Wait-Free Registers

Ellis Michael

Congrats! You're Now Paxos Experts!

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- More practically, Paxos can have bad availability during failure scenarios (e.g., if a leader fails, it takes time to elect a new one).

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- Weaken the safety guarantees and accept weaker consistency (at your own peril).
- Constrain the problem.

Registers

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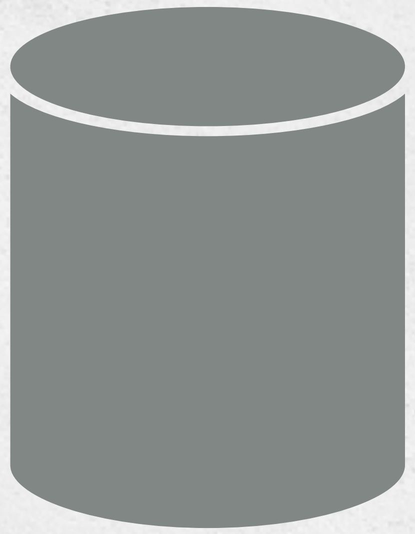
- Allows reads and writes only. Does not allow appends or other read-modify-write operations.
- Recall **safe**, **regular**, and **atomic**/**linearizable** semantics. We want *linearizability*.



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If you can wait-free implement an appendable register, you can solve consensus (safety and liveness), which is impossible.

Implementing a Register

- We will use the **client**/**server** model, where servers are replicas storing the value and clients send **reads** and **writes**.
- We want linearizability of reads and writes.
- As usual, we want to tolerate up to f server *crash failures*. Clients can also fail by crashing.

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- **Lock-free** algorithms guarantee system-wide progress.
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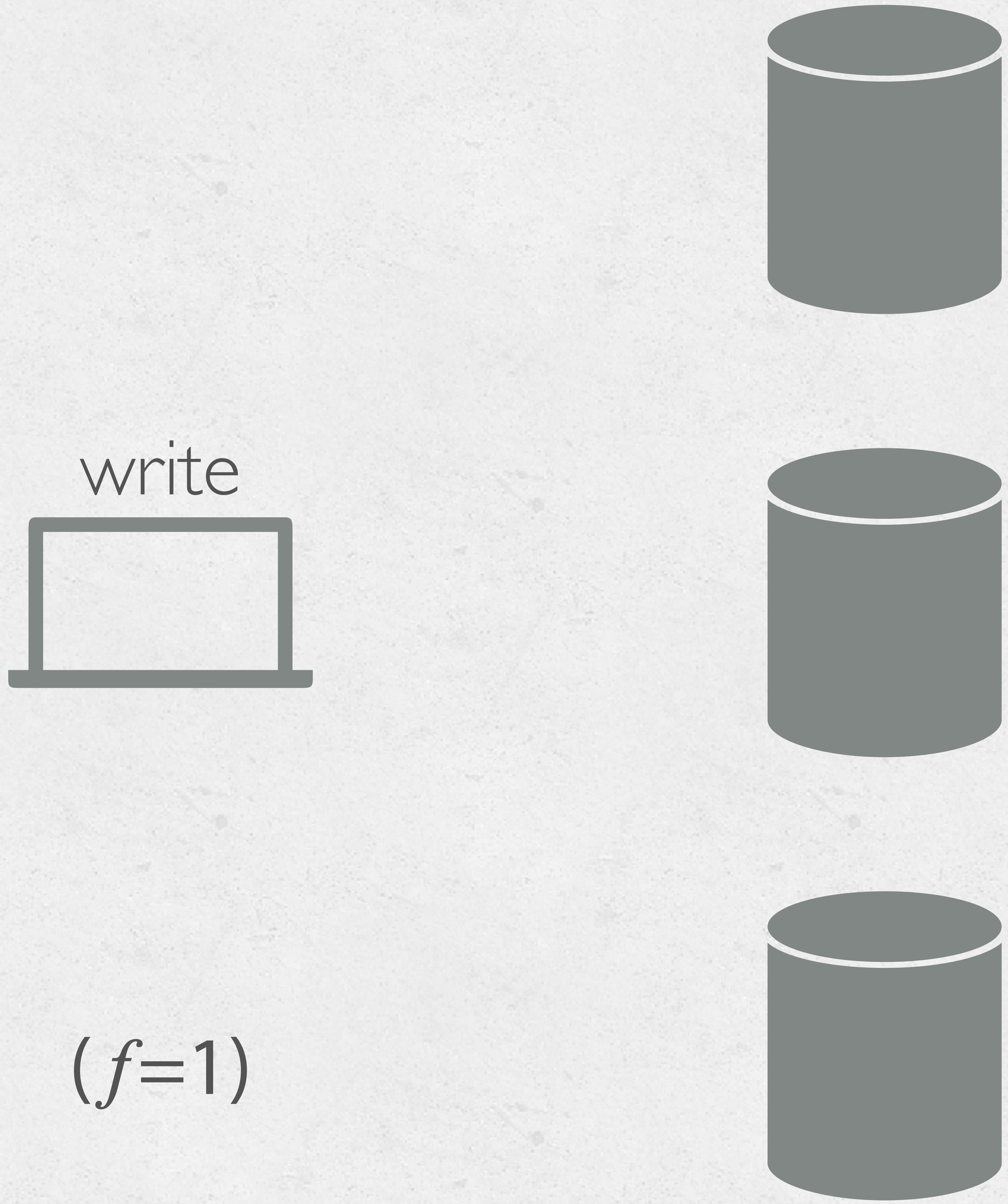

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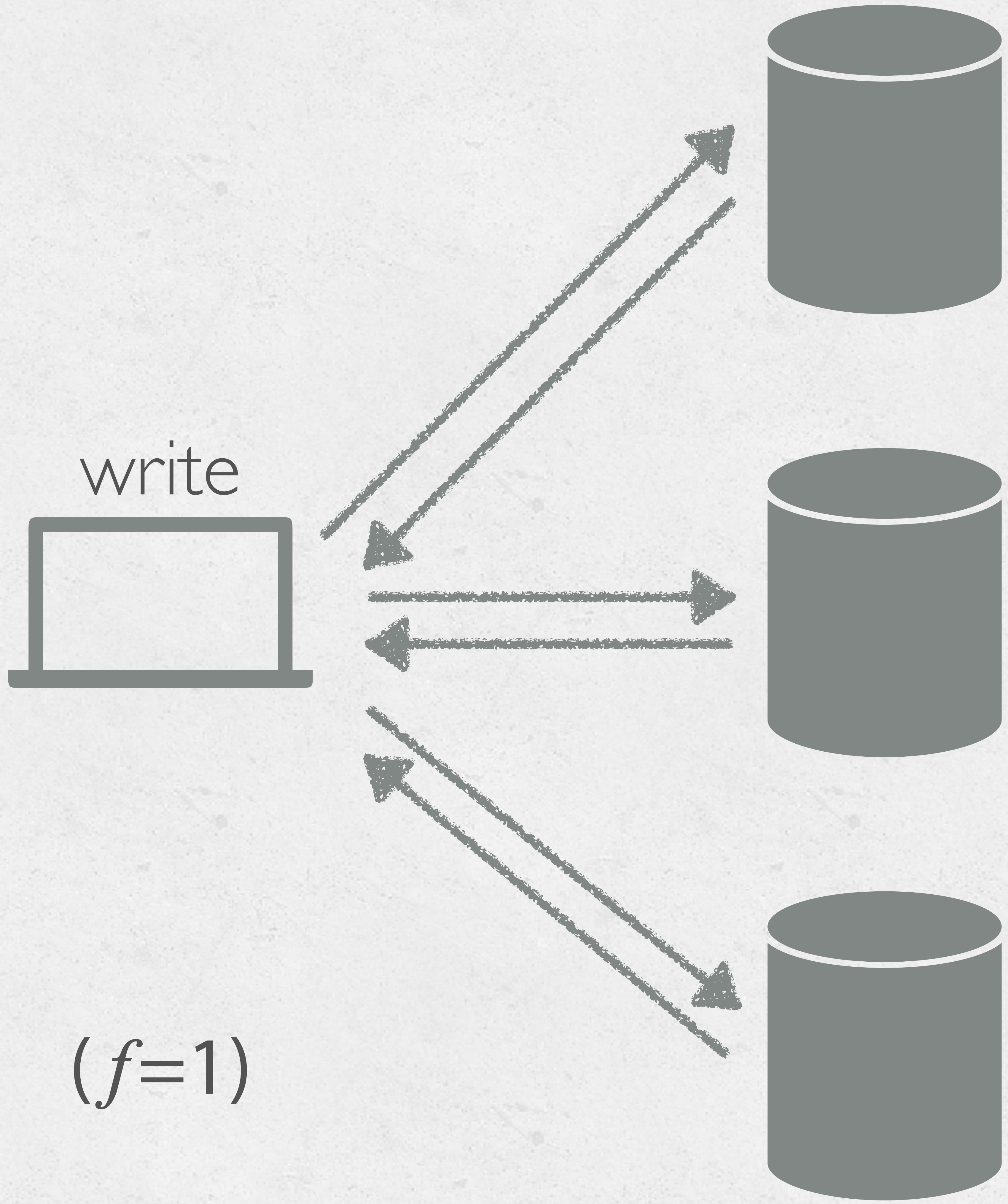

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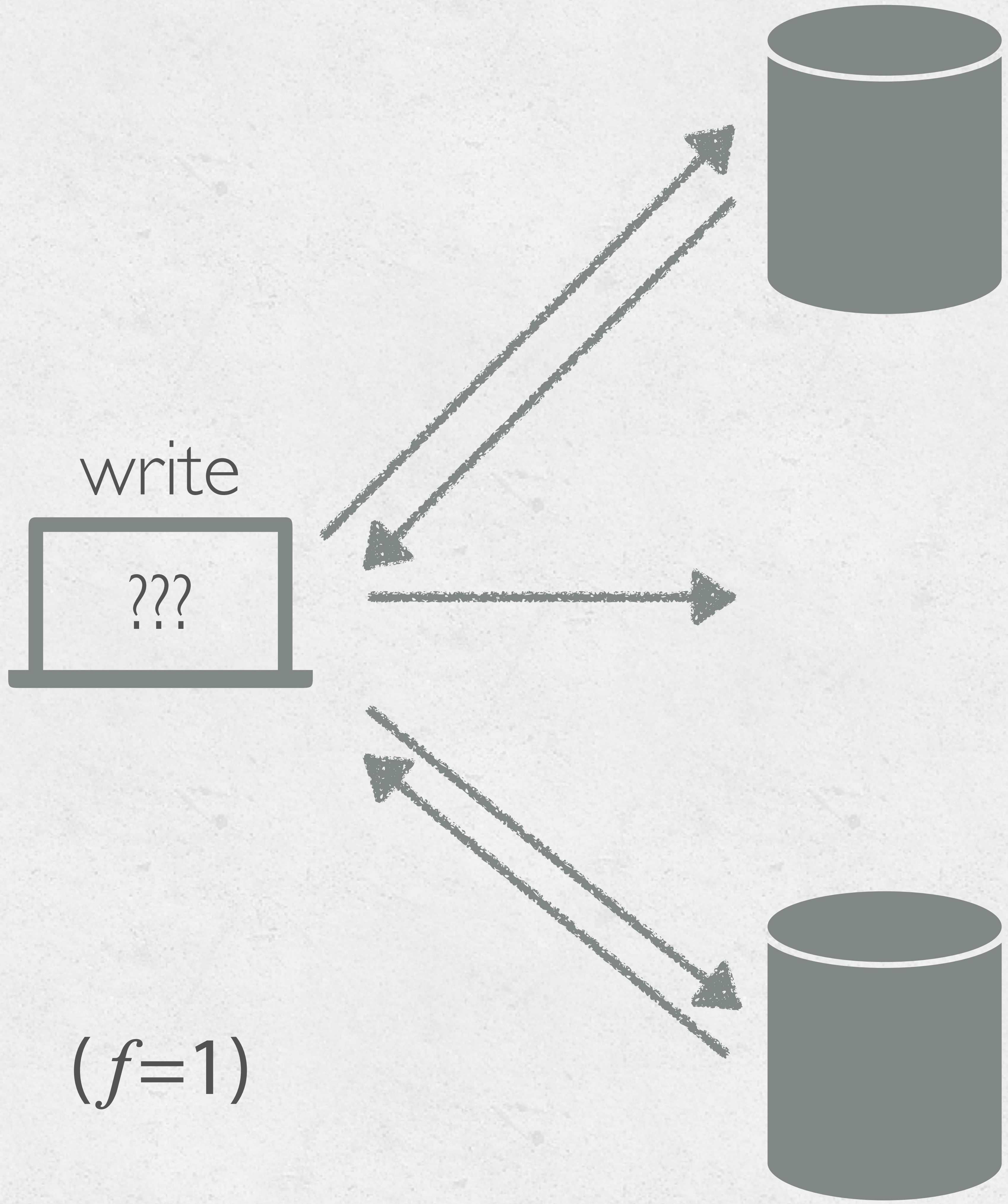

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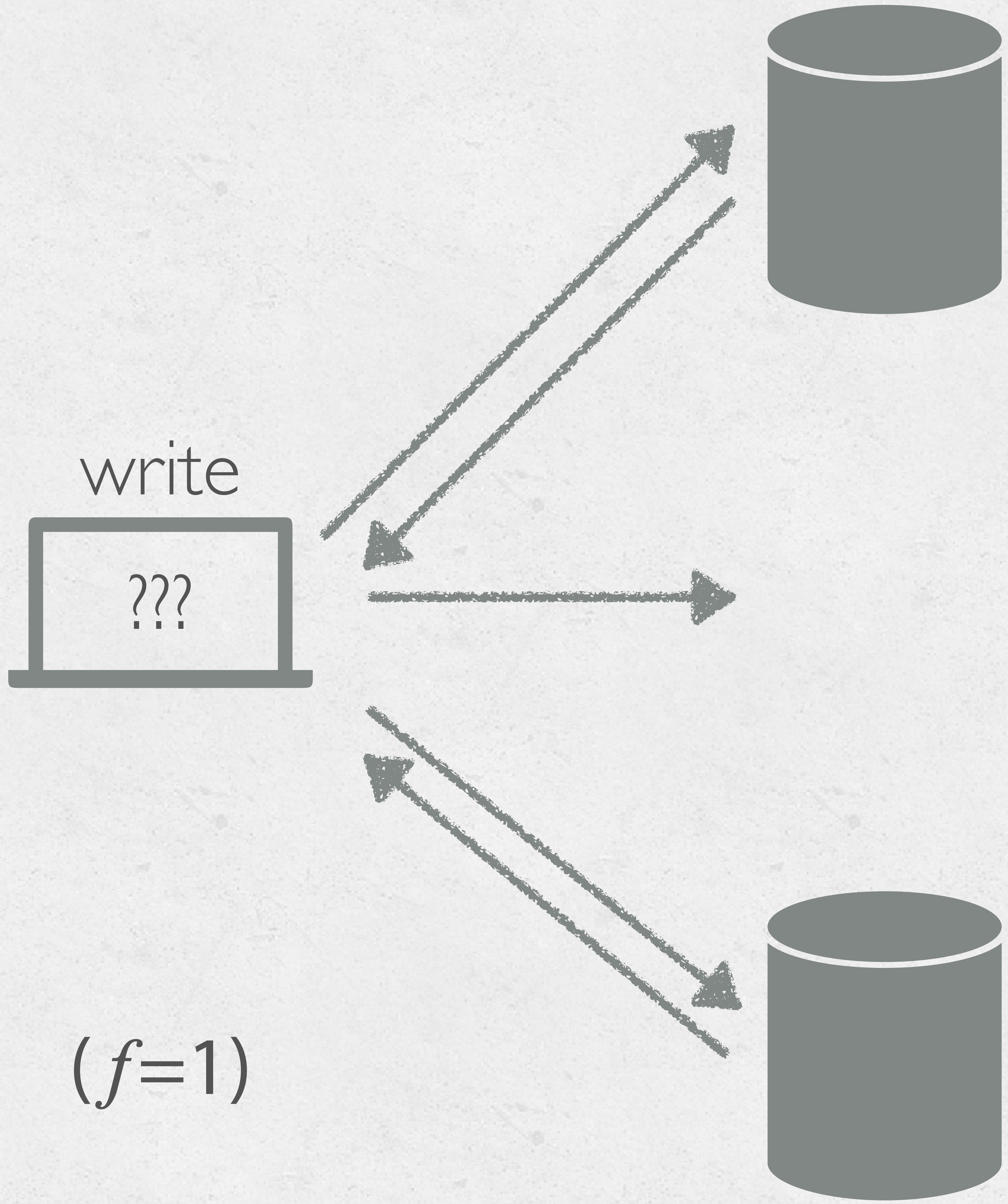

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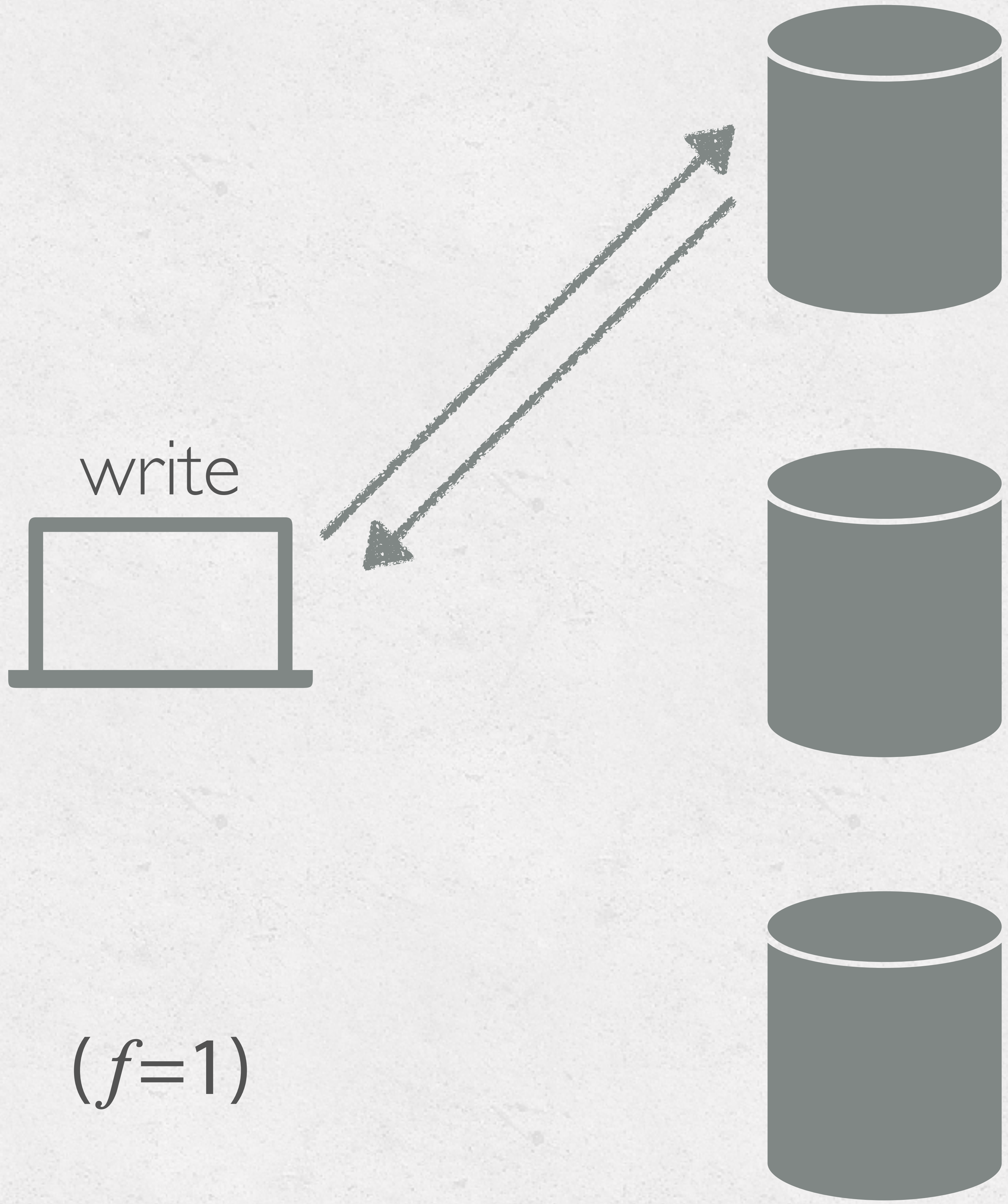

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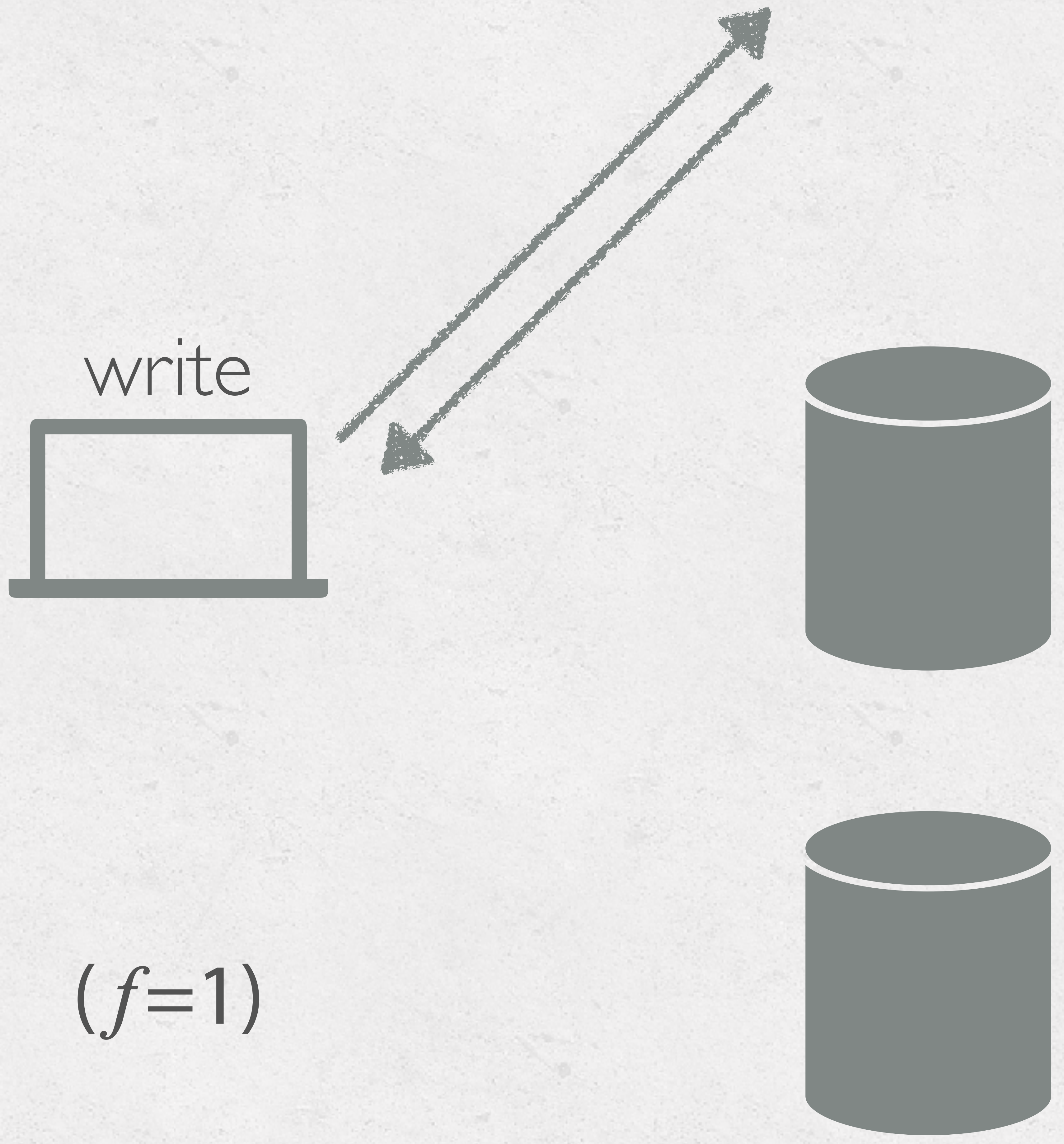

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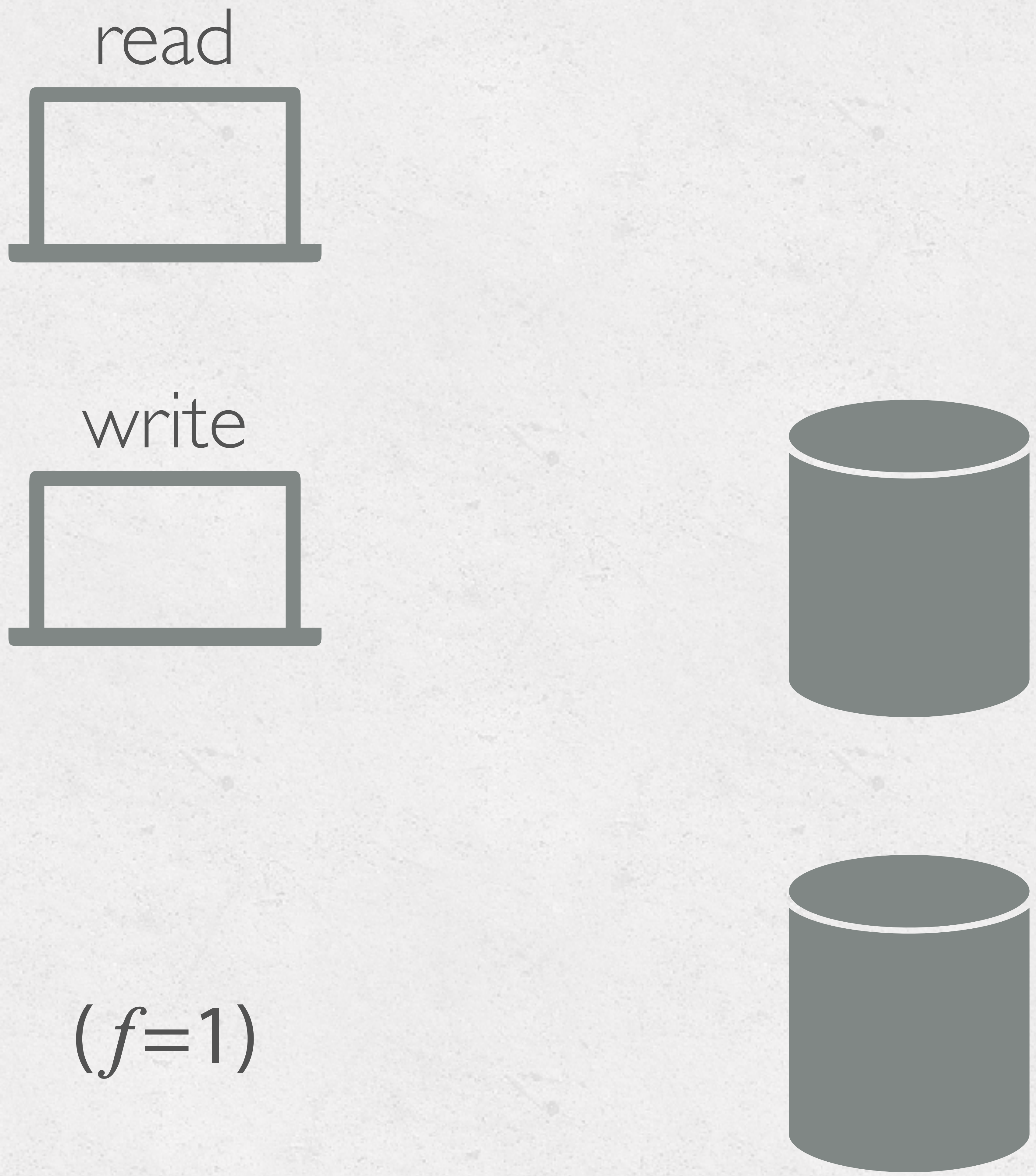

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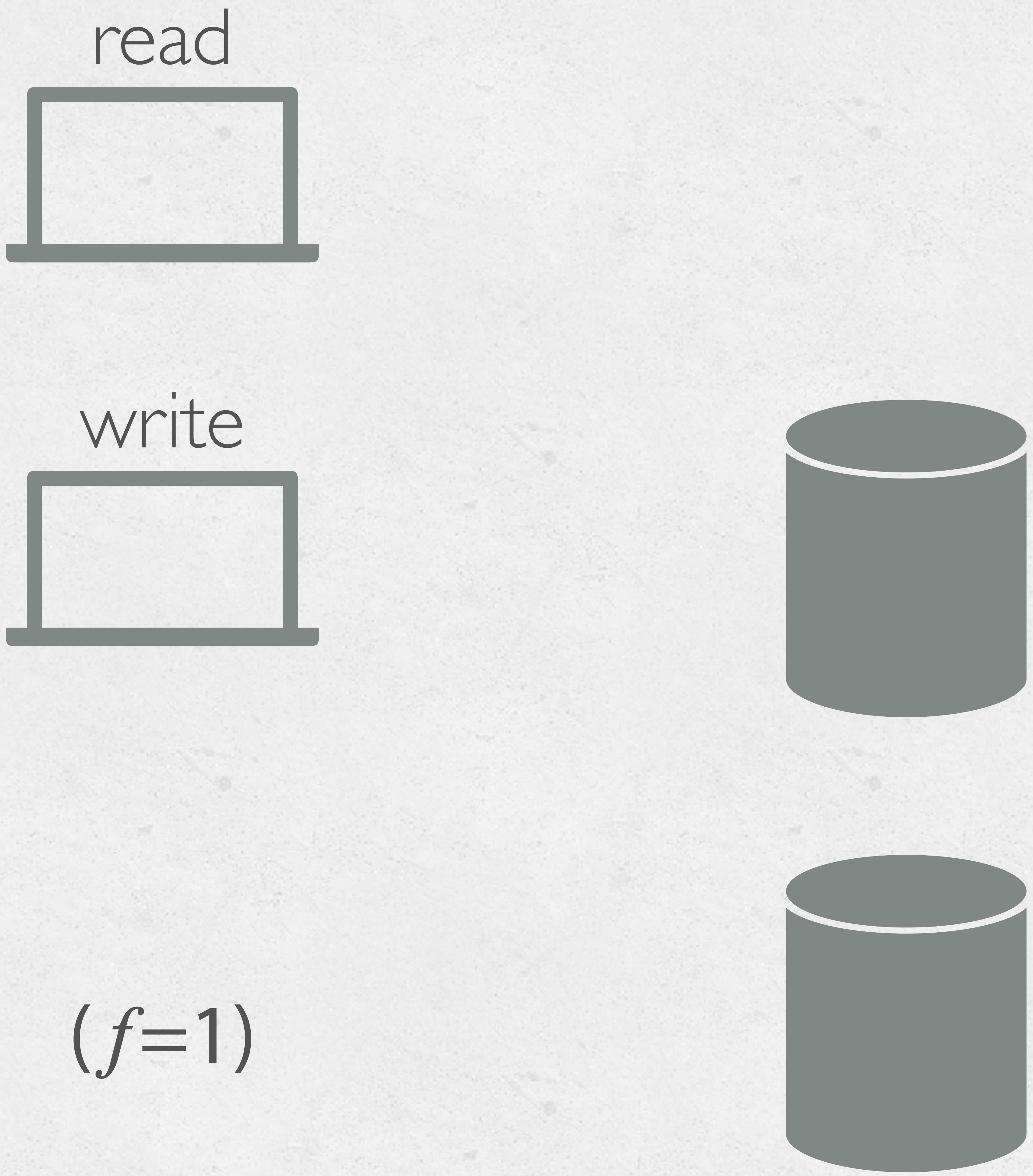

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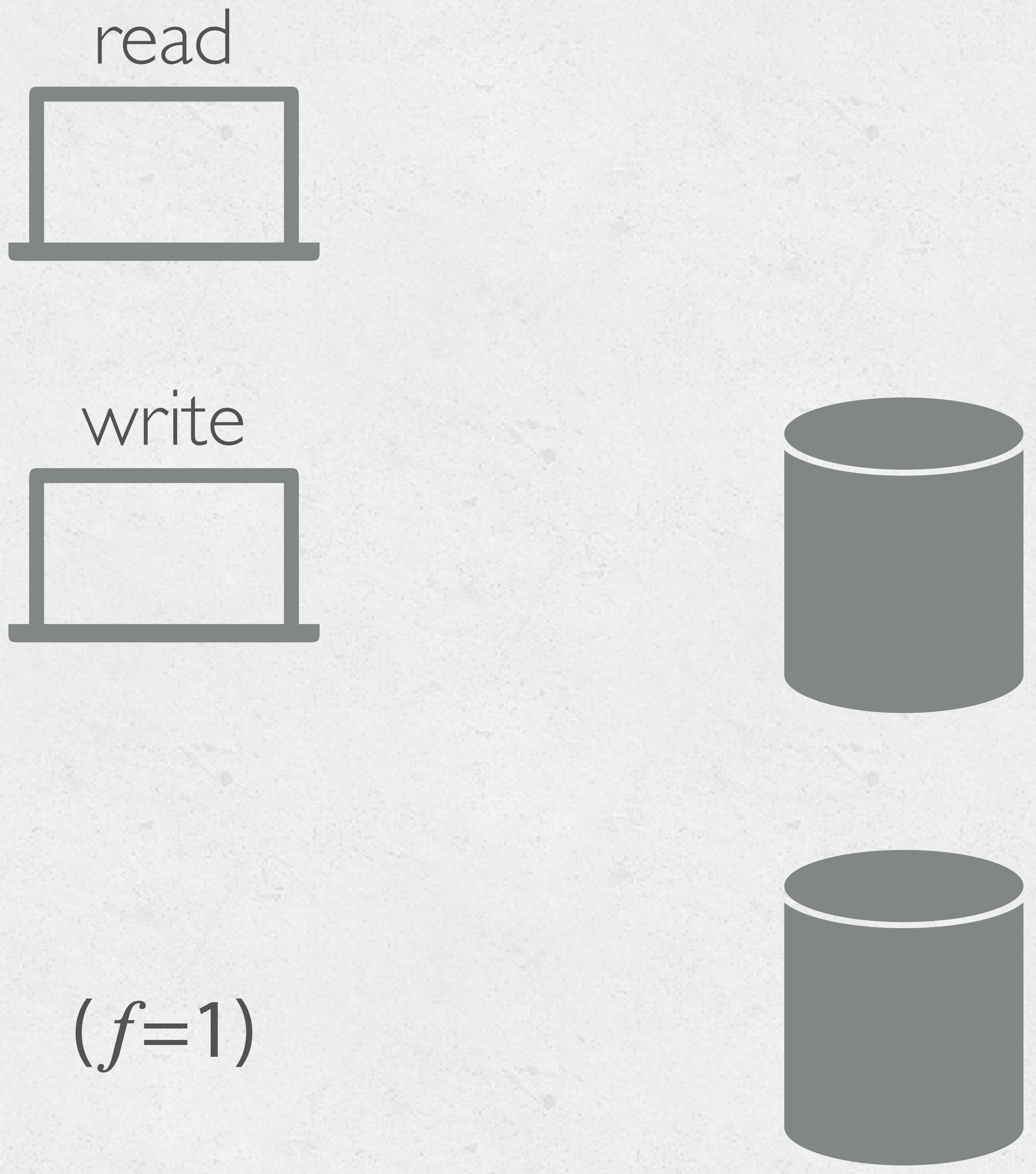

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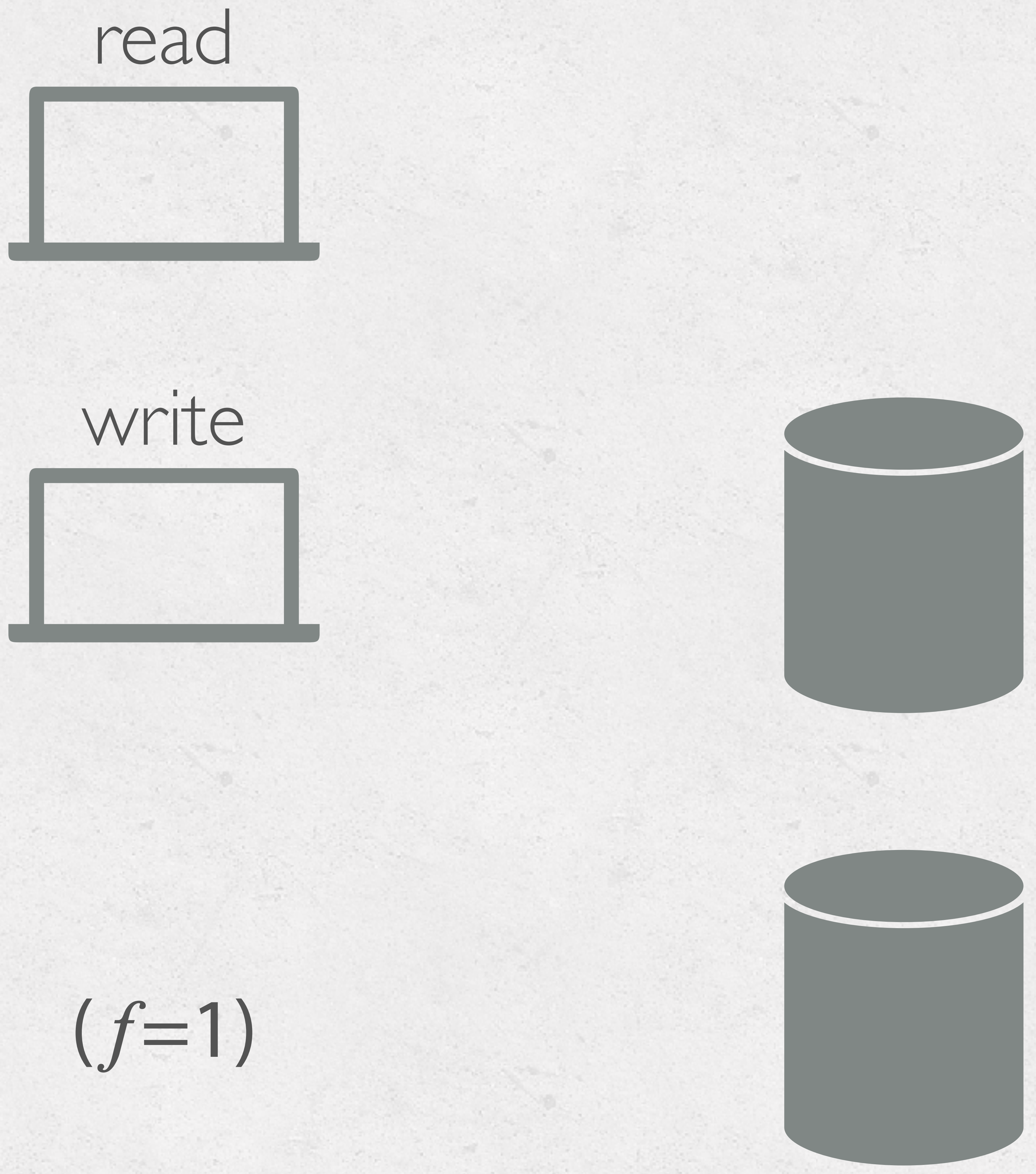
- So we need *at least* $2f+1$ servers. And, in fact, we will use $2f+1$.
- Read quorum size plus write quorum size should be greater than n (i.e., they should overlap). We'll use simple majorities.



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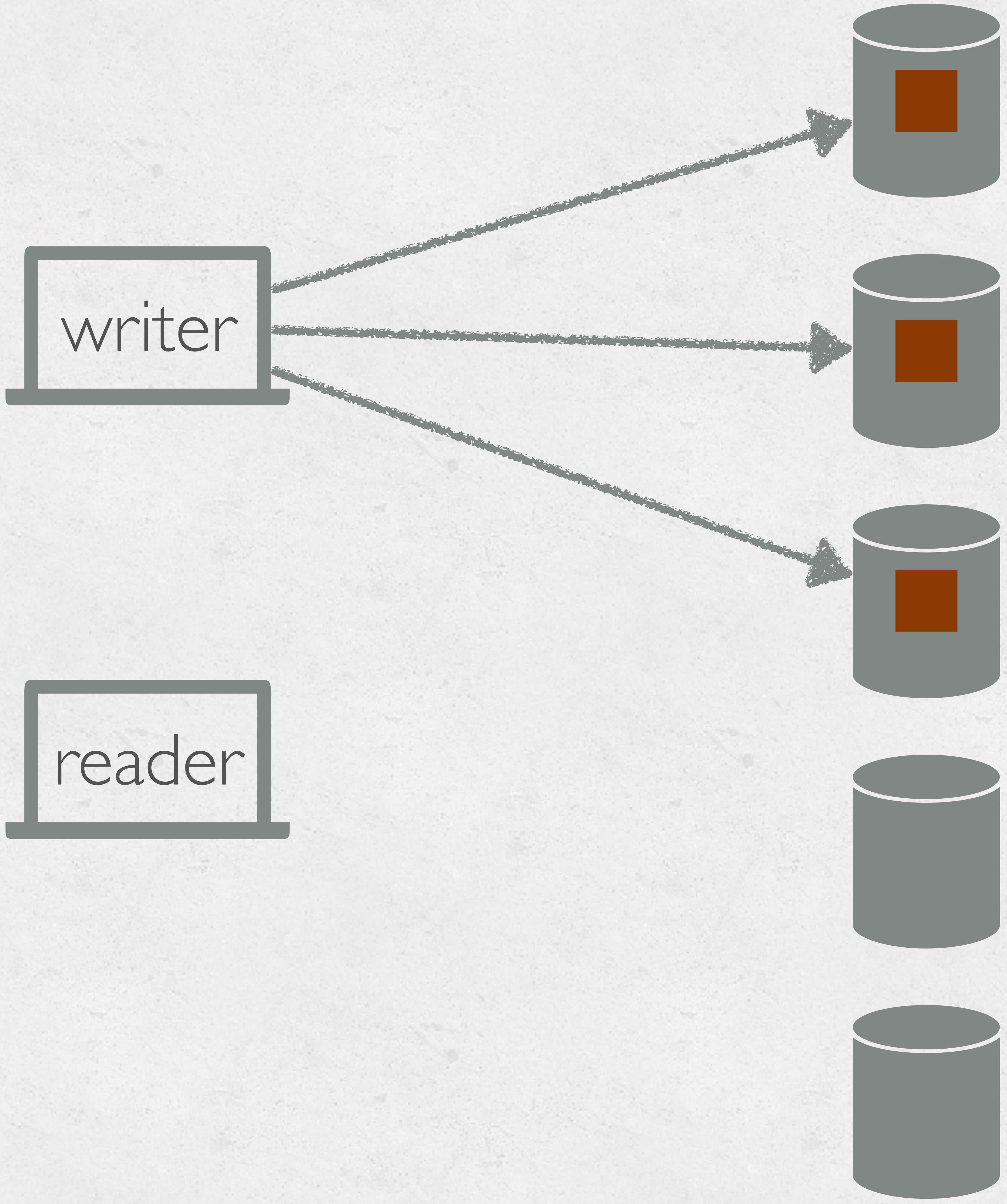

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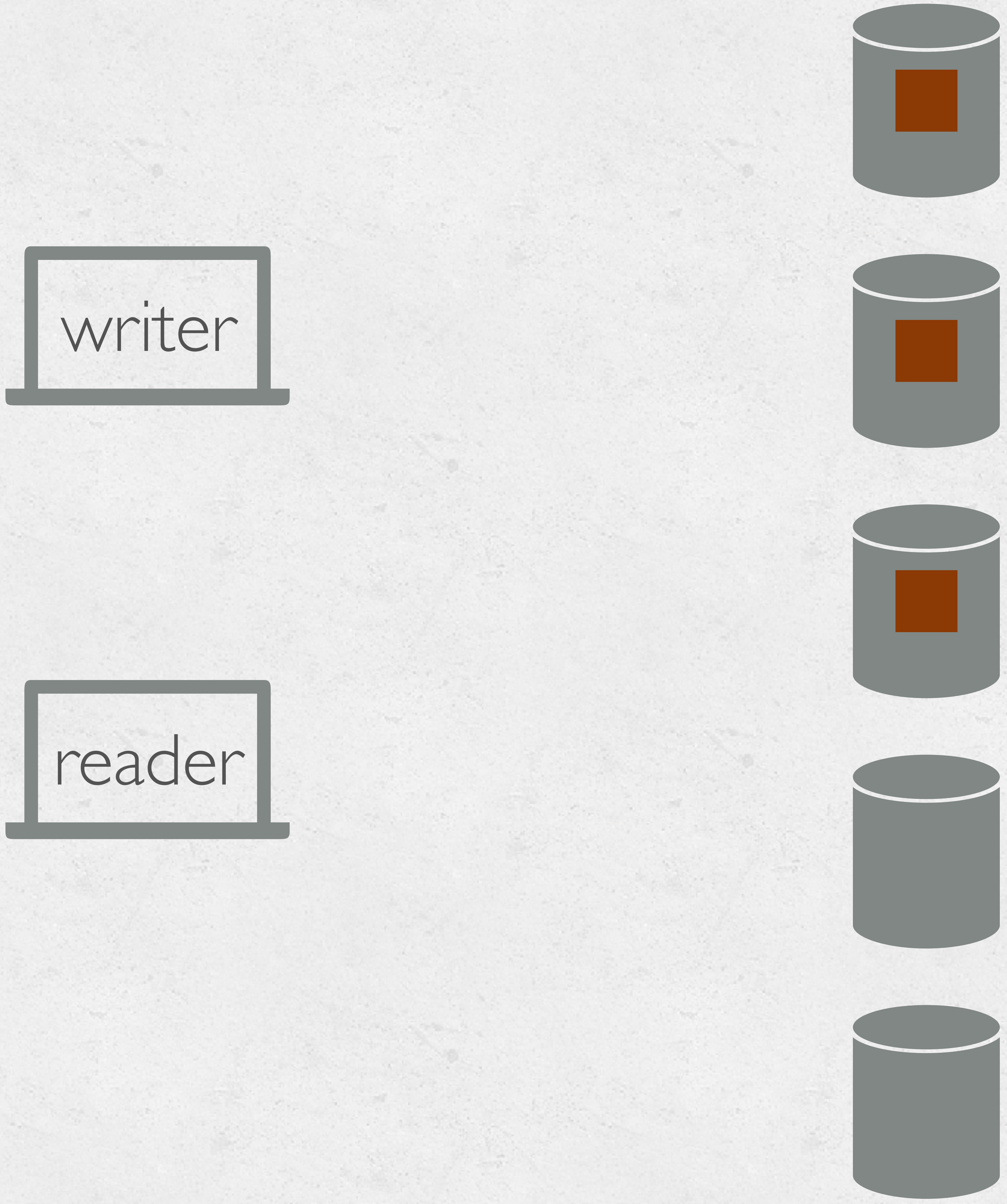

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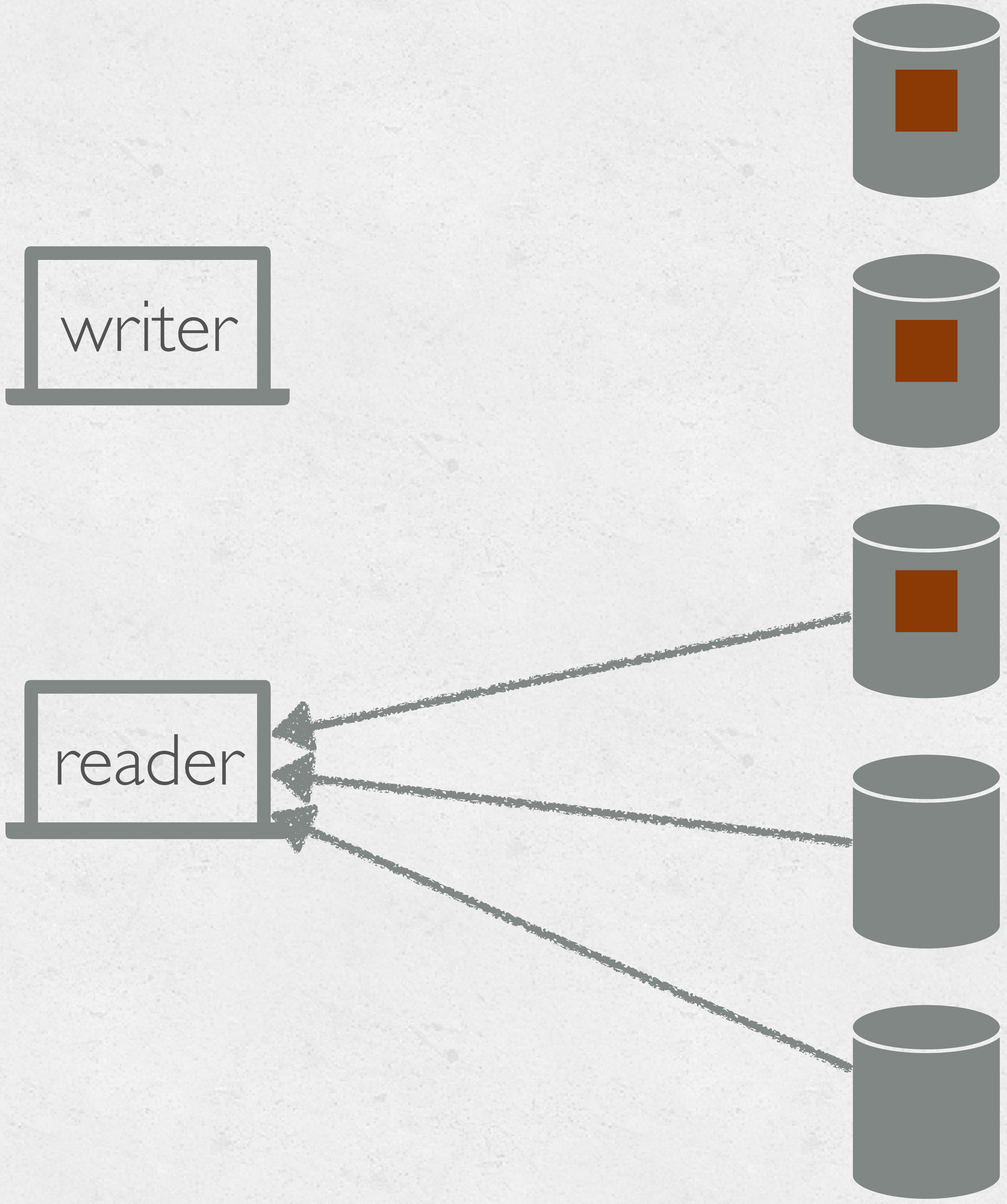

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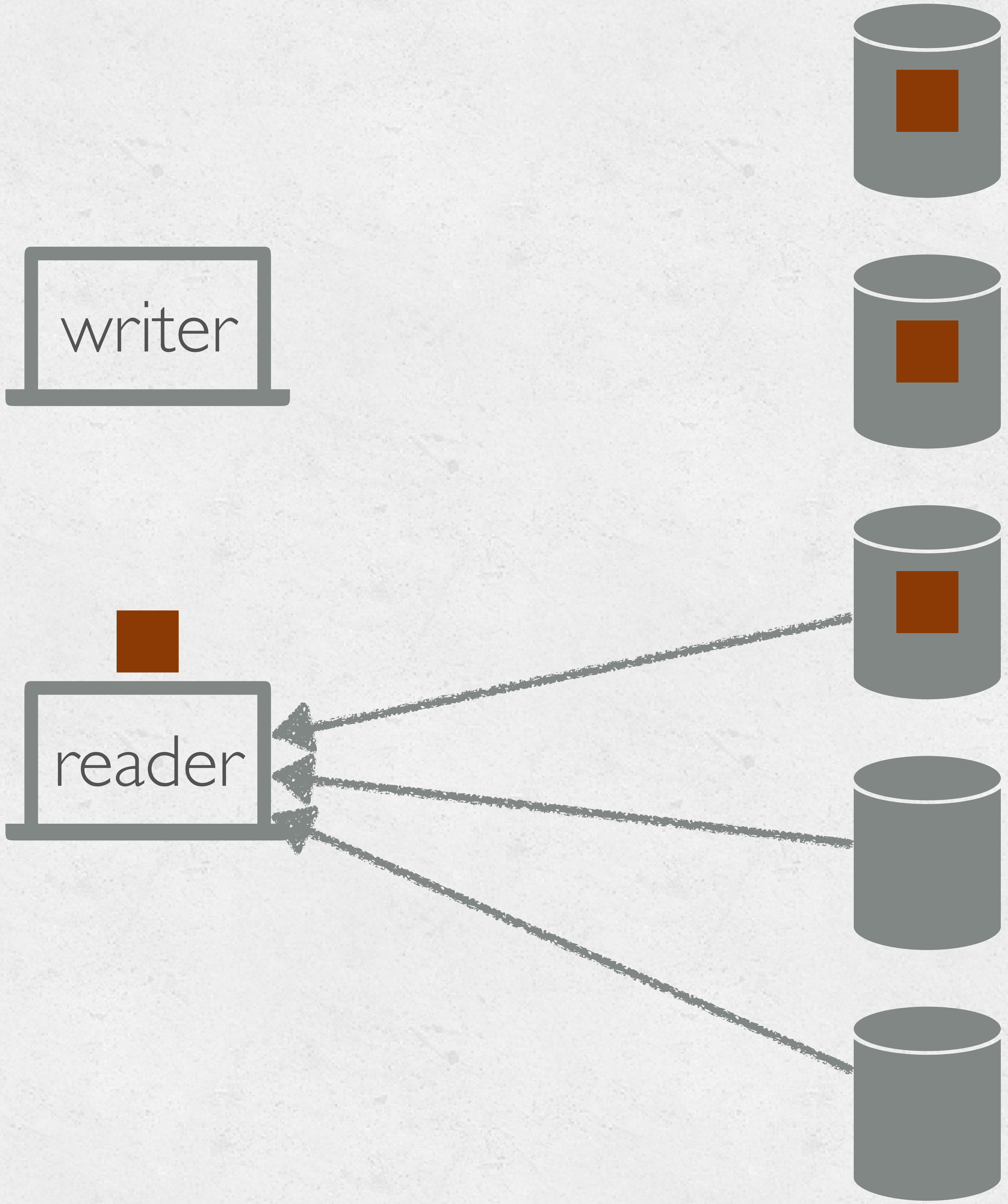

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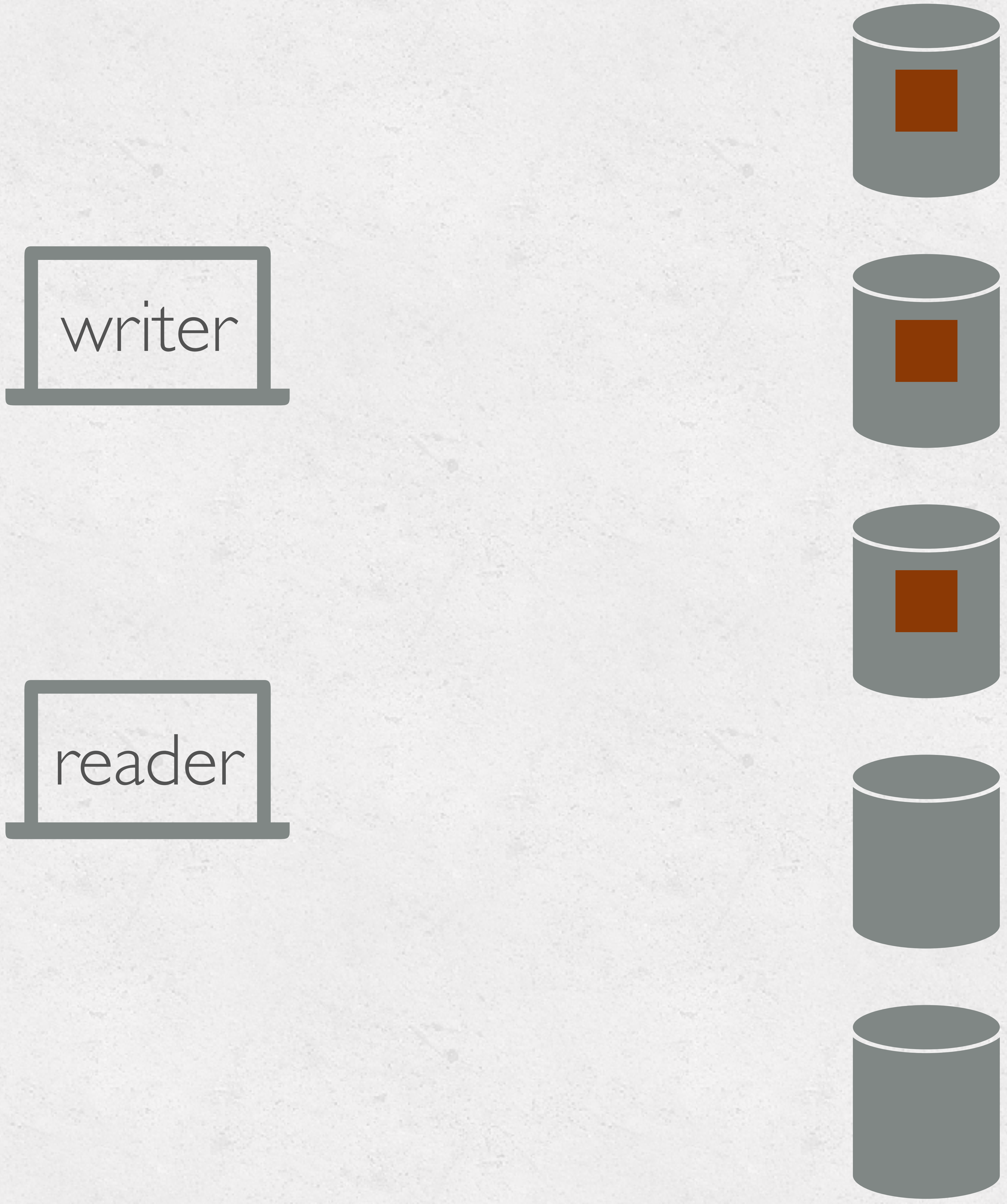

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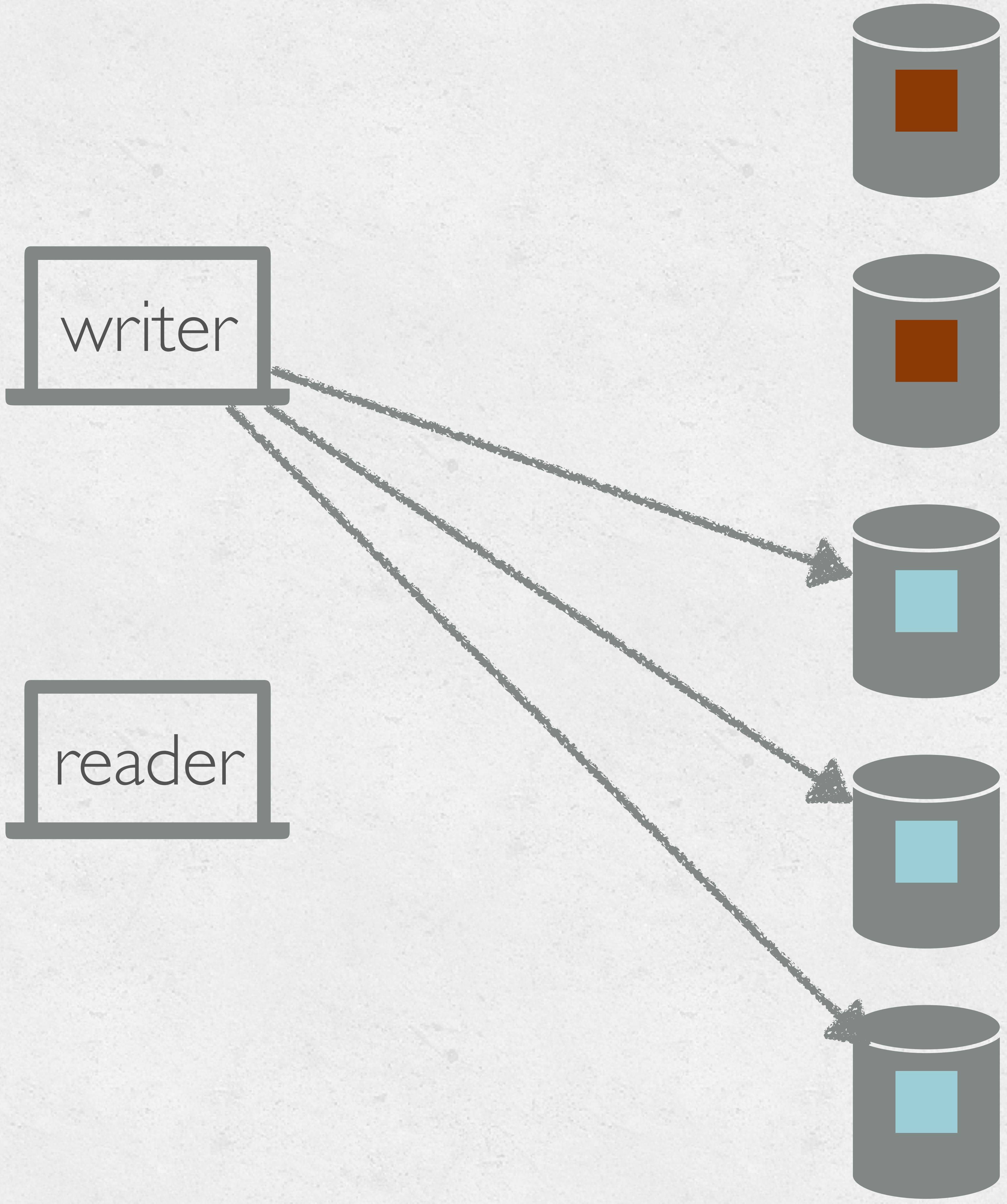

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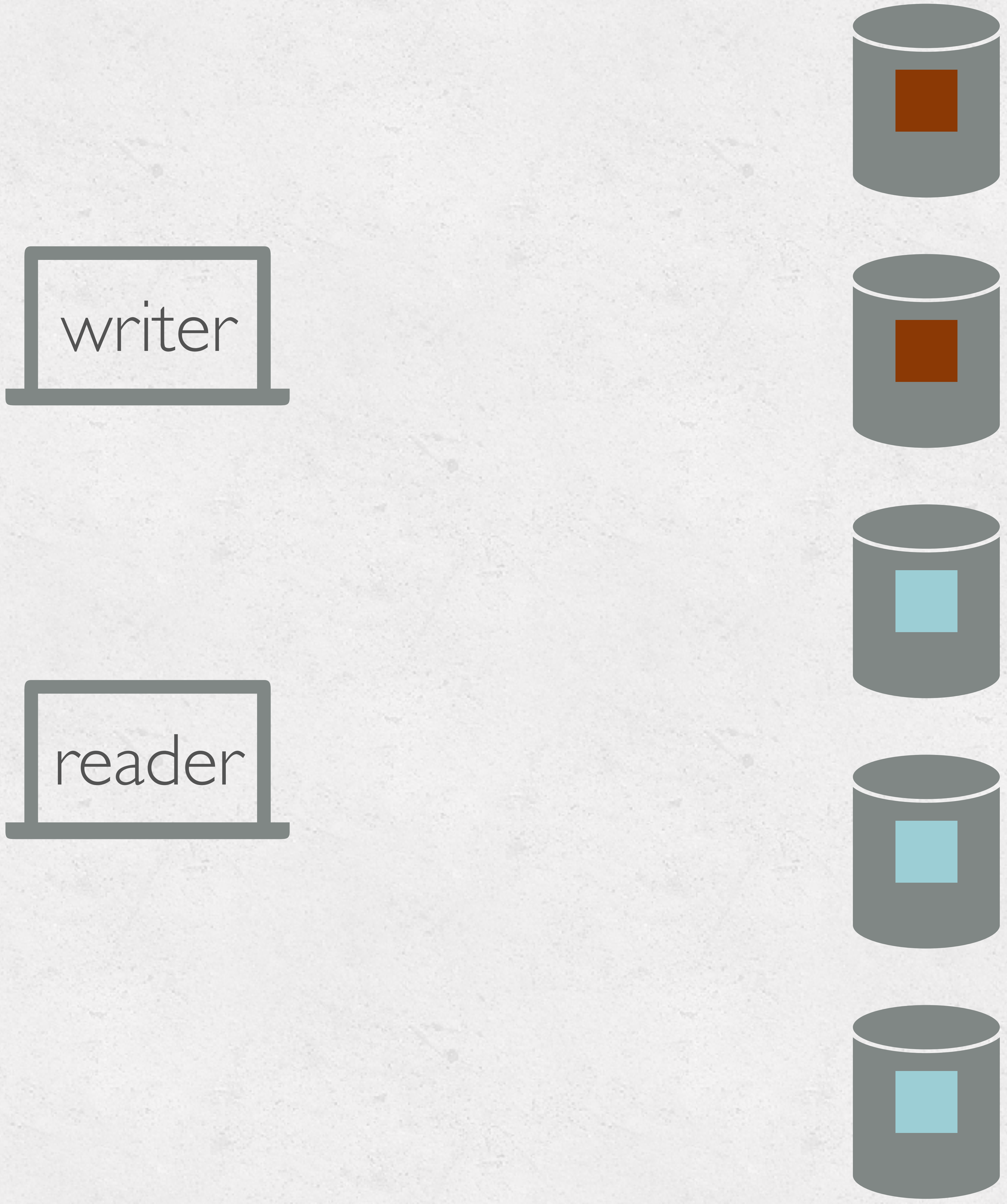

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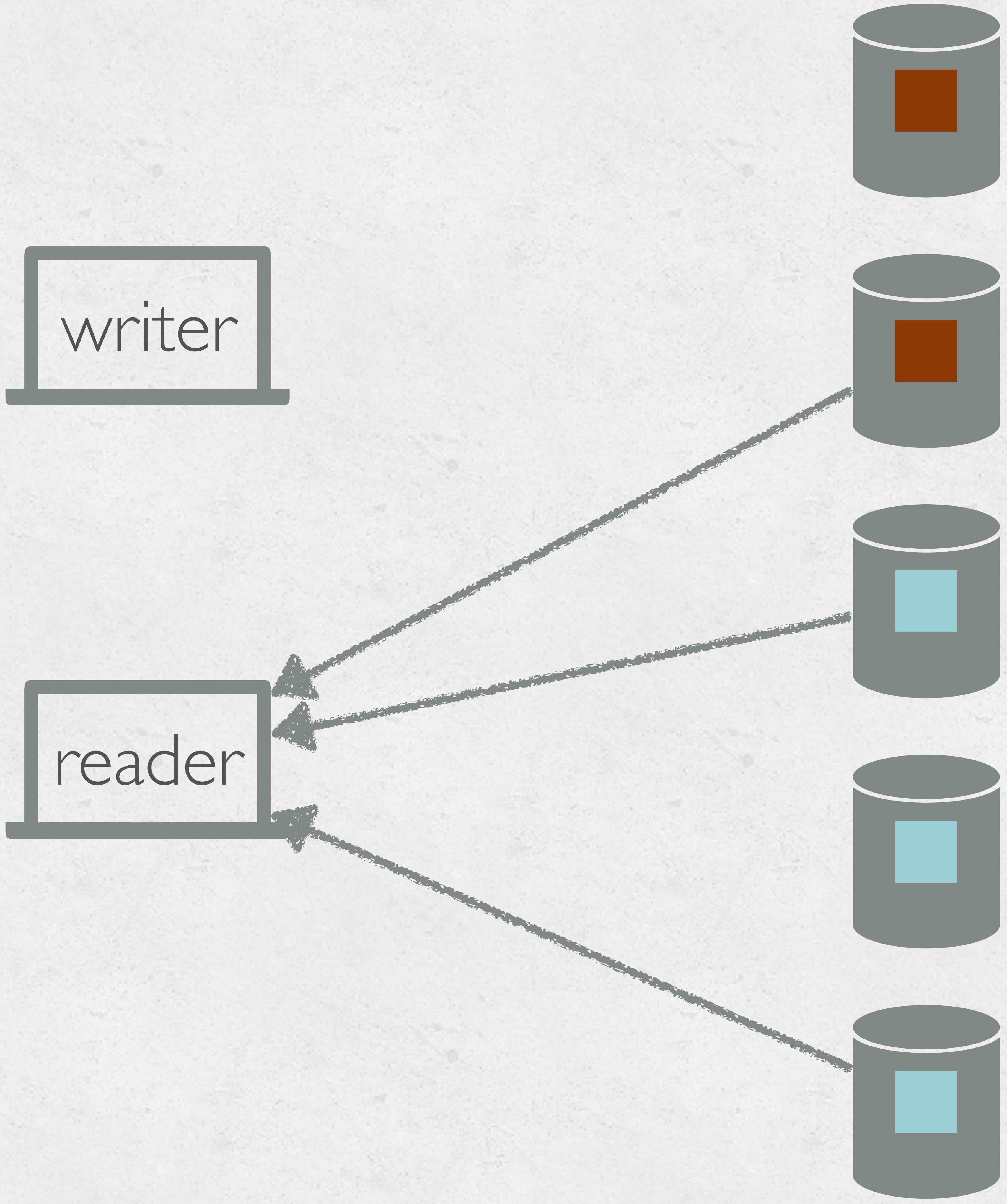

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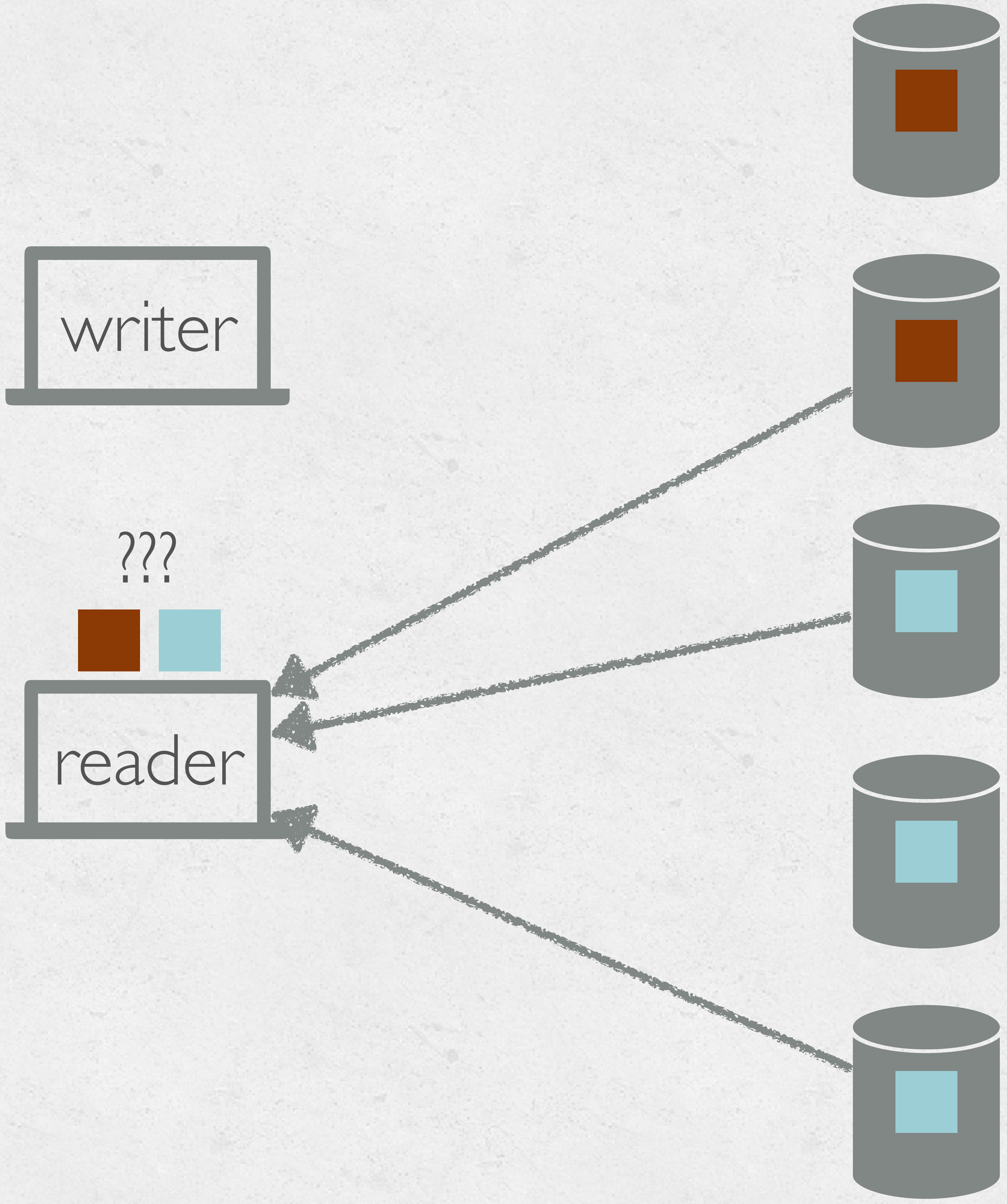

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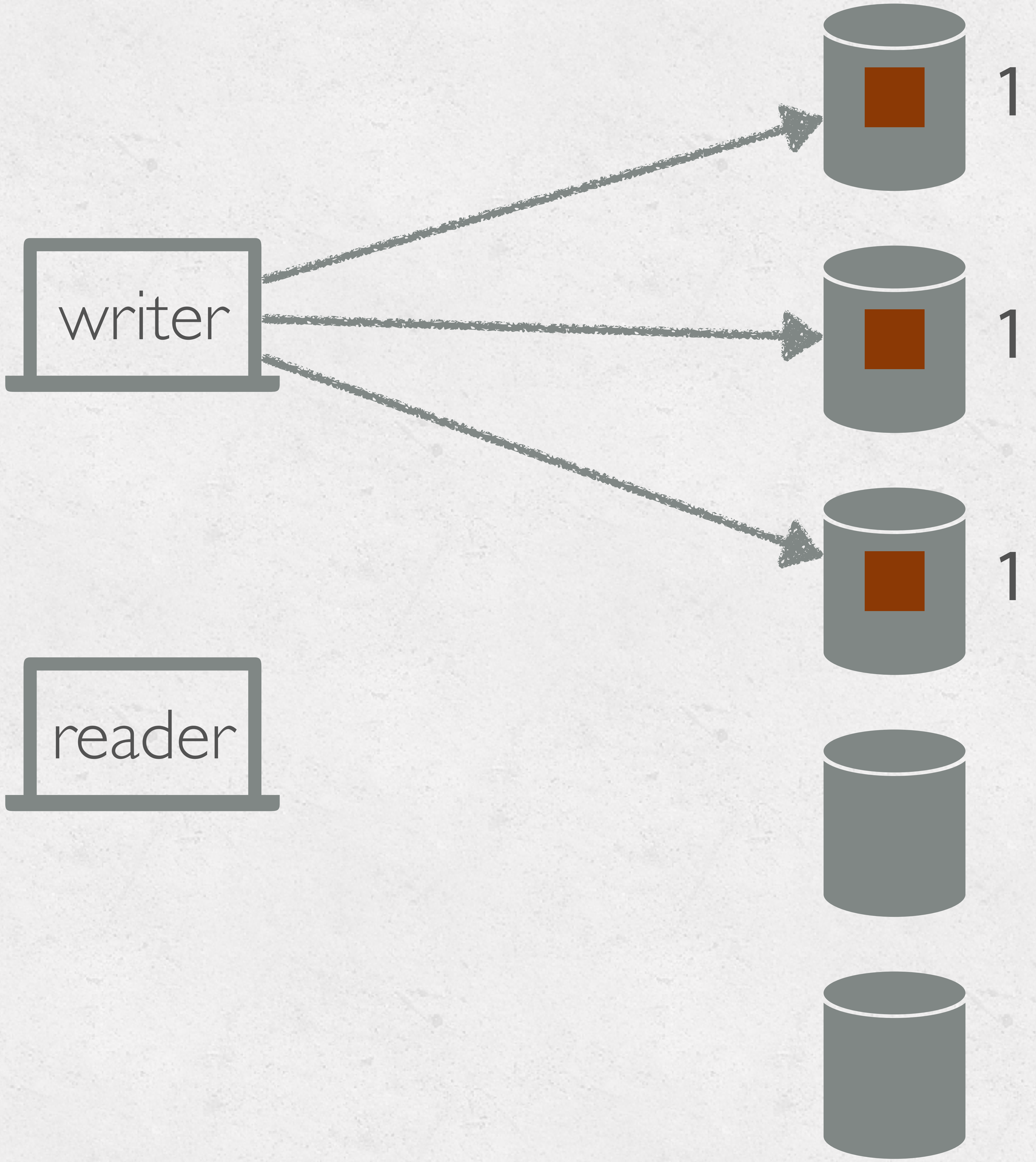

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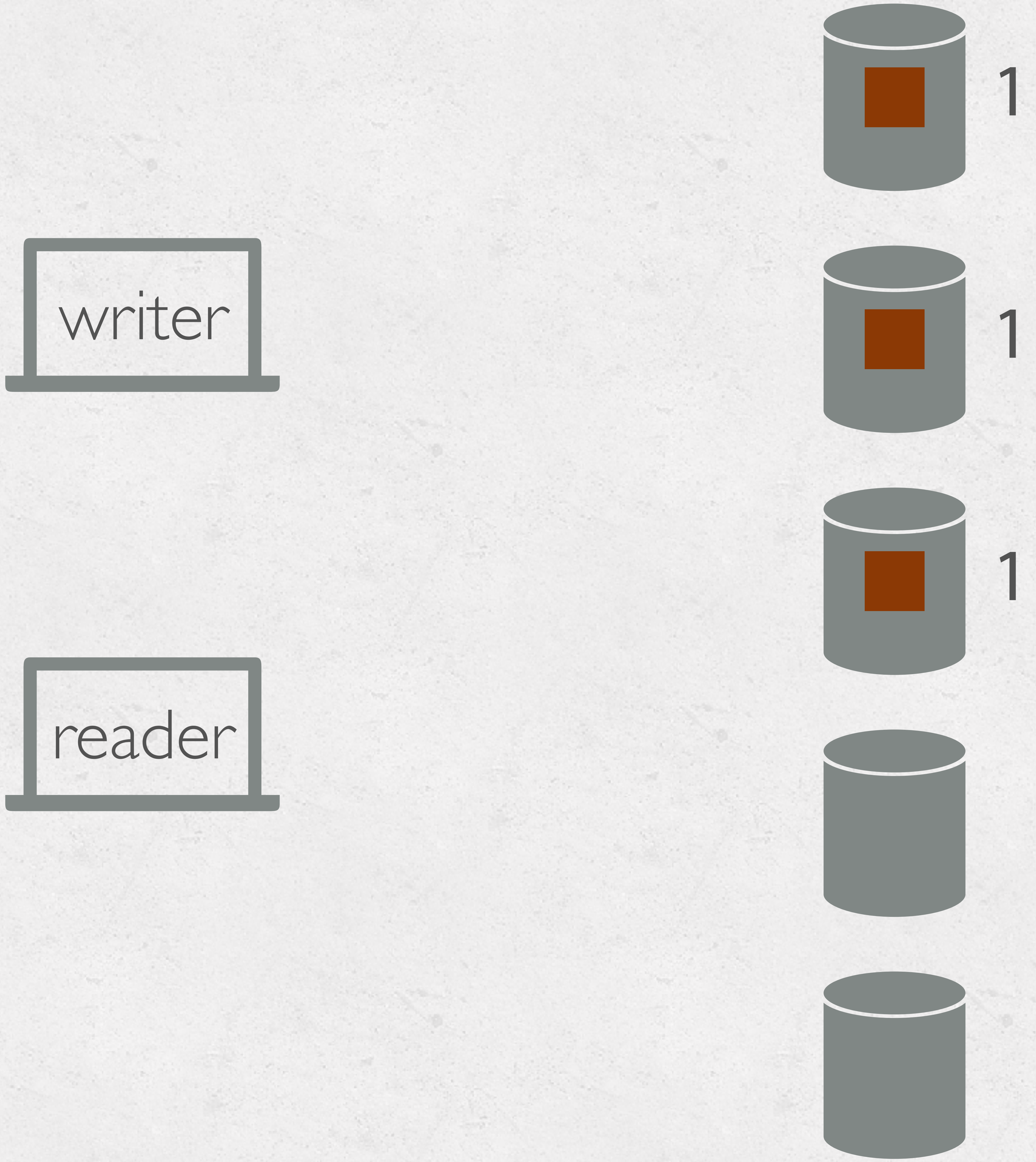

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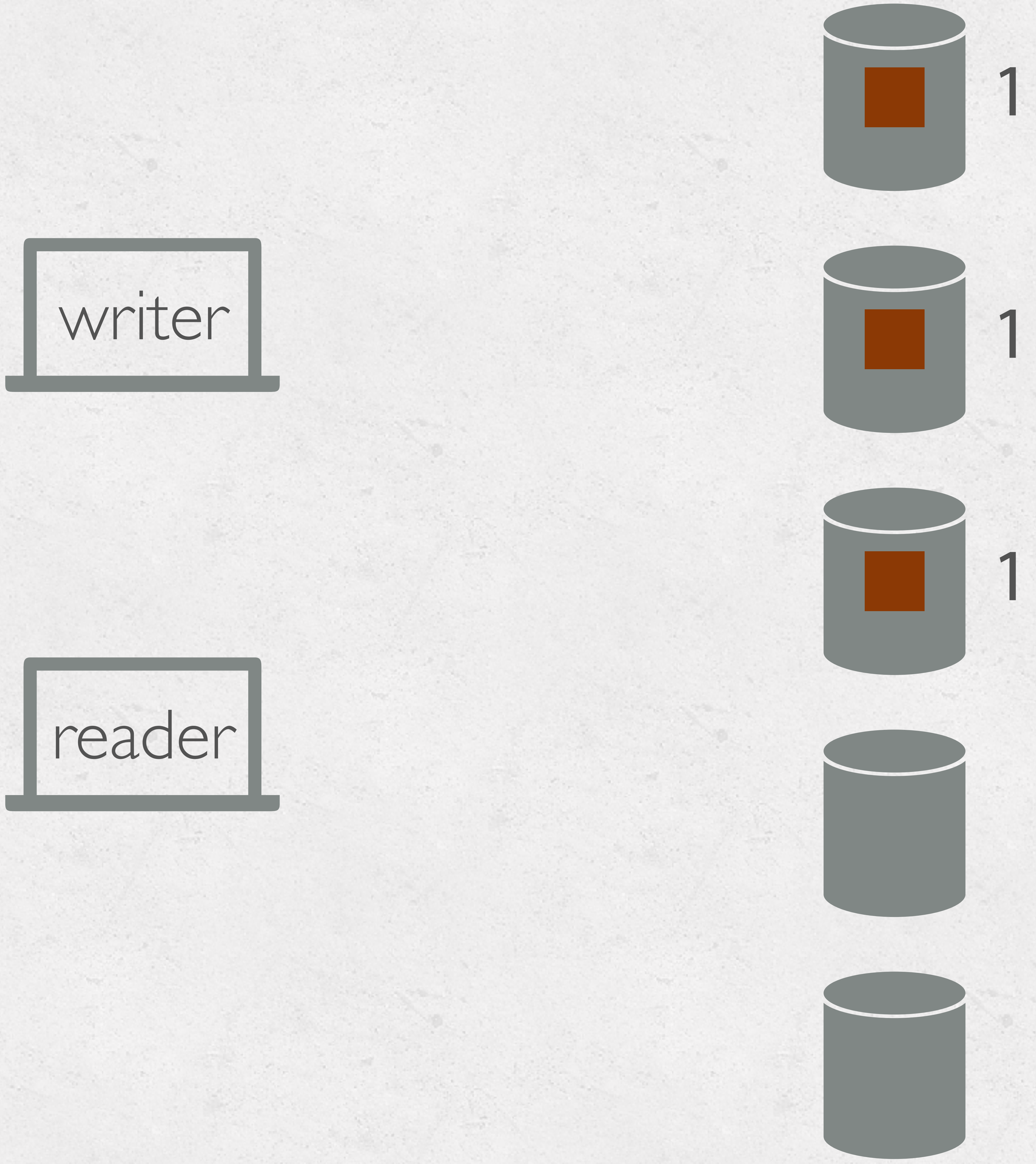

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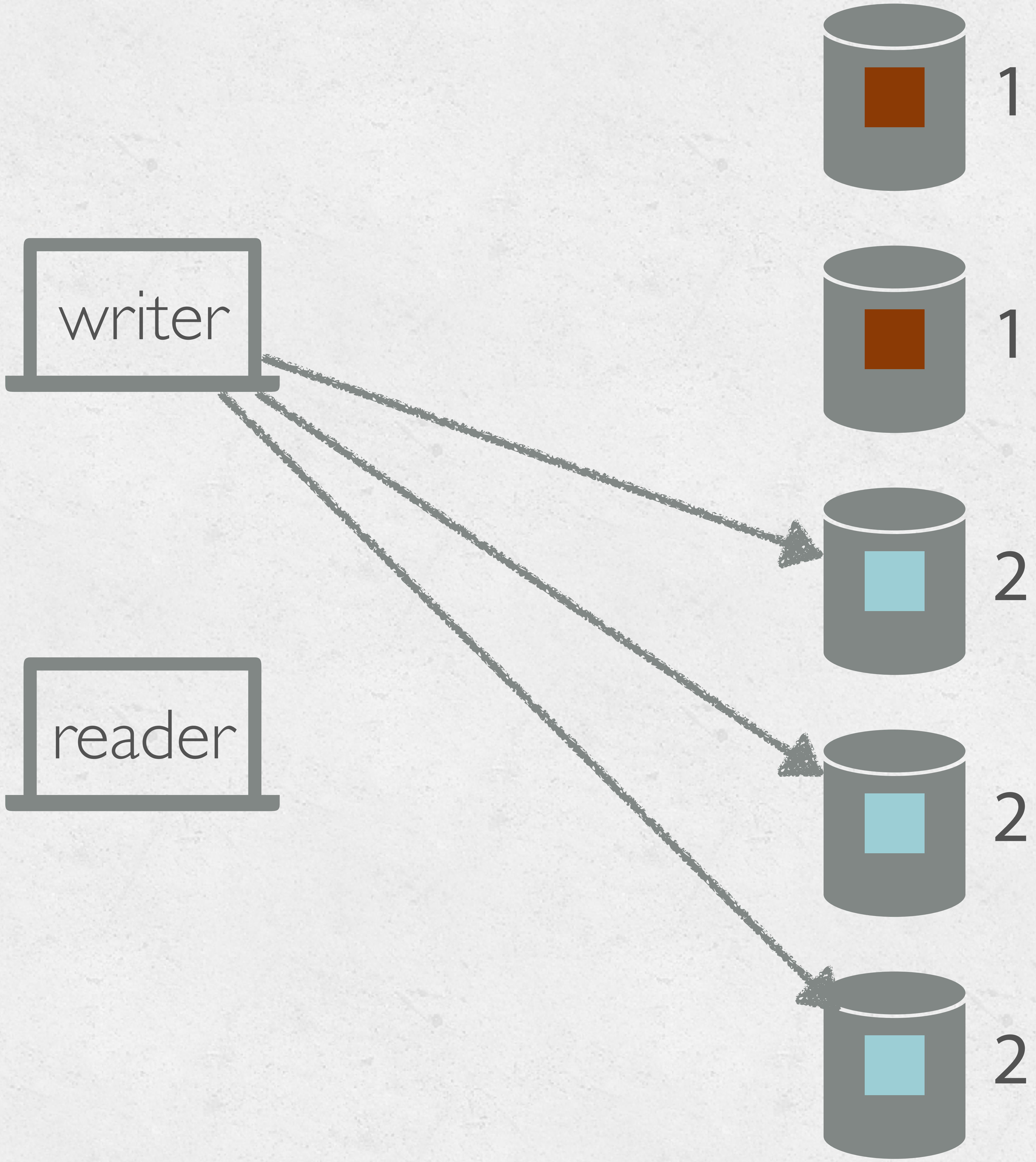

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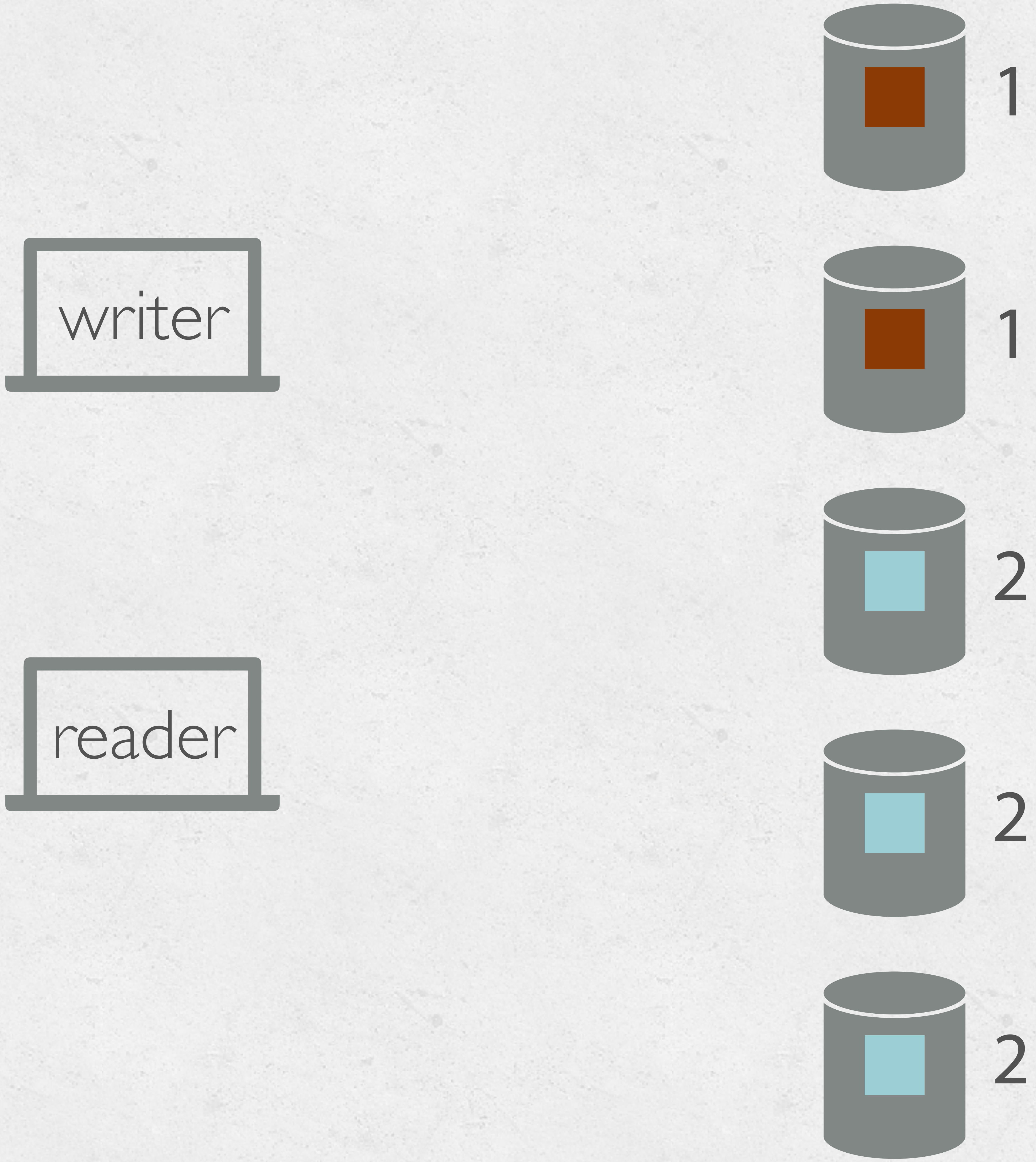

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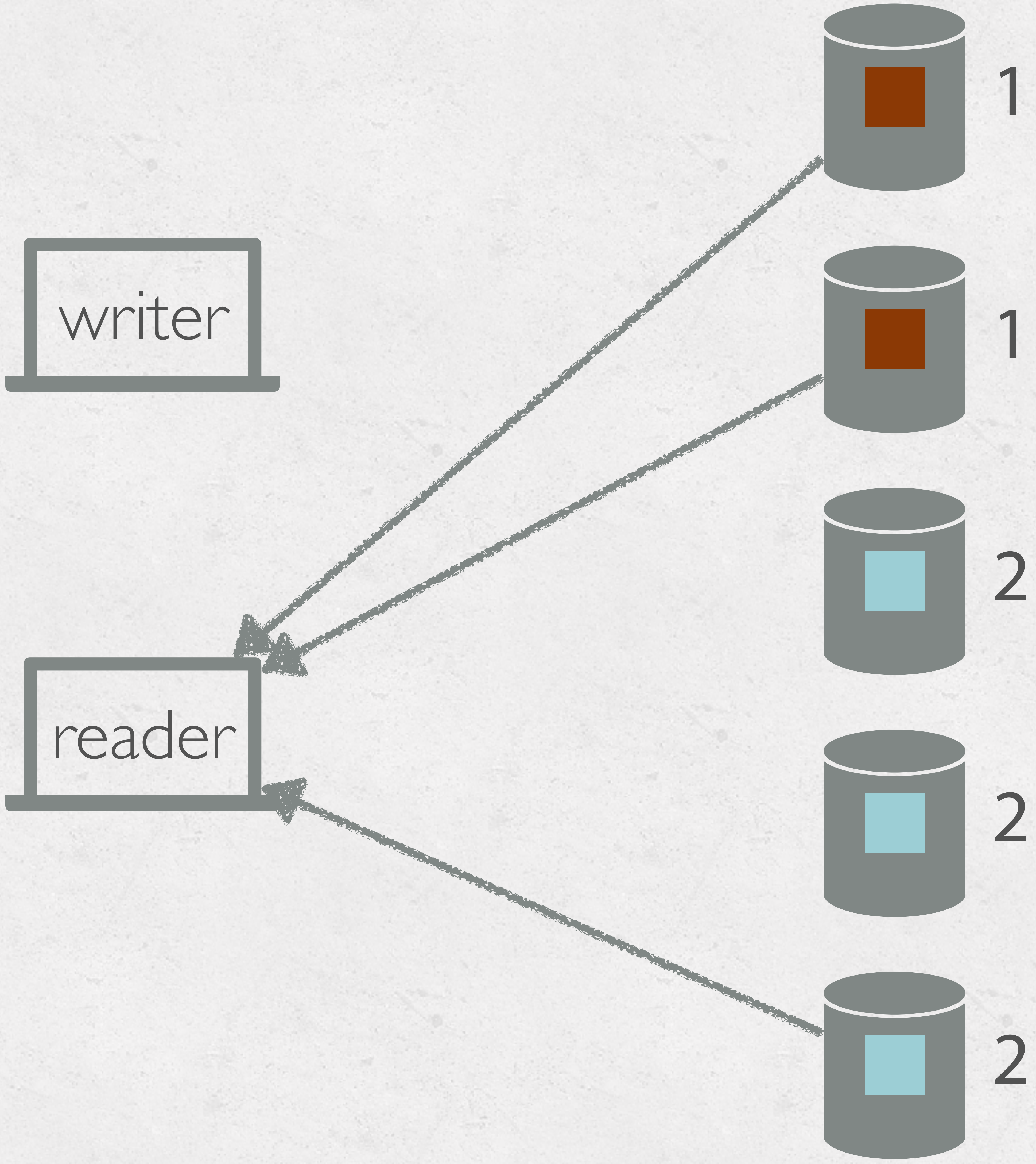

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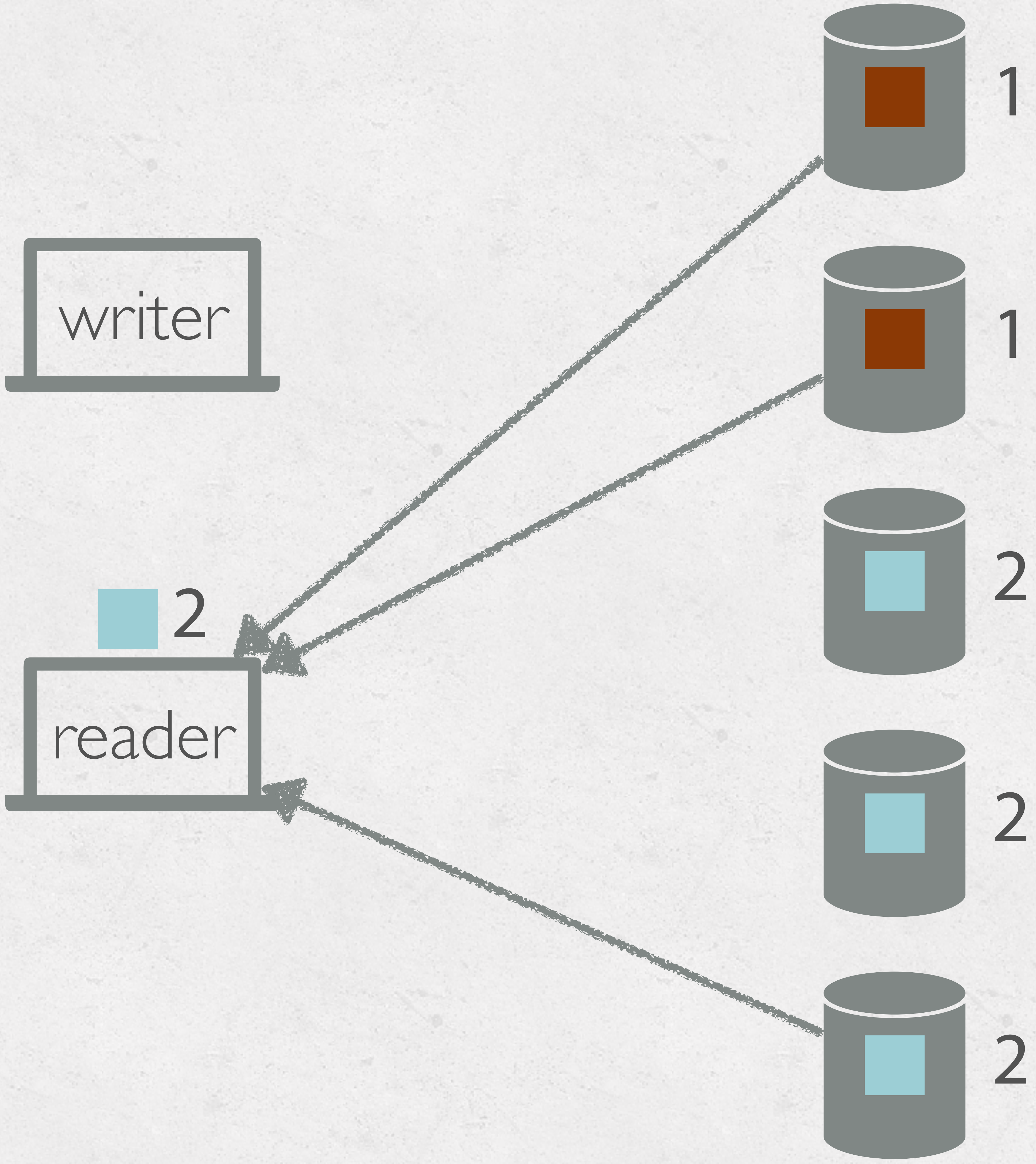


SWSR III

Servers' algorithm:

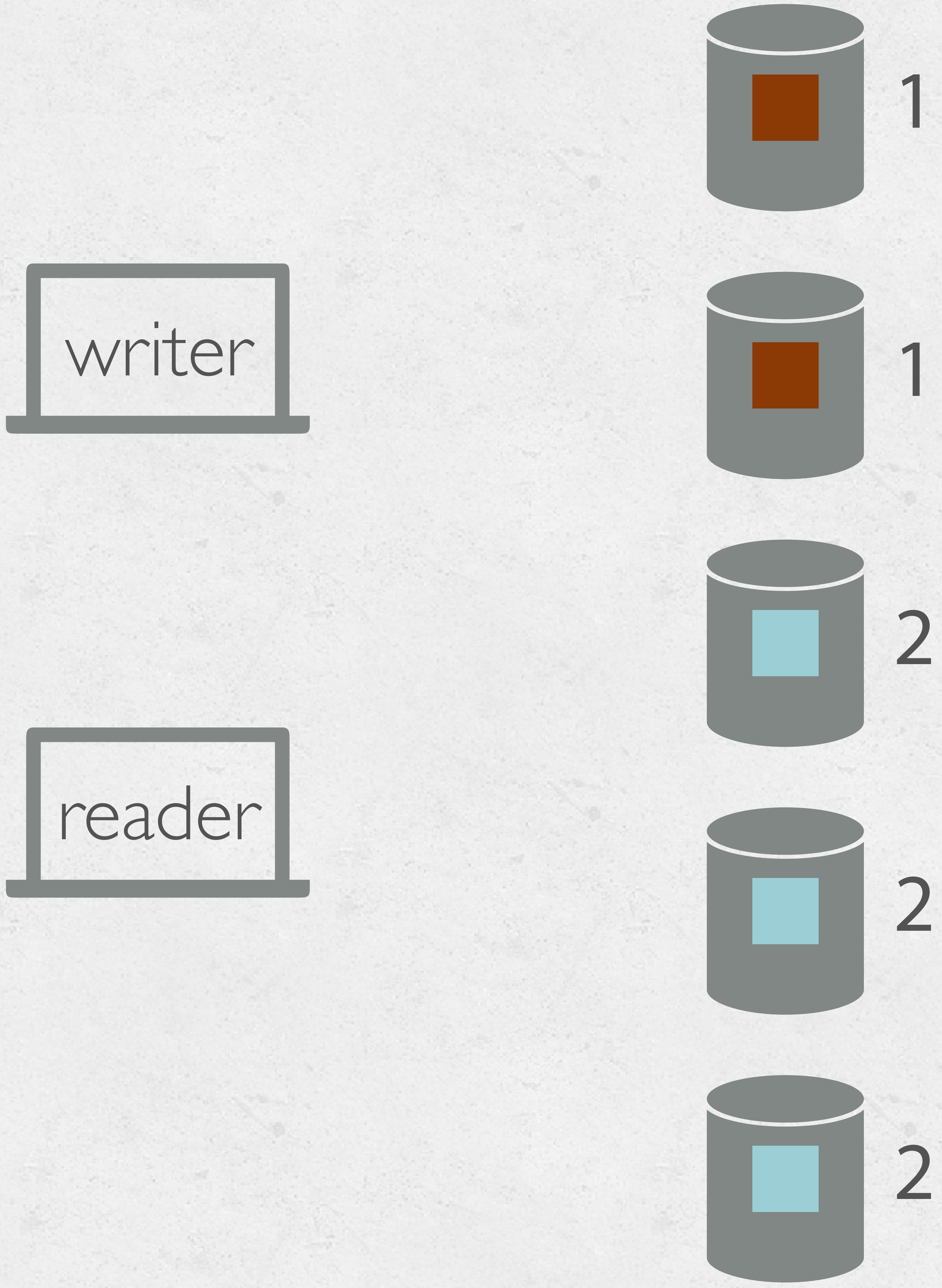
- Upon receiving a write, update local timestamp and value if write's timestamp is greater; send ack.
- Respond to reads with local timestamp and value.

Writer's algorithm:

- When writing, increment local timestamp, send timestamp and value to all.
- Wait for acks from a majority.

Reader's algorithm:

- Read from a majority, take value with highest timestamp.
- Maintain local value, return local value if servers' timestamps smaller.



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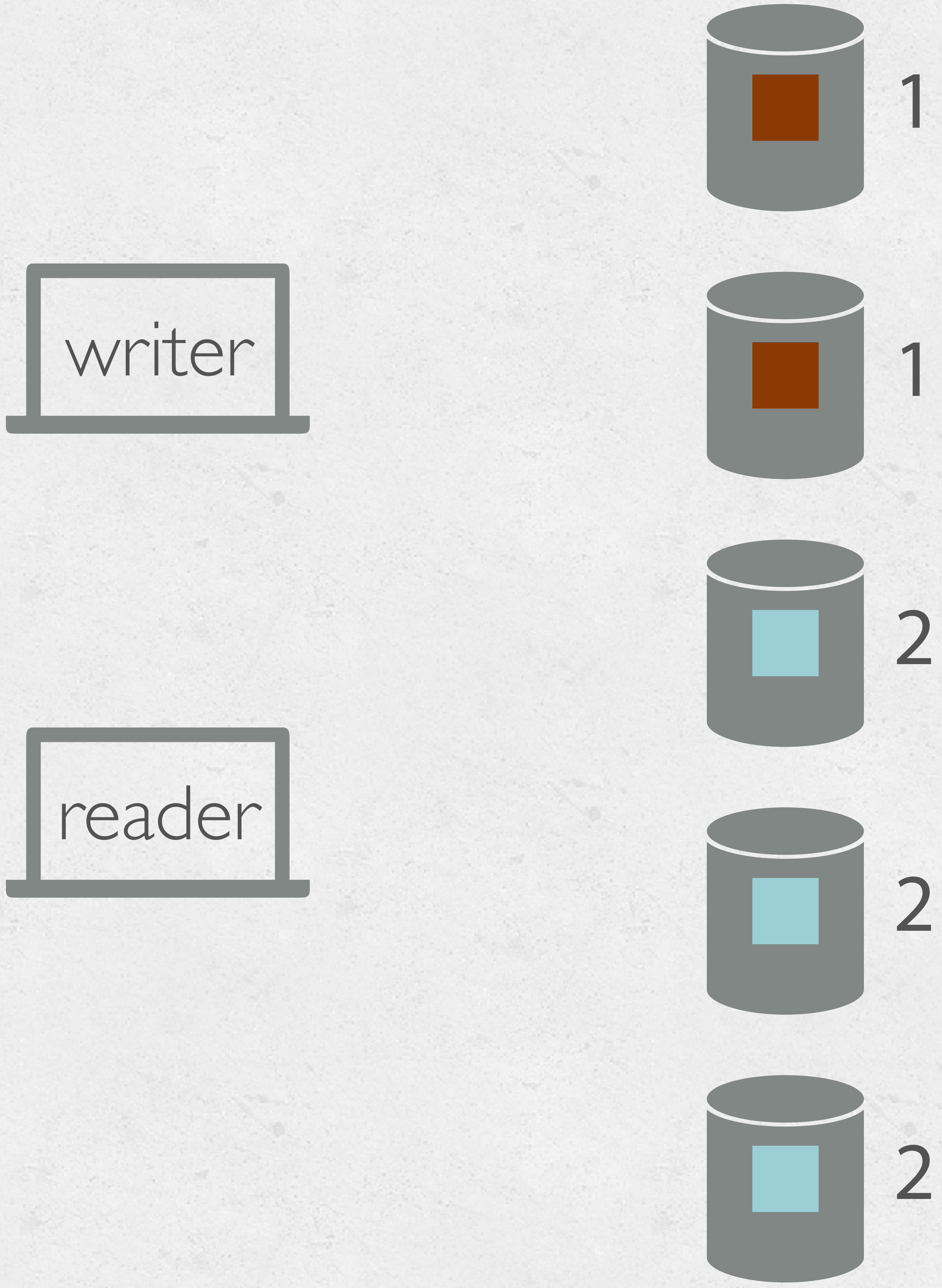
Assume clients can associate requests with responses (i.e., ignore responses from old requests)



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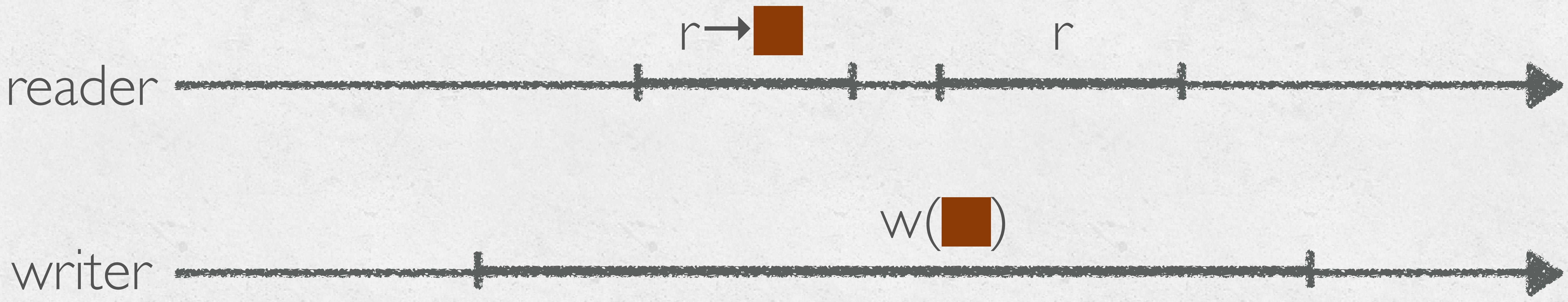

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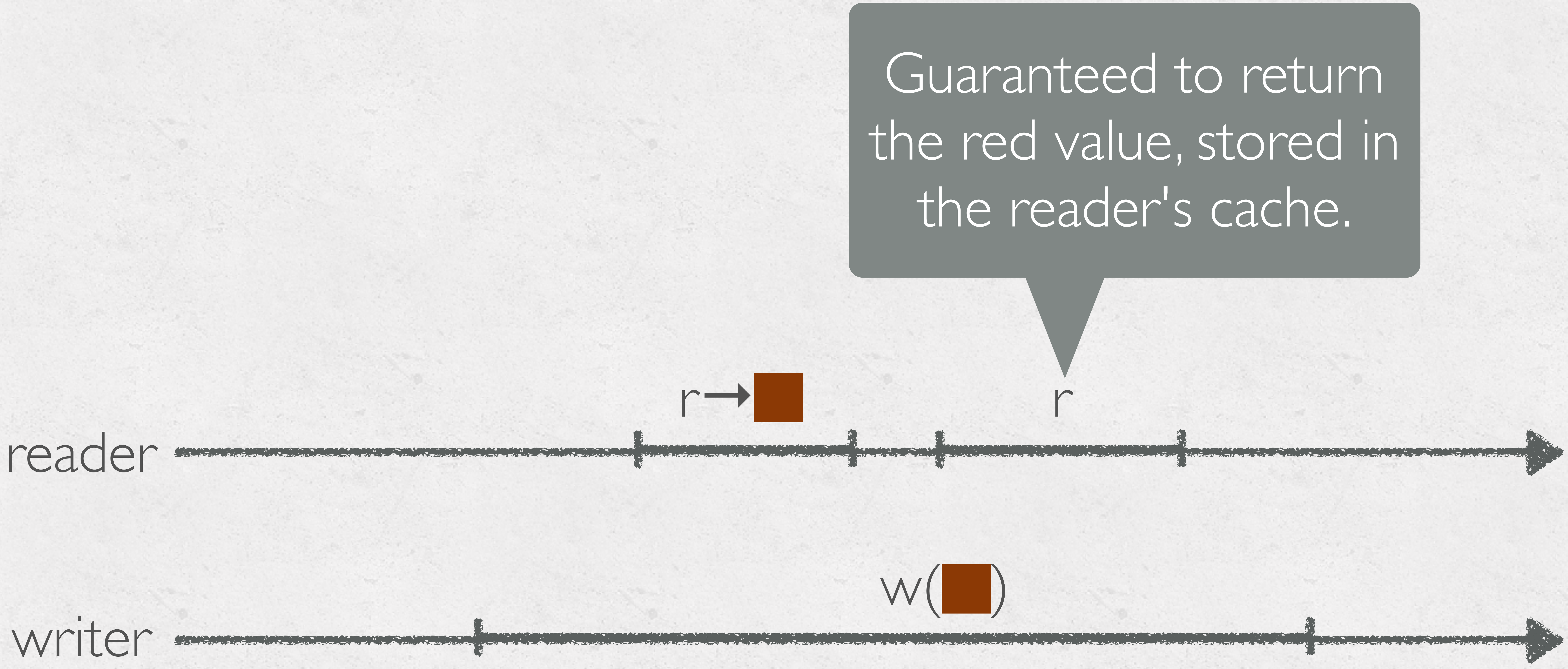

If there's only one writer and one reader, why do we need the servers at all? Couldn't the writer just send its value to the reader directly?

Multiple Readers, Single Writer (MRSW)

Does this previous solution just work?

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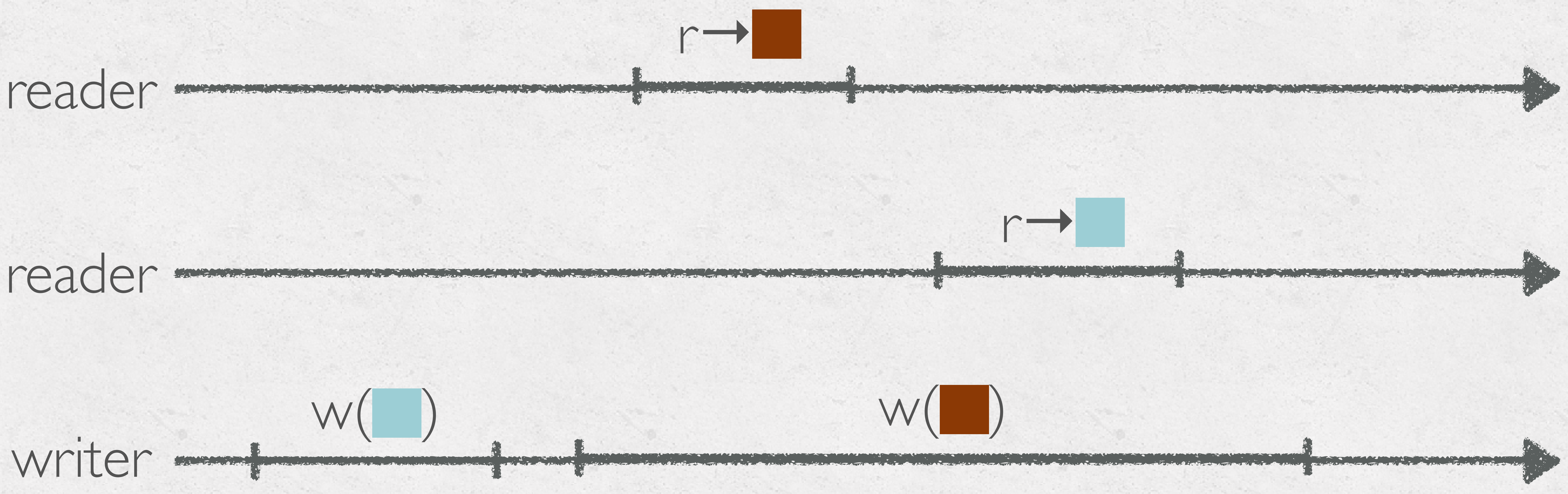
What happens if there are multiple reads by **different processes** overlapping the same write?

MRSW: Revenge of the Reads



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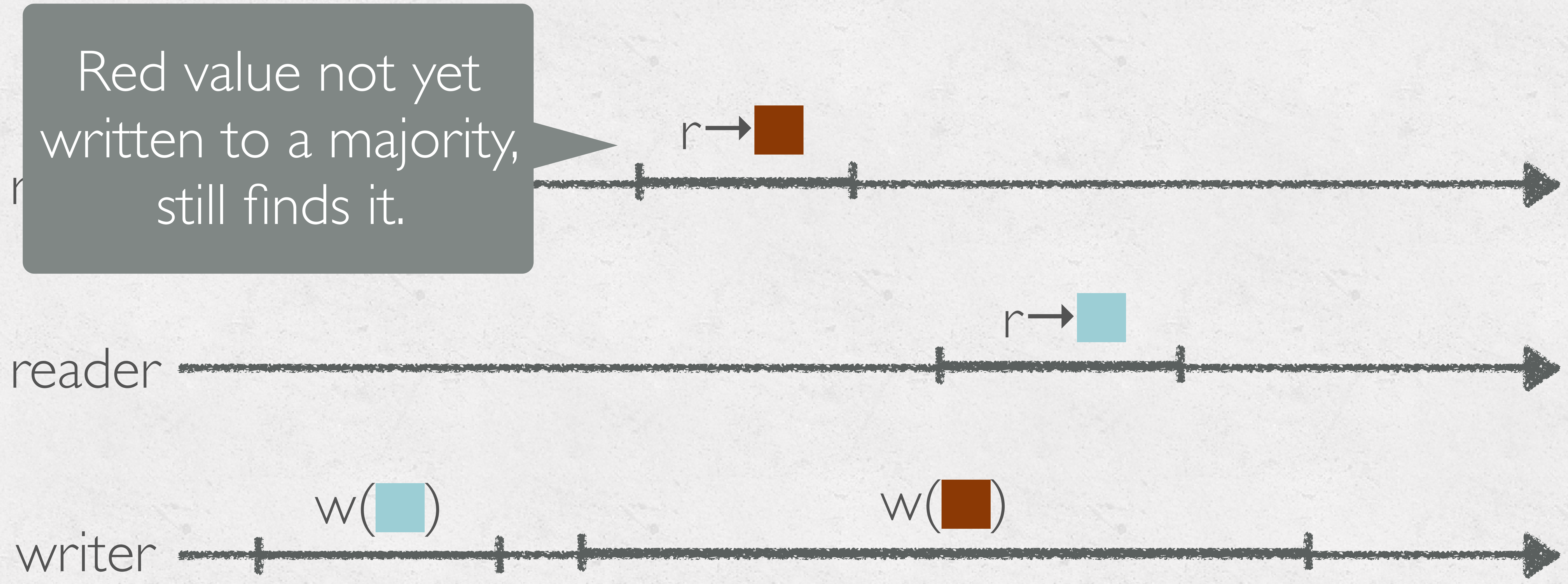

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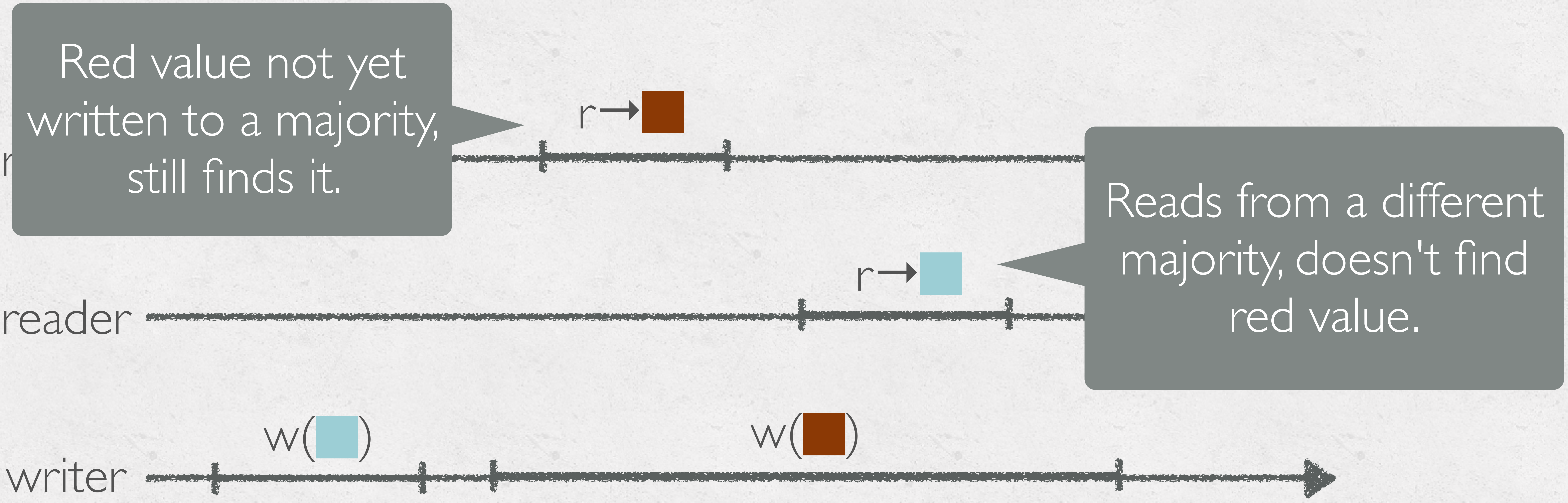

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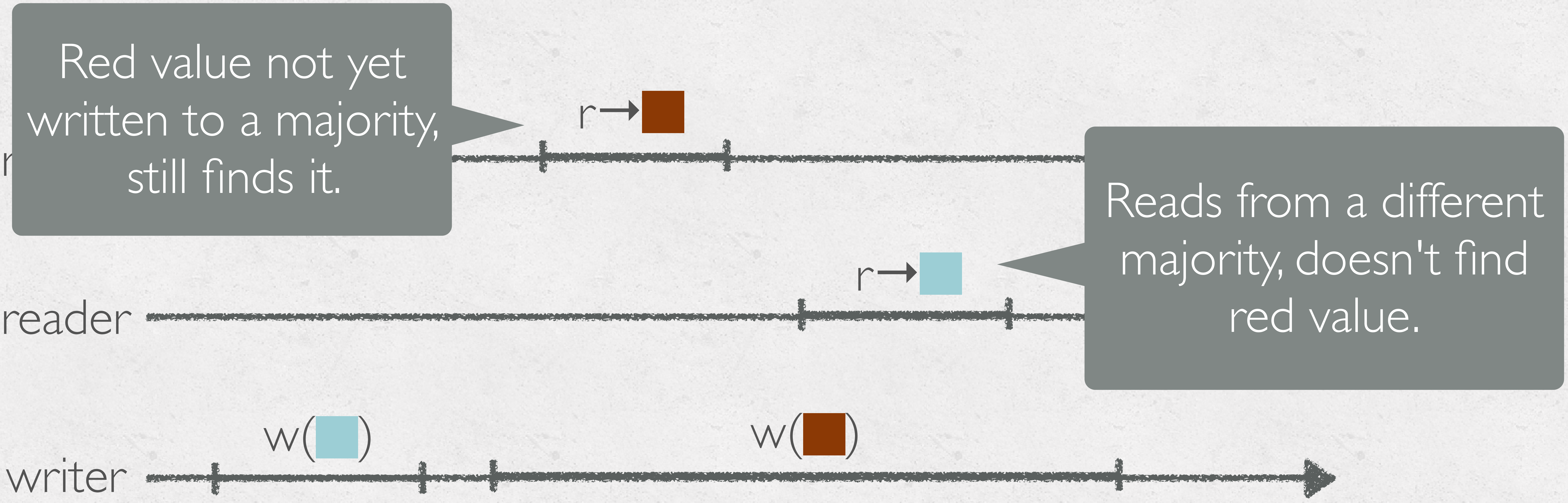
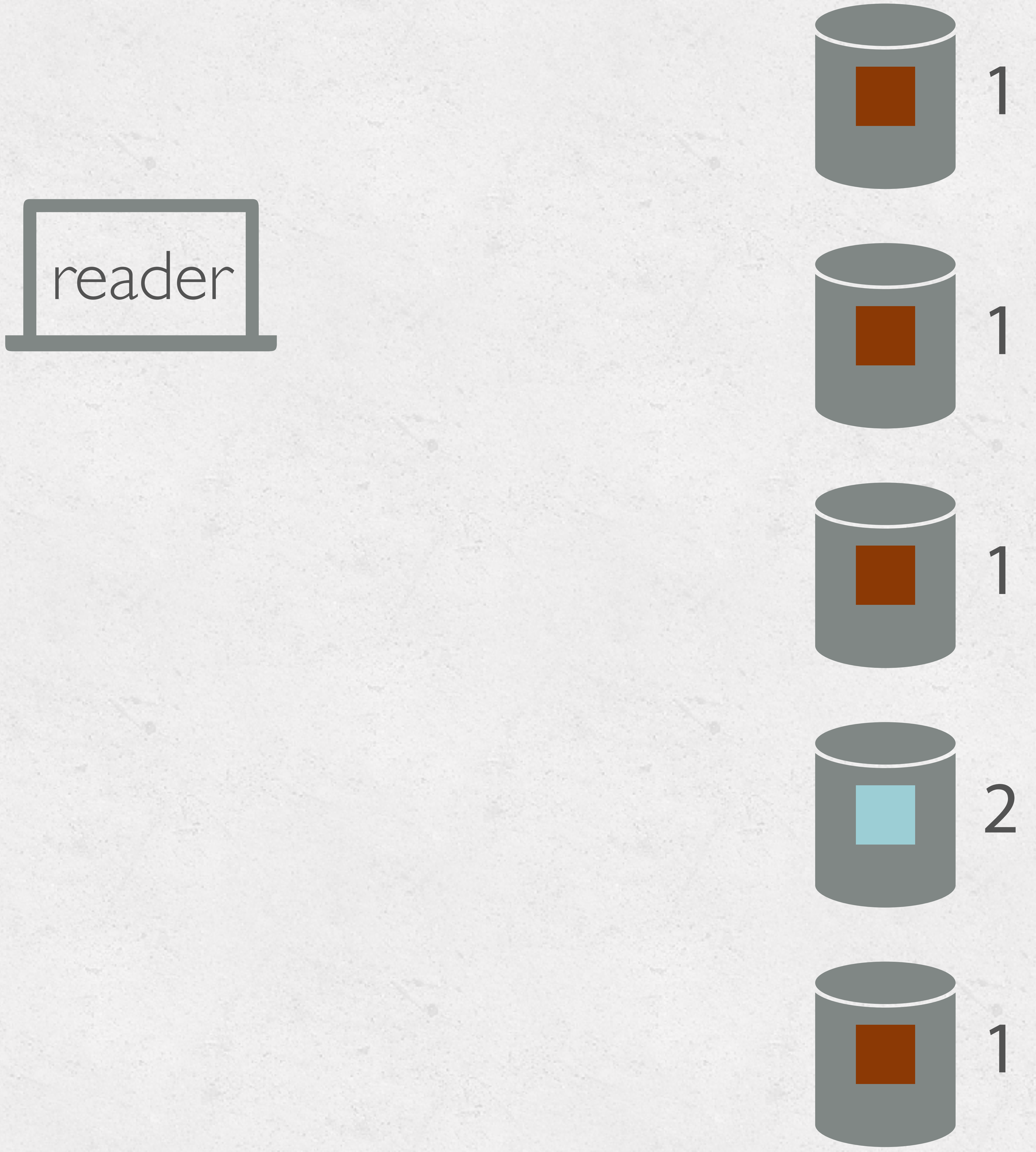


Not linearizable!

MRSW II

Suppose a write is ongoing (or the writer died).

- Reader reads value from a majority, takes the one with the highest timestamp.
- Reader then performs a **write-back**, writing the value to a majority (not necessarily the same one). Only returns from read after write-back is complete.
- Later readers are guaranteed to read a value **at least as new** as the previously returned one.



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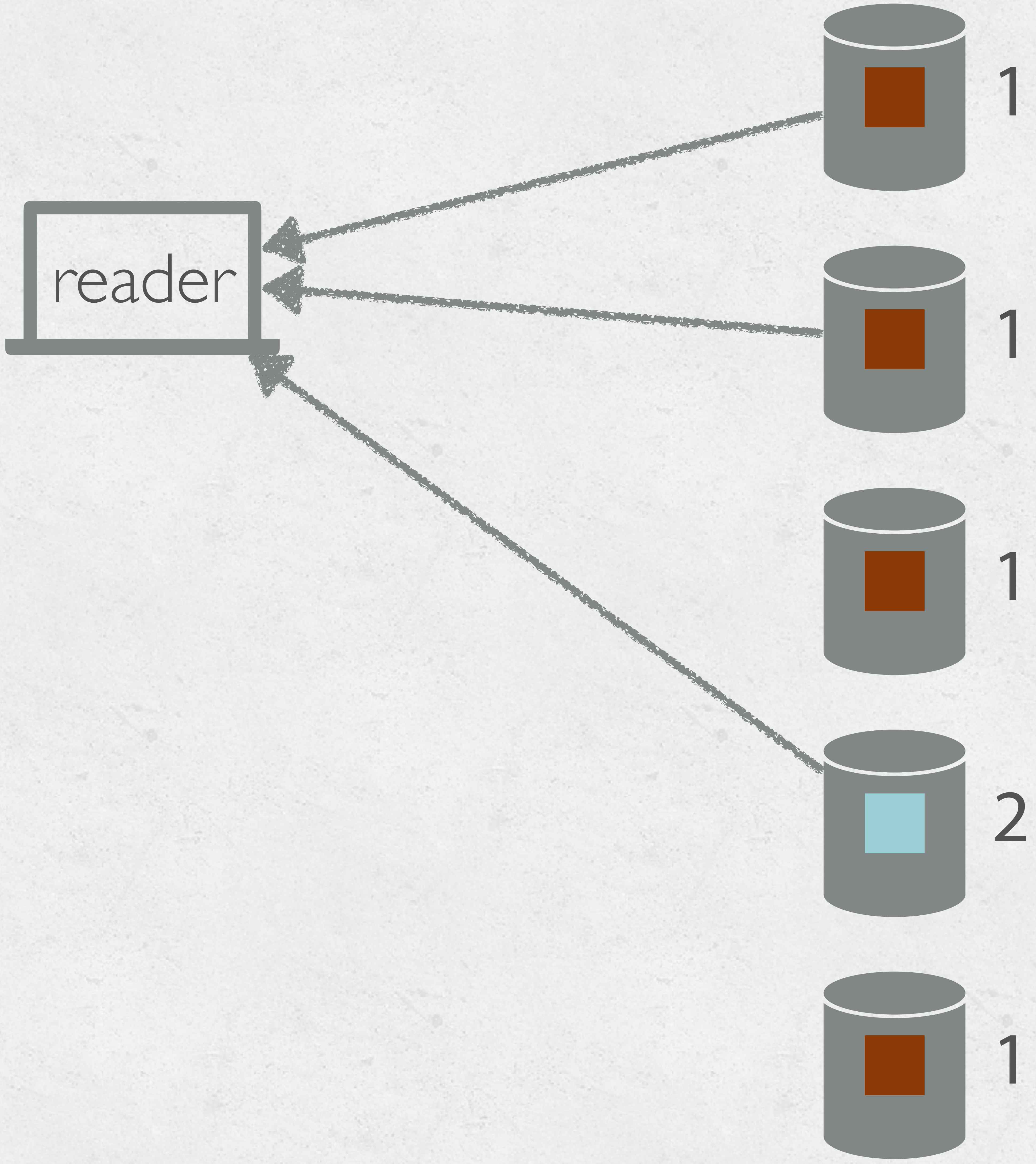

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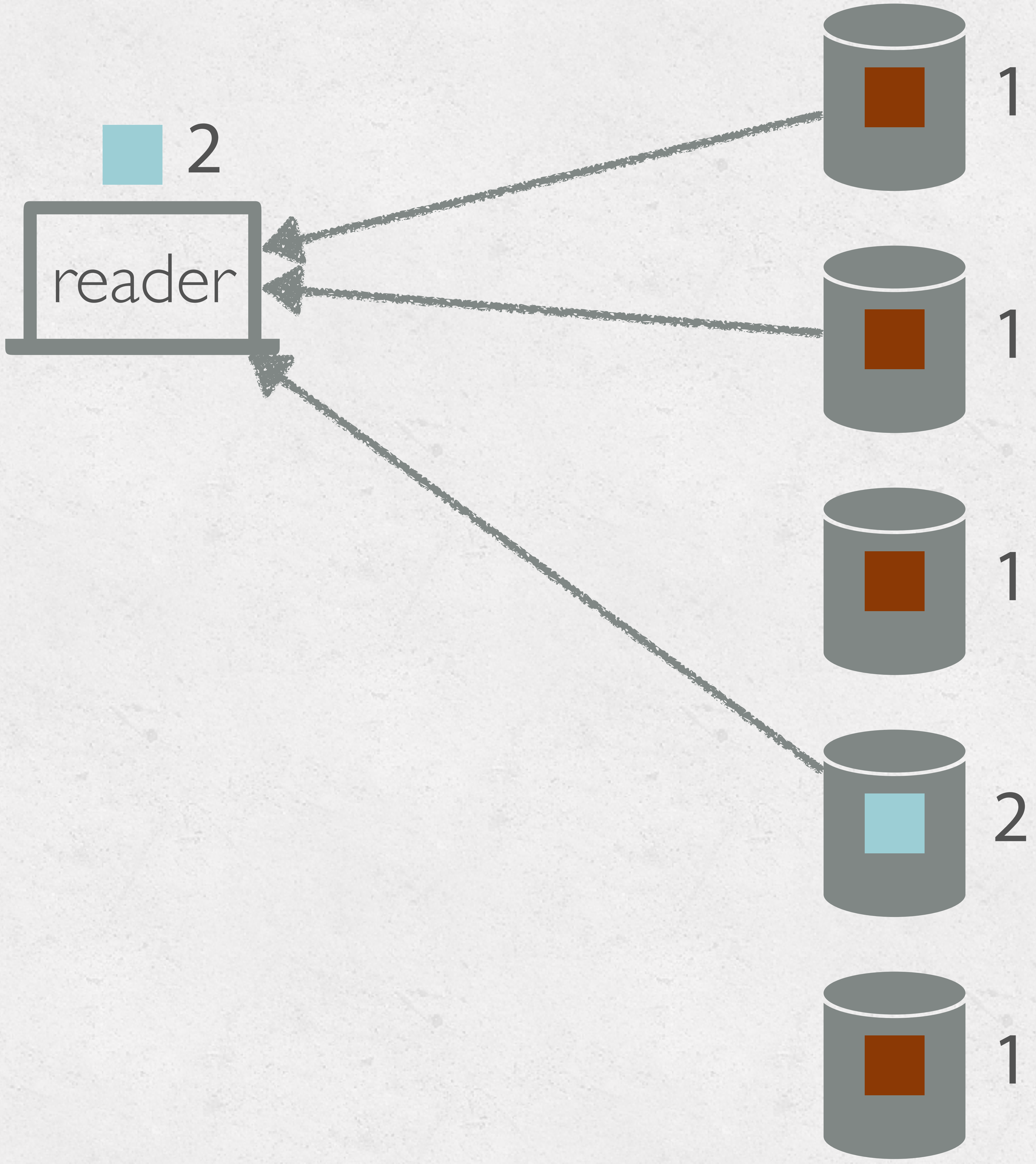

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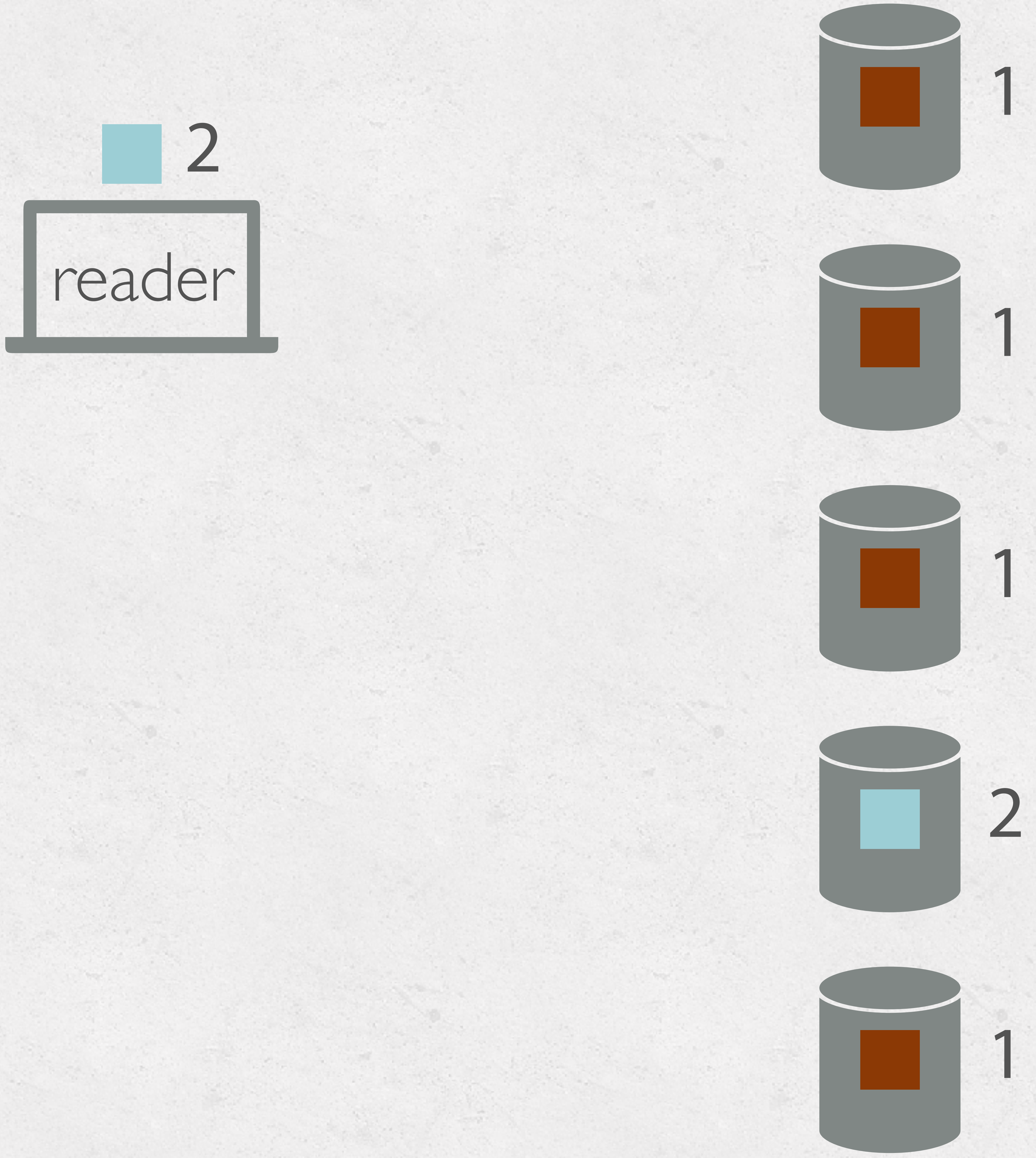

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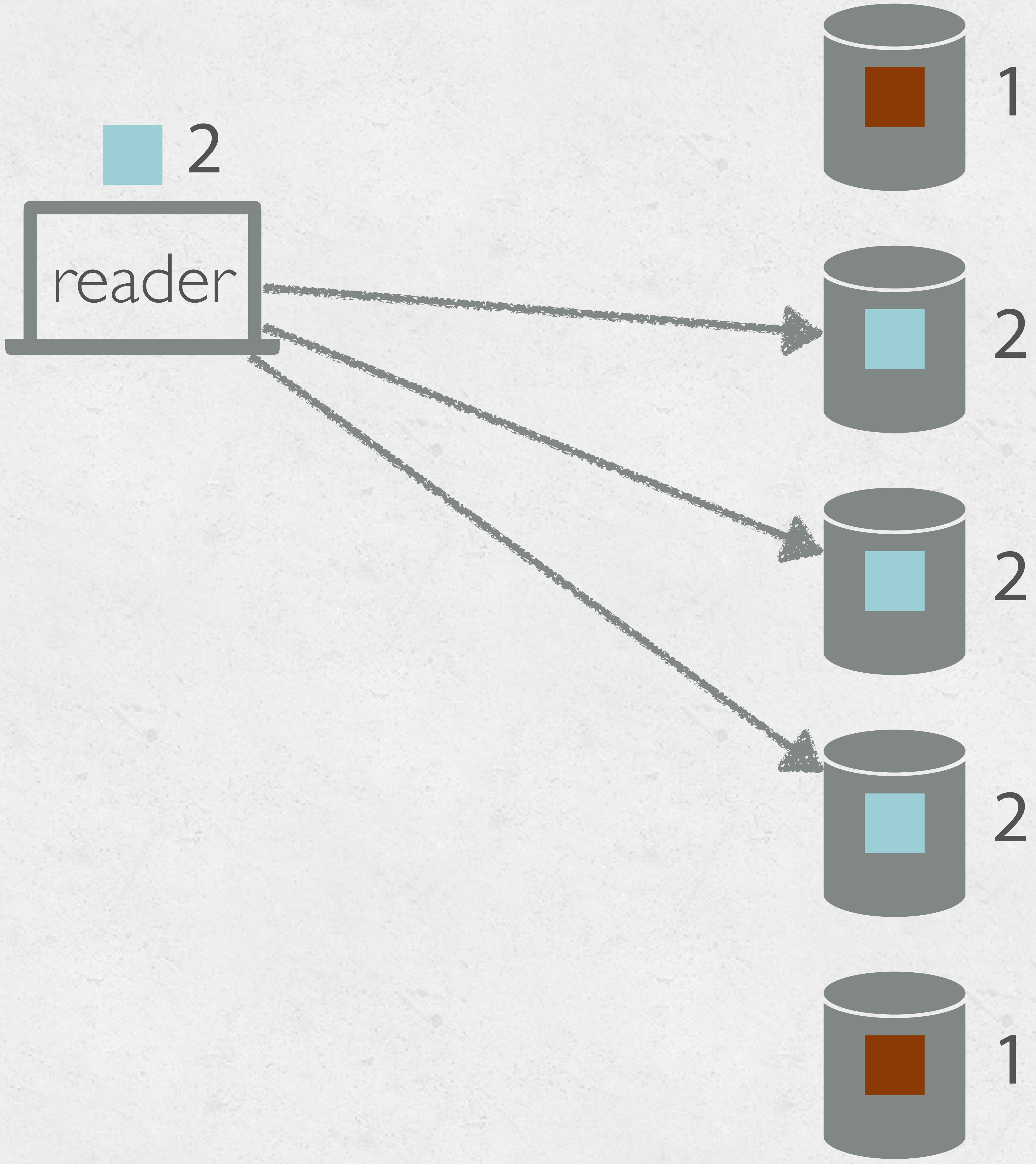

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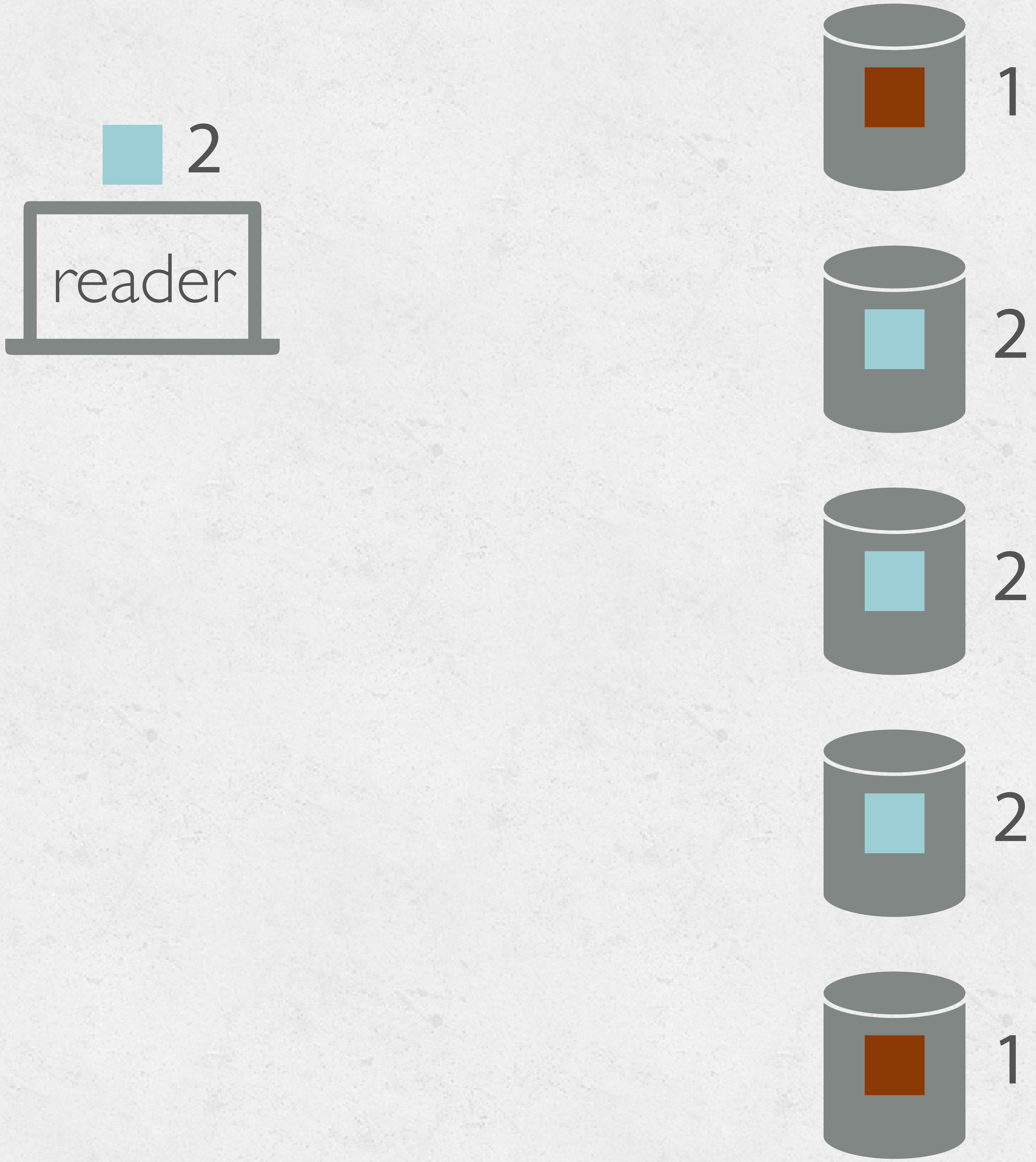

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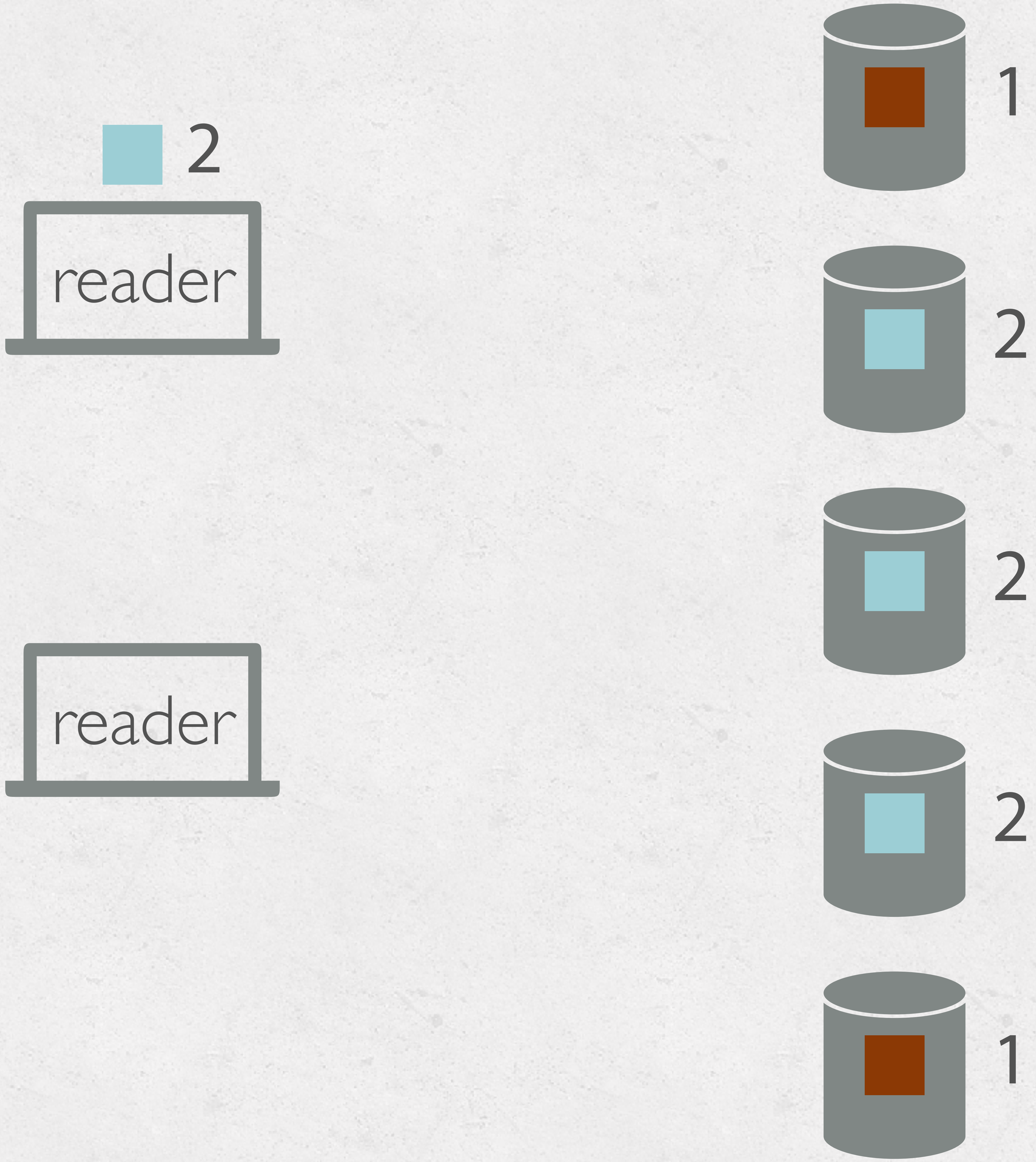
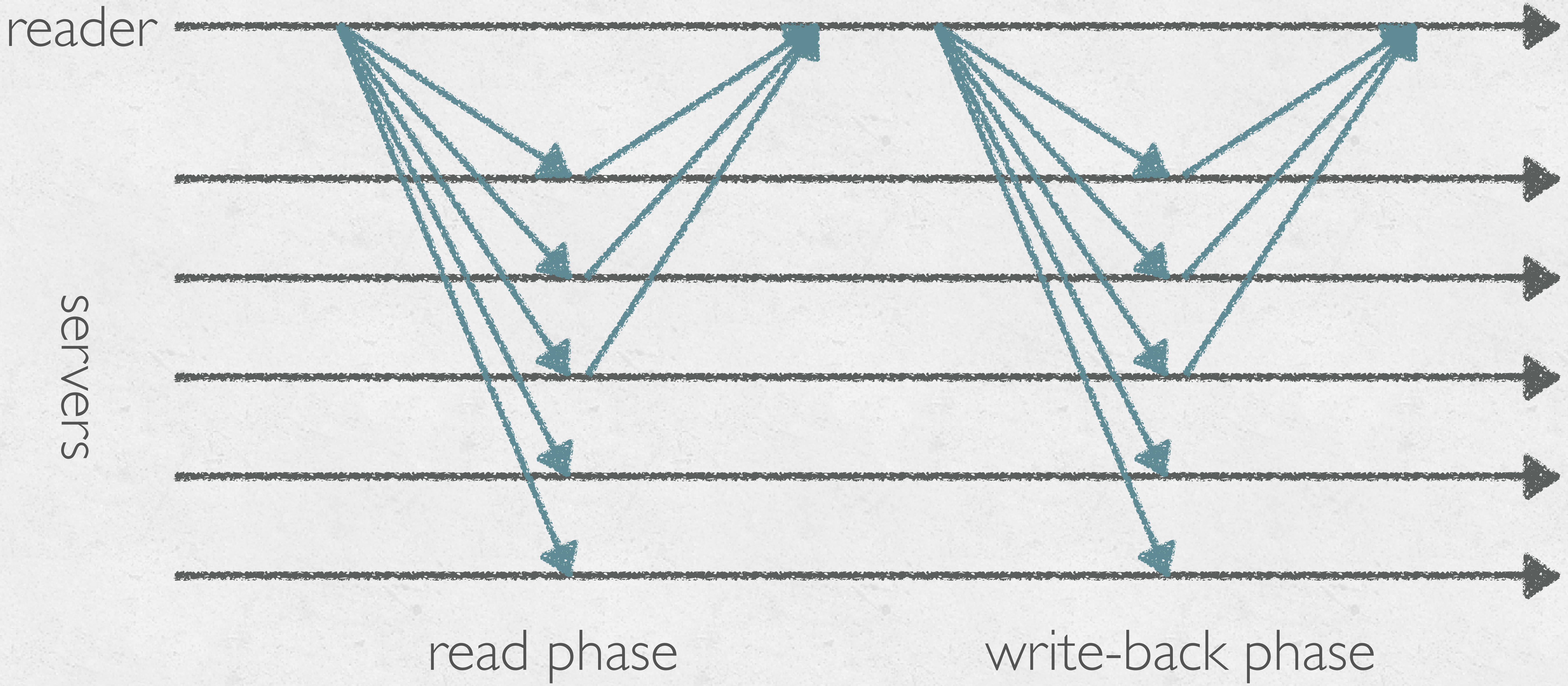


MRSW III



Do we always need to execute the write-back phase?

What if we only care about sequential consistency?
Do we care about the write-back phase at all?

Putting It All Together: MRMW

Does the previous solution just work?

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What if a write that starts after a previous write ended uses a **smaller timestamp**?

MRMW: Untimely Timestamps

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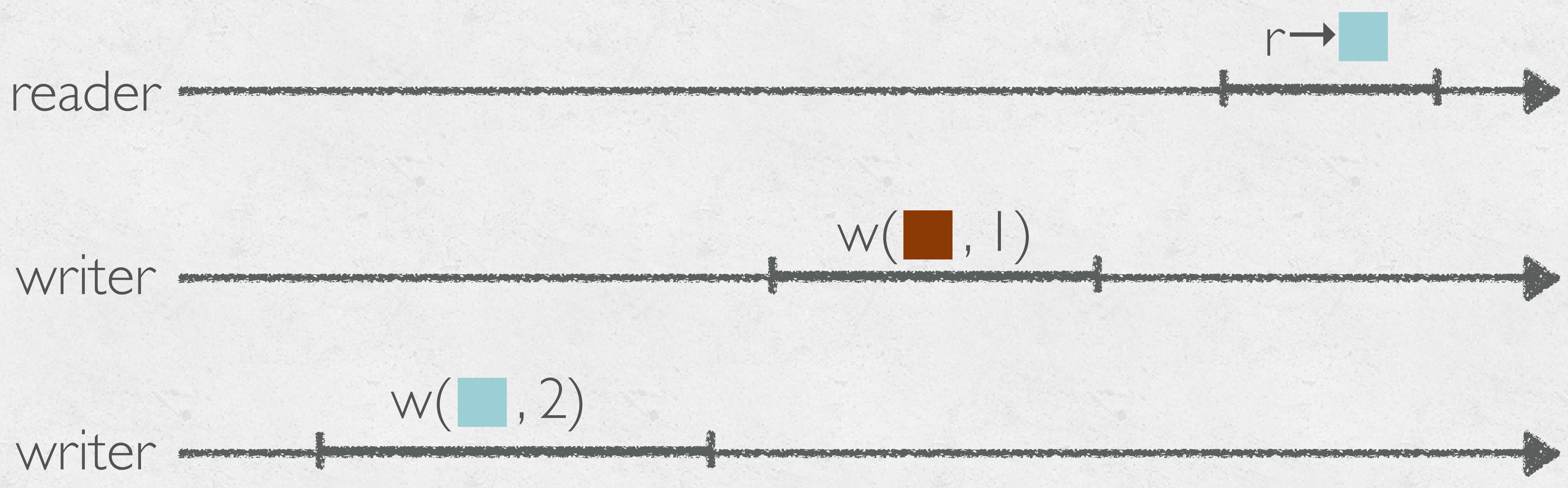
Reads from a majority, sees blue value has the highest timestamp.



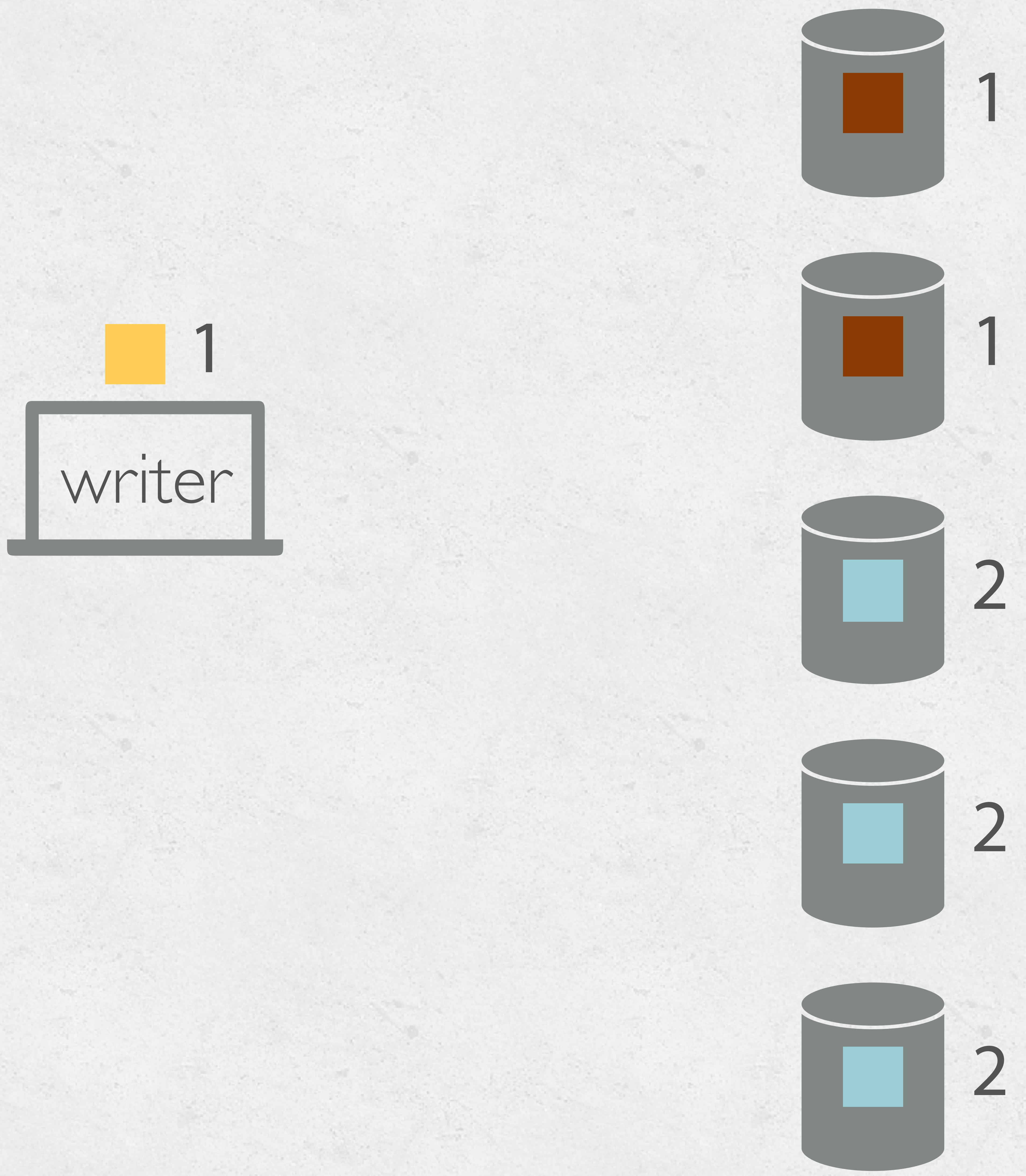
MRMW: Untimely Timestamps

Reads from a majority, sees blue value has the highest timestamp.

Not linearizable!

MRMW II: Ensuring Timestamp Ordering

- Writer first **queries** a majority, updates its timestamp to be larger than largest timestamp found.
- Writer then writes value to majority as usual.
- Written value guaranteed to have a timestamp larger than previously written values, readers will read latest value (again, writer IDs break timestamp ties).



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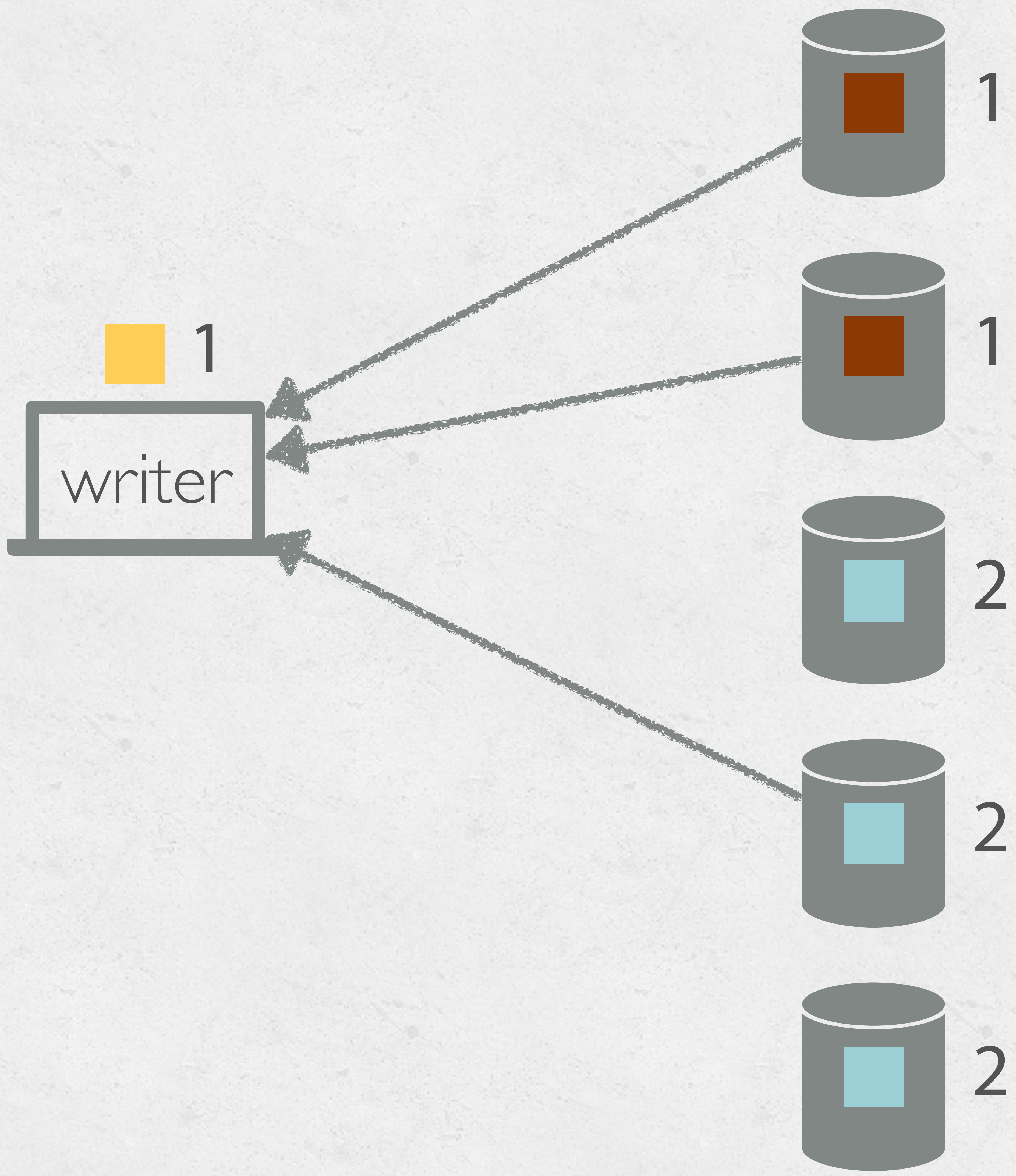

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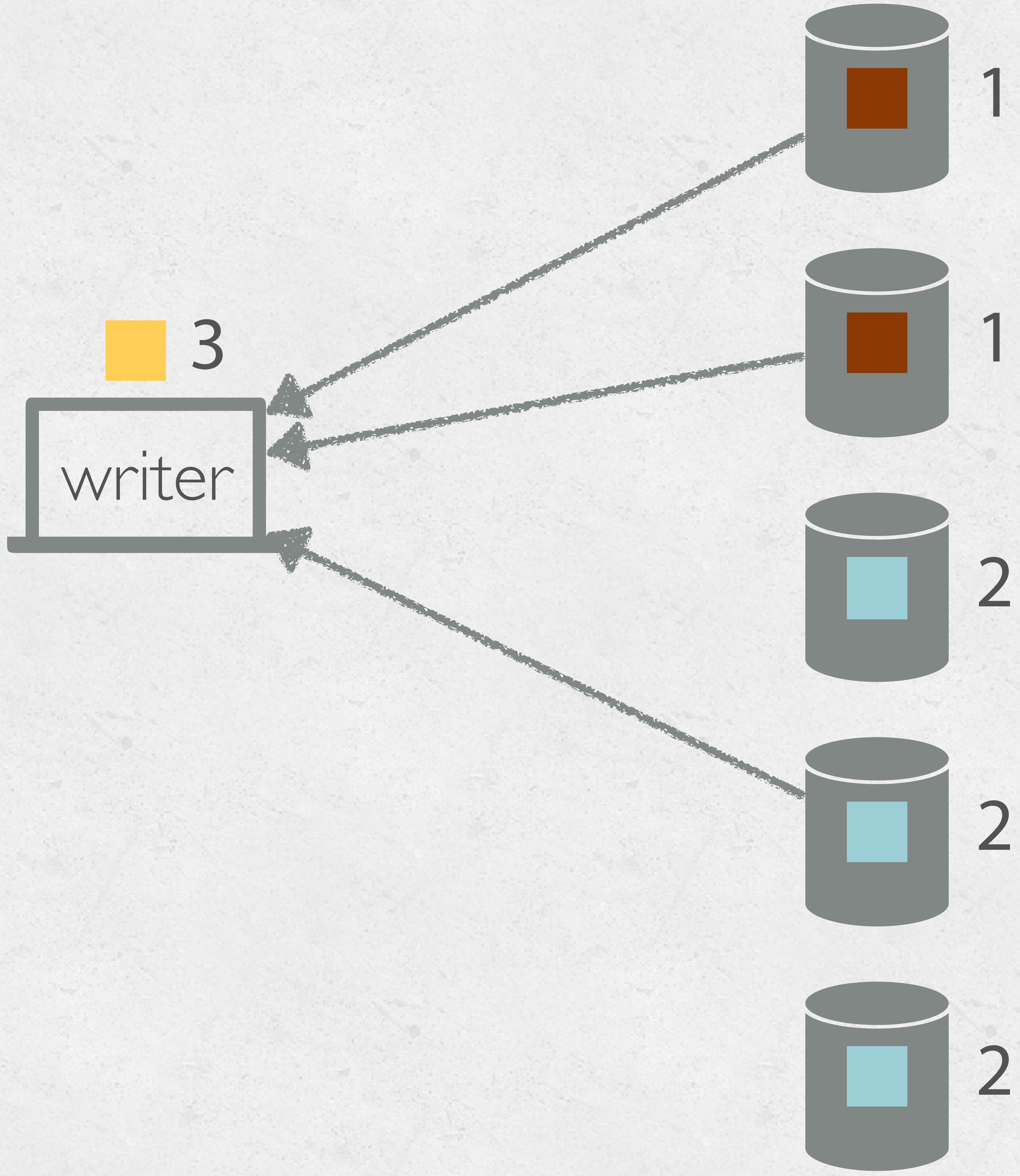

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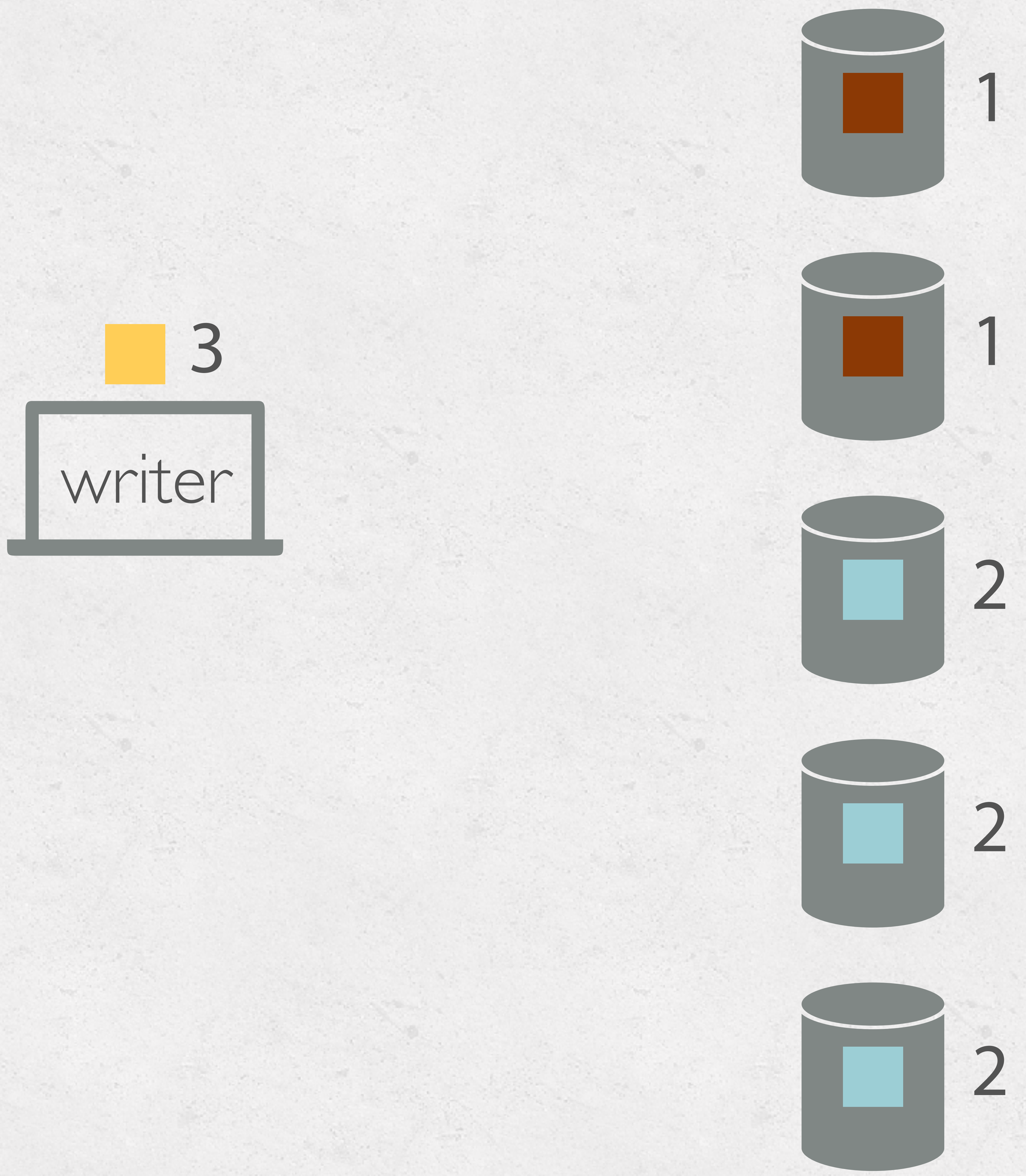

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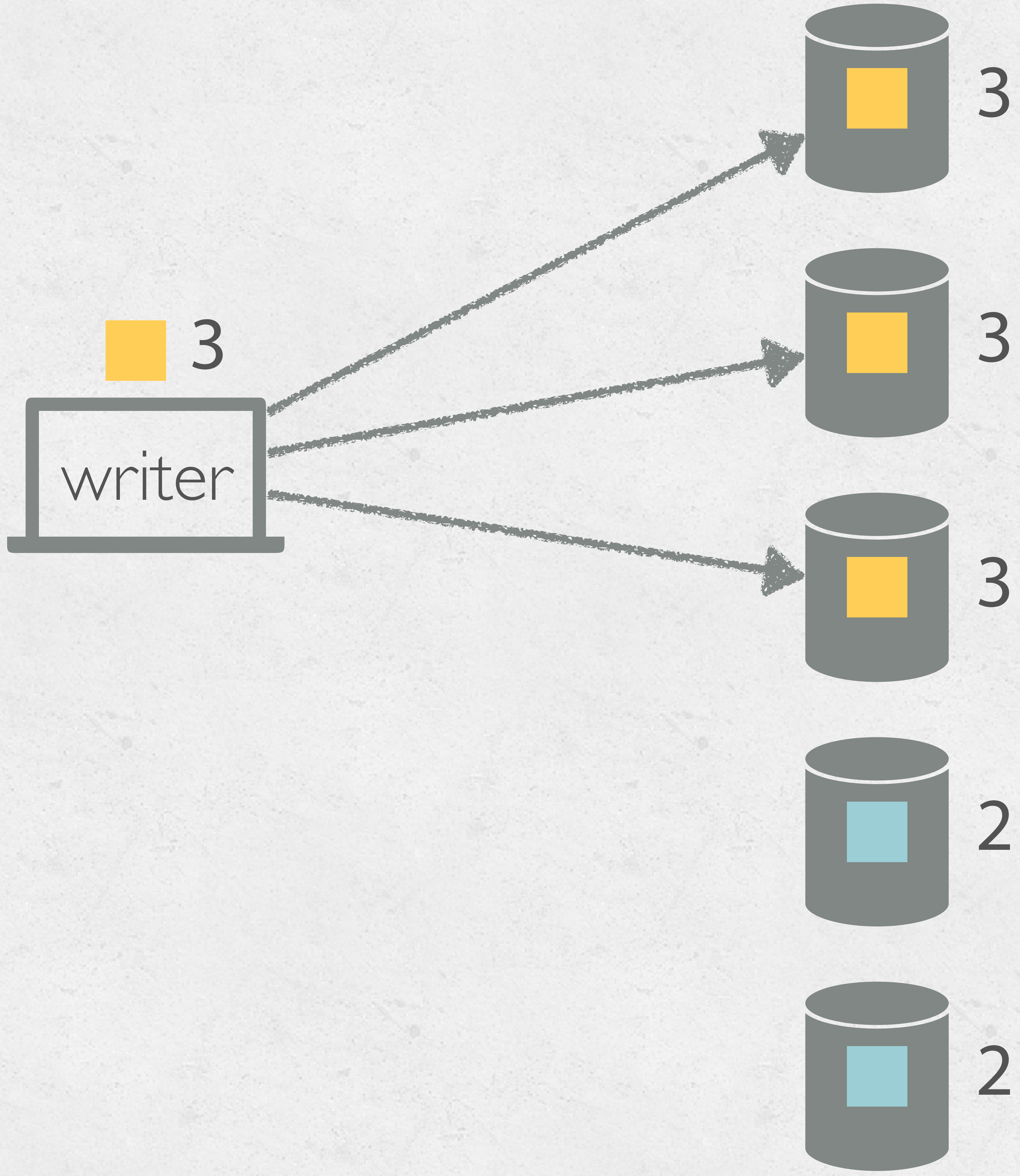

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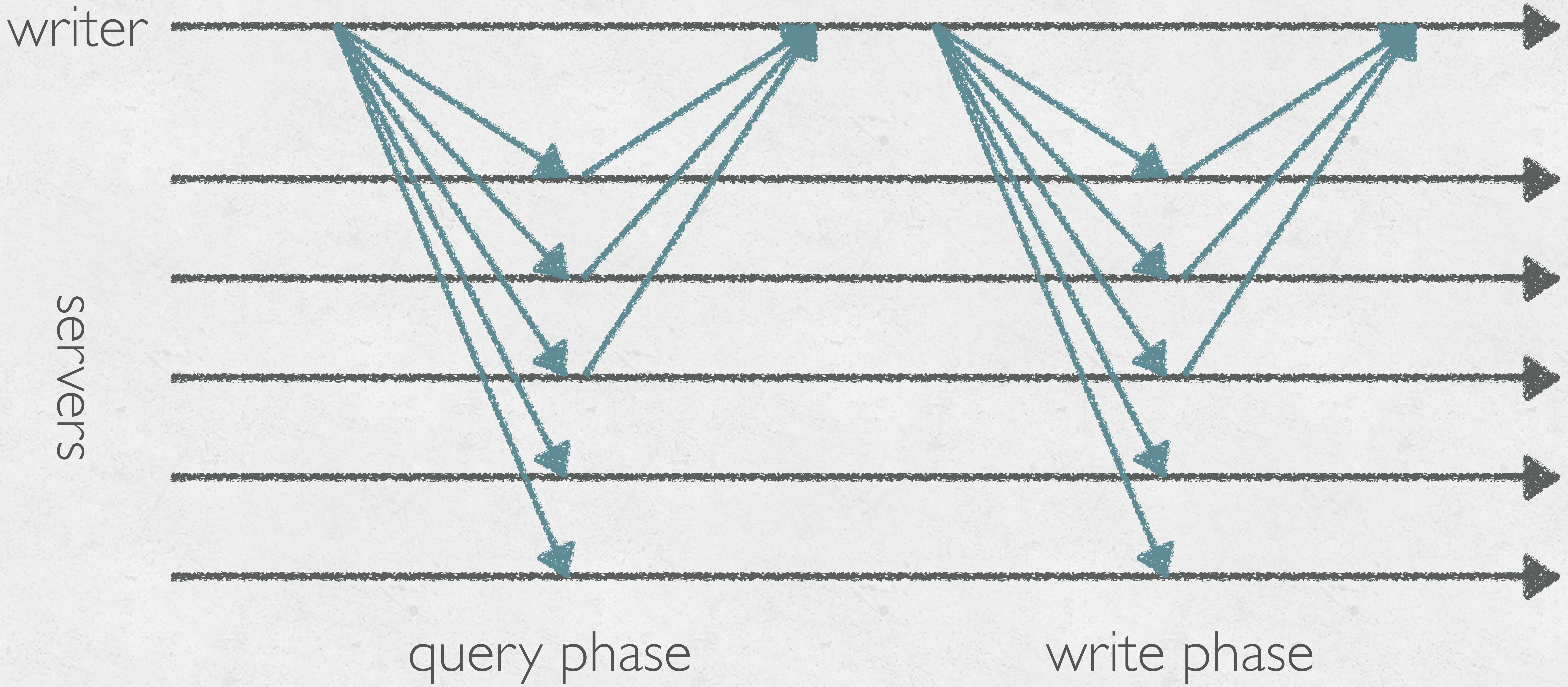

Wait A Second!

- The methods for reading and writing are now the exact same.
- The only difference is that a read writes and returns the value that was read, but a write writes the value to be written.
- Also, for the record, there's no reason that processes can't be both readers and writers.

Attiya, **B**ar-Noy, **D**olev 1995 **ABD Algorithm**

ABD vs. Paxos

- Paxos doesn't guarantee liveness when the network is asynchrony. ABD guarantees wait-freedom, even when there are multiple writers.

- Paxos-based state-machine replication (SMR) can support arbitrary state machines. The ABD algorithm only allows a read/write interface.

- ABD removes the leader bottleneck, has the same latency cost as leader-based Paxos.

What Can We Do With Registers?

- Implement a read/write key-value store.
- Emulate shared memory.

Consensus isn't always the right problem! Don't solve it if you don't have to!