tools.
- Create a model… then present equations that predict costs in terms of event rates

[Bringing order to BGP: decreasing time and message complexity. Anat Bremler-barr, Nir Chen, Jussi Kangasharju, Osnat Mokryn, Yuval Shavitt. ACM Principles of Distributed Computing (PODC), Aug. 2007, pp. 368-369.]

But more common to just use practical tools

- For example, back in 1979, Internet developers simply measured the percentage of network traffic that was due to network management protocols
- They discovered it was quite high and rising
- Concluded that steps were needed to reduce costs
  - Eliminated routing protocols that had higher overheads
  - Reduced rate of routing adaptations

Today's Internet?

- There are *many* reasons routing adapts slowly
  - Old desire to keep overheads low
  - Modern need to route heavy traffic on economically efficient paths
  - Many policies and "cross-border" deals between ASs enter the picture
  - Best route is the cheapest route to operate not necessarily the route that makes the A-B file transfer move fastest!

How RON approaches this

- They built an infrastructure that supports *IP tunneling*
  - Means that a packet from A to B might be treated as data and placed within a packet from A to C
  - Sometimes called "IP over IP"
- Now they can implement their own special routing layer that decides how to get data from A to B
  - A sends packet
  - RON intercepts it and "encapsulates" it for tunneling
  - Routes on its own routing infrastructure (still on the Internet)
  - On arrival, de-encapsulate and deliver

How RON approaches this

- Build an all-to-all monitoring tool to track bandwidth and delay (latency)
  - Part of the trick was to estimate one-way costs
  - For brevity won't delve into those details
- This results in a table (we'll just show latency):

	A	B	C
A	-	17	9
B	5	-	22
C	14	2	-

- Note that A-B delay is 17ms, but A-C is 9 and C-B 2

Source routing

- RON sender
  - Computes the best route considering direct and also one-hop indirect routes
  - Encapsulated packets
  - Specifies the desired routing in a special header: a form of "source routing"
- RON daemons relay the packet as instructed
- On arrival, extract inner packet and deliver it

RON really works!

- MIT studies showed big performance speedups using this technique!
  - In fact the direct routes are almost *always* worse than the best indirect routes
  - And a single indirect hop is generally all they needed (double indirection adds too much delay)
- RON also adapts quickly
  - Internet routes much more slowly

Learning from history…

- Concept: *Tragedy of the Commons* (or "Crisis")
  - We share a really great resource (the "commons")
  - But someone decides to use the commons for themseles in an unsustainable way and gains economic advantage
  - We need to be competitive, so all of us do the same
  - This denudes the commons… Everyone loses
- When we share a limited resource, sometimes the bet shared policy isn't the best *individual* one

What does this say about RON?

- For the individual user, RON makes things better
- But if we believe that economics has "shaped" the Internet, RON basically cheats!
  - In effect, the RON user is getting more network resource than he's paying for by circumventing the normal sharing policy
  - If everyone did this, the RON approach would break down much as the commons ends up with no grass left

Broader theory...

- The research community has been interested in what are called "Nash Equillibria"
- Idea is that a set of competitors each have a "utility" function (a measure of happiness) and sets of strategies that guide their action
  - Such as "decide to graze my cow on the commons"
- Goal is to find a configuration where if any player were to use some other strategy, they would lose utility
  - In principle we all see the logic of the optimal strategy
  - But assumes that players are logical and able to see big picture

Other cases for overlays?

- A major use of overlays has been in *peer to peer file sharing services* such as Napster, Gnutella, dc++

- These generally have two aspects
  - A way to create a list of places that have the file you want (perhaps, a movie you want to download)
  - A way to connect to one of those places to pull the file from that machine to yours
    - Once you have the file, your system becomes a possible source for other users to download from
    - In practice, some users tend to run servers with better resources and others tend to be mostly downloaders

A mix of technical and non-technical issues

- Non-technical: what is the "tragedy of the commons" scenario if everyone uses these sharing services?
- How should the law deal with digital IP ownership
- If a web search helps you find "inappropriate" content, or an ISP happens to carry that, were they legally responsible for doing so?

Technical issue

- What's the very best way for a massive collection of computers in the wide-area Internet (the WAN) to implement these two aspects
  - Best way to do search?
  - Best way to implement peer-to-peer downloads?

- Cloud computing solutions often have a search requirement so we'll focus on that
  - Useful even within a single data center

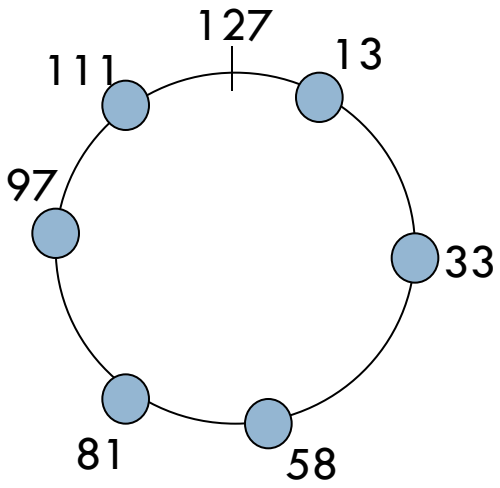
Context

- We have a vast number of machines (millions)
- Goal is to support (key,value) operations
  - Put(key,value) stores this value in association with key
  - Get(key) finds the value currently bound to this key
- Some systems allow updates, some allow multiple bindings for a single key. We won't worry about those kinds of detail today

P2P "environment"

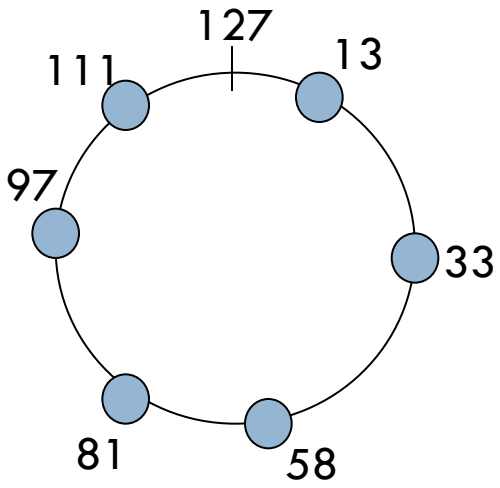
- Nodes come and go at will (possibly quite frequently---a few minutes)
- Nodes have heterogeneous capacities
  - Bandwidth, processing, and storage
- Nodes may behave badly
  - Promise to do something (store a file) and not do it (free-loaders)
  - Attack the system

Basics of all DHTs



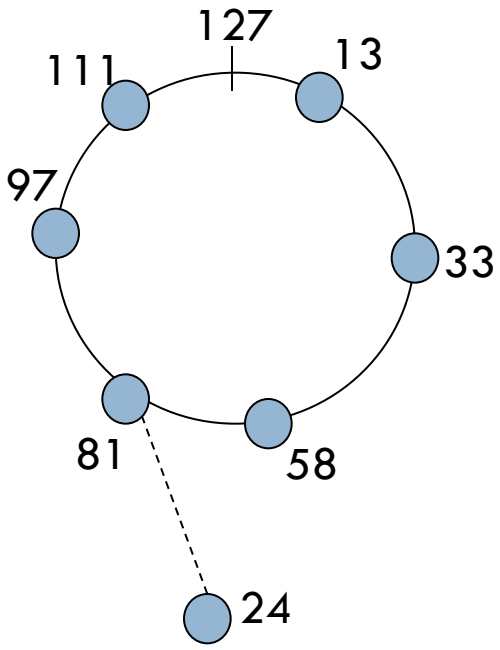
- Goal is to build some "structured" overlay network with the following characteristics:
  - Node IDs can be mapped to the hash key space
  - Given a hash key as a "destination address", you can route through the network to a given node
  - Always route to the same node no matter where you start from

Simple example (doesn't scale)



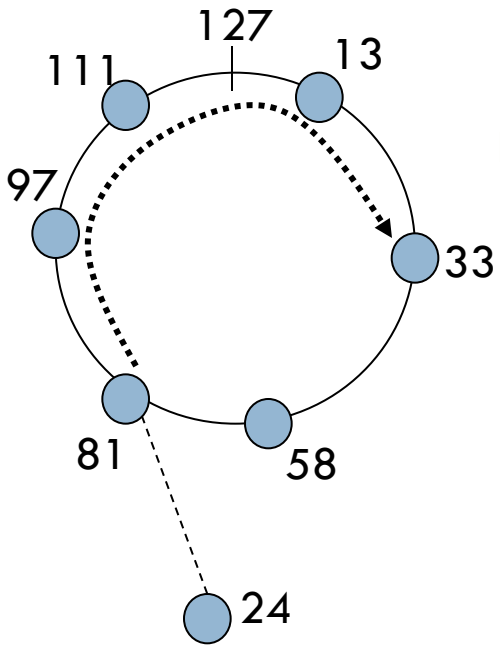
- Circular number space 0 to 127
- Routing rule is to move counter-clockwise until current node ID ≥ key, and last hop node ID < key
- Example: key = 42
- Obviously you will route to node 58 from no matter where you start

Building any DHT



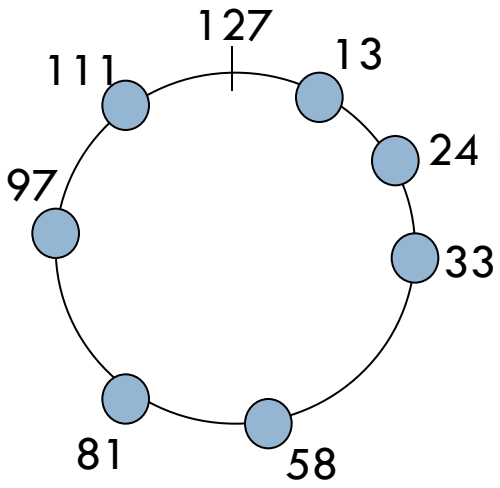
- Newcomer always starts with at least one known member

Building any DHT



- Newcomer always starts with at least one known member
- Newcomer searches for "self" in the network
  - hash key = newcomer's node ID
  - Search results in a node in the vicinity where newcomer needs to be

Building any DHT



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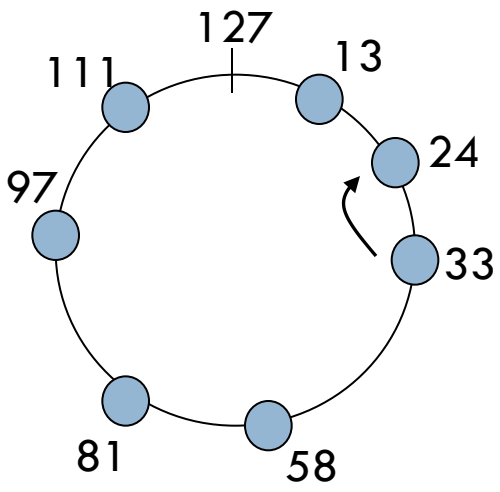
- Links are added/removed to satisfy properties of network

Building any DHT



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- Newcomer searches for "self" in the network
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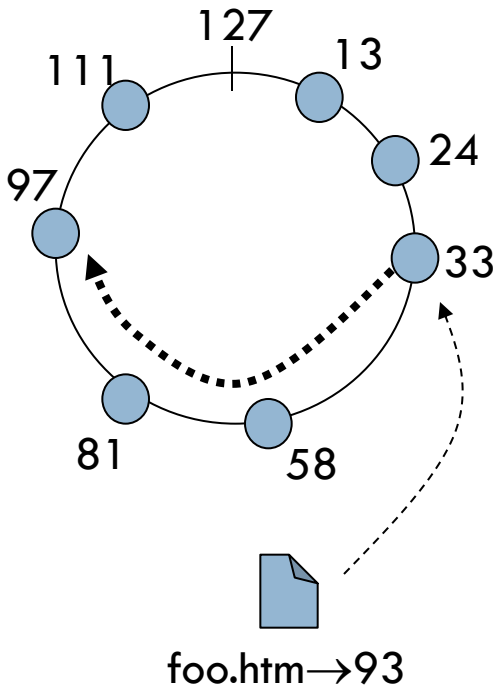
- Search results in a node in the vicinity where newcomer needs to be
- Links are added/removed to satisfy properties of network
- Objects that now hash to new node are transferred to new node

Insertion/lookup for any DHT



- Hash name of object to produce key
  - Well-known way to do this
- Use key as destination address to route through network
  - Routes to the target node
- Insert object, or retrieve object, at the target node

Properties of most DHTs

- Memory requirements grow (something like) logarithmically with N
- Unlike our "any DHT", where routing is linear in N, real DHTs have worst possible routing path length (something like) logarithmic with N
- Cost of adding or removing a node grows (something like) logarithmically with N
- Has caching, replication, etc…

DHT Issues

- Resilience to failures
- Load Balance
  - Heterogeneity
  - Number of objects at each node
  - Routing hot spots
  - Lookup hot spots
- Locality (performance issue)
- Churn (performance and correctness issue)
- Security

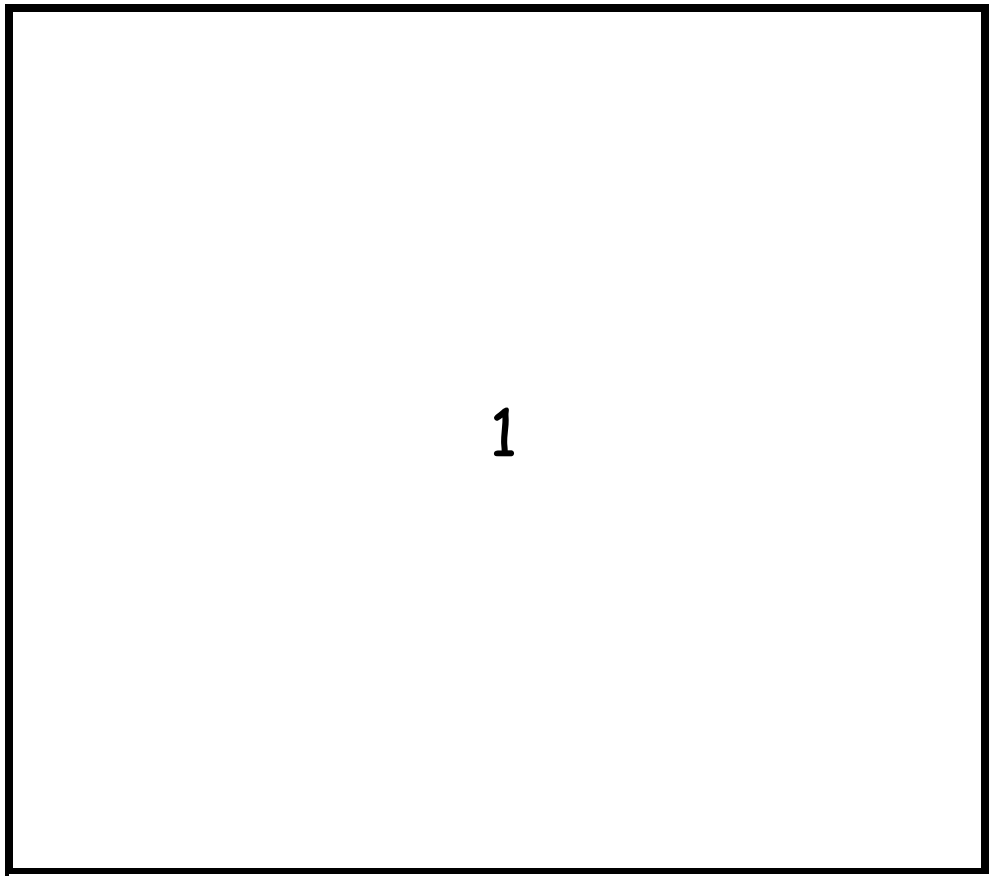
We're going to look at four DHTs

- At varying levels of detail…
  - CAN (Content Addressable Network)
    - ACIRI (now ICIR)
  - Chord
    - MIT
  - Kelips
    - Cornell
  - Pastry
    - Rice/Microsoft Cambridge

Things we're going to look at

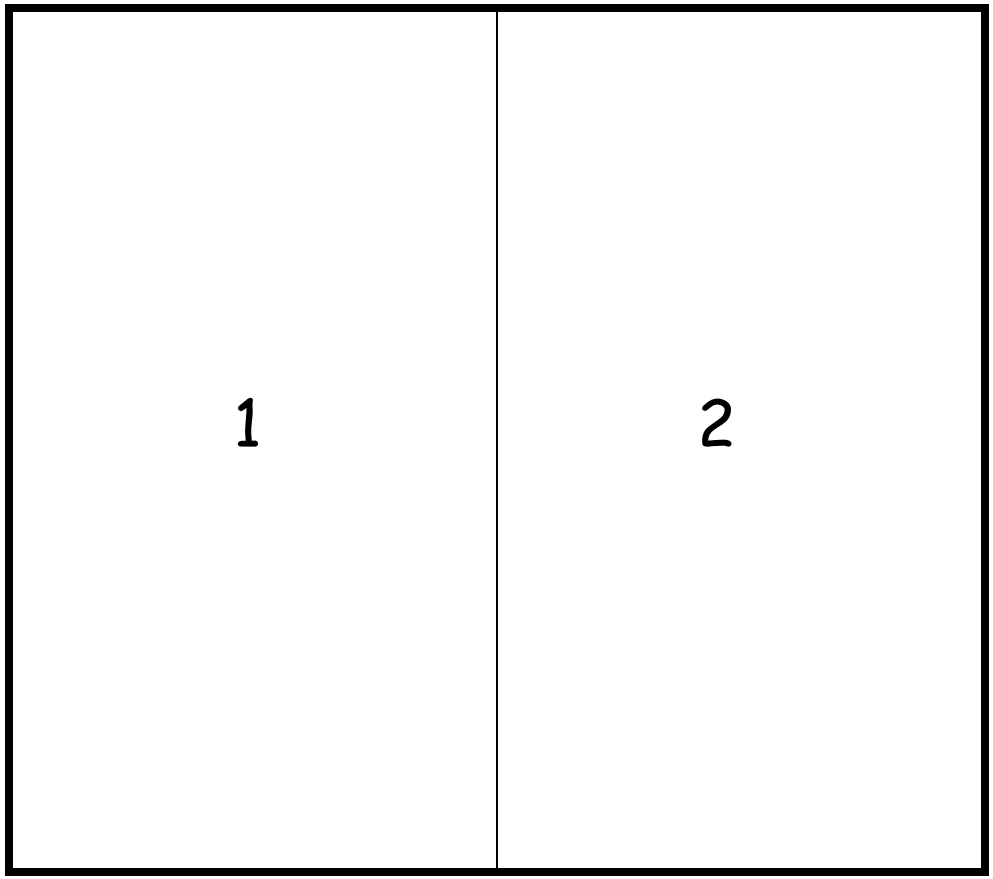
- What is the structure?
- How does routing work in the structure?
- How does it deal with node departures?
- How does it scale?
- How does it deal with locality?
- What are the security issues?

CAN structure is a cartesian coordinate space in a D dimensional torus

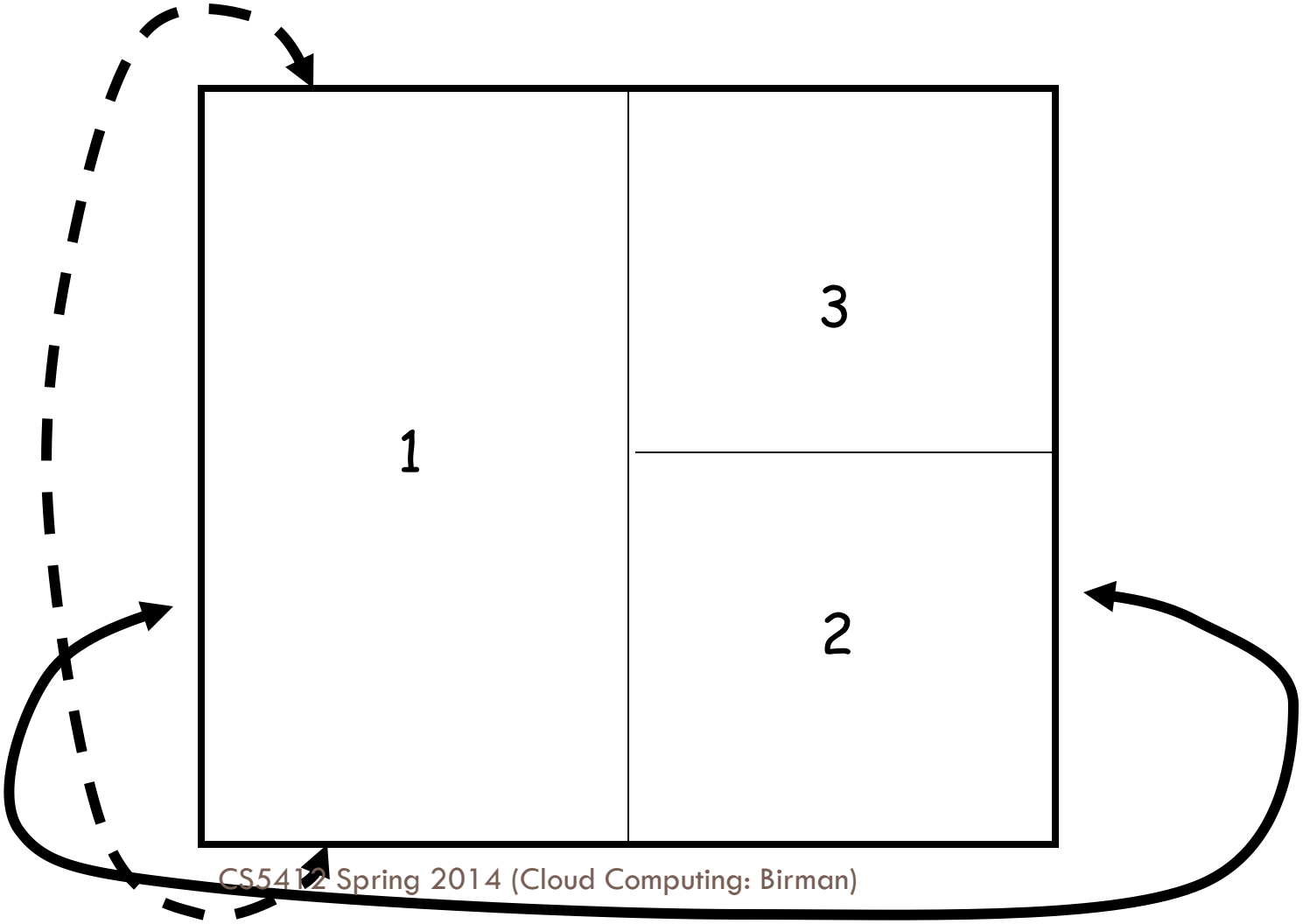


CAN graphics care of Sanjashil PalChaudhuri, Rice Univ

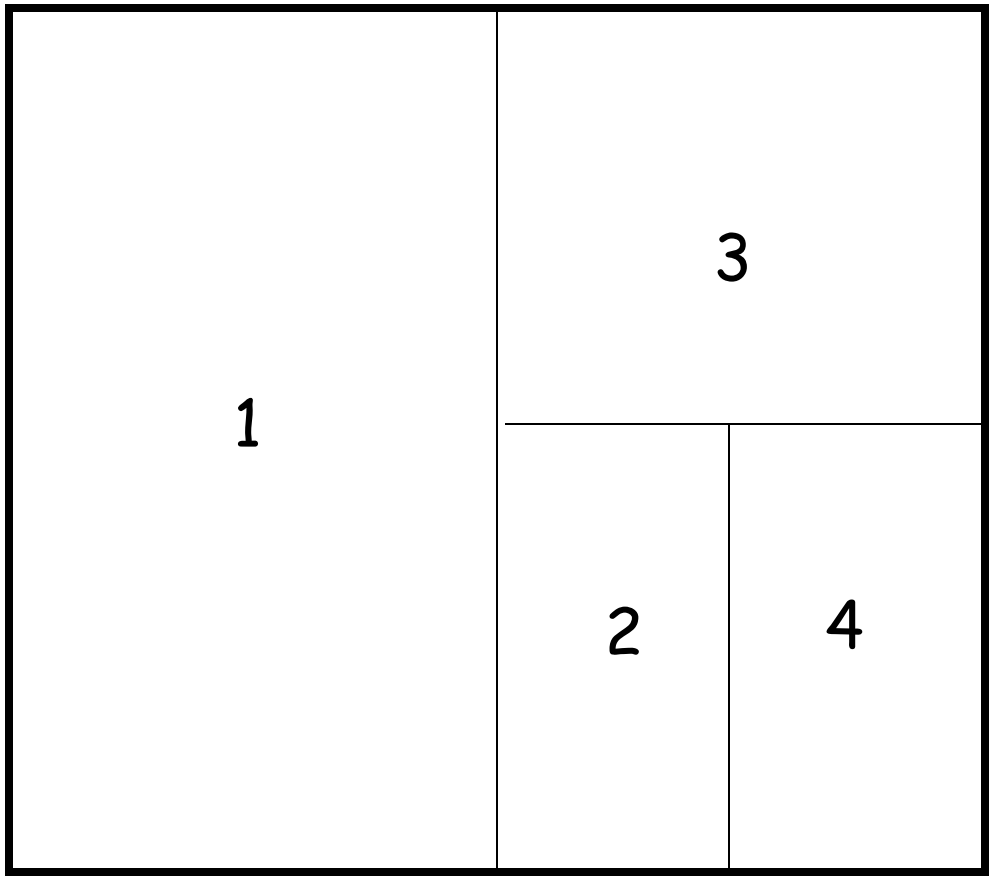
Simple example in two dimensions



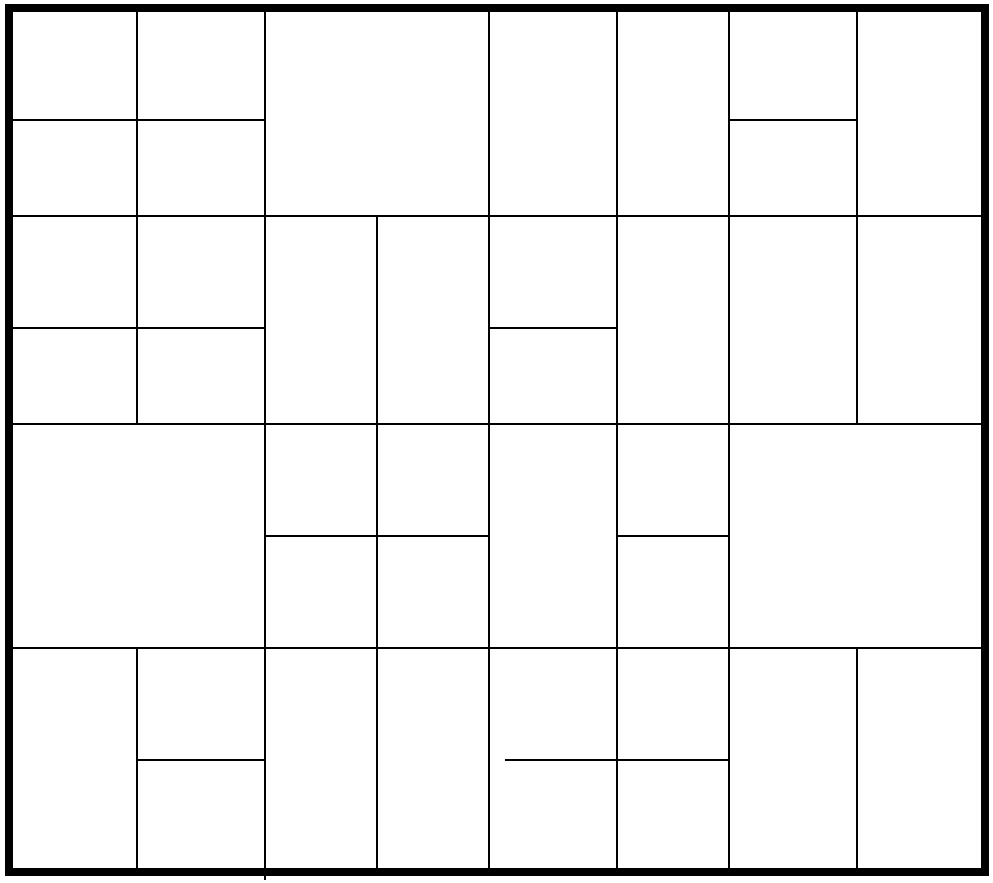
Note: torus wraps on "top" and "sides"



Each node in CAN network occupies a "square" in the space

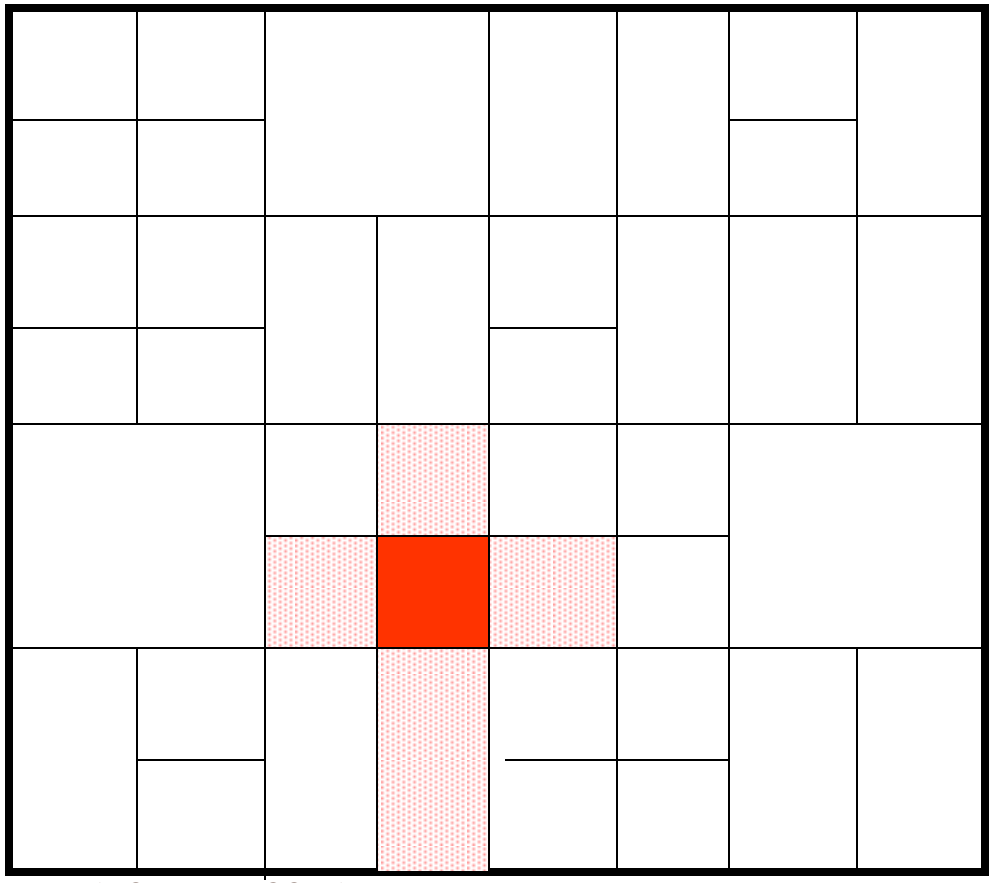


With relatively uniform square sizes



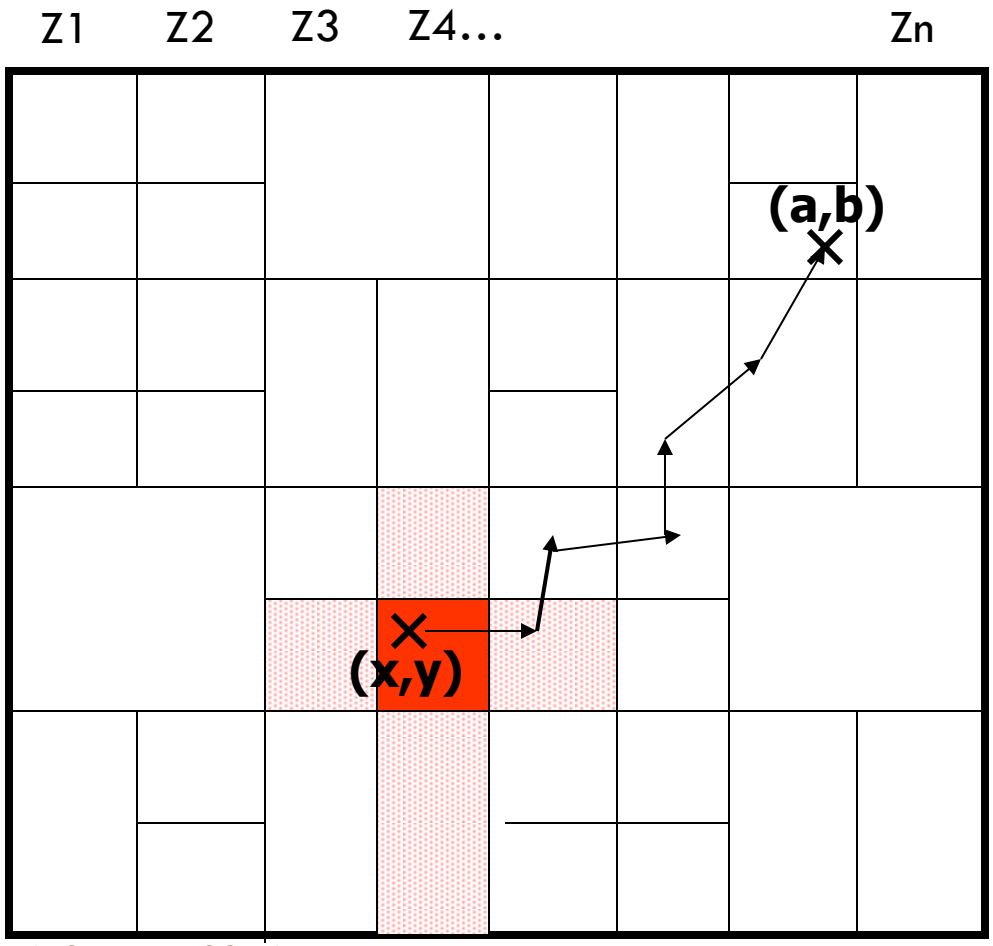
Neighbors in CAN network

- Neighbor is a node that:
- Overlaps d-1 dimensions
- Abuts along one dimension

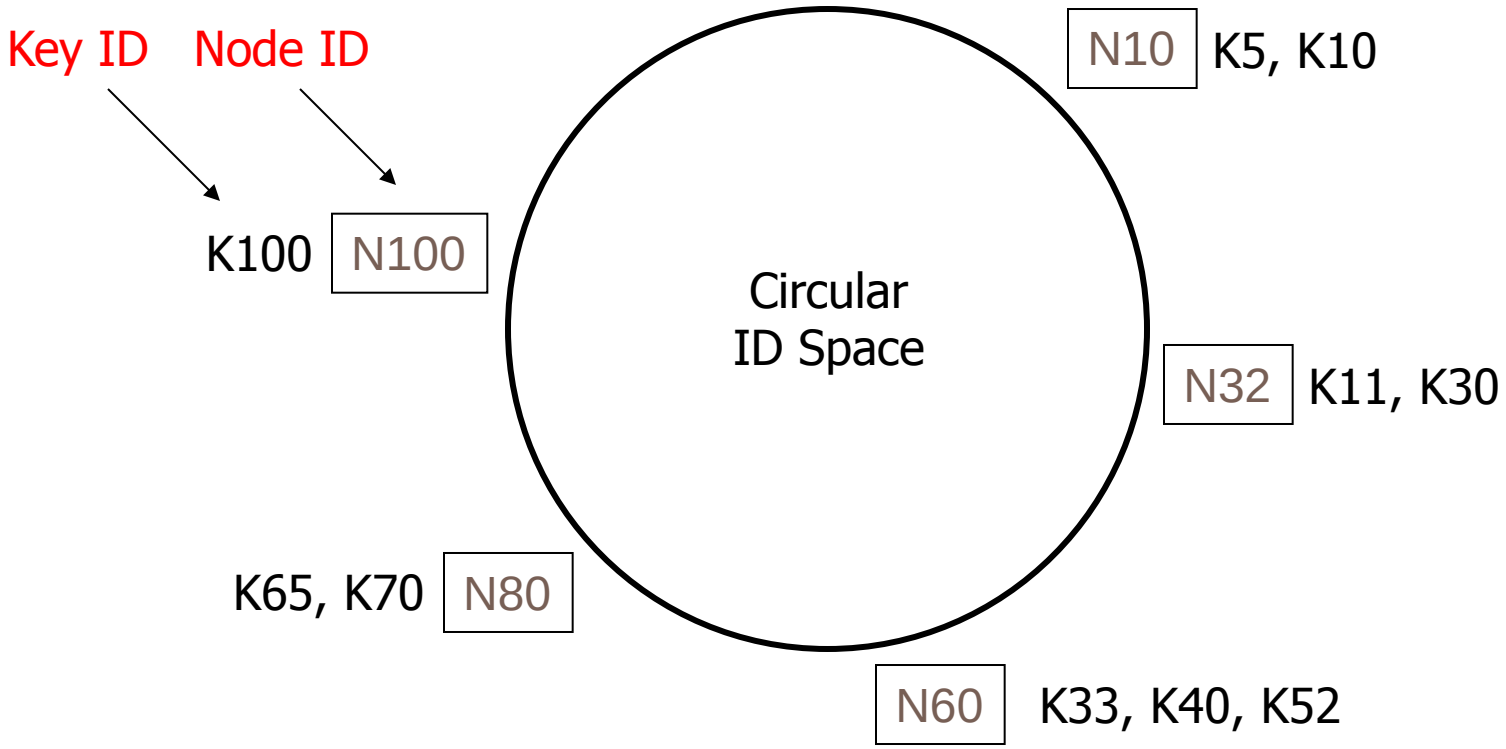


Route to neighbors closer to target

- d-dimensional space
- n zones
  - Zone is space occupied by a "square" in one dimension
- Avg. route path length
  - $(d/4)(n^{1/d})$
- Number neighbors = O(d)
- Tunable (vary d or n)
- Can factor proximity into route decision



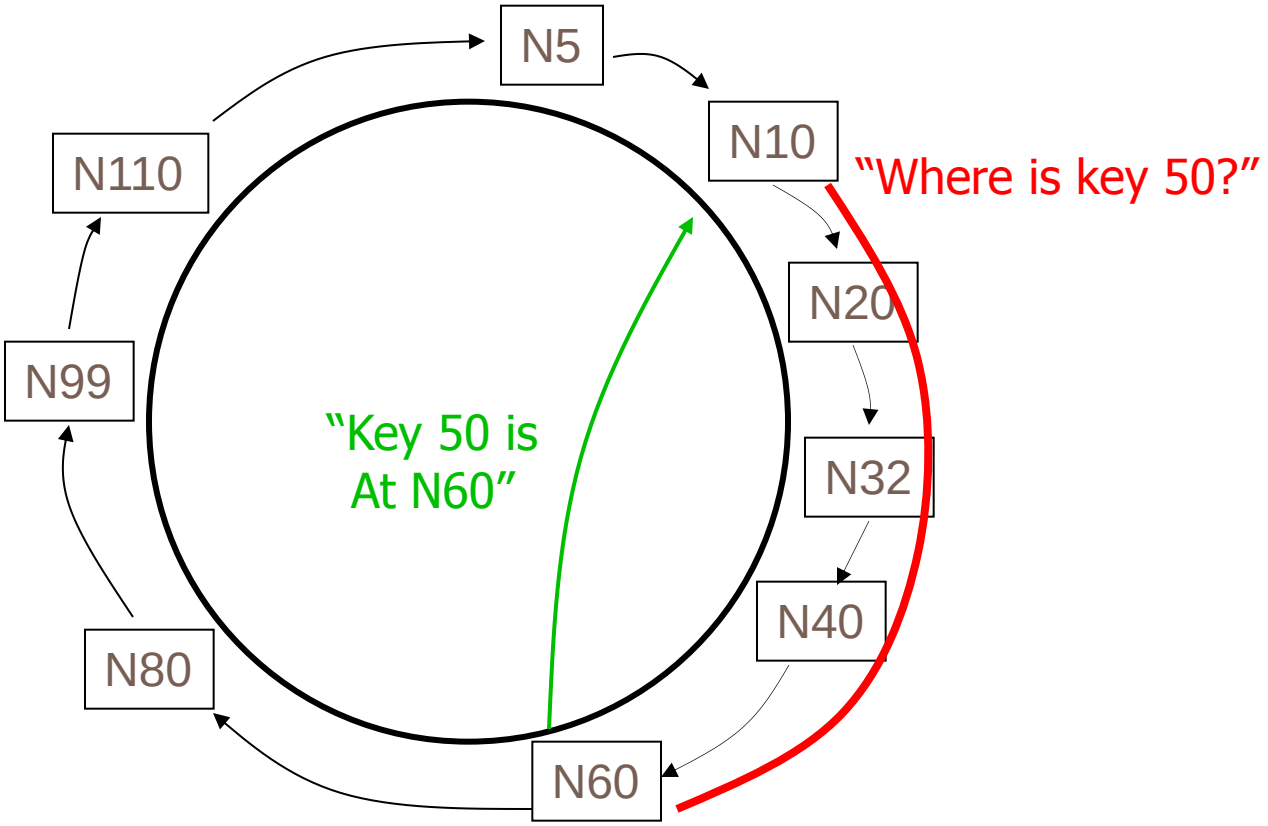
Chord uses a circular ID space



- Successor: node with next highest ID

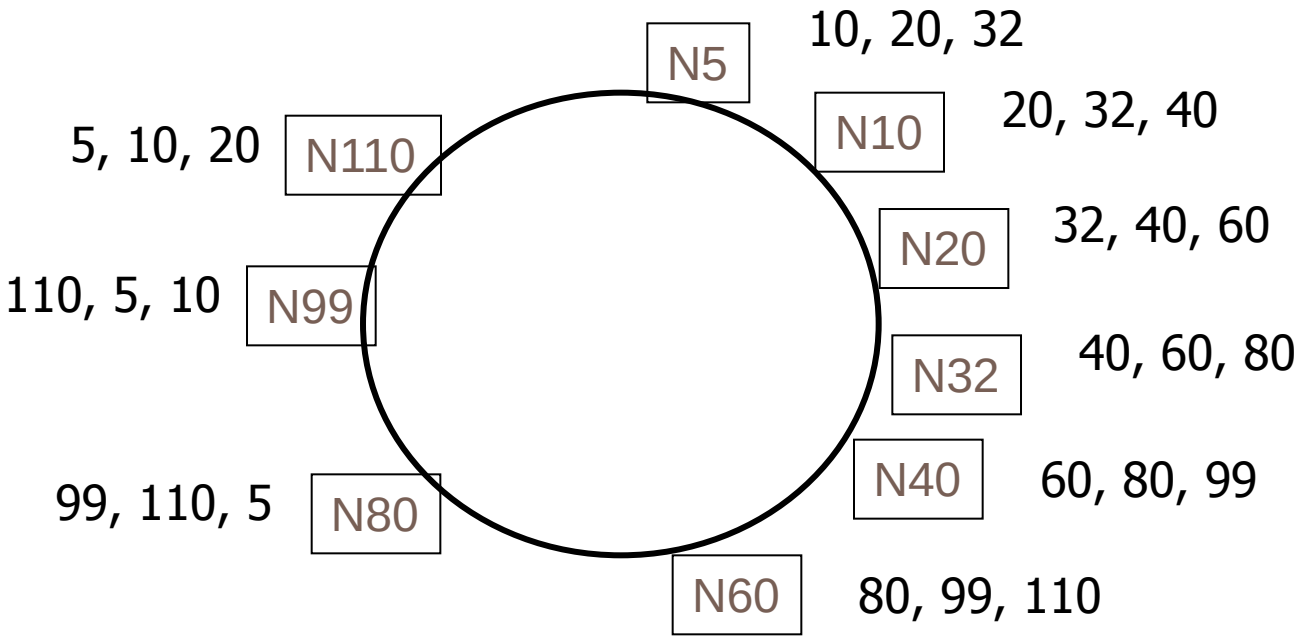
Chord slides care of Robert Morris, MIT

Basic Lookup



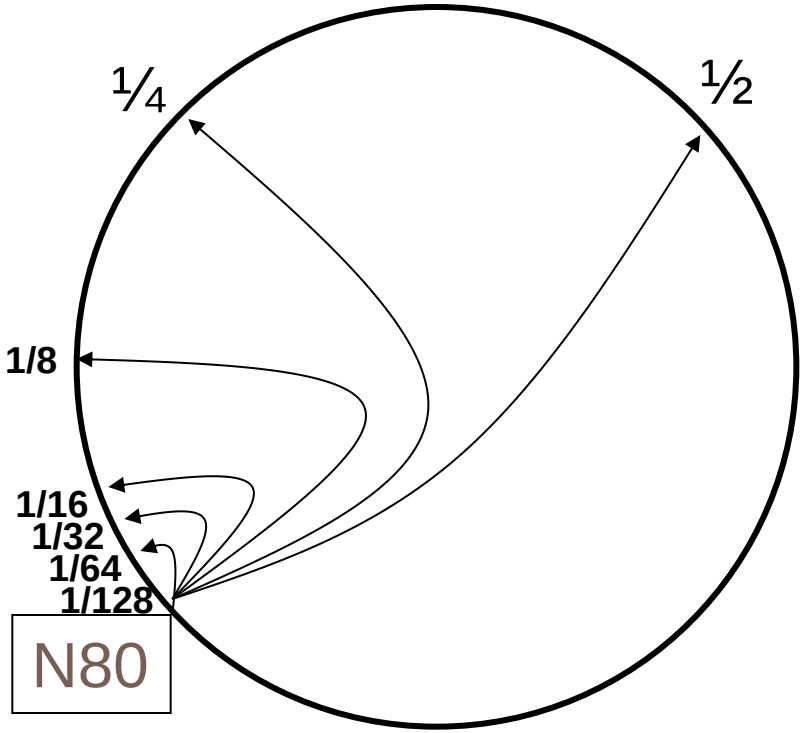
- Lookups find the ID's predecessor
- Correct if successors are correct

Successor Lists Ensure Robust Lookup



- Each node remembers r successors
- Lookup can skip over dead nodes to find blocks
- Periodic check of successor and predecessor links

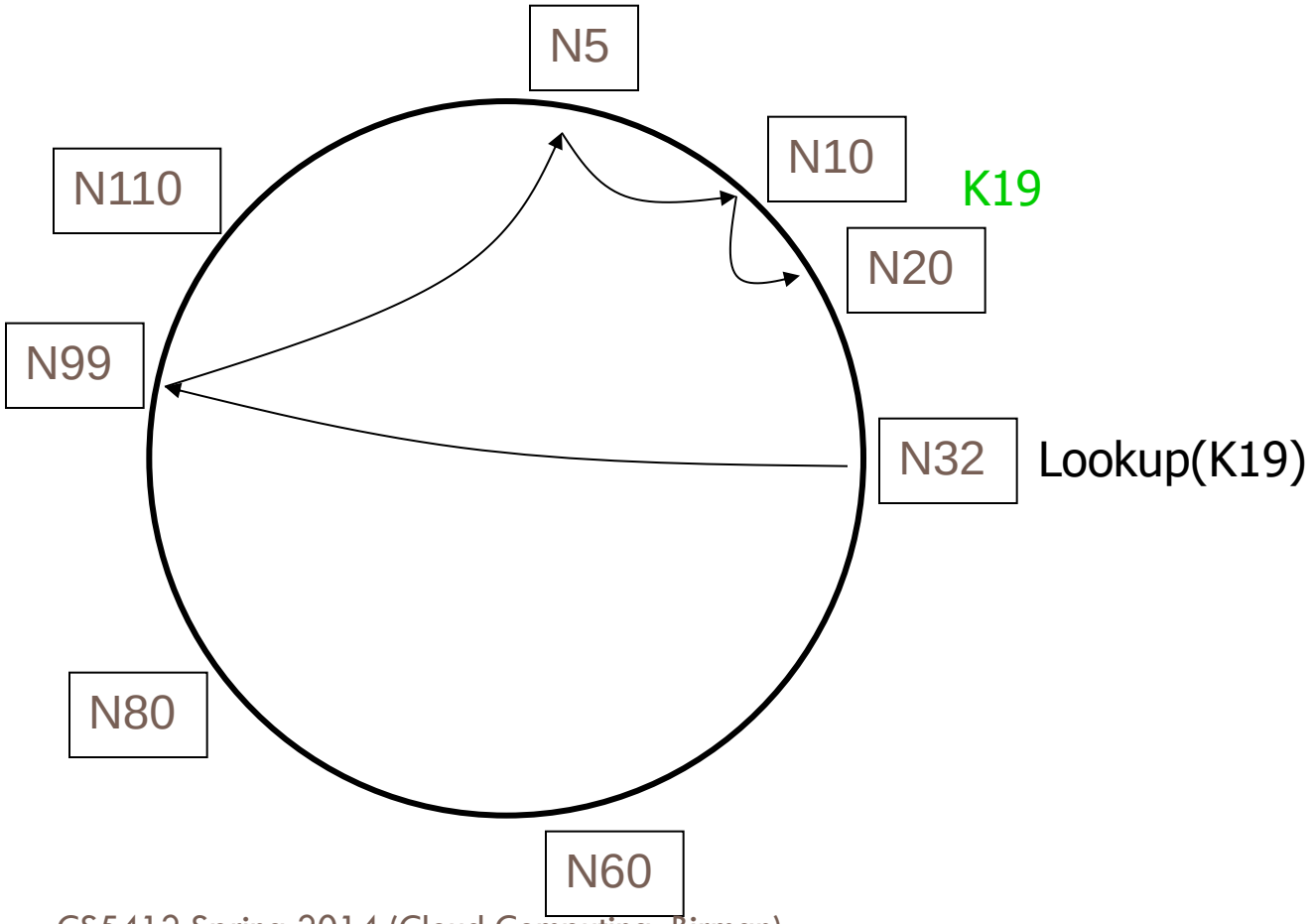
Chord "Finger Table" Accelerates Lookups



To build finger tables, new node searches for the key values for each finger

To do it efficiently, new nodes obtain successor's finger table, and use as a hint to optimize the search

Chord lookups take O(log N) hops



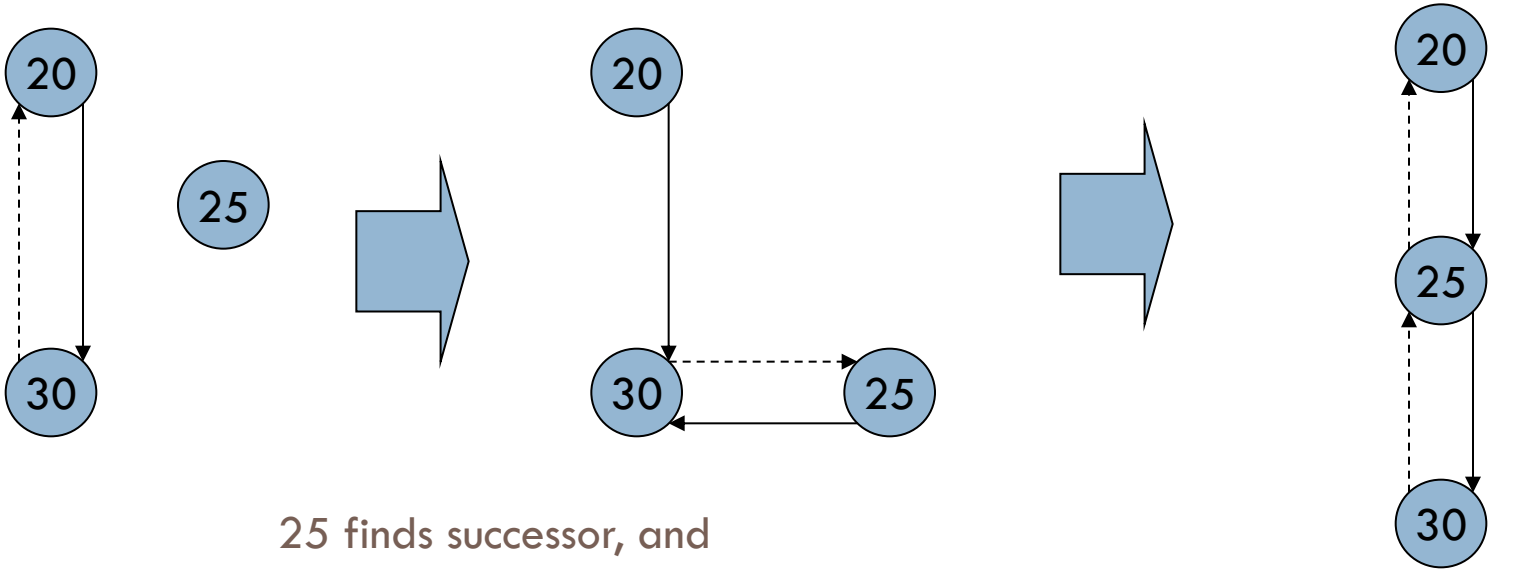
Drill down on Chord reliability

- Interested in maintaining a correct routing table (successors, predecessors, and fingers)
- Primary invariant: correctness of successor pointers
  - Fingers, while important for performance, do not have to be exactly correct for routing to work
  - Algorithm is to "get closer" to the target
  - Successor nodes always do this

Maintaining successor pointers

- Periodically run "stabilize" algorithm
  - Finds successor's predecessor
  - Repair if this isn't self
- This algorithm is also run at join
- Eventually routing will repair itself
- Fix_finger also periodically run
  - For randomly selected finger

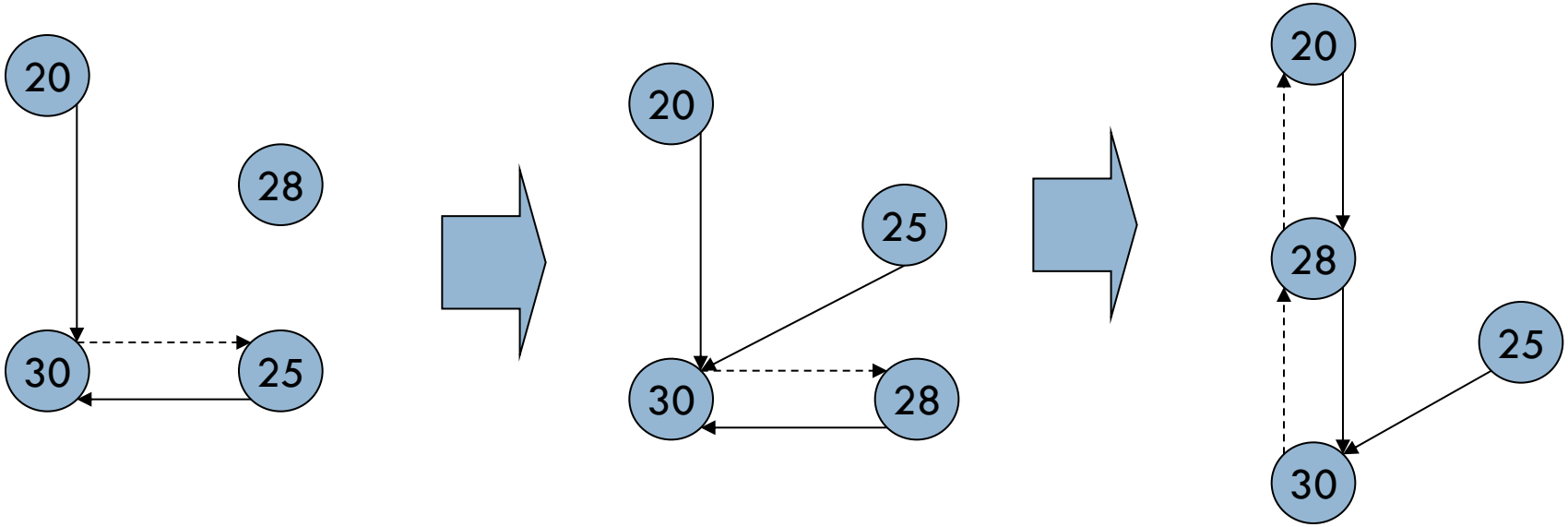
Initial: 25 wants to join correct ring (between 20 and 30)



25 finds successor, and tells successor (30) of itself

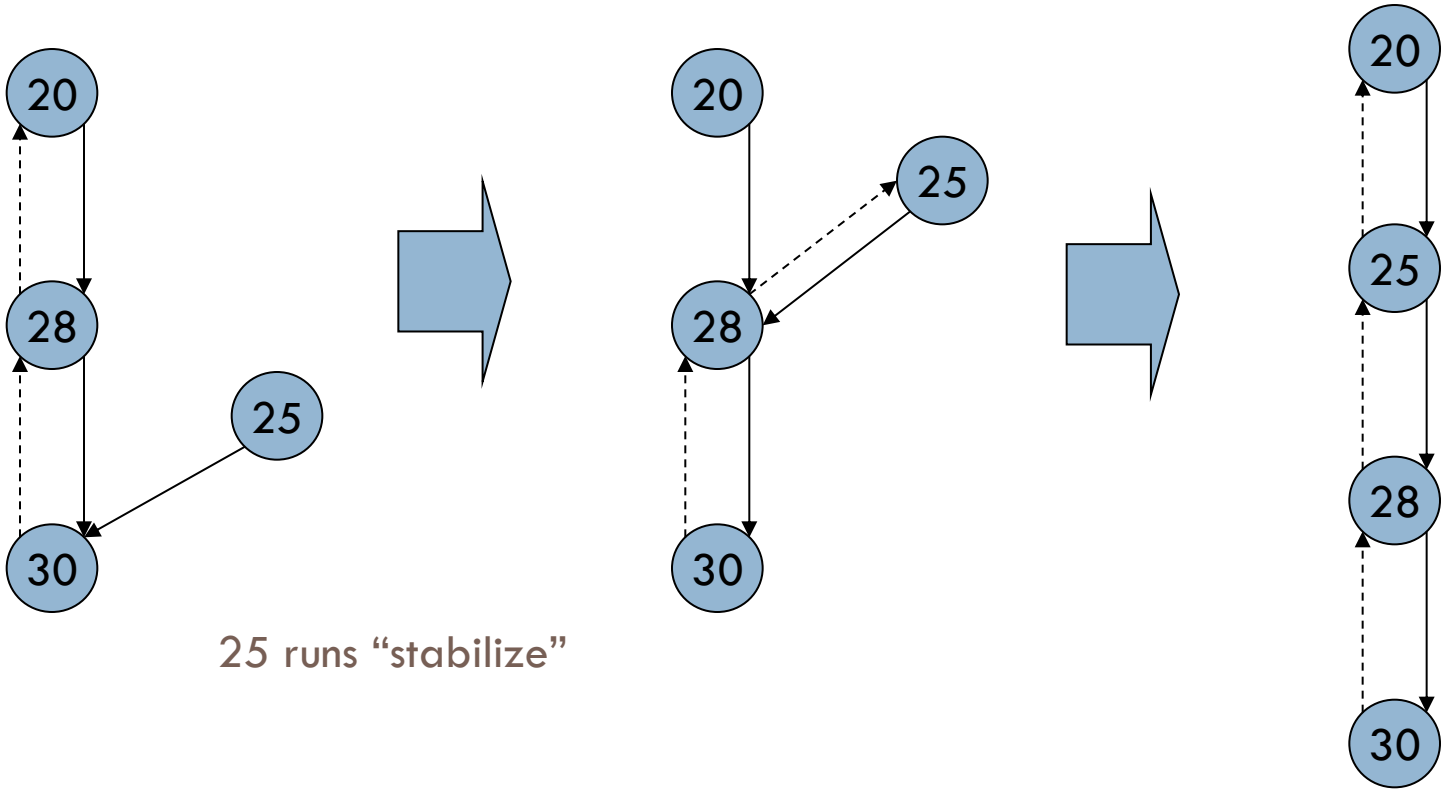
20 runs "stabilize":
20 asks 30 for 30's predecessor
30 returns 25
20 tells 25 of itself

This time, 28 joins before 20 runs "stabilize"



28 finds successor, and tells successor (30) of itself

20 runs "stabilize":
20 asks 30 for 30's predecessor
30 returns 28
20 tells 28 of itself



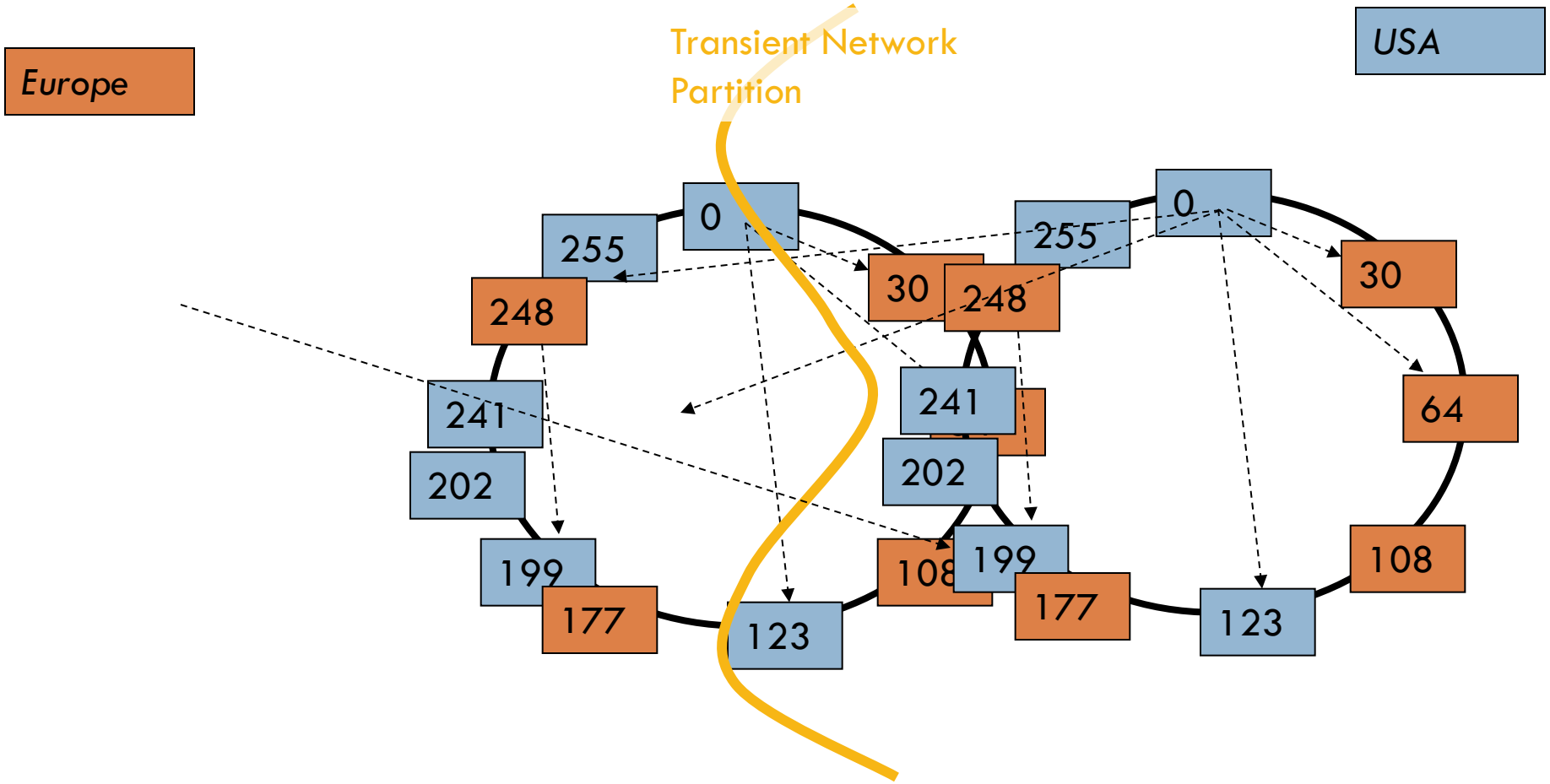
25 runs "stabilize"

20 runs "stabilize"

Chord summary

- Ring with a kind of binary-search
- Self-repairing and self-organizing
- Depends on having a "good" hash function; otherwise some nodes might end up with many (key,value) pairs and others with few of them

Chord can malfunction if the network partitions…



Chord has no sense of "integrity"

- The system doesn't know it should be a ring... so it won't detect that it isn't a ring!
- MIT solution is to make this very unlikely using various tricks, and they work
- But an attacker might be able to force Chord into a partitioned state and if so, it would endure

… so, who cares?

- Chord lookups can fail… and it su… m high overheads when nodes churn
  - Loads surge just when thing… eady disrupted… quite often, because of…
  - And can't predict h… Chord might remain disrupted once… hat way
- Worst case… o: *Chord can become inconsistent and st… ay*

The Fine Print

The scenario you have been shown is of low probability. In all likelihood, Chord would repair itself after any partitioning failure that might really arise. Caveat emptor and all that.

More issues

- Suppose my machine has a (key,value) pair and your machine, right in this room, needs it.
- Search could still take you to Zimbabwe, Lima, Moscow and Paris first!
- Chord paths lack "locality" hence can be very long, and failures that occur, if any, will disrupt the system

Impact?

- Other researchers began to look at Chord and ask if they could design similar structures that
  - Implement the DHT interface
  - But have better locality and are better at self-healing after disruptive events

- We'll examine some of them in the next lecture