Amazon Dynamo

DS 5110/CS 5501: Big Data Systems

Spring 2024

Lecture 10c

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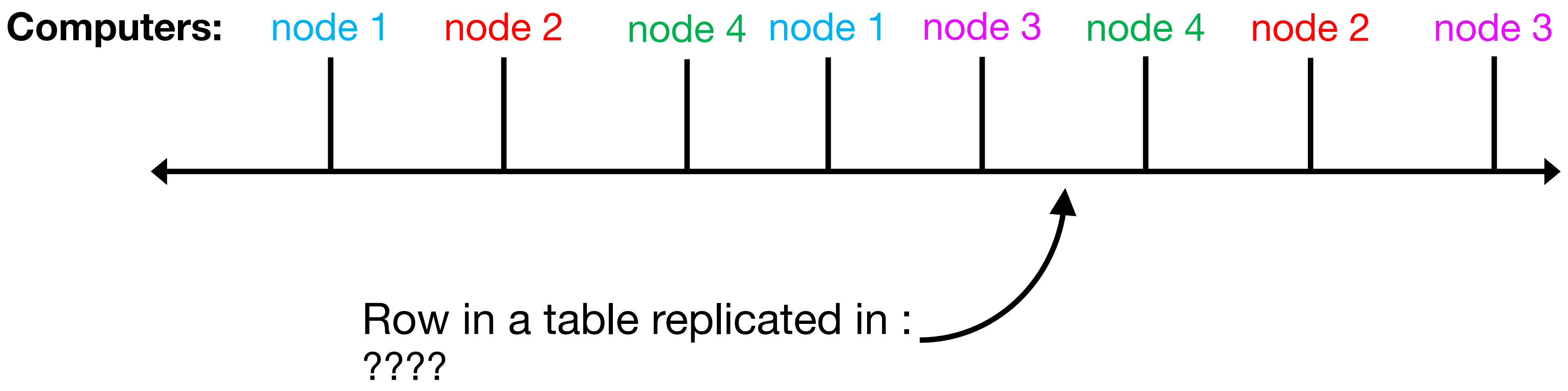
Learning objectives

- Learn how Dynamo replicates data
  - Walk a token ring to identify multiple nodes responsible for a given key (row)
- Tune read and write quorum requirements to achieve desired tradeoffs in availability, durability, and performance
- Describe common approaches to eventual consistency and conflict resolution

Replication

Token map:
token(node1) = {t1, t2}
token(node2) = {t3, t4}
token(node3) = {t5, t6}
token(node4) = {t7, t8}



Replication factor (RF) of N (where N == **2**)

Replication

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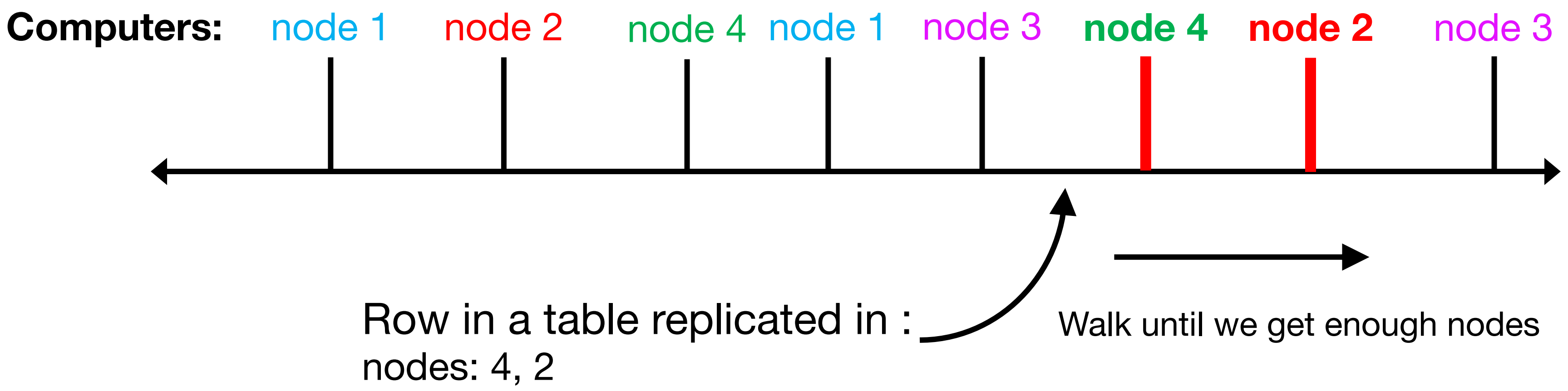

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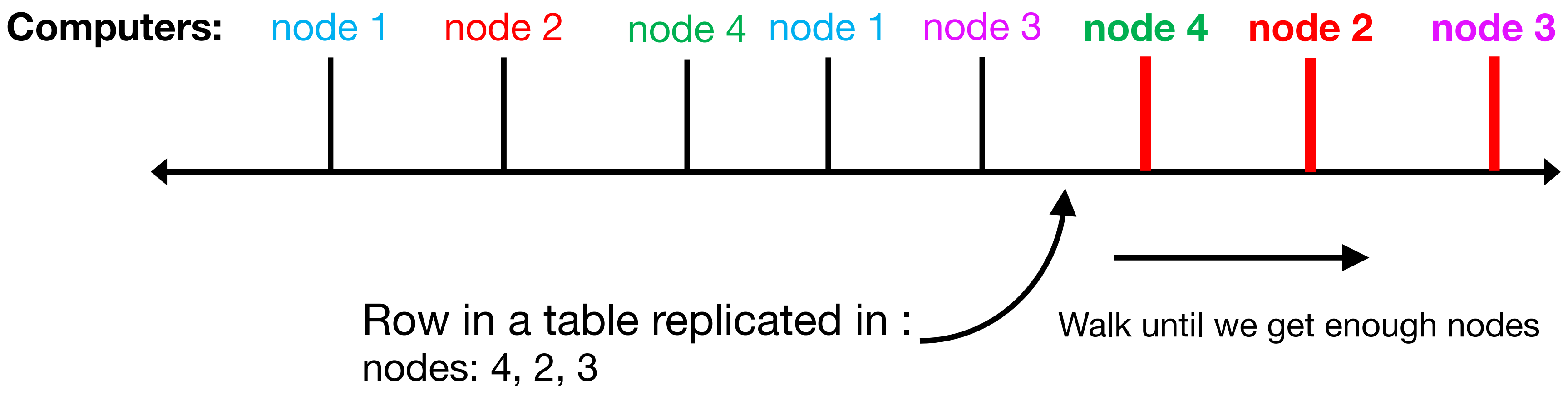

RF = N (where N == **3**)

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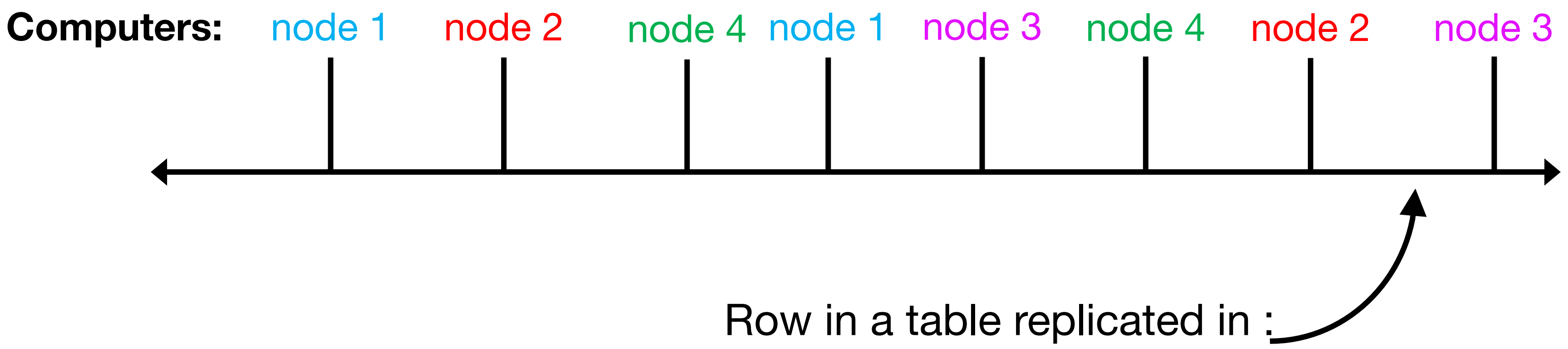

Row in a table replicated in :
nodes: ????

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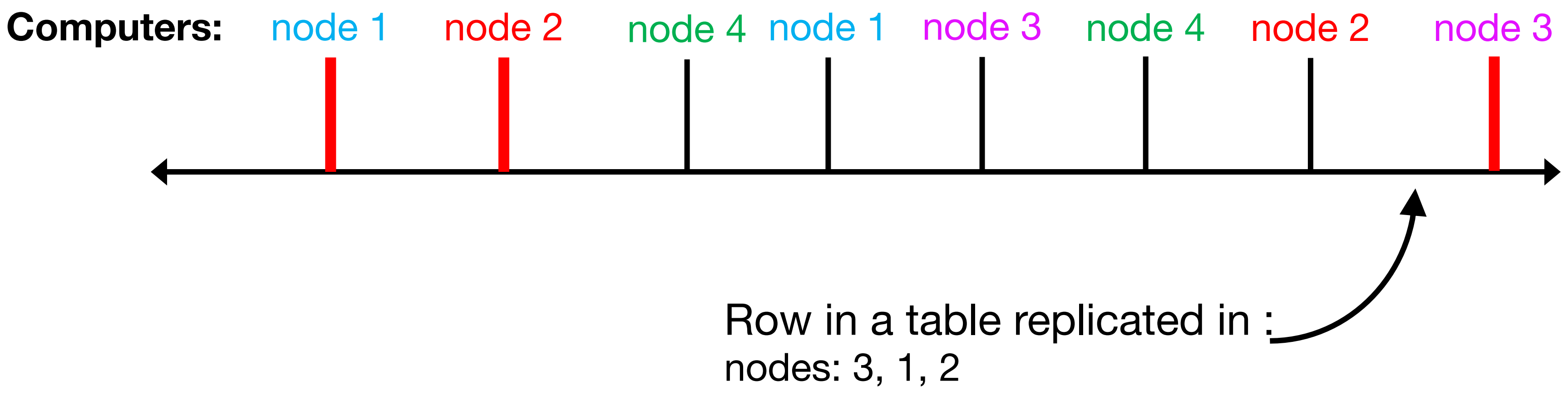

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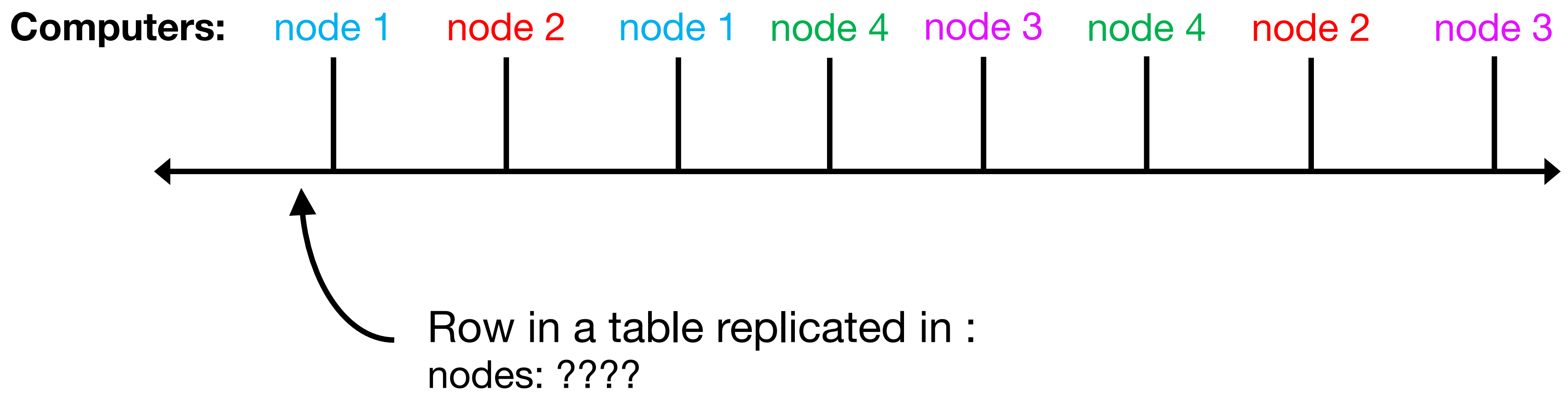

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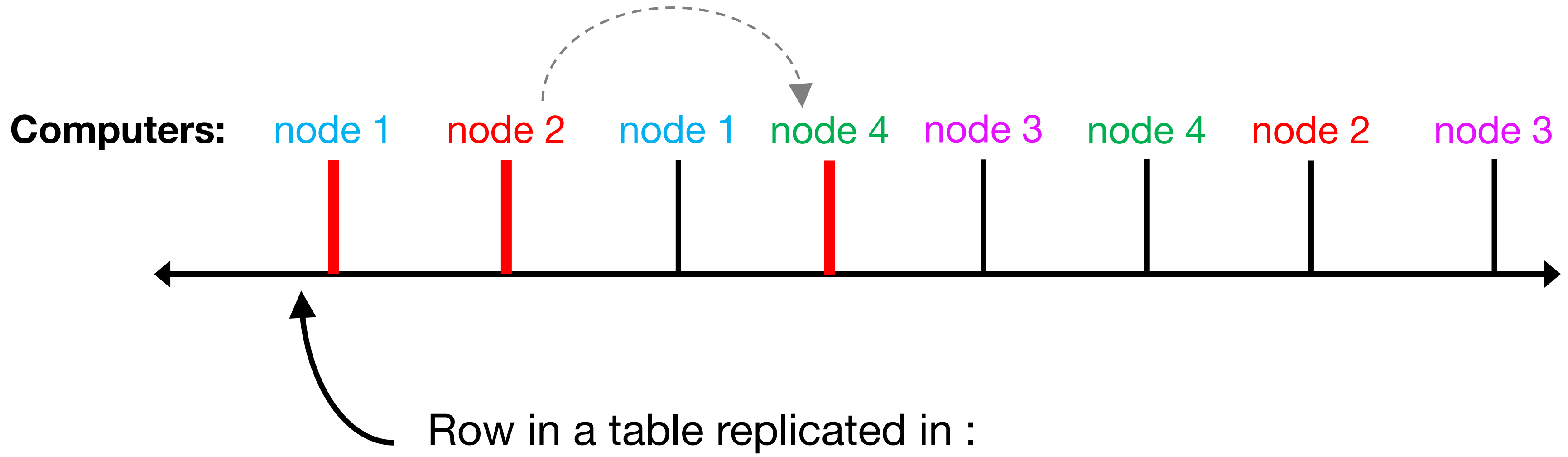


Row in a table replicated in :
nodes: 1, 2, 4

RF = N (where N == **3**)

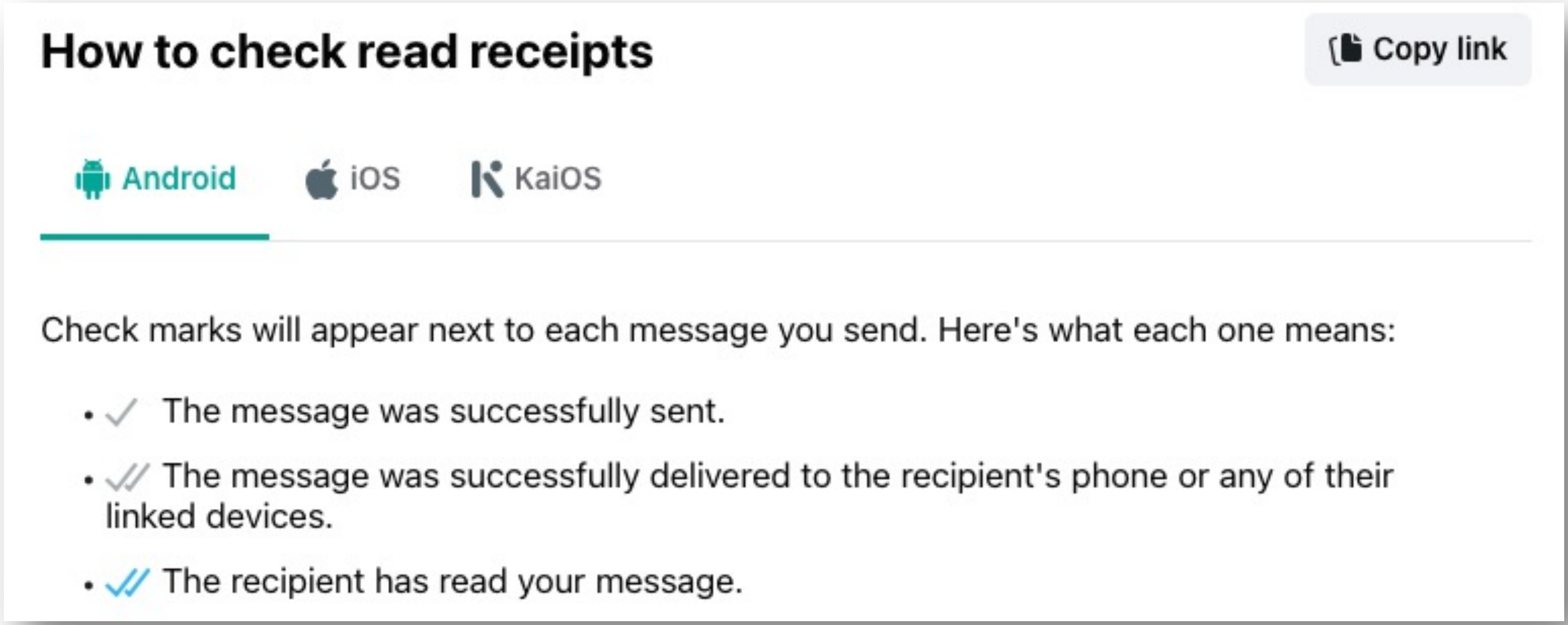
Important: Keeping multiple copies on vnodes on the same node provides little safety (when a node dies, all its vnodes die). Same **"failure domain"**.
Dynamo skips nodes to ensure replicas reside on different nodes.

Write acks

- In distributed storage/database systems, an ***ack*** means our data is ***committed***

- "Committed" means our data is "safe", even if bad things happen. The definition varies system to system, based on what bad things are considered. For example:
  - A node could hang until rebooted; a node's disk could permanently fail
  - A rack could lose power; a datacenter could be destroyed

Write acks: WhatsApp example



How to check read receipts

Check marks will appear next to each message you send. Here's what each one means:

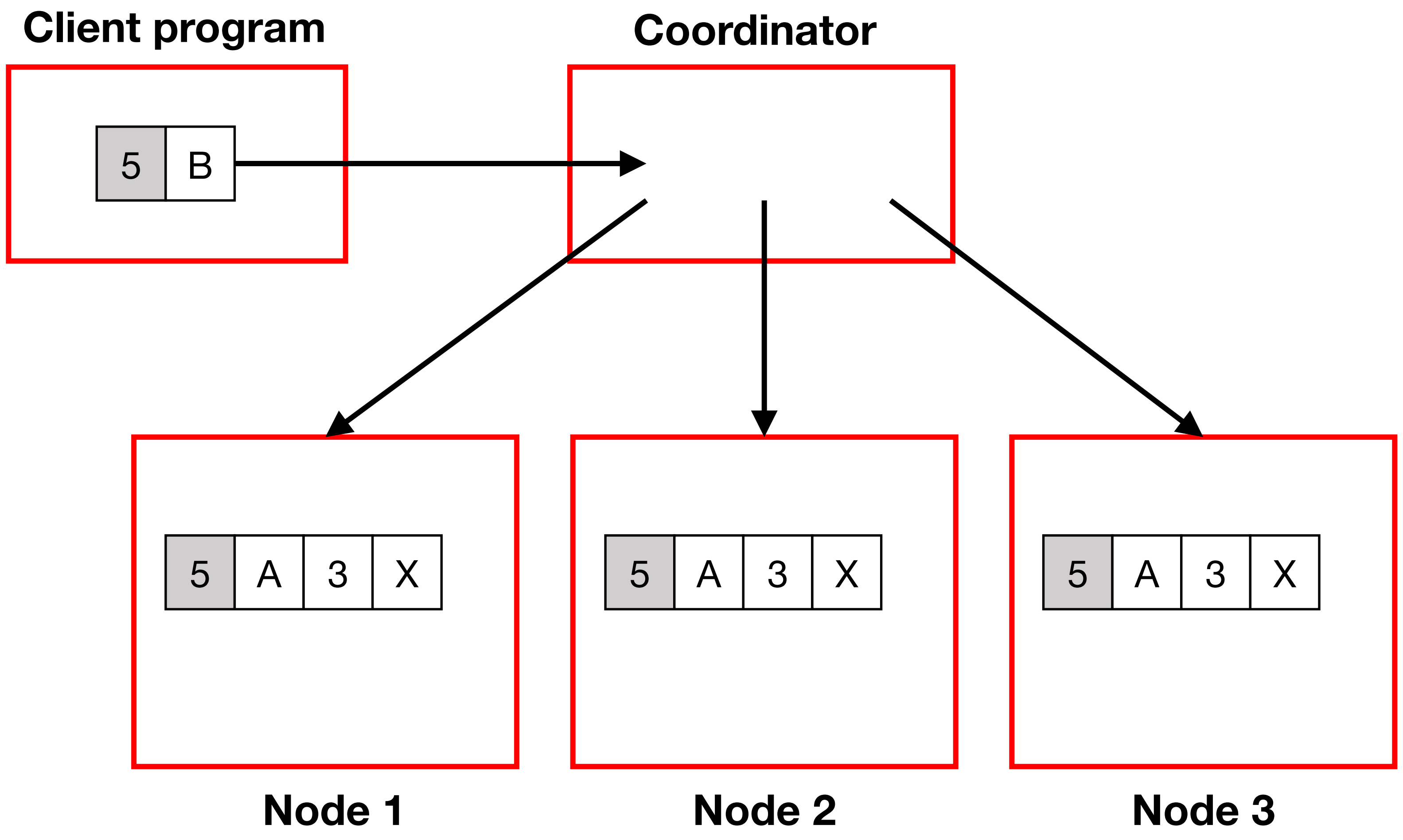
- ✓ The message was successfully sent.
- ✓✓ The message was successfully delivered to the recipient's phone or any of their linked devices.
- ✓✓ The recipient has read your message.

These are examples of “**acks**” (acknowledgments)

https://faq.whatsapp.com/665923838265756/?cms_platform=android&helpref=platform_switcher

Dynamo writes

RF = 3. Coordinator will attempt to write data to all 3 replicas.



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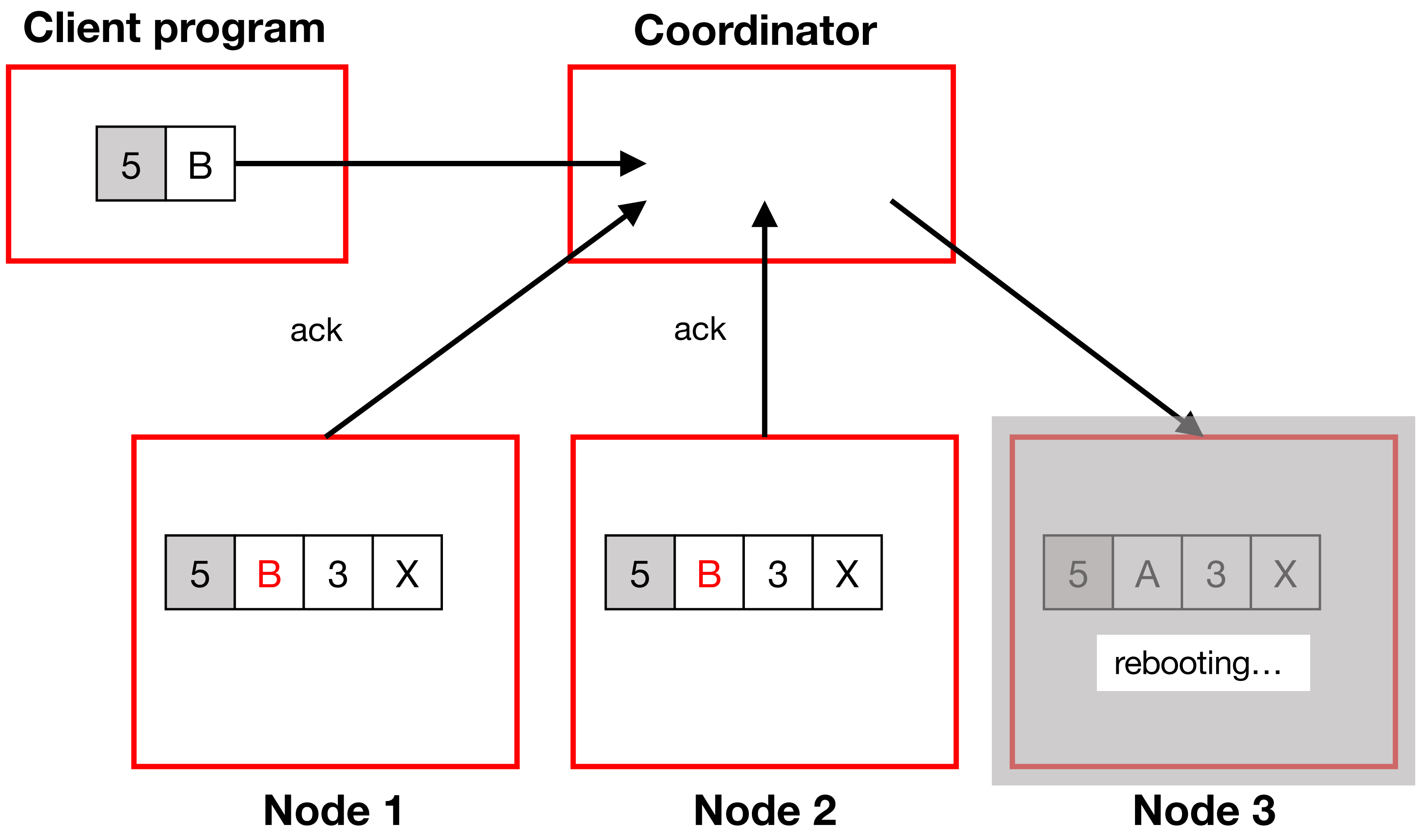

At what point should we send an ack back to the client?

Dynamo writes

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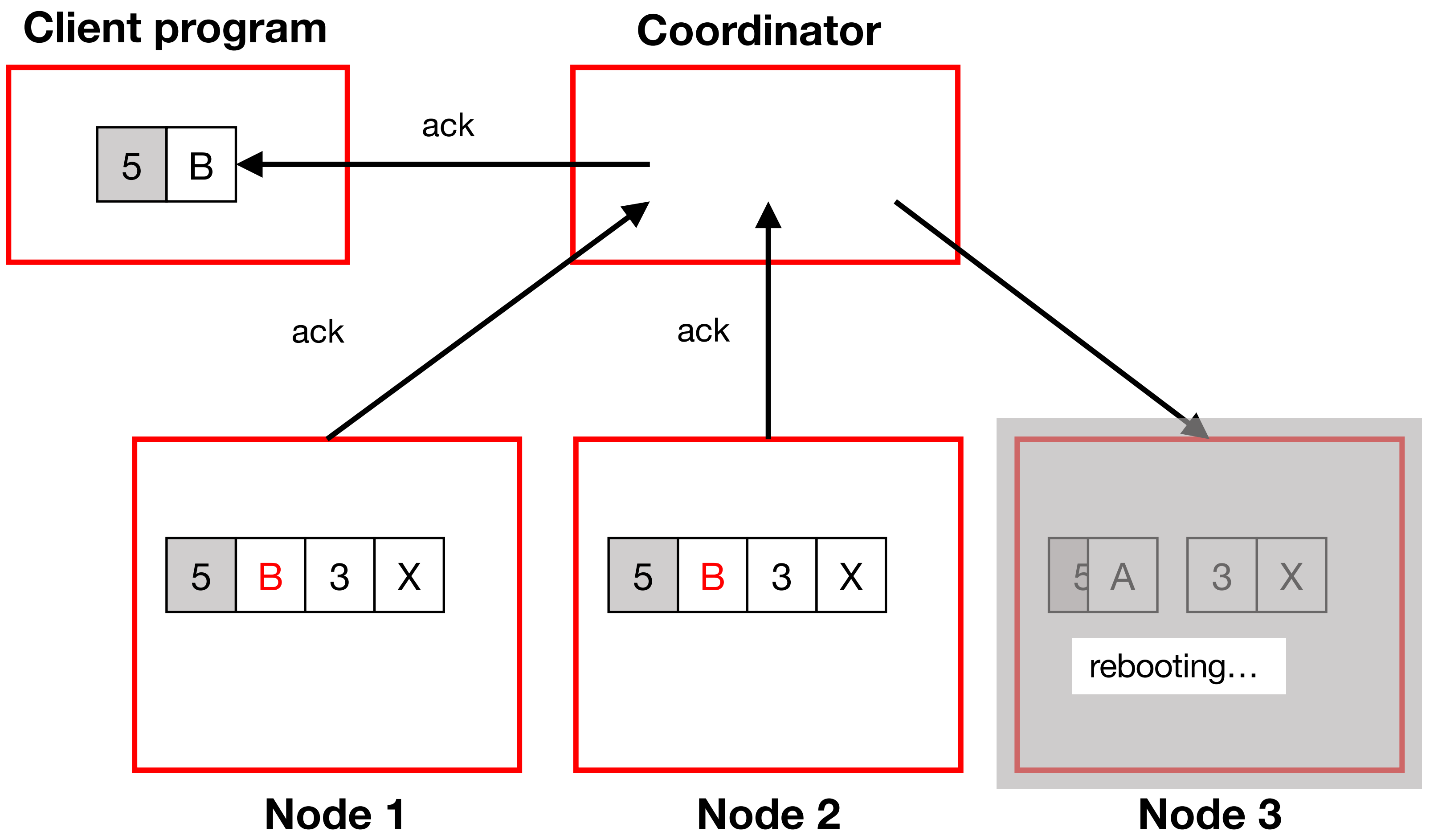
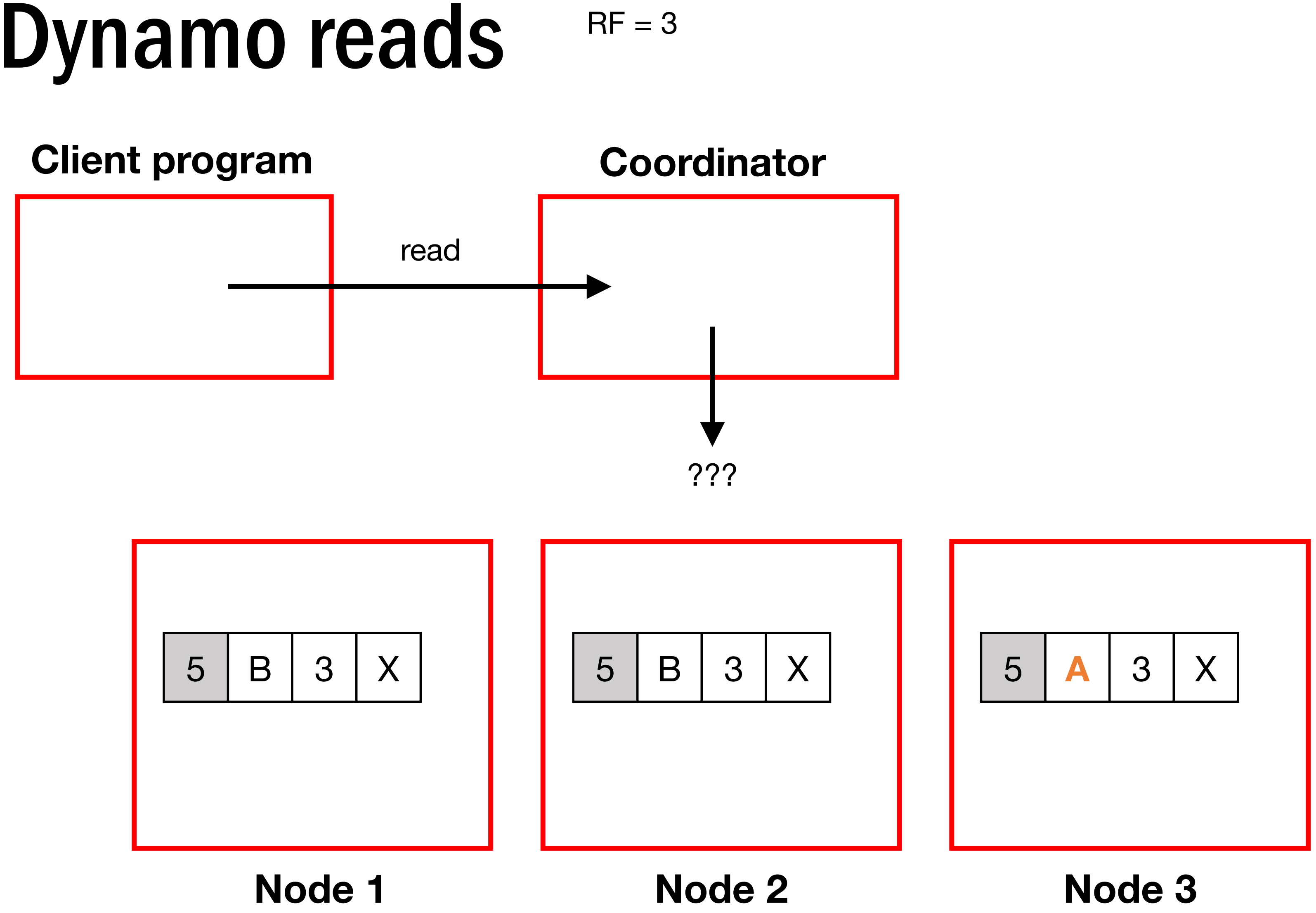


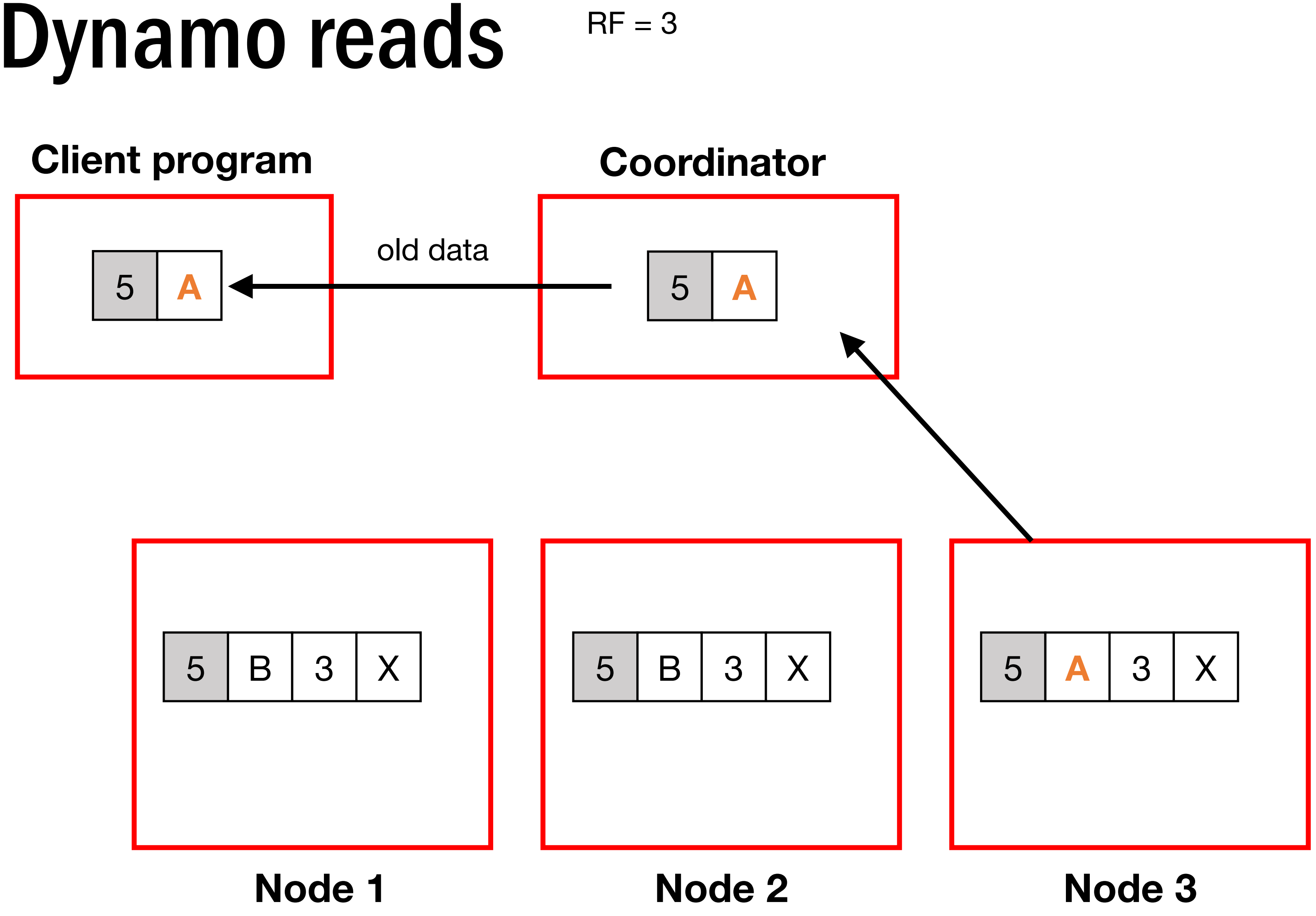
At what point should we send an ack back to the client?
Configurable: **W = 2** lets coordinator ack now, and data is fairly safe.

Dynamo reads



HDFS reads go to one replica. What if Dynamo tries that?

Dynamo reads



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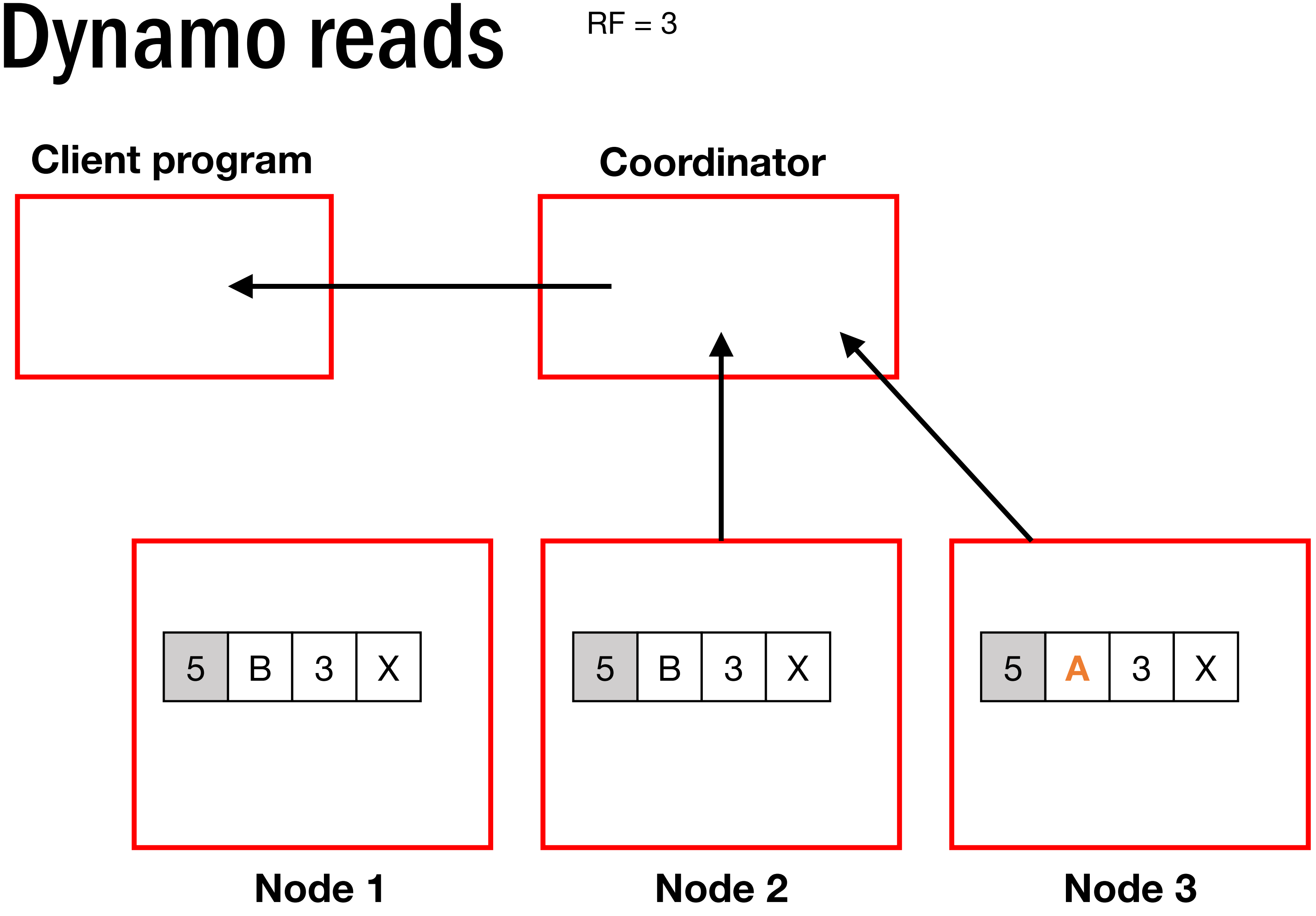
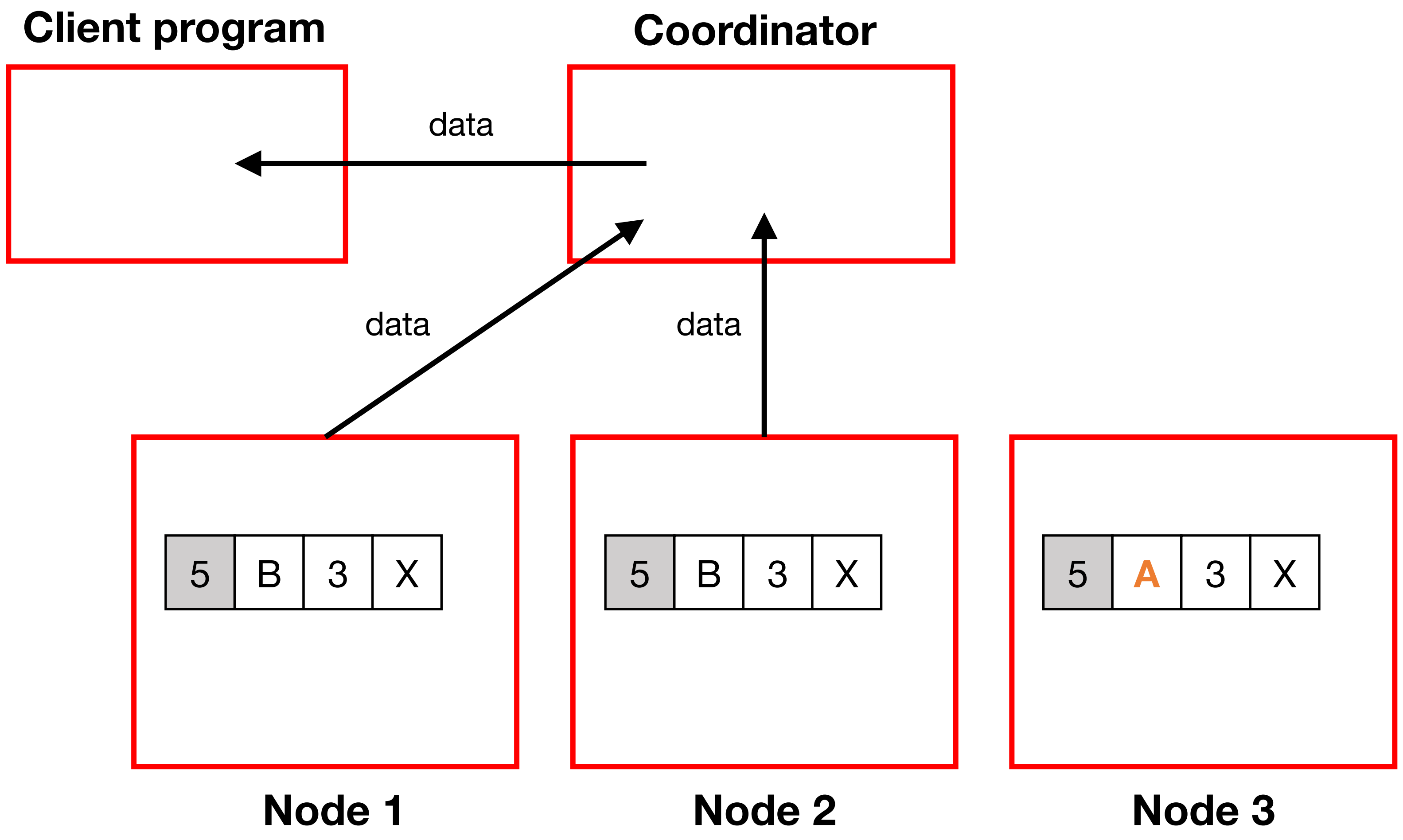


Read from **R** replicas (R is configurable). Here R = 2.
Hopefully at least one of the replicas has new data.

Dynamo reads

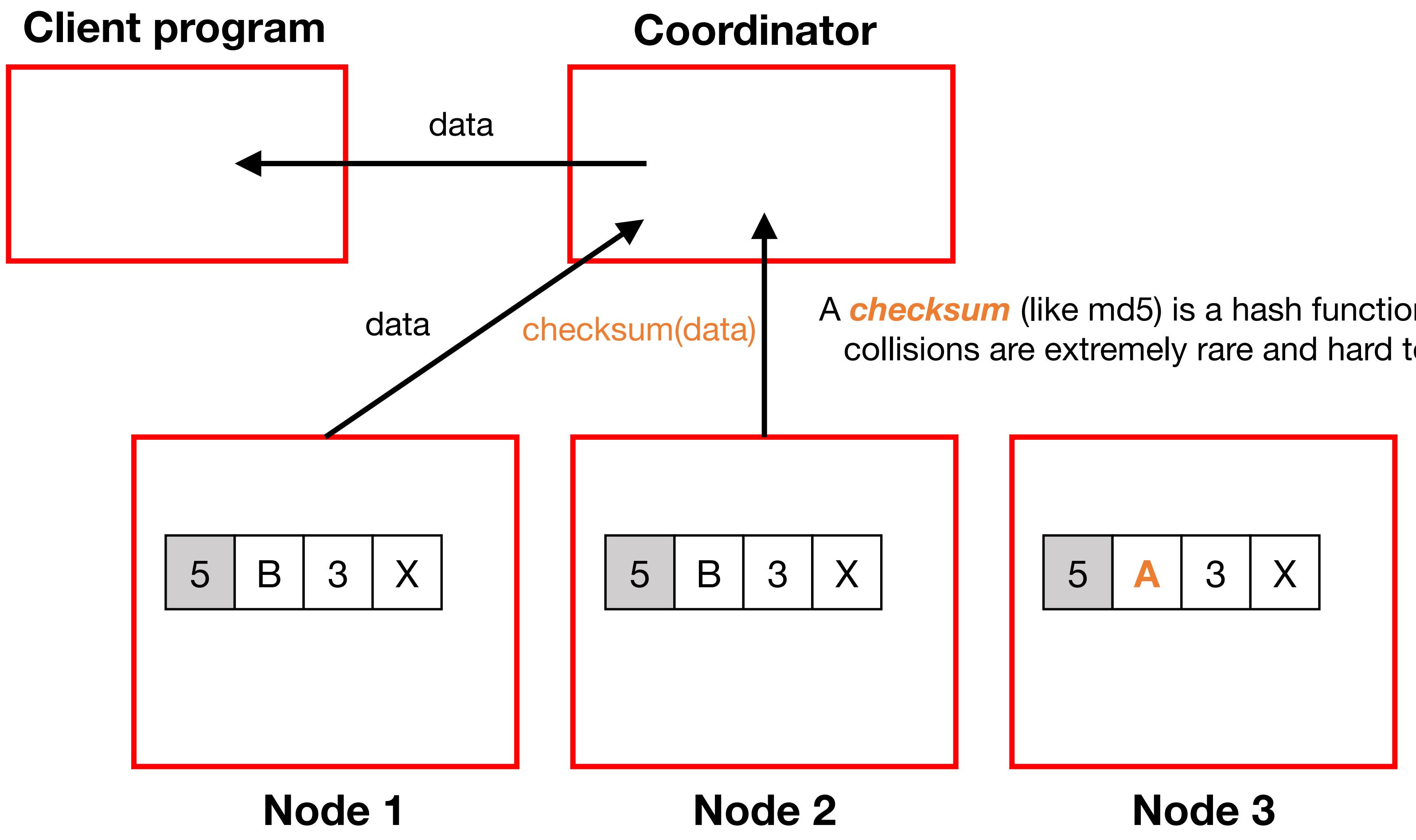
RF = 3



R = 2 means we'll often read identical data from two replicas (wasteful)

Dynamo reads

RF = 3



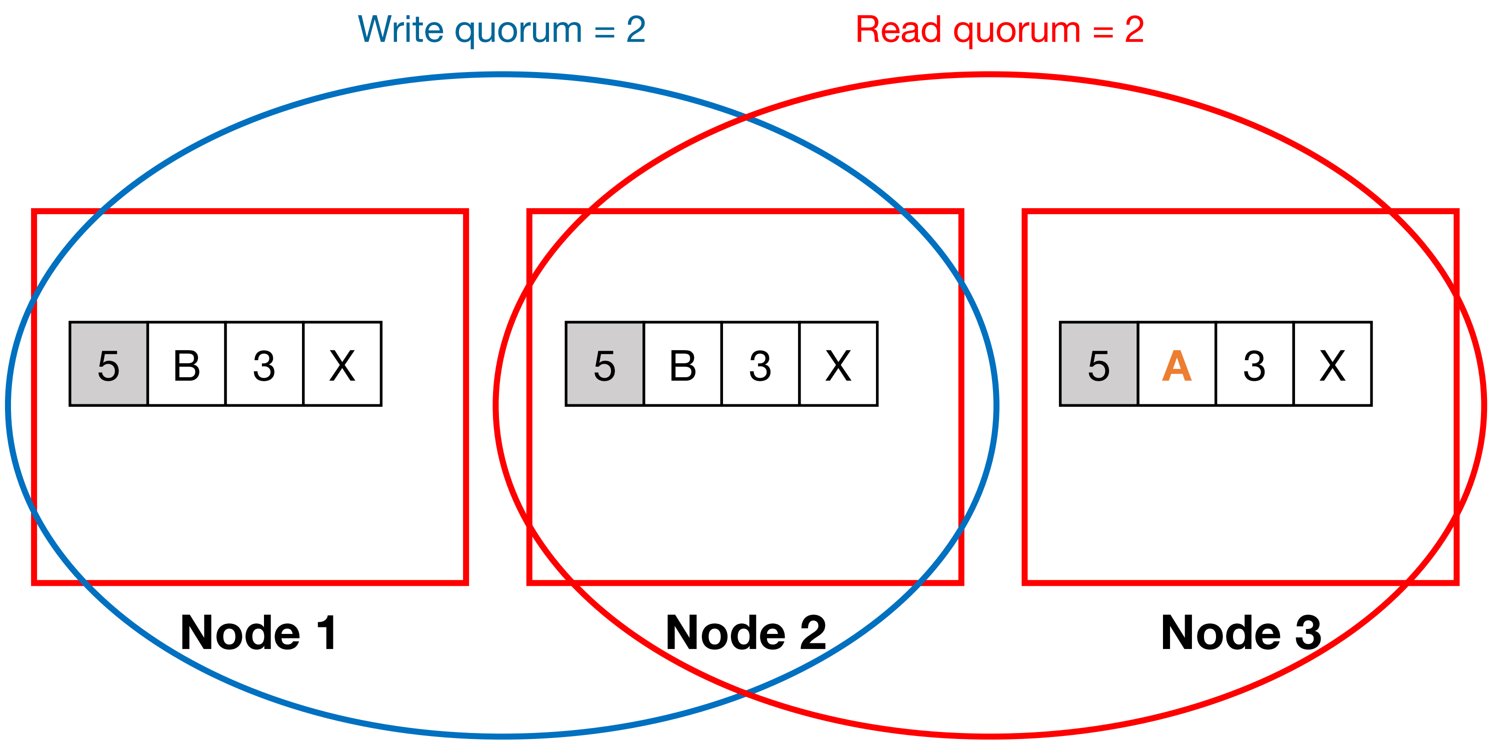
A ***checksum*** (like md5) is a hash function where collisions are extremely rare and hard to find.

R = 2 means we'll often read identical data from two replicas (wasteful)
Optimization: Read one copy, and only request checksum from others.

When R + W > RF

RF = 3

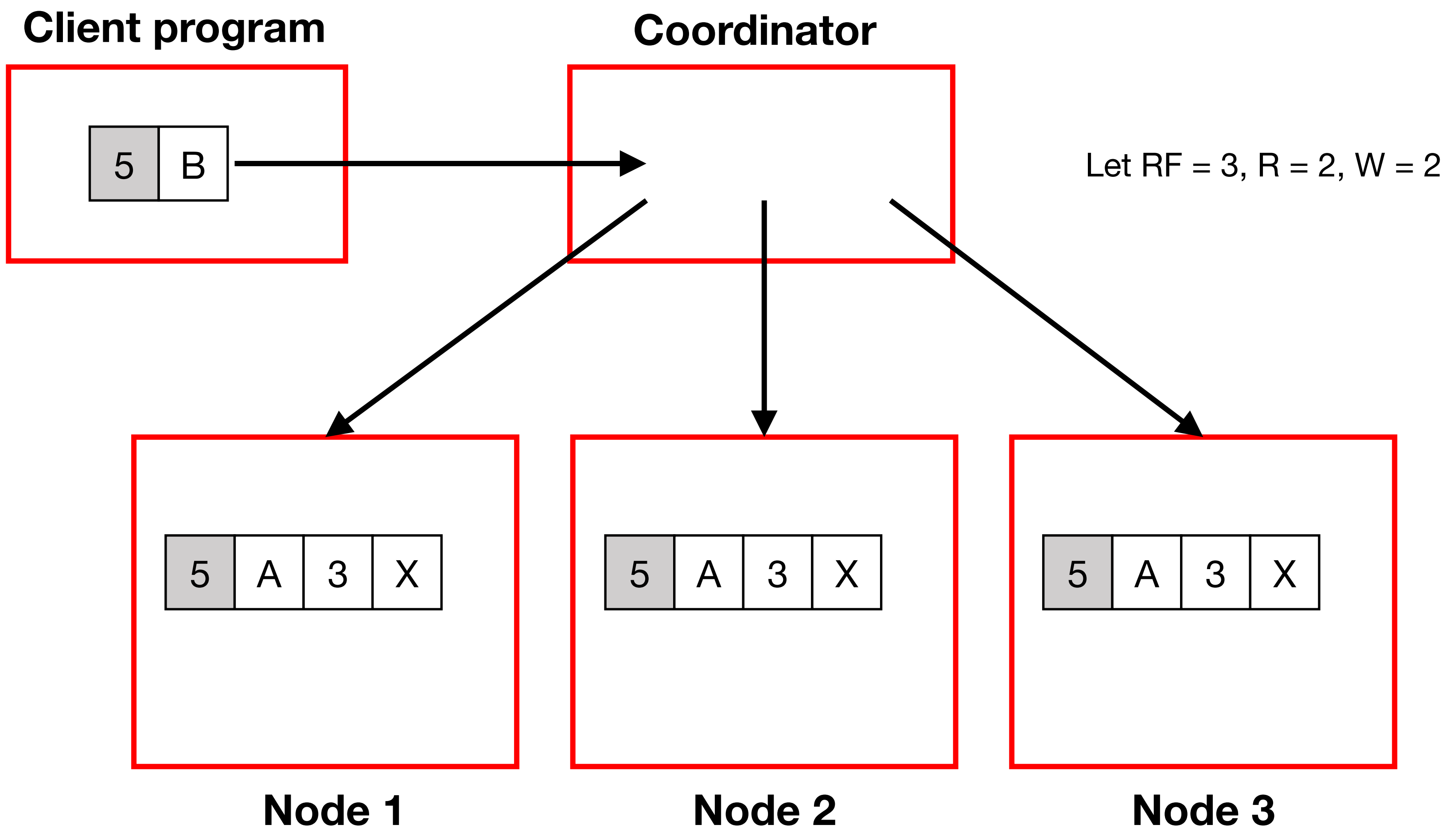
When R + W > RF, the replicas read + written will **overlap**.



Tradeoff: Tuning R and W

RF	R	W	Behavior
3	**2**	**2**	**Parameters from the Dynamo paper:** **Relatively balanced configuration;** **Good durability, good R/W latency**
3	3	1	Slow reads, **weak durability,** **fast writes** Writes are highly available, therefore fast; Reads will not return data even if one node is down; reads may fail; Risk: If the one node that took the write fails permanently, we'll lose committed data.
3	1	3	**Slow writes,** strong durability, **fast reads** Reads are highly available, therefore fast; Writes are slow (from client's perspective) as they involve writing to three replicas.
3	3	3	More likely that **reads see all prior writes**?
3	1	1	Read quorum **doesn't overlap** write quorum Speed + availability more important than consistency

Getting conflicting versions



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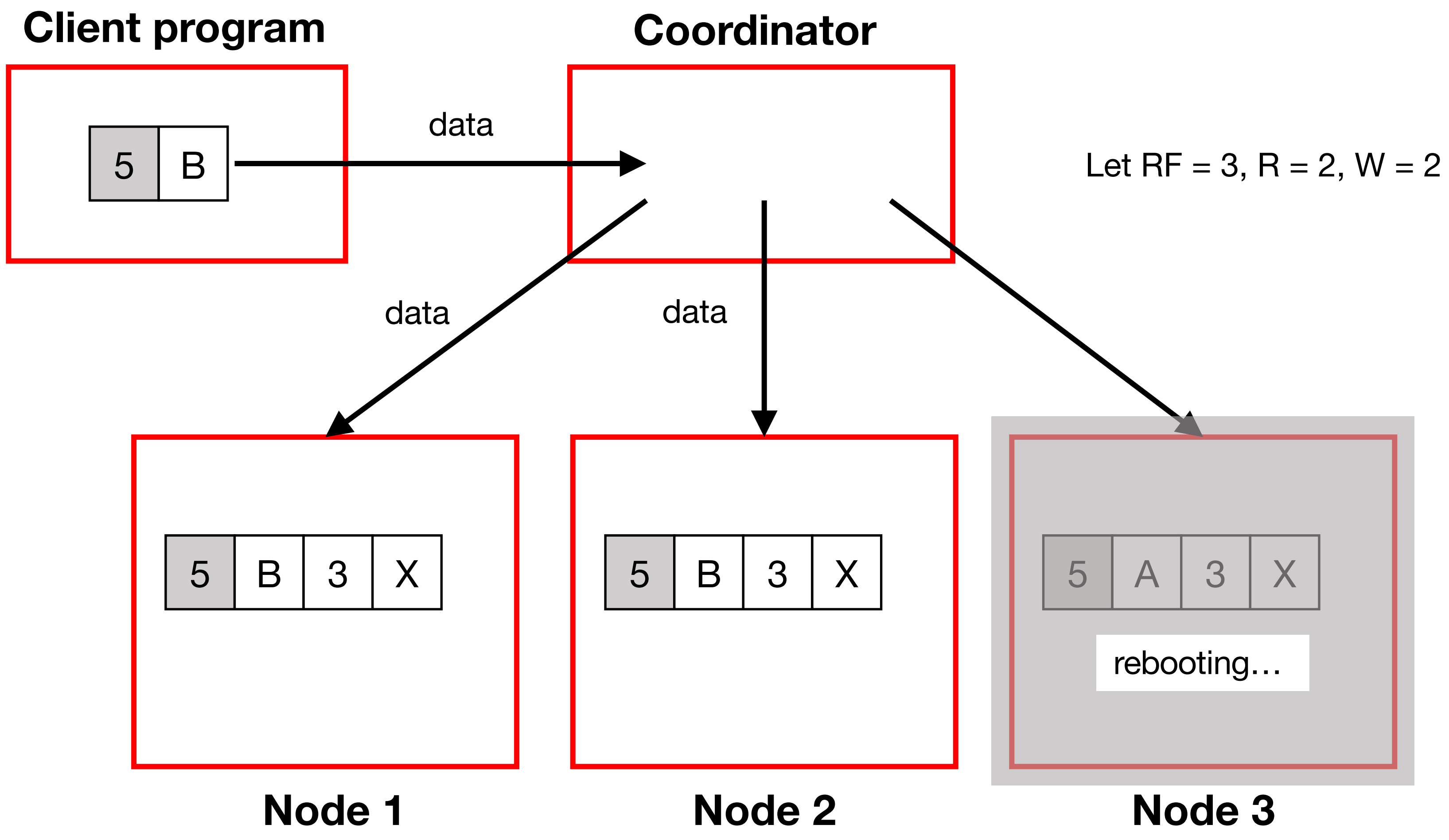

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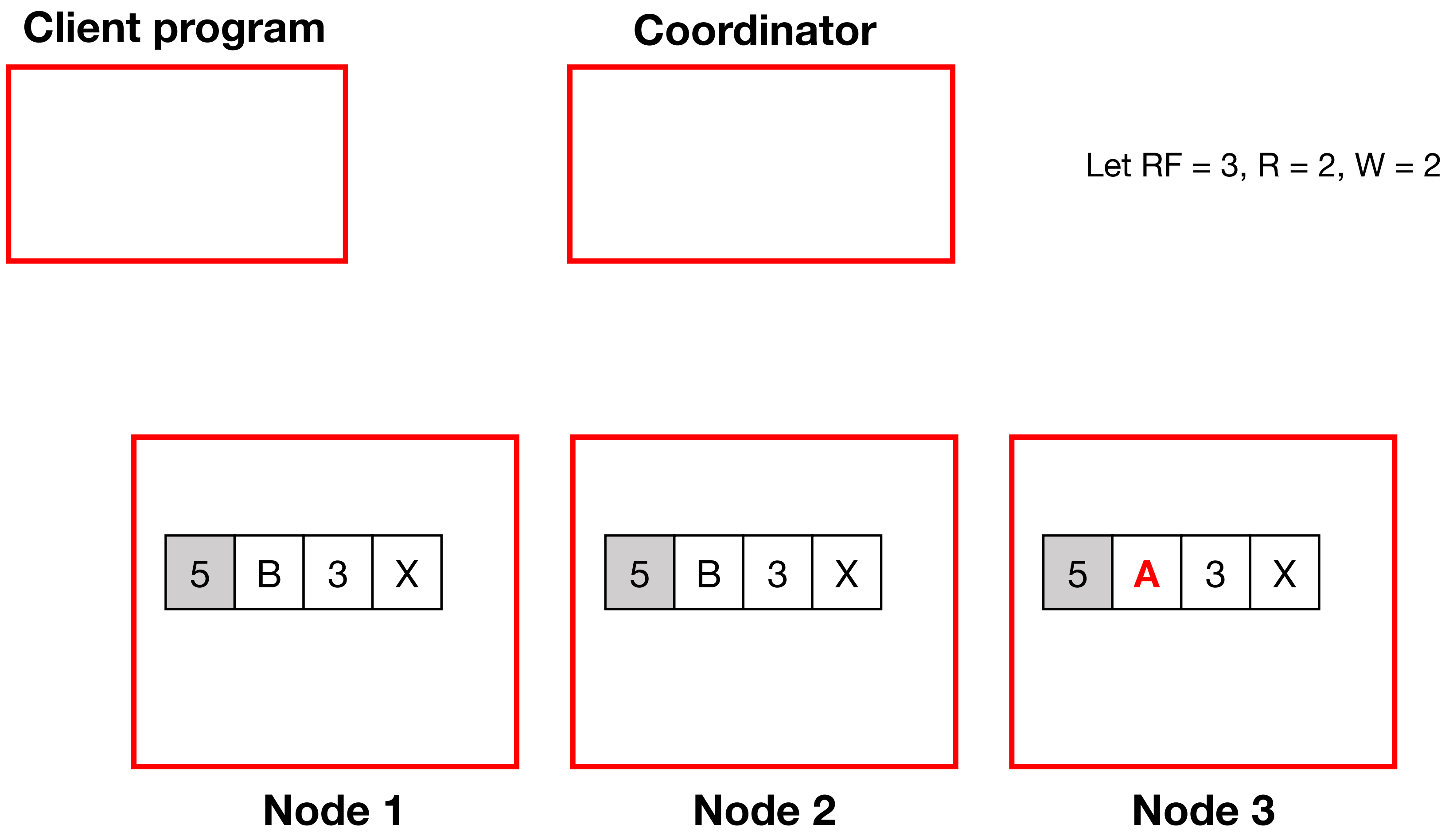

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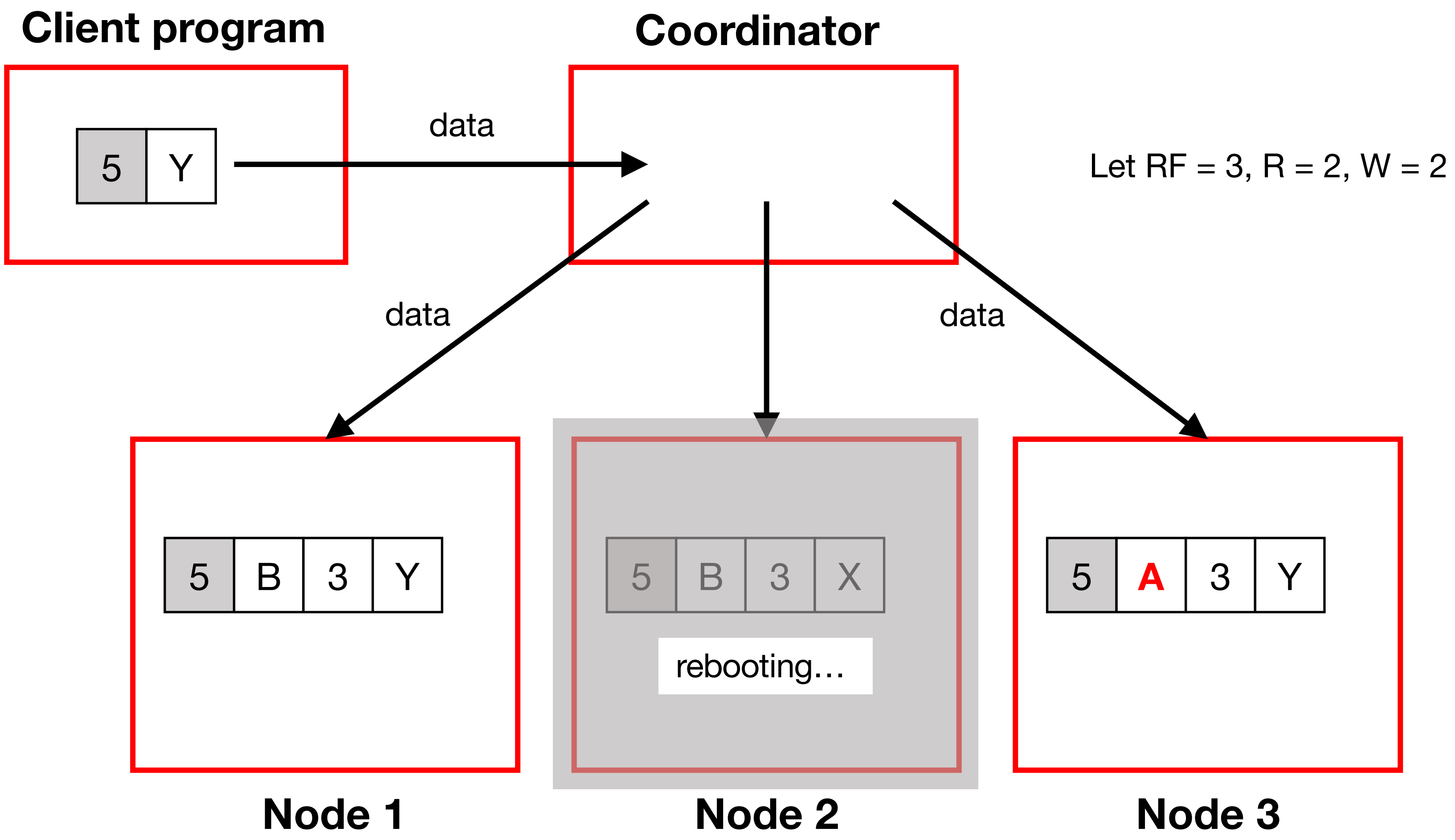

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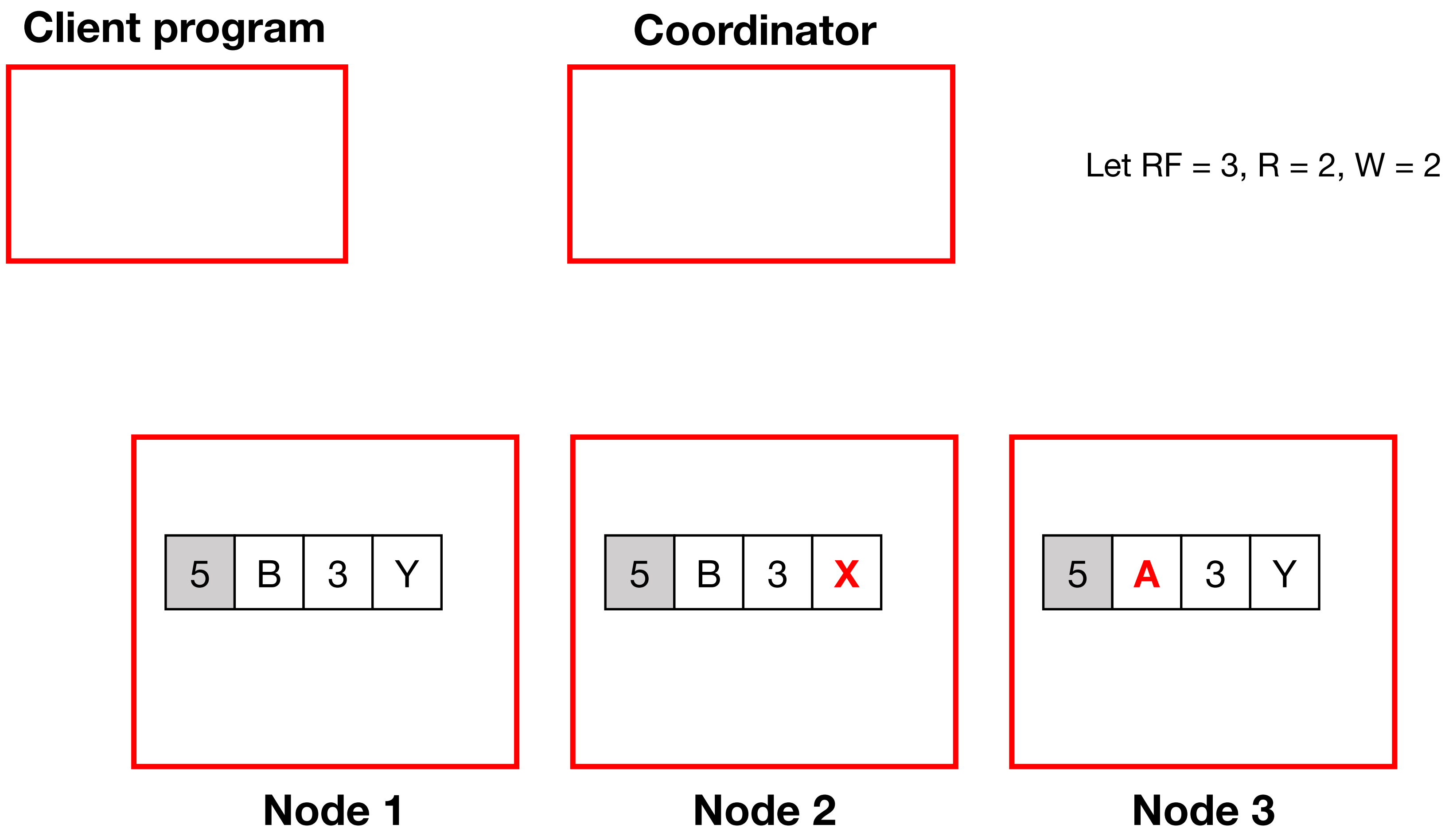

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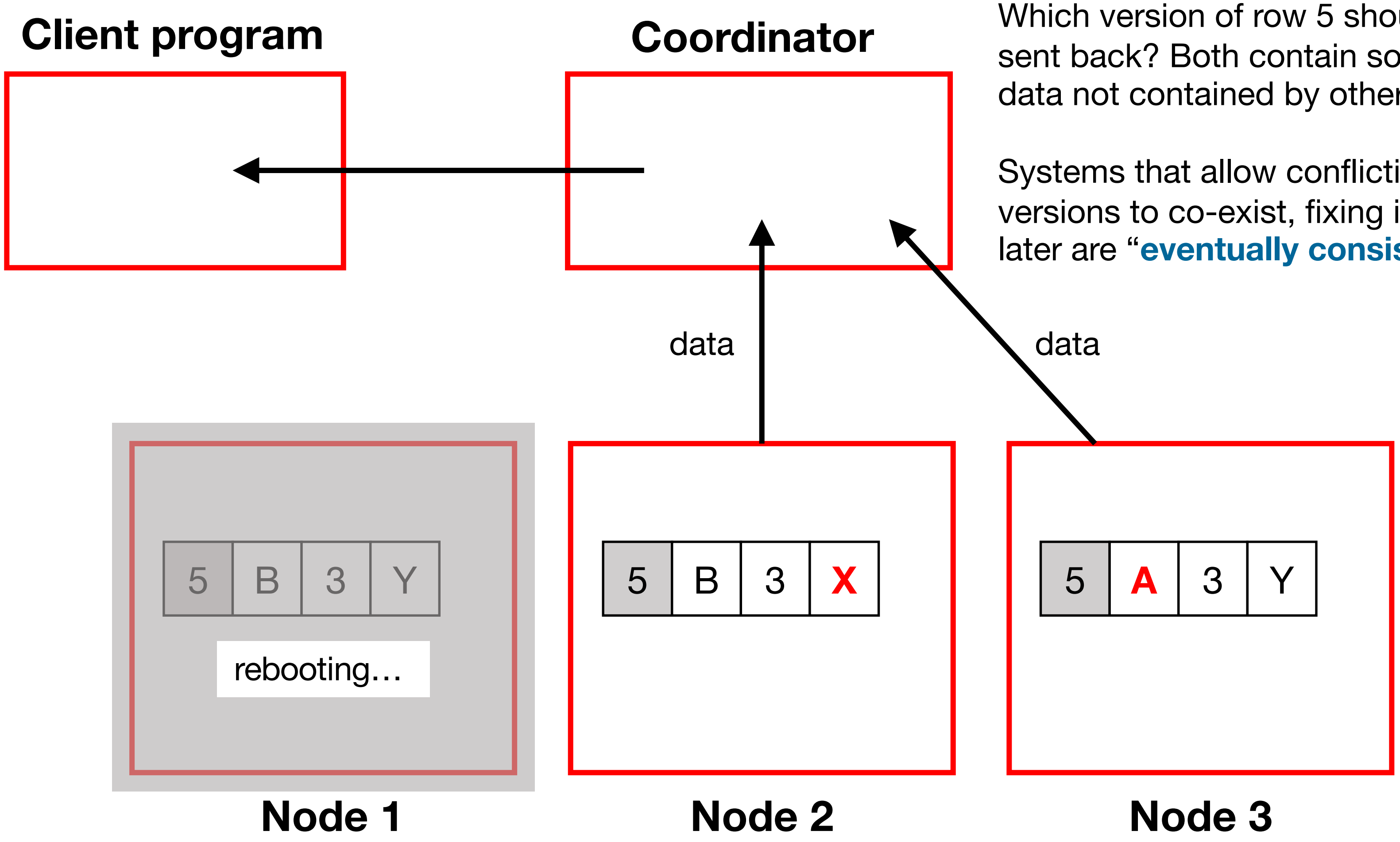
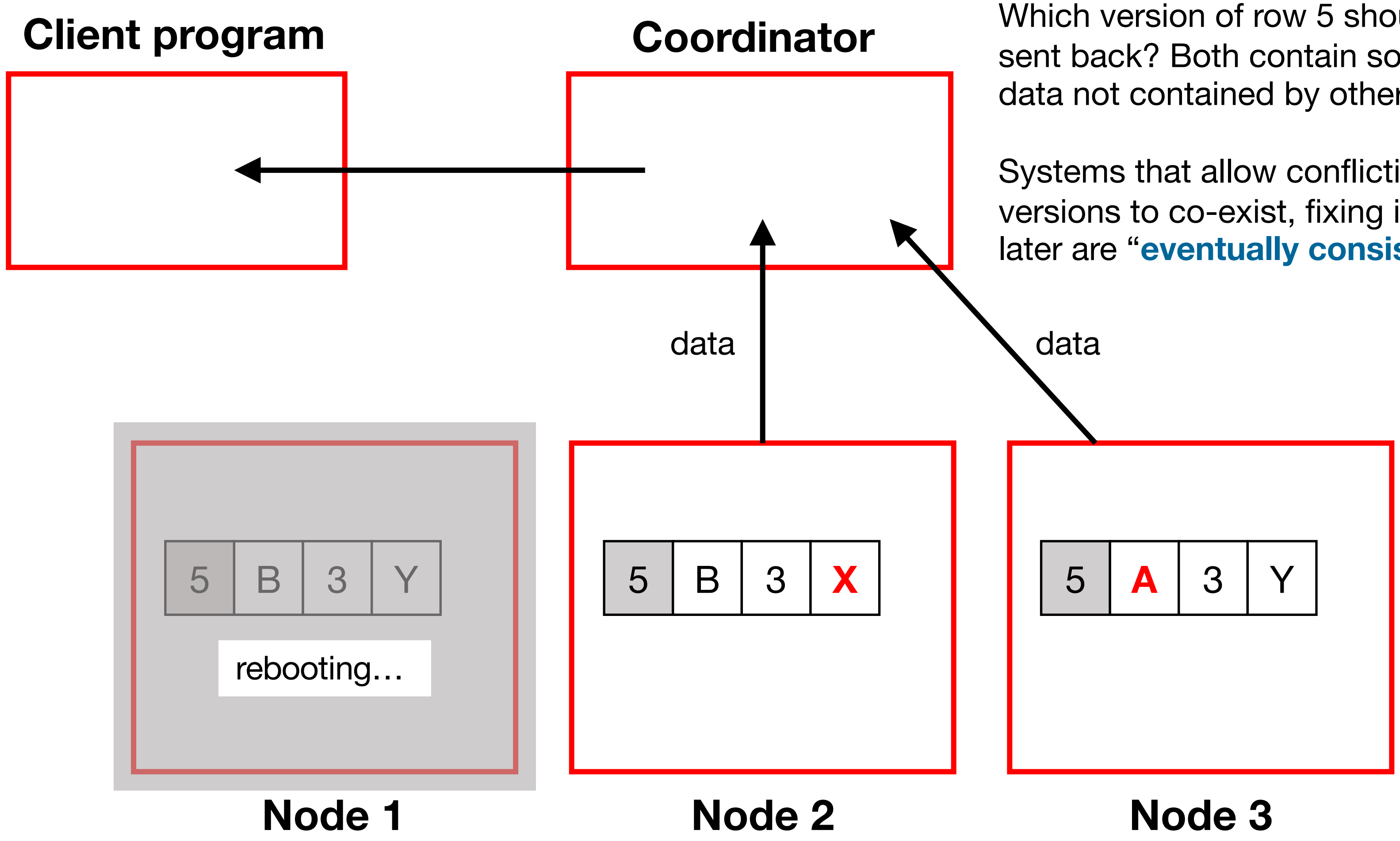


Which version of row 5 should be sent back? Both contain some new data not contained by others.

Systems that allow conflicting versions to co-exist, fixing it up later are "**eventually consistent**".

Getting conflicting versions



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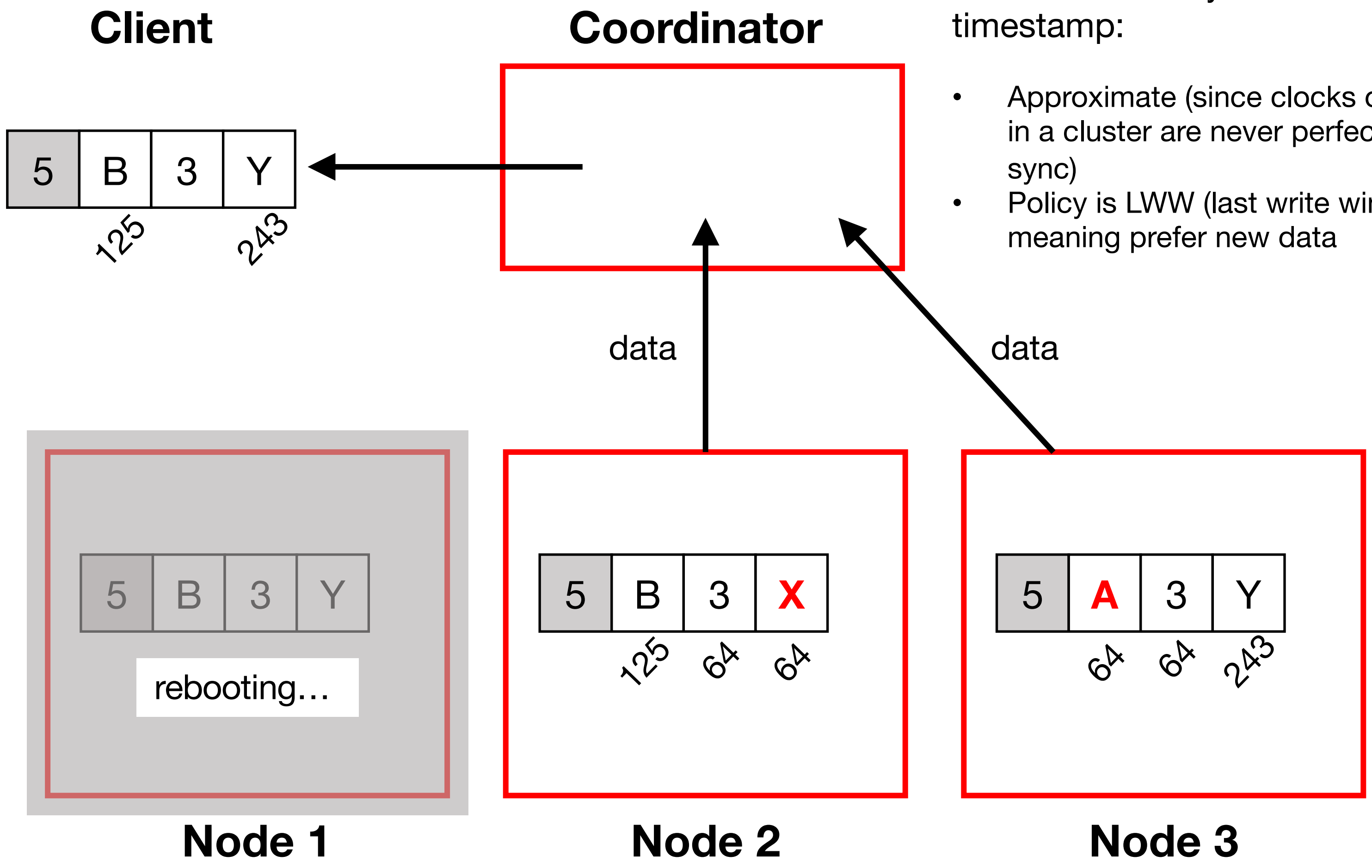
Systems that allow conflicting versions to co-exist, fixing it up later are "**eventually consistent**".

Approach:

- Send all versions back to client, which will need specialized conflict resolution code
- Automatically combine them into a new row, and write that (if possible to all replicas)

Timestamps (logical clock)



Each cell of every table has a timestamp:

- Approximate (since clocks of nodes in a cluster are never perfectly in sync)
- Policy is LWW (last write wins), meaning prefer new data

Extra slides

Dynamo API

- Basic interface is a key-value store
  - **`get(k)`** and **`put(k, v)`**
  - Keys and values opaque to Dynamo

- `get(key) → value, ` **`context`**
  - Returns one value or multiple conflicting values
  - Context describes version(s) of value(s)

Contains the (logical) timestamp info.

- `put(key, ` **`context`**`, value) → "OK"`
  - Context indicates which versions this version supersedes or merges

Version vector (vector clocks)

- **Version vectors:** List of (data node, counter) pairs
  - *e.g.*, [(A, 1), (B, 3), …]

- Dynamo stores a version vector with **each stored** key-value **pair**

- Tracks causal relationship between different versions of data stored under the same key **k**

Version vector in Dynamo

- **Rule:** If vector clock comparison of v1 < v2, then the first is an ancestor of the second – Dynamo can forget v1

- Each time a `put()` occurs, Dynamo increments the counter in the V.V. for the corresponding data node

- Each time a `get()` occurs, Dynamo returns the V.V. for the value(s) returned (in the "context")
  - Then users must supply that context to `put()`s that modify the same key

Fig 3 example