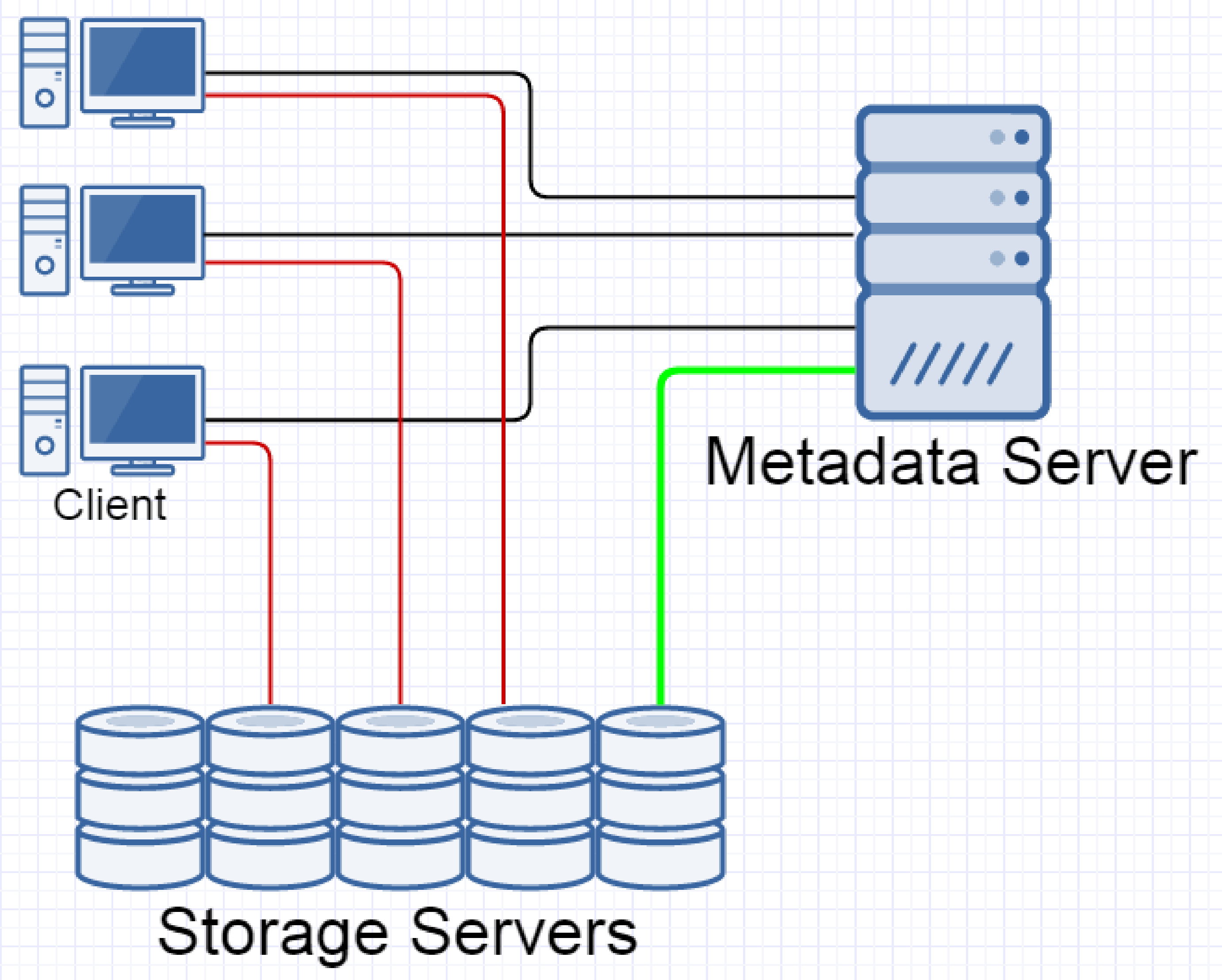
The basics of file systems

Neapolis University Pafos

Consensus in a distributed system

Today we are going to see how to implement a reliable distributed FSM.

A reminder about Parallel NFS



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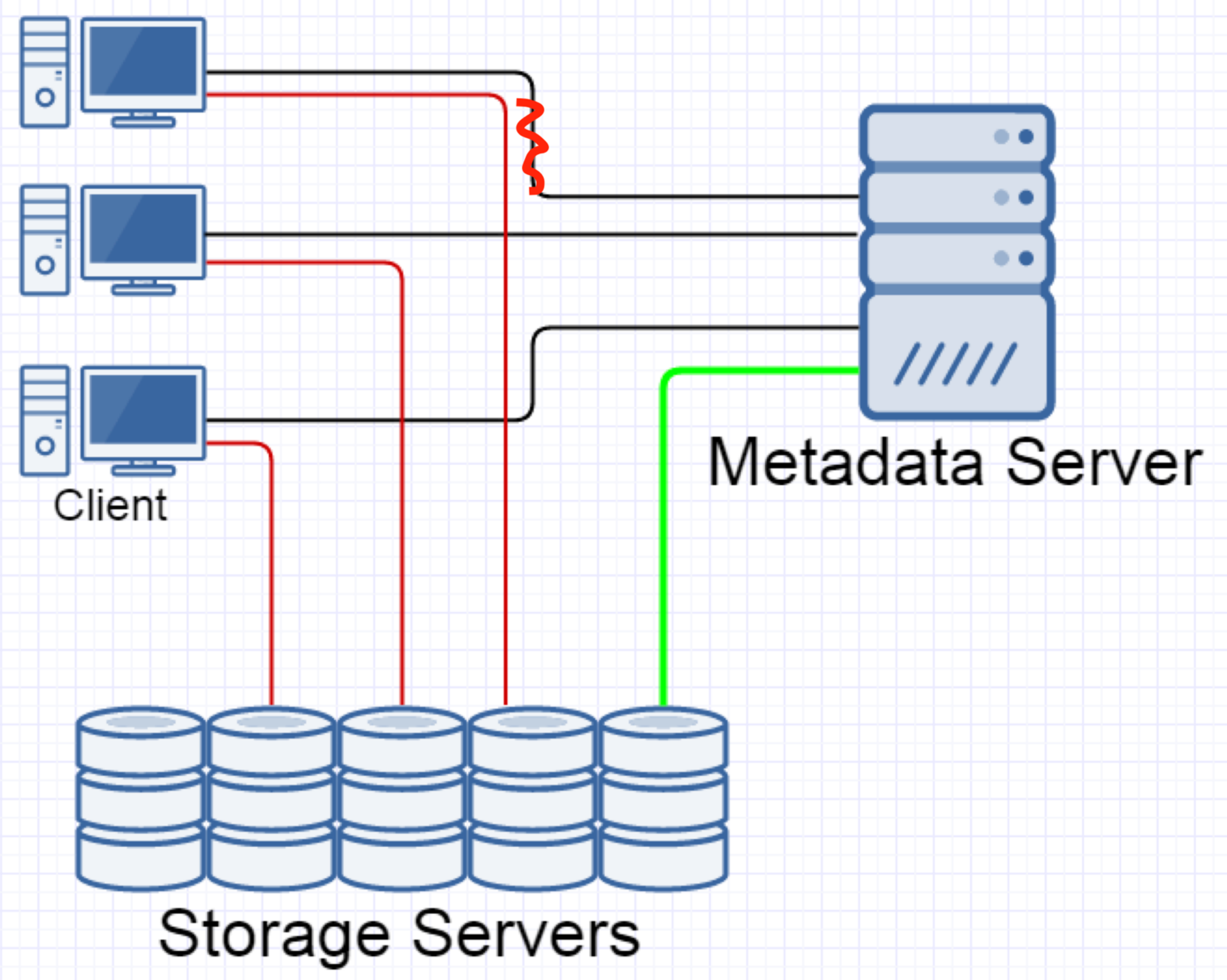

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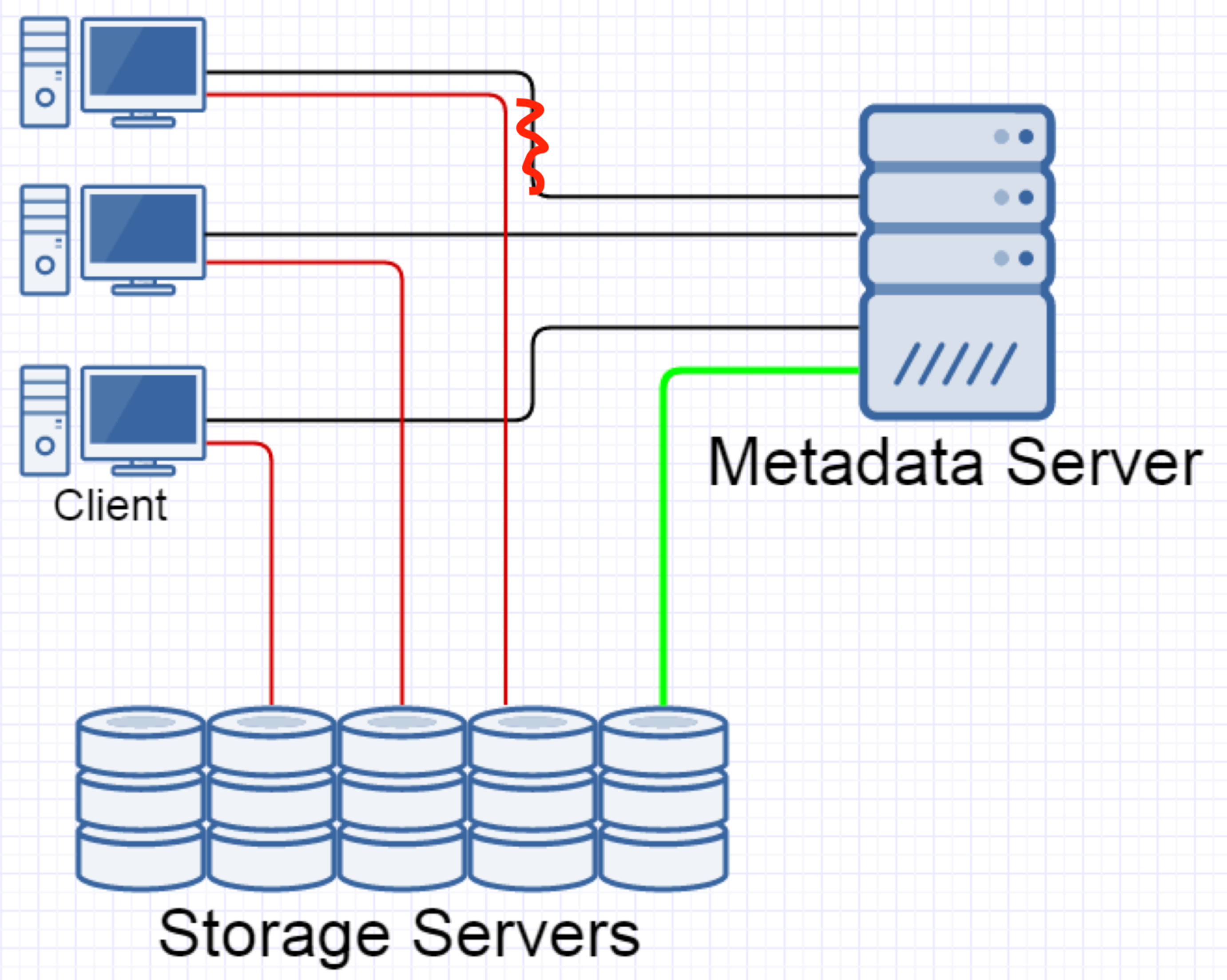

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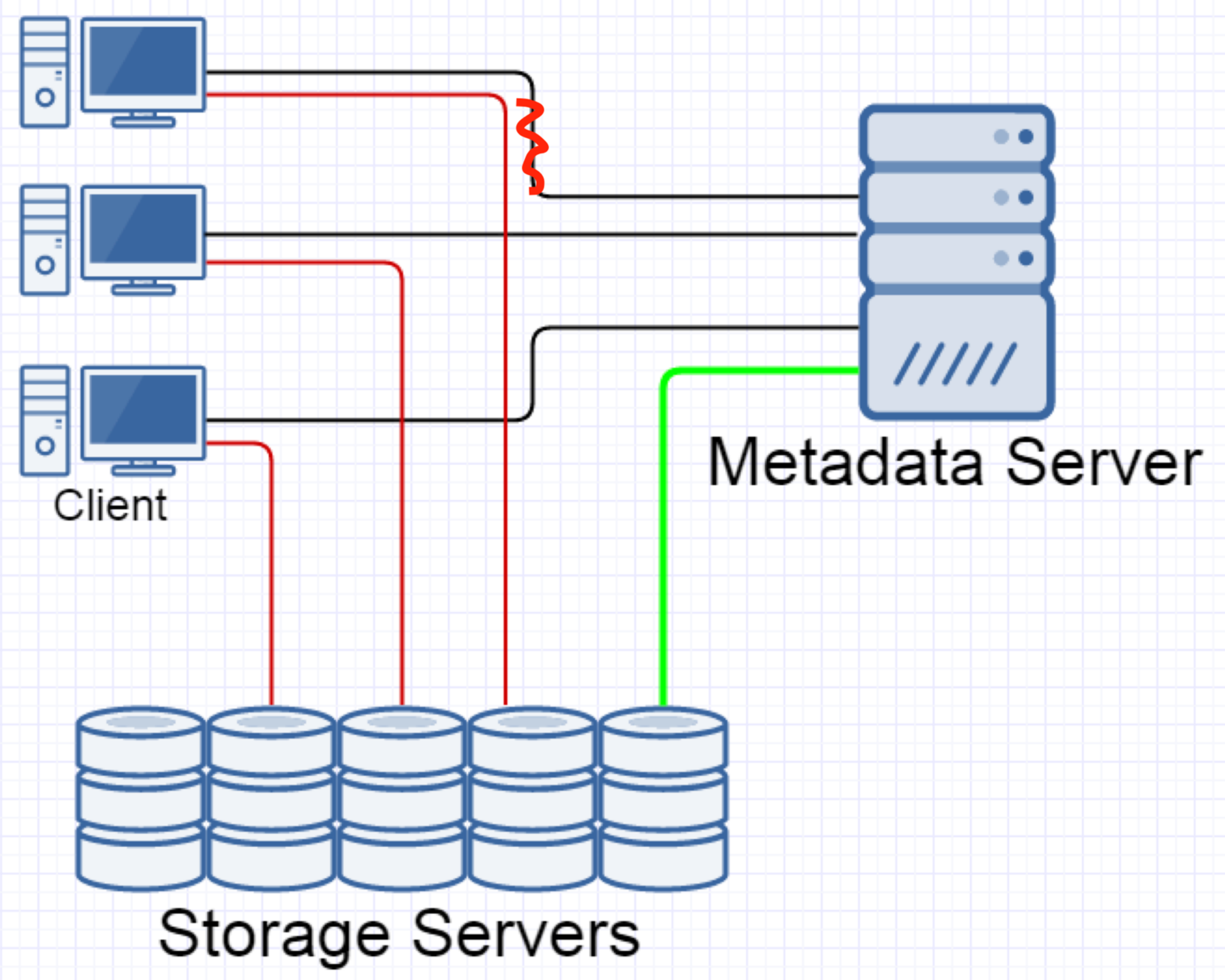

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Quiz: layout lease may not rely on clock of different clients being synchronised. How can we implement that?

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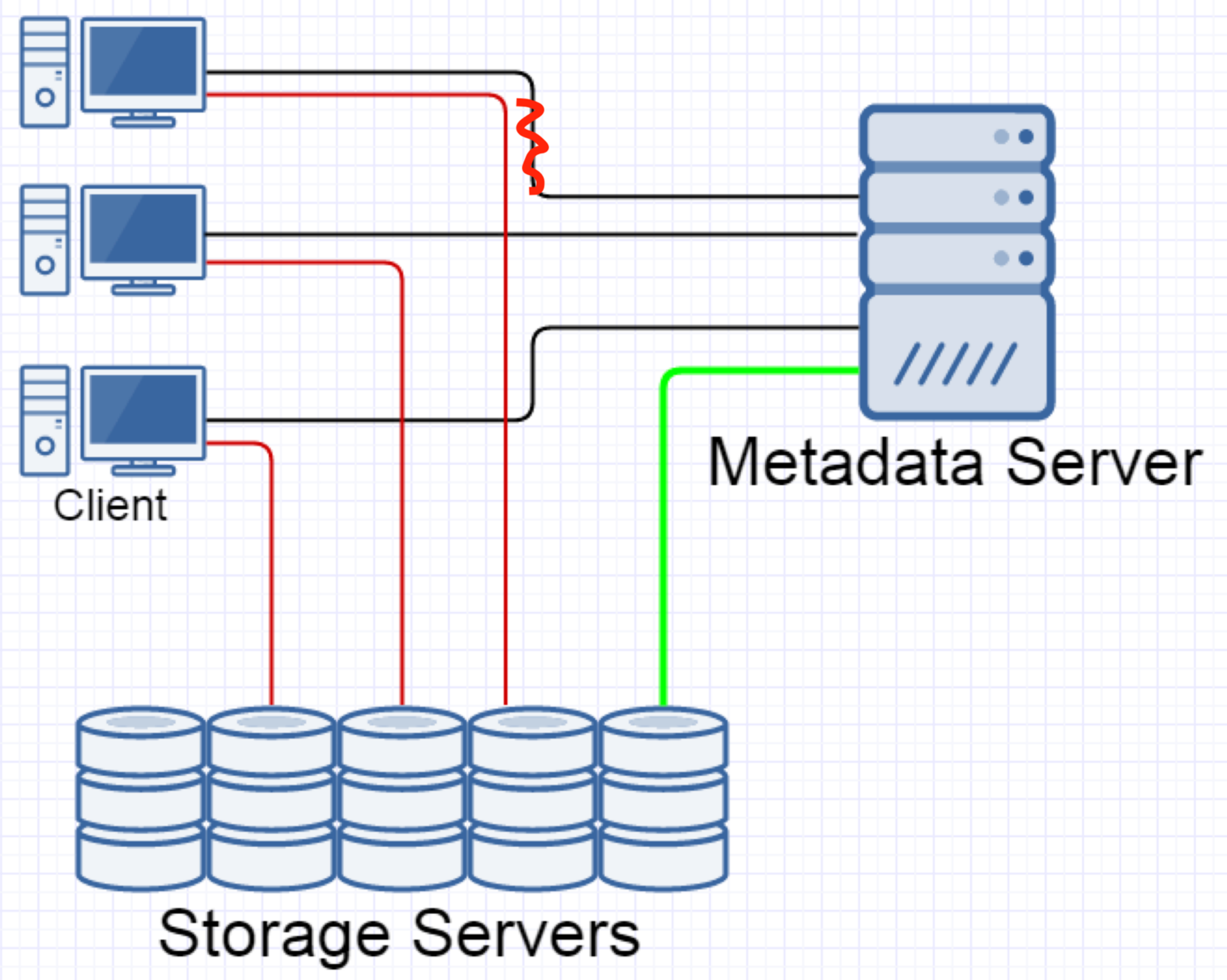

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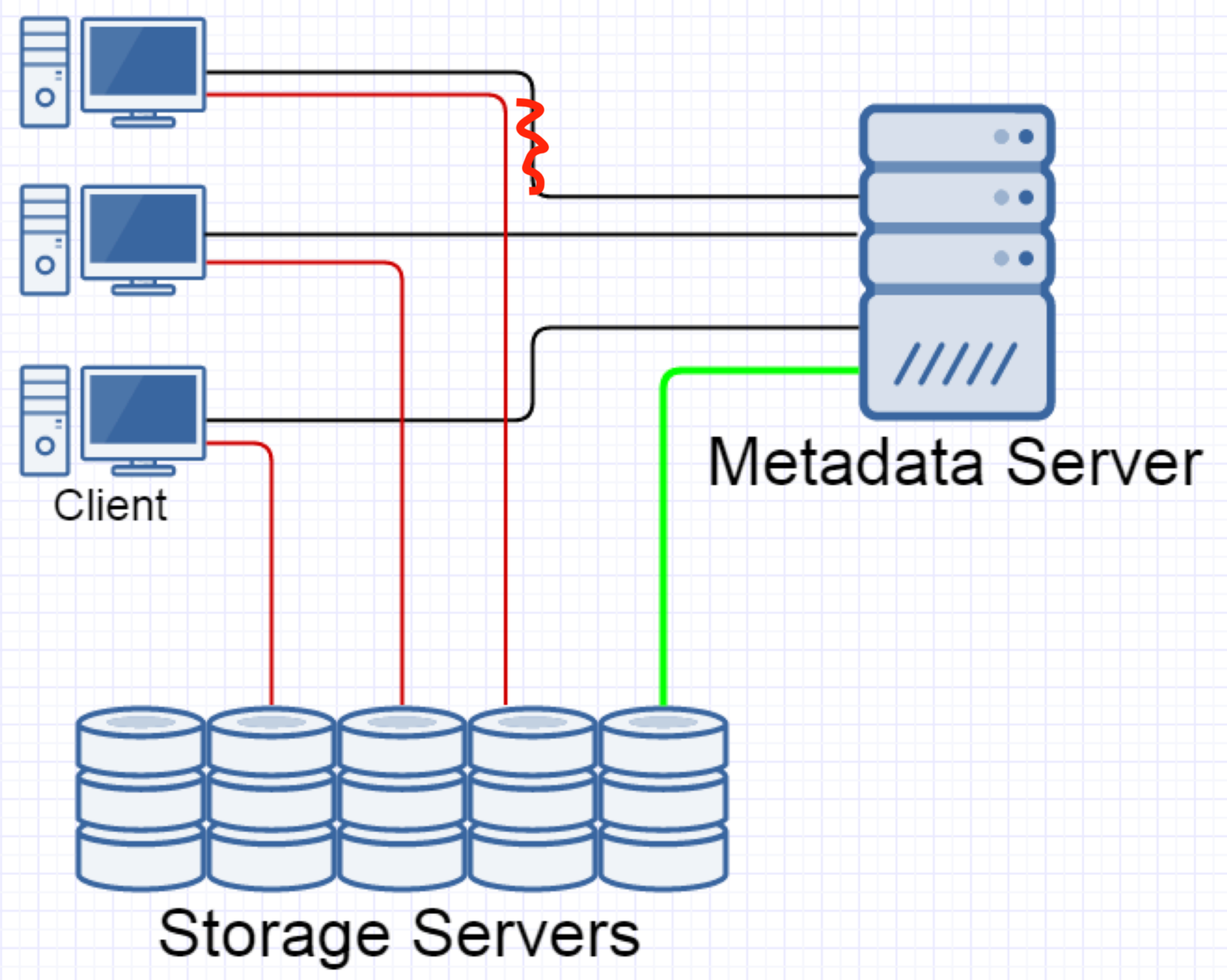

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See also: client fencing.

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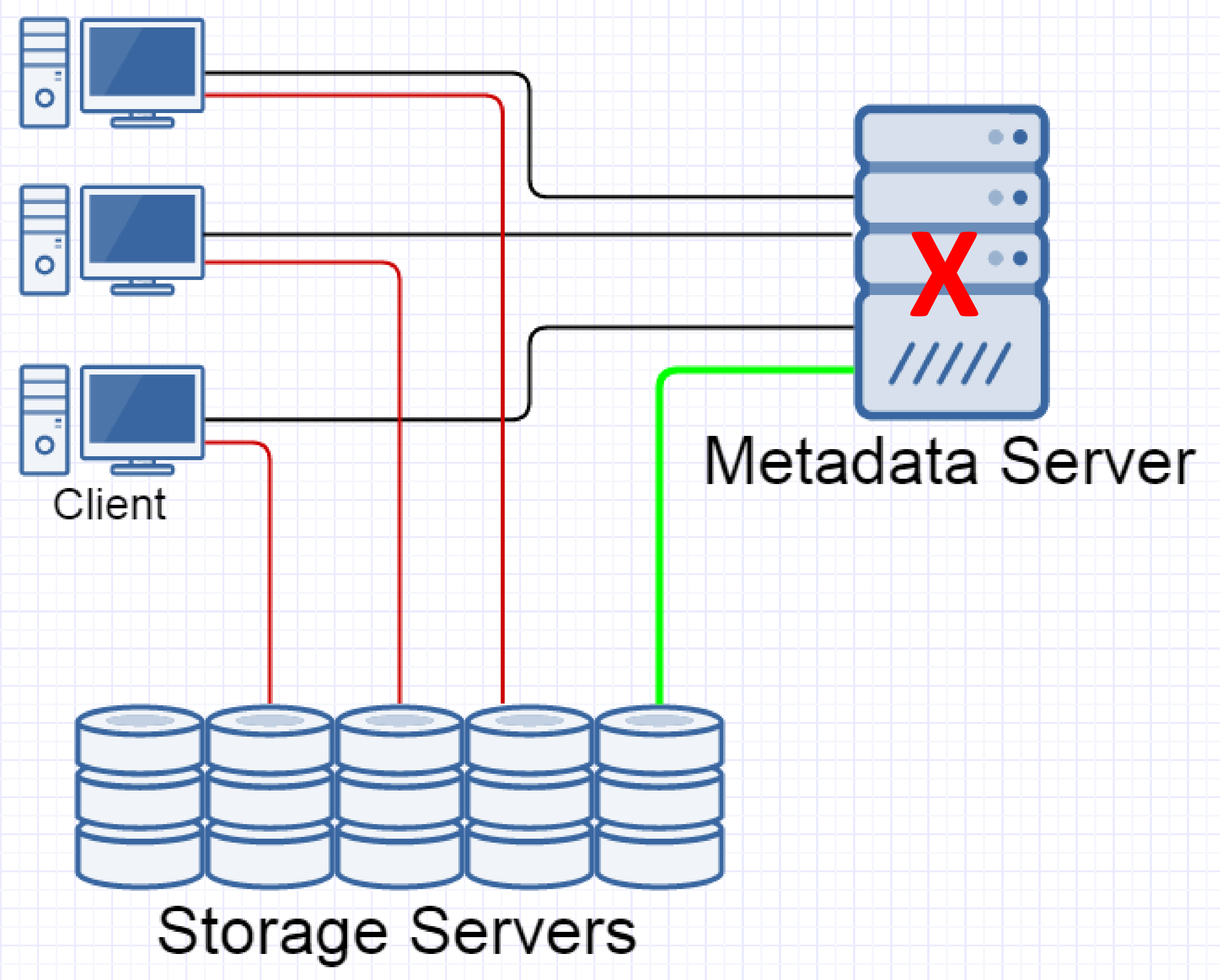

The metadata server is a ”single point of failure” of this system.

Question: how can we replicate the state of the metadata server to multiple machines and have them all agree on ”the state” of the metadata server?

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- To replicate a journal, cluster nodes need to agree on values to append to the log at every step.
- It suffices to solve the following problem: nodes of a cluster must agree on a value to append to a journal.

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Proposer processes send `propose()` requests. Their arguments are called *proposed* values.

Acceptor processes receive `propose()` requests from proposers.

Acceptor processes send `accept()` requests to learners. Their arguments are called *accepted* values.

Typically, every cluster member plays all three roles.

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Proposer processes may be regarded as the source of requests “at step N, create a file F” or “at step N, grant a lease on file F to client C”.

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The model of the network and process failure modes:
1. participant processes may work at arbitrary speed,
2. processes may crash and restart at any moment,
3. messages may be delayed (in particular, reordered), lost, or duplicated, but they cannot be corrupted.

Motivation for definitions and rules

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This definition makes sense if the following property holds:

Requirement 0: an acceptor accepts at most one value.

In a set with N elements any two subsets with $\lfloor {}^{N}/_{2} \rfloor + 1$ elements have a non-empty intersection. Suppose M_0 and M_1 are majorities of acceptors that have accepted v_0 and v_1, respectively. An acceptor that belongs to $M_0 \cap M_1$ has accepted both values. Thus, $v_0 = v_1$ and all acceptors in $M_0 \cup M_1$ have accepted this value.

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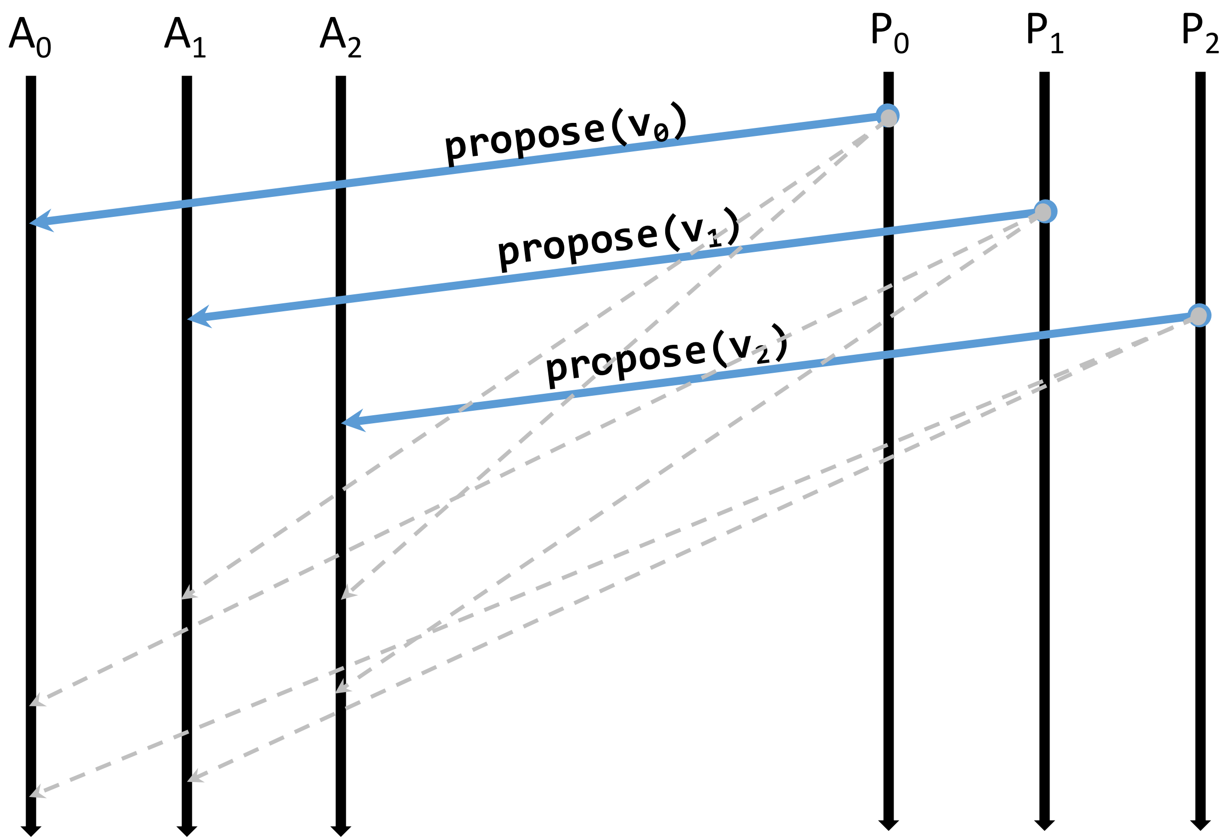

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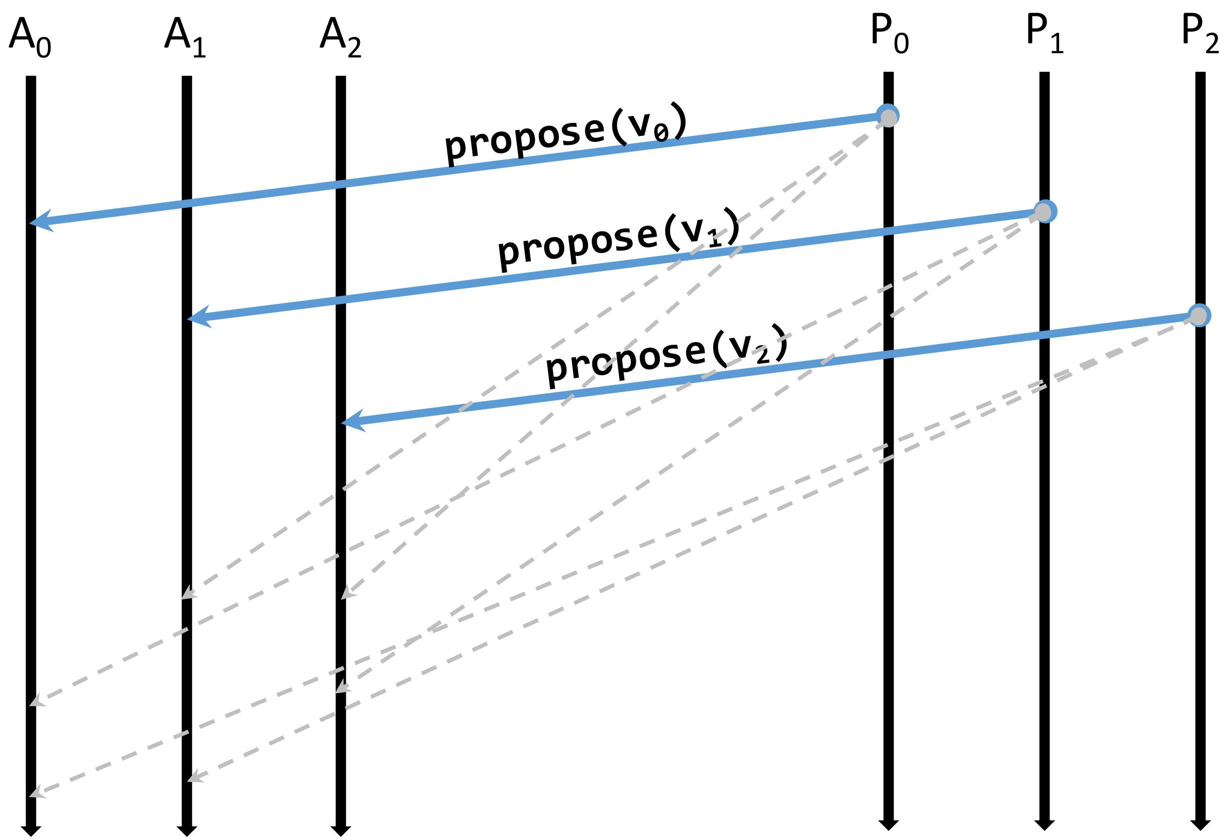

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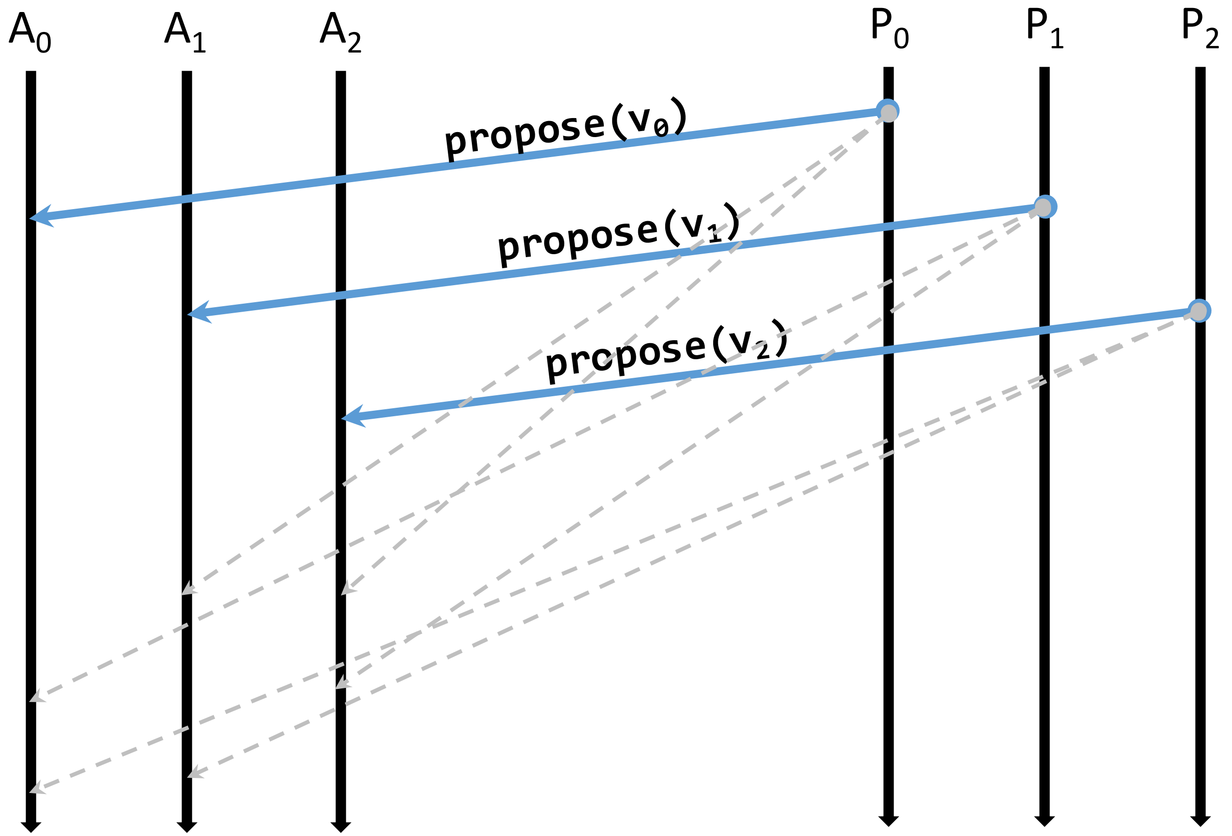

In this scenario all acceptor have accepted different values. There can be no majority that will accept the same value.

Idea: one must not propose plain values v, but must propose pairs (n, v) where n is a natural number, the epoch number of a proposer. Acceptors must accept pairs (n, v) and (n', v) with the same v.

The epoch number enables us to distinguish newer requests from stale ones. Proposers can use this numbering to coordinate among themselves and avoid proposing **known-stale values**.

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Requirement 2a: every proposer issues requests `propose(n, v)` with epoch numbers that are unique and ascending.

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Requirement 2a: every proposer issues requests `propose(n, v)` with epoch numbers that are unique and ascending.
Requirement 2b: different proposers choose their epoch numbers from disjoint sets to ensure that epoch numbers are globally unique.

** In a system with N proposers their epochs from sets* $\{0, N, 2N, \ldots\}$, $\{1, N+1, 2N+1, \ldots\}$, …

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Requirement 0': an acceptor accepts pairs that have the same value and ascending epoch numbers:
$(n_0, v), (n_1, v), \ldots\ (n_k, v)$ with $n_0 < n_1 < \ldots < n_k$.

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Now that we allow acceptors to accept multiple proposals (n, v) and (n', v), we must allow situations where a majority of acceptors have accepted pairs $\{(n_i, v)\}$ with different epochs. We only need to require that all accepted pairs have the same value v.

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The algorithm of a proposer:

1. Choose an epoch number n that was not used earlier.
2. Send $\mathrm{prepare}(n)$ to all acceptors. It is a request to ignore requests with the epoch number $< n$.

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5. Wait for $\text{accept}()$ from a majority of acceptors.
6. If timed out, go to #1.

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Safety (only one value can be chosen)

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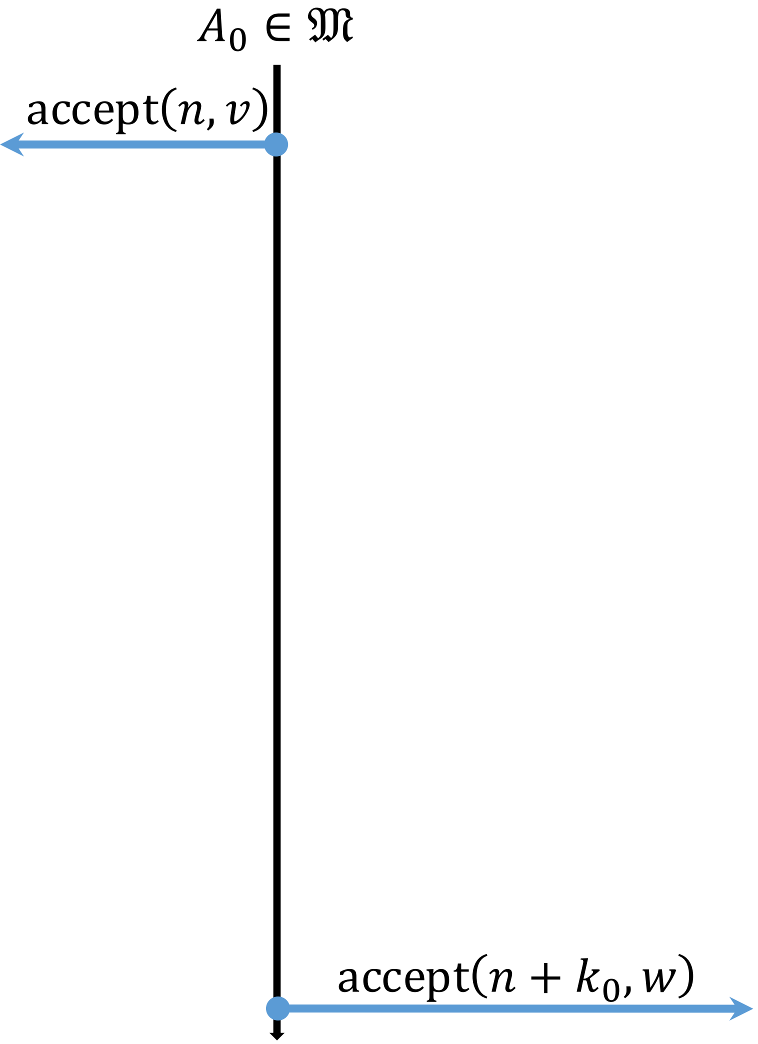

Remark: let us consider **the minimal epoch number** $n + k_0$ when some acceptor from $\mathfrak{M}$ sent $\mathrm{accept}(n+k_0, w)$ after having accepted (n, v).

In this epoch the other acceptors from $\mathfrak{M}$ have not yet sent any $\mathrm{accept}(\cdot, w)$ after $\mathrm{accept}(n, v)$.

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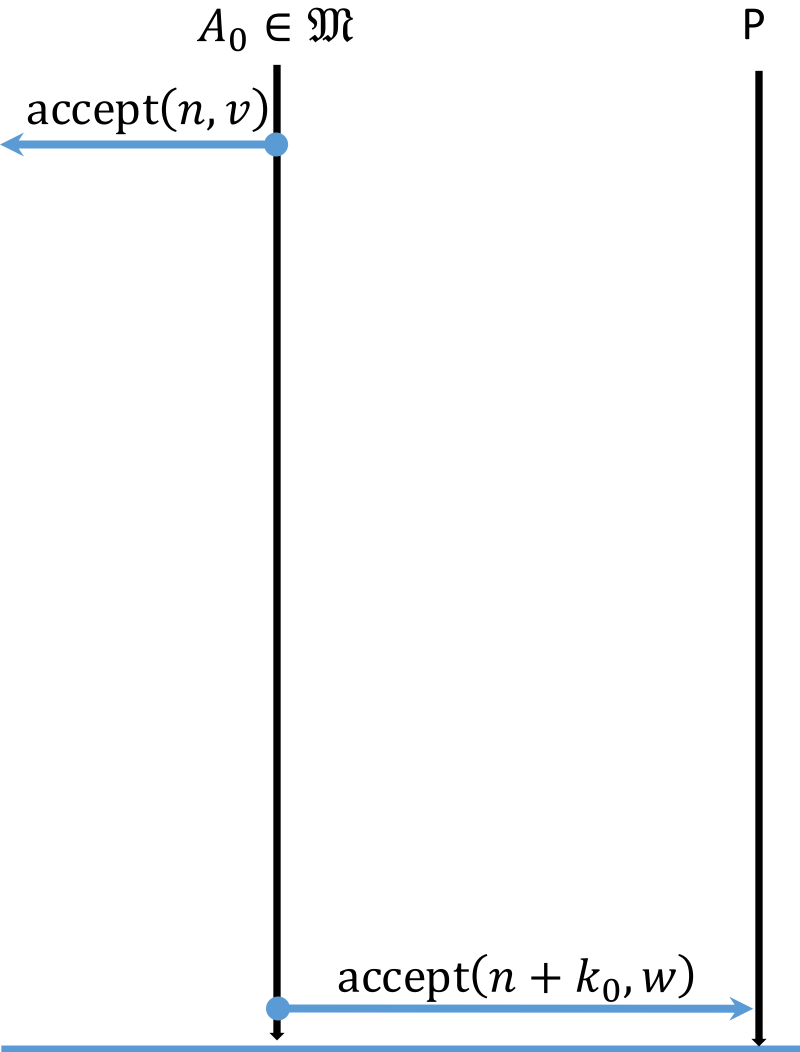

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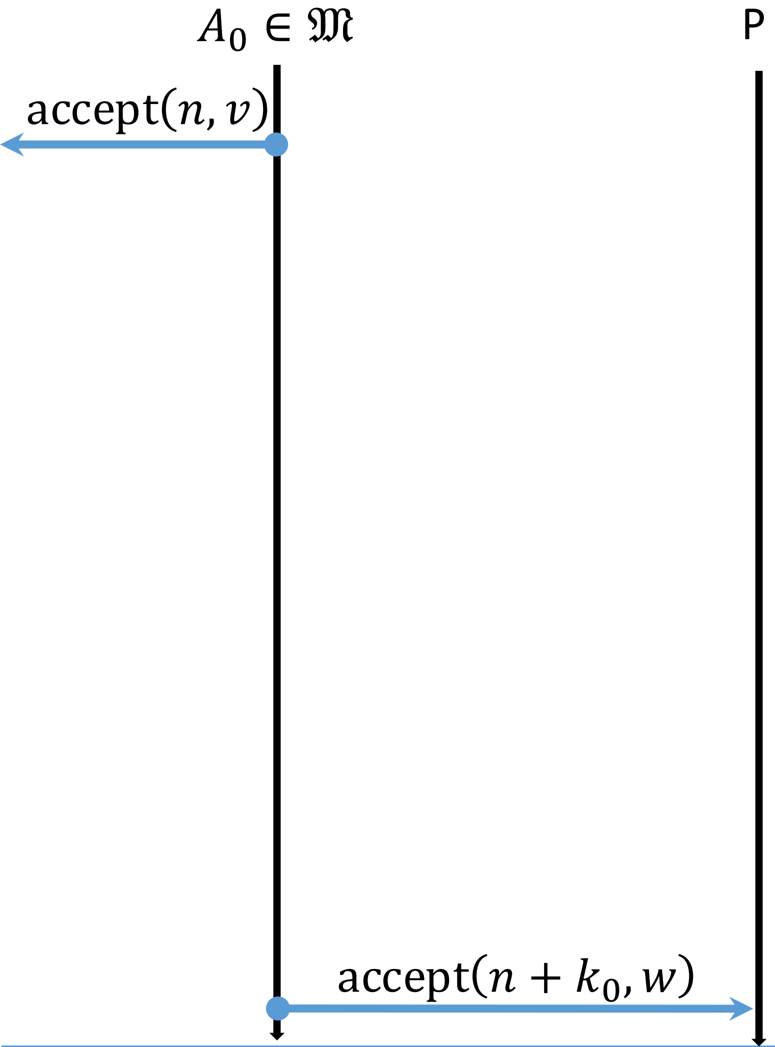

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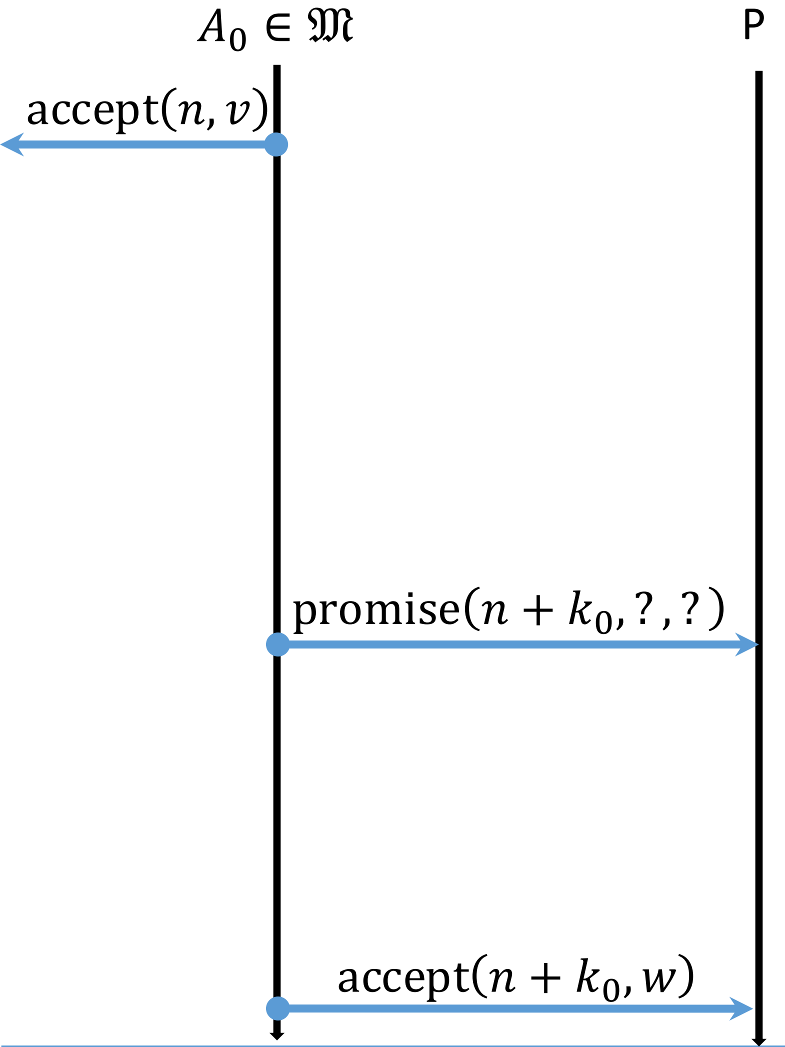

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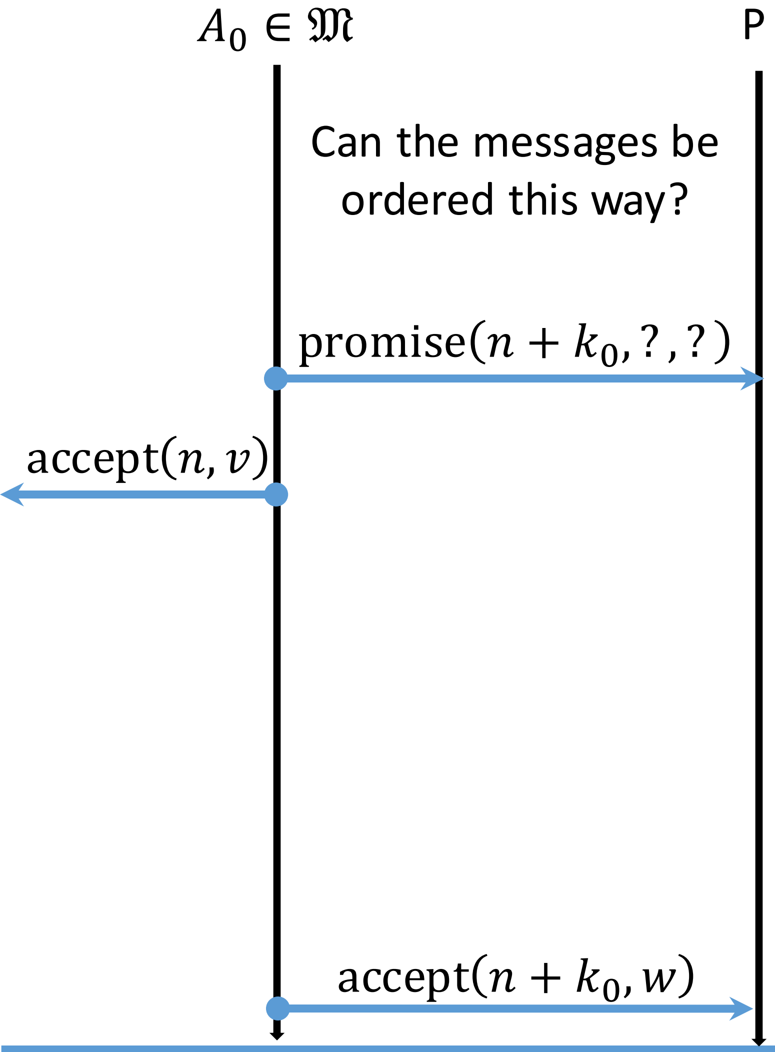

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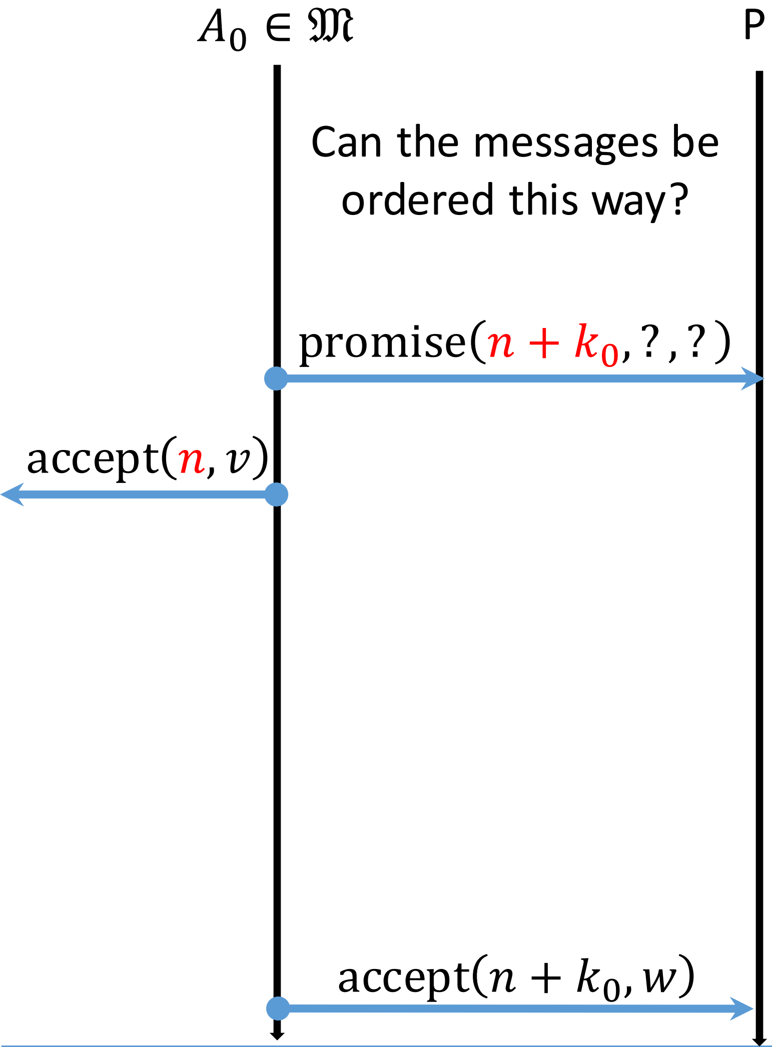

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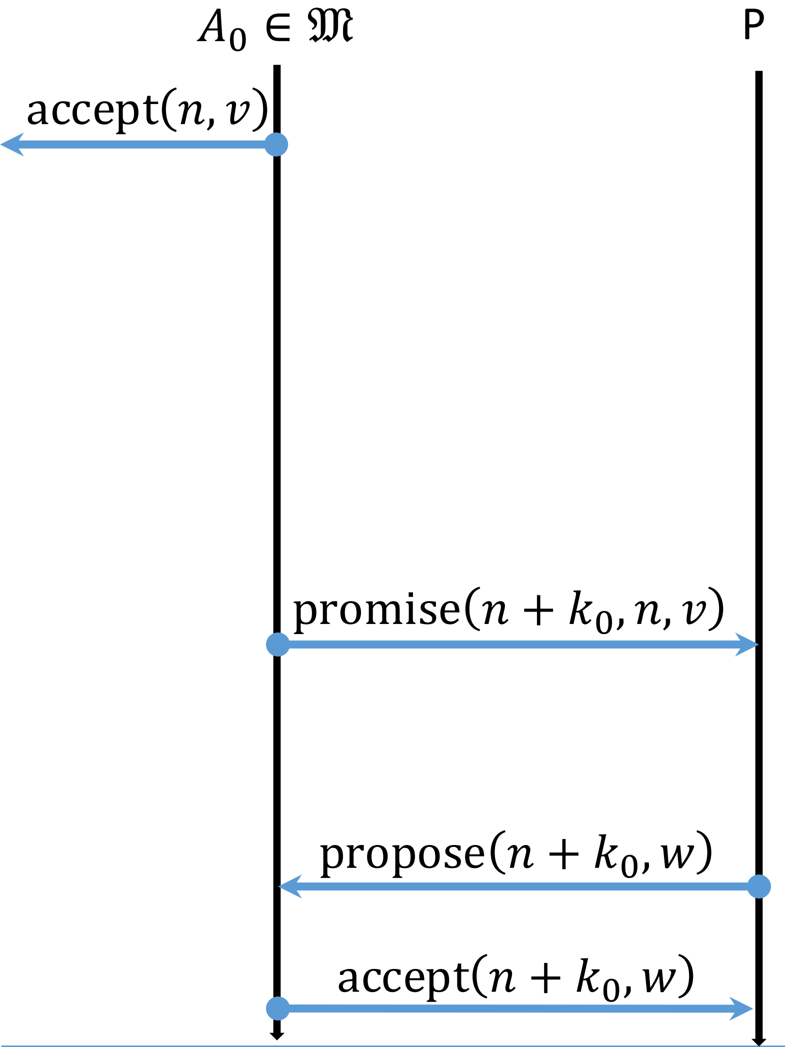

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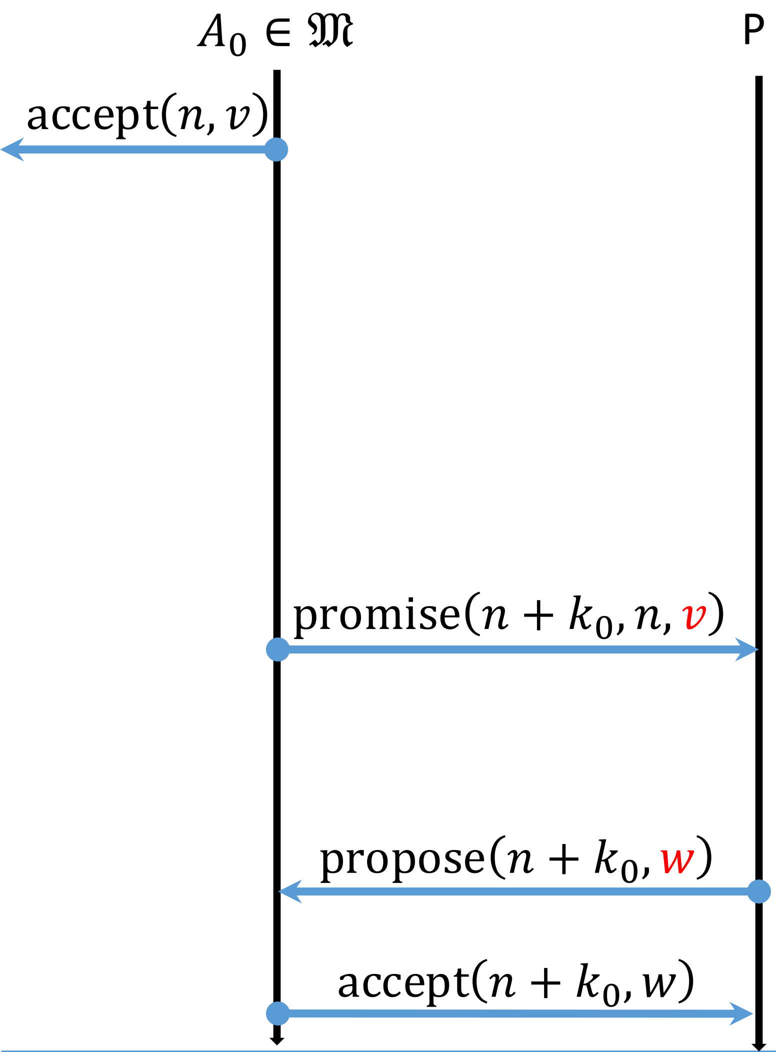

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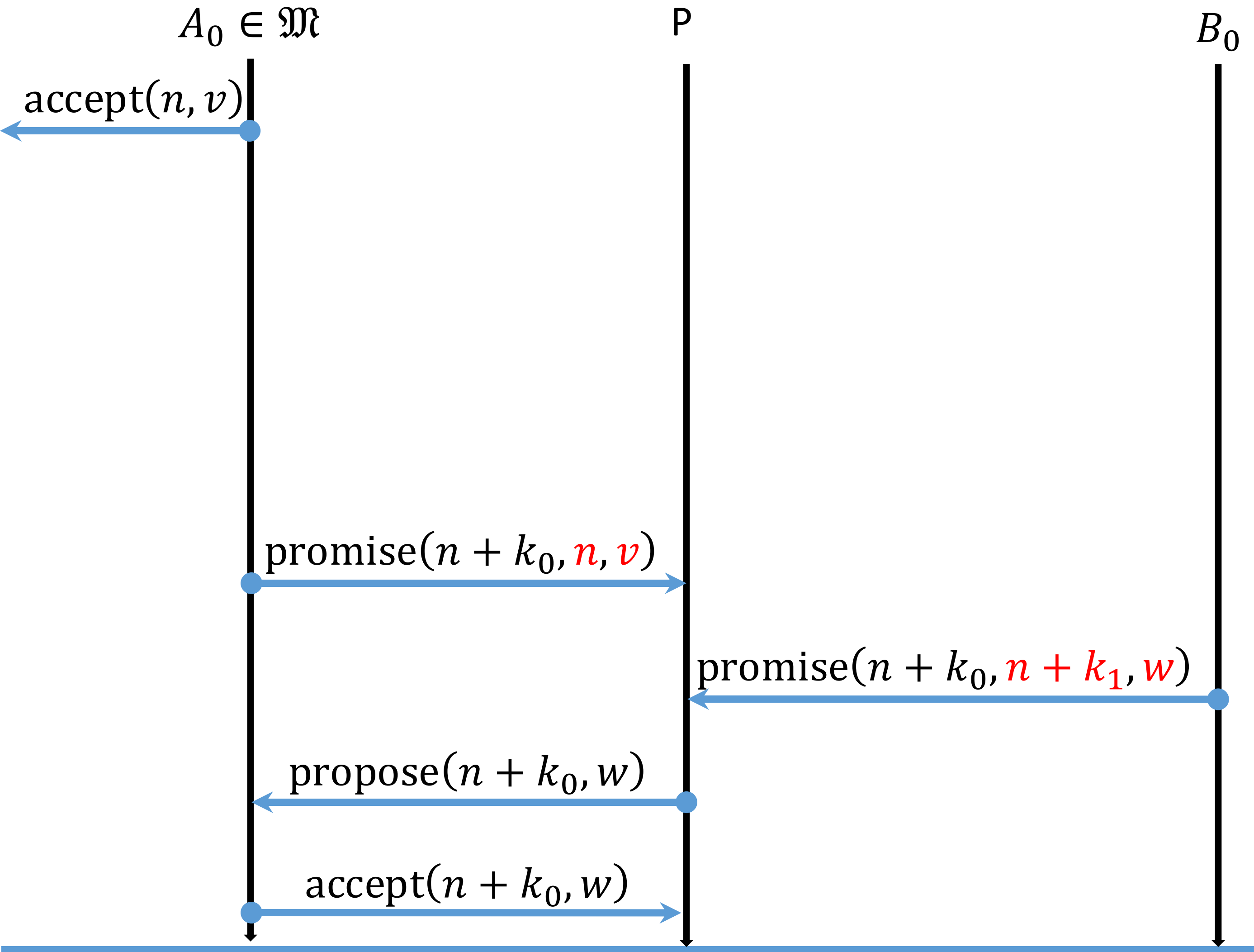

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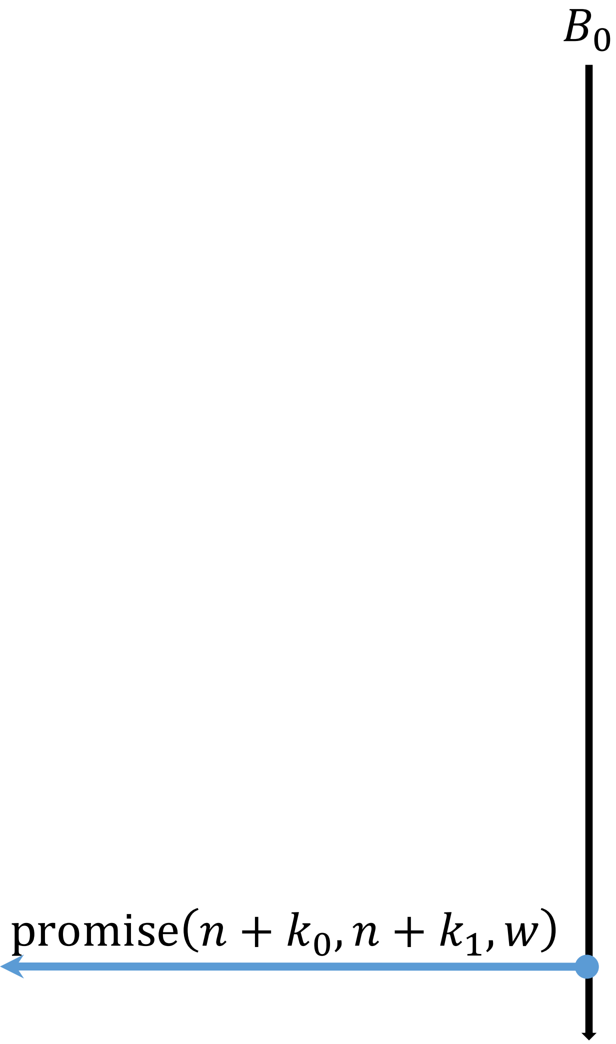

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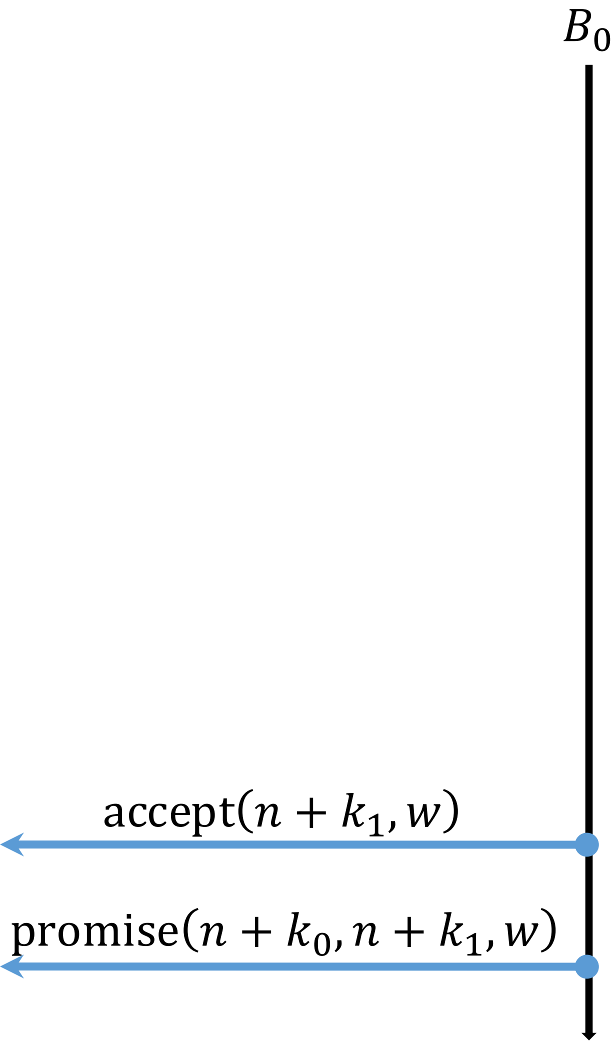

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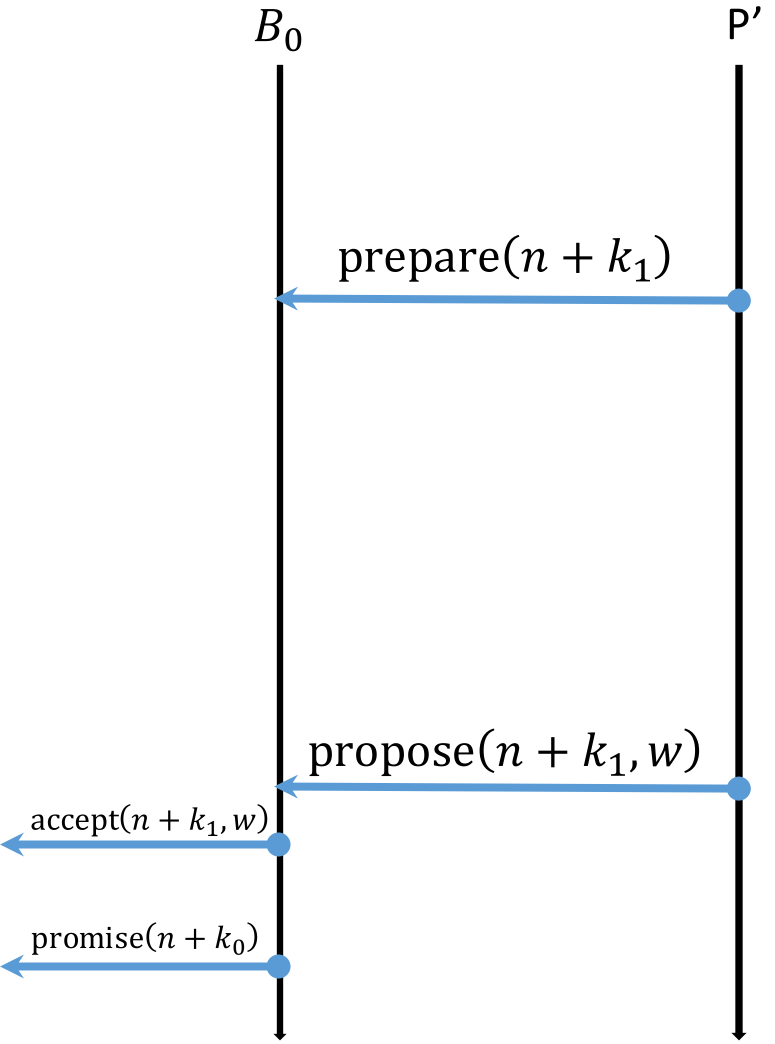

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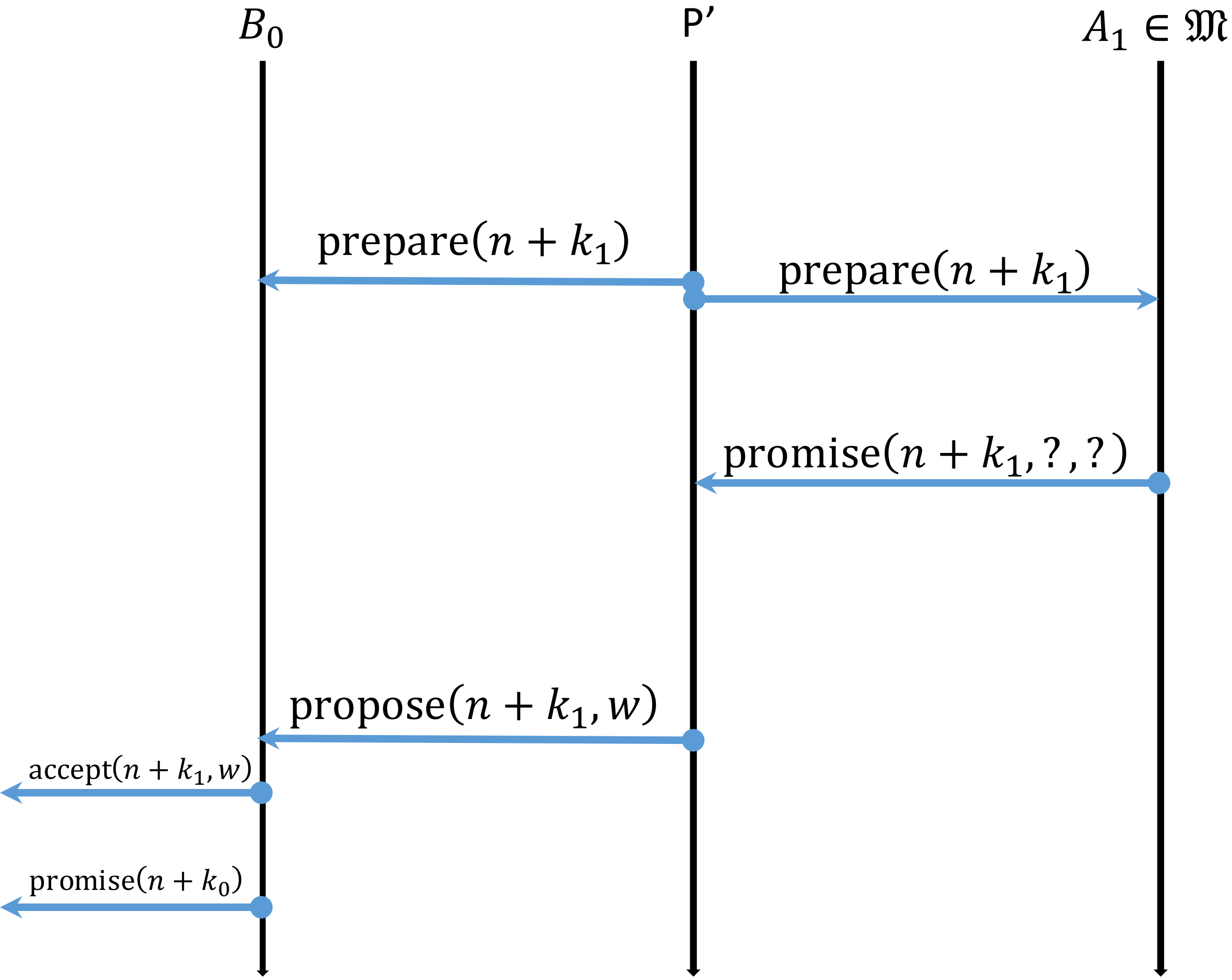

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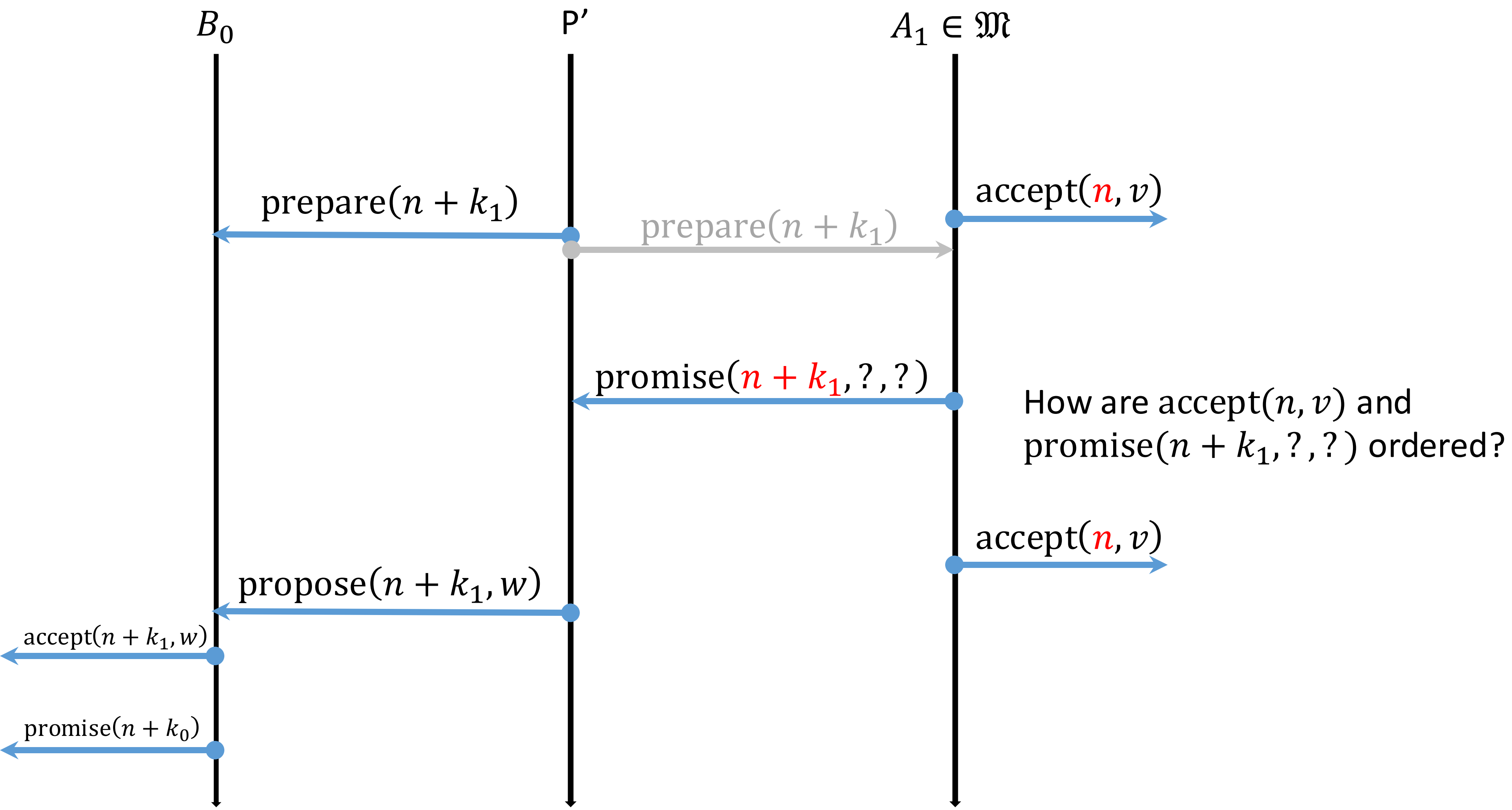

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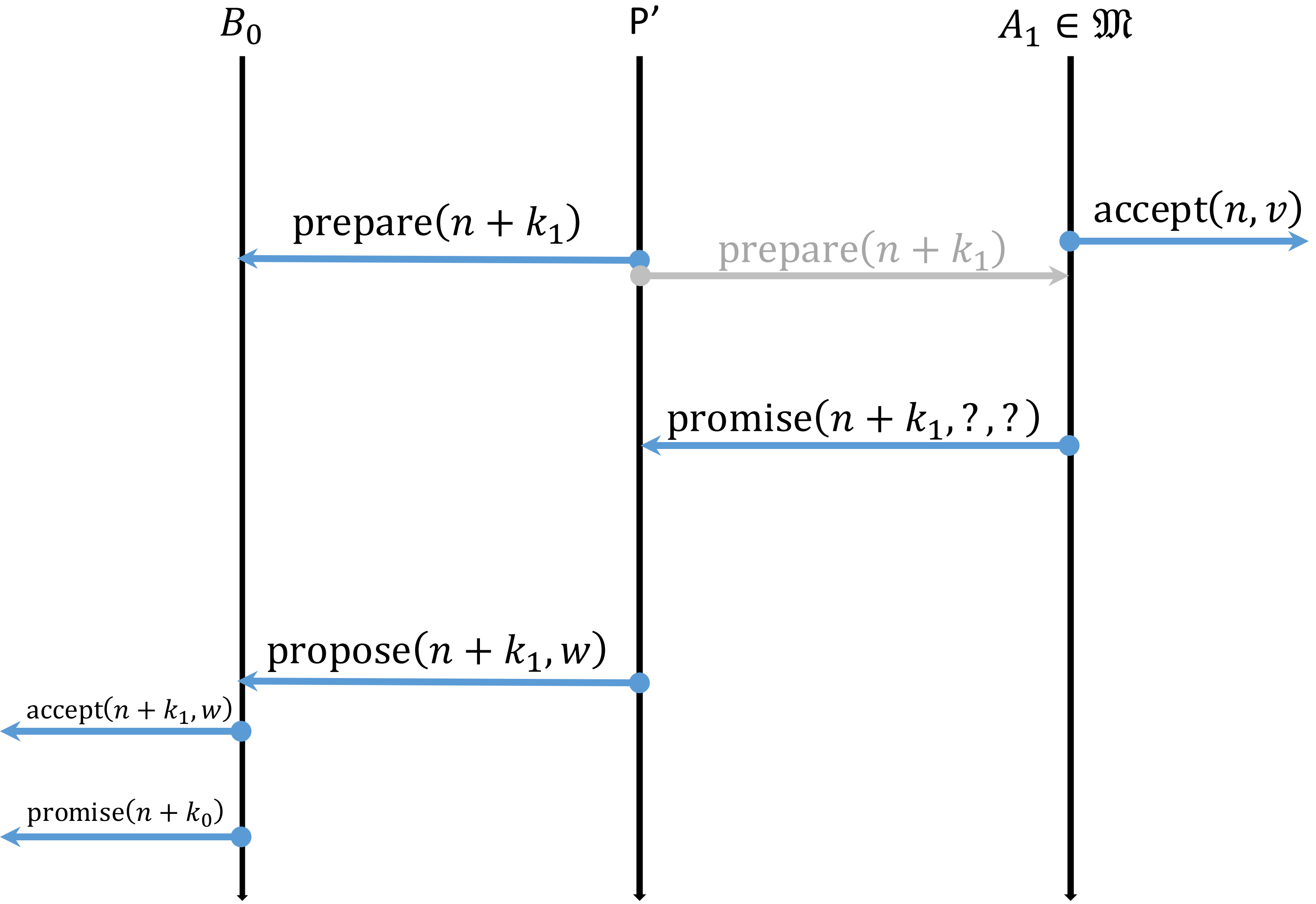

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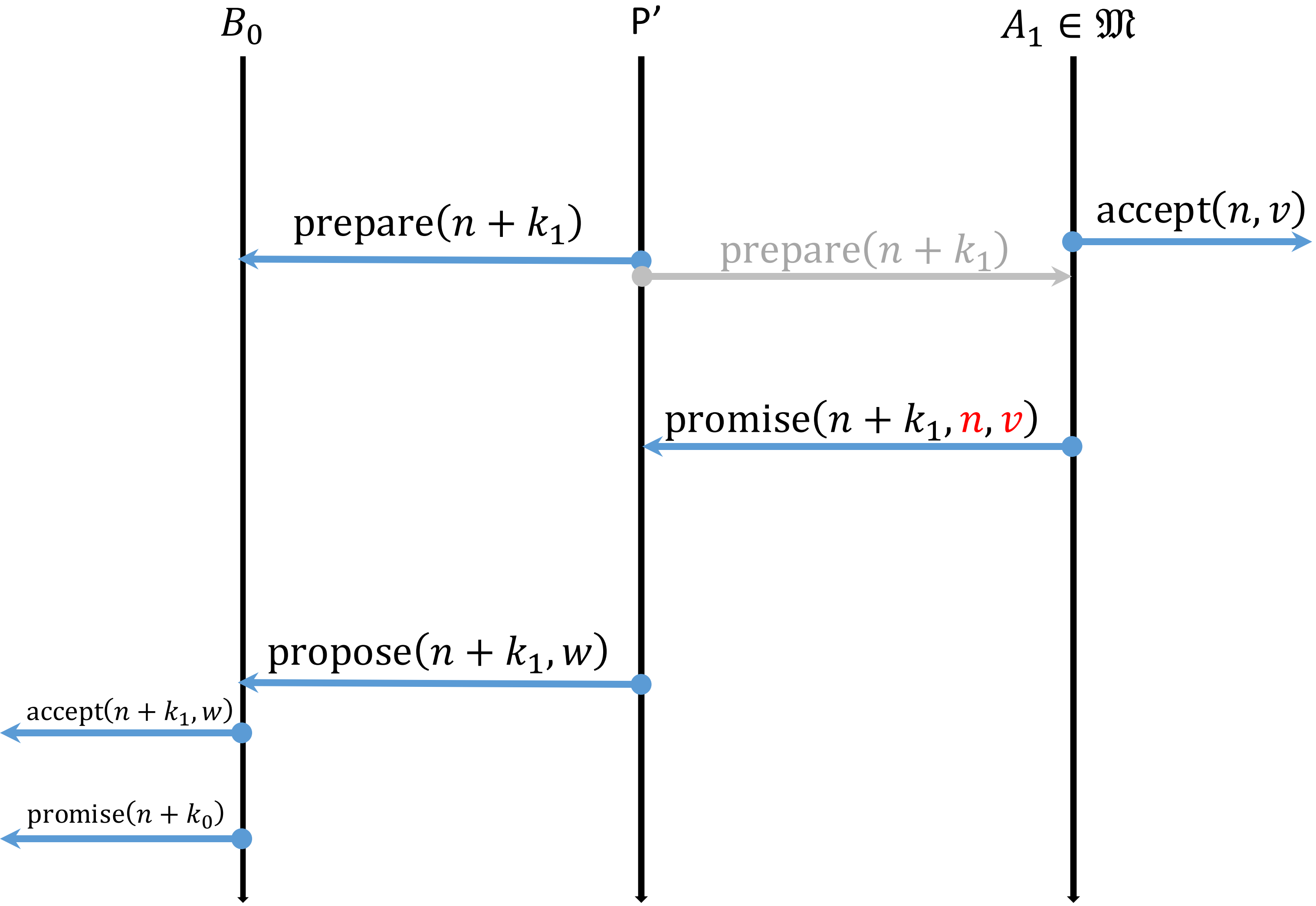

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4. Recall that $n + k_0$ is the minimal epoch when an acceptor in $\mathfrak{M}$ replies with a value $w \neq v$. Thus, A_1 has replied $\text{promise}(n + k_1, n, v)$.

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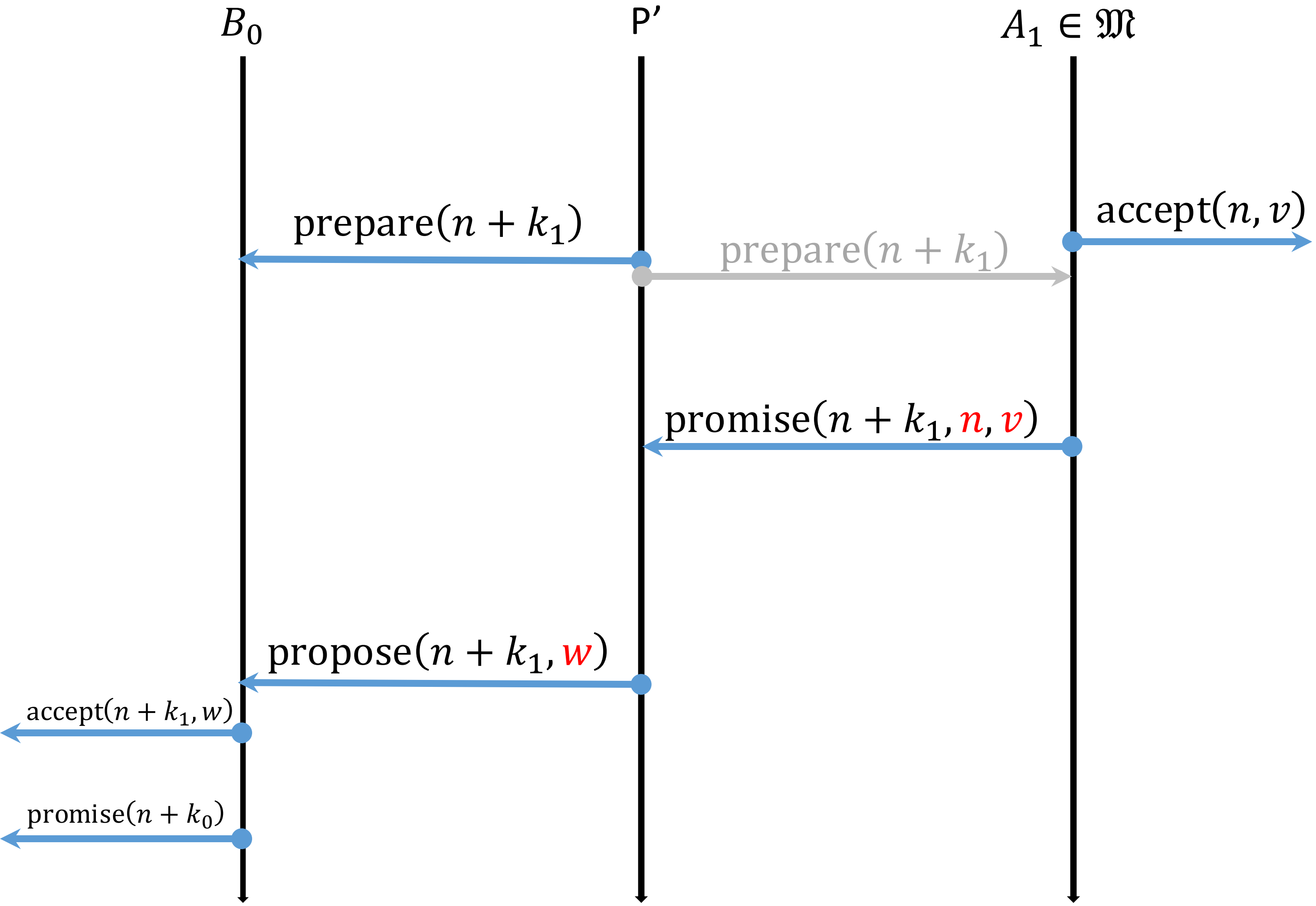

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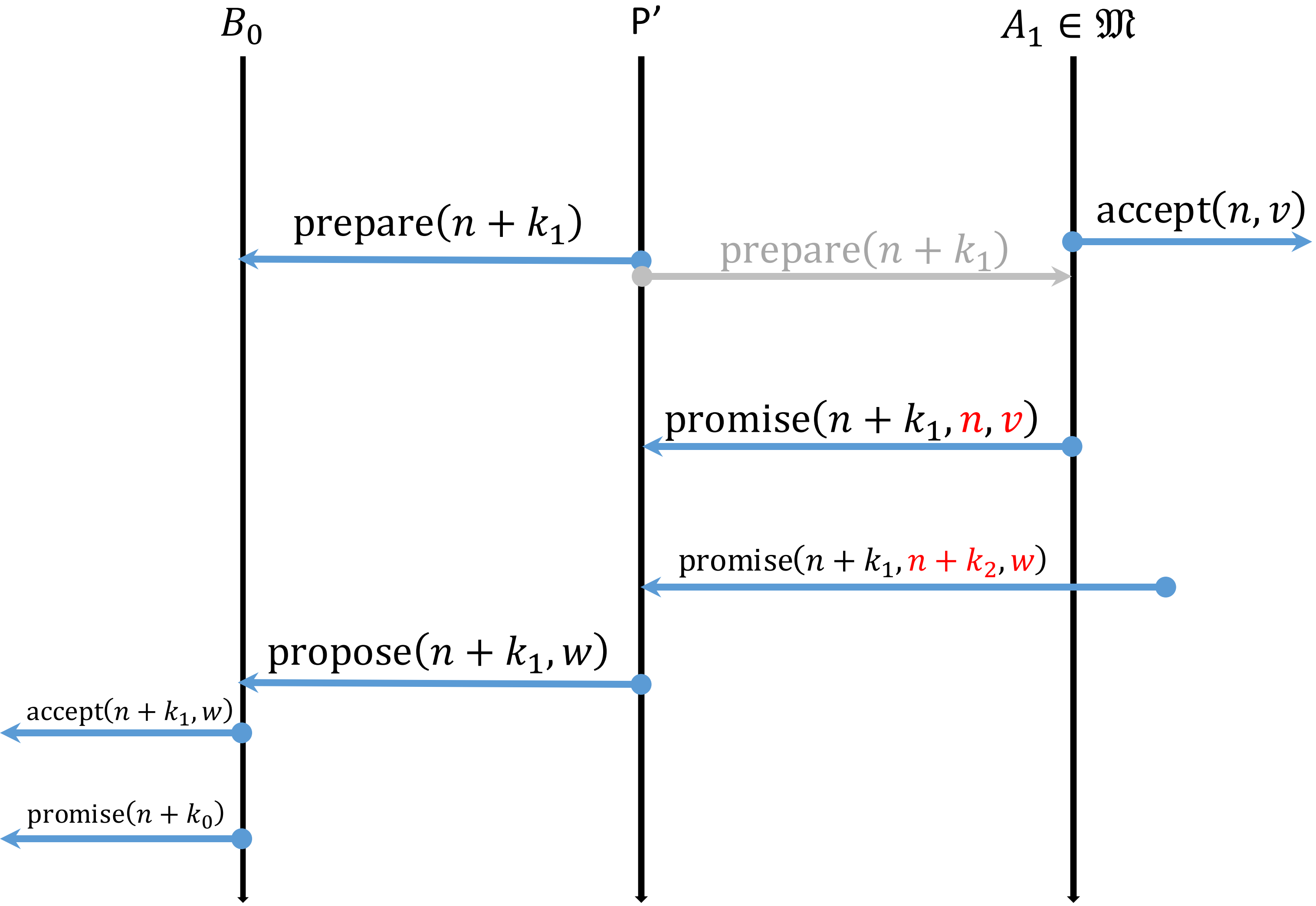

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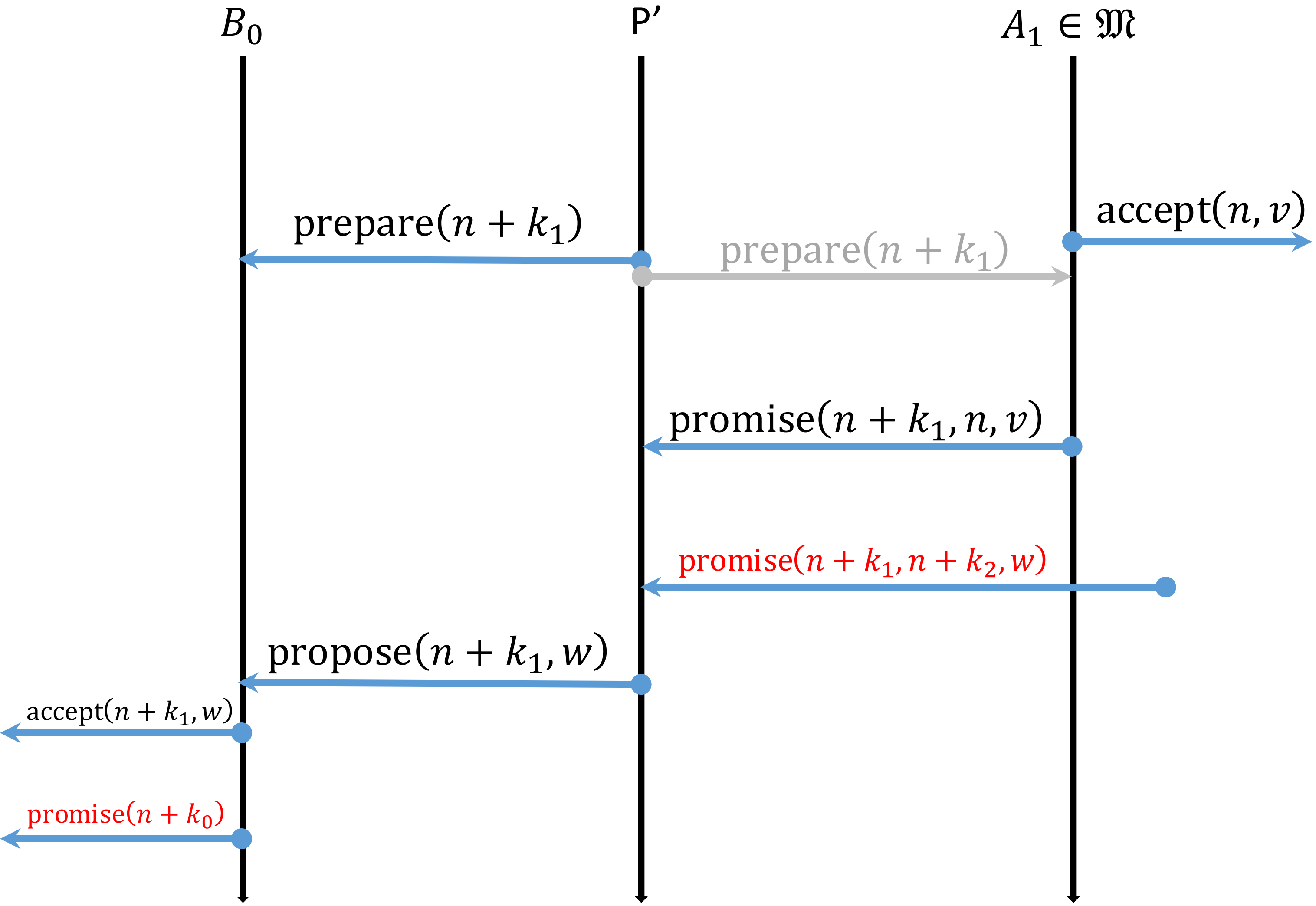

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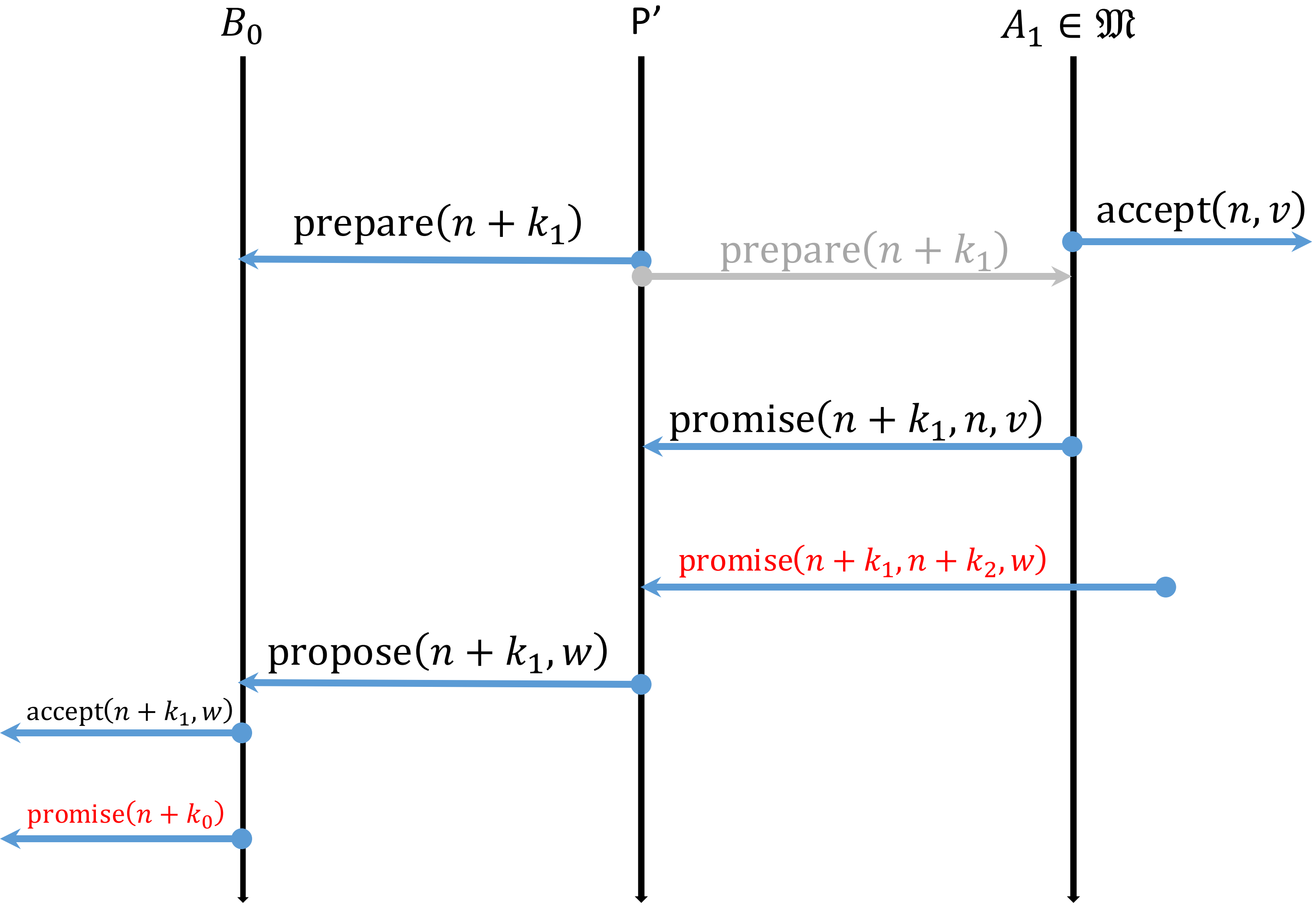

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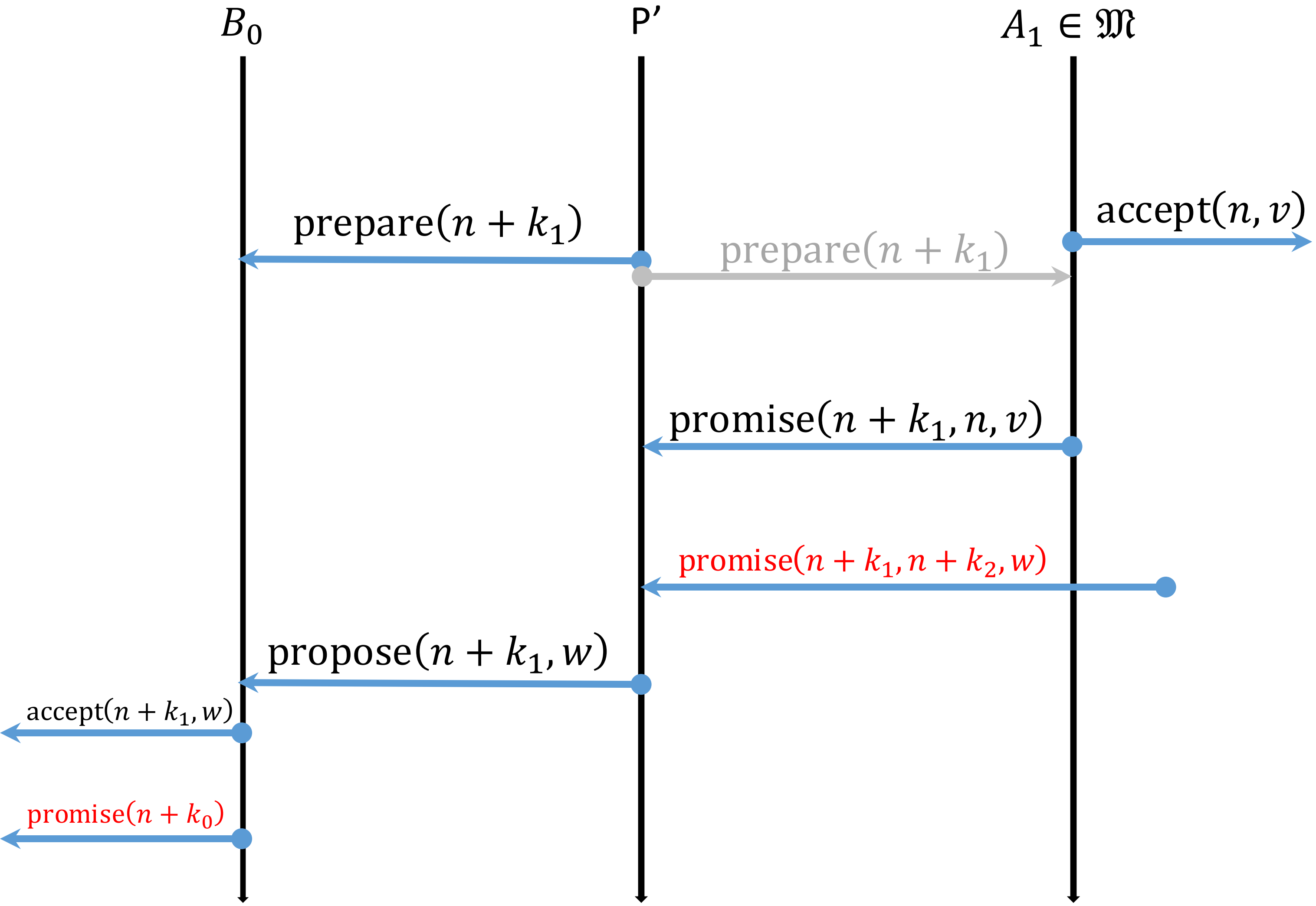

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If an acceptor replied $\mathrm{accept}(n, v)$, it can no longer reply $\mathrm{accept}(n+k_0, w)$.

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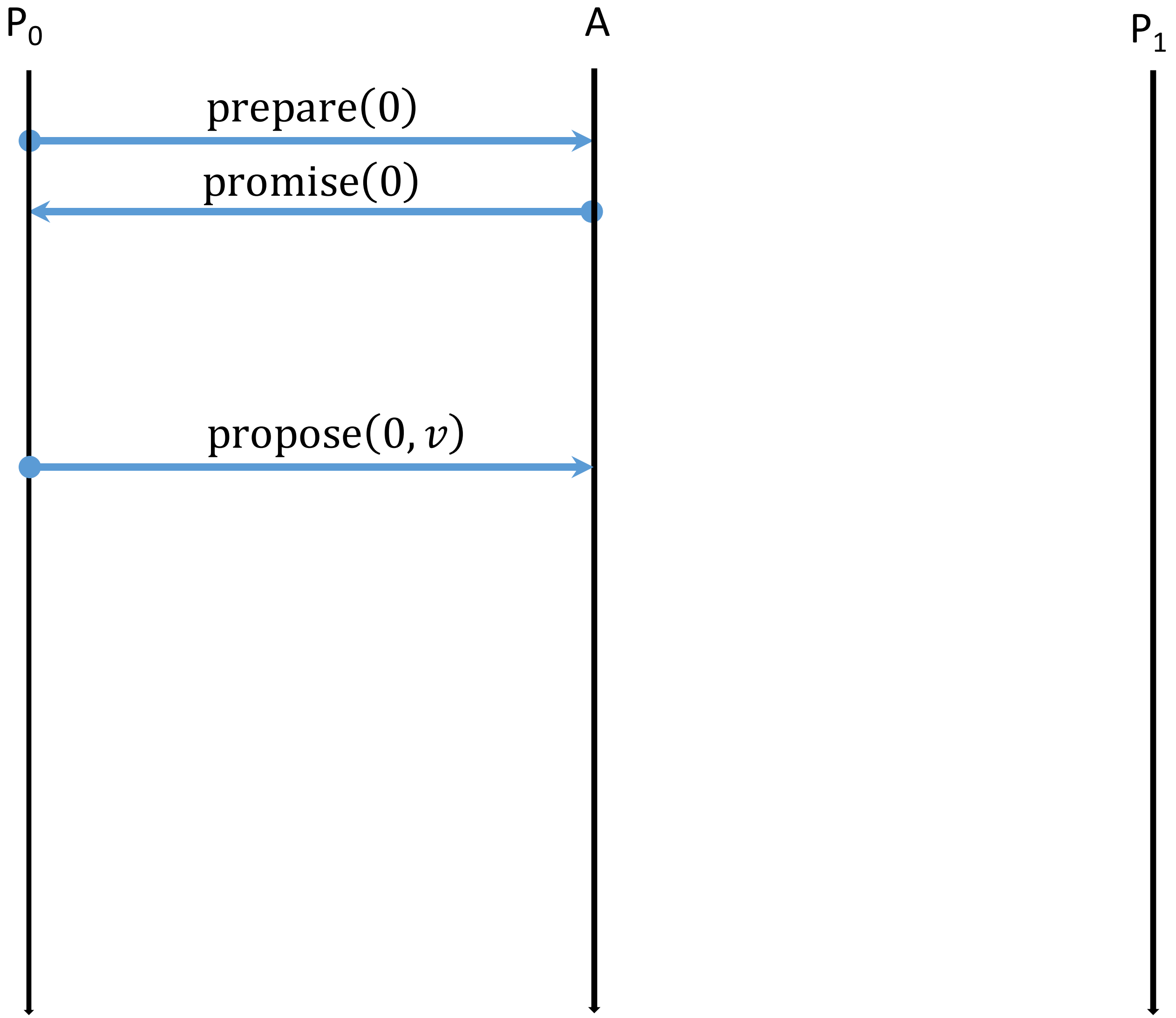

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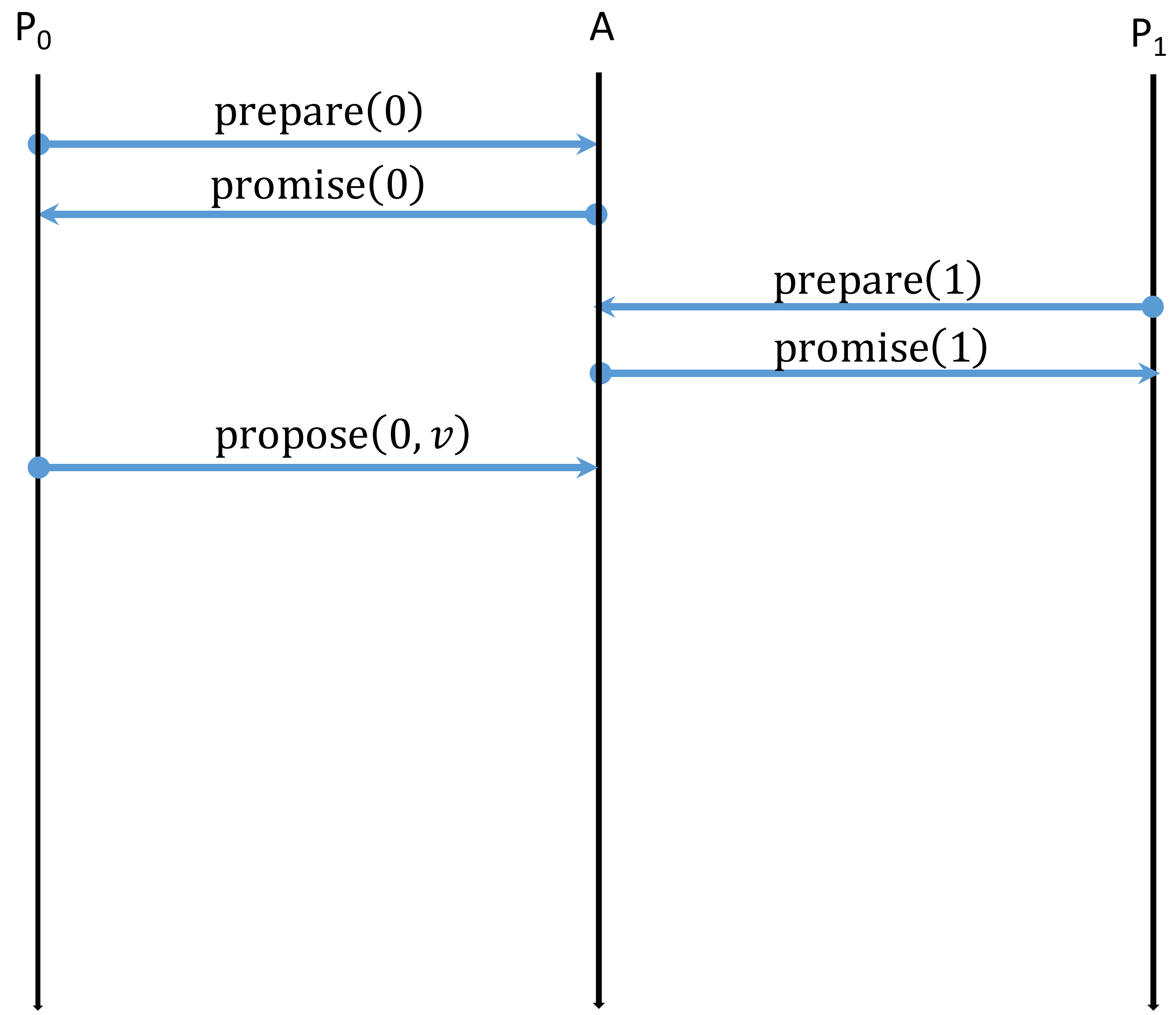

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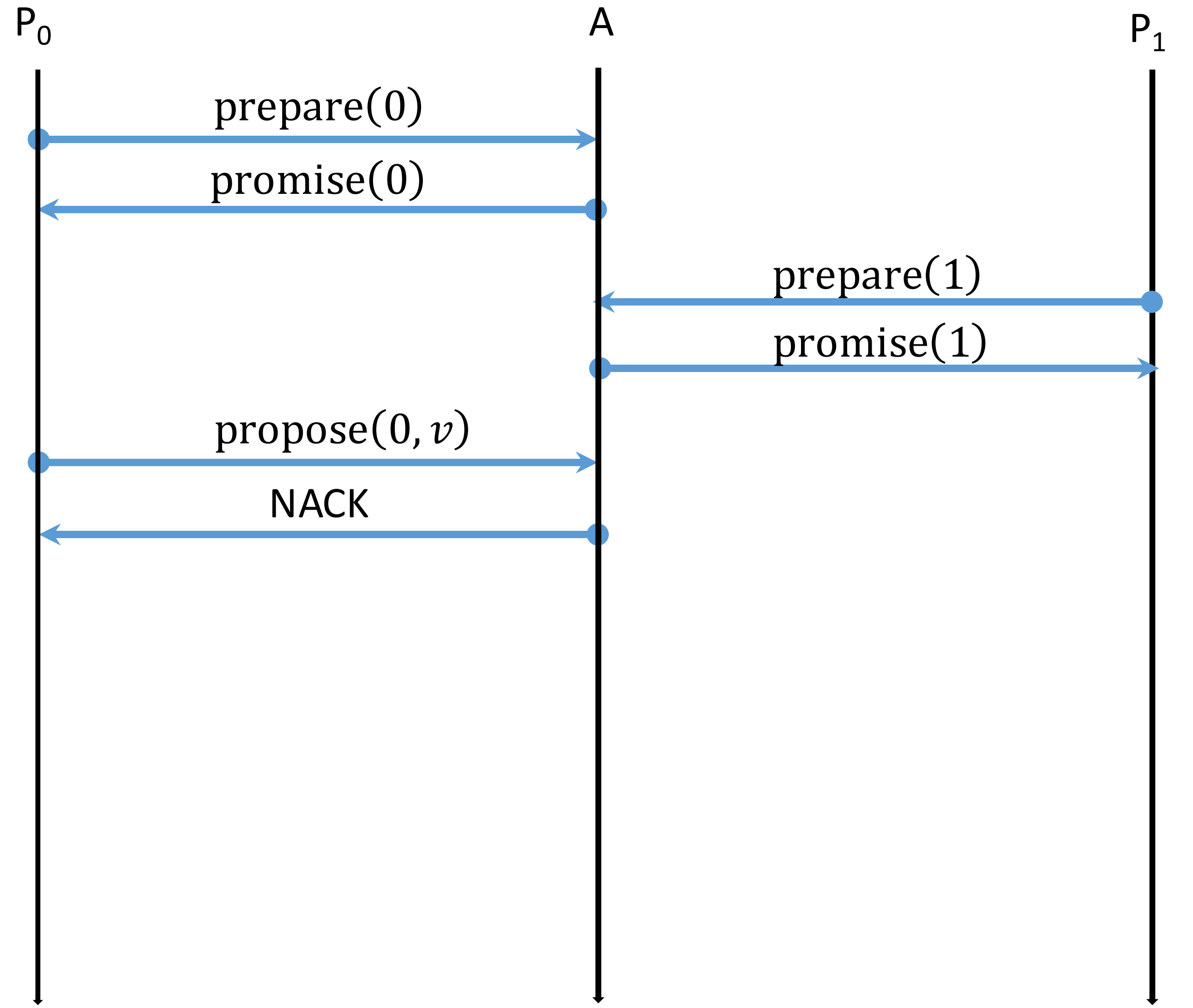

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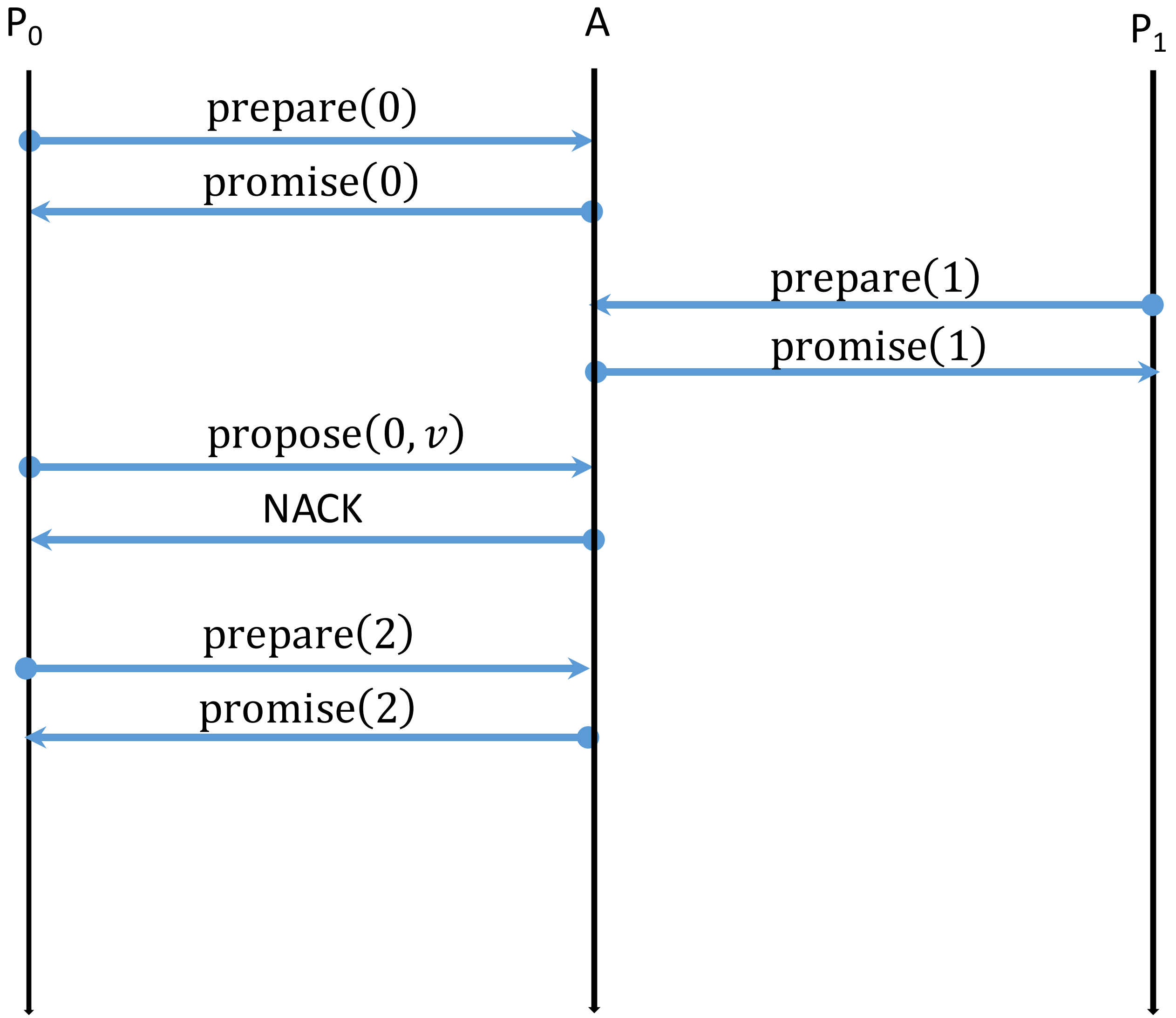

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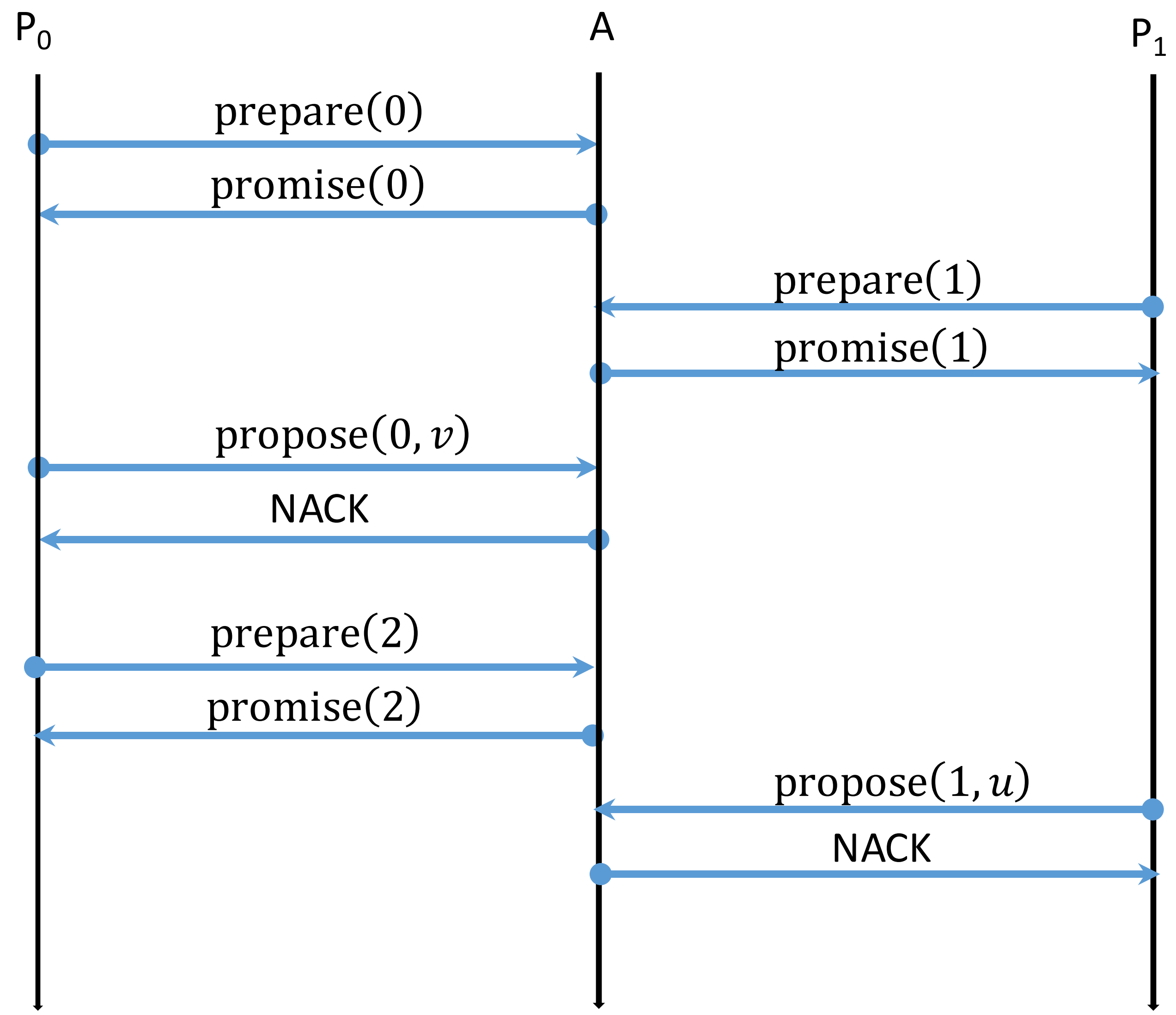

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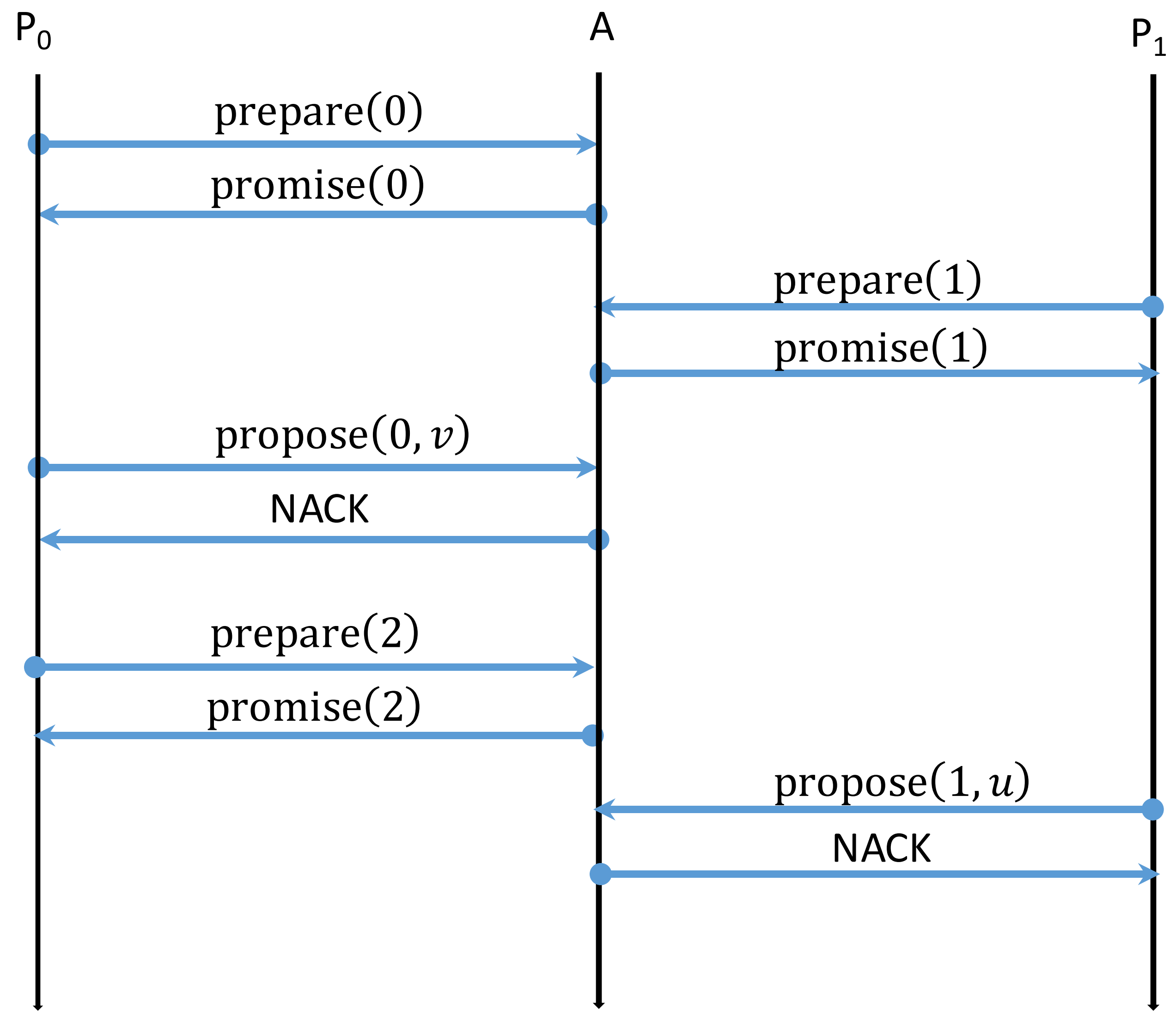

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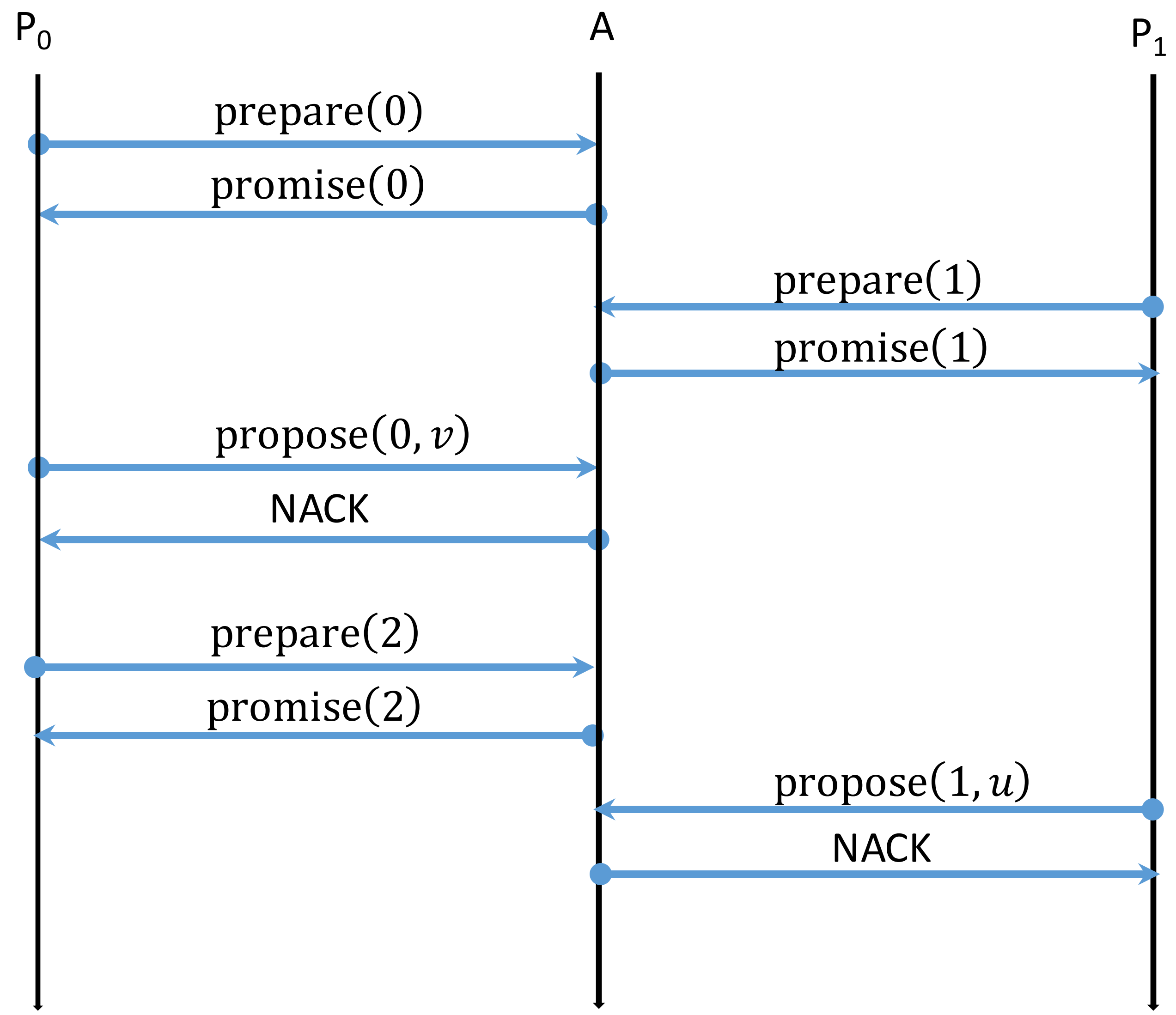

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In practice, this problem can be solved by electing one process to issue all proposals.

The election can be made sufficiently reliable by adding random delays to candidate proposals.

Cf. jitter in exponential backoffs.

Wrong ways to handle FS corruption

The paper [1] ran an experiment where the data of the following applications was located on a file system that would randomly corrupt the content of blocks:

- Redis,
- ZooKeeper,
- Cassandra,
- Kafka,
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[1] https://www.usenix.org/system/files/conference/fast17/fast17-ganesan.pdf
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Mistakes in Redis and Cassandra highlight the importance of the model of faults that PAXOS protects from.
PAXOS assumes fail-stop participants and a network that does not corrupt messages.

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3. There must be a way to add and delete cluster nodes.
4. The FSM log cannot grow infinitely long. Periodically, one must make snapshots of the FSM and truncate the journal.

To read

1. Distributed consensus revised.
   https://www.cl.cam.ac.uk/techreports/UCAM-CL-TR-935.pdf
2. PAXOS made live.
   https://www.cs.utexas.edu/users/lorenzo/corsi/cs380d/papers/paper2-1.pdf