CSE 486/586 Distributed Systems Consistency --- 2

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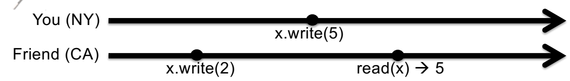
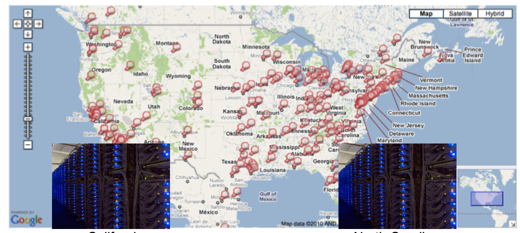
Implementing Linearizability

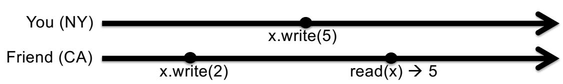
- Will this be difficult to implement?





Implementing Linearizability

- Will this be difficult to implement?
  - It depends on what you want to provide.

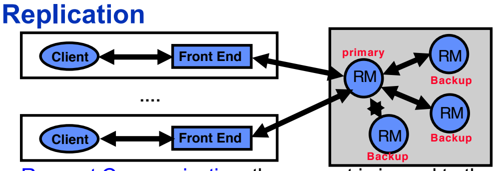


- How about:
  - All clients send all read/write to CA datacenter.
  - CA datacenter propagates to NC datacenter.
  - A request never returns until all propagation is done.
  - Correctness (linearizability)? yes
  - Performance? No

Implementing Linearizability

- Importance of latency
  - Amazon: every 100ms of latency costs them 1% in sales.
  - Google: an extra .5 seconds in search page generation time dropped traffic by 20%.
- Linearizability typically requires *complete* synchronization of multiple copies before a write operation returns.
  - So that any read over any copy can return the most recent write.
  - No room for asynchronous writes (i.e., a write operation returns before all updates are propagated.)
- It makes less sense in a global setting.
  - Inter-datecenter latency: ~10s ms to ~100s ms
- It might still make sense in a local setting (e.g., within a single data center).

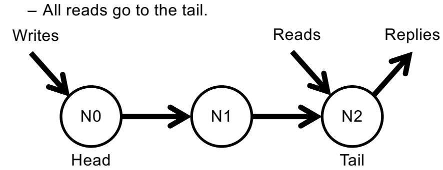
Passive (Primary-Backup) Replication



- Request Communication: the request is issued to the primary RM and carries a unique request id.
- Coordination: Primary takes requests atomically, in order, checks id (resends response if not new id.)
- Execution: Primary executes & stores the response
- Agreement: If update, primary sends updated state/result, req-id and response to all backup RMs (1-phase commit enough).
- Response: primary sends result to the front end

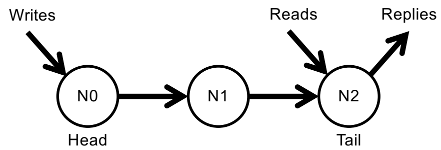
Chain Replication

- One technique to provide linearizability with better performance
  - All writes go to the head.
  - All reads go to the tail.



- Linearizability?
  - Clear-cut cases: straightforward
  - Overlapping ops?

Chain Replication



- What ordering does this have for overlapping ops?
  - We have freedom to impose an order.
  - Case 1: A write is at either N0 or N1, and a read is at N2. The ordering we're imposing is read then write.
  - Case 2: A write is at N2 and a read is also at N2. The ordering we're imposing is write then read.
- Linearizability
  - Once a write becomes visible (at the tail), all following reads get the write result.

CSE 486/586 Administrivia

- PA4 deadline: 5/10 (Friday)
- 486/586 survey

Relaxing the Guarantees

- Do we need linearizability?

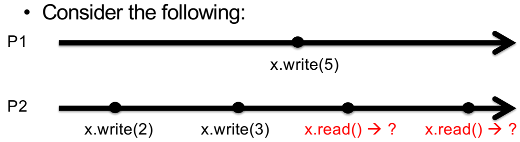
- Does it matter if I see some posts some time later?

Relaxing the Guarantees

- Linearizability advantages
  - It behaves as expected.
  - There's really no surprise.
  - Application developers do not need any additional logic.
- Linearizability disadvantages
  - It's difficult to provide high-performance (low latency).
  - It might be more than what is necessary.
- Relaxed consistency guarantees
  - Sequential consistency
  - Causal consistency
  - Eventual consistency
- It is still all about client-side perception.
  - When a read occurs, what do you return?

Sequential Consistency

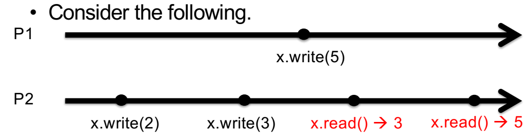
- A little weaker than linearizability, but still quite strong
  - Essentially linearizability, except that it doesn't need to return the most recent write according to physical time.
- Consider the following:



- What do you expect to read?
  - 5 & 5? (Linearizability)
  - What about 3 & 5 or 3 & 3?
  - Is it necessary to read 5 & 5?

Delayed Write Visibility

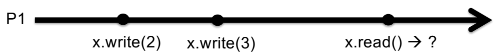
- Consider the following.



- Let's assume P1 and P2 are two users separately using Facebook. x is the same wall.
  - The first read at P2 is reading P2's own wall post.
  - The second read at P2 is reading P1's wall post at a delayed point in time, not right away.
  - With linearizability, P2's first read should read P1's wall post (the most recent write).
  - But again do we always need to? For applications like Facebook, delayed write visibility is probably fine.

Delayed Write Visibility

- Consider the following single process.



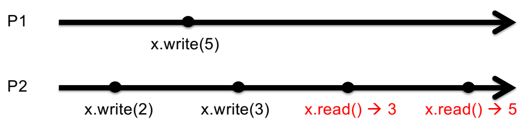
- If delayed write visibility is fine, is it okay for x.read() to return 2, not 3?
- If not, why not?
  - Now we're violating the program order for a single process.
  - Developers will start getting really confused.
  - With a single copy, that will never happen.

Sequential Consistency Definition

- Insight
  - For many applications, we don't need to make other processes' writes immediately visible, as long as we preserve each process's program order.
  - Still a strong guarantee: If a process doesn't know what other processes are doing (e.g., when other processes' writes are occurring), this still meets the natural expectation of the process.
- You can say that your storage system provides sequential consistency if:
  - All requests appear to come from a single client with a single interleaving of all requests.
  - In the single interleaving, the program order of each and every process is preserved.
- This still works like a single copy, but all program orders are only logically preserved.

Sequential Consistency Definition

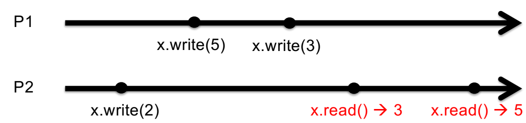
- Sequential consistency: providing single-client semantics while preserving each process's logical program order.
- Previous example:



- We can explain this behavior with the following ordering of requests from a single client
  - x.write(2), x.write(3), x.read() → 3, x.write(5), x.read() → 5

Sequential Consistency Examples

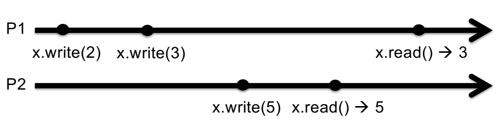
- Example 1: Does this satisfy sequential consistency?



- No: even if P1's writes show up later, we can't explain the last two writes.

Sequential Consistency Examples

- Example 2: Does this satisfy sequential consistency?



- Yes

Sequential Consistency Examples

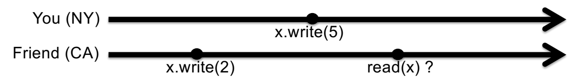
- Example 3
  - P1: a.write(A)
  - P2: a.write(B)
  - P3: a.read()->B a.read()->A
  - P4: a.read()->B a.read()->A
- Example 4
  - P1: a.write(A)
  - P2: a.write(B)
  - P3: a.read()->B a.read()->A
  - P4: a.read()->A a.read()->B

Sequential Consistency

- Your storage *appears* to process all requests in a single interleaved ordering (single client), where…
  - …each and every process's program order is preserved (single copy),
  - …and each process's program order is only *logically preserved*, i.e., it doesn't need to preserve its physical-time ordering.
- It works as if all clients are reading out of a single copy.
  - This meets the expectation from an (isolated) client, working with a single copy.
  - Linearizability meets the expectation of all clients even if they all know what others are doing.
  - Both sequential consistency and linearizability provide an illusion of a single copy.

Sequential Consistency vs. Linearizability

- Both should behave as if there were only a single copy, and a single client.
  - It's just that SC doesn't preserve the physical-time order, but just the program order of each client.
- Difference



  - Linearizability: Once a write is returned, the system is obligated to make the result visible to all clients based on physical time. I.e., the system has to return 5 in the example.
  - Sequential consistency: Even if a write is returned, the system is not obligated to make the result visible to other clients immediately. I.e., the system can still return 2 in the example.

Implementing Sequential Consistency

- In what implementation would the following happen?
  - P1: a.write(A)
  - P2: a.write(B)
  - P3: a.read()->B a.read()->A
  - P4: a.read()->A a.read()->B
- Possibility
  - P3 and P4 use different copies.
  - In P3's copy, P2's write arrives first and gets applied.
  - In P4's copy, P1's write arrives first and gets applied.
  - Writes are applied in different orders across copies.
  - This doesn't provide sequential consistency.

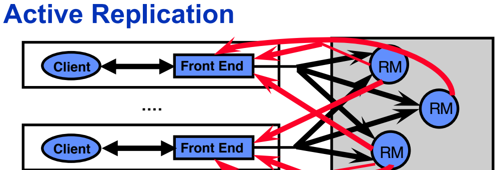
Implementing Sequential Consistency

- When implementing a consistency model, we need to think about how to handle writes and how to handle reads
- Handling writes
  - Write synchronization should occur (or writes should be applied) in the same order everywhere across different copies, while preserving each process's logical write order.
  - The synchronization does not have to be complete at the time of return from a write operation. (I.e., actual writes on different copies can be done at different times.)
- Handling reads
  - A read from a process should be done on a copy that already has applied the process's latest write. And all reads should be processed by the program order.

Implementing Sequential Consistency

- Typical implementation
  - You're not obligated to make the most recent write (according to physical time) visible (i.e., applied to all copies) right away.
  - But you are obligated to apply all writes in the same order for all copies.
- What is this ordering guarantee?
  - FIFO-total.

Active Replication



- A front end FIFO-orders all reads and writes.
- A read can be done completely with any single replica.
- Writes are totally-ordered and asynchronous (after at least one write completes, it returns).
  - Total ordering doesn't determine deliver times, i.e., writes can happen at different times at different replicas.
- Sequential consistency, not linearizability
  - Read/write ops from the same client will be ordered at the front end (program order preservation).
  - Writes are applied in the same order by total ordering (single copy).
  - No guarantee that a read will read the most recent write based on physical time.

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.

Summary

- Linearizability
  - The ordering of operations is determined by time.
  - Primary-backup can provide linearizability.
  - Chain replication can also provide linearizability.
- Sequential consistency
  - The ordering of operations preserves the program order of each client.
  - Active replication can provide sequential consistency.

Acknowledgements

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