

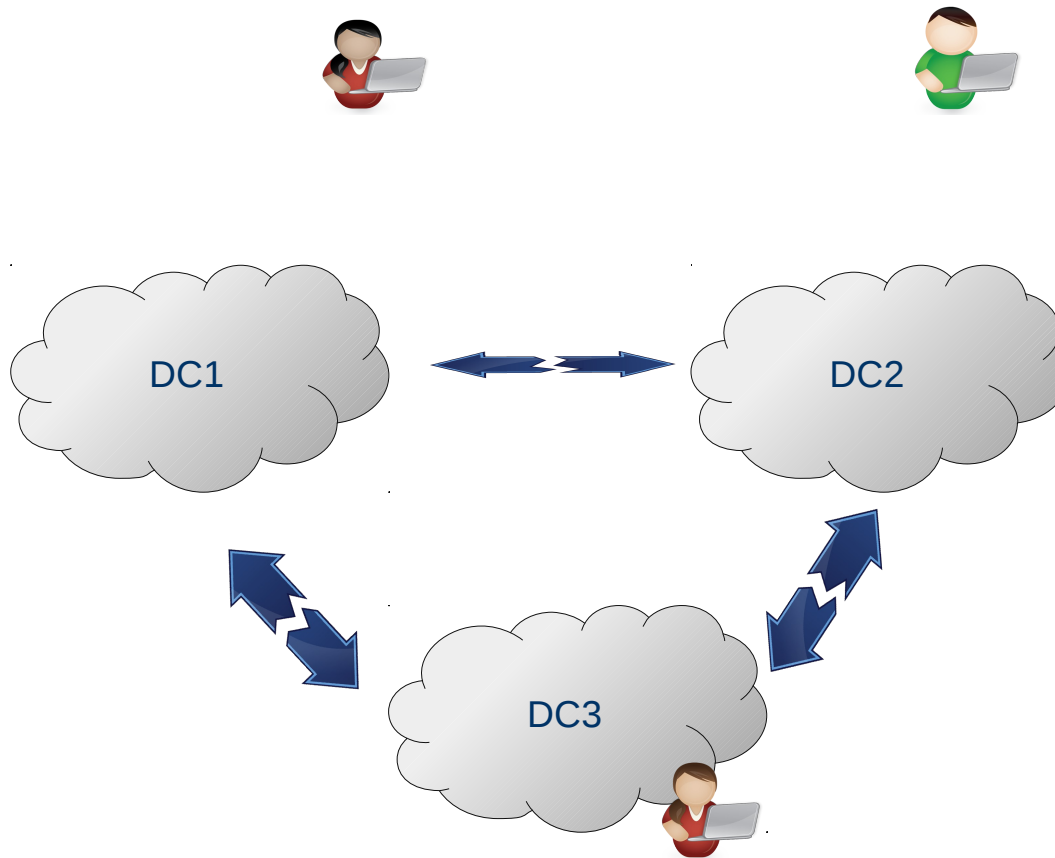


Causal consistency in Geo-replicated Systems

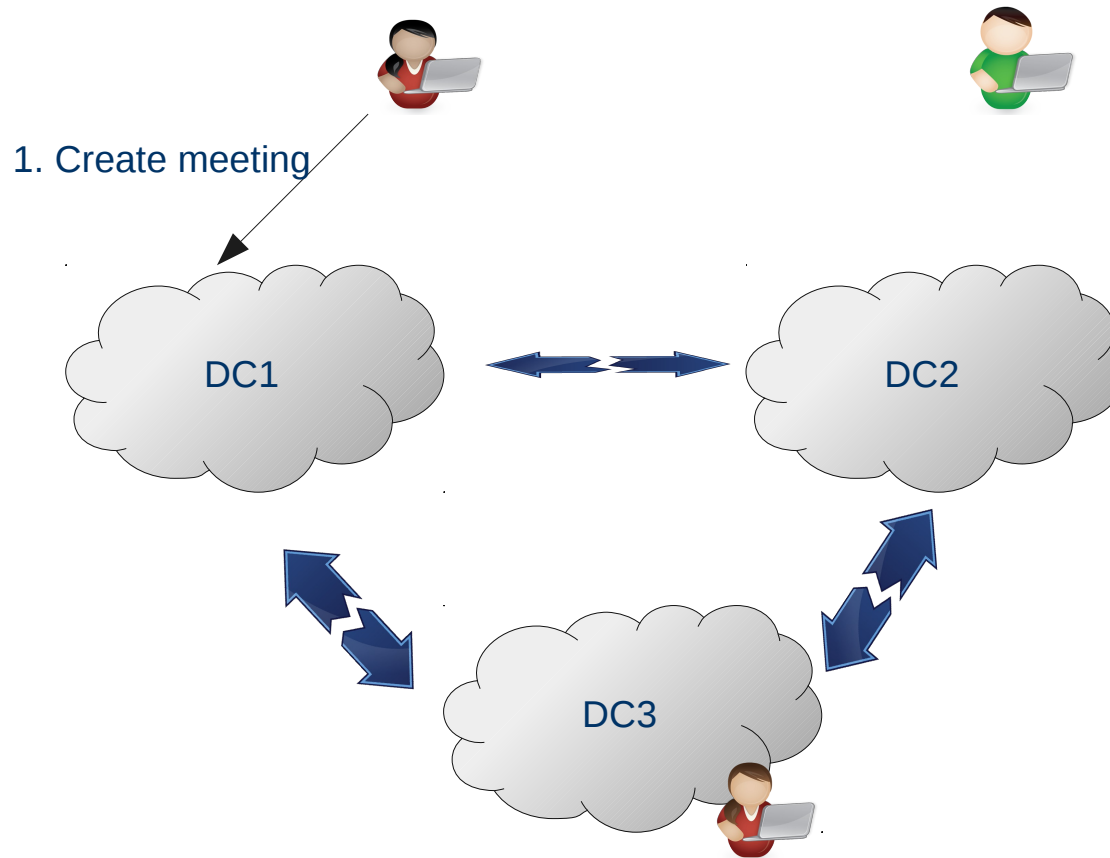
Deepthi Akkoorath

AG SoftTech

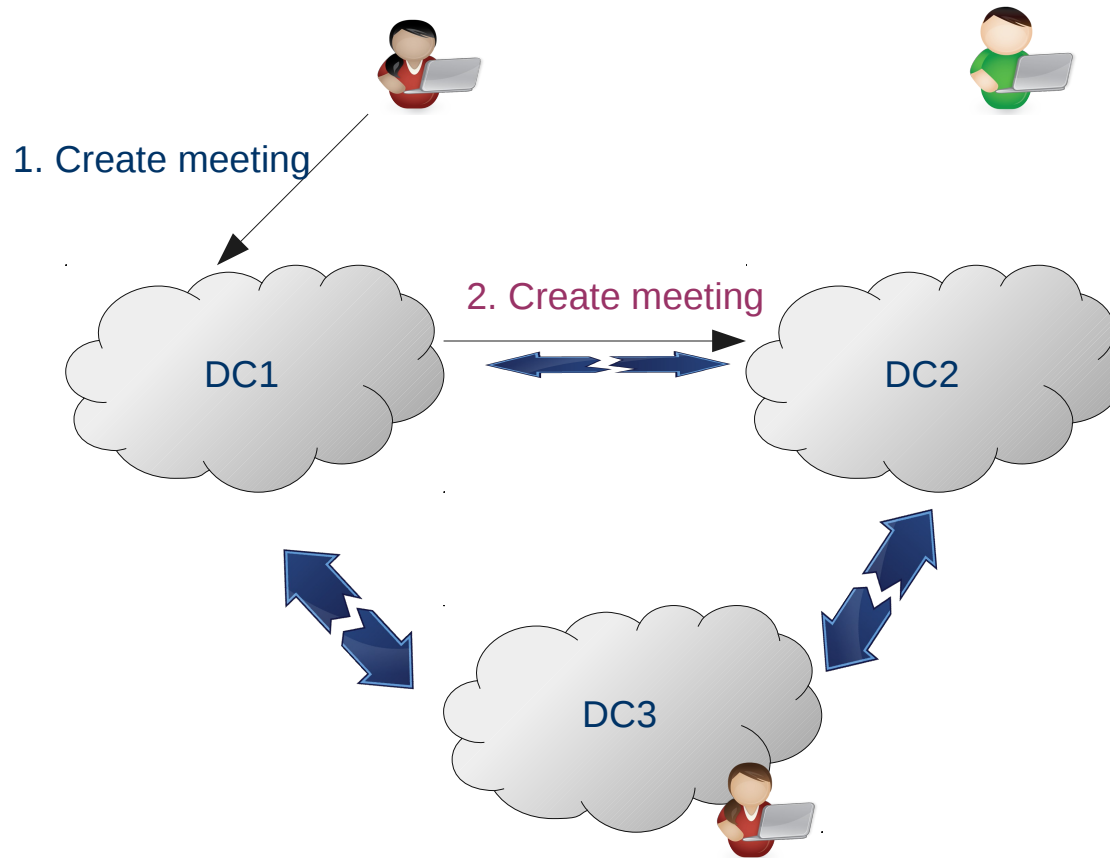
Geo-Replicated Distributed Application



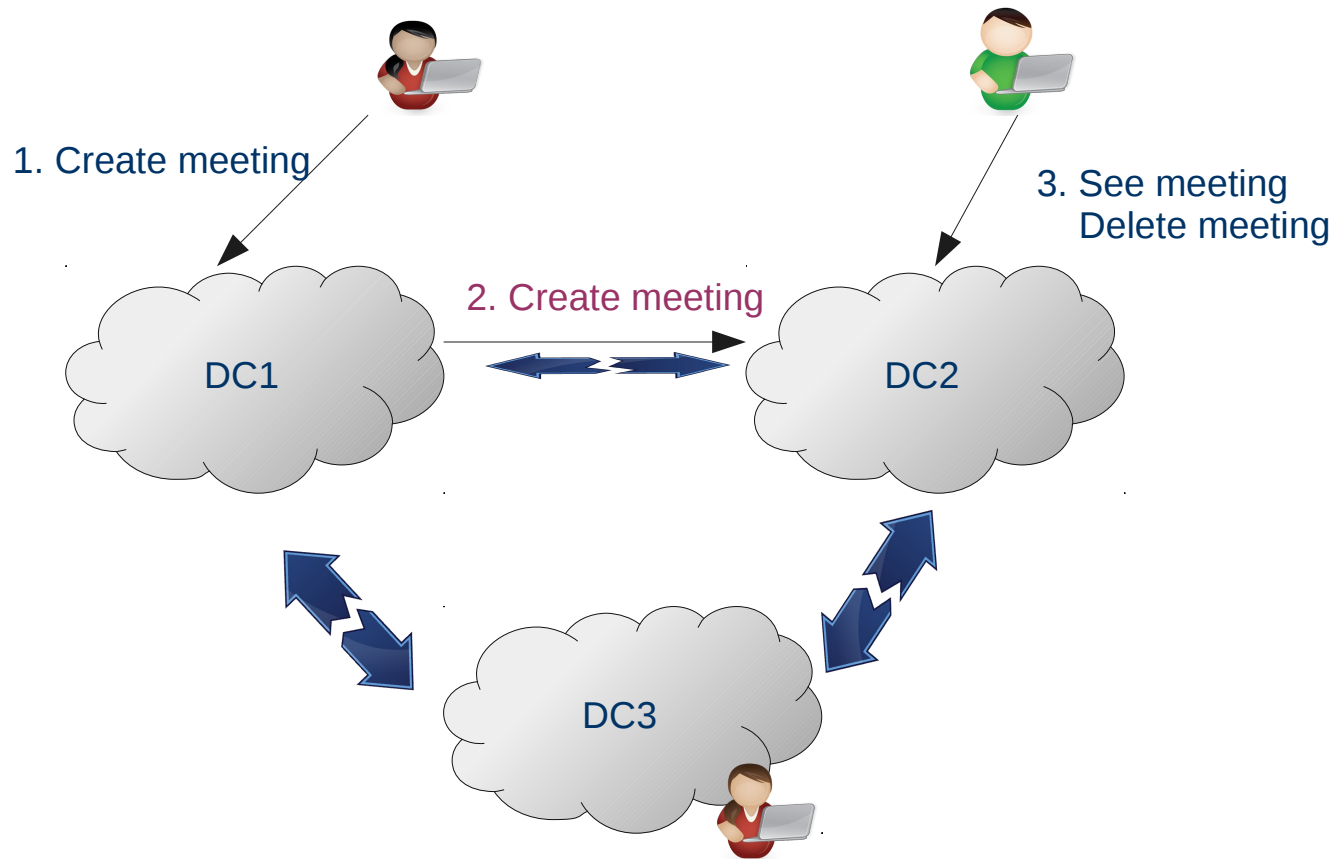
Geo-Replicated Distributed Application



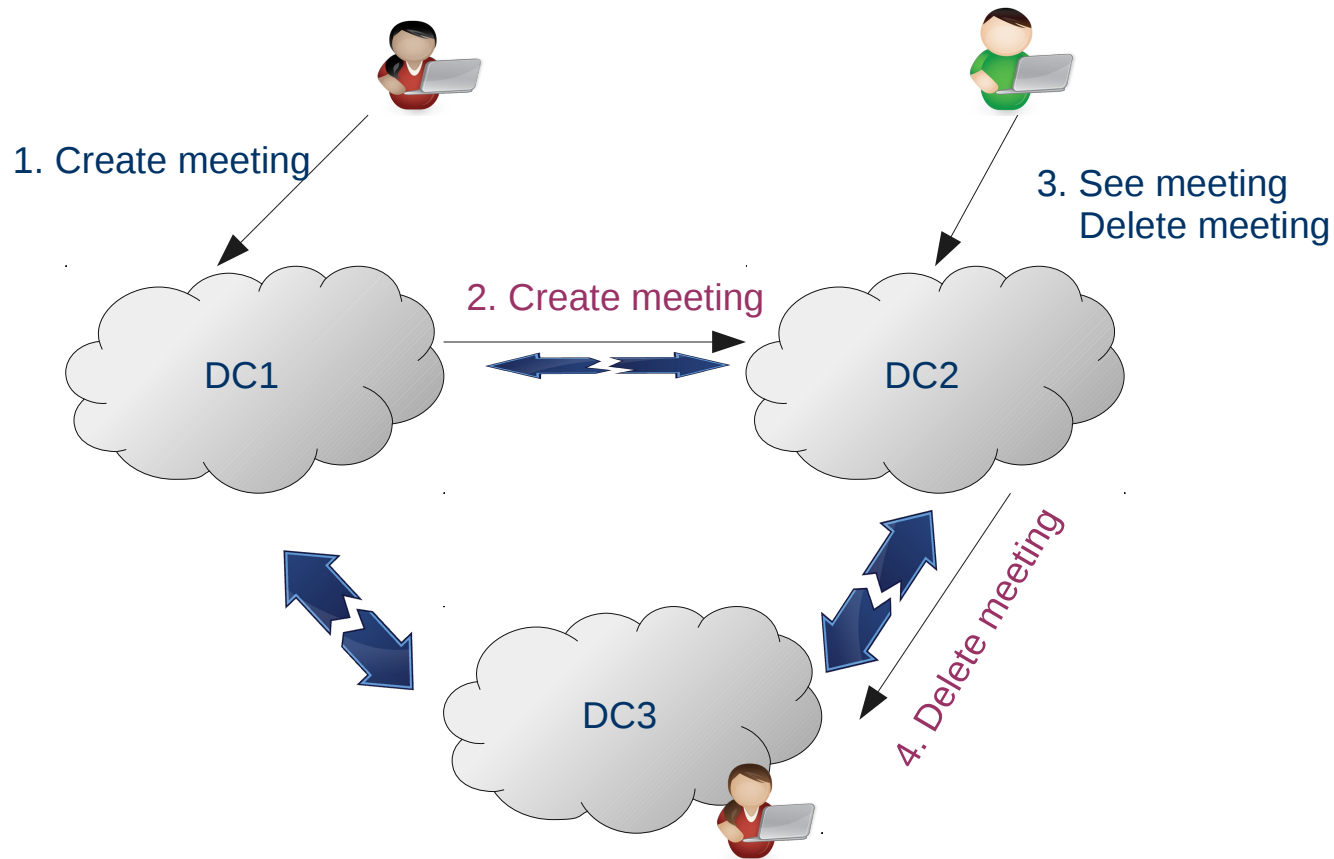
Geo-Replicated Distributed Application



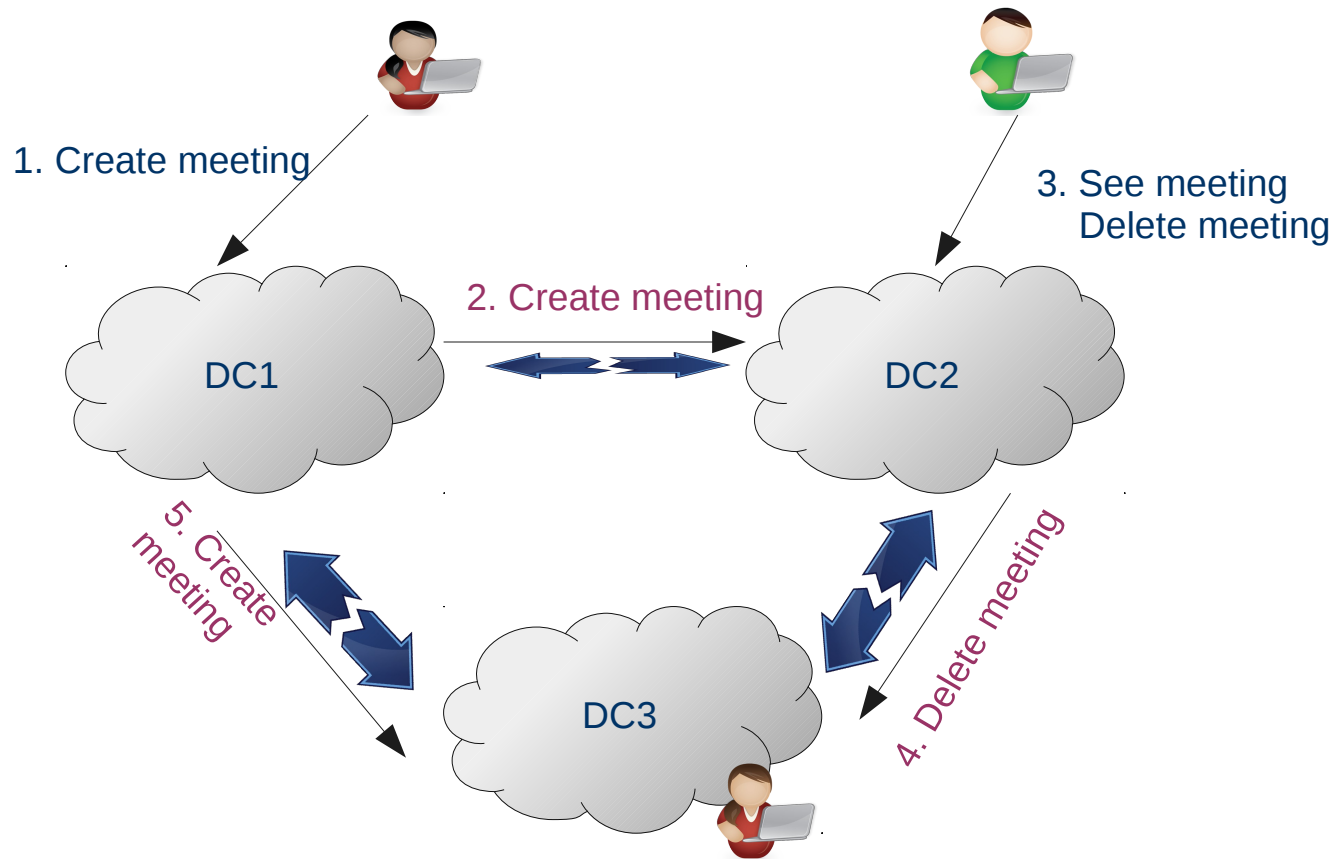
Geo-Replicated Distributed Application



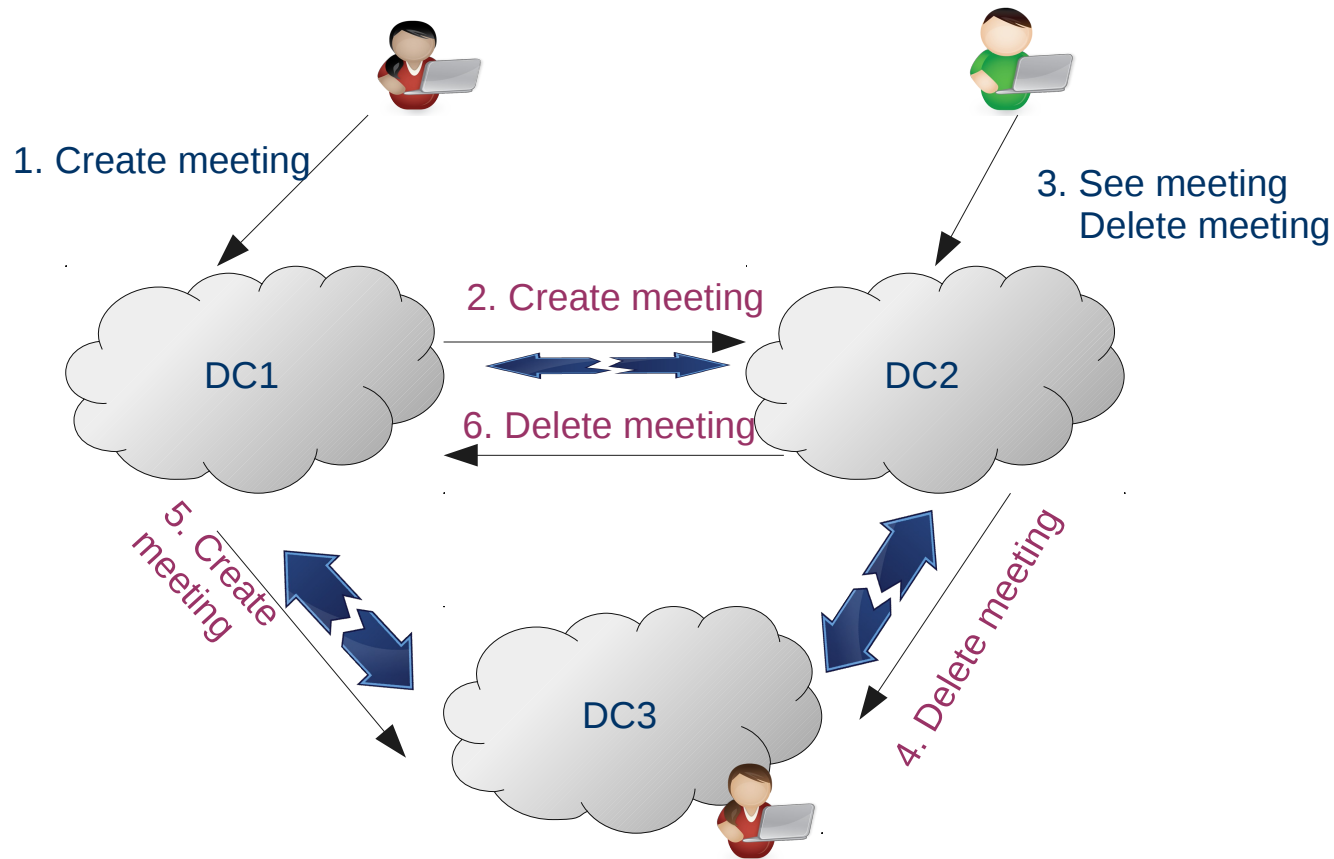
Geo-Replicated Distributed Application



Geo-Replicated Distributed Application



Geo-Replicated Distributed Application



Lamport's Timestamps

- Total order of events satisfying Happened-before relation
- Each process has a Logical clock
- A process increments its clock for each event
- Sends clock with each message it sends
- On receiving a message
 - Sets clock = $\max(\text{own clock}, \text{received clock})$

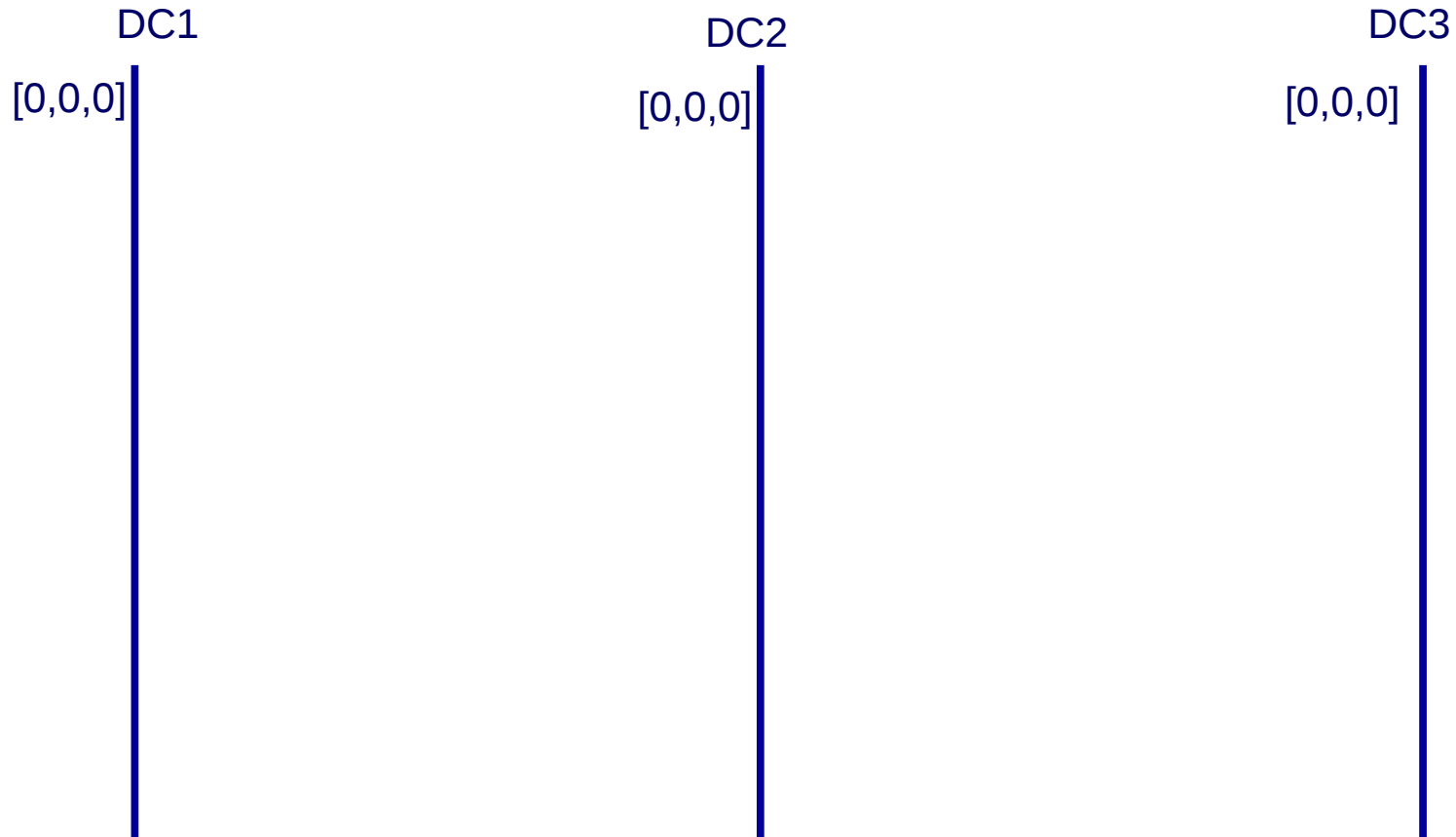
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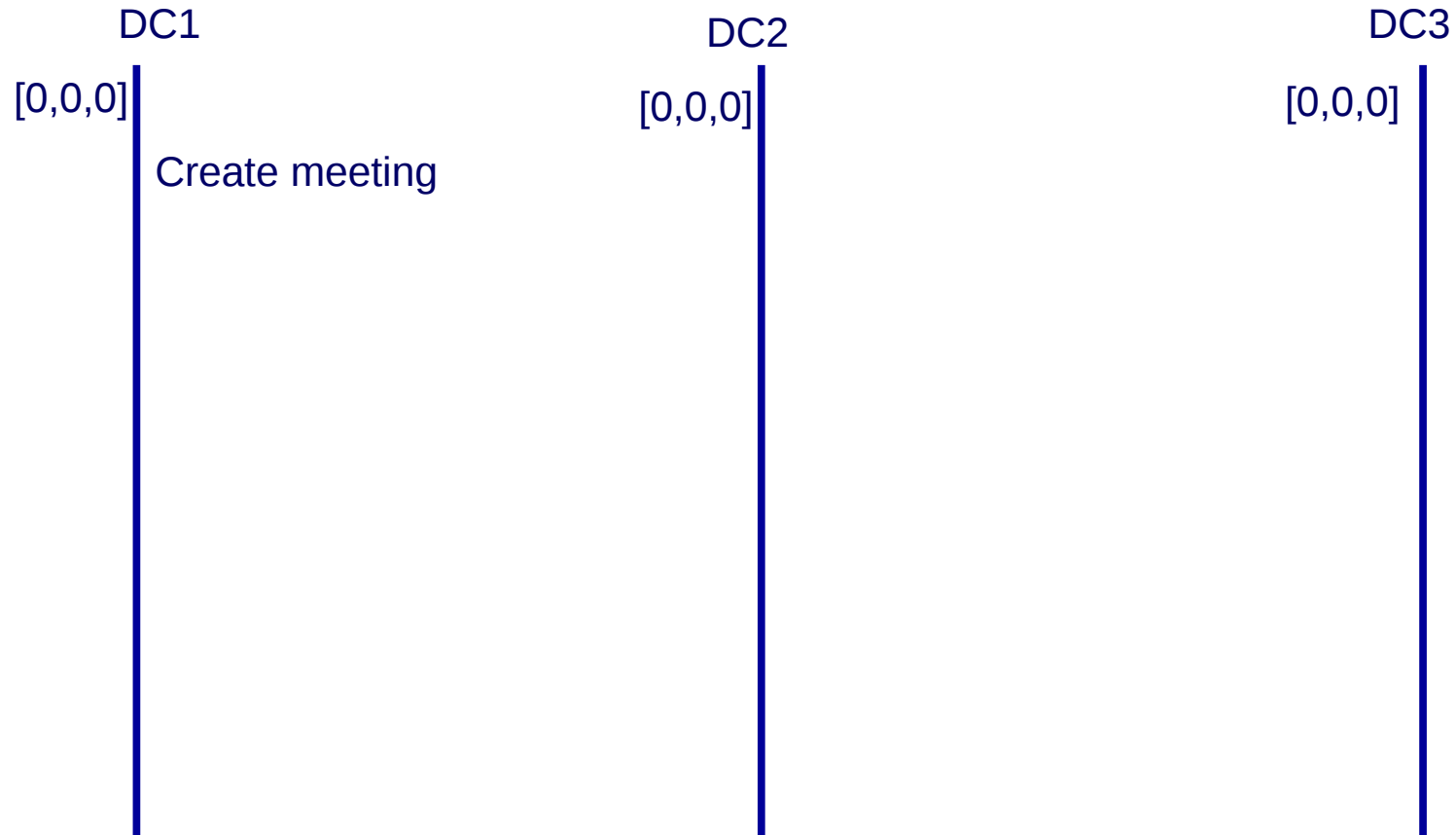
Vectorclocks

- Similar to Lamport's timestamp
- **Partial order** and detect causality violations
- A system on N process
 - Vectorclock = array of N logical clocks
 - Each process has a vectorclock
 - Increment its own logical clock for each event
 - On receiving a message
 - Set each entry in vc to be $\max(\text{local entry}, \text{corresponding entry in received vc})$

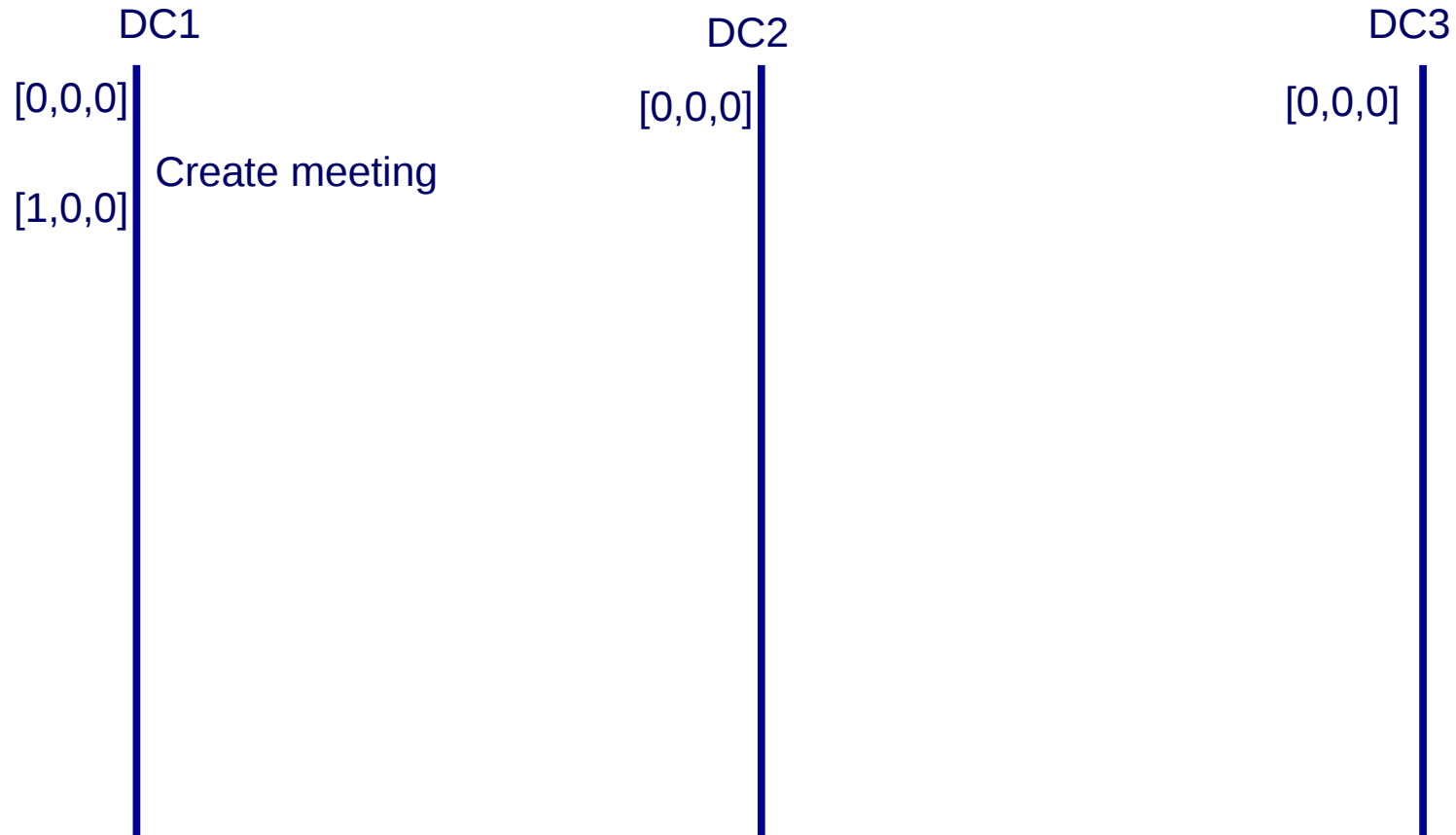
Detect Causality violation using Vectorclocks



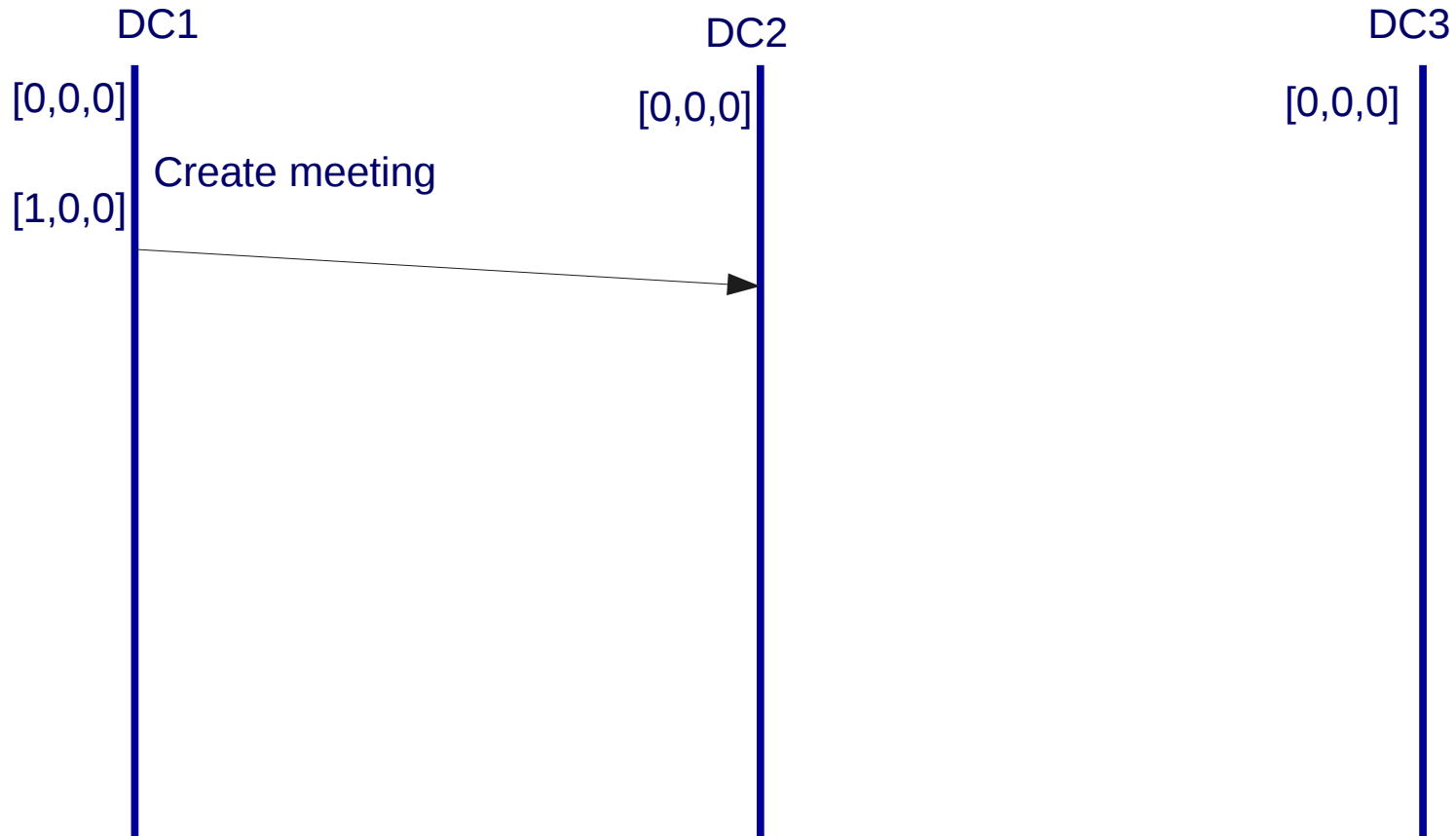
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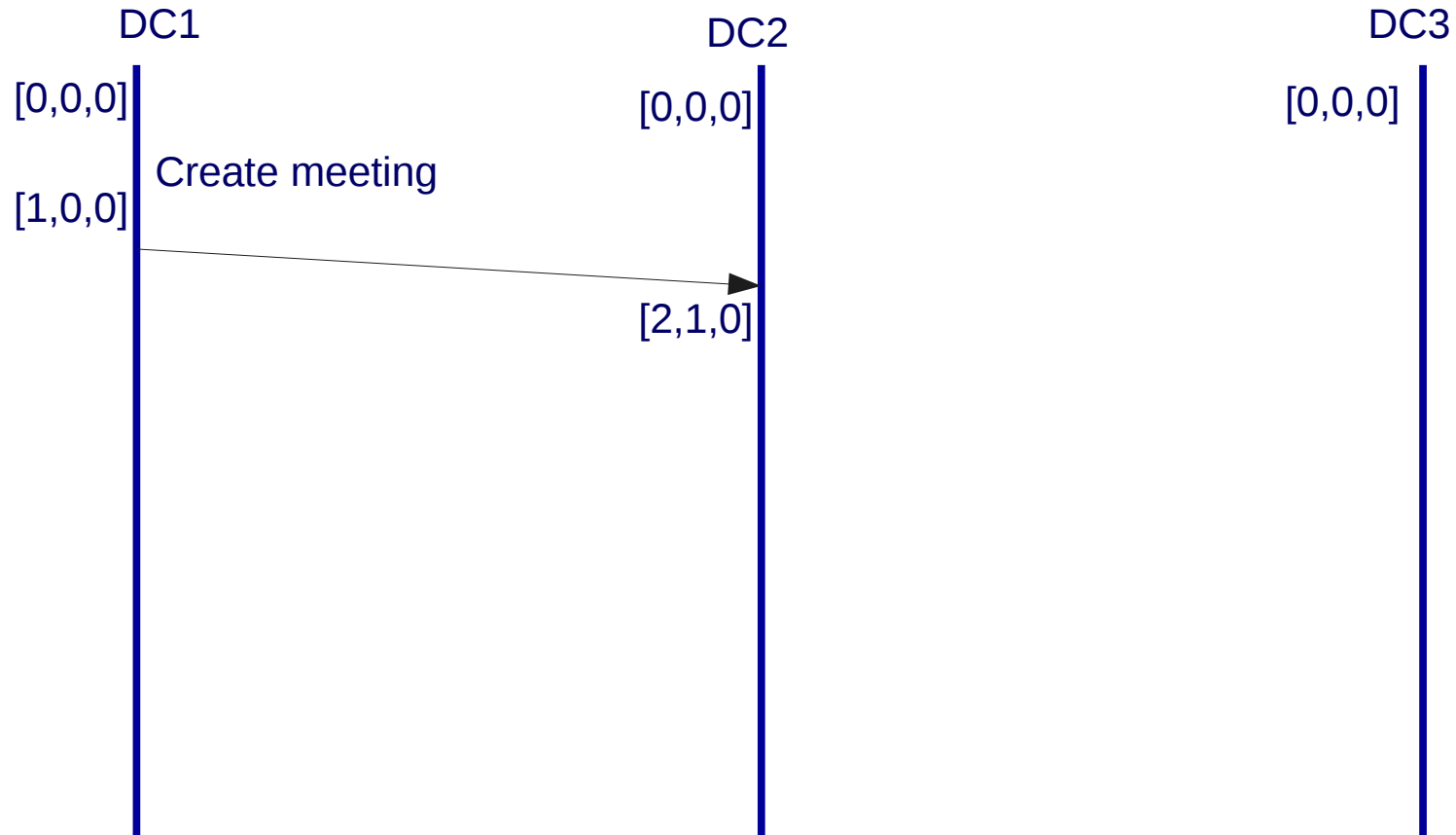
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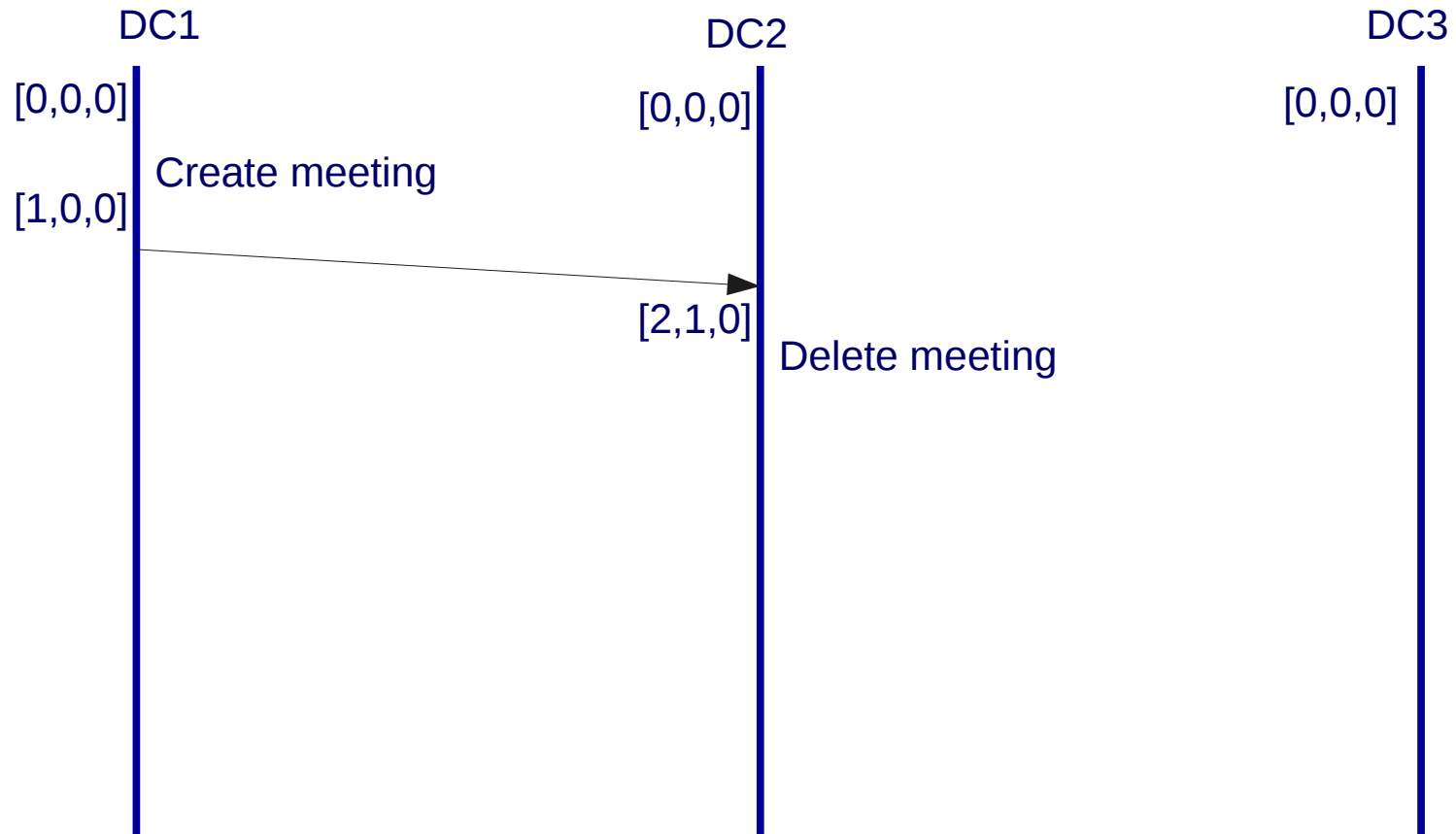
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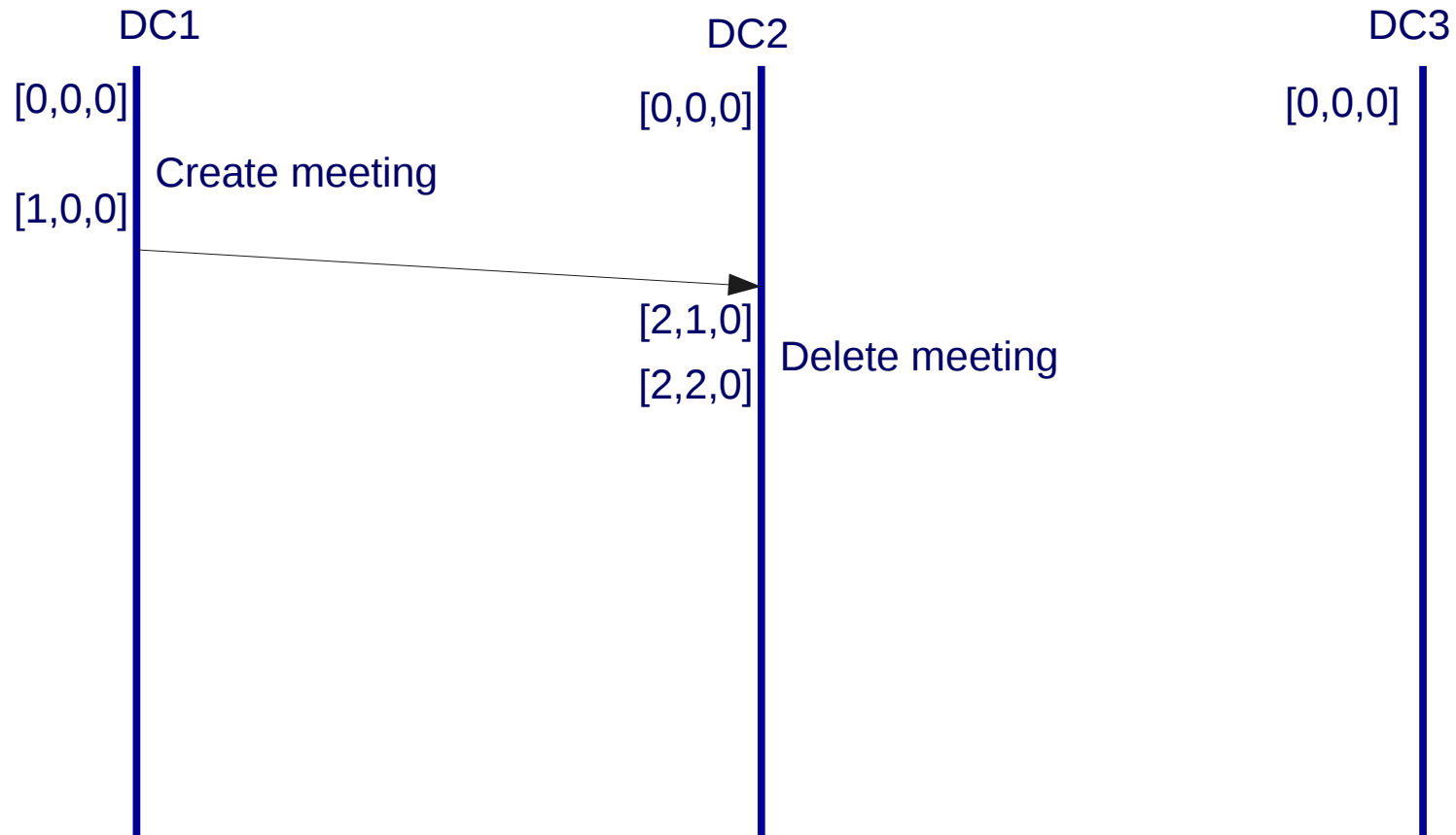
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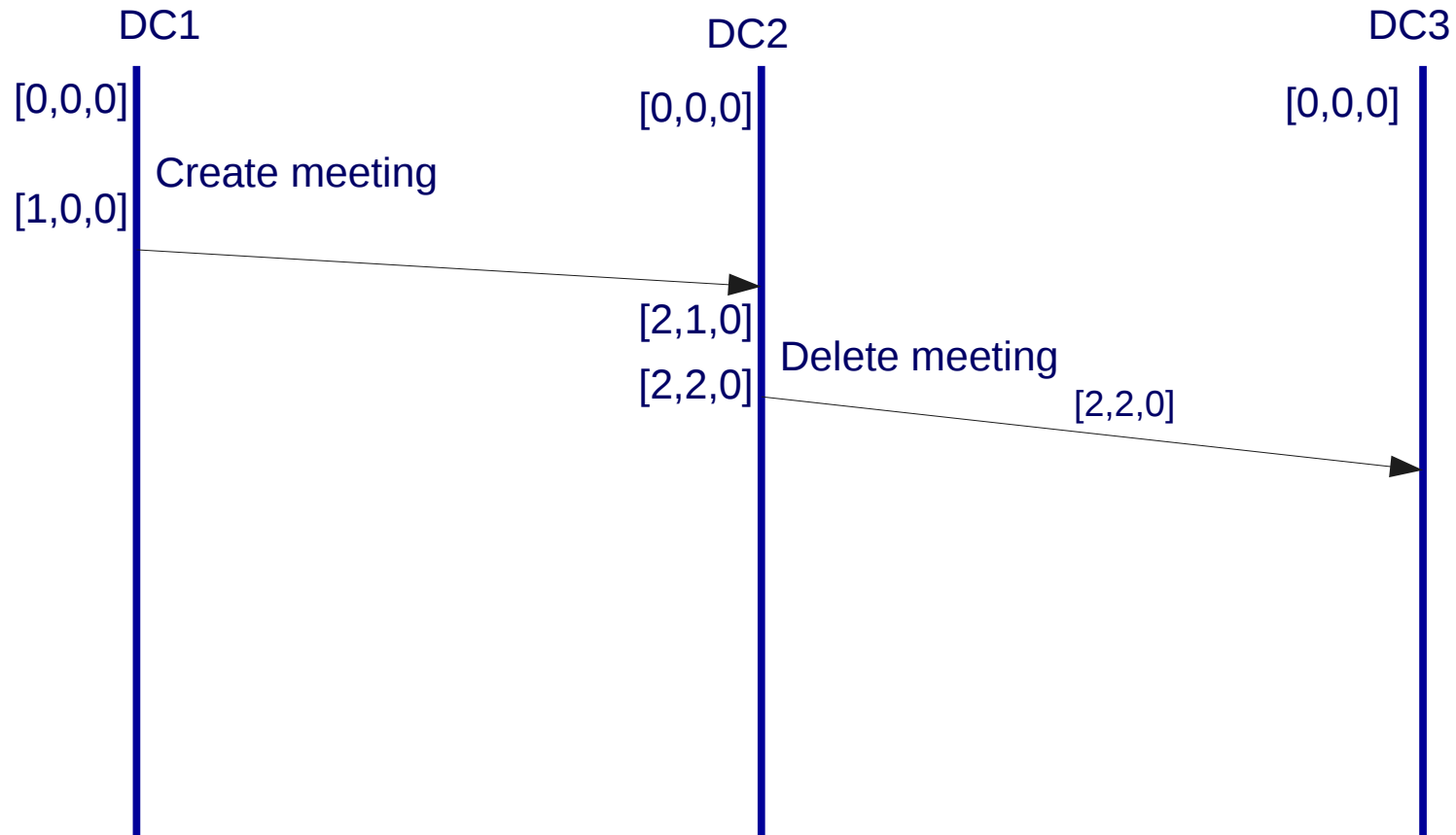
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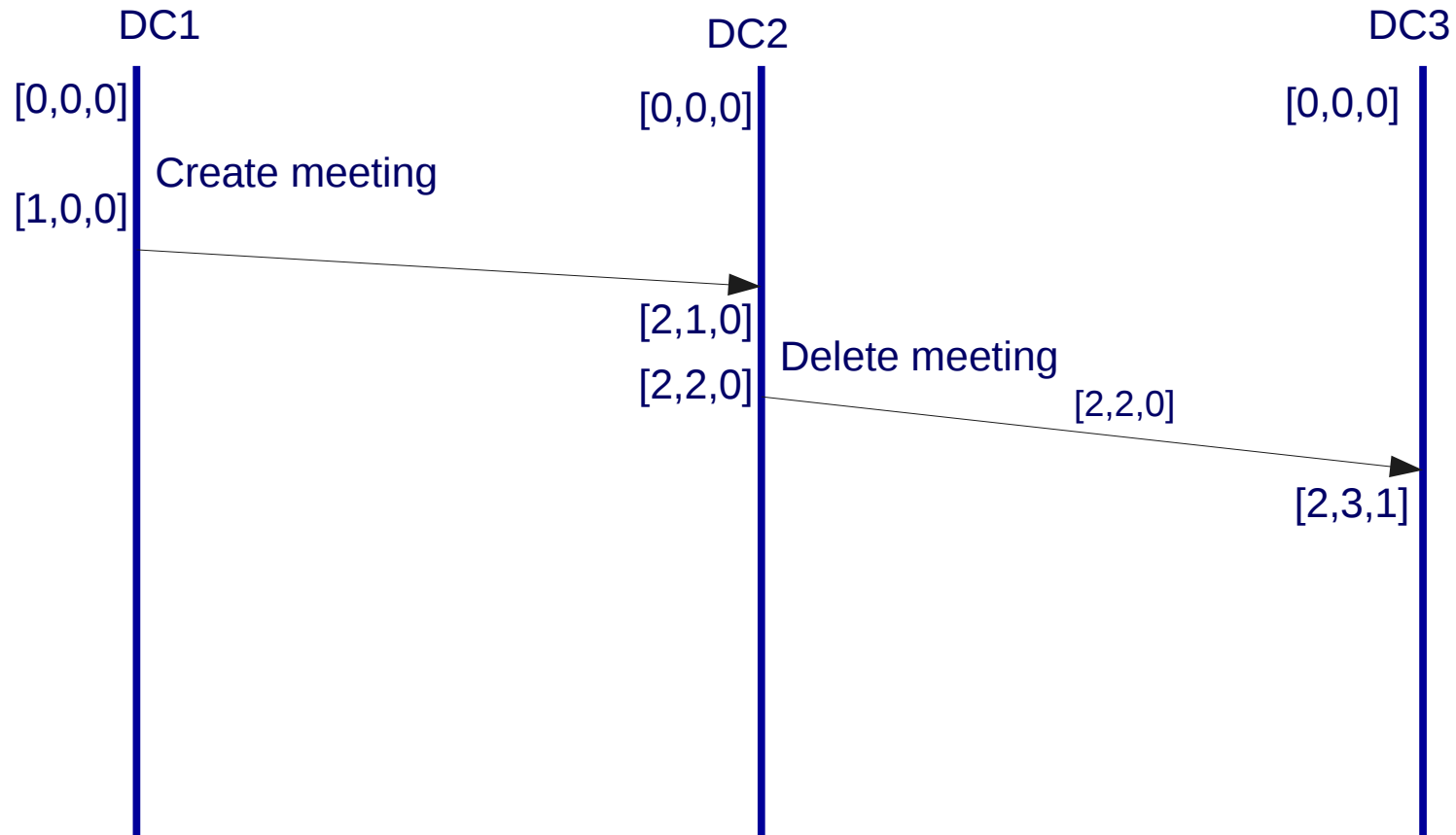
Detect Causality violation using Vectorclocks



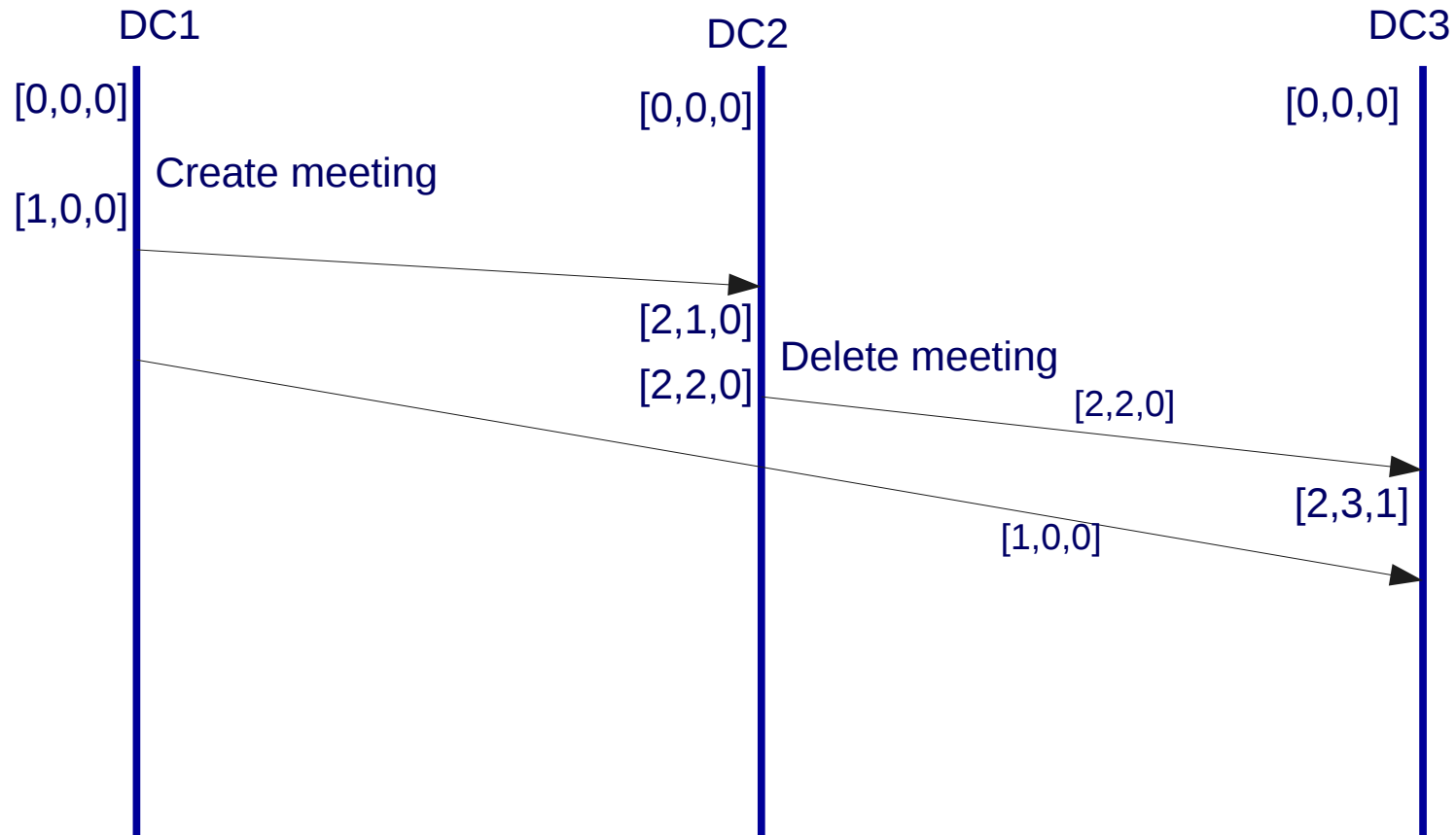
Detect Causality violation using Vectorclocks



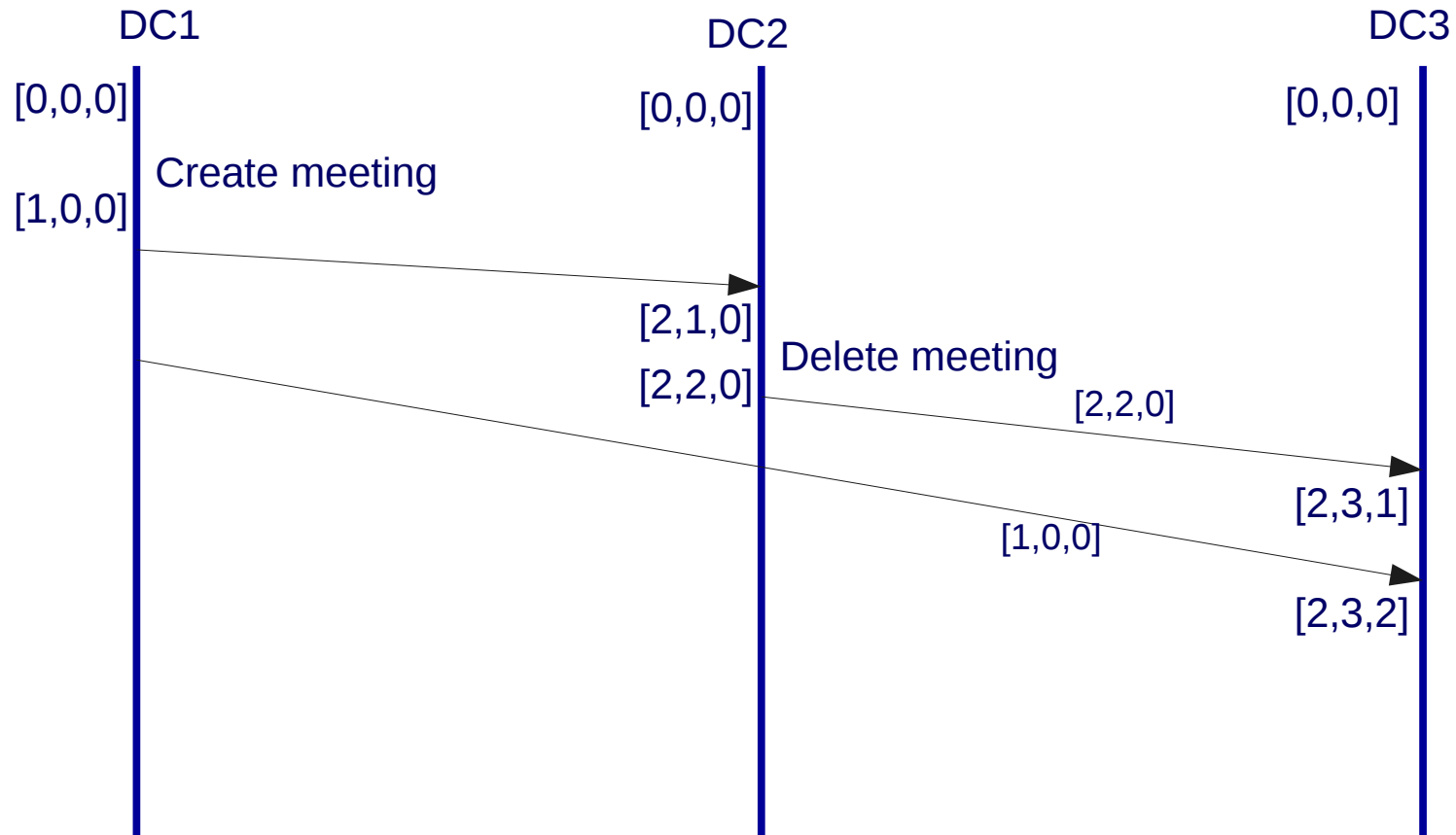
Detect Causality violation using Vectorclocks



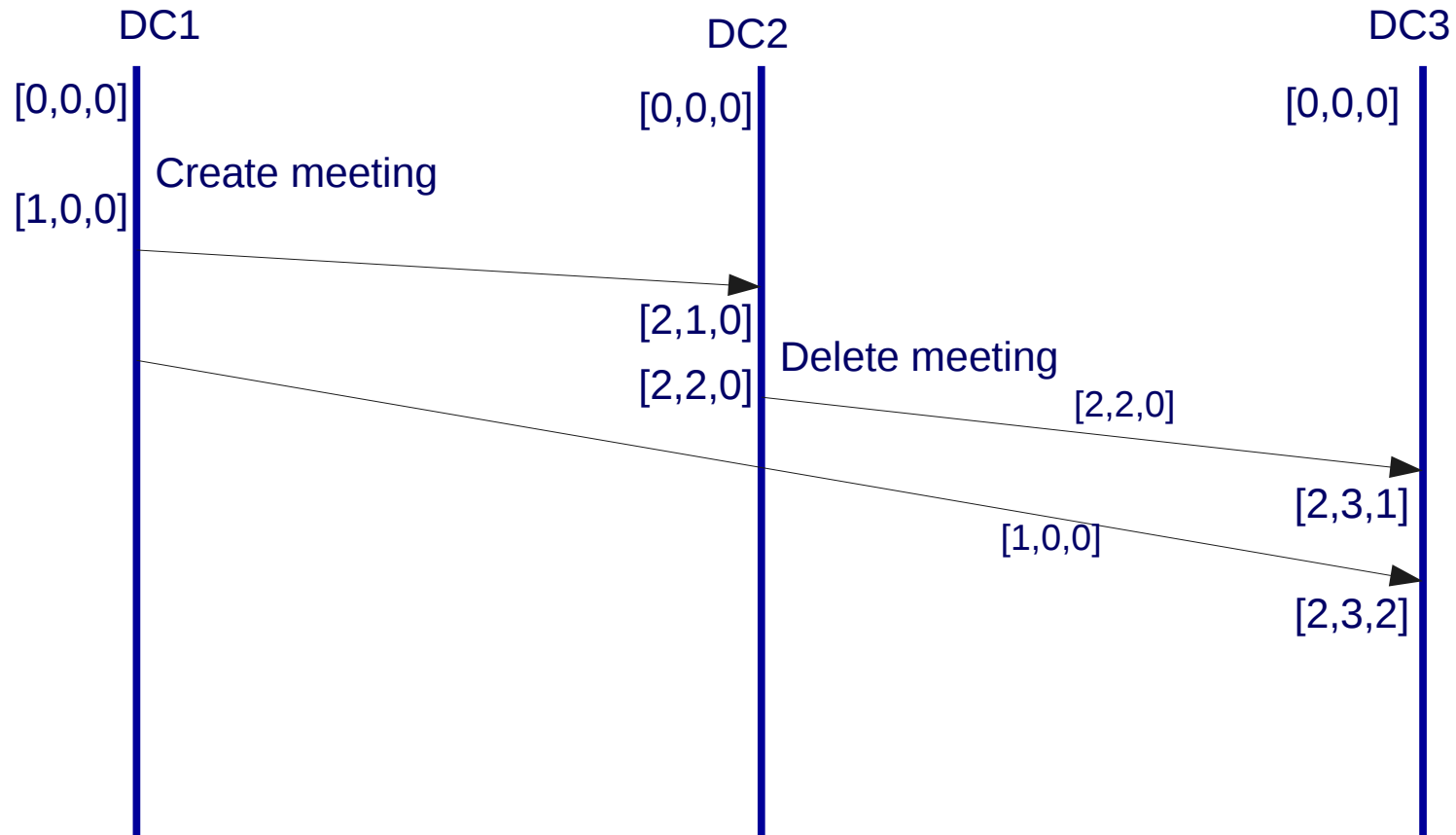
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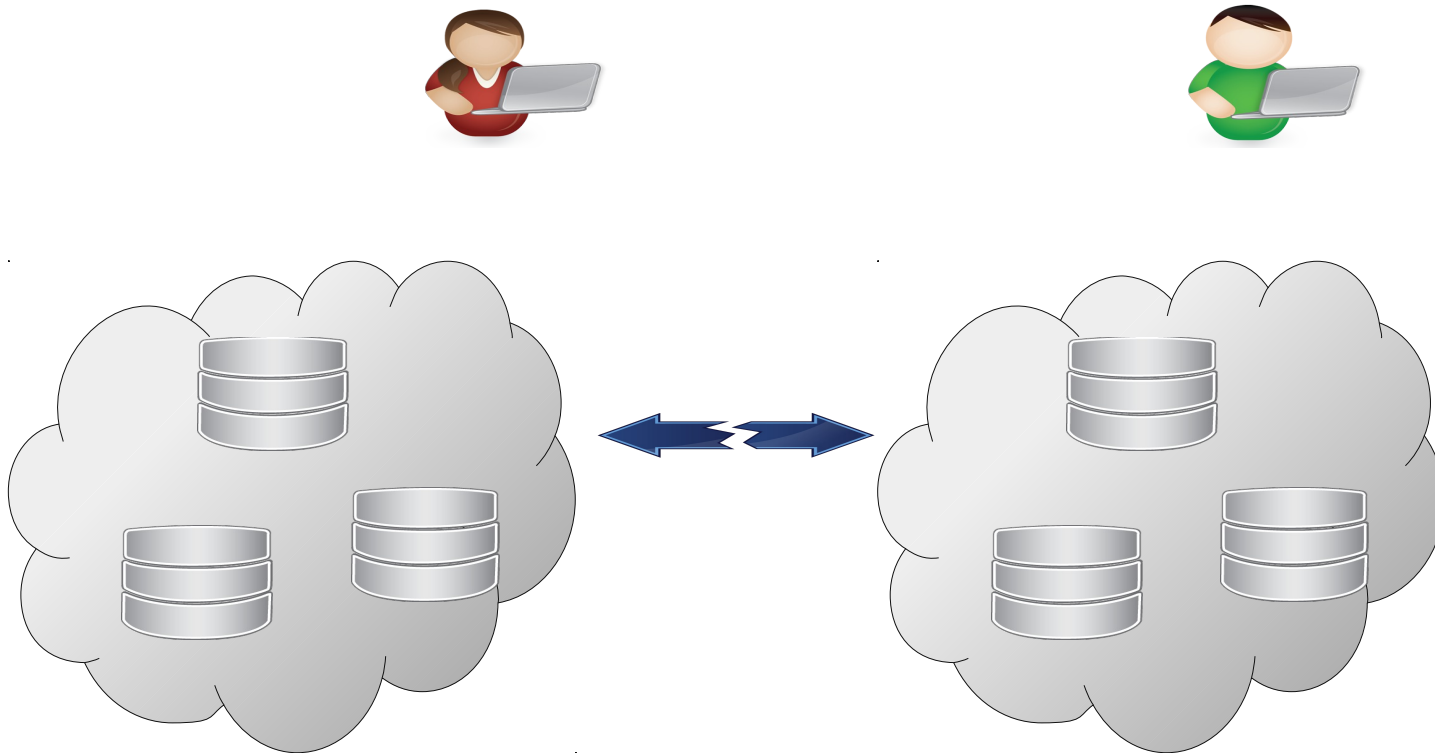
Detect Causality violation using Vectorclocks



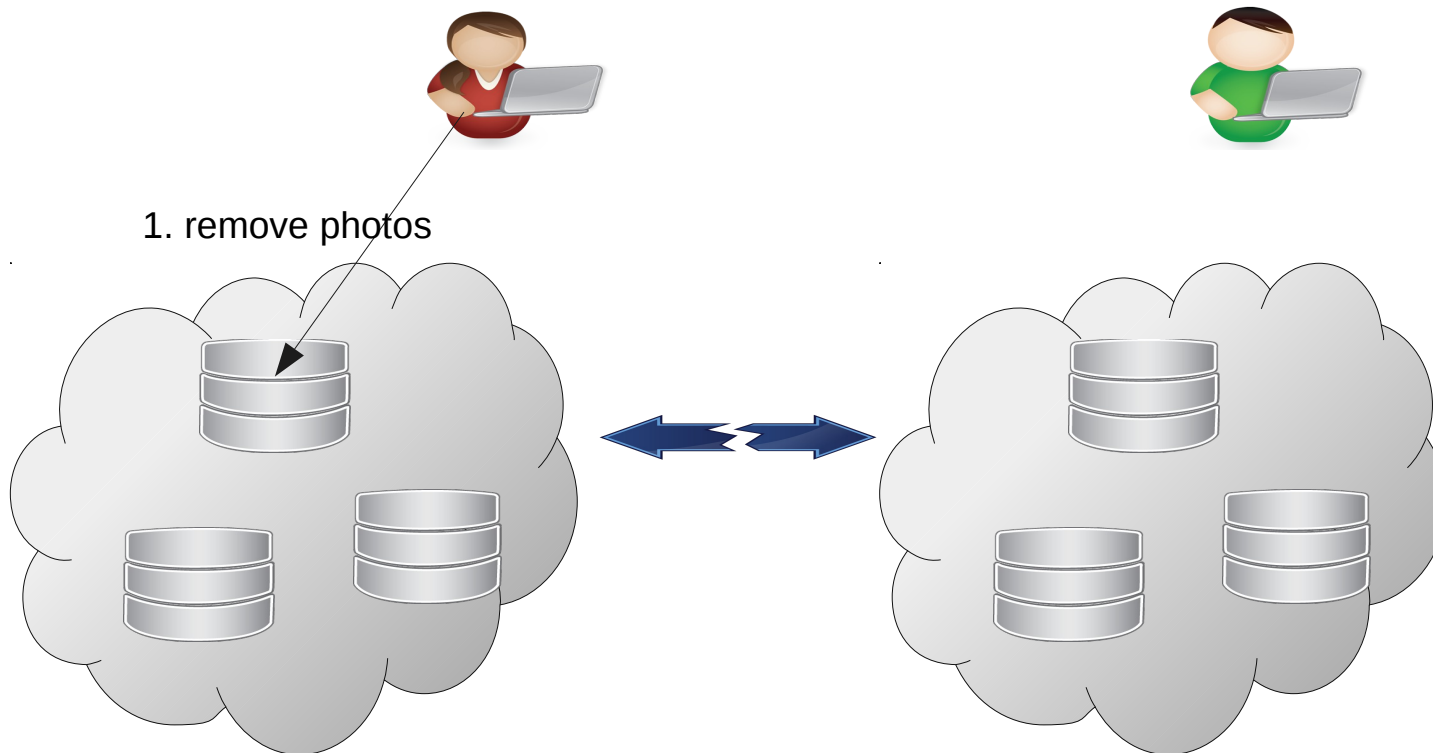
Version Vectors

- Similar to vector clocks
- Partial order among replicas of an object
- Several mechanisms to keep size of version vector small
 - Bounded Version Vectors
 - Dotted Version Vectors
- Causality across objects cannot be tracked

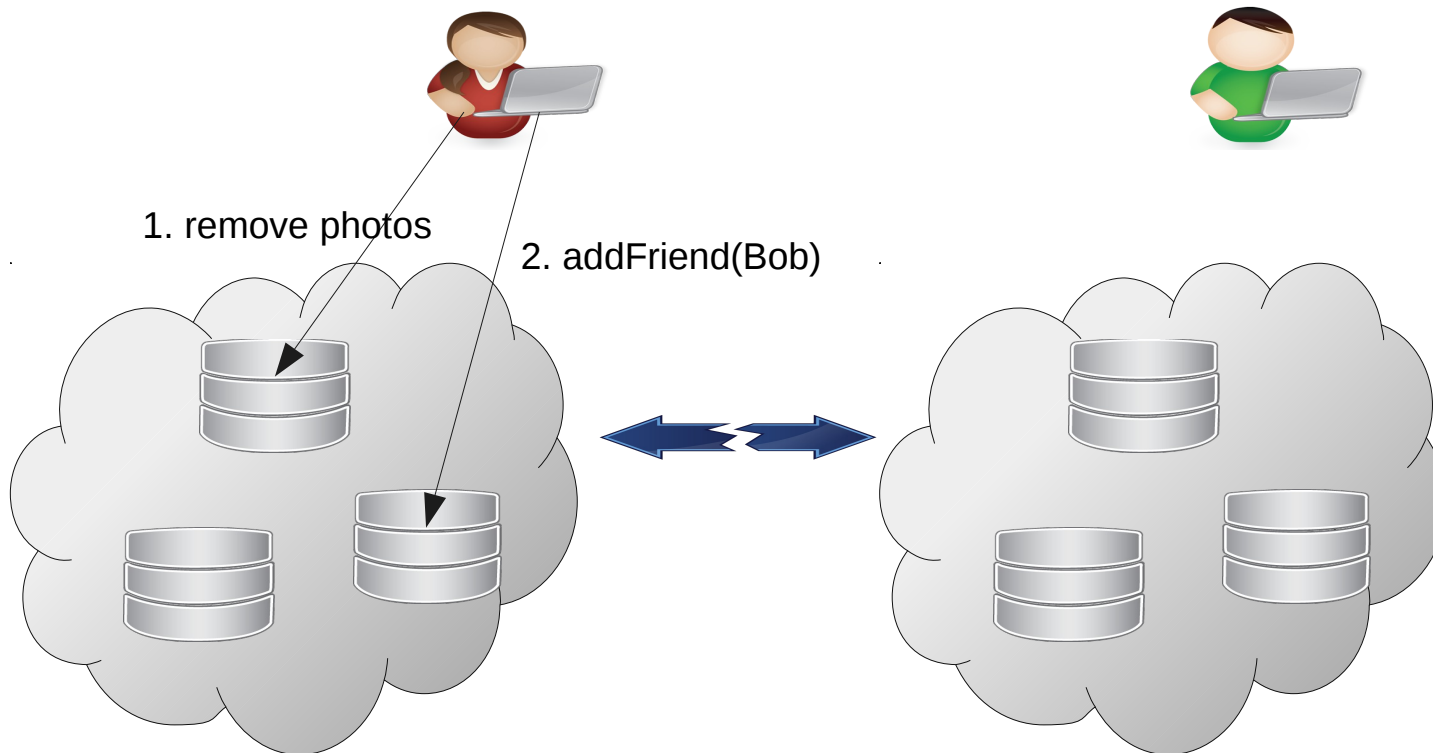
Partitioned and Geo-Replicated Distributed System



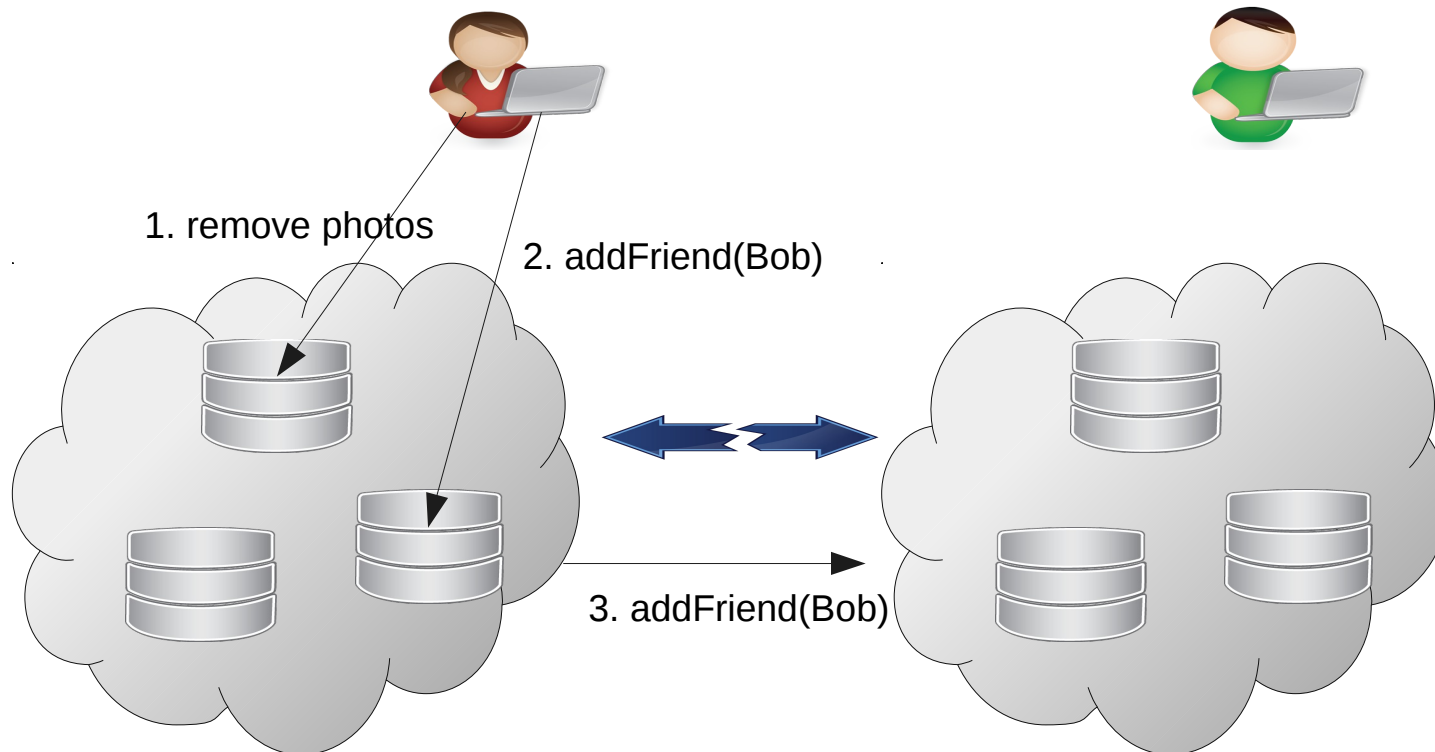
Partitioned and Geo-Replicated Distributed System



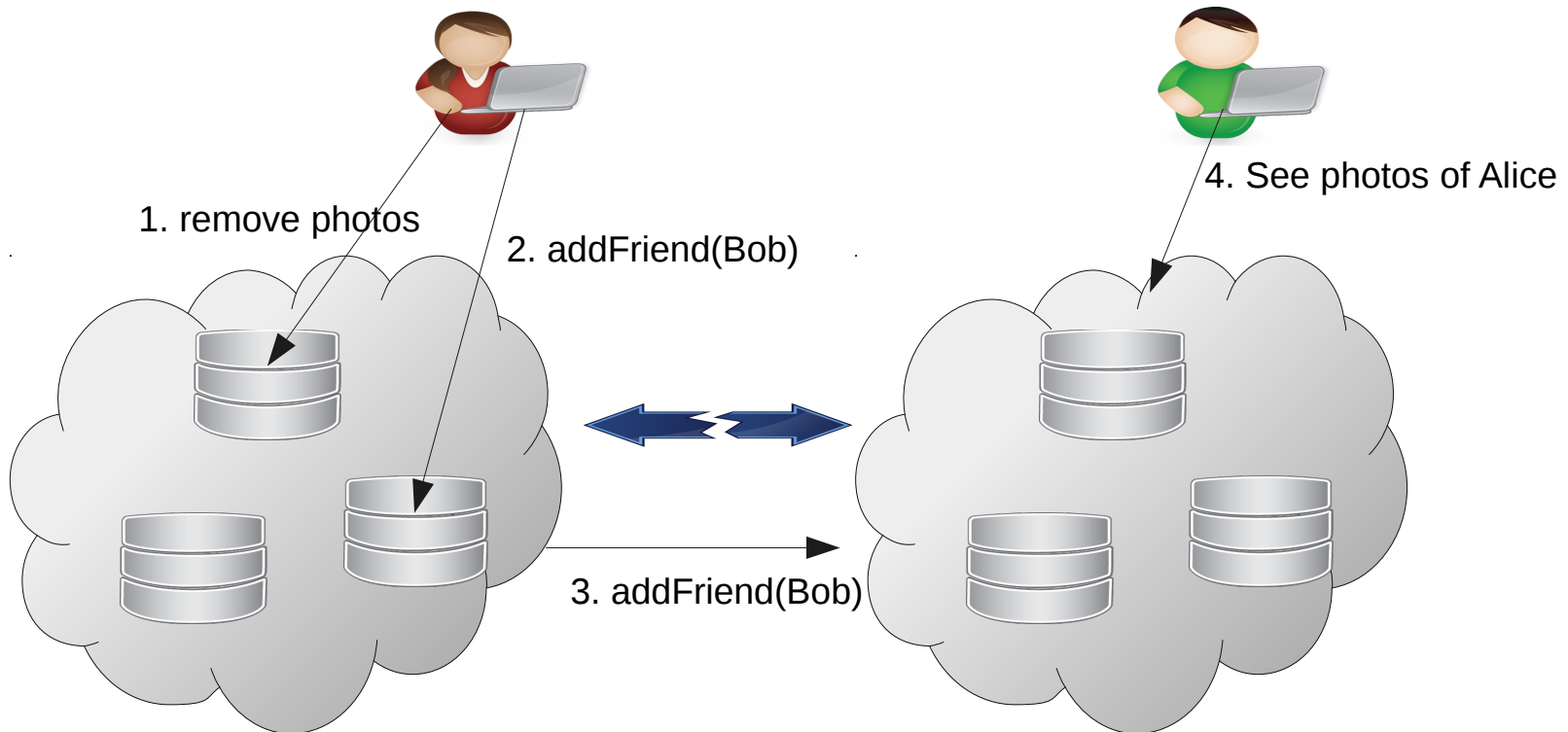
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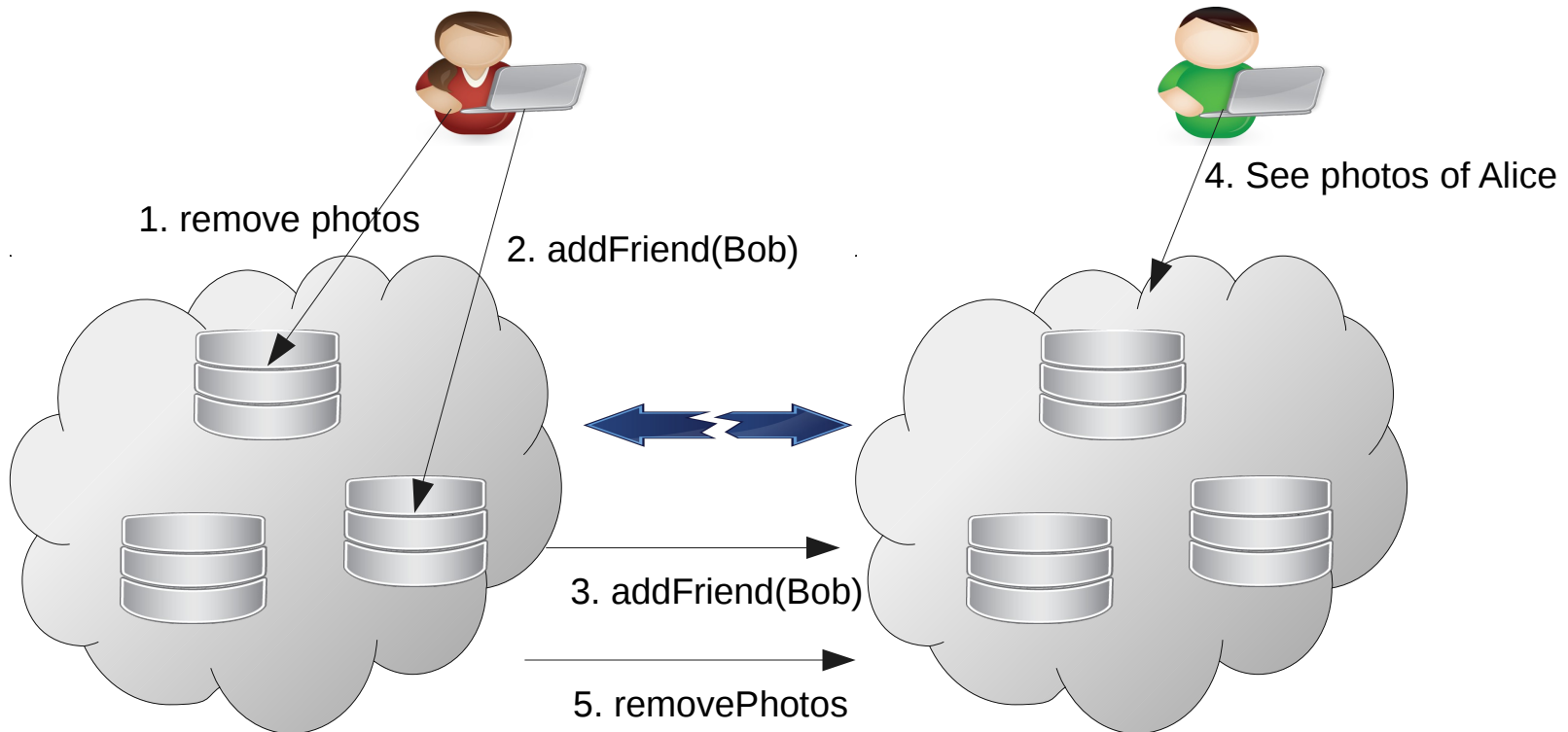
Partitioned and Geo-Replicated Distributed System



Partitioned and Geo-Replicated Distributed System



Partitioned and Geo-Replicated Distributed System



Orbe: Causal Consistency with Dependency Matrix

Clock	R1	R2	R3	R4
P1	0	2	0	0
P2	1	0	3	0
P3	0	0	0	1

Orbe: Causal Consistency with Dependency Matrix

- Dependency matrices to track causality
- Client updates its DM when ever it reads a new version

Clock	R1	R2	R3	R4
P1	0	2	0	0
P2	1	0	3	0
P3	0	0	0	1

- Client has seen first 2 updates at replica 2 of partition 1

Orbe: Causal Consistency with Dependency Matrix

- Each Partition has its own version vector - VV

VV	R1	R2	R3	R4
P1/R1	1	2	1	0

- P1 at DC1 has
 - 1 local update
 - 2 updates from R2
 - 1 update from R3

Orbe: Causal Consistency with Dependency Matrix

- Client send $\text{put}(k, v, \text{DM})$ to partition P1 at DC1
- P1 at DC1
 - Increment its own $\text{VV}[\text{R1}]$
 - $\text{Ts} = \text{VV}[\text{R1}]$
 - New entry $\text{U}\langle k, v, 2, \text{DM}, \text{R1} \rangle$
 - Replicate U to P1 at DC2 and DC3
- On receiving $\text{U}\langle k, v, \text{ts}, \text{DM}, \text{replicaId} \rangle$ at Pn
 - Check $\text{VV} \geq \text{DM}[\text{n}]$
 - Check if causality is satisfied at other partitions
 - Update $\text{VV}[\text{replicaId}] = \text{ts}$

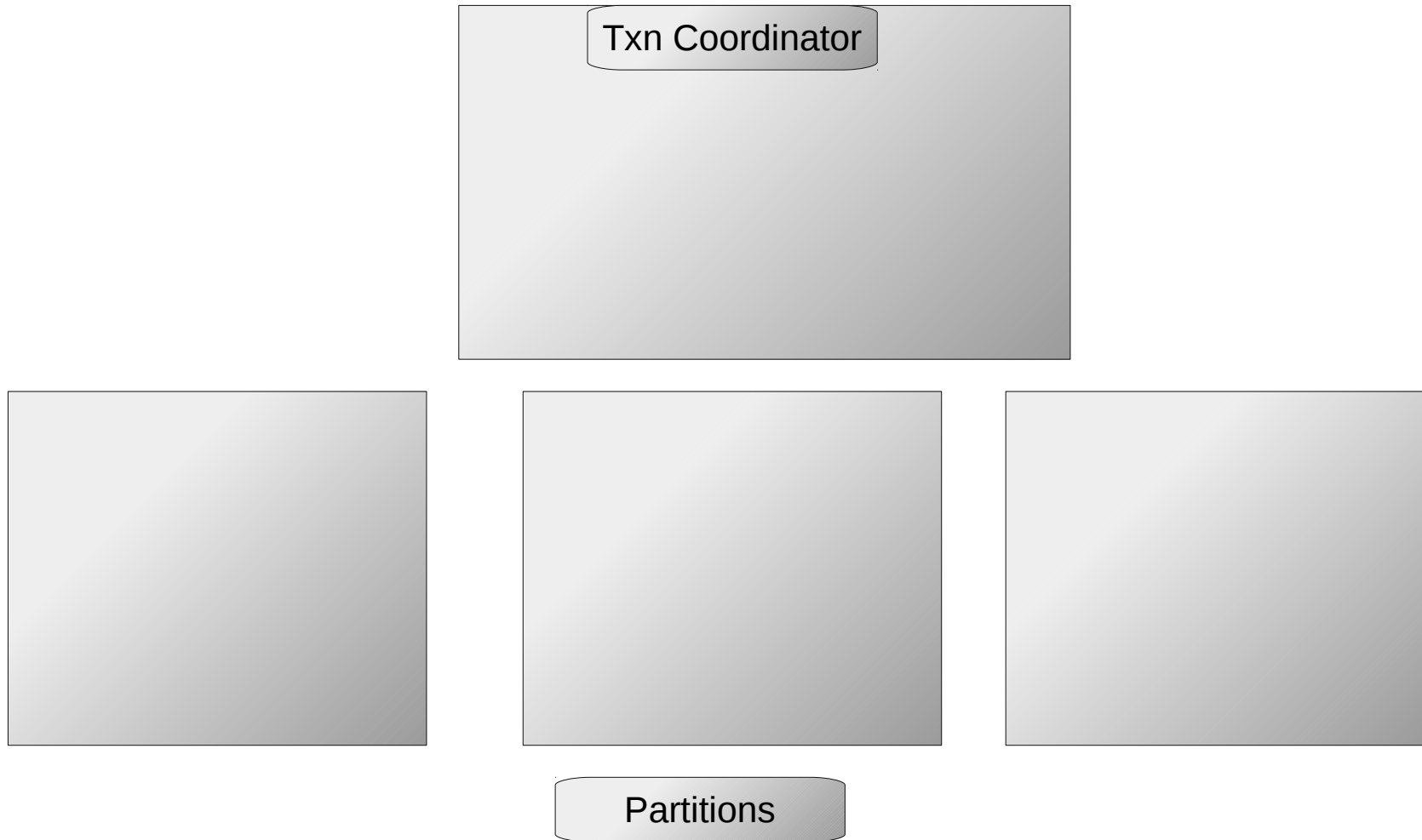
Total order in a partitioned system

- Snapshot isolation
 - Reads a consistent snapshot
- Consistent Snapshot
 - Includes all updates committed before snapshot time
- Transactions commit in total order
- Snapshot identified by its commit time
- Update A is causally before B if $A.\text{commit-time} < B.\text{commit-time}$

Clock SI – Snapshot Isolation using physical clocks

- Loosely synchronized clocks
- No centralized time-stamp generator
- Distributed protocol
- Snapshot-time
 - Time when transaction begins
 - Reads return values committed on or before this time
- Commit-time decided by transaction coordinator and partitions involved in transaction

ClockSI – Commit Protocol



ClockSI – Commit Protocol



ClockSI – Commit Protocol



ClockSI – Commit Protocol

Txn Coordinator

- $T.\text{snapshottime} = \text{Localclock} = 8$
- Send prepare to partitions
- $\text{Commit-time} = \max(11, 9, 10)$
- Commit to partitions

- Receive Prepare
- Localclock = 11
- Reply 11
- Commit-time = 11

- Receive Prepare
- Localclock = 9
- Reply 9
- Commit-time = 11

- Receive Prepare
- Localclock = 10
- Reply 10
- Commit-time = 11

Partitions

ClockSI – Commit Protocol

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Partitions

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Partitions

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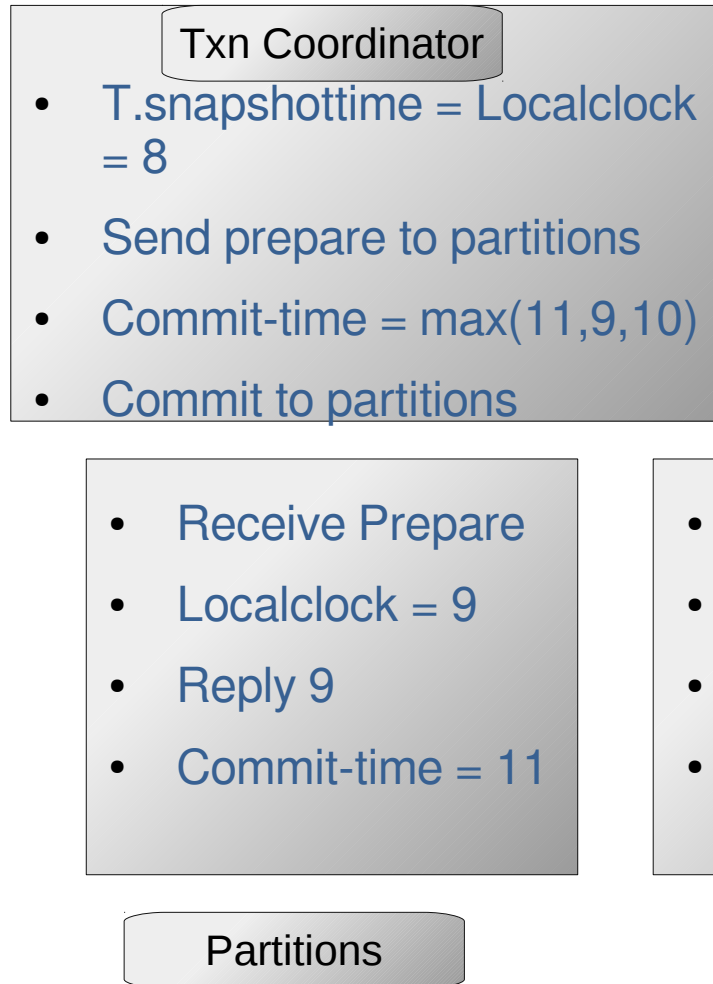
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Partitions

ClockSI – Commit Protocol



Clock SI – Read protocol

Read(Transaction T, dataitem Obj)

- Wait if $T.\text{snapshottime} > \text{localclock}$
- If any pending Transaction T' with possible commit-time $< T'.\text{snapshottime}$
 - wait until T' is committed
- Return latest snapshot before snapshot-time

Extended ClockSI: Partitioned and Replicated System

- Vectorclock per partition

	R1	R2	R3	R4
P1/R1	10	9	13	8

- P1 at DC1 has seen all updates from DC2 before time 9
- Snapshot-time is Vectorclock of coordinator at the time when transaction begins
- Updates in a transaction depends on Snapshot which it reads from
- Snapshot-time encodes causal dependency

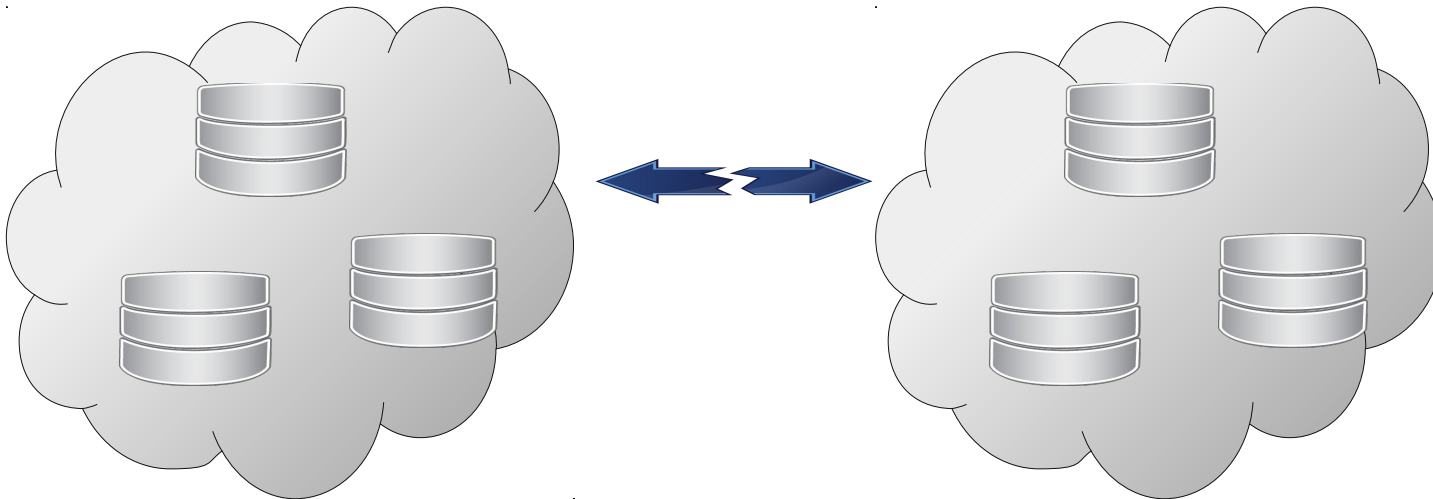
Extended ClockSI: Replication

- P1 at DC1 sends updates to P1 at DC2 in *Commit-time order*
- Send snapshot-time and commit-time with every update
- On receiving an update $U \langle DC, \text{Commit-time}, \text{Snapshot-time} \rangle$ from a partition
 - Apply U if **local** vectorclock $>$ Snapshot-time
 - Set vectorclock[DC] = Commit-time

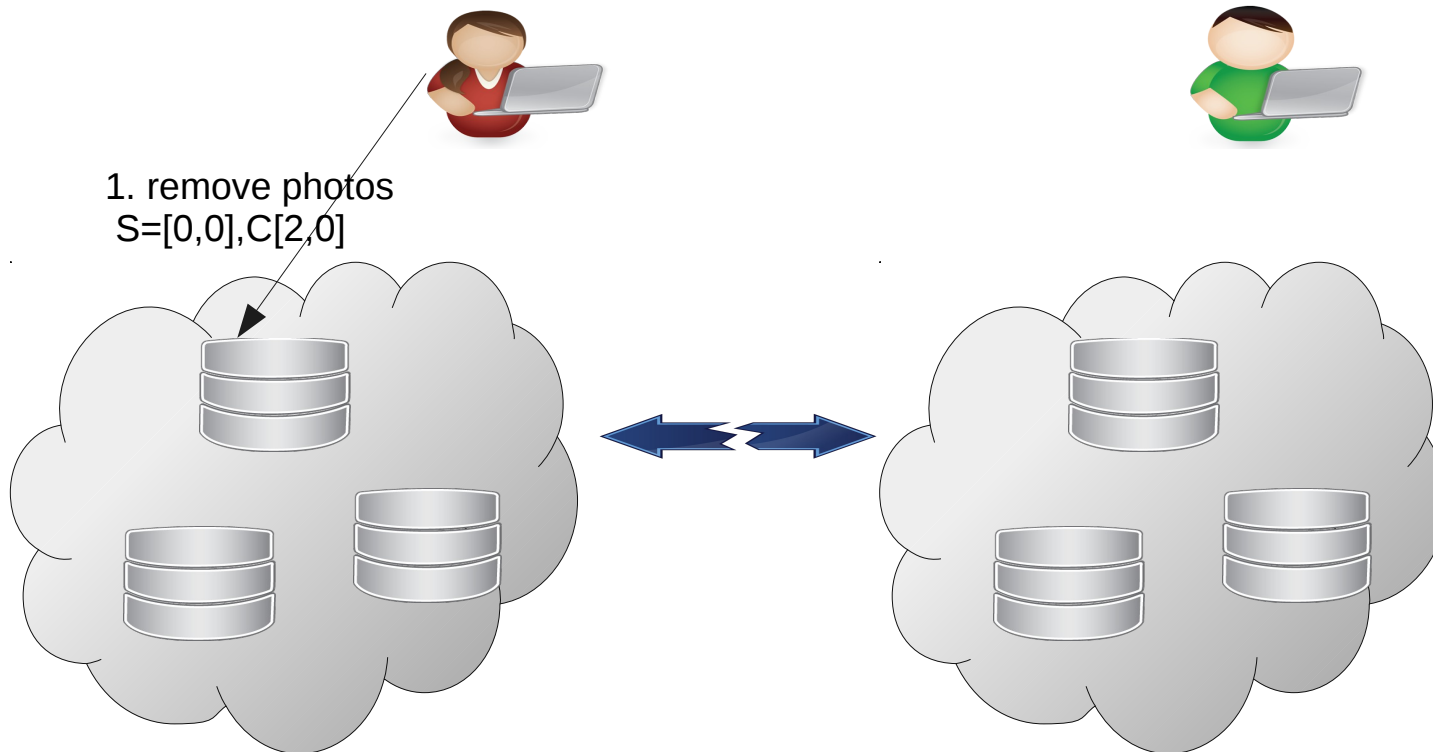
Extended ClockSI: Read

- Upon receiving a read request in a partition
 - Wait until local vectorclock \geq snapshot-time
 - Return latest value before snapshot-time
- Causality metadata = $O(N)$
- No communication between partitions

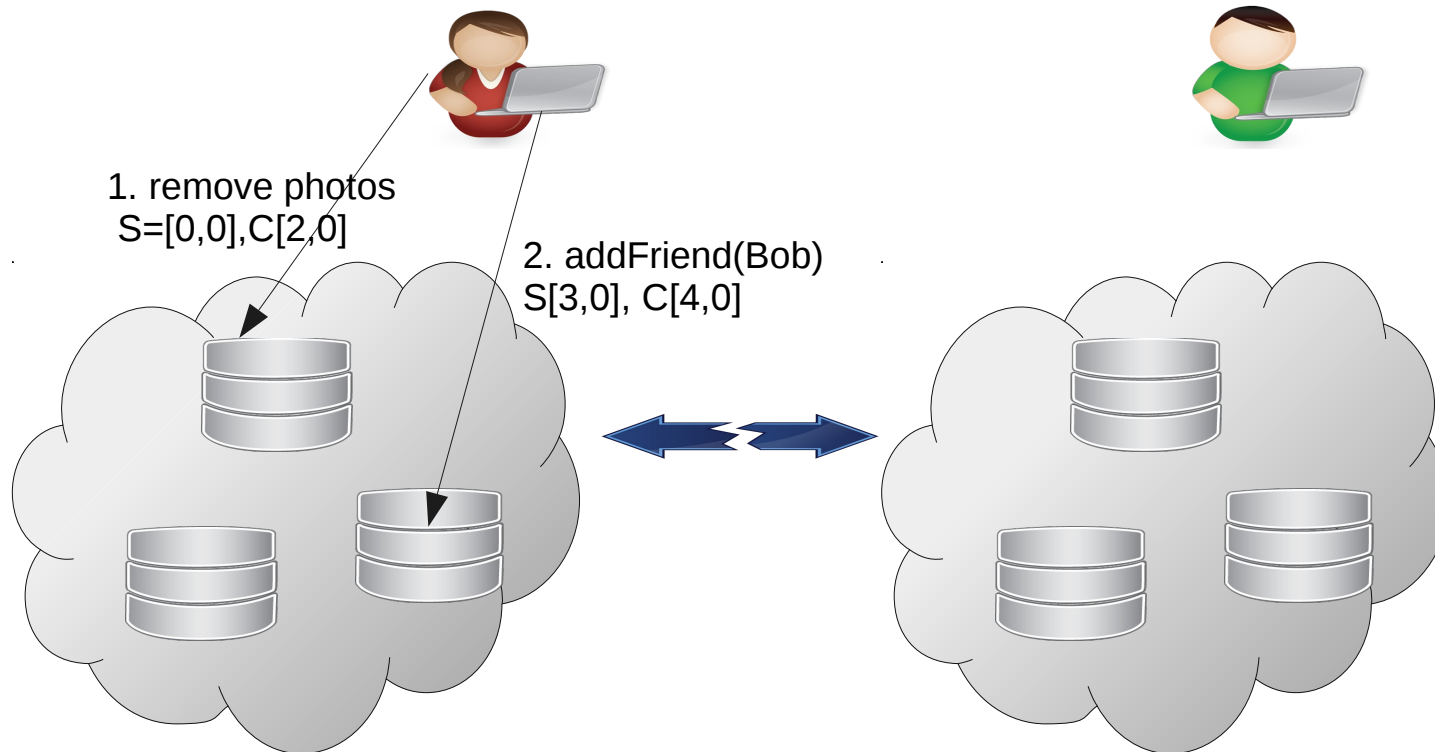
Social Network Application



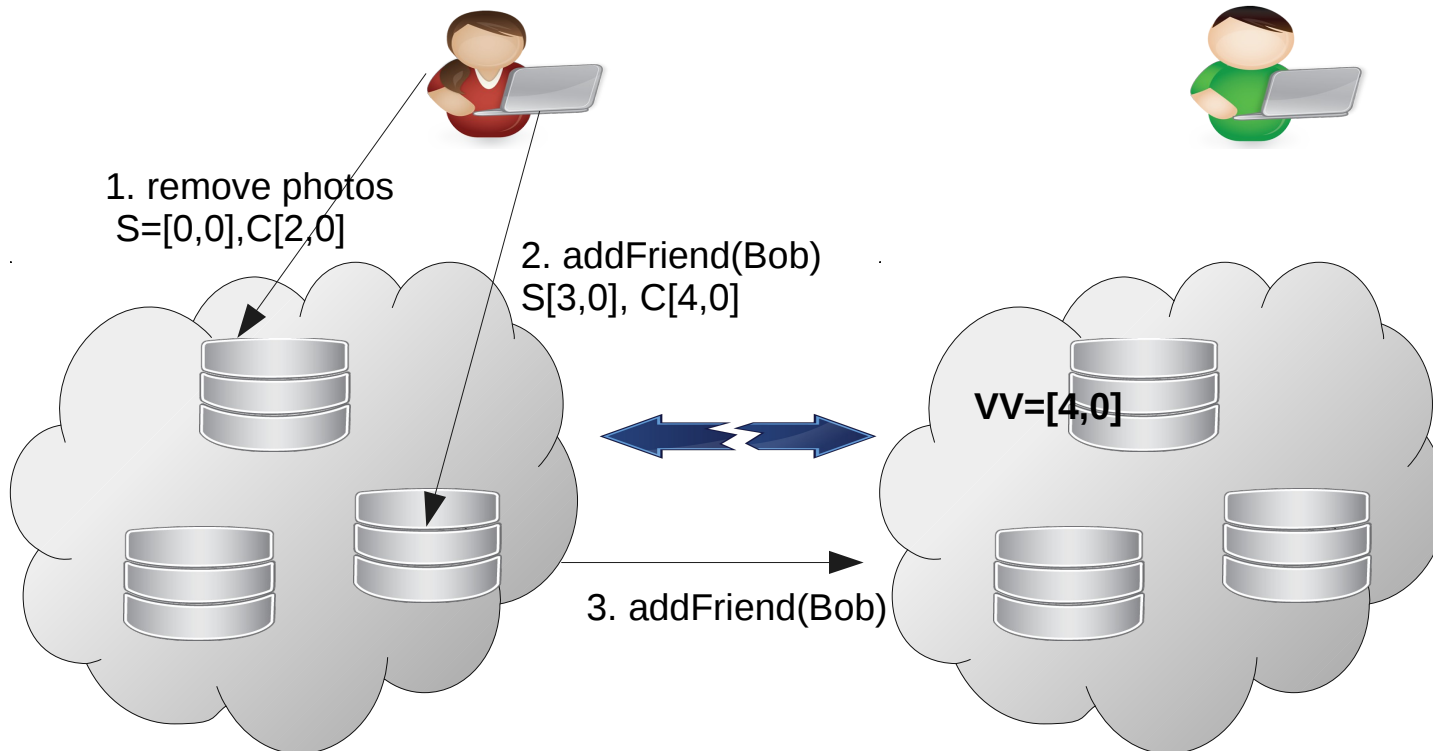
Social Network Application



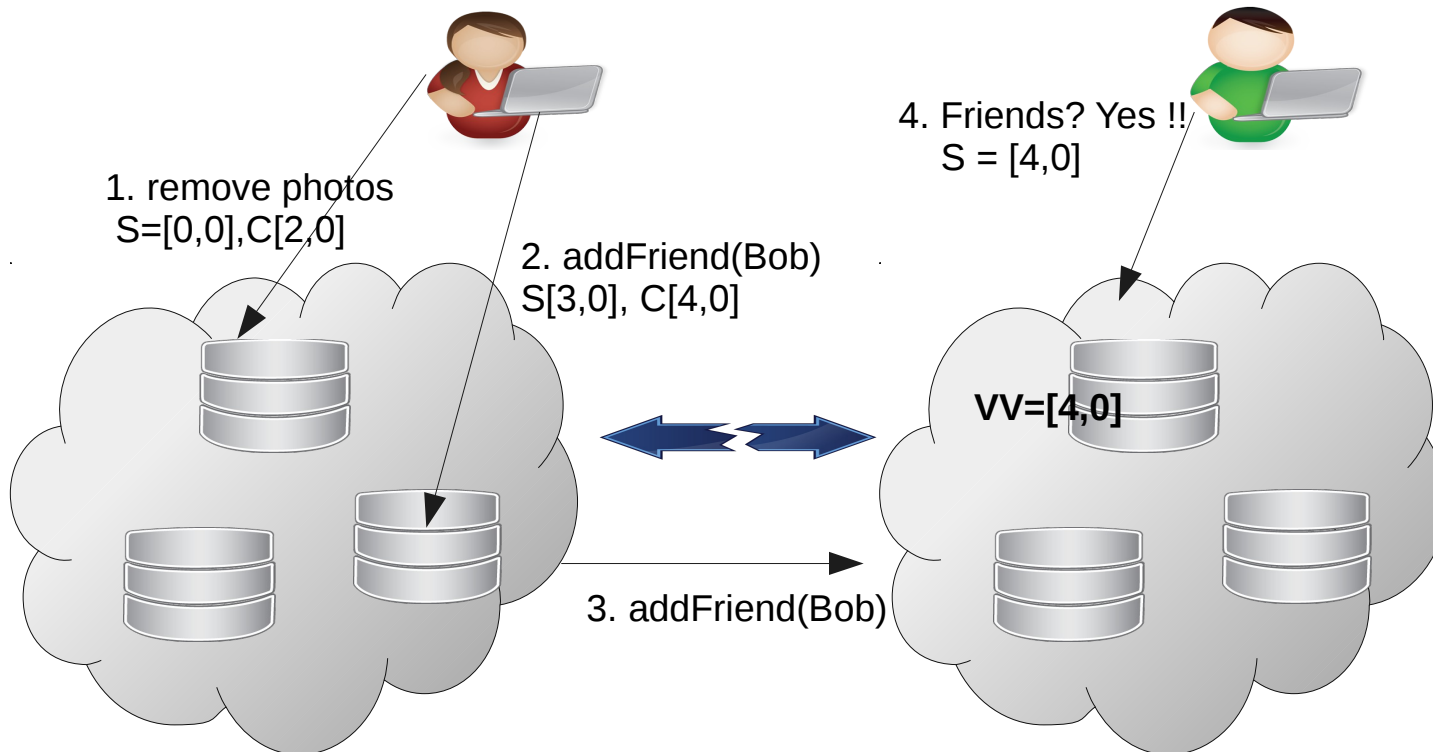
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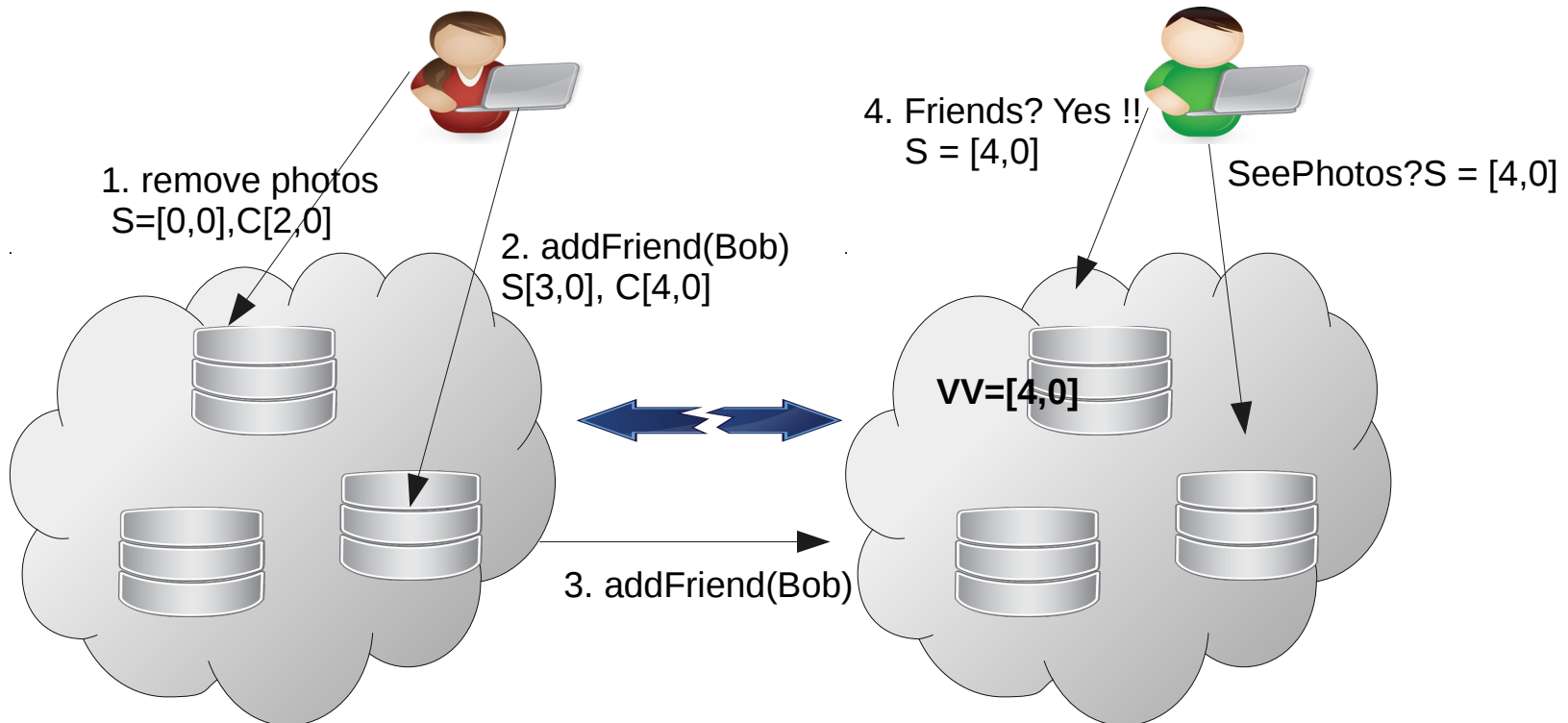
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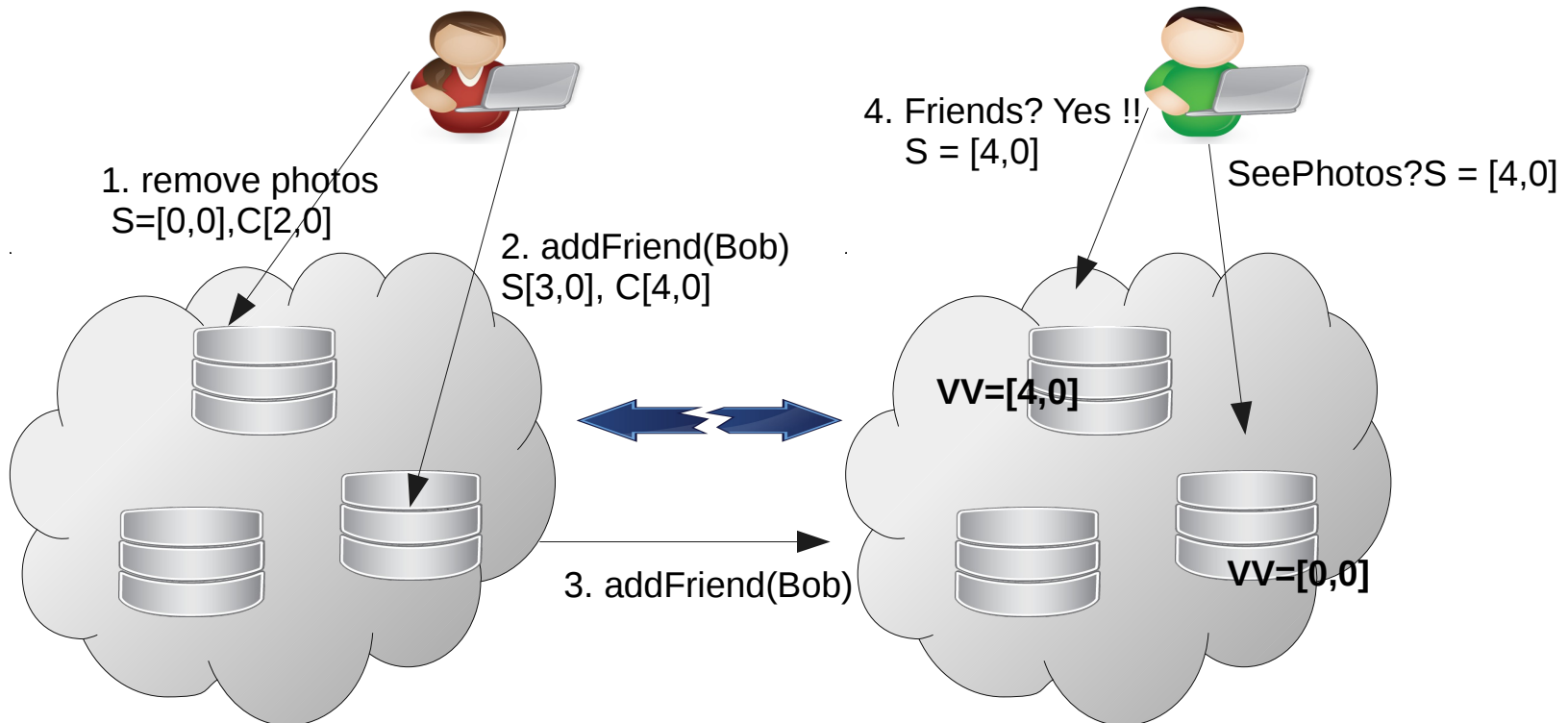
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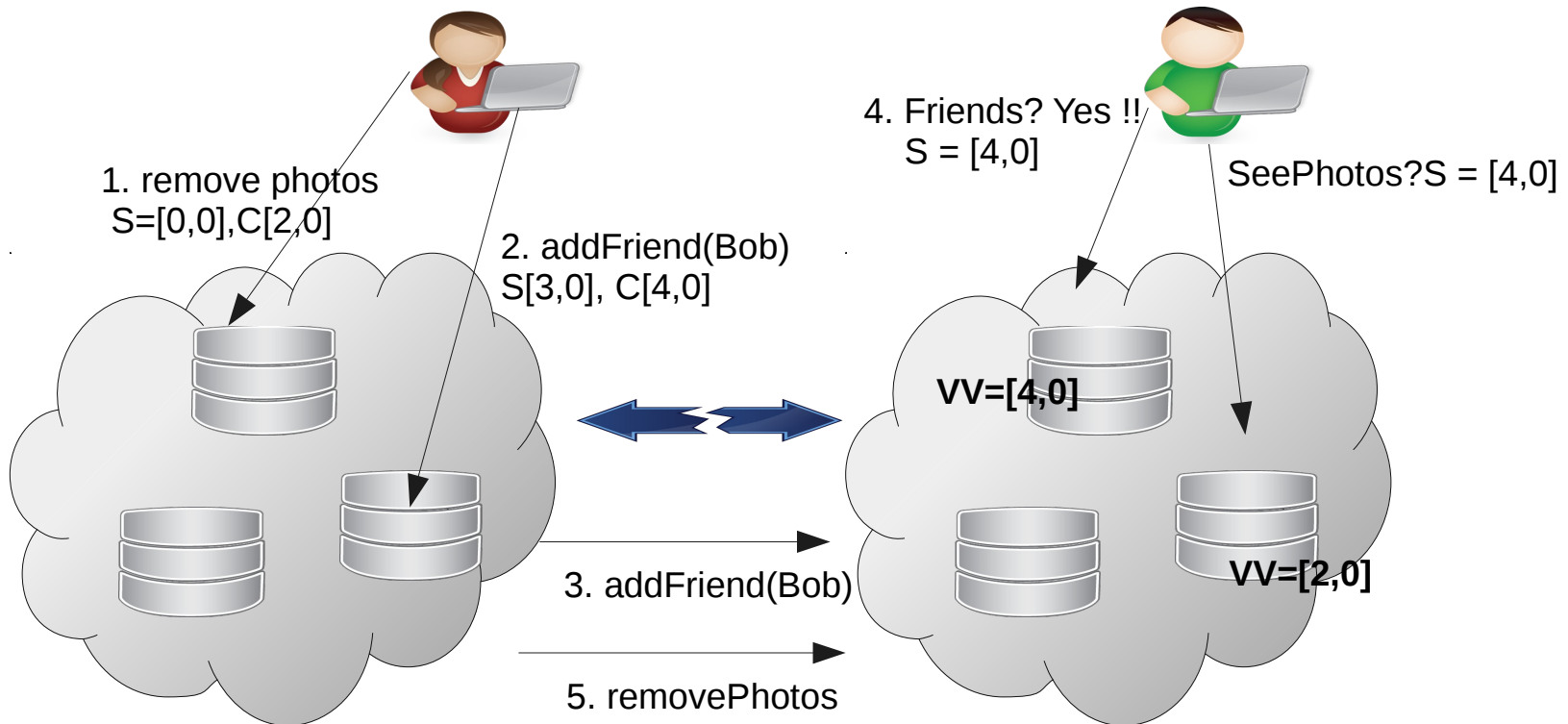
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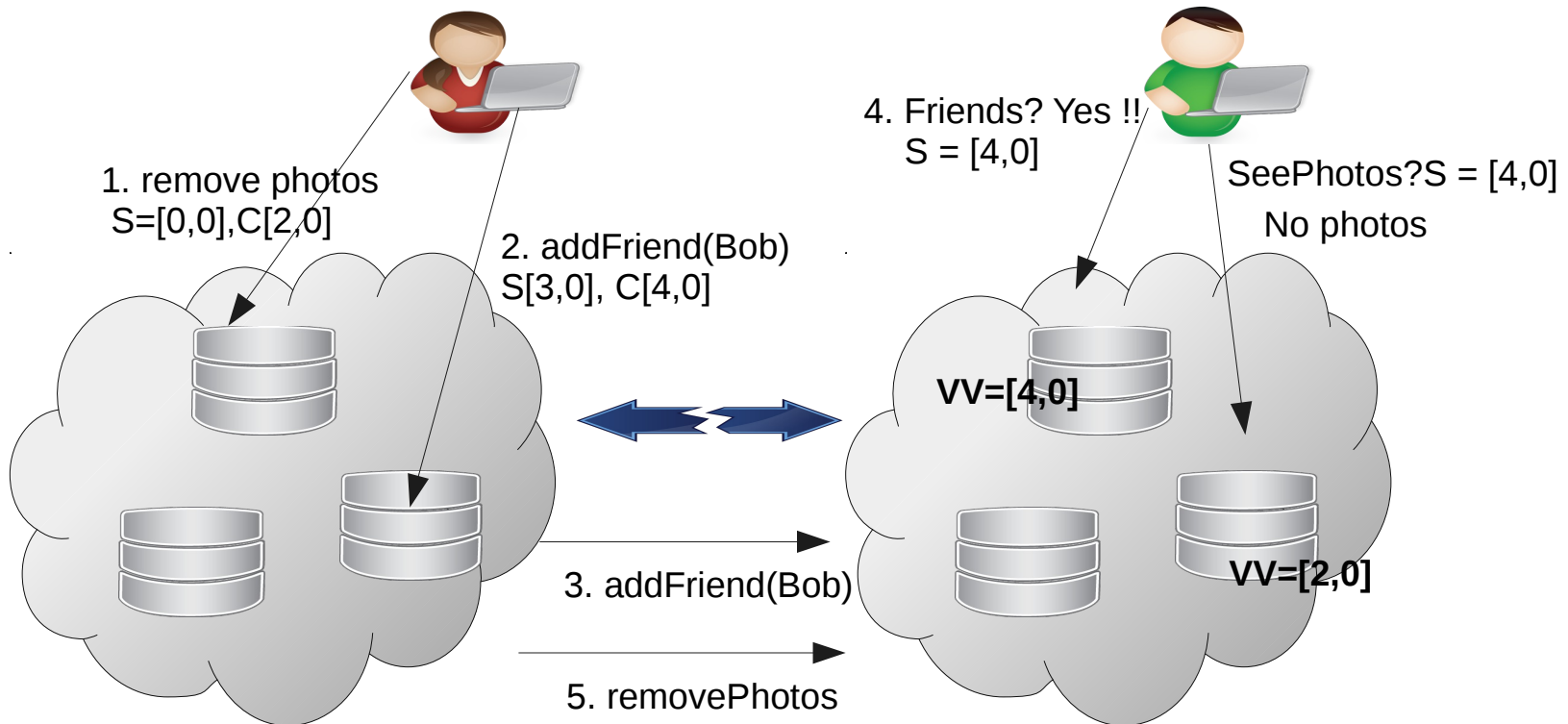
Social Network Application



Social Network Application



Social Network Application



Conclusion

- Total ordering using Lamport's timestamp
- Causality tracking using Vectorclocks
- Explicit causality tracking
 - Orbe using dependency matrix
 - ClockSI using physical clock and dependency vector

Reference

1. Leslie Lamport, 1978, "*Time, Clocks and the Ordering of Events in a Distributed System*", Communications of the ACM, Vol. 21
2. Colin J. Fidge, 1988, "*Timestamps in Message-Passing Systems That Preserve the Partial Ordering*". In K. Raymond (Ed.). Proc. of the 11th Australian Computer Science Conference (ACSC'88). pp. 56–66. Retrieved 2009-02-13.
3. D. Stott Parker et.al, "*Detection of mutual inconsistency in distributed systems*" Transactions on Software Engineering, 9(3):240–246, 1983.
4. B. Charron-Bost, "*Concerning the size of logical clocks in distributed systems*", Information Processing Letter, Vol. 39, 1991
5. Jiaqing Du et.al, "*Orbe: scalable causal consistency using dependency matrices and physical clocks*" SOCC'13 Proceedings of 4th annual Symposium on Cloud Computing, 2013
6. Jiaqing Du et.al, "*ClockSI: Snapshot Isolation for Partitioned Data Stored Using Loosely Synchronized Clocks*", SRDS'13 Proceedings of the 2013 IEEE International Symposium of Reliable Distributed Systems