Distributed Systems

CS425/ECE428

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Acknowledgements for some of the materials: Indy Gupta

Grade distribution

	3-credit	4-credit
Homework	33%	16% (drop 2 worst HWs)
Midterm	23%	17%
Final	43%	33%
MPs	N/A	33%
Participation	1%	1%

Grading

- Midterm curving formula (tentative)
  - relative: 80 + 10*(your score – avg_UG_score) / standard_dev
  - We will use max(absolute, relative) to get final score out of 100.
  - Midterm:
    - avg_UG_score = 71.61%
    - standard_dev = 13.95
  - Multiply the final score (out of 100) for each midterm by:
    - 0.23 for 3-credit students
    - 0.17 for 4-credit students.
- Finals will be similarly curved, but has higher weightage.

Grading

- Homeworks will not be curved.
    - For 3-credit students:
        - (sum of all 5 homework scores) * 100 * 0.33 / 200
    - For 4-credit students:
        - (sum of best 3 homework scores) * 100 * 0.16 / 120

- MPs will not be curved.
    - (sum of all four MP scores) * 100 * 0.33 / 330

- Participation score: directly taken from Campuswire
    - if reported score > 100, you get full 1%
    - Else you get (reported score /100)%
        - Bonus for active participation in class.

Tentative Grades Cutoff

- Tentative mapping from score to grade (*rough estimate*):
  - Cutoff for B: 80%
  - Bump up a grade for each 4% leap above 80%.
    - B+ 84%, A- 88%, A 92%, A+ 96%
  - Bump down a grade for each 4% leap below 80%
    - B- 76%, C+ 72%, …..
- This is subject to change!
- Last year grade cutoff for D- was 45.

Our agenda for the next 3-4 classes

- Brief overview of key-value stores

- Distributed Hash Tables
  - Peer-to-peer protocol for efficient insertion and retrieval of key-value pairs.

- Key-value stores in the cloud
  - How to run large-scale distributed computations over key-value stores?
    - Map-Reduce Programming Abstraction
  - How to design a large-scale distributed key-value store?
    - Case-study: Facebook's Cassandra

Quick Recap

- Distributed Hash Tables
  - Peer-to-peer protocol for efficient insertion and retrieval of key-value pairs.
  - Other required properties: load balancing, fault tolerance.

- Case-study: Chord

Quick Recap: Chord

- Uses **consistent hashing** to map nodes on a ring with m-bits identifiers.
- Uses consistent hashing to map a key to a node.
  - stored at **successor(key)**
- Each node maintains a **finger table** with m fingers.
  - With high probability, results in O(logN) hops for a look-up.
  - O(log(N)) hops true only if finger and successor entries correct.
    - What happens when nodes fails or when new nodes join in?
      - Our focus today.

Quick Recap: Chord

- Handling node failures:
  - For lookups:
    - maintain r multiple ring successor entries
    - in case of failure, use another successor entries
    - if r is sufficiently large (logN), can handle a high rate of failures (50%) with a very high probability.
  - When storing keys:
    - replicate key-value at r successors and predecessors

Need to deal with dynamic changes

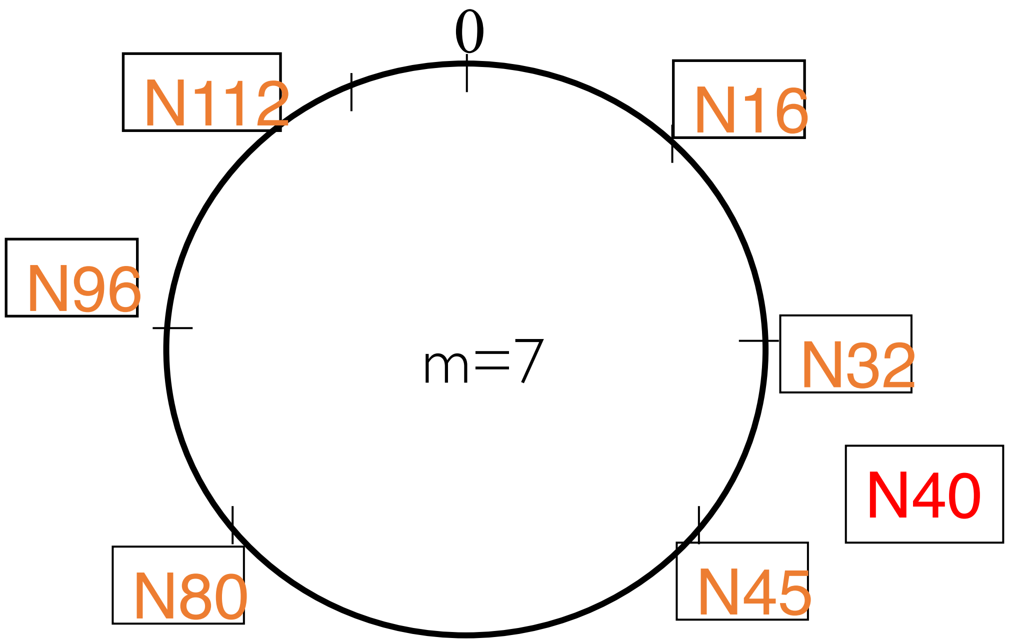
- Nodes fail
- New nodes join
- Nodes leave

So, all the time, need to:

→ Need to update successors and fingers, and copy keys

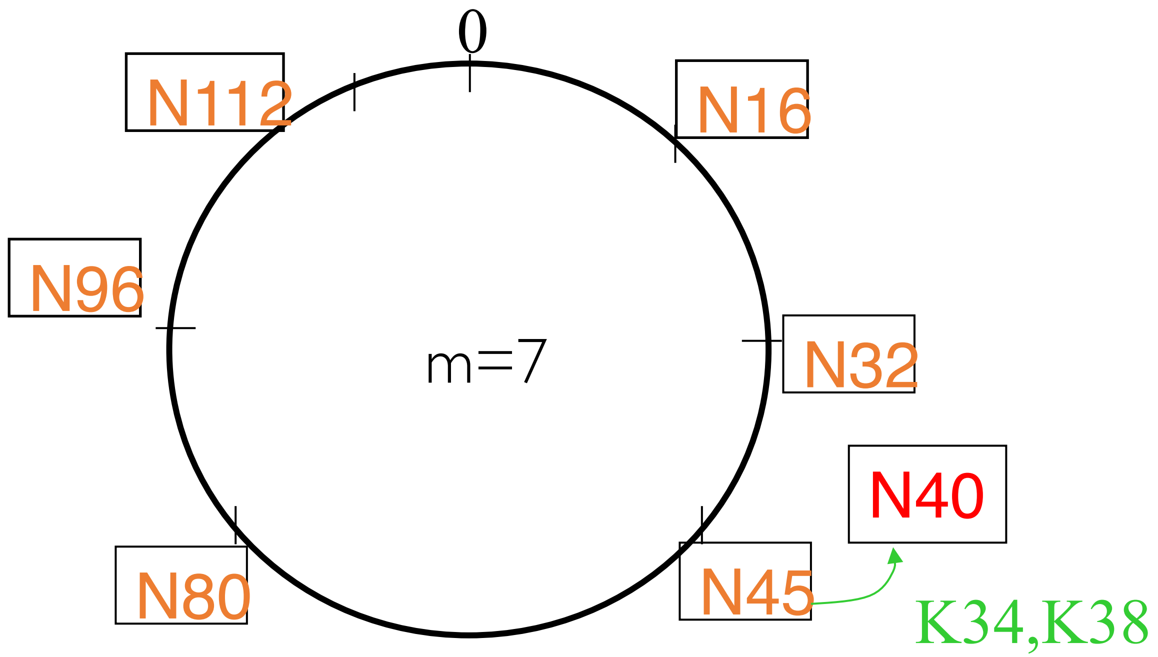
New node joins

New node contacts an existing Chord node (introducer).
Introducer directs N40 to N45 (and N32).
N32 updates its ring successor to N40.
N40 initializes its ring successor to N45, and initializes its finger table.
Other nodes also update their finger table.



New node joins

N40 may need to copy some files/keys from N45 (files with fileid between 32 and 40)



Concurrent Joins

- Aggressively maintaining and updating finger tables each time a node joins can be difficult under high *churn*.
    - E.g. when new nodes are concurrently added.
- Correctness of lookup does not require all nodes to have fully "correct" finger table entries.
- Need two invariants:
    - Each node, n, correctly maintains its ring successor (*next(n)*)
        - First entry in the finger table.
    - The node, successor(k), is responsible for key k.

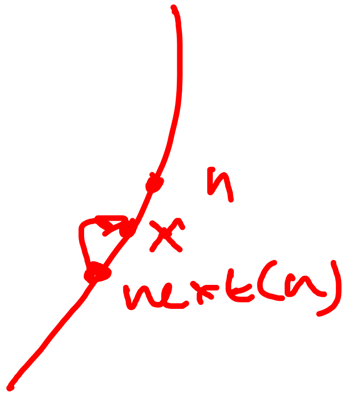
Stabilization Protocol

- When a node n joins (via an introducer)
  - initialize next(n), i.e. the ring successor
  - notify next(n).

- When node n gets notified by node n':
  - // update prev(n), i.e. the ring predecessor of n
  - if (prev(n) == nil or n' is in (prev(n), n))
    - prev(n) = n'.

Stabilization Protocol (contd)

- Each node n will periodically run stabilization:
  - x = prev(next(n))
  - if x in (n, next(n)), then next(n) = x.
  - notify next(n).



- Each node n periodically updates a random finger entry.
  - Pick a random i in [0, m-1]
  - Lookup successor(n + 2^i)

New node joins

New node contacts an existing Chord node (introducer).

Introducer informs N40 of N45.

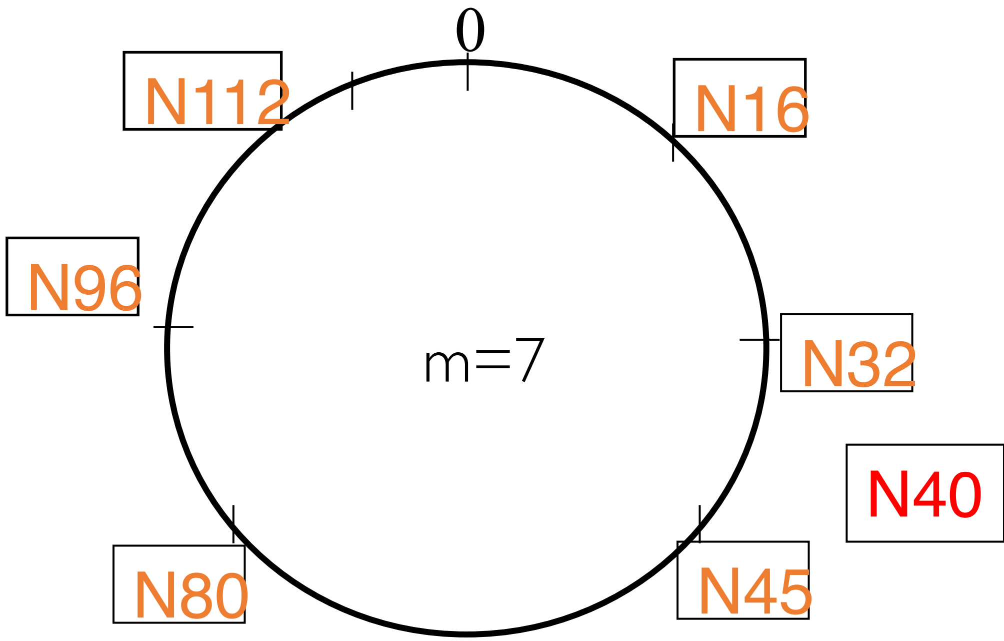
N40 initializes its ring successor to N45.

N40 notifies N45, and N45 ~~initializes~~ updates its ring predecessor to N40.

N32 realizes its new successor is N40 when it runs stabilization.

N32 notifies N40, and N40 initializes its ring predecessor to N32.

Periodically and eventually, each node update their finger table entries.



Stabilization Protocol (contd)

- Failures can be handled in a similar way.
  - *Also need failure detectors (you've seen them!)*
  - Maintain knowledge of **r** ring successors.
  - The predecessor of a failed node update's its ring successor, and notifies it.

Stabilization Protocol (contd)

- Look-ups may fail while the Chord system is getting stabilized.
  - Such failures are transient.
    - Eventually ring successors and finger-table entries will get updated.
    - Application can then try again after a timeout.
  - Such failures are also unlikely in practice
    - Multiple key-value replicas and ring successors.

Chord Summary

- Consistent hashing for load balancing.
- O(logn) lookups via correct finger tables.
- *Correctness* of lookups requires correctly maintaining ring successors.
- As nodes join and leave a Chord network, runs a stabilization protocol to periodically update ring successors and finger table entries.
- Fault tolerance: Maintain **r** ring successors and **r** key replicas.

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Cloud Computing

Many Cloud Providers

- AWS: Amazon Web Services
  - EC2: Elastic Compute Cloud
  - S3: Simple Storage Service
- Microsoft Azure
- Google Cloud/Compute Engine/AppEngine
- Rightscale, Salesforce, EMC, Gigaspaces, 10gen, Datastax, Oracle, VMWare, Yahoo, Cloudera
- And many many more!

What is a cloud?

- Cloud = Lots of storage + compute cycles nearby

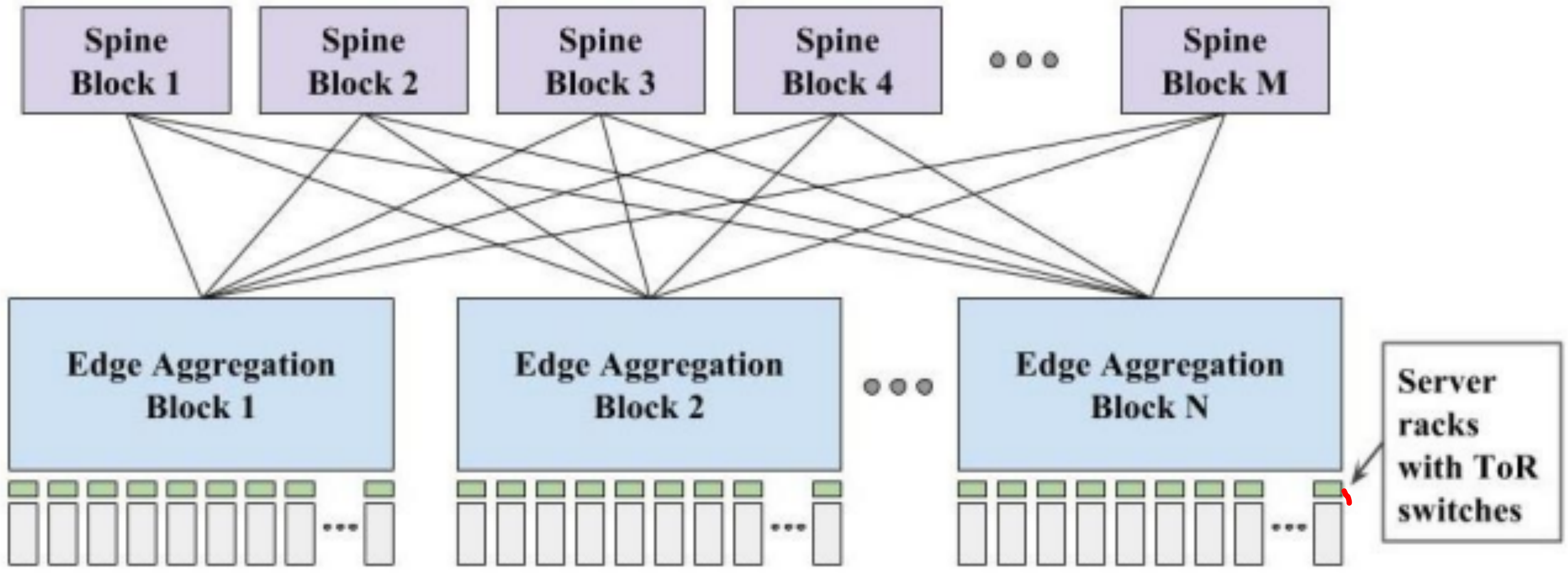
- Cloud services provide:
  - managed *clusters* for distributed computing.
  - managed *distributed datastores*.

What is a cloud?

- A single cloud-site (aka "Datacenter") consists of
  - Compute nodes (grouped into racks) (2)
  - Switches, connecting the racks in a hierarchical network topology.
  - Storage (backend) nodes connected to the network (3)
  - Front-end for submitting jobs and receiving client requests (1)
  - (1-3: Often called "three-tier architecture")
- A geographically distributed cloud consists of
  - Multiple such sites
  - Each site perhaps with a different structure and services

Picture of Google's Datacenter

Typical Datacenter Topology



Features of cloud

I. Massive scale.
   - Tens of thousands of servers and cloud tenants, and hundreds of thousands of VMs.

II. On-demand access:
   - Pay-as-you-go, no upfront commitment, access to anyone.

III. Data-intensive nature:
   - What was MBs has now become TBs, PBs and XBs.
     - Daily logs, forensics, Web data, etc.

Must deal with immense complexity!

- Fault-tolerance and failure-handling
- Replication and consensus
- Cluster scheduling

- How would a cloud user deal with such complexity?
  - **Powerful abstractions and frameworks**
  - Provide **easy-to-use** API to users.
  - Deal with the complexity of distributed computing under the hood.

MapReduce
is one such powerful
abstraction.

MapReduce Abstraction

- Map/Reduce
  - Programming model inspired from LISP (and other functional languages).

- Expressive: many problems can be phrased as map/reduce.

- Easy to distribute across nodes.
  - High-level job divided into multiple independent "map" tasks, followed by multiple independent "reduce" tasks.

- Nice retry/failure semantics.

MapReduce Architecture

- *MapReduce programming abstraction:*
  - Easy to program distributed computing tasks.
- MapReduce programming abstraction offered by multiple open-source *application frameworks*:
  - Handle creation of "map" and "reduce" tasks.
  - *e.g. Hadoop: one of the earliest map-reduce frameworks.*
  - *e.g. Spark: easier API and performance optimizations.*
- Application frameworks use *resource managers*.
  - Deal with the hassle of distributed cluster management.
  - *e.g. Kubernetes, YARN, Mesos, etc.*

MapReduce Architecture

- *Map/Reduce abstraction:*
  - Easy to program distributed computing tasks.
- MapRe le
  open-s
  - Cre
  - e.g. s.
  - e.g.

- Automatic parallelization & distribution
- Fault tolerance
- Scheduling
- Monitoring & status updates

- Application frameworks use *resource managers*.
  - Deal with the hassle of distributed cluster management.
  - e.g. *Kubernetes, YARN, Mesos, etc.*

MapReduce Architecture

- *Map/Reduce abstraction:*
  - Easy to program distributed computing tasks.
- MapReduce programming abstraction offered by multiple open-s
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  - e.g. s.
  - e.g. *Spark: easier API and performance optimizations.*

Next class: more details on MapReduce

- Application frameworks use *resource managers*.
  - Deal with the hassle of distributed cluster management.
  - e.g. *Kubernetes, YARN, Mesos, etc.*