CSE 486/586 Distributed Systems
Consistency --- 3

Steve Ko
Computer Sciences and Engineering
University at Buffalo

Recap

- Consistency
  - Linearizability?
  - Sequential consistency?
- Chain replication
- Primary-backup (passive) replication
- Active replication

Linearizability vs. Sequential Consistency

- Both care about giving an illusion of a single copy.
  - From the outside observer, the system should (almost) behave as if there's only a single copy.
- Linearizability cares about time.
  - Steve writes on his facebook wall at 11am.
  - Atri writes on his facebook wall at 11:05am.
  - Everyone will see the posts in that order.
- Sequential consistency cares about program order.
  - Steve writes on his facebook wall at 11am.
  - Atri writes on his facebook wall at 11:05am.
  - It's not necessarily that the posts will be ordered that way (though everyone will see the same order).

Two More Consistency Models

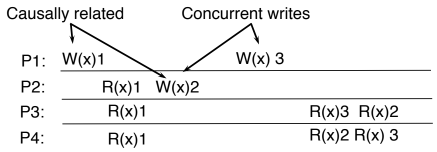
- Even more relaxed
  - We don't even care about providing an illusion of a single copy.
- Causal consistency
  - We care about ordering causally related write operations correctly.
- Eventual consistency
  - As long as we can say all replicas converge to the same copy eventually, we're fine.

Causal Consistency

- Writes that are potentially causally related must be seen by all processes in the same order. Concurrent writes may be seen in a different order on different machines.
  - Weaker than sequential consistency
- How do we define "causal relations" between two writes?
  - (Roughly) One client reads something that another client has written; then the client writes something.

Causal Consistency

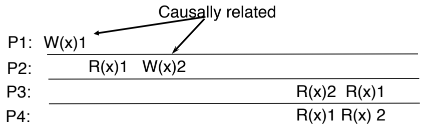
- Example 1:


Causally related
Concurrent writes
P1: W(x)1 W(x) 3
P2: R(x)1 W(x)2
P3: R(x)1 R(x)3 R(x)2
P4: R(x)1 R(x)2 R(x) 3

This sequence obeys causal consistency

Causal Consistency Example 2

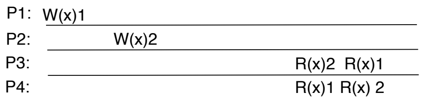
- Causally consistent?



- No!

Causal Consistency Example 3

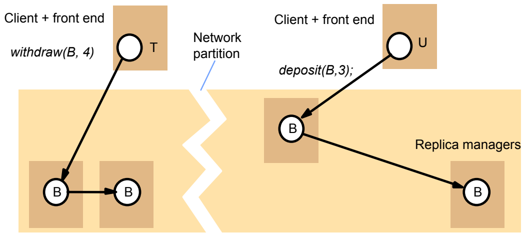
- Causally consistent?



- Yes!

Eventual Consistency

- Popularized by the CAP theorem.
- The main problem is network partitions.



Dilemma

- In the presence of a network partition:
- In order to keep the replicas consistent, you need to block.
  - From the outside observer, the system appears to be unavailable.
- If we still serve the requests from two partitions, then the replicas will diverge.
  - The system is available, but no consistency.
- The CAP theorem explains his dilemma.

CAP Theorem

- Consistency
- Availability
  - Respond with a reasonable delay
- Partition tolerance
  - Even if the network gets partitioned
- Choose two!
- Brewer conjectured in 2000, then proven by Gilbert and Lynch in 2002.

Coping with CAP

- The main issue is the Internet.
  - As the system grows to span geographically distributed areas, network partitioning becomes inevitable.
- Then the choice is either giving up availability or consistency
- A design choice: What makes more sense to your scenario?
- Giving up availability and retaining consistency
  - E.g., use 2PC
  - Your system blocks until everything becomes consistent.
- Giving up consistency and retaining availability
  - Eventual consistency

CSE 486/586 Administrivia

- PA4 will be released soon.
- Anonymous feedback form still available.
- Please come talk to me!

Dealing with Network Partitions

- During a partition, pairs of conflicting transactions may have been allowed to execute in different partitions. The only choice is to take corrective action after the network has recovered
  - Assumption: Partitions heal eventually
- Abort one of the transactions after the partition has healed
- Basic idea: allow operations to continue in one or some of the partitions, but reconcile the differences later after partitions have healed

Quorum Approaches

- Quorum approaches used to decide whether reads and writes are allowed
- There are two types: pessimistic quorums and optimistic quorums
- In the pessimistic quorum philosophy, updates are allowed only in a partition that has the majority of RMs
  - Updates are then propagated to the other RMs when the partition is repaired.

Static Quorums

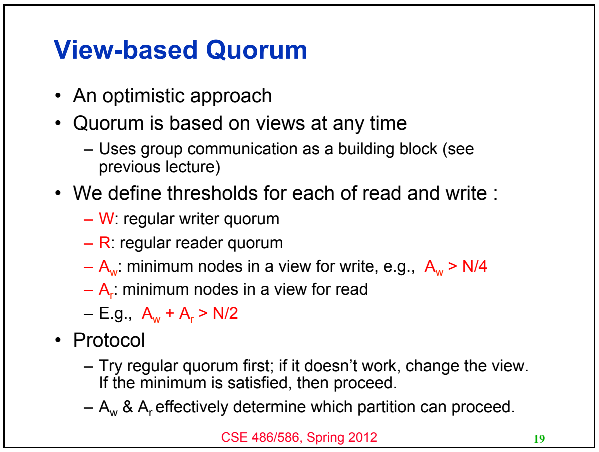
- The decision about how many RMs should be involved in an operation on replicated data is called Quorum selection
- Quorum rules state that:
  - At least r replicas must be accessed for read
  - At least w replicas must be accessed for write
  - r + w > N, where N is the number of replicas
  - w > N/2
  - Each object has a version number or a consistent timestamp

Static Quorums

- What does r + w > N mean?
  - The only way to satisfy this condition is that there's always an overlap between the reader set and the write set.
  - There's always some replica that has the most recent write.
- What does w > N/2 mean?
  - When there's a network partition, only the partition with more than half of the RMs can perform write operations.
  - The rest will just serve reads with stale data.
- R and W are tunable:
  - E.g., N=3, r=1, w=3: High read throughput, perhaps at the cost of write throughput.

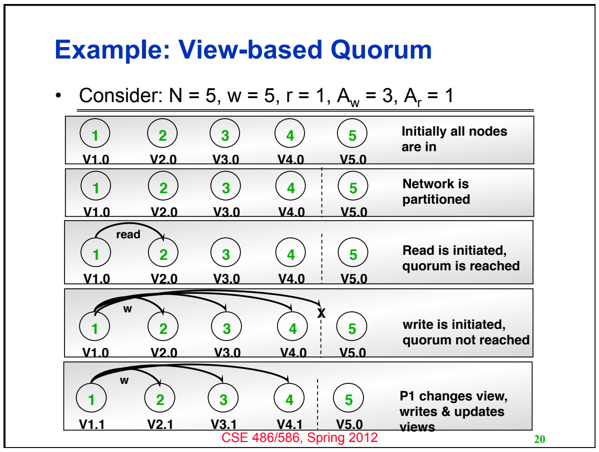
Optimistic Quorum Approaches

- An Optimistic Quorum selection allows writes to proceed in any partition.
- "Write, but don't commit"
  - Unless the partition gets healed in time.
- Resolve write-write conflicts after the partition heals.
- Optimistic Quorum is practical when:
  - Conflicting updates are rare
  - Conflicts are always detectable
  - Damage from conflicts can be easily confined
  - Repair of damaged data is possible or an update can be discarded without consequences
  - Partitions are relatively short-lived



View-based Quorum

- An optimistic approach
- Quorum is based on views at any time
  - Uses group communication as a building block (see previous lecture)
- We define thresholds for each of read and write :
  - W: regular writer quorum
  - R: regular reader quorum
  - A_w: minimum nodes in a view for write, e.g., $A_w > N/4$
  - A_r: minimum nodes in a view for read
  - E.g., $A_w + A_r > N/2$
- Protocol
  - Try regular quorum first; if it doesn't work, change the view. If the minimum is satisfied, then proceed.
  - A_w & A_r effectively determine which partition can proceed.



Example: View-based Quorum

- Consider: N = 5, w = 5, r = 1, $A_w = 3$, $A_r = 1$

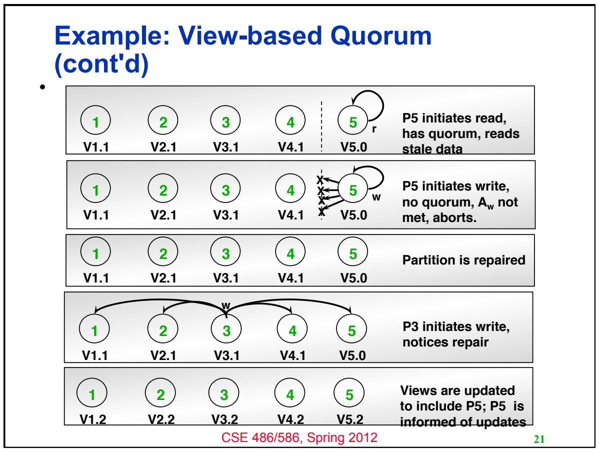
Initially all nodes are in

Network is partitioned

Read is initiated, quorum is reached

write is initiated, quorum not reached

P1 changes view, writes & updates views



Example: View-based Quorum (cont'd)

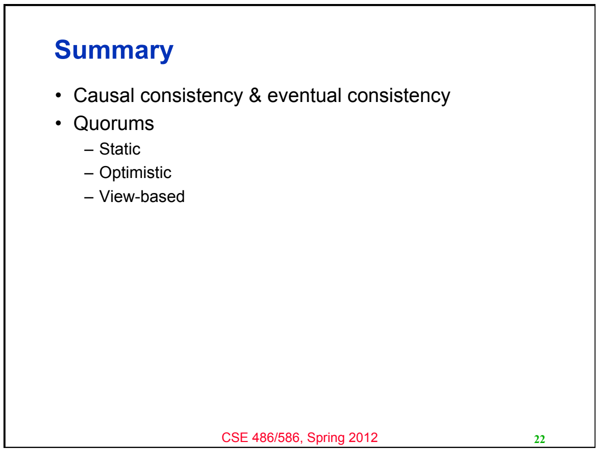
P5 initiates read, has quorum, reads stale data

P5 initiates write, no quorum, A_w not met, aborts.

Partition is repaired

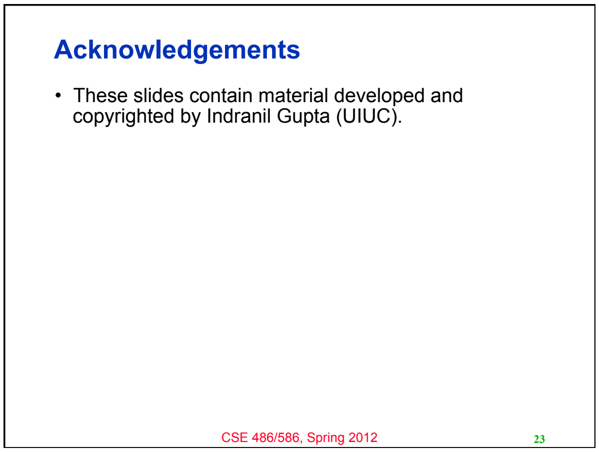
P3 initiates write, notices repair

Views are updated to include P5; P5 is informed of updates



Summary

- Causal consistency & eventual consistency
- Quorums
  - Static
  - Optimistic
  - View-based



Acknowledgements

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