UNIVERSITY OF ILLINOIS
AT URBANA-CHAMPAIGN

CS411 - Distributed Hash Tables

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Announcements

- HW4 released today
  - Due on last day of class
  - We're dropping your lowest HW/MP score
- Project Stage 5 due next week
- Final Exam
  - Friday 05/03 at 8-11am
  - Multiple rooms. Go to the right one!

Review

- What is “blind SQL injection”?
- Why do we “sanitize” user input?
- Why do we “hash” passwords?
- Why do we “salt” a hash?
- How can we mitigate SQL injection?

Peer-to-Peer Network

- Nodes are:
  - autonomous: nodes join and leave at will
  - loosely coupled: communicate over the internet
  - equal: no central control node
  - willing to share resources

Peer-to-Peer Search

- We want to be able to search for items on a P2P system
- Examples:
  - distributed BitTorrent search
  - FreeNet/GnuNet
  - CloudSNAP, Space Monkey
  - distributed relational database
  - NoSQL

NoSQL

- Throw away:
  - relational model
  - schemas/tables
  - transactions, integrity, etc. etc.
- Data stored as keys and objects
- Examples: CouchDB, MongoDB, Cassandra, BigTable, Dynamo, Voldemort

NoSQL

- Throw away:
  - relational model
  - schemas/tables
  - transactions, integrity, etc. etc.
- Data stored as keys and objects
- Examples: Facebook, Amazon, LinkedIn, Google, Oracle, TOR

Example

```
{“id”: “034e5fc4097b5f243266cbb918678c59640b501a”,
   ”name” : ”value”}
{”id”: ”a1e756f676bcac92ed5127215dfb6c638bd3b596”,
   “x”: 1}
{”id”: ”941dac88b5360264af152db2b02c654d5f5bc87f”,
   “x”: 1, “y”: ”happy”}
{”id”: ” 0f6879a27088581129ad2da99437ae93aa6ee570”,
   “x”: 1, “y”: ”tree”}
{”id”: ” a64ab7b189cdddfd691c4044f75e8e73b494ab1a”,
   “x”: 1, “y”: 12901}
```

Distributed Hash Table

- Search for items using a hash value
  - Key-value pairs
- Key-value table can't belong to one node
  - violates P2P principles
  - could be too big for one node
- Values must be distributed through the network in a balanced way

Hash Function

- Same input always produces same output
- Given the output, can't infer the input
- Output is evenly distributed across codomain (range, image)

Distributed Hash Table

- Choose a hash function with m bit output
  - MD5 m=128 bits
  - SHA-1 m=160 bits
  - Example m=6
    - Output from 0 to 63

Side note

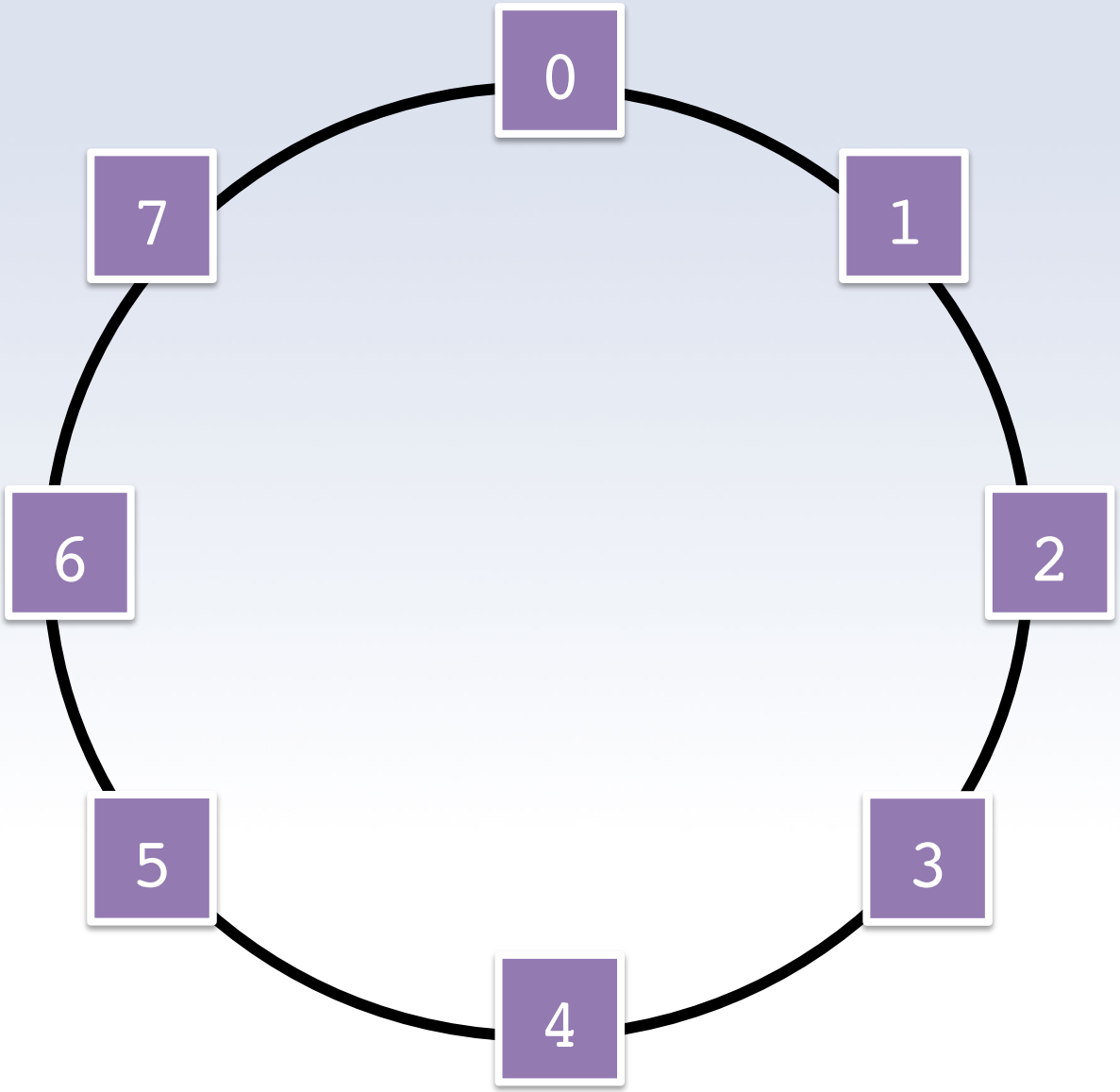
2^{128}=340 undecillion, 282 decillion, 366 nonillion, 920 octillion, 938 septillion, 463 sextillion, 463 quintillion, 374 quadrillion, 607 trillion, 431 billion, 768 million, 211 thousand and 456 (thanks Wolfram Alpha!)

2^{160}=more than one value for every grain of sand on every beach on Earth

Distributed Hash Table

- Imagine output space (range, image) of hash as a circle
  - Like a clock, starts at 0 and proceeds clockwise to 2^m-1

Circle (m=3)



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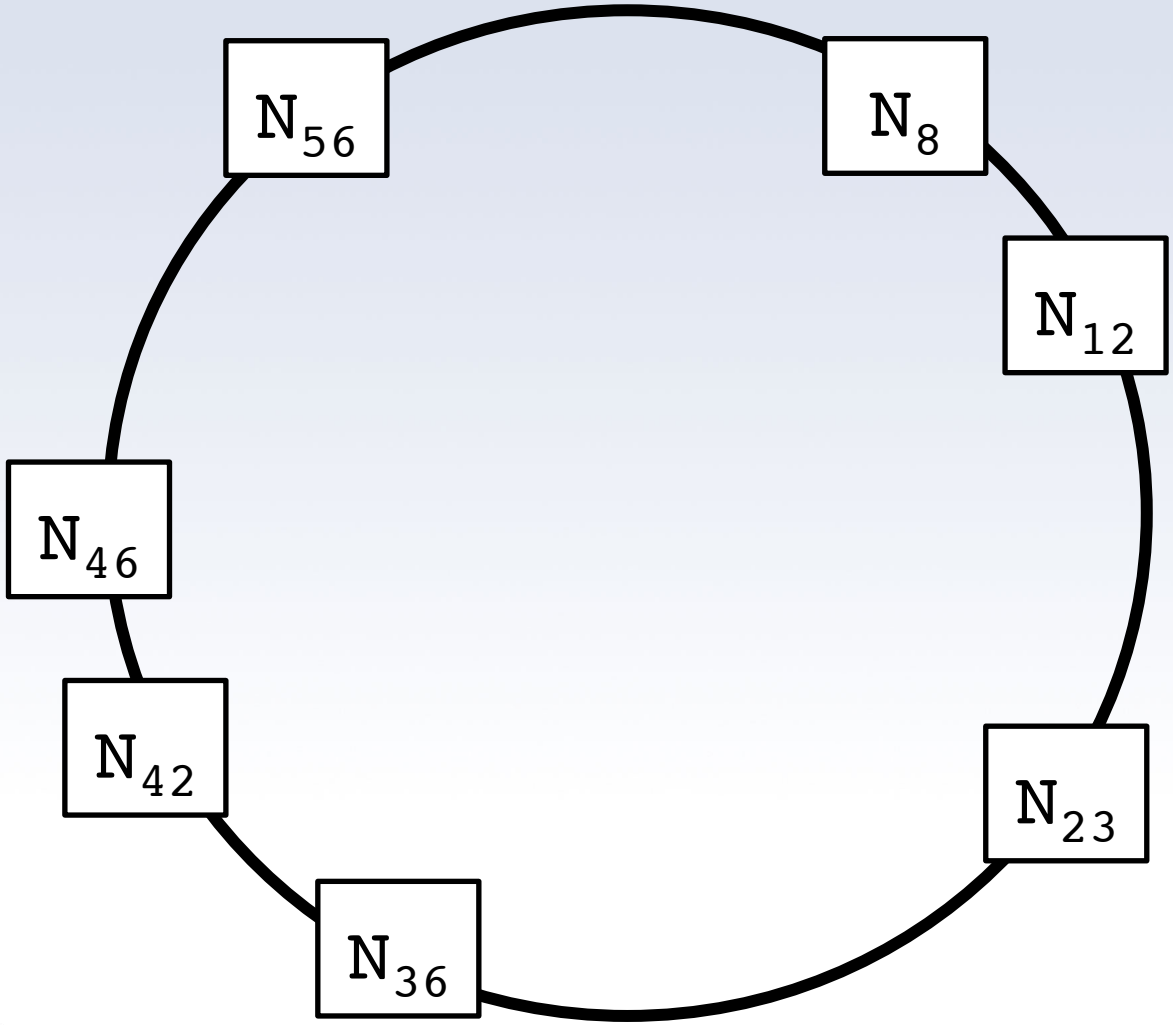
Chord Circle

- Nodes are distributed on this hash circle:
  - Hash unique identifier (e.g. IP address, username, etc.)
  - Track predecessor and successor
    - predecessor - first node with a lower hash
    - successor - first node with a higher hash
  - Predecessor and successors “wrap around” the origin (just like a clock)

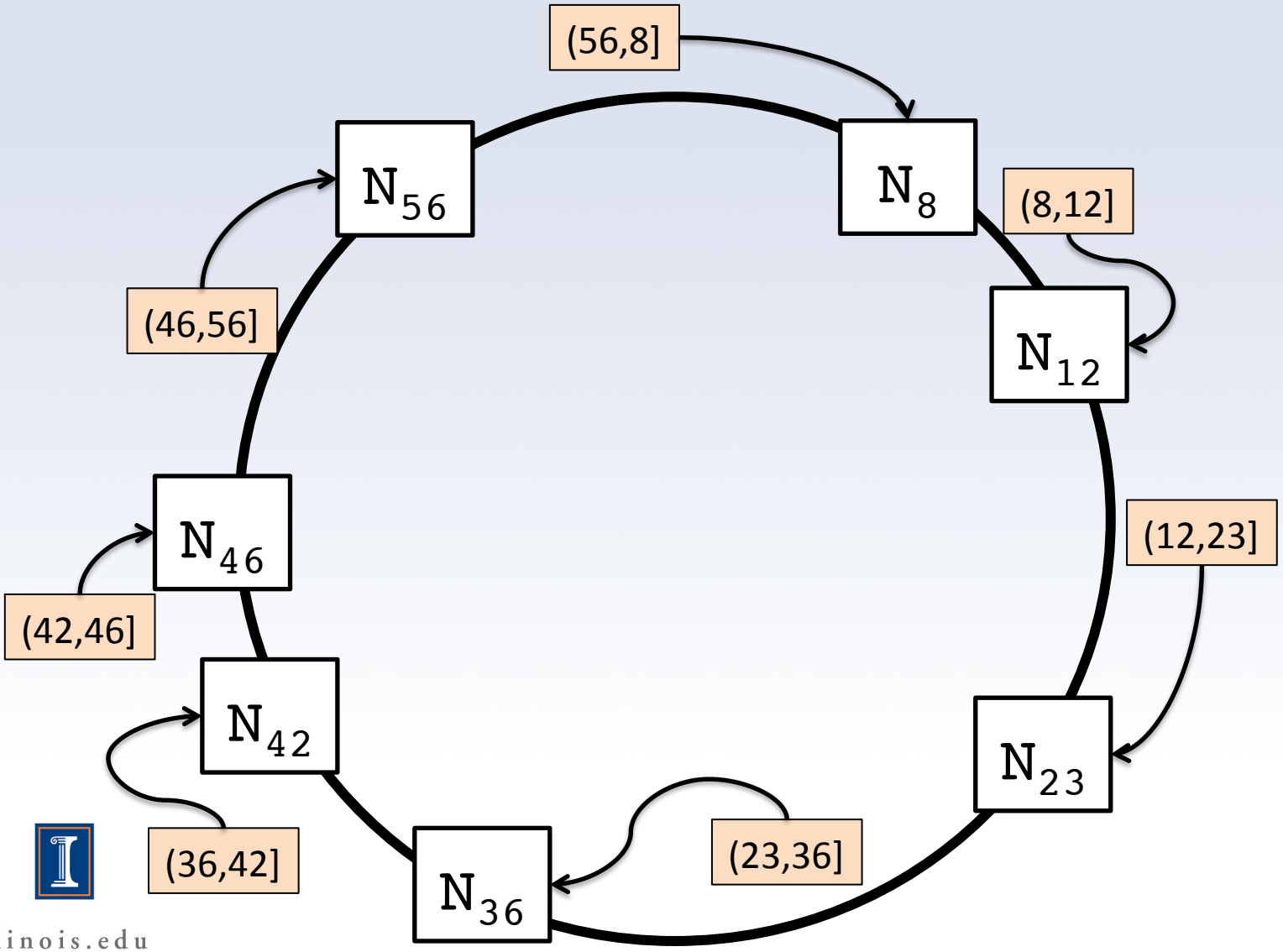
Chord Circle (m=6)



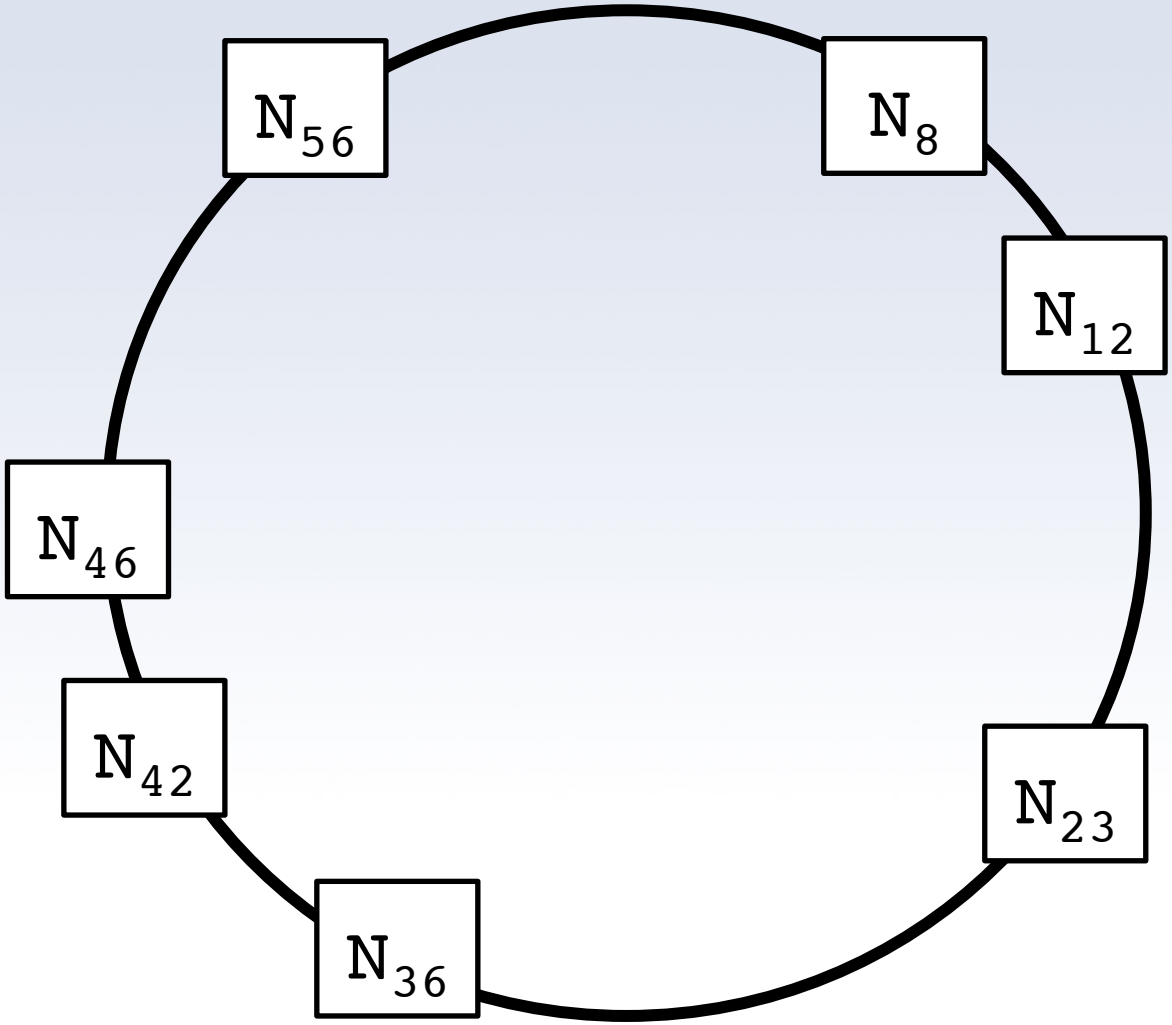
Chord Circle

- Nodes organized
- What about data? <K,V>
  - Use the same hash function!
  - Find smallest node where h(K)≤h(N)
  - Store <K,V> there

Example



<“Electric Feel, MGMT”,electricfeel.mp3>



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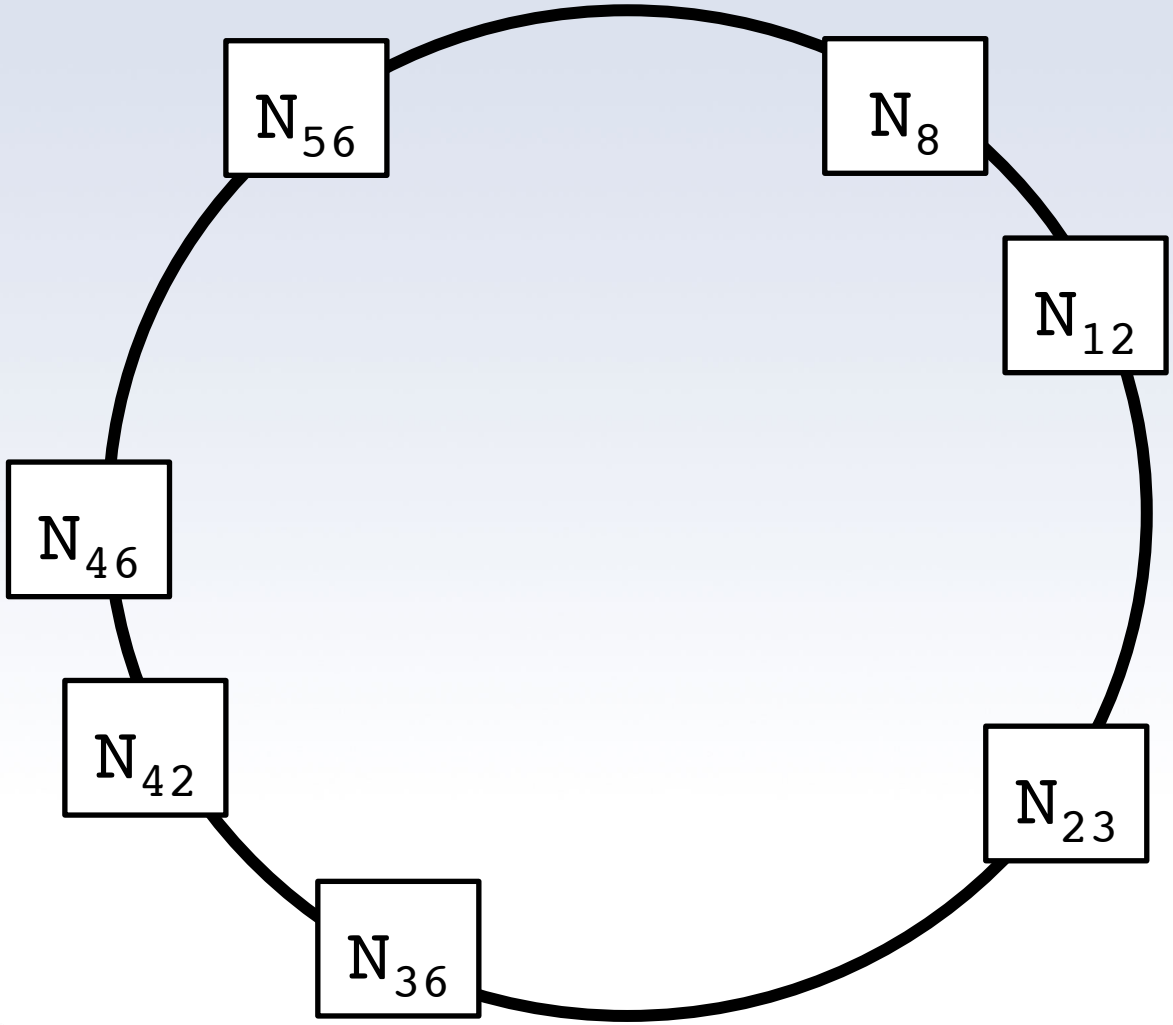
h(“Electric Feel”)=54



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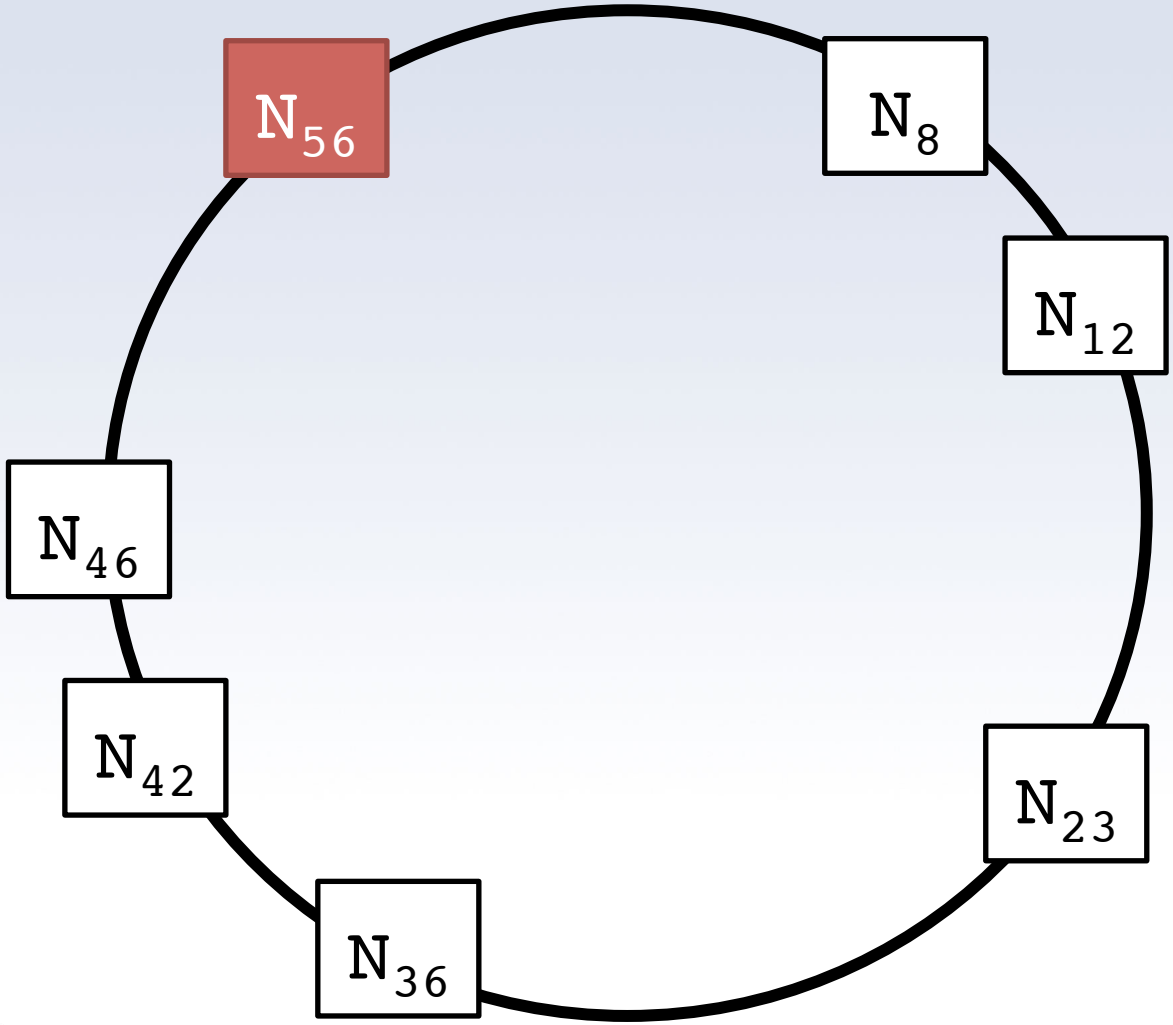

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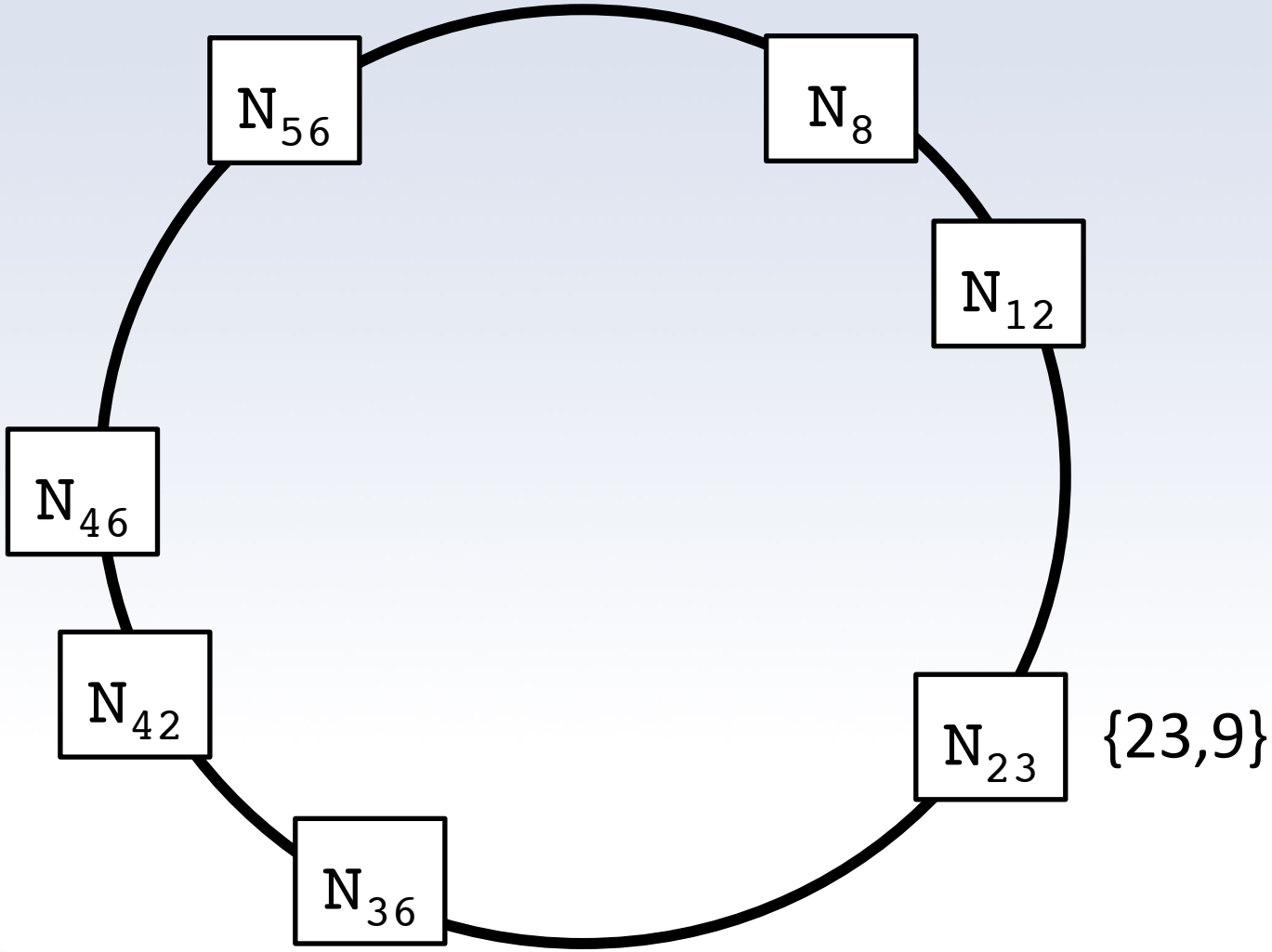
Naïve Search

- Send a message around the circle until we find the right node
  - Send out our hash and hash of the search key
    - e.g. {23,9} “node 23 is looking for file with hash 9”
  - Correct node directly sends back result



{23,9}

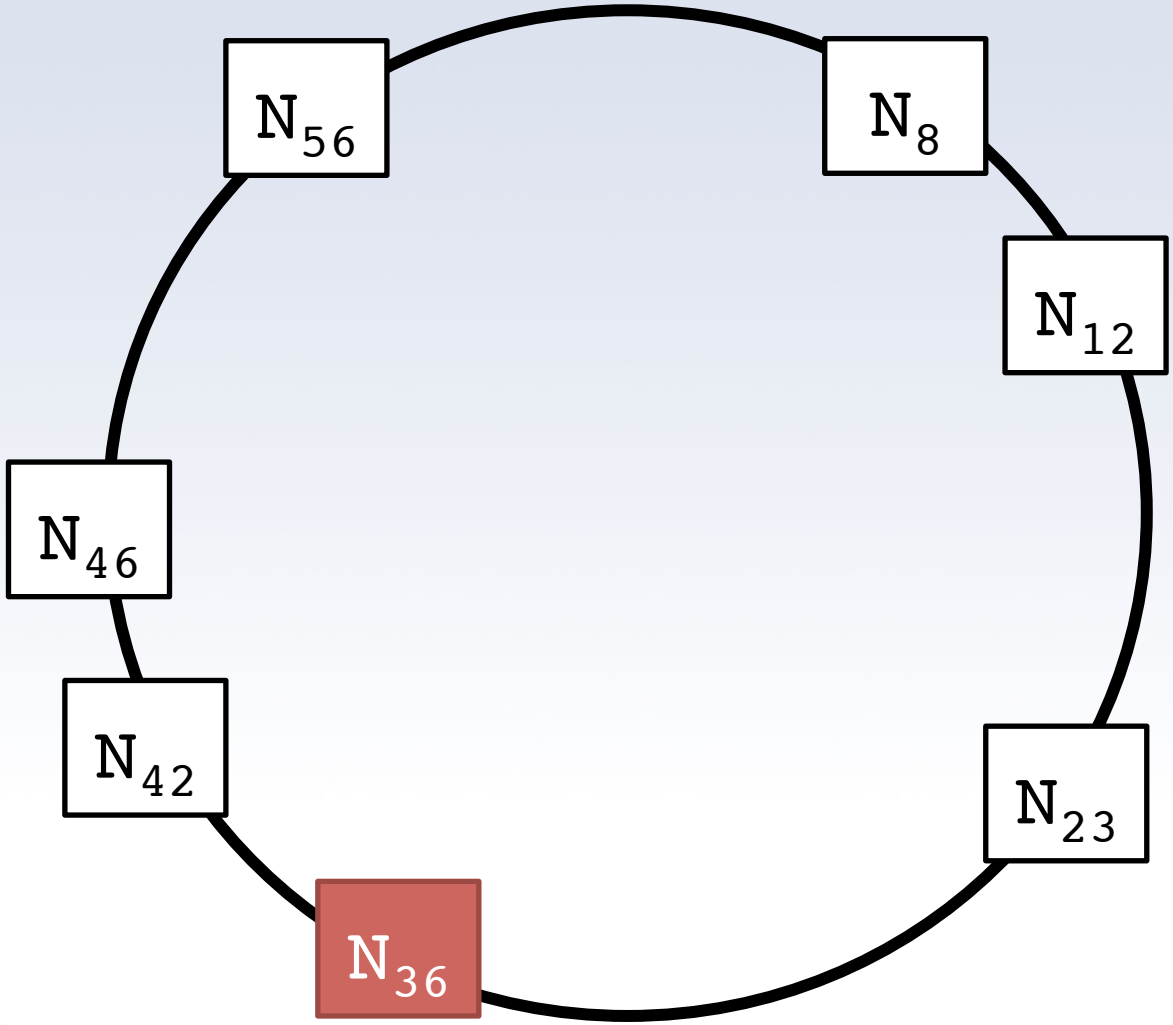
Naïve Search

- Too expensive
  - Have to send, on average O(Nodes) messages
  - Too slow!
- Keep track of all other nodes?
  - Have to store O(Nodes) messages
  - Too big!

Finger Table

- Track all nodes at power of 2 distances
  - $1,2,4,8,16,\ldots,2^{m-1}$
  - Distance in hash codomain (range, image)
- Basically, look up value that distance away
  - Find h(N)+distance mod 2^m

Distance	1	2	4	8	16	32
Node	42	42	42	46	56	8



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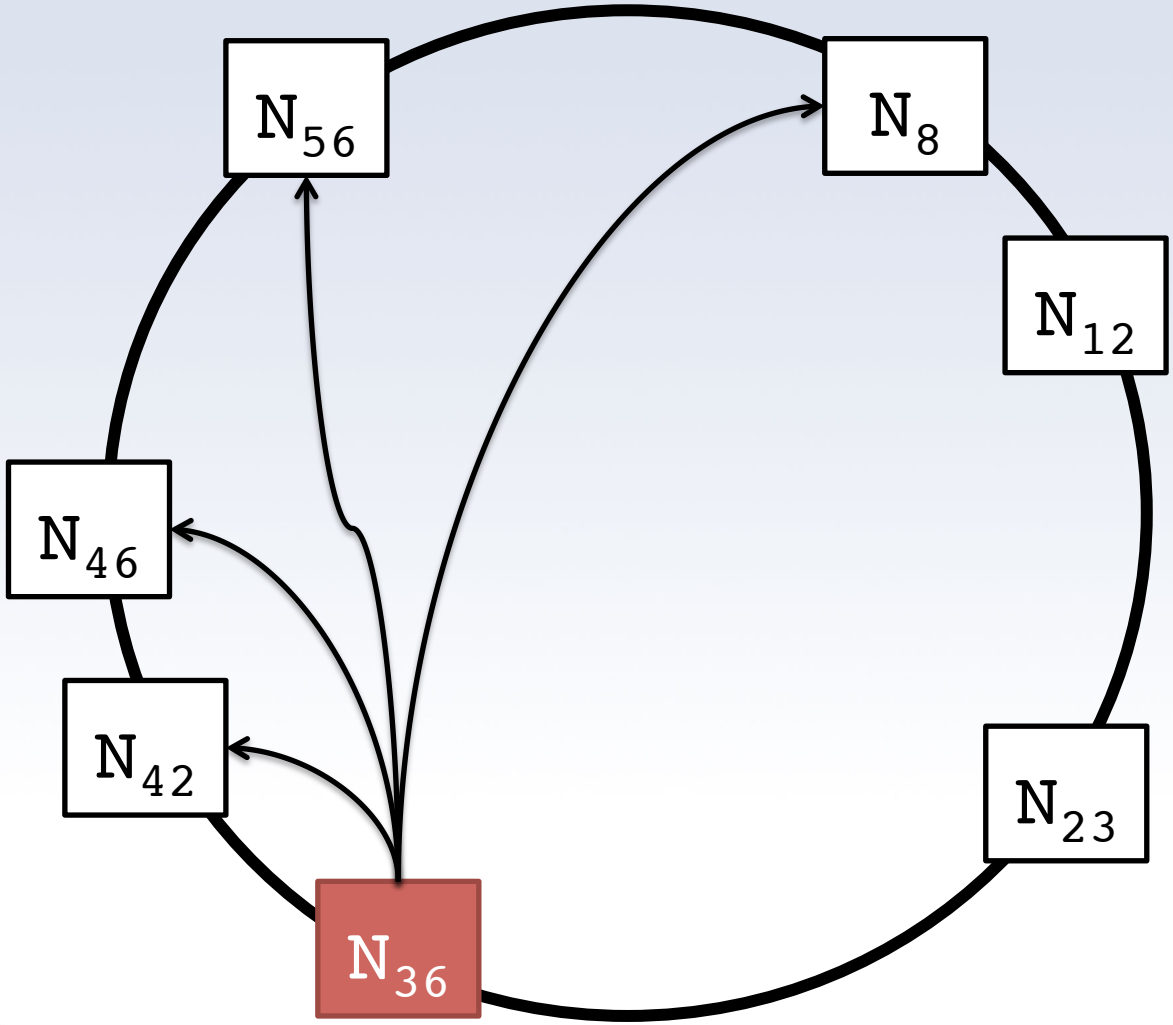
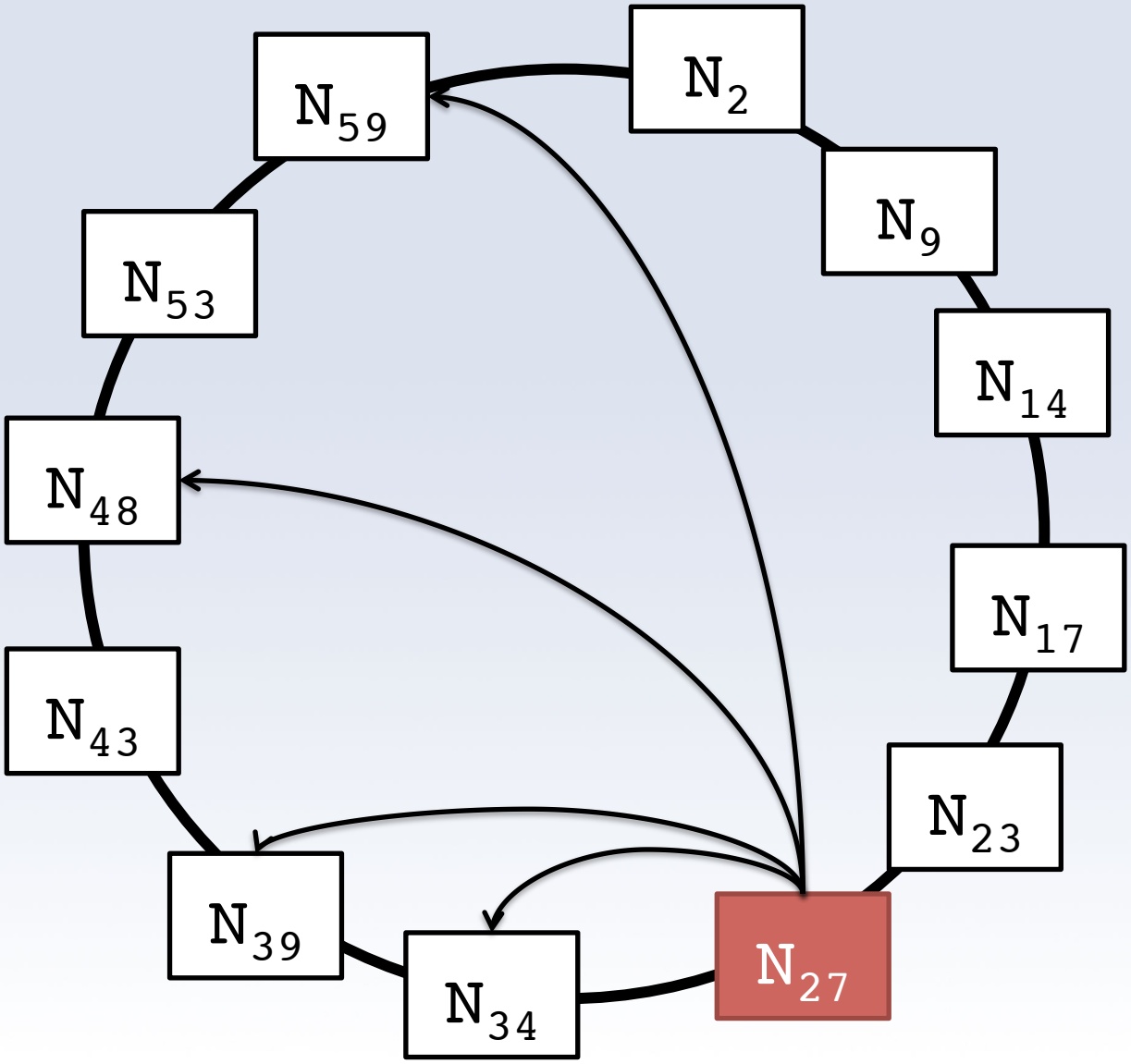




Distance	1	2	4	8	16	32
Node	34	34	34	39	48	59

Finger Table

- How does this help?
  - Route our searches like a binary search
  - First node sends it halfway there
  - Next node sends it halfway again
  - Repeat until we find the right node

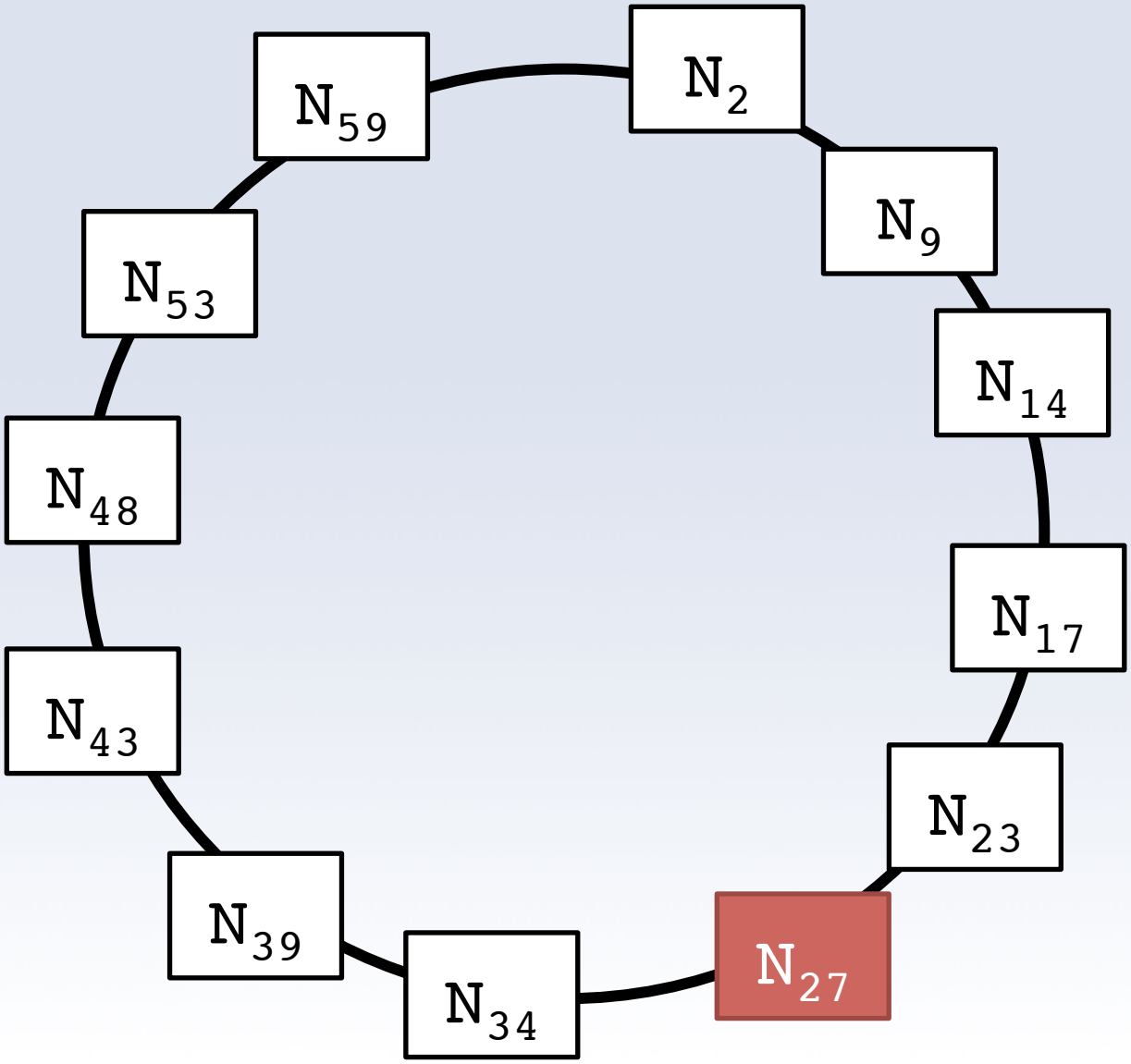
Finger Table Search

- Terminology
  - N_r is requesting node (initiated search)
  - N_c is current node (initially N_c=N_r)
  - x is the hash of search key (h(K)=x)

Finger Table Search

1. N_c checks if its successor N_s has search key ($c<x\leq s$)
   - If so, N_s looks up x and returns result to N_r.
   - Search is done.
2. N_c searches its finger table for highest numbered node N_h less than x.
   - Tell N_h to search for x on behalf of N_r
   - Now $N_c=N_h$ and search continues

N_{27} searching for h(x)=19



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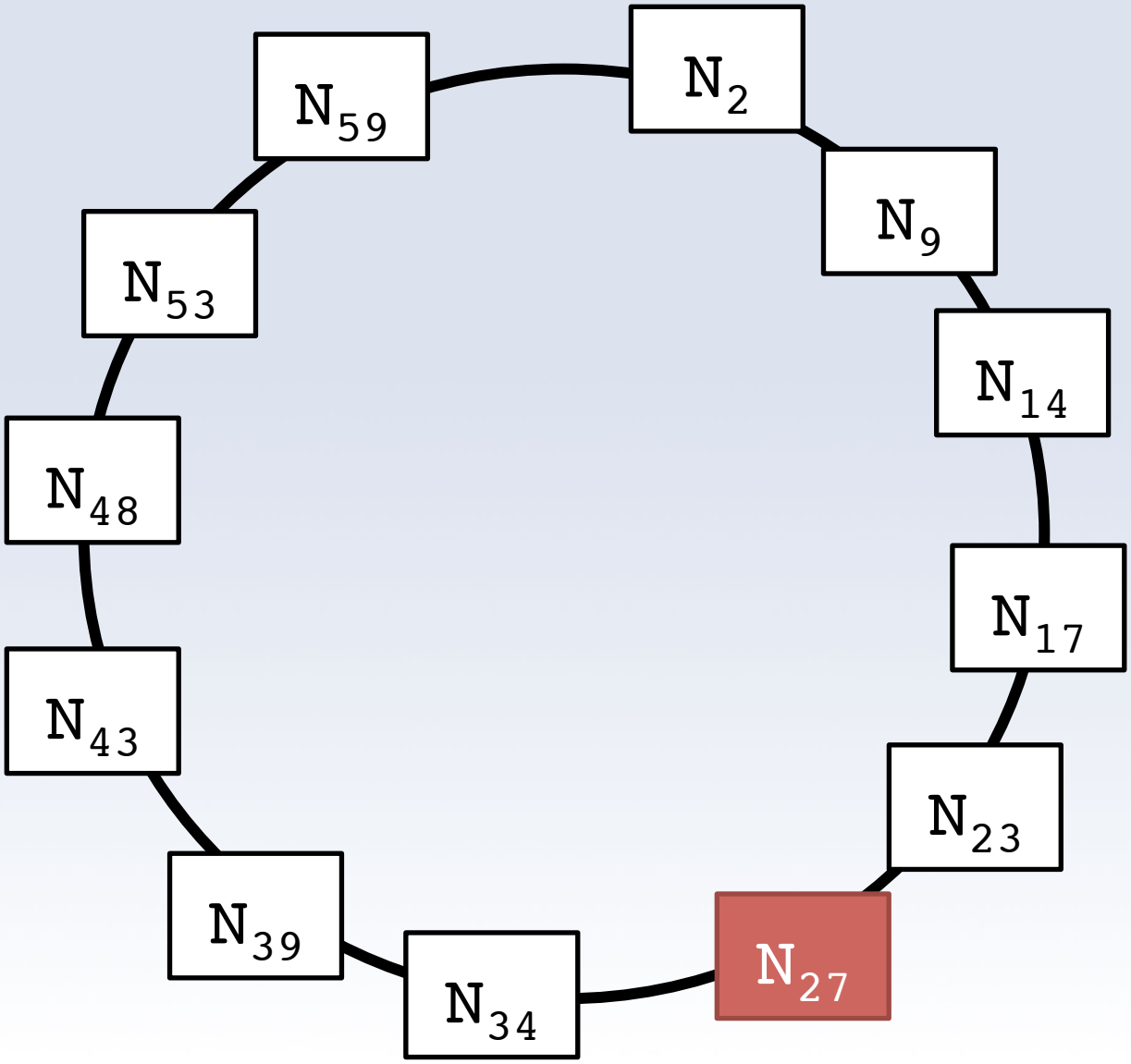

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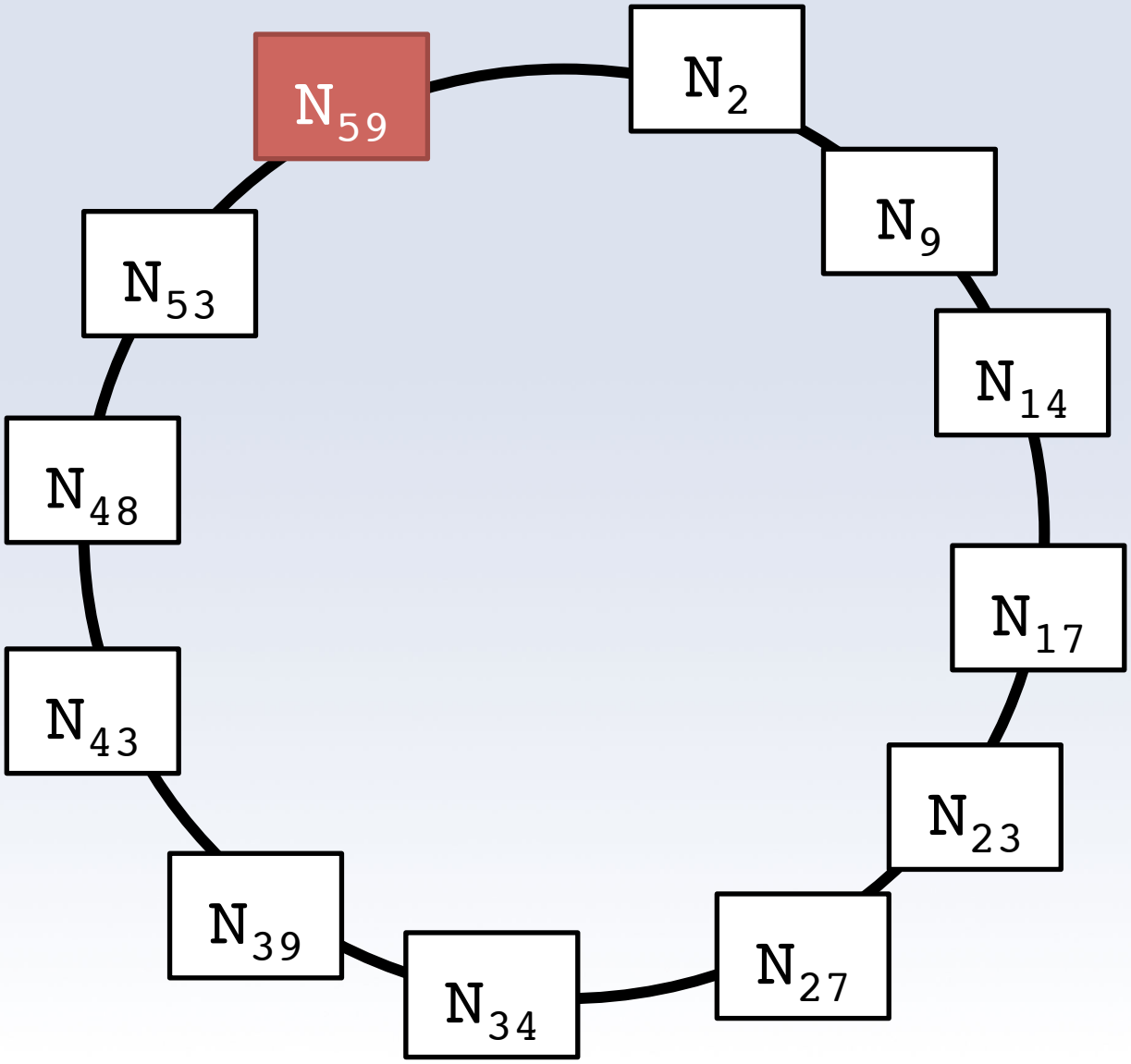

Distance	1	2	4	8	16	32
Node	2	2	2	9	14	27

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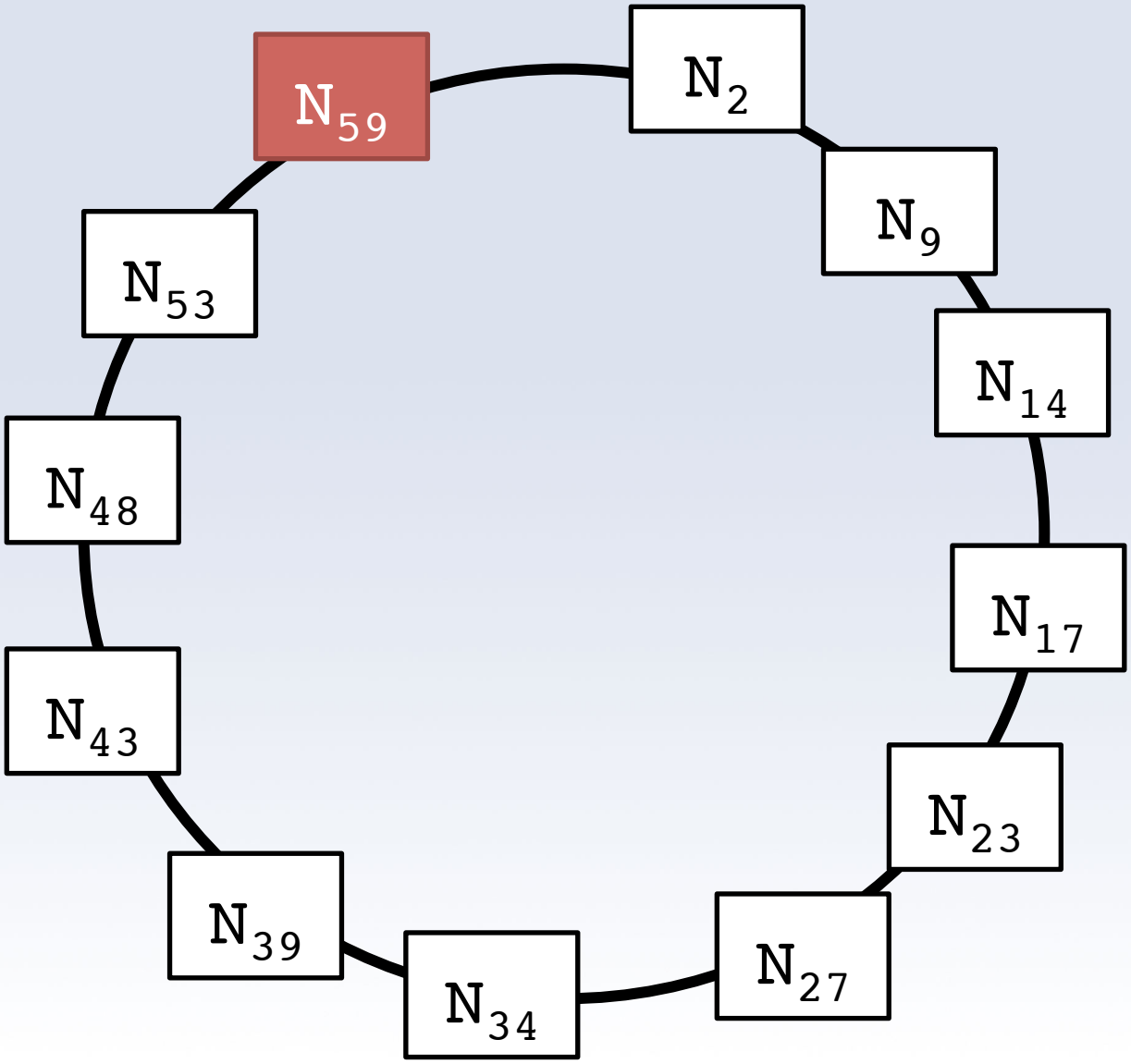

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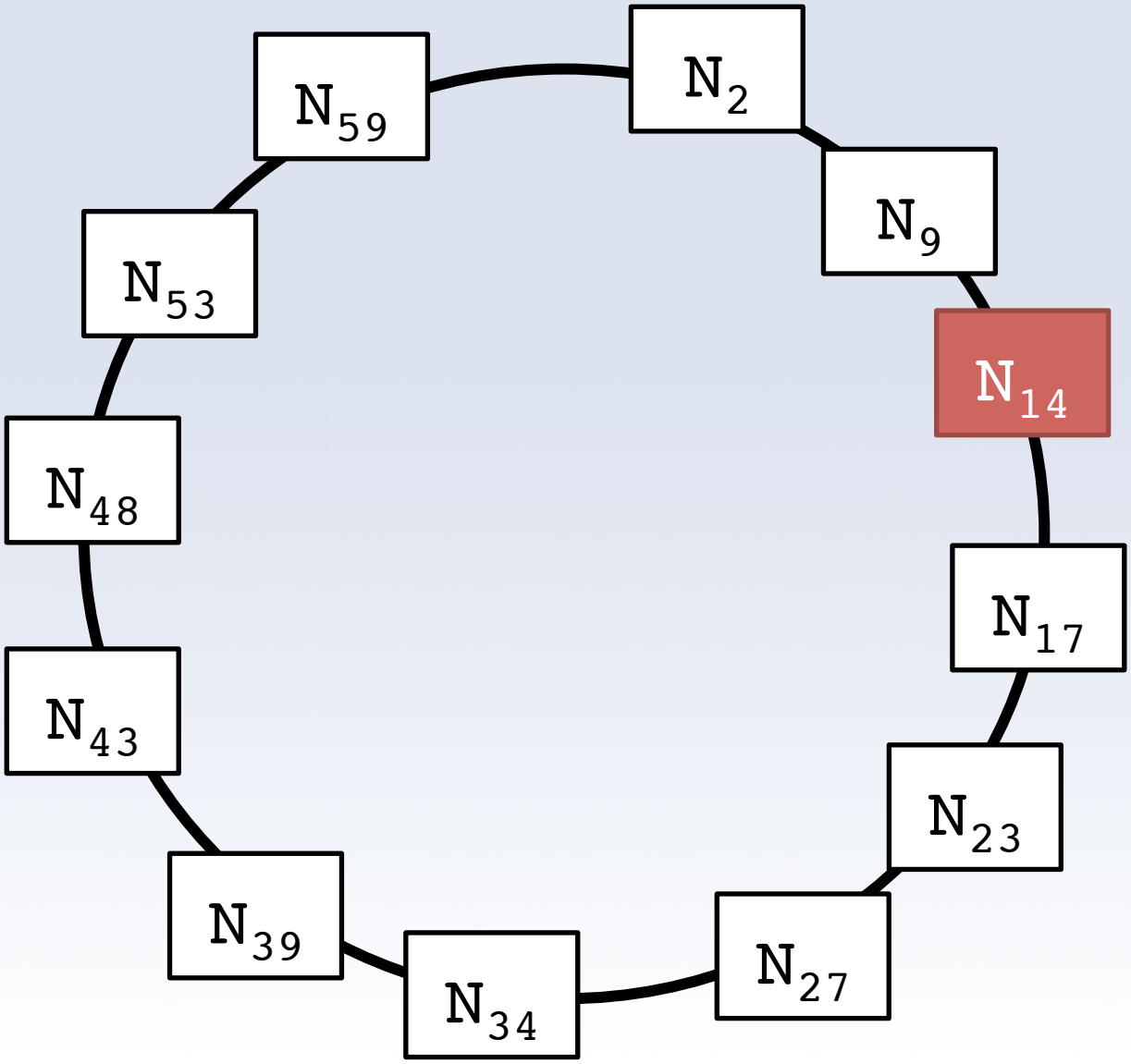

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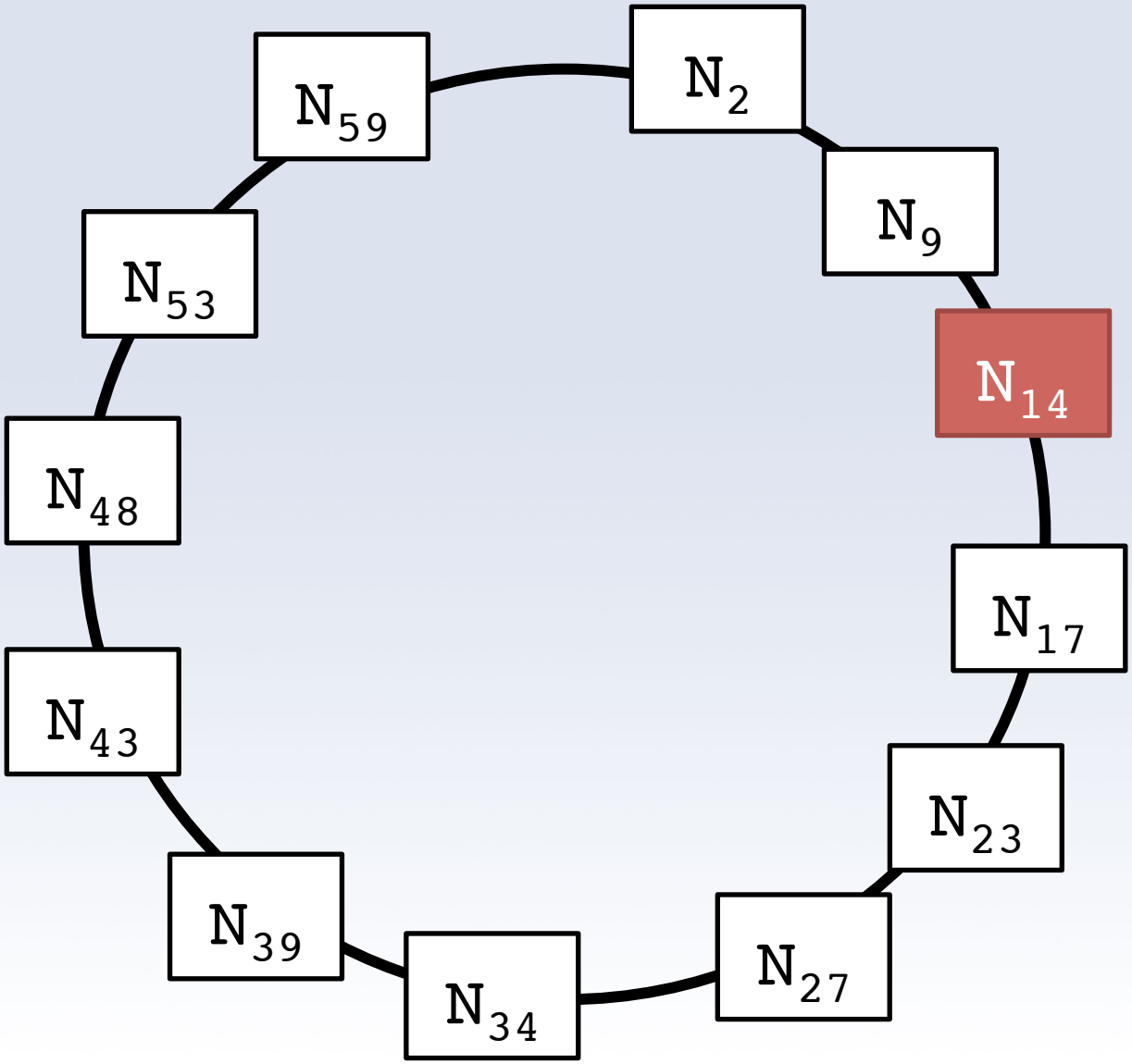

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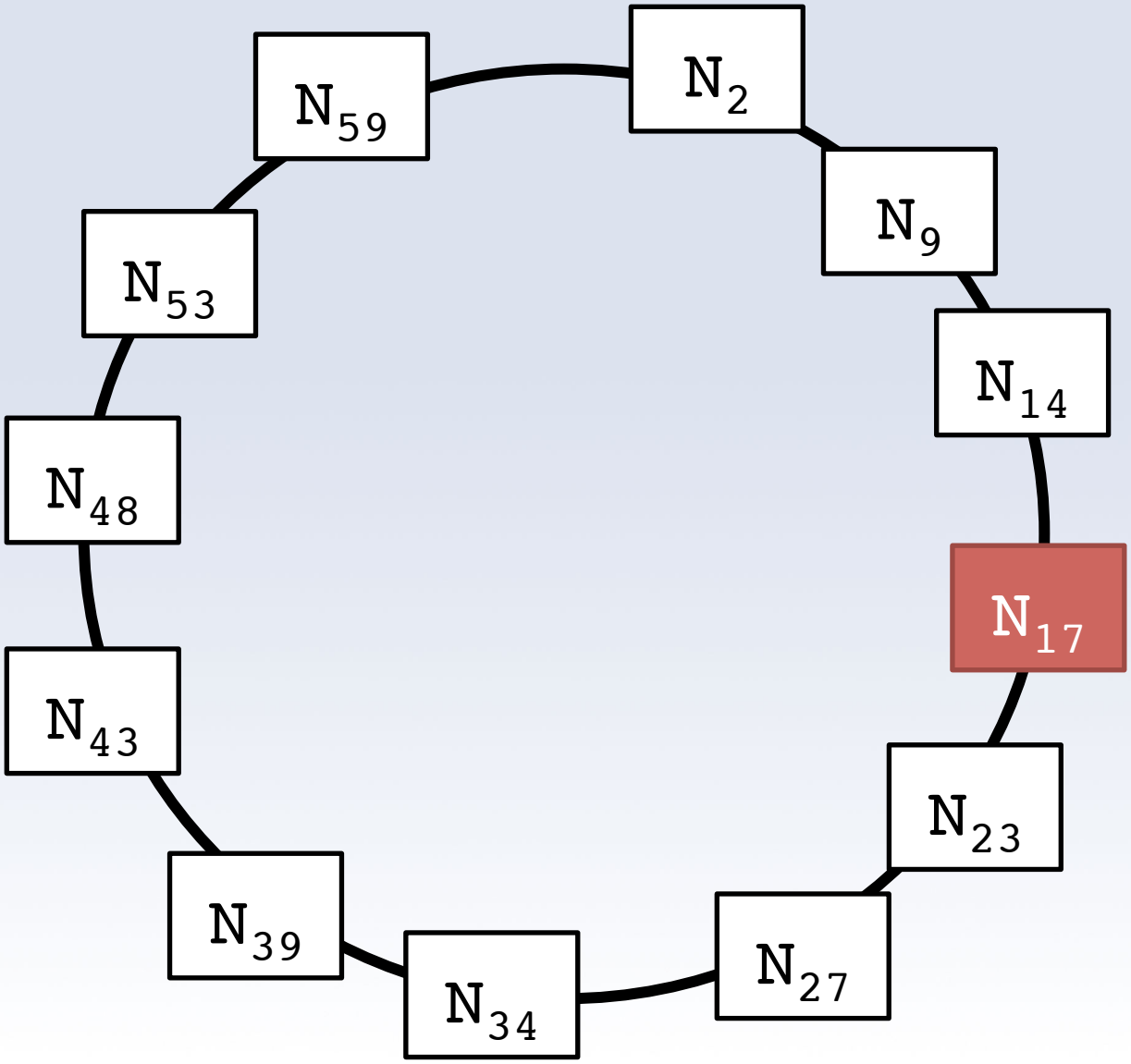

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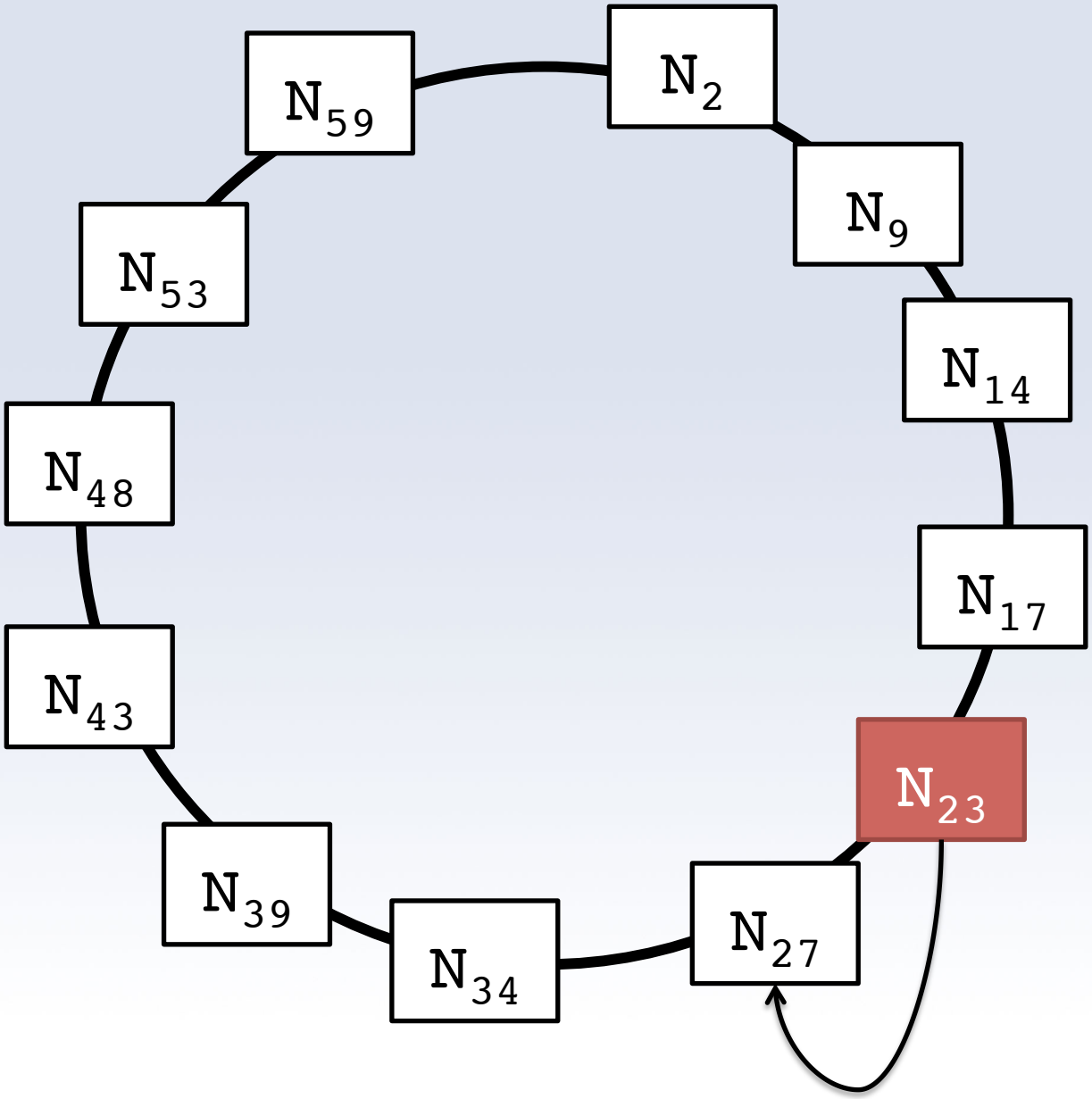

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Finger Table Search

- Number of entries in table: m-1
- Number of messages sent for search:
  O(log(nodes))

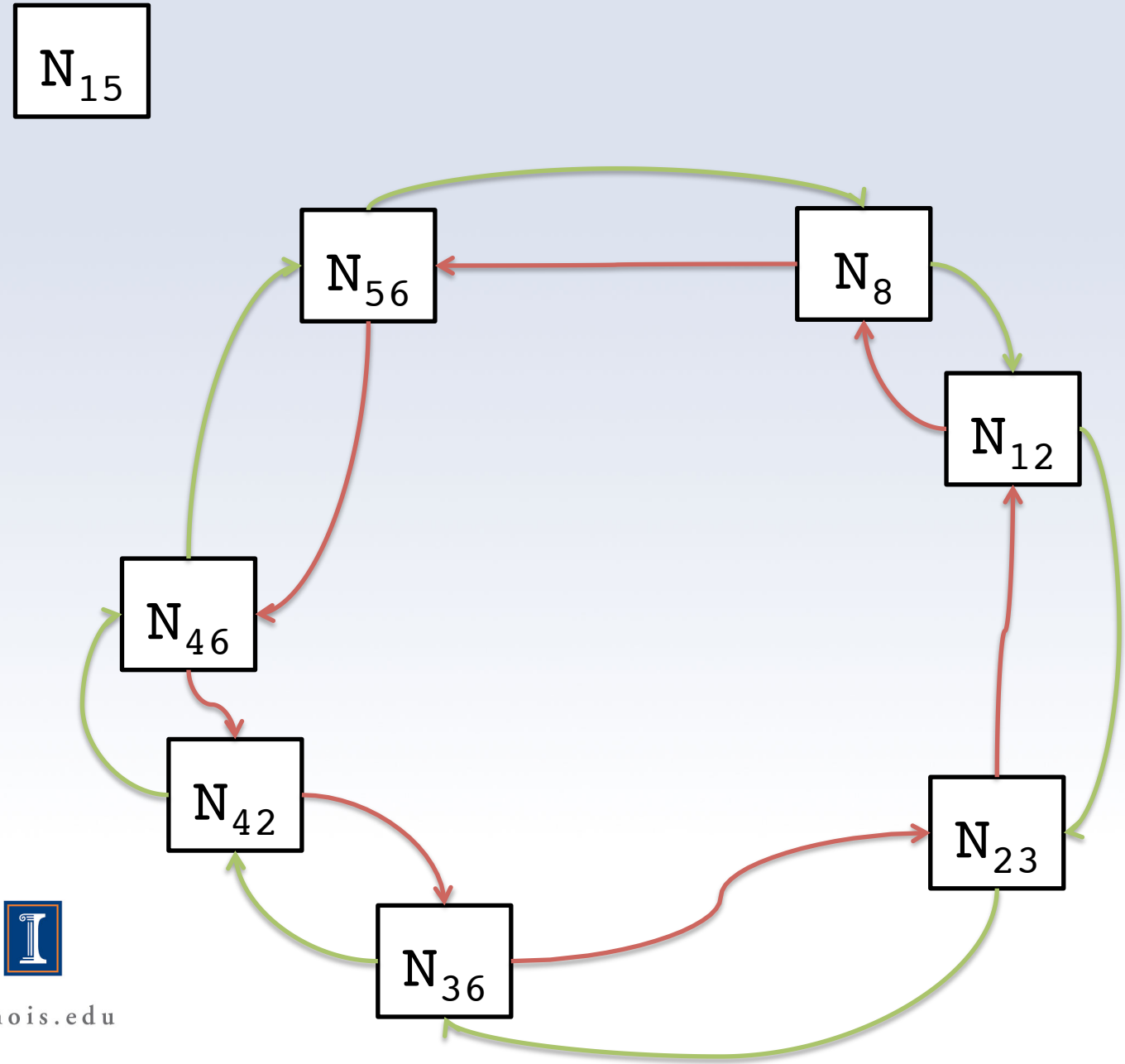
So…

- Given a chord-circle
  - We can search for a key
  - We know where to store keys and values
- But wasn't this supposed to be an ad-hoc peer-to-peer network?
- How do we add a node?

Adding a Node

1. Search for node's key value
2. Set successor to result
3. Leave predecessor as null

That's really it! We'll let the stabilization algorithm clean up our mess.



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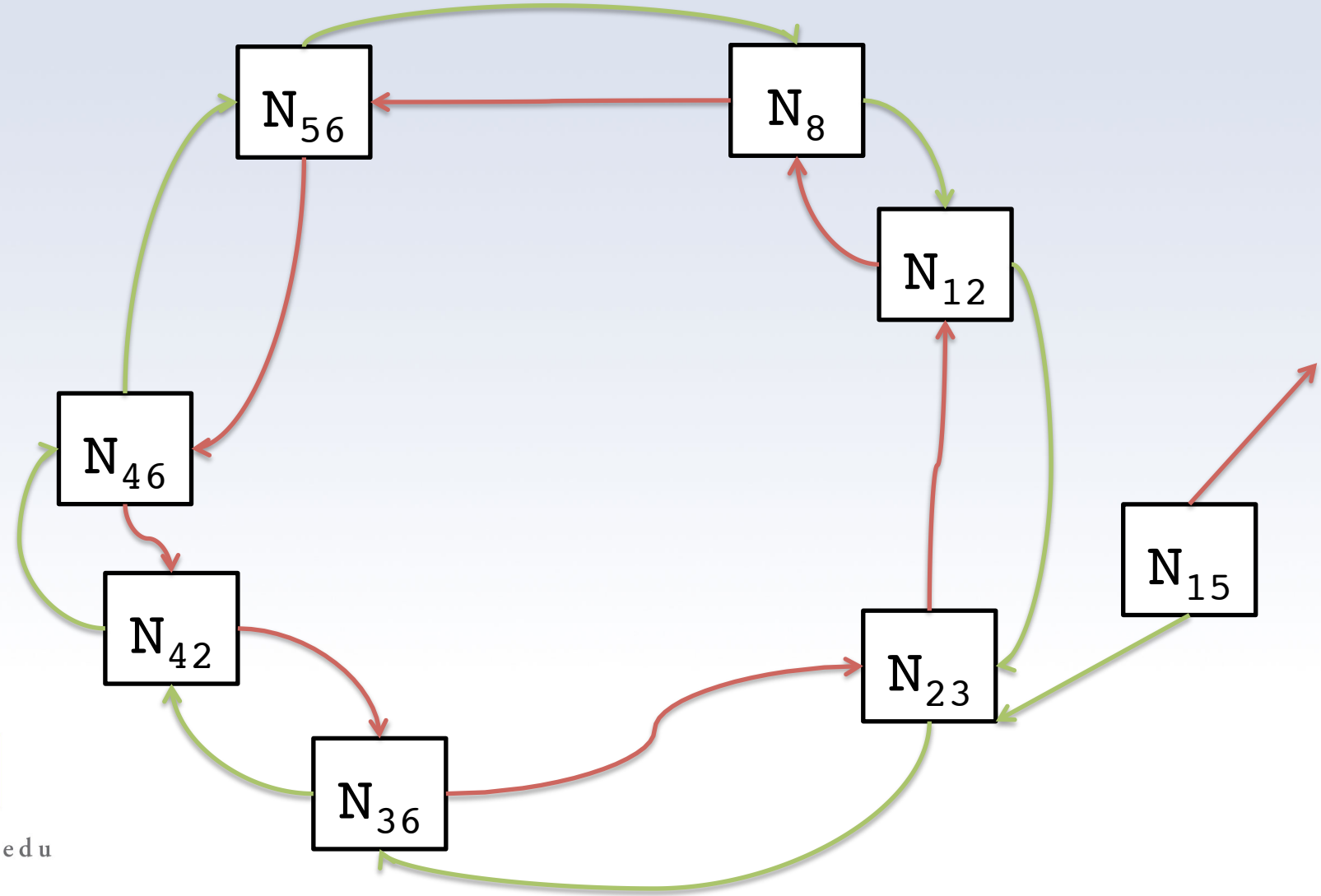

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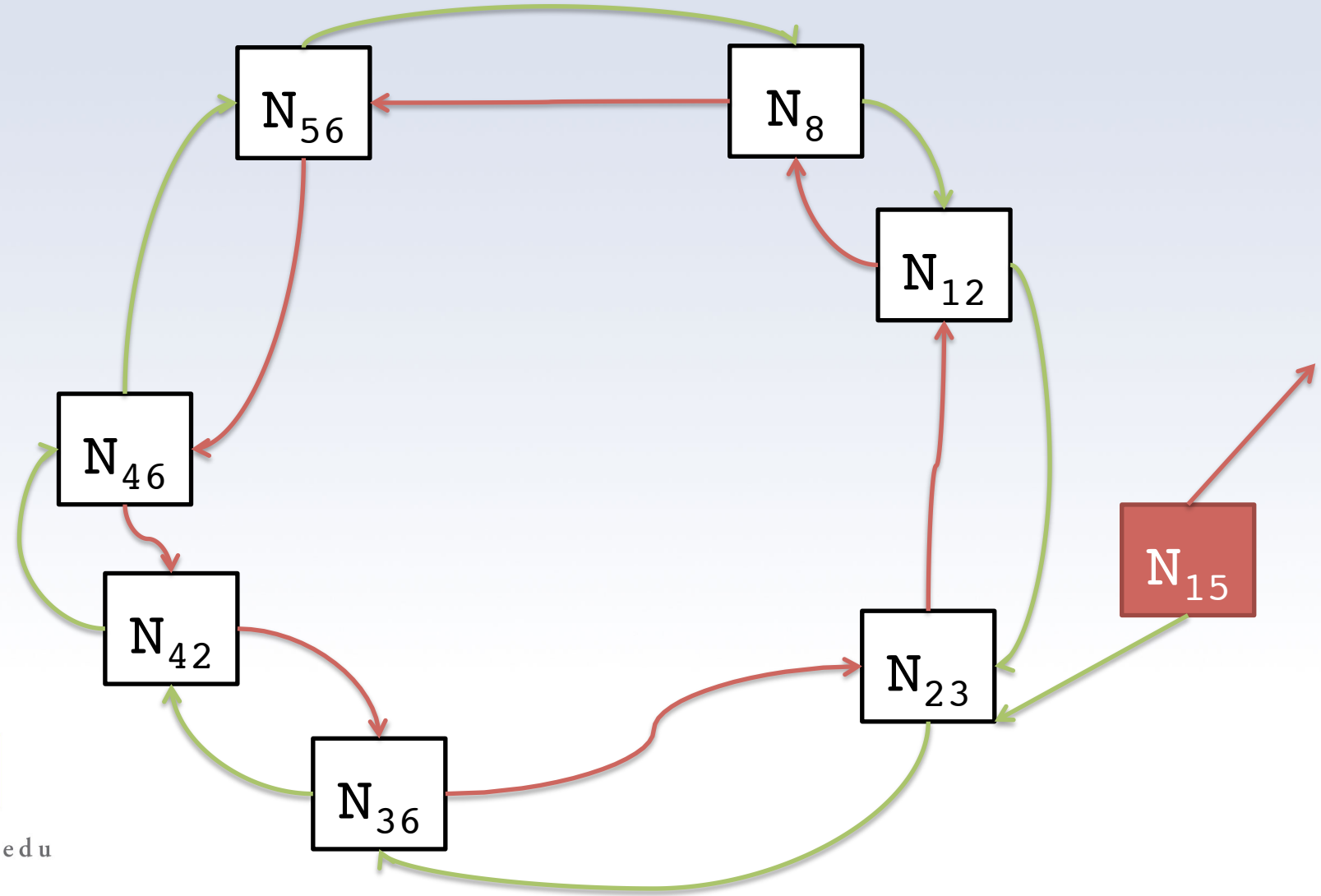
Stabilization

- Each node periodically updates successor and predecessor pointers
- Asynchronously restores/updates structure of chord circle

Stabilization

1. N asks S (its successor) for P (successor's predecessor).
   - If P=N, done.
2. If N<P<S, N records P as its successor.
3. If predecessor of S is nil, or S<N<P, S sets N as its predecessor.
4. S shares data with N.



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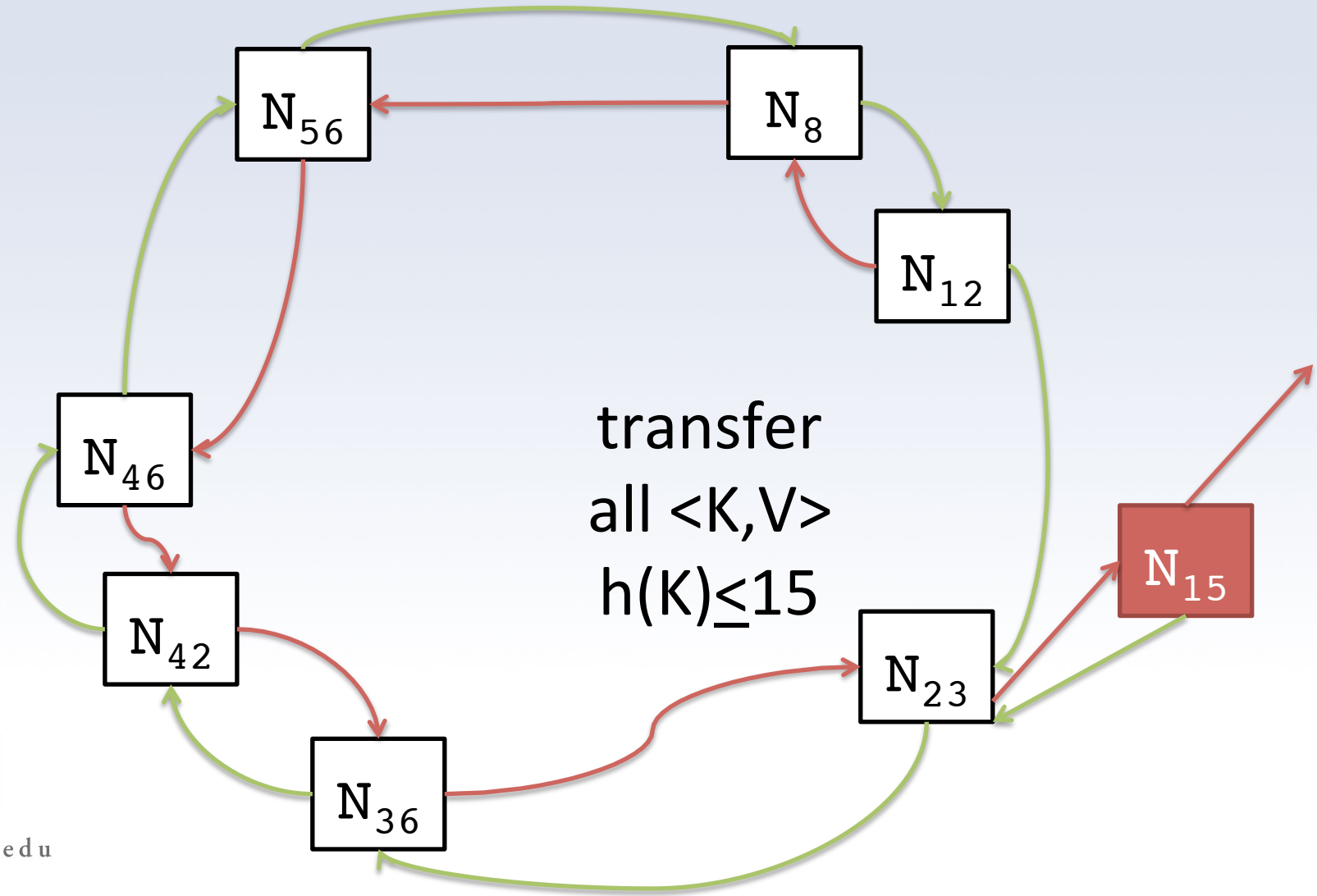
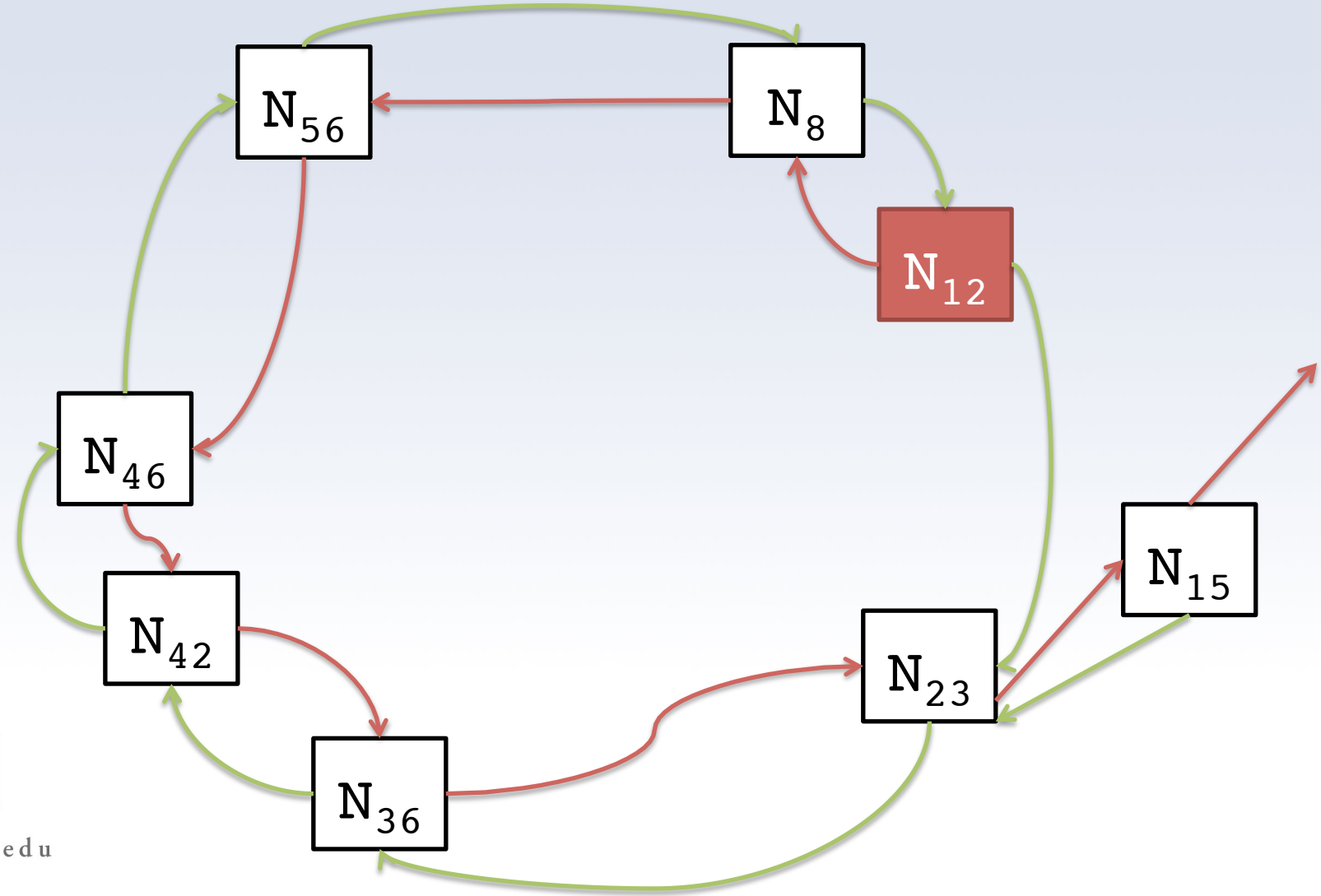

N56
N8
N12
N46
N42
N36
N23
N15
transfer
all <K,V>
h(K)≤15



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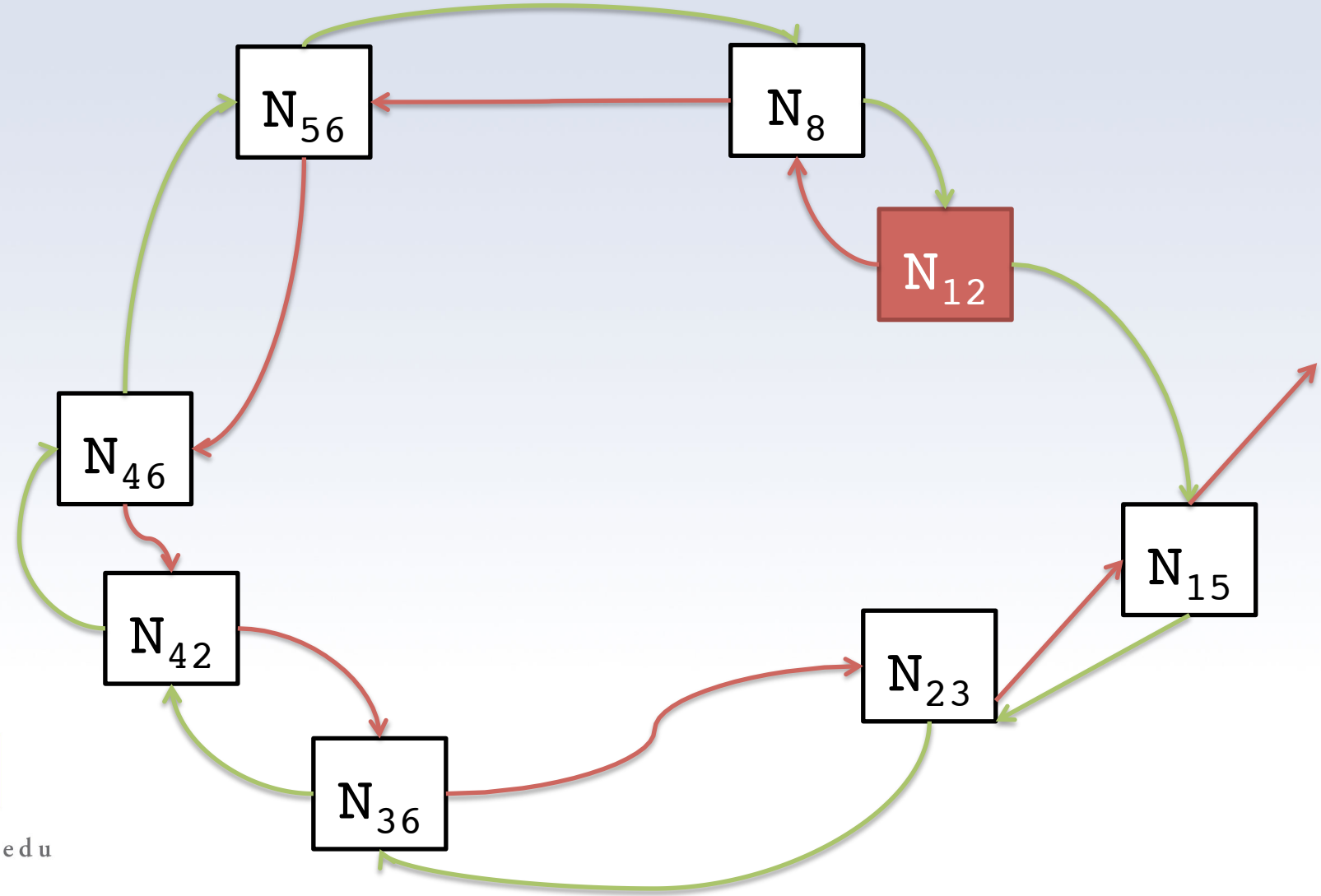
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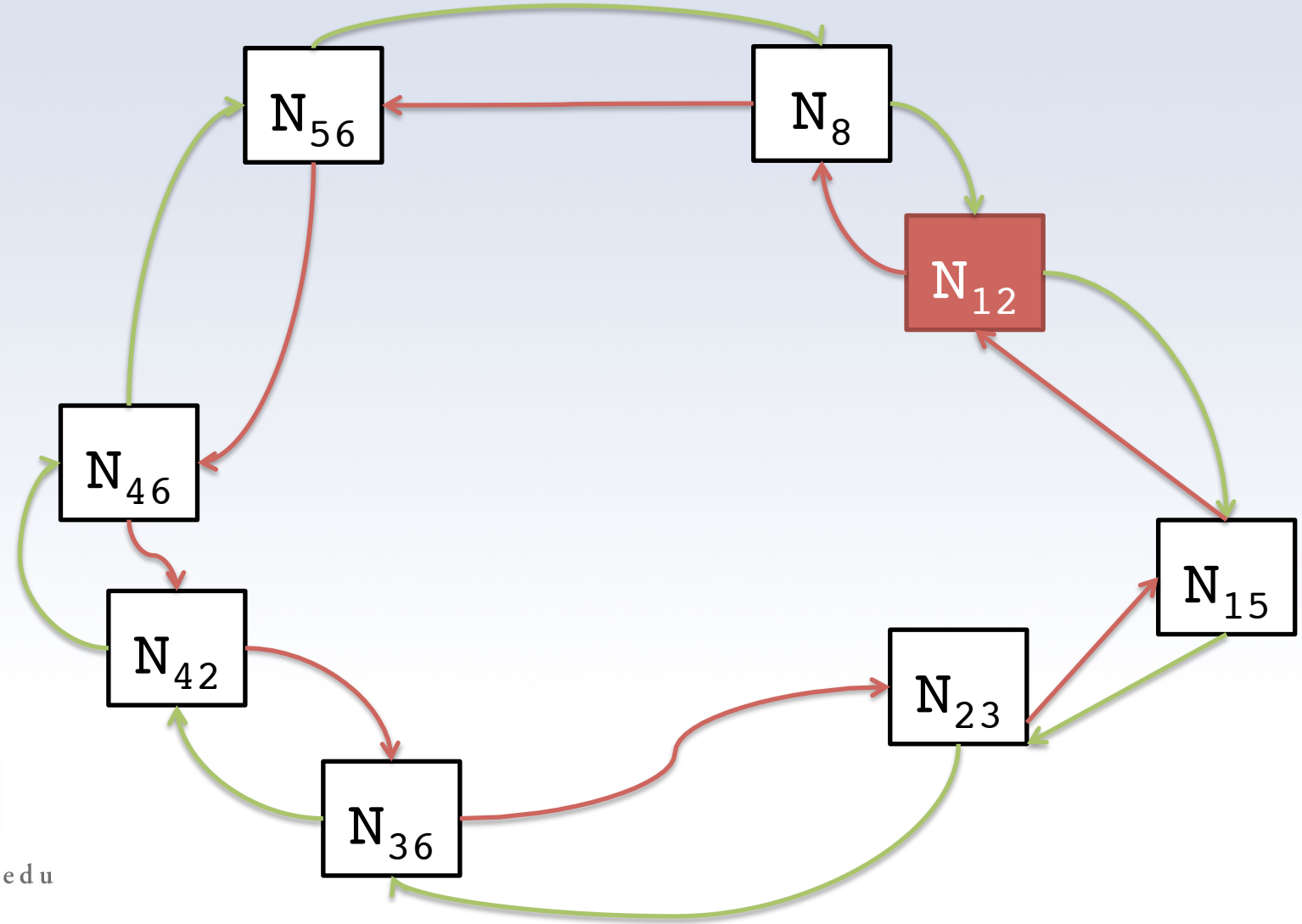
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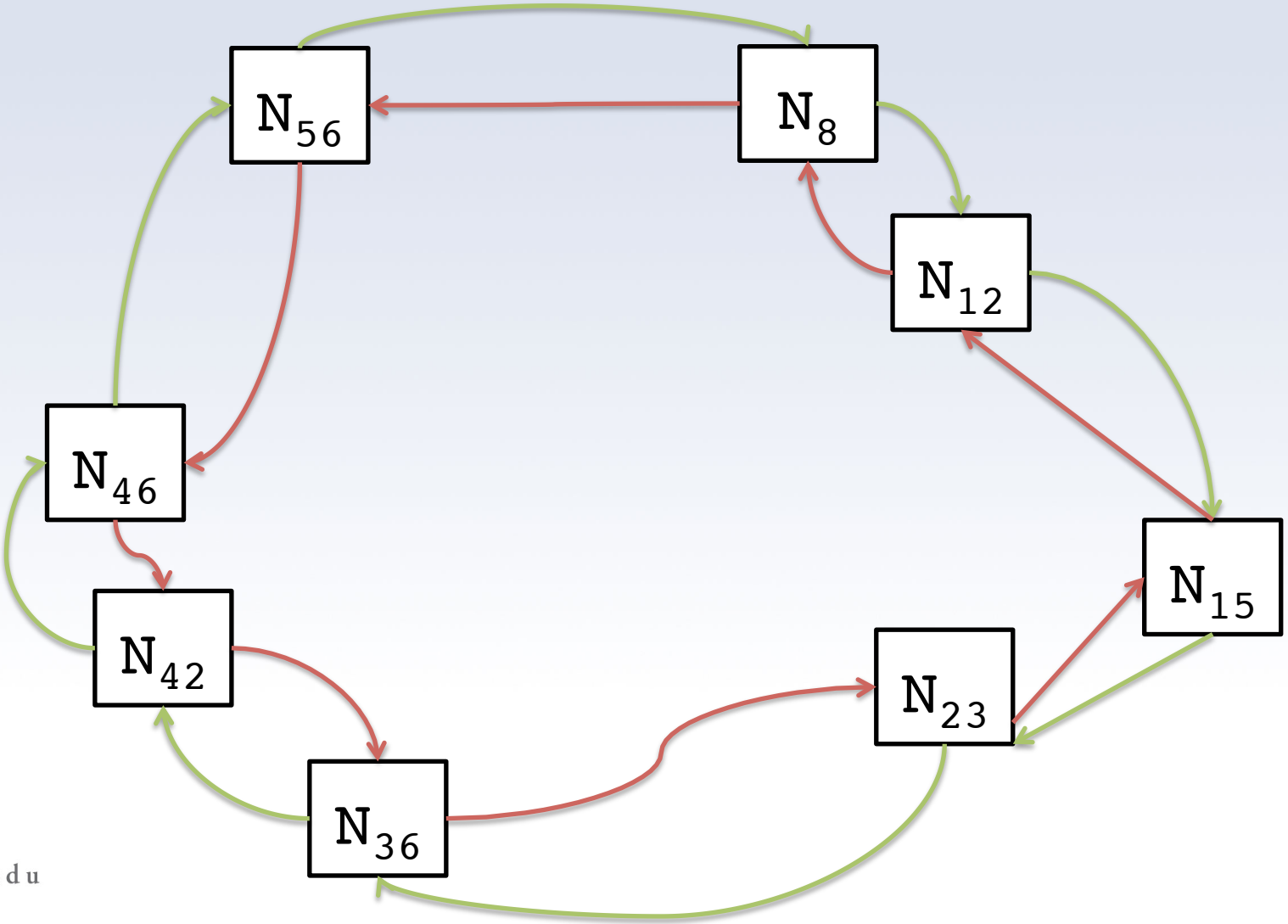
N56
N8
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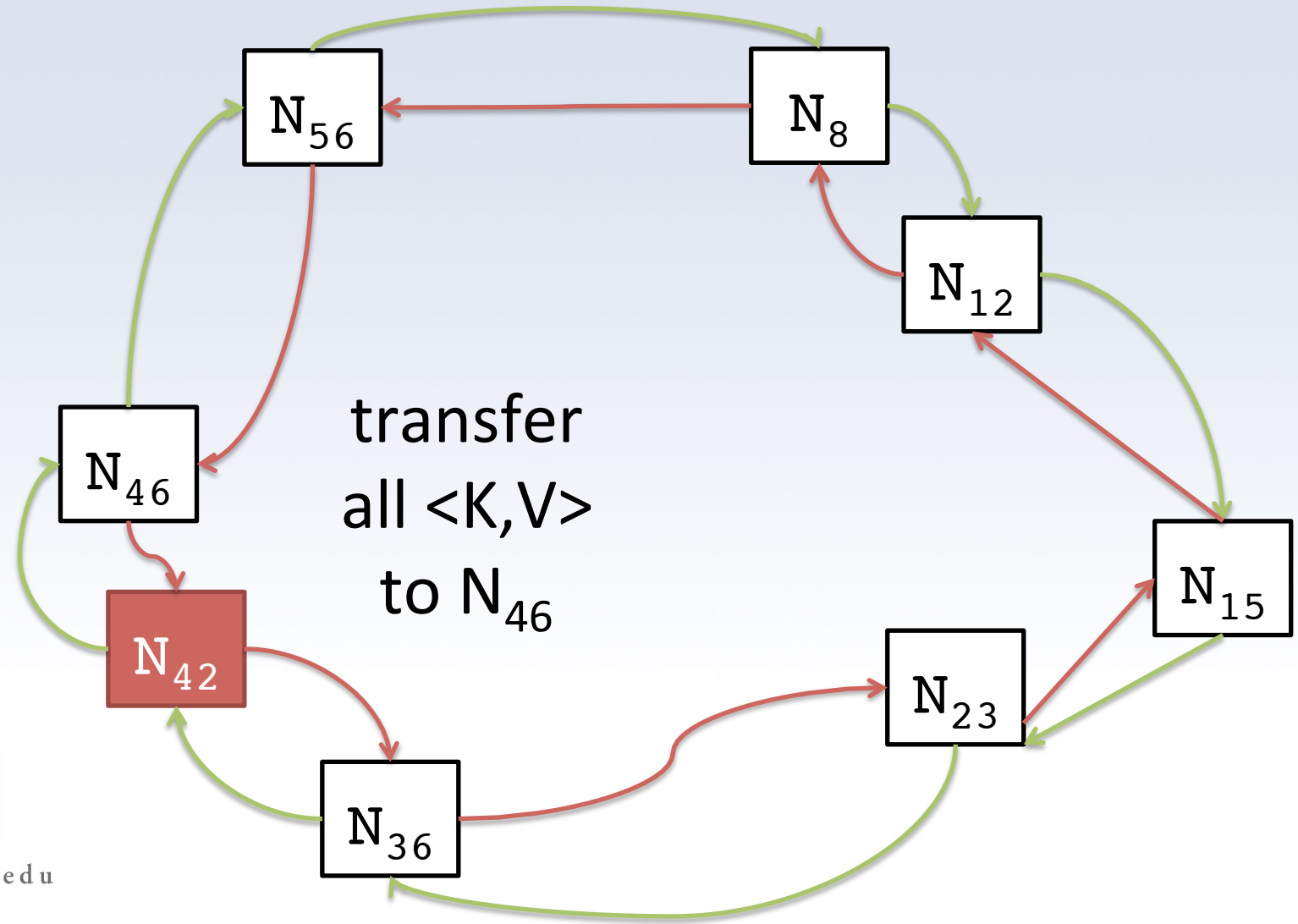
N46
N15
N42
N23
N36

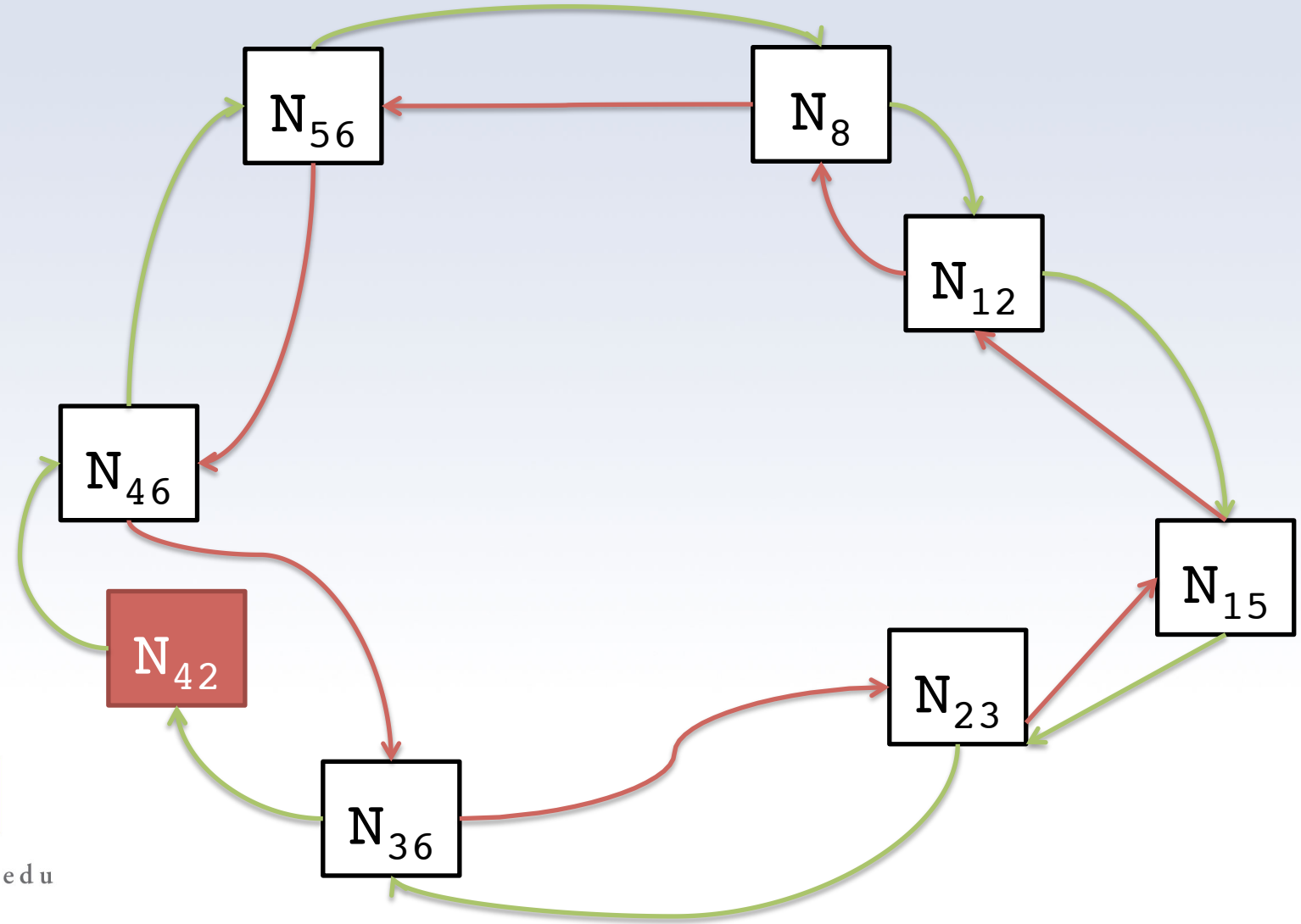
Stabilization

- Should also periodically update finger table
- Look up values and update based on results
- Entry for 1 is successor, so we always have a place to start

Leaving the network

- Notify predecessor and successor
- Transfer data to successor


N56
N8
N12
N46
transfer
all <K,V>
to N46
N15
N42
N23
N36



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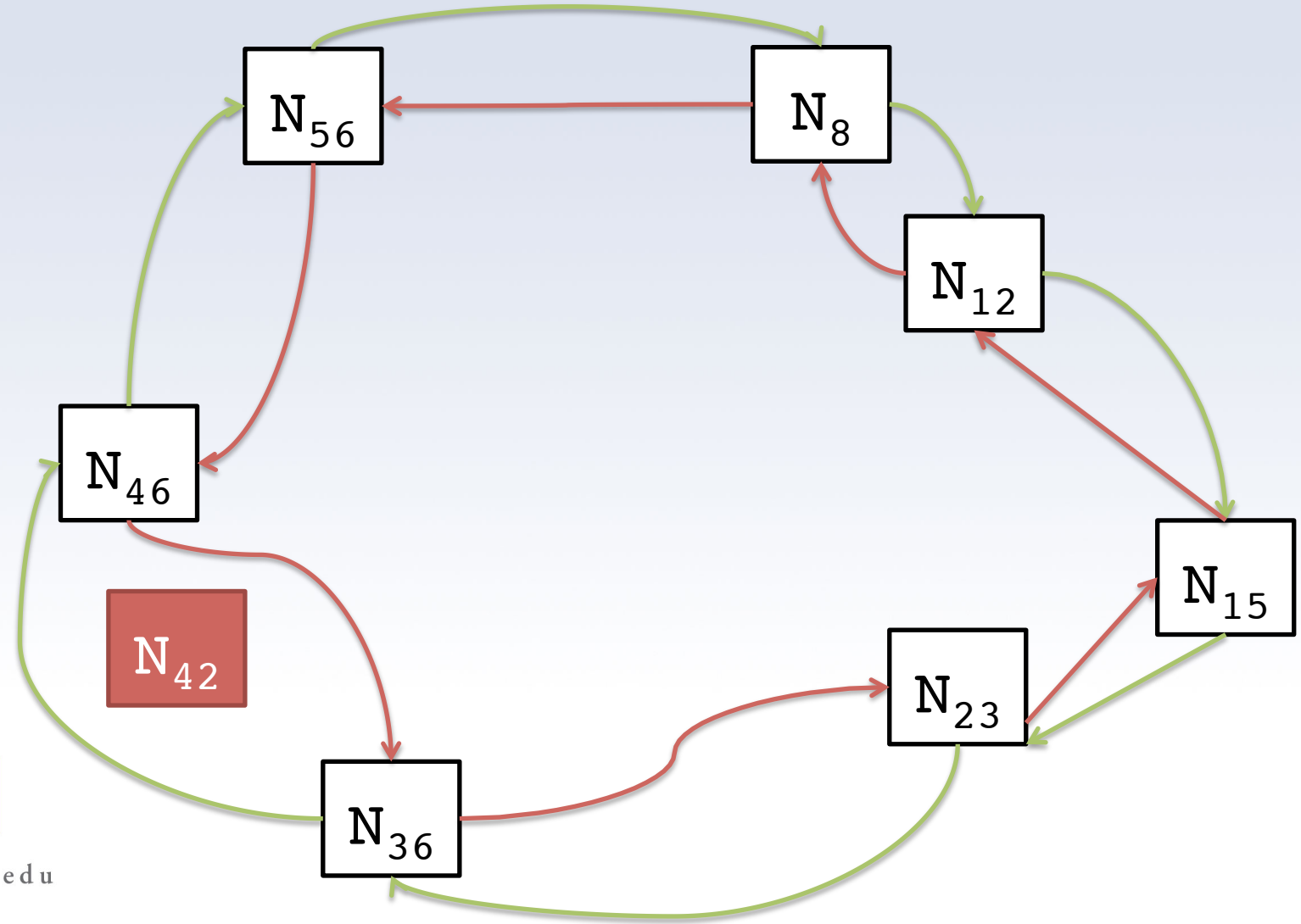
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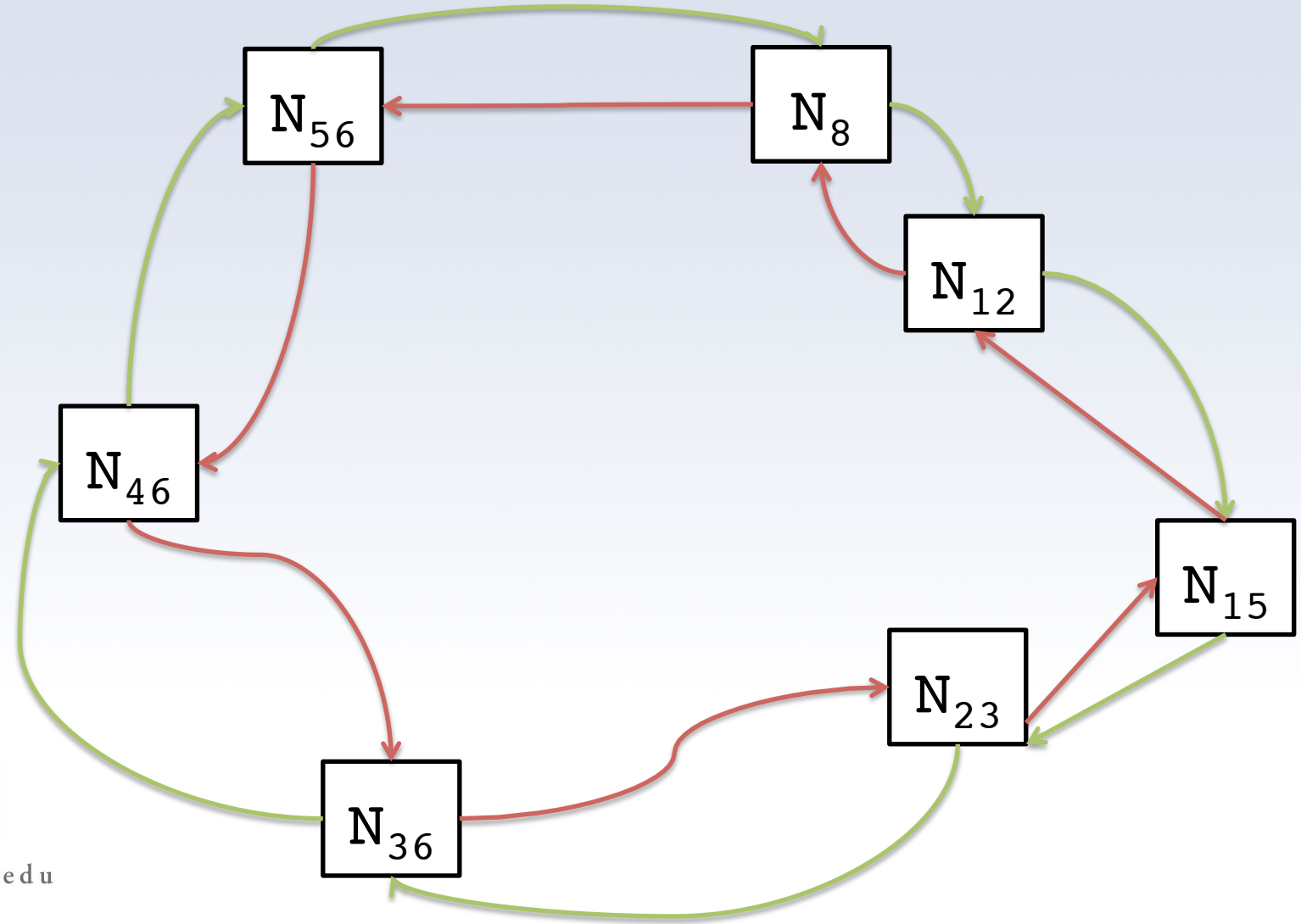
N56
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N36

Durability

- If a node fails, we lose
  - Our circle structure
  - Some of our <K,V> pairs
- Add redundancy
  - Successor's successor pointers
  - Predecessor's predecessor pointer
  - Replicate <K,V> pairs of successor and predecessor

If this is interesting…

- NoSQL/MapReduce/DHT
  - CS425 Distributed Systems
- SQL Injection/Hashing/Encryption
  - Computer Security/Applied Cryptography courses

Next time…

- We'll talk about some interesting data mining topics