Distributed Systems

The second half of *Concurrent and Distributed Systems*

https://www.cl.cam.ac.uk/teaching/current/ConcDisSys

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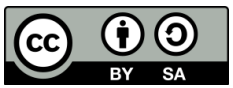
Computer Science Tripos, Part IB



Lecture 7

Replica consistency

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- **Read-after-write consistency** (lecture 5)
- **Replication**: replica should be "consistent" with other replicas

  "consistent" = in the same state? (when exactly?)

  "consistent" = read operations return same result?

- **Consistency model**: many to choose from

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If the transaction updates data on multiple nodes, this implies:

- Either all nodes must commit, or all must abort
- If any node crashes, all must abort

Ensuring this is the **atomic commitment** problem.
Looks a bit similar to consensus?

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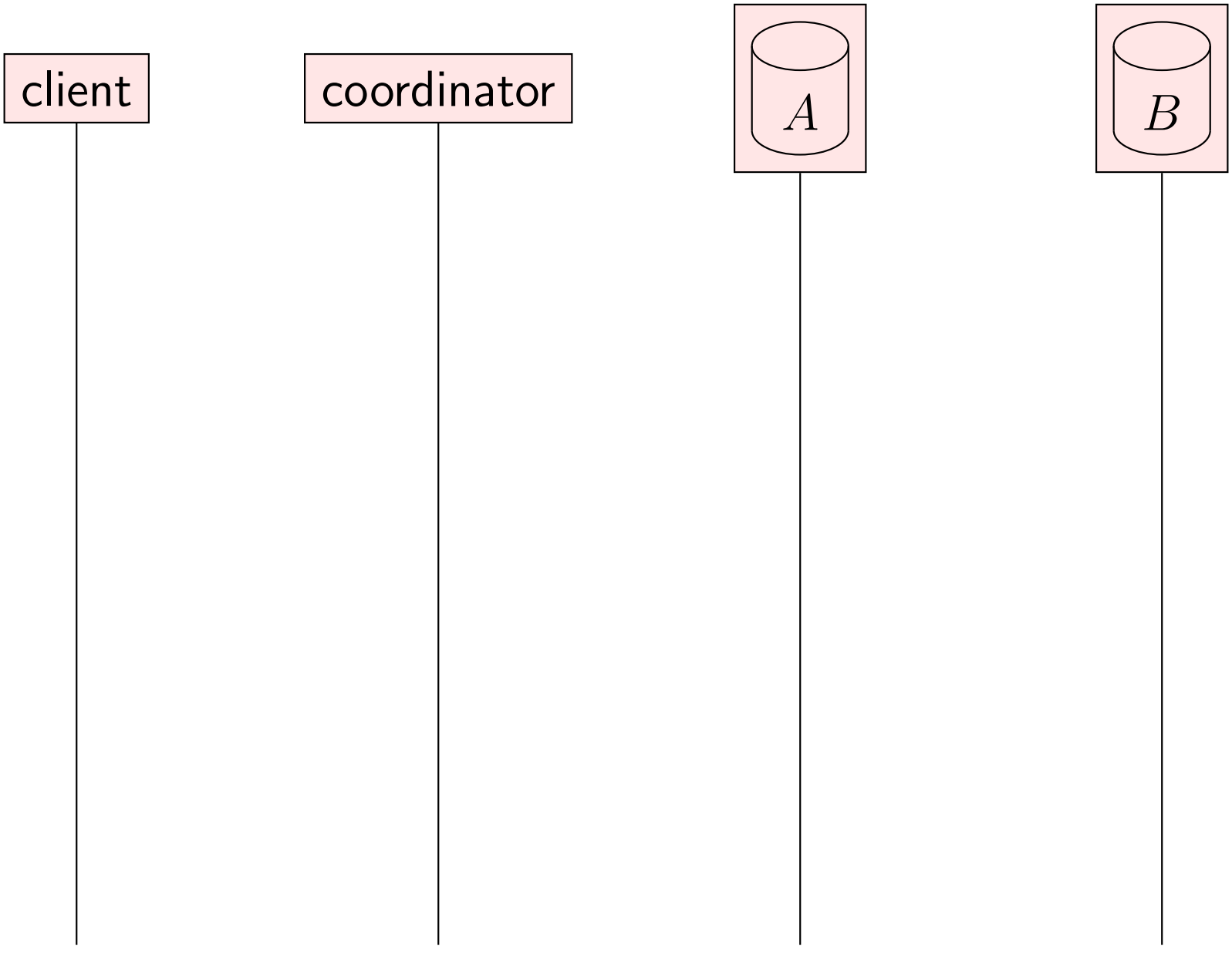
Any one of the proposed values is decided	Must commit if all nodes vote to commit; must abort if ≥ 1 nodes vote to abort
Crashed nodes can be tolerated, as long as a quorum is working	Must abort if a participating node crashes

Two-phase commit (2PC)



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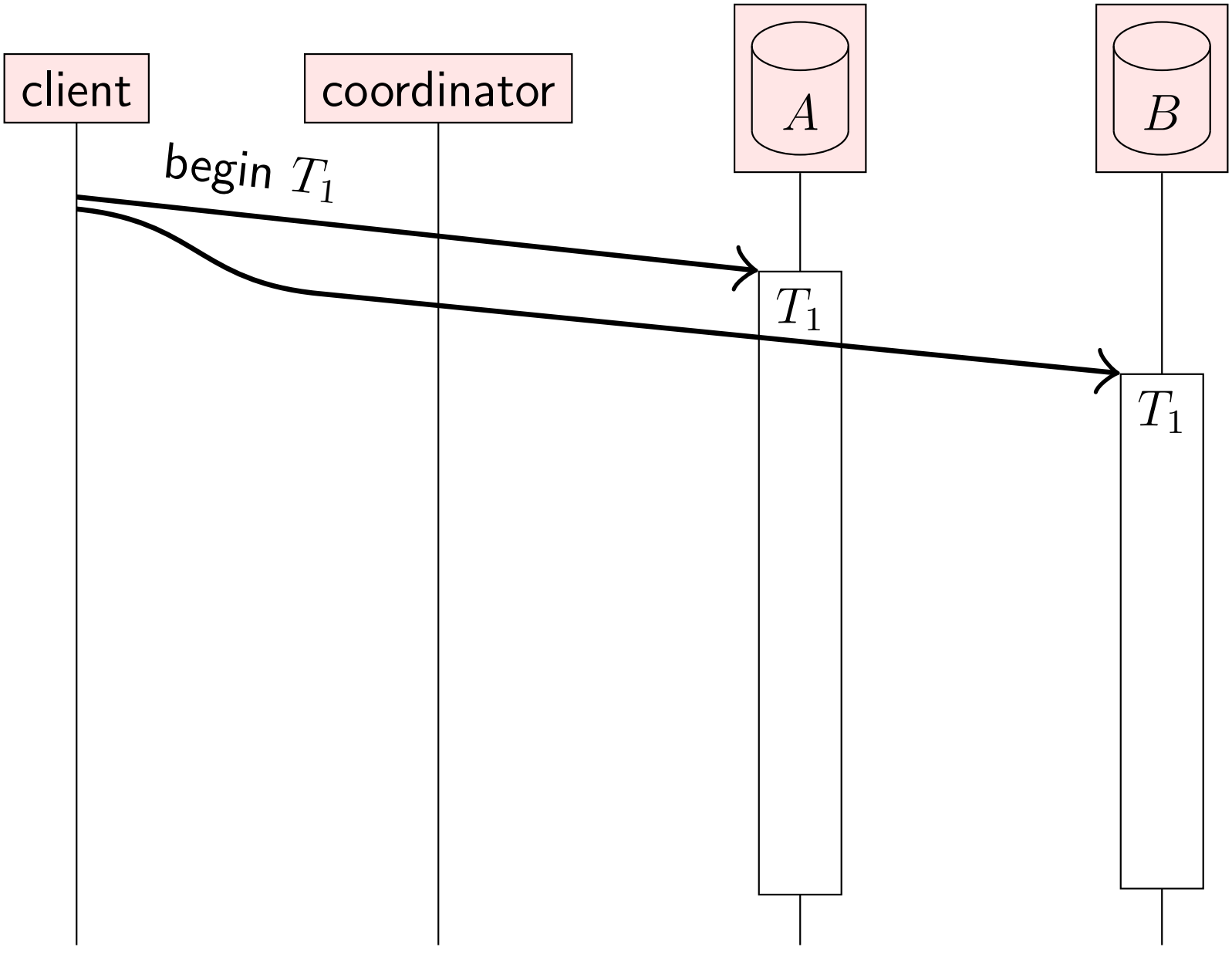

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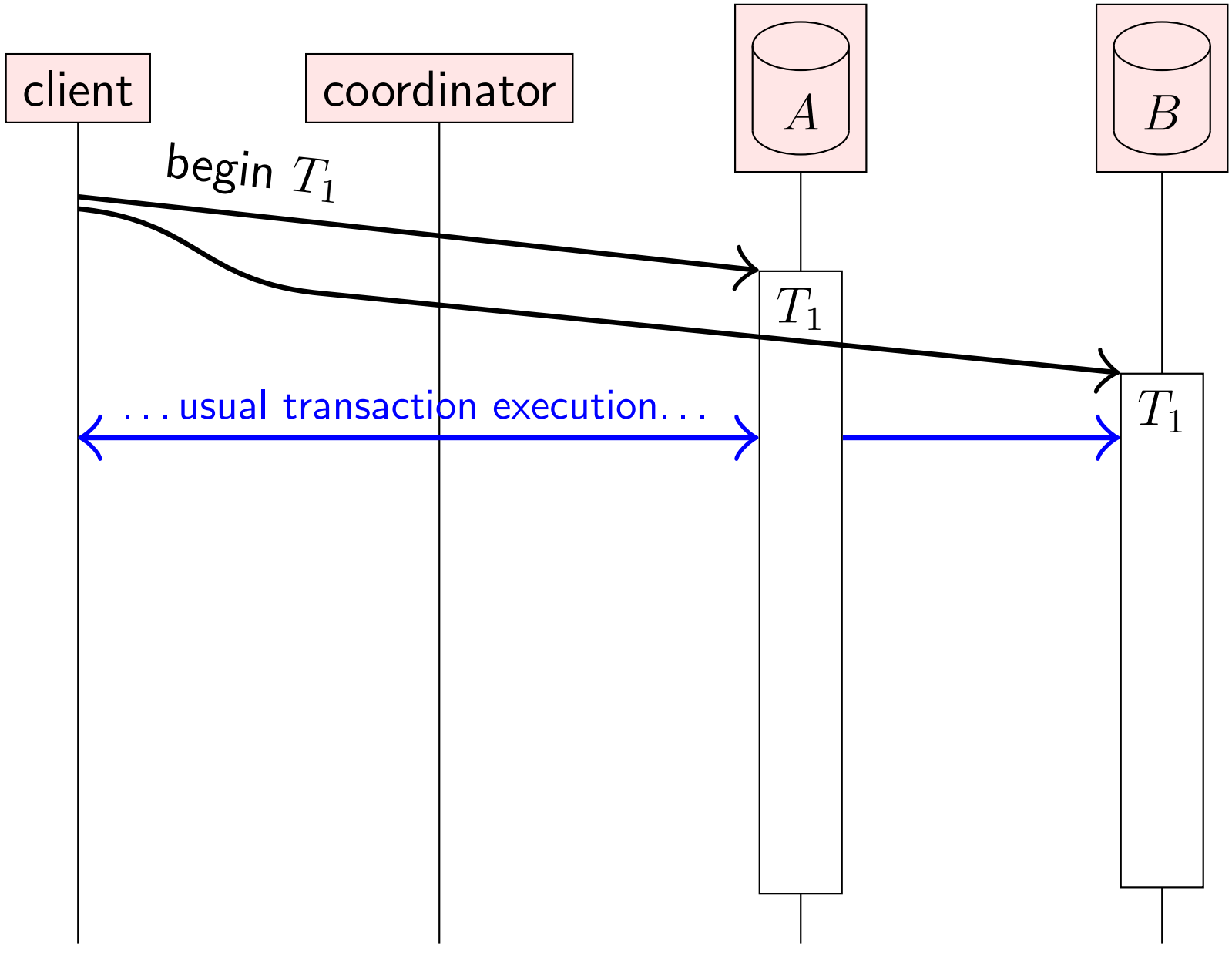

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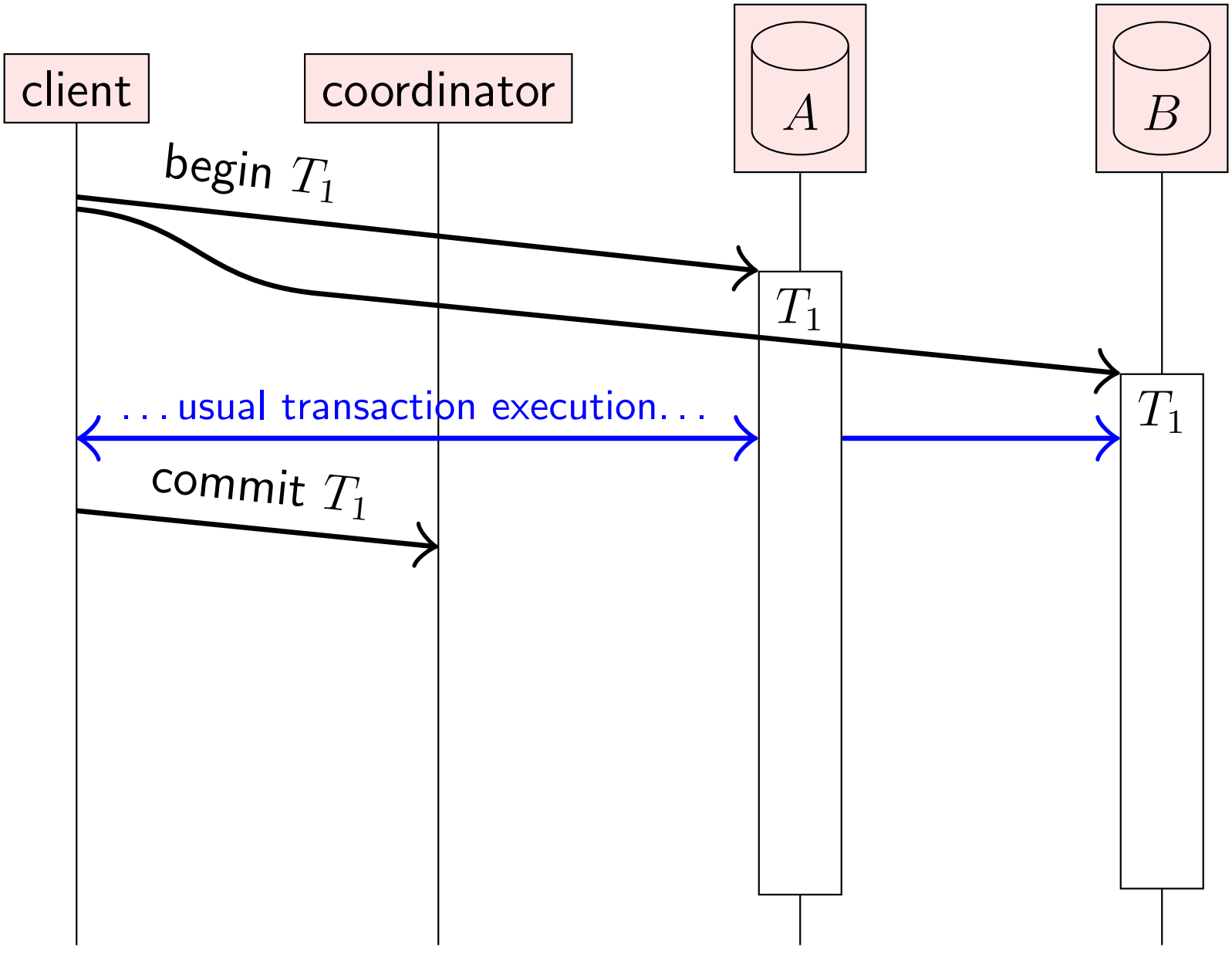

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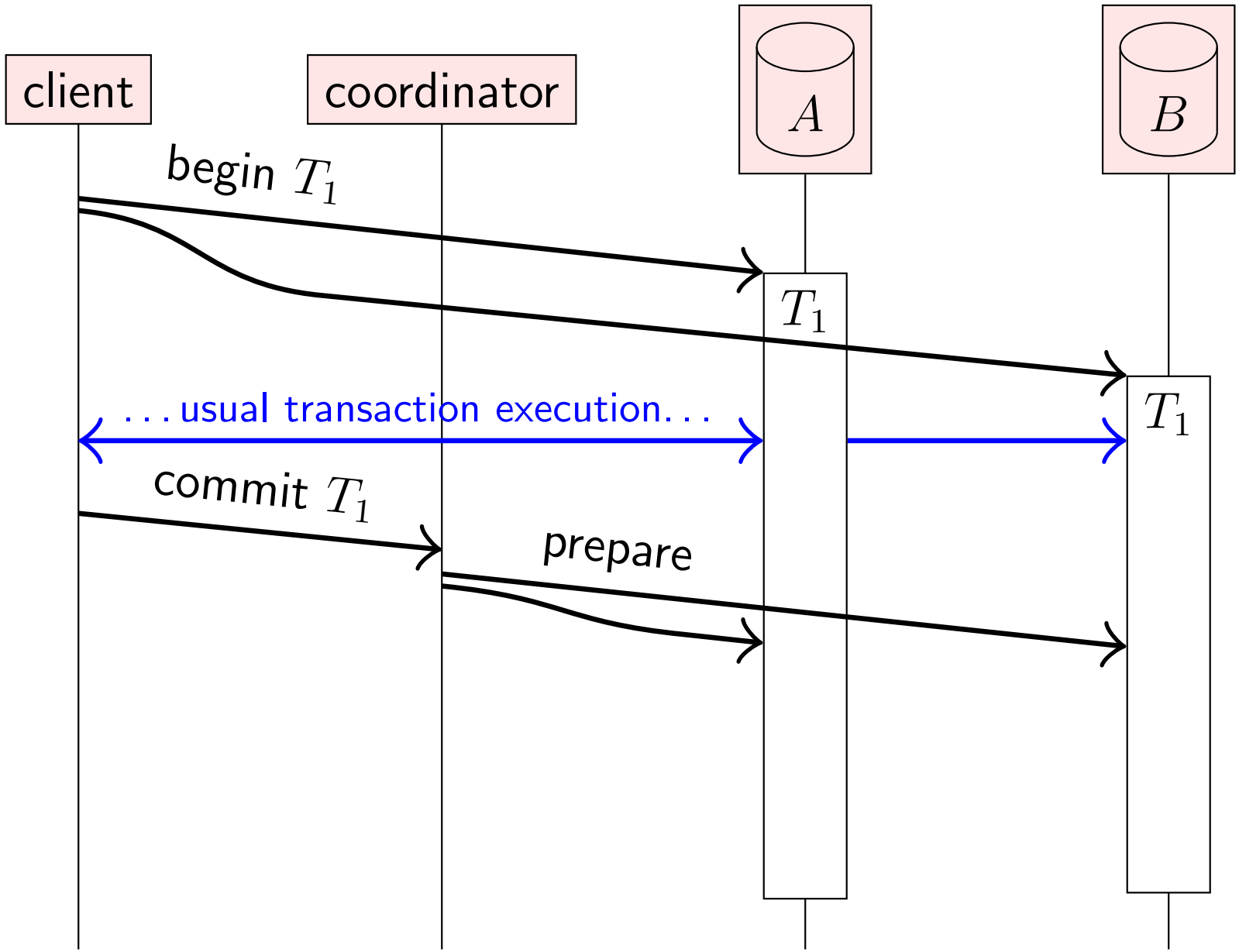

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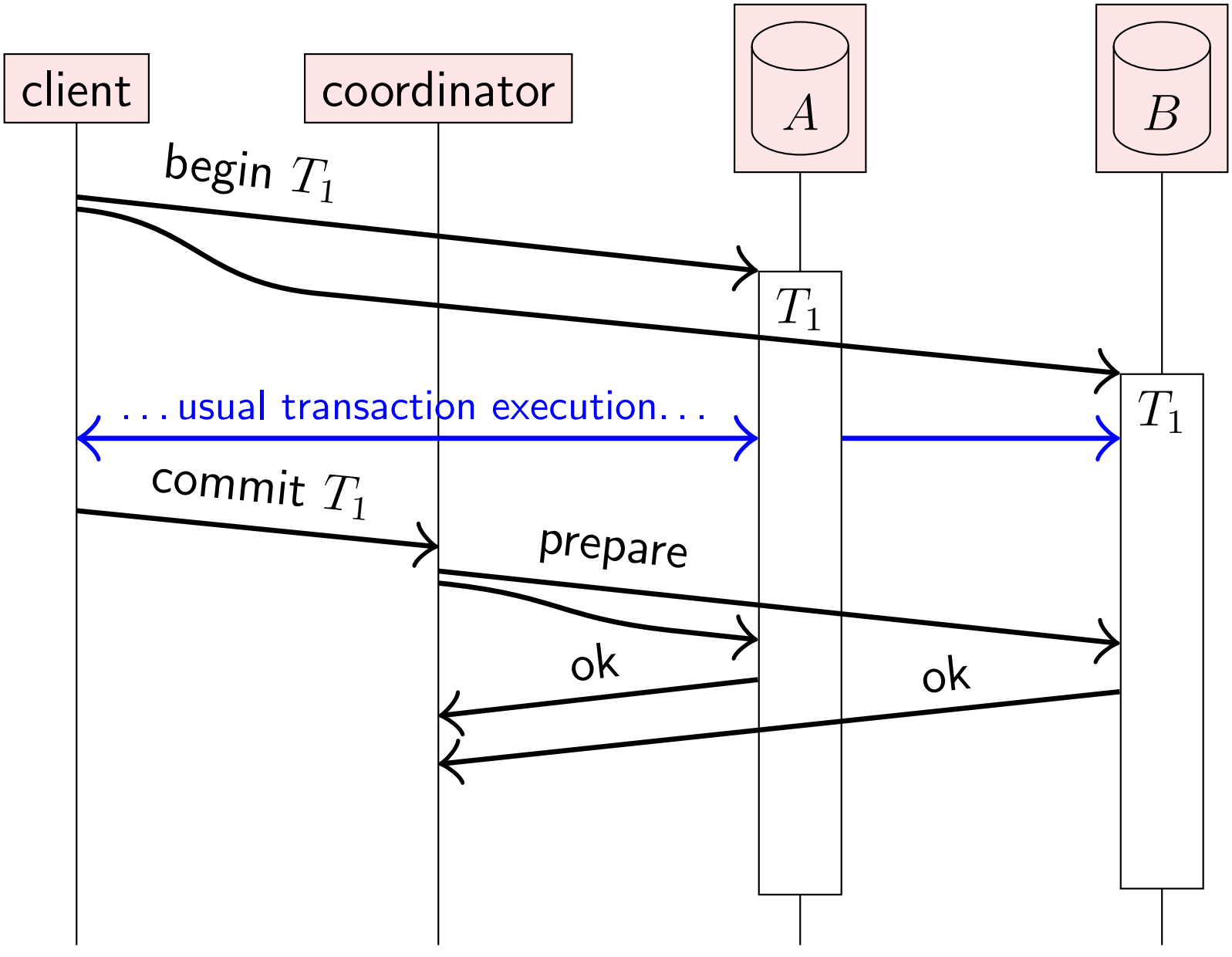

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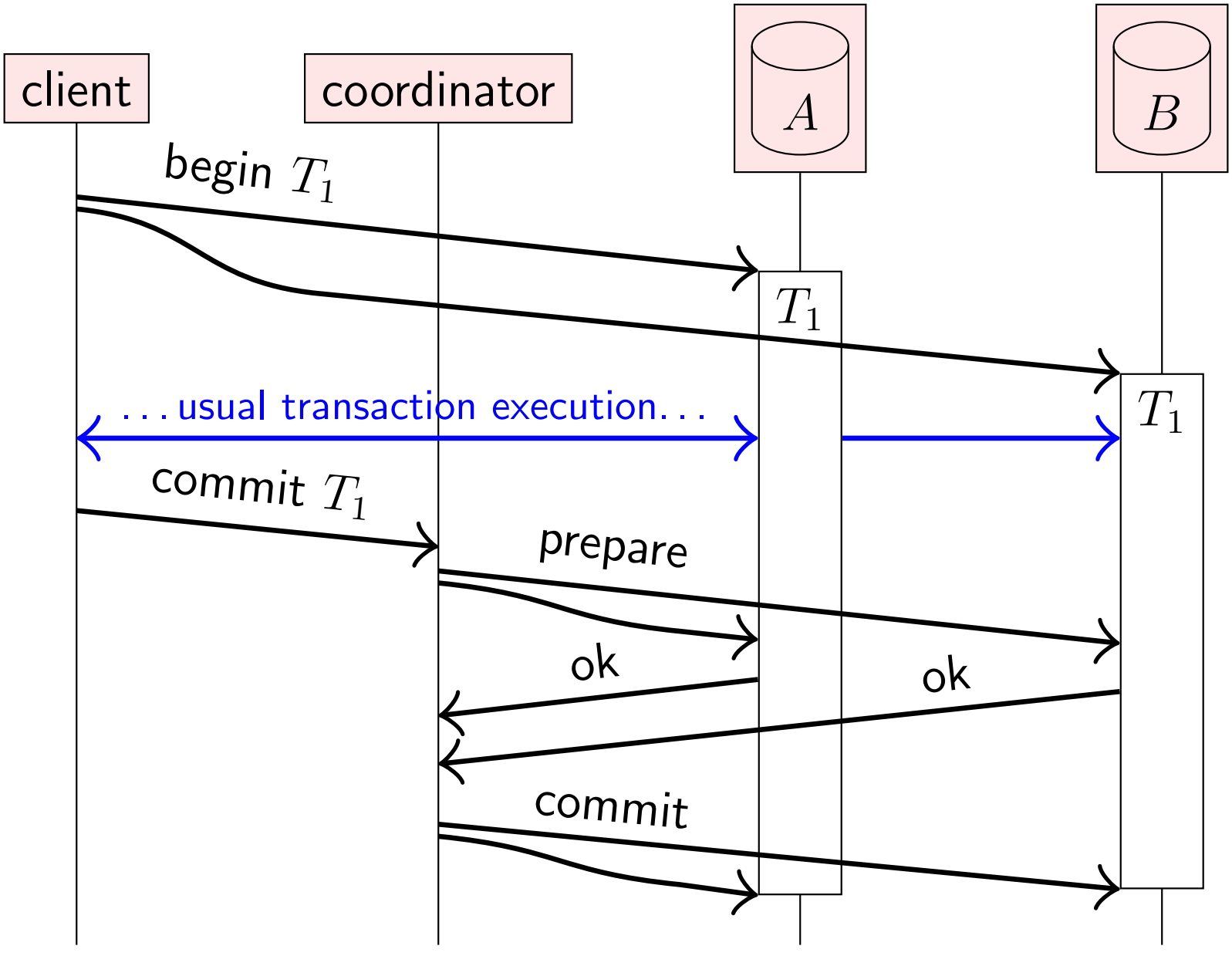

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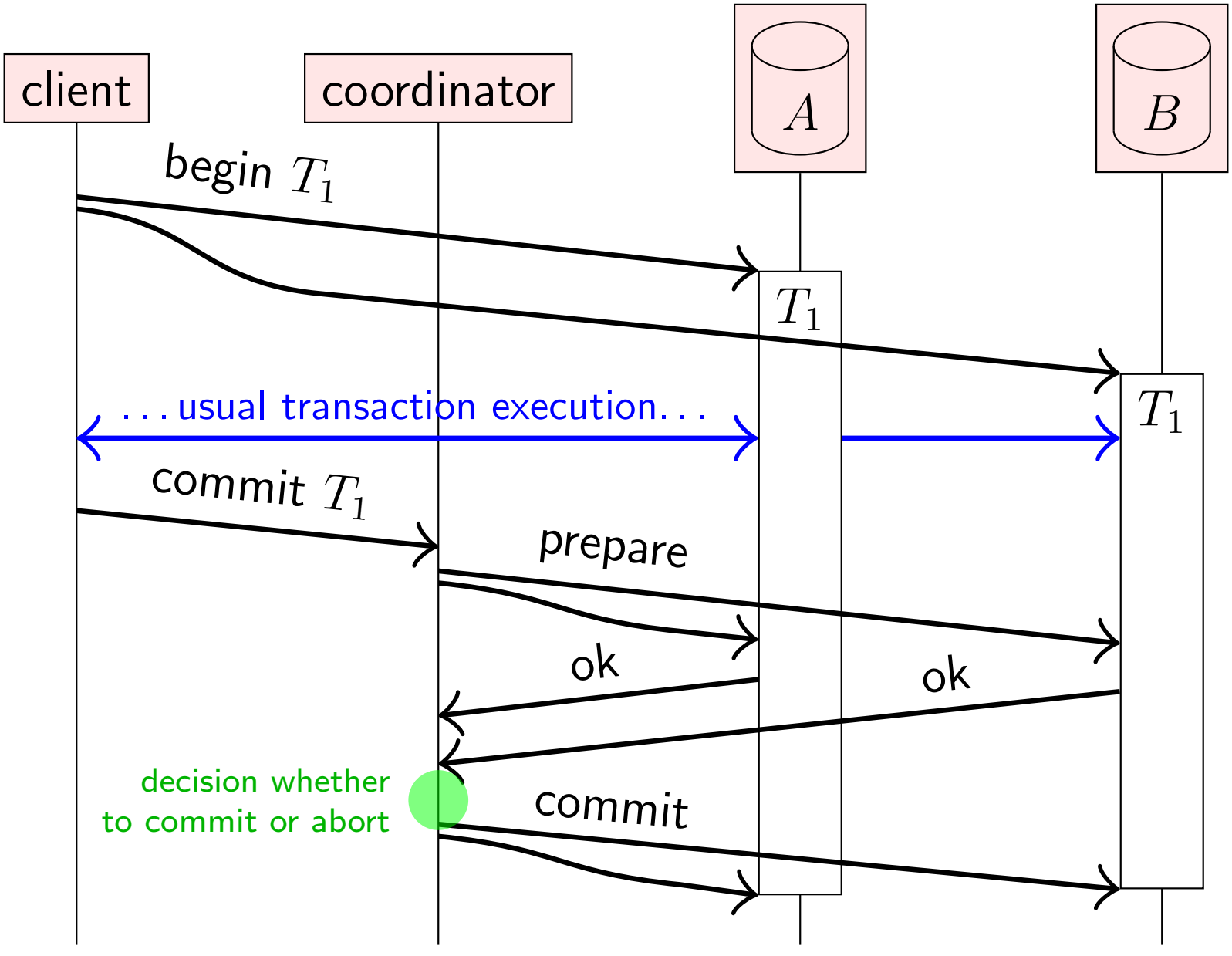

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- Replicas participating in transaction cannot commit or abort after responding "ok" to the *prepare* request (otherwise we risk violating atomicity)

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- Replicas participating in transaction cannot commit or abort after responding "ok" to the *prepare* request (otherwise we risk violating atomicity)
- Algorithm is blocked until coordinator recovers

Fault-tolerant two-phase commit (1/2)

on initialisation for transaction T **do**
    $commitVotes[T] := \{\};\ replicas[T] := \{\};\ decided[T] :=$ false
end on

on request to commit transaction T with participating nodes R **do**
    for each $r \in R$ **do** send $(\text{Prepare}, T, R)$ to r
end on

on receiving $(\text{Prepare}, T, R)$ at node $replicaId$ **do**
    $replicas[T] := R$
    $ok =$ "is transaction T able to commit on this replica?"
    total order broadcast $(\text{Vote}, T, replicaId, ok)$ to $replicas[T]$
end on

on a node suspects node $replicaId$ to have crashed **do**
    for each transaction T in which $replicaId$ participated **do**
        total order broadcast $(\text{Vote}, T, replicaId, \text{false})$ to $replicas[T]$
    end for
end on

Fault-tolerant two-phase commit (2/2)

on delivering $(\text{Vote}, T, replicaId, ok)$ by total order broadcast **do**
  if $replicaId \notin commitVotes[T] \ \wedge \ replicaId \in replicas[T] \wedge \neg decided[T]$ **then**
    if $ok = \text{true}$ **then**
      $commitVotes[T] := commitVotes[T] \cup \{replicaId\}$
      if $commitVotes[T] = replicas[T]$ **then**
        $decided[T] := \text{true}$
        commit transaction T at this node
      end if
    else
      $decided[T] := \text{true}$
      abort transaction T at this node
    end if
  end if
end on

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Note: linearizability $\neq$ serializability!

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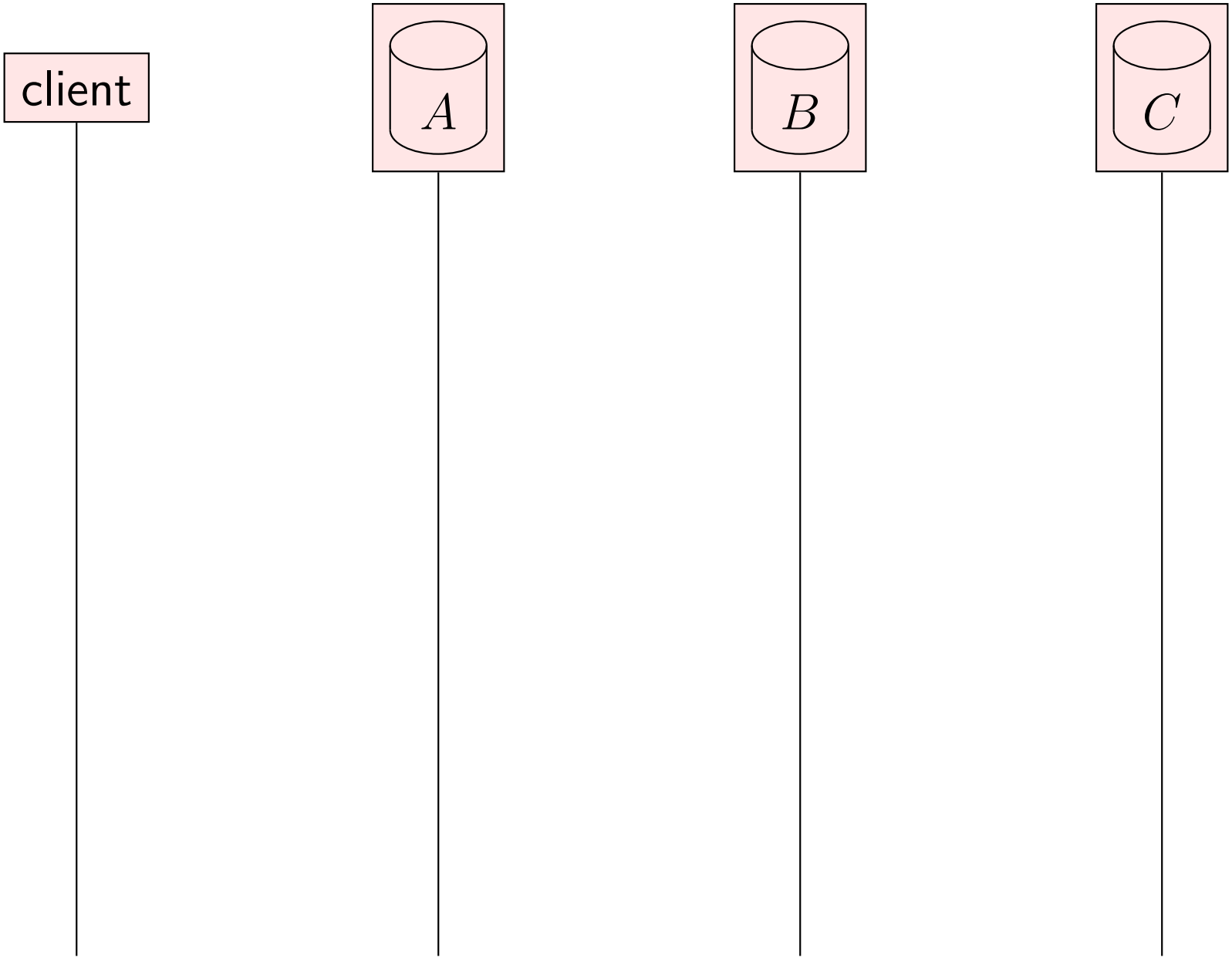

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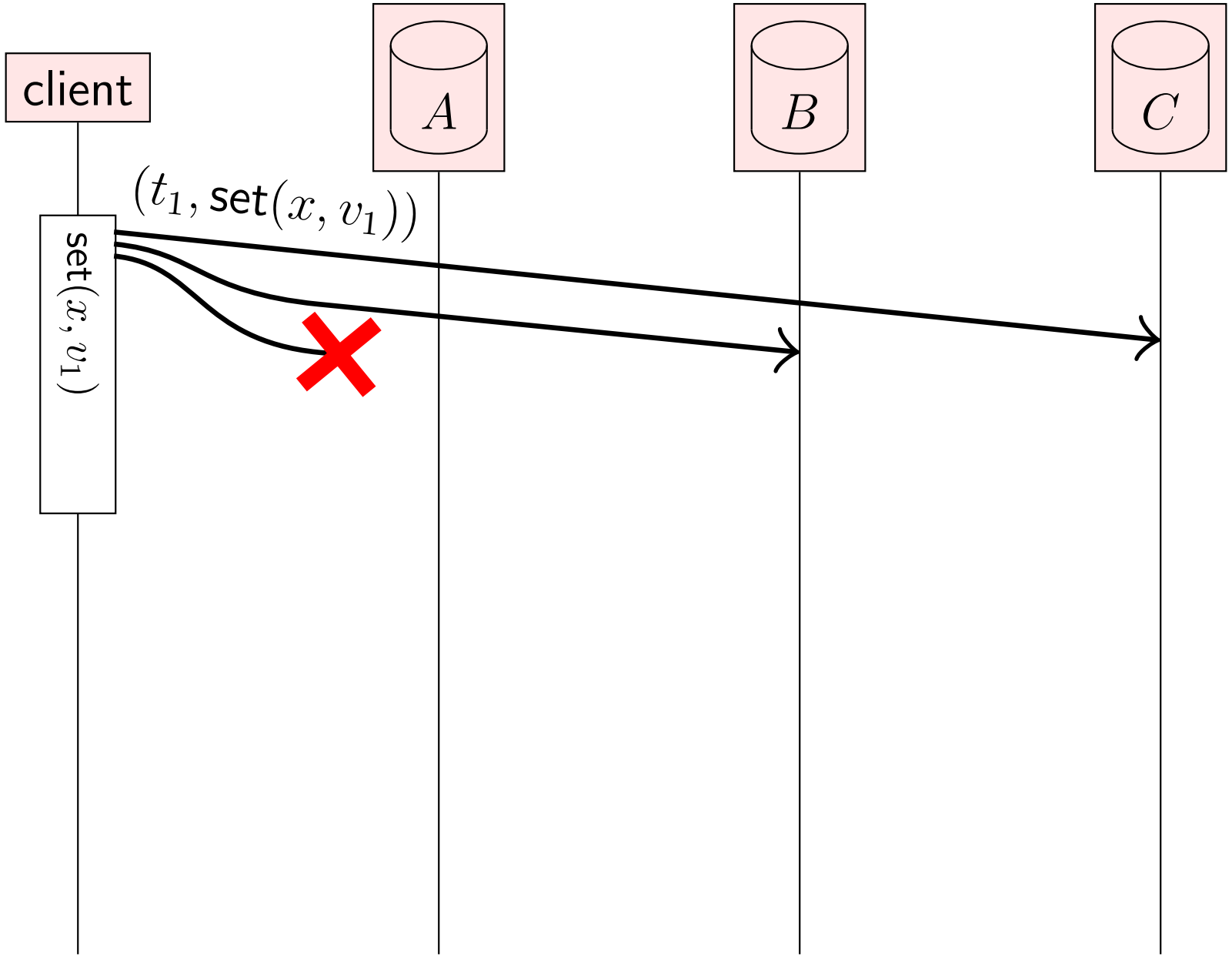

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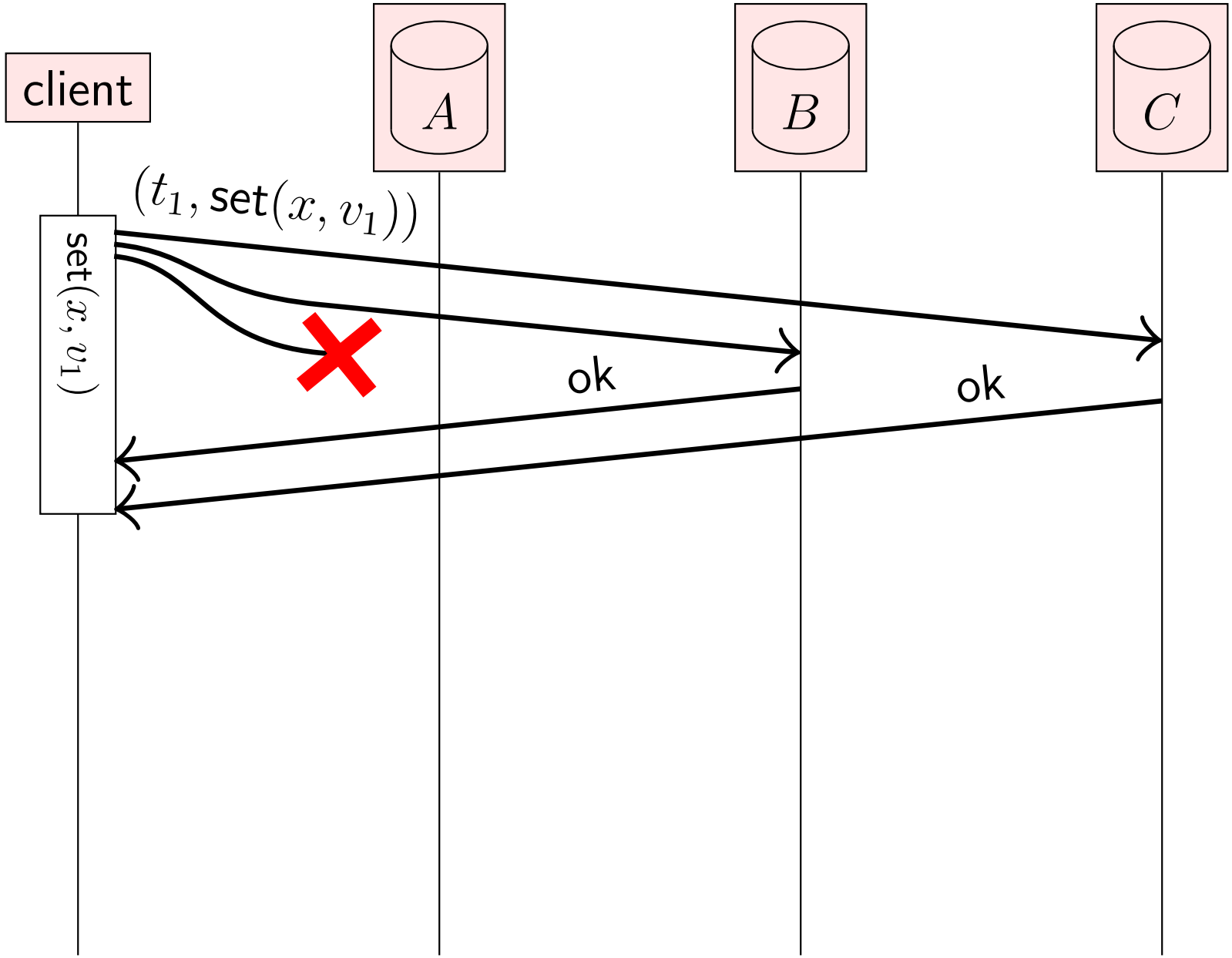

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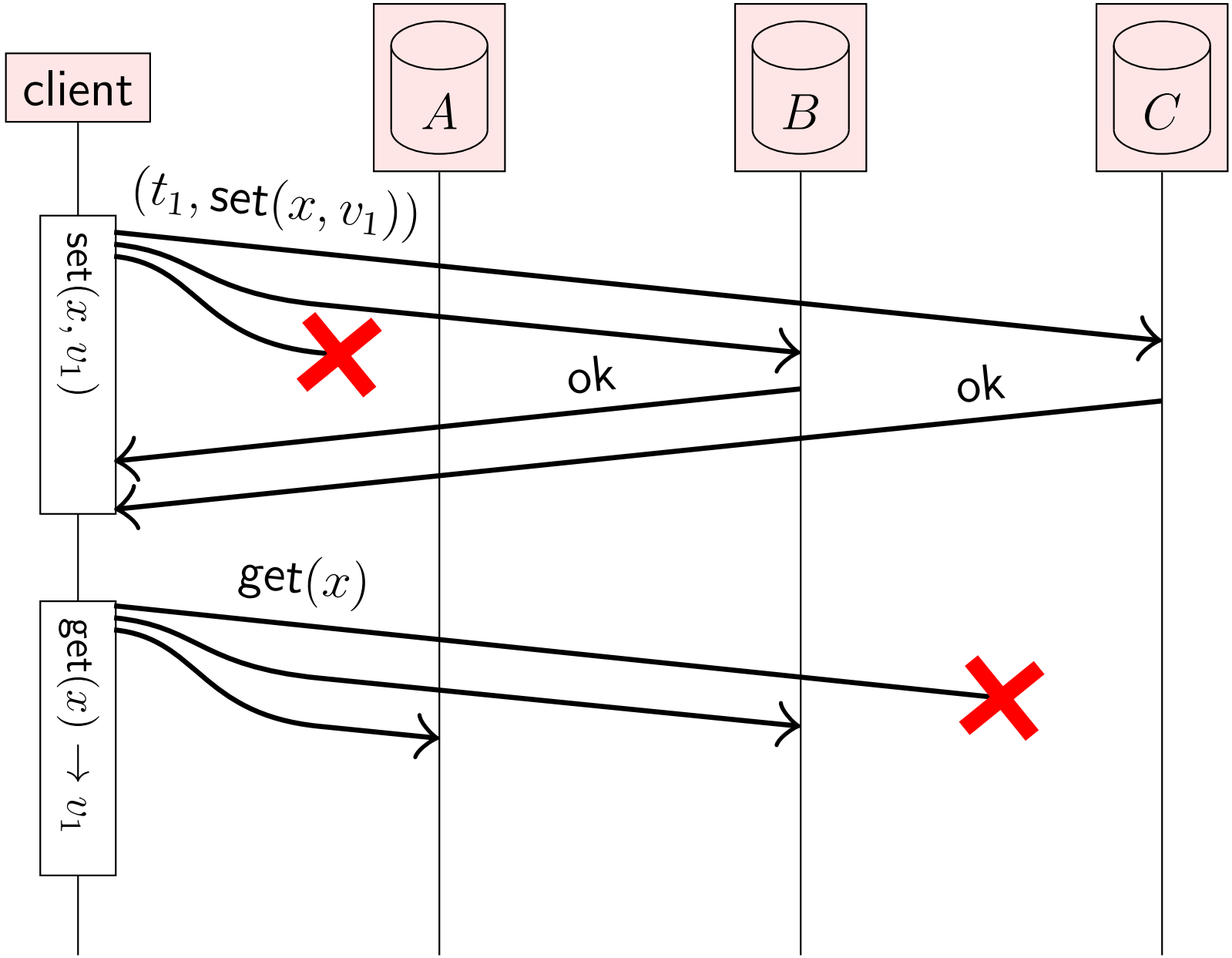

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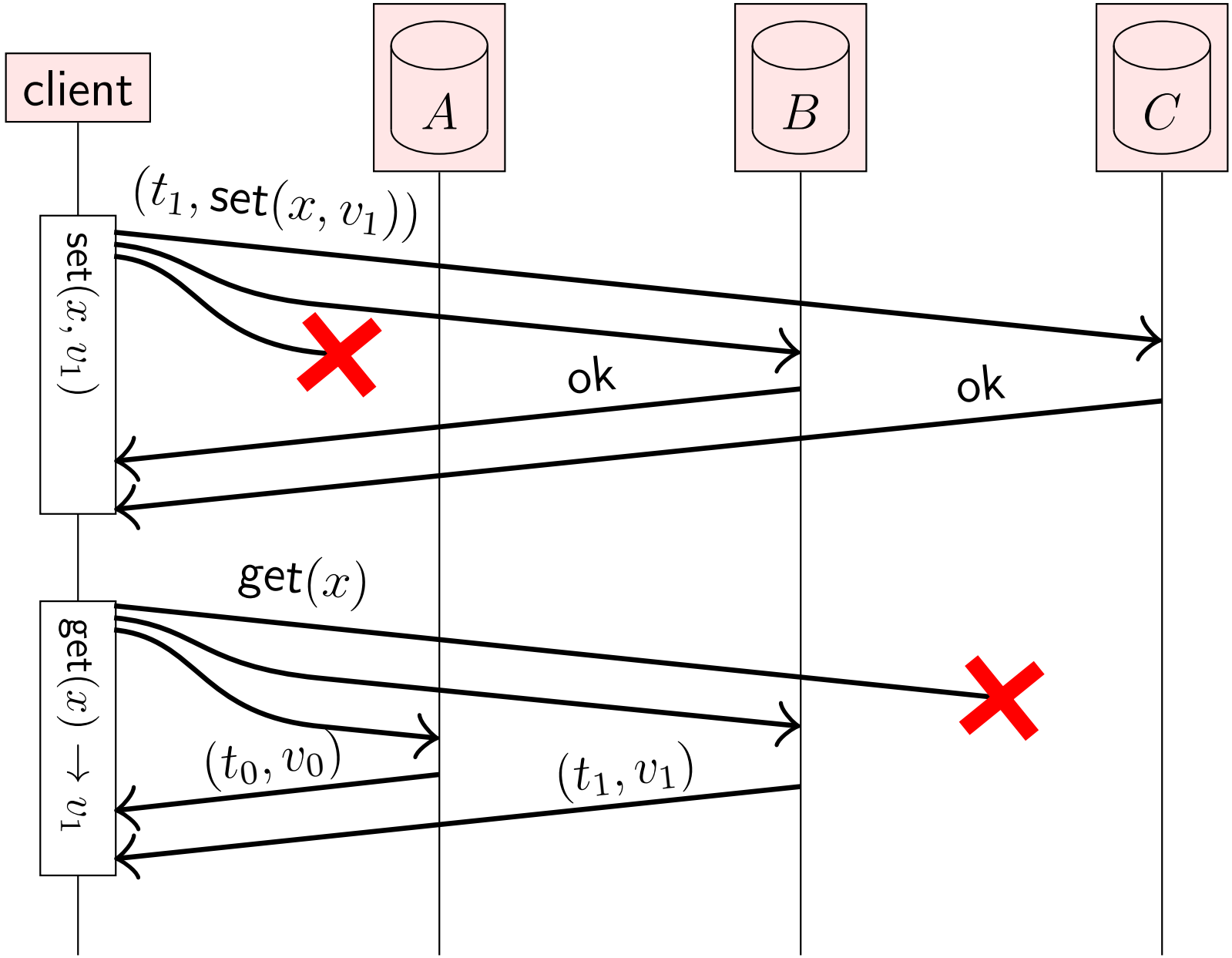
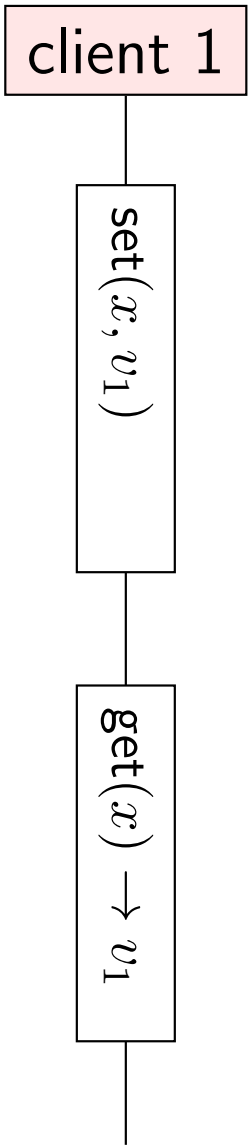


From the client's point of view



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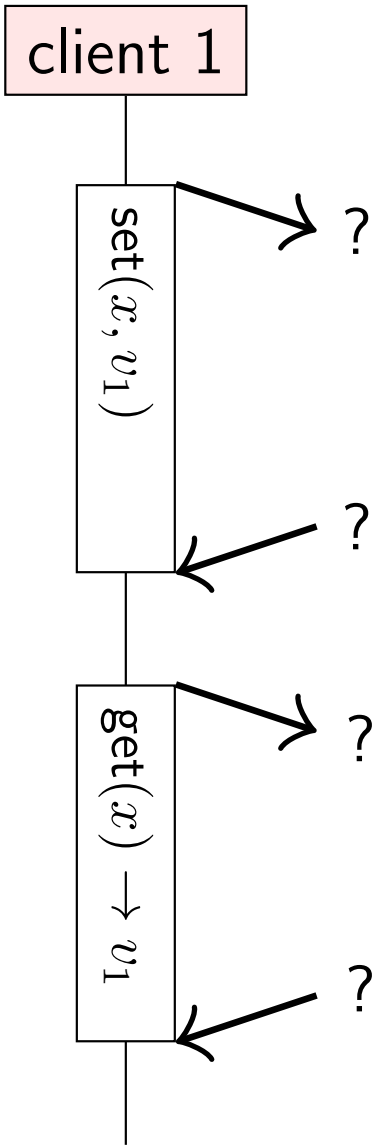

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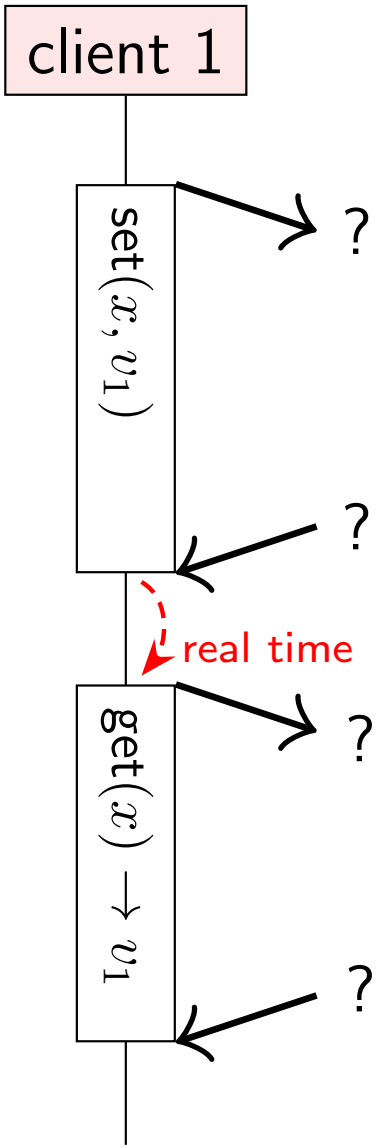

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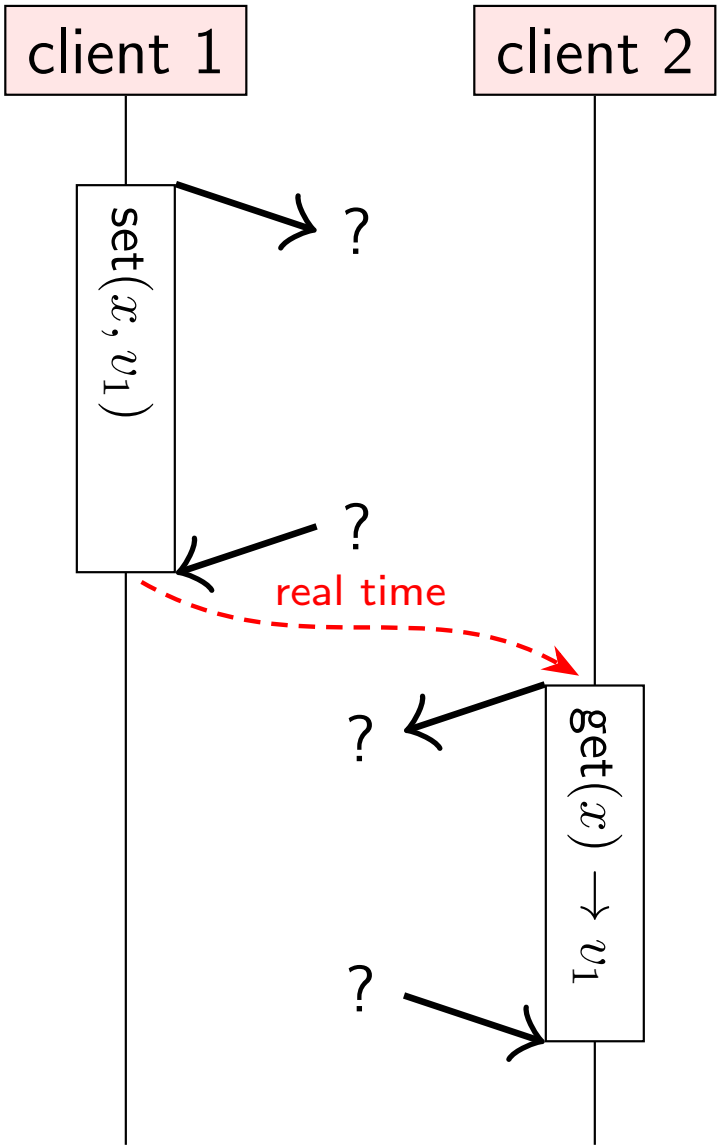

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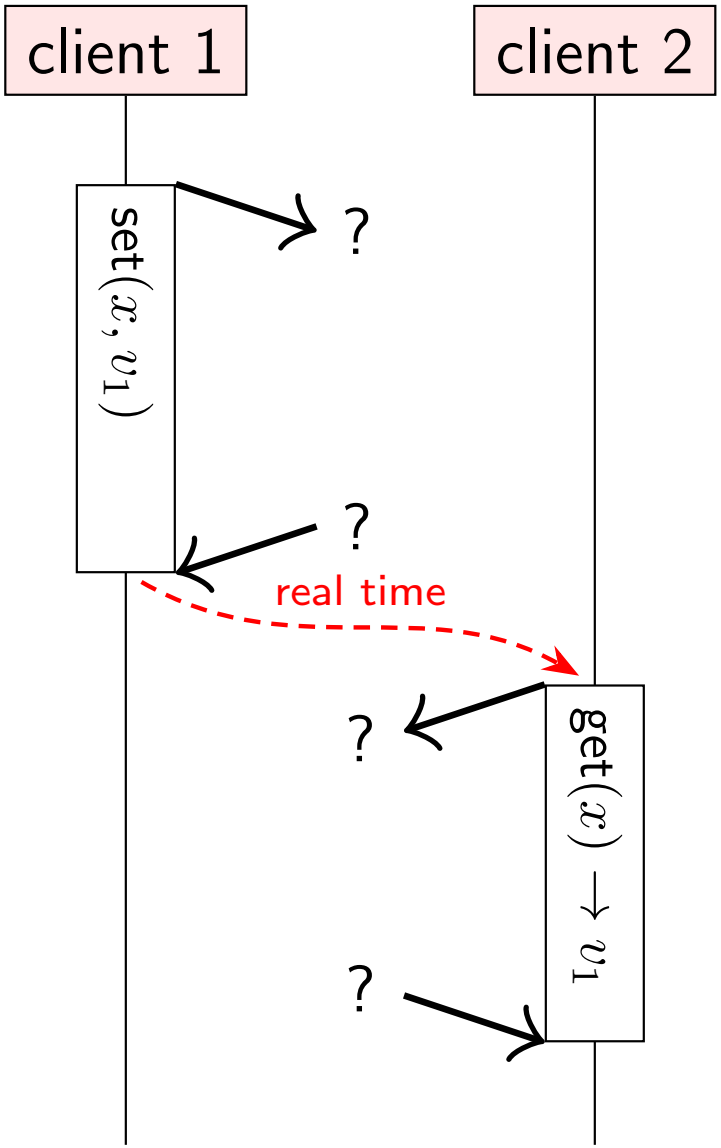

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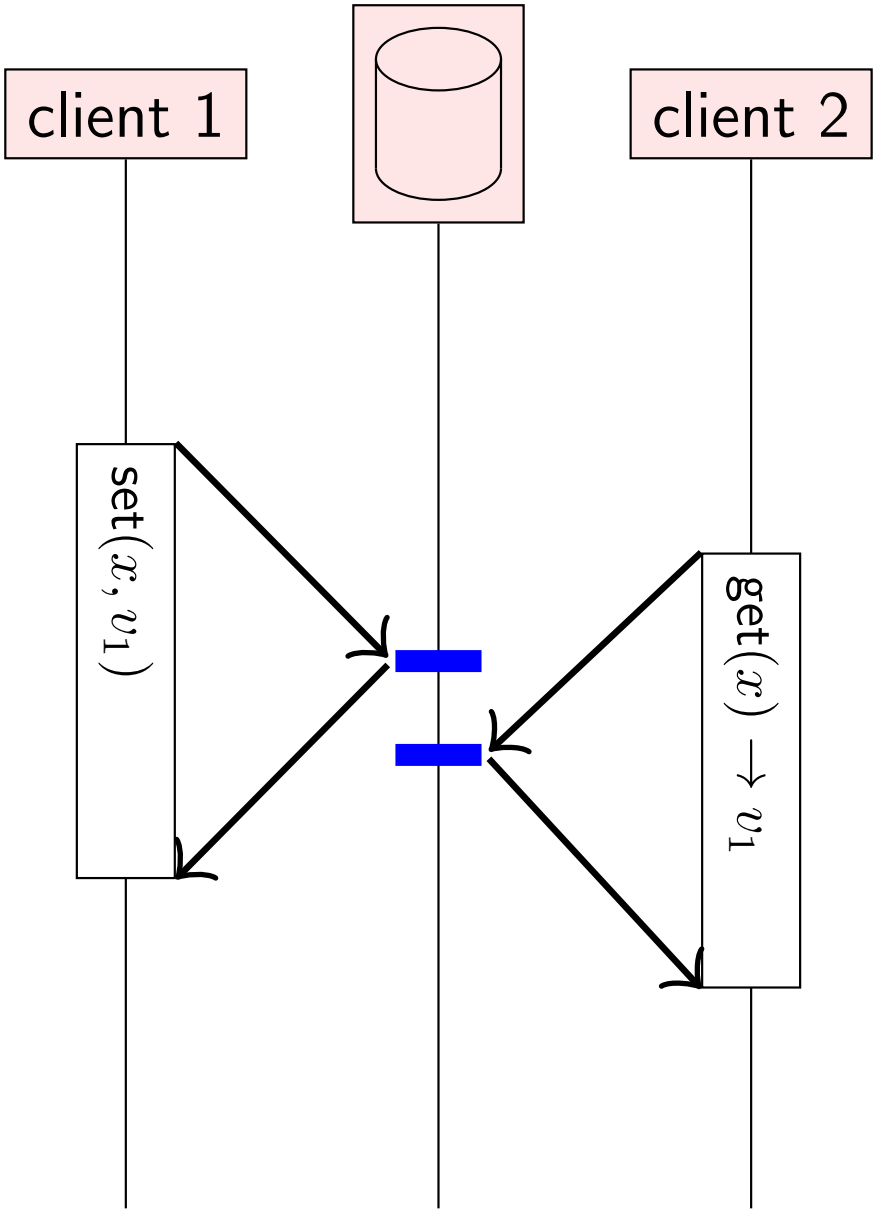
- **This is not happens-before**: we want client 2 to read value written by client 1, even if the clients have not communicated!

Operations overlapping in time



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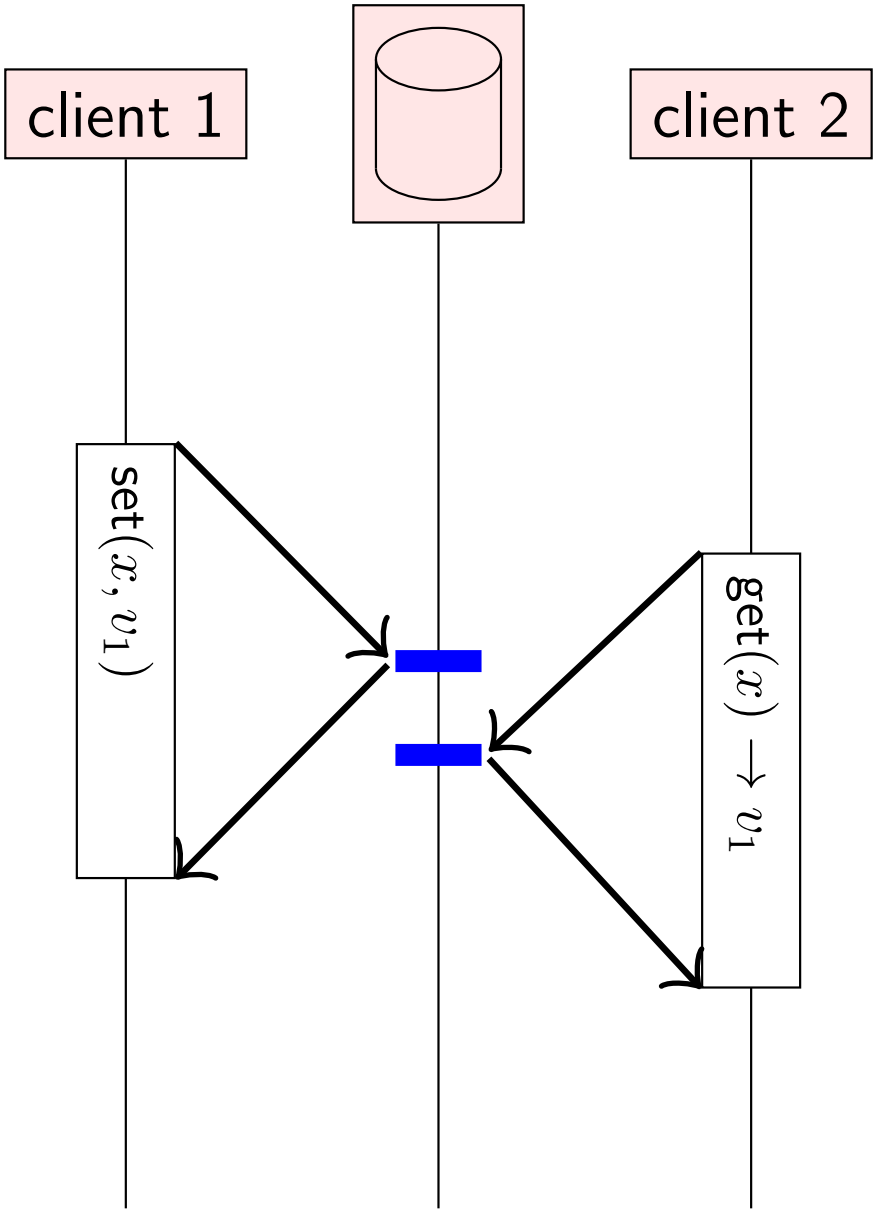

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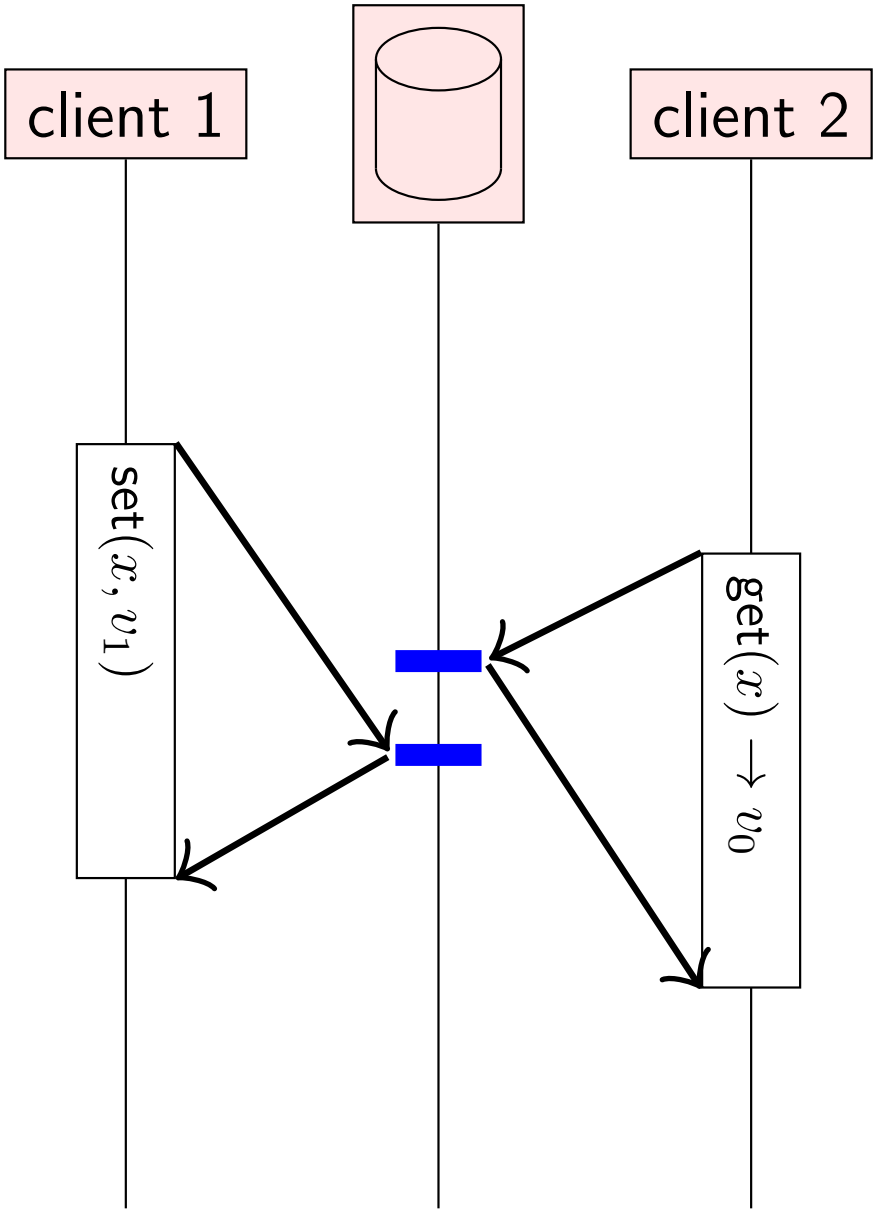

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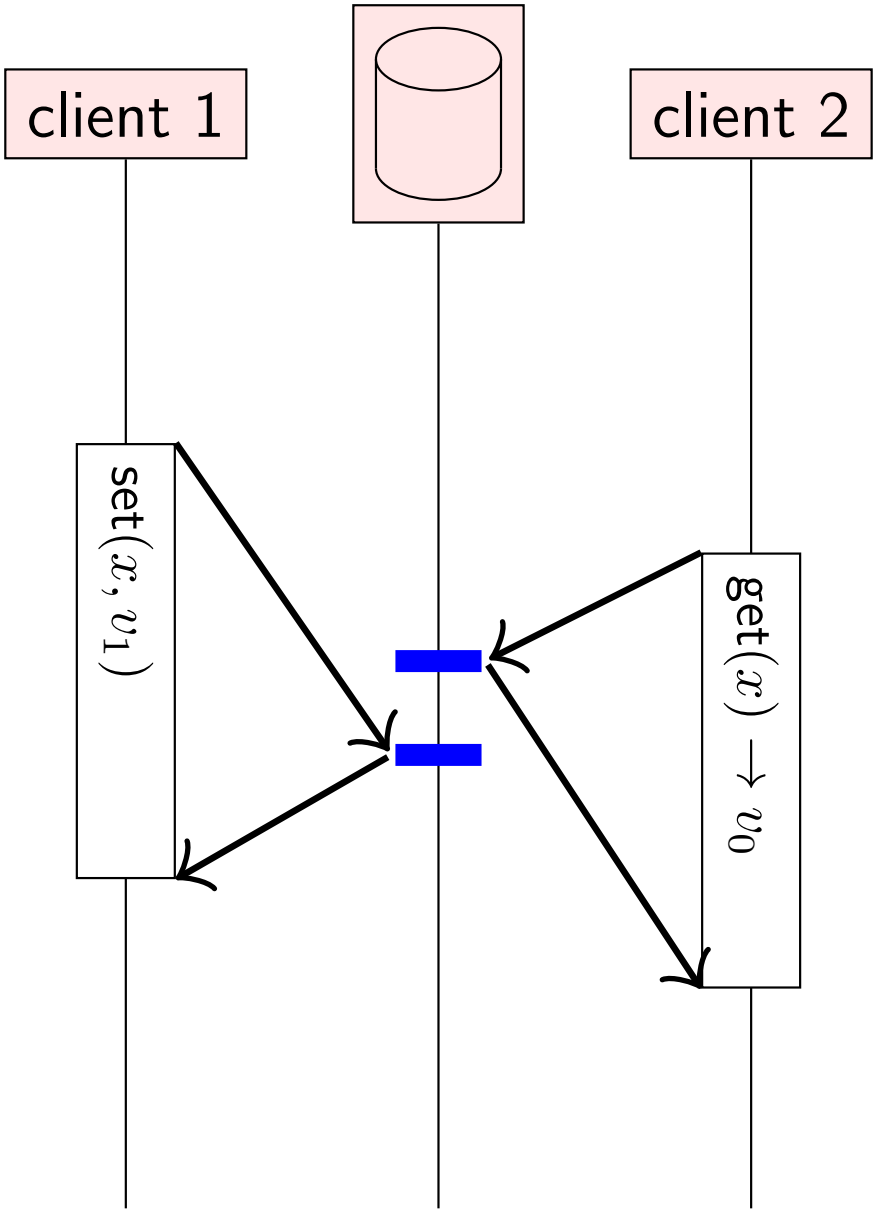

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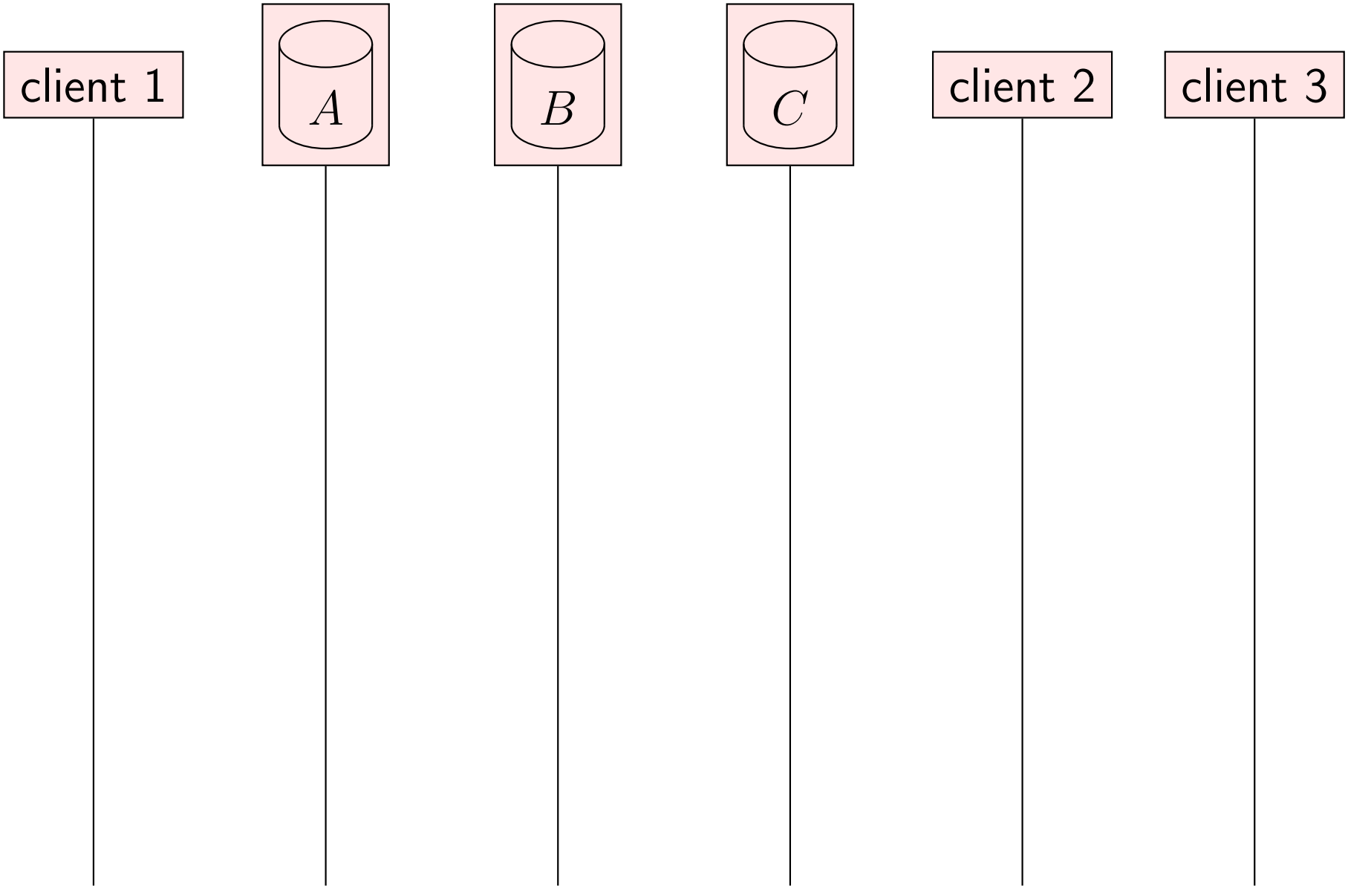

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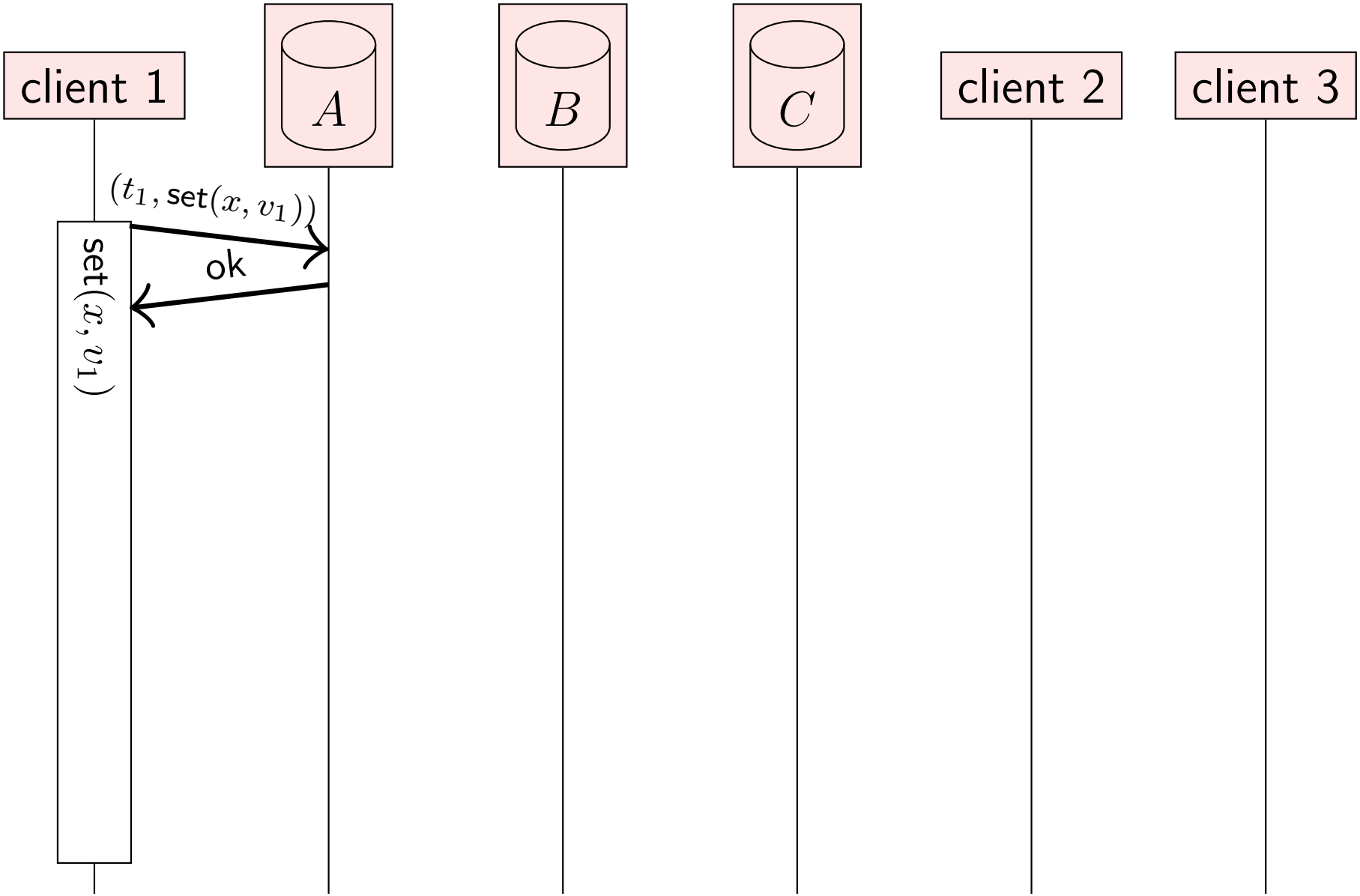

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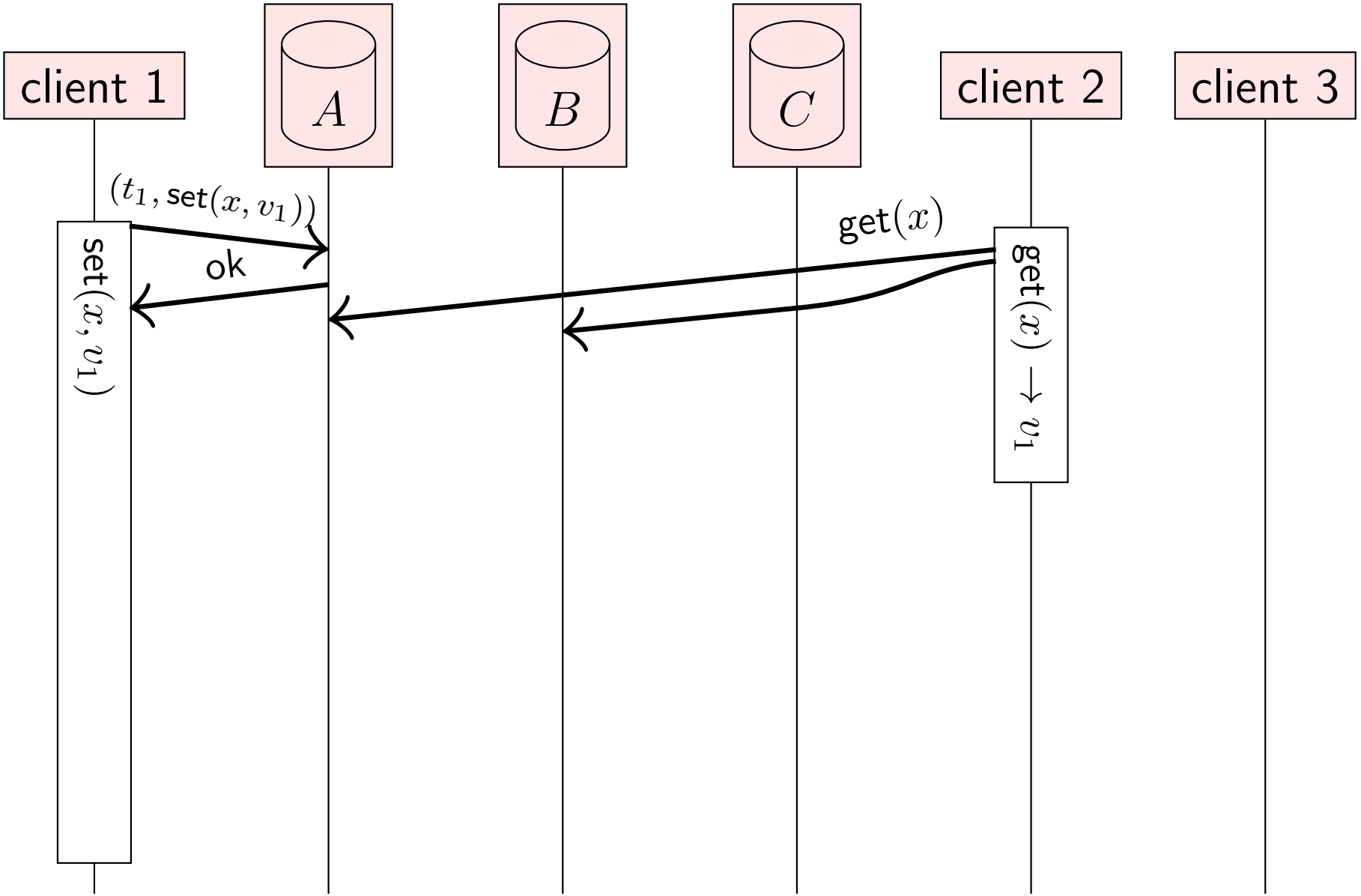

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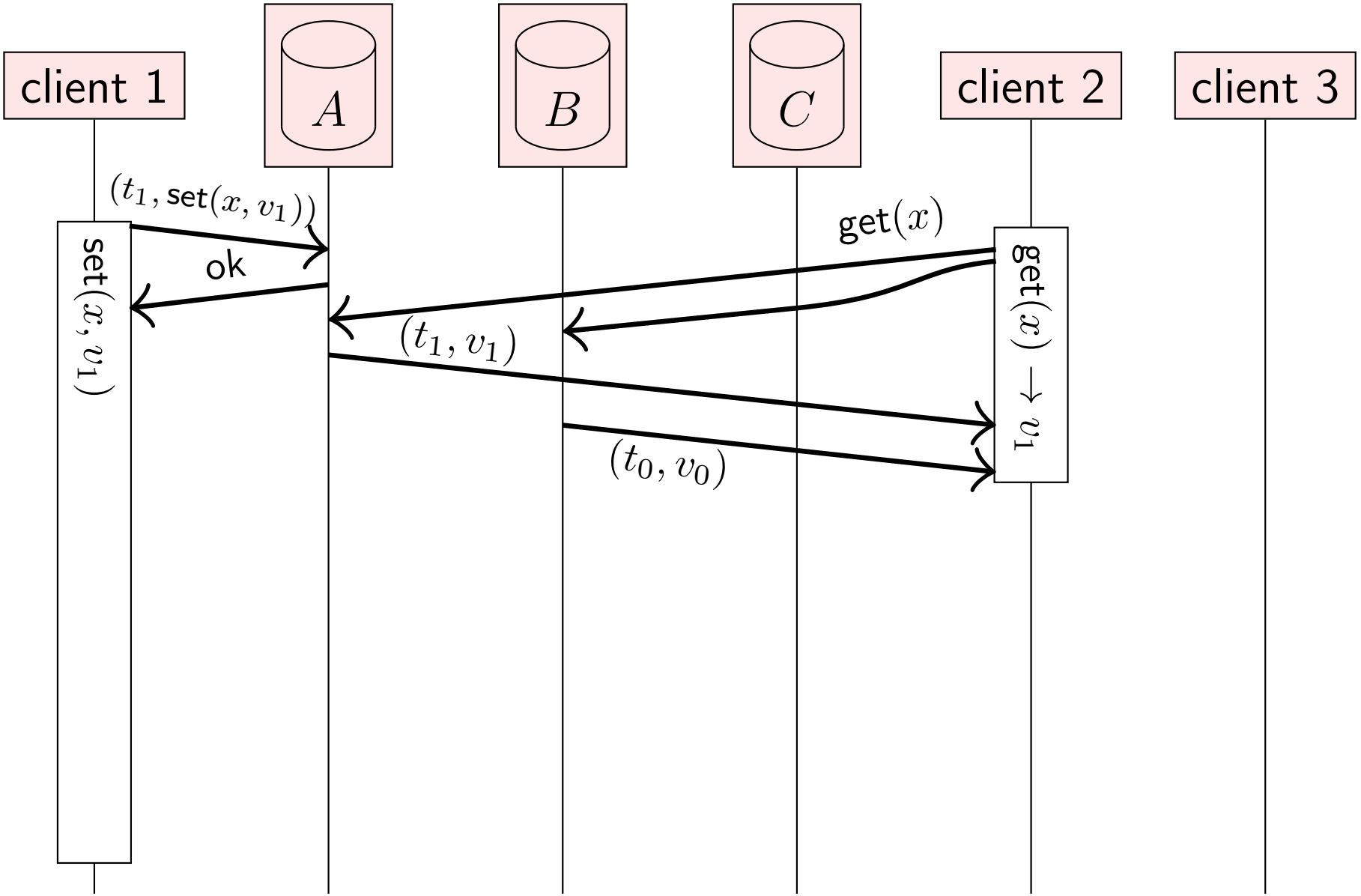

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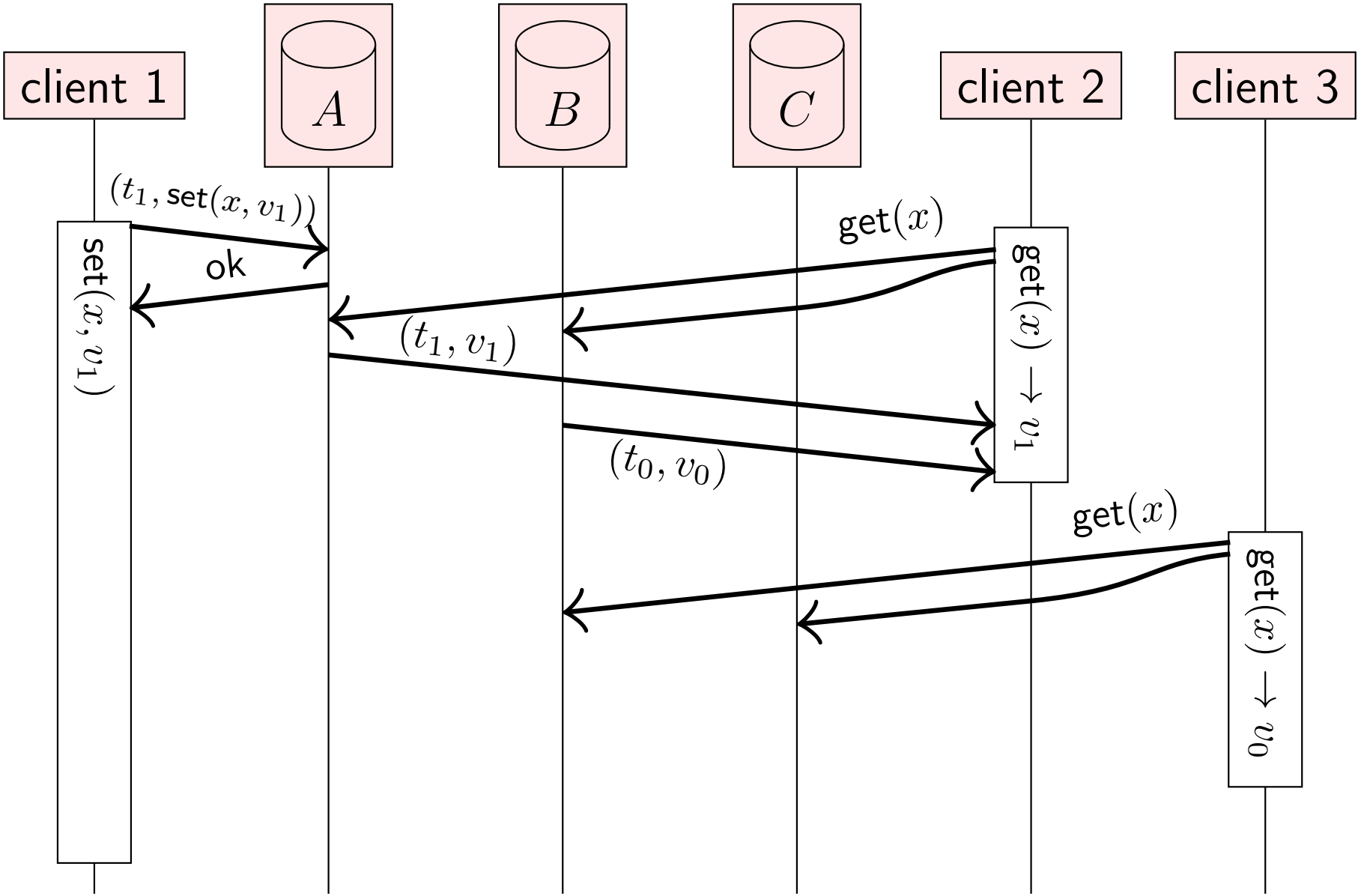

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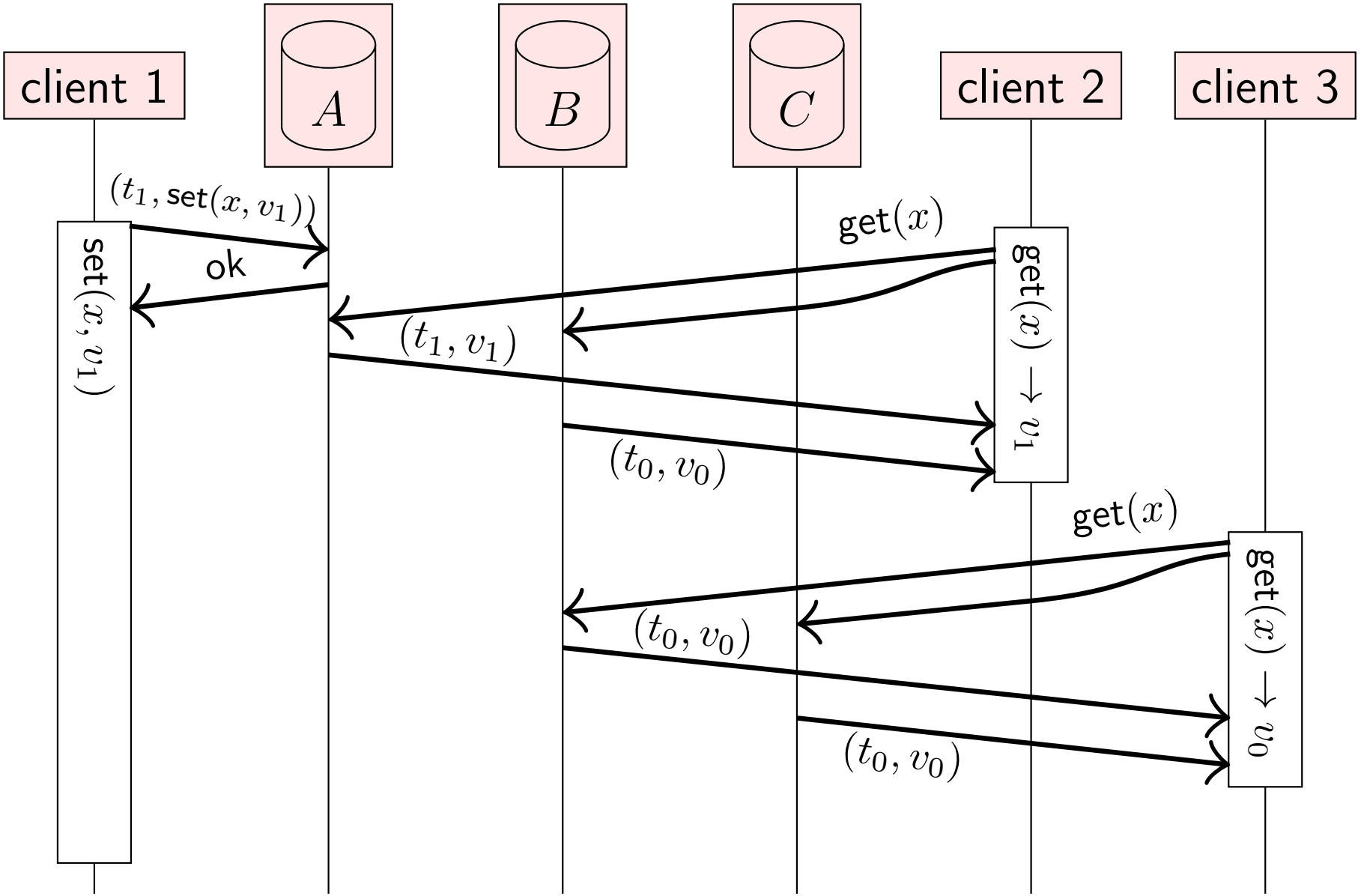

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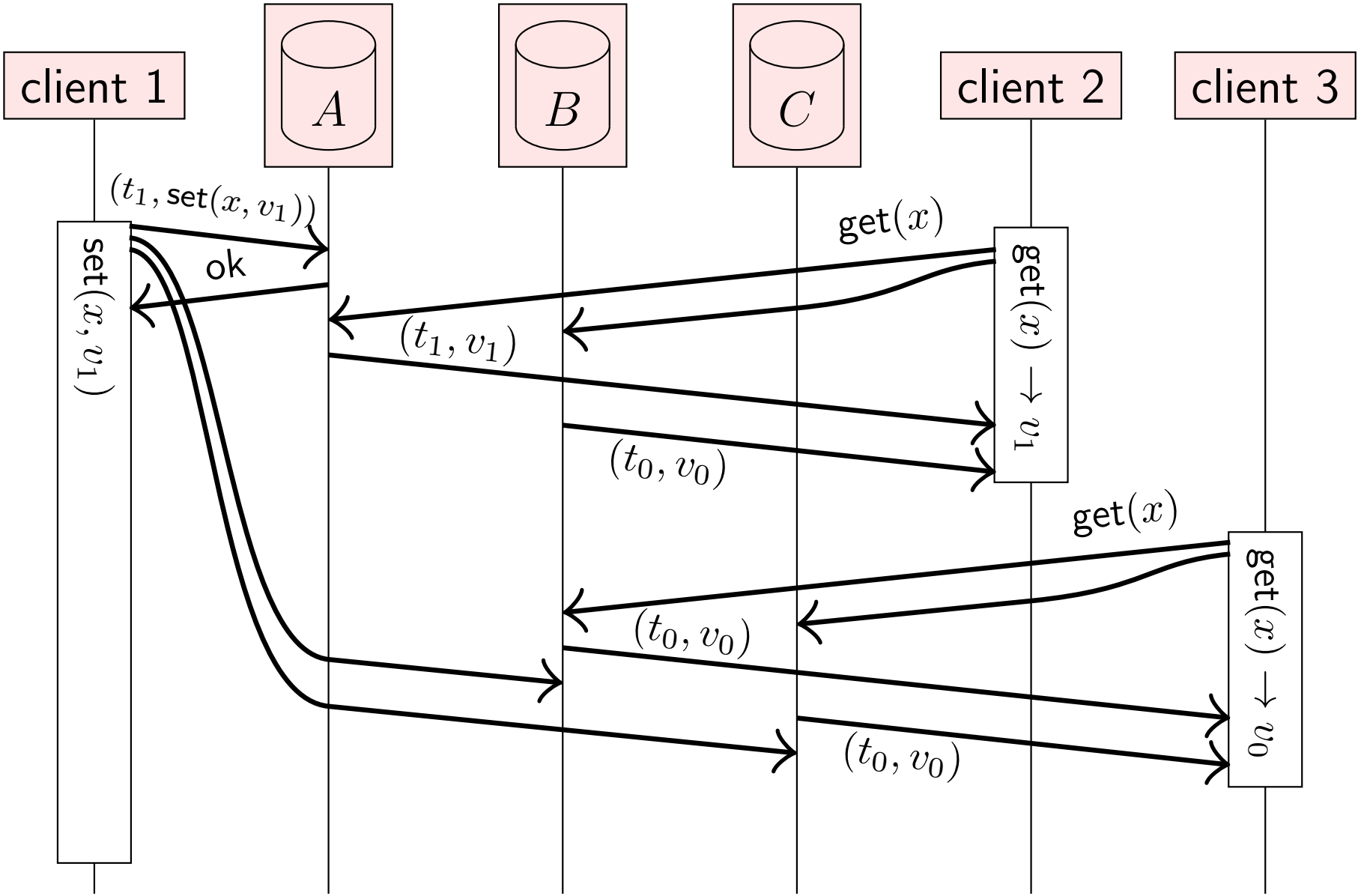

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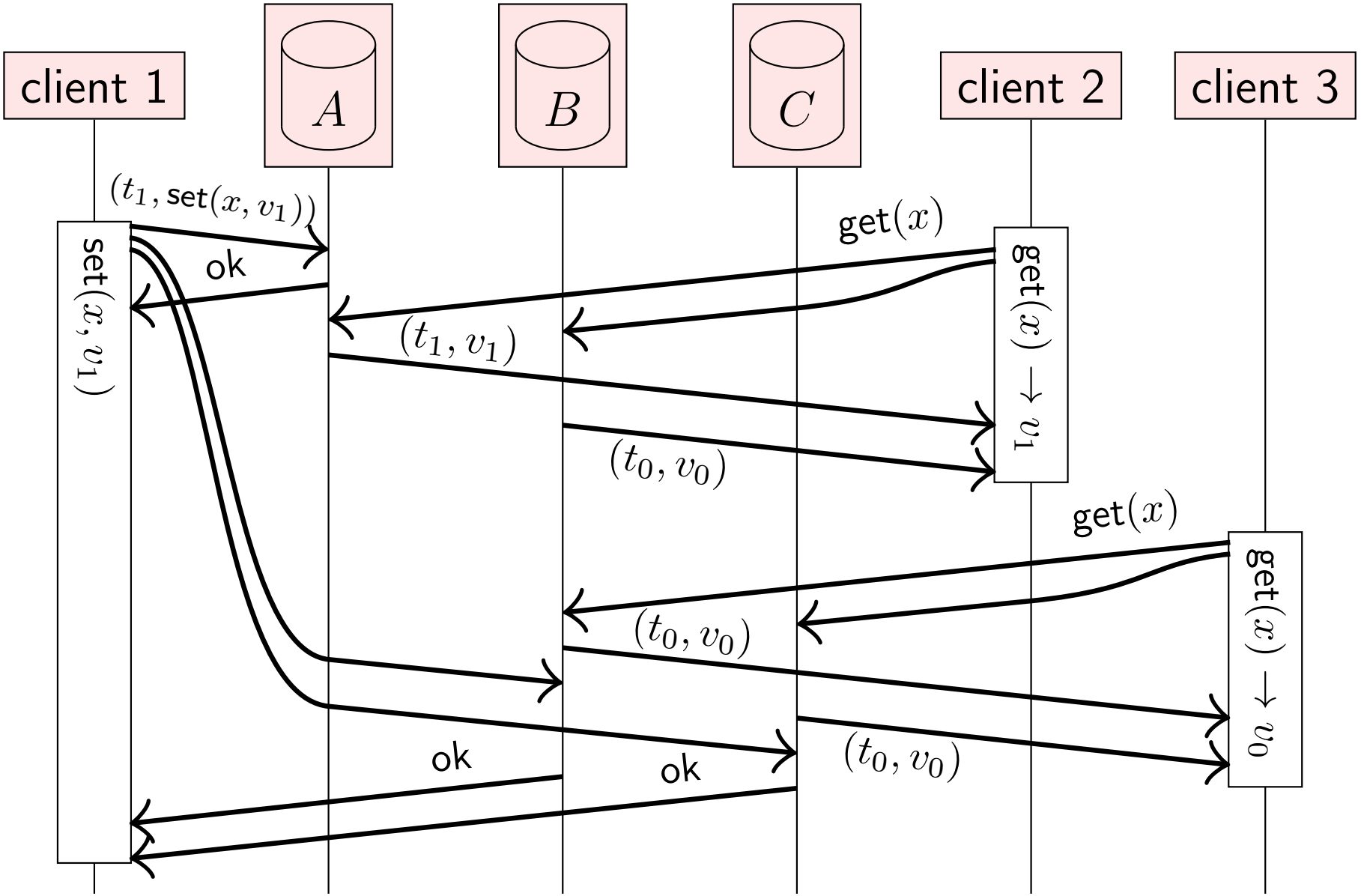

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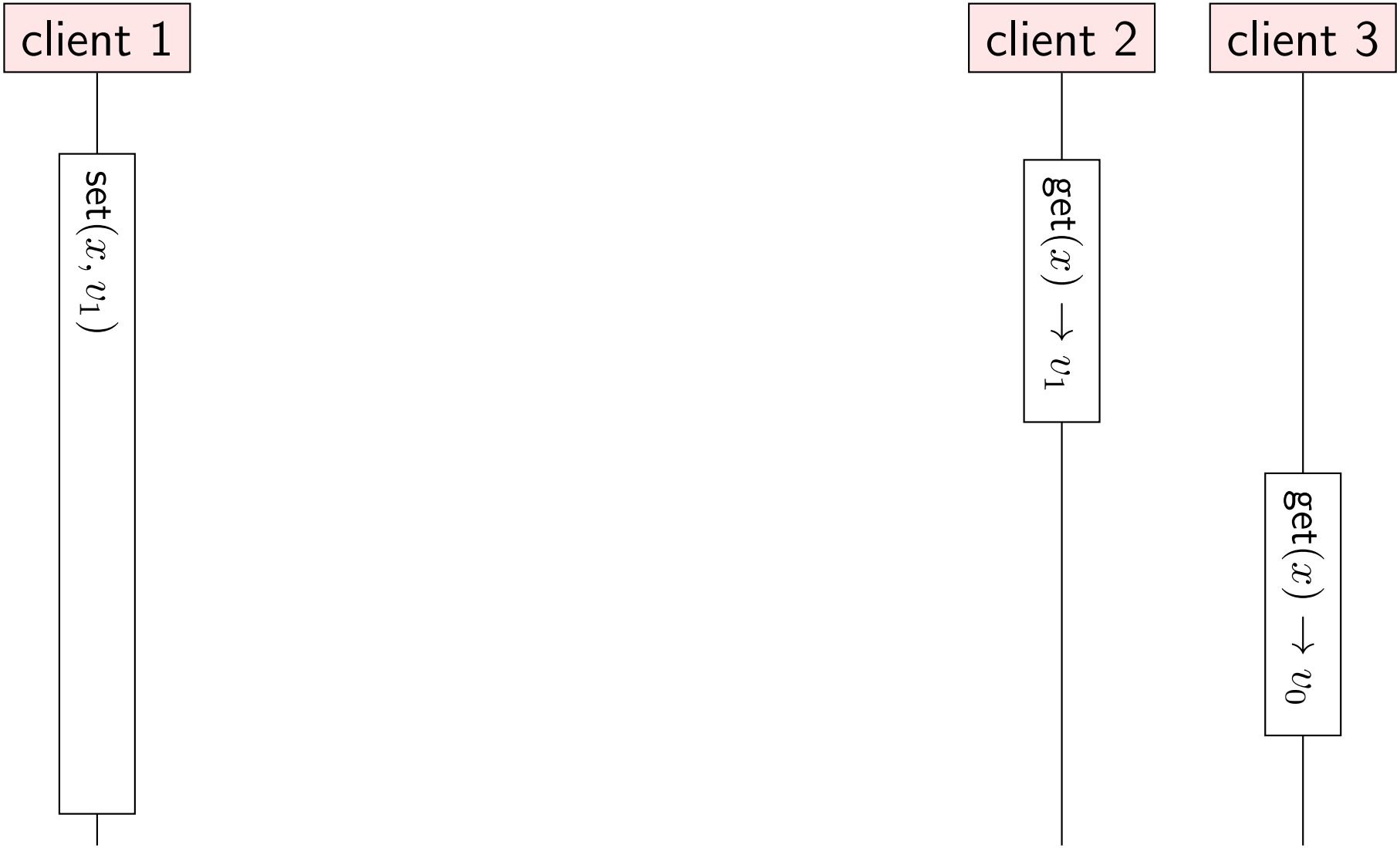

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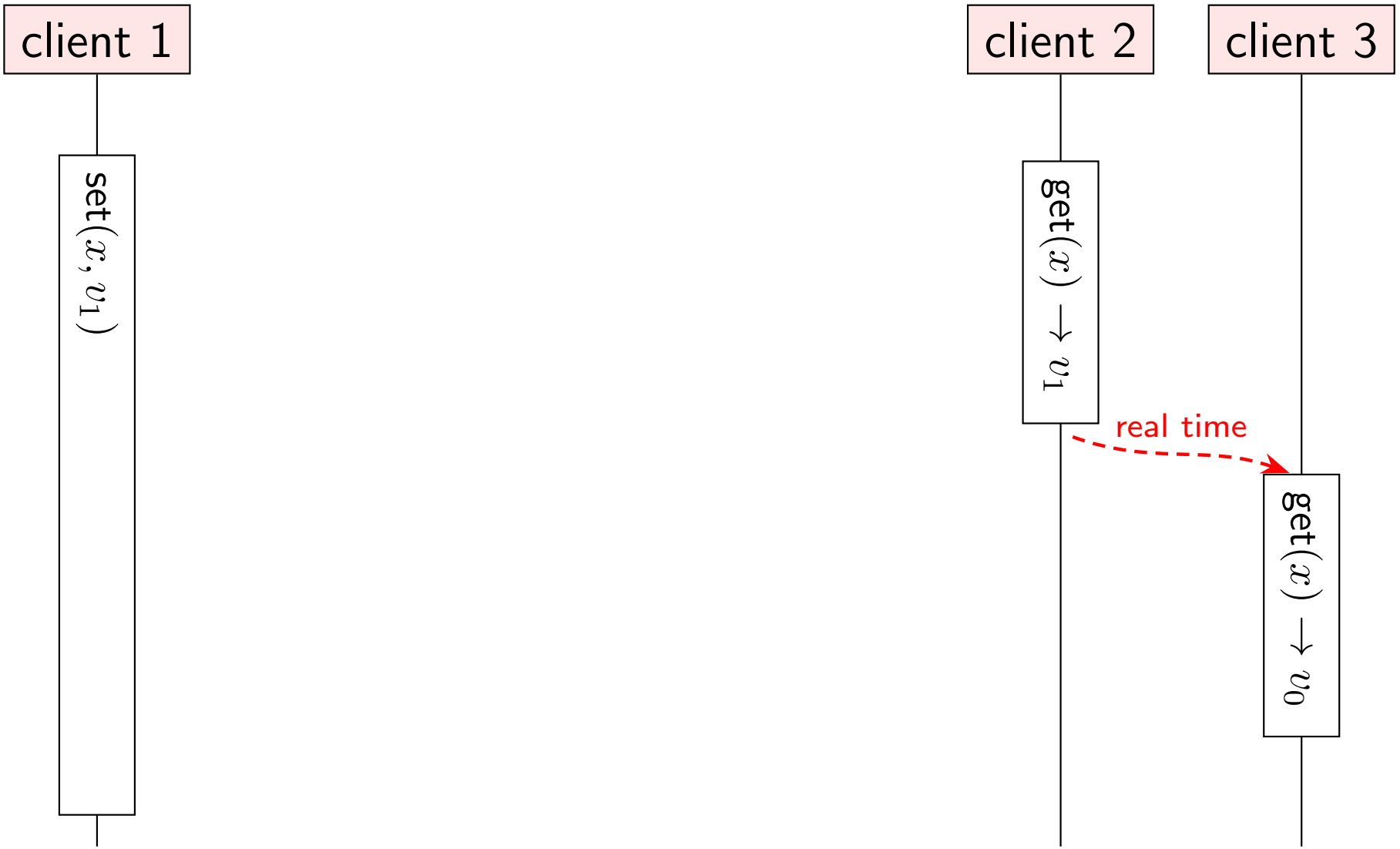

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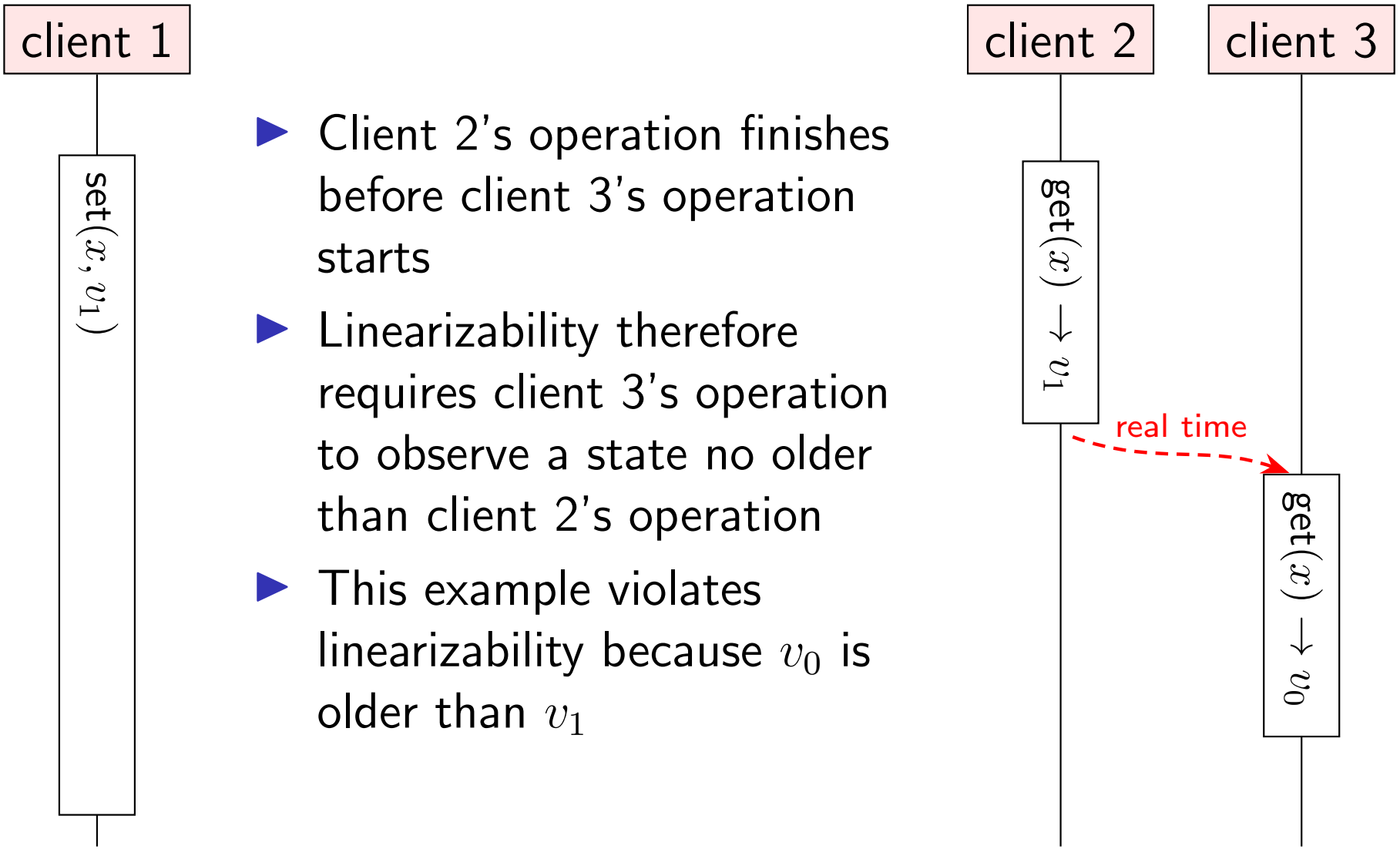
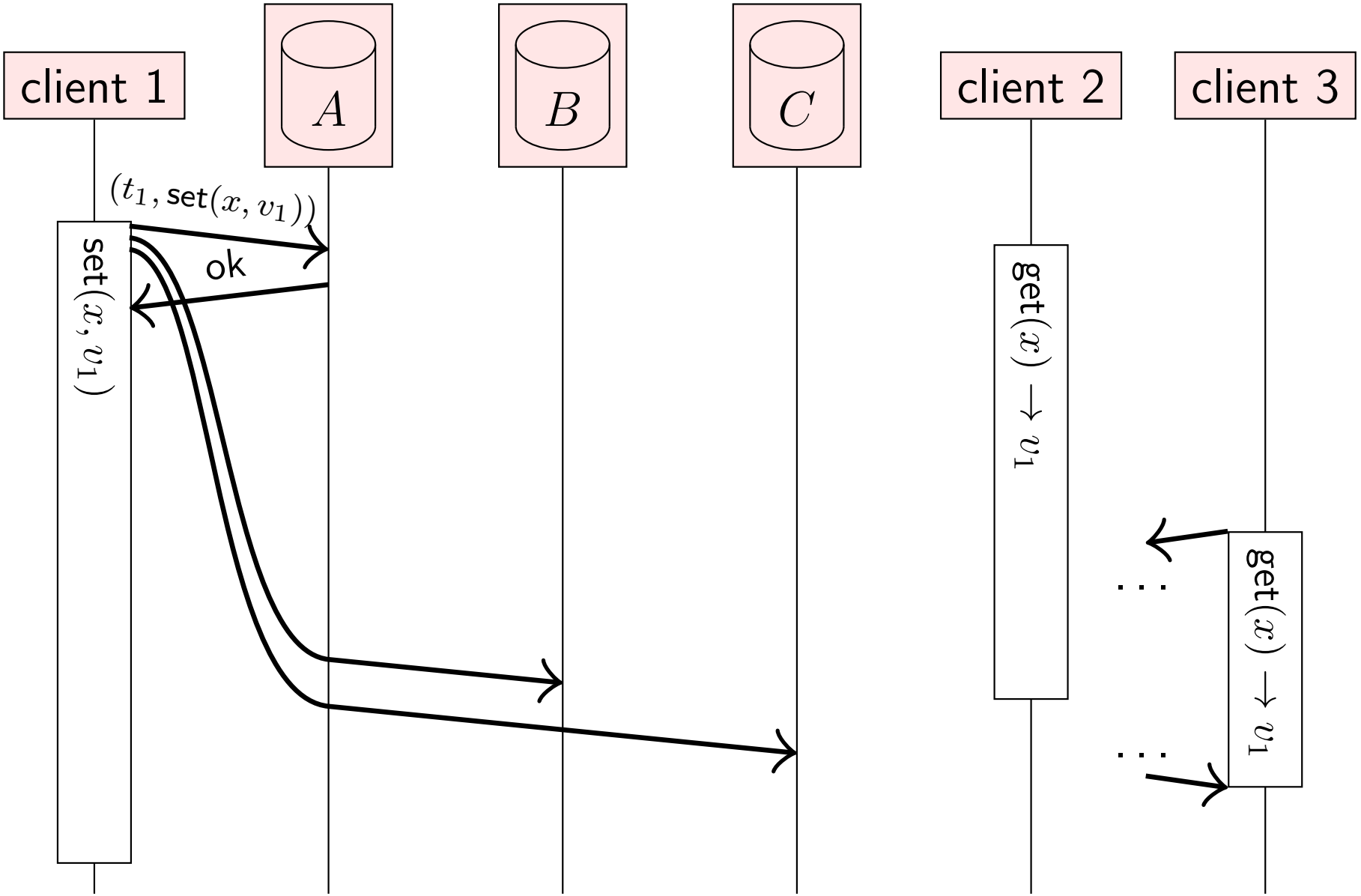


- Client 2's operation finishes before client 3's operation starts
- Linearizability therefore requires client 3's operation to observe a state no older than client 2's operation
- This example violates linearizability because v_0 is older than v_1

Making quorum reads/writes linearizable



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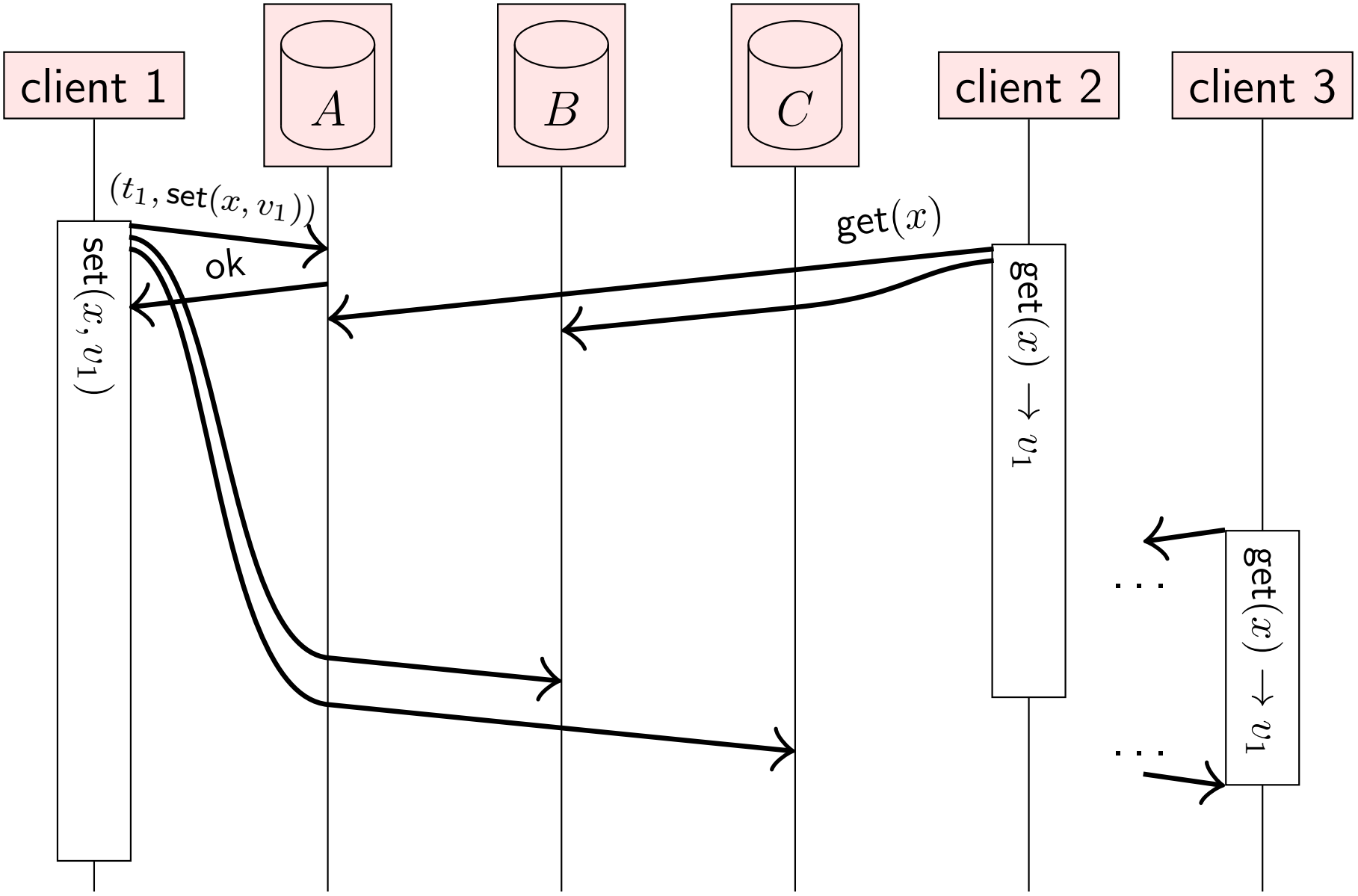

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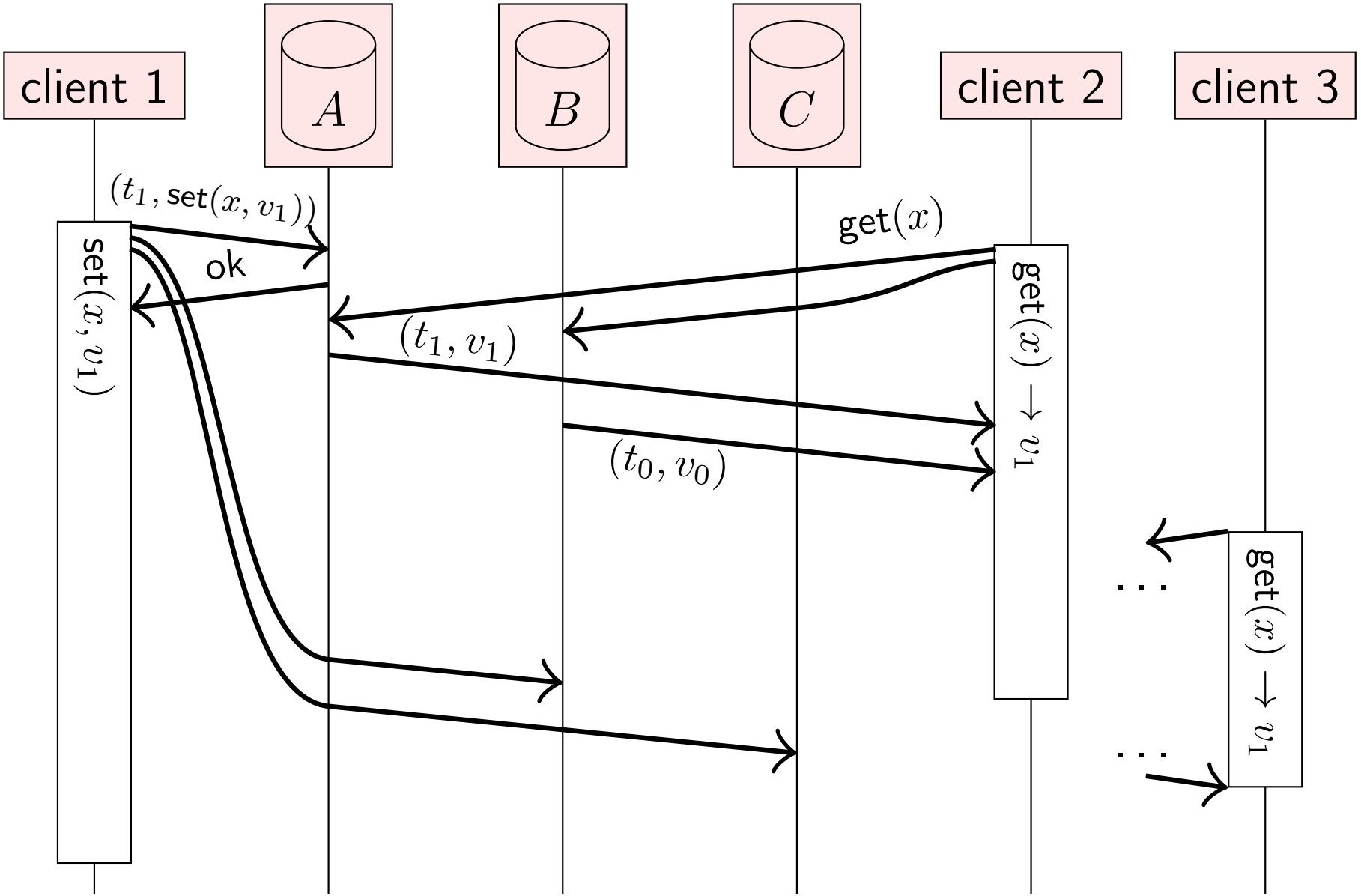

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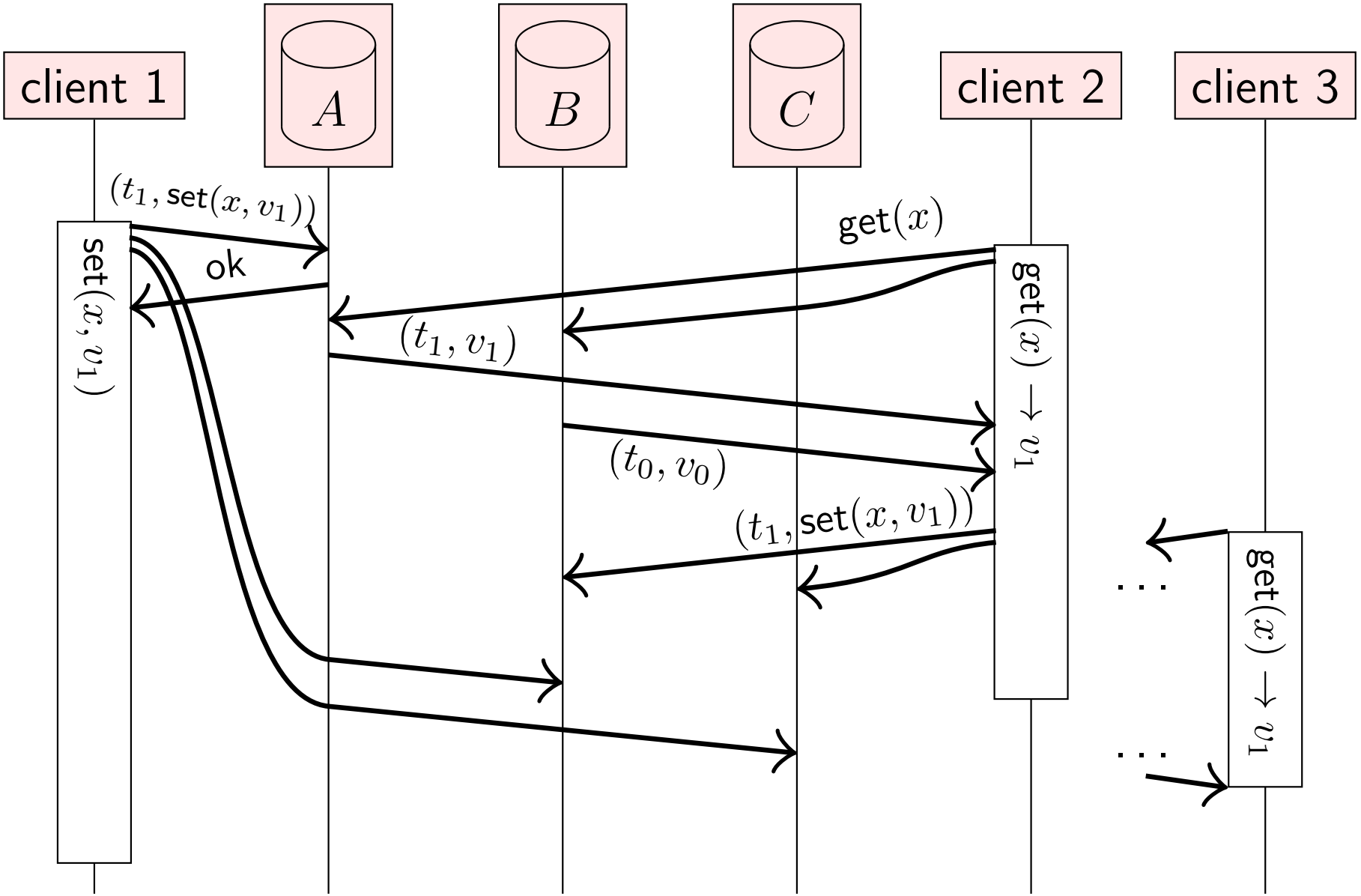

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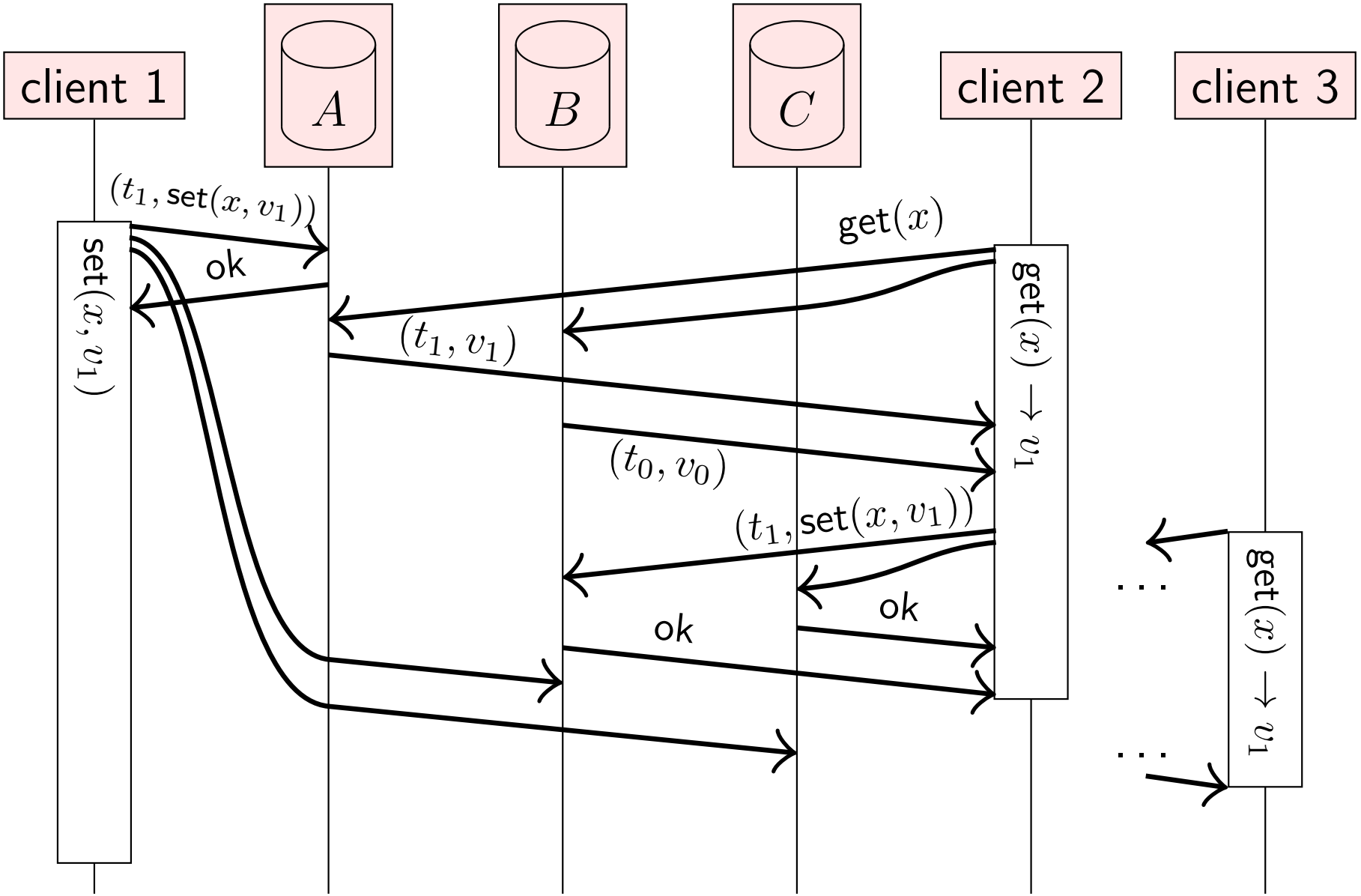

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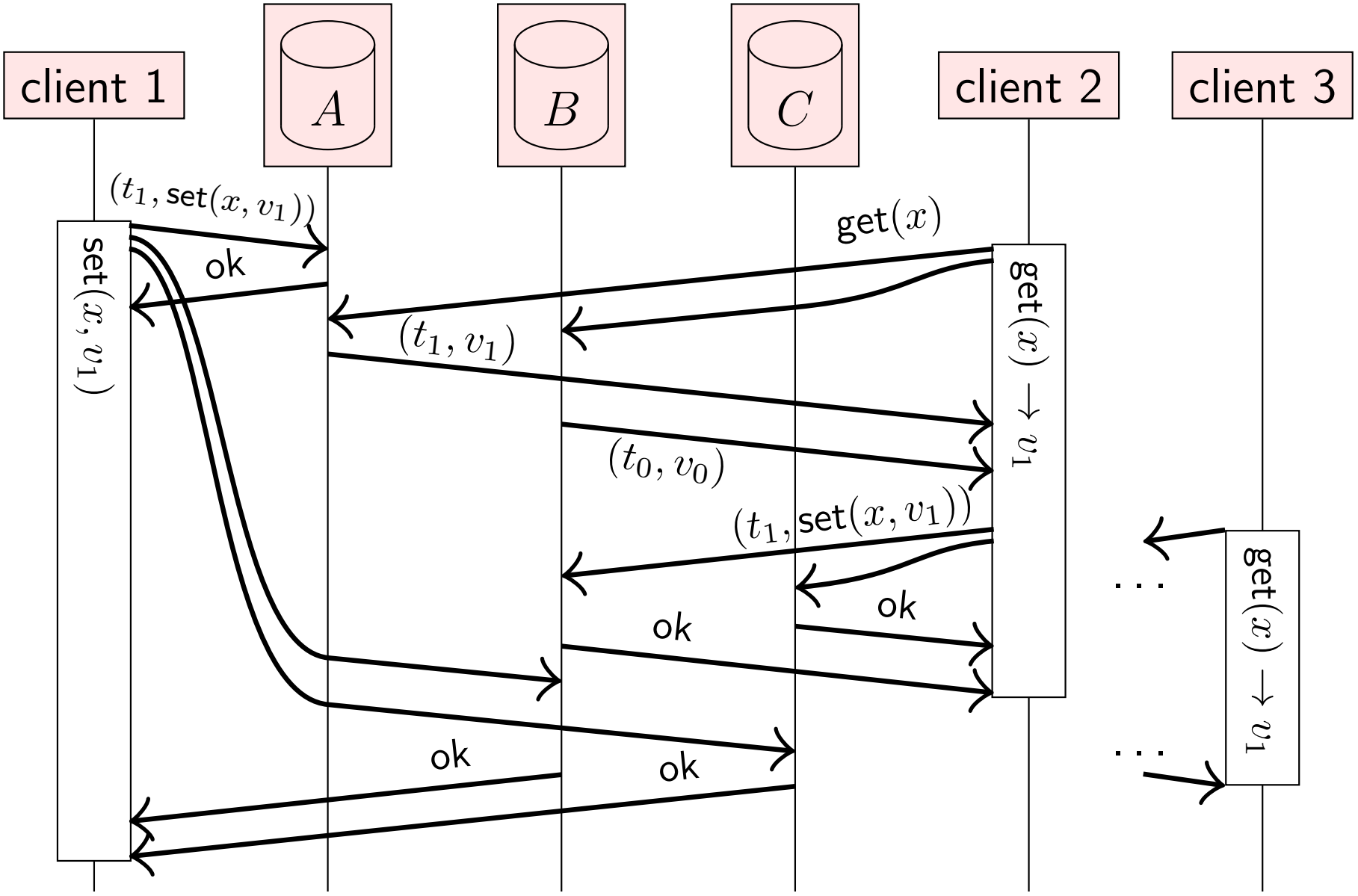

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- Can we implement **linearizable** compare-and-swap in a distributed system?
- **Yes:** total order broadcast to the rescue again!

Linearizable compare-and-swap (CAS)

on request to perform get(x) **do**
    total order broadcast (get, x) and wait for delivery
end on

on request to perform CAS(x, old, new) **do**
    total order broadcast $(\text{CAS}, x, old, new)$ and wait for delivery
end on

on delivering (get, x) by total order broadcast **do**
    return $localState[x]$ as result of operation get(x)
end on

on delivering $(\text{CAS}, x, old, new)$ by total order broadcast **do**
    $success :=$ false
    if $localState[x] = old$ **then**
        $localState[x] := new;\ success :=$ true
    end if
    return $success$ as result of operation CAS(x, old, new)
end on

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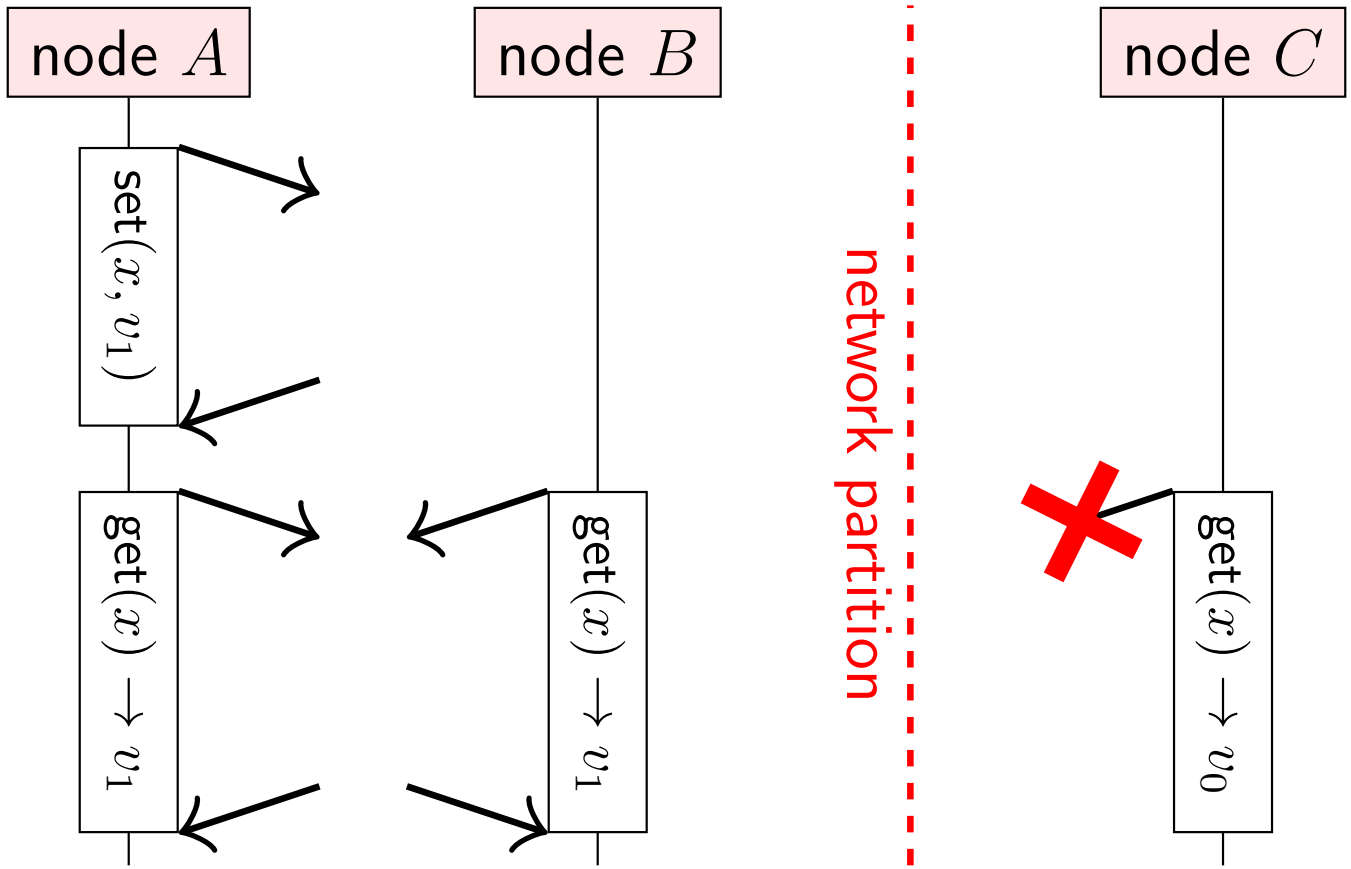
Eventual consistency: a weaker model than linearizability. Different trade-off choices.

The CAP theorem

A system can be either strongly **Consistent** (linearizable) or **Available** in the presence of a network **Partition**



C must either wait indefinitely for the network to recover, or return a potentially stale value

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If there are no more updates, **eventually** all replicas will be in the same state. (No guarantees how long it might take.)

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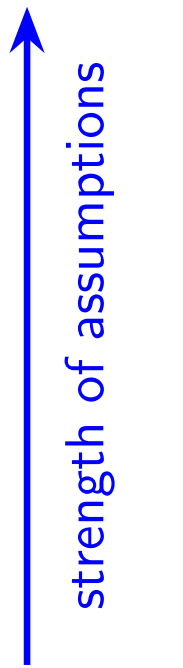
- Causal broadcast (or weaker) can disseminate updates
- Concurrent updates $\Longrightarrow$ **conflicts** need to be resolved

Summary of minimum system model requirements

Problem	**Must wait for communication**	**Requires synchrony**
atomic commit	all participating nodes	partially synchronous



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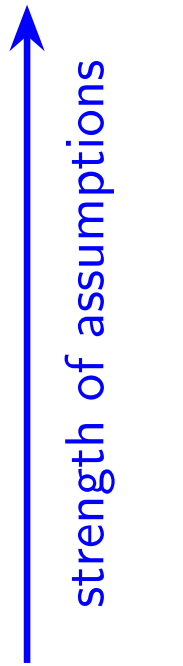

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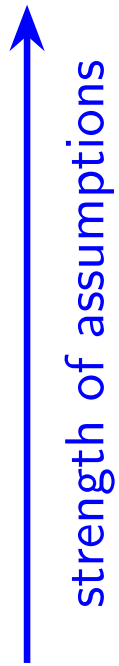

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