Causal consistency in Geo-replicated Systems

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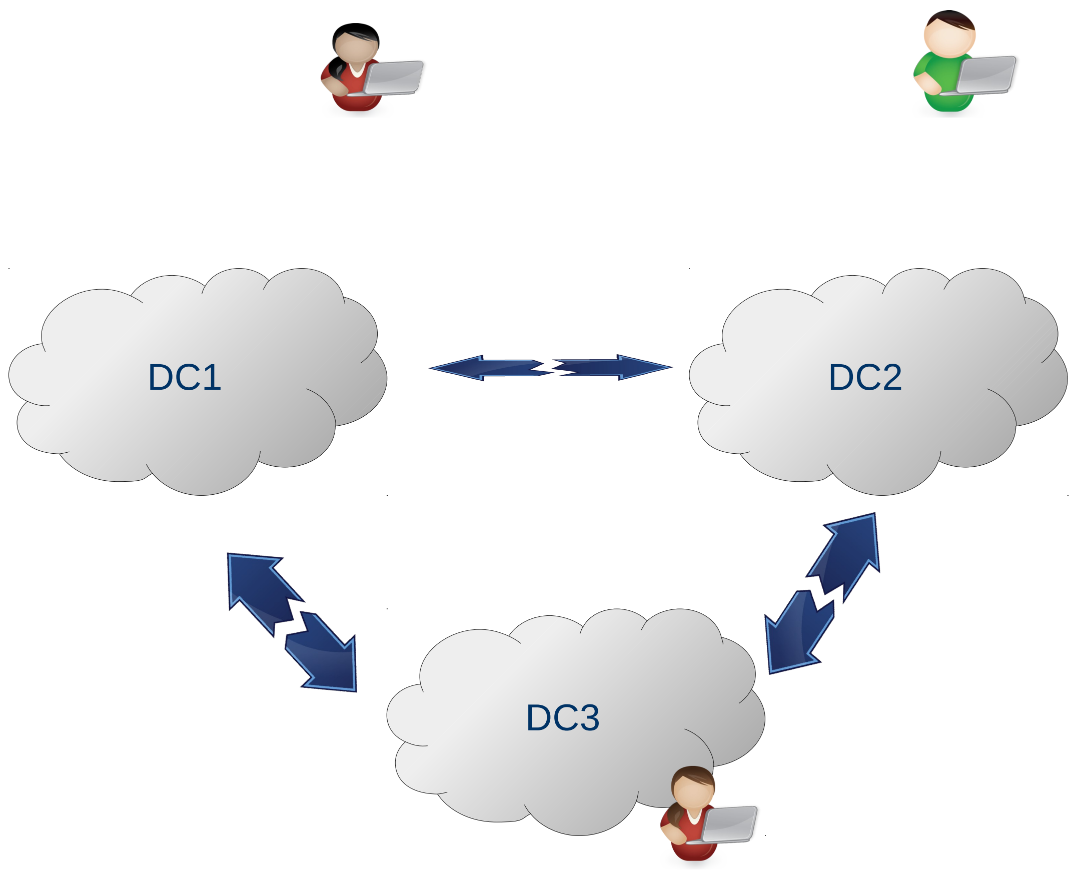
AG SoftTech

Geo-Replicated Distributed Application



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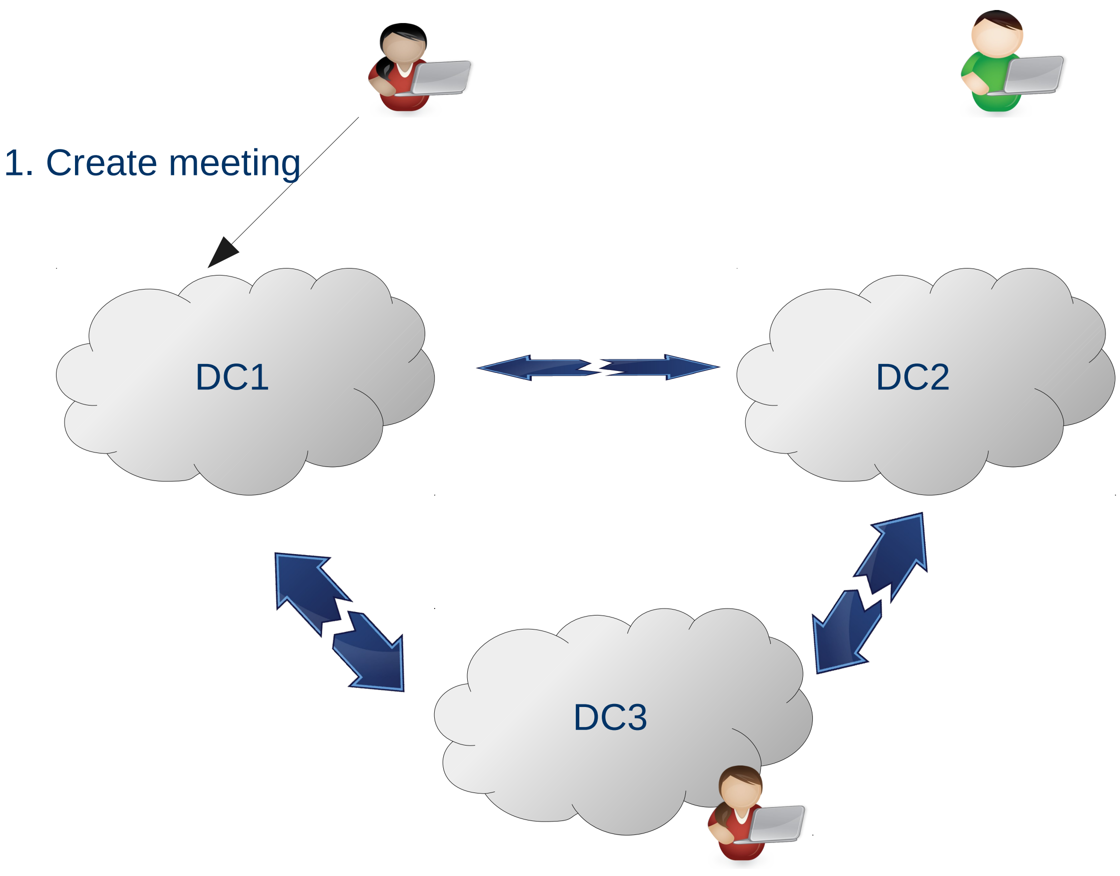

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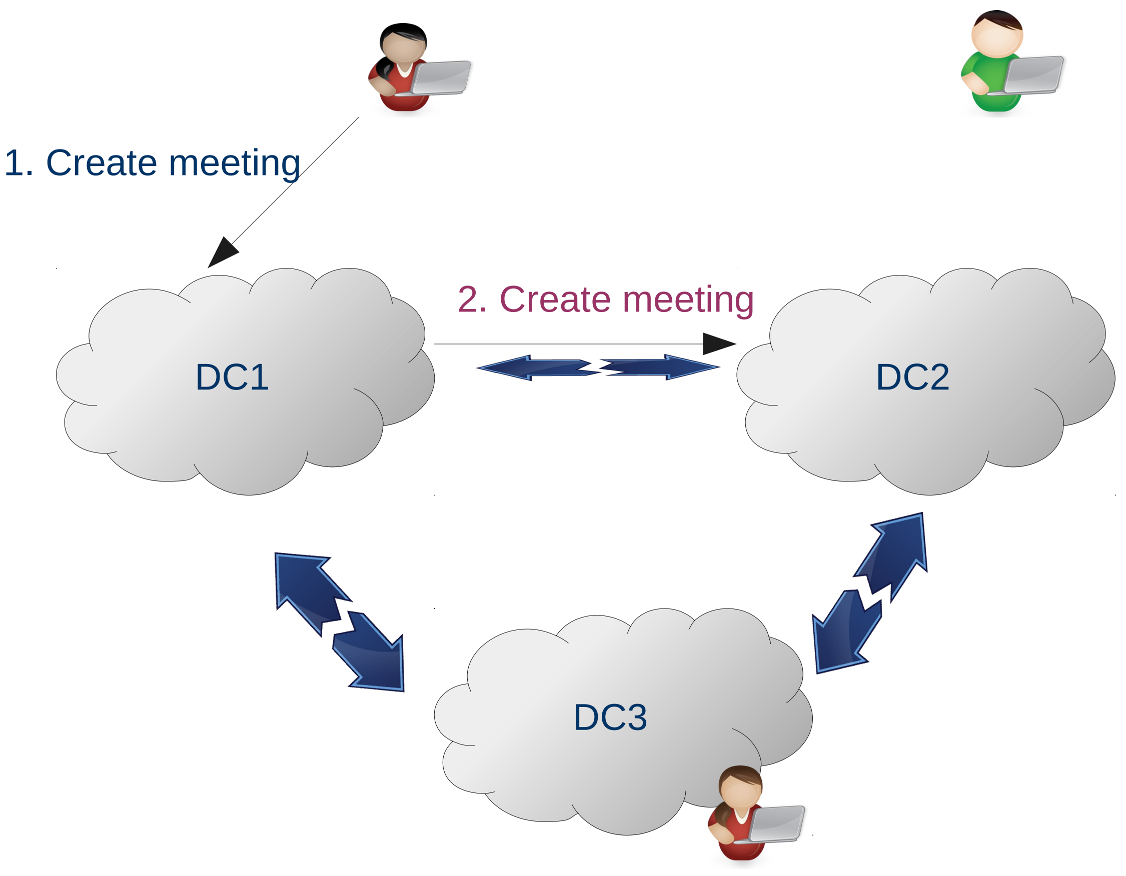

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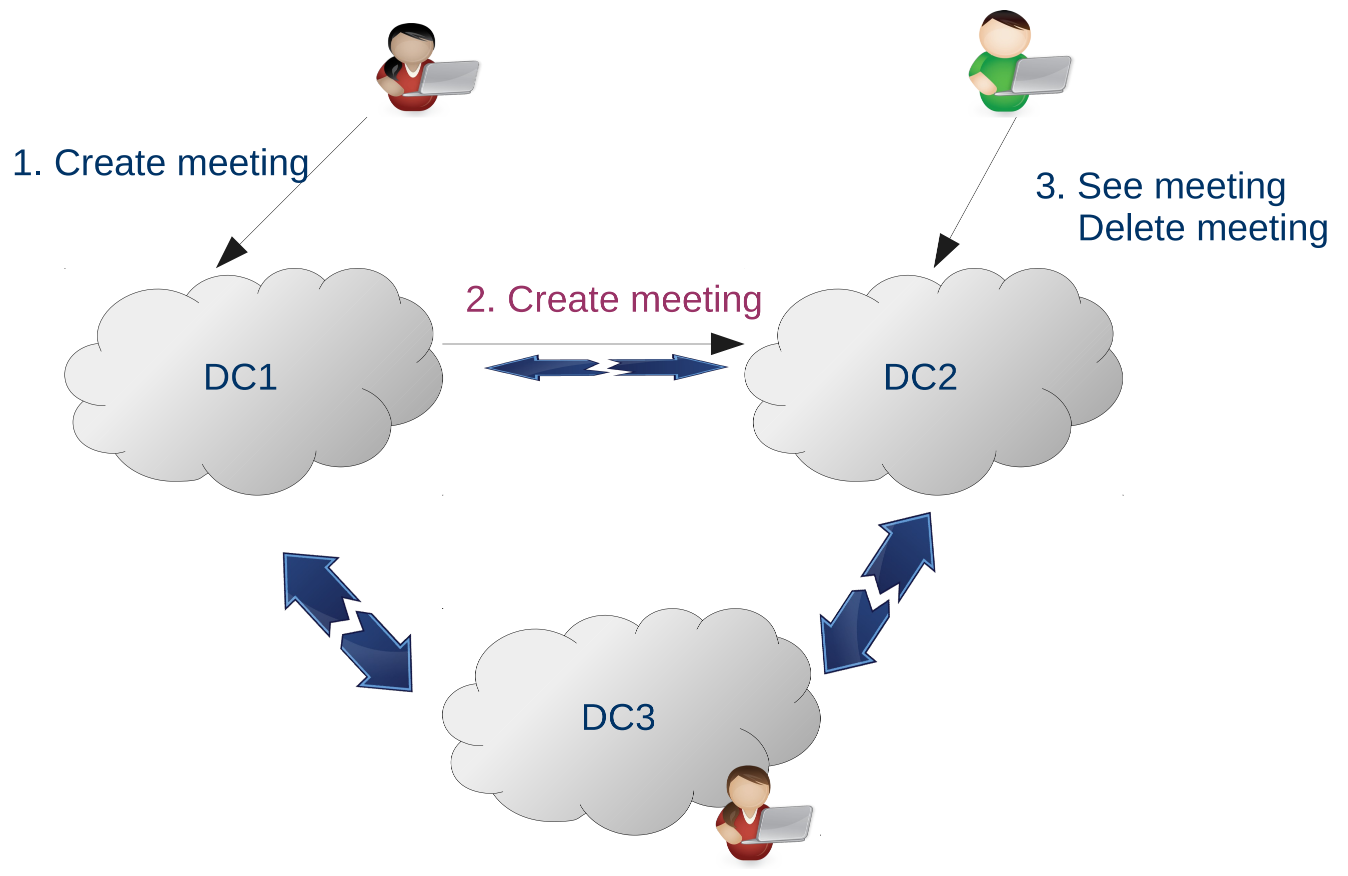

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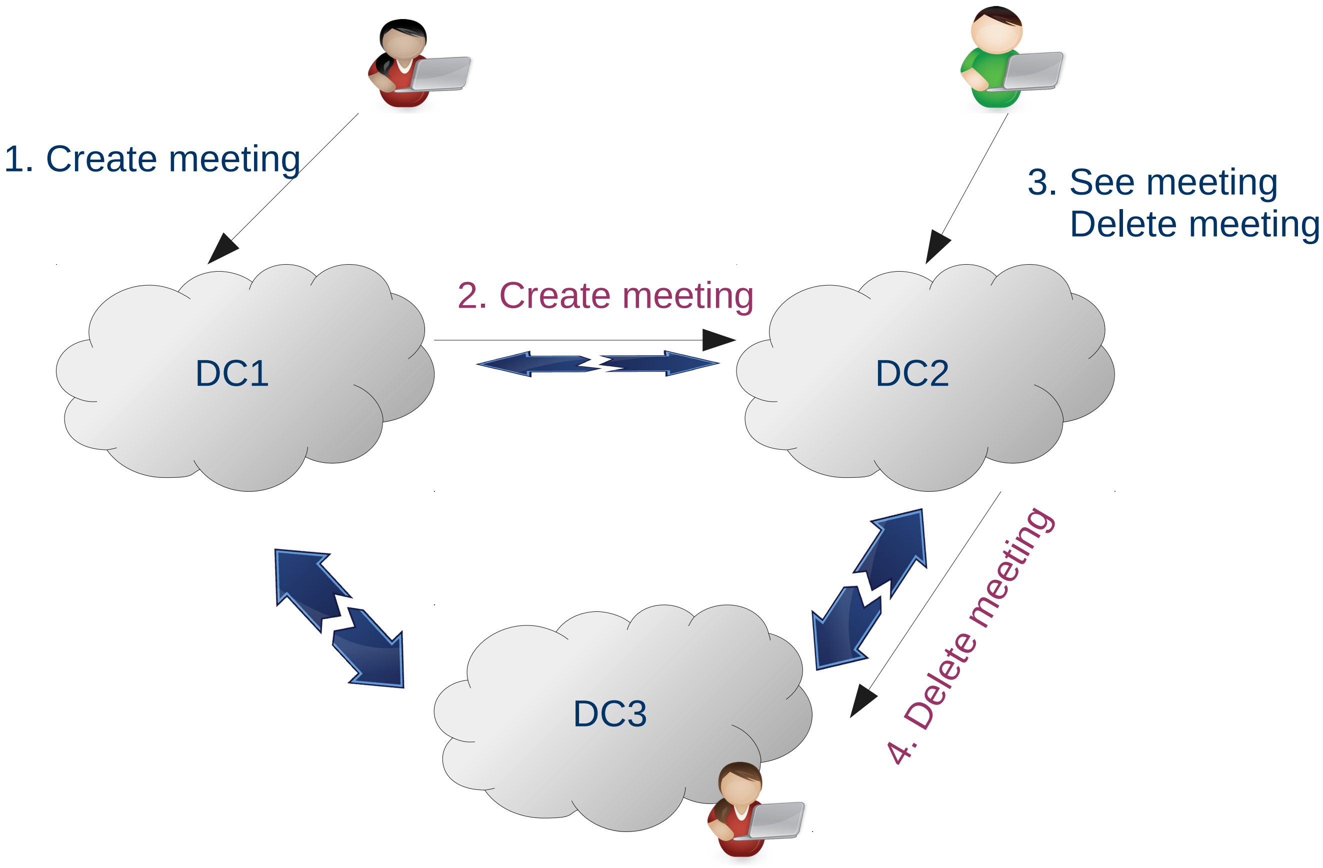

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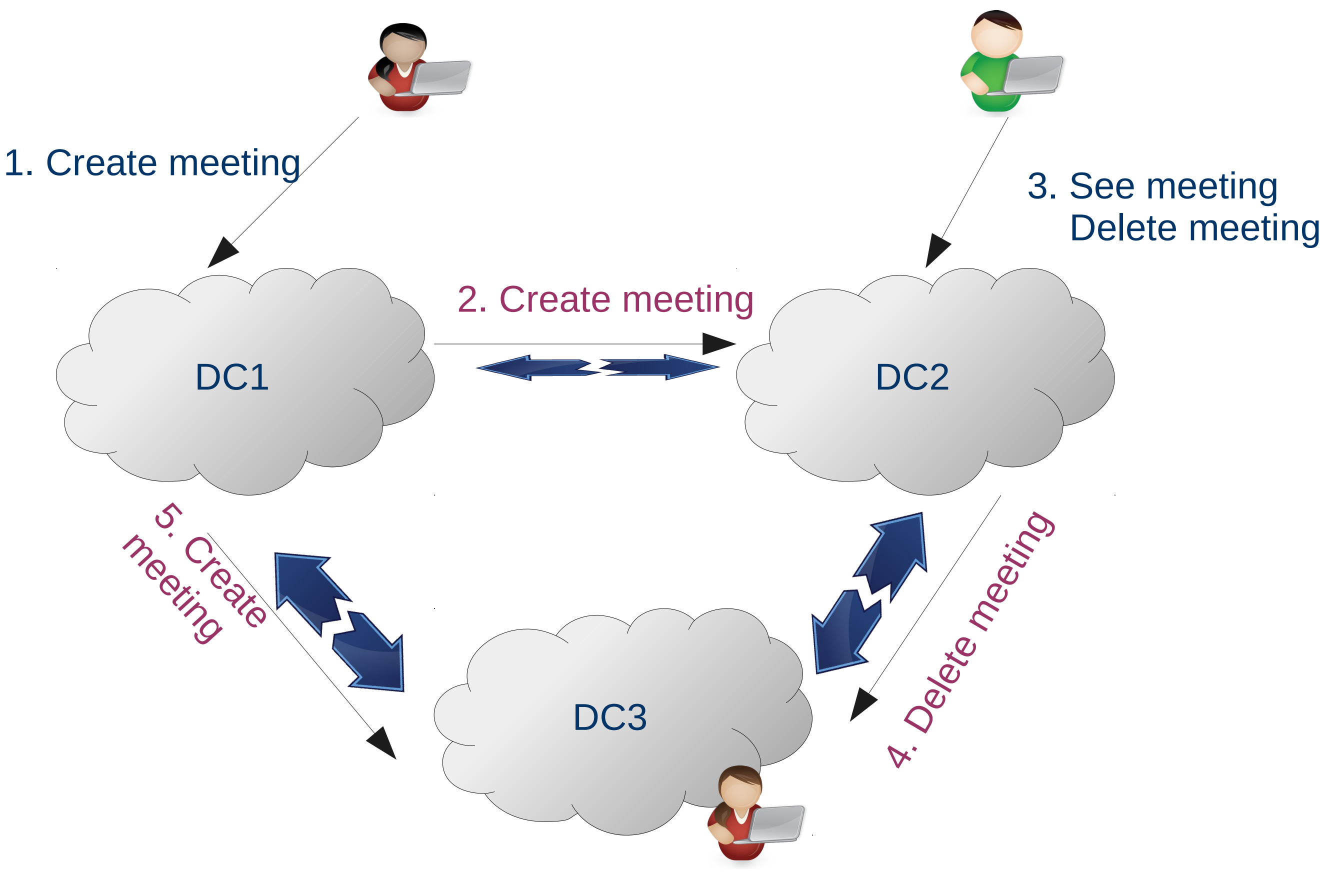

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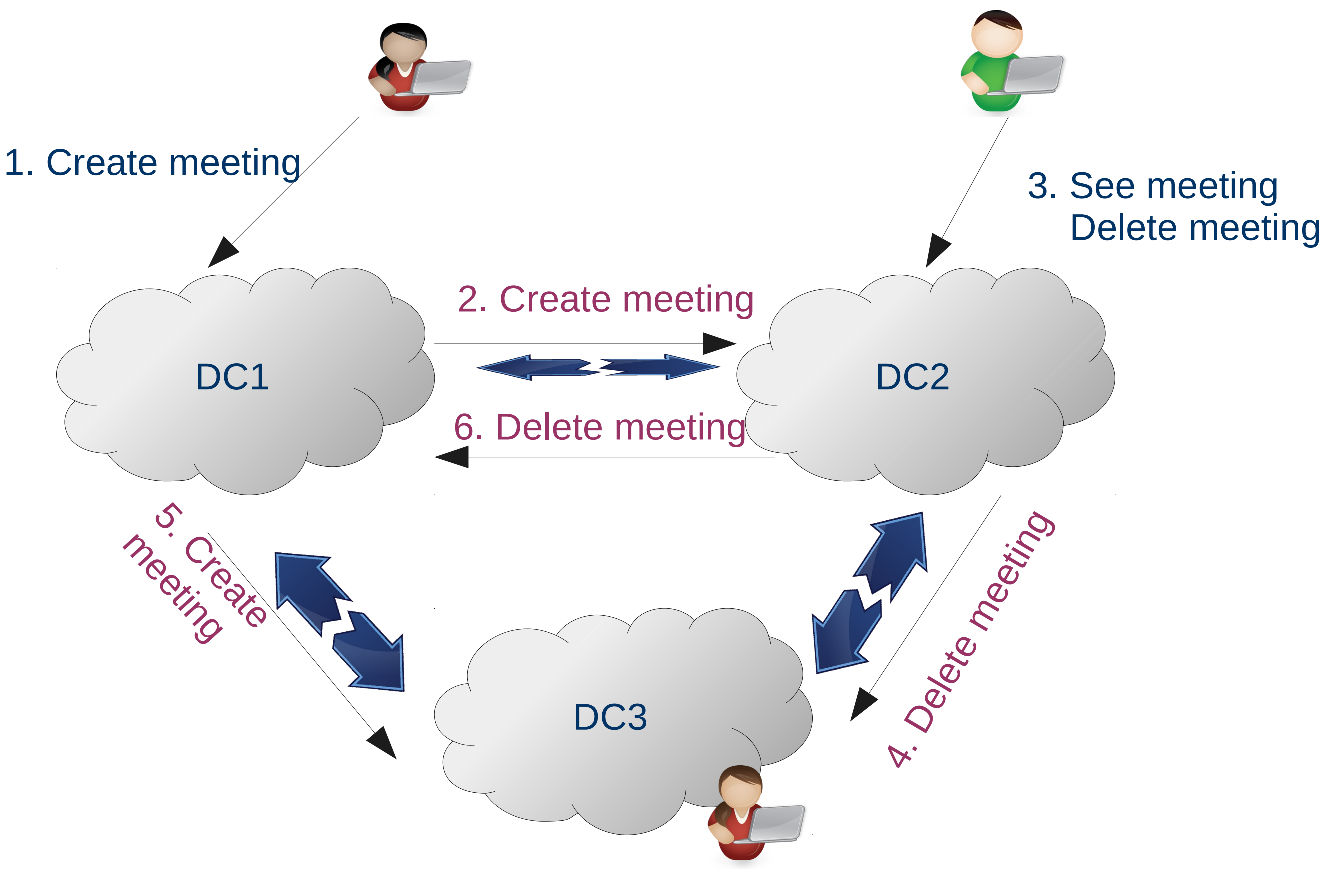

Lamport's Timestamps

- 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(own clock, received clock)

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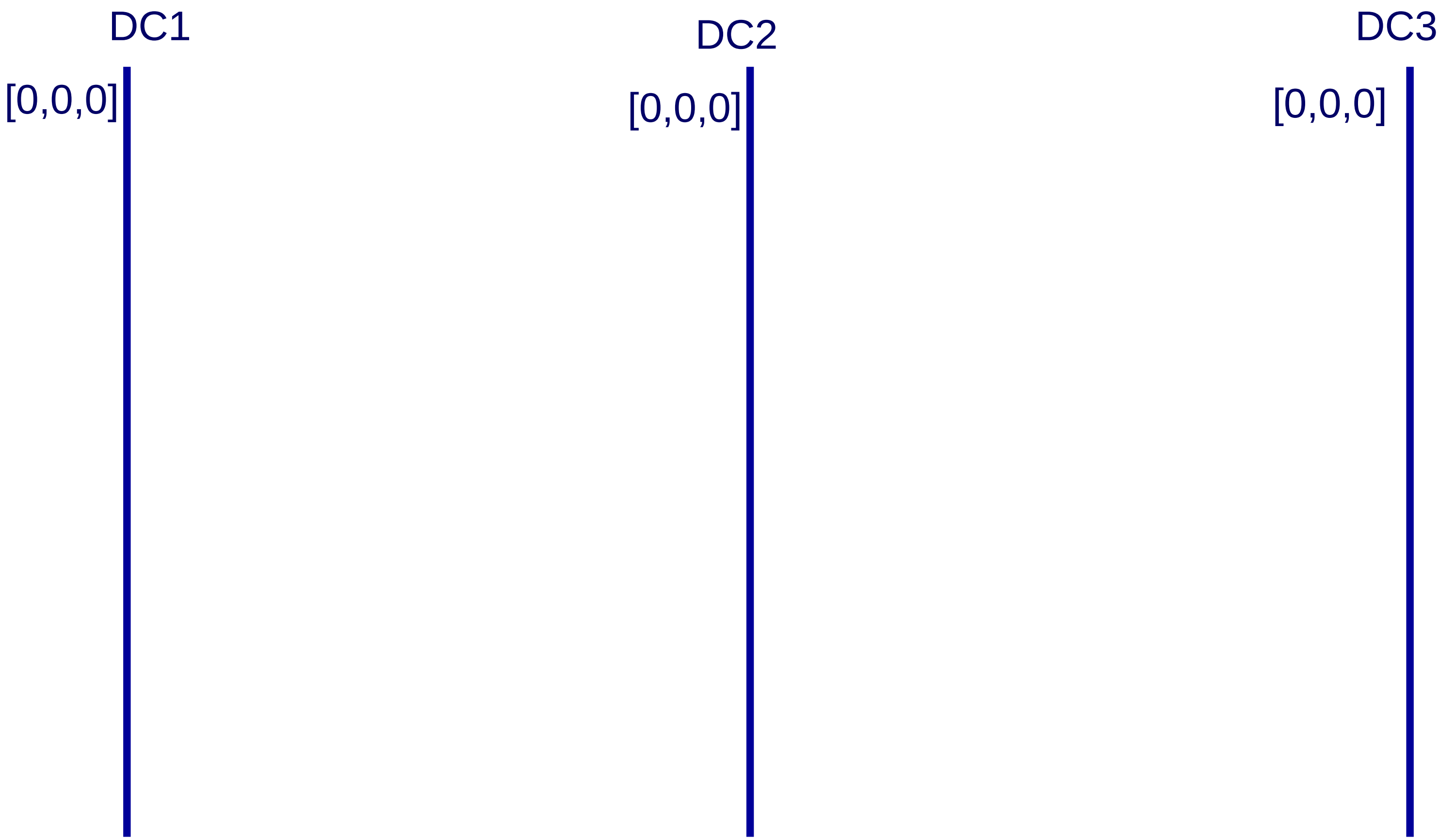
Vectorclocks

- 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(local entry, corresponding entry in received vc)

Detect Causality violation using Vectorclocks



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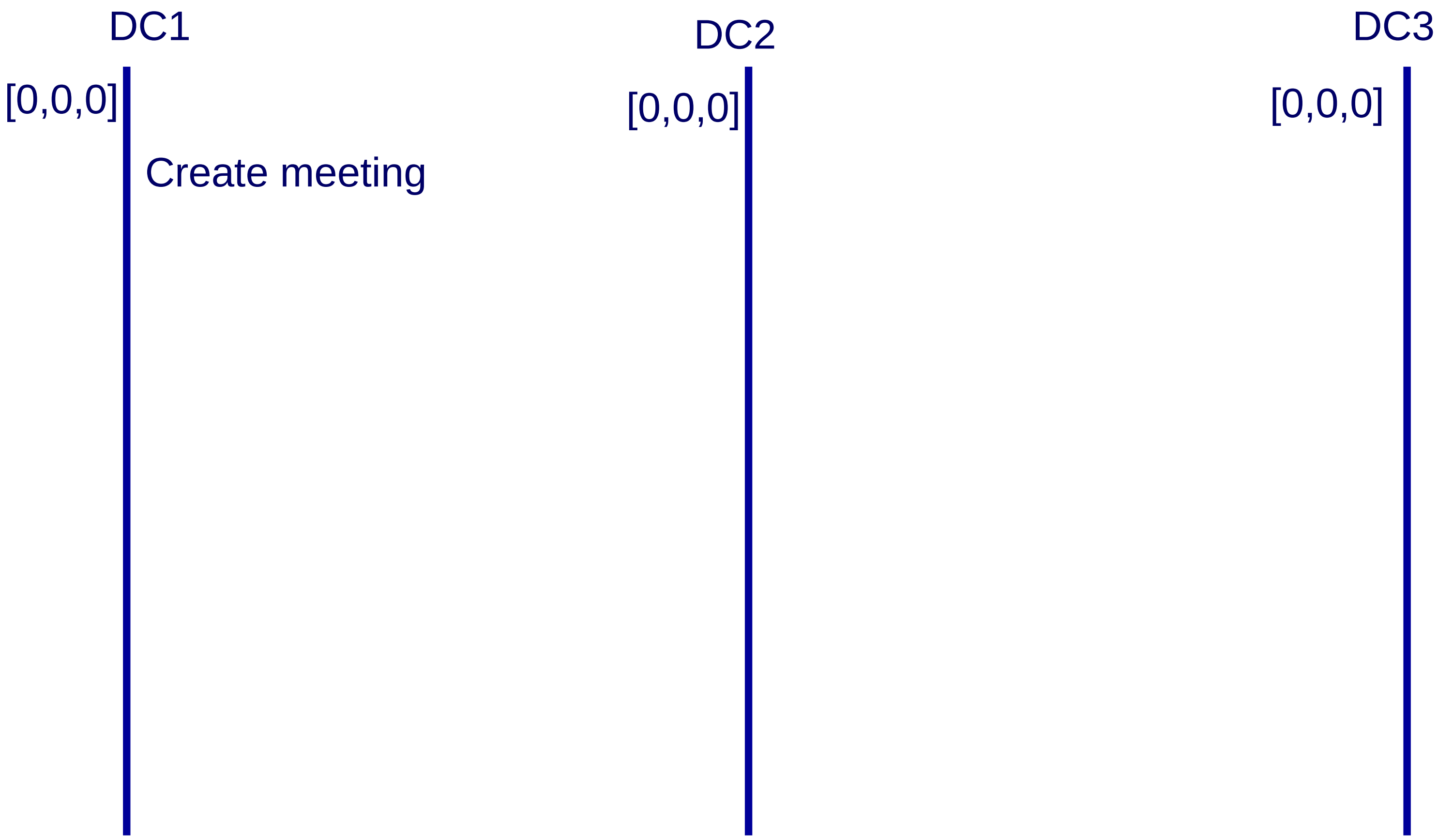

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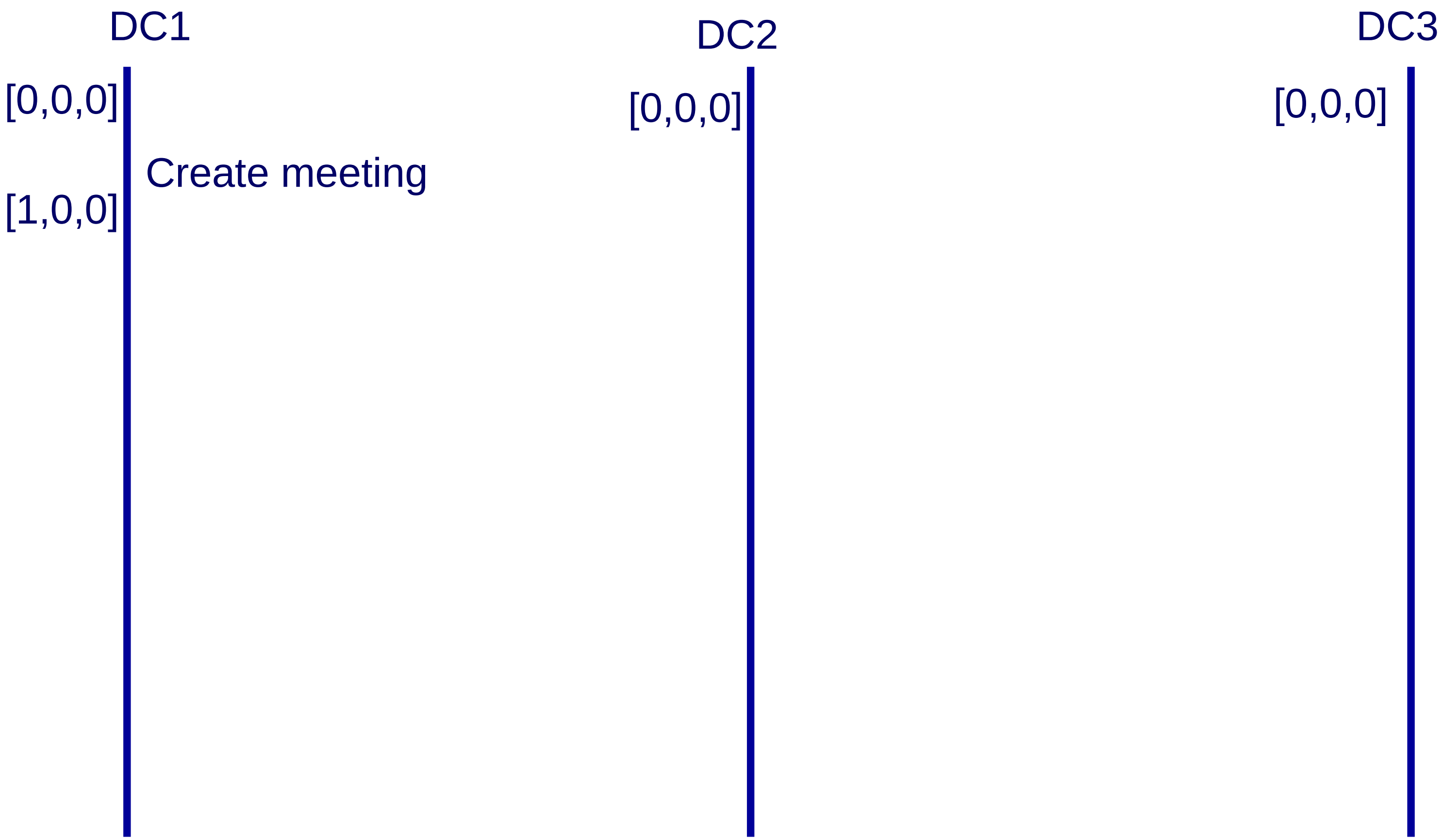

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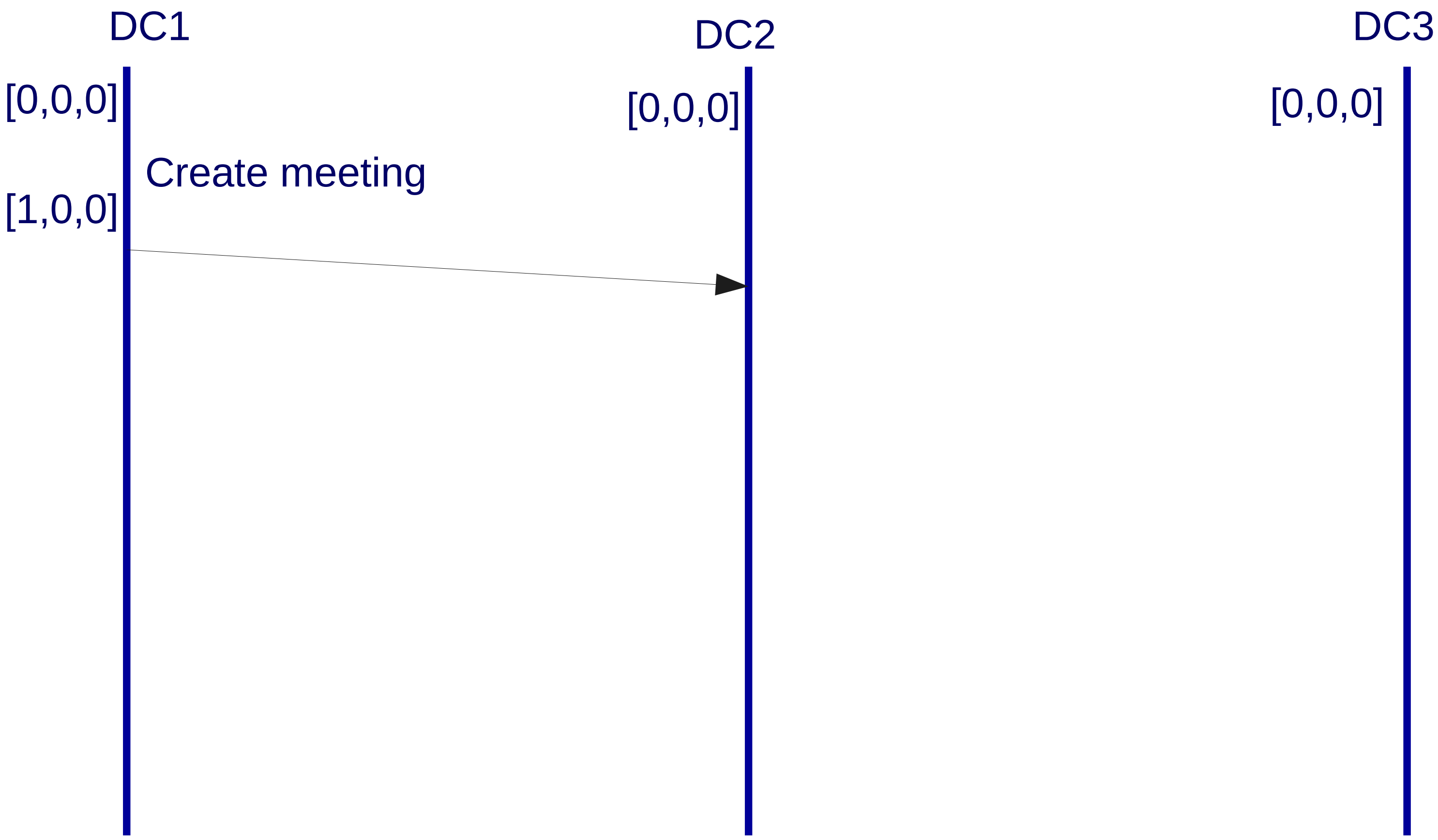

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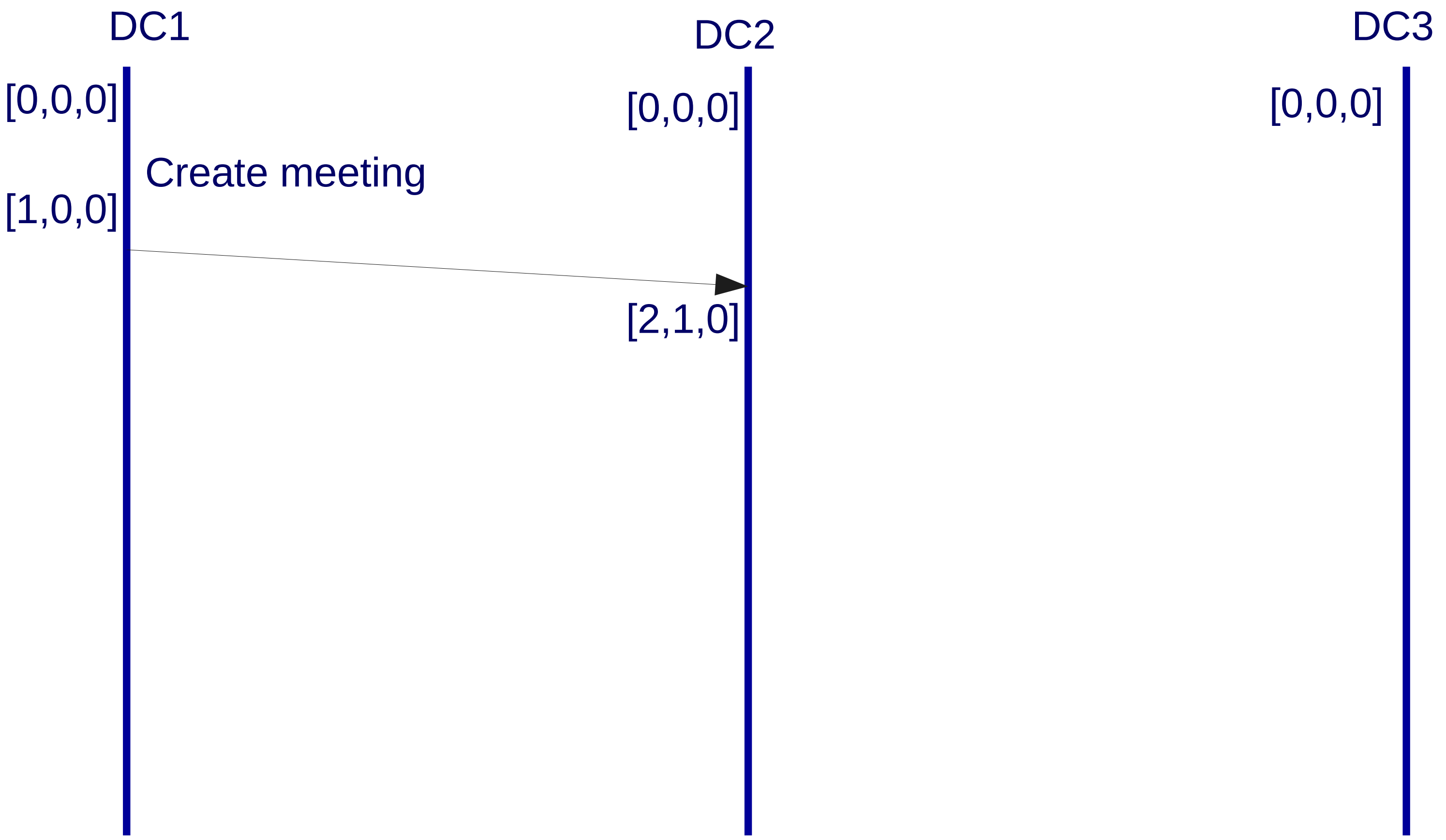

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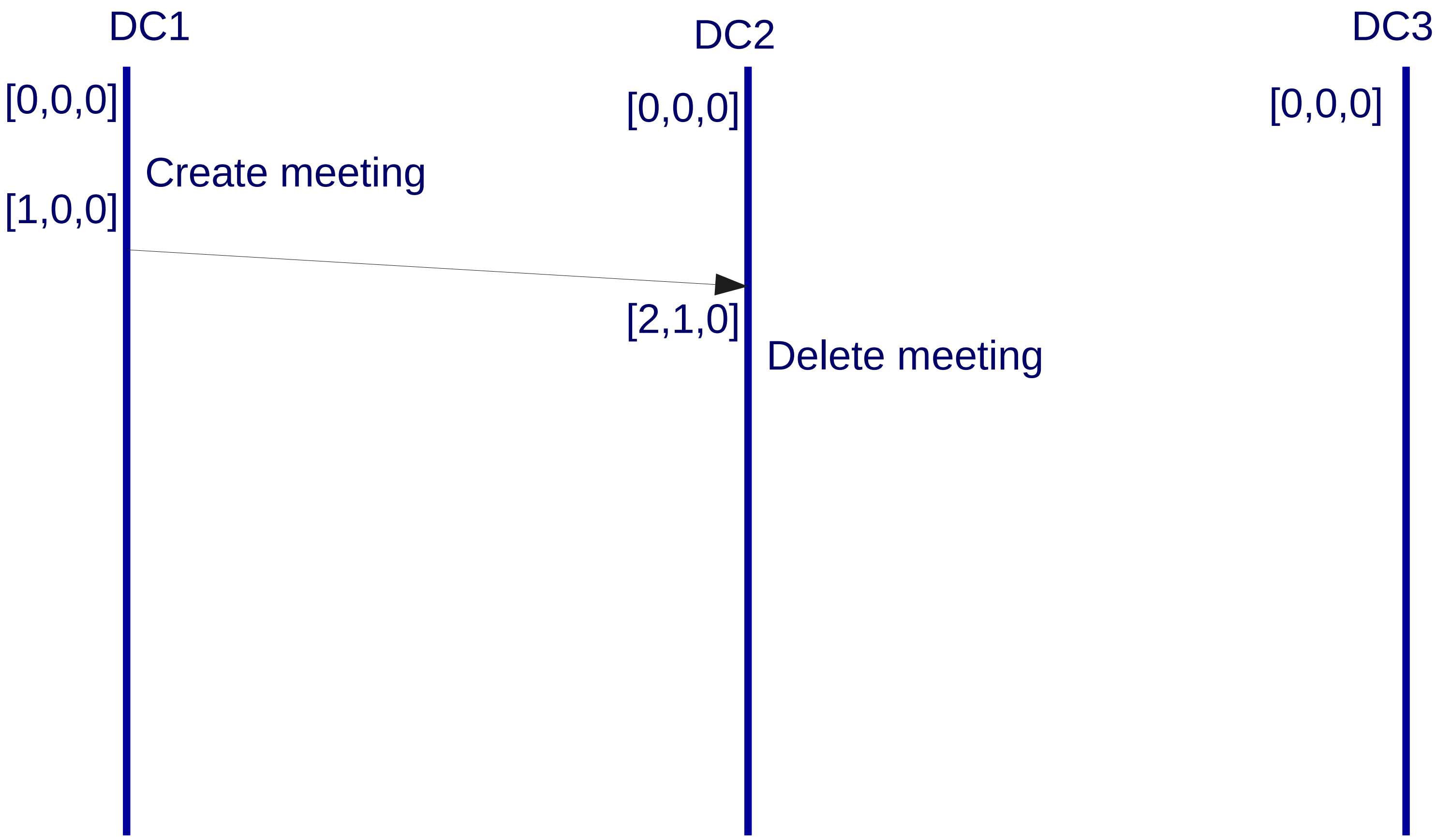

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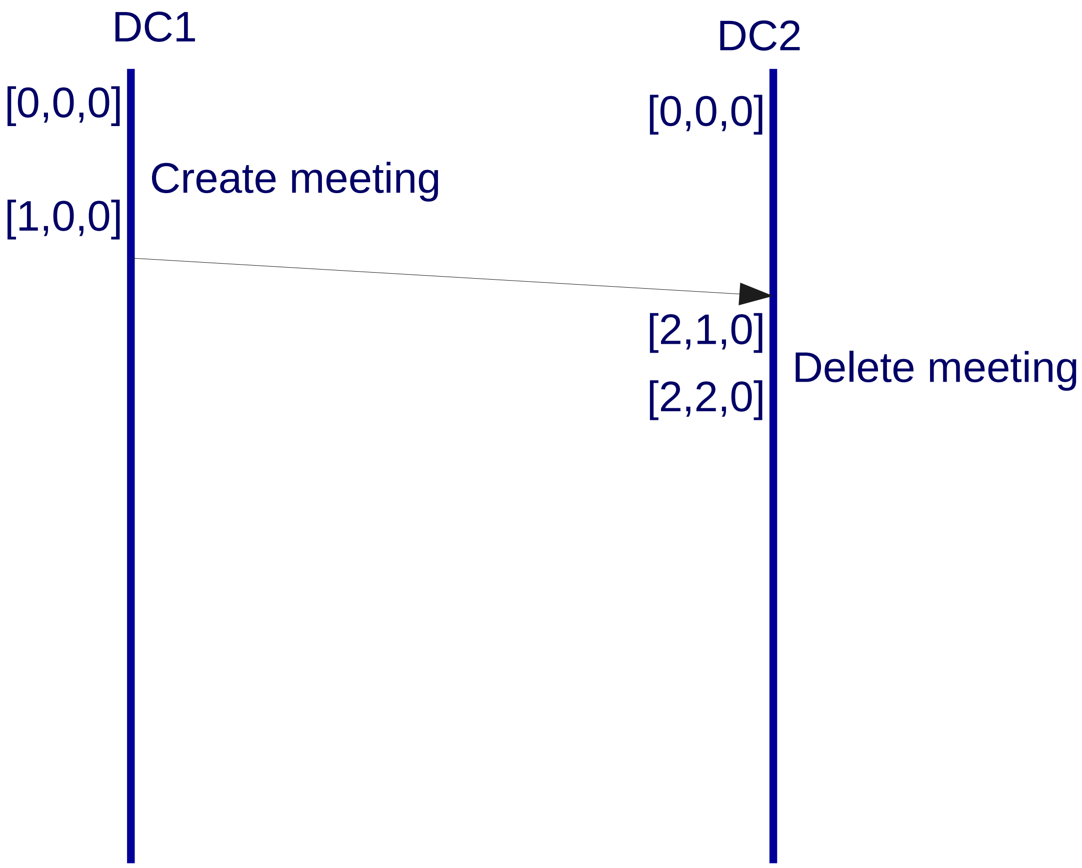

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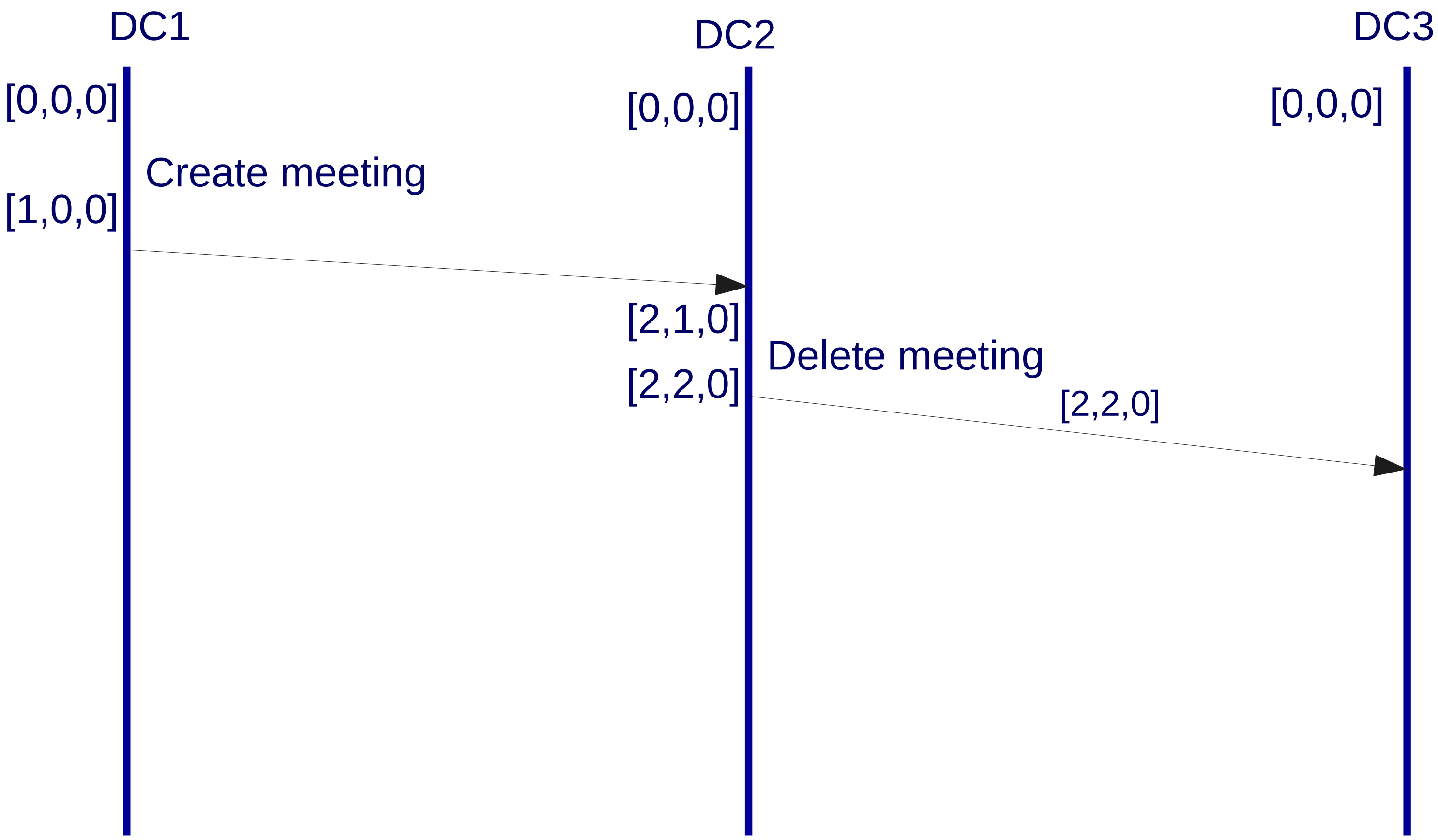

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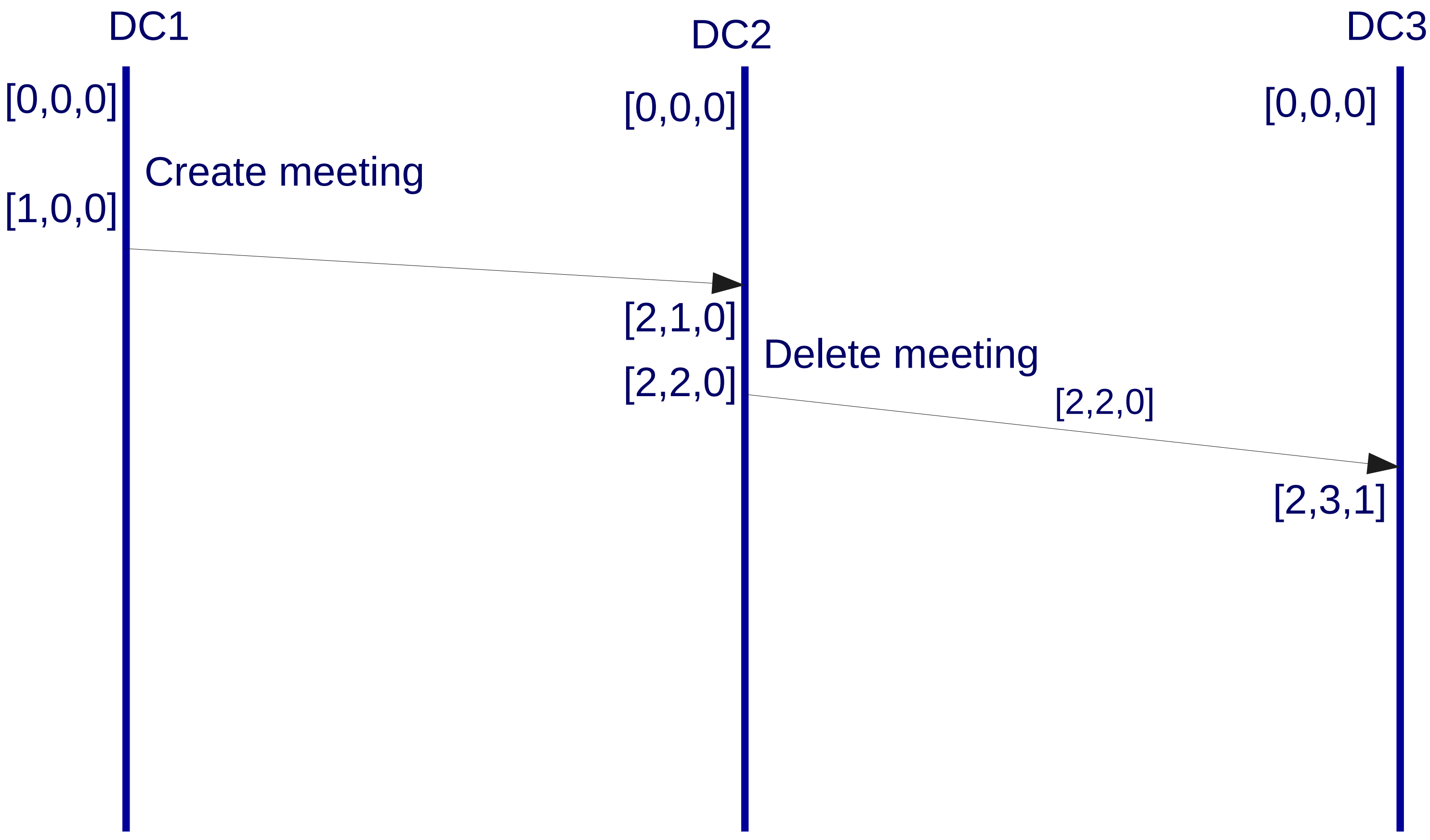

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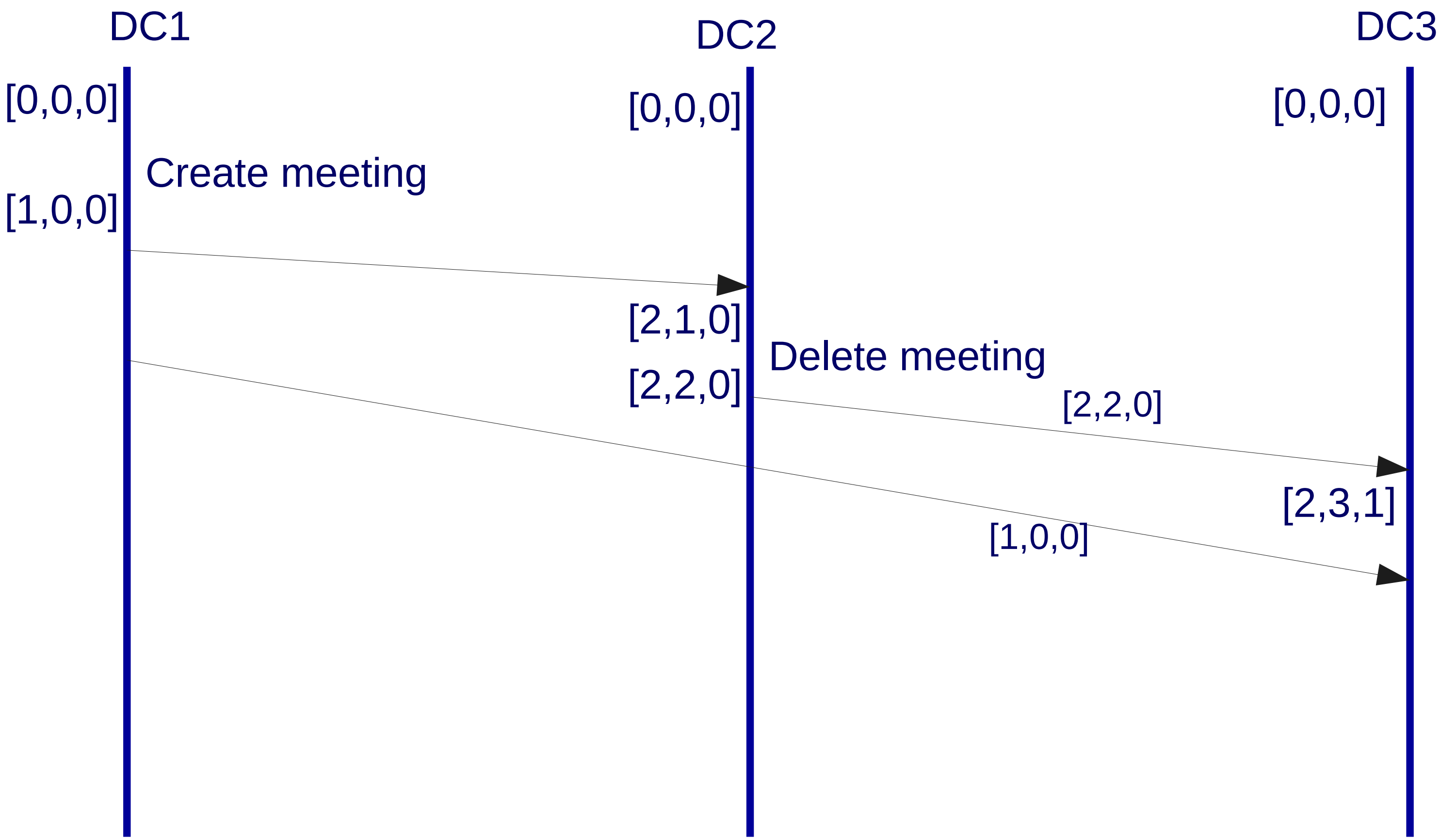

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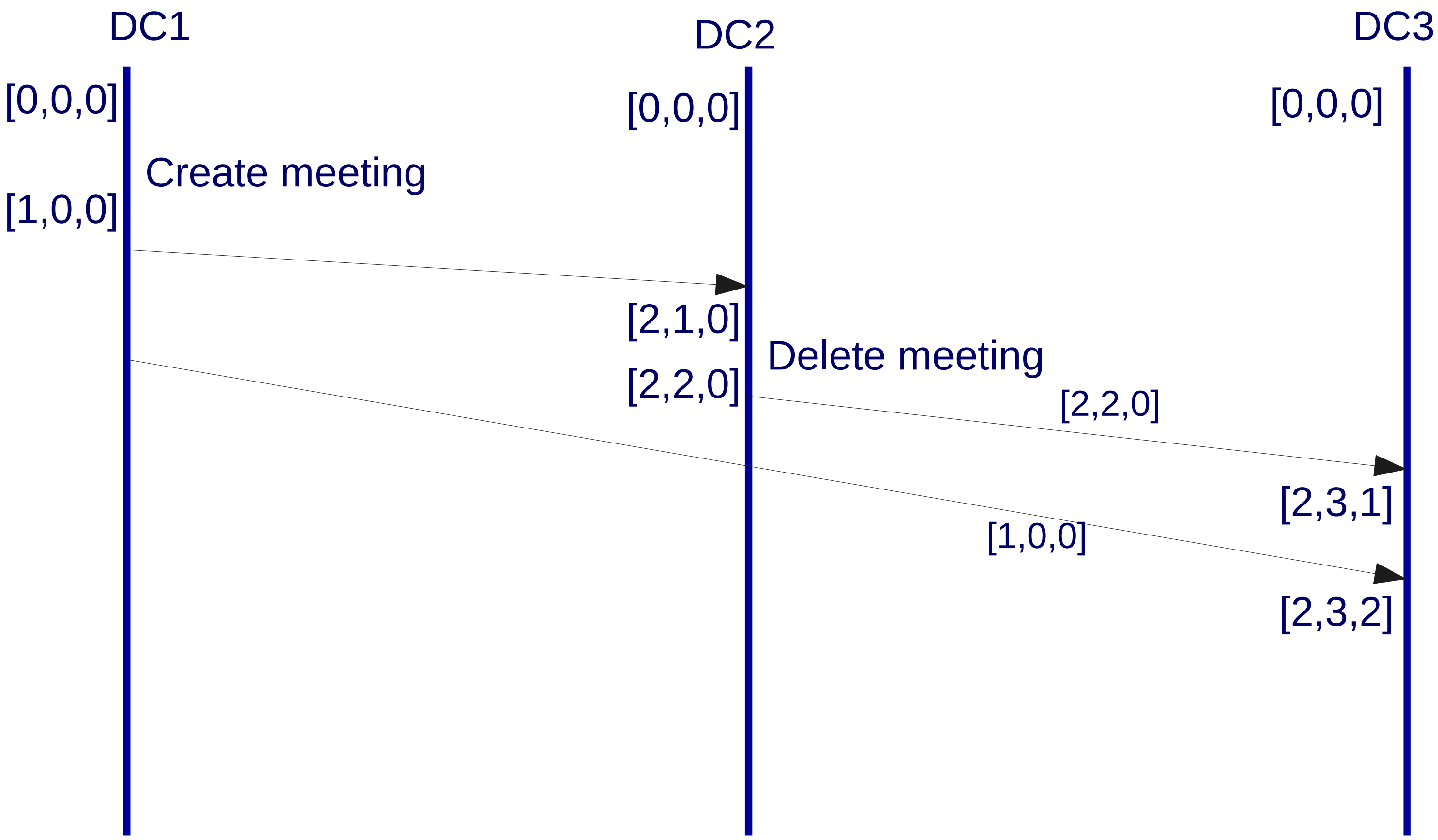

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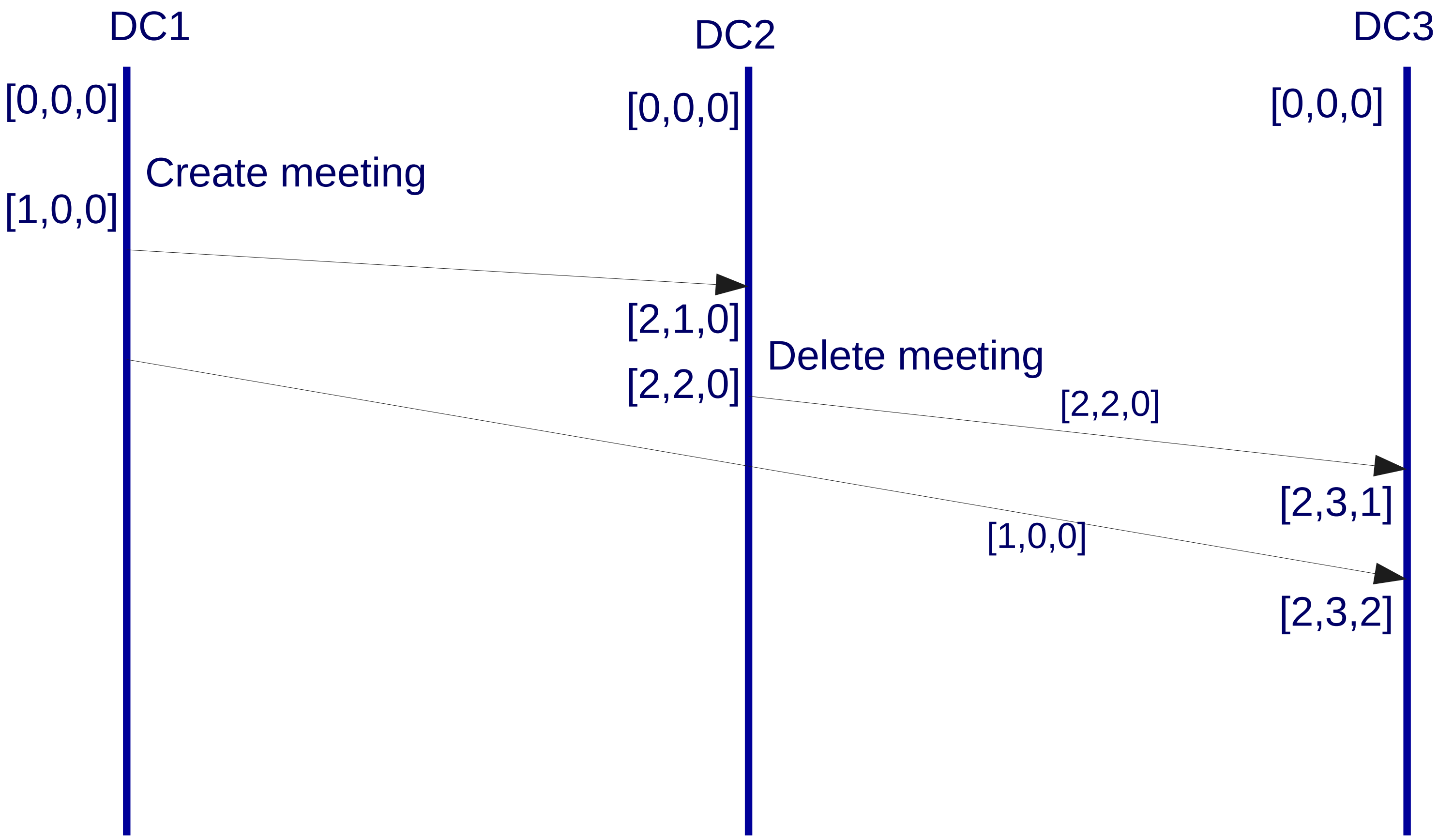
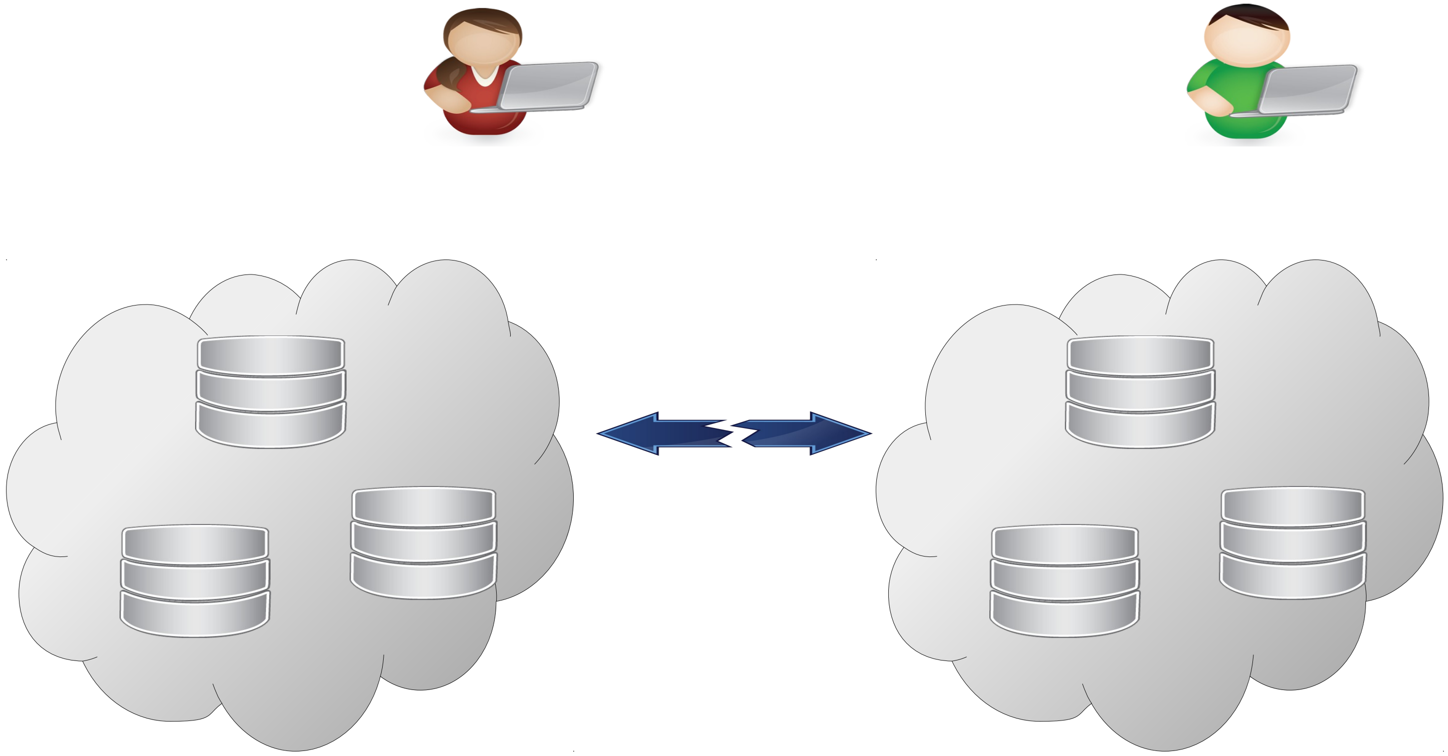


Version Vectors

- 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



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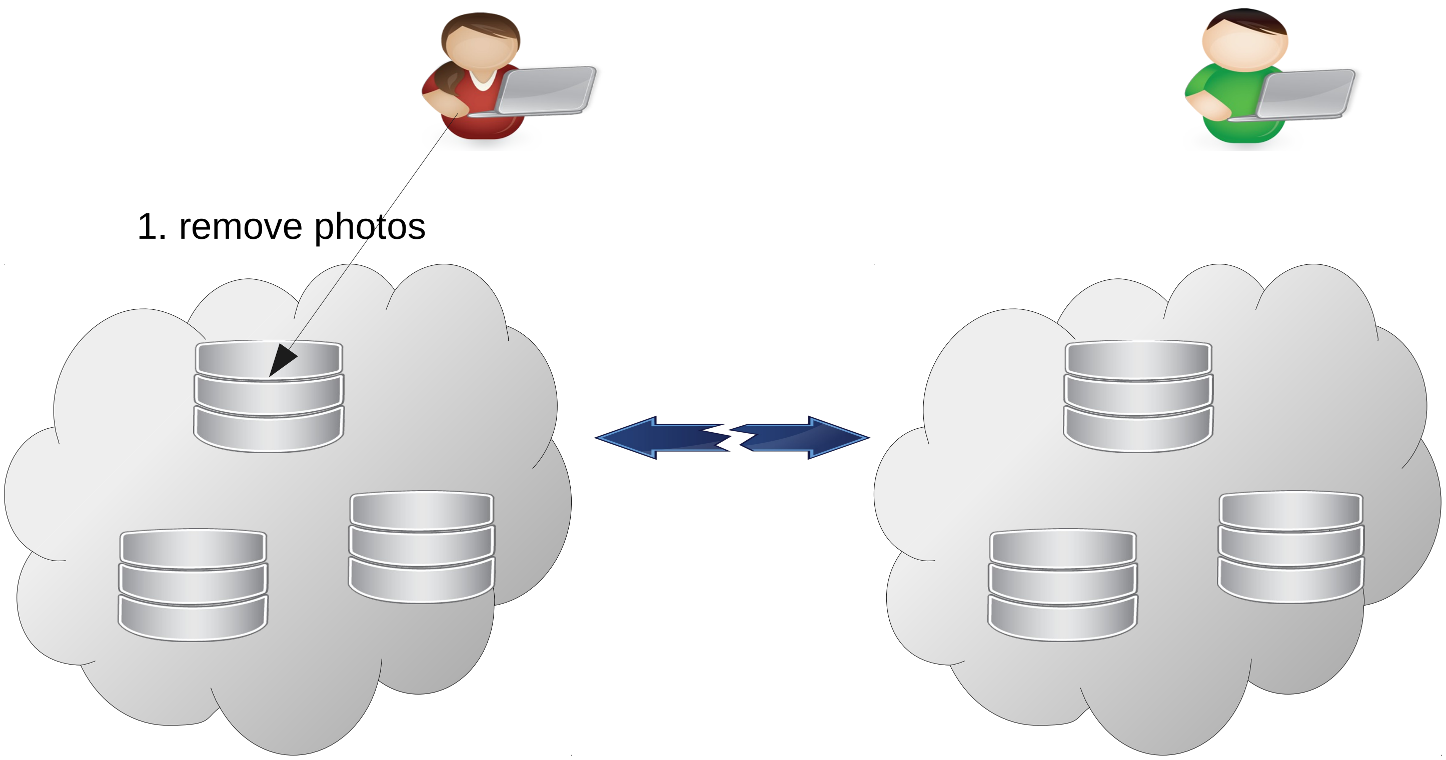

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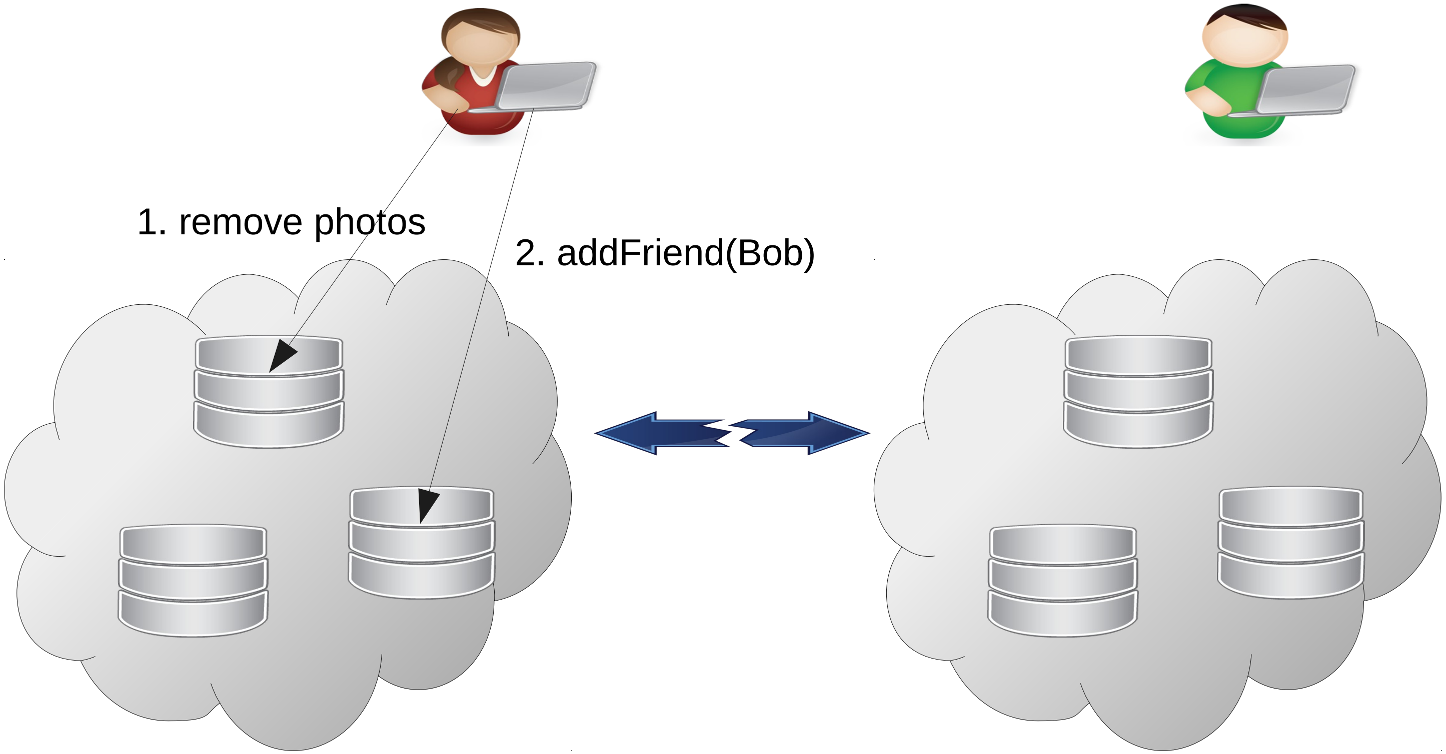

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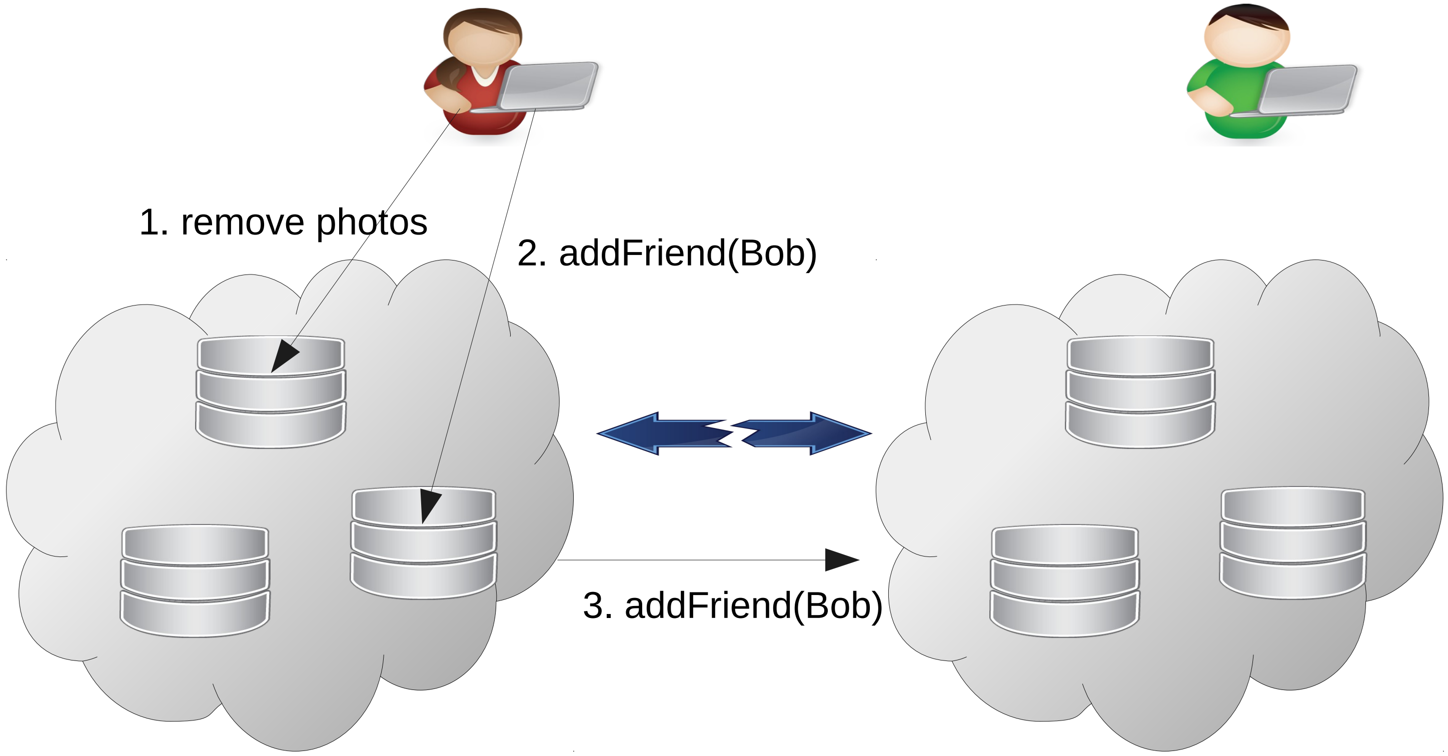

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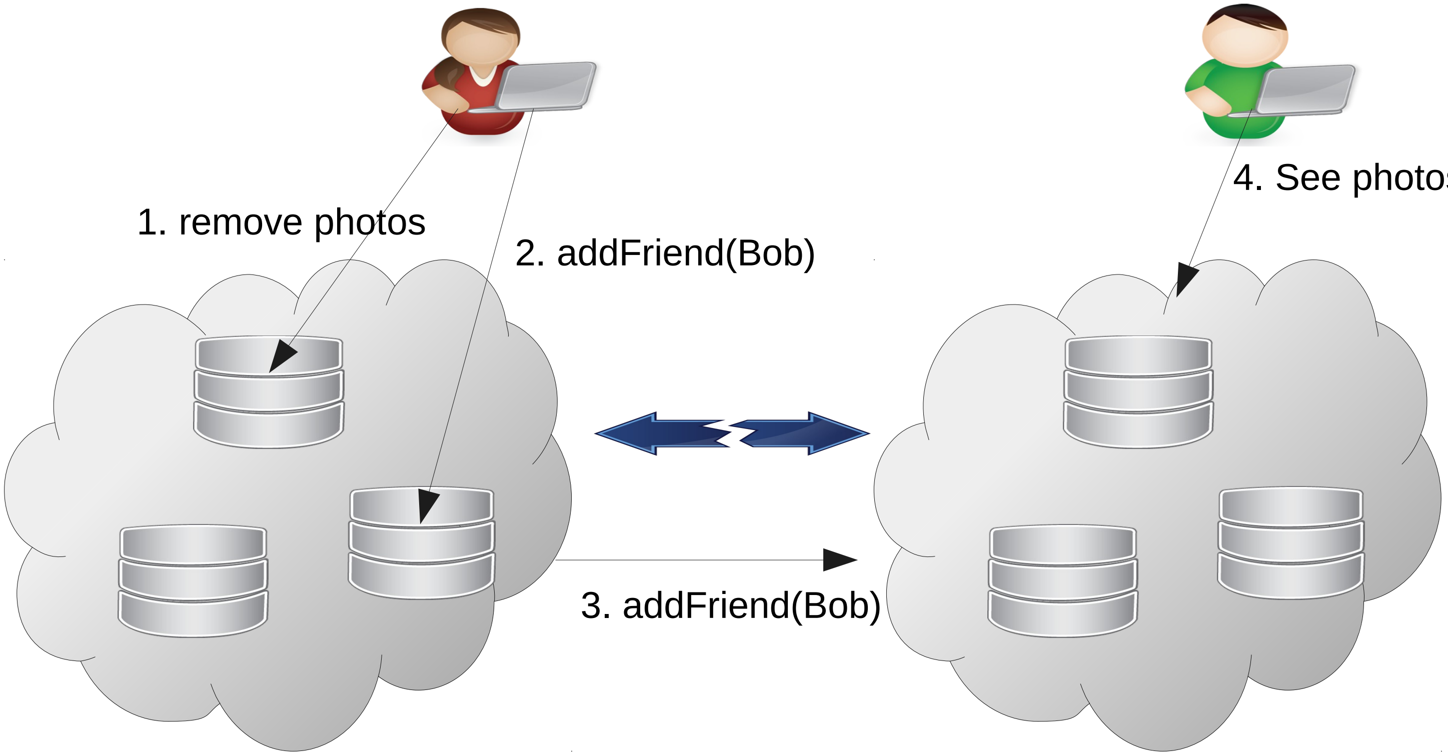

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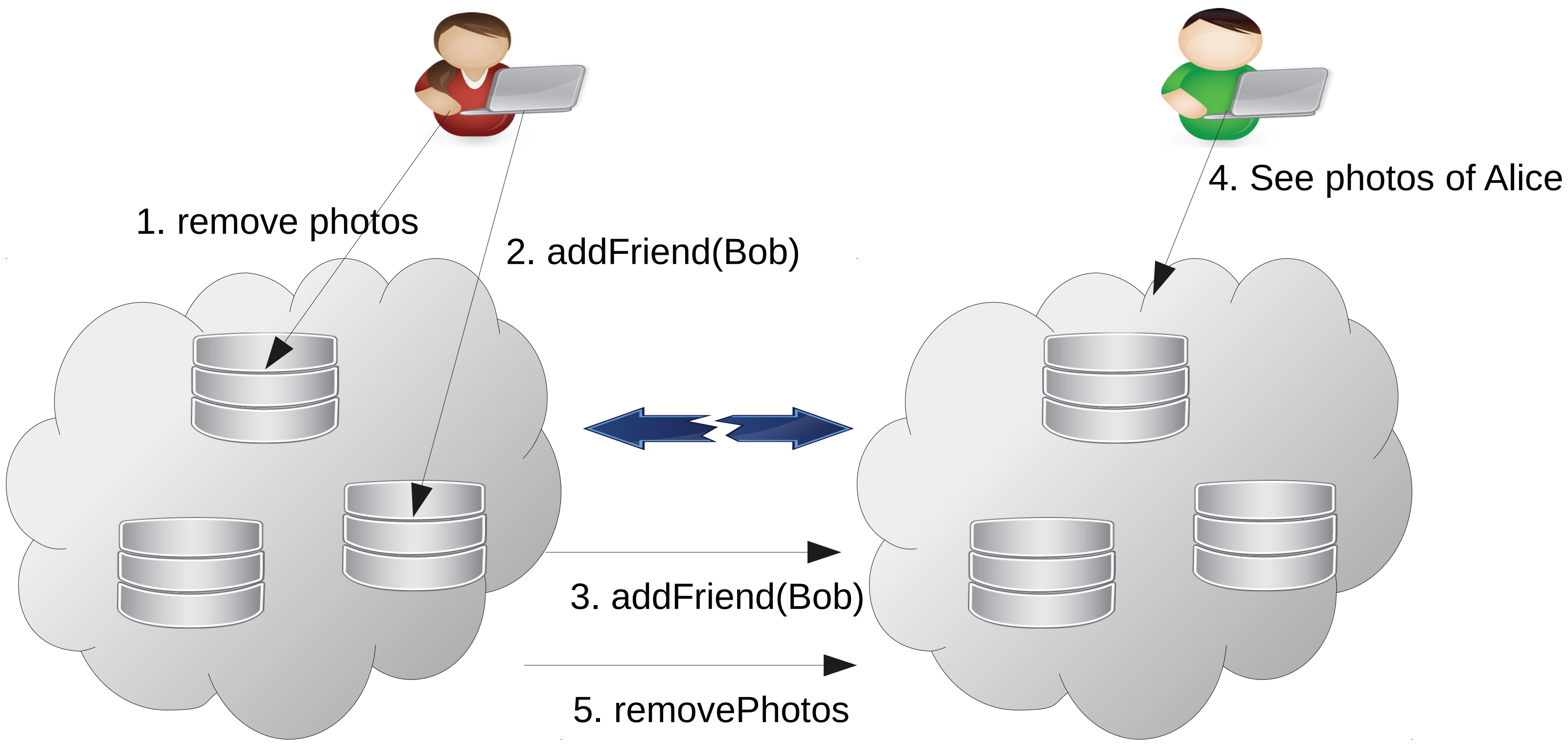


Orbe: Causal Consistency with Dependency Matrix

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 put(k,v,DM) to partition P1 at DC1
- P1 at DC1
  - Increment its own VV[R1]
  - Ts = VV[R1]
  - New entry U<k, v, 2, DM, R1>
  - Replicate U to P1 at DC2 and DC3
- On receiving U< k, v, ts, DM, replicaid> at Pn
  - Check VV >= DM[n]
  - Check if causality is satisfied at other partitions
  - Update VV[replicaid] = ts

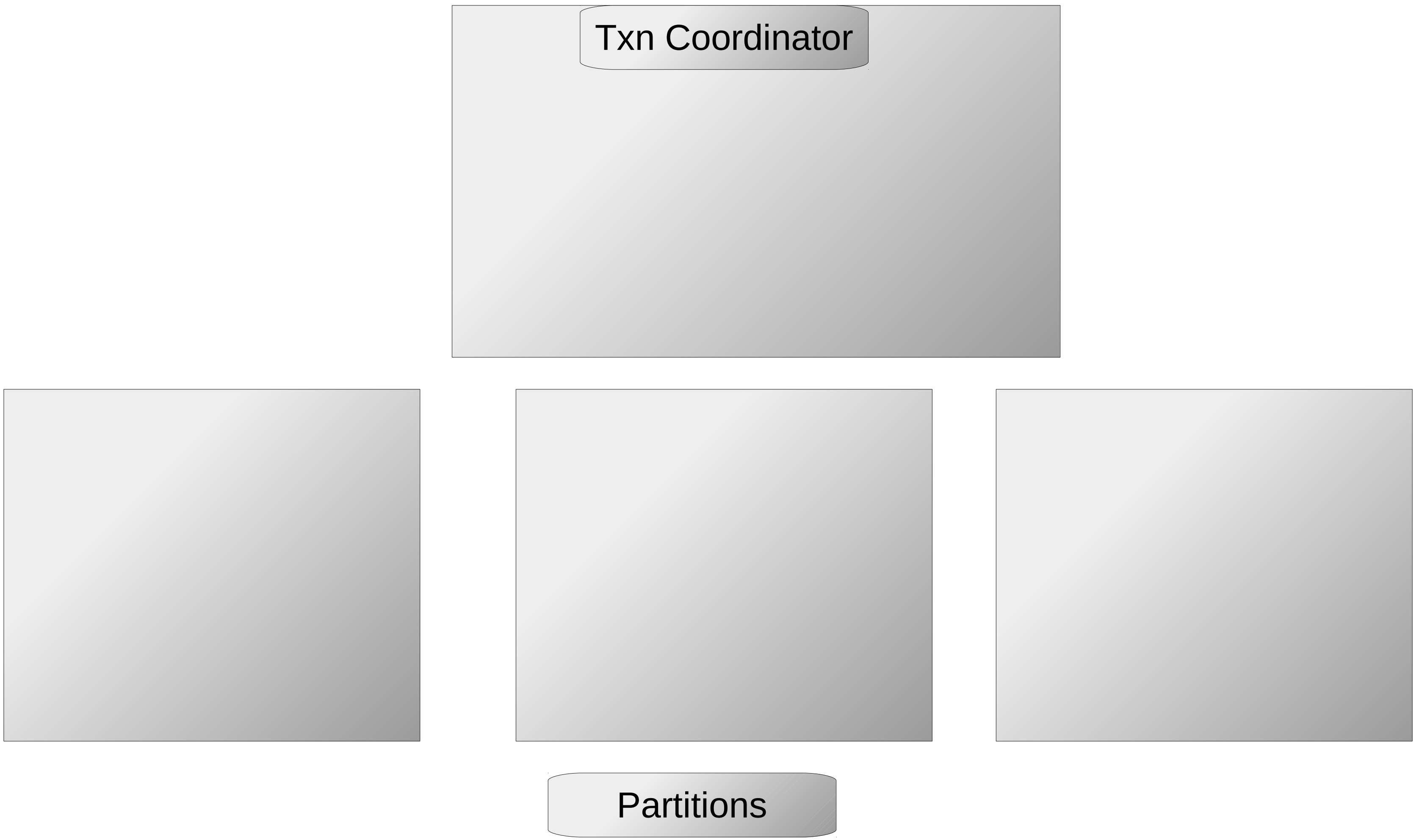
Total order in a partitioned system

- 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.commit-time < B.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

Txn Coordinator

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

Partitions

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- Reply 11
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- Localclock = 9
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Partitions

Clock SI – Read protocol

Read(Transaction T, dataitem Obj)

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

Extended ClockSI: Partitioned and Replicated System

- Vectorclock per partitio

	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

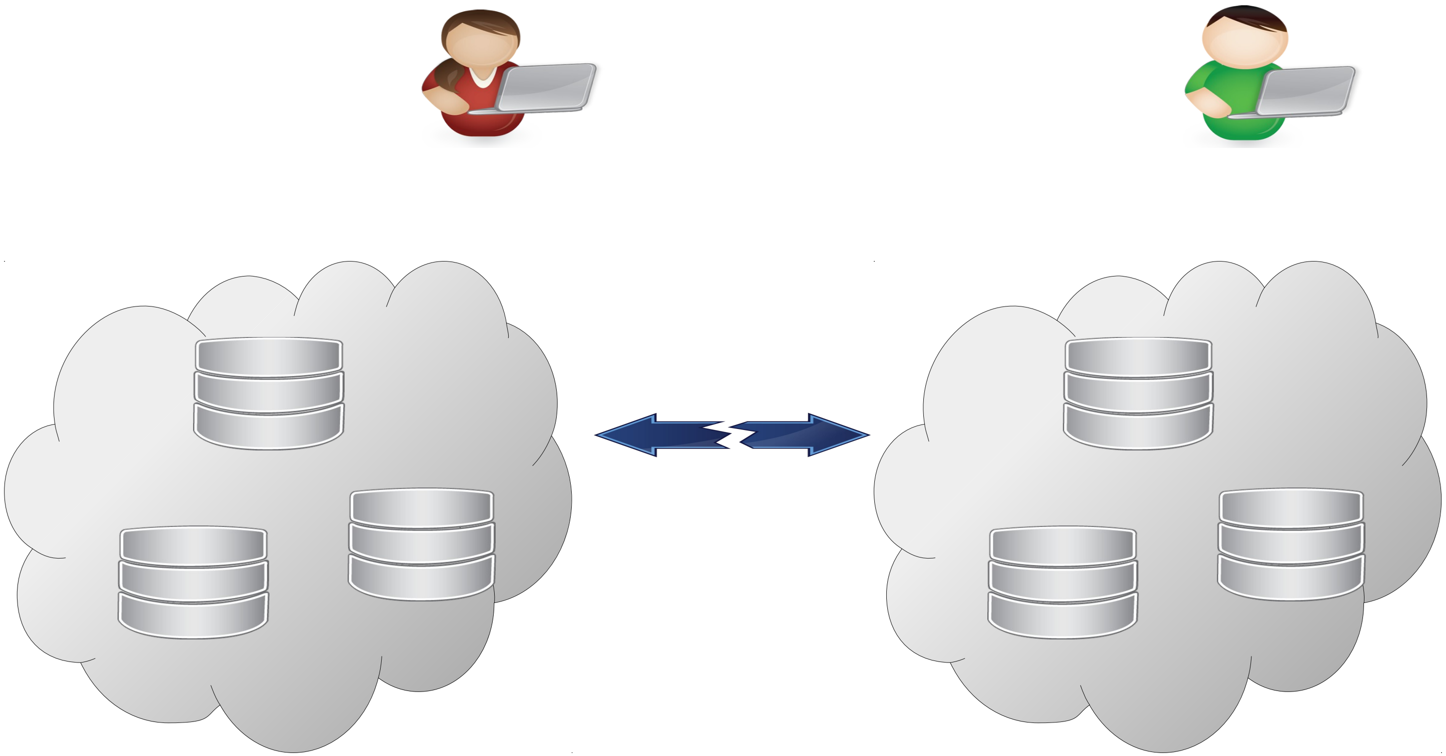
- P1 at DC1 sends updates to P1 at DC2 in *Commit-time order*
- Send snapshot-time and commit-time with every update
- On receiving an update U<DC, Commit-time, Snapshot-time> from a partition
  - Apply U if local vectorclock > Snapshot-time
  - Set vectorclock[DC] = Commit-time

Extended ClockSI: Read

- Upon receiving a read request in a partition
  - Wait until local vectorclock >= snapshot-time
  - Return latest value before snapshot-time

- Causality metadata = O(N)
- No communication between partitions

Social Network Application



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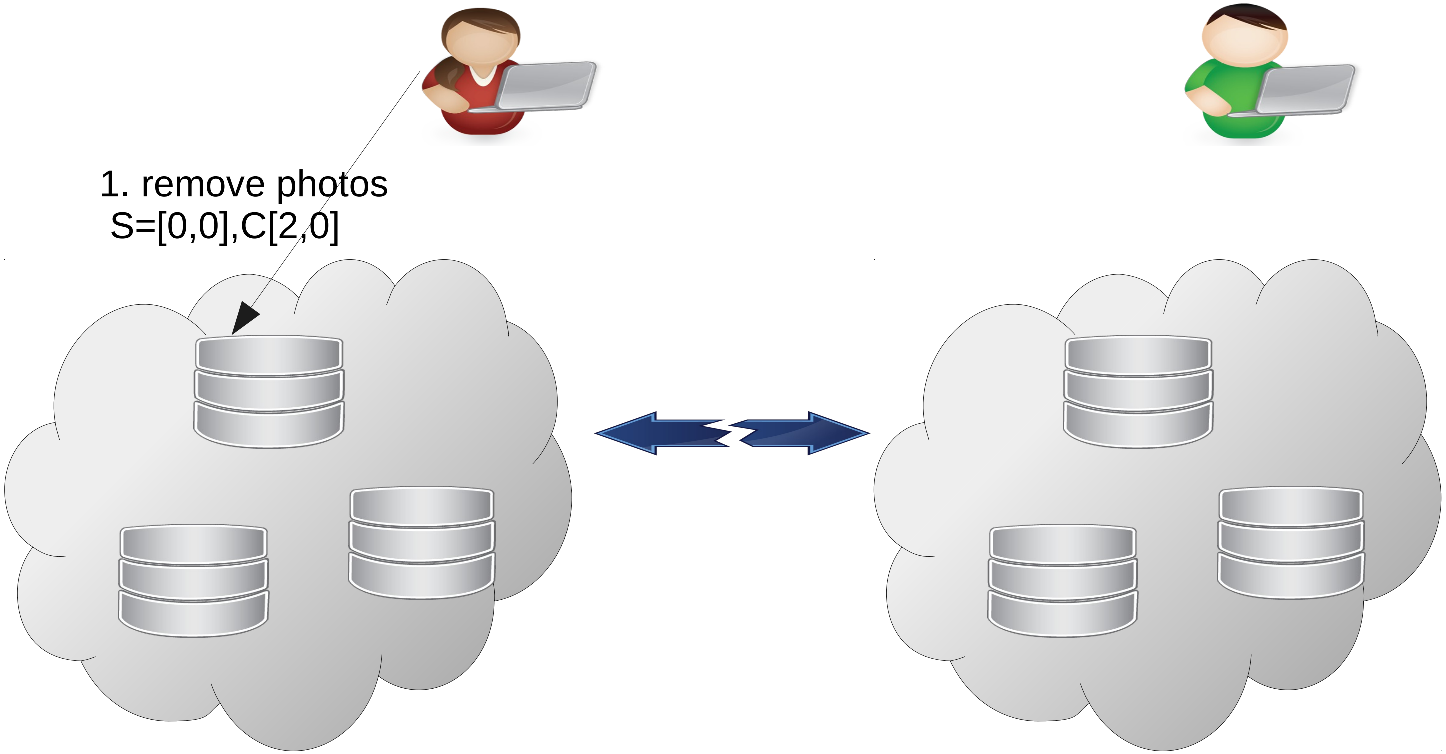

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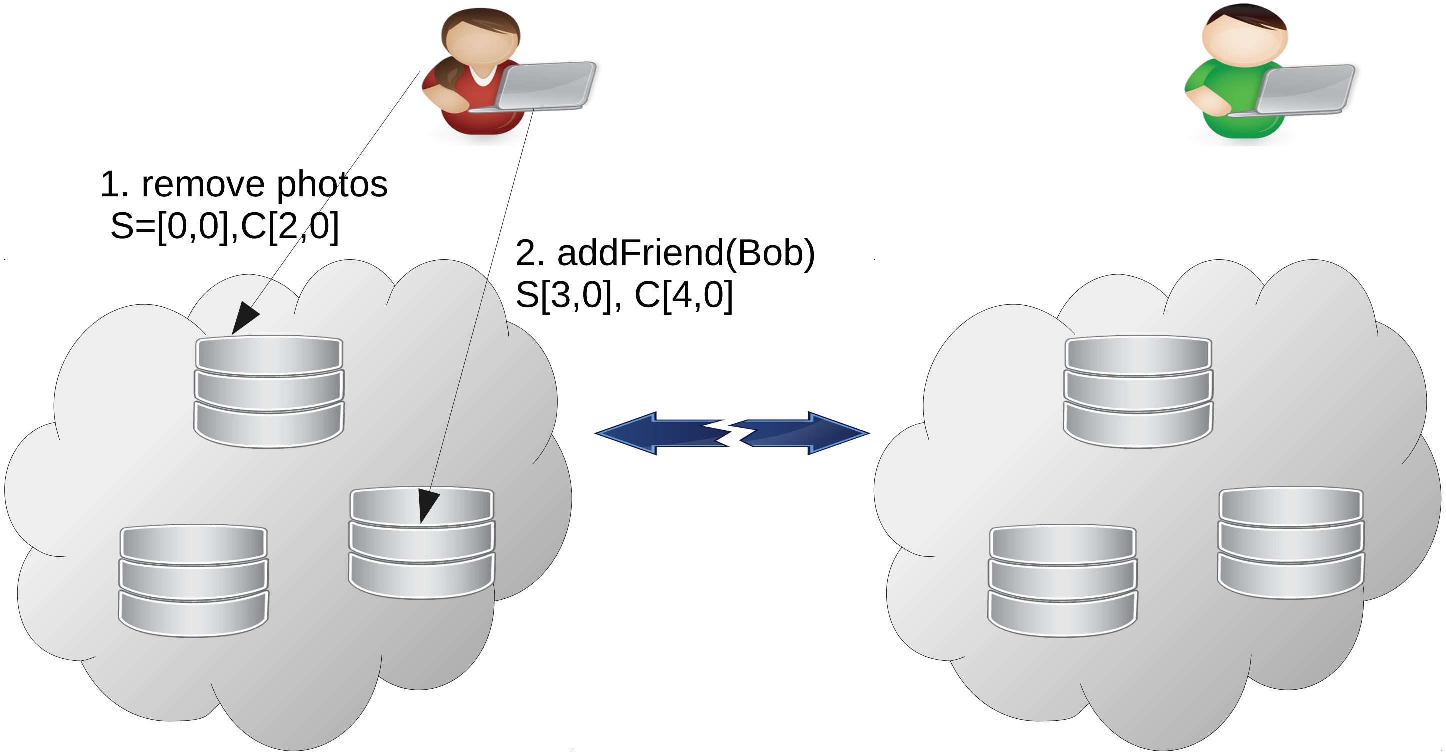

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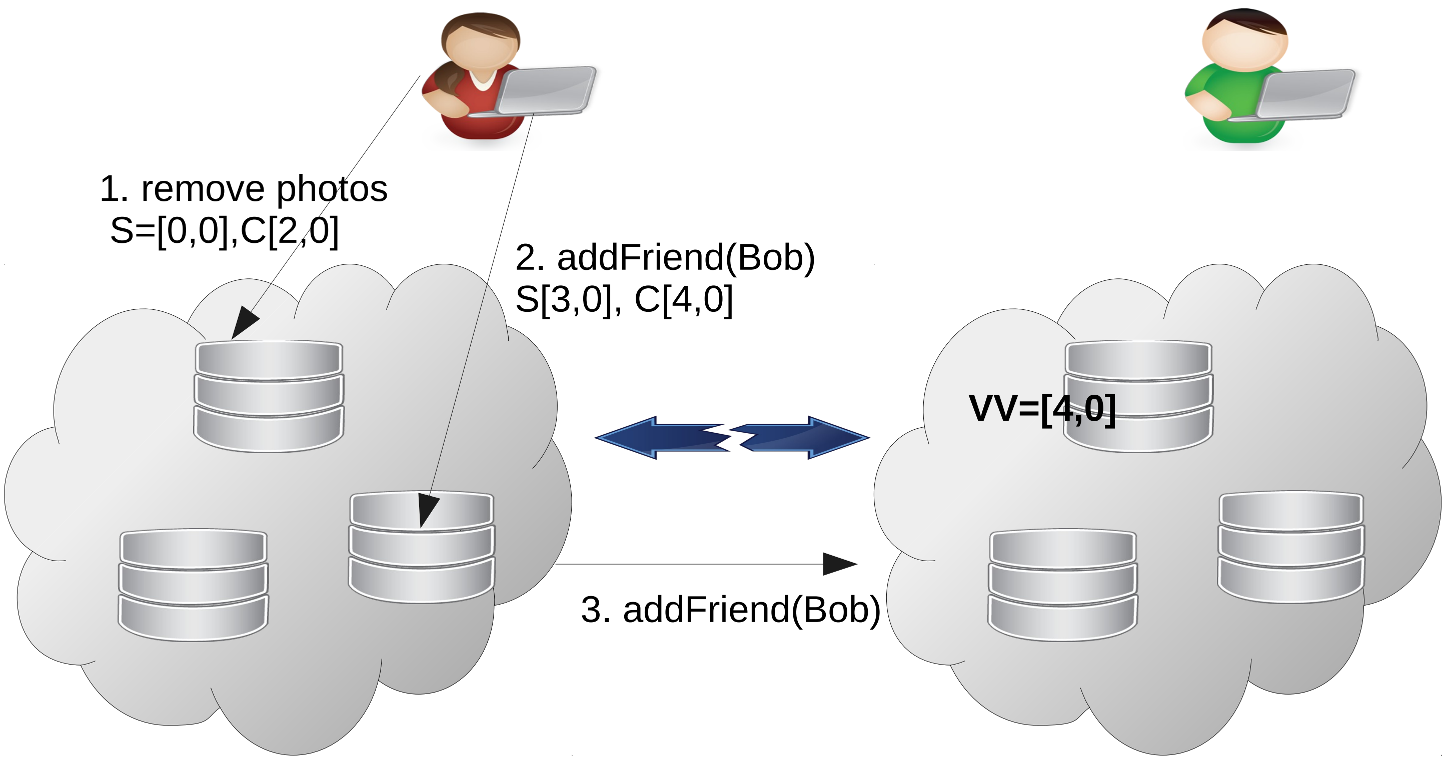

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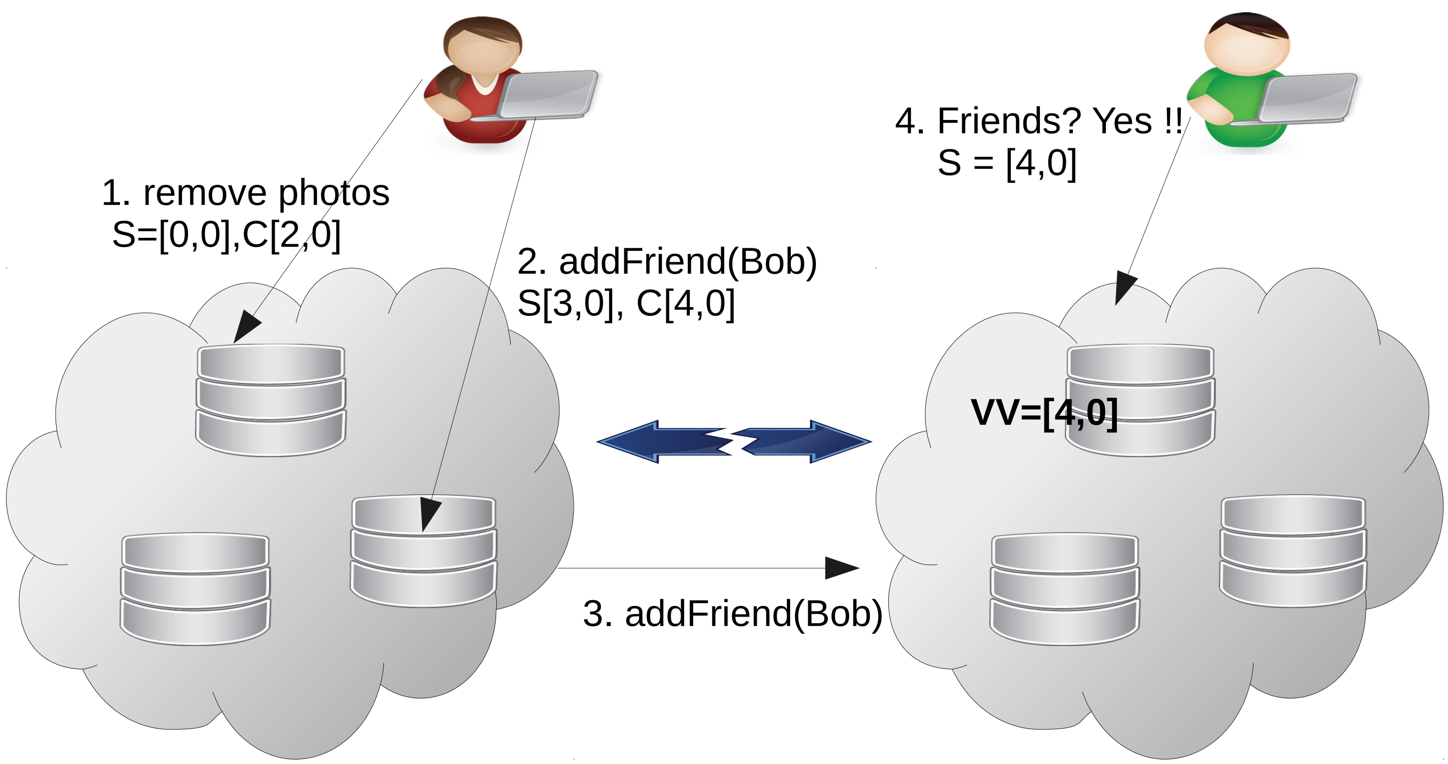

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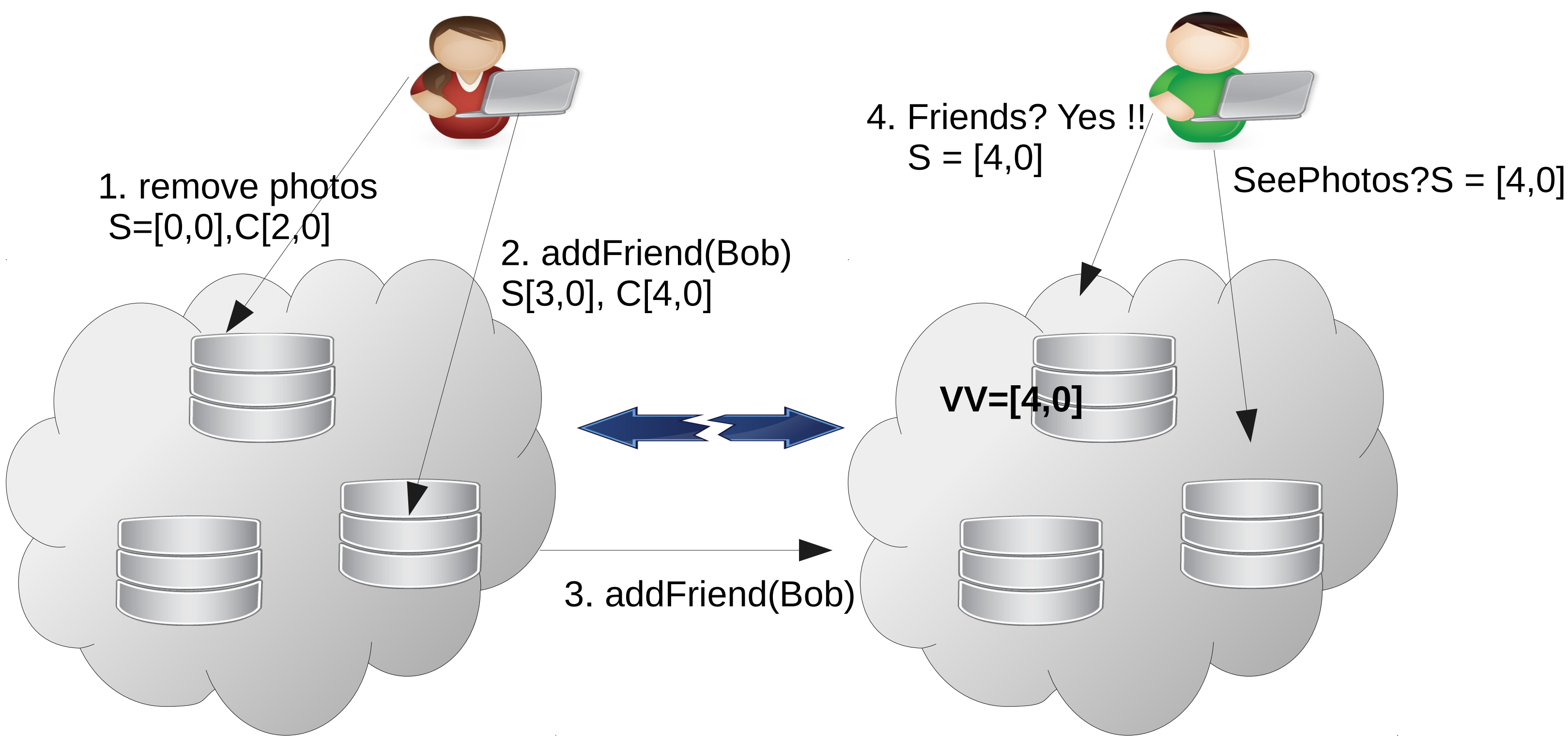

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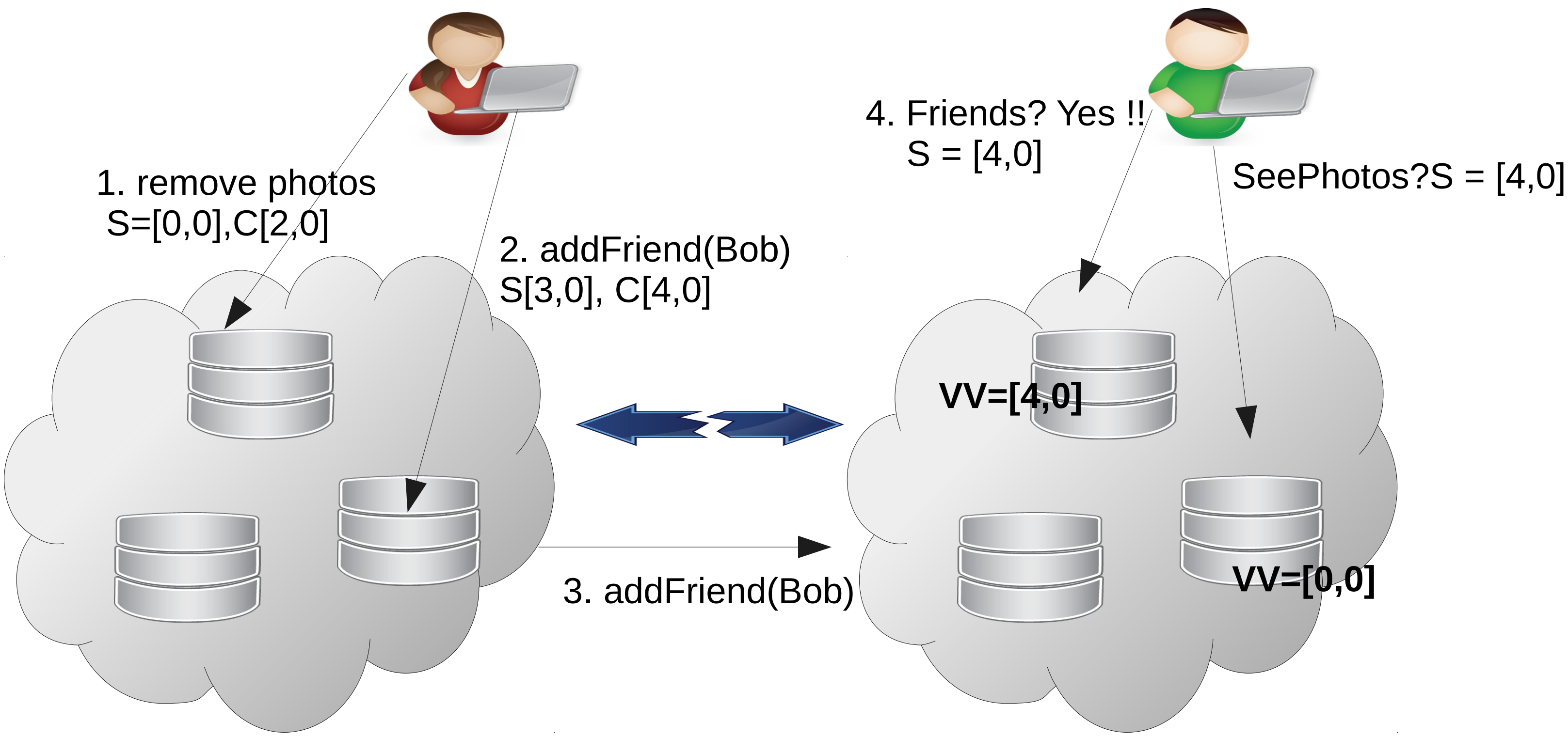

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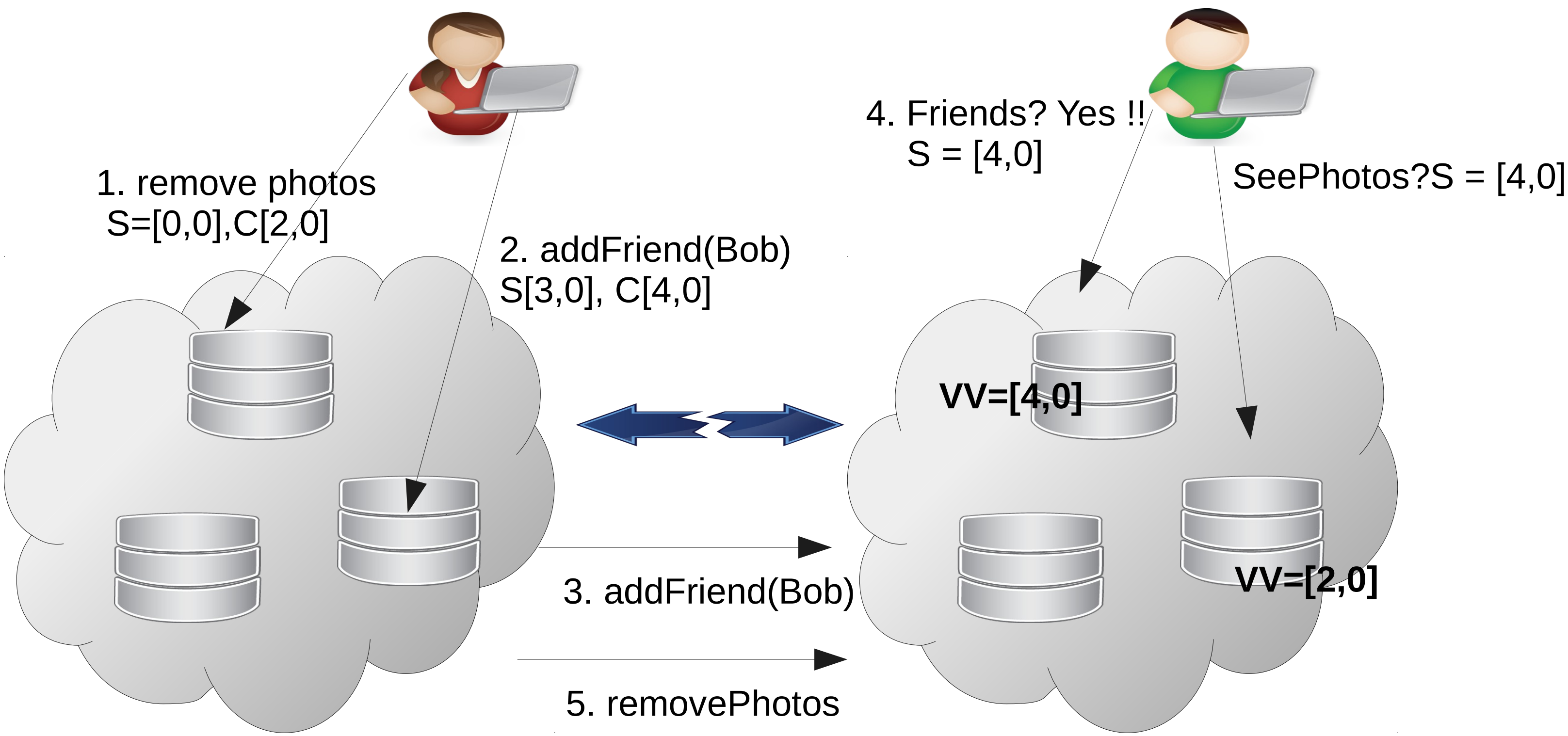

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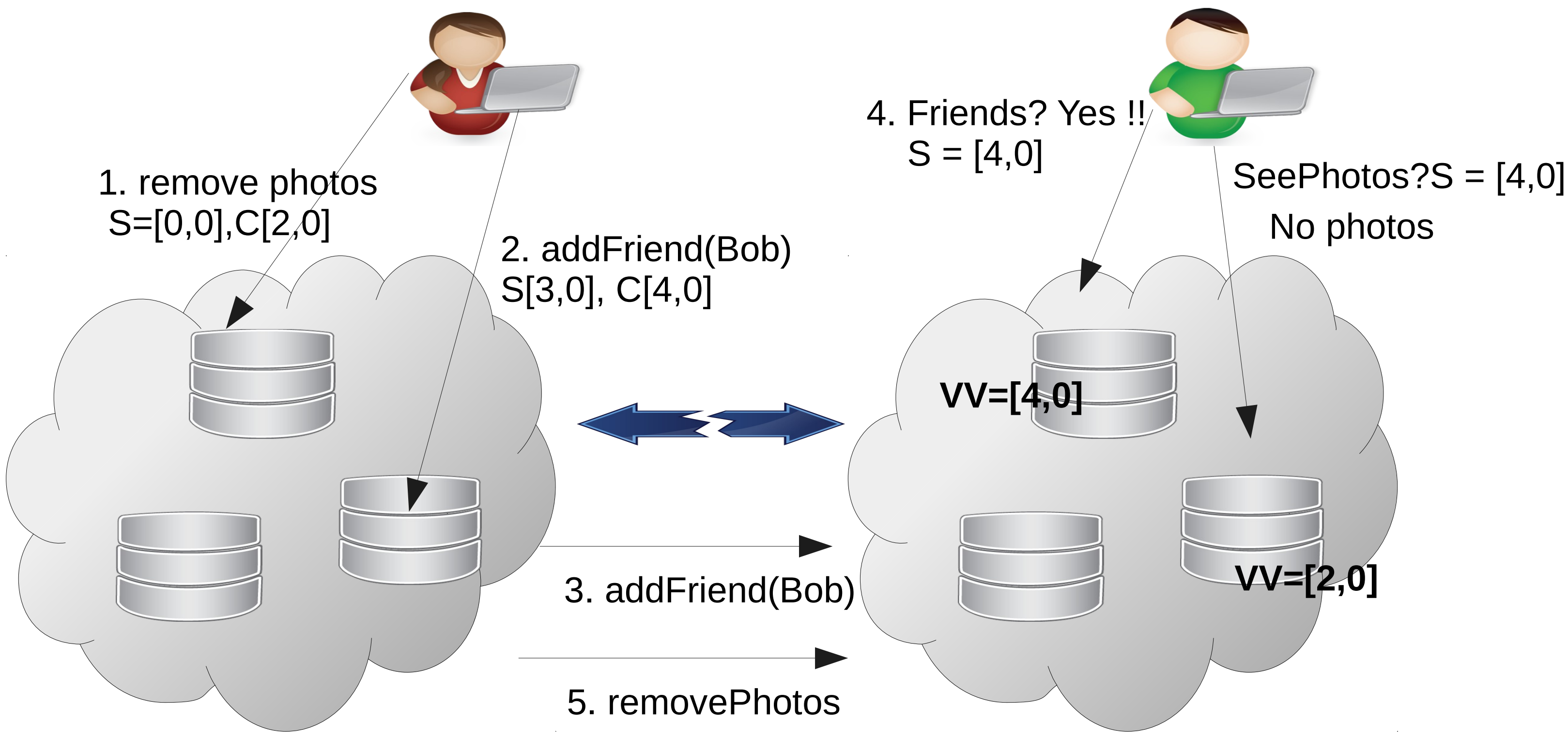

Conclusion

- 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

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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