2110446 - Data Science and Data Engineering

Foundation of Scalable Architecture

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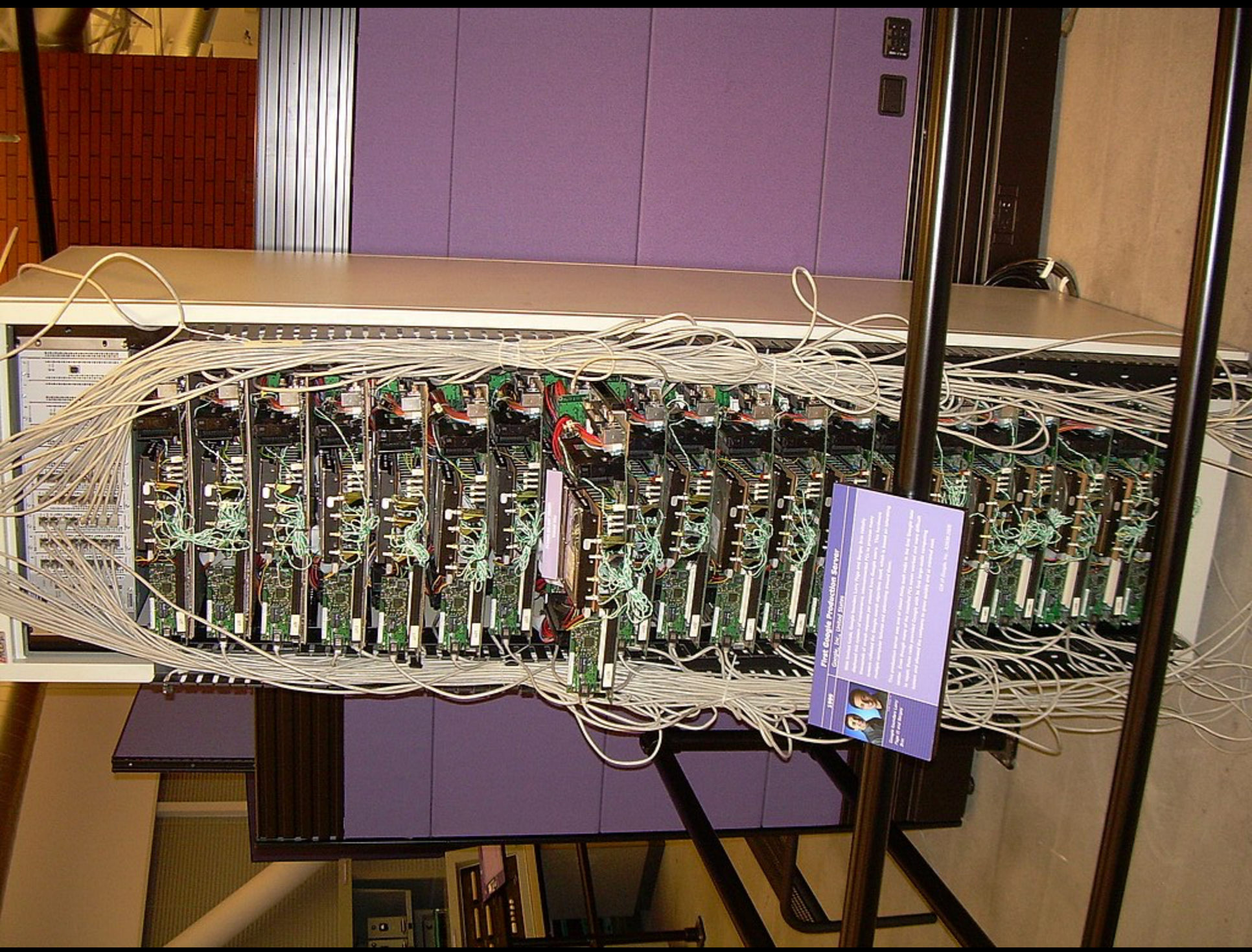
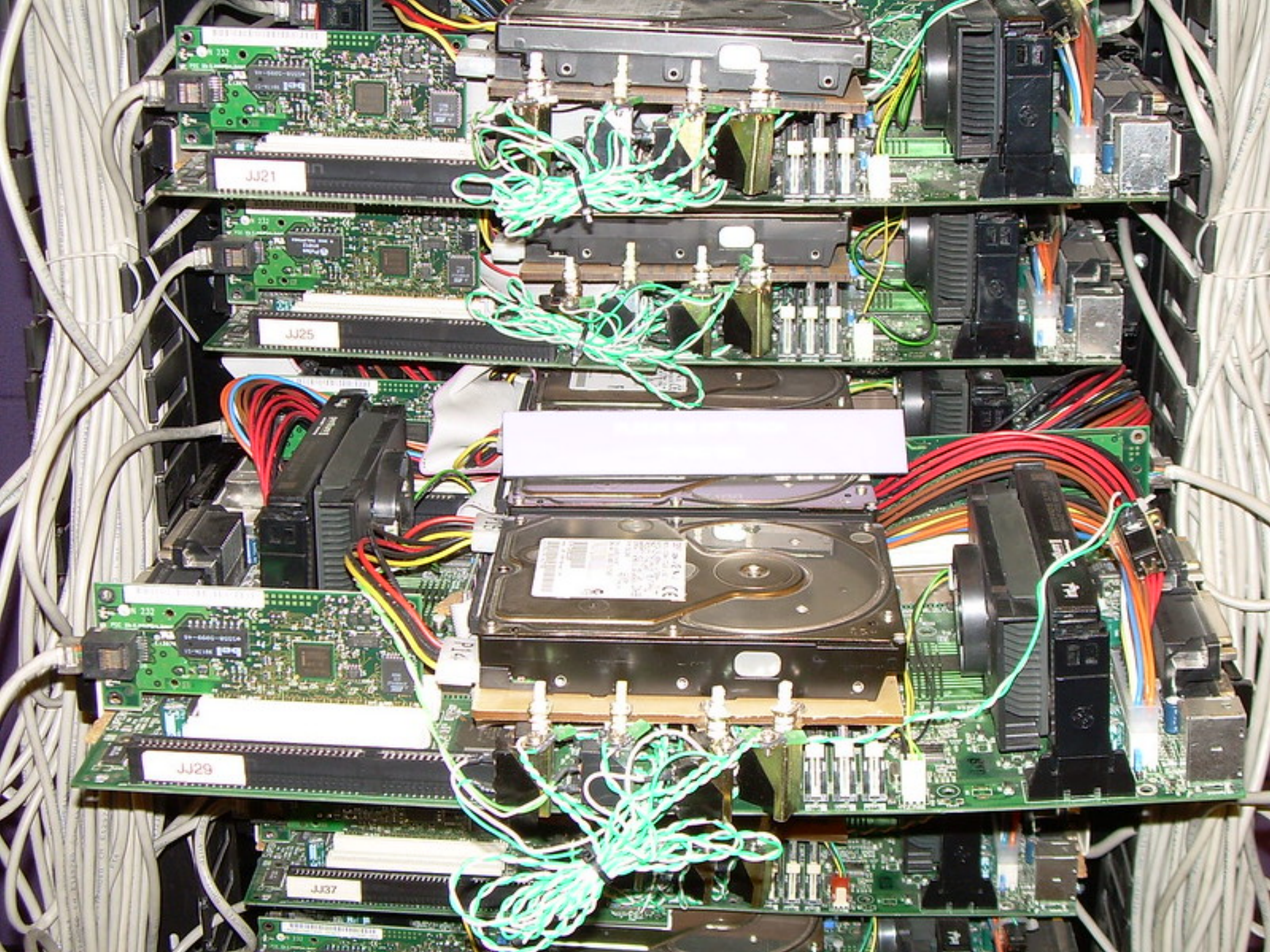
Scale Up vs Scale Out

Scale Up

Scale Out


First Google Production Server
1999
Google, Inc., United States


JJ21
JJ25
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JJ37

Nature of Big Data Architecture

- Base on distributed and parallel processing paradigm
- Hardware or software components located at networked computers communicate and coordinate their actions only by passing messages
- This leads to
  - Concurrency
  - No global clock
  - Independent failure

Concurrency

- Large number of resources (or nodes) are working together
  - Tencent - from 8,800 servers in 2014 to > 30,000 servers in 2017
  - Data is usually replicated into multiple copies to improve performance and availability
- Coordination and agreement are required
  - ensure pace of execution - everyone must reach at some execution point before continue
  - handle shared resources - data, devices
  - maintain data consistency

No Global Clock

- Coordination of programs' actions depends on the shared idea of time, but computers in a network cannot accurately synchronize their clocks

- Each computer has its own internal clock; there is no single global clock for every computer

- Thus, no two computers running independently can have the same clock values

- How can we know the order of executions?

  - This is important for guaranteeing correctness e.g transaction

Independent Failure

- Each component of the system (e.g. network, computer, program) can fail independently, leaving the others still running

- Google's studies showed 3% of hard disks will be failed after 3 months and up to 8% after 2 years
  - for 30,000 servers, 900 servers will experience hard disk failures within 3 months

- How can we mask (to hide or make it less severe) these failures?
  - System can continue executing the jobs correctly even when failures occur

Ordering in Distributed Systems

- Execution of distributed systems usually bases on series of events

- An event is the occurrence of a single action that a process carries out as it executes

- Since we cannot synchronize clocks perfectly, we cannot in general use physical time to find out the ordering of events that occur at different computers

- We usually rely on ordering of events, rather than exact timestamp of occurrence e.g. we are certain that A is executed before B even if A and B are on different nodes

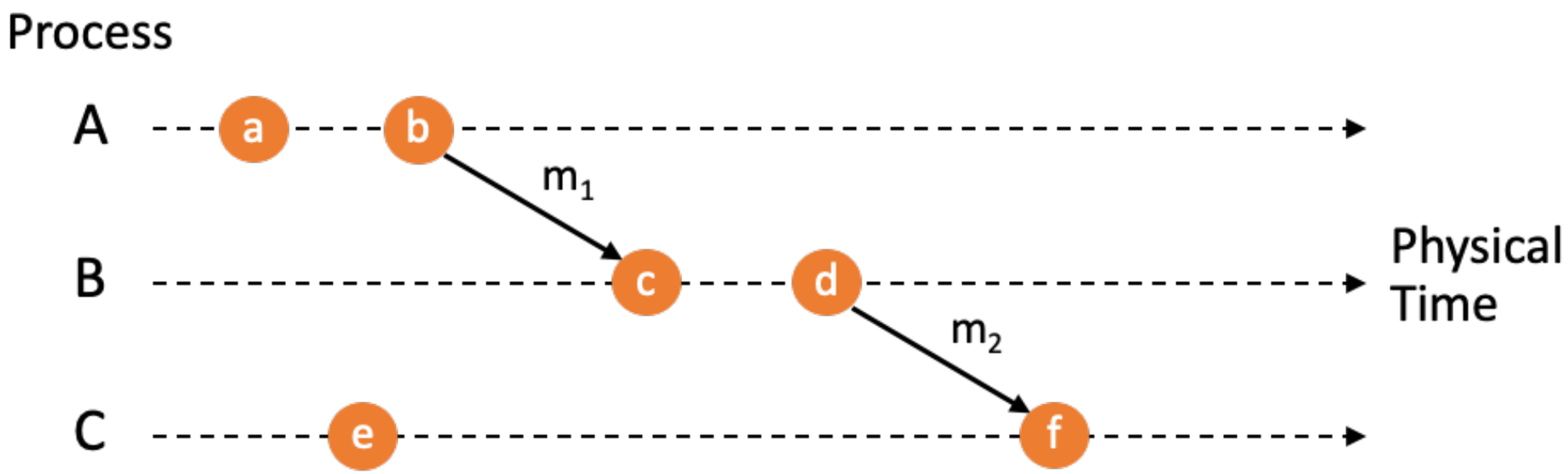
Ordering Models

- Total ordering
  - Each event can be placed in a specific order, which is based on what time they occurred
- Partial ordering
  - We do not know the exact order of every event, just the order of certain events that rely on one another
  - Causal ordering is a special case of partial ordering based on Happened-Before relation

Happened-Before Relation

- A partial order of events that reflects a flow of information
  - HB1: for any events in process A, if e is executed before e' then $e \rightarrow e'$ (e is happened before e')
  - HB2: for any message m, $send(m) \rightarrow recv(m)$
  - HB3: if $e \rightarrow e'$ and $e' \rightarrow e''$ then $e \rightarrow e''$

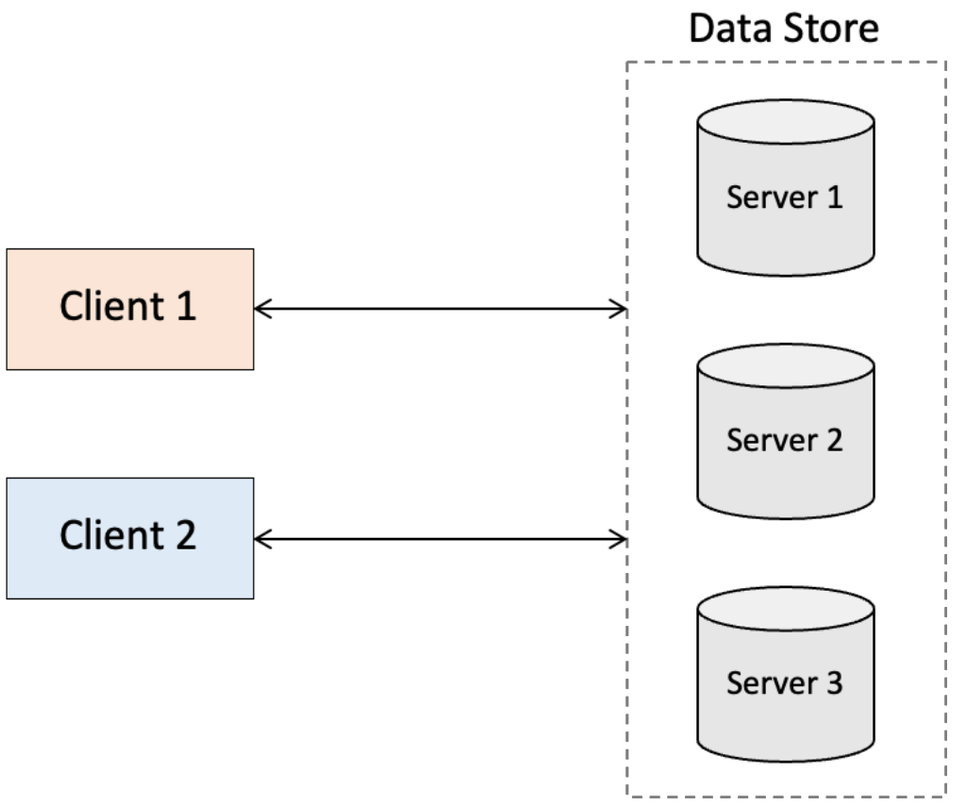
Causal Ordering

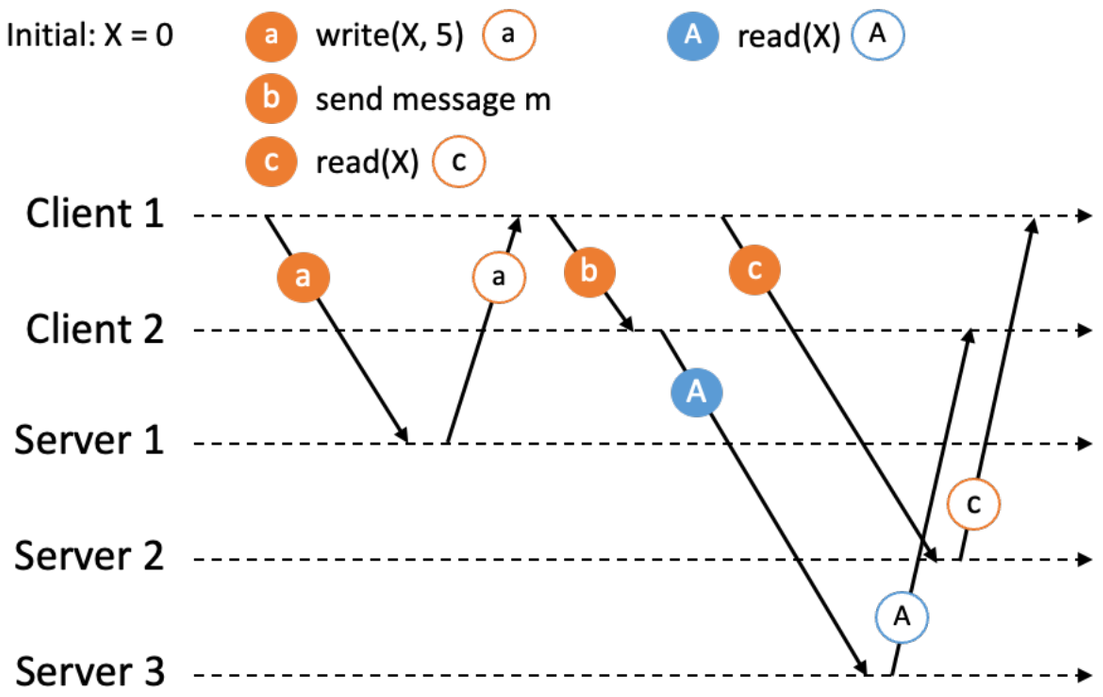


From HB1: $a \rightarrow b$ (at A) $\quad c \rightarrow d$ (at B) $\quad e \rightarrow f$ (at C)
From HB2: $b \rightarrow c$ (at m_1) $\quad d \rightarrow f$ (at m_2)
From HB3: $a \rightarrow c \quad b \rightarrow d \quad \ldots \quad a \rightarrow f$

Not all events are related by Happened-Before relation
Consider a and e (different processes and no chain of messages to relate them), they are not related by $\rightarrow$; they are said to be concurrent; write as a || e

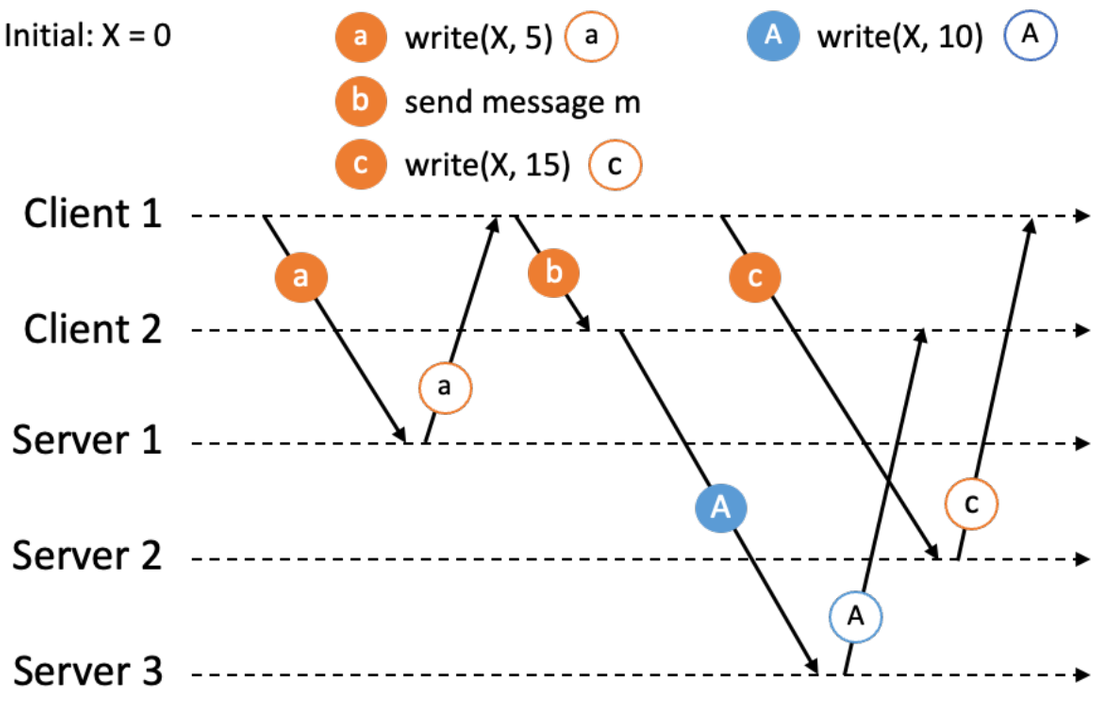
Ordering and Data Store





- Suppose a client can send a request to any server and the system guarantees ordering
- For FIFO ordering: as long as execute (c) after (a) สมมติว่า 3 server เป็นเครื่องเดียวกัน ลำดับเหตุการณ์ที่ Client สังเกตได้
- Causal ordering - as long as execute (A) after (a)

Total Ordering

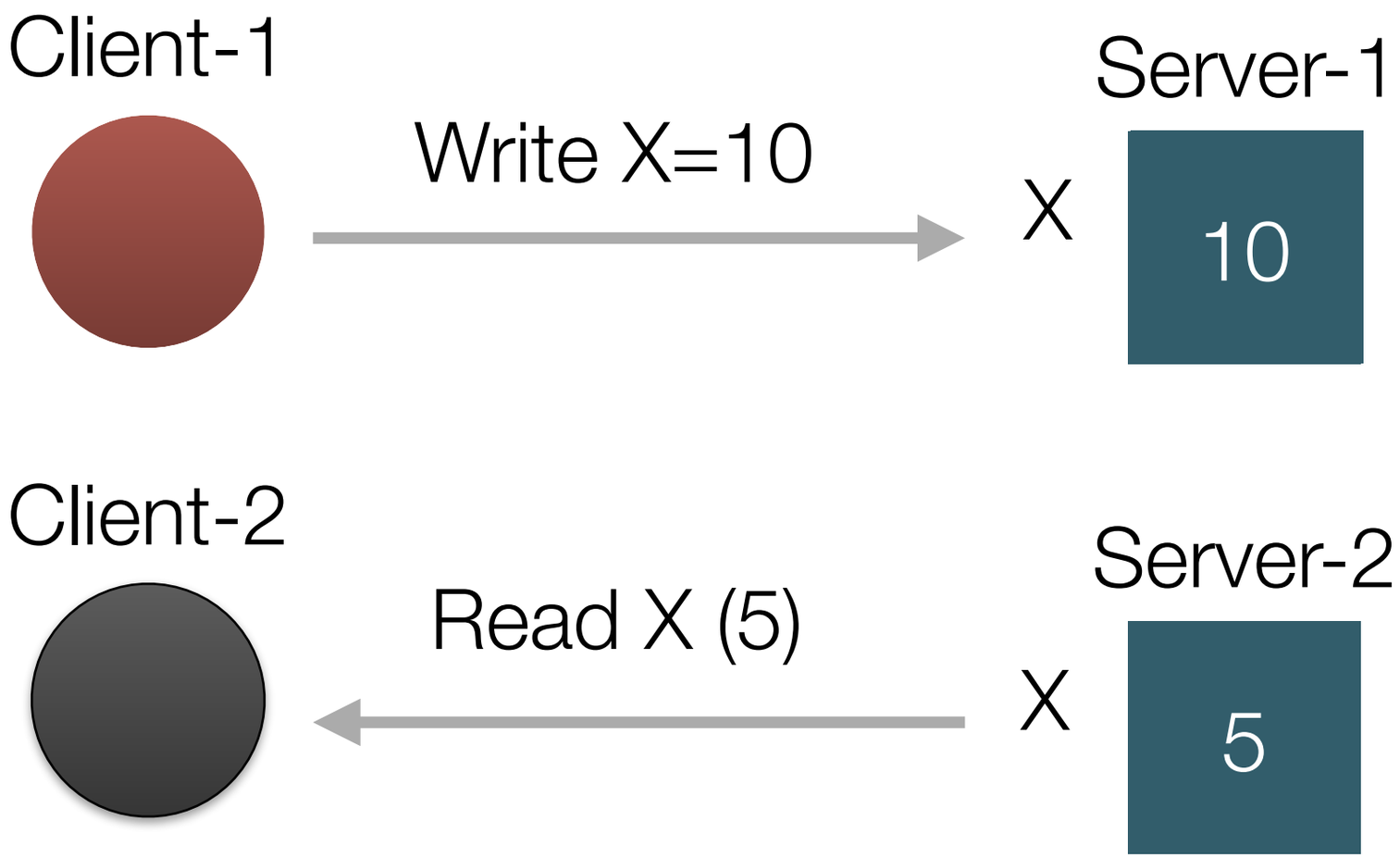


- All servers will execute requests in the same order
- Arbitrary-total - in any order
- FIFO-total - as long as execute (c) after (a)
- Causal-total - as long as execute (A) after (a)

Scalability and Strong Consistency Model

- For scalability, the same data is stored on multiple servers (replica)
- Lead to difficulties to keep all copies in-sync
  - Concurrent write
  - Read and write on different replica
- Even more problems if
  - Data is replicated to lots of servers (hundreds or thousands)
  - Servers are distributed around the world

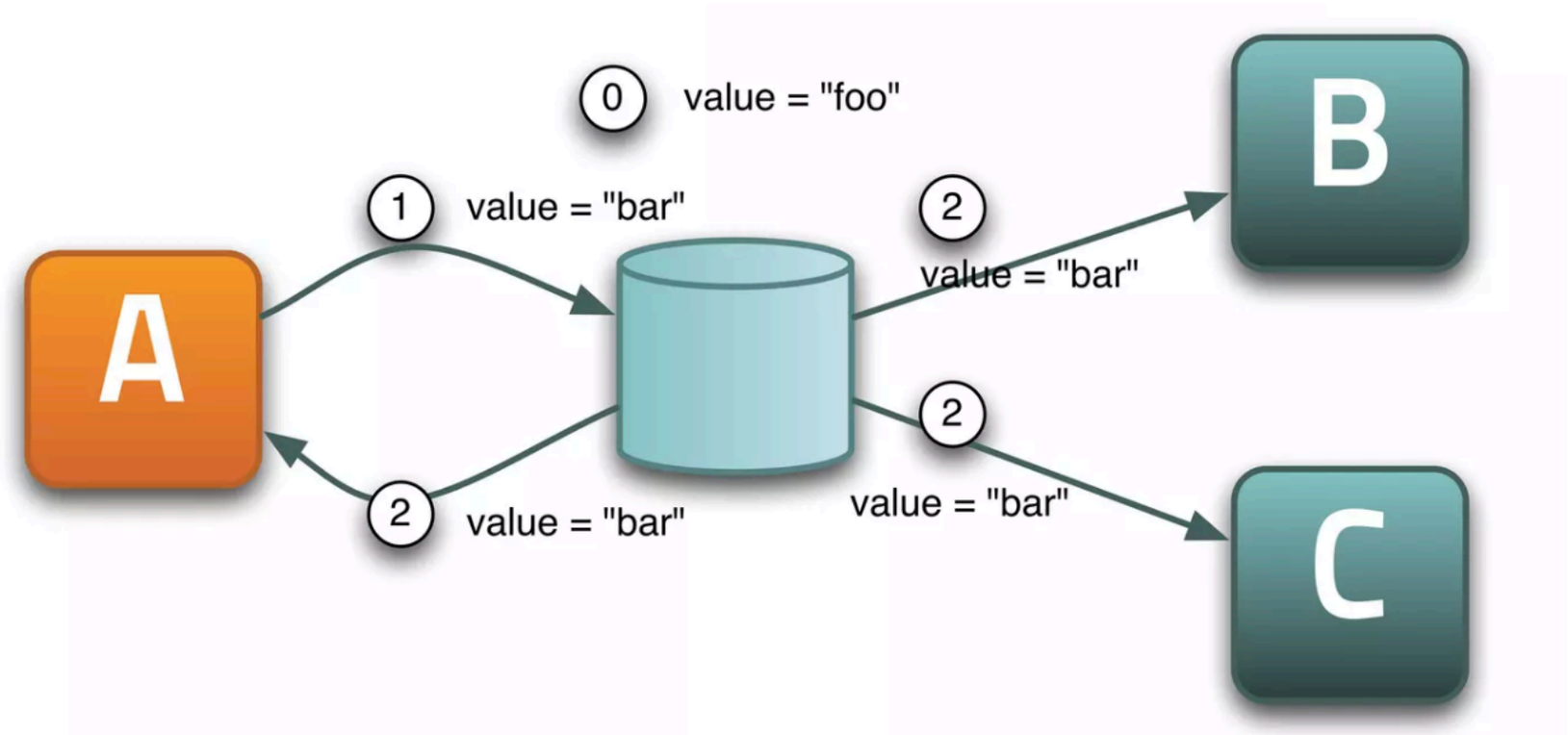
Replication and Data Consistency Problem



Consistency Models (based on Vogels' Paper)

- Strong consistency
  - After update completes, any access will return the updated value
  - High costs for large scale system
- Weak consistency
  - Certain conditions must be met before the consistency is guaranteed
  - Time between update completion and guaranteed consistency is called inconsistency window

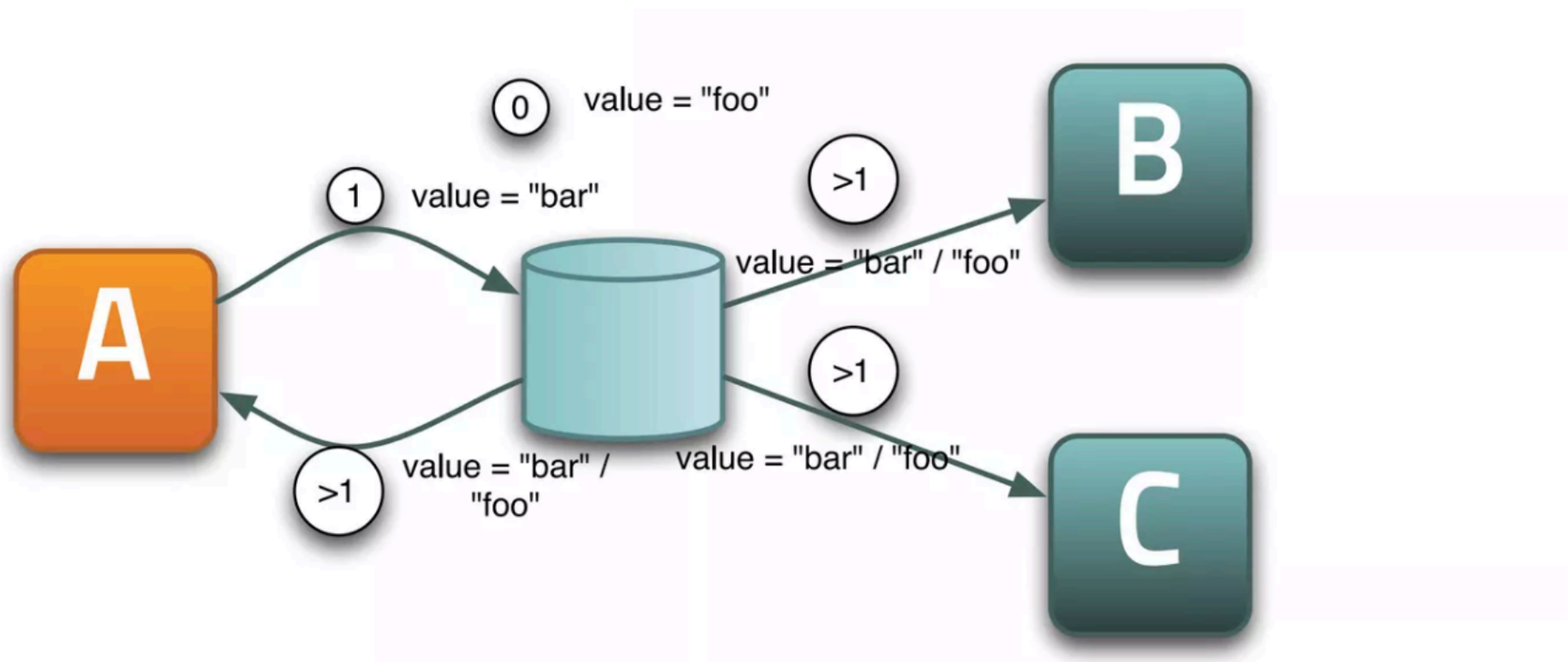
Strong Consistency



After the update, any subsequent access will return the updated value.

Source: https://www.slideshare.net/springerw/eventually-consistent

Weak Consistency



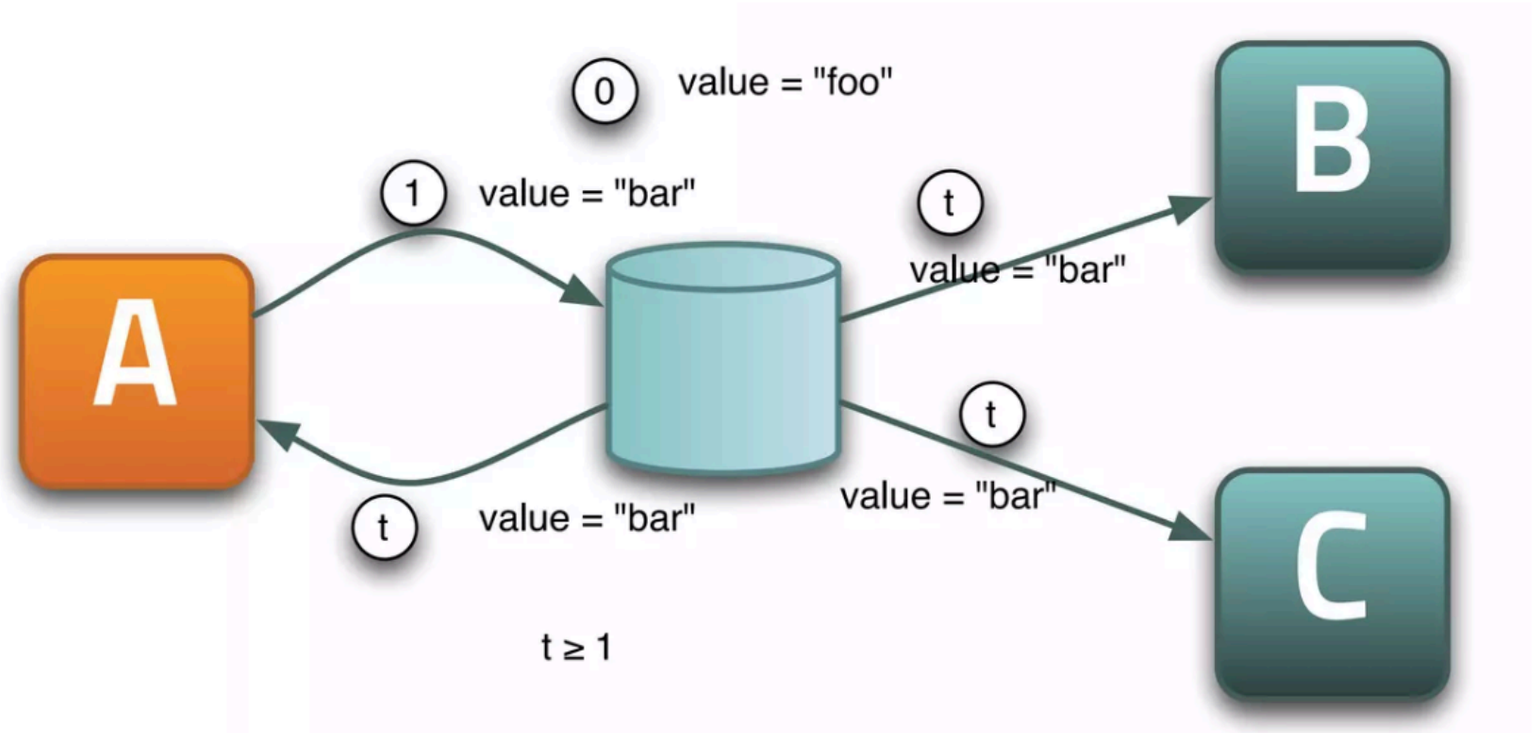
The system does not guarantee that at any given point in the future subsequent access will return the updated value

Source: https://www.slideshare.net/springerw/eventually-consistent

Eventual Consistency

- Specific forms of weak consistency - if no new update are made to the object, eventually all accesses will return the last updated value
  - Causal consistency (A updates data, A informs B, B will always get updated value after that, also true for C if B informs C after B being informed)
  - Read-your-write consistency (A updates data, A will always get updated value after that — special case of causal consistency)
  - Others (reading assignments)

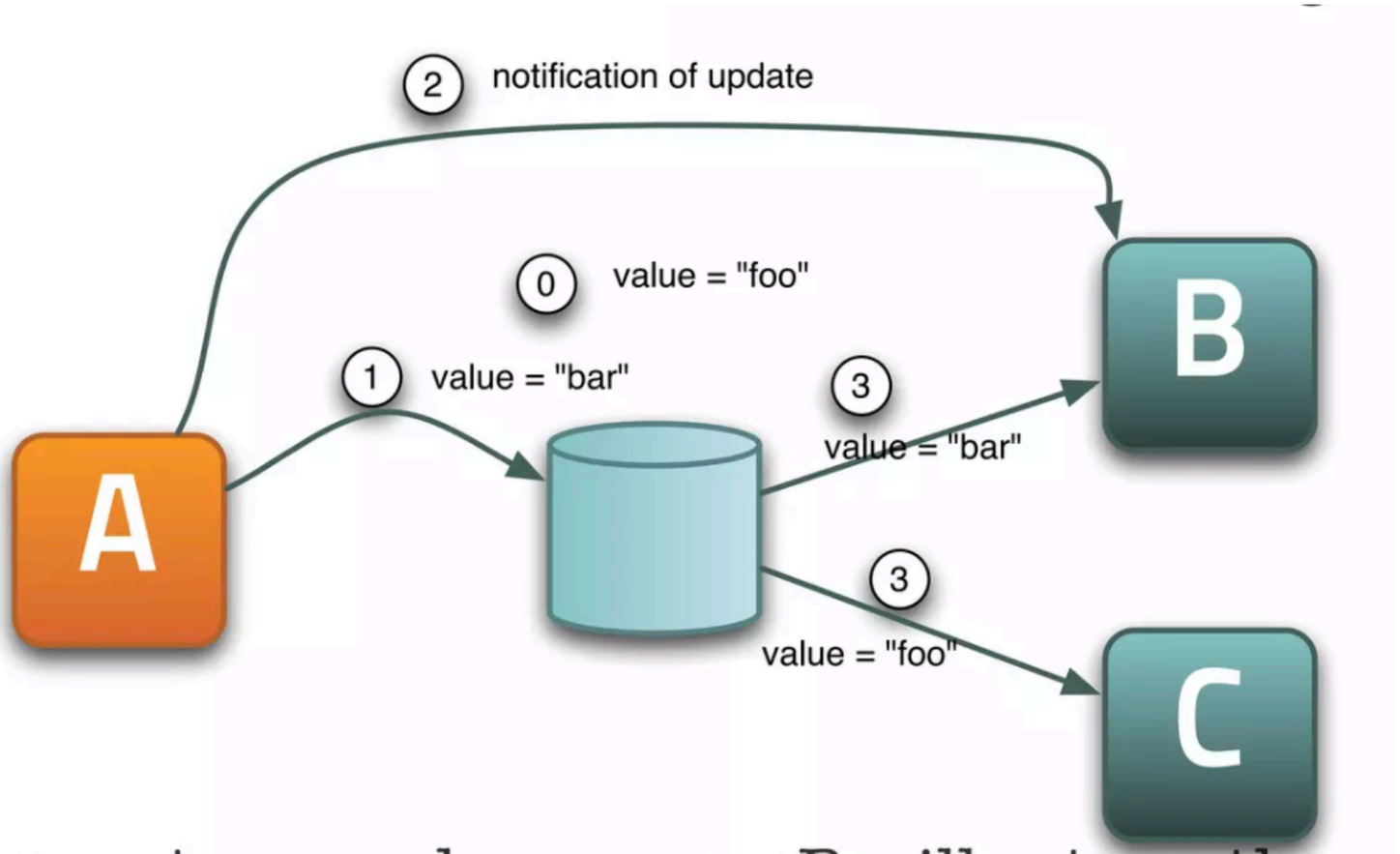
Eventual Consistency



If no updates are made to the object, eventually all accesses will return the last updated value.

Source: https://www.slideshare.net/springerw/eventually-consistent

Causal Consistency

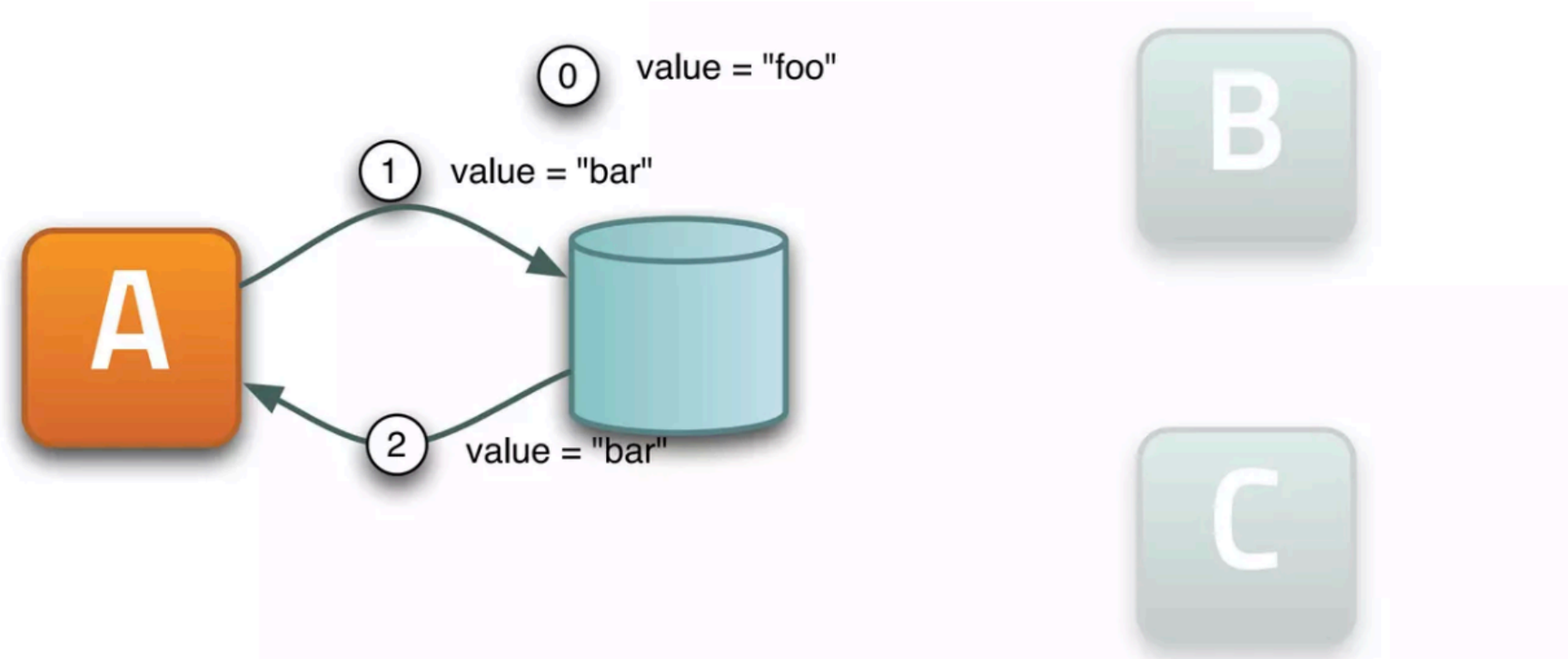


Subsequent access by process B will return the updated value, and a write is guaranteed to supersede the earlier write.

Source: https://www.slideshare.net/springerw/eventually-consistent

Read-Your-Write Consistency

(FIFO)



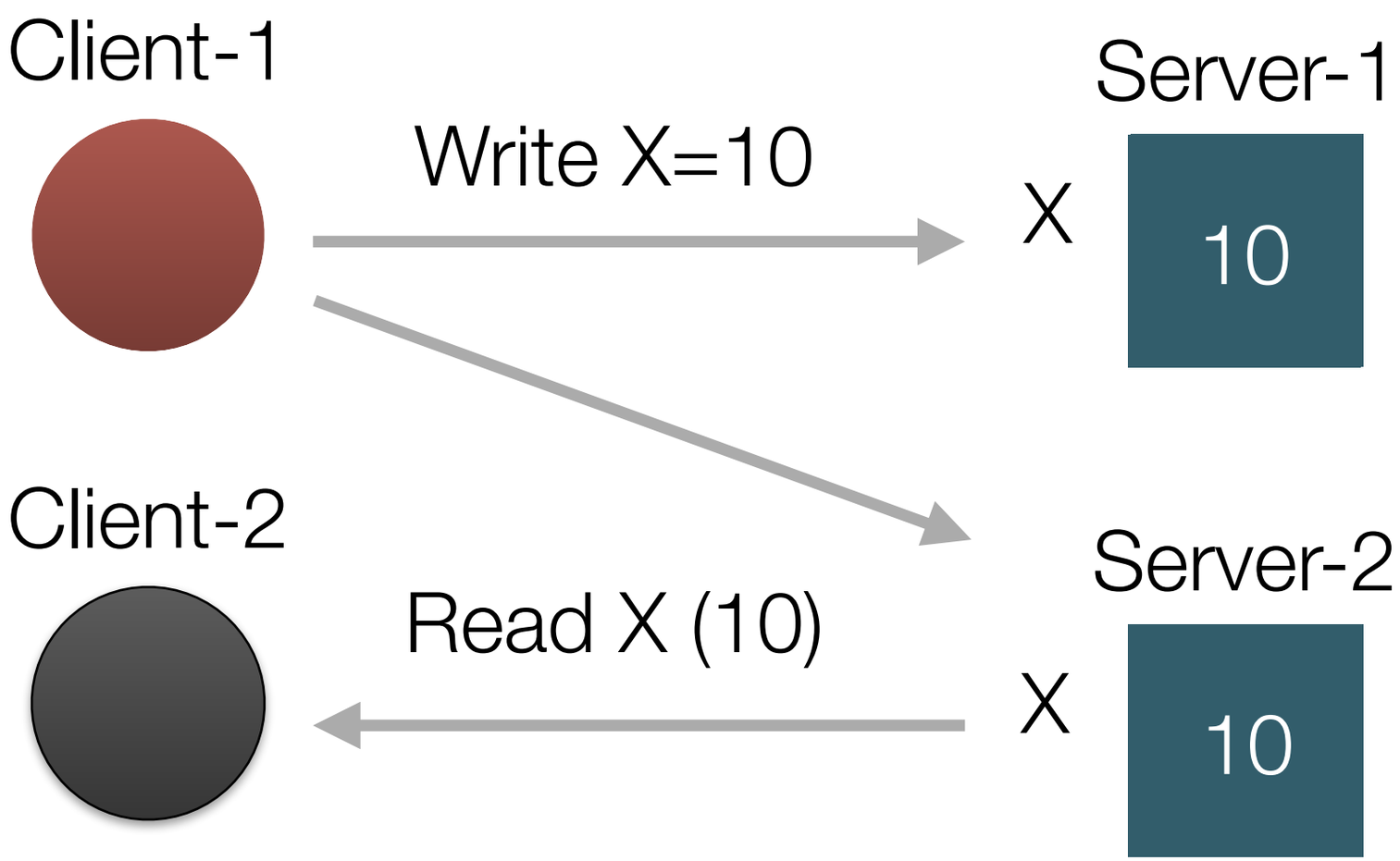
Process A, after updating a data item always access the updated value and never sees an older value

Source: https://www.slideshare.net/springerw/eventually-consistent

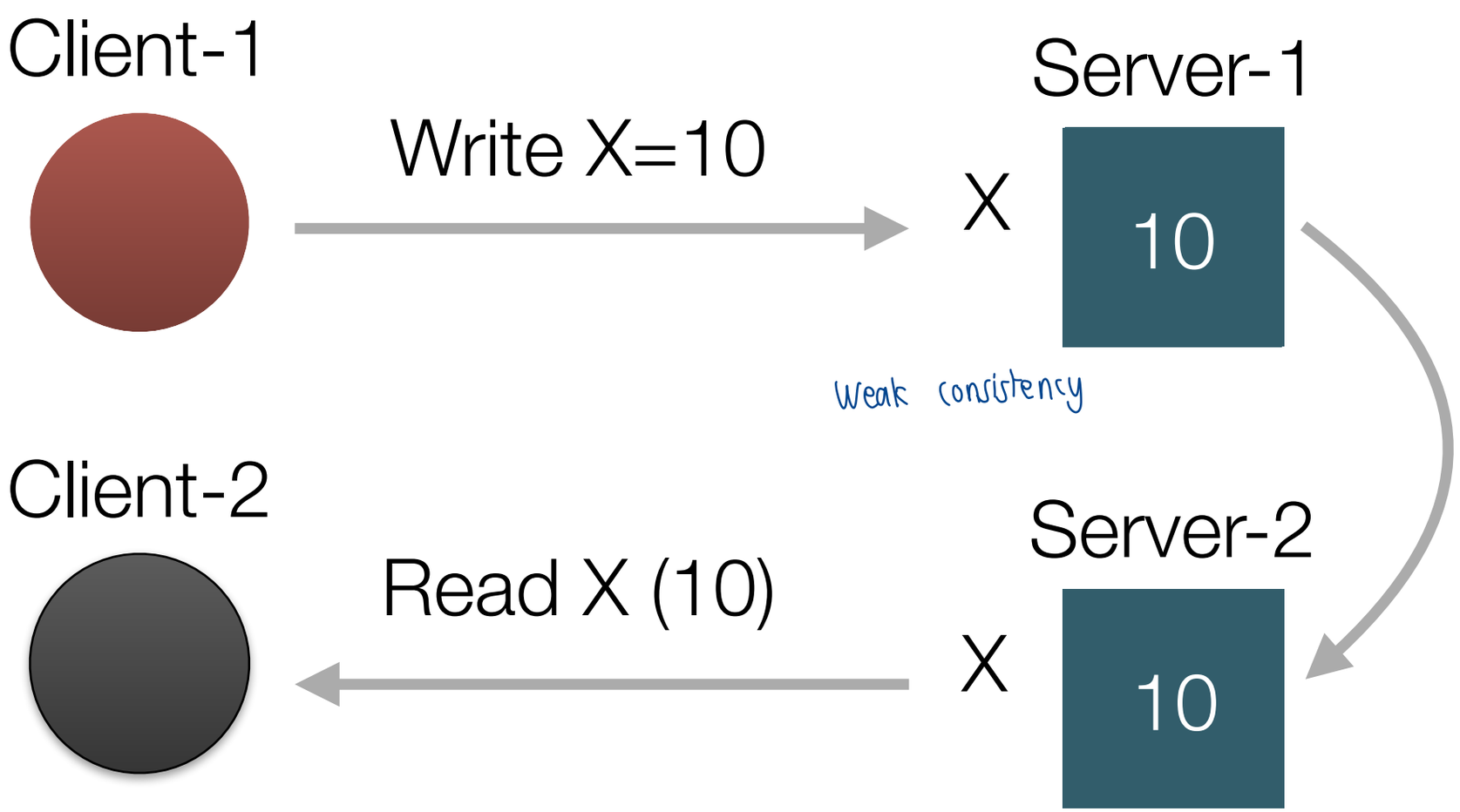
Providing Server-Side Consistency

- Read-only = no synchronization (HDFS)
- Handle consistency
  - Read and Write from multiple servers
    - Strong consistency (R + W > N)
      - Limit number of replications, limit synchronization time
    - Eventual data consistency (R + W < N)
      - Let it inconsistent and resolve it later

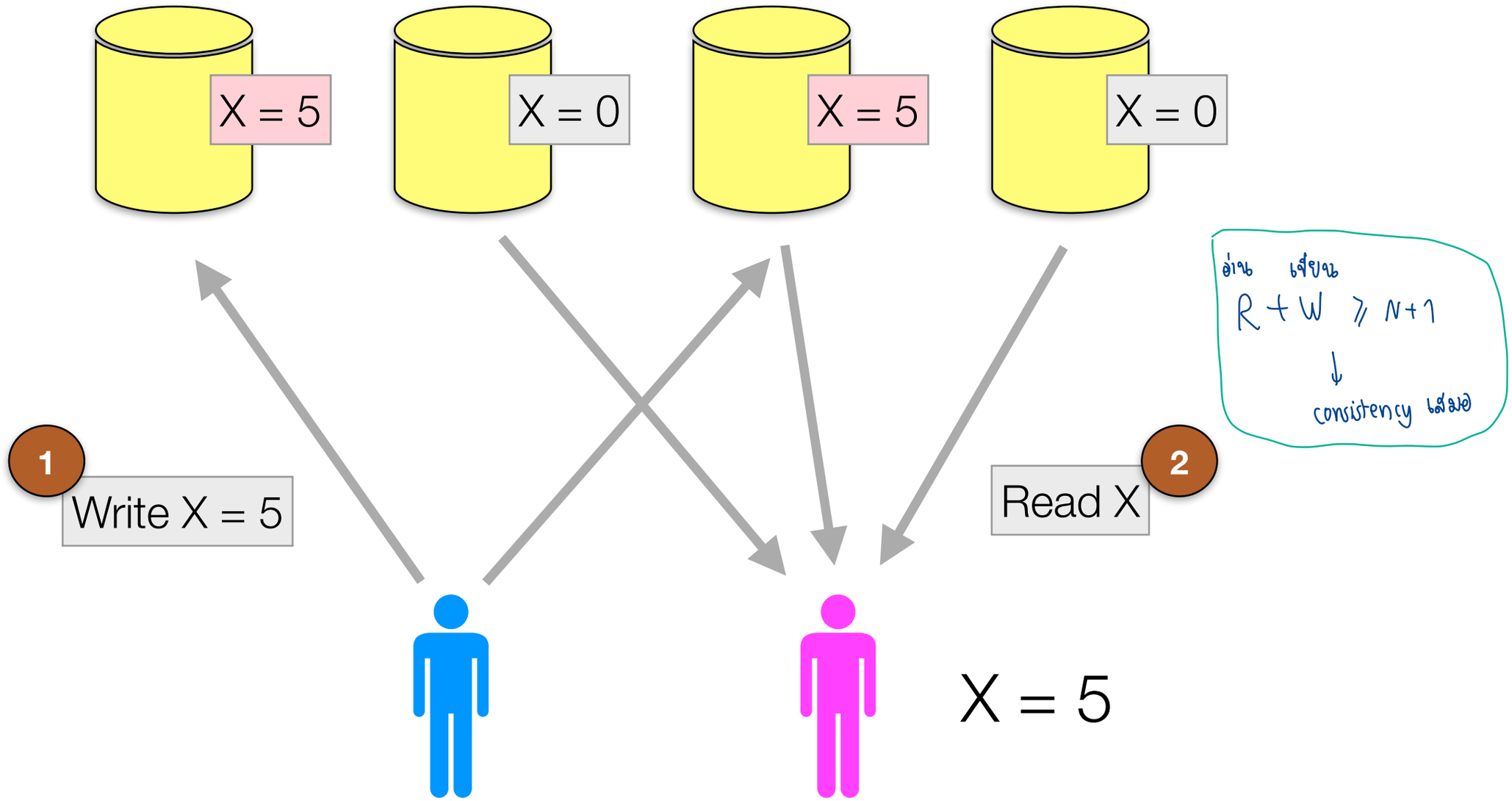
Providing Strong Consistency - Active Replication (W = N, R = 1, R+W > N)



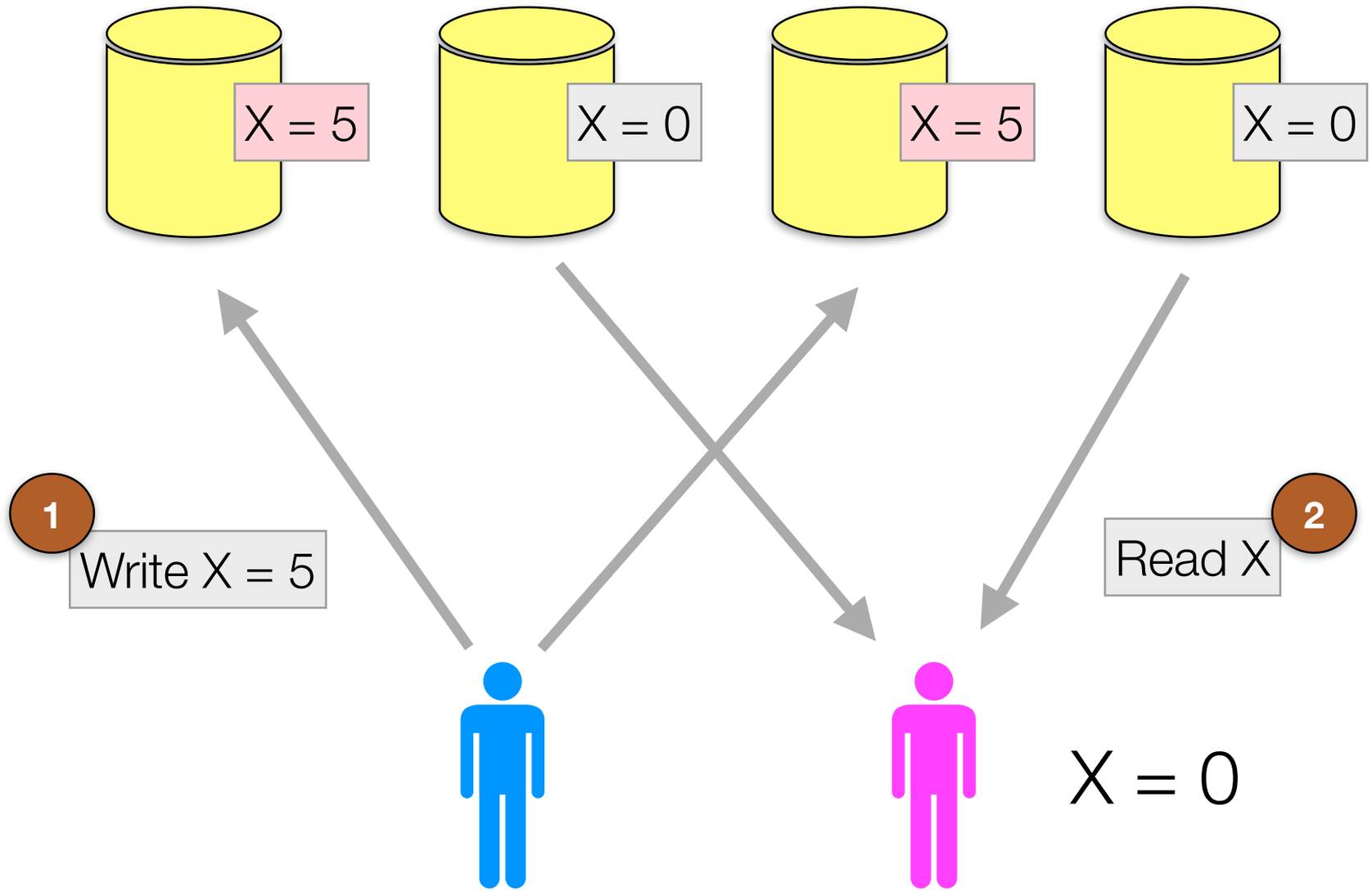
Providing Weak Consistency - Passive Replication (W = 1, R = 1, R+W <= N)



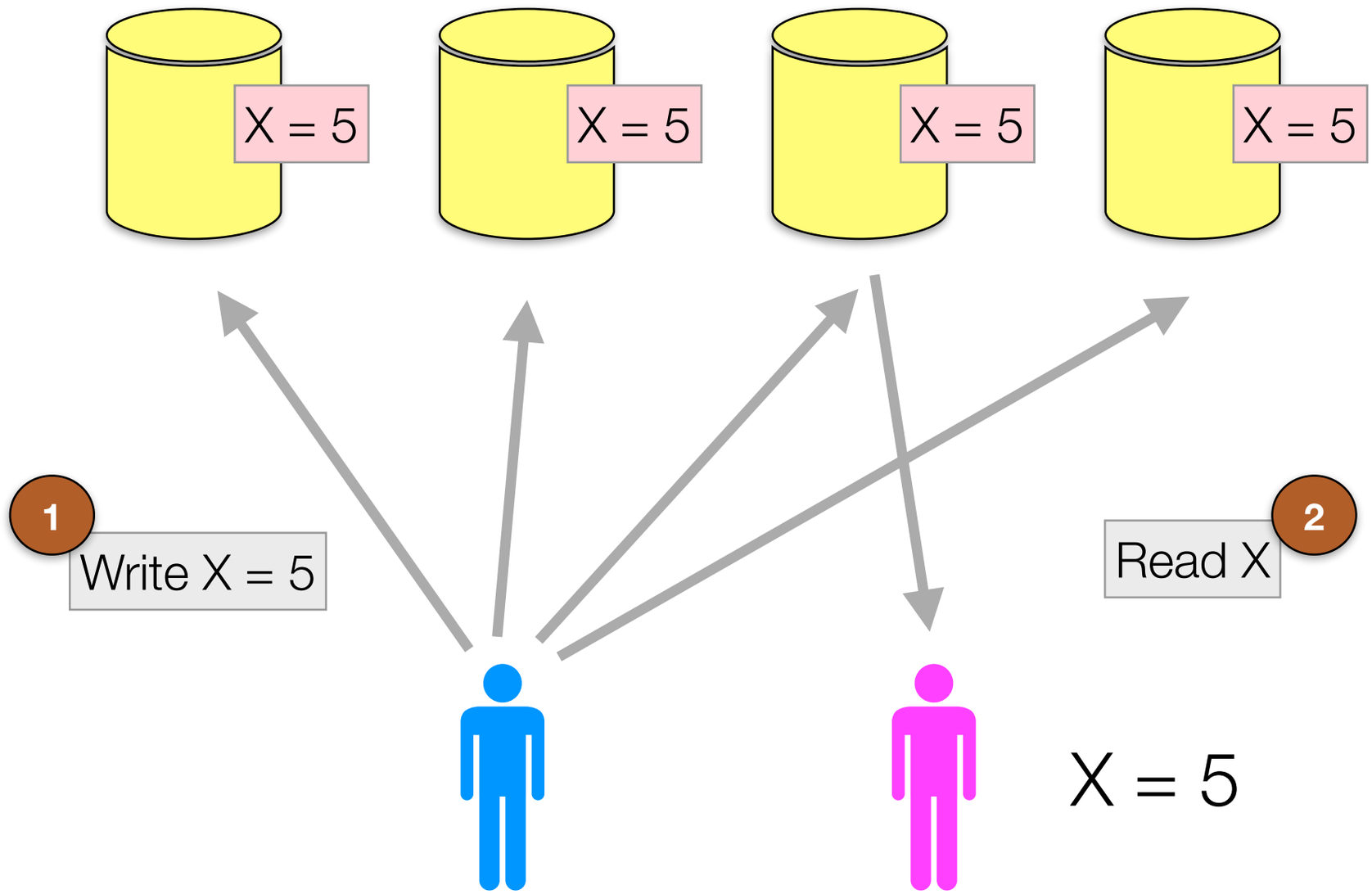
Consistency and Latency Trade-off
N = 4, R = 3, W = 2 (Consistency Guaranteed)



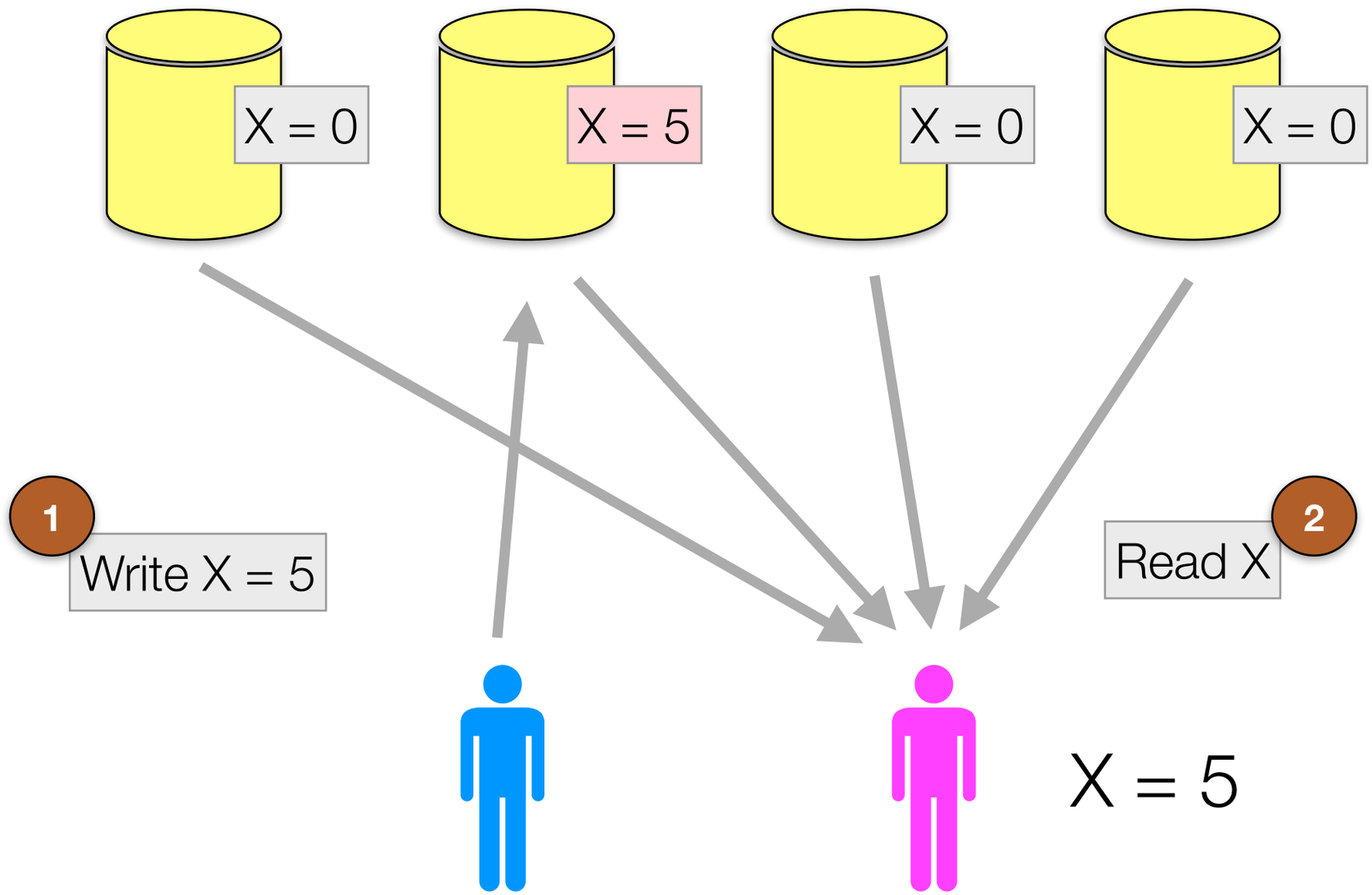
Consistency and Latency Trade-off
N = 4, R = 2, W = 2 (Consistency not Guaranteed)



Consistency and Latency Trade-off
N = 4, R = 1, W = 4 (Fast Read, Slow Write)



Consistency and Latency Trade-off
N = 4, R = 4, W = 1 (Fast Write, Slow Read)



References

- V. Joshi, “Ordering Distributed Events”, https://medium.com/baseds/ordering-distributed-events-29c1dd9d1eff

- W. Vogels, "Eventually consistent”, Communications of the ACM, Vol. 52, pp. 40–44, 2009.

- W. Springer, "Eventually consistent”, https://www.slideshare.net/springerw/eventually-consistent