CSE 486/586 Distributed Systems
Consistency --- 1

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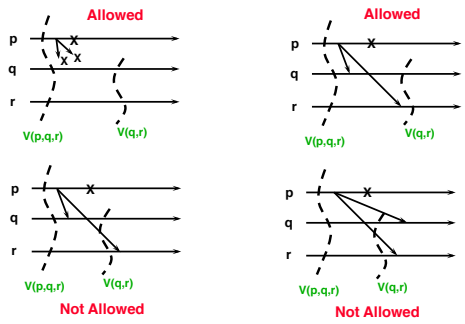
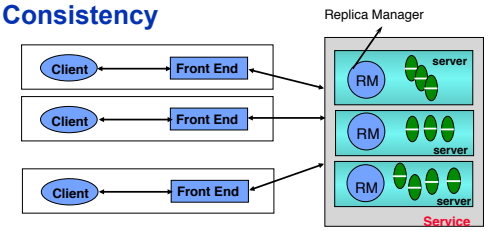
Recap

- Views?
  - Versioned membership
- View-synchronous group communication?
  - Providing group communication with a dynamic group
  - A way to design replicated state machines
  - "What happens in the view, stays in the view."

Examples



Consistency



- Consider that this is a storage service that serves read/write requests.
- Need consistent updates to all copies of object

Consistency Question

- How do we ensure that multiple copies have the same object?
- Let's think about this in terms of read/write operations…
- From the client's perspective, when do you know if an object has a new value?
- It depends on when writes become visible to reads.
- There are several guarantees we can provide.
  - Linearizability
  - Sequential consistency
  - Causal consistency
  - …
- We'll see the first two; and later the third.

Linearizability

- What would be the strongest (and probably most natural) form of consistency?
- Linearizability
  - A read operation returns the most recent write, regardless of the clients.
- Think of a single system read/write. What happens for a write followed by a read?
- Why does this mean in a distributed setting?
  - Multiple clients can interact with different servers. Servers maintain replicas.
  - Client C1 writes to server S1 at time t, client C2 reads from server S2 at time t+1. S2 should return what C1 wrote.

Linearizability: Deriving the Definition

- What's the first requirement in maintaining replicas?
  - It should act as a single copy.
  - I.e., if you say that your system provides linearizability then it should appear to your clients that your system only has single copies of objects.
- How (conceptually, not algorithmically)?
  - Hint with a single server with a single client as follows.
  - Given a set of operations from the client, there is a single order (program order) that explains what values were written and what values were read on a single copy.
  - Adapt that in a distributed setting?
- Single copy semantics
  - There should be a *single interleaving of operations* that explains the results of all clients' read/write operations as if all of them were done over a single copy.

Linearizability: Deriving the Definition

- Can you come up with a single interleaving?
  - C1: write A
  - C2: write B
  - C3: read B, read A
  - C4: read B, read A
  - One possibility: C2 (write B) -> C3 (read B) -> C4 (read B) -> C1 (write A) -> C3 (read A) -> C4 (read A)
- Can you come up with a single interleaving?
  - C1: write A
  - C2: write B
  - C3: read B, read A
  - C4: read A, read B

CSE 486/586 Administrivia

- PA3 deadline: 4/11 (Friday)

Linearizability: Deriving the Definition

- Linearizability
  - Single-copy semantics
  - A read operation returns *the most recent* write, regardless of the clients.
- Real-time aspect
  - You always should read what is written right before you.
  - I.e., A write should be *visible* to the next read immediately.
- Problem: read and write operations take time

Linearizability Subtleties

- Clear-cut (black---write & red---read)
- Not-so-clear-cut (parallel)
  - Case 1:
  - Case 2:
  - Case 3:

Linearizability Subtleties

- An operation takes time to finish.
  - E.g., a read op R starts at X ms and finishes at Y ms.
- A value written by a write operation becomes (physically) visible at some point during the operation.
  - E.g., a write op W starts at X ms and finishes at Y ms. At Z ms (X < Z < Y), the value gets actually written and becomes visible.
- What's a reasonable thing to do with this?
  - If W finishes at X, R starts at Y, and X < Y, then R should read what W wrote.
  - If R overlaps with W, then it can read either the previous value or the value written by W.

Linearizability Subtleties

- Definite guarantee
- Relaxed guarantee when overlap
- Case 1
- Case 2
- Case 3

Linearizability

- Let's say you're an oracle.
- Let your clients make requests (concurrent read/write).
- Let your system (with replicas) execute the requests.
- Write down the *real-time* execution of operations of your system. Two things to write down:
  - At what points in time each operation starts and ends.
  - Real-time precedence among operations: if A ends then B starts in real time, then A precedes B. (Caution: this is not a total order.)
- See if you can come up with an ordering of operations that meets three conditions:
  - All operations in the ordering appear one at a time as if each operation happened atomically.
  - The ordering gives the correct result as if it was done over a single copy.
  - The ordering preserves the real-time precedence of operations (i.e., the ordering written down from the above).

Linearizability

- Let the sequence of read and update operations that client i performs in some execution be oi1, oi2,….
  - "Program order" for the client
- (Textbook definition) A replicated shared object service is linearizable if for any execution (real), there is some interleaving of operations (virtual) issued by all clients that:
  - meets the specification of a single correct copy of objects
  - is consistent with the real times at which each operation occurred during the execution
- Main goal: any client will see (at any point of time) a copy of the object that is correct and consistent
- The strongest form of consistency

Linearizability Examples

- Example 1

a.write(x)

a.read() -> x

a.read() -> x

- Example 2

a.write(x)

a.read() -> 0

a.read() -> x

a.read() -> x

If this were a.read() -> 0, it wouldn't support linearizability.

Linearizability Examples

- Example 3

a.write(x)

a.read() -> x

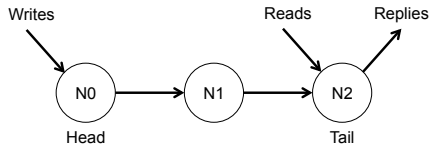
a.read() -> x

a.read() -> y

a.write(y)

Chain Replication

- One technique to provide linearizability



Summary

- Linearizability
  - Single-copy semantics
  - Real-time aspect
- A read operation returns *the most recent* write, regardless of the clients.

Acknowledgements

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