

CAP Theorem

Big Data Systems

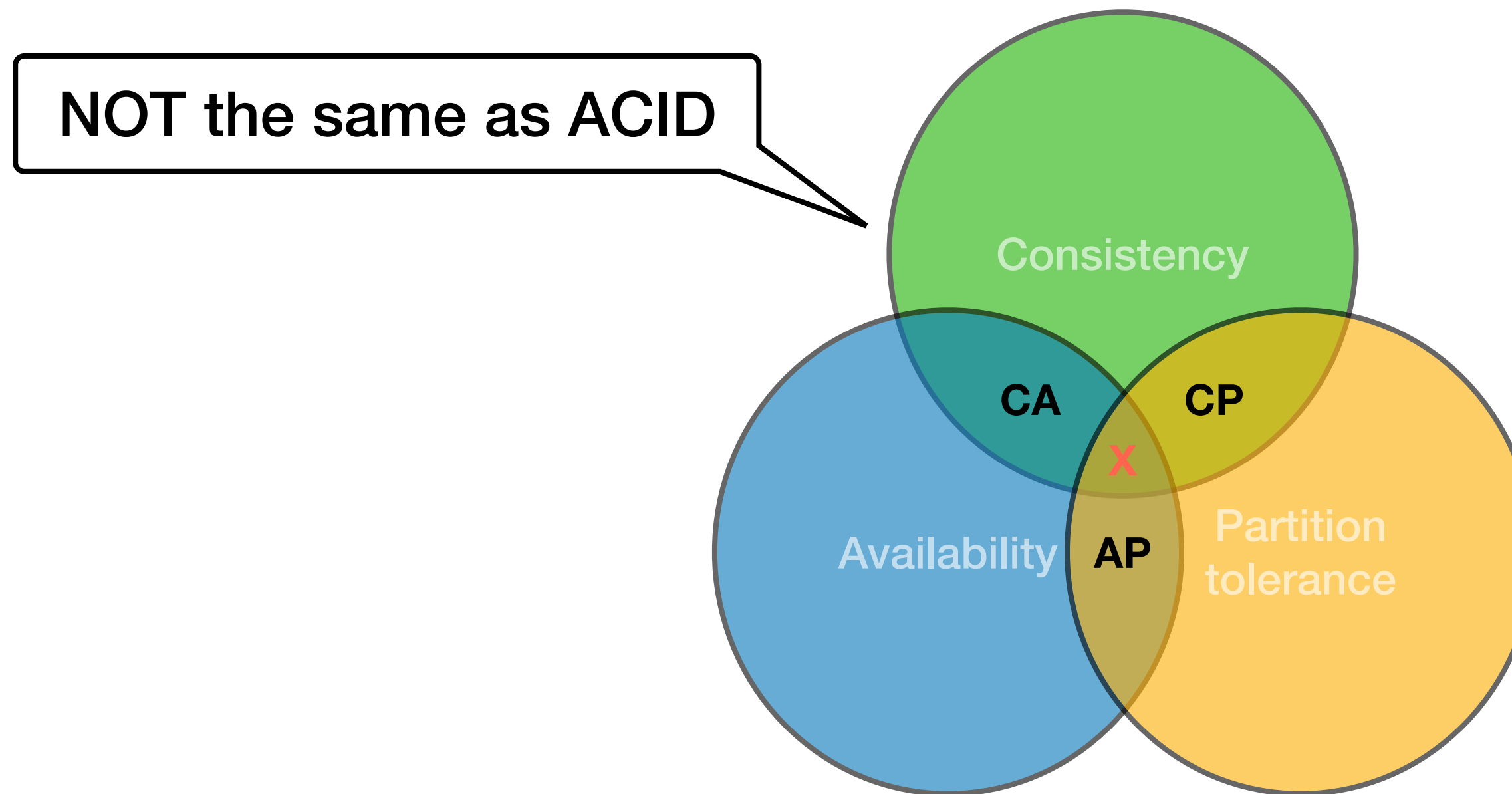
Dr. Rubi Boim

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”

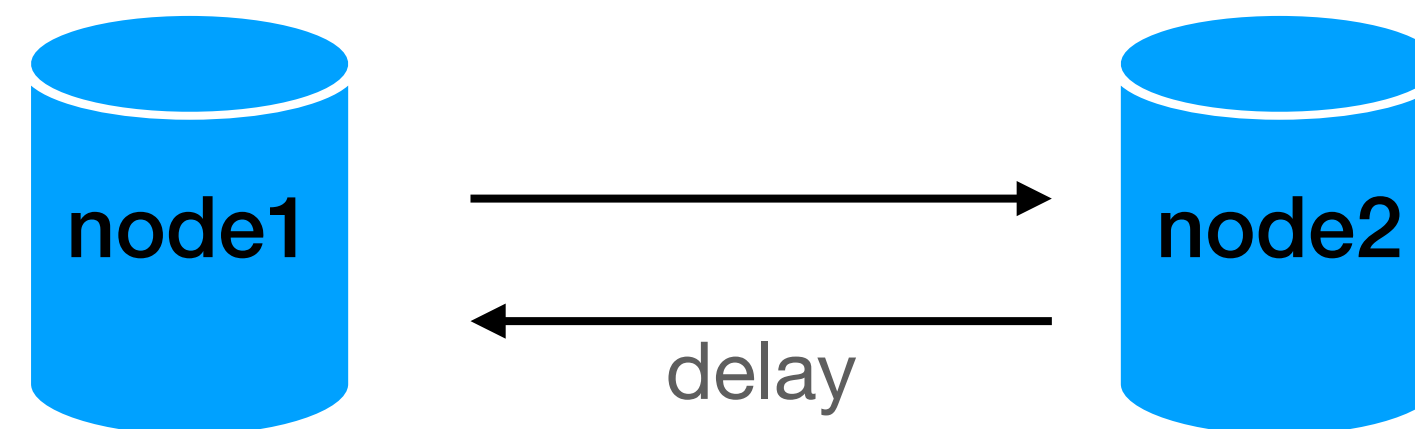
Some terms



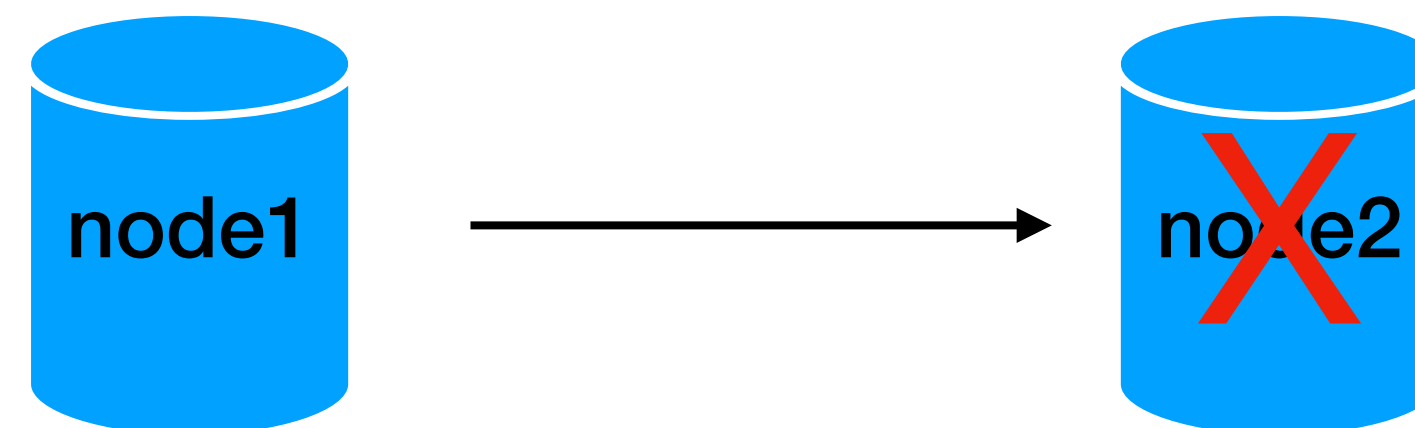
TLDR: You can only satisfy 2 out of 3
in a distributed database

Asynchronous network model

- Messages can be (randomly) delayed



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

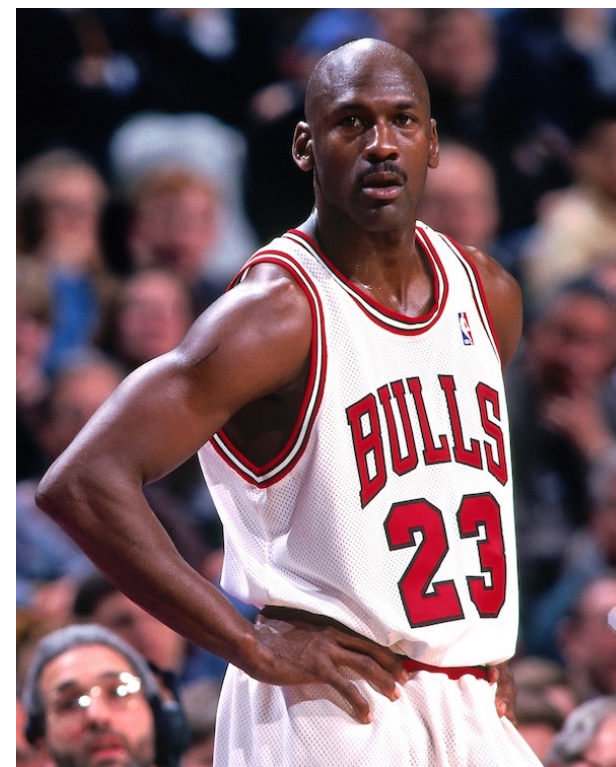


Consistency

- Every read receives the most recent write or an error

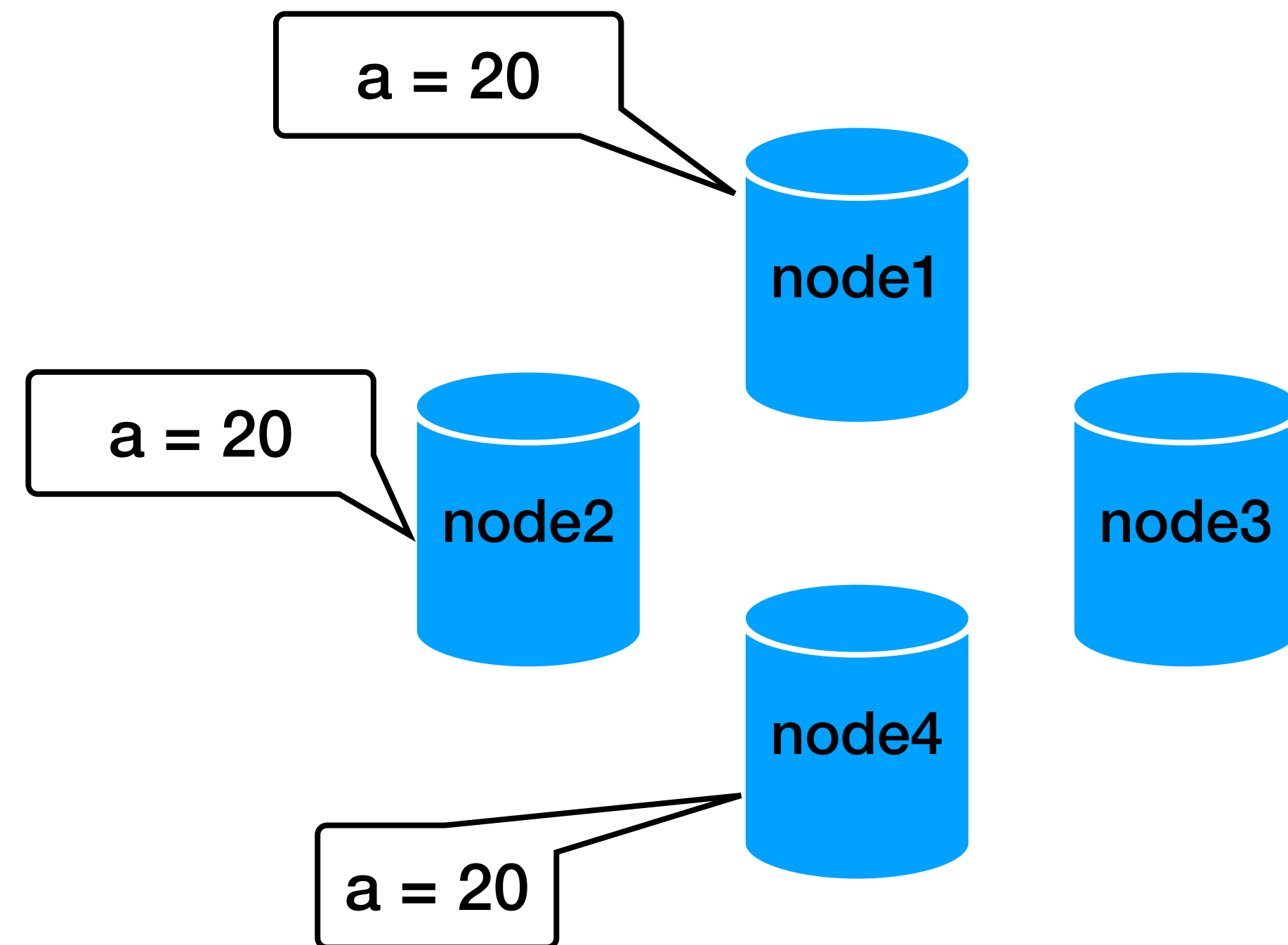
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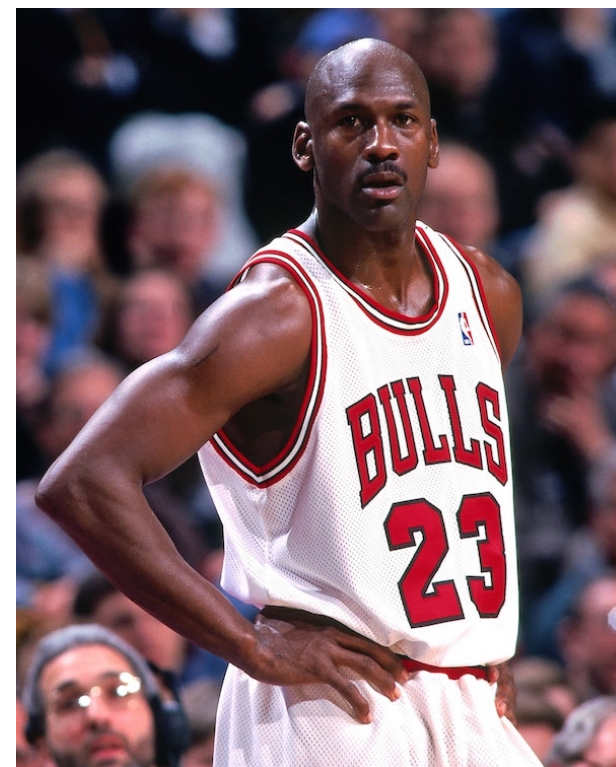
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* example for inconsistency



Consistency

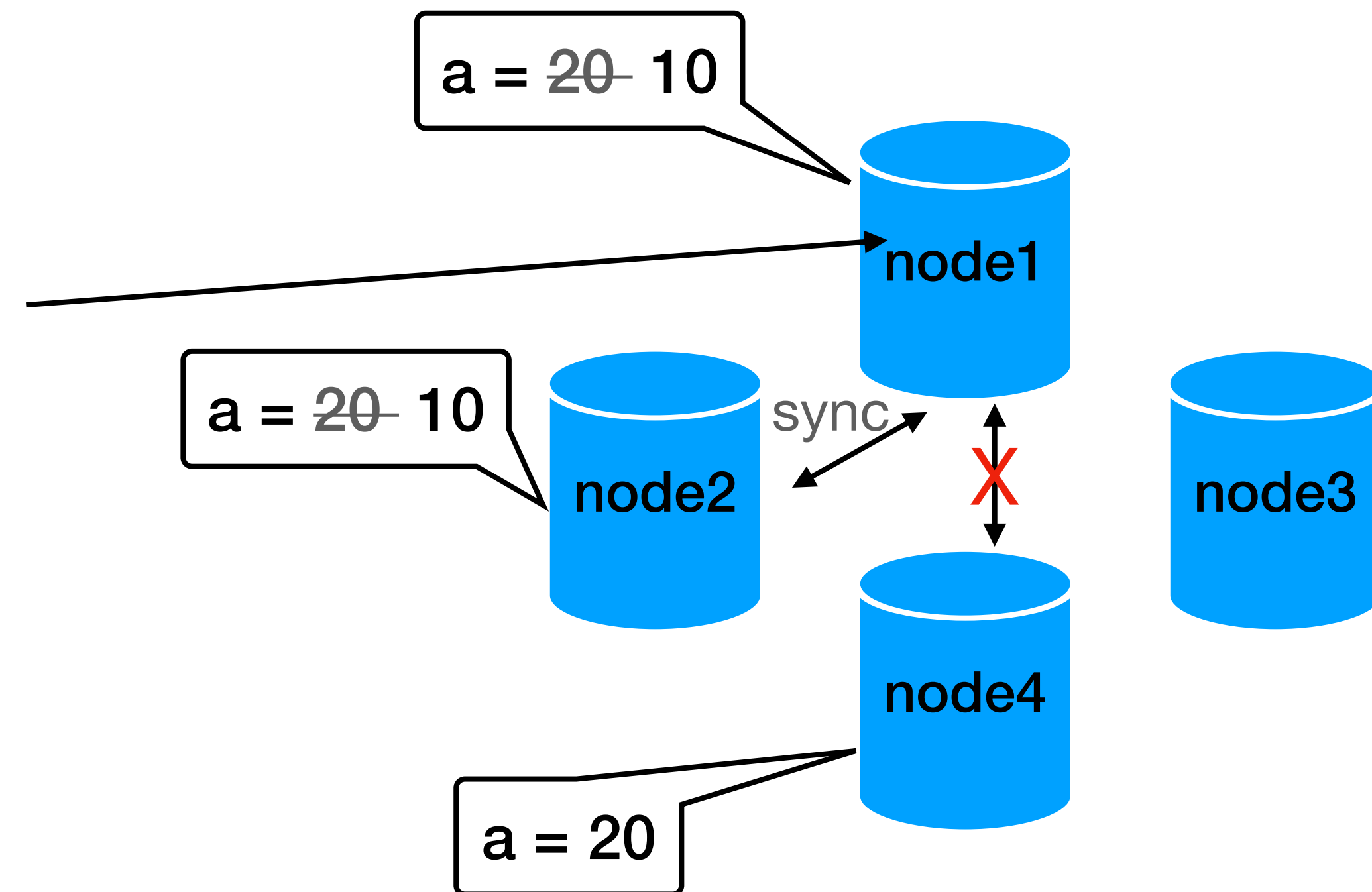
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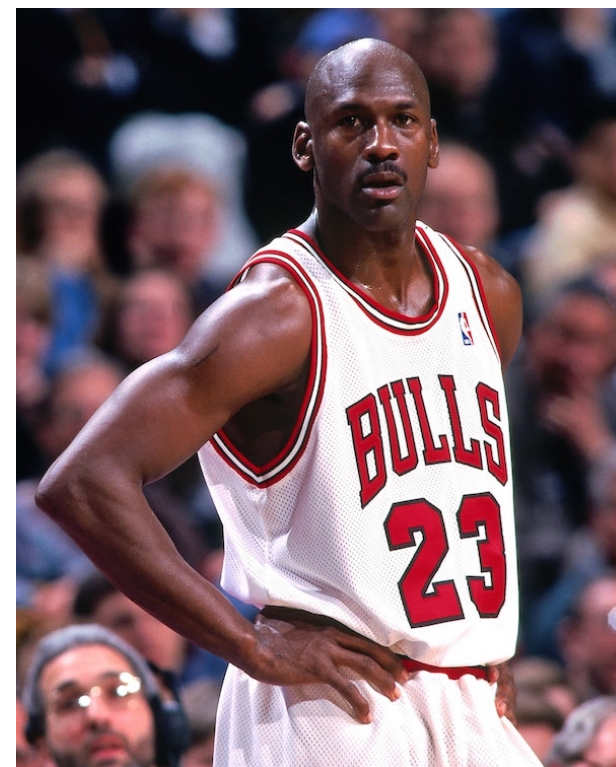
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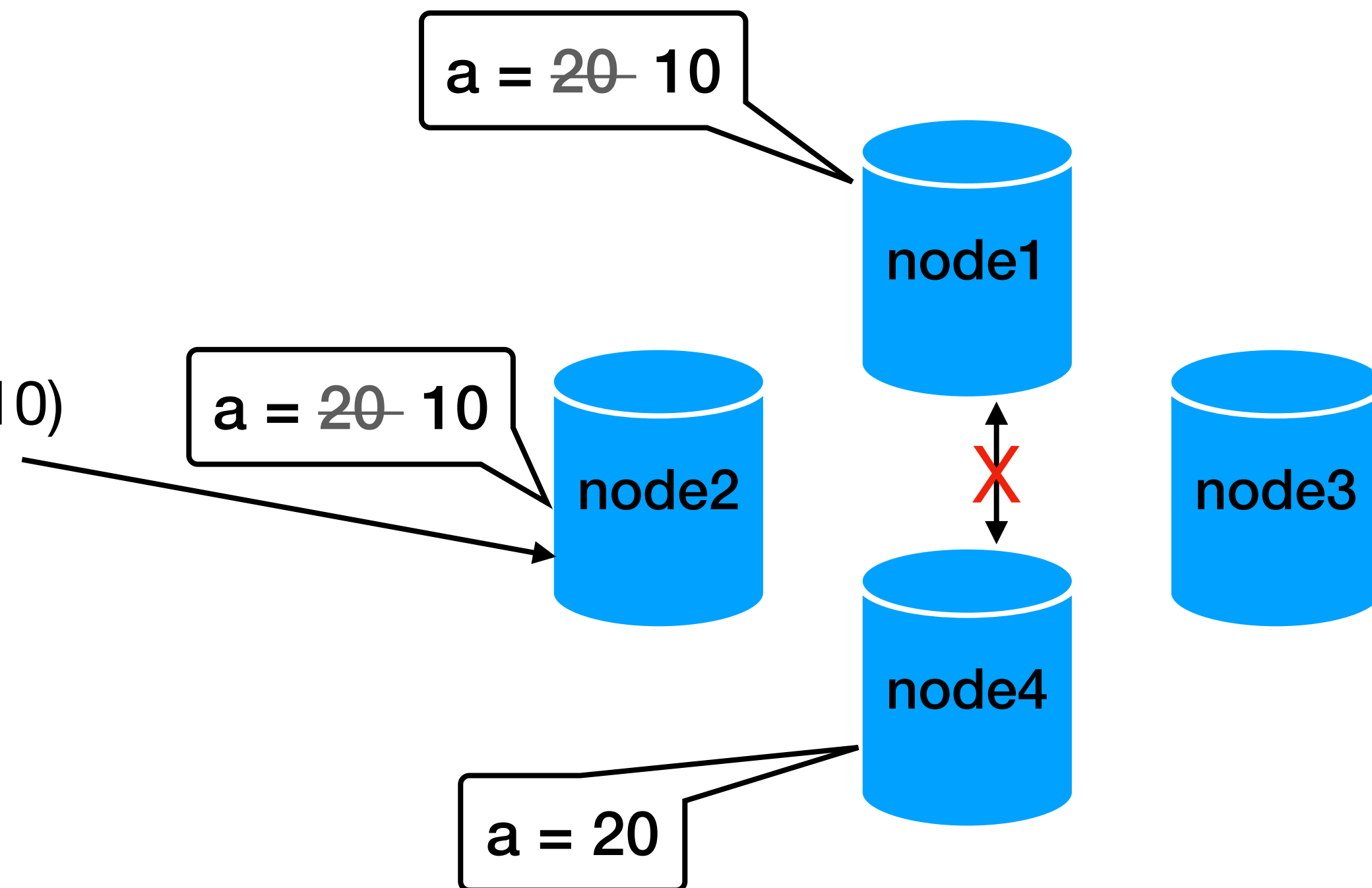


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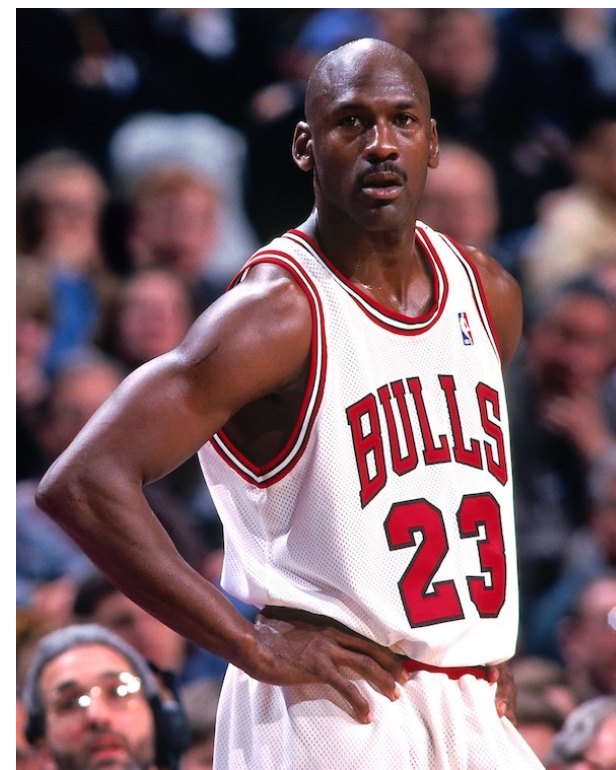
10:02: read a (value = 10)

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Consistency

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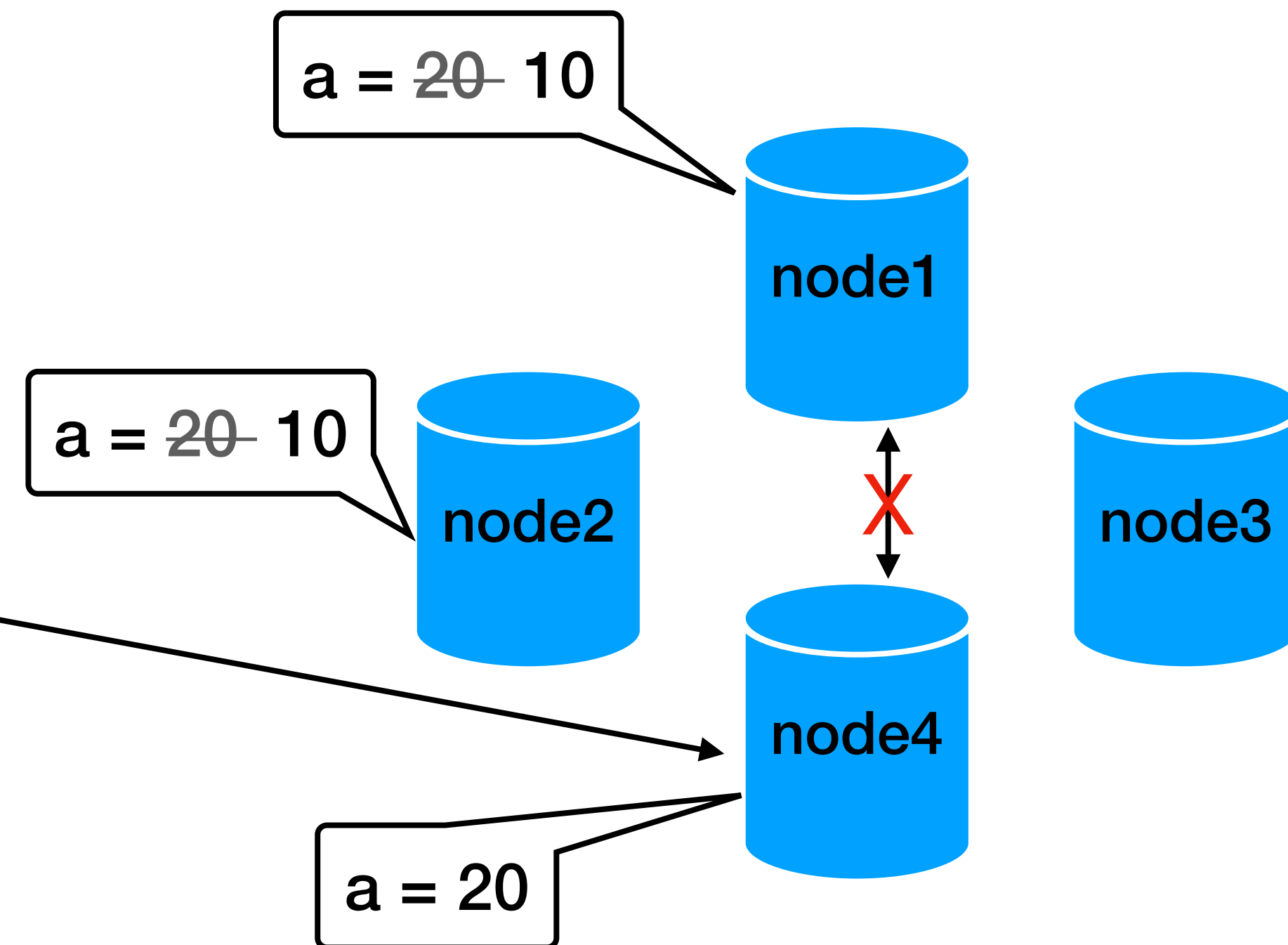
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* example for inconsistency



Consistency warning

Do not get confused with consistency from ACID

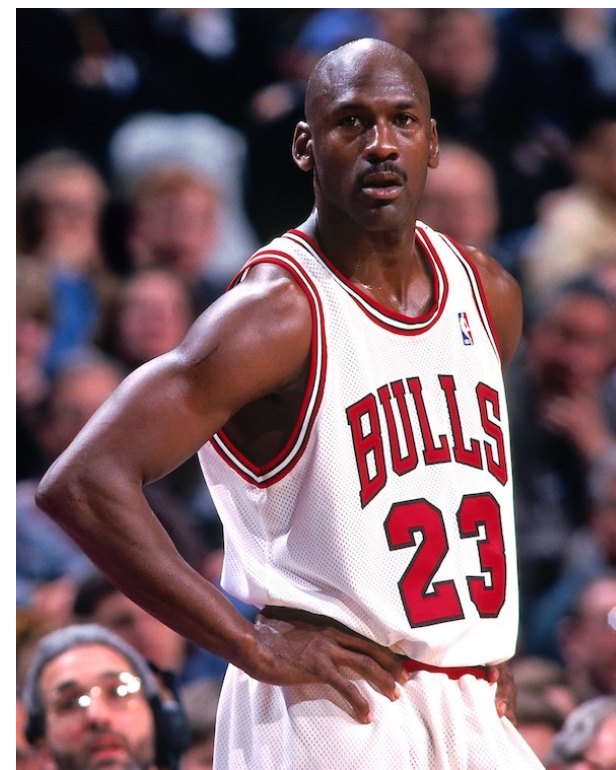
- **Atomicity**
- **Consistency**
correctness / referential integrity (foreign key)
- **Isolation**
- **Durability**

Availability

- All requests (read/write) receives a non-error response
for reads there is no guarantee that it contains the most recent write

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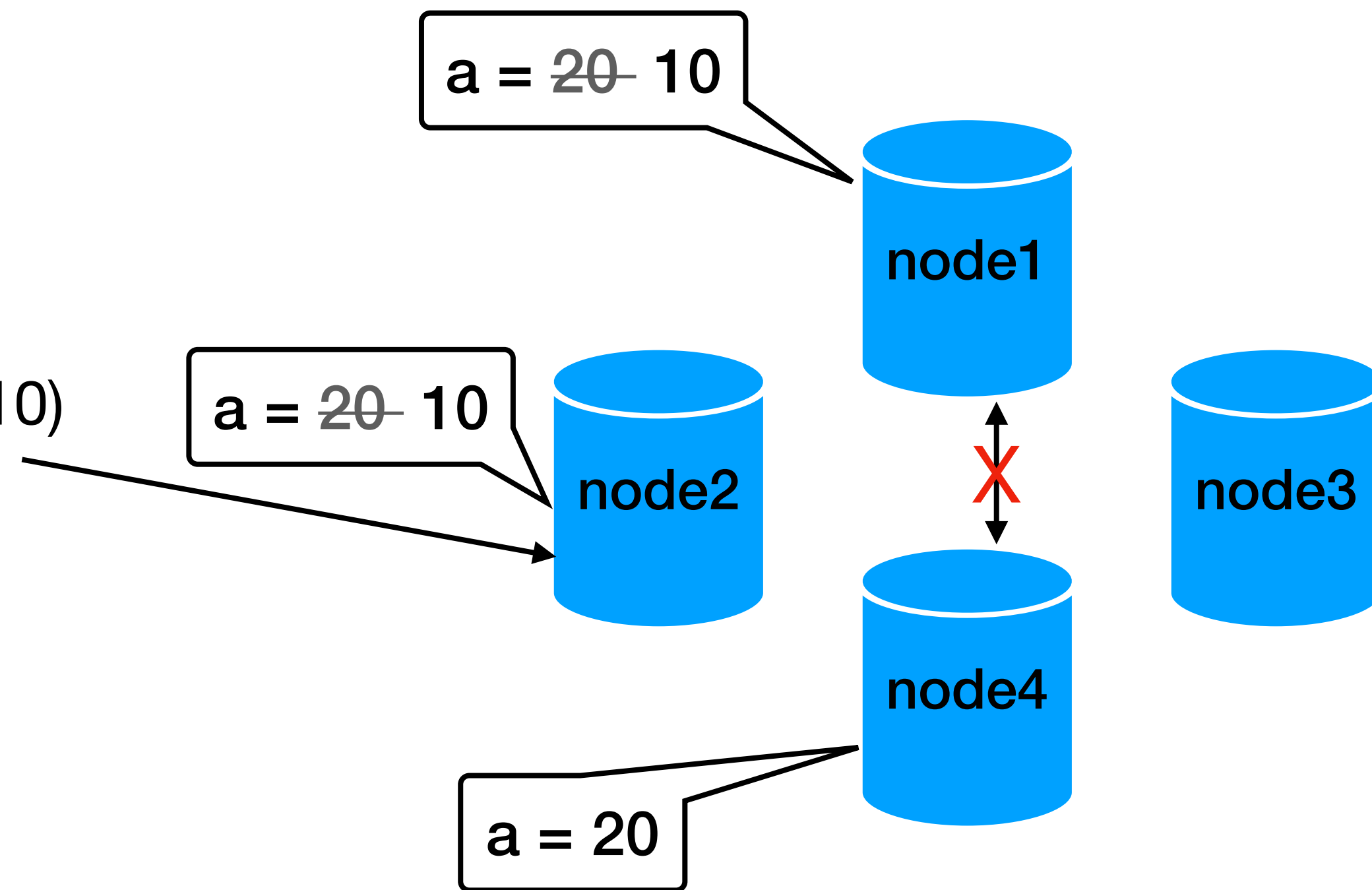


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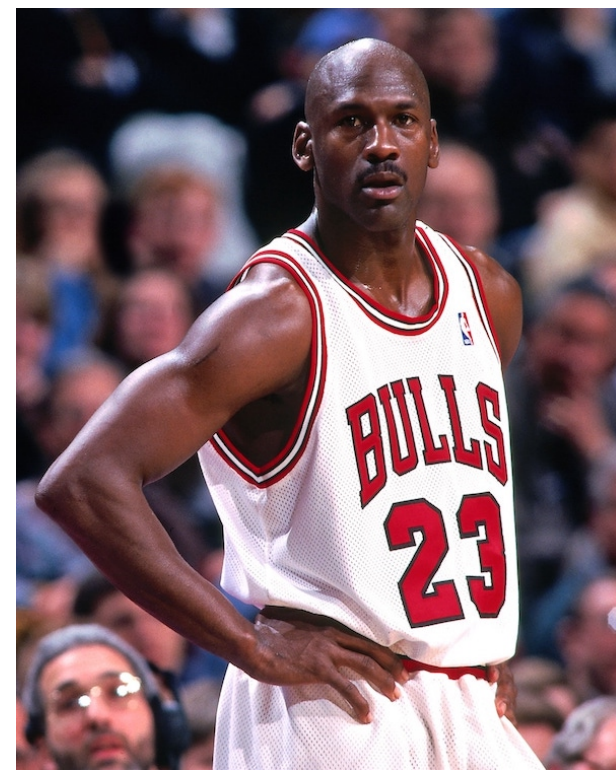
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(without consistency)



Availability

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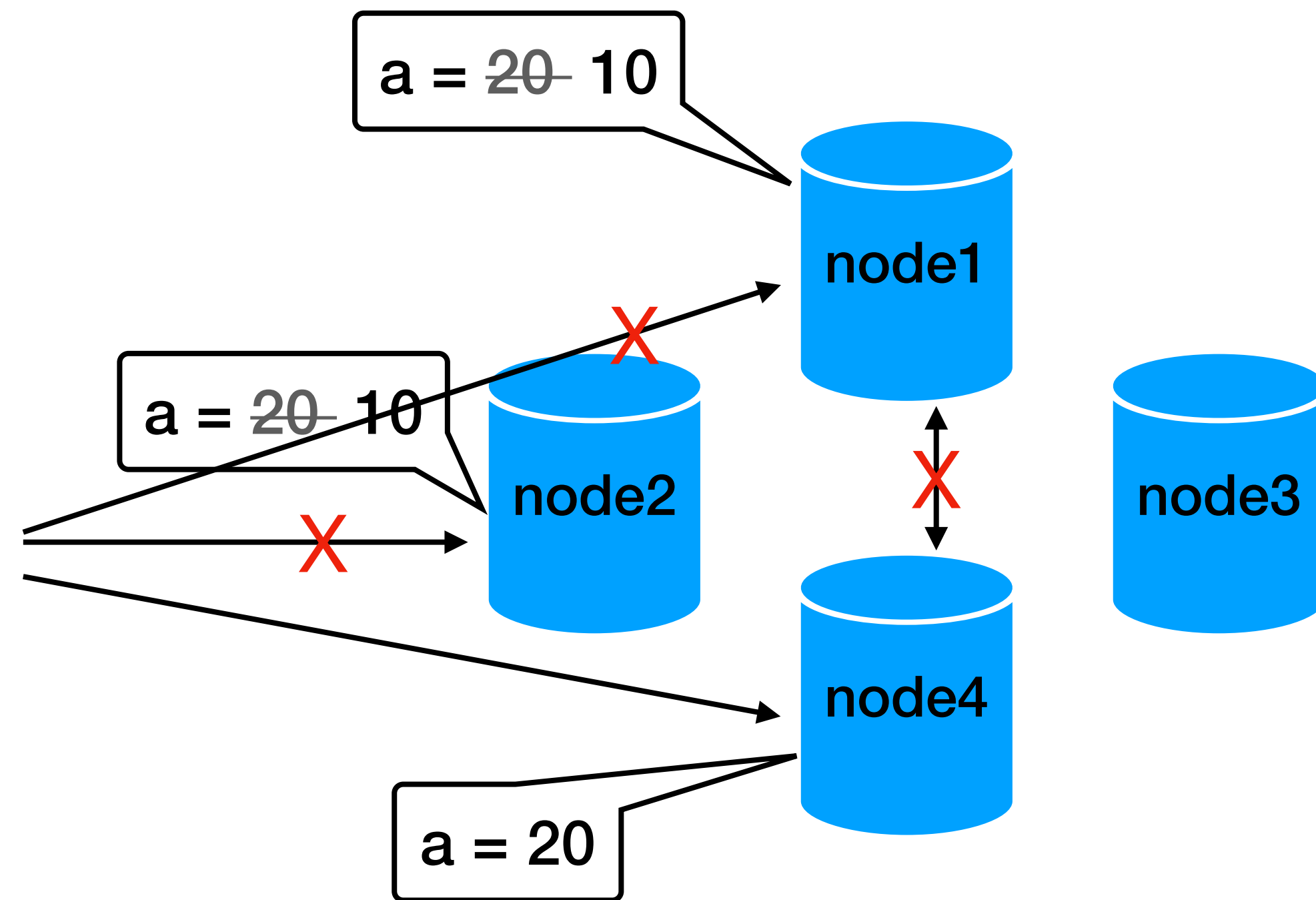
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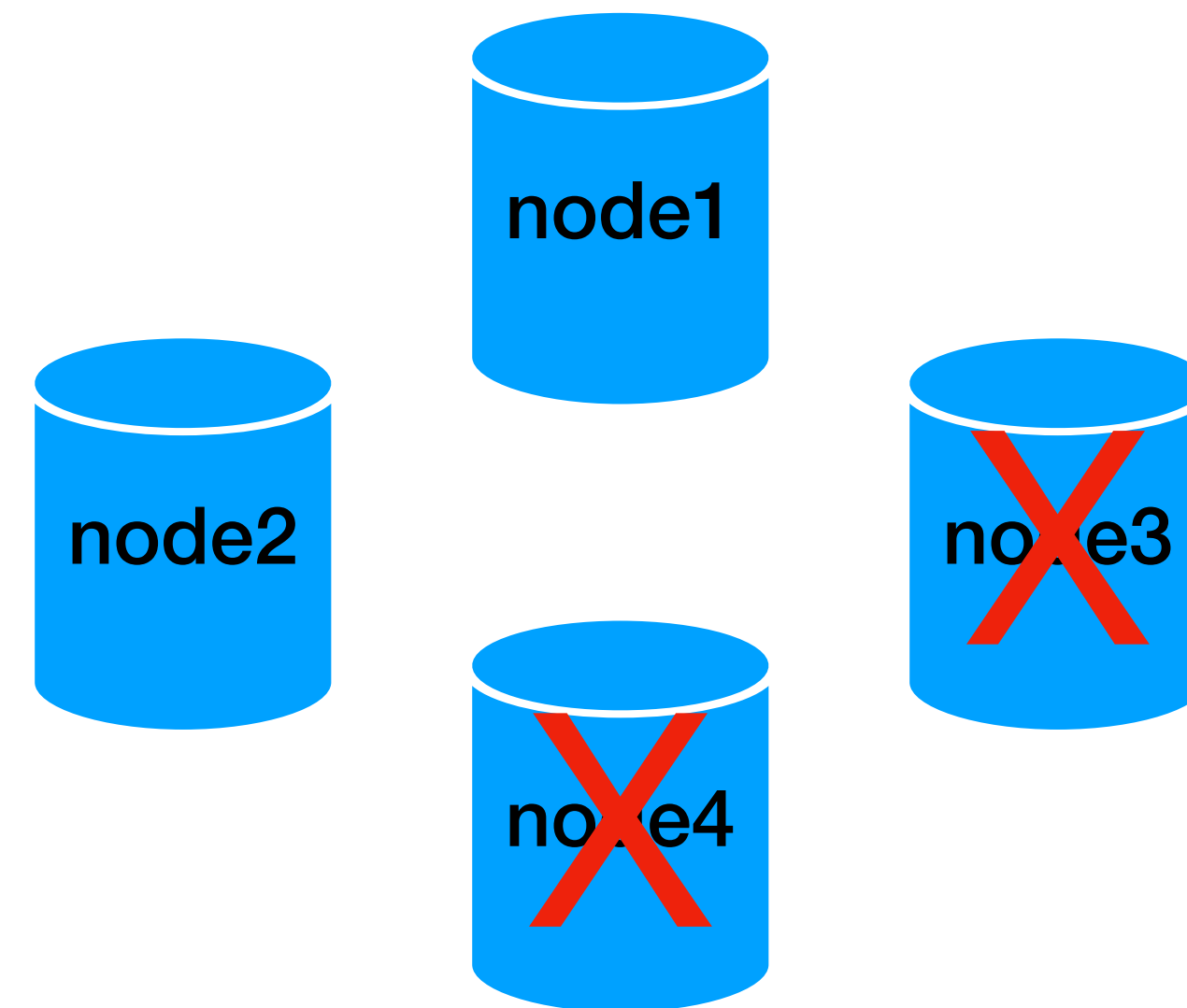
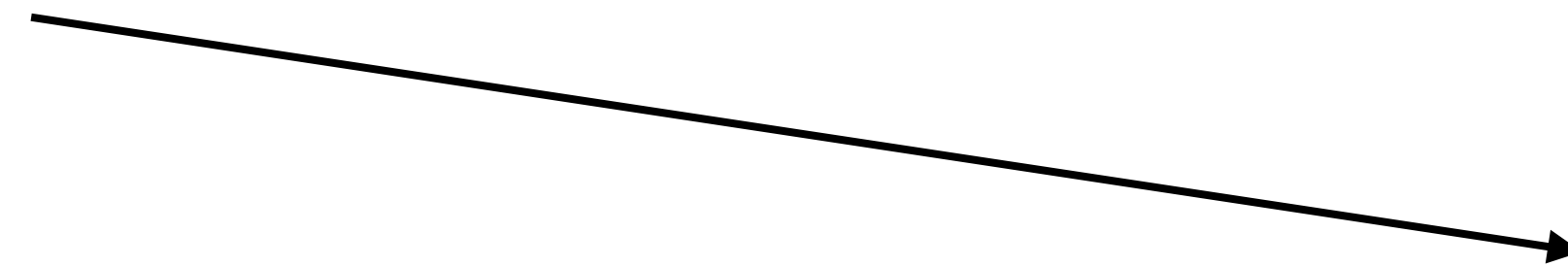
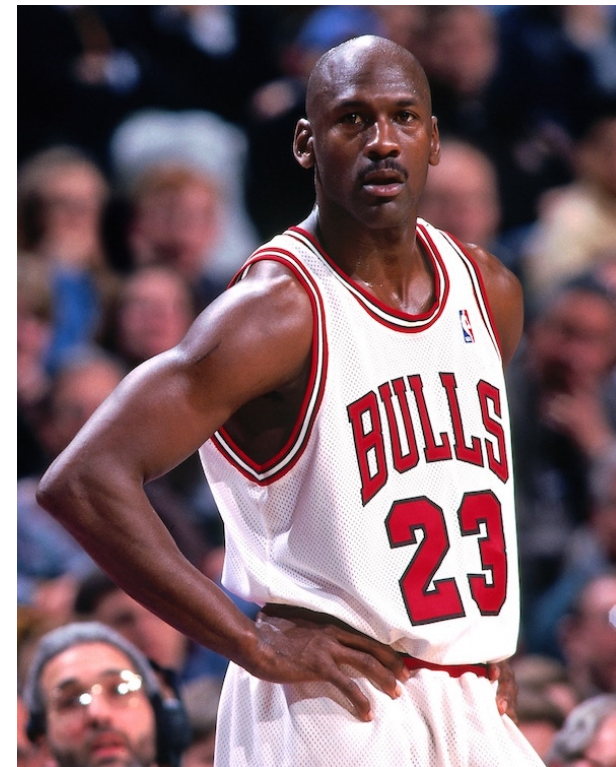


Partition tolerance

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

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



* 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**

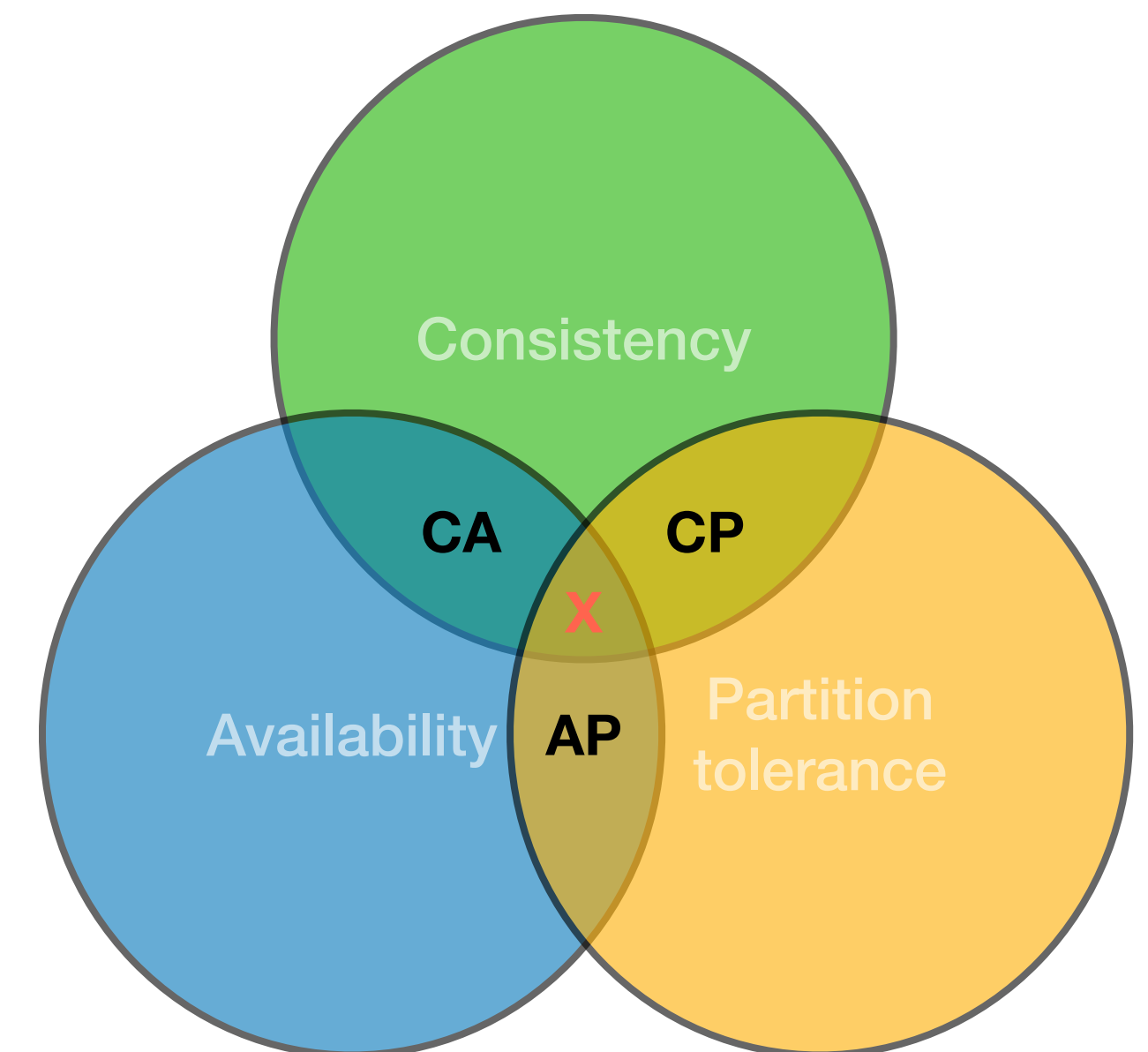
Every read receives the most recent write or an error

- **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
how can we detect / force consistency?

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how they observe updates?

how it affects the application logic?

- **From server side**

how can we detect / force consistency?

Application side consistency



DNS Server

Which consistency type
do we need?

Application side consistency



DNS Server

Weak / Eventual consistency

Application side consistency



Bank

Which consistency type
do we need?

Application side consistency



Bank

Strong consistency

Application side consistency



Bank

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?

how it affects the application logic?

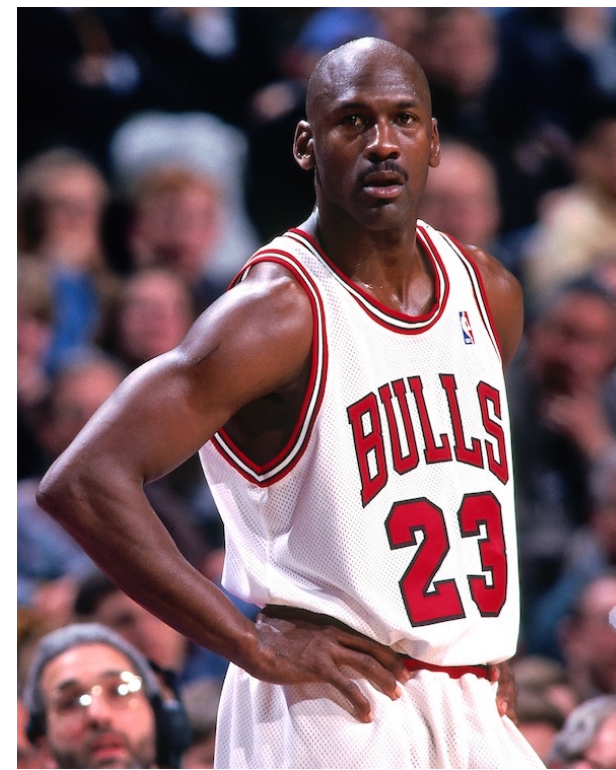
- **From server side**

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

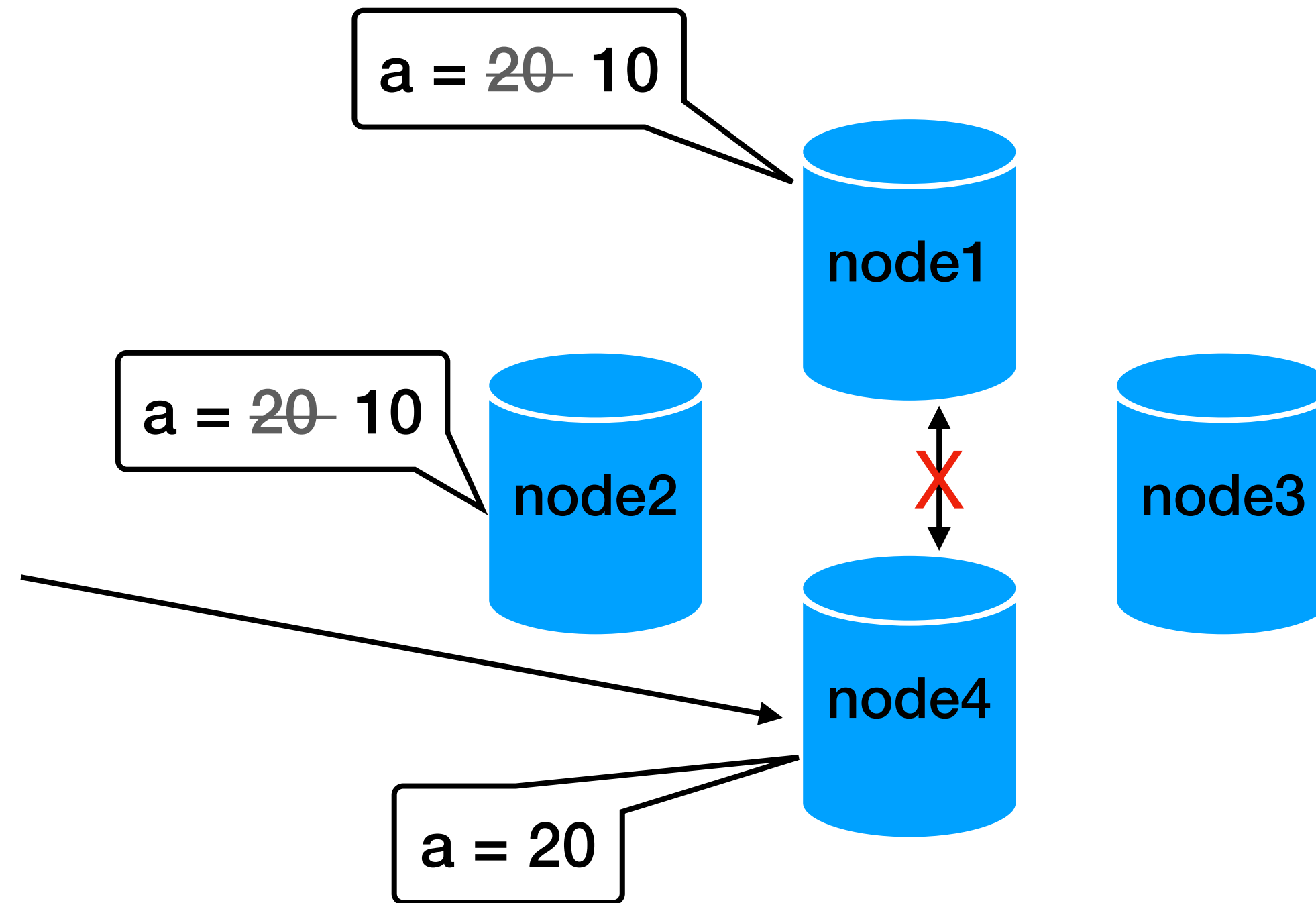


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Server side consistency

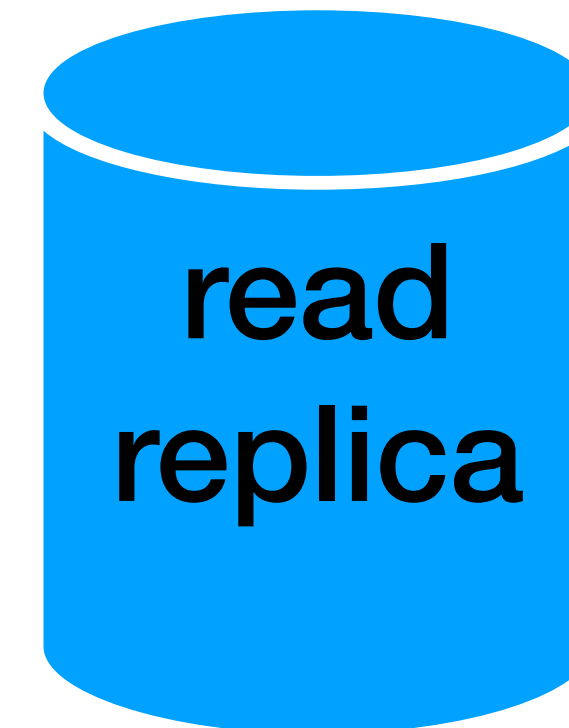
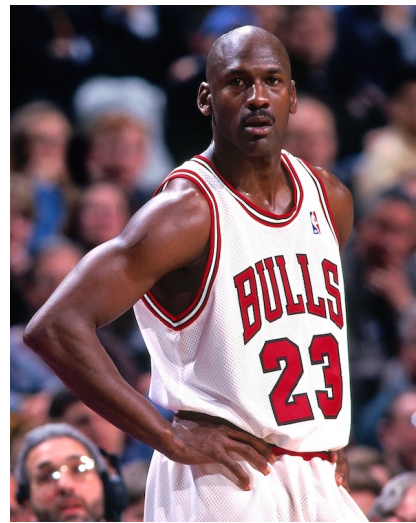
- **N** #nodes that store replicas of the data
- **W** #replicas that need to acknowledge the receipt of the update before the update completes
- **R** #replicas that are contacted for a read

If $W+R > N$ then strong consistency is guaranteed

If $W+R \leq N$ then weak / eventual consistency

Server side consistency - example 1

- Master + read replica RDBMS



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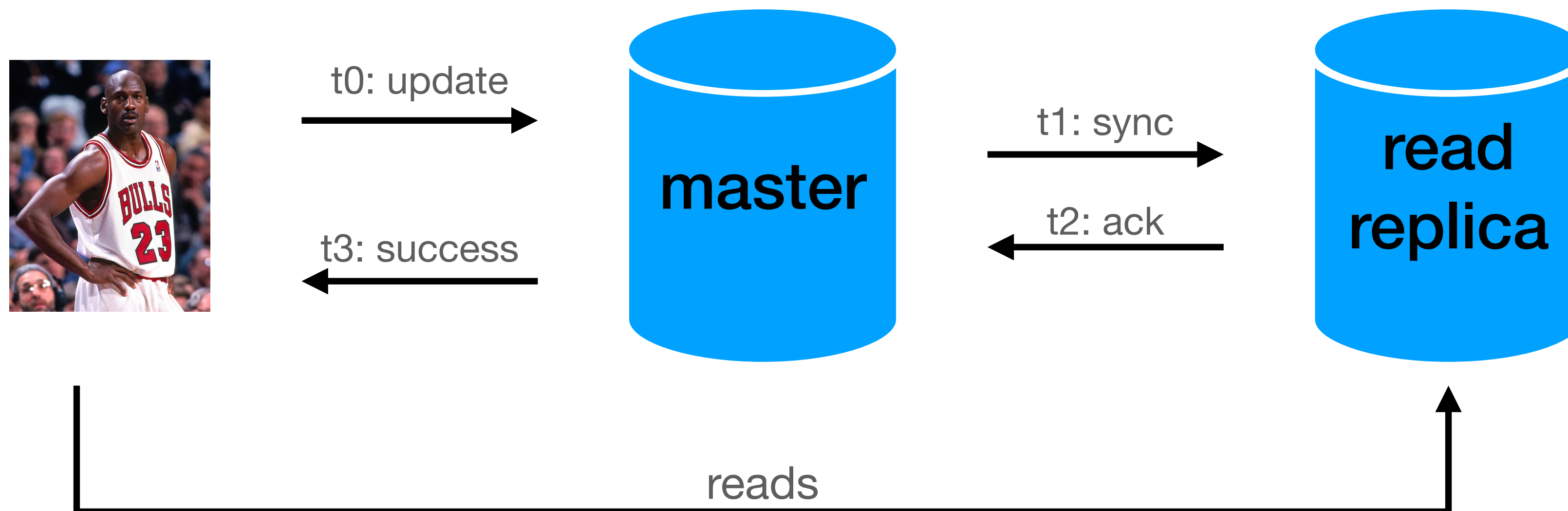
Server side consistency - example 1

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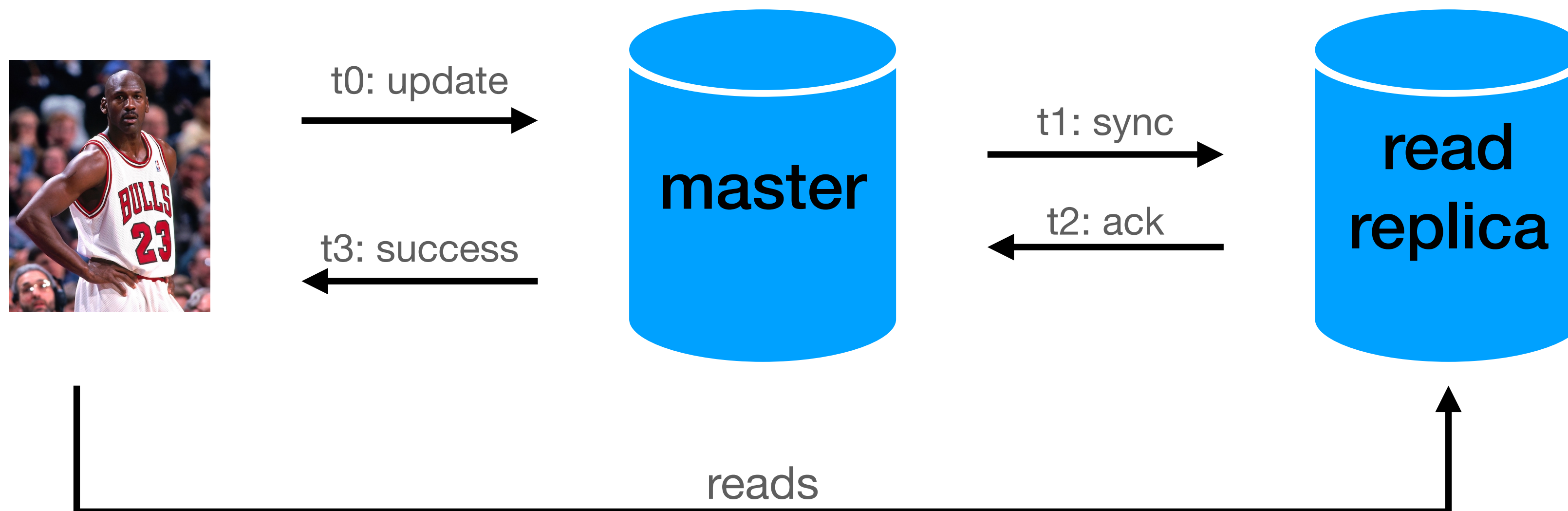
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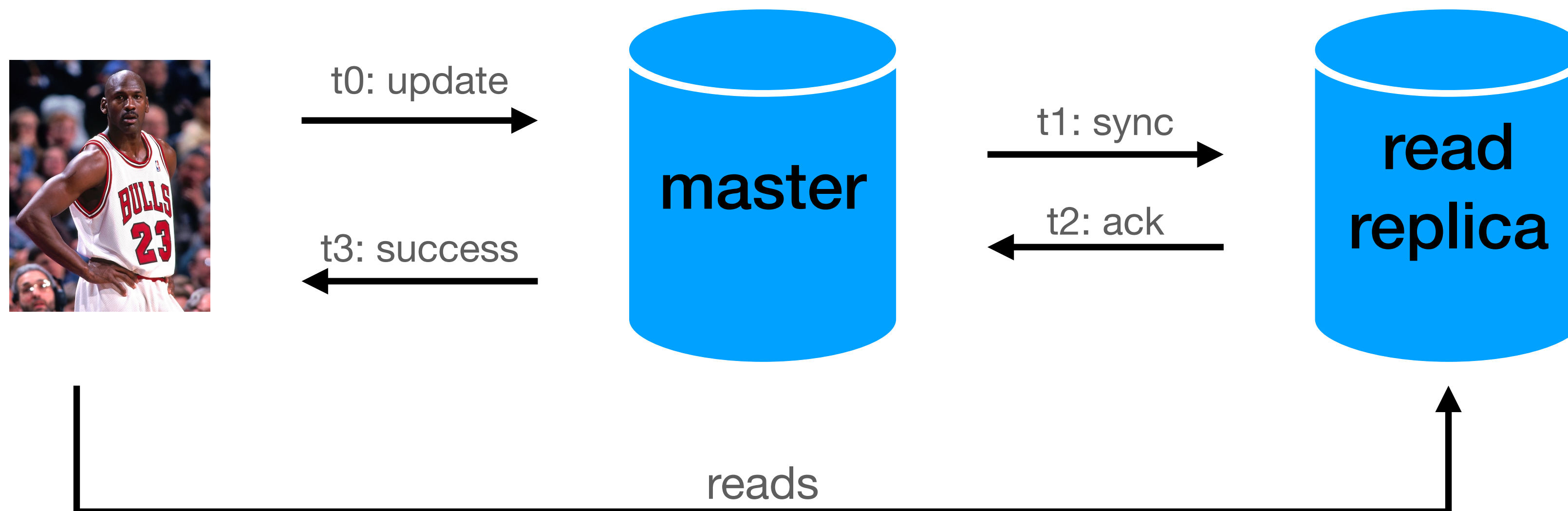
- Master + read replica RDBMS



$W(2) + R(1) > N(2)$
strong consistency

Server side consistency - example 1

- Master + read replica RDBMS



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strong consistency

What happens if the
read replica fails?

Server side consistency - example 1

- Master + read replica RDBMS



Server side consistency - example 1

- Master + read replica RDBMS



Server side consistency - example 1

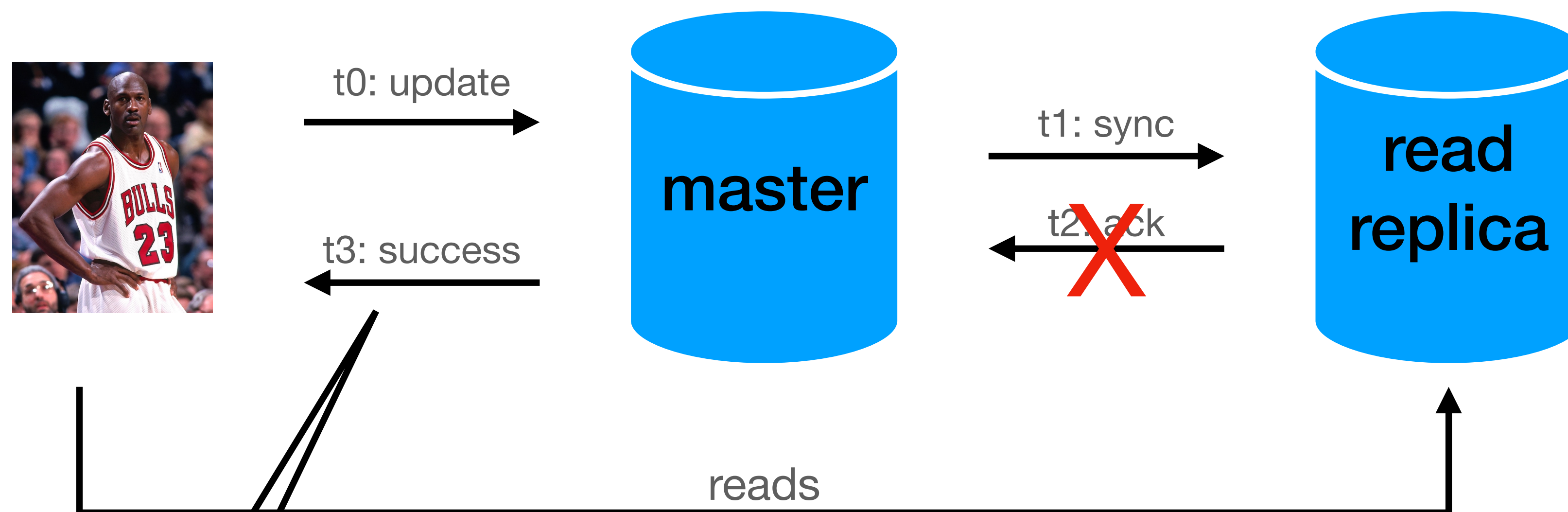
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Assume we do not need to get ack from the read replica to return success

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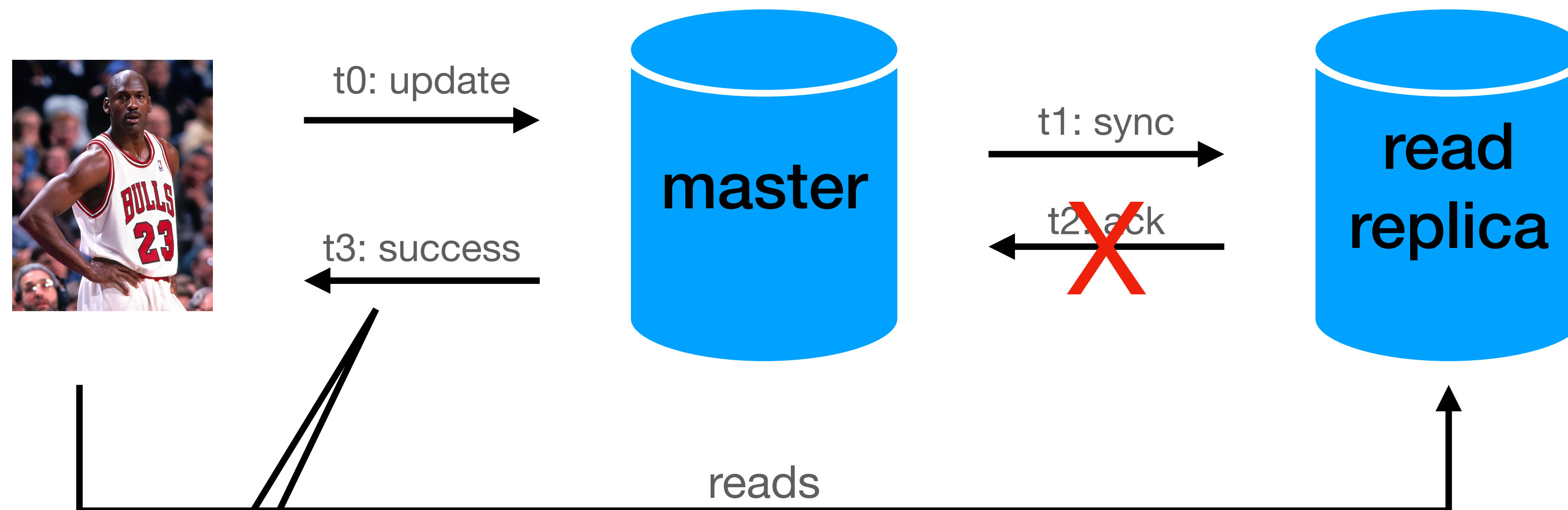
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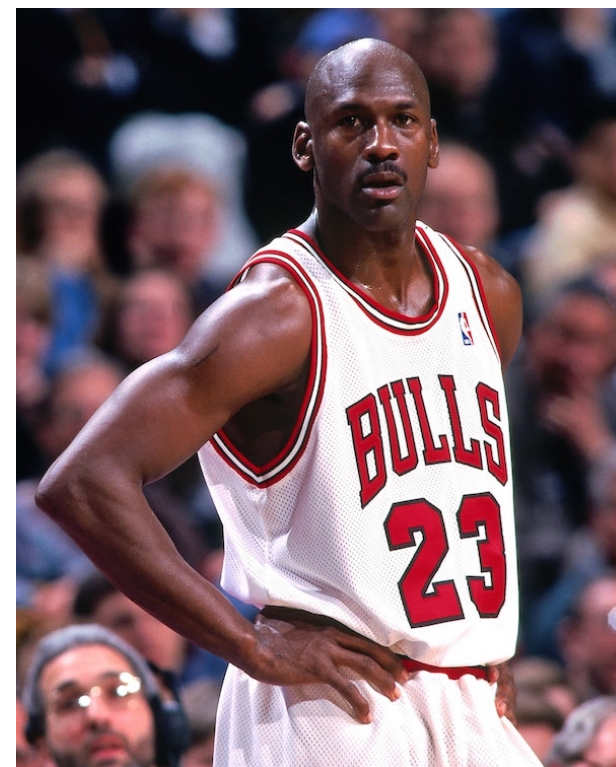
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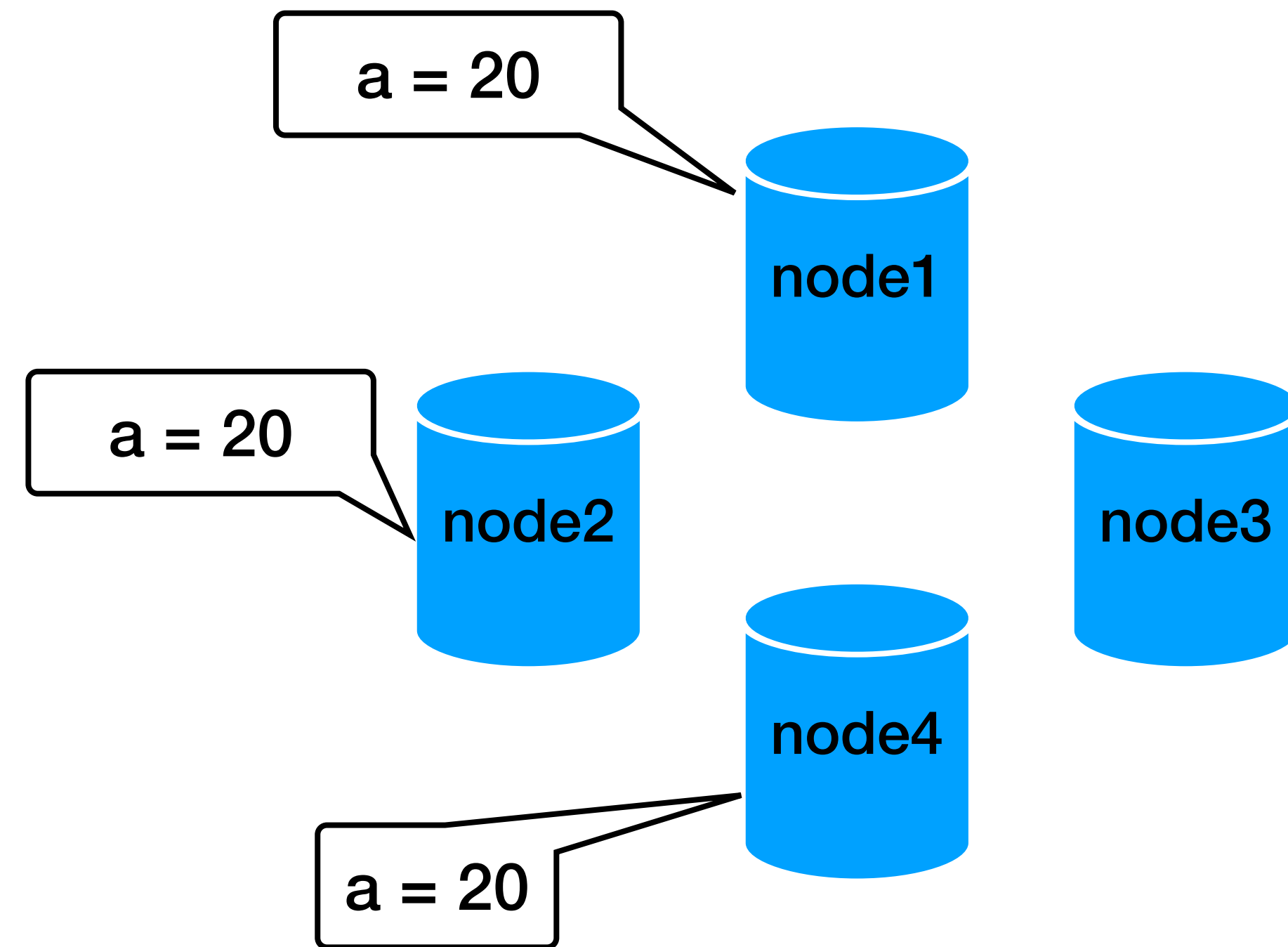
Server side consistency - example 2

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



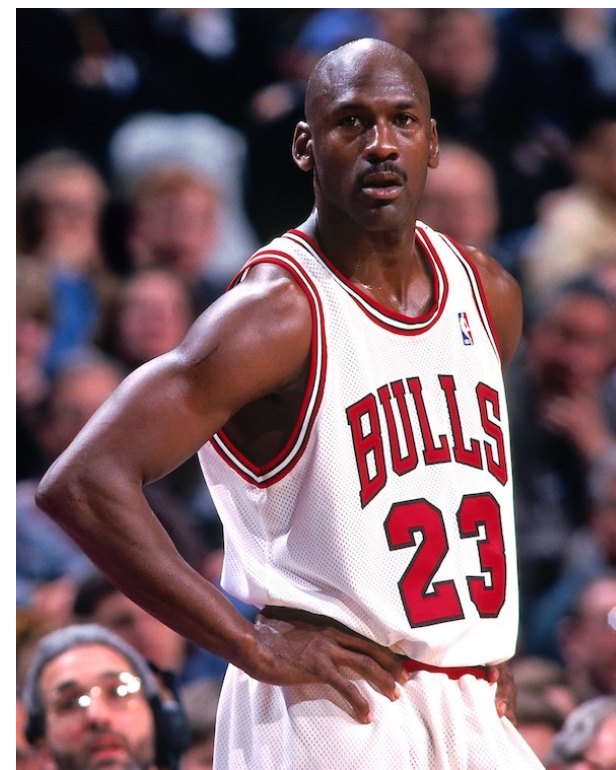
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* example for availability



Server side consistency - example 2

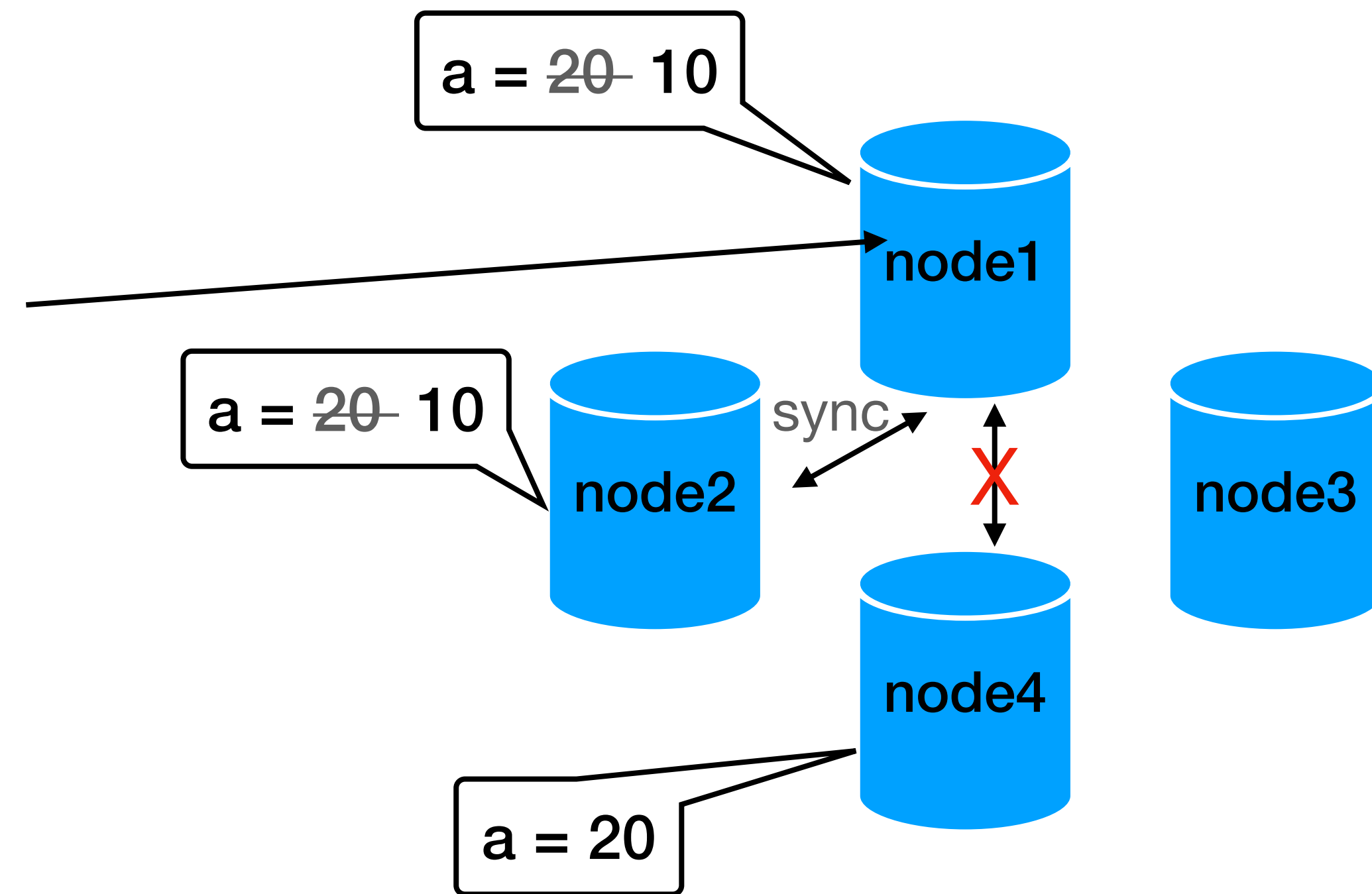
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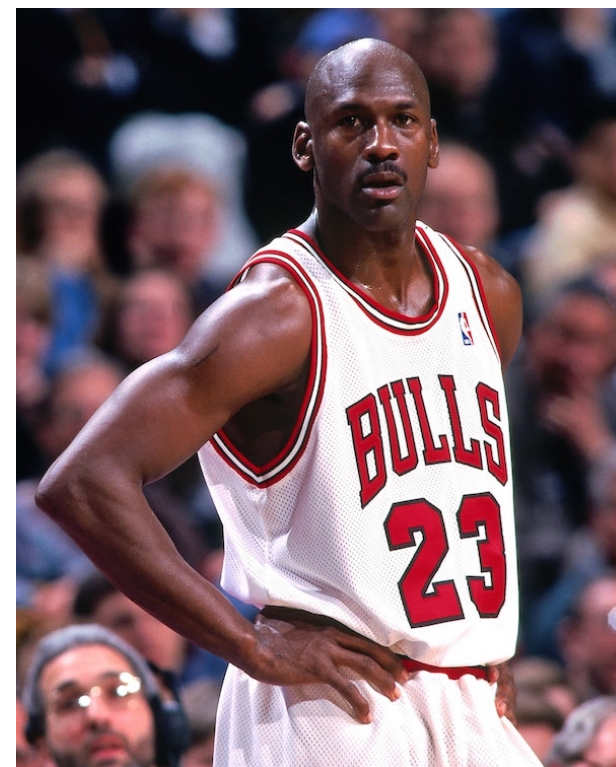
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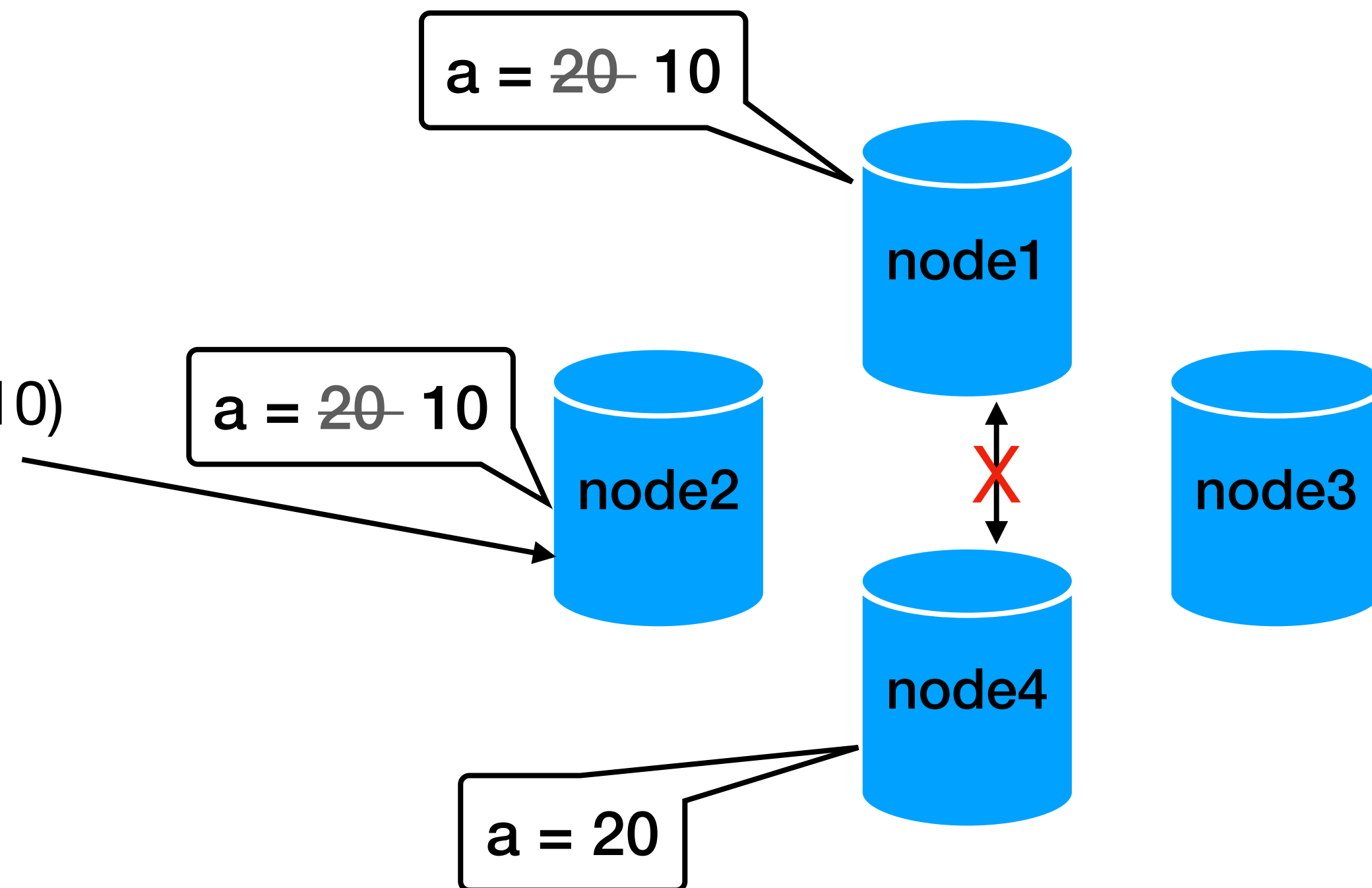


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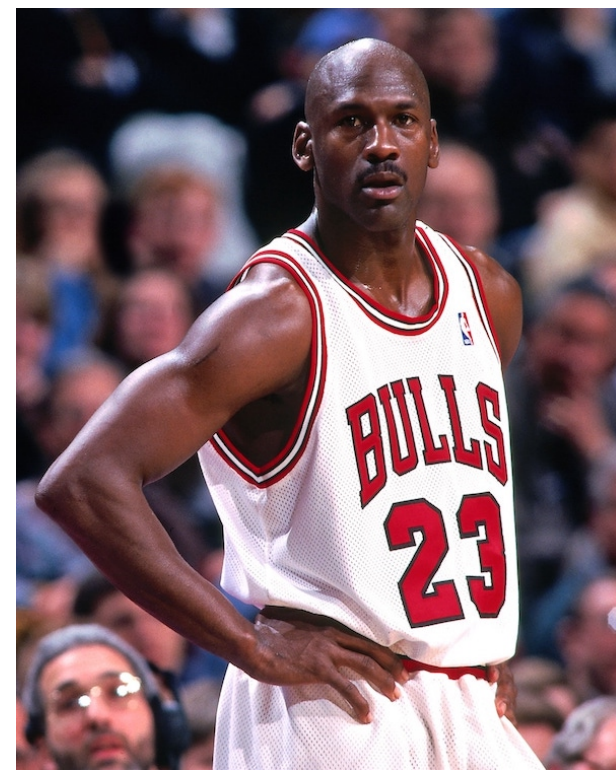
10:02: read a (value = 10)

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Server side consistency - example 2

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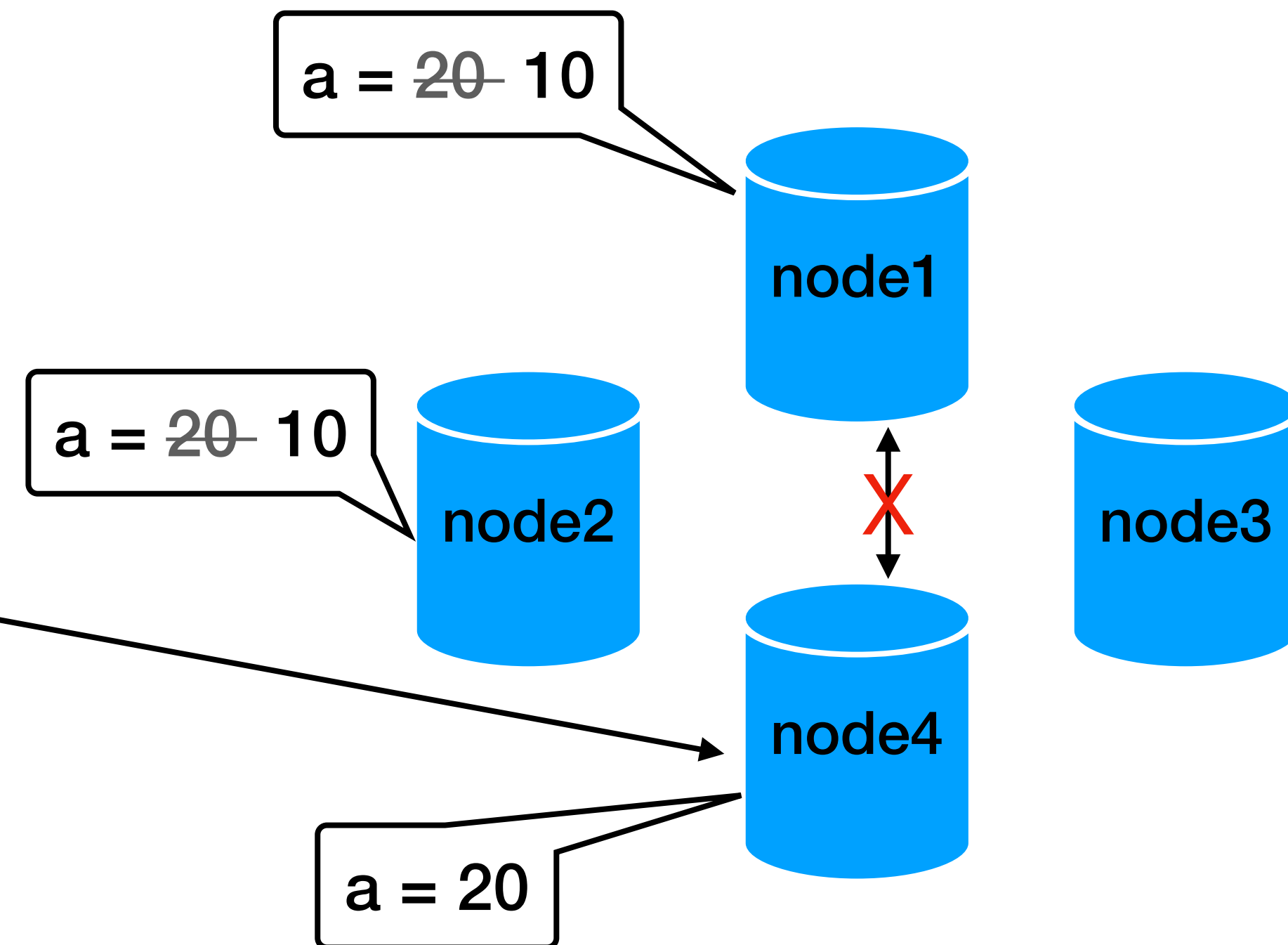
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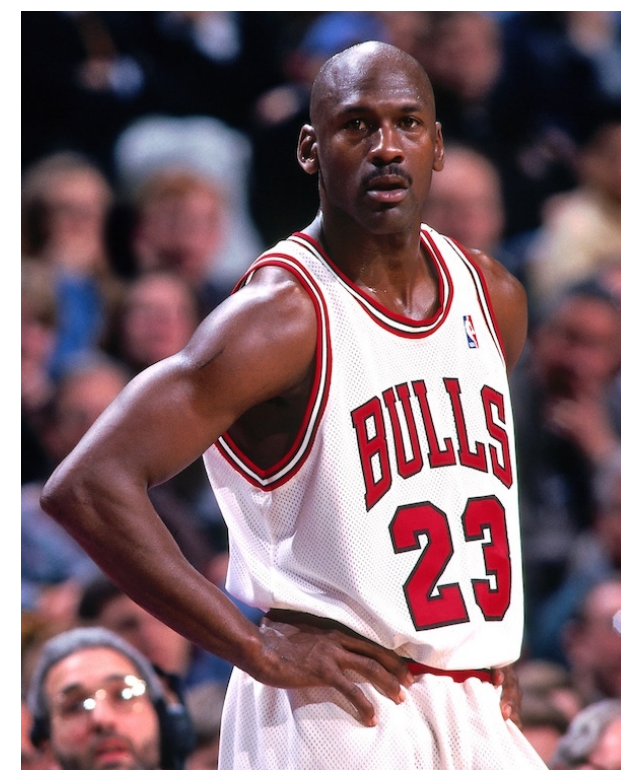
10:03: read a (value = 20)

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Server side consistency - example 2

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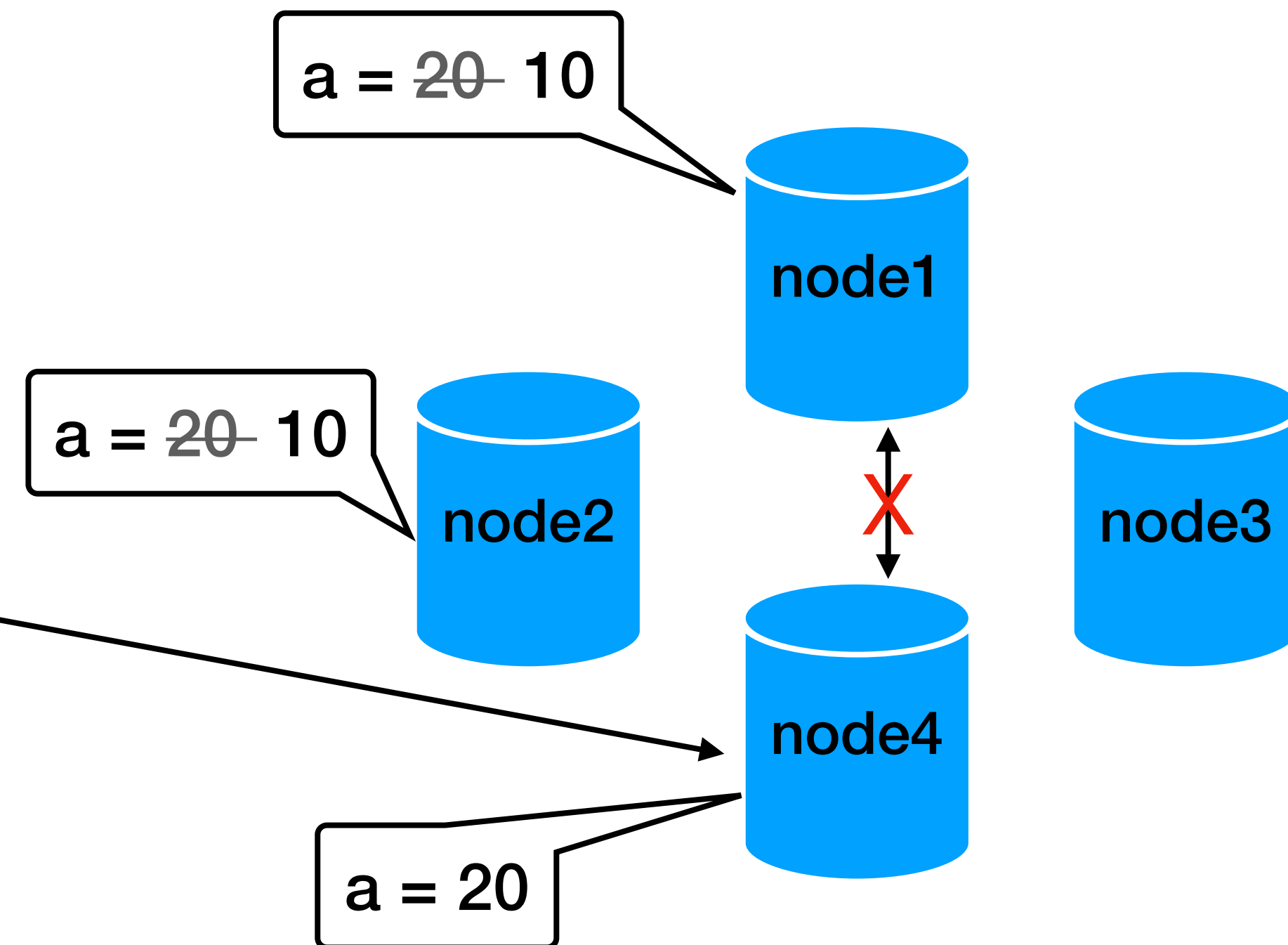
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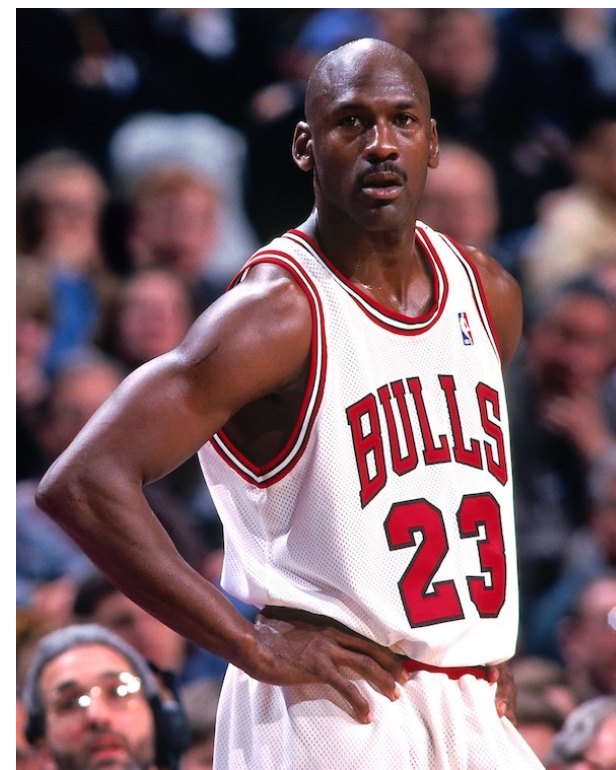
* example for availability



$W(1) + R(1) \leq N(3)$
weak / eventual consistency

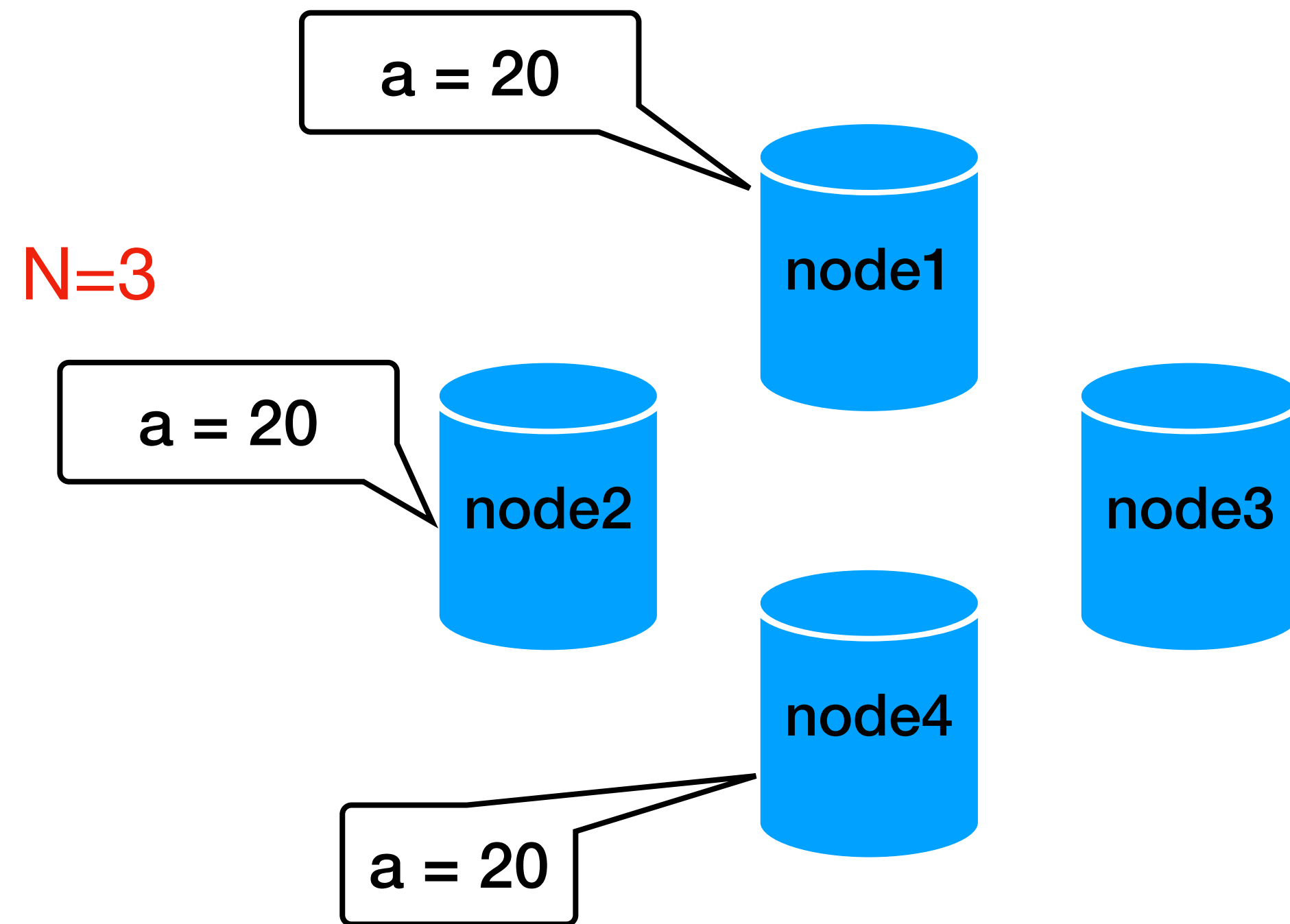
Server side consistency - example 3

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



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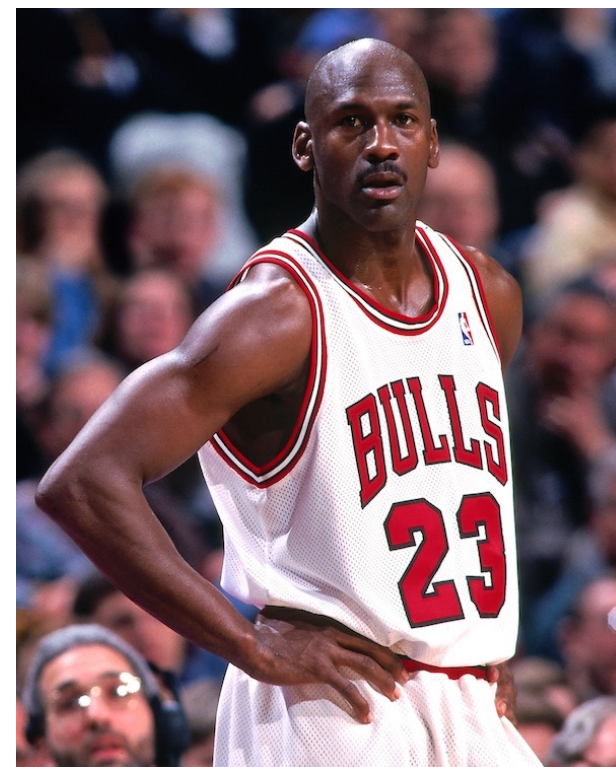
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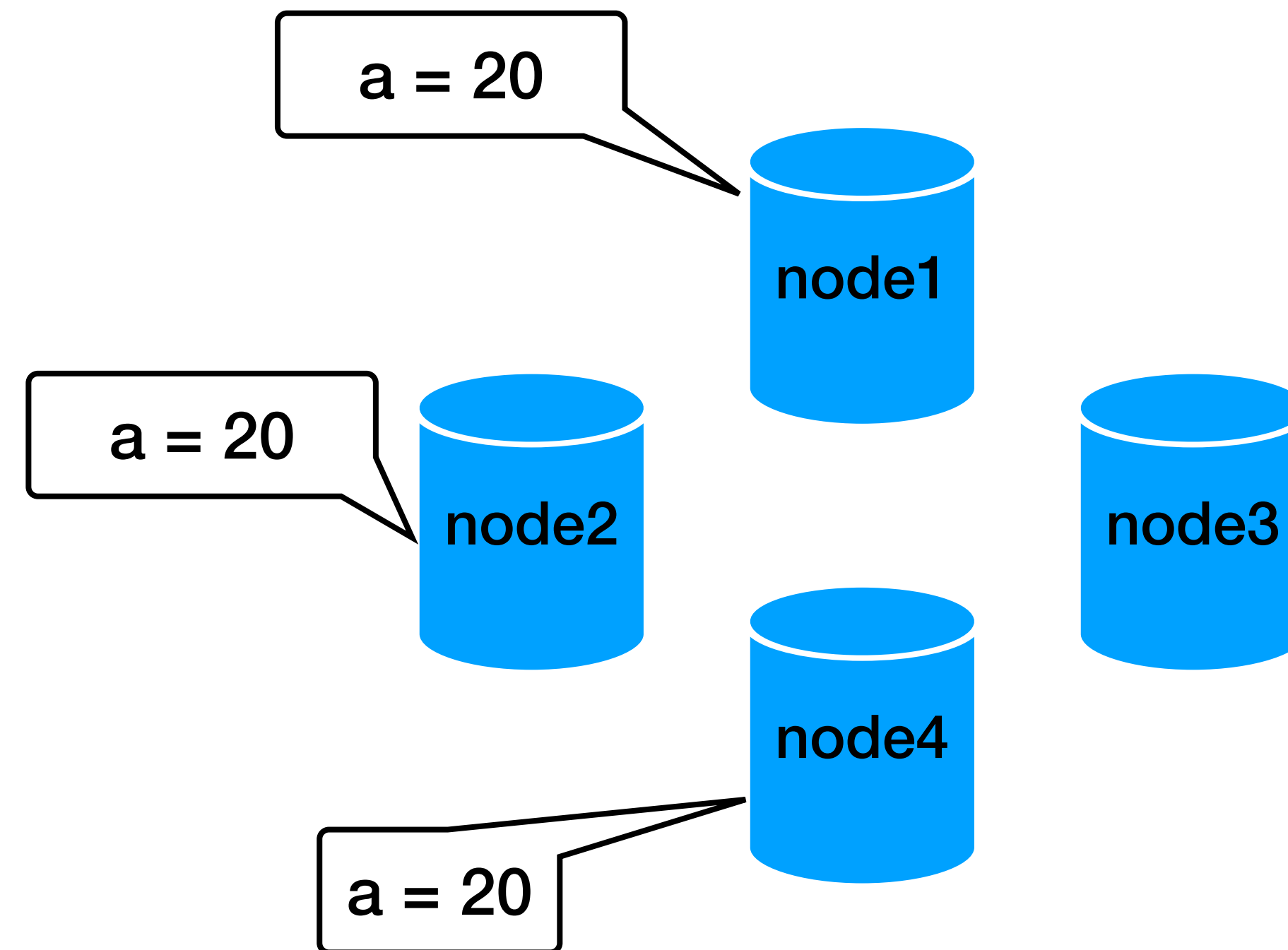
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What is quorum ack?



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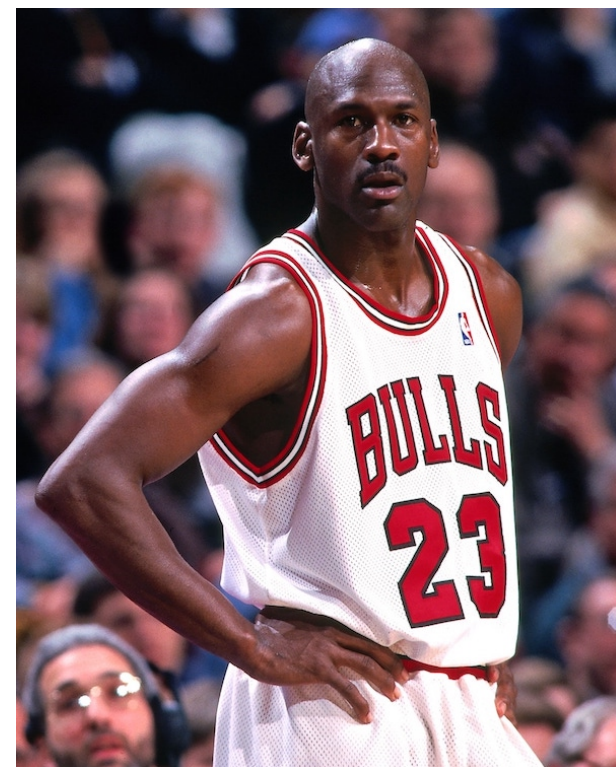
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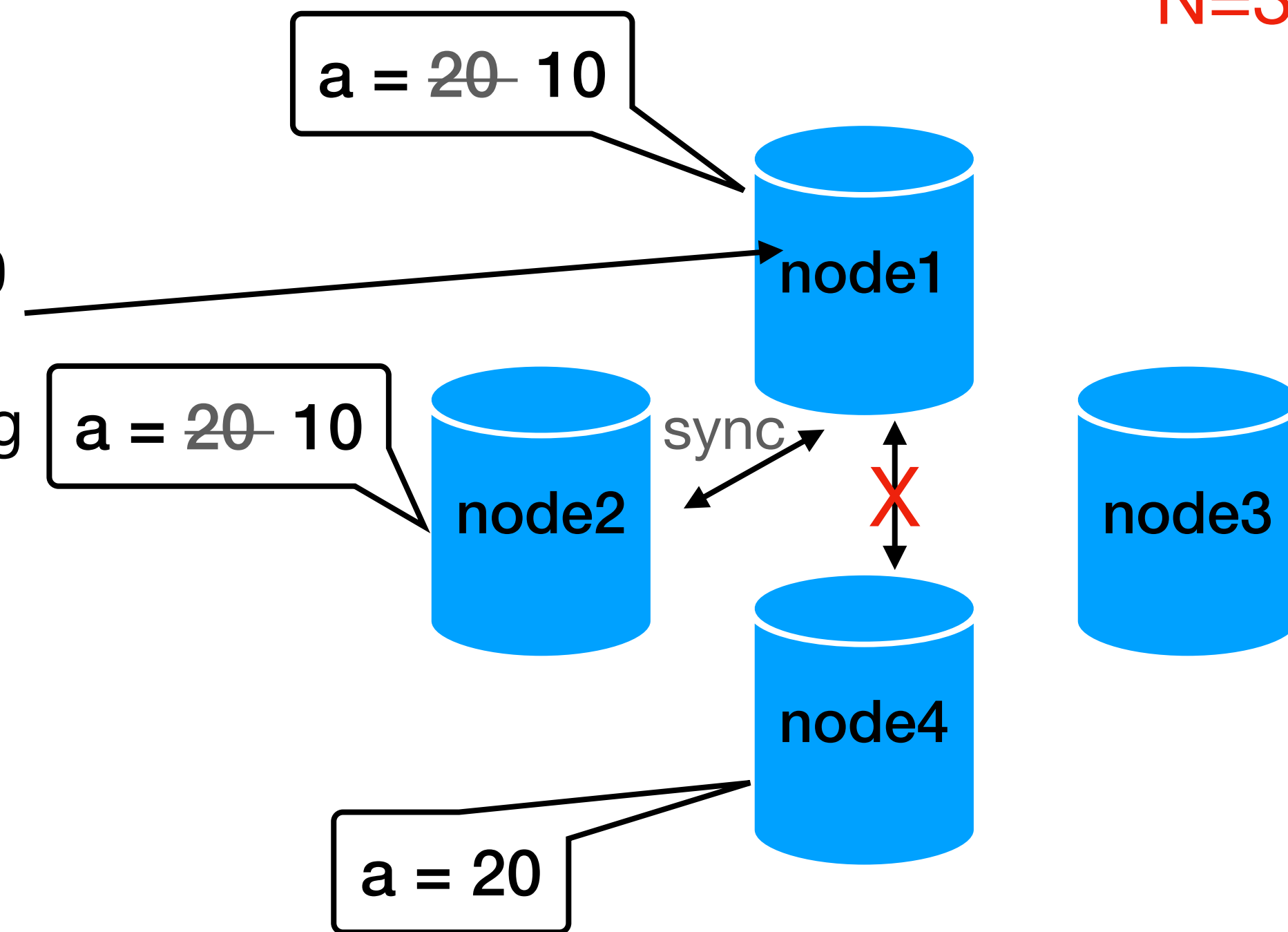


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10:01: update node1 $a = 10$

—> node2 returned ack
node4 is not responding

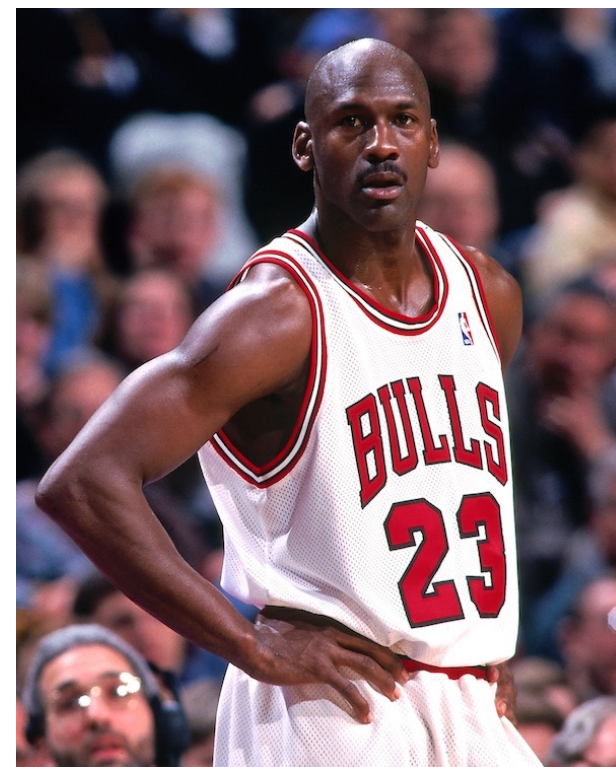
—> **return success**



Server side consistency - example 3

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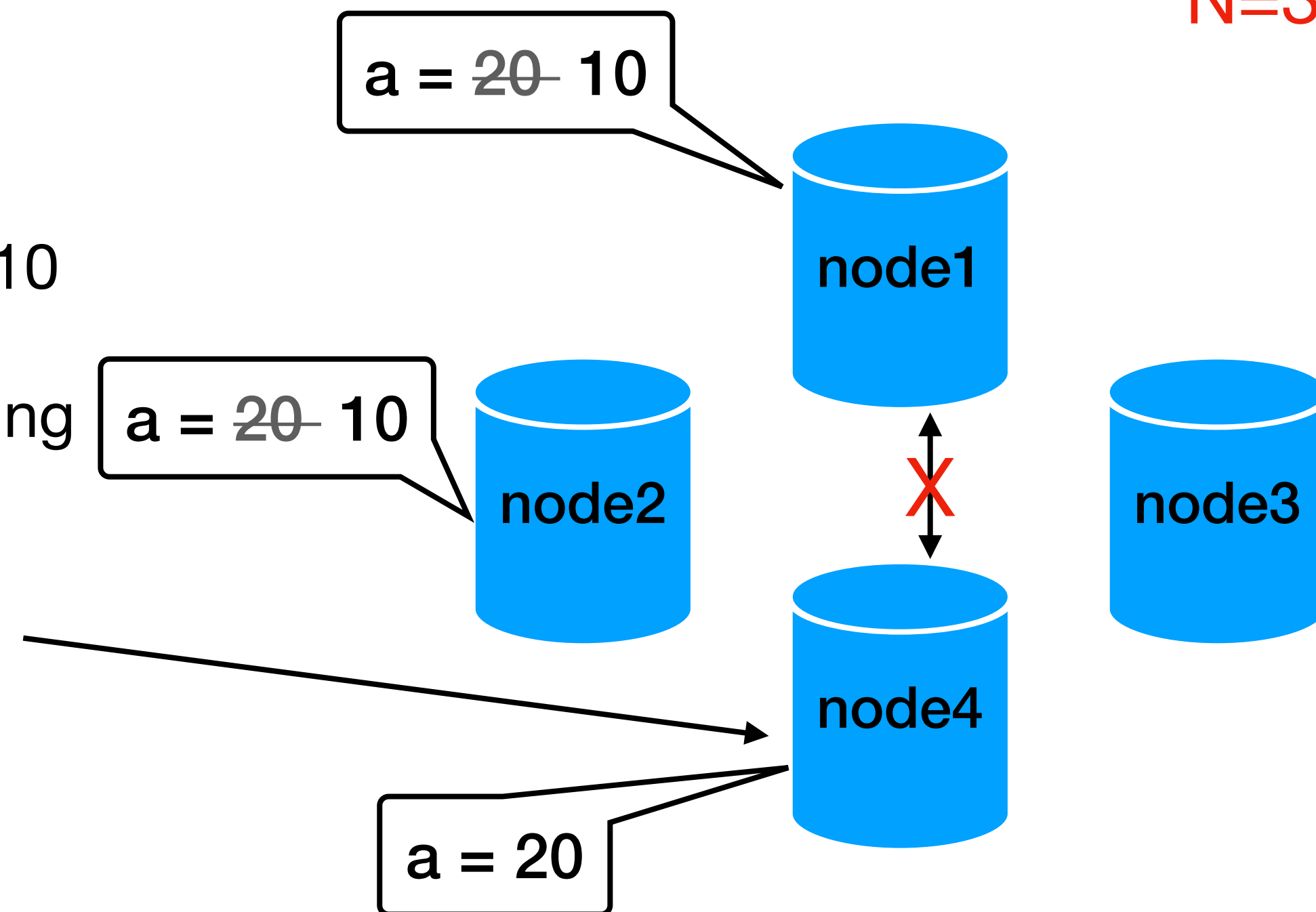
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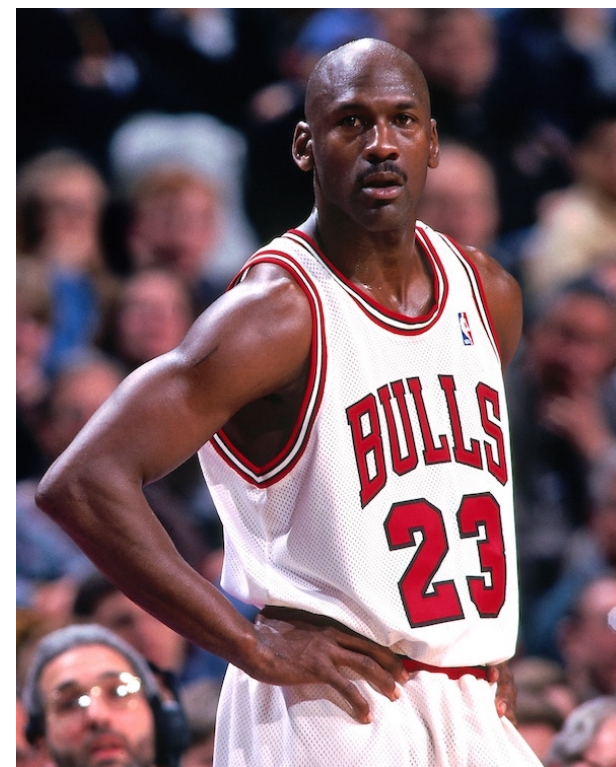
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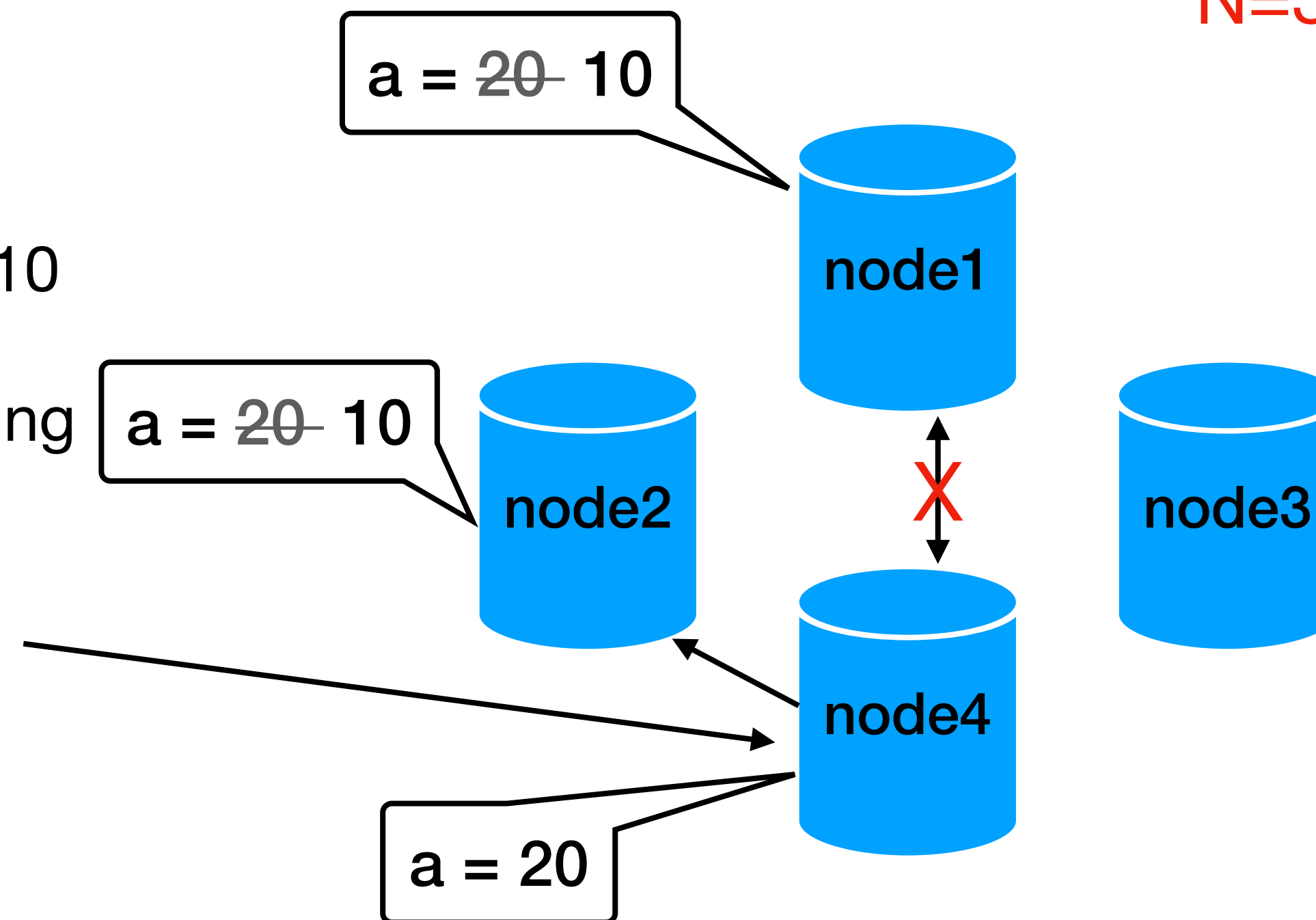
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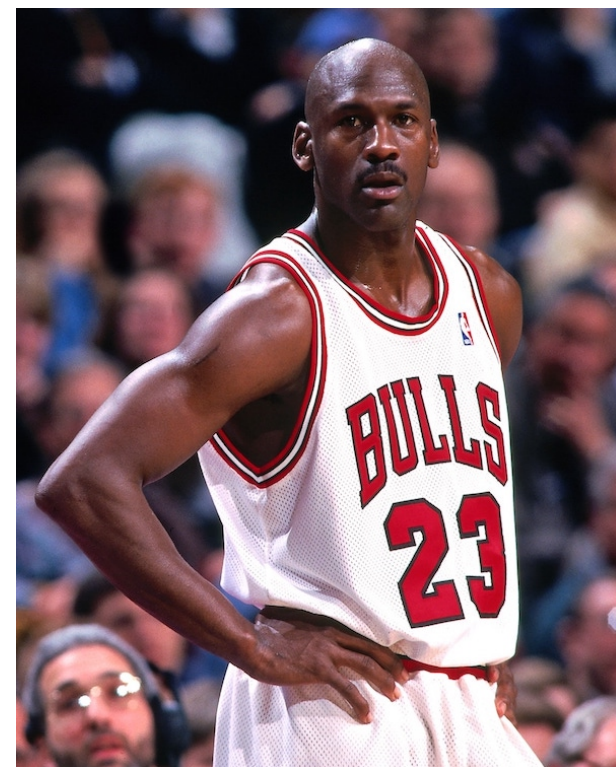
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Server side consistency - example 3

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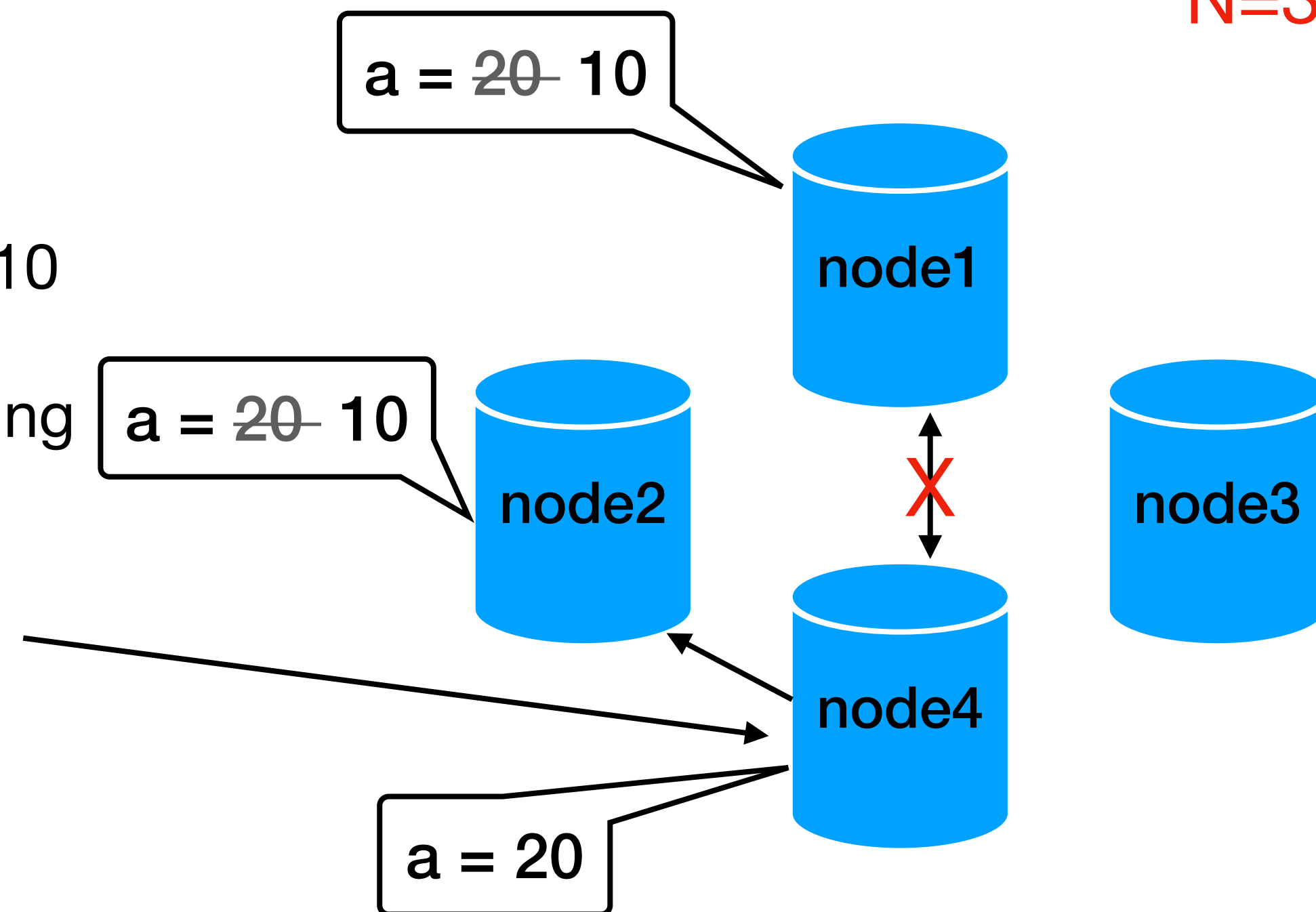
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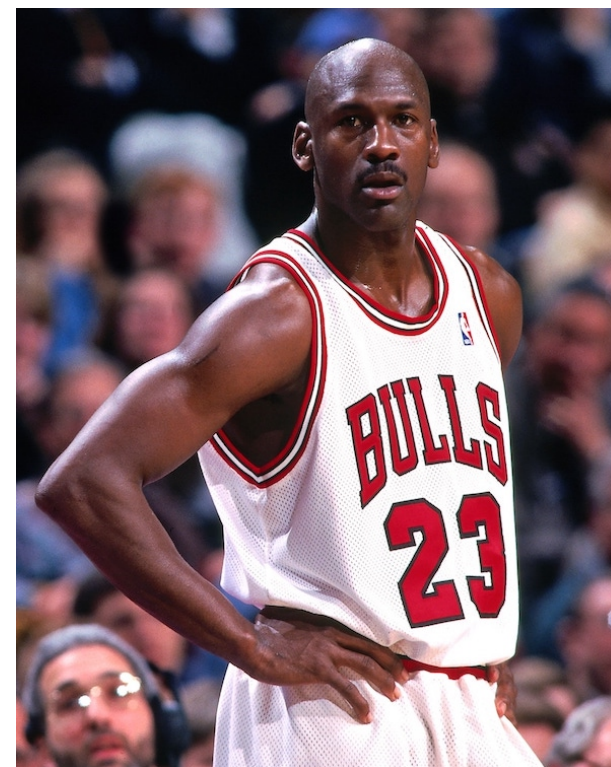
—> read node2 ($a=10$)
—> **there is NO quorum**



Server side consistency - example 3

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

$N=3, W=2, R=2$



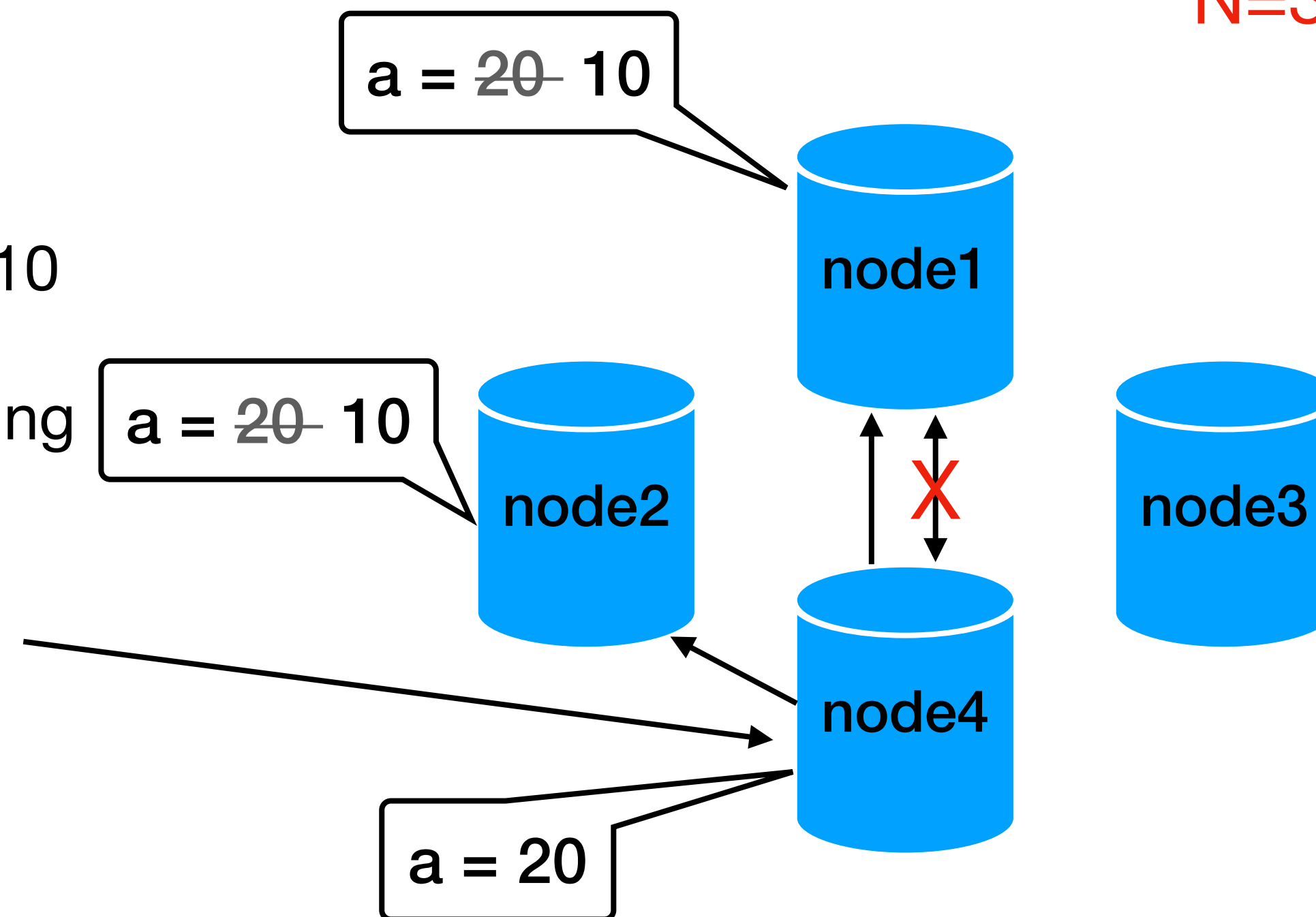
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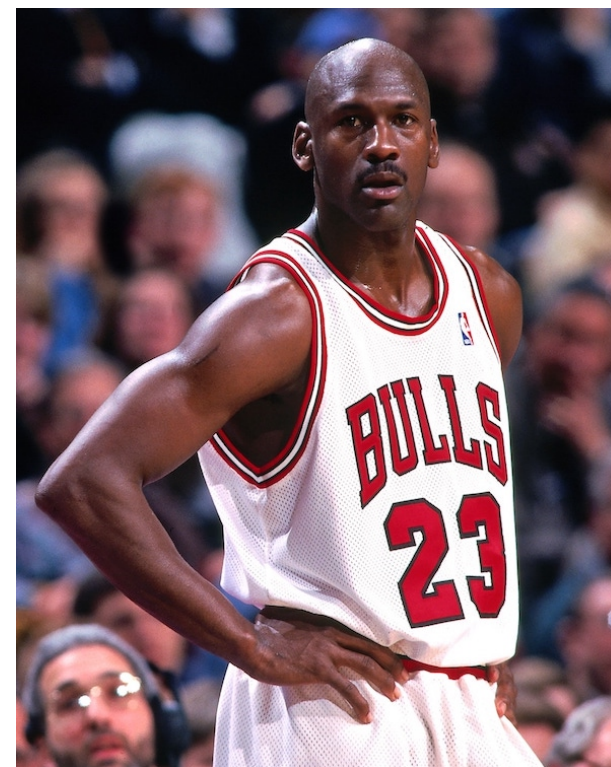
—> read node2 ($a=10$)
—> there is NO quorum
—> in node1 $a=10$



Server side consistency - example 3

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$N=3, W=2, R=2$



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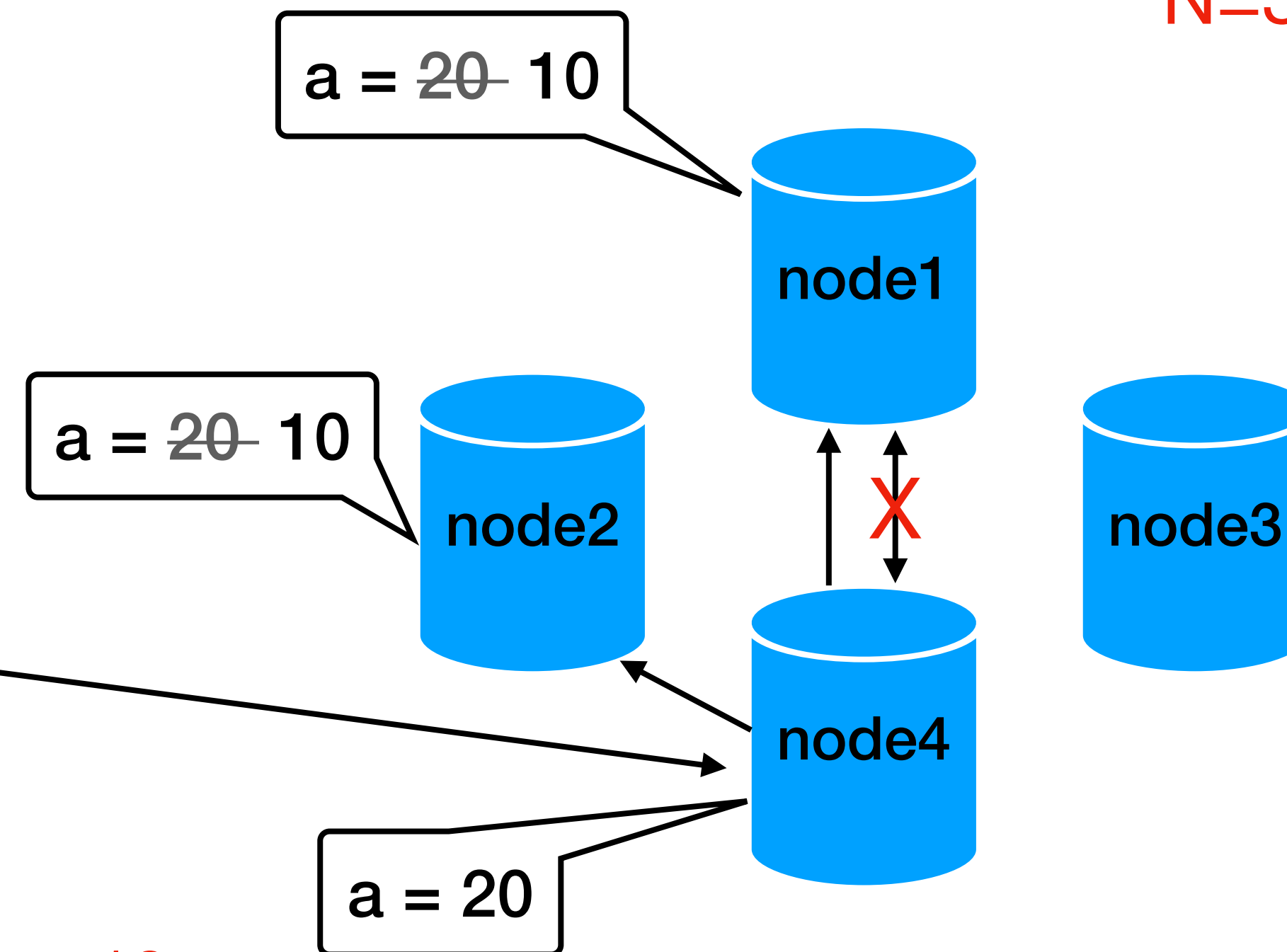
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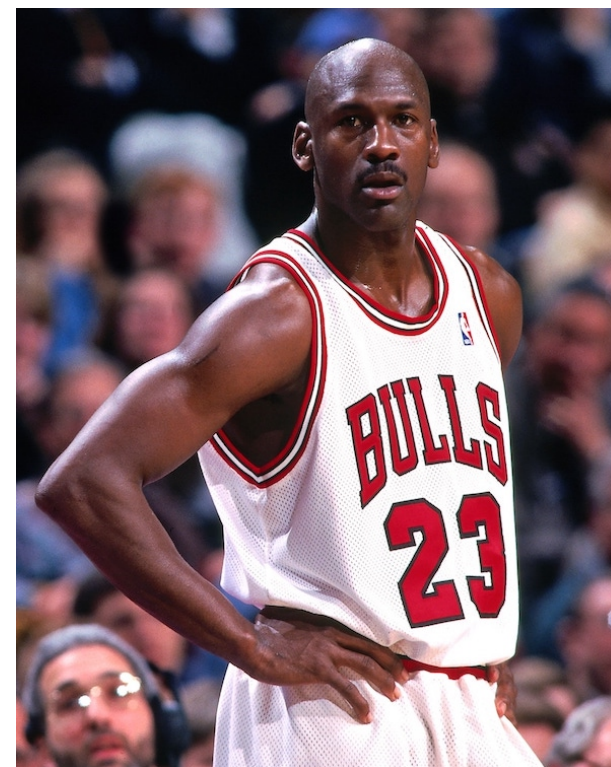
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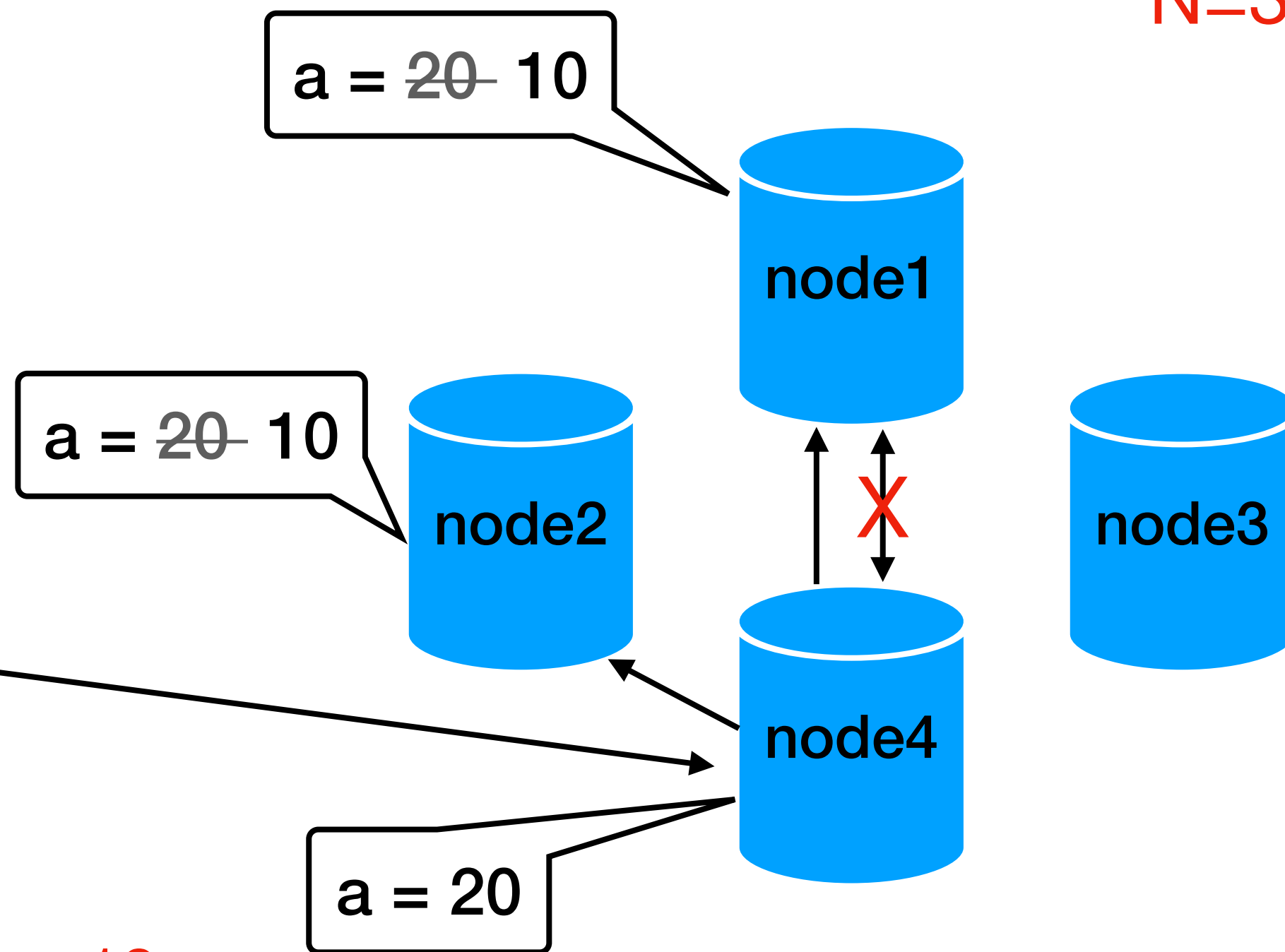
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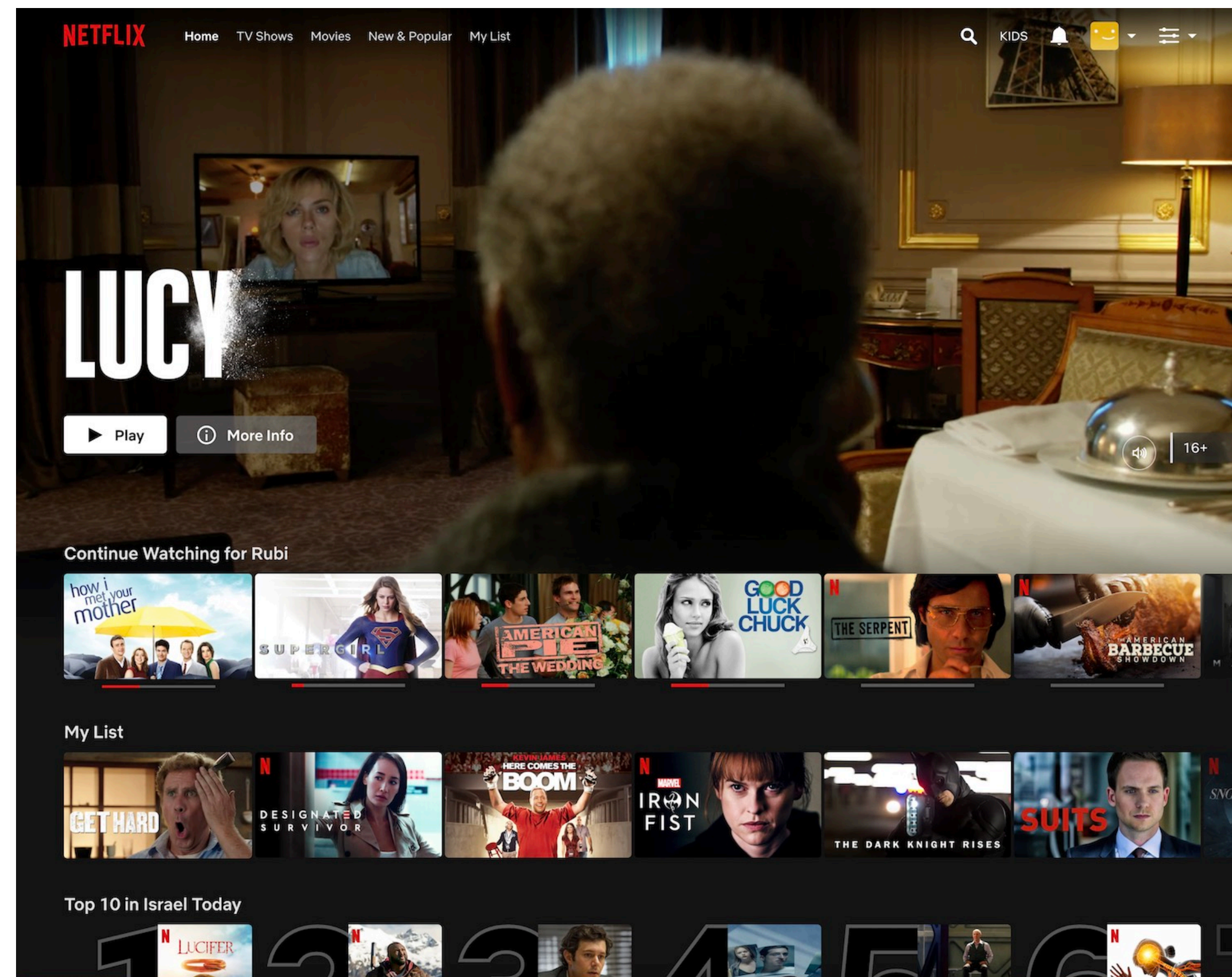
—> **there is a quorum, return $a=10$**



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

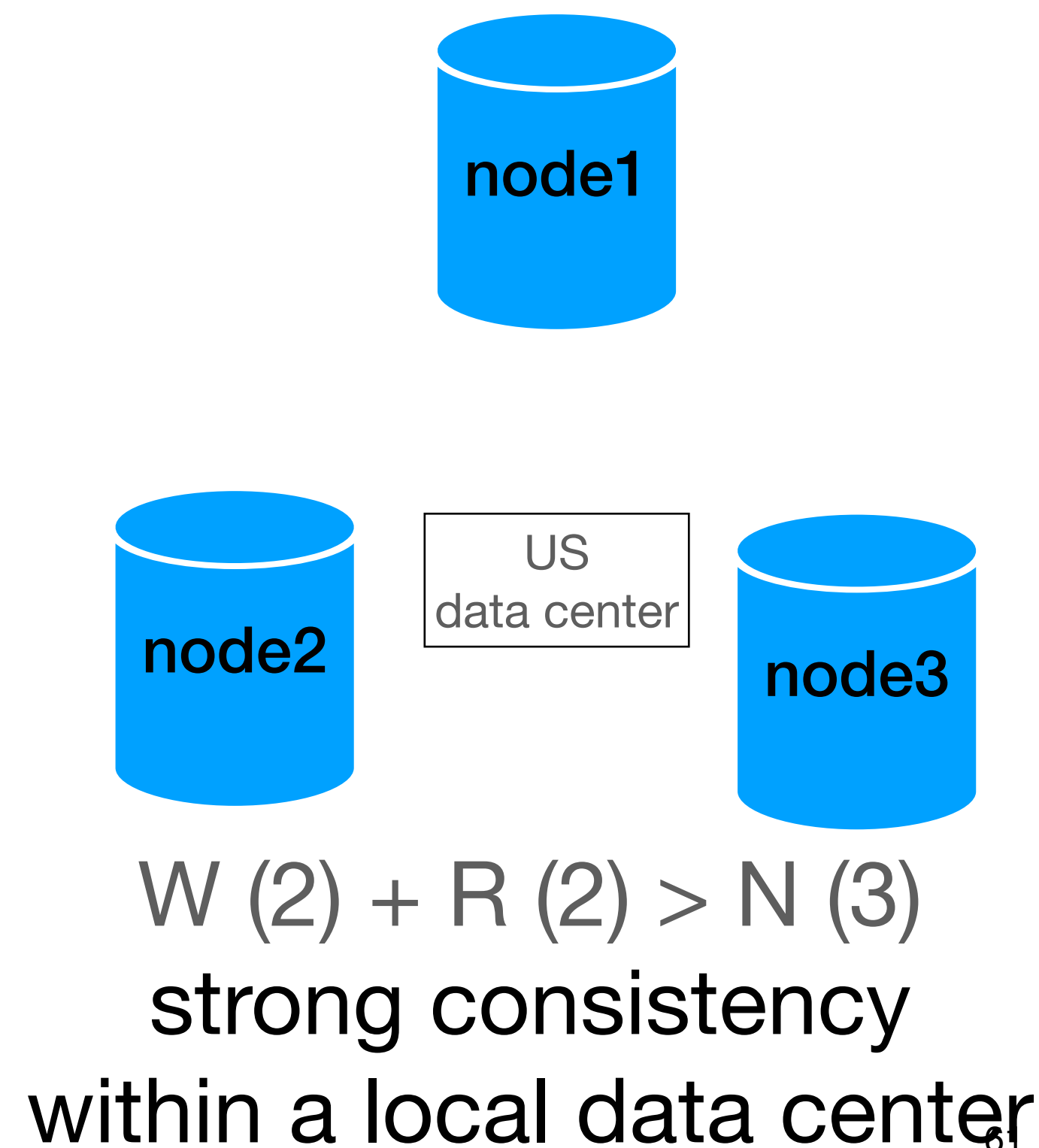
Server side consistency - example 4

- Distributed database, multi data center



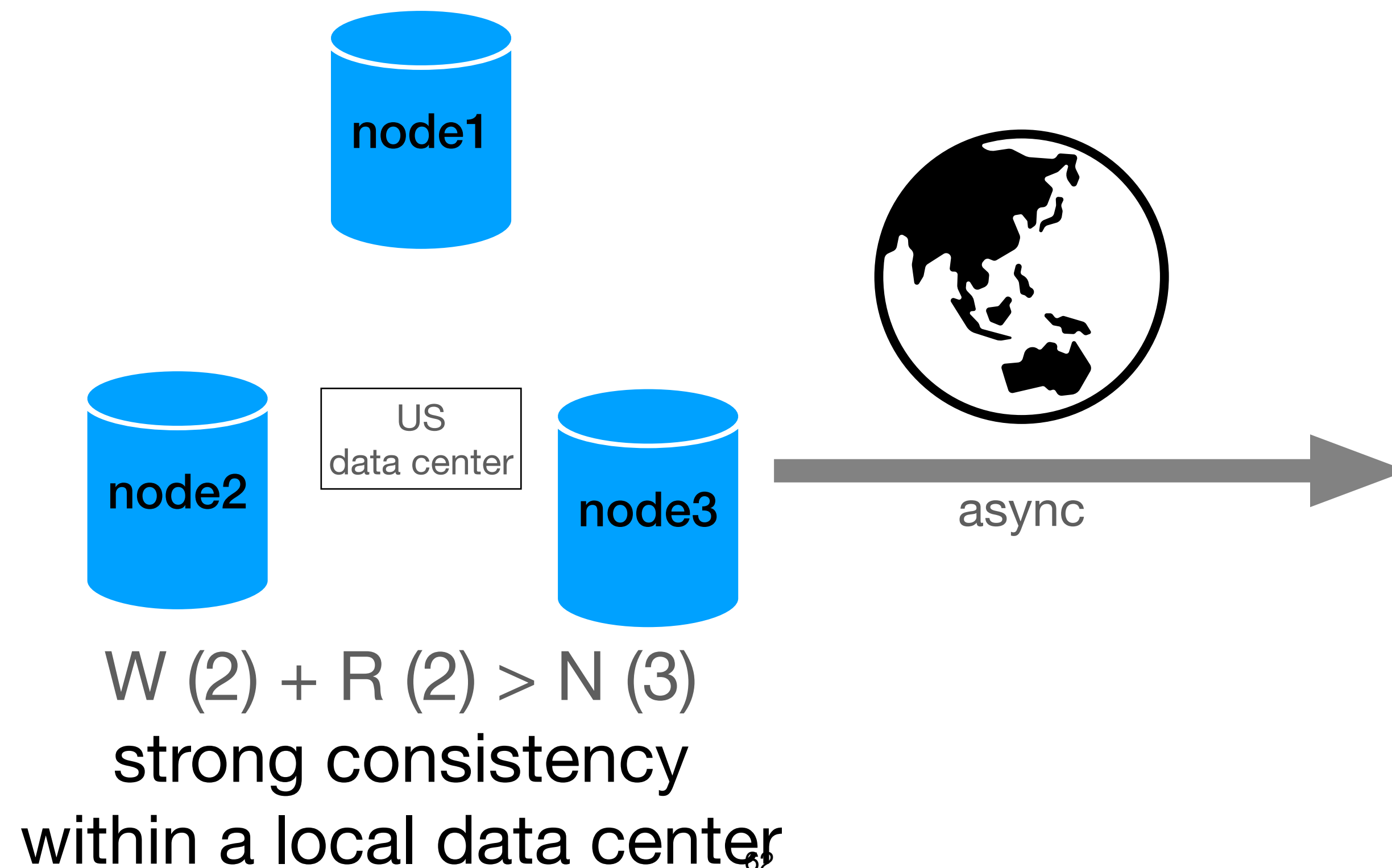
Server side consistency - example 4

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



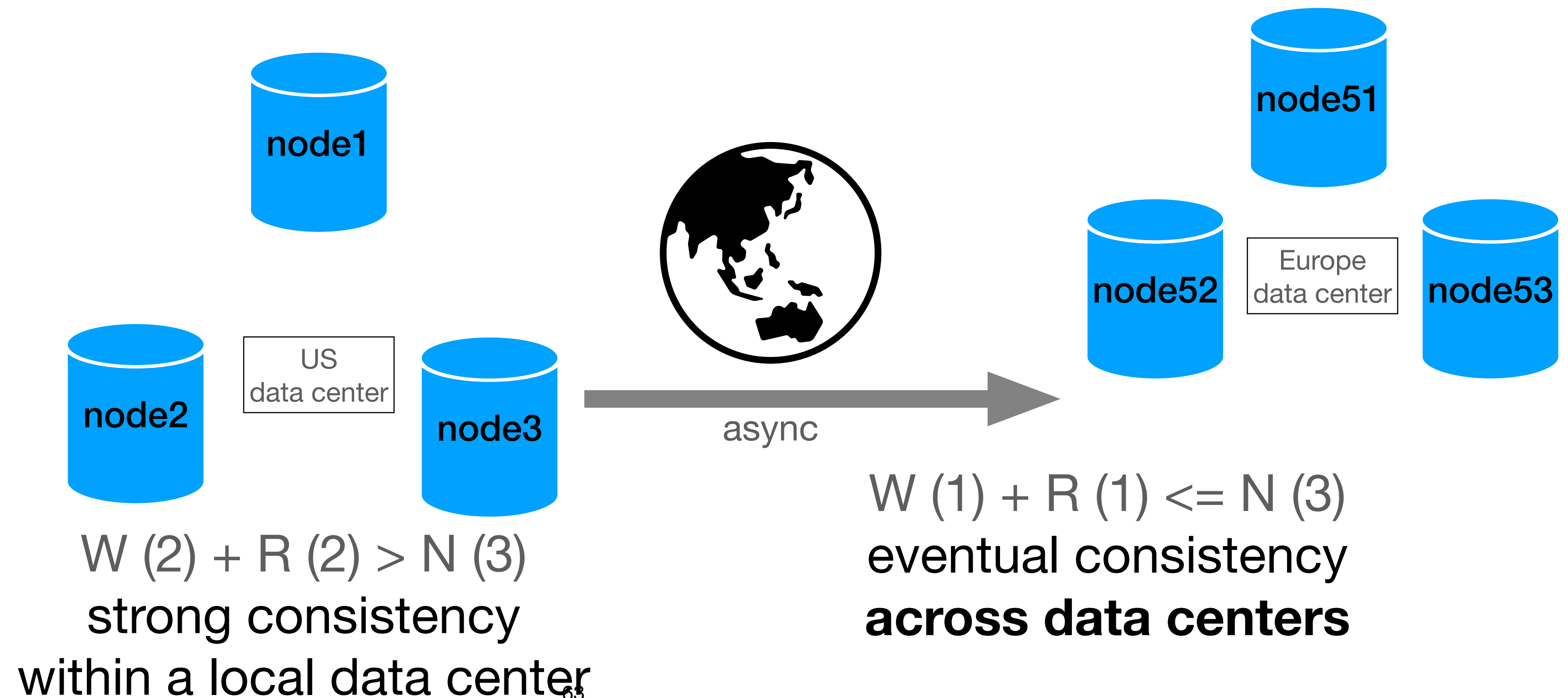
Server side consistency - example 4

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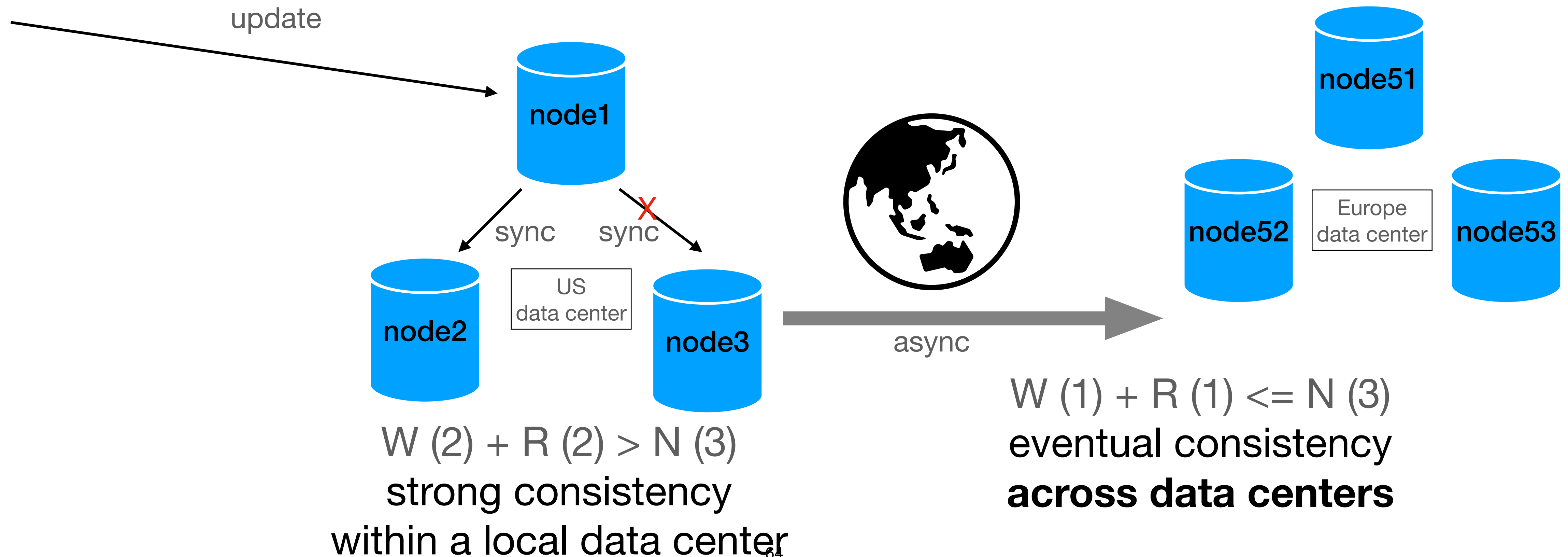
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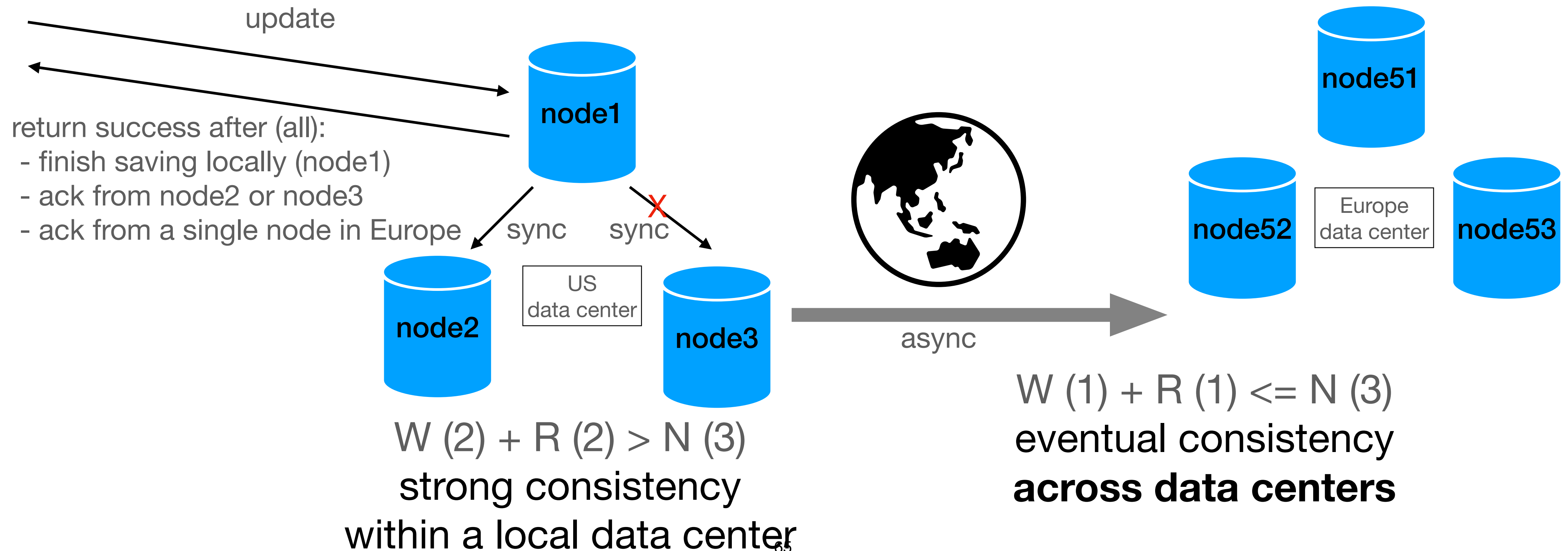
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- No distributed system is safe from network failures.
—> we need to choose between CP and AP
- If a node is down/unreachable we can:
 - cancel the operation (CP)
 - Return result with (maybe) inconsistency (AP)
- Multi data center adds more options