CAP Theorem

Big Data Systems

Dr. Rubi Boim

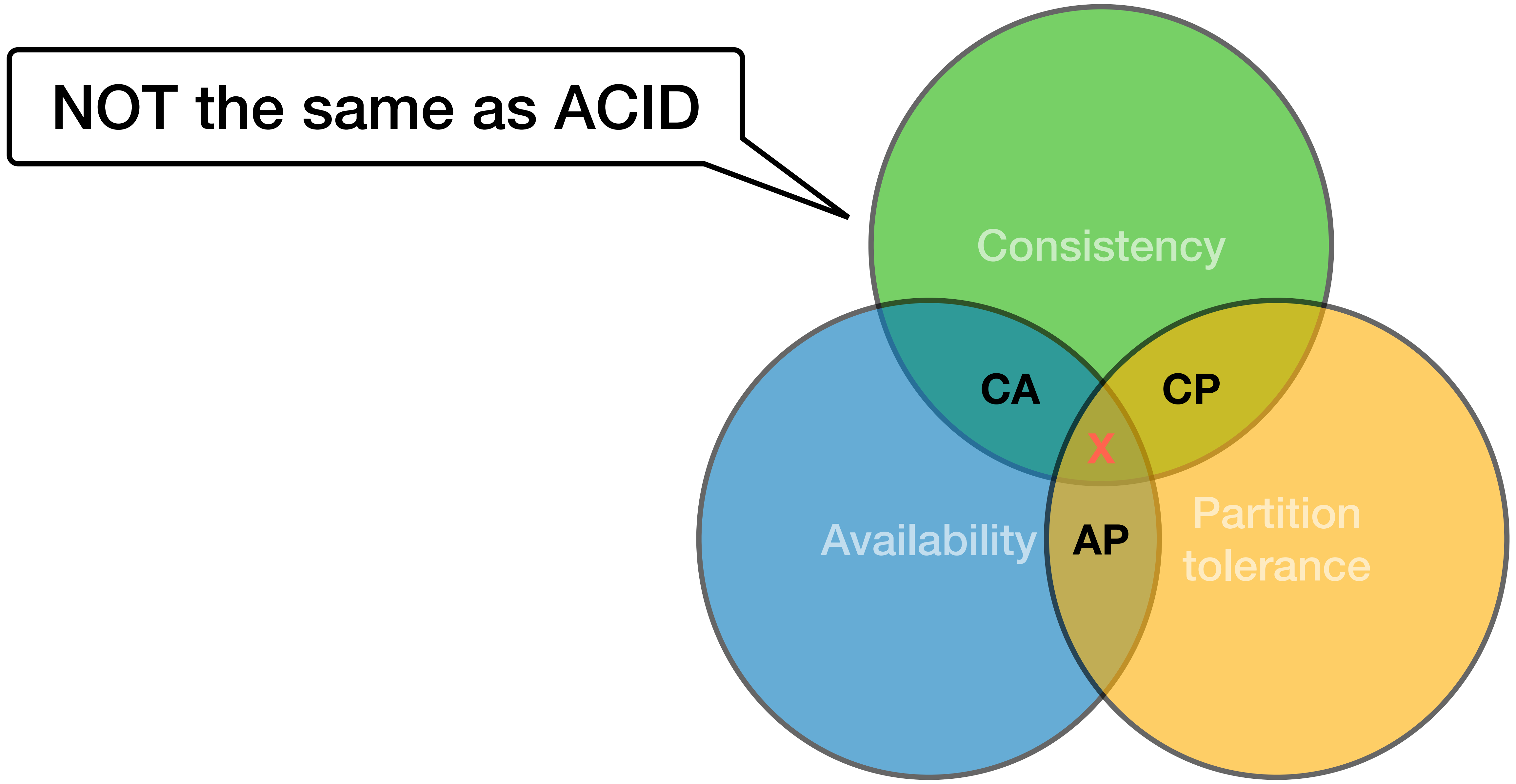
Motivation

We just learn it is “not trivial” to “go distributed”

- Data fragmentation
- Data distribution
- Data replication

- Things get (much) more complicated
- CAP Theorem - “Everything comes with a price”

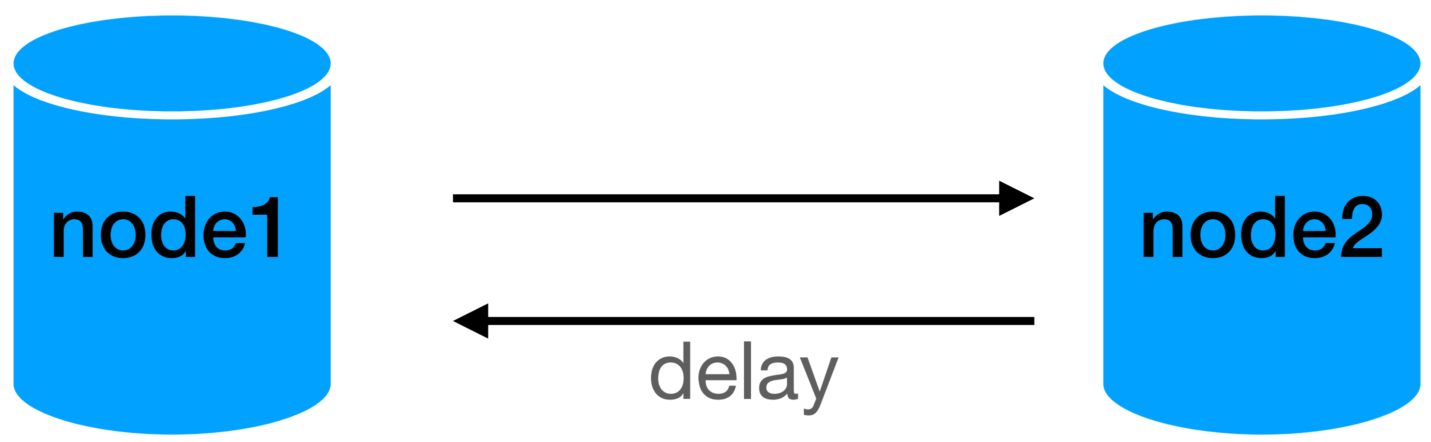
Some terms



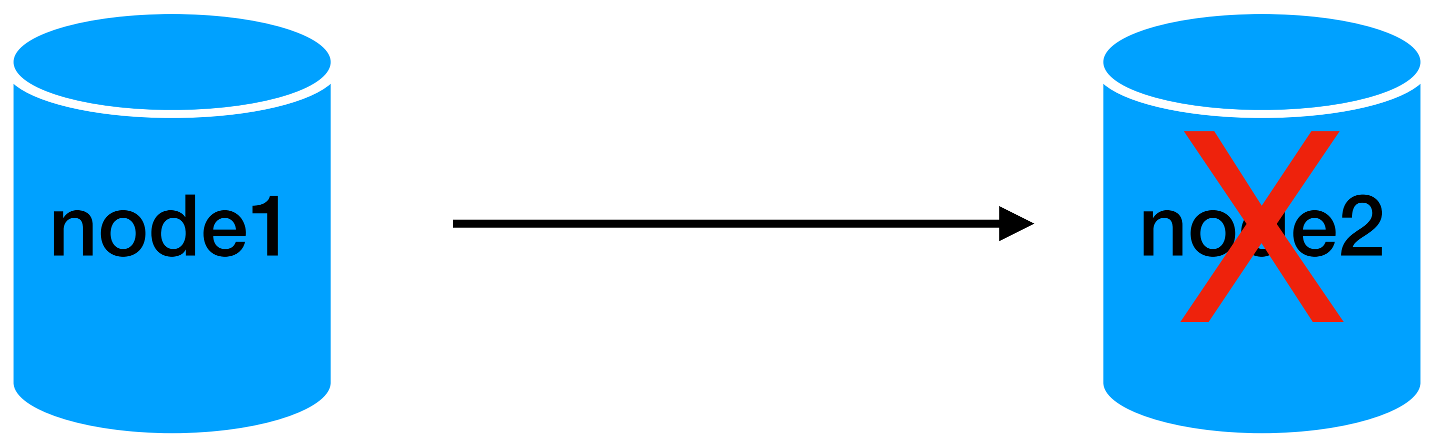
TLDR: You can only satisfy 2 out of 3 in a distributed database

Asynchronous network model

- Messages can be (randomly) delayed



- Can't distinguish between failed nodes and delayed messages in a finite amount of time



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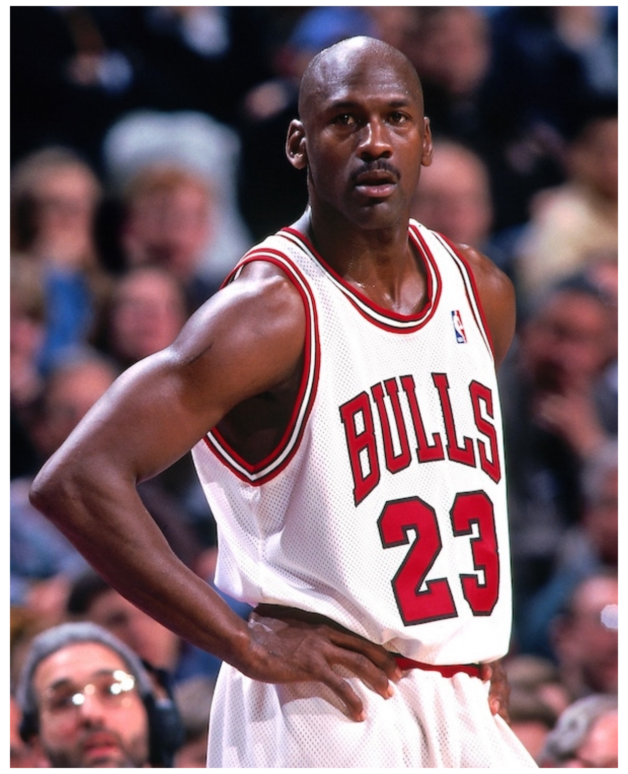
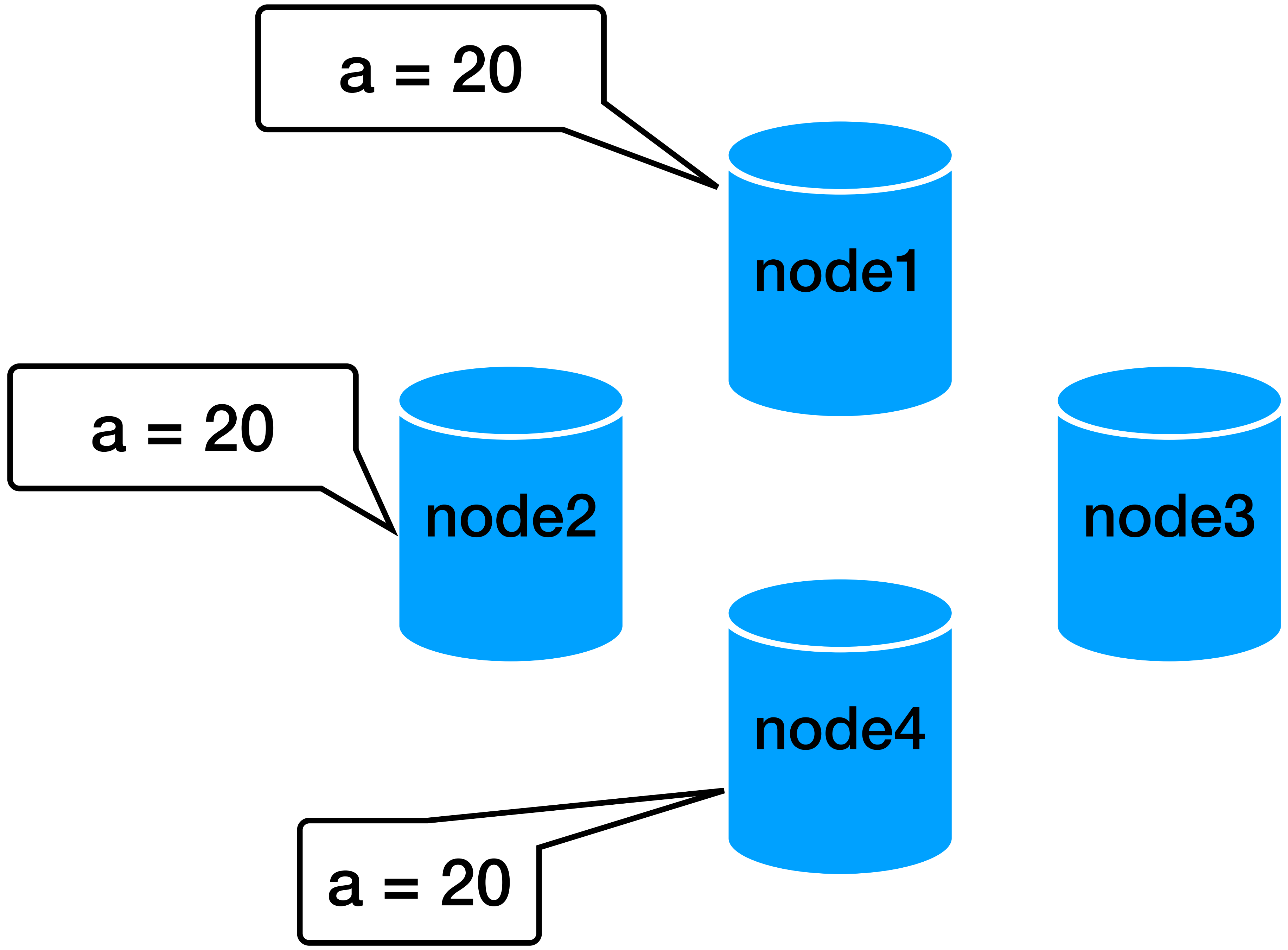


10:00: a = 20

* example for inconsistency



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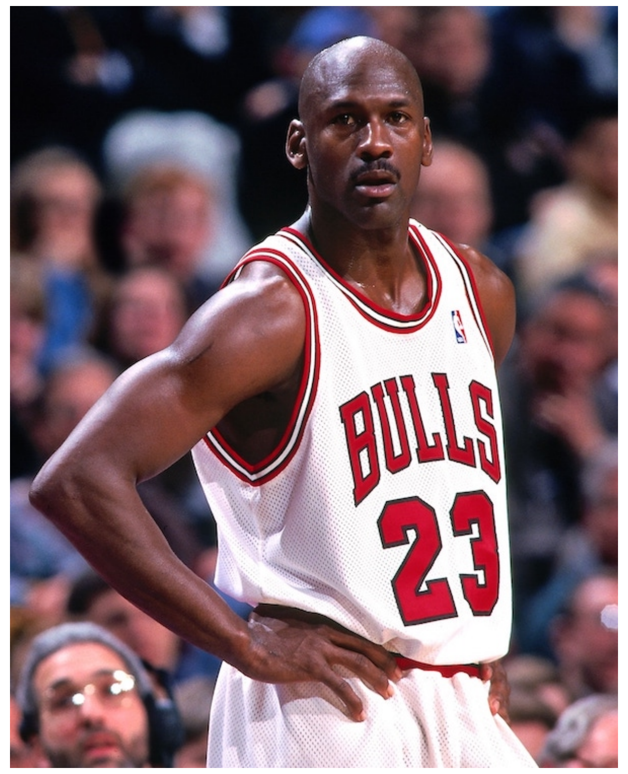

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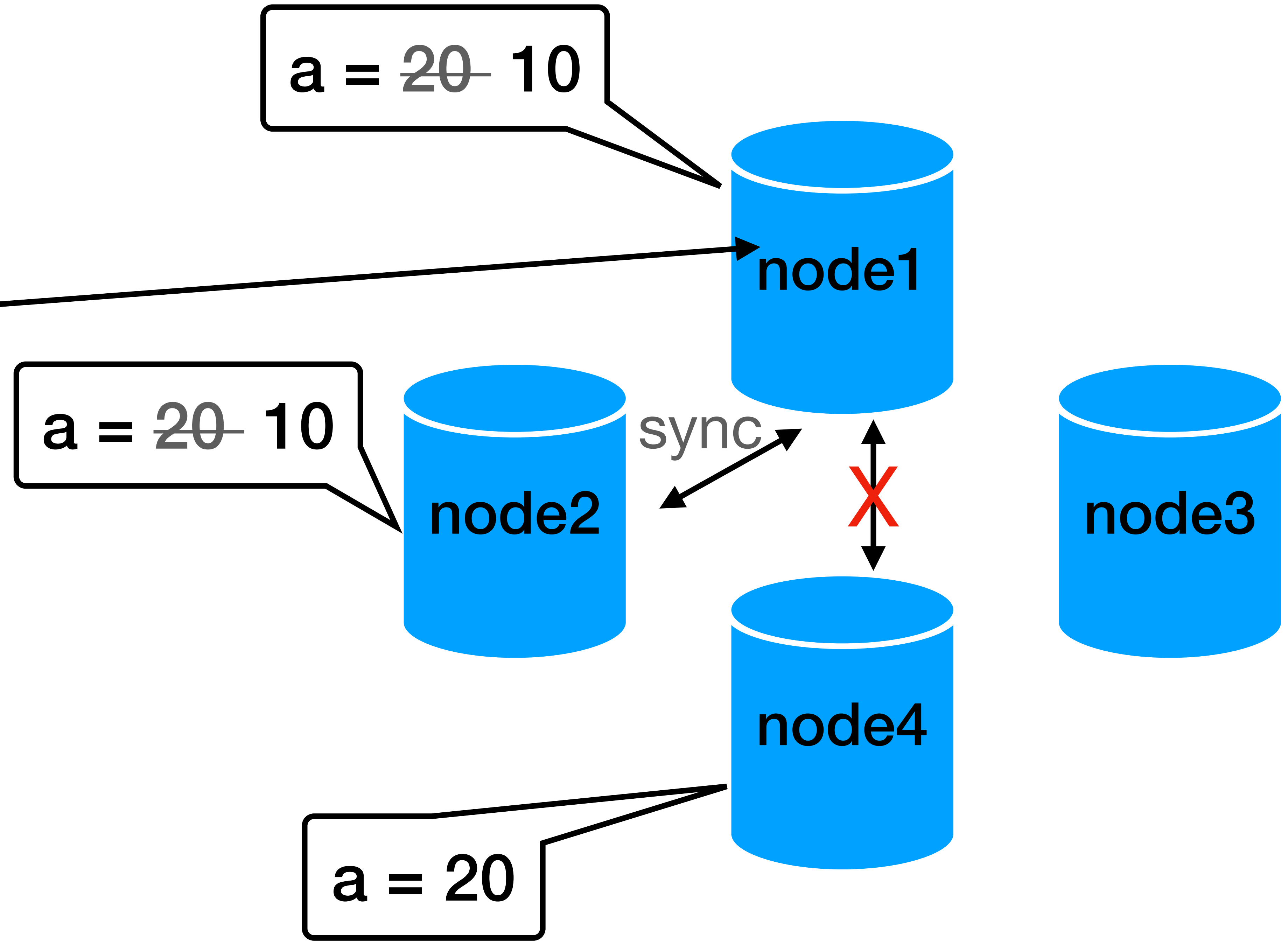

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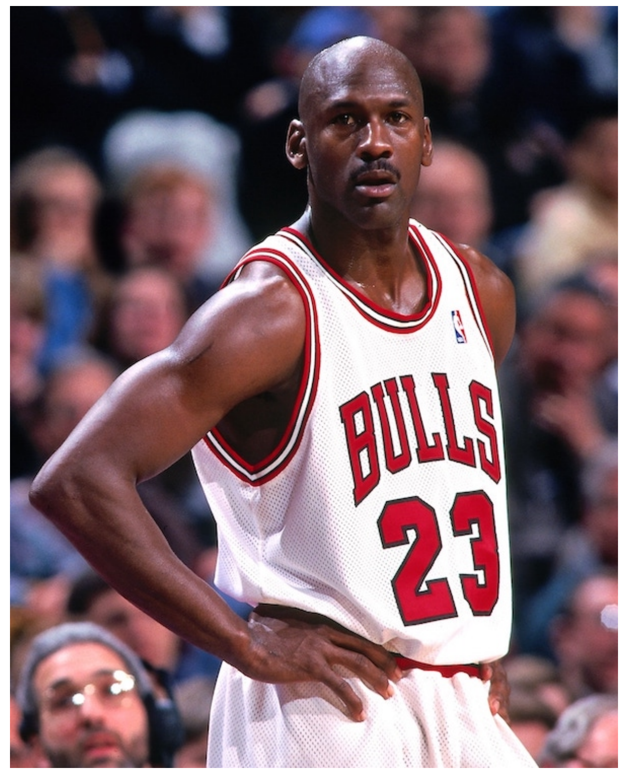

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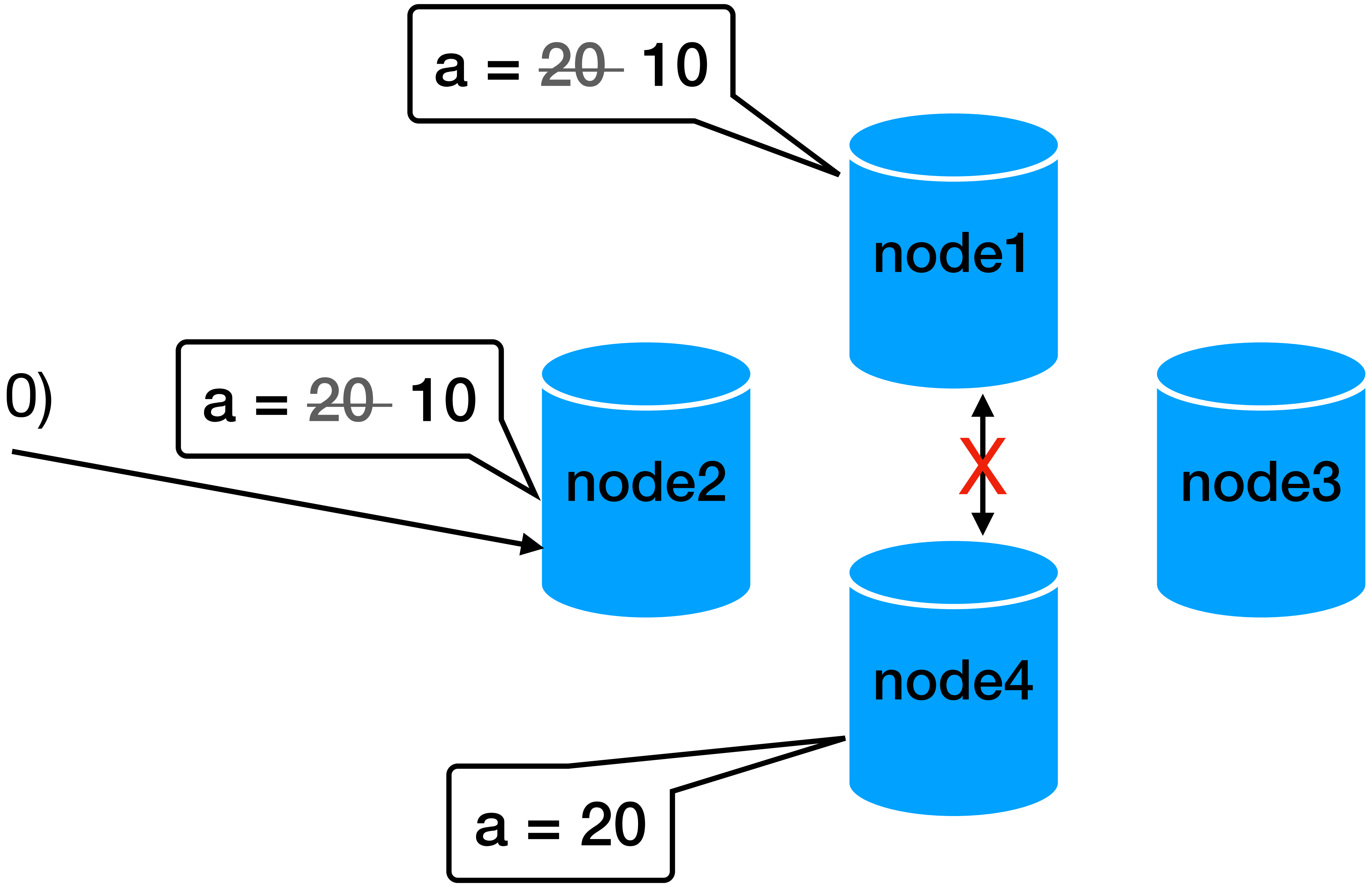

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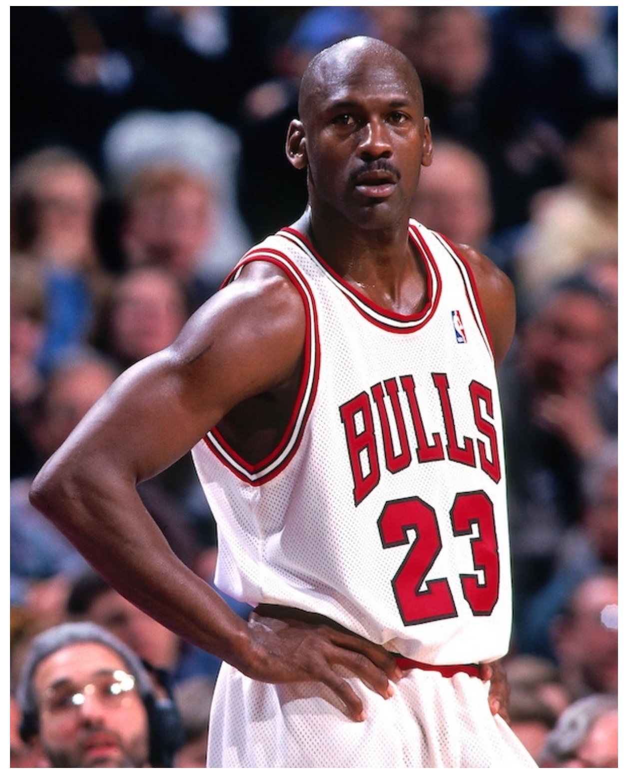

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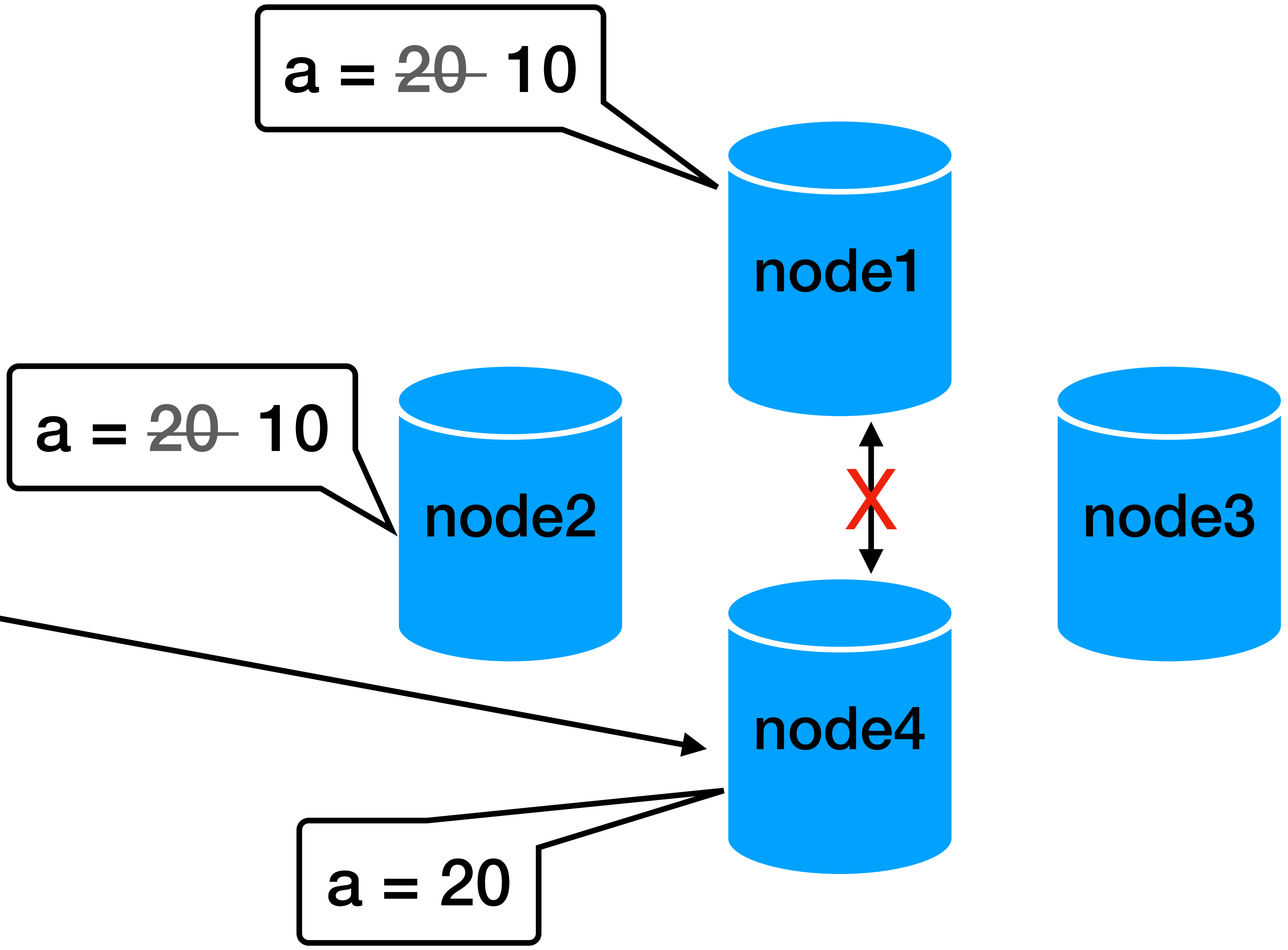

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Consistency warning

Do not get confused with consistency from ACID

- **A**tomicity
- **C**onsistency
  correctness / referential integrity (foreign key)
- **I**solation
- **D**urability

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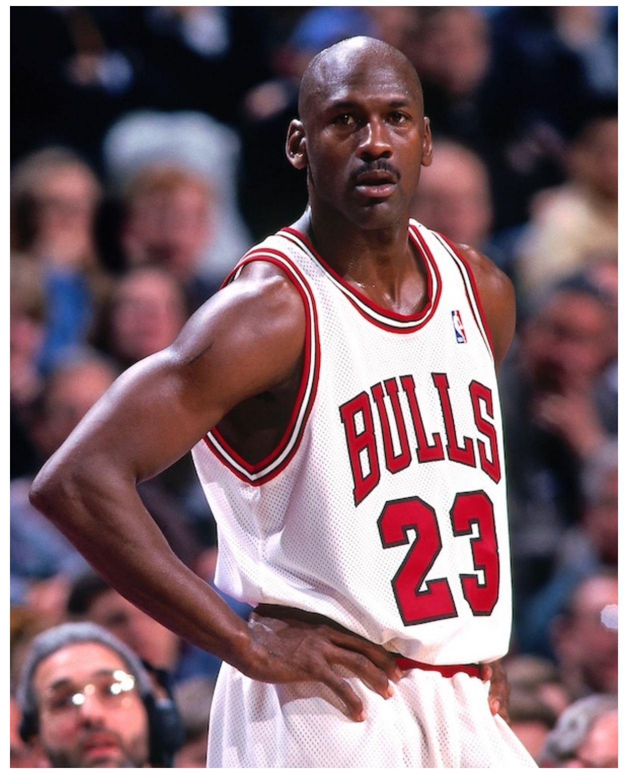

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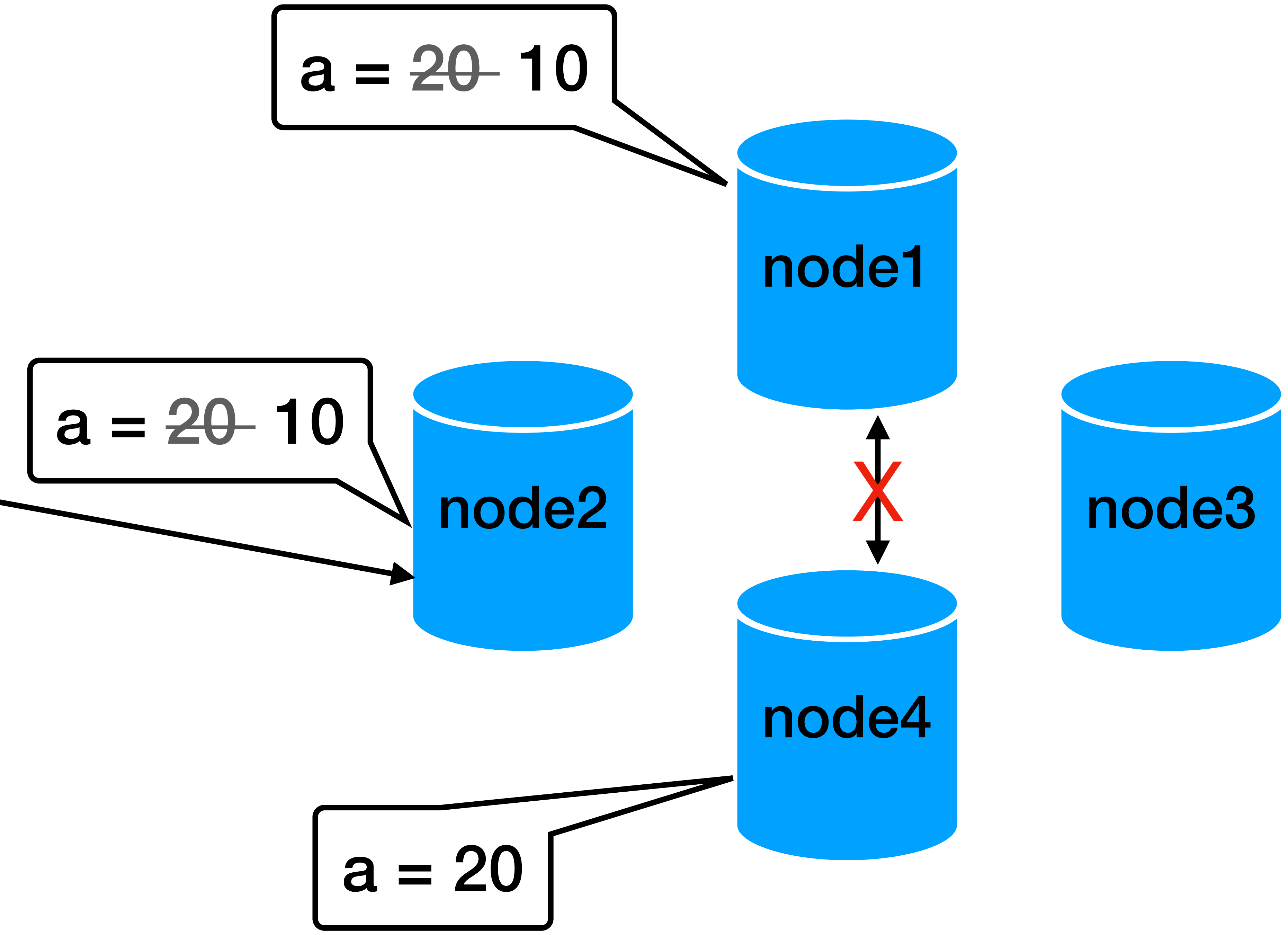

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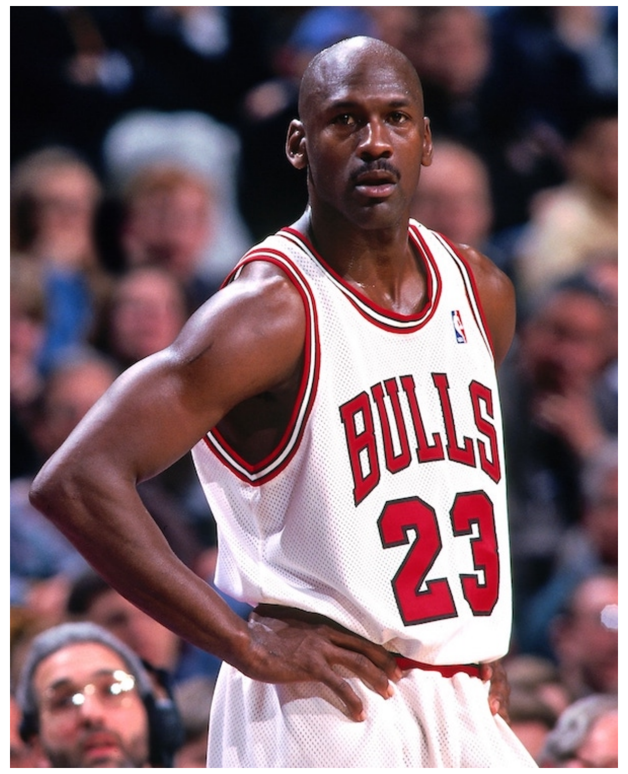

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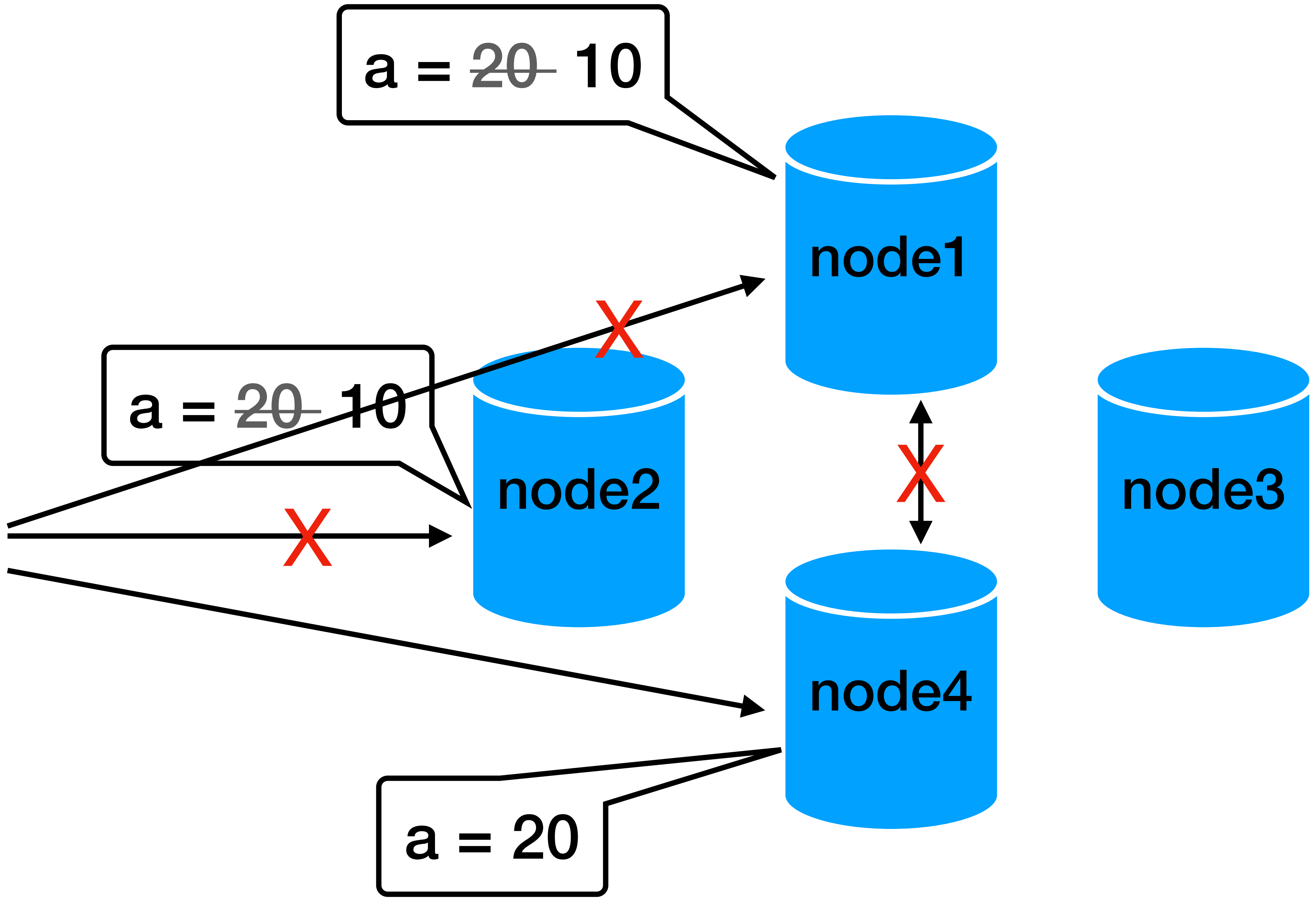

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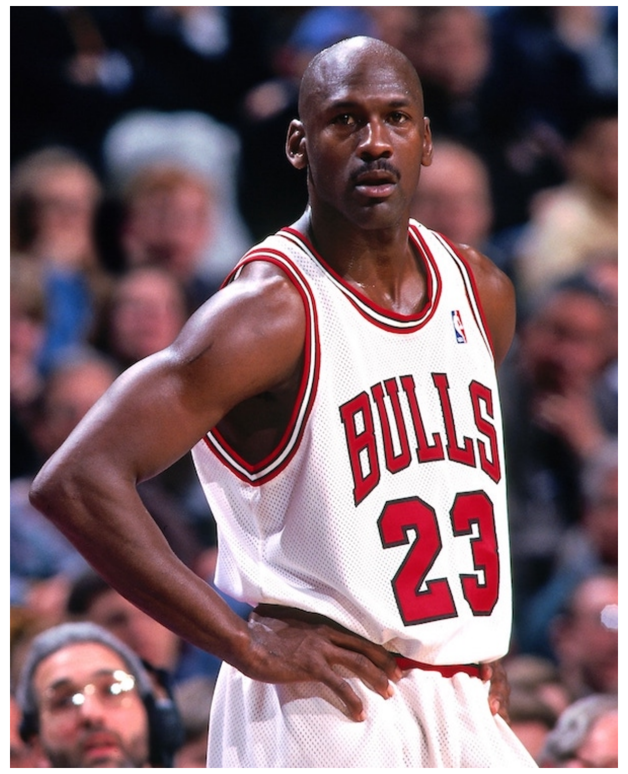
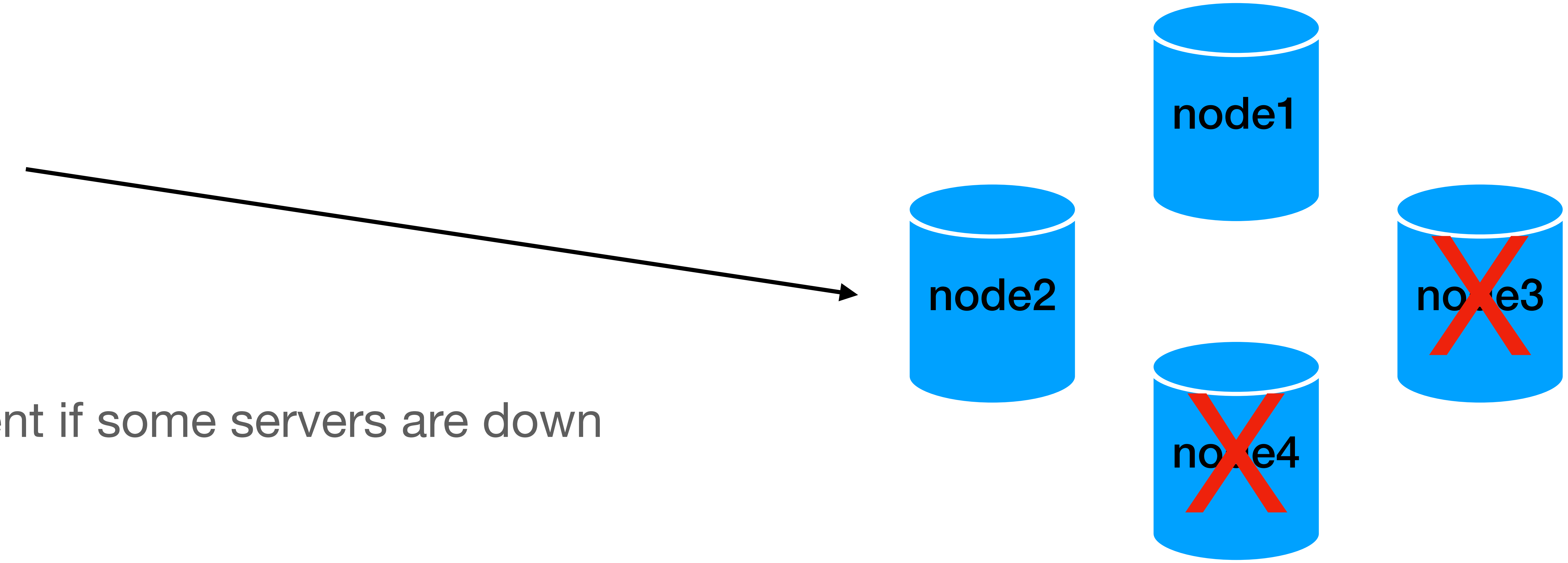




* success call event if some servers are down

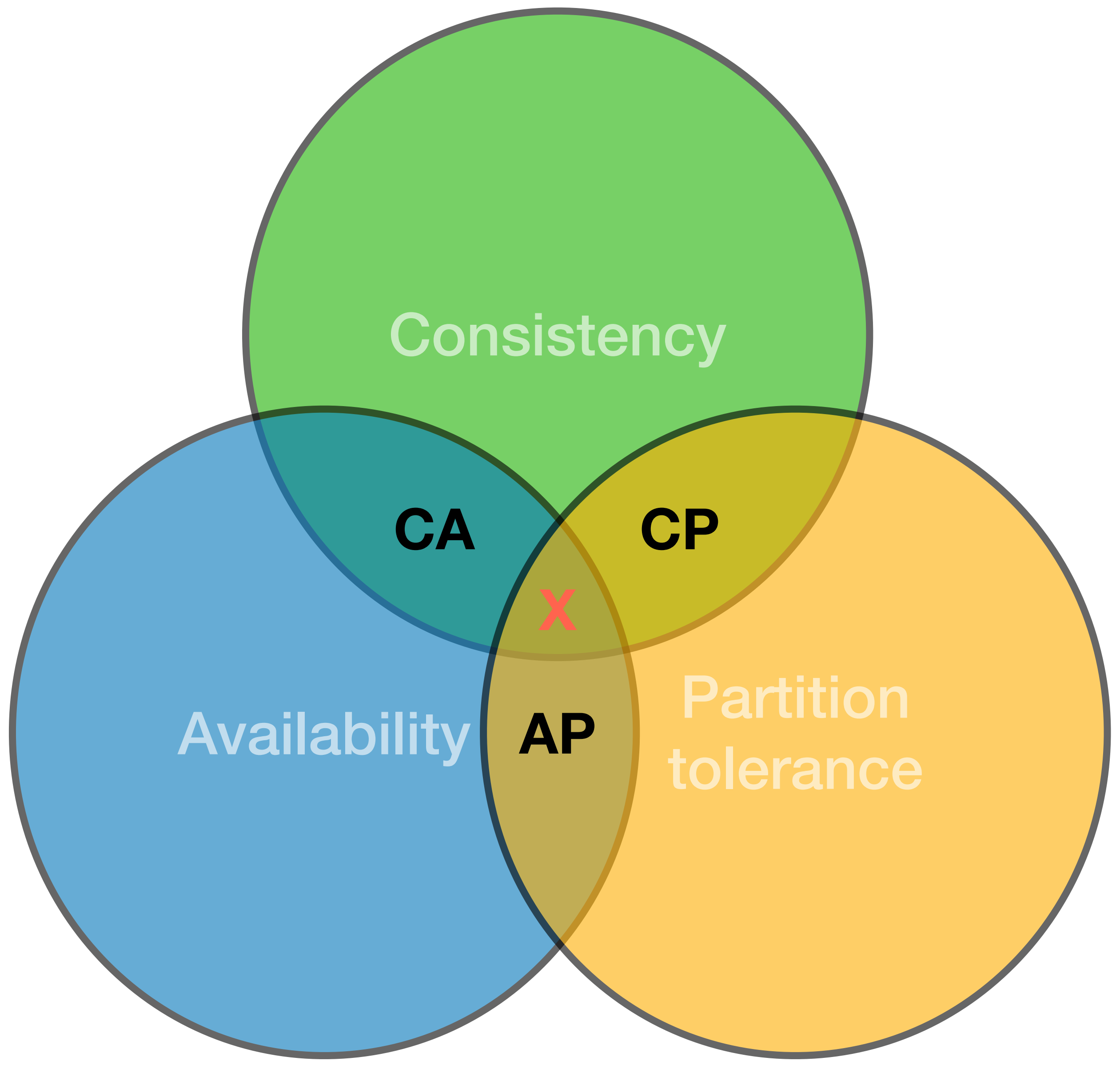
CAP Theorem

- For distributed data, it is impossible to satisfy more than two out of the three

- Consistency
  Every read receives the most recent write or an error

- Availability
  Every request receives a (non-error) response,
  without the guarantee that it contains the most recent write

- Partition tolerance
  The system continues to operate despite an arbitrary number of messages being dropped (or delayed) by the network



CAP Theorem - in practice

No distributed system is safe from network failures.
—> we need to choose between CP and AP

In practice - If a node is down/unreachable we can:

- cancel the operation (CP)
- Return result with (maybe) inconsistency (AP)

CAP Theorem - why is it important?

- No free lunch for distributed systems

- This will be (among other stuff) a differentiator between different types of distributed databases and NoSQL systems
(not just how to model data, but how to write)

A bit more on Consistency

Consistency types

- Weak / Eventual consistency
  If we stop updating, the system will eventually be consistent

- Strong consistency
  consistent on all calls

Consistency types - different views

- From developer / application side
  how they observe updates?
  how it affects the application logic?

- From server side
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Application side consistency

DNS Server

Which consistency type do we need?

Application side consistency

DNS Server

Weak / Eventual consistency

Application side consistency

Bank

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Strong consistency

Application side consistency

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Note that some “logic” is usually “eventual”

Strong consistency

Now with the CAP

DNS Server

Weak / Eventual consistency

Bank

Strong consistency

Should we prefer consistency or availability support?

Consistency types - different views

- **From developer / application side**
  how they observe updates?
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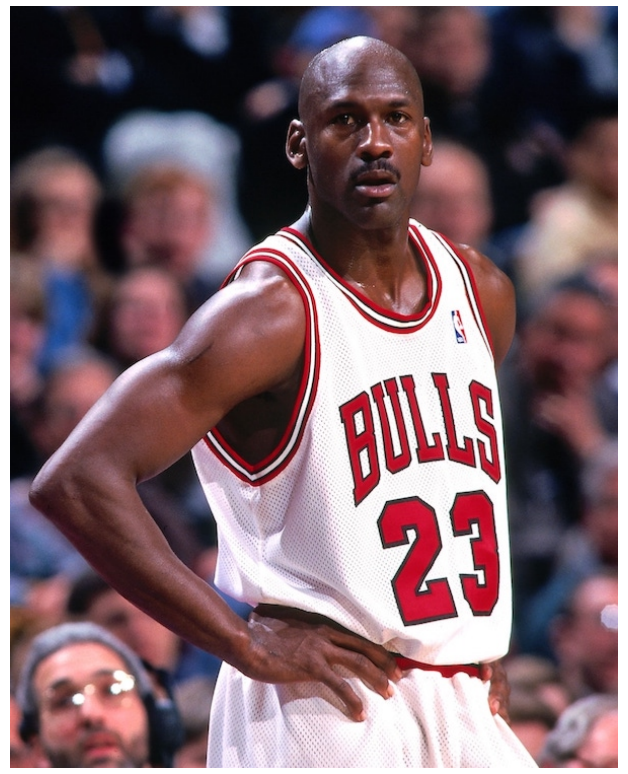
  how can we detect / force consistency?

Discussion

Server side consistency

Discussion - How do we know if we satisfy consistency?
if one, two or more (how much?) are down



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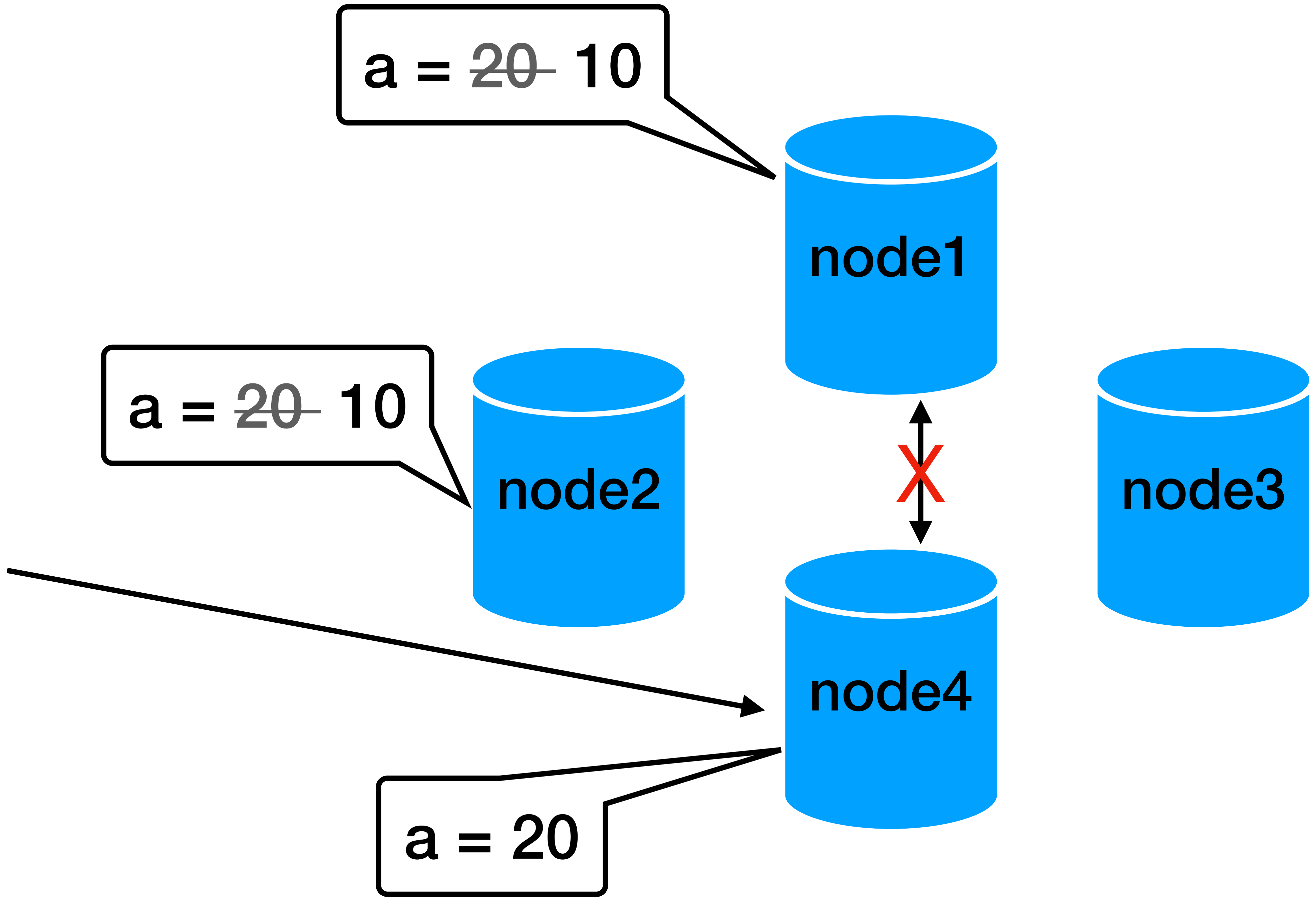


Server side consistency

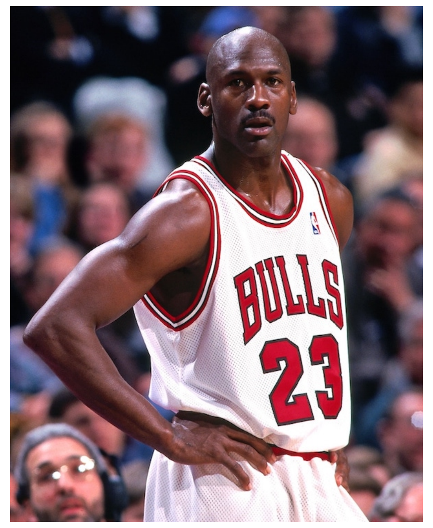
- **N** #nodes that store replicas of the data
- **W** #replicas that need to acknowledge the receipt of the update before the update completes
- **R** #replicas that are contacted for a read

If W+R > N then strong consistency is guaranteed

If W+R <=N then weak / eventual consistency

Server side consistency - example 1

- Master + read replica RDBMS



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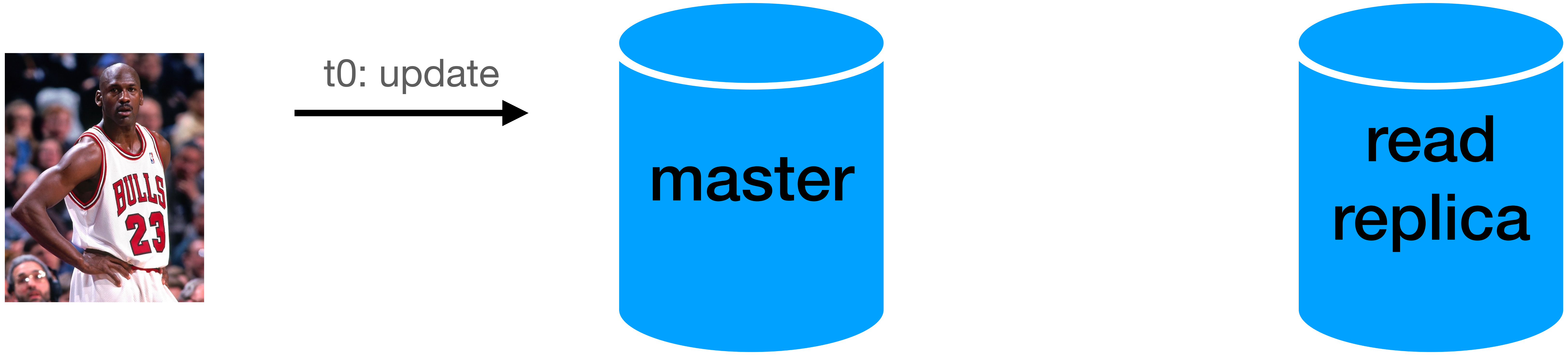

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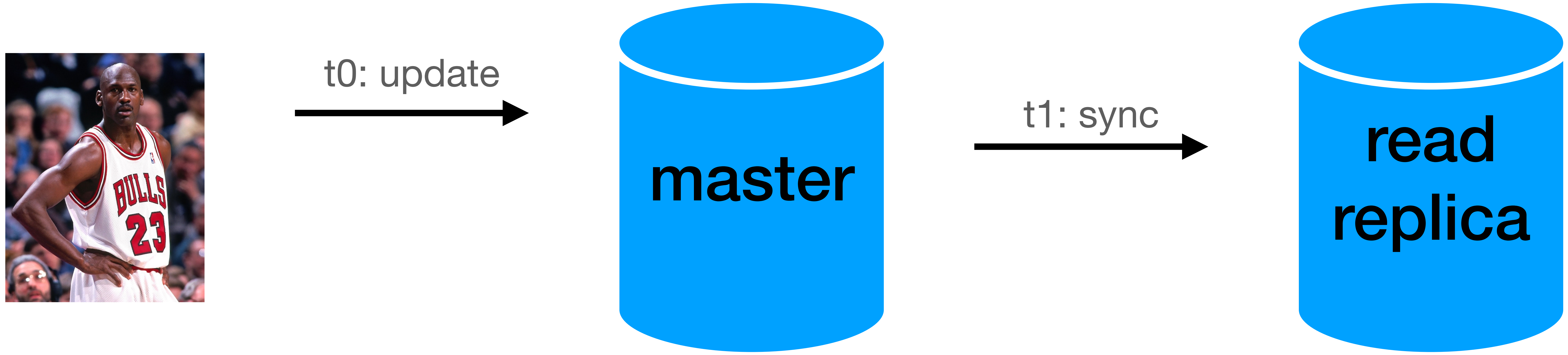

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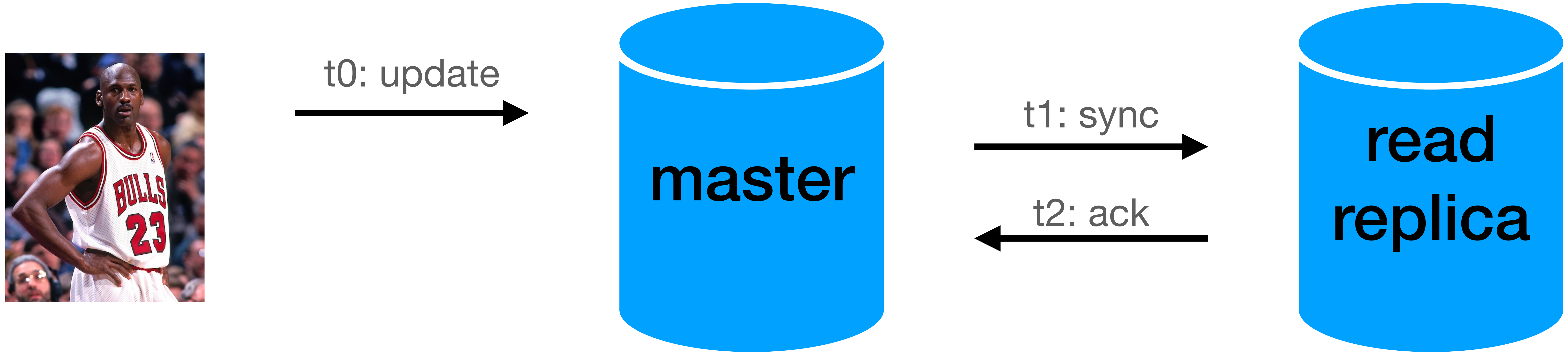

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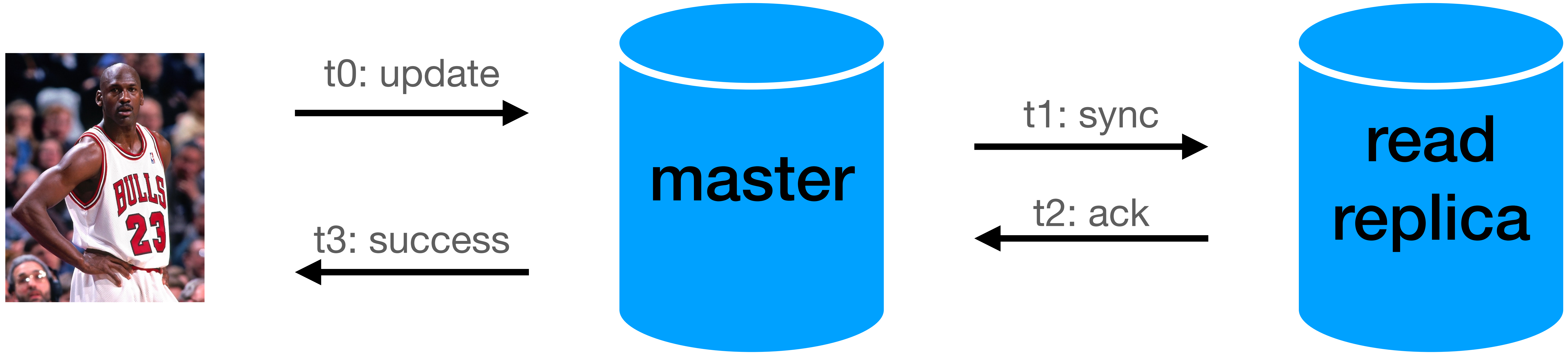

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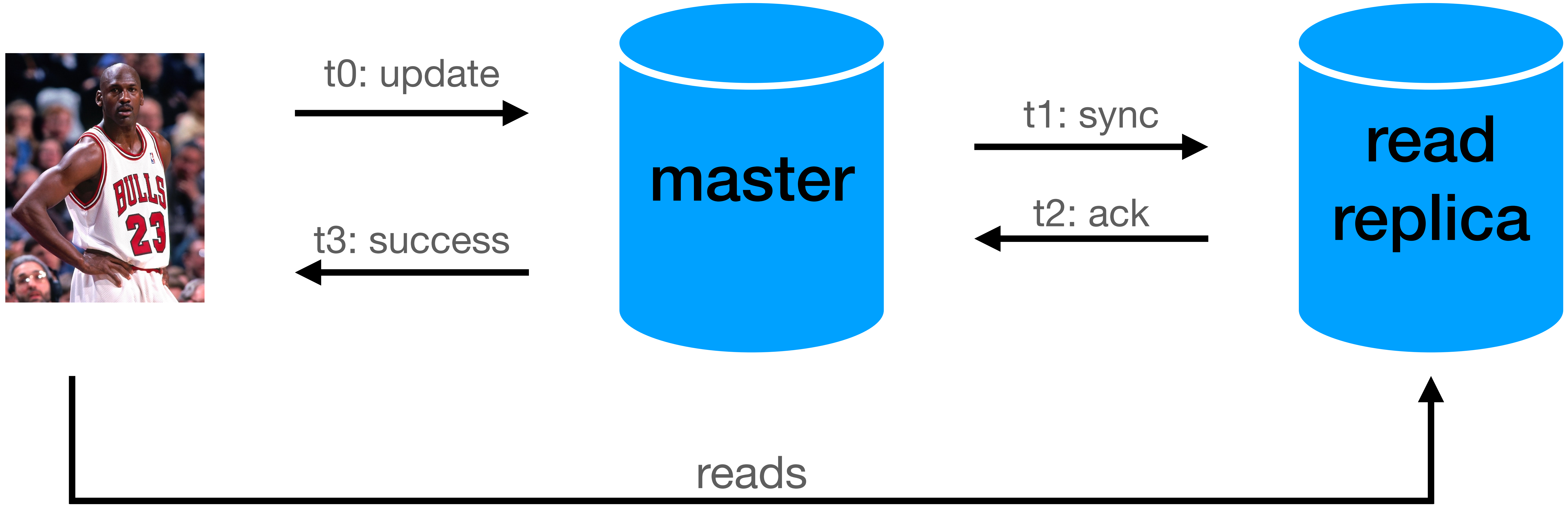

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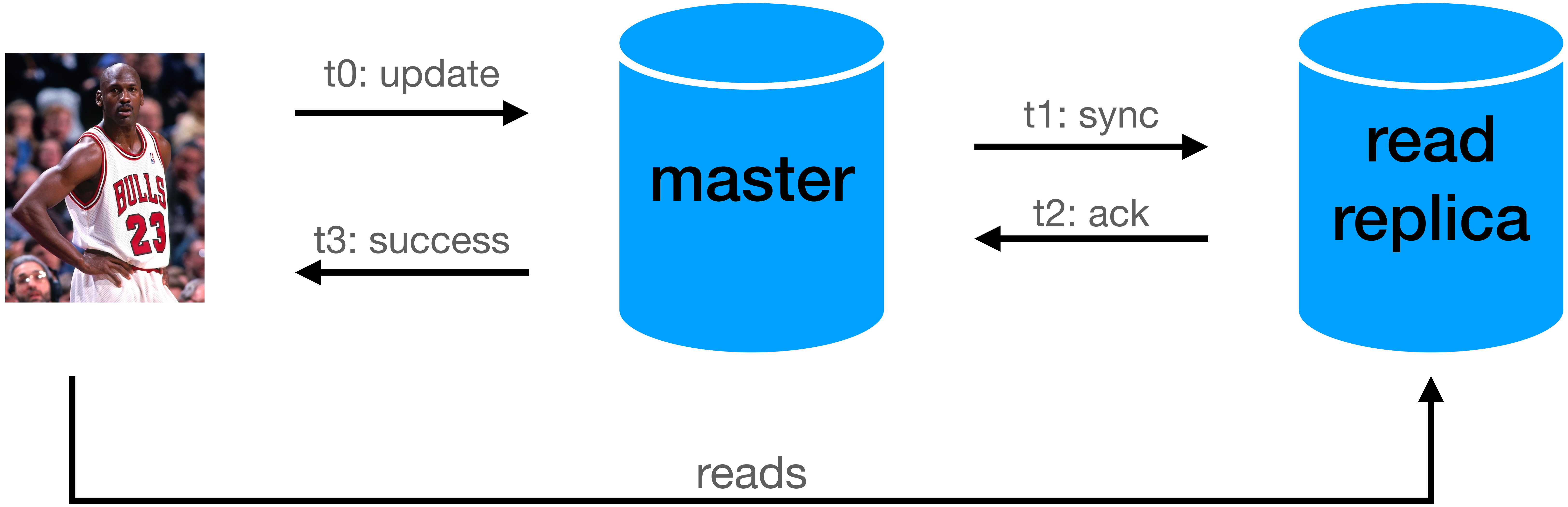

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strong consistency

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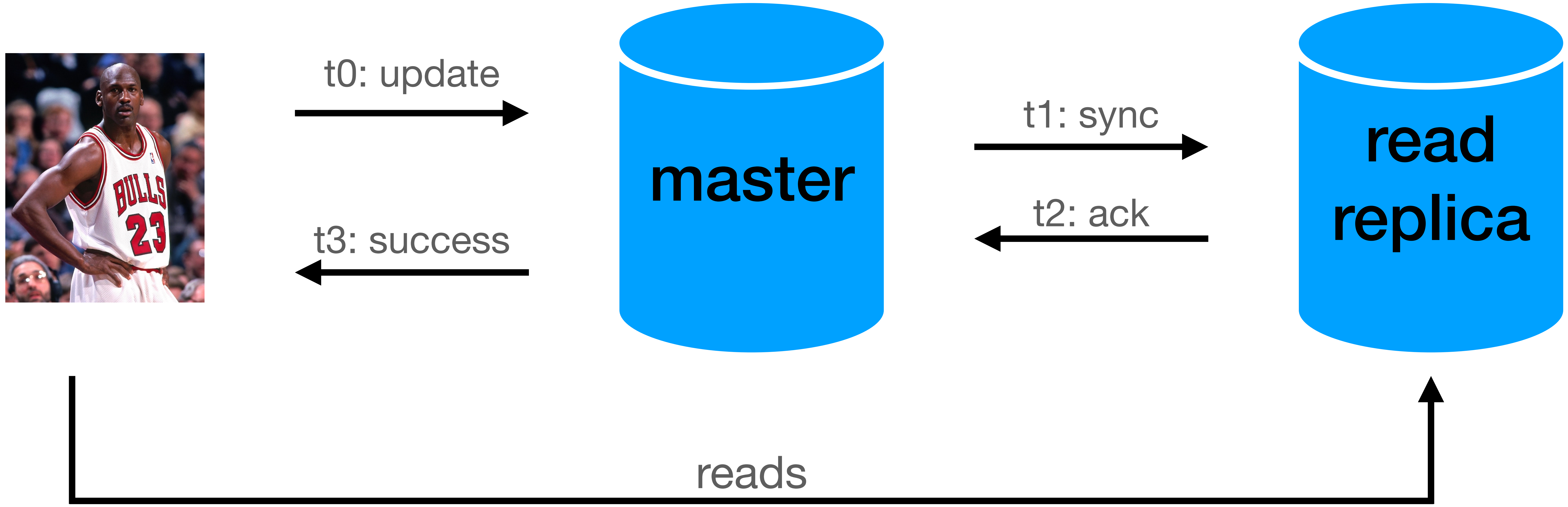

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What happens if the read replica fails?

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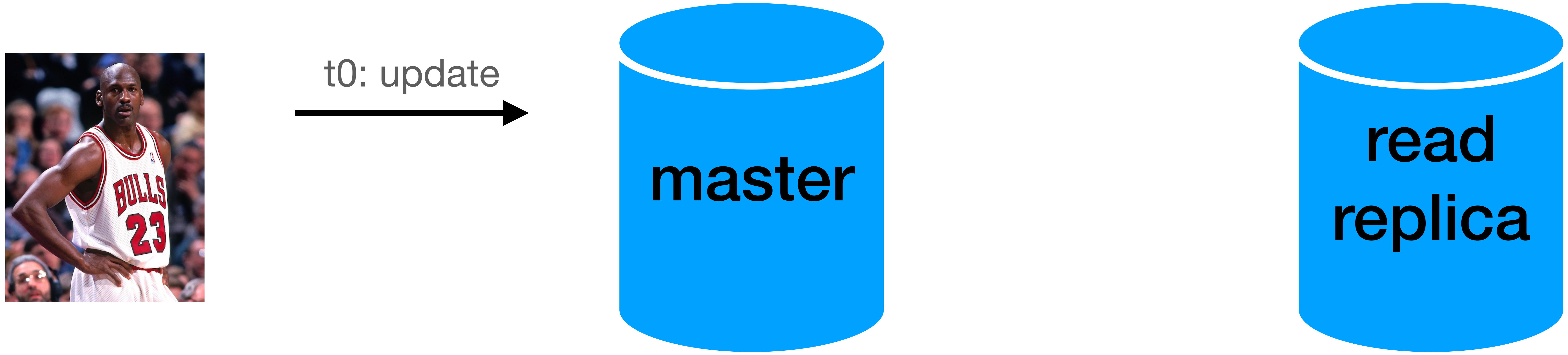

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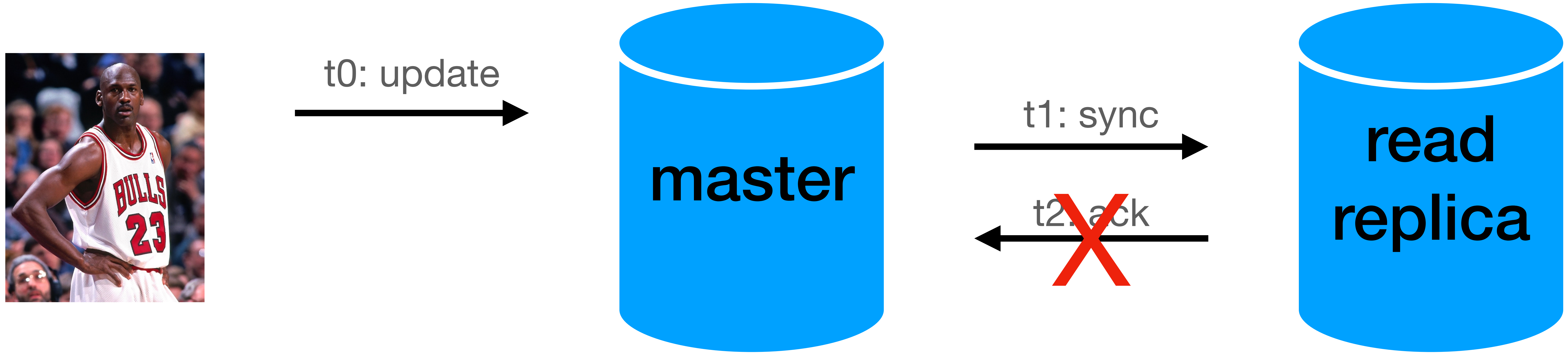

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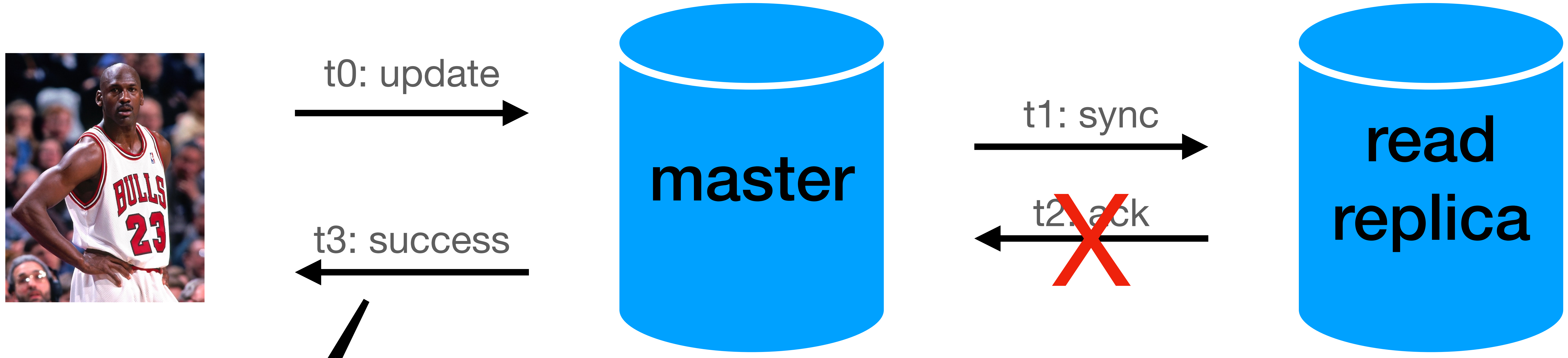

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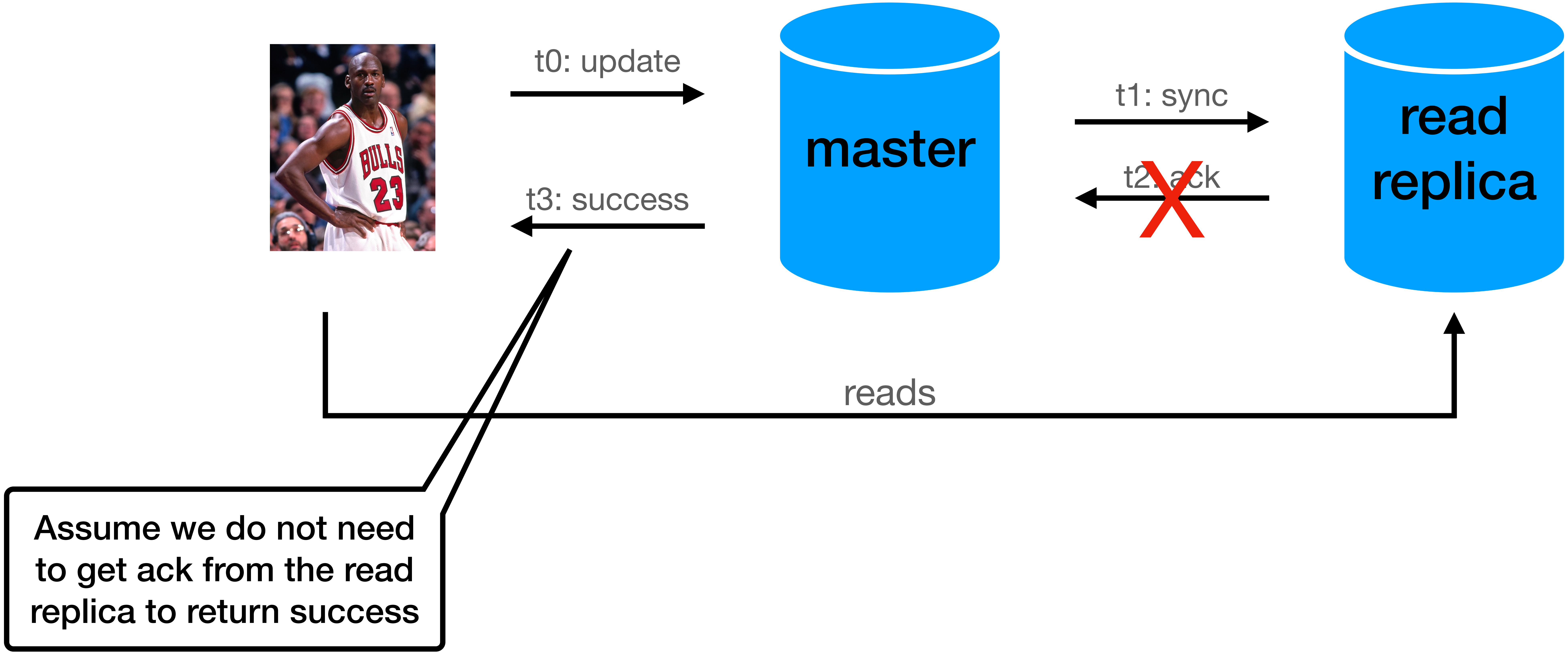

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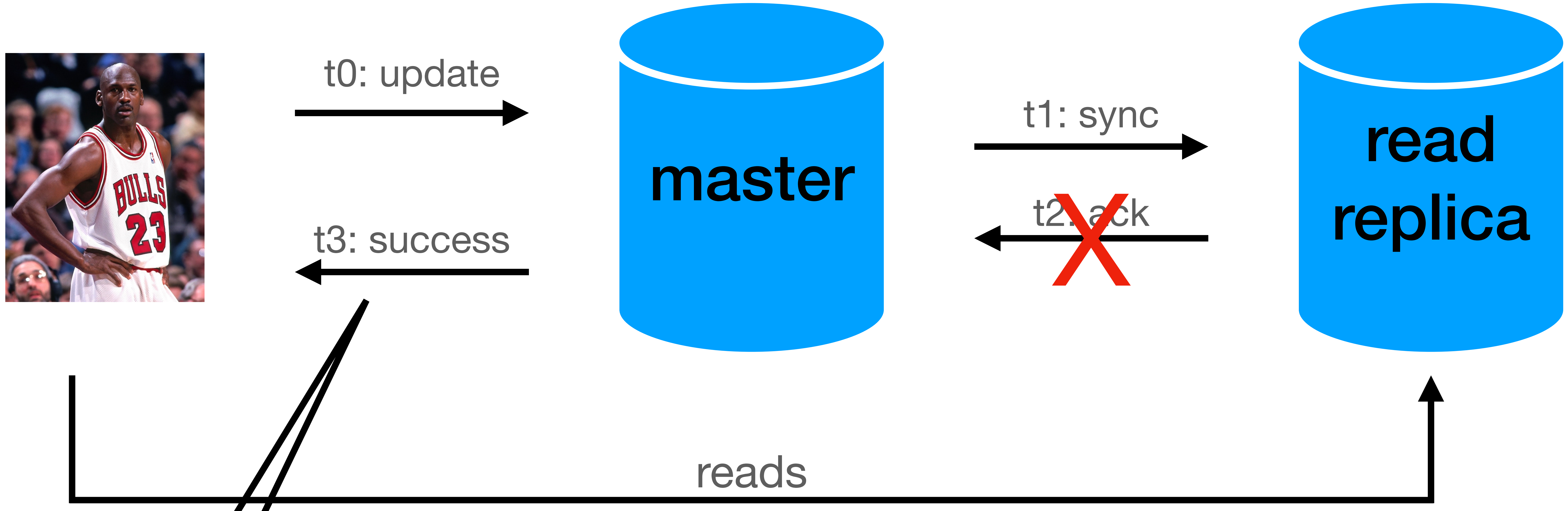

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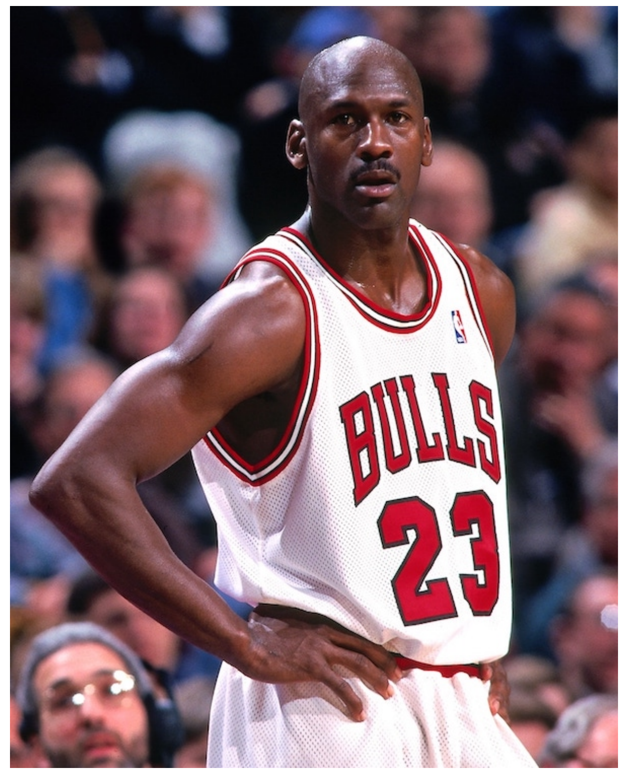
weak / eventual consistency

Server side consistency - example 2

- Distributed database, set to performance (availability)
  updates other nodes asynchronously



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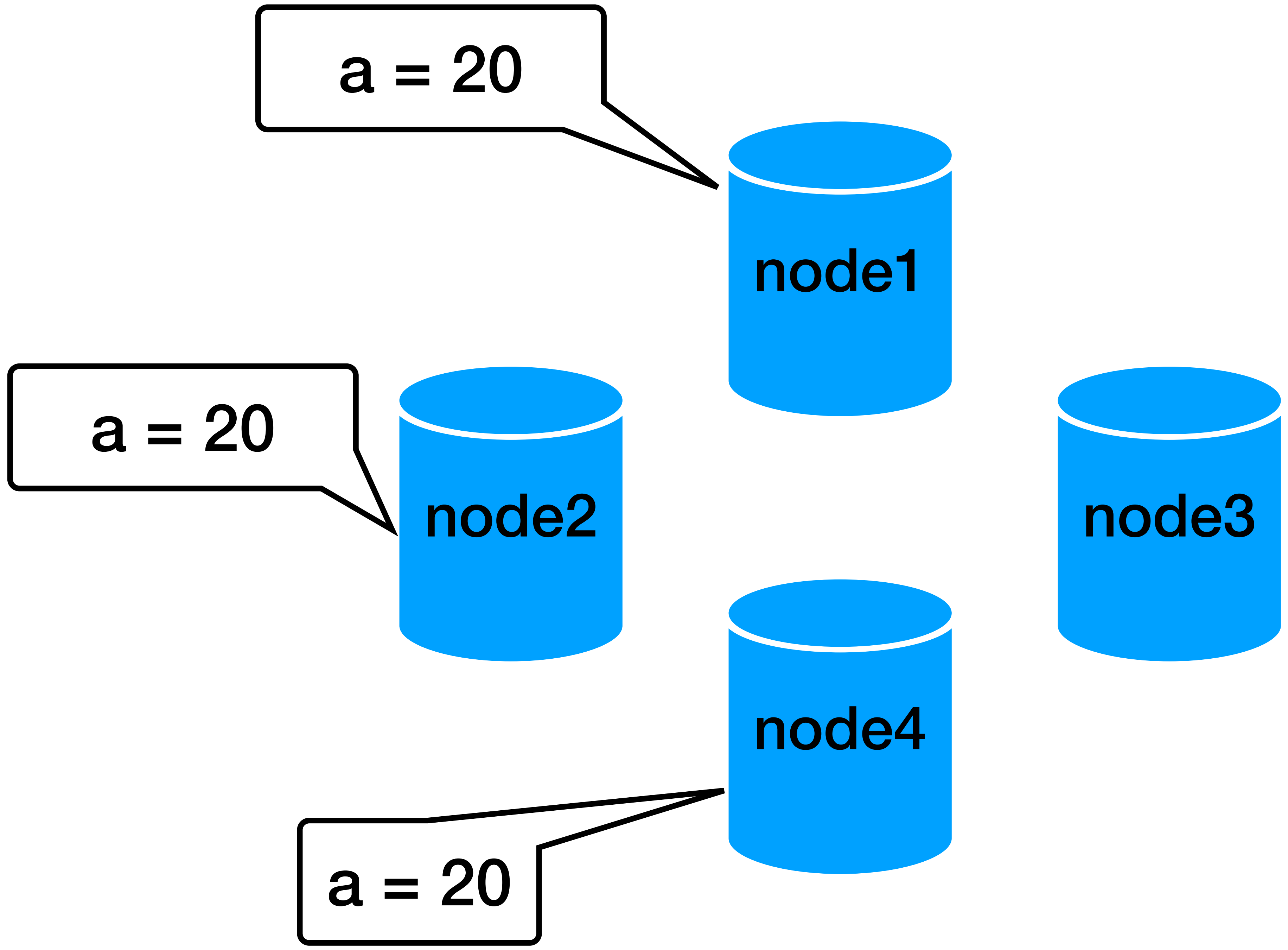

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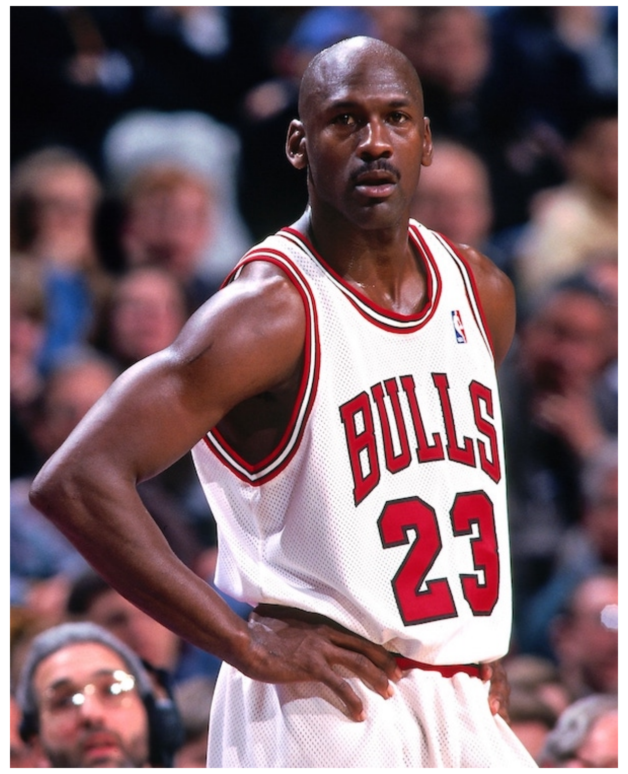

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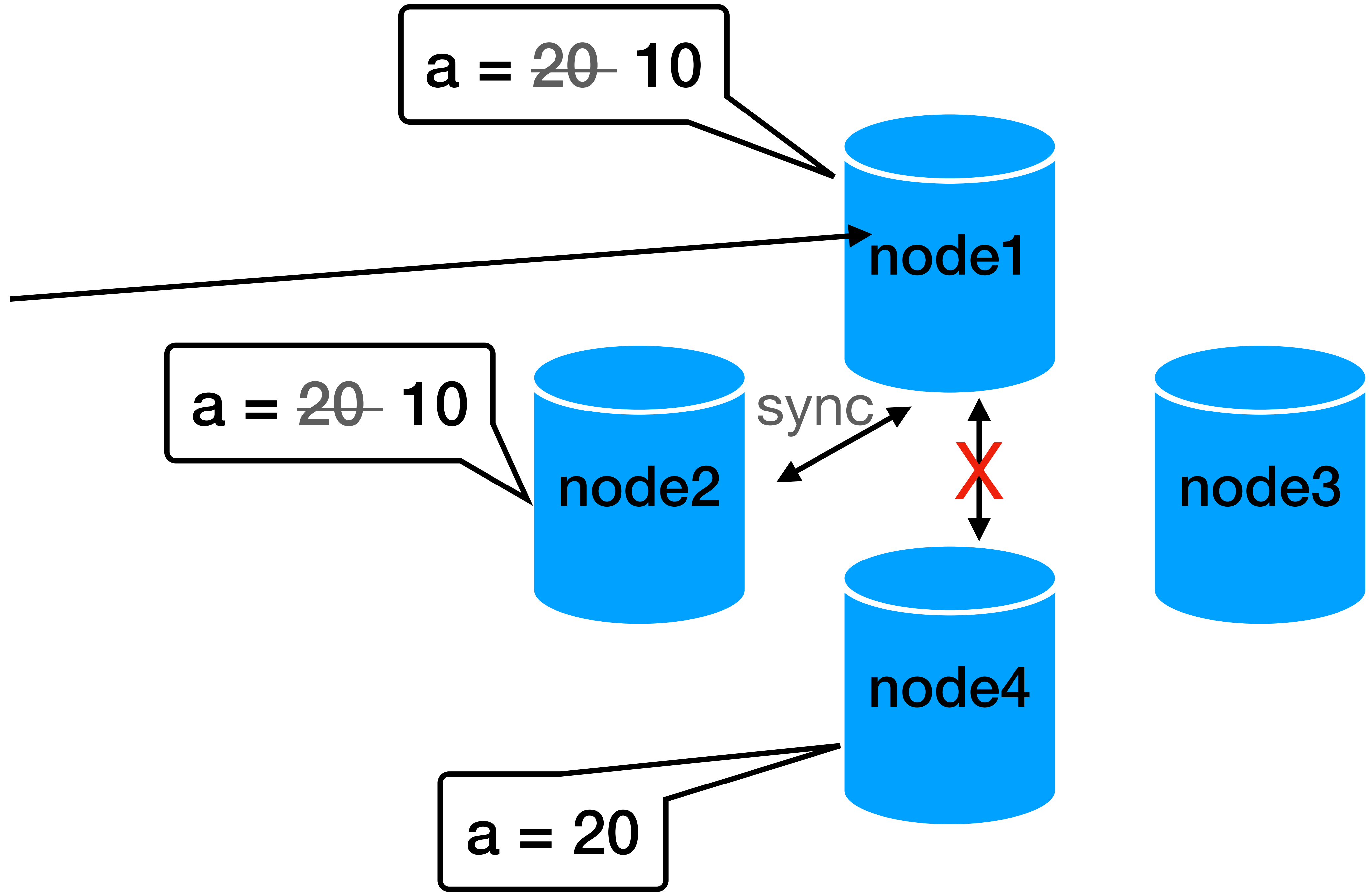

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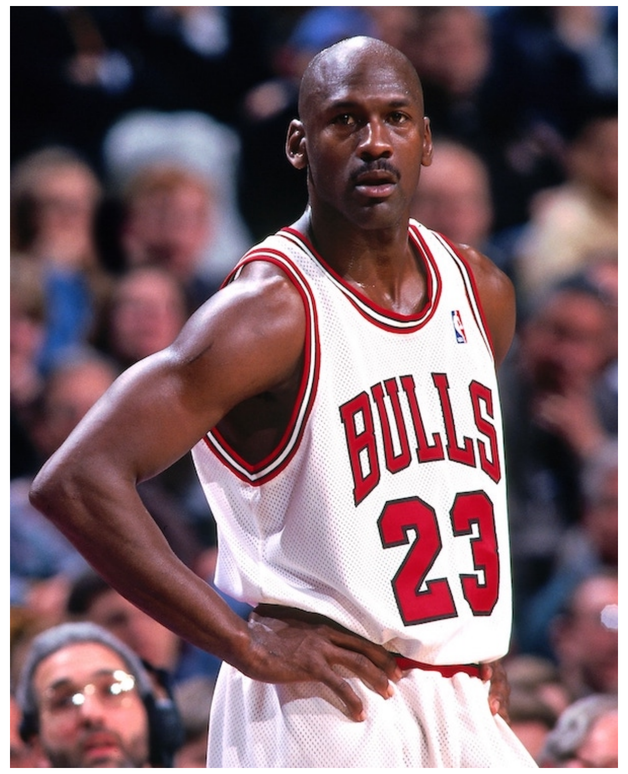

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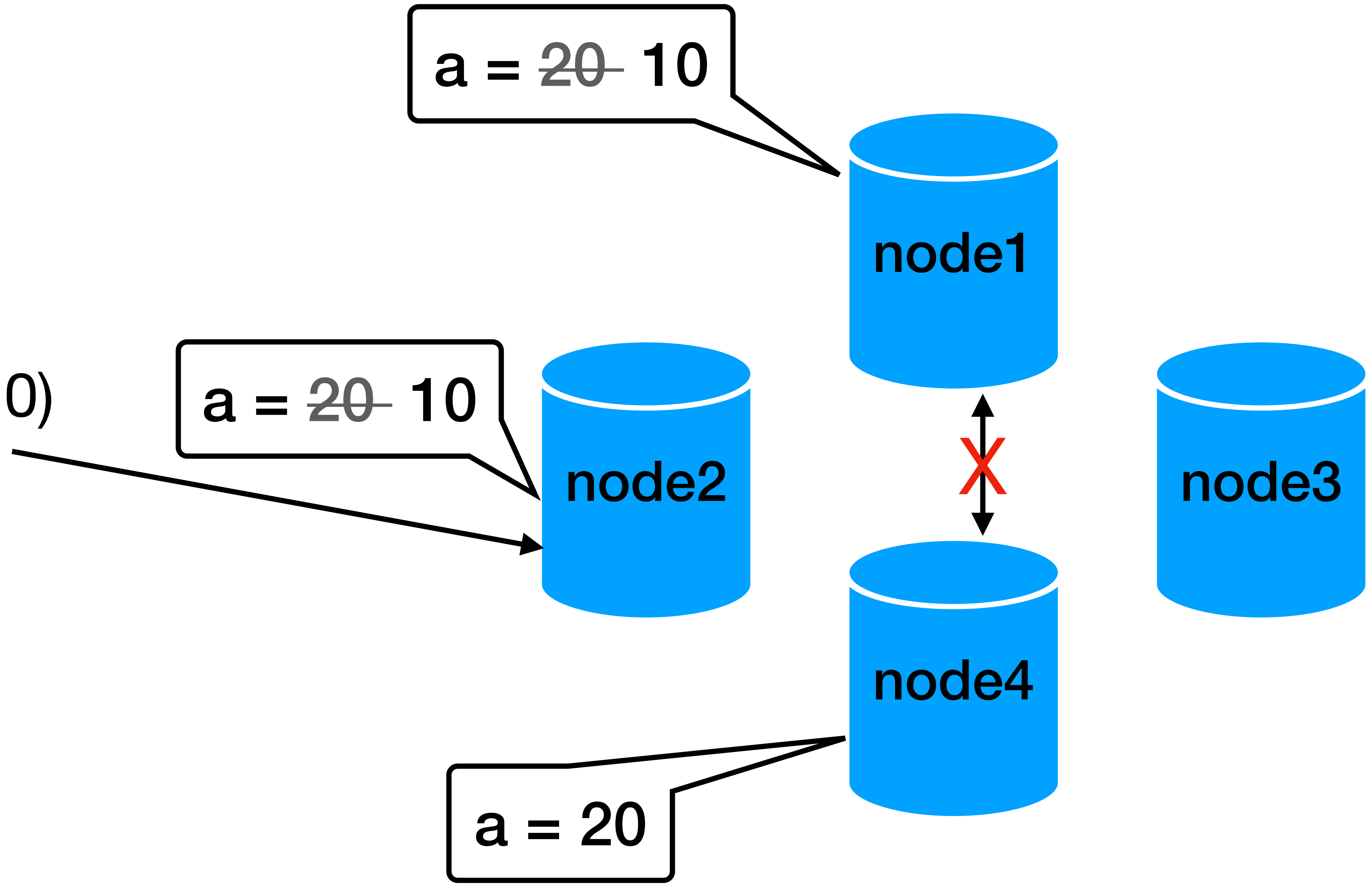

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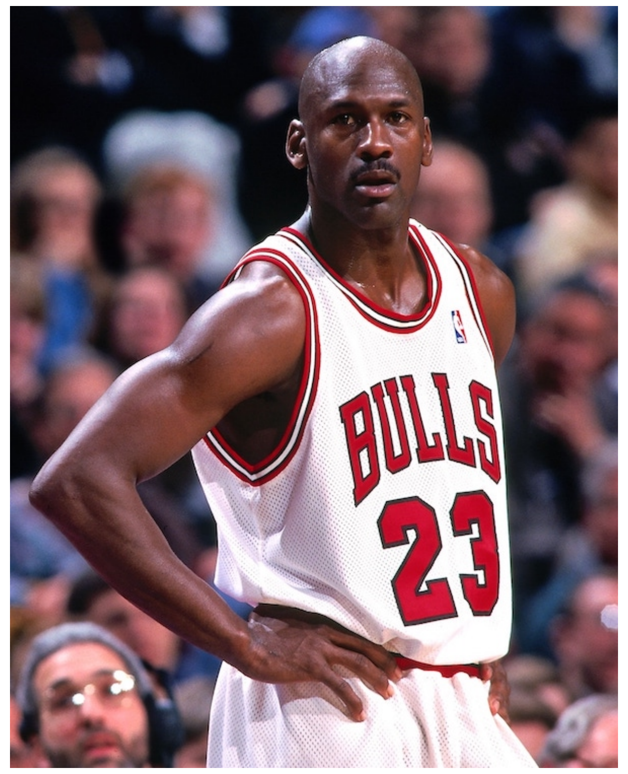

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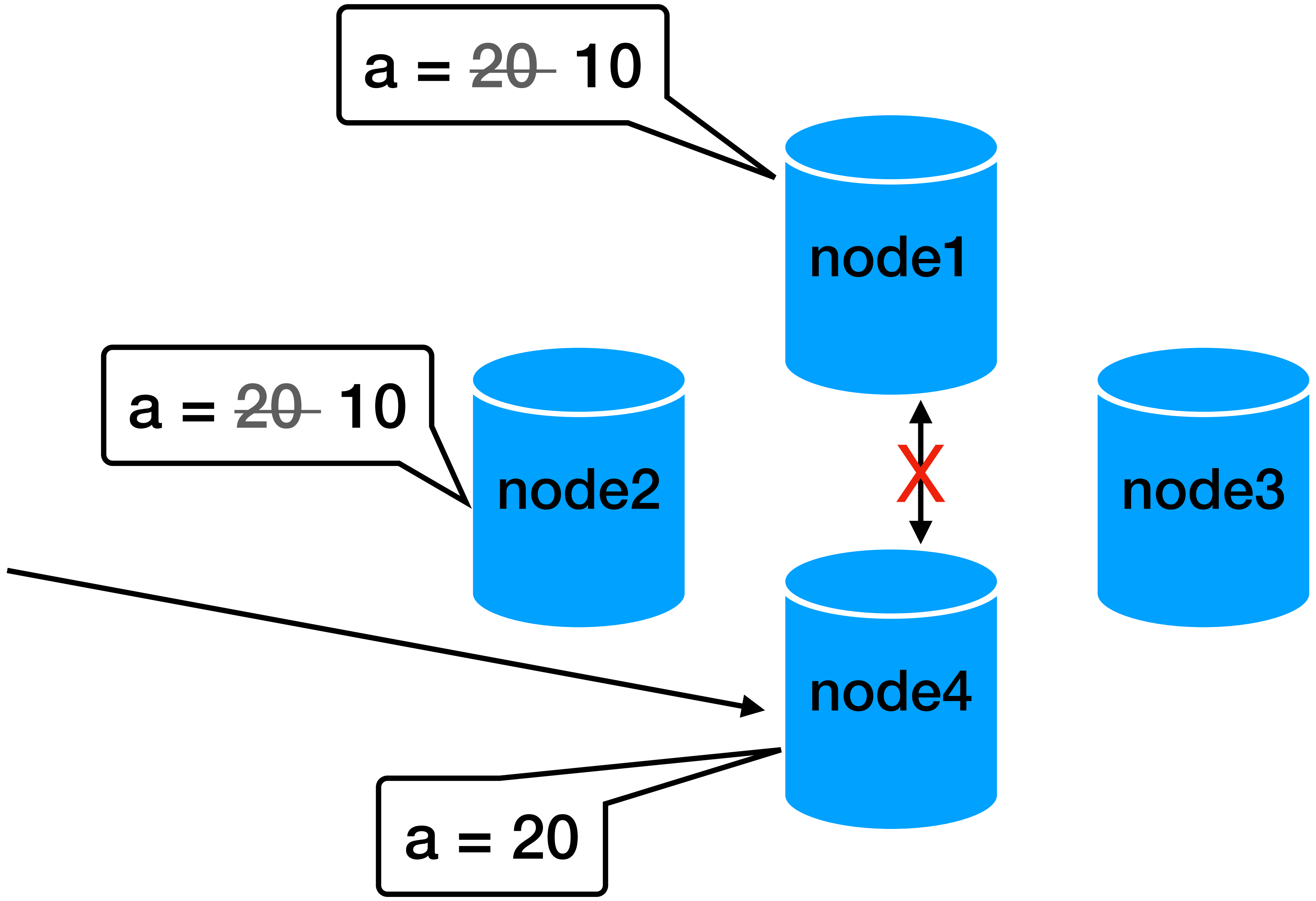

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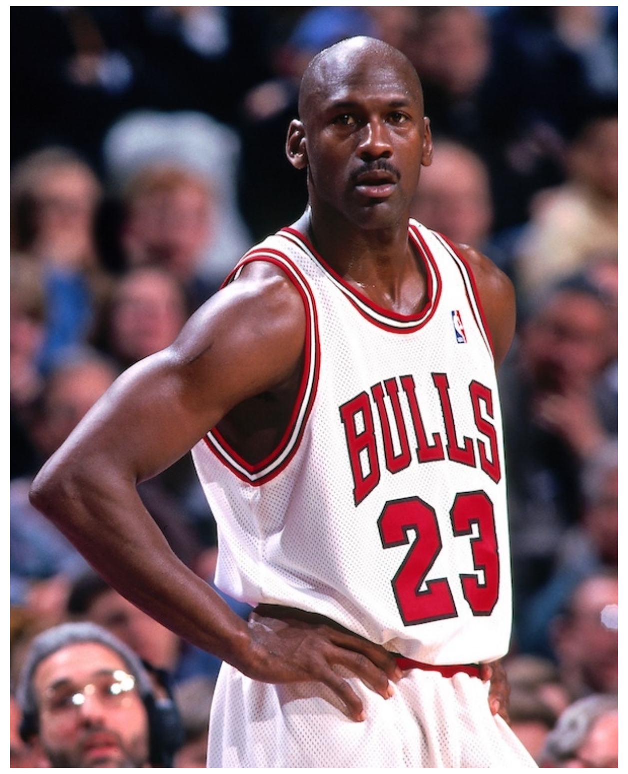

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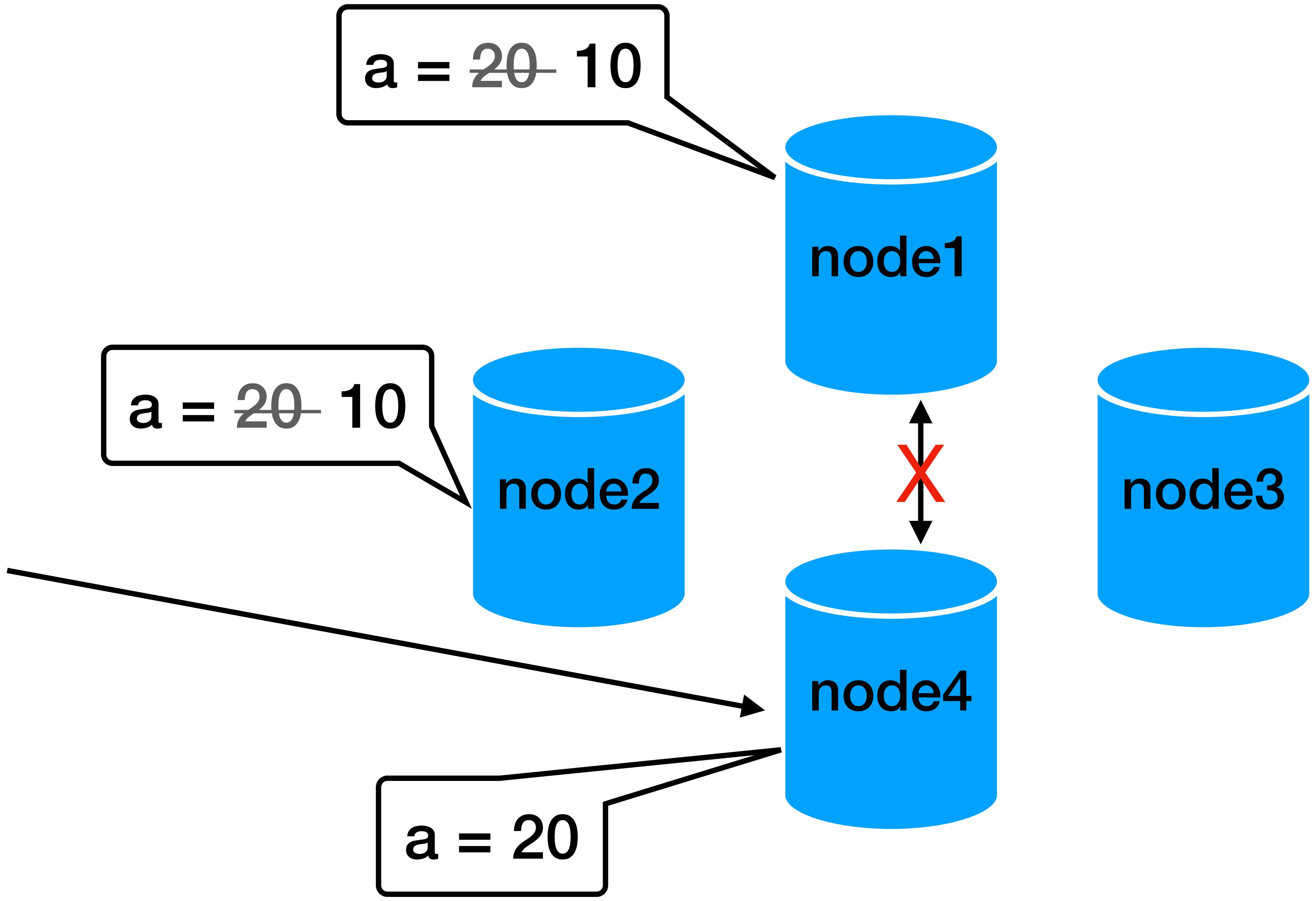

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weak / eventual consistency

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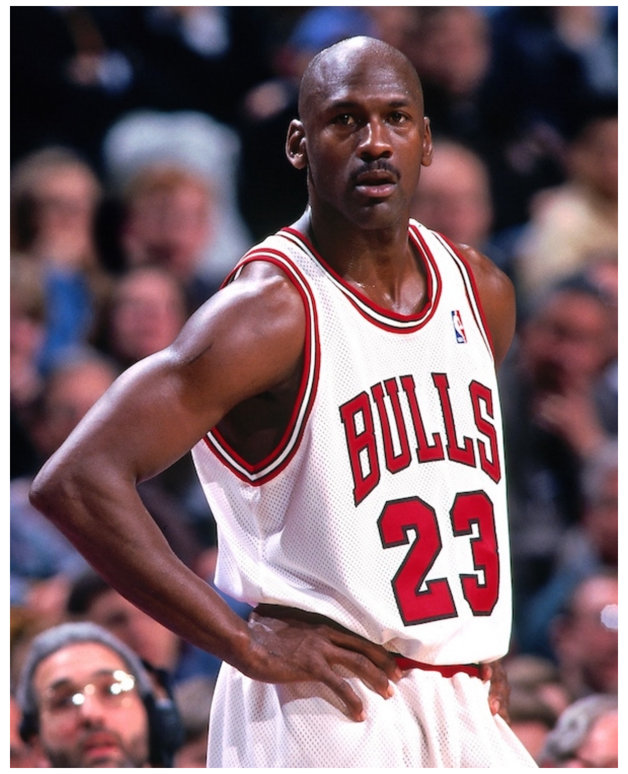

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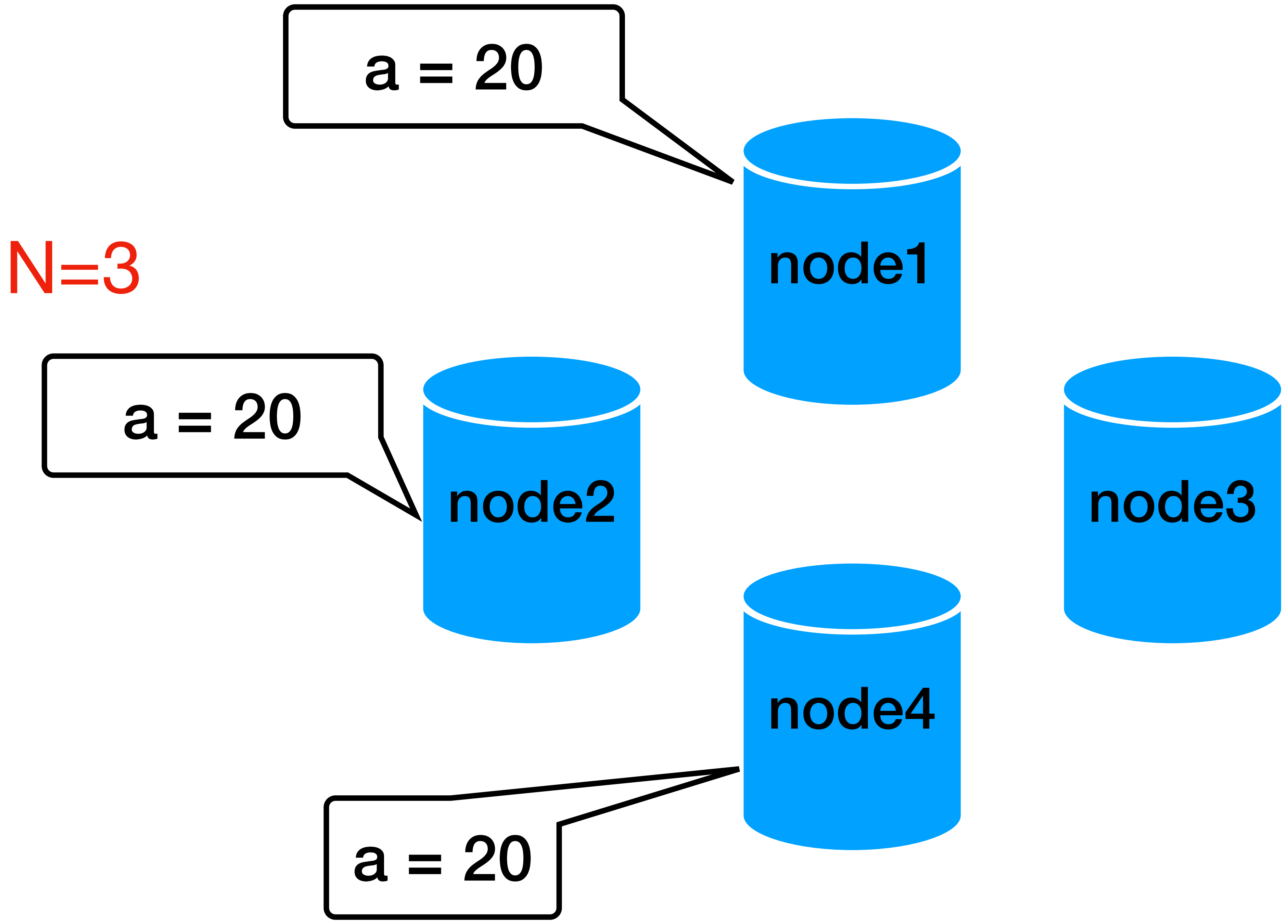

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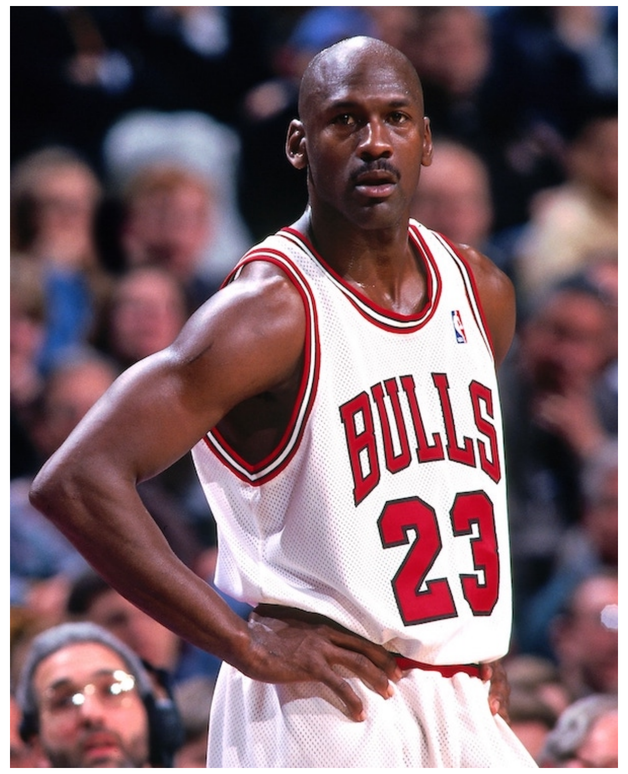

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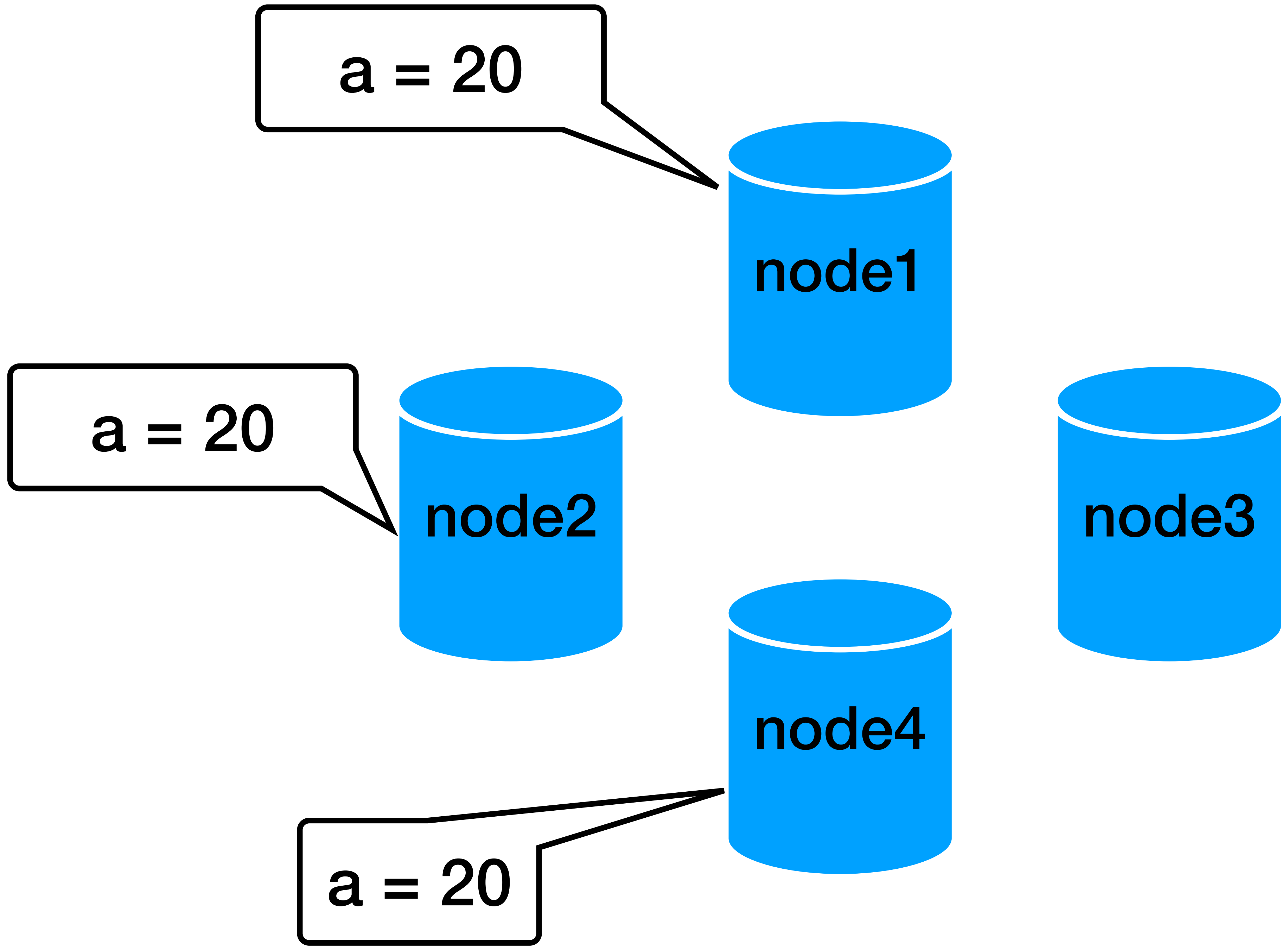

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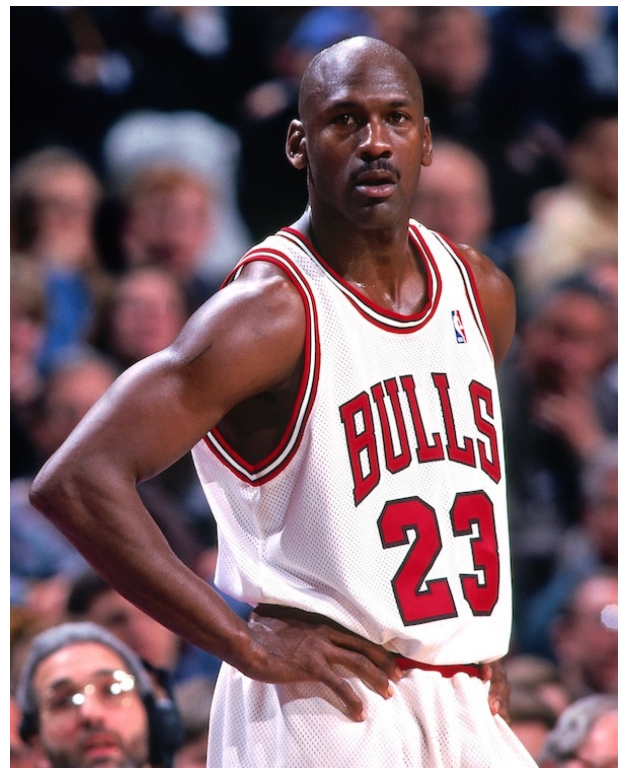

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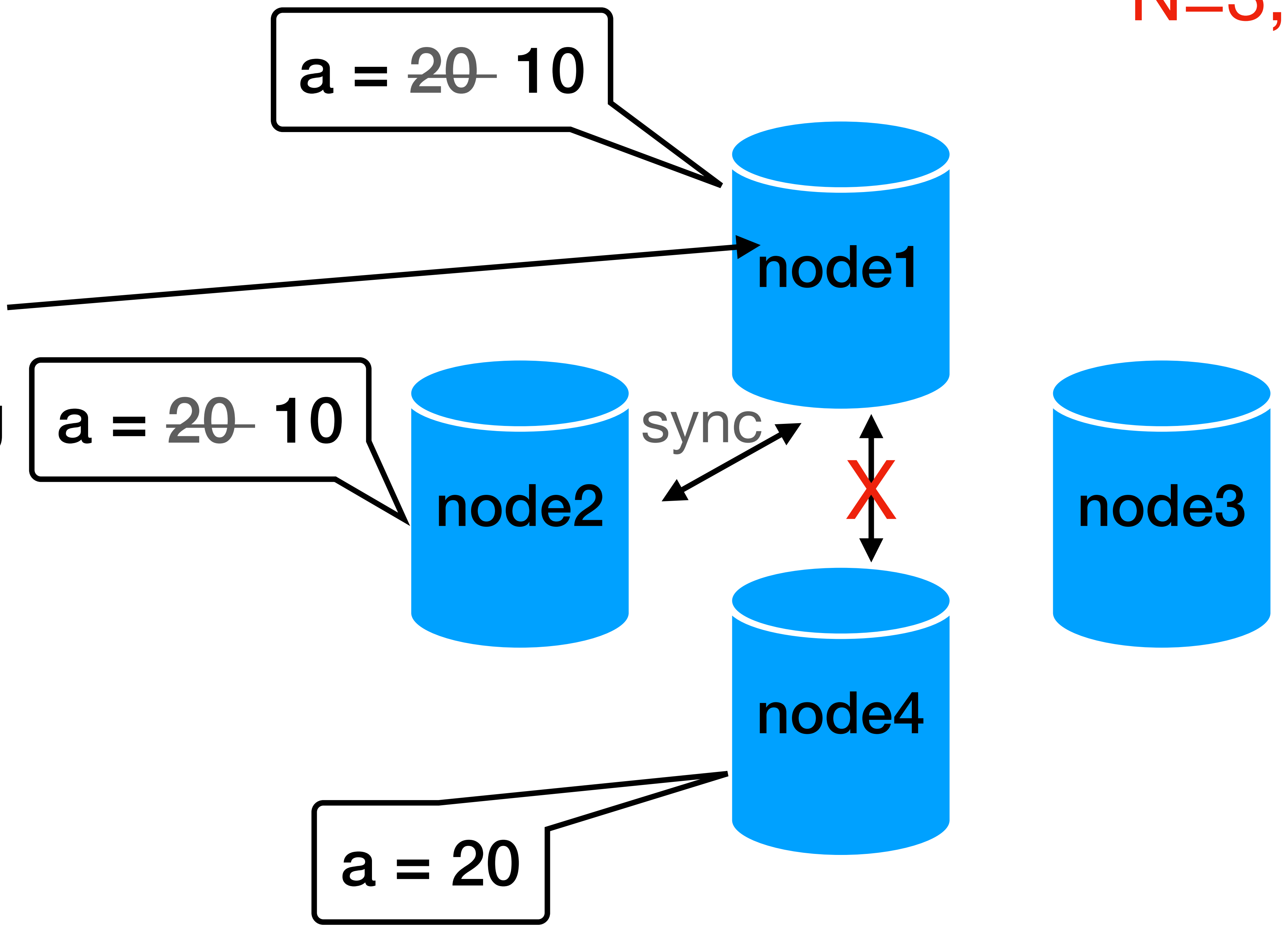

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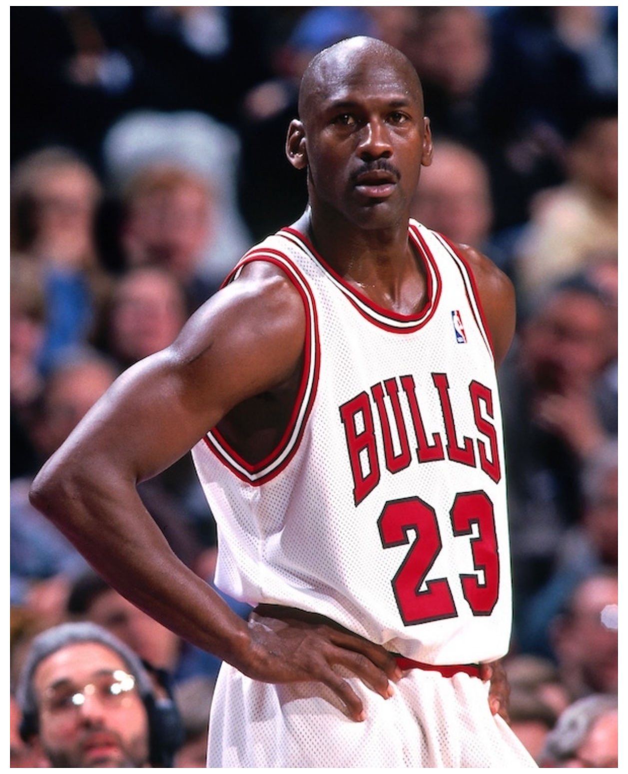

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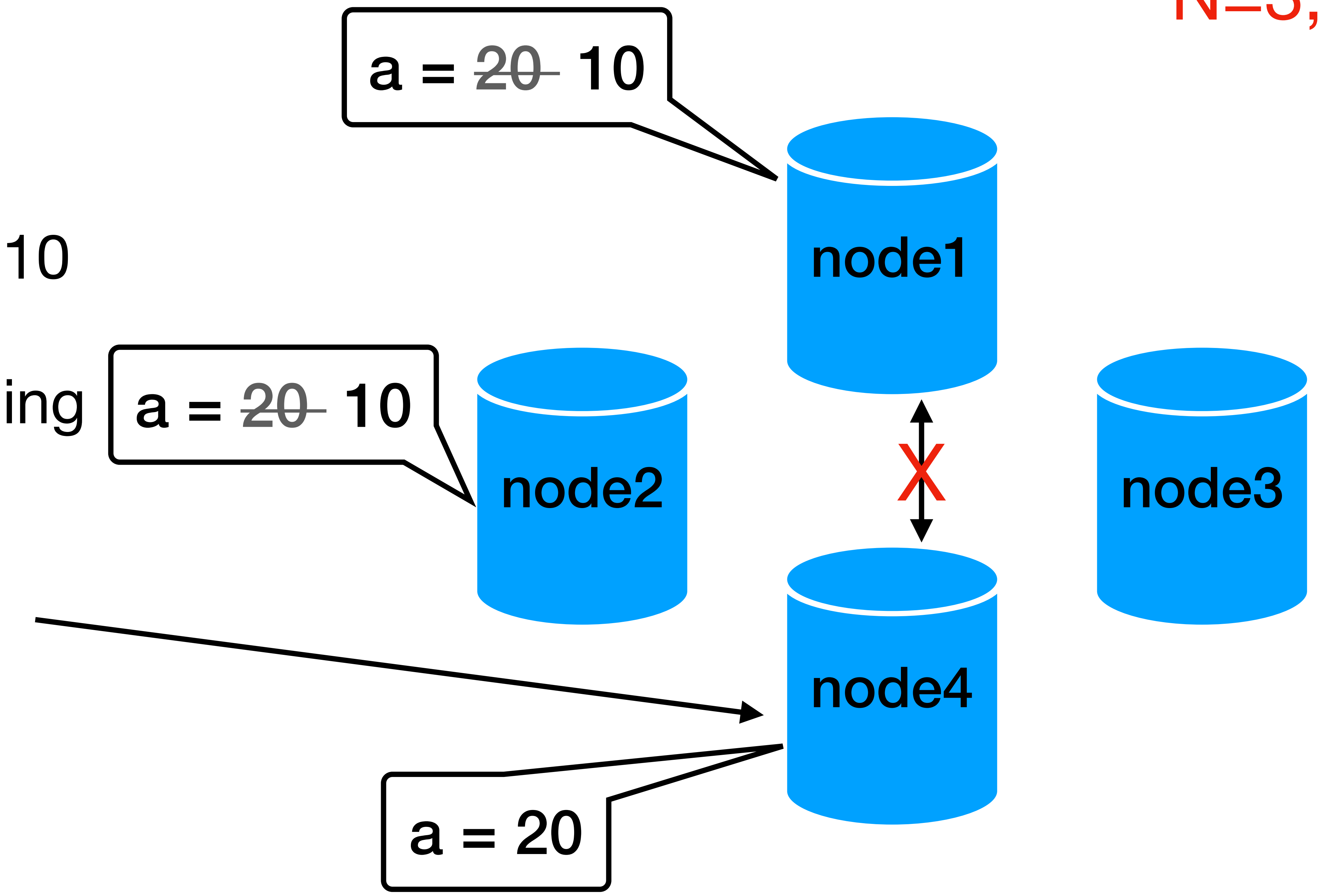

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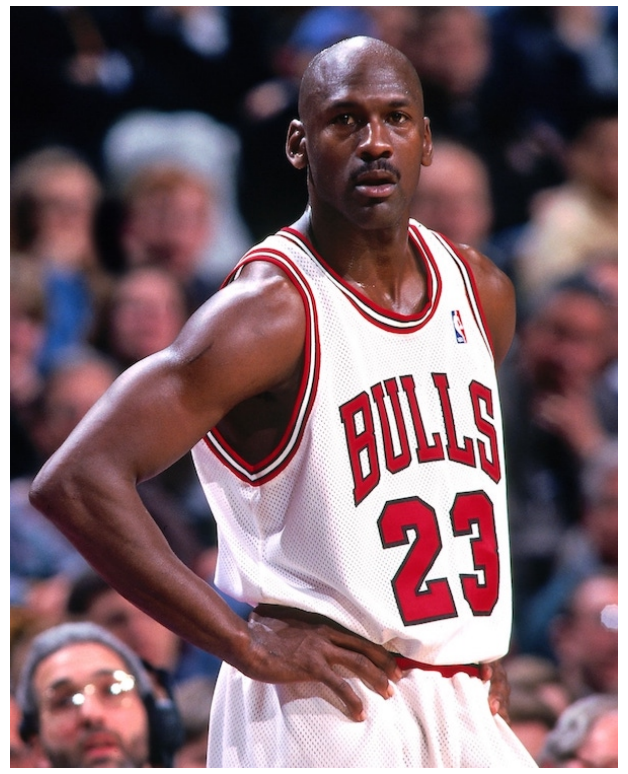

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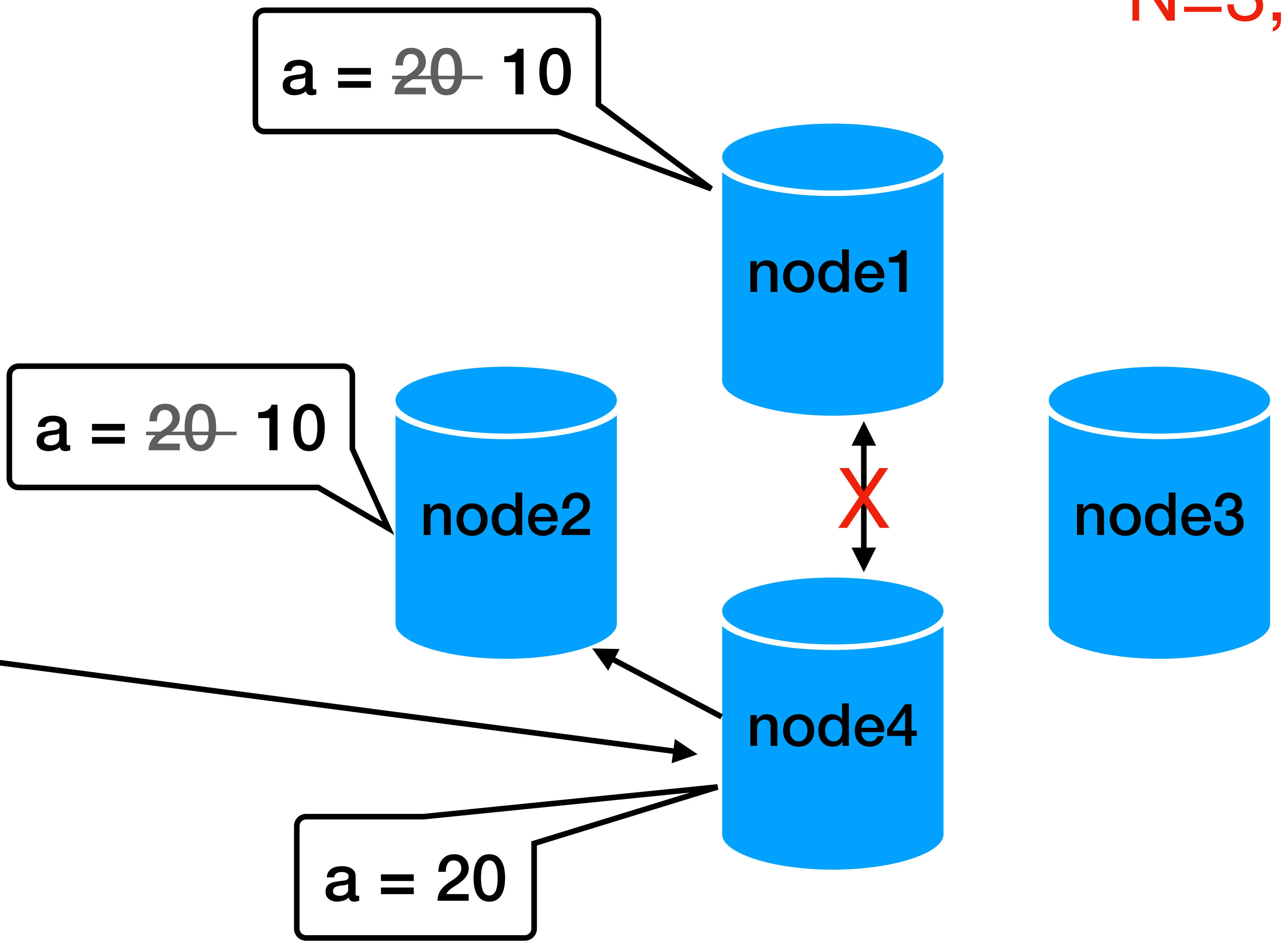

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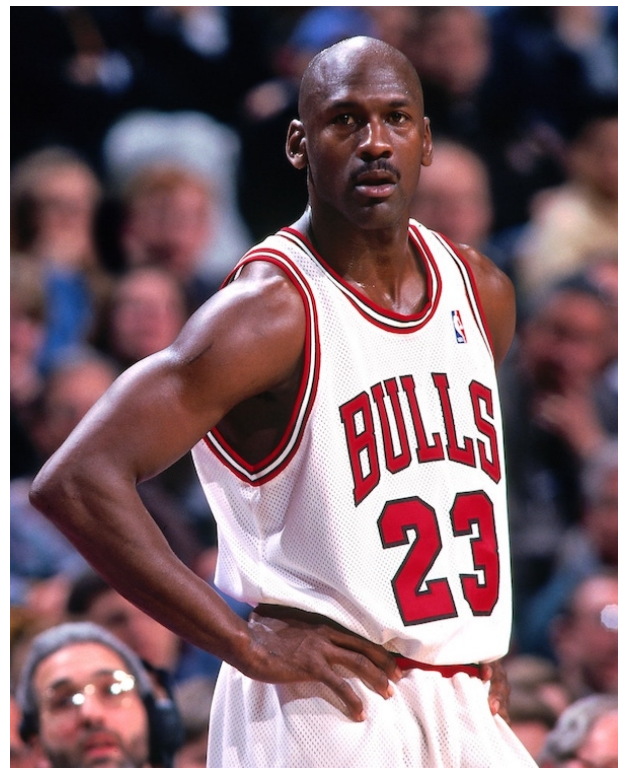

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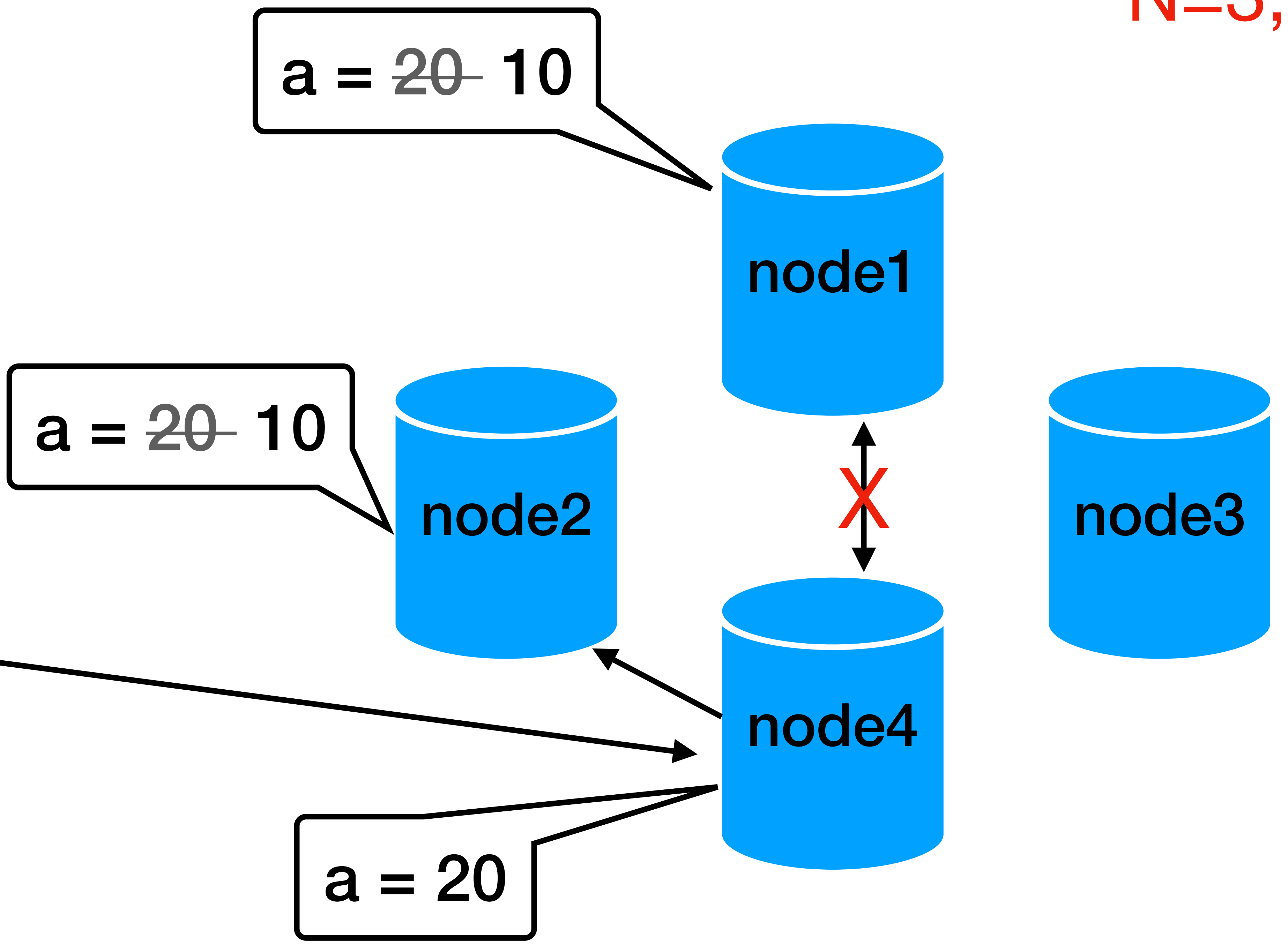
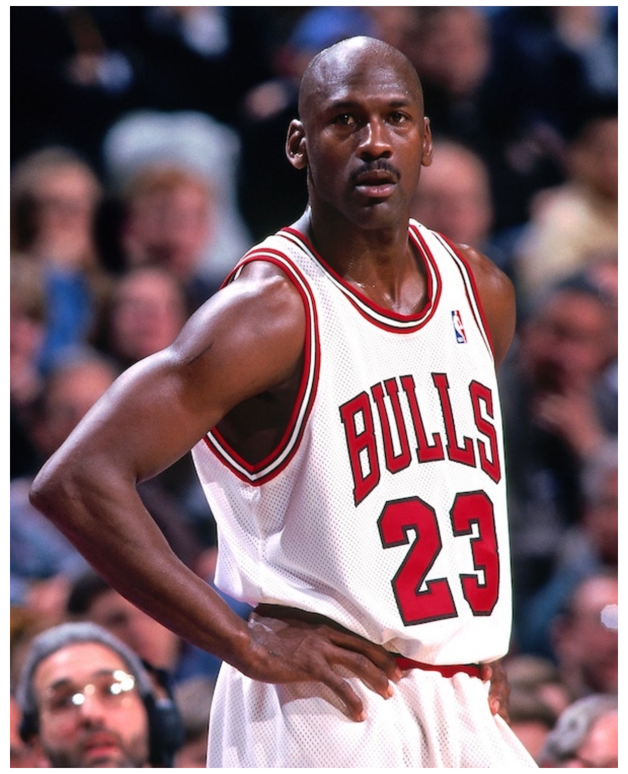
—> read node2 (a=10)
—> there is NO quorum



Server side consistency - example 3

- Distributed database, set to consistency
  updates & reads needs quorum ack

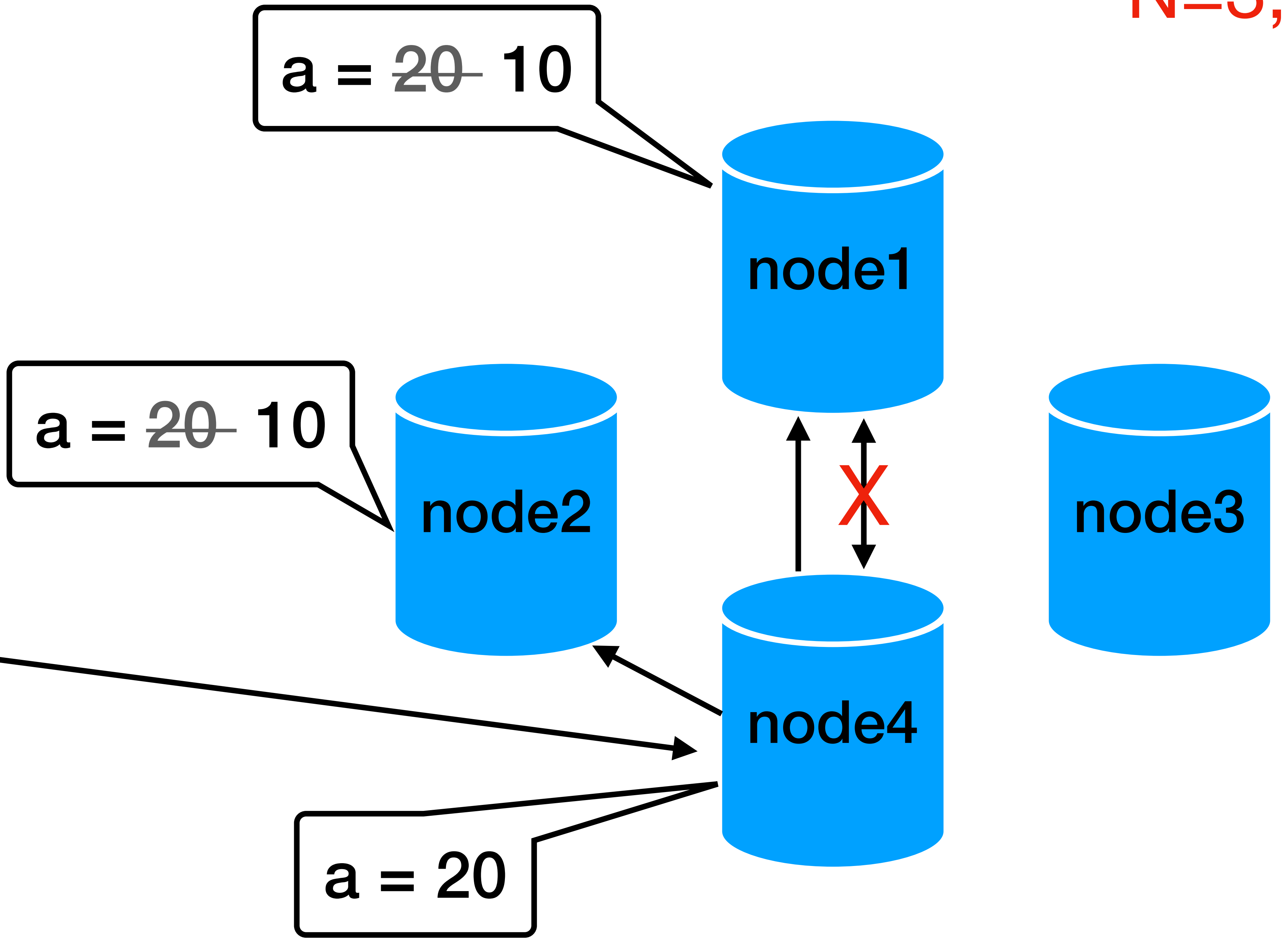
N=3, W=2, R=2



10:00: a = 20

10:01: update node1 a = 10
—> node2 returned ack
node4 is not responding
—> return success

10:02: read node4 (a=20)
—> read node2 (a=10)
—> there is NO quorum
—> in node1 a=10



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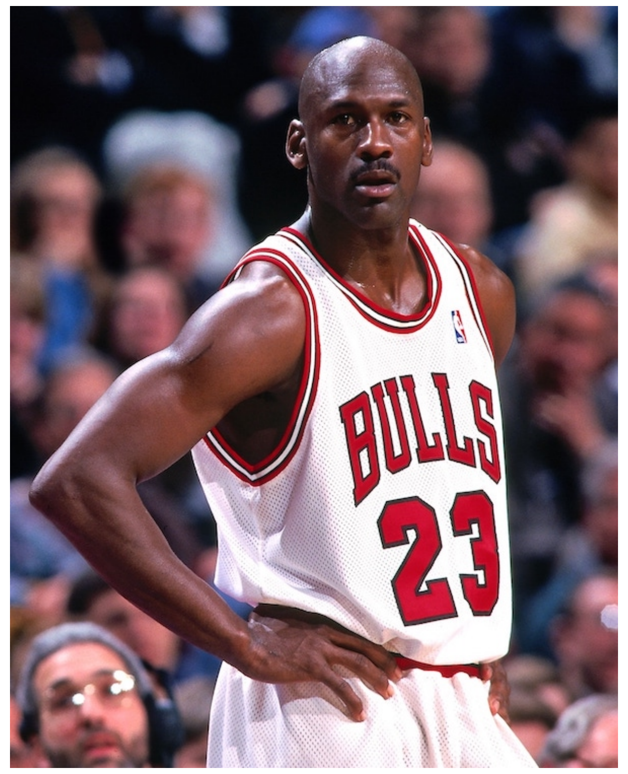

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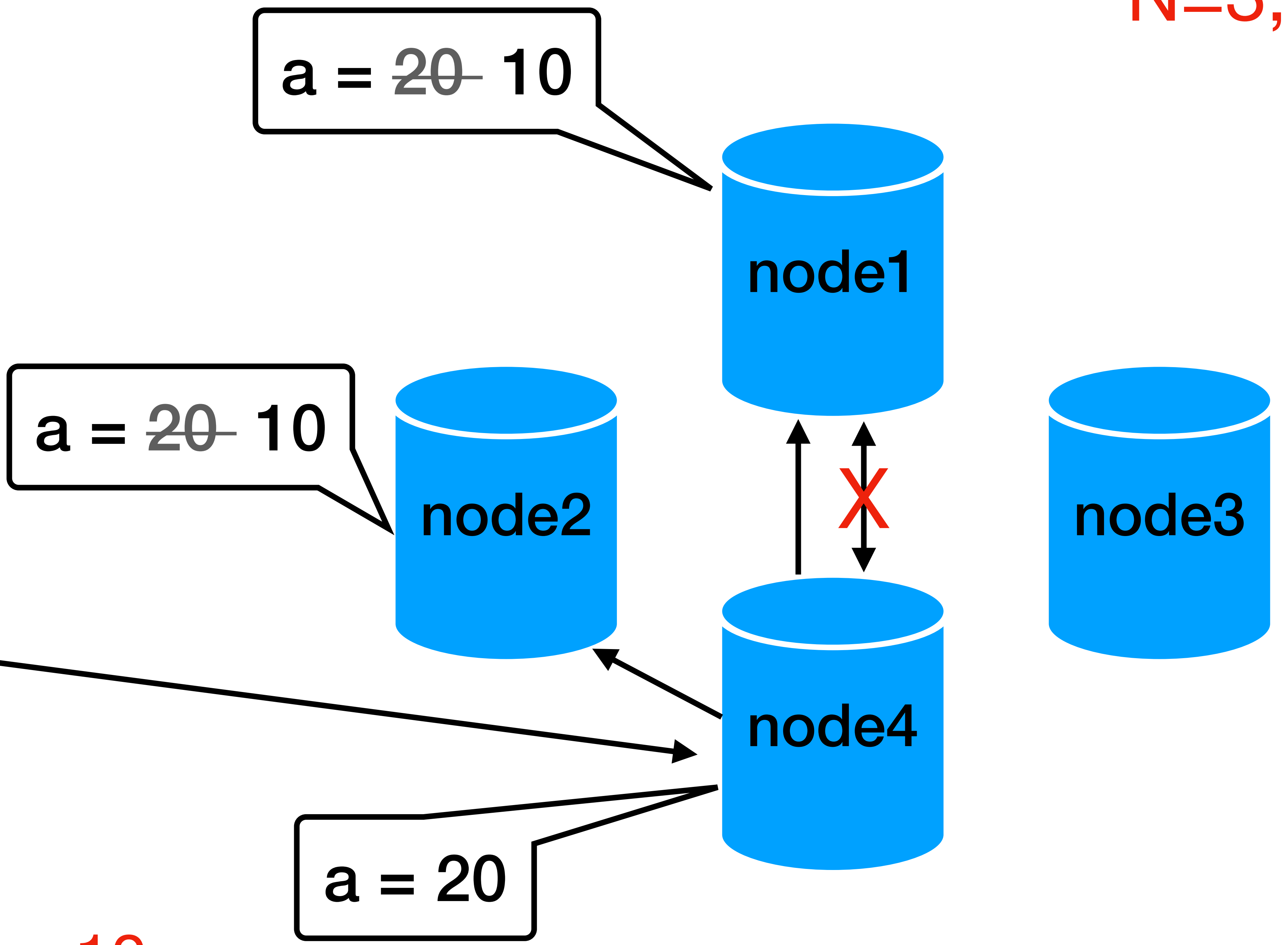

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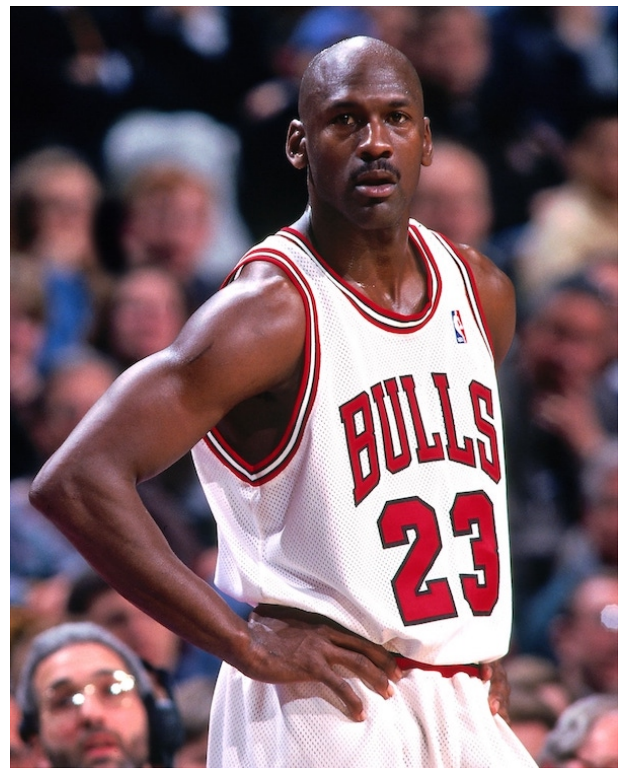

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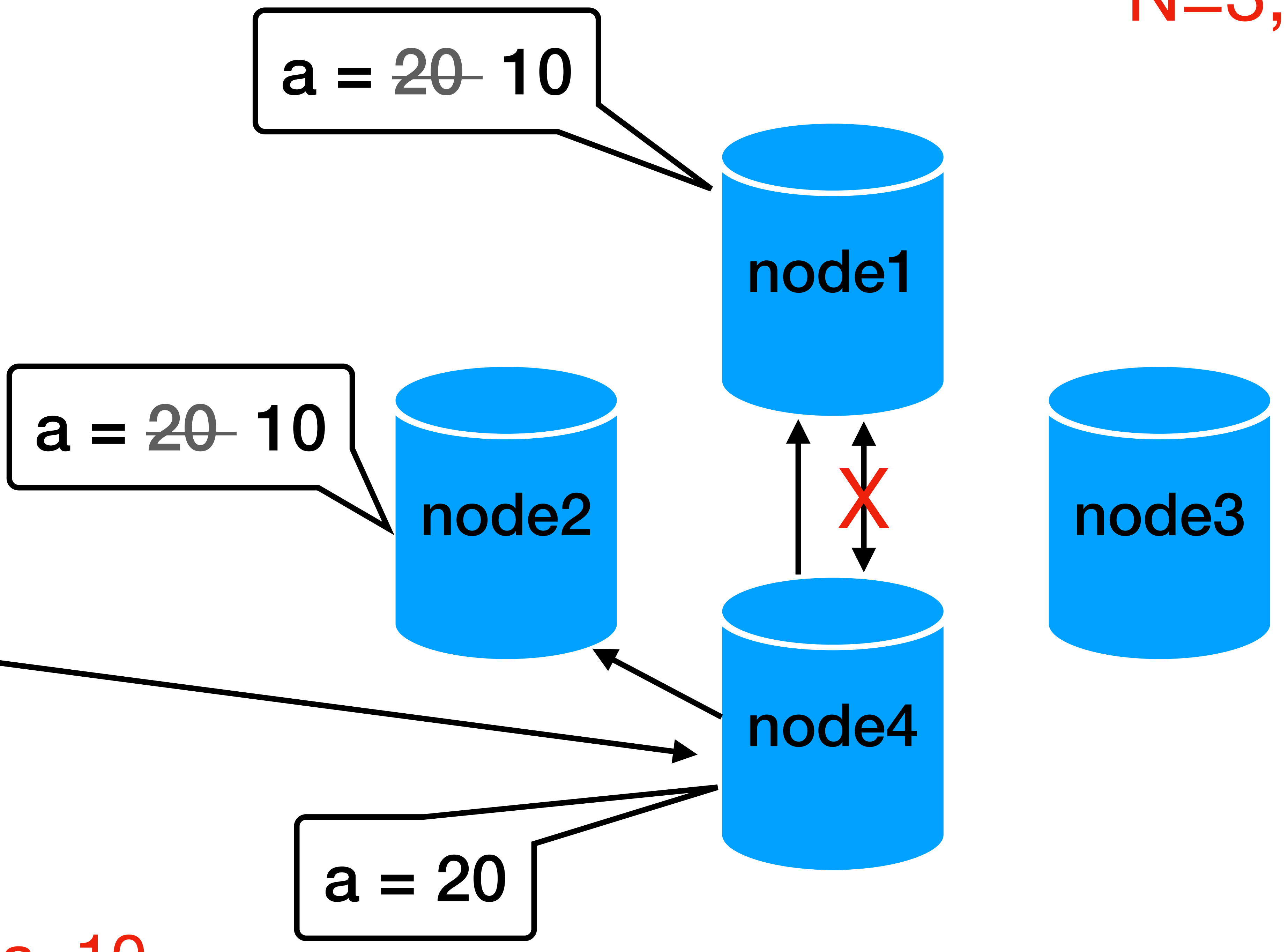
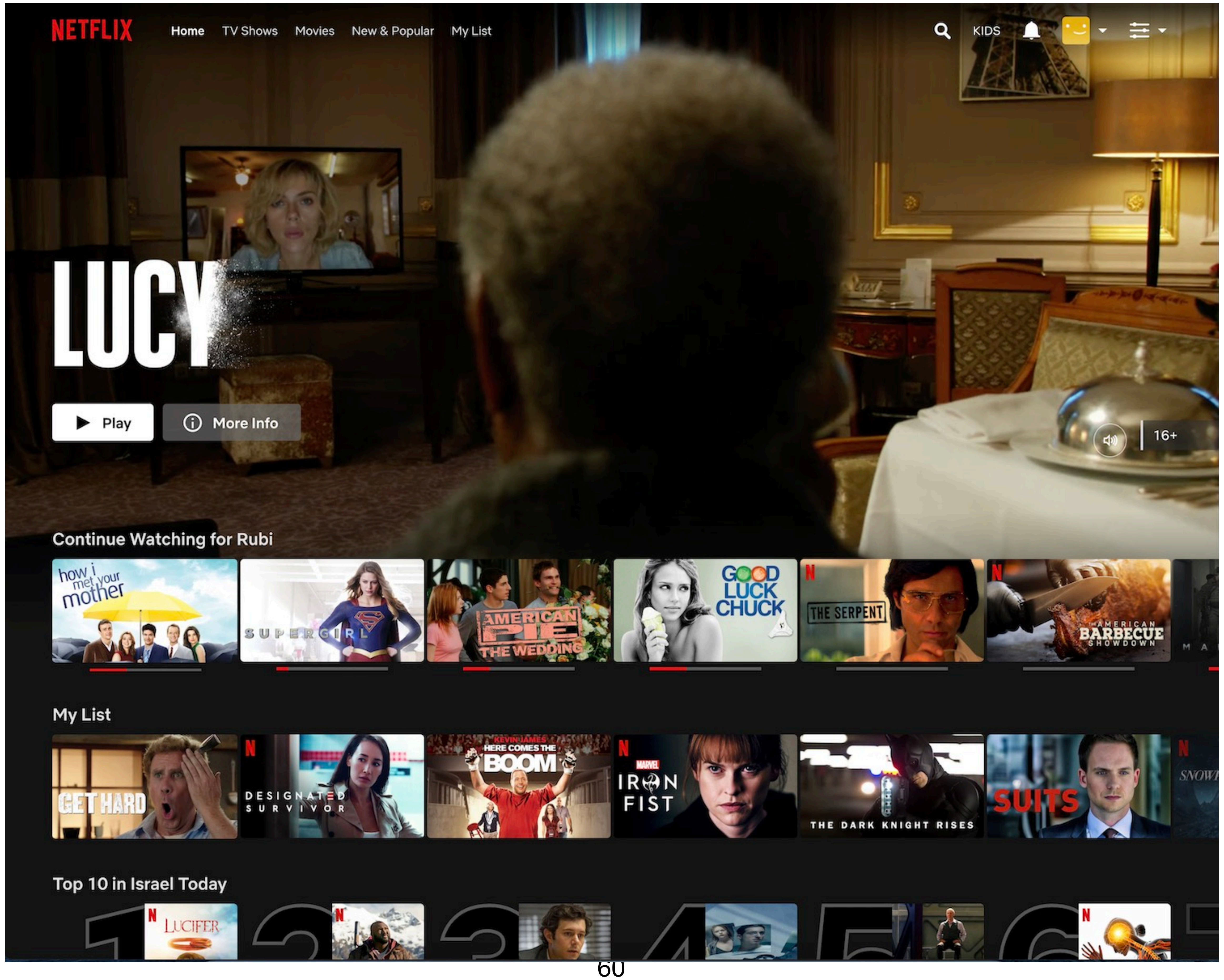


W (2) + R (2) > N (3)
strong consistency

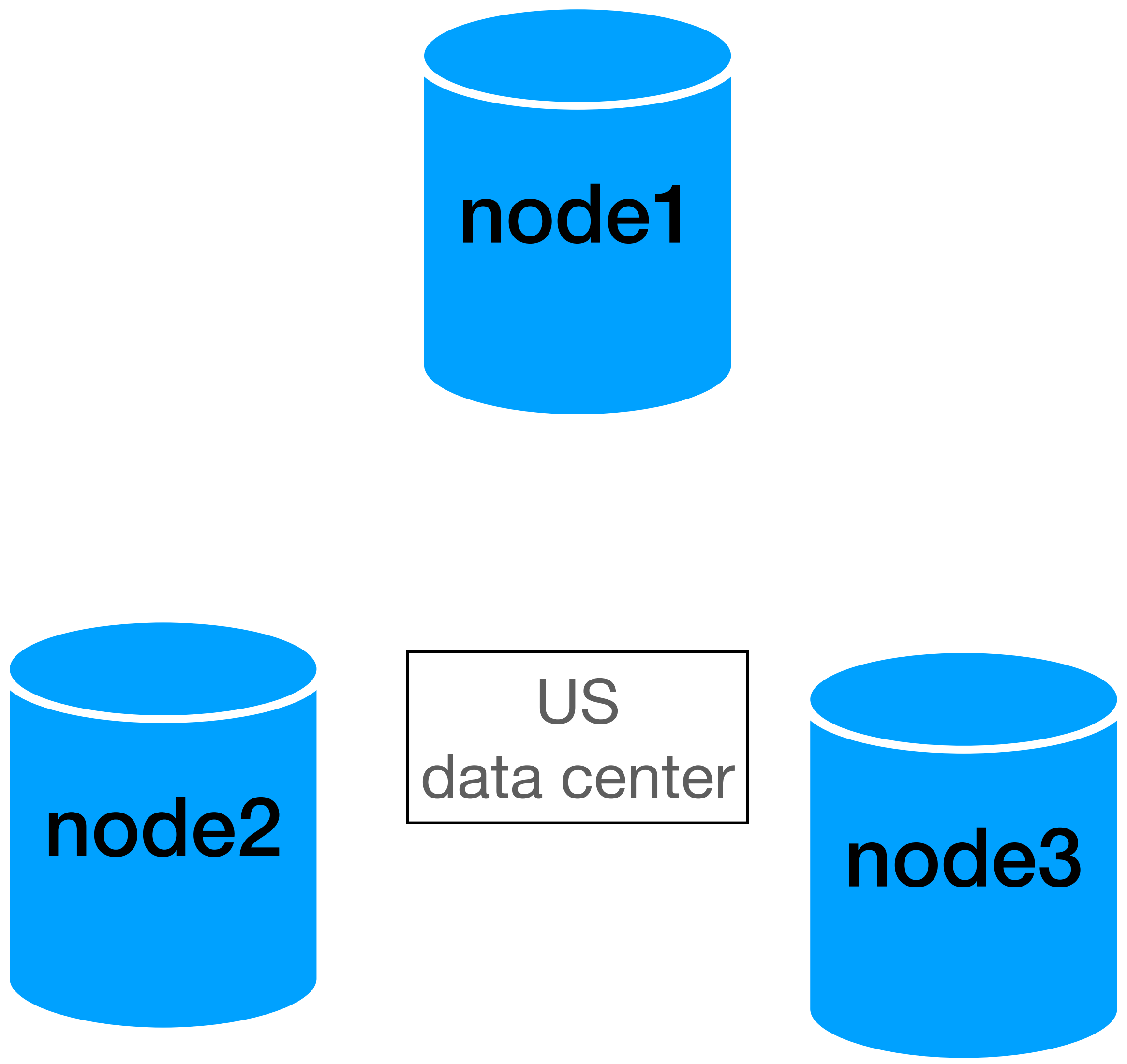
Server side consistency - example 4

- Distributed database, multi data center



Server side consistency - example 4

- Distributed database, mixed consistency
  updates needs quorum ack in the same datacenter
  single ack from remote datacenter



W (2) + R (2) > N (3)
strong consistency
within a local data center

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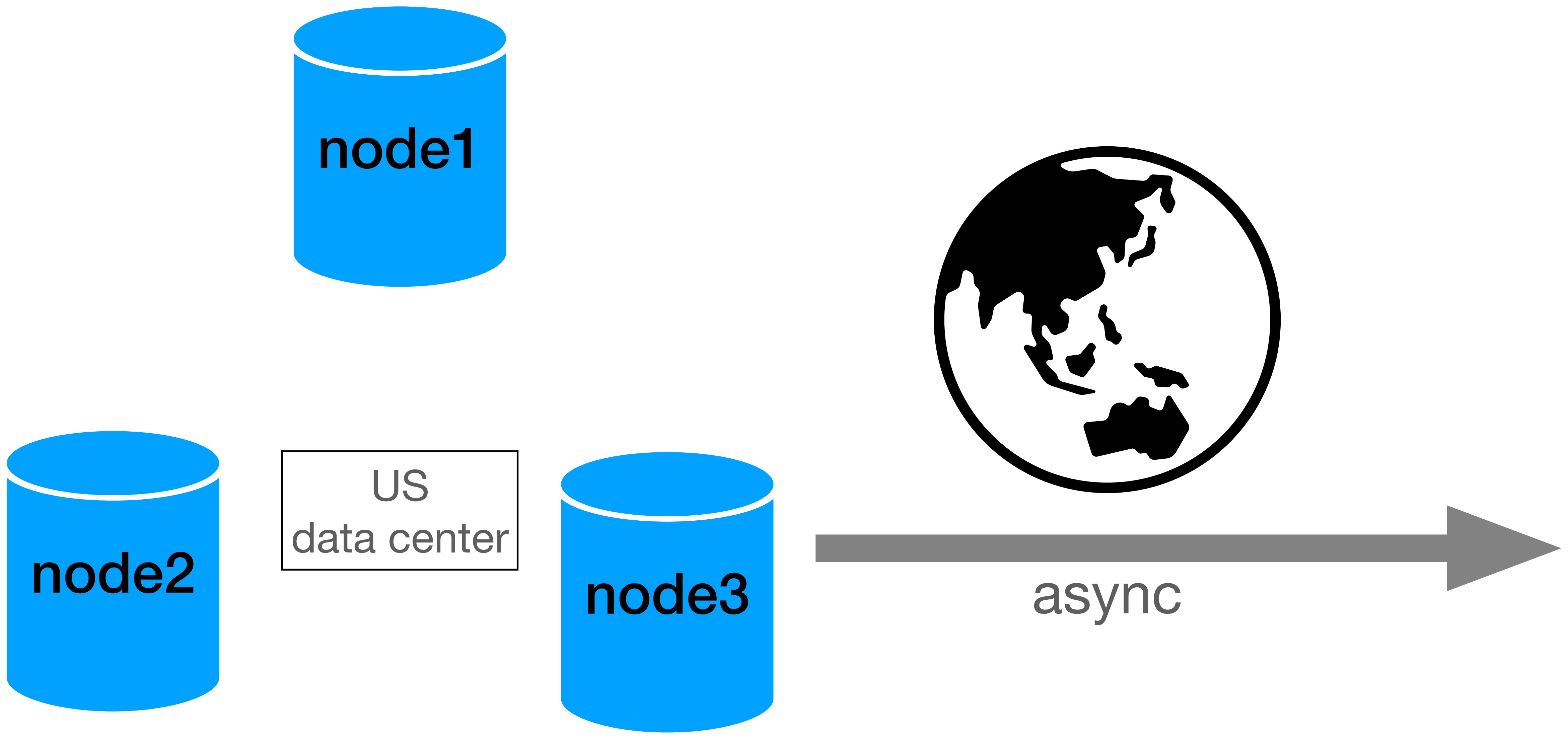

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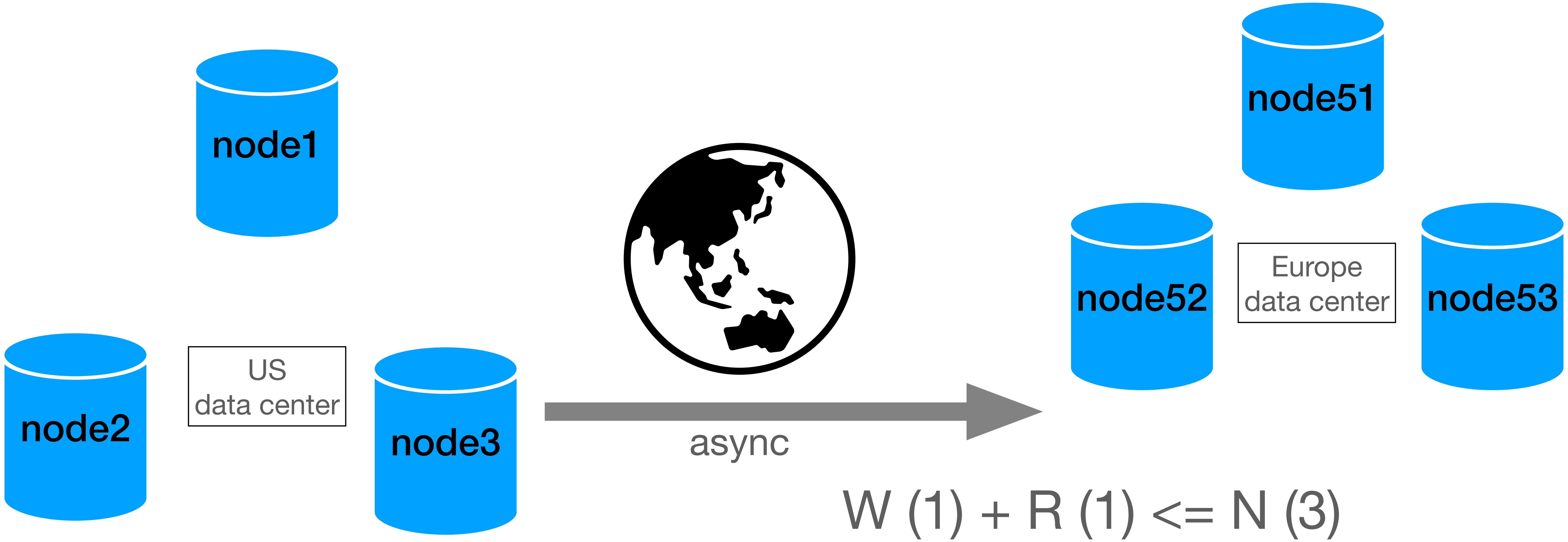

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strong consistency
within a local data center

W (1) + R (1) <= N (3)
eventual consistency
across data centers

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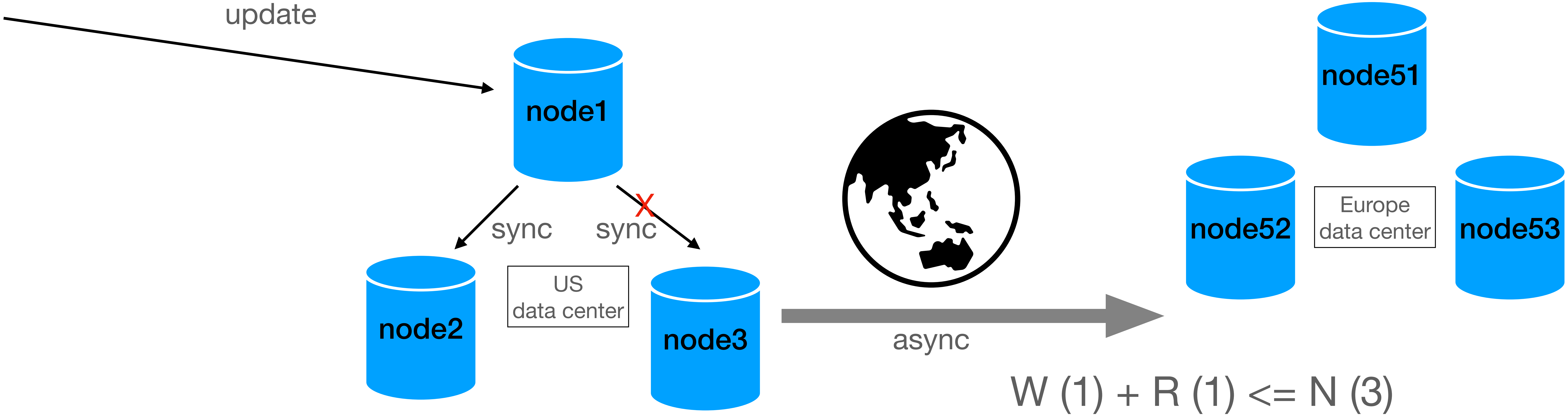

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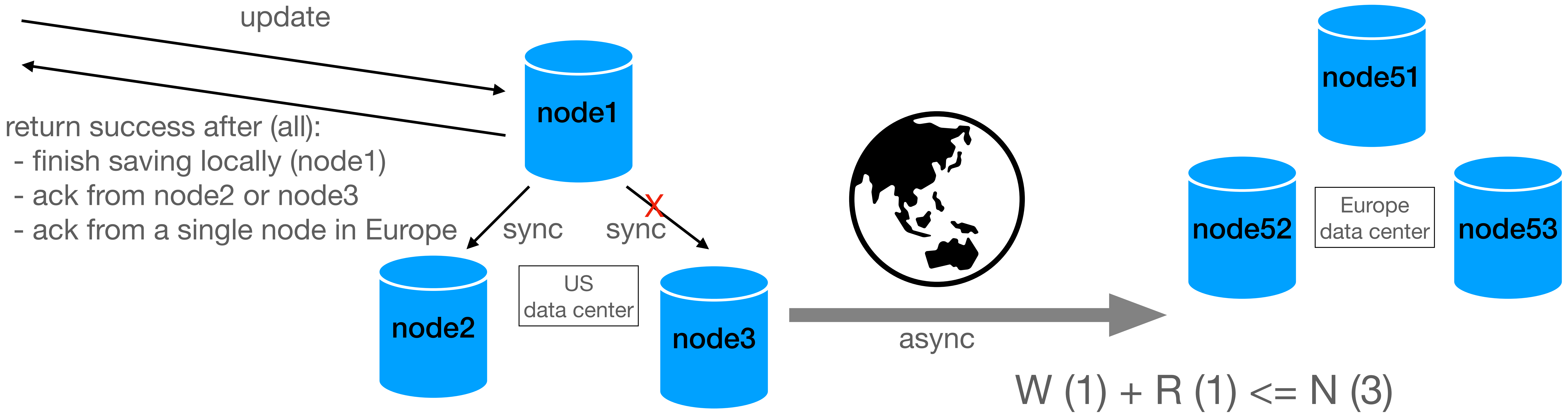

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Summary - CAP Theorem

- No distributed system is safe from network failures.
  —> we need to choose between CP and AP

Summary - CAP Theorem

- No distributed system is safe from network failures.
  —> we need to choose between CP and AP
- If a node is down/unreachable we can:
  - cancel the operation (CP)
  - Return result with (maybe) inconsistency (AP)
- Multi data center adds more options