

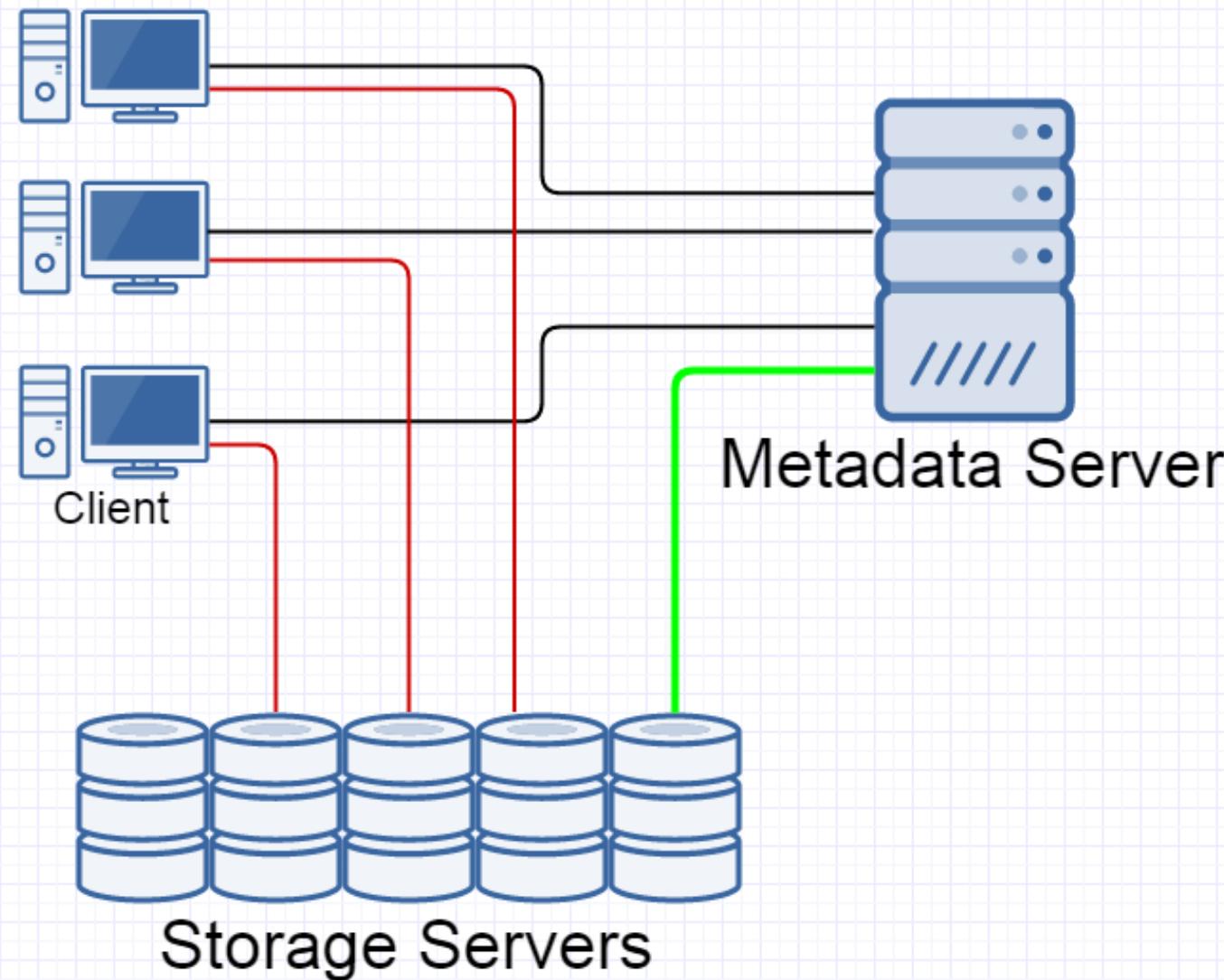
The basics of file systems



Consensus in a distributed system

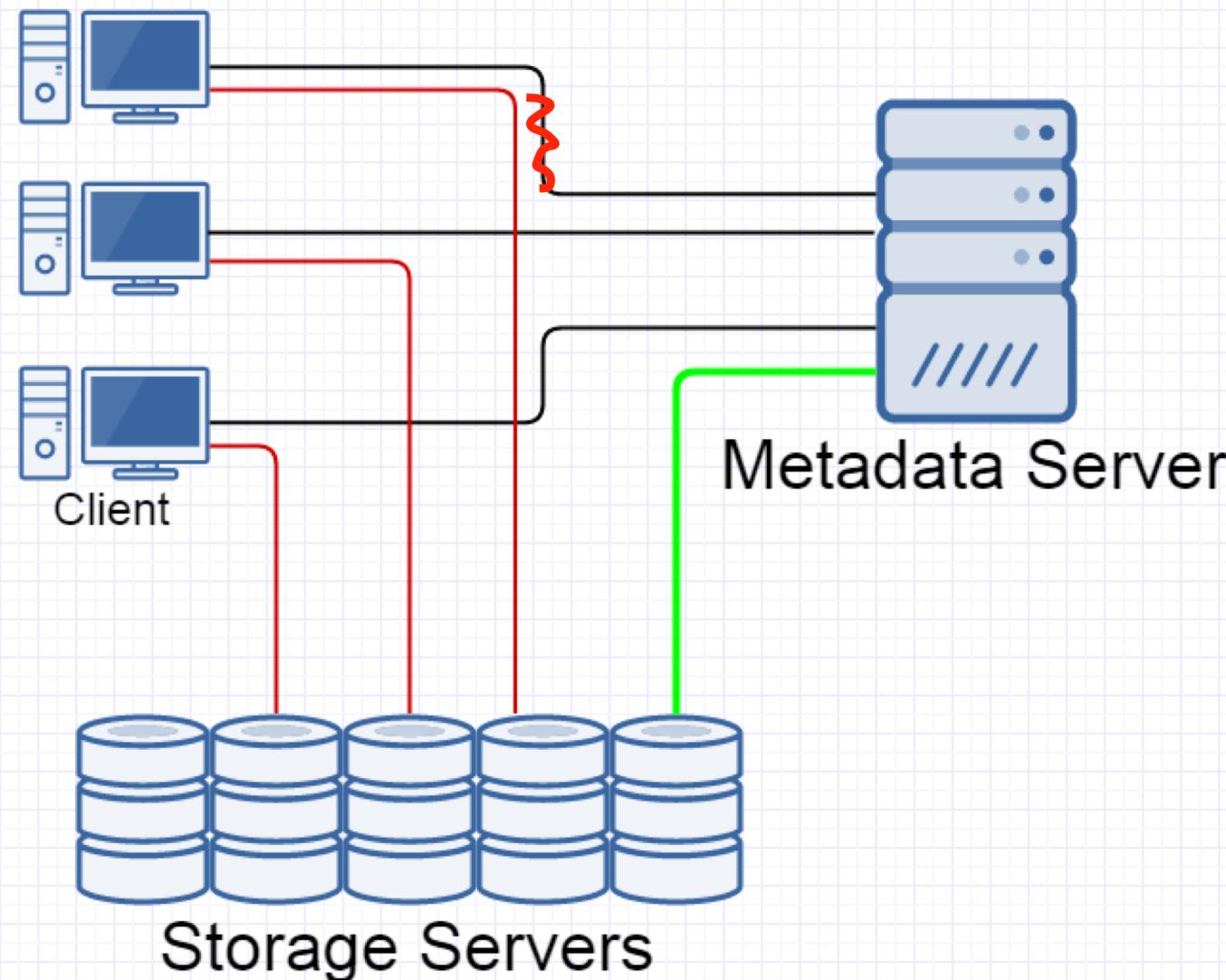
Today we are going to see how to implement a reliable distributed FSM.

A reminder about Parallel NFS



When a client opens a file, the metadata server sends it a “file layout”. It describes which storage server contains the file, and what protocol that server uses.

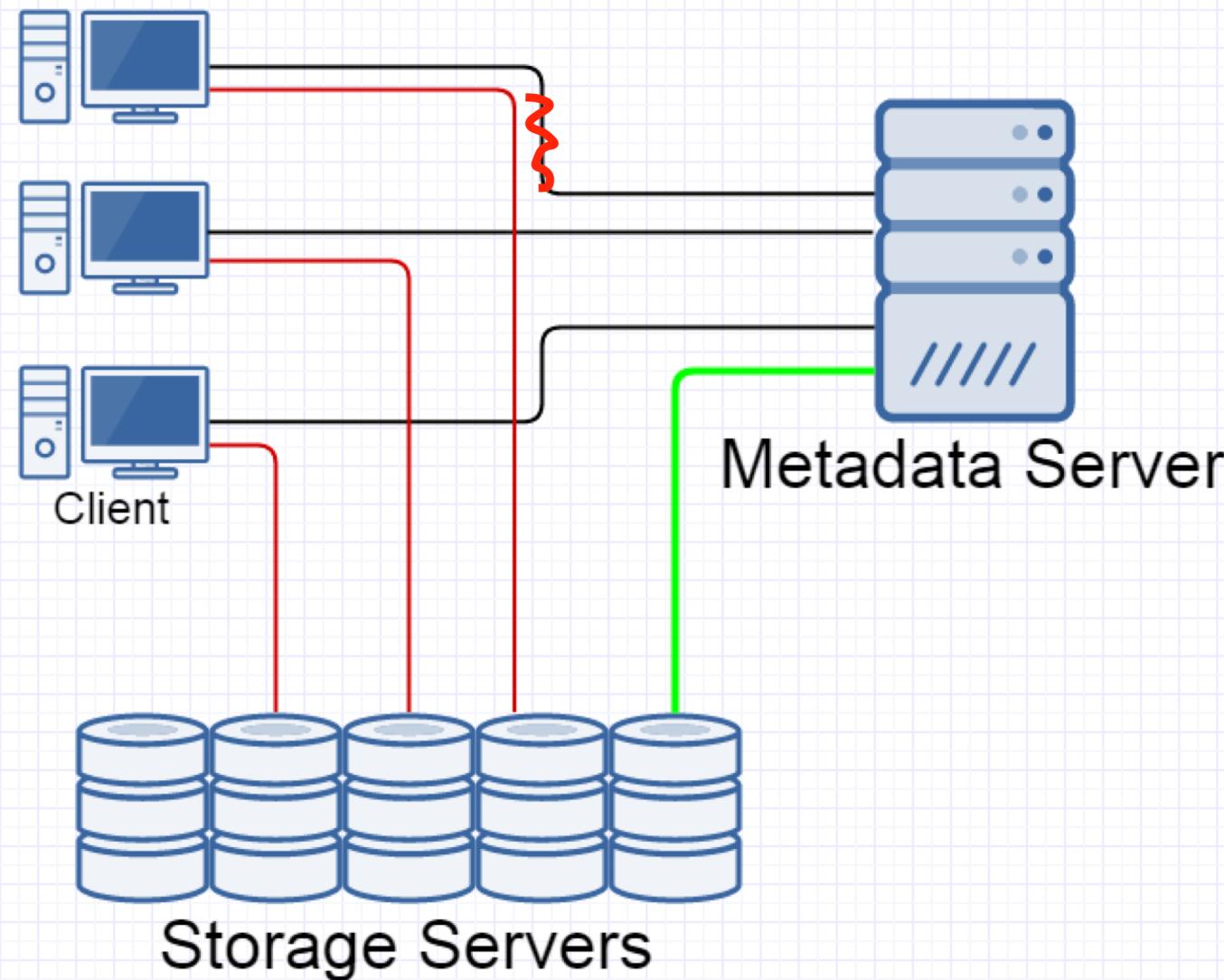
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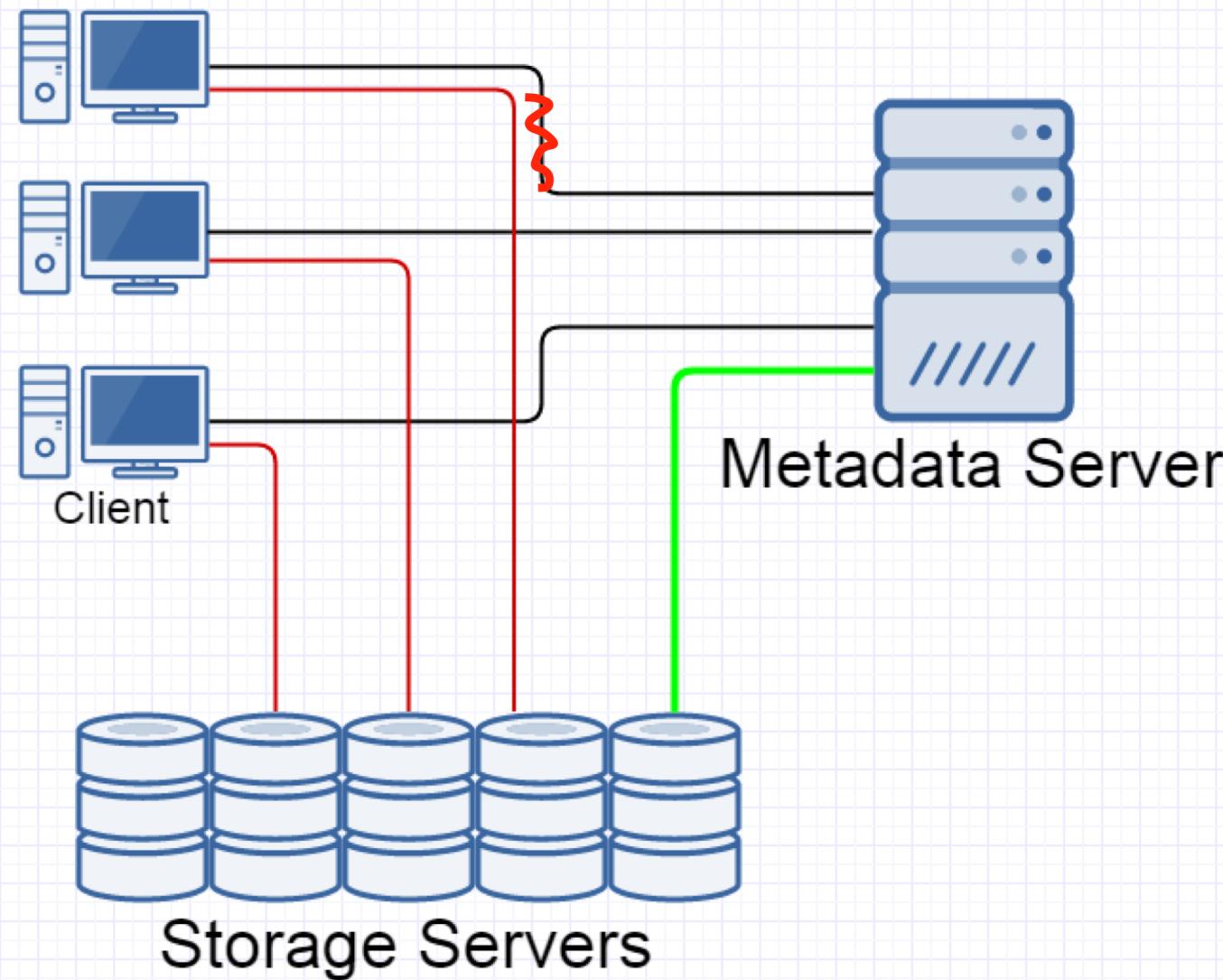


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A solution by NFSv4.1: the metadata server assigns a layout lease to each file layout. A layout lease has a period when the client may use the layout. If the client does not renew its layout lease, then the storage server stops accepting requests that the stale layout.

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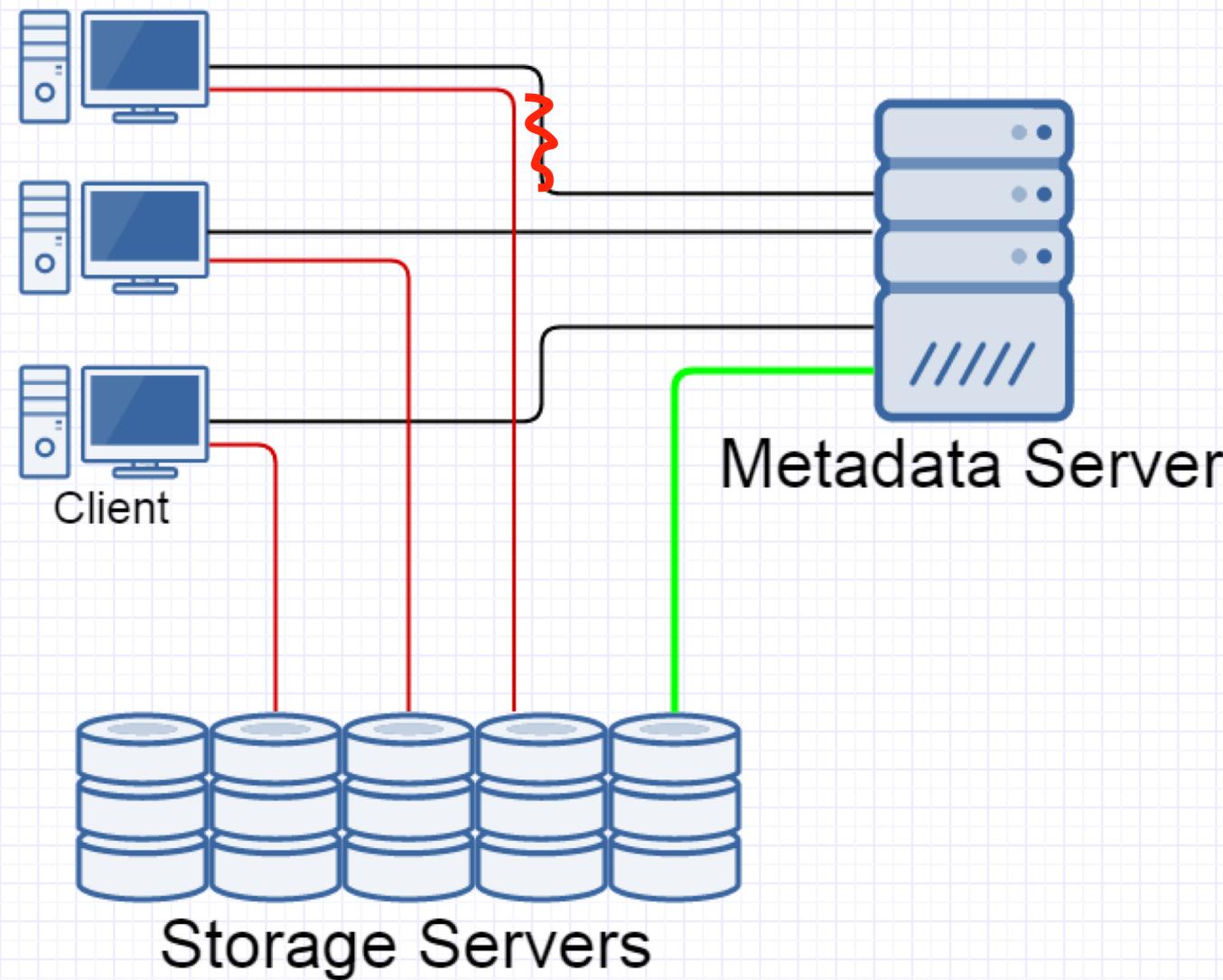
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Quiz: layout lease may not rely on clock of different clients being synchronised. How can we implement that?

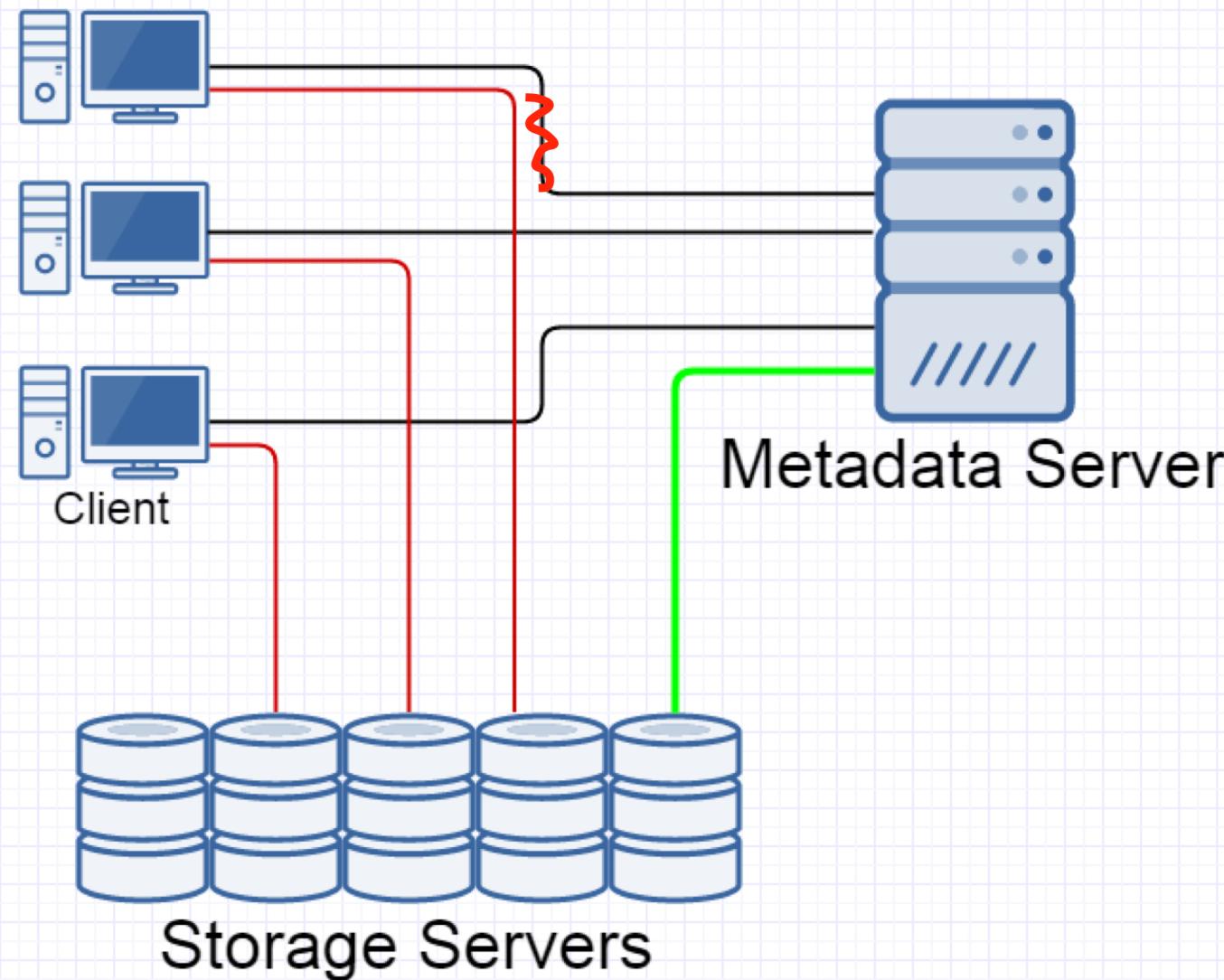
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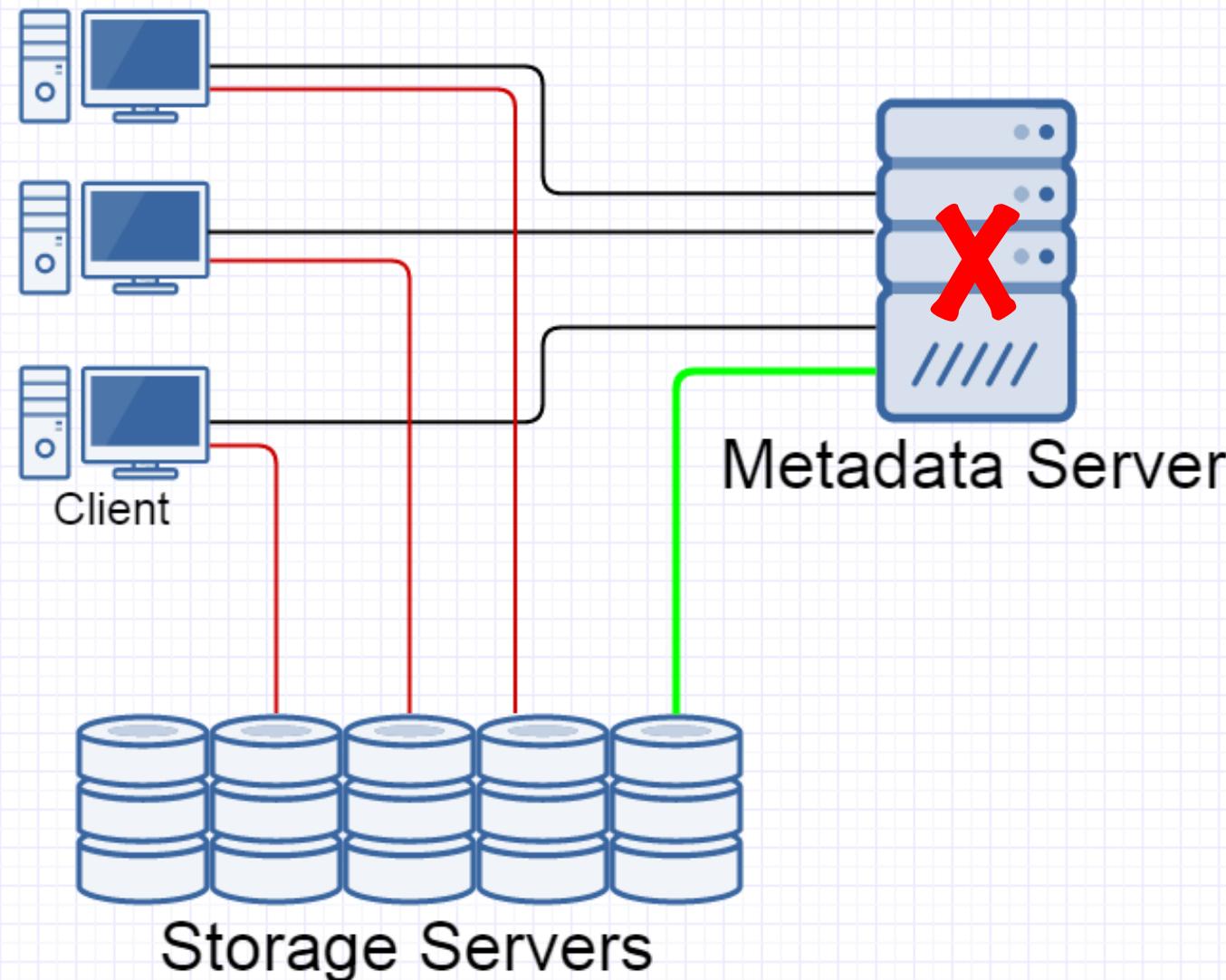


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See also: client fencing.

A reminder about Parallel NFS



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?

Consensus in a distributed system

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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 their journals.

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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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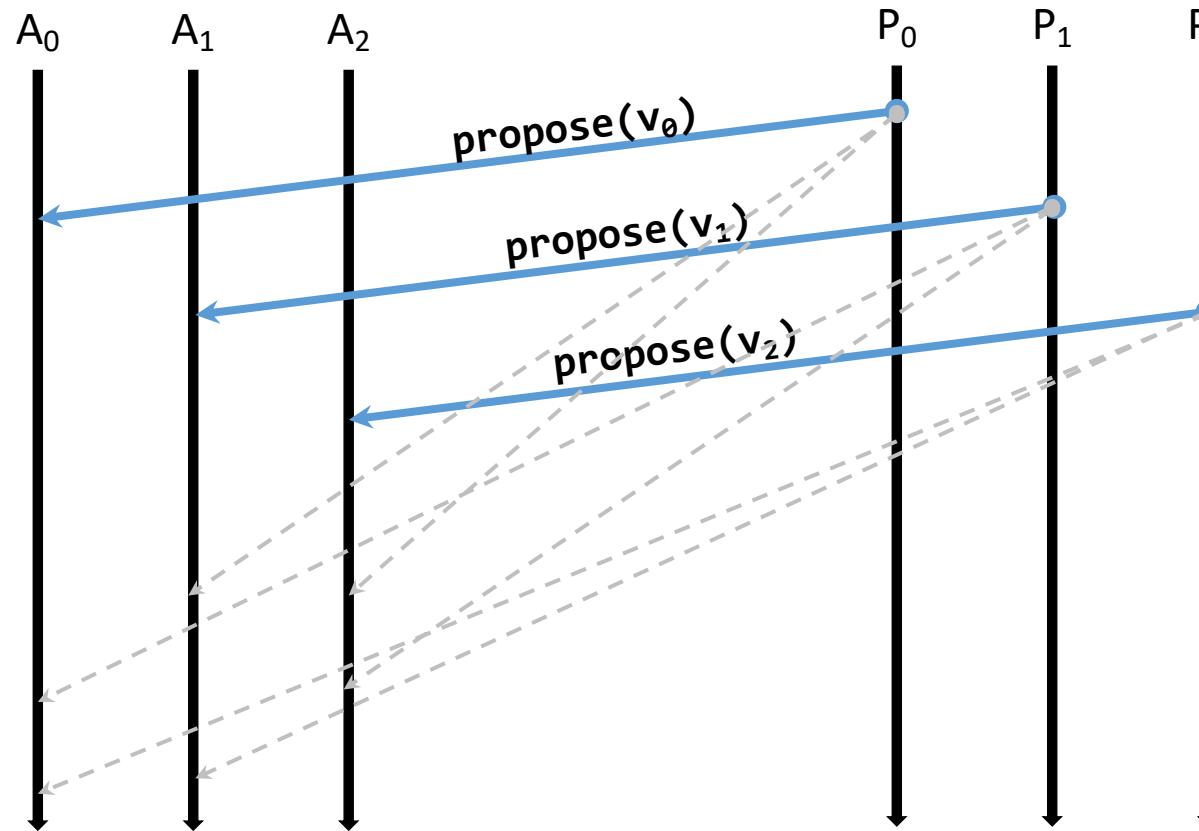
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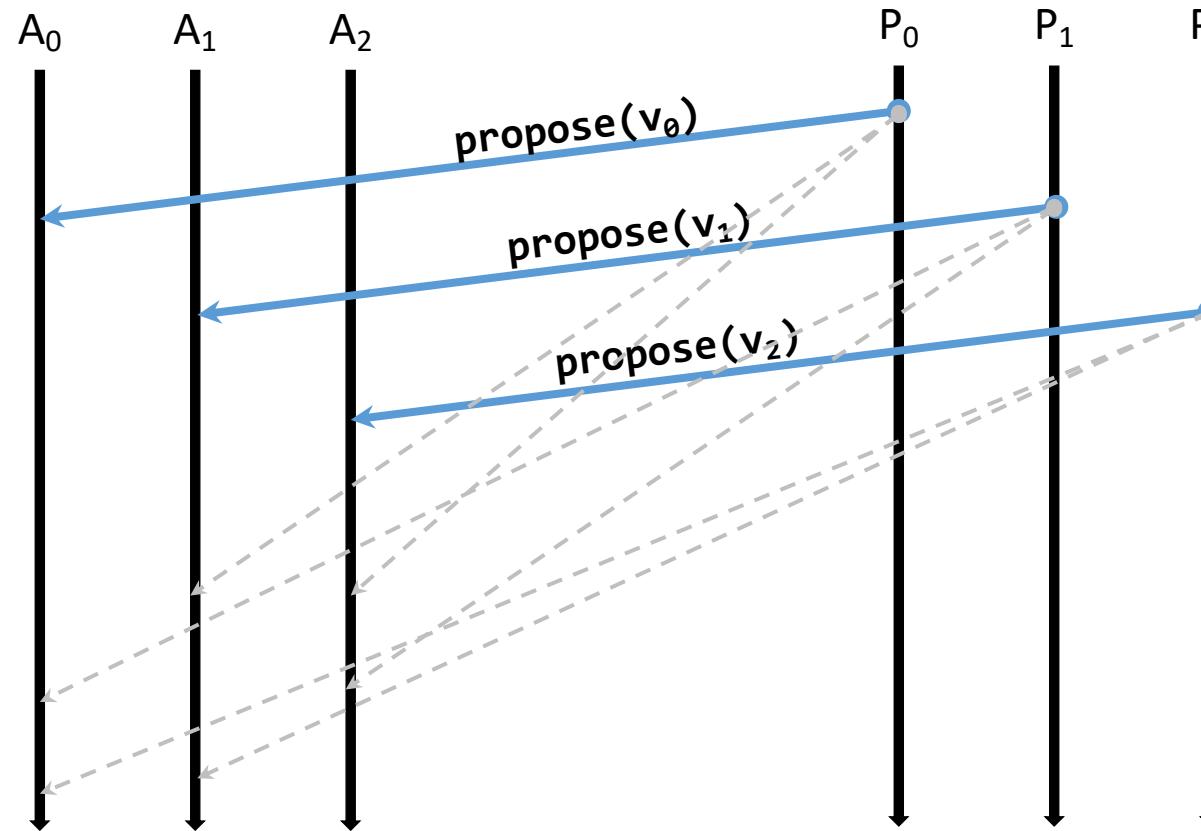


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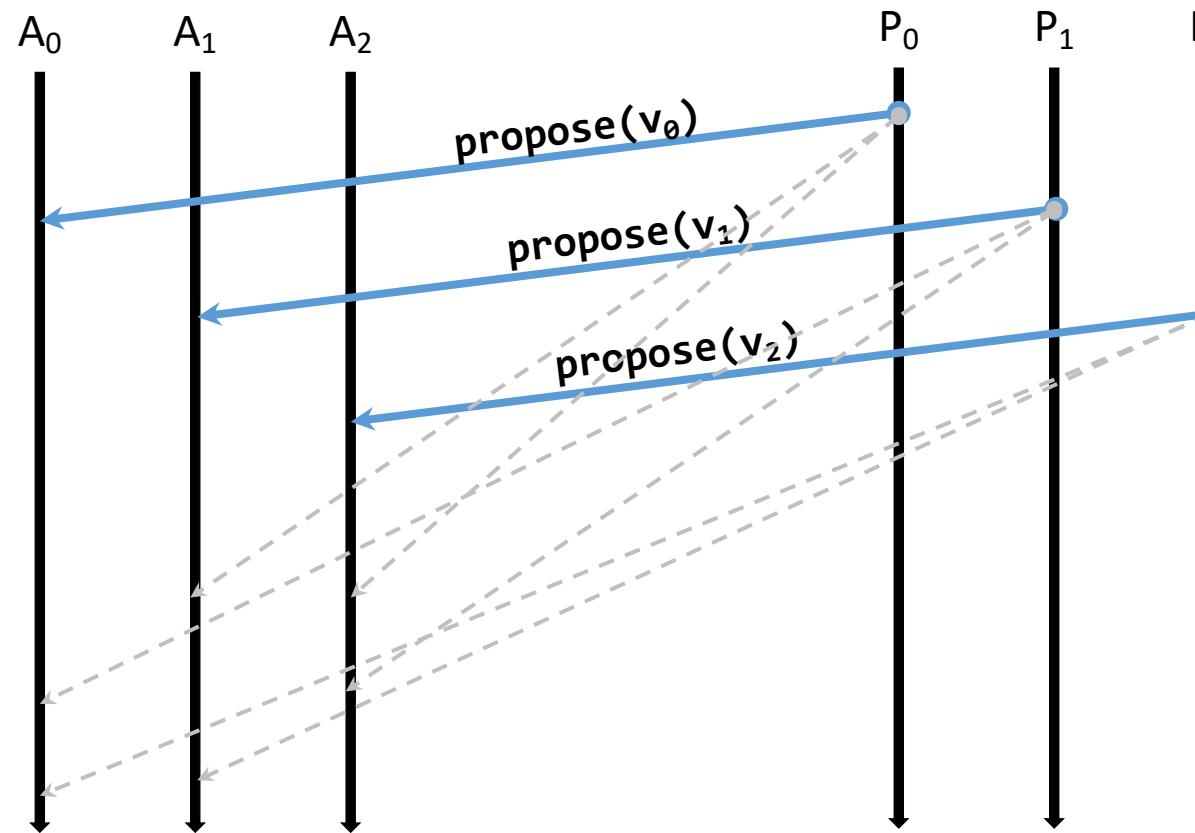
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Idea: one must not propose plain values v , but must propose pairs (n, v) where n is a natural number, the epoch number of a proposer. Acceptors must accept pairs (n, v) and (n', v) with the same v .

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Requirement 2a: every proposer issues requests $\text{propose}(n, v)$ with epoch numbers that are unique and ascending.

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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 $\{0, N, 2N, \dots\}$, $\{1, N + 1, 2N + 1, \dots\}$, ...

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Requirement 0': an acceptor accepts pairs that have the same value and ascending epoch numbers:

$(n_0, v), (n_1, v), \dots (n_k, v)$ with $n_0 < n_1 < \dots < n_k$.

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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 $\text{prepare}(n)$ 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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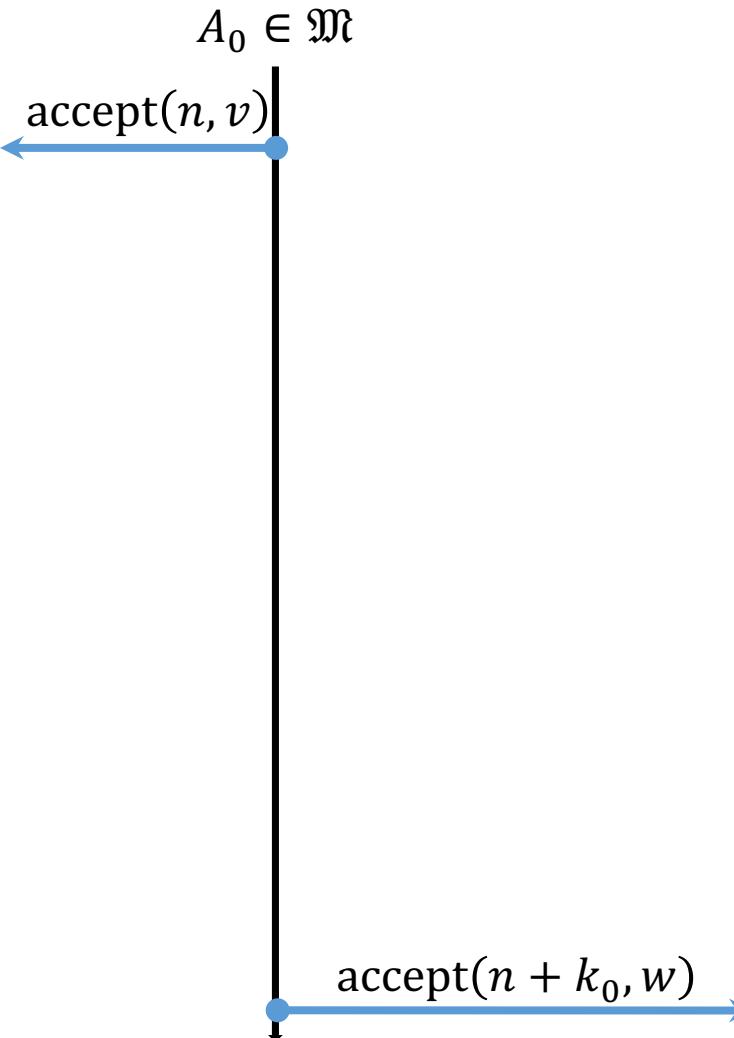
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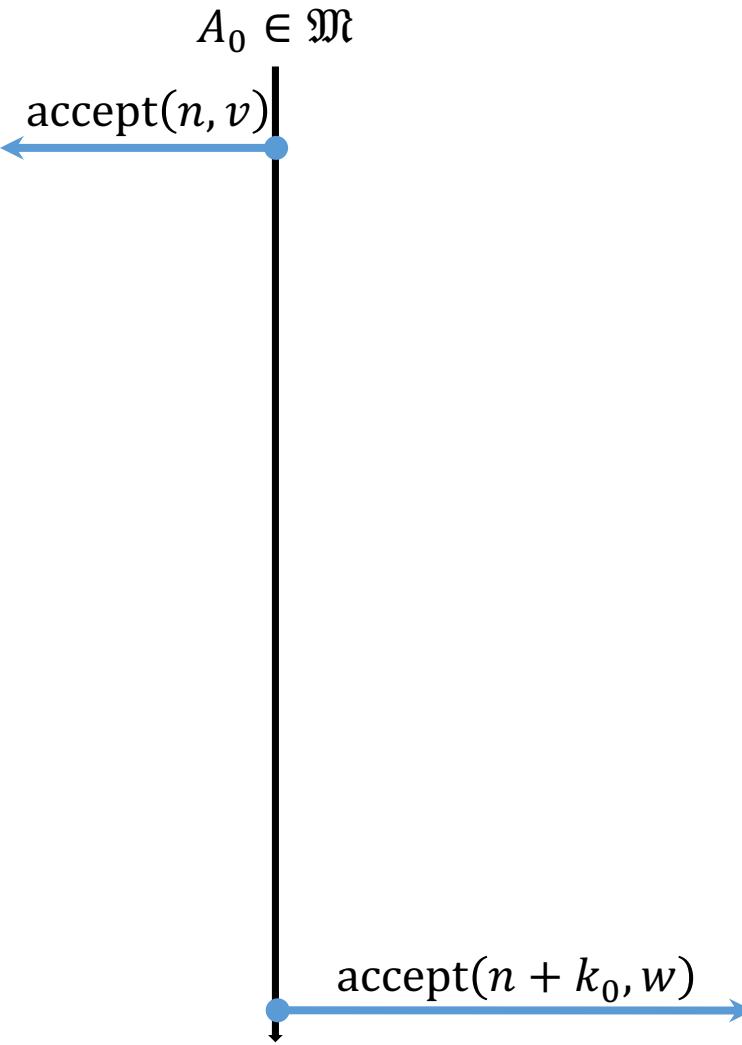


Remark: let us consider **the minimal epoch number** $n + k_0$ when some acceptor from \mathfrak{M} sent $\text{accept}(n + k_0, w)$ after having accepted (n, v) .

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

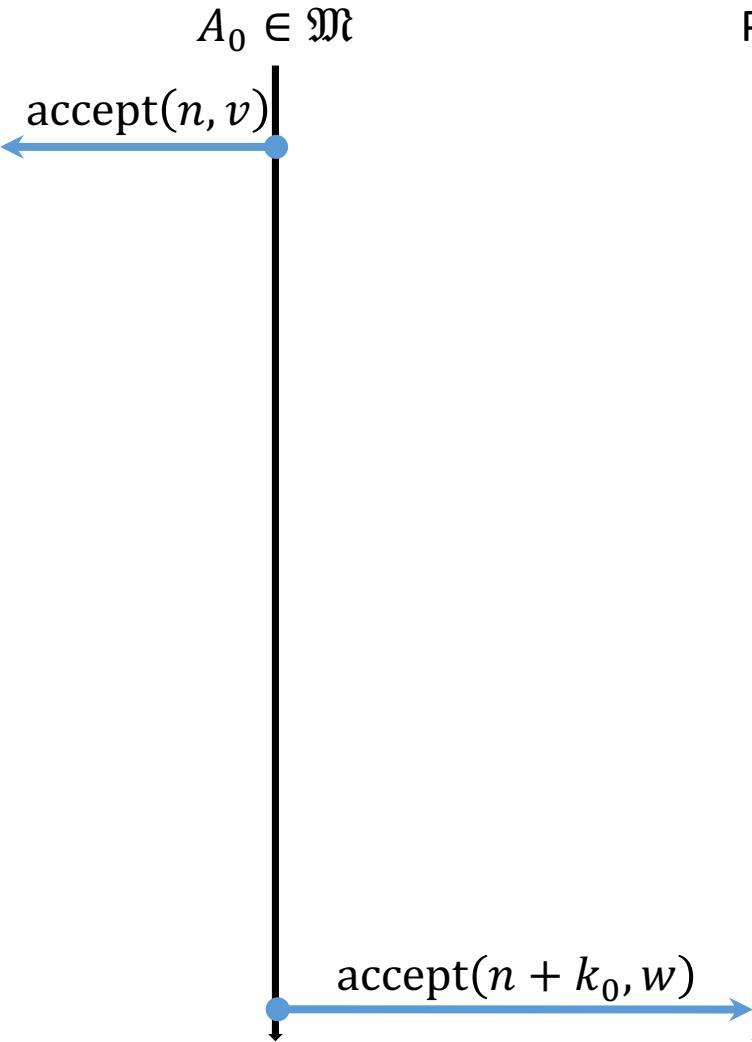
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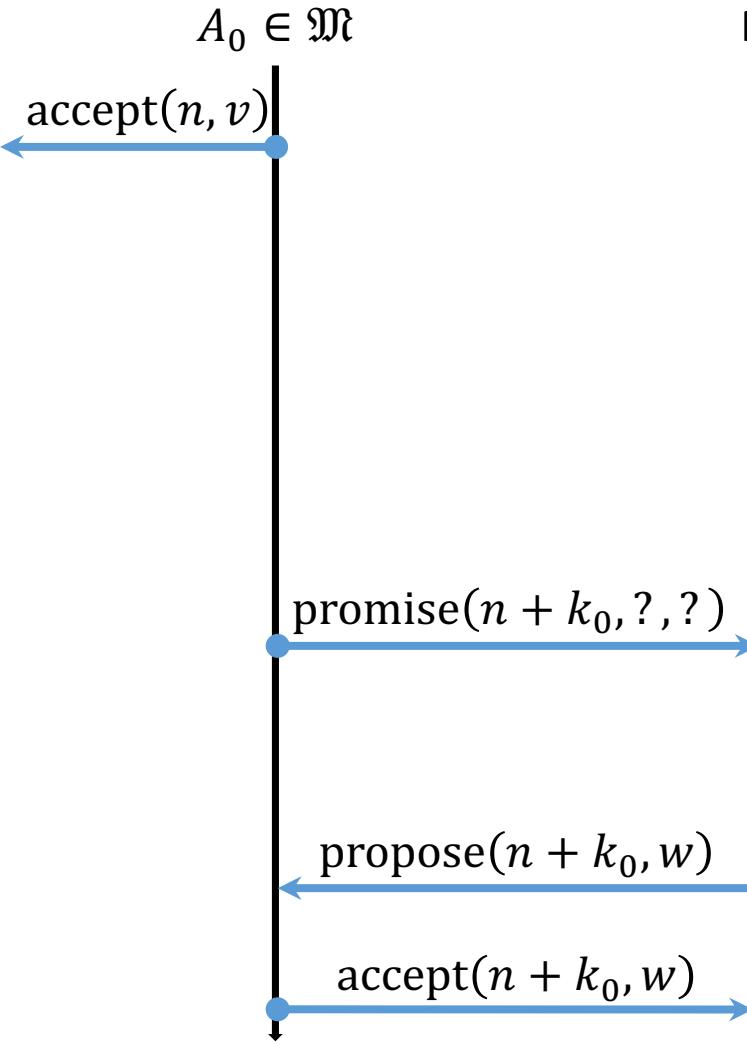
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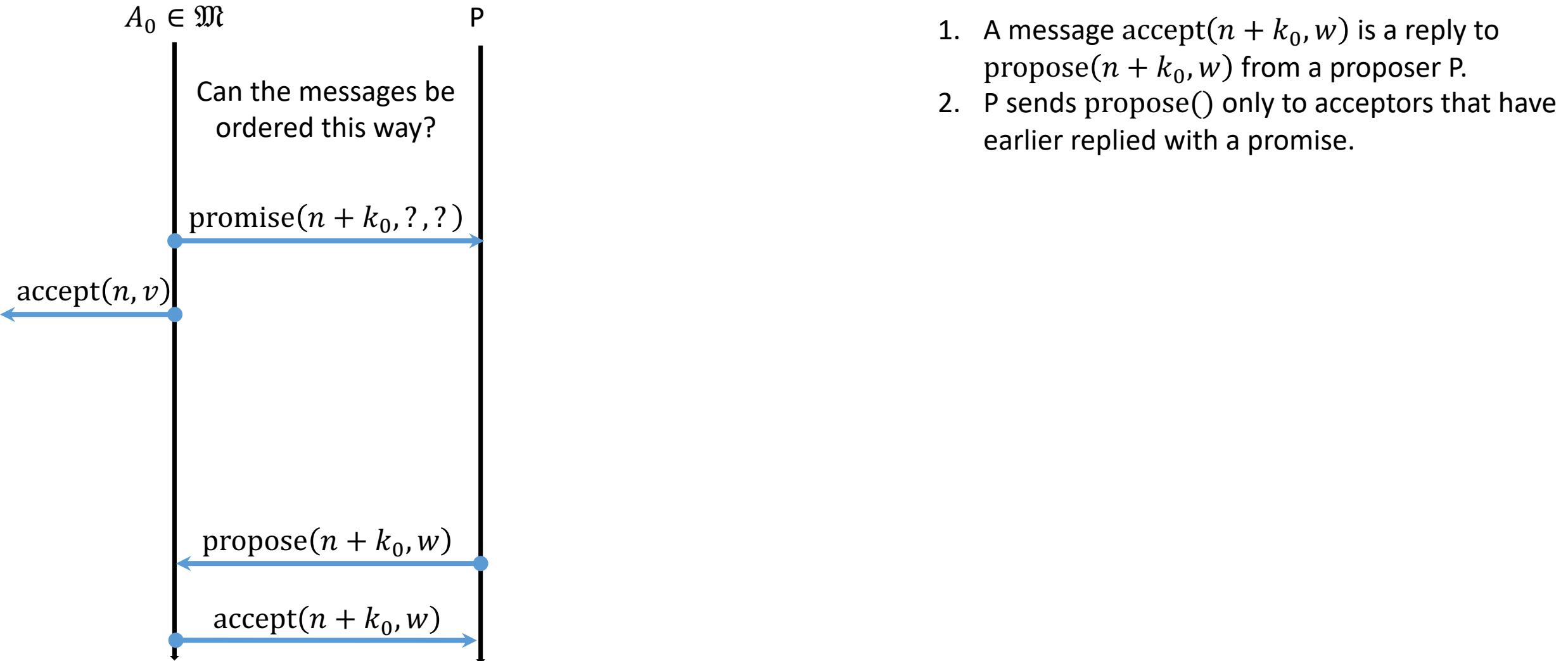
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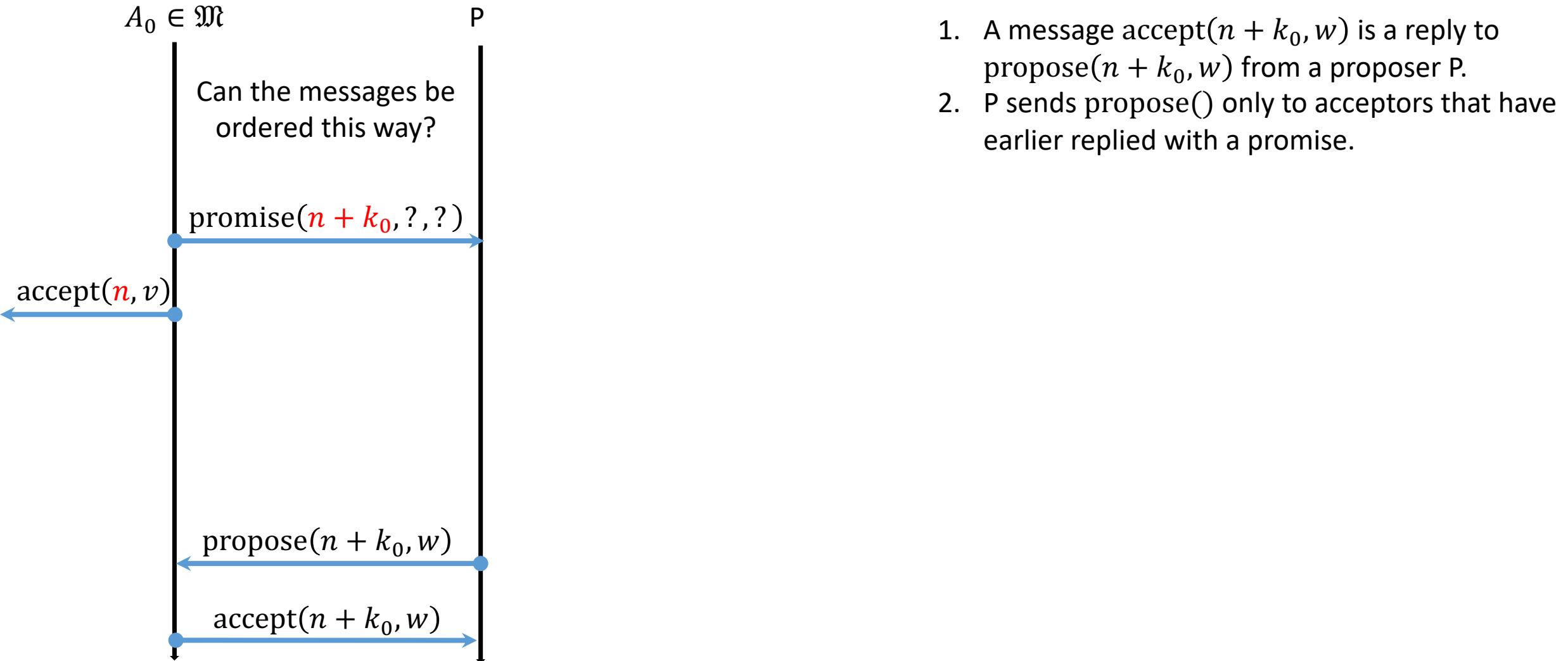
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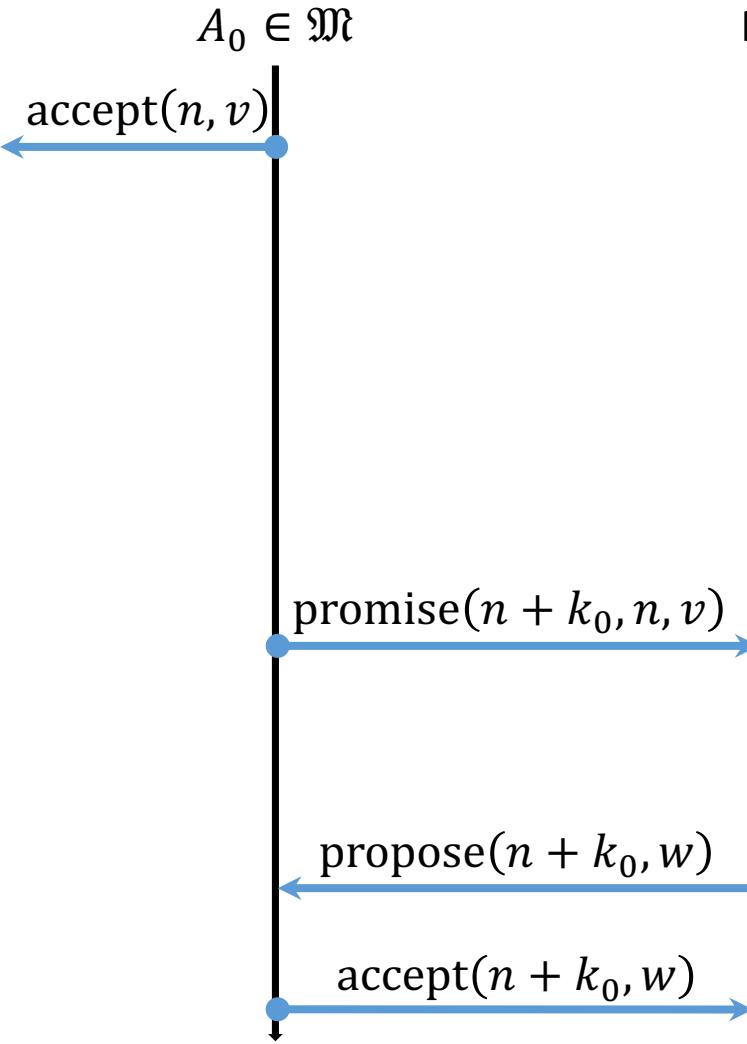
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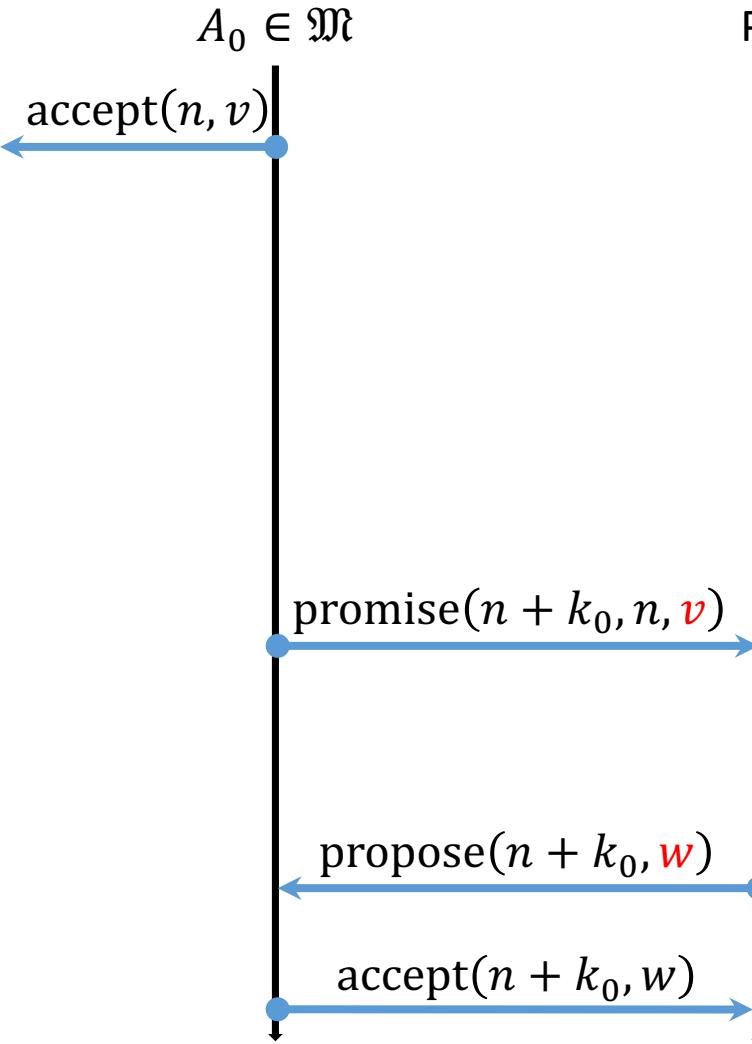
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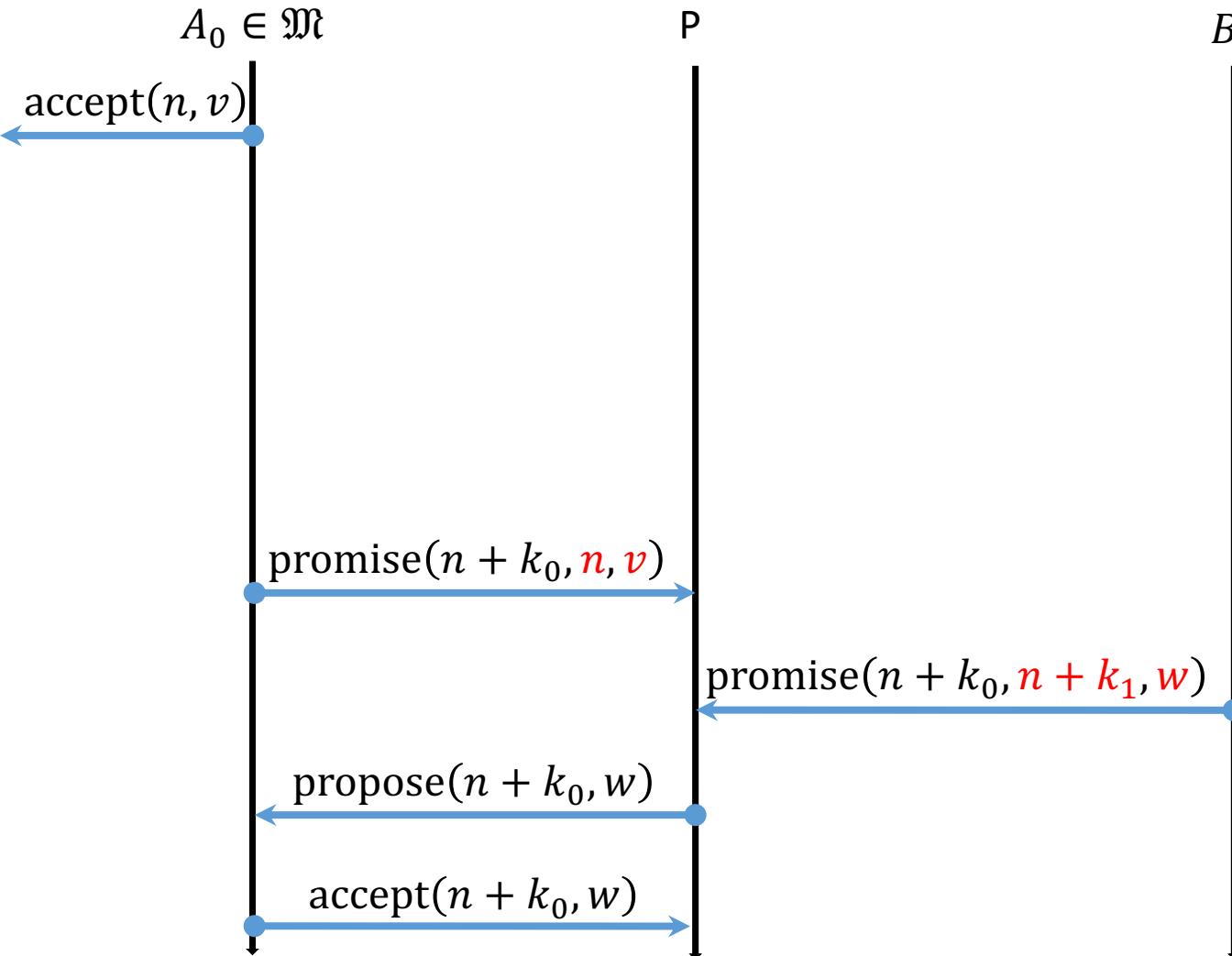
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2. P sends $\text{propose}()$ only to acceptors that have earlier replied with a promise.
3. P has received $\text{promise}(n + k_0, n, v)$. How can it be that P sent $\text{propose}(n + k_0, w)$?

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3. P has received $\text{promise}(n + k_0, n, v)$. How can it be that P sent $\text{propose}(n + k_0, w)$?

This is only possible if P received $\text{promise}(n + k_0, n + k_1, w)$ with $n < n + k_1 < n + k_0$.

Safety (only one value can be chosen)

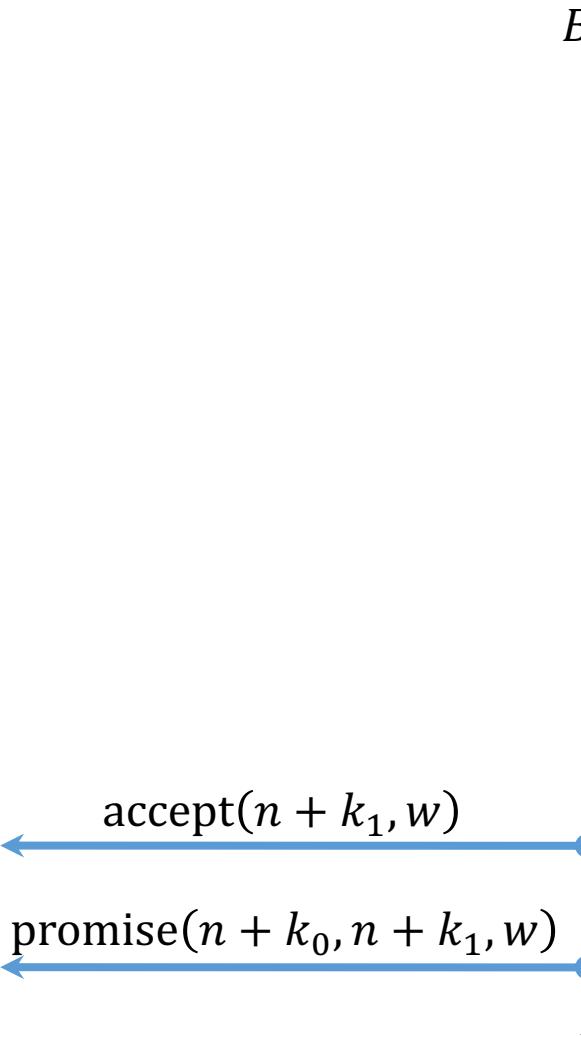
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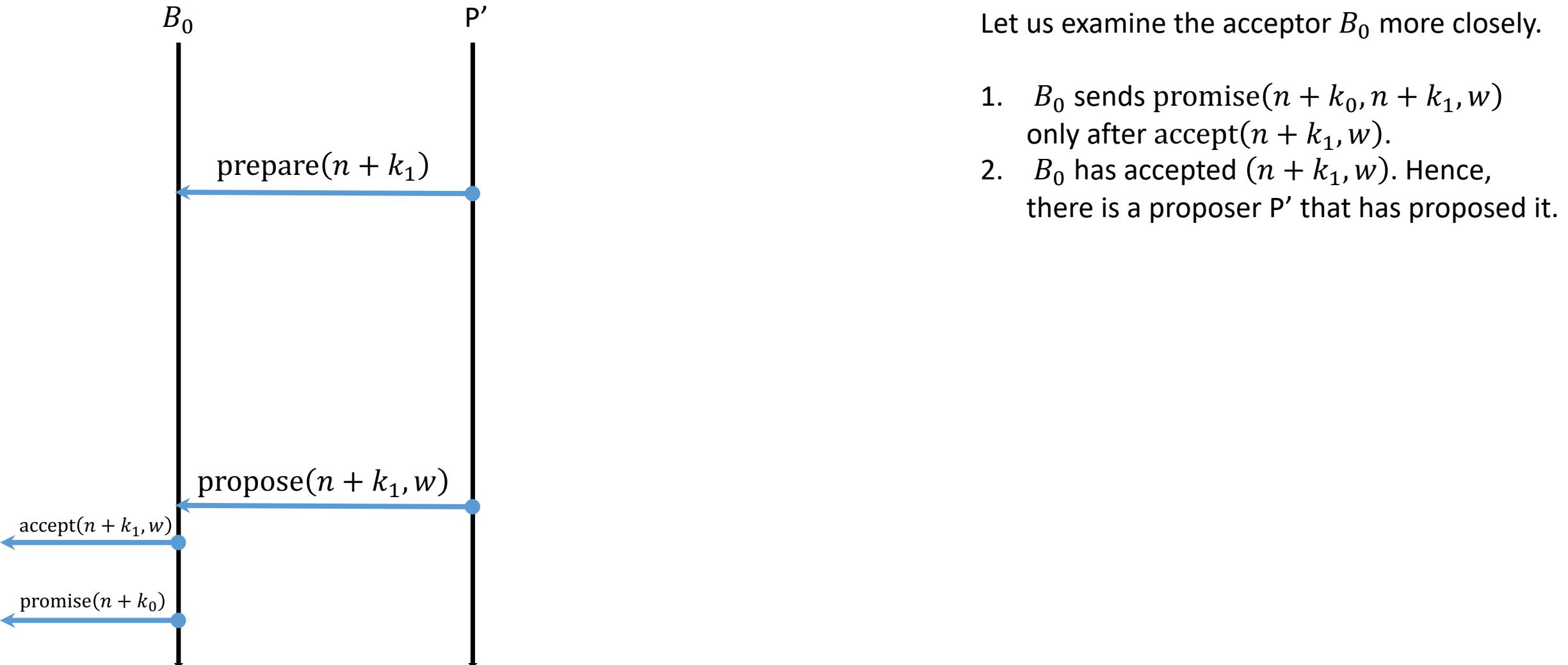


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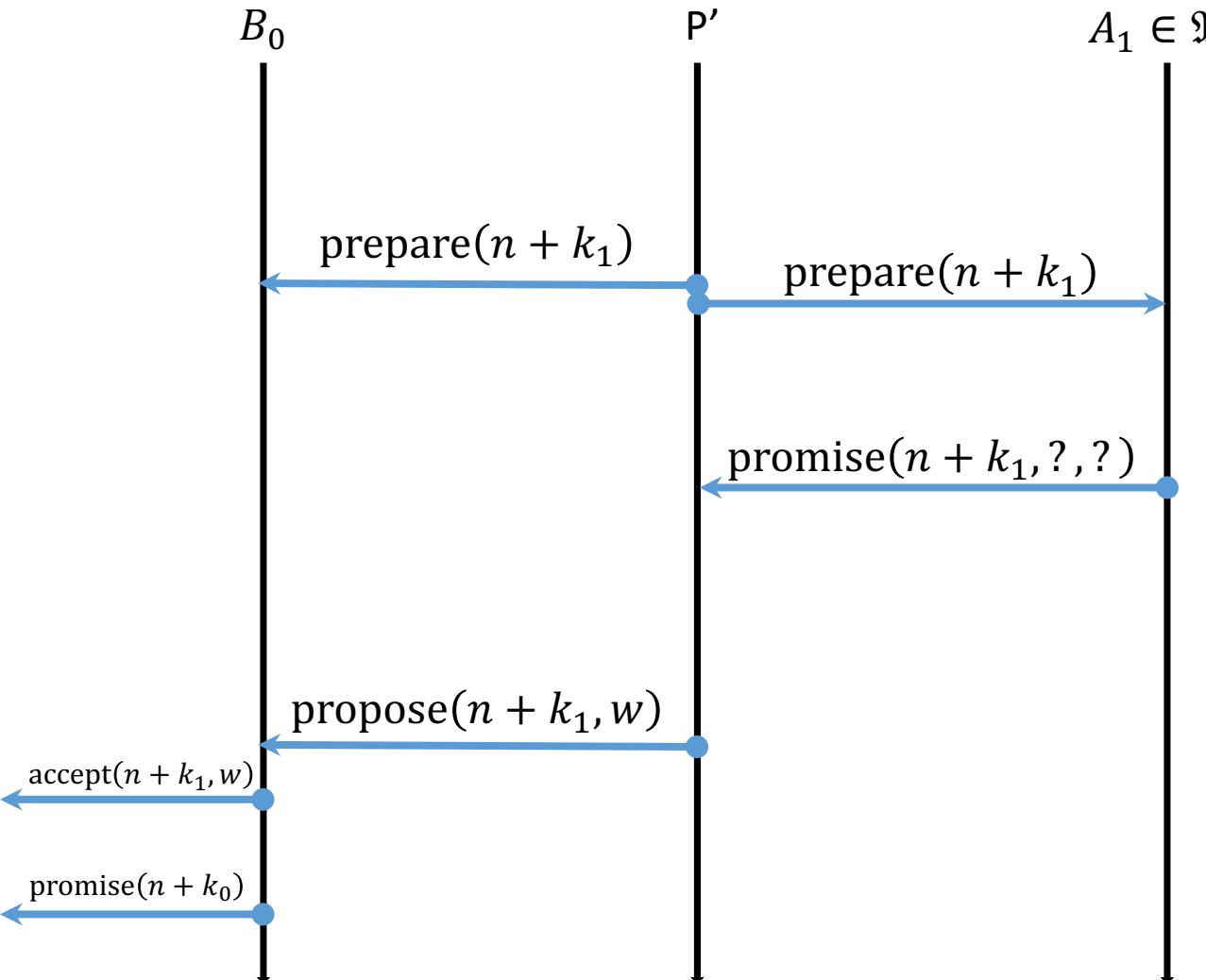
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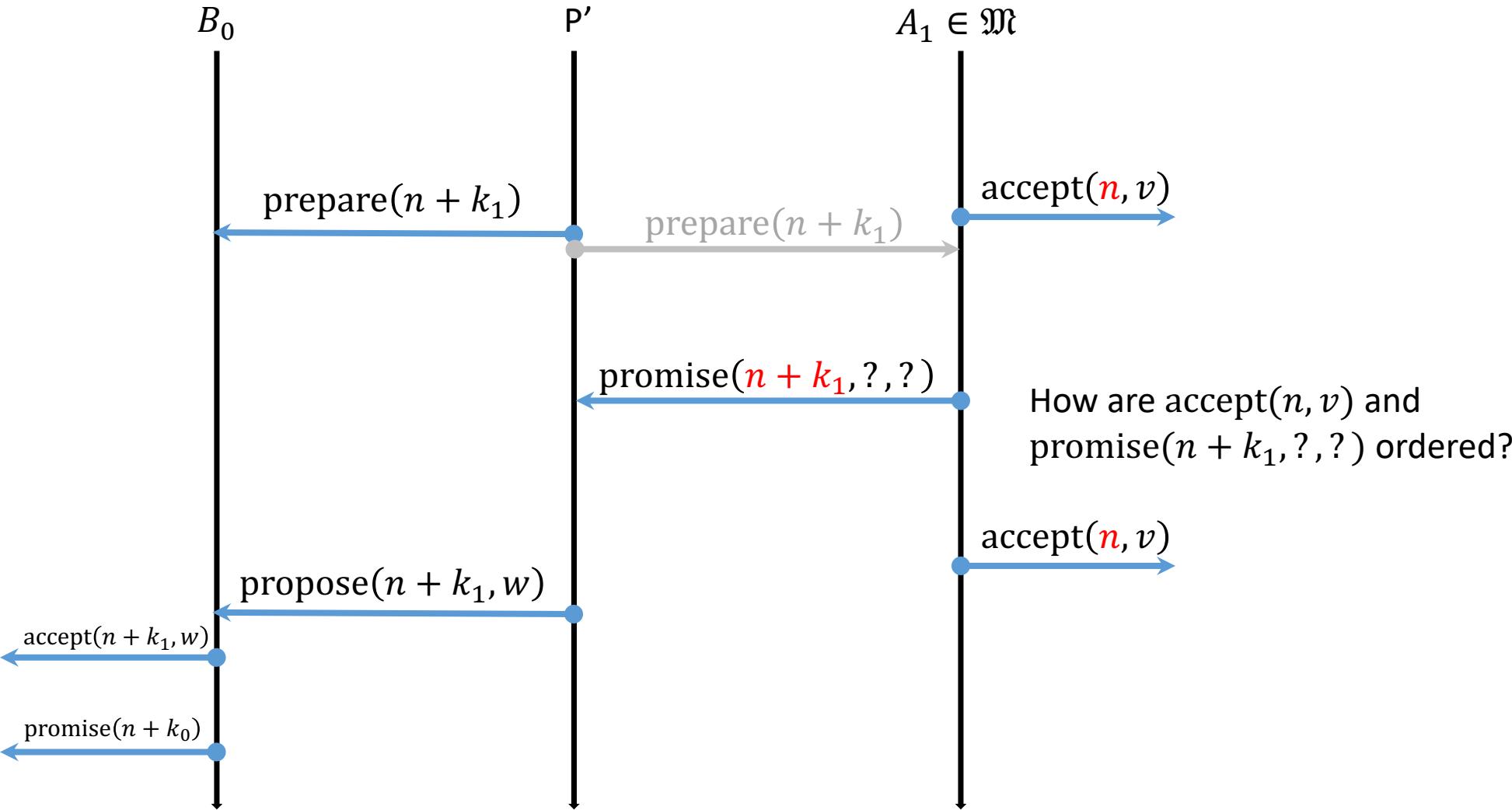


Let us examine the acceptor B_0 more closely.

1. B_0 sends `promise($n + k_0, n + k_1, w$)` only after `accept($n + k_1, w$)`.
2. B_0 has accepted $(n + k_1, w)$. Hence, there is a proposer P' that has proposed it.
3. P' proposes $(n + k_1, w)$ only after receiving `promise($n + k_1$)` from a majority of acceptors. In particular, it must have received `promise($n + k_1$)` from an acceptor $A_1 \in \mathfrak{M}$.

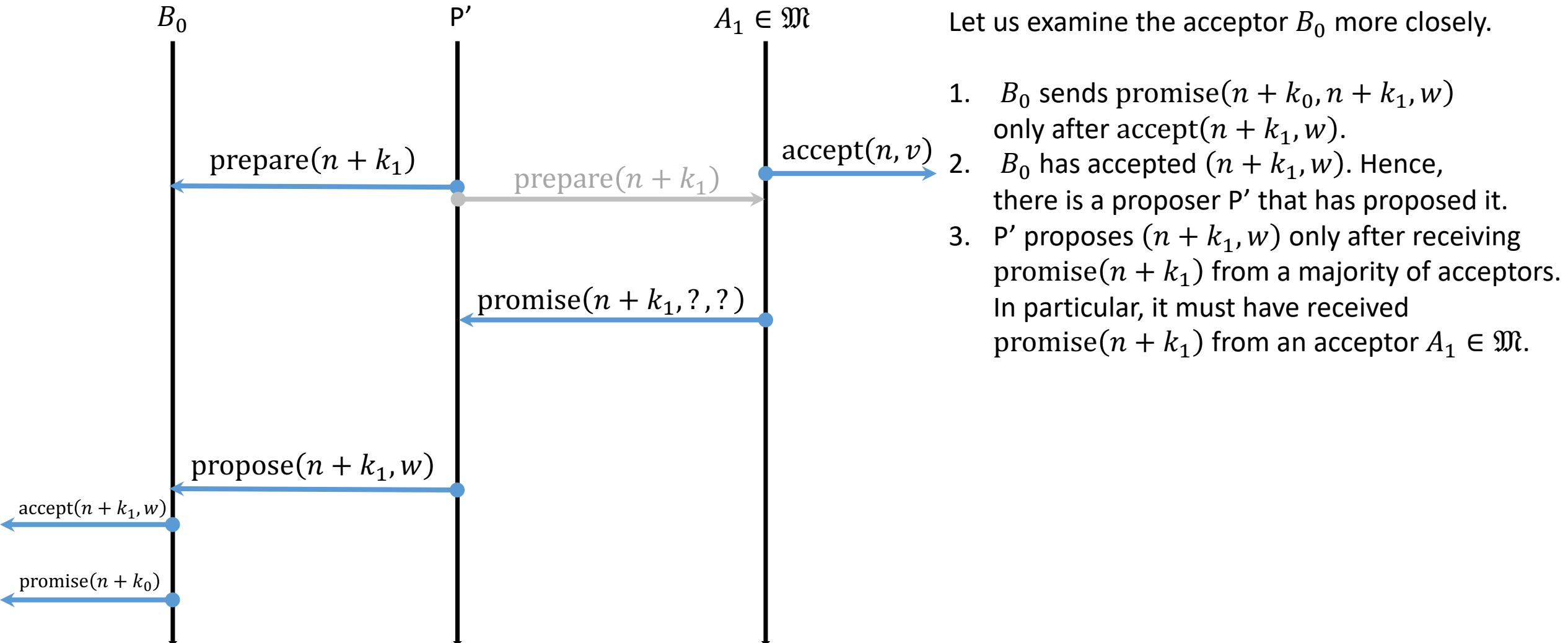
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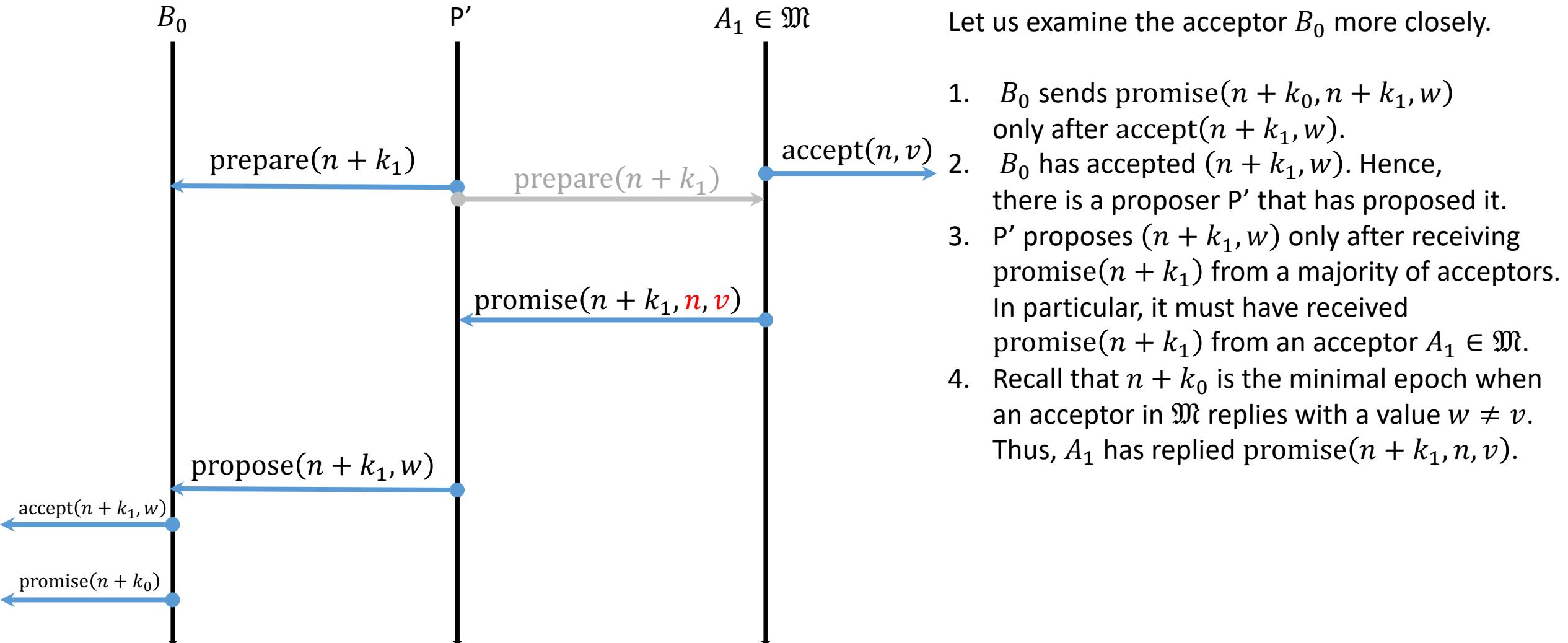
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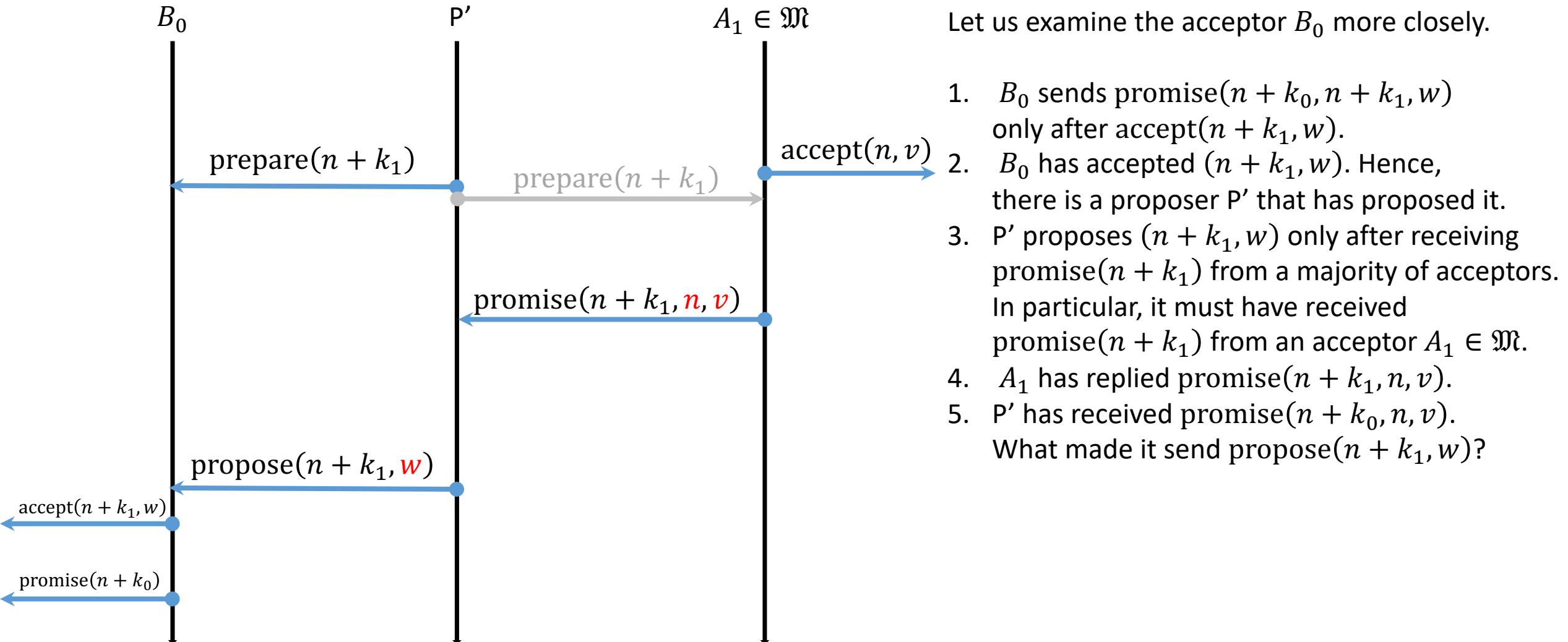
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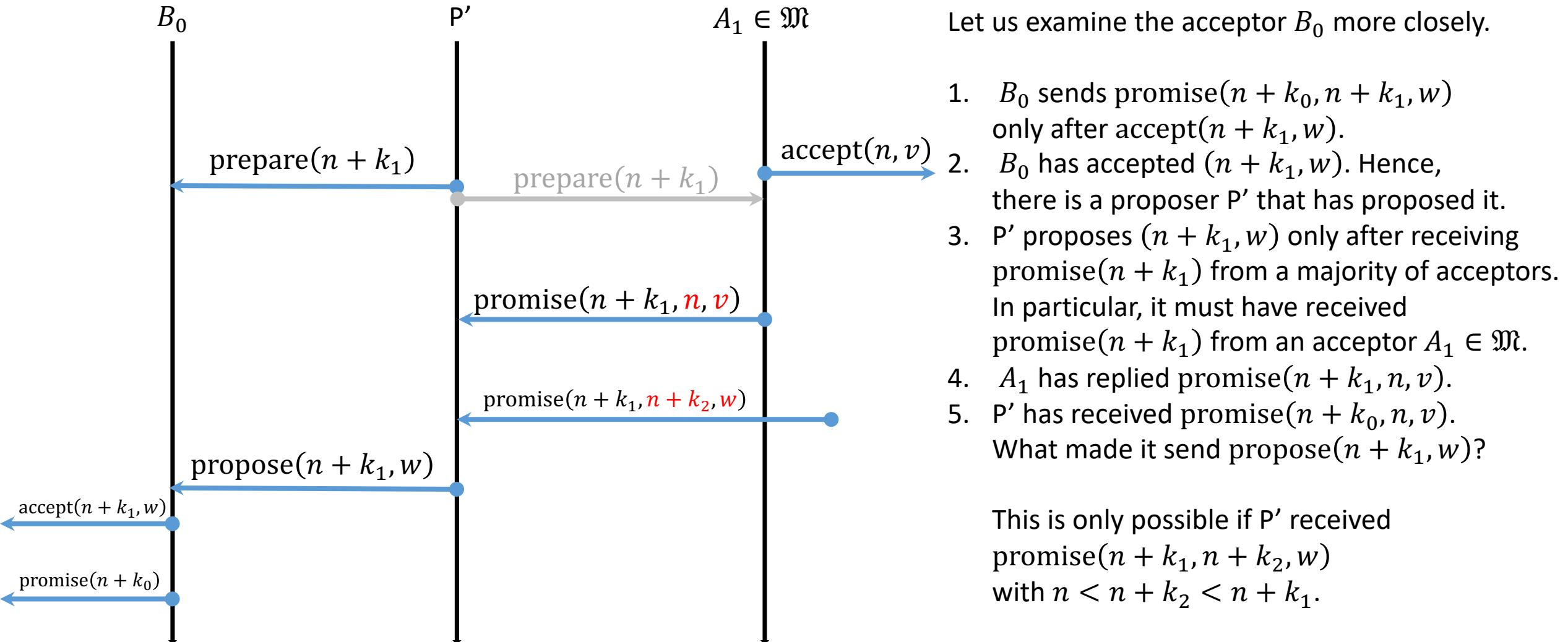
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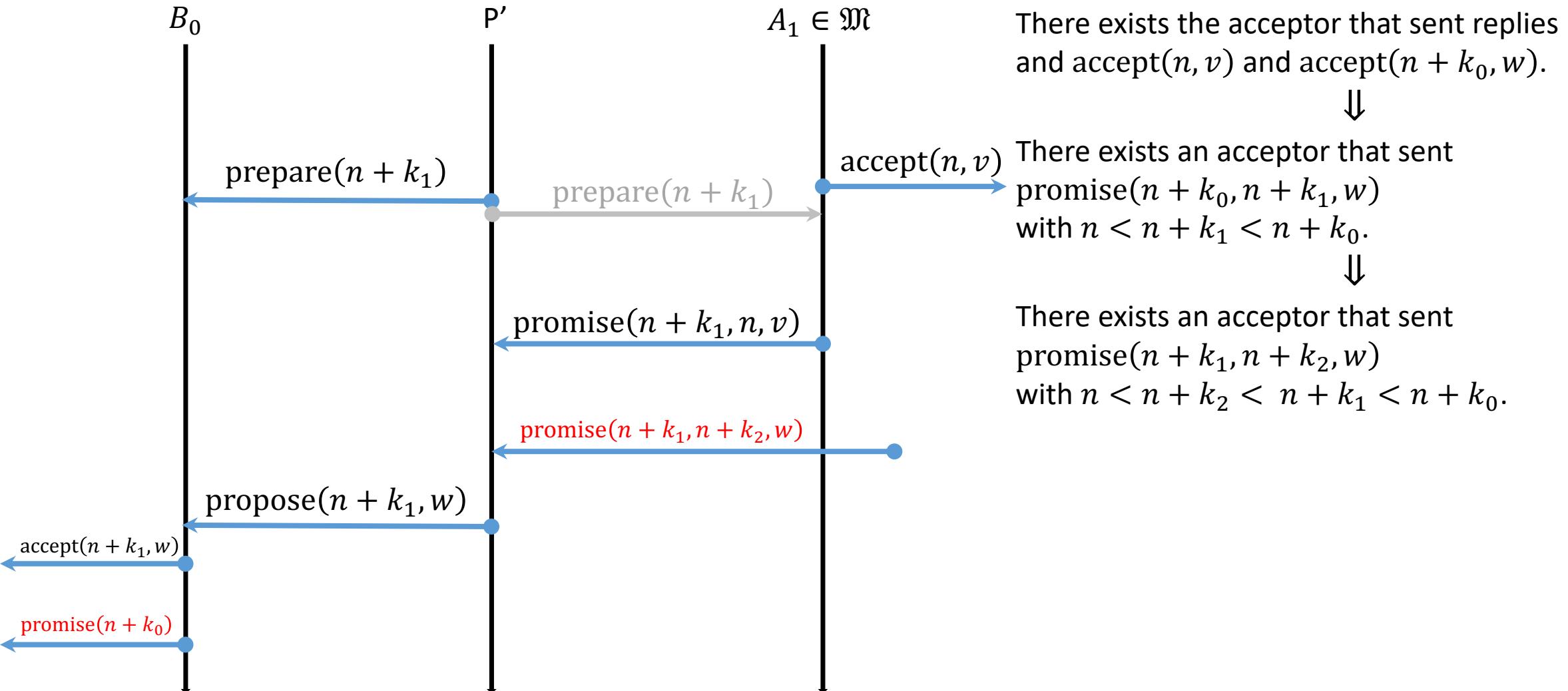
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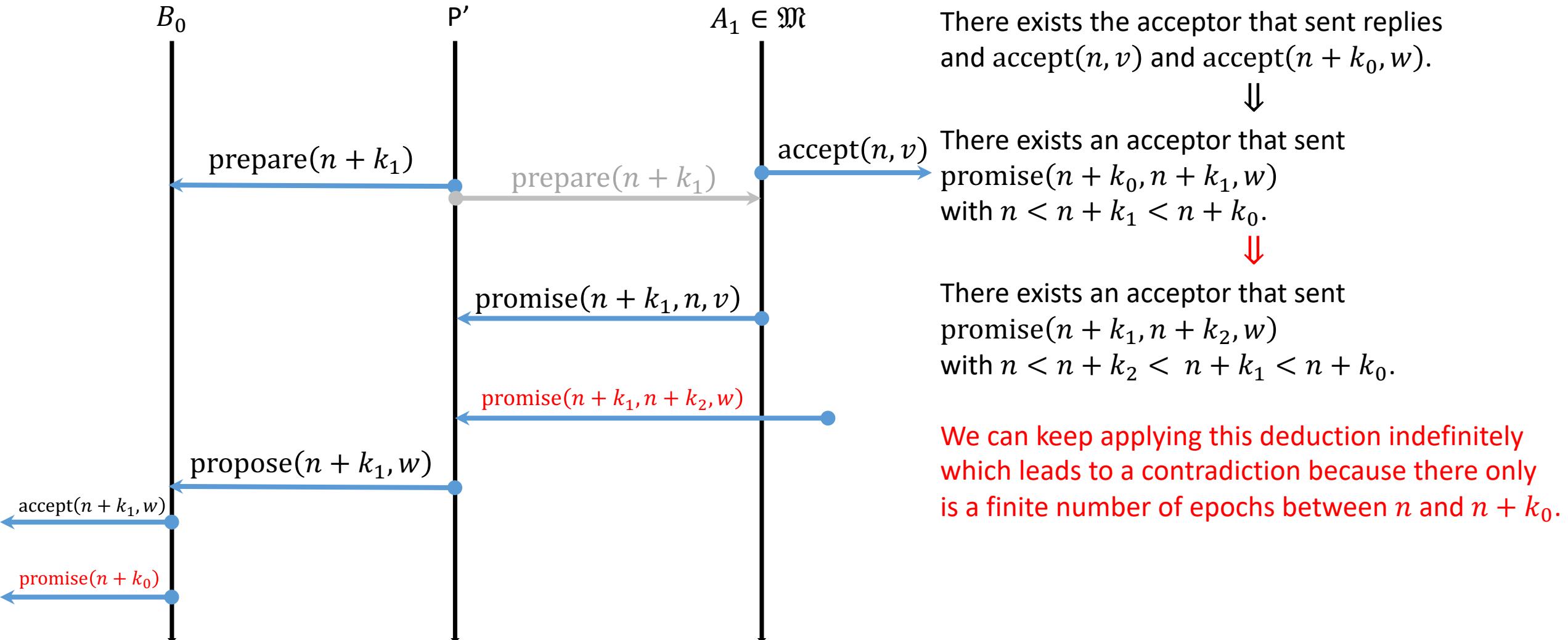
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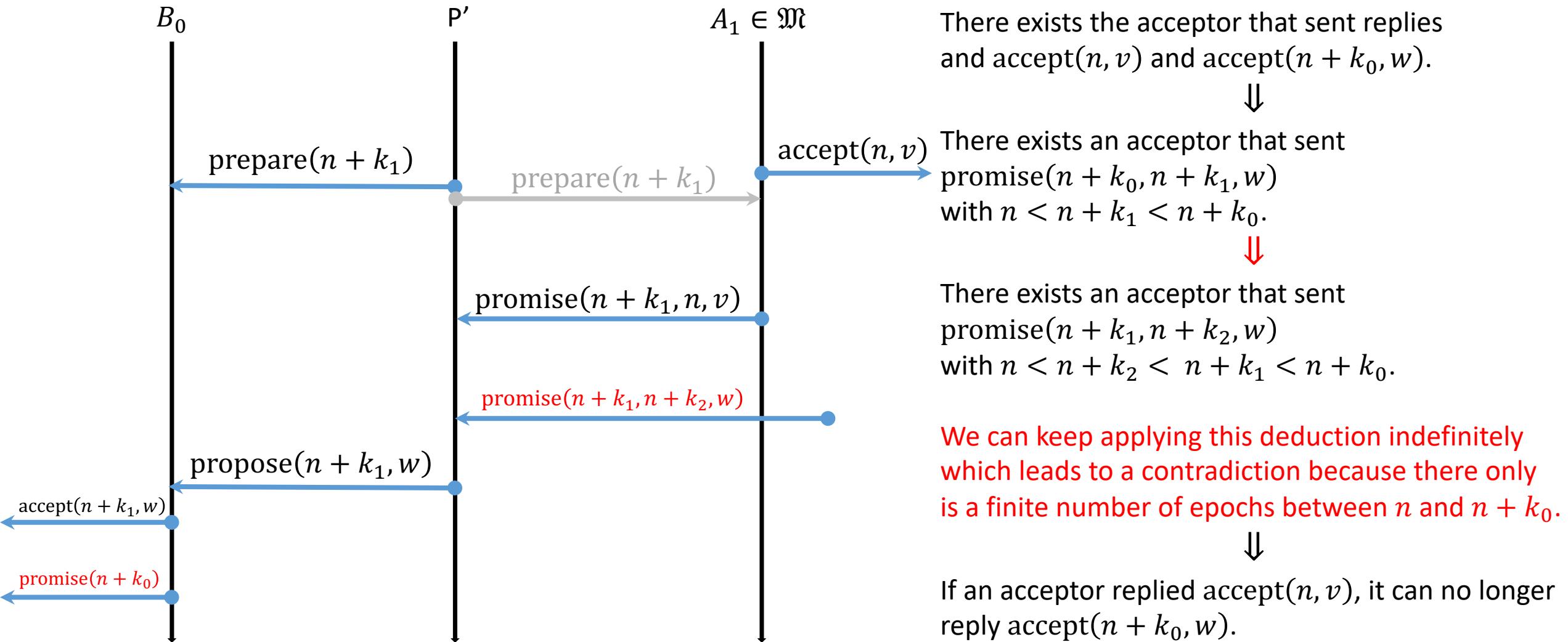
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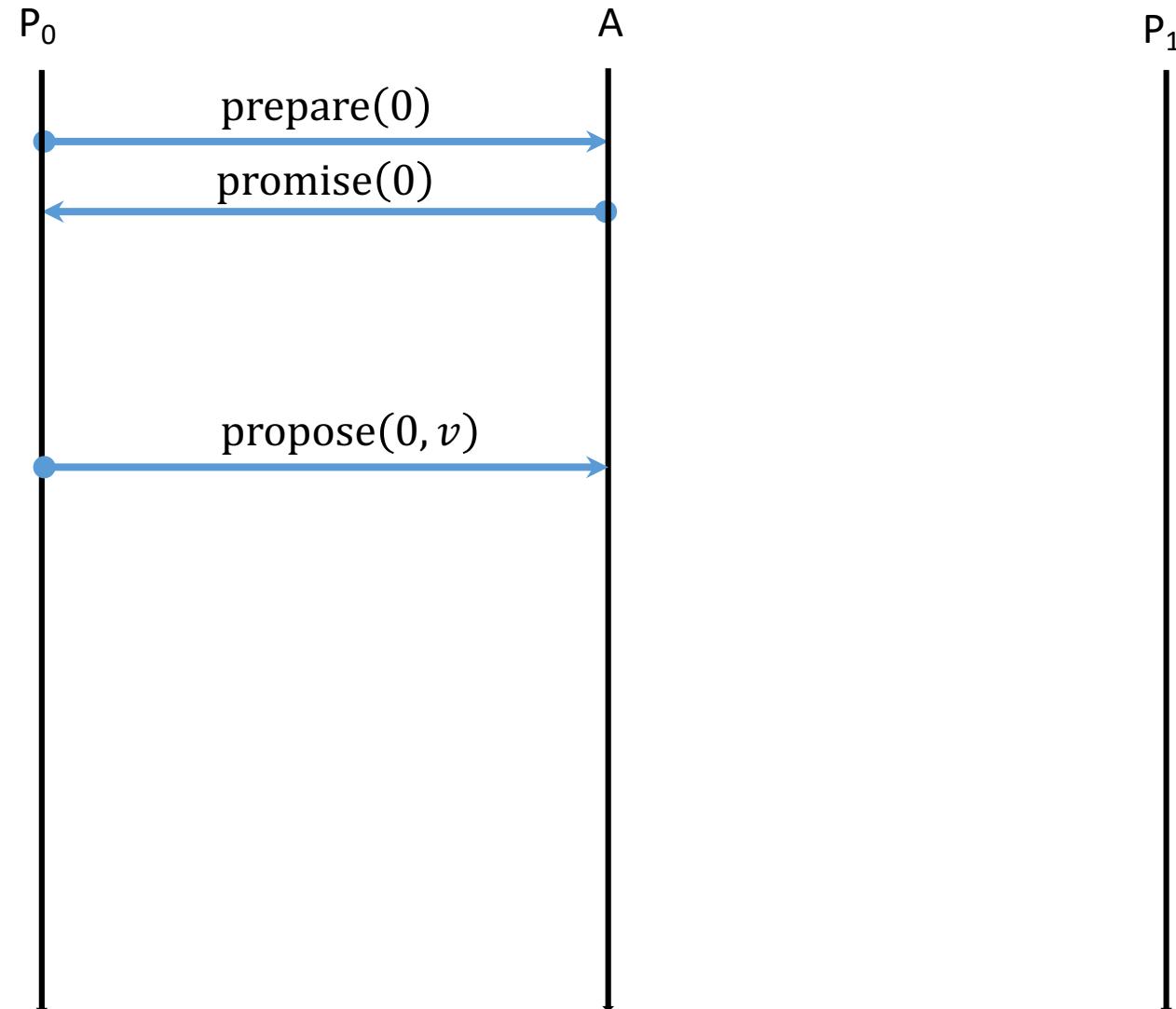
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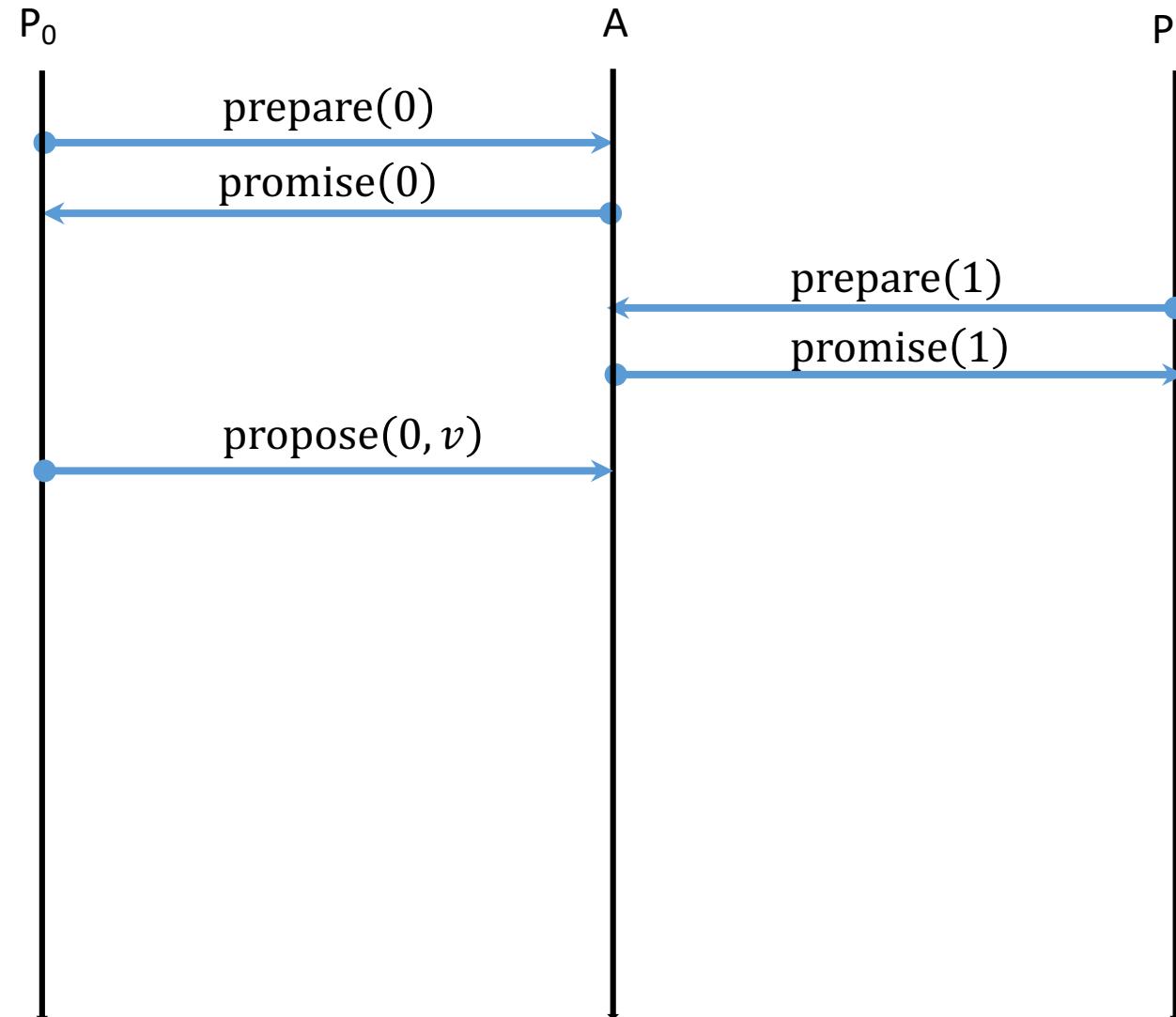
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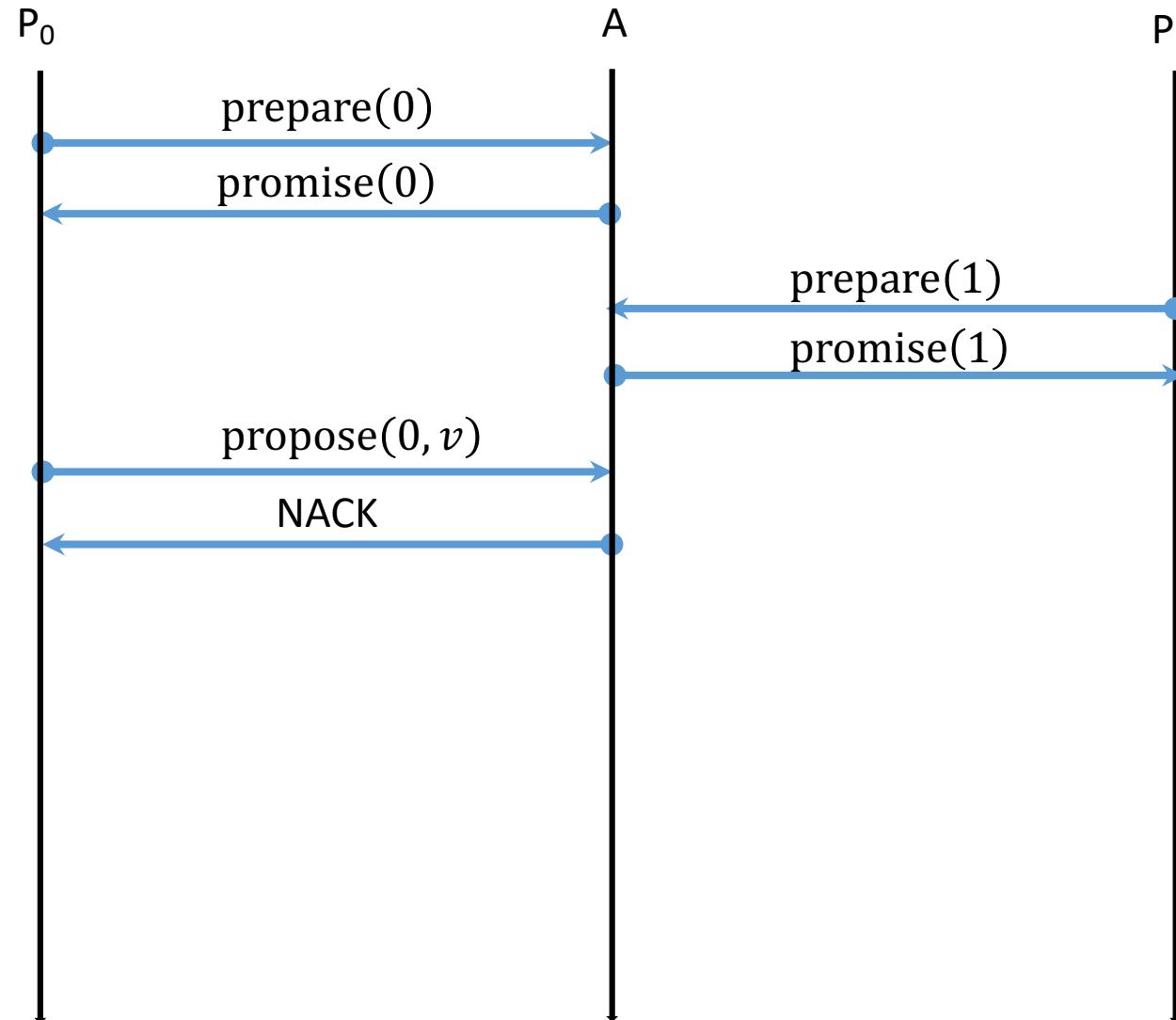
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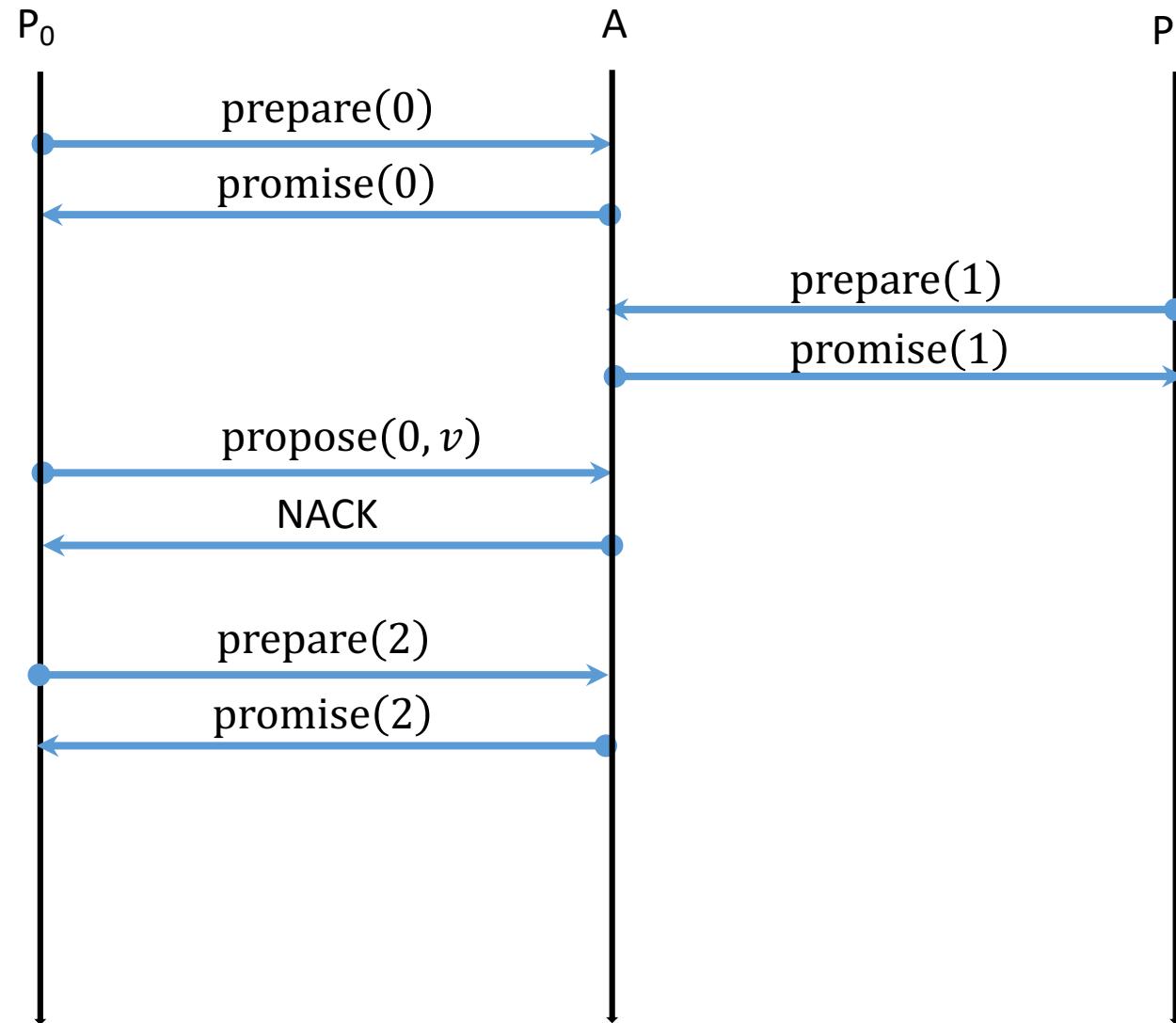
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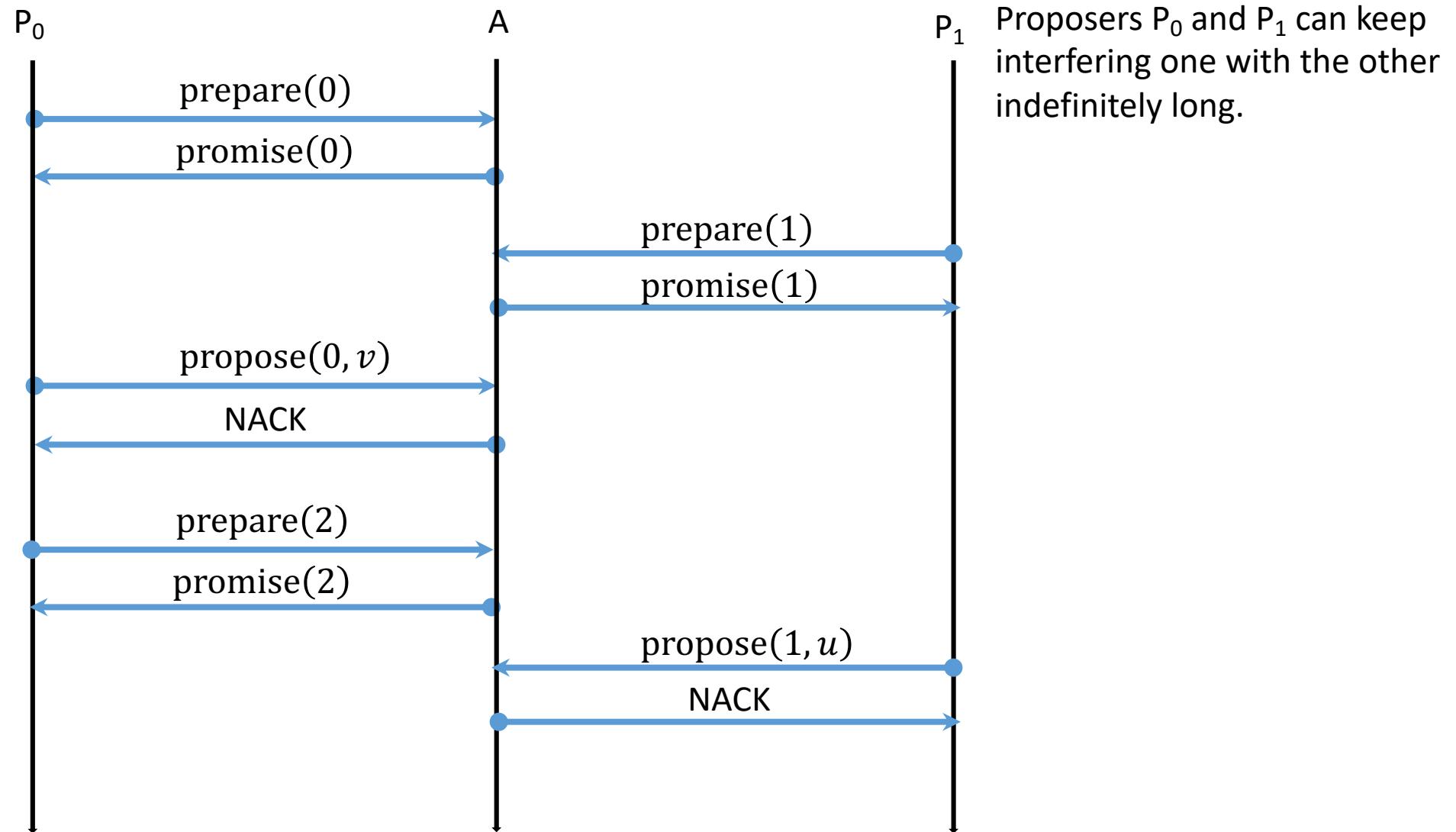
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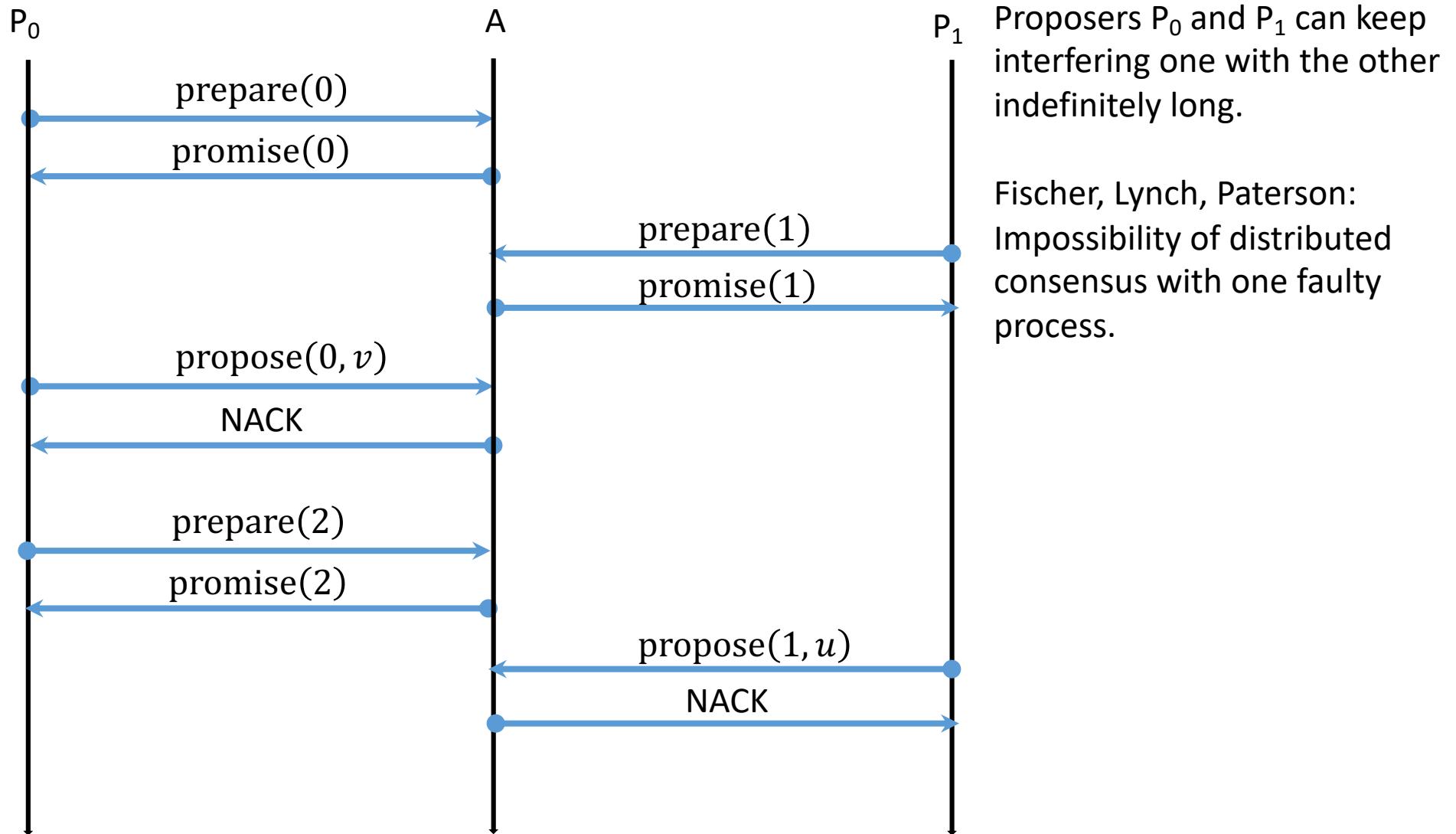
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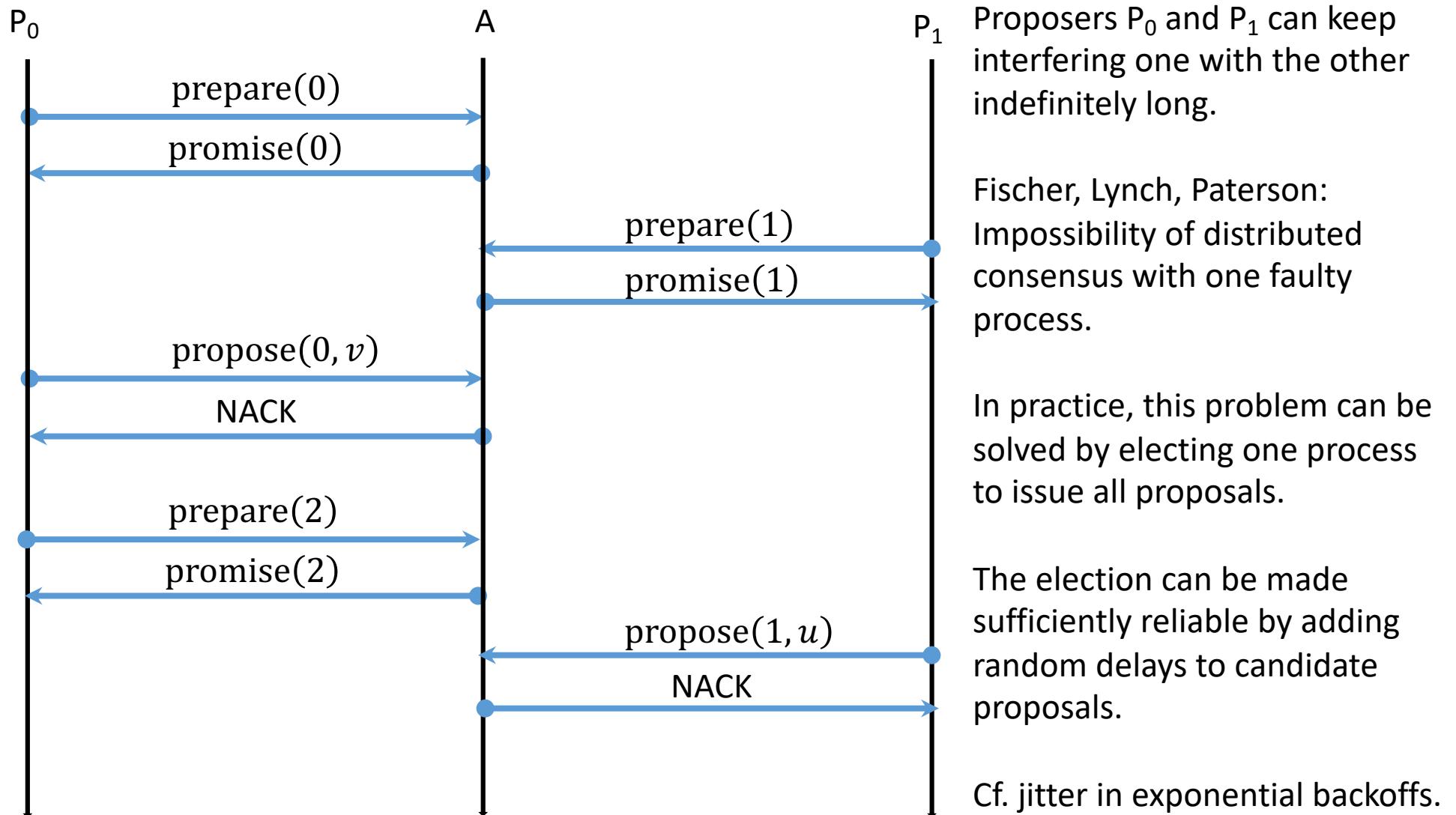
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- Redis,
- ZooKeeper,
- Cassandra,
- Kafka,
- RethinkDB,
- LogCabin.

[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>