Infrastructure Technologies for Large-Scale Service-Oriented Systems

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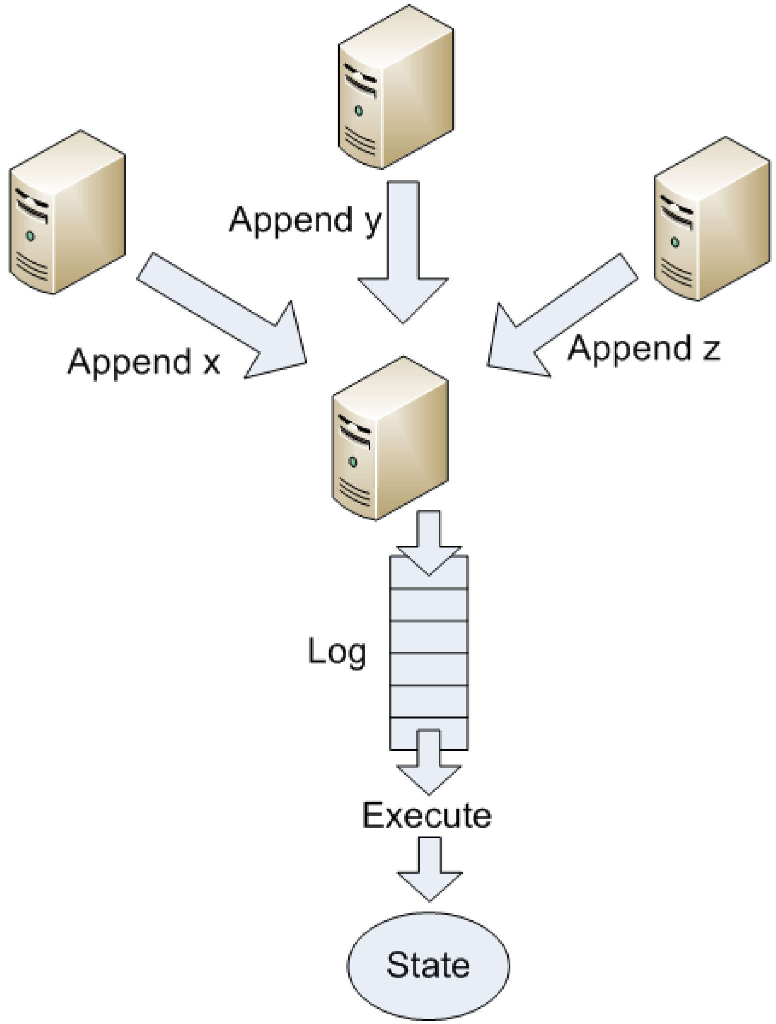
Order on state updates



Paxos algorithm

- Way to build fault-tolerant distributed systems
  - Replicated state machines (RSM)
- Consensus via message exchange
  - Asynchronous: no timing guarantees
  - Network can delay, reorder, lose (but not corrupt) packets
- Can guarantee safety
  - Replicas will agree on a single value
- Need additional assumptions to ensure progress

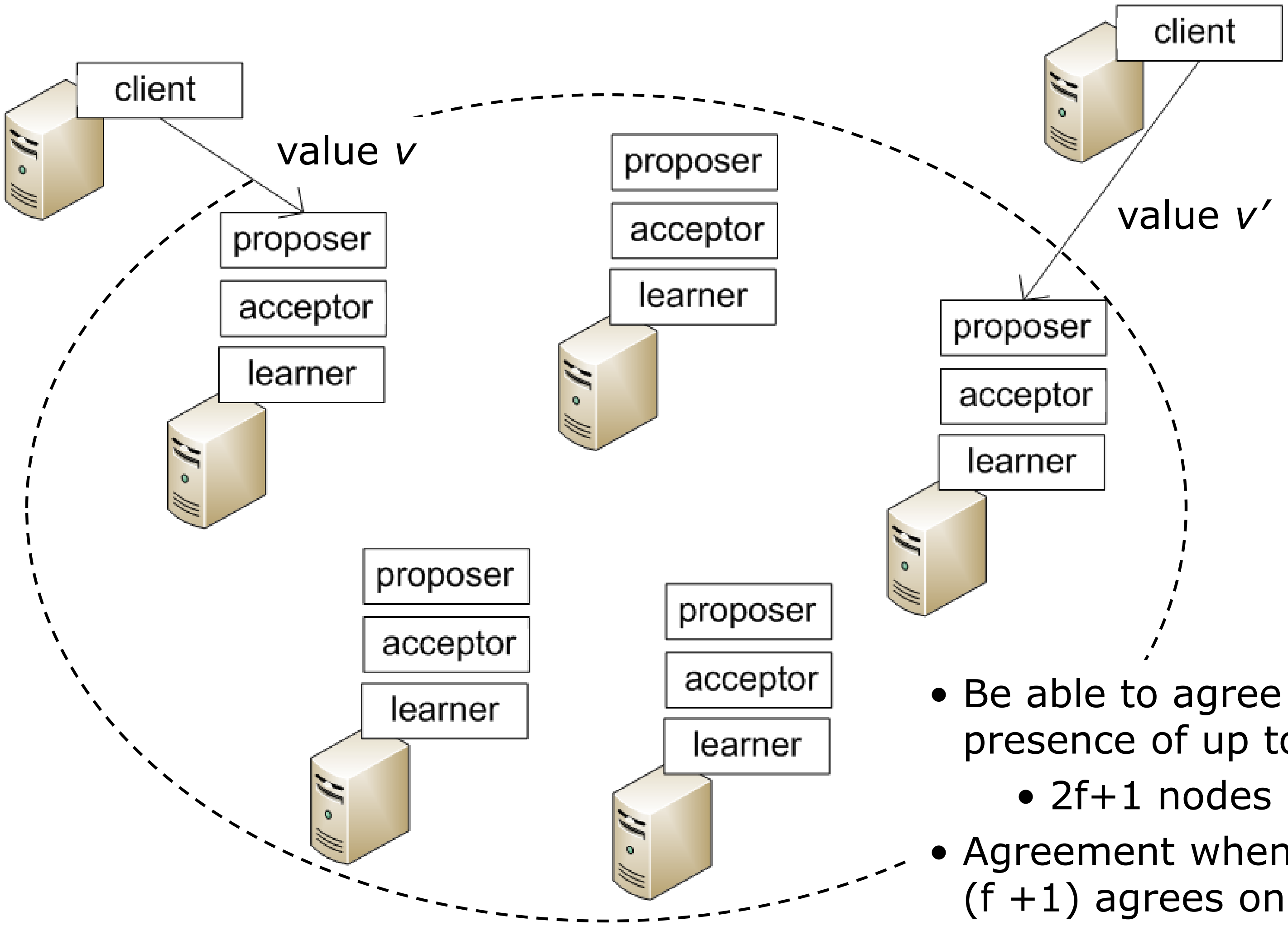
Informally

- Three roles: Proposer, acceptor, learner
- Simplest, but fault-intolerant solution: single acceptor
- With >1 acceptors, agreement by a majority required
- If single value proposed, that value should be chosen
  - Thus, an acceptor must accept the first value proposed to it
- However, this may lead to fragmented electorate
  - Multiple proposals by each proposer should be possible
  - Identify each proposal by a unique integer N

Informally

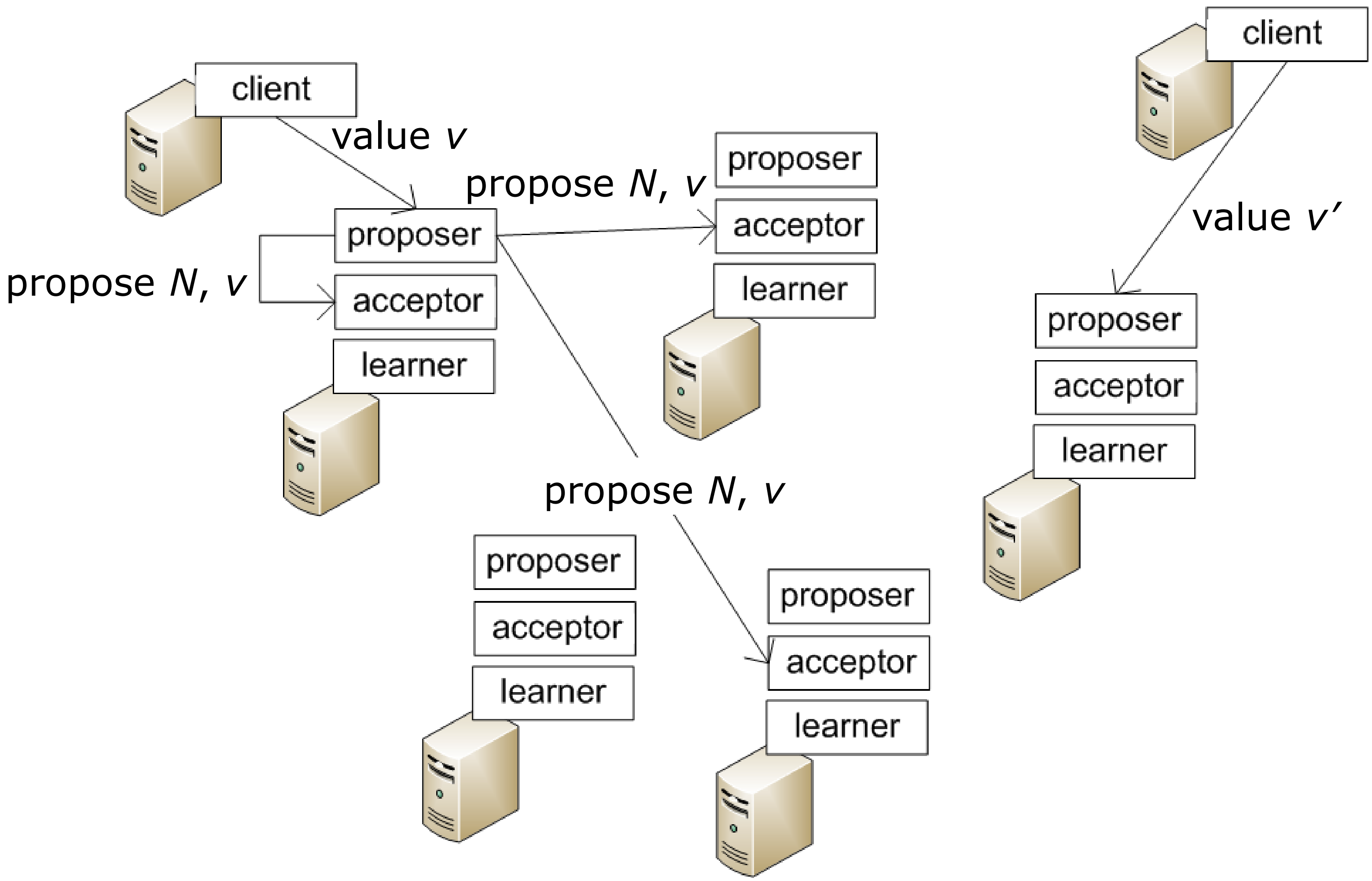
- After consensus, an acceptor cannot change its mind
  - A value is chosen when single proposal with that value accepted by a majority of the acceptors
- Allow multiple proposals to be chosen, but guarantee that all chosen proposals have <u>the same value</u>

Paxos setup



- Be able to agree in the presence of up to f failures
  - 2f+1 nodes
- Agreement when majority (f +1) agrees on a value

Need to try to get a majority to accept



Informally

- Allow multiple proposals to be chosen, but guarantee that all chosen proposals have the same value

- If proposal N with value v is chosen, every higher numbered proposal issued by any proposer should have value v

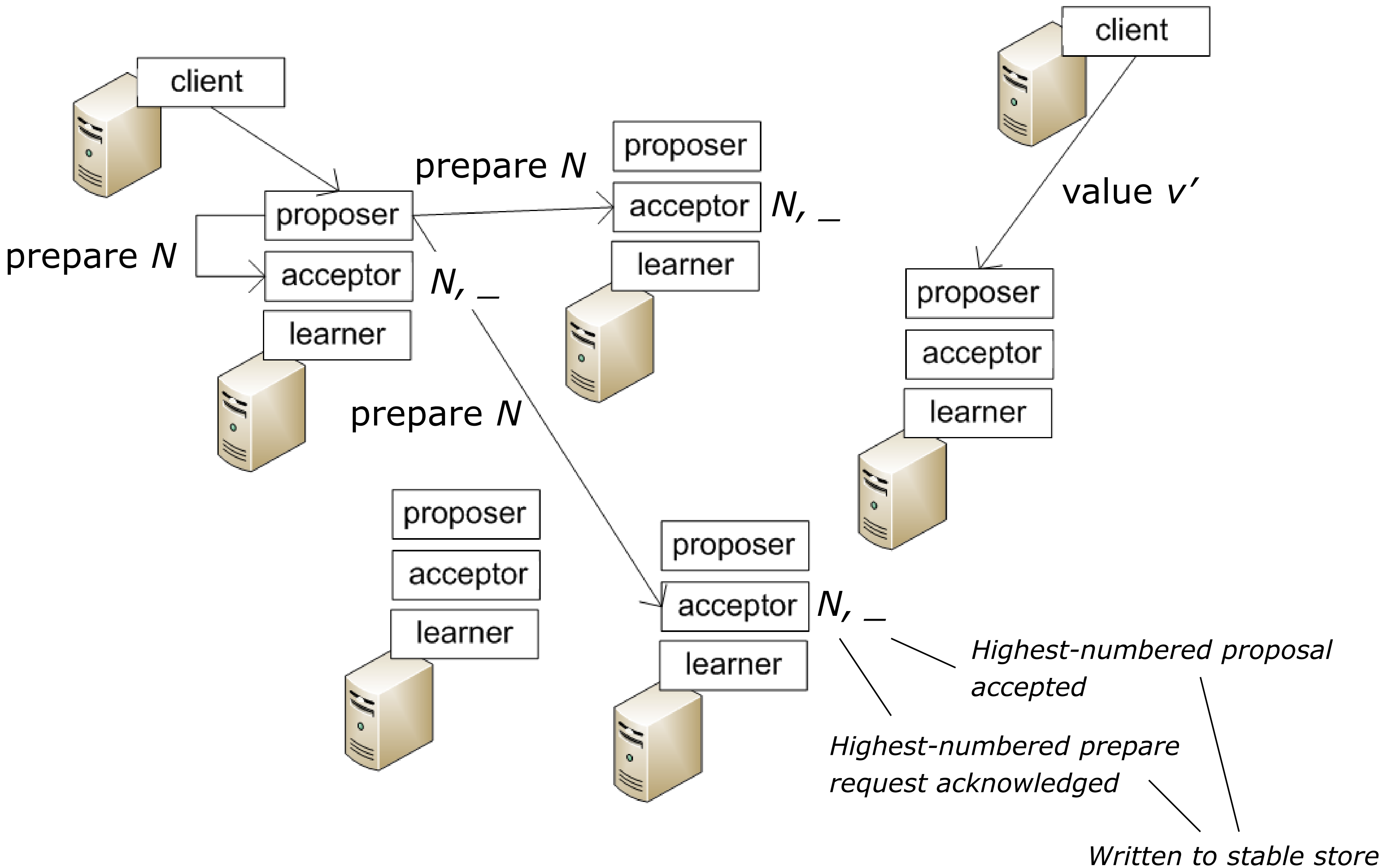
- A proposer wanting to issue a proposal numbered N must learn the highest-numbered proposal $< N$ (if any) that has been or will be accepted by a majority

Informally

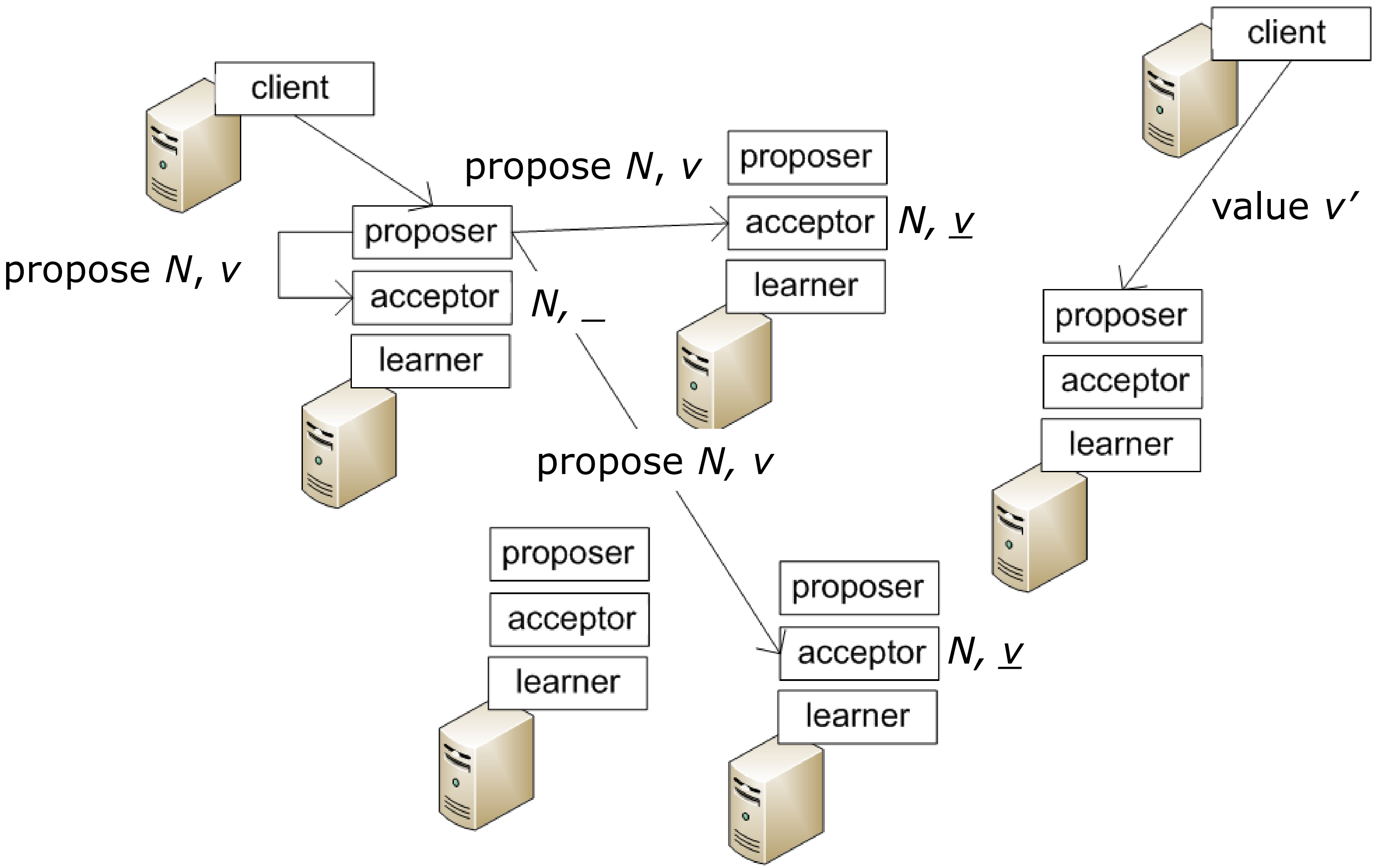
- A proposer wanting to issue a proposal numbered *N* must learn the highest-numbered proposal $< N$ (if any) that has been or will be accepted by a majority
  - Easy to learn about values already accepted
  - Hard to predict the future

- Control the future by extracting a promise that there will not be any acceptances of proposals $< N$

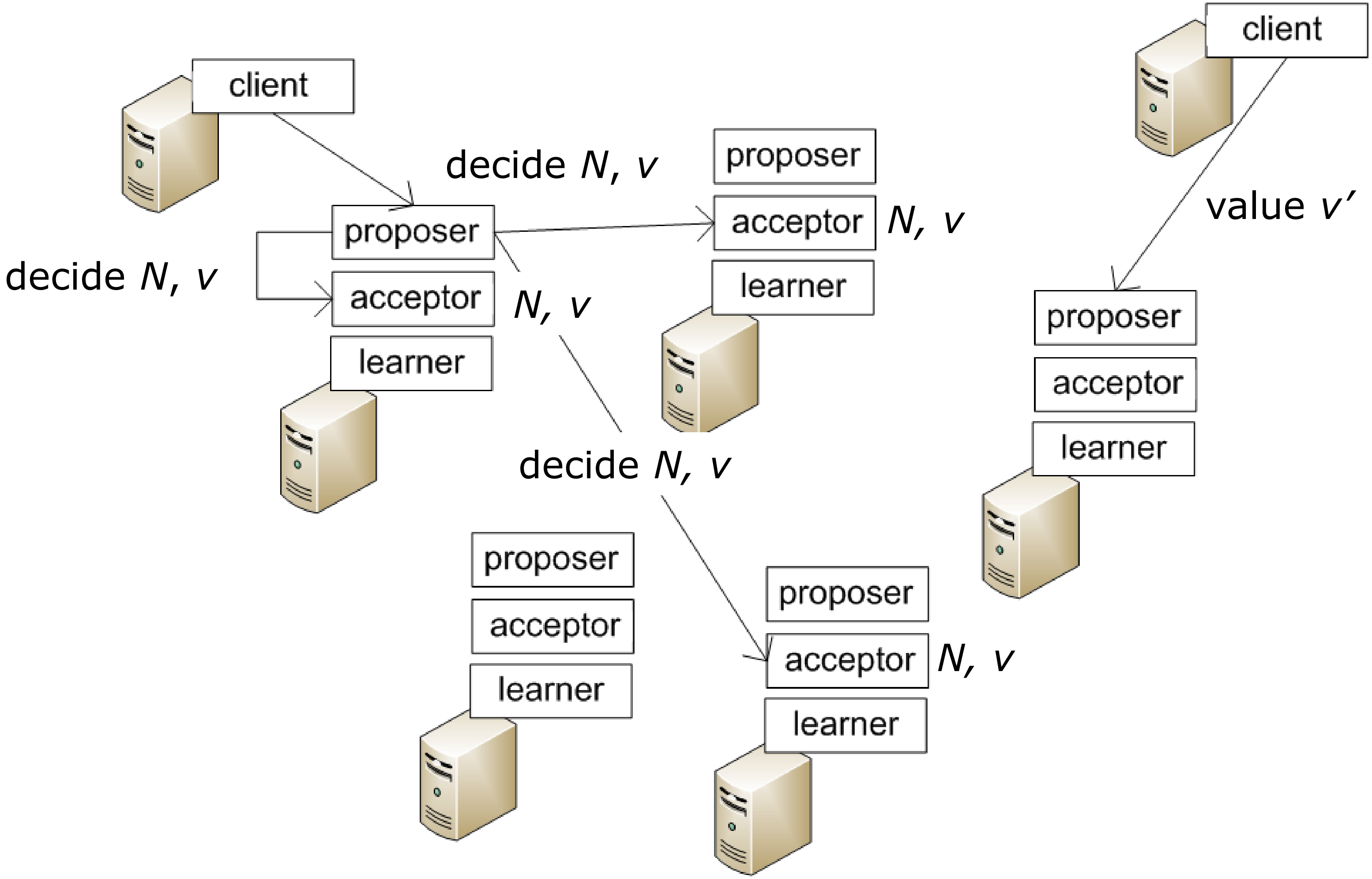
Paxos – phase 1



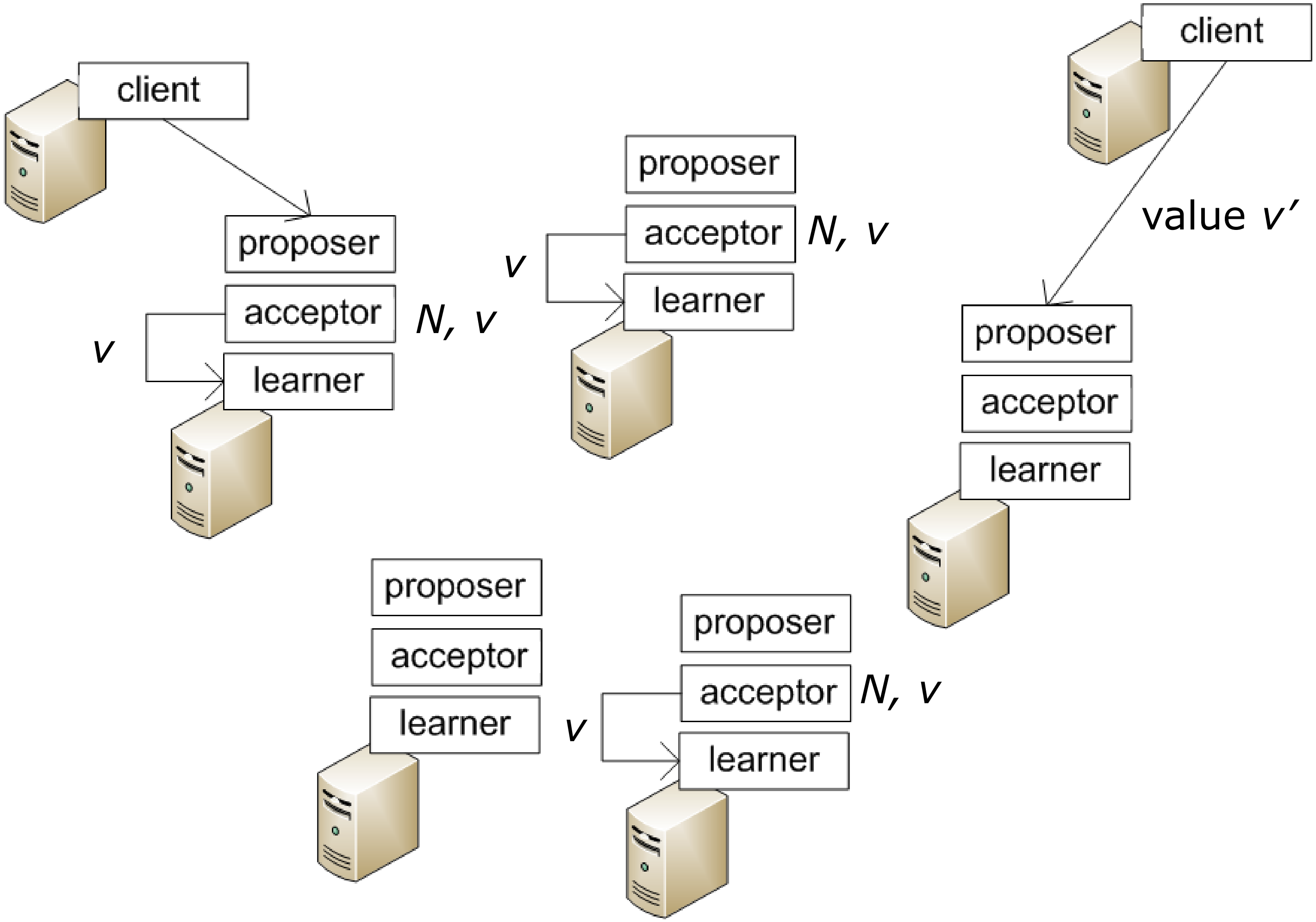
Paxos – phase 2



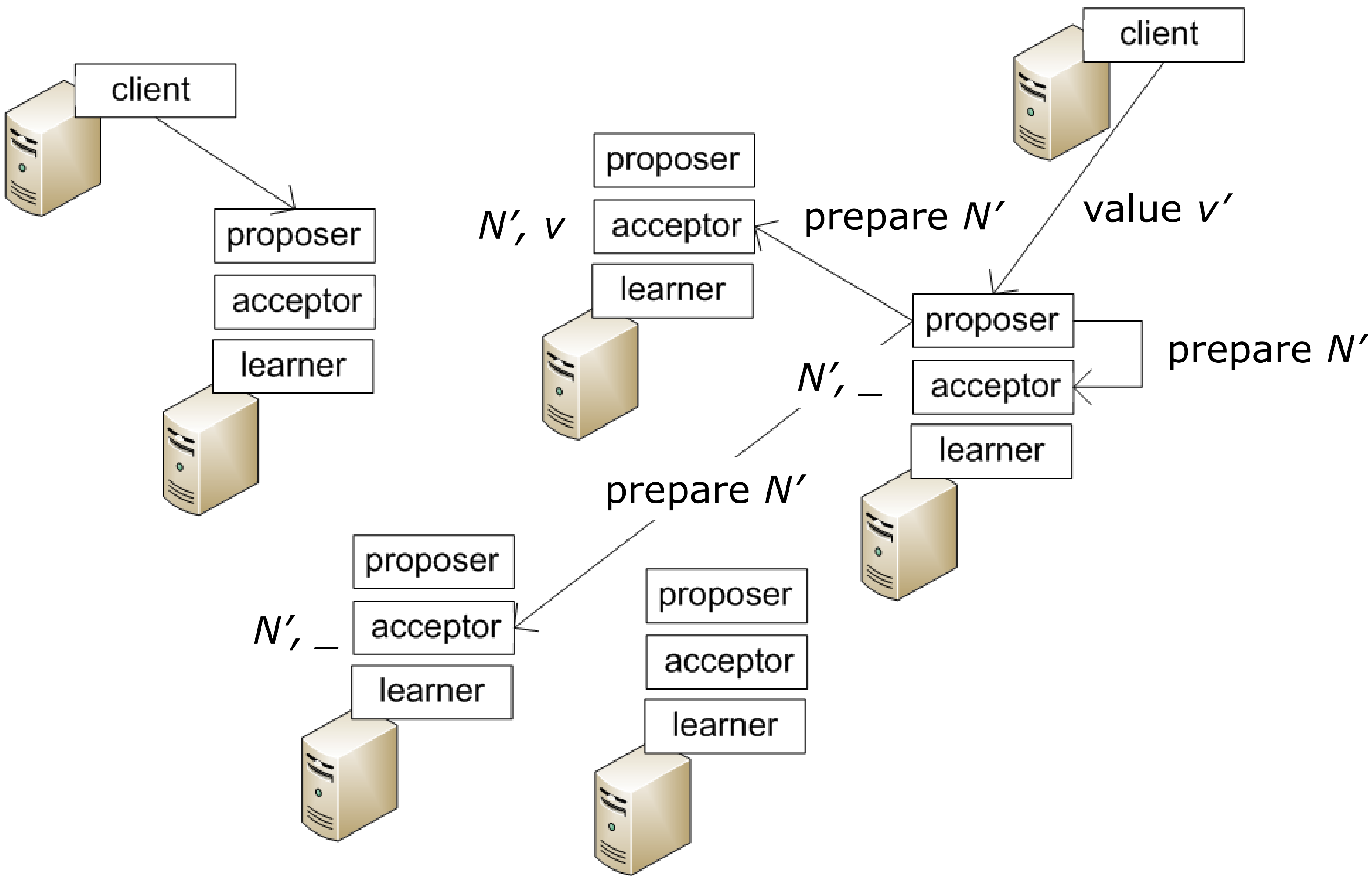
Paxos – communicate agreement



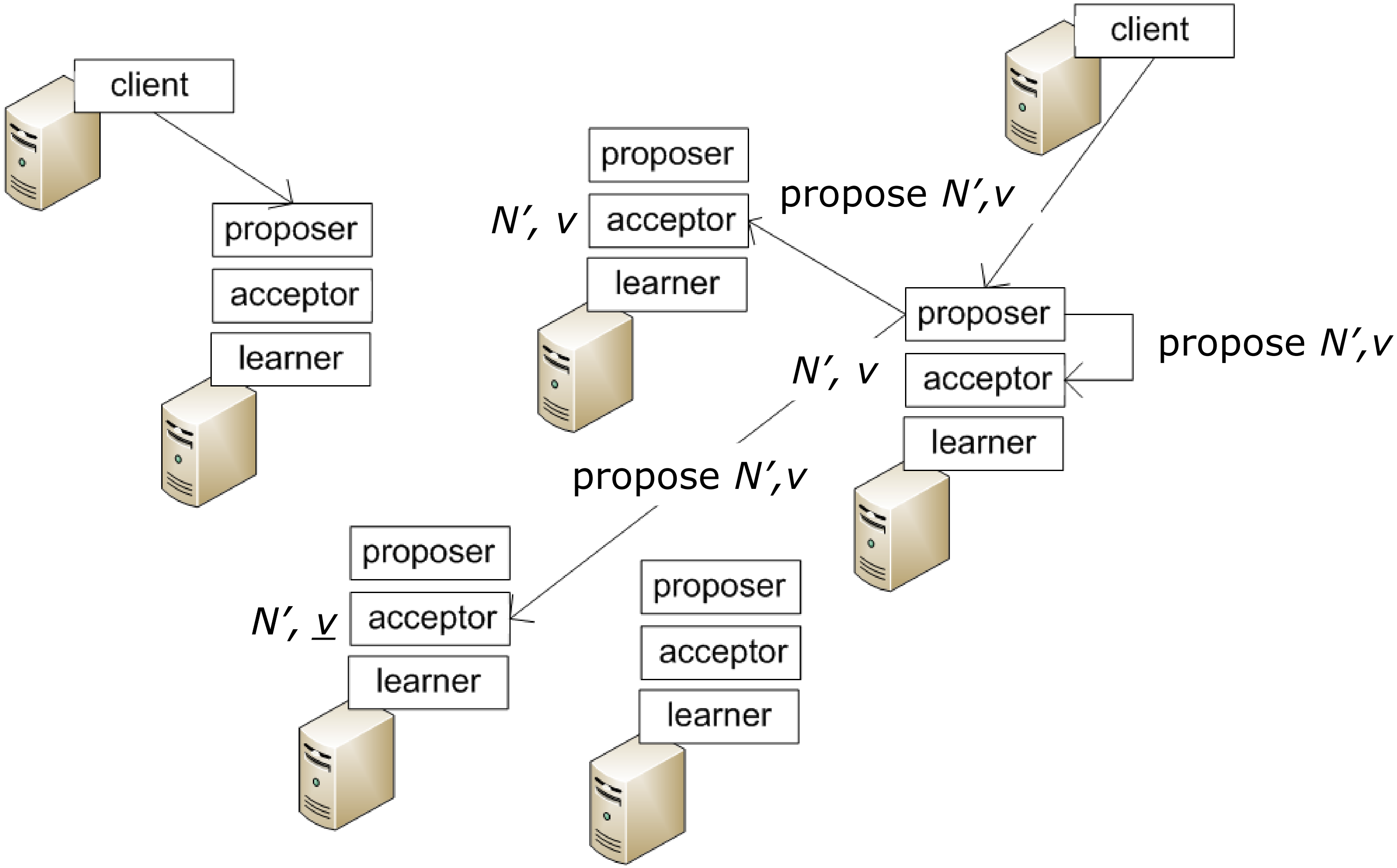
Paxos – majority learns outcome



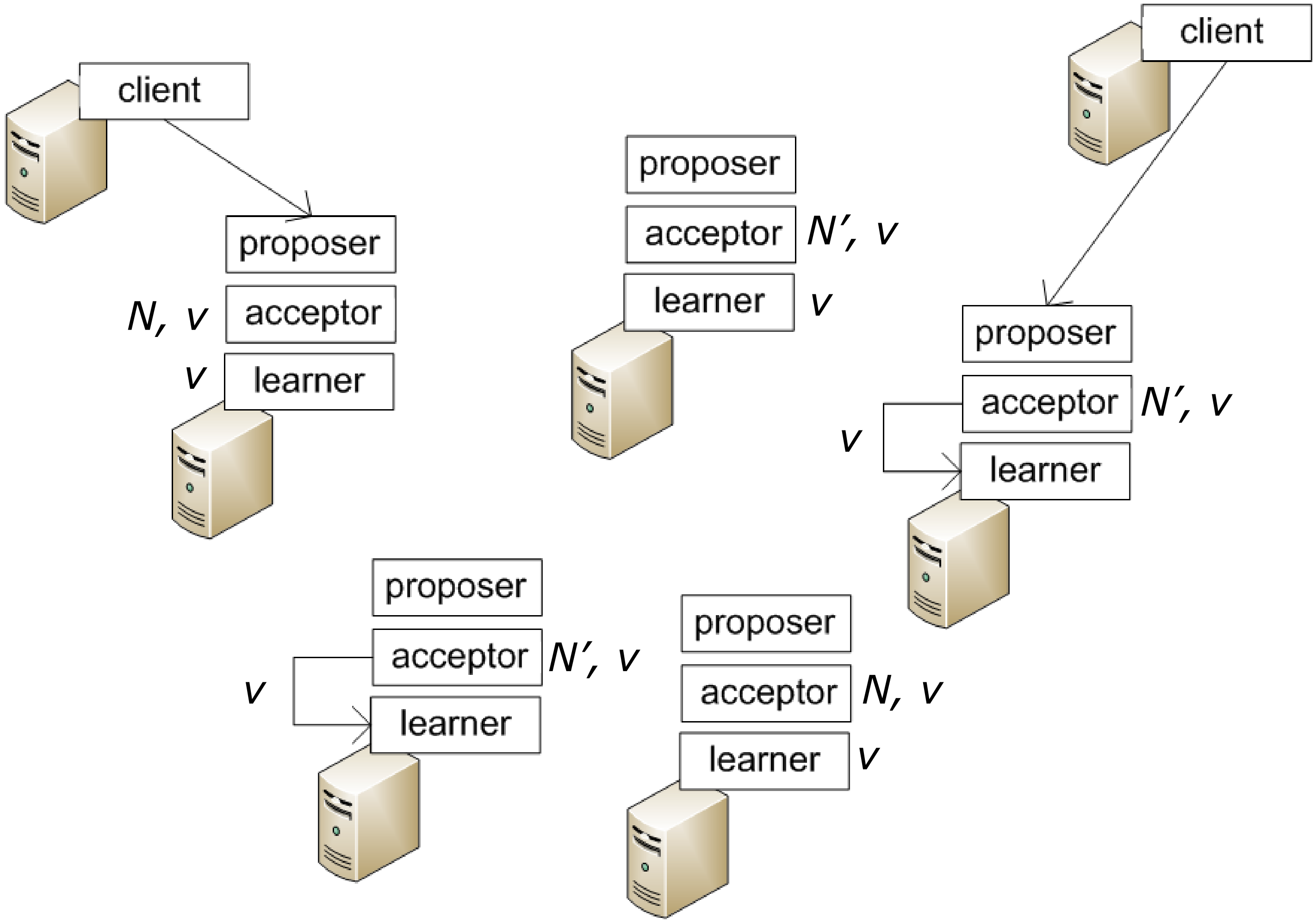
Paxos – learning chosen value



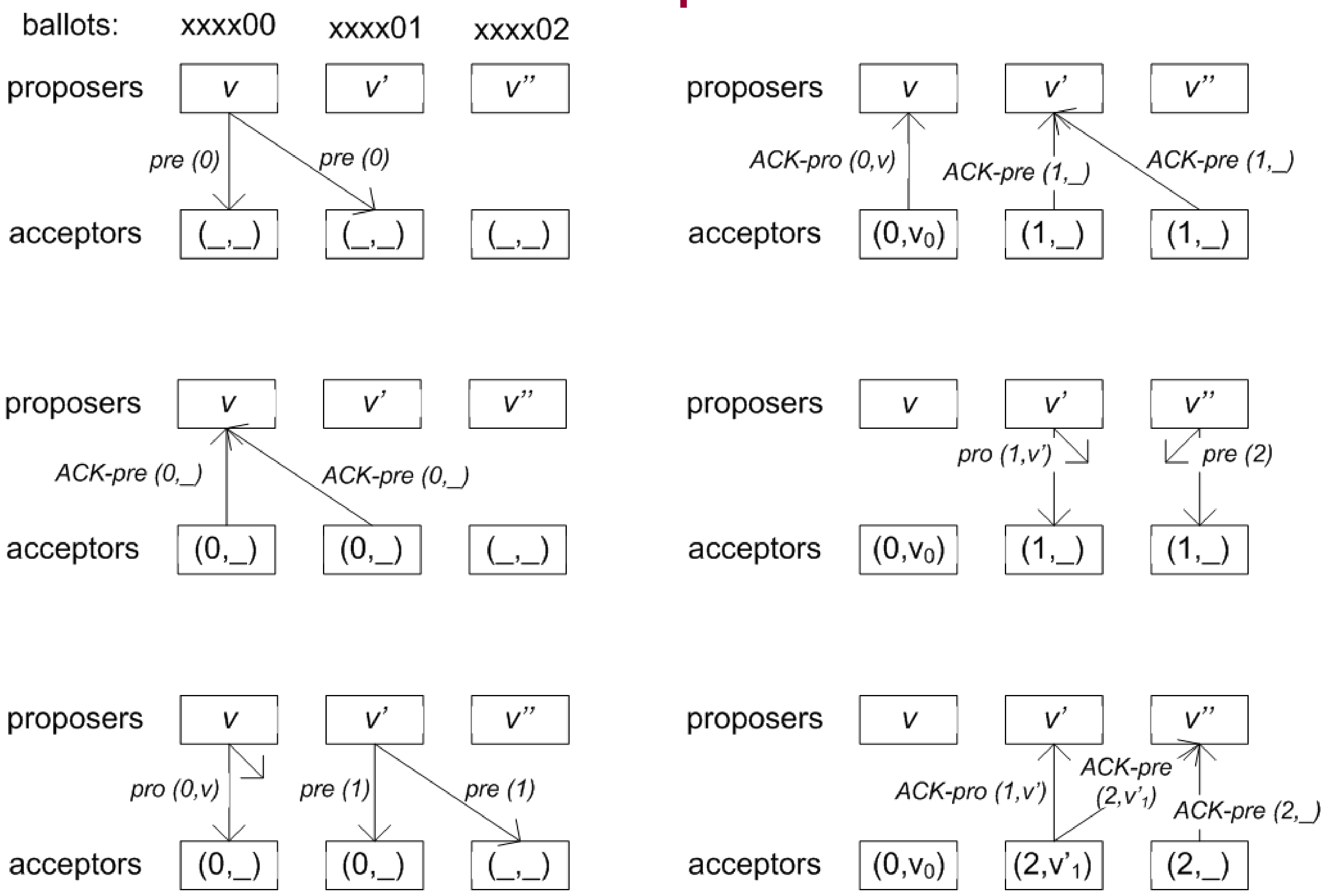
Paxos – propagate chosen value



Paxos – everyone learns outcome

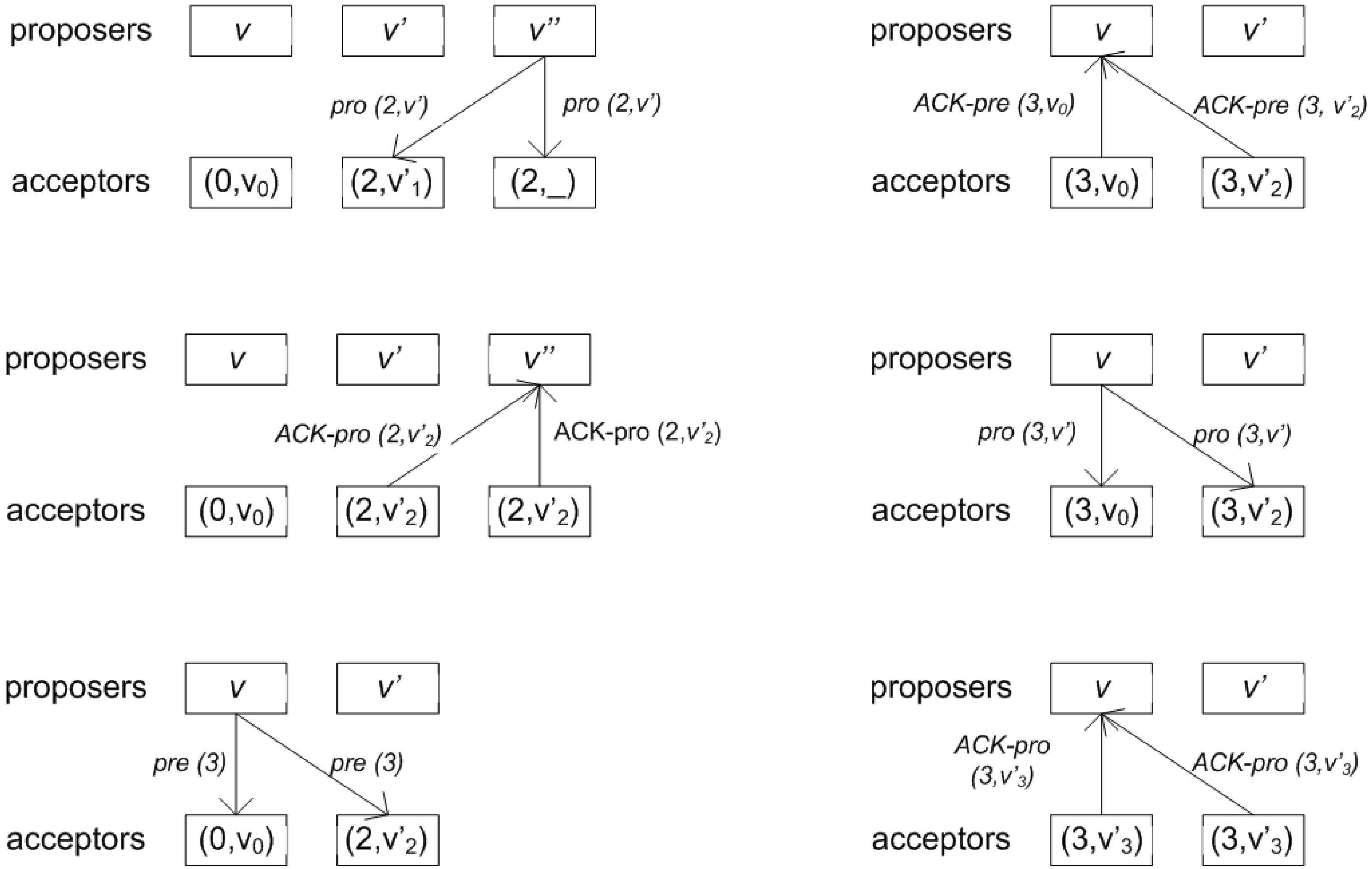


Example



ballots:
xxxx00
xxxx01
xxxx02
proposers
v
v'
v''
pre (0)
pre (0)
acceptors
(_,_)
(_,_)
(_,_)
proposers
v
v'
v''
ACK-pro (0,v)
ACK-pre (1,_)
ACK-pre (1,_)
acceptors
(0,v0)
(1,_)
(1,_)
proposers
v
v'
v''
ACK-pre (0,_)
ACK-pre (0,_)
acceptors
(0,_)
(0,_)
(_,_)
proposers
v
v'
v''
pro (1,v')
pre (2)
acceptors
(0,v0)
(1,_)
(1,_)
proposers
v
v'
v''
pro (0,v)
pre (1)
pre (1)
acceptors
(0,_)
(0,_)
(_,_)
proposers
v
v'
v''
ACK-pro (1,v')
ACK-pre (2,v'1)
ACK-pre (2,_)
acceptors
(0,v0)
(2,v'1)
(2,_)

Example (*contd.*)



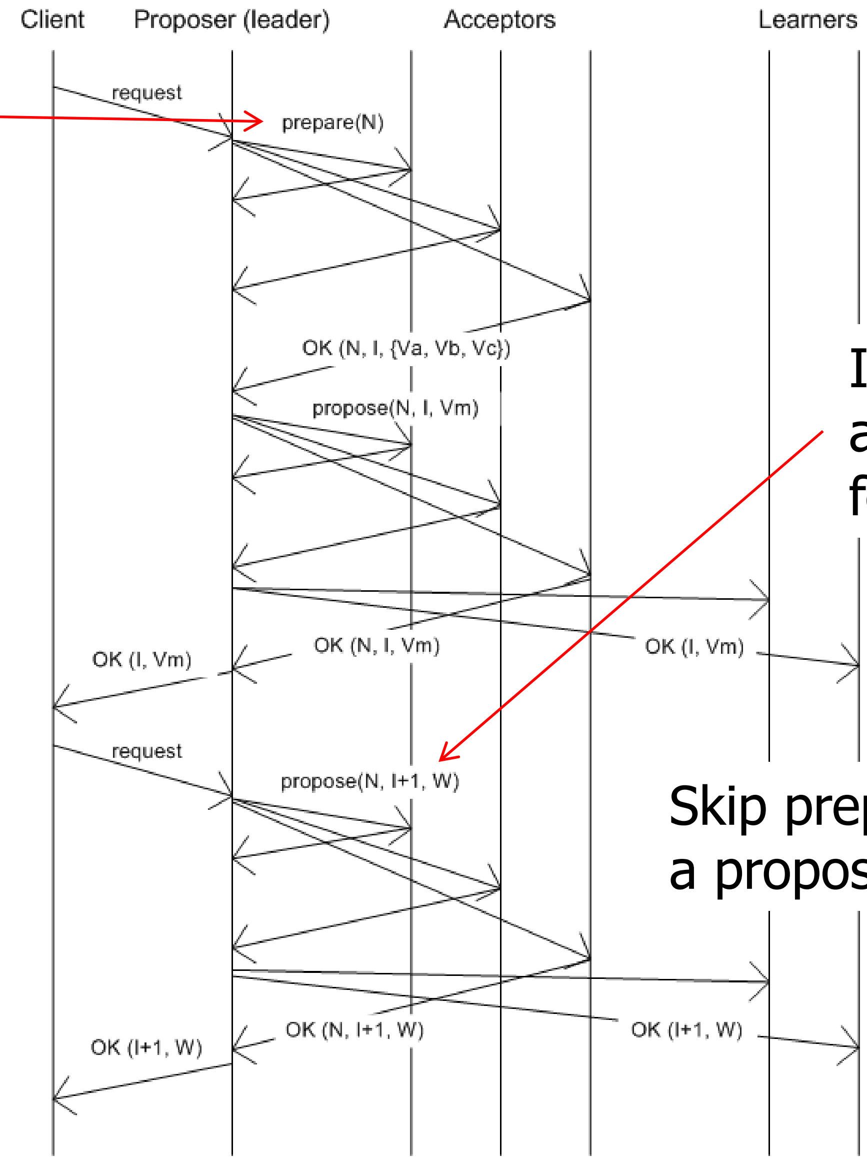
Lamport: implementing a state machine

- How to run multiple instances of Paxos
  - Assume the existence of a distinguished proposer (leader)
  - A leader will run Paxos for a number of instances
  - The leader may crash, at which point there may be gaps in the chosen instances (1-134, 138, ..)
  - A new leader will try to fill in those slots or propose *no-op*
  - As soon as gap fills, commands can be executed

- Multi-Paxos
  - New leader: execute phase 1 for infinitely many instances
  - Acceptors can respond with reasonably short messages
  - Cost of Paxos effectively the cost of executing phase 2

Multi-Paxos

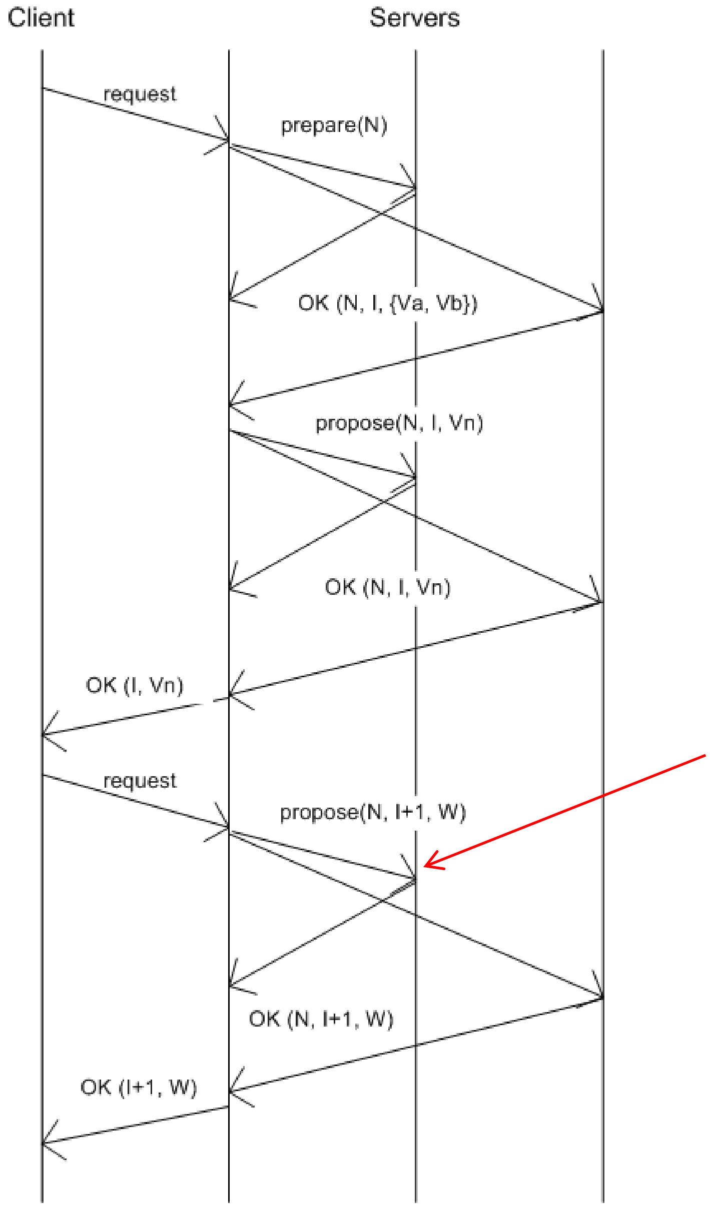
Block acceptance of proposal # < N & learn accepted values



If a majority has not accepted anything for instances > I

Skip prepare phase until a propose is rejected!

Multi-Paxos



Servers play all roles

Replicas write to disk prior to sending ACK