Final Review

Grading Update

- HW5 and MP2 graded
- This leaves:
  - HW6 (6%) + final (33%) for 3-credit
  - HW6 (0-~4%) + MP3 (7% + 3% bonus) + final (25%) for 4-credit
- Participation grade (1%)
  - Will be used to bump people to next grade
  - Based on your activity in CampusWire
- Reminder:
  - CR/NC means course does not affect GPA, but grade < C- means no credit
  - If you keep a letter grade, anything >= D- is a pass

Final Logistics

Timed Exam: Wed, May 13, 8–11 a.m.

- Format similar to midterm 2
  - Exam released to you at 8 a.m.
  - Upload answer sheet to Gradescope by 11 a.m.
  - Open book, but individual work
  - Zoom room + Google doc for clarifications
- Topic coverage: 50% from MT1+MT2, 50% new material
- Exam structure similar to MT1/MT2
  - Some multiple choice
  - Some short answer / synthesis
  - ~50% longer

Topic coverage (Part III, 50% of final)

- DHTs
- RPCs
- Distributed transactions
    - Concurrency, isolation, and deadlocks
    - Atomicity and 2PC
- Combining 2PC and Paxos; Spanner and linearizability
- Cloud computing and MapReduce
- Distributed data stores and Cassandra

Topic coverage (Parts I and II, 50% of final)

- System model and Failures
- Failure Detection
- Clock Synchronization
- Event ordering and Logical Timestamps
- Global Snapshot
- Multicast
- Mutual Exclusion
- Leader election
- Consensus
  - Formulation
  - Synchronous consensus
- Paxos
- FLP Theorem
- Bitcoin
- Raft

Distributed Hash Tables / Chord

Goal: horizontal scaling to millions of peers and data items

- Consistent hashing of keys, node IDs into a large (2^{128}–2^{256}) key space
- Neighbor table: successors and fingers
- Finger-based routing:
  - O(log N) neighbors and O(log N) lookup steps
- Resilient structure to departing nodes / incorrect fingers
  - Track multiple successors and replicated keys at succ’s/pred’s
- Stabilization to restore DHT structure

RPC / RMI

Goal: Execute functions / procedures / methods on remote system, and implement *remote objects*

- Interface definition languages (
- External data representation (JSON, protobuf, etc.)
  - Marshaling / unmarshaling arguments
- Dealing with failures (at least once, at most once, idempotence)
- Remote objects
  - Proxy objects (client)
  - Dispatcher and skeleton (server)
  - Remote reference module

Transactions & Isolation/Concurrency

Goal: support high-level updates to data while maintaining useful properties

- ACID properties (Atomicity, Consistency, Isolation, Durability)
- Isolation
  - Lost update problem
  - Inconsistent retrieval problem
  - Serial equivalence
  - Conflicts (R/W, W/W)
  - Conflicts follow tx ordering === serial equivalence

Concurrency Techniques

Goal: achieve isolation / serial equivalence of transactions

- Two-phase locking: acquire locks during tx, release during commit/abort
  - Exclusive or shared locks
  - Lock promotion
- Timestamp ordering: ensure operations consistent with tx timestamp
  - Don’t read data from newer tx’s
  - Don’t overwrite data from newer tx’s
  - Abort (or skip writes) if order not satisfied
- Optimistics vs. pessimistic concurrency

Deadlocks

Goal: Avoid or detect deadlocks

- Deadlock requirements:
  - no preemption
  - hold and wait
  - circular wait
- Deadlock detection
  - timeout
  - centralized
  - edge chasing
- Deadlock avoidance: lock ordering
  - E.g., wait-die / wound-wait
  - E.g., dependency lists in timestamped concurrency
- Deadlock resolution
  - Abort newer tx

Two-phase Commit

Goal: ensure atomic commit across distributed participants

- Problem: need *unanimous* agreement to commit
    - not majority like Paxos / Raft
- First phase: precommit
    - any participant who agrees to commit must be able to proceed
- Second phase: commit/abort
- Crash-recover semantics
    - Use participant or coordinator log after recovery
    - Sacrifice availability

Distributed, replicated txs

Goal: combine distributed tx's (for horizontal scaling) with replication (for availability / durability)

- Run distributed transactions w/ 2PL, 2PC
- Replace each participant / coordinator with replica group
    - Use Paxos / Raft for replica consistency
- Expensive!

Spanner

Goal: make previous approach more efficient

- Maintain versioned / timestamped database
  - A log of each previous value of each object with tx timestamp
  - Enables read at a past time
- Transaction timestamp is *global time* that occurred during tx commit phase
  - Needs time with known bound on error
  - Commit wait to ensure property (can overlap with consensus protocols)
  - External consistency
- Reads can be lock free

What is a cloud?

- Cloud = Lots of storage + compute cycles nearby

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

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 Architecture

- *MapReduce programming abstraction:*
  - Easy to program distributed computing tasks.

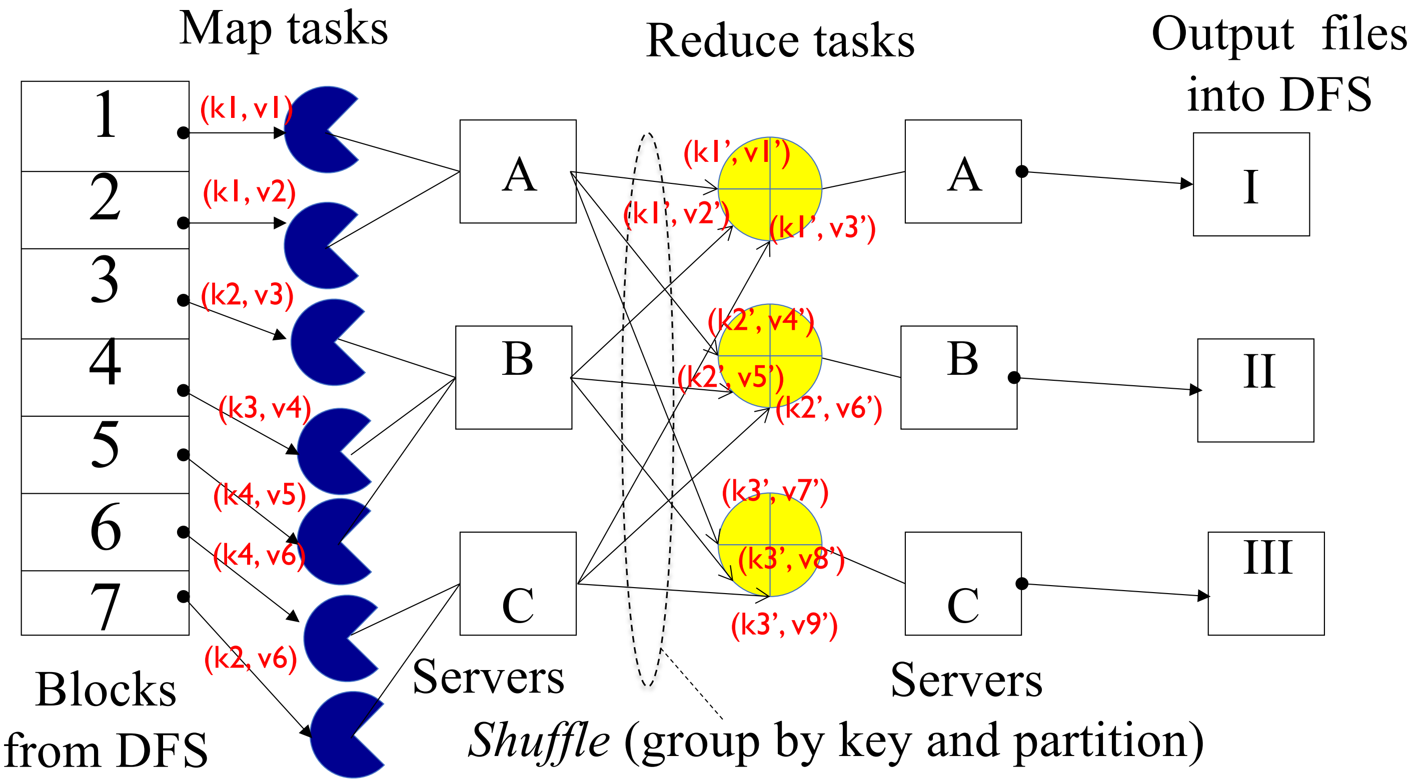
- MapReduce programming abstraction offered by multiple open-source *application frameworks*:
  - Handle creation of “map” and “reduce” tasks.
  - *e.g. Hadoop: one of the earliest map-reduce frameworks.*
  - *e.g. Spark: easier API and performance optimizations.*

- Application frameworks use *resource managers*.
  - Deal with the hassle of distributed cluster management.

MapReduce Overview

- Input: a set of key/value pairs
- User supplies two functions:
  - map(k,v) → list(k1,v1)
  - reduce(k1, list(v1)) → v2
- (k1,v1) is an intermediate key/value pair.
- Output is the set of (k1,v2) pairs.

MapReduce Execution



Shuffle (group by key and partition)
Barrier between map and reduce phases.

Resource Manager (assigns map and reduce tasks to servers)

Distributed Datastores

- NoSQL datastores:
  - Similar to databased (RDBMS), but,
    - lack schema and structure.
    - simplified API; might not support ‘joins’.
    - typically do support ACID semantics.

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Design Requirements

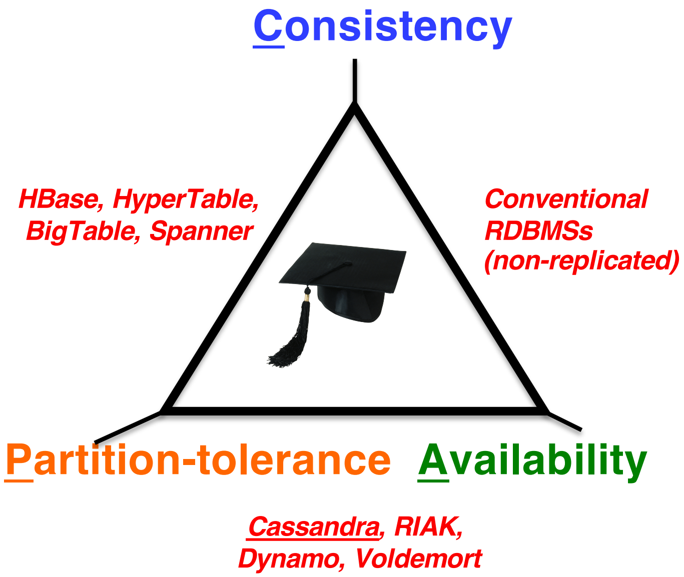
- High performance, low cost, and scalability.
- Avoid single-point of failure
  - Replication across multiple nodes.
- Consistency: reads return latest written value by any client (all nodes see same data at any time).
  - *Different from the C of ACID properties for transaction semantics!*
- Availability: every request received by a non-failing node in the system must result in a response (quickly).
  - Follows from requirement for high performance.
- Partition-tolerance: the system continues to work in spite of network partitions.

CAP Theorem

- Consistency: reads return latest written value by any client (all nodes see same data at any time).
- Availability: every request received by a non-failing node in the system must result in a response (quickly).
- Partition-tolerance: the system continues to work in spite of network partitions.
- In a distributed system you can only guarantee at most 2 out of the above 3 properties.
  - Proposed by Eric Brewer (UC Berkeley)
  - Subsequently proved by Gilbert and Lynch (NUS and MIT)

CAP Tradeoff

- Starting point for NoSQL Revolution
- A distributed storage system can achieve at most two of C, A, and P.
- Partition-tolerance important for distributed datastores:
  - choose between consistency and availability



Consistency

HBase, HyperTable, BigTable, Spanner

Conventional RDBMSs (non-replicated)

Partition-tolerance

Availability

Cassandra, RIAK, Dynamo, Voldemort