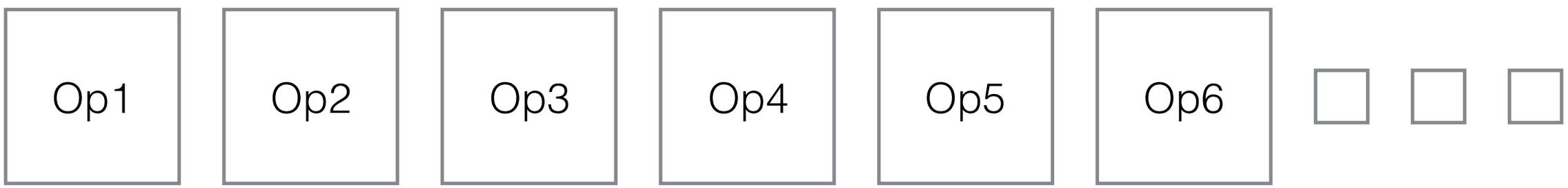
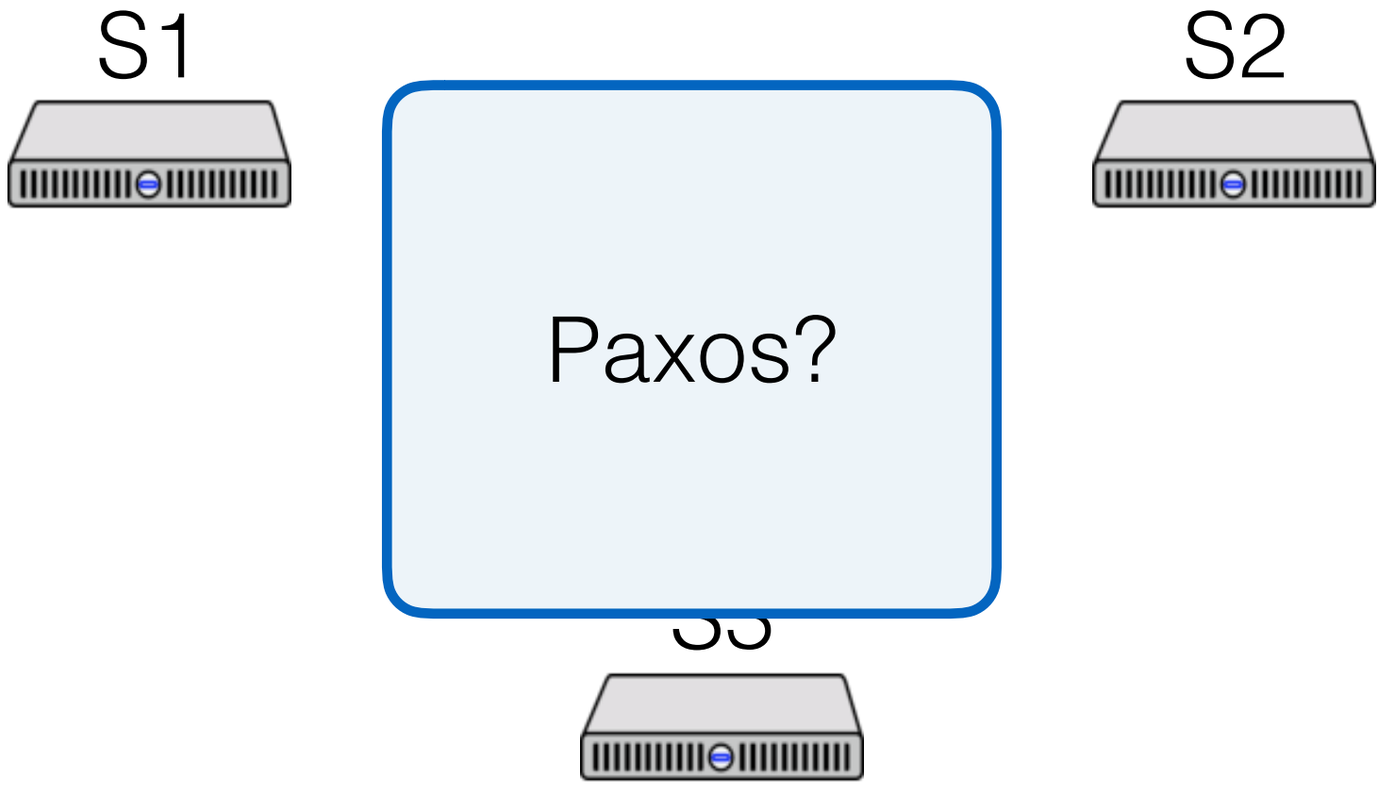
“Paxos Made Moderately Complex” Made Moderately Simple

State machine replication

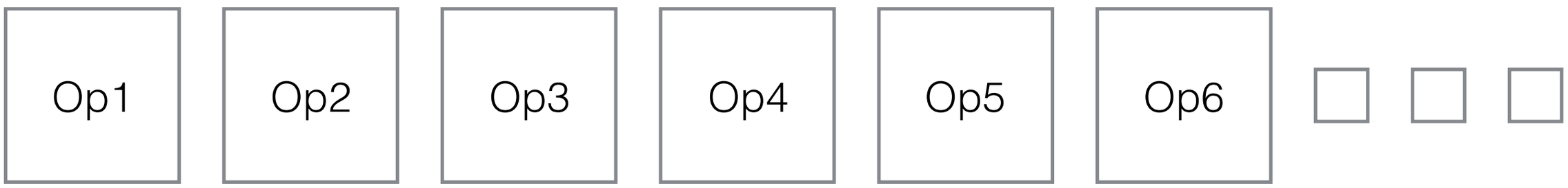
Reminder: want to agree on order of ops

Can think of operations as a log





Put k1 v1 Put k2 v2



Paxos

Paxos

=

Phase 1

- Send prepare messages
- Pick value to accept

Phase 2

- Send accept messages

Can we do better?

Phase 1: “leader election”

- Deciding whose value we will use

Phase 2: “commit”

- Leader makes sure it’s still leader, commits value

What if we split these phases?

- Lets us do operations with one round-trip

Roles in PMMC

Replicas (like learners)

- Keep log of operations, state machine, configs

Leaders (like proposers)

- Get elected, drive the consensus protocol

Acceptors (*simpler* than in Paxos Made Simple!)

- “Vote” on leaders

A note about ballots in PMMC

(leader, seqnum) pairs

Isomorphic to the system we discussed earlier

0. 0, 4, 8, 12, 16, …
1. 1, 5, 9, 13, 17, …
2. 2, 6, 10, 14, 18, …
3. 3, 7, 11, 15, 19, …

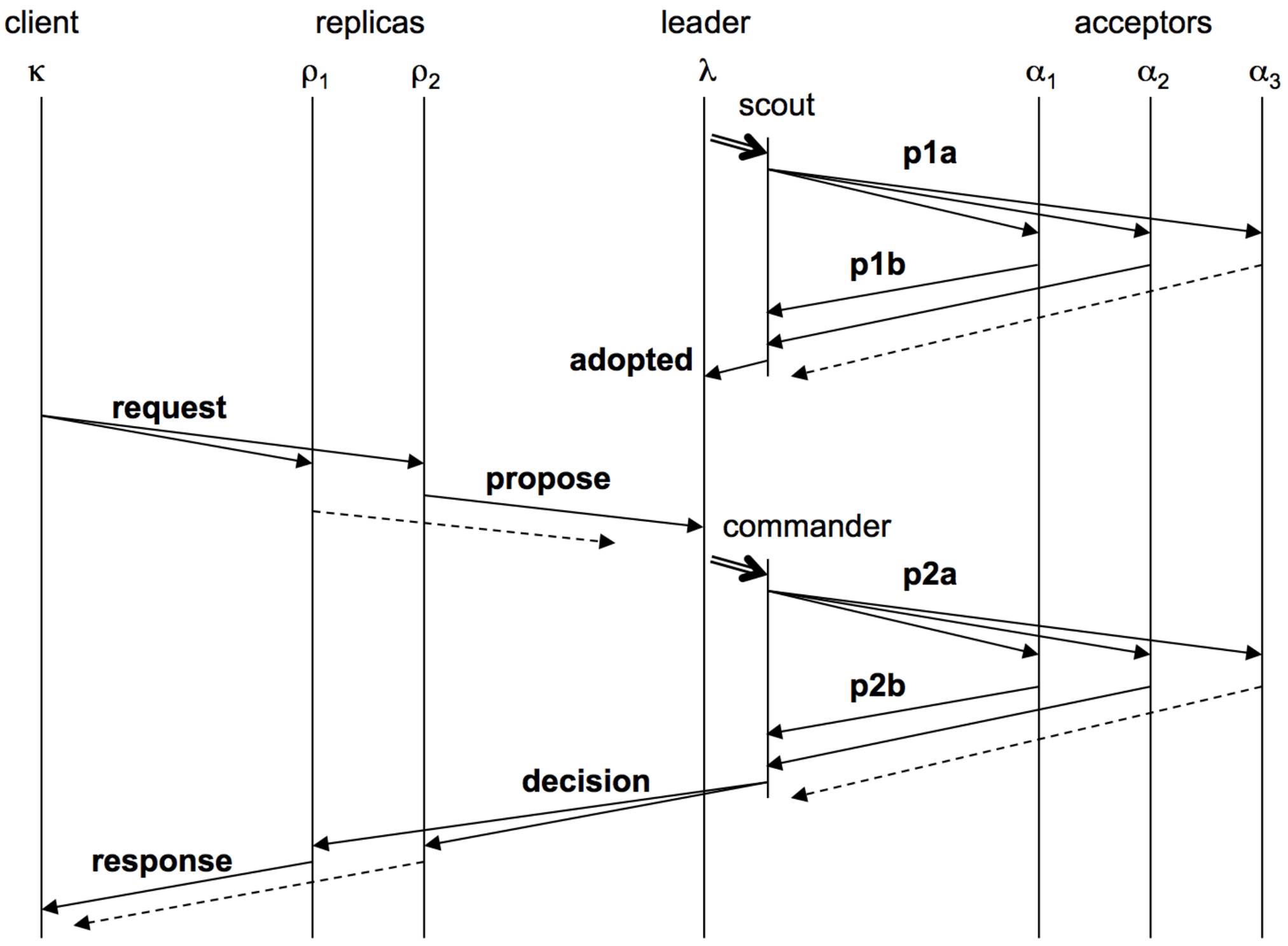
A note about ballots in PMMC

(leader, seqnum) pairs

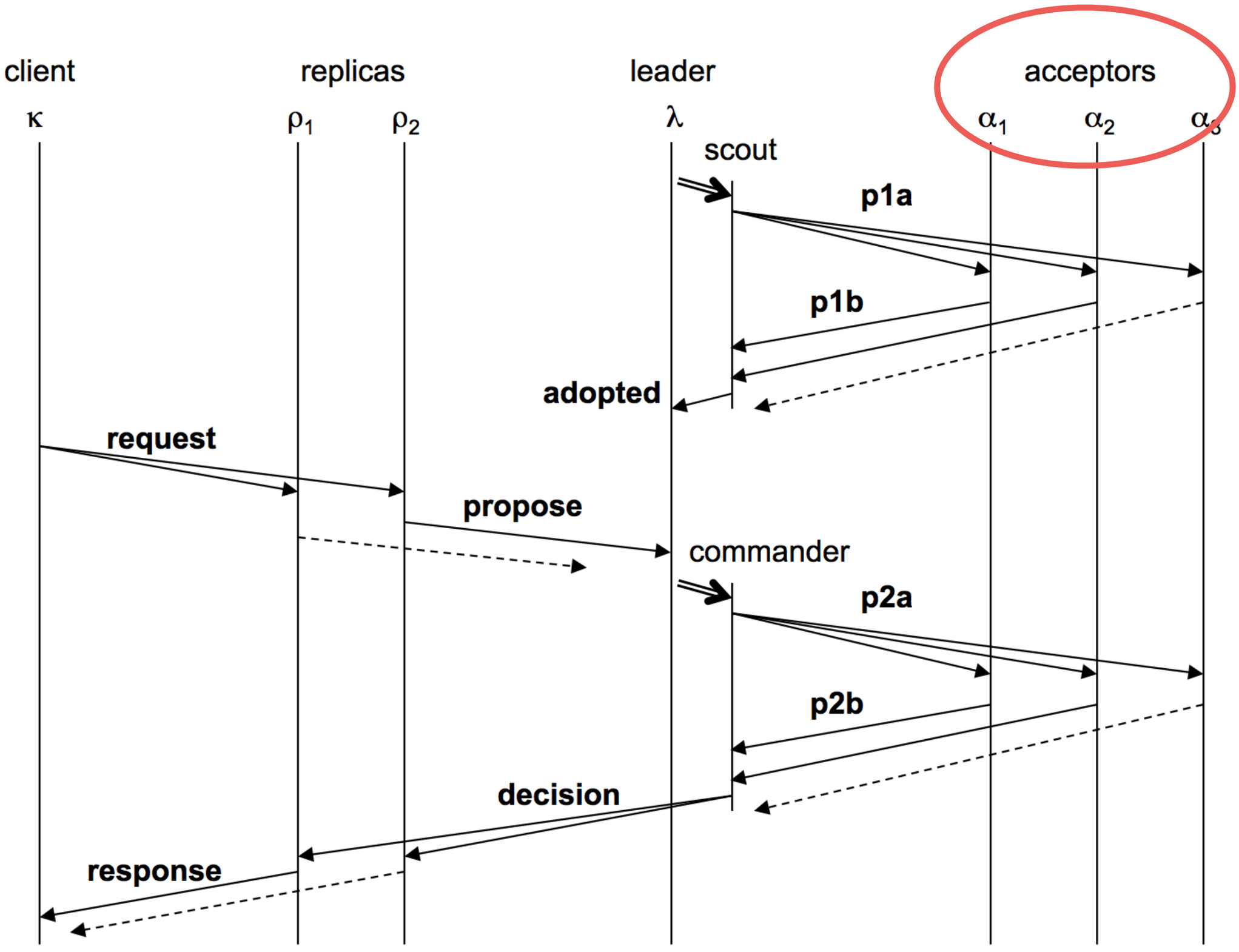
Isomorphic to the system we discussed earlier

0. 0.0, 1.0, 2.0, 3.0, 4.0, …
1. 0.1, 1.1, 2.1, 3.1, 4.1, …
2. 0.2, 1.2, 2.2, 3.2, 4.2, …
3. 0.3, 1.3, 2.3, 3.3, 4.3, …

Paxos Made Moderately Complex Made Simple



Paxos Made Moderately Complex Made Simple

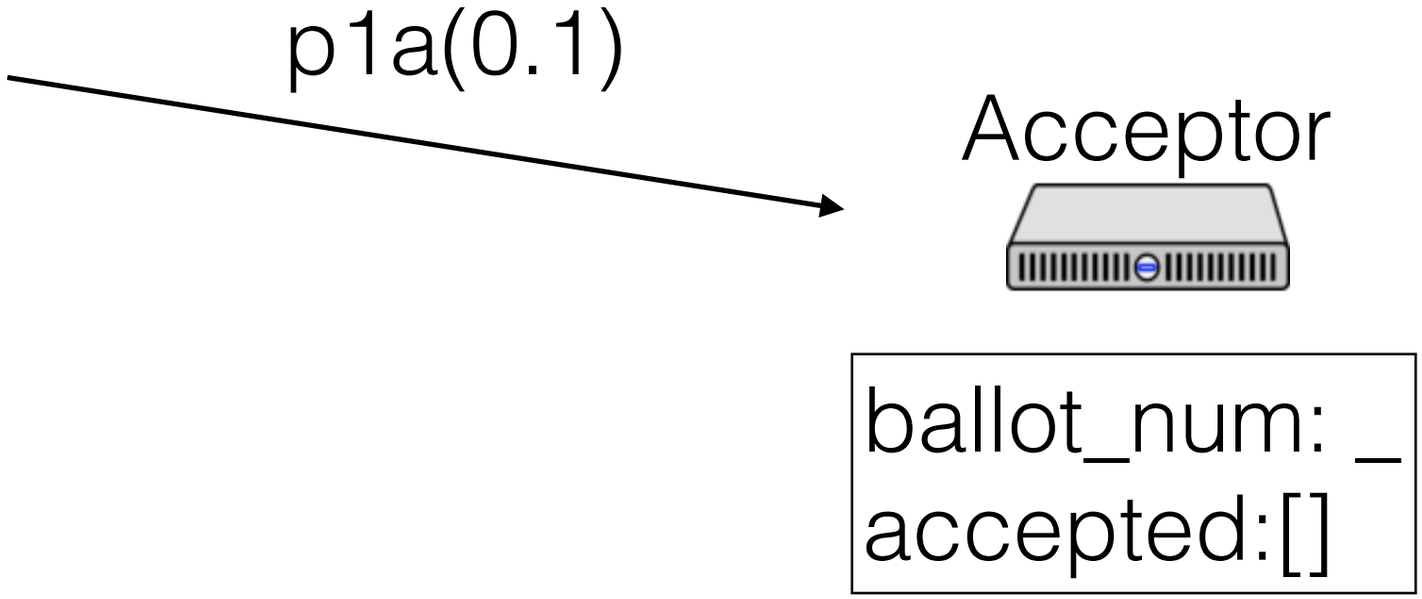


Acceptors

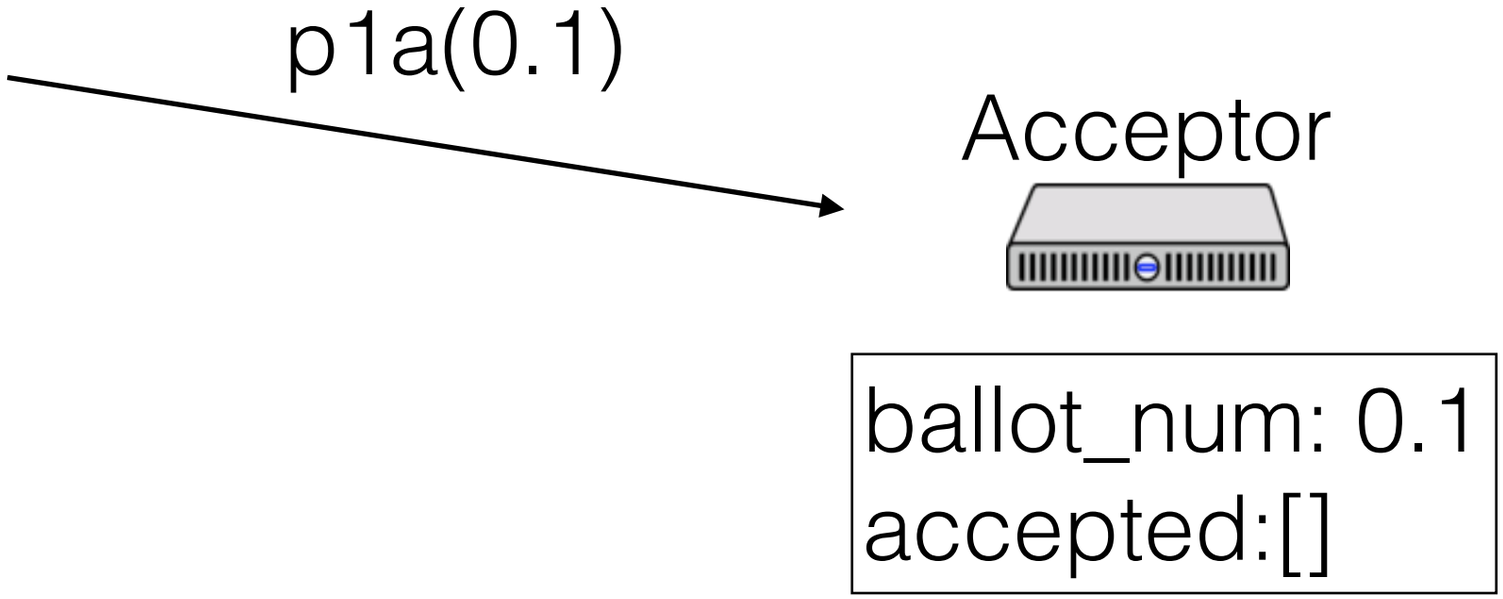
Acceptor

ballot_num: 0
accepted:[]

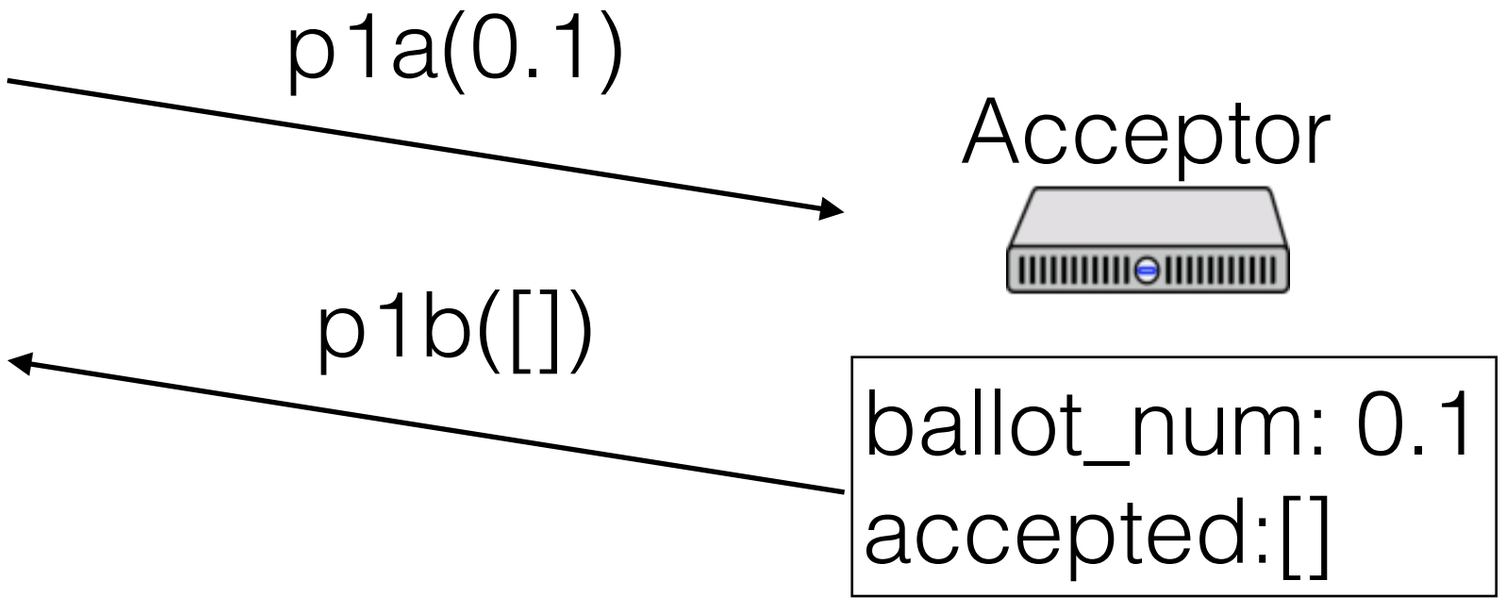
Acceptors



Acceptors



Acceptors



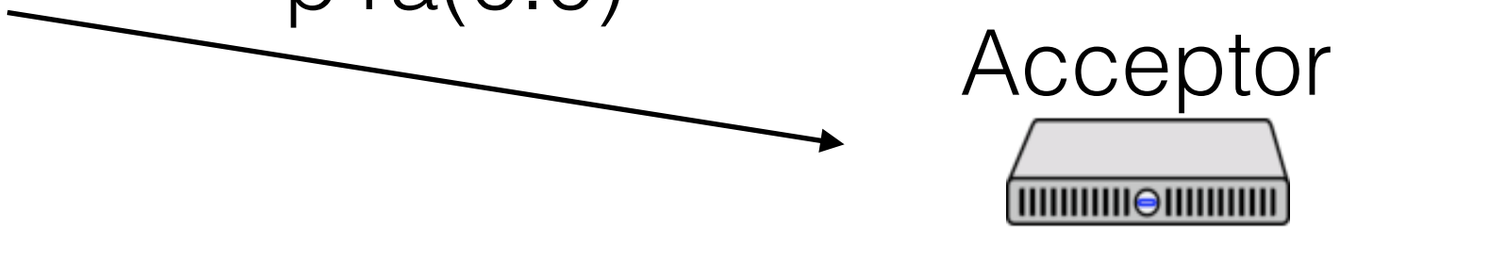
Acceptors

Acceptor

ballot_num: 0.1
accepted:[]

Acceptors

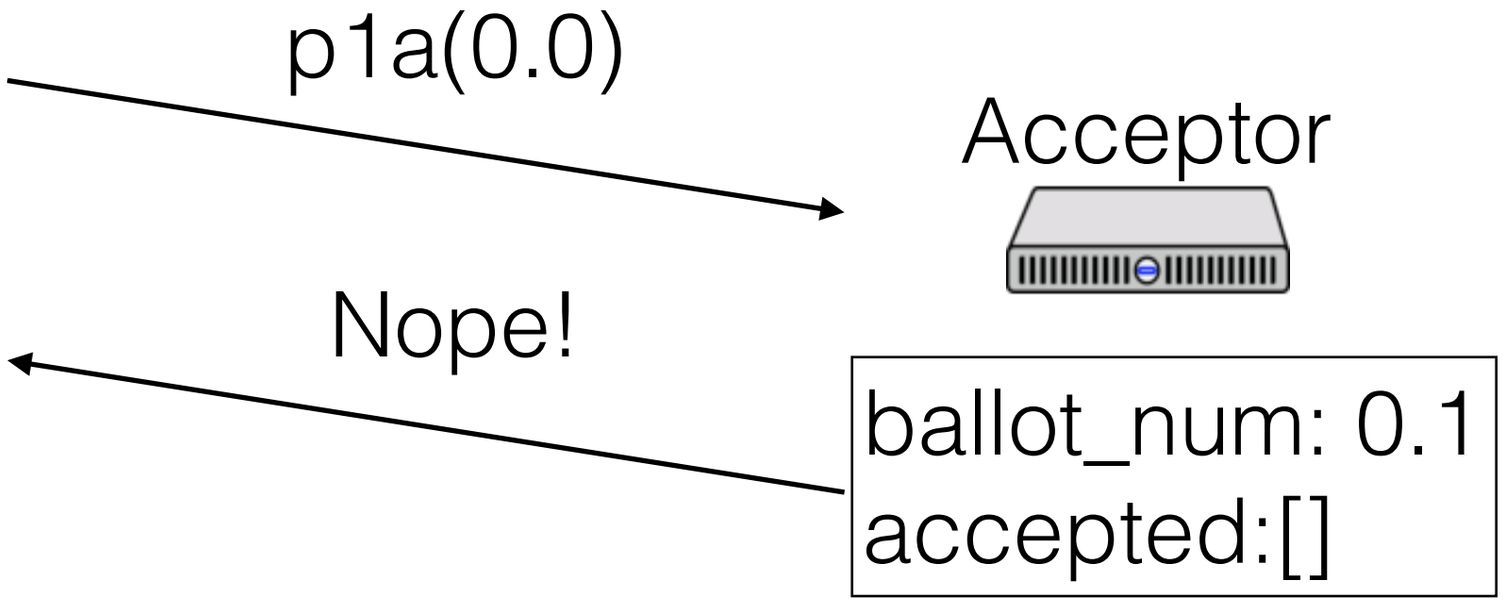
p1a(0.0)



Acceptor

ballot_num: 0.1
accepted:[]

Acceptors



Acceptors

Acceptor

ballot_num: 0.1
accepted:[]

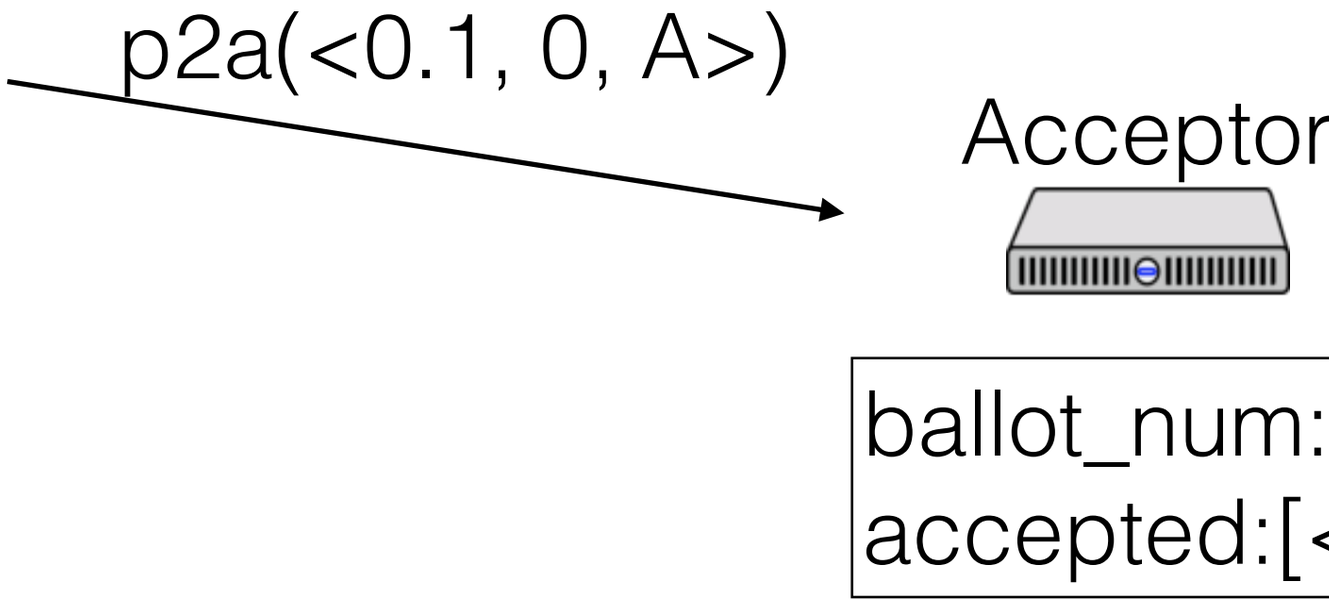
Acceptors

p2a(<0.1, 0, A>)

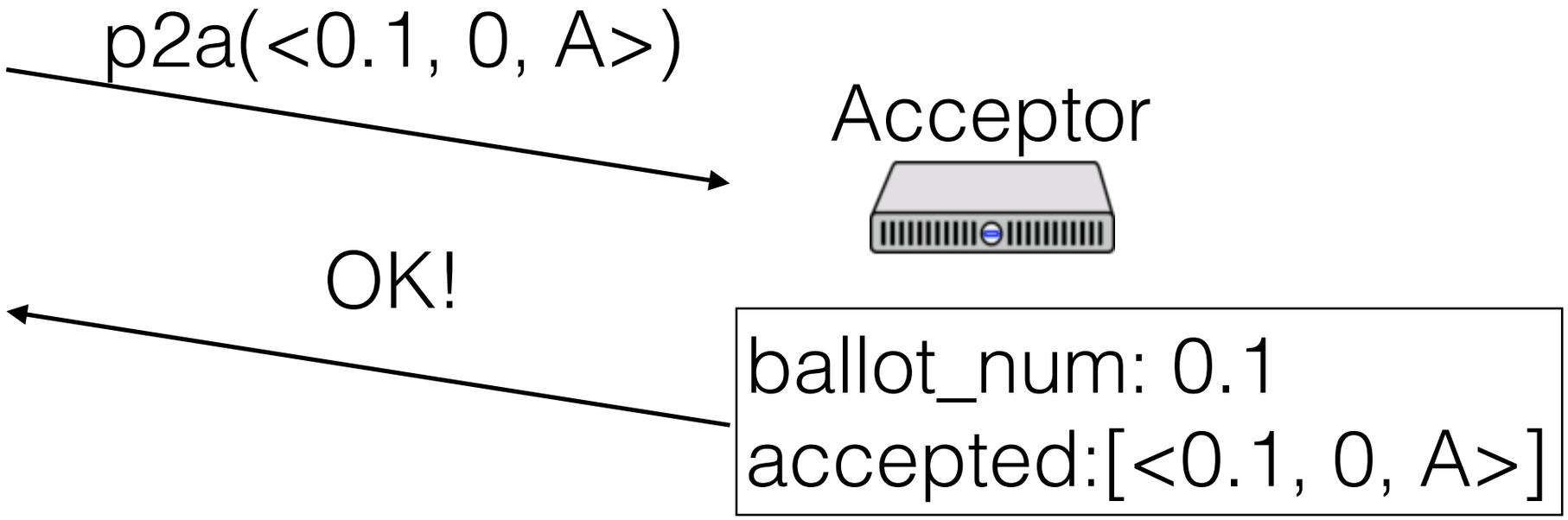
Acceptor

ballot_num: 0.1
accepted:[]

Acceptors



Acceptors



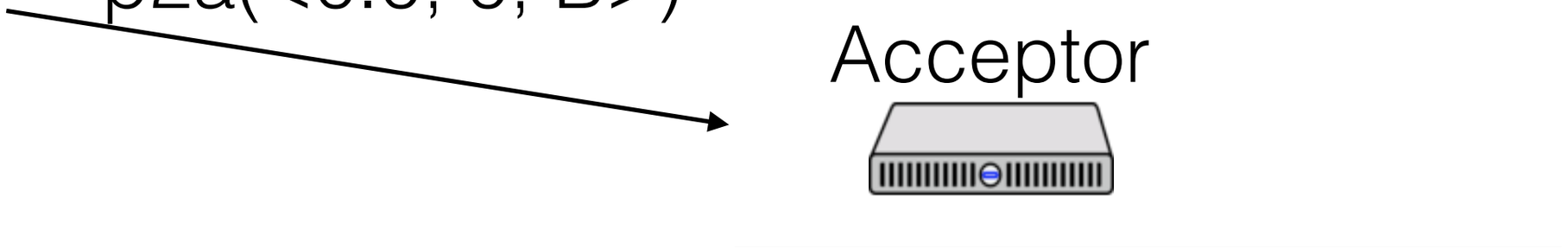
Acceptors

Acceptor

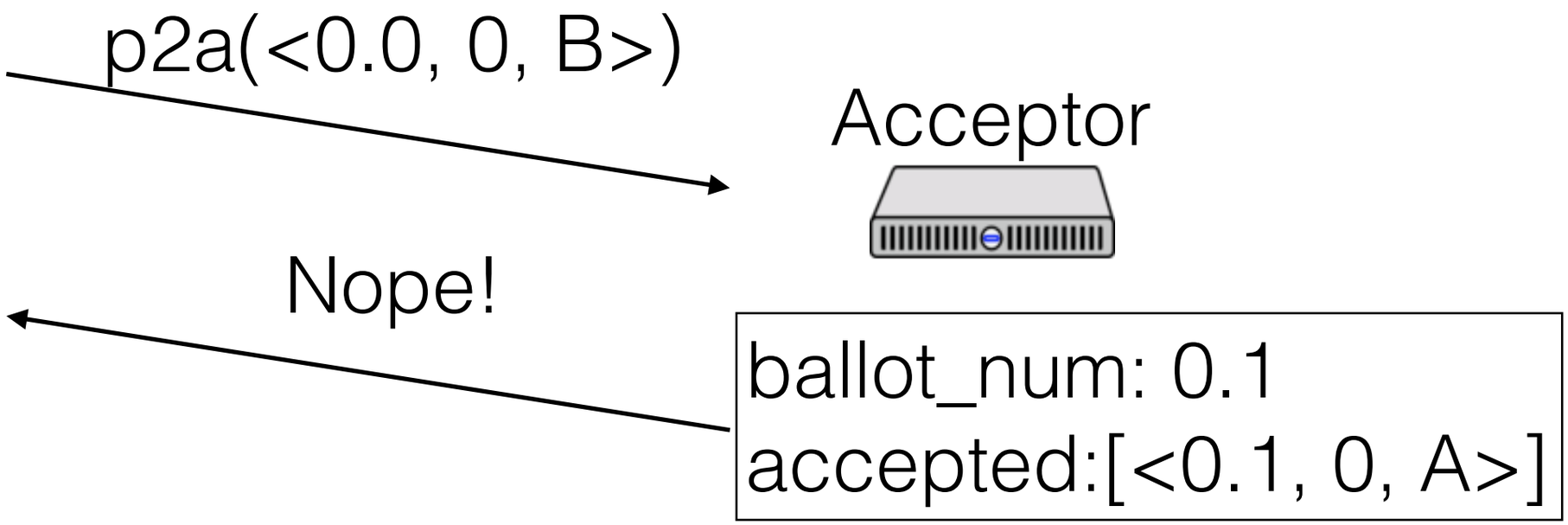
ballot_num: 0.1
accepted:[<0.1, 0, A>]

Acceptors

p2a(<0.0, 0, B>)



Acceptors



Acceptors

Acceptor

ballot_num: 0.1
accepted:[<0.1, 0, A>]

Acceptors

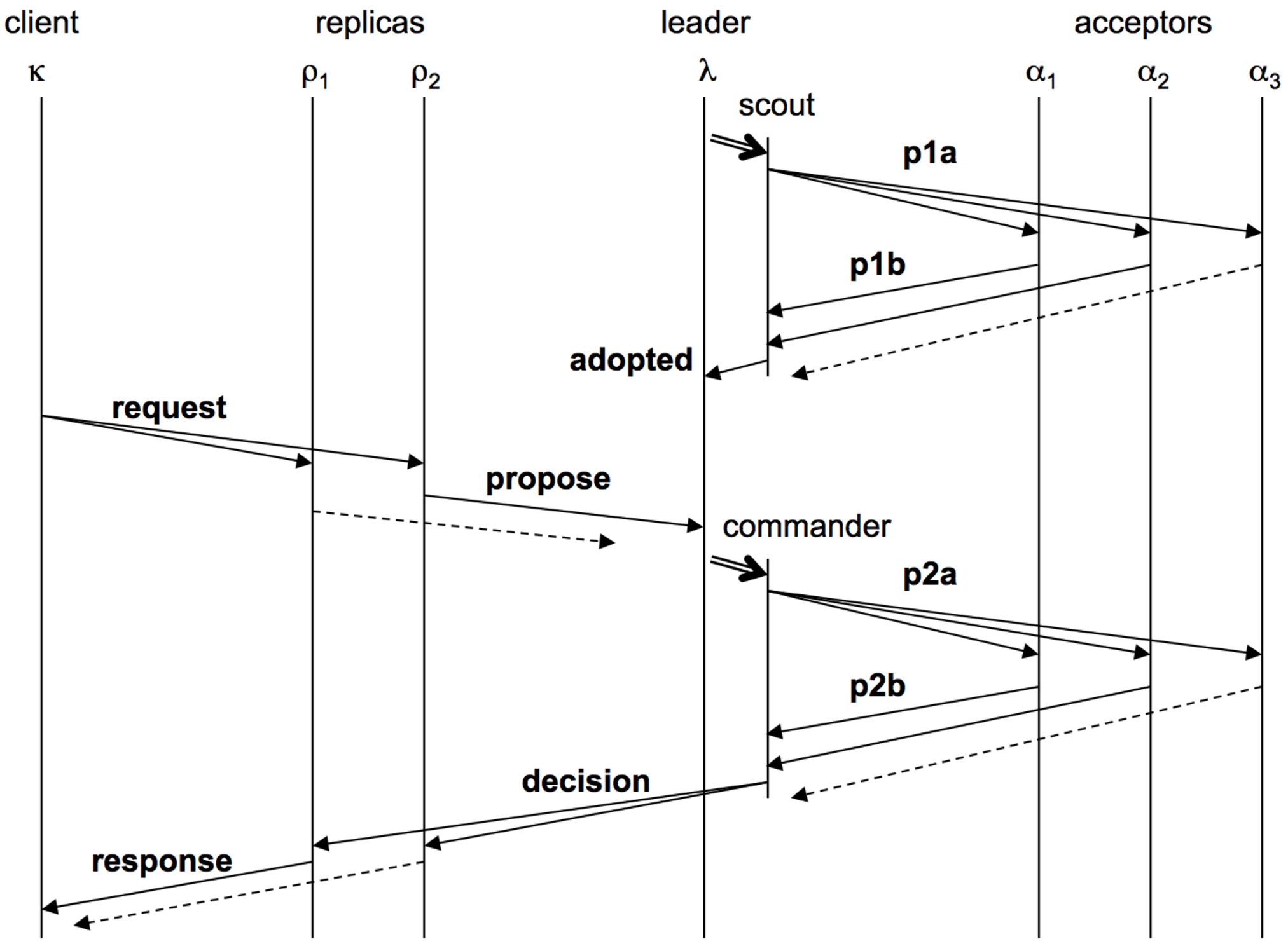
- Ballot numbers increase

- Only accept values from current ballot

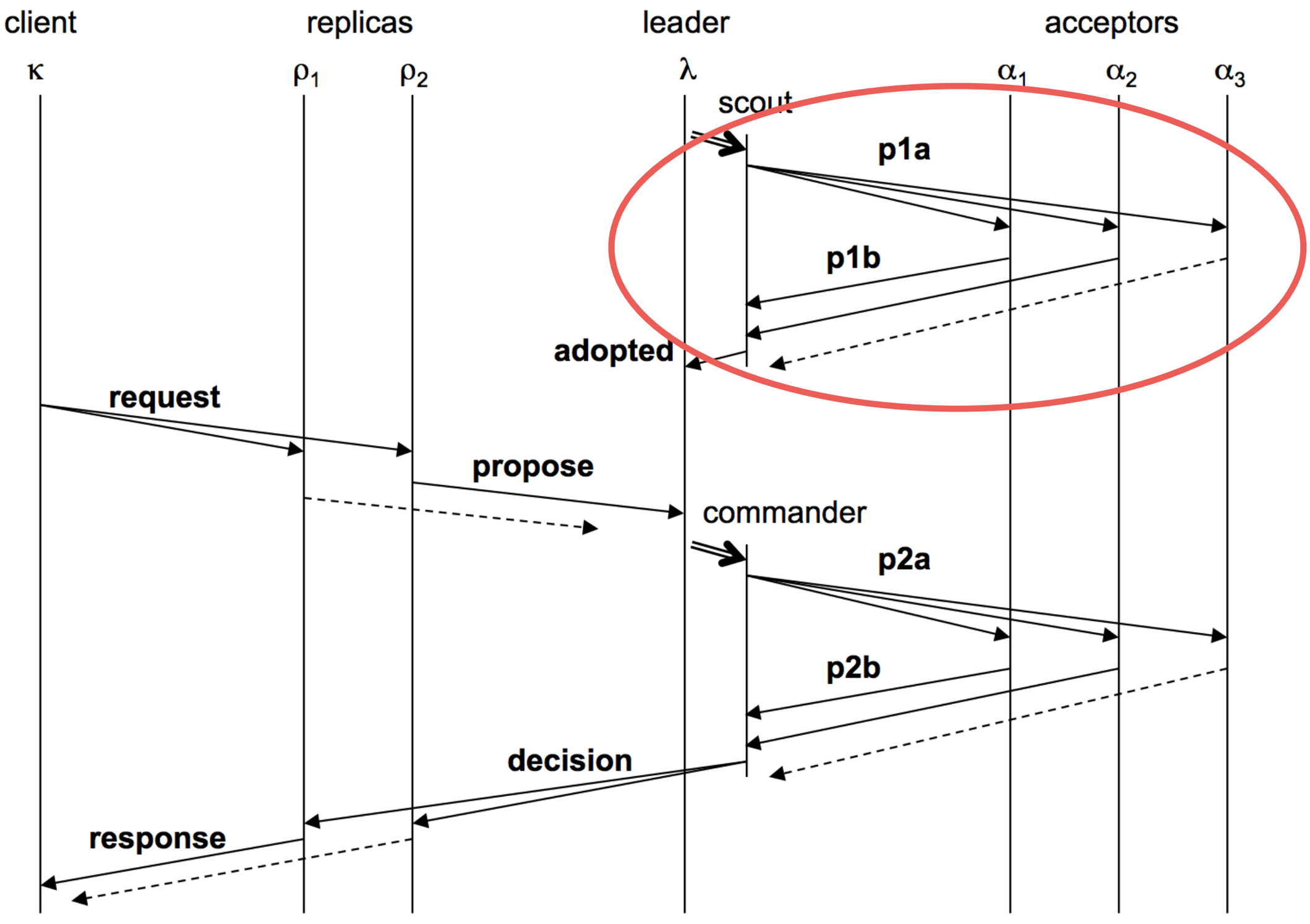
- Never remove ballots

- If a value *v* is chosen by a majority on ballot *b*, then any value accepted by any acceptor in the same slot on ballot *b'* > *b* has the same value

Paxos Made Moderately Complex Made Simple



Paxos Made Moderately Complex Made Simple

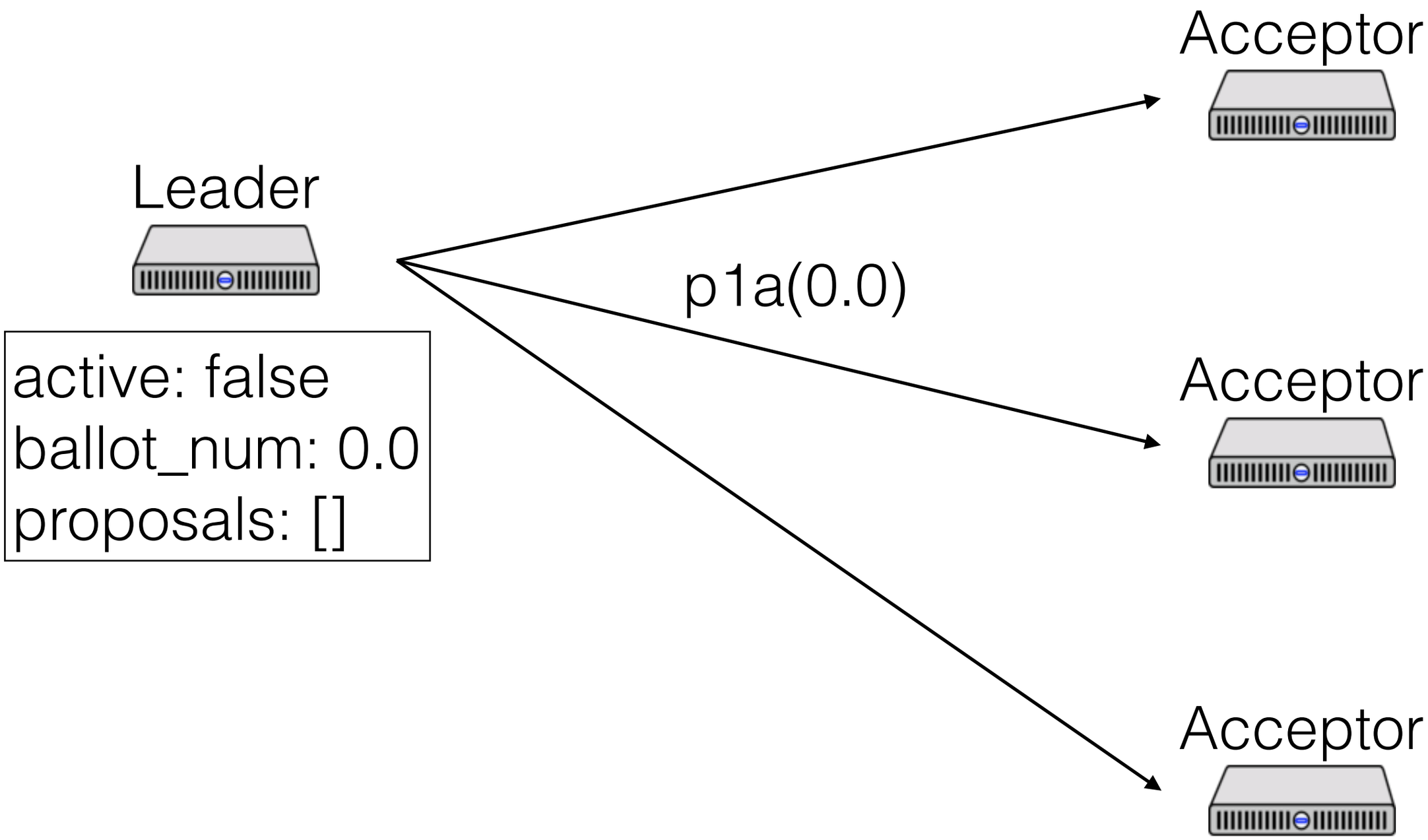


Leader: Getting Elected

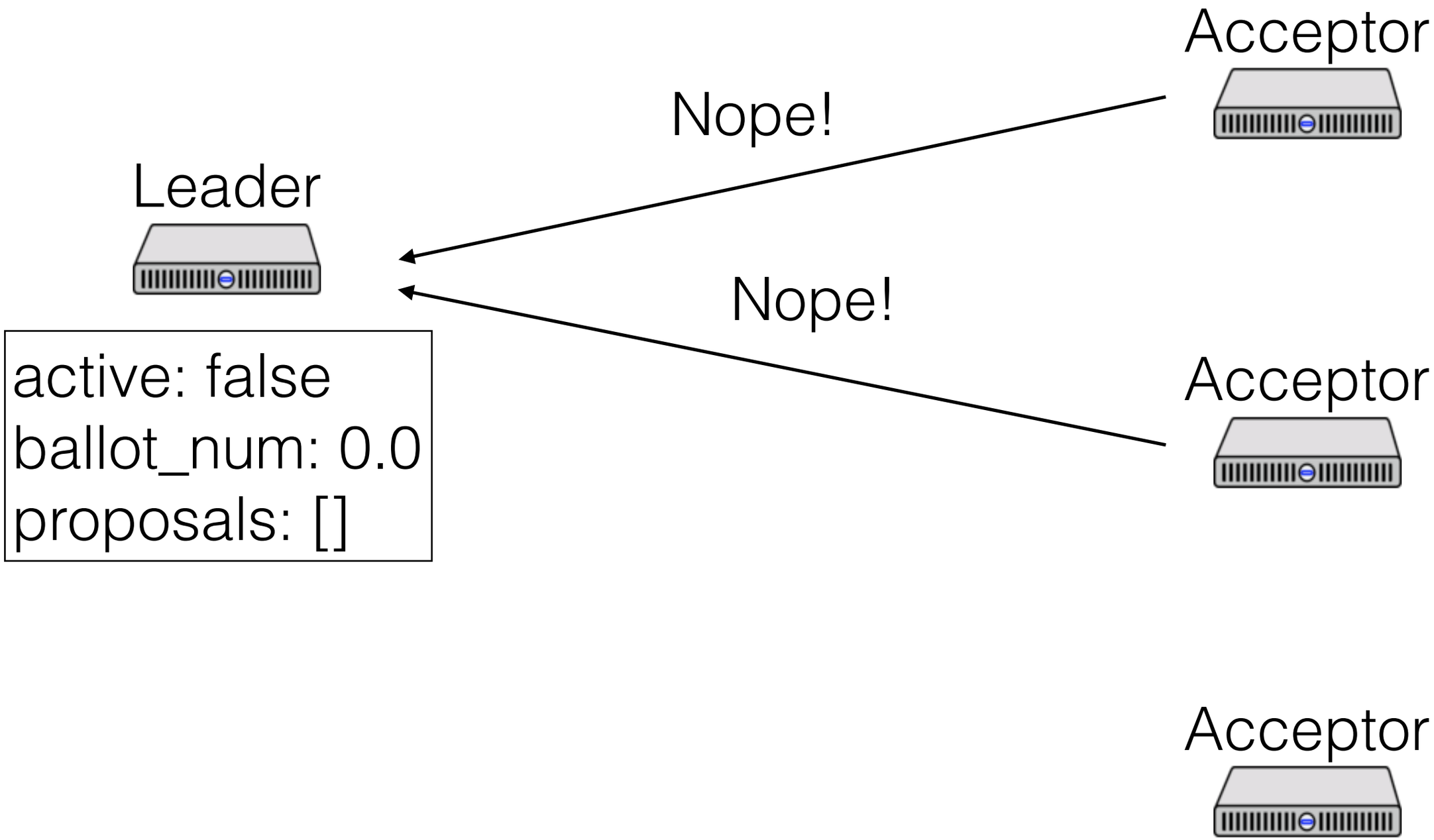
Leader

active: false
ballot_num: 0.0
proposals: []

Leader: Getting Elected



Leader: Getting Elected



Leader: Getting Elected

Acceptor

Leader

active: false
ballot_num: 1.0
proposals: []

Acceptor

Acceptor

Leader: Getting Elected

Acceptor

Leader

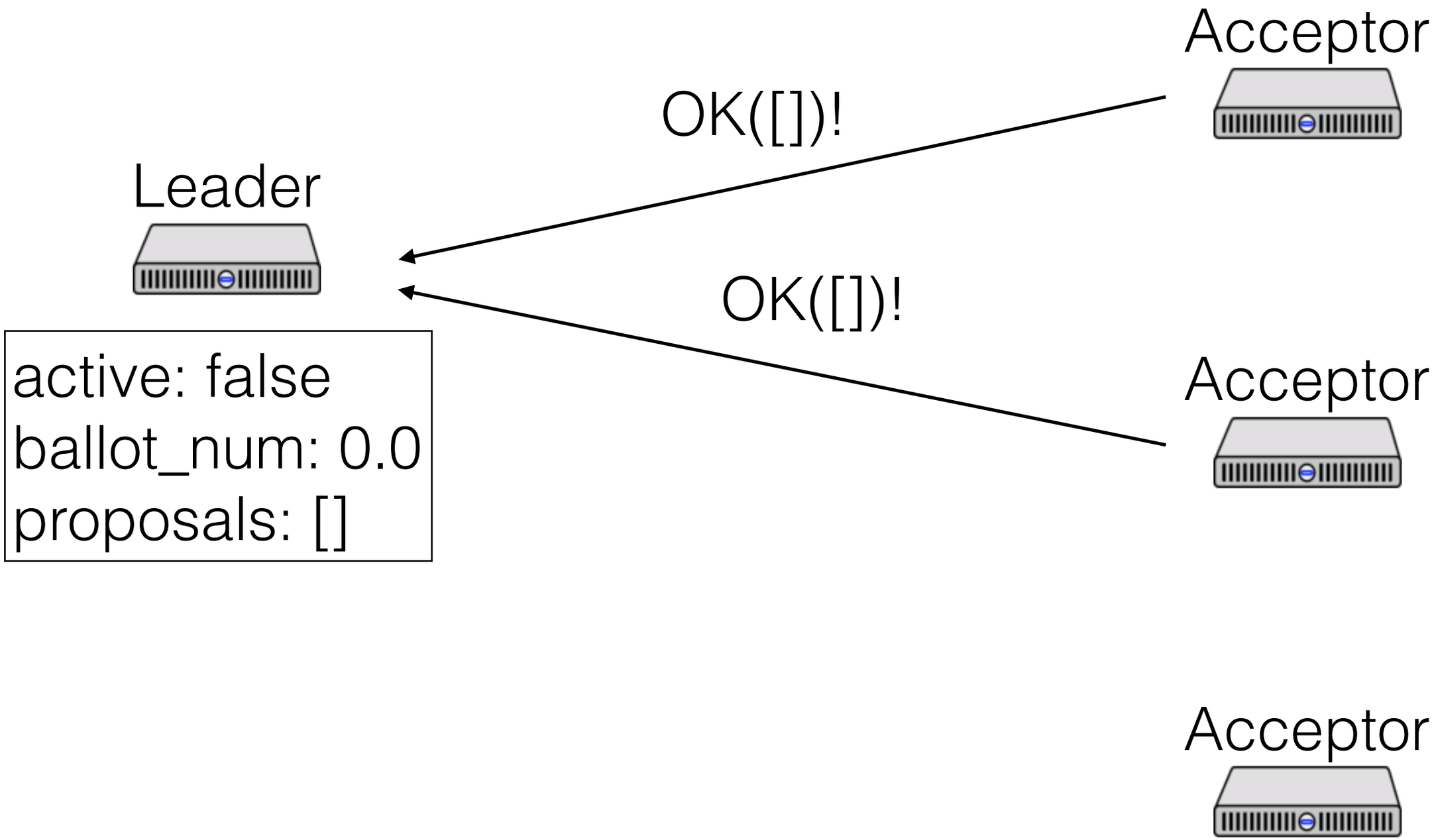
active: false
ballot_num: 1.0
proposals: []

Or…

Acceptor

Acceptor

Leader: Getting Elected



Leader: Getting Elected

Acceptor

Leader

active: true
ballot_num: 0.0
proposals: []

Acceptor

Acceptor

When to run for office

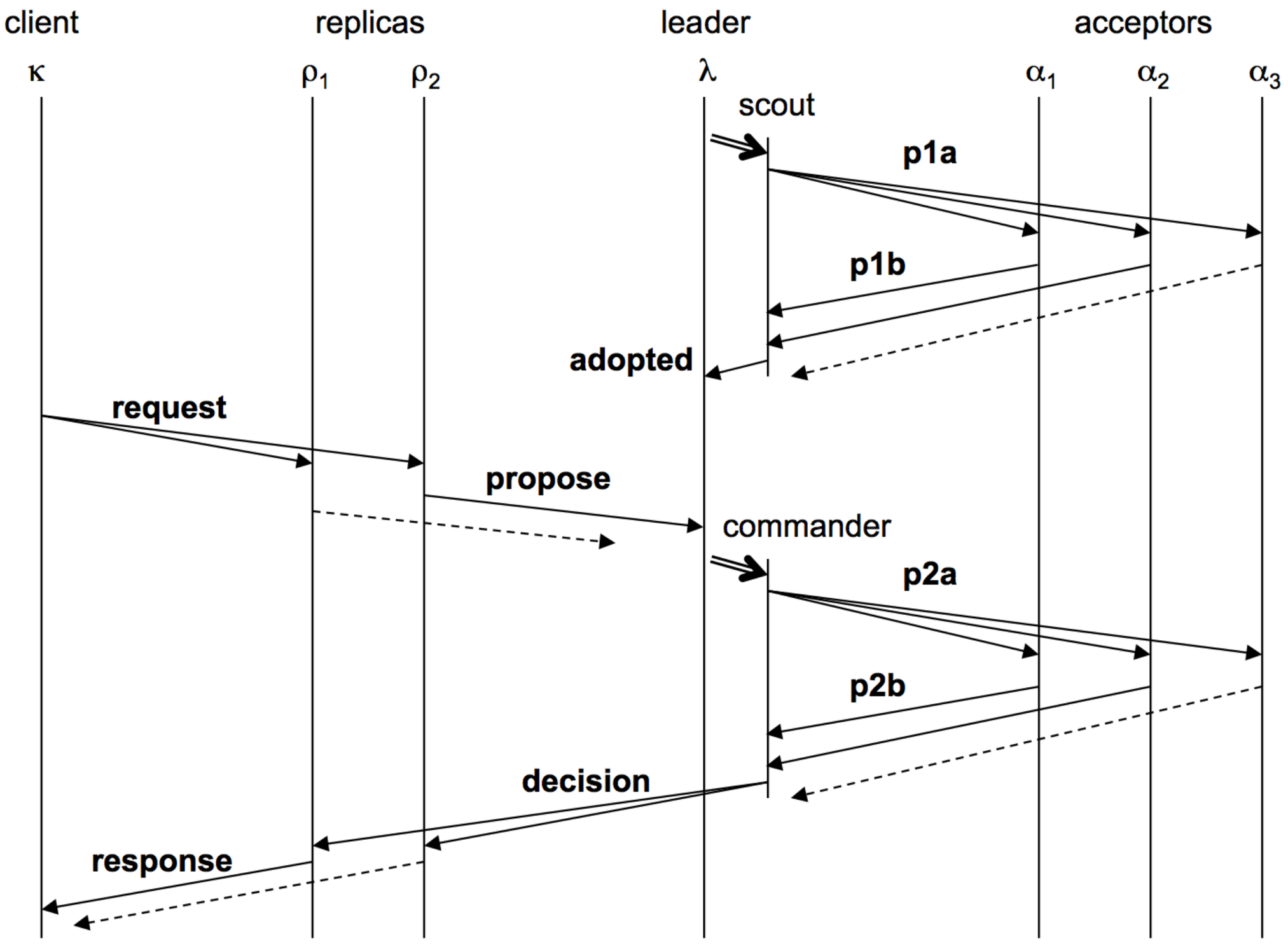
When should a leader try to get elected?

- At the beginning of time
- When the current leader seems to have failed

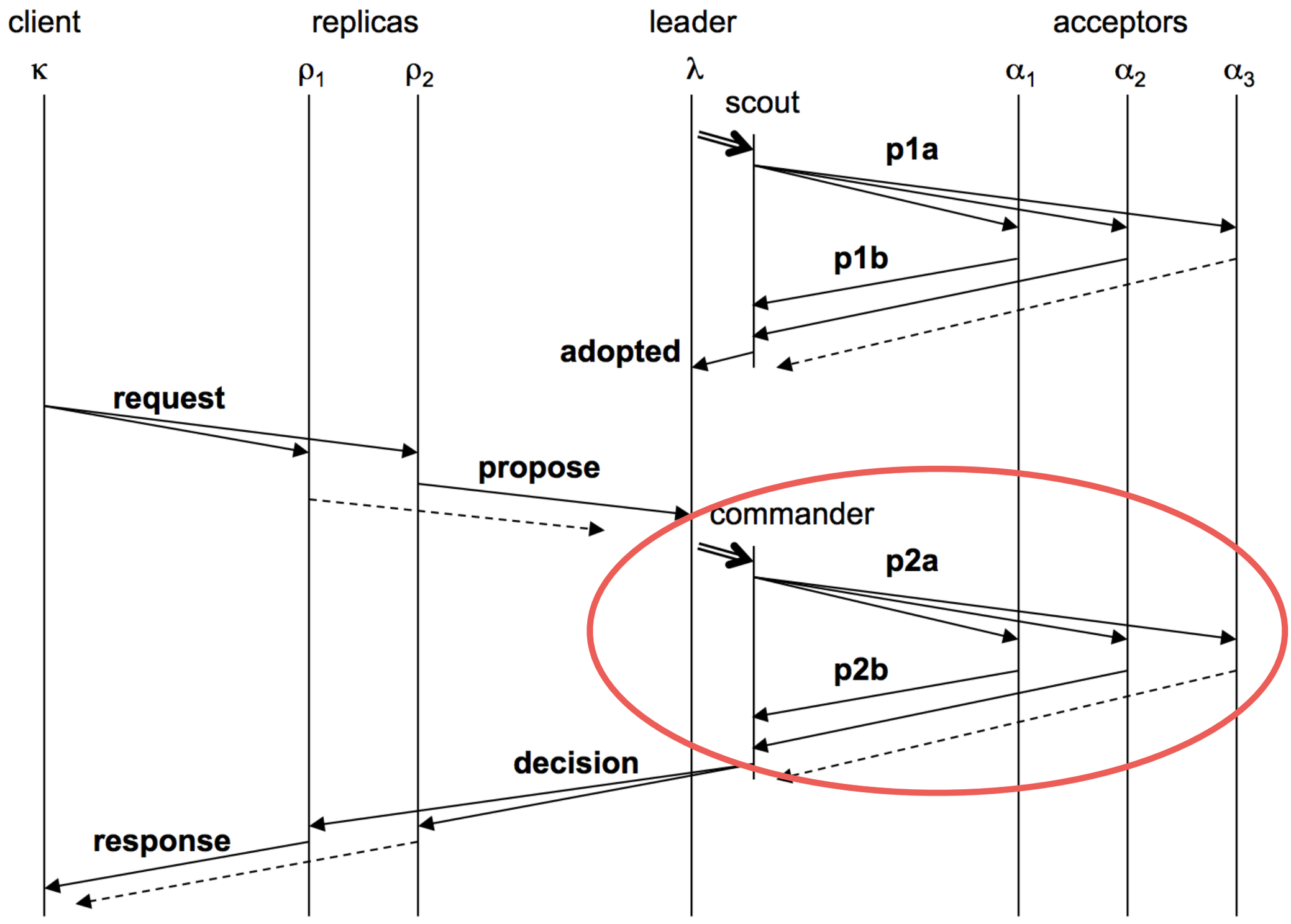
Paper describes an algorithm, based on pinging the leader and timing out

If you get preempted, don't immediately try for election again!

Paxos Made Moderately Complex Made Simple



Paxos Made Moderately Complex Made Simple



Leader: Handling proposals

Acceptor

Leader

active: true
ballot_num: 0.0
proposals: []

Op1 should be A
(A = “Put k1 v1”)

Acceptor

Acceptor

Replica

Leader: Handling proposals

Acceptor

Leader

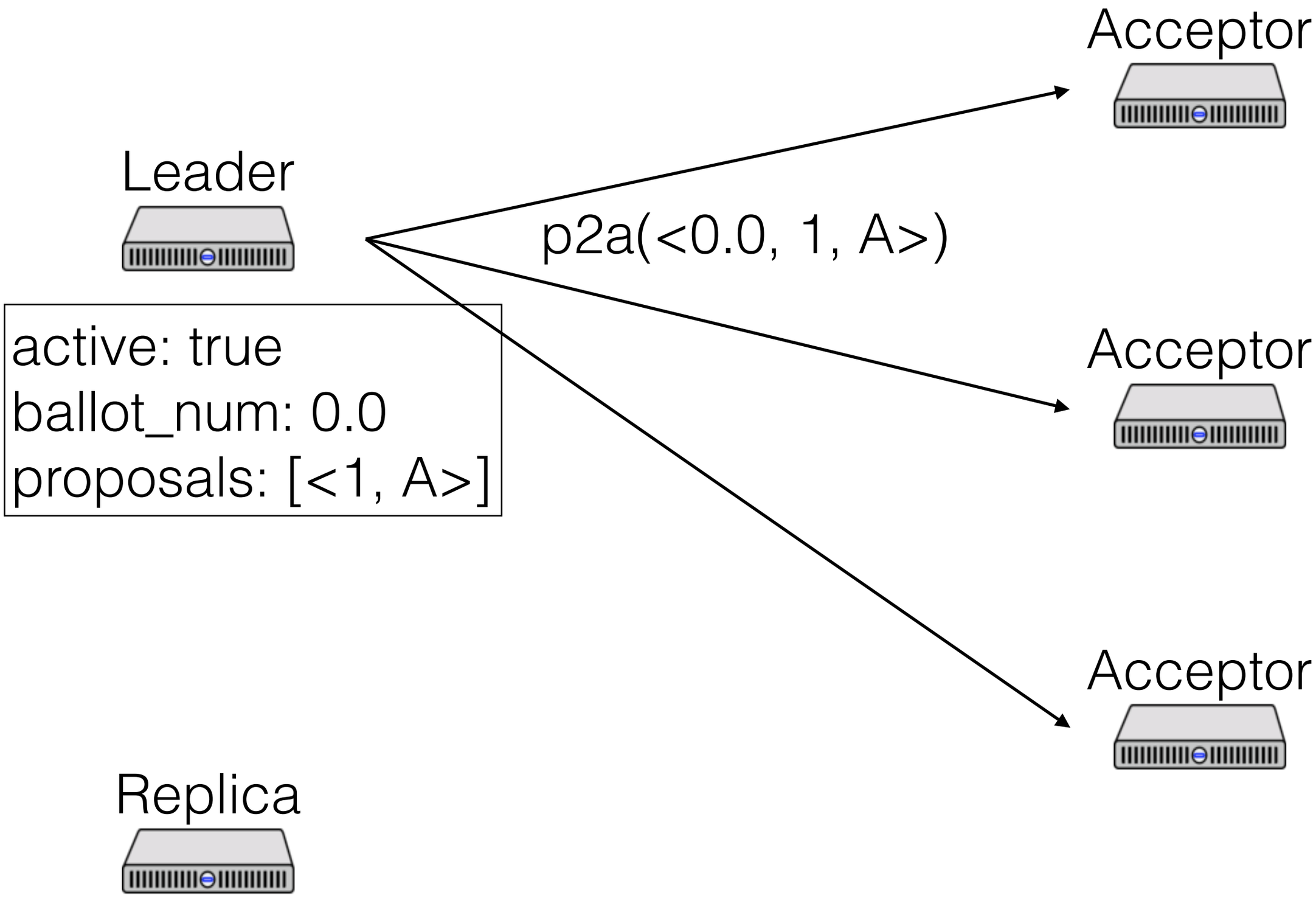
active: true
ballot_num: 0.0
proposals: [<1, A>]

Acceptor

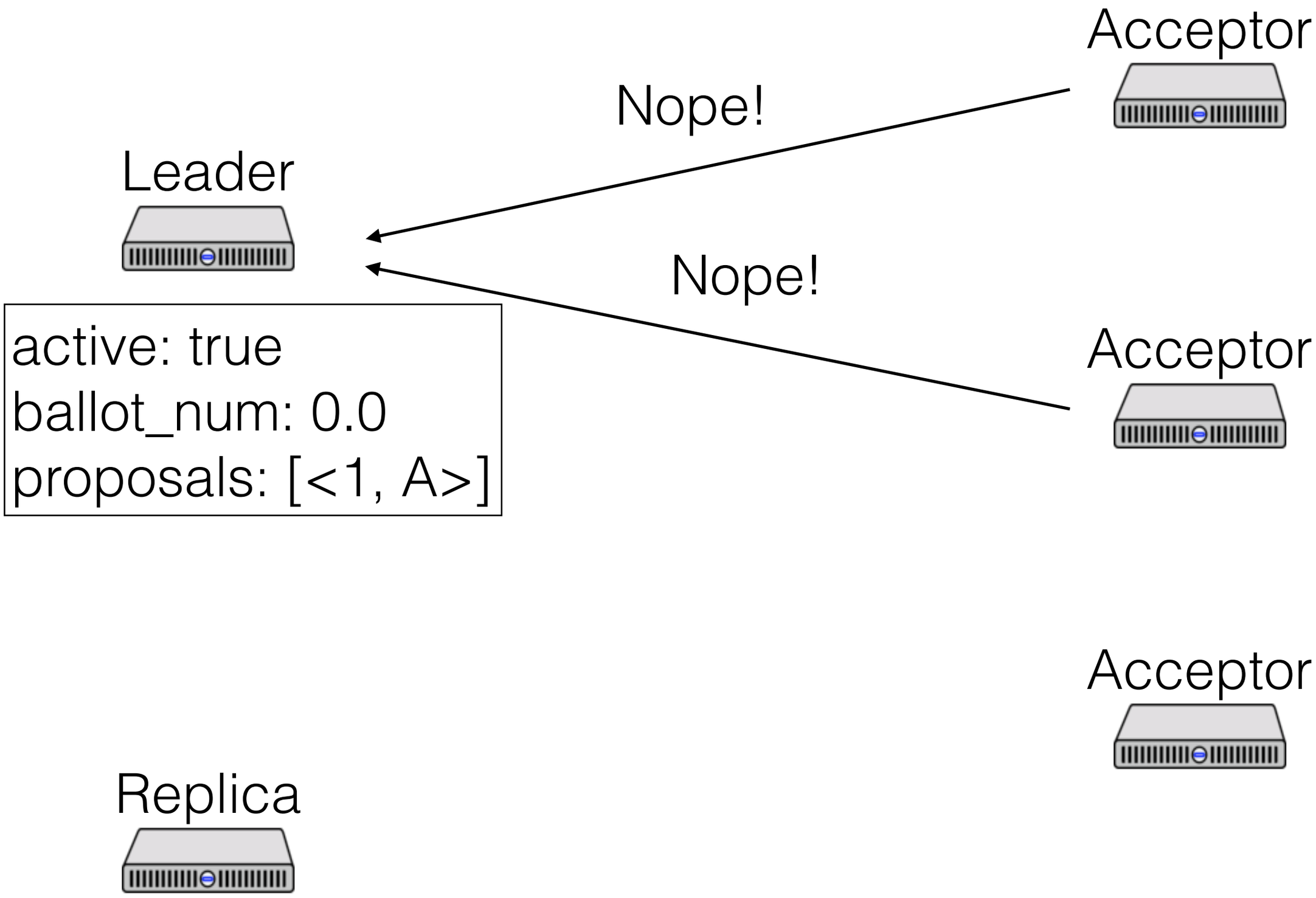
Acceptor

Replica

Leader: Handling proposals



Leader: Handling proposals



Leader: Handling proposals

Acceptor

Leader

active: false
ballot_num: 0.0
proposals: [<1, A>]

Acceptor

Acceptor

Replica

Leader: Handling proposals

Acceptor

Leader

active: false
ballot_num: 0.0
proposals: [<1, A>]

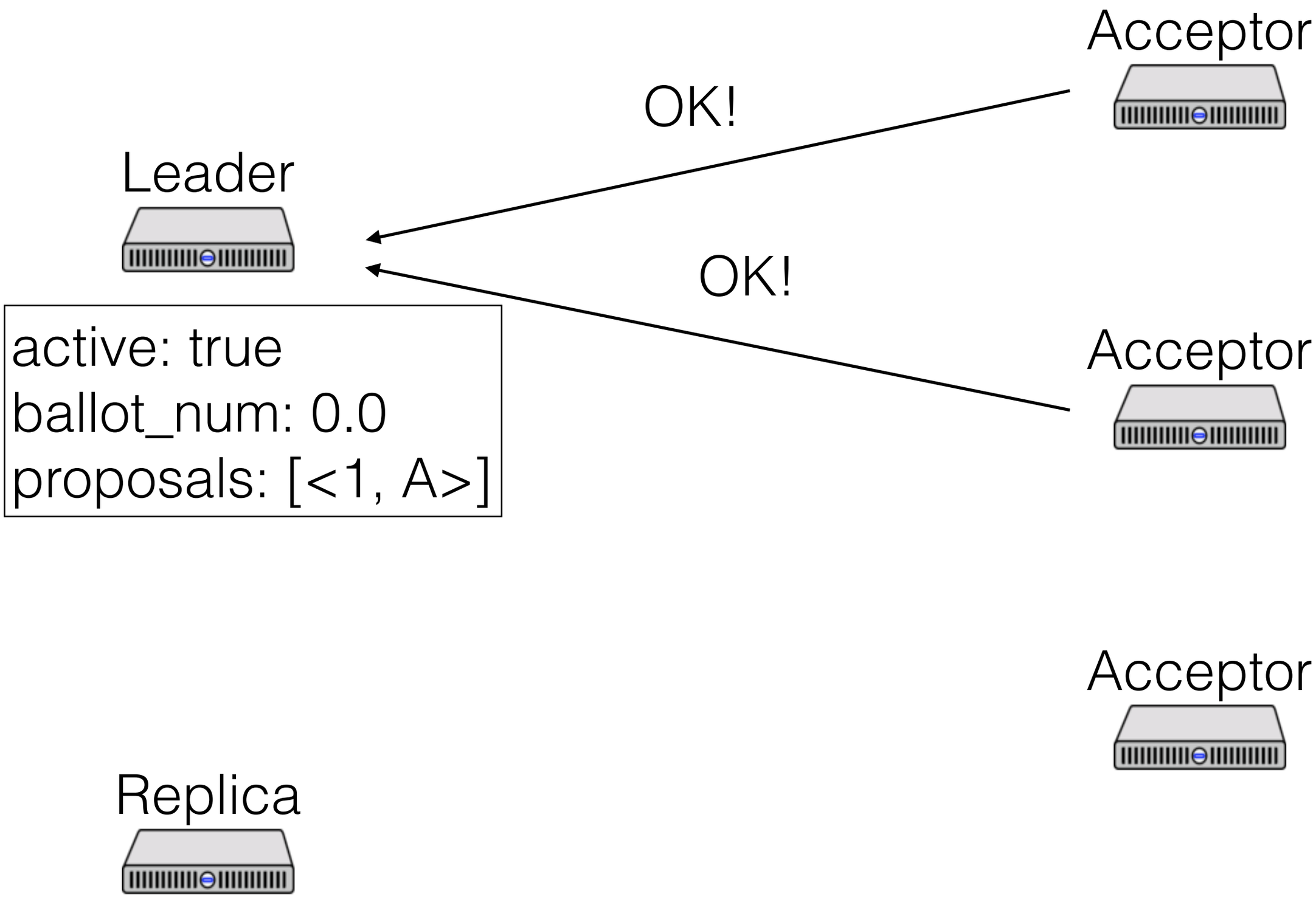
Or…

Acceptor

Acceptor

Replica

Leader: Handling proposals



Leader: Handling proposals

Acceptor

Leader

active: true
ballot_num: 0.0
proposals: [<1, A>]

Acceptor

Op1 is A

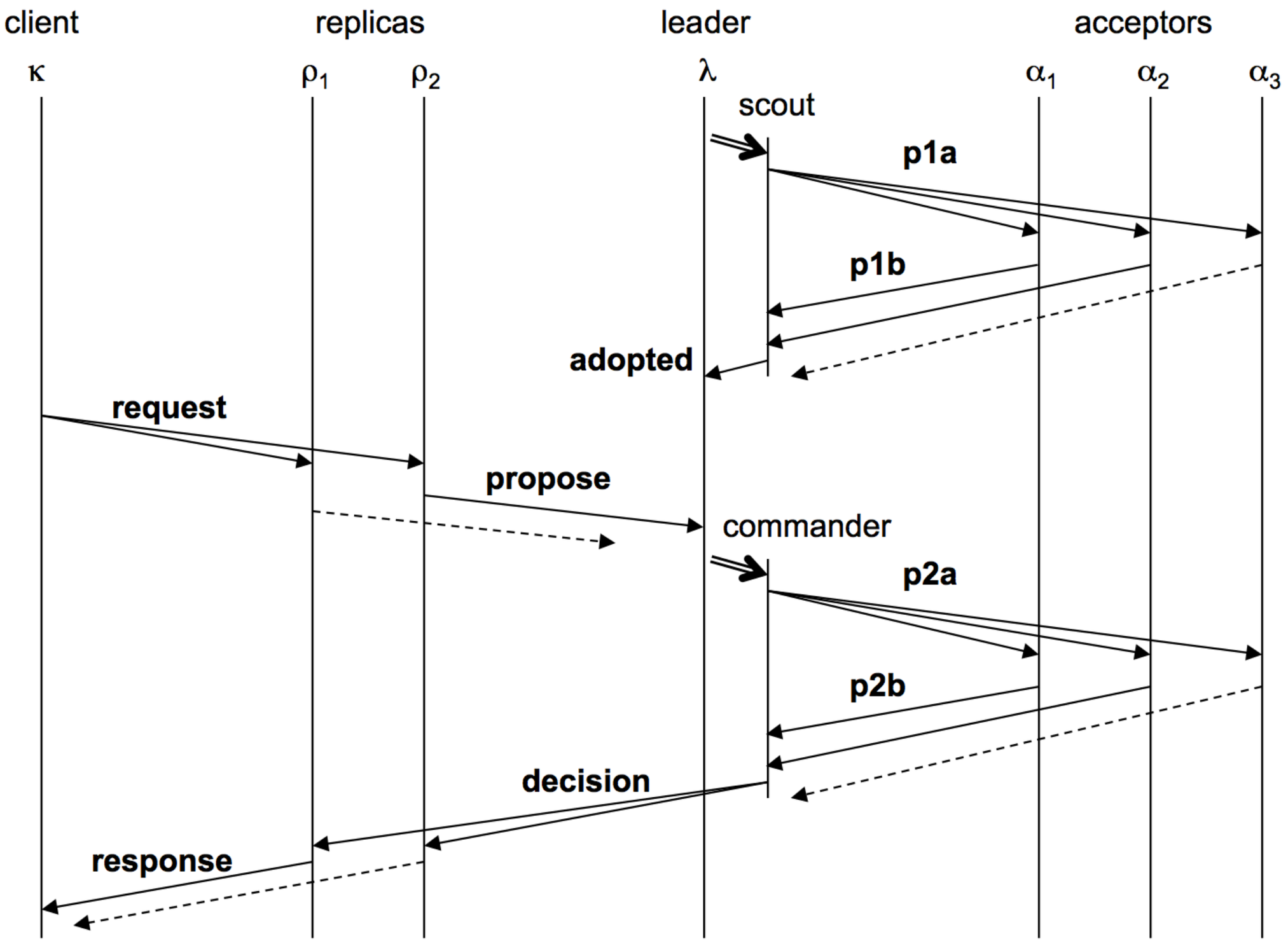
Acceptor

Replica

Replica

Replica

Paxos Made Moderately Complex Made Simple



Election revisited

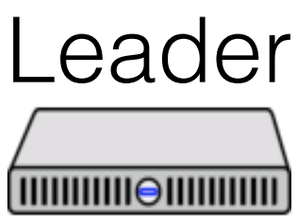
Leader

active: false
ballot_num: 3.0
proposals: [<1, B>]

Acceptor

ballot_num: 2.1
accepted:[<2.1, 1, A>]

Election revisited


Leader

p1a(3.0)


Acceptor

active: false
ballot_num: 3.0
proposals: [<1, B>]

ballot_num: 2.1
accepted:[<2.1, 1, A>]

Election revisited

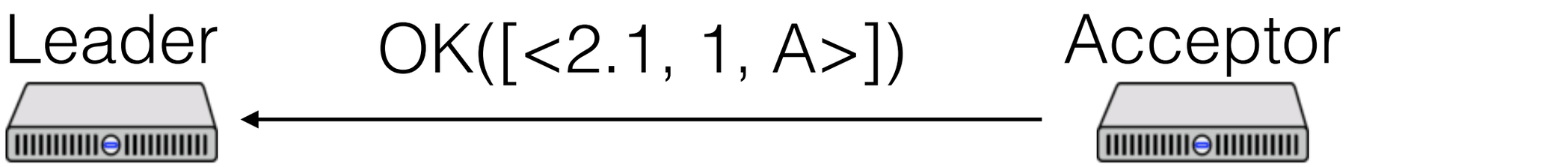
Leader

active: false
ballot_num: 3.0
proposals: [<1, B>]

Acceptor

ballot_num: 3.0
accepted:[<2.1, 1, A>]

Election revisited



active: false
ballot_num: 3.0
proposals: [<1, B>]

ballot_num: 3.0
accepted:[<2.1, 1, A>]

Election revisited

Leader

active: true
ballot_num: 3.0
proposals: [<1, A>]

Acceptor

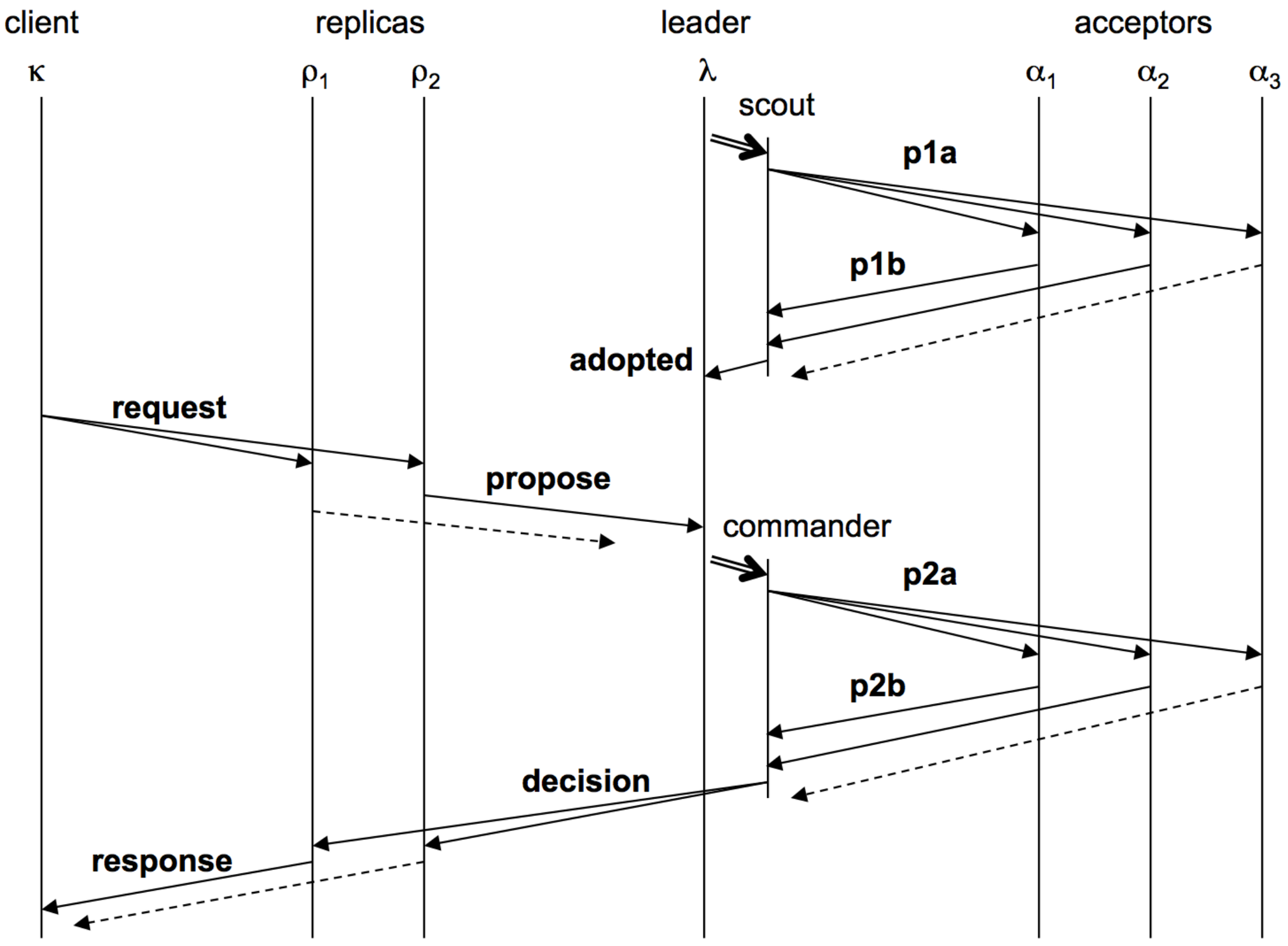
ballot_num: 3.0
accepted:[<2.1, 1, A>]

Leaders

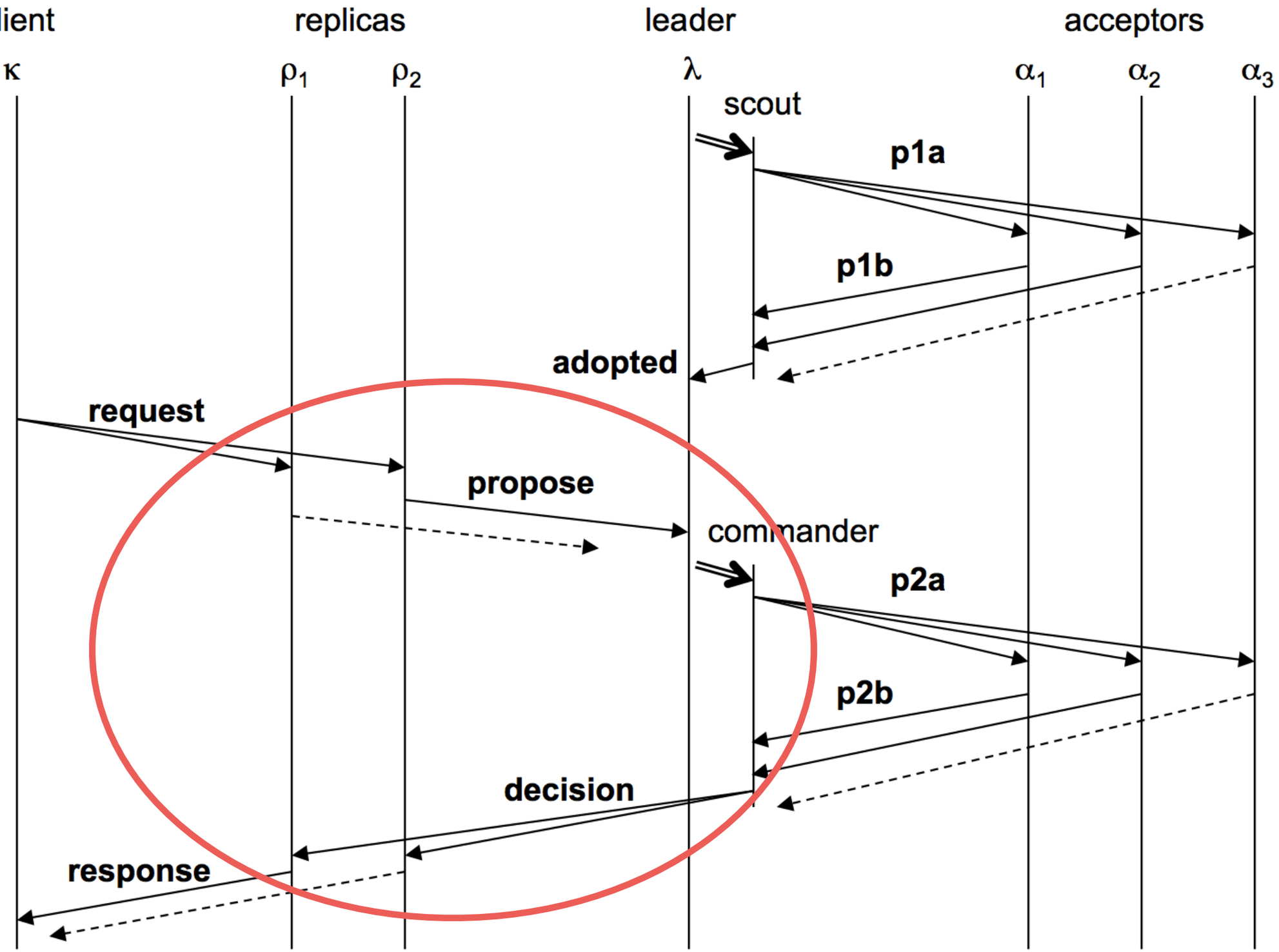
- Only propose one value per ballot and slot

- If a value *v* is chosen by a majority on ballot *b*, then any value proposed by any leader in the same slot on ballot *b'* > *b* has the same value

Paxos Made Moderately Complex Made Simple



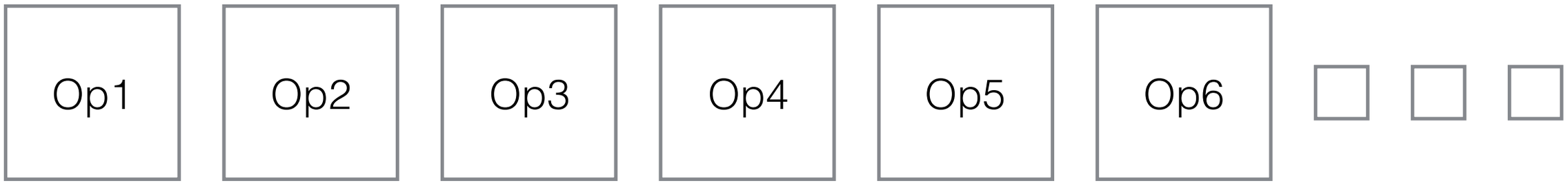
Paxos Made Moderately Complex Made Simple



Replicas

Replica

Put k1 v1 Put k2 v2



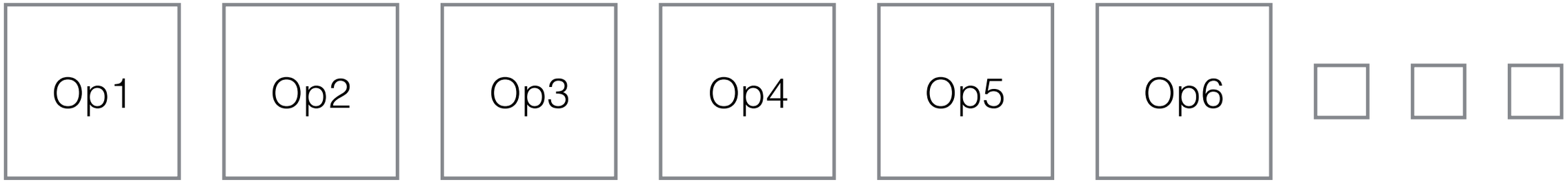
Replicas

Replica

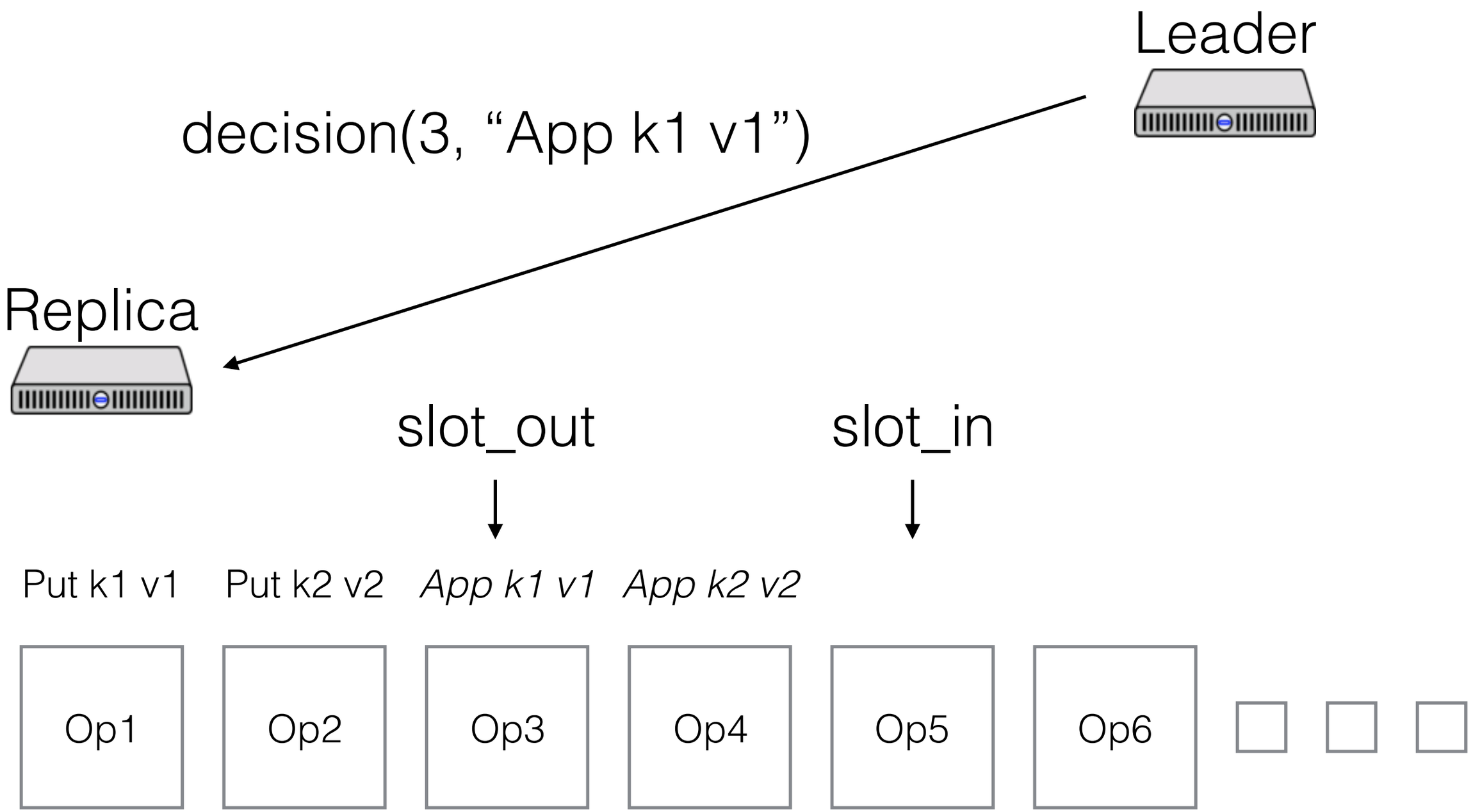
slot_out

slot_in

Put k1 v1 | Put k2 v2 | *App k1 v1* | *App k2 v2*



Replicas


Leader
decision(3, “App k1 v1”)
Replica
slot_out
slot_in
Put k1 v1
Put k2 v2
App k1 v1
App k2 v2
Op1
Op2
Op3
Op4
Op5
Op6

Replicas

Leader

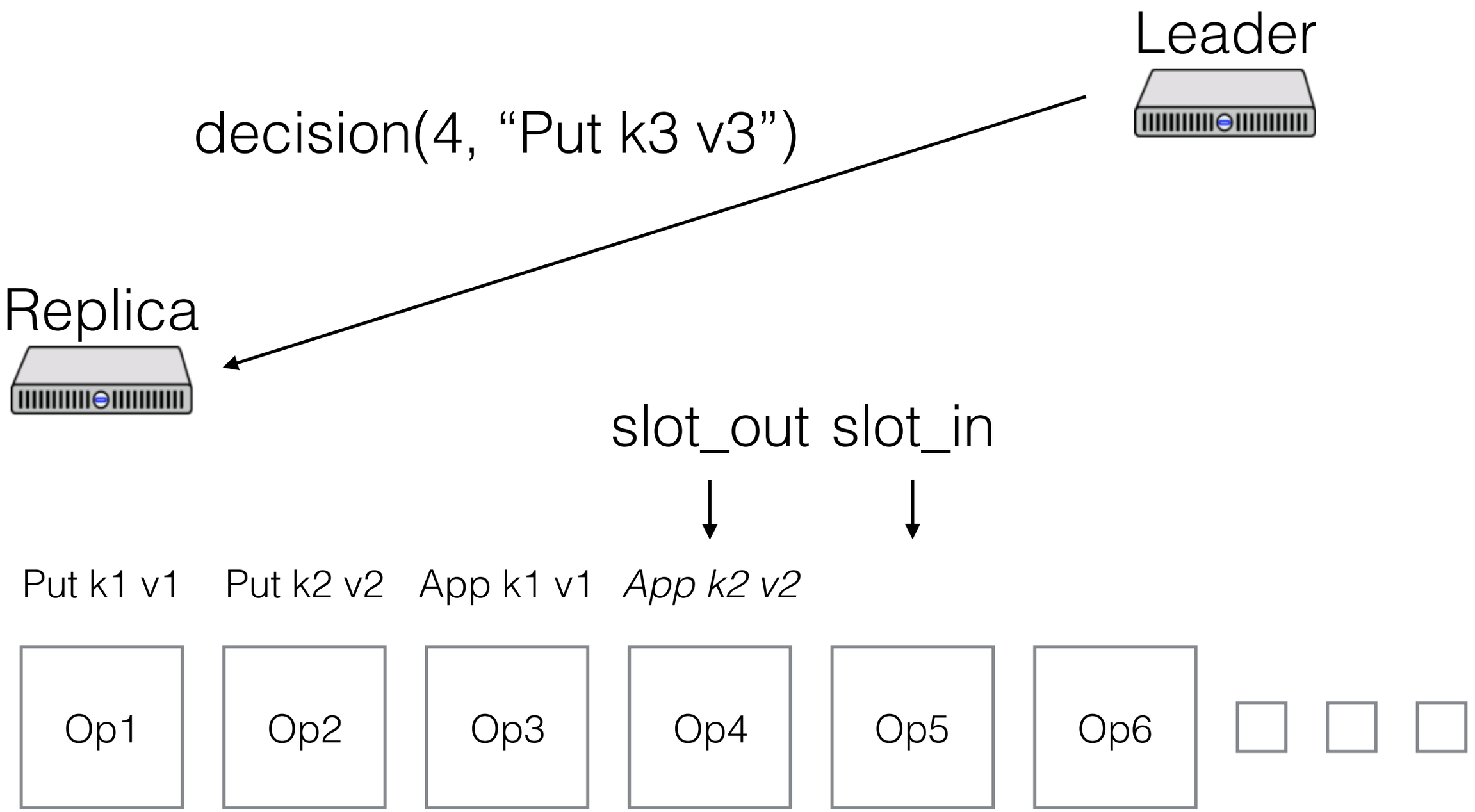
Replica

slot_out slot_in

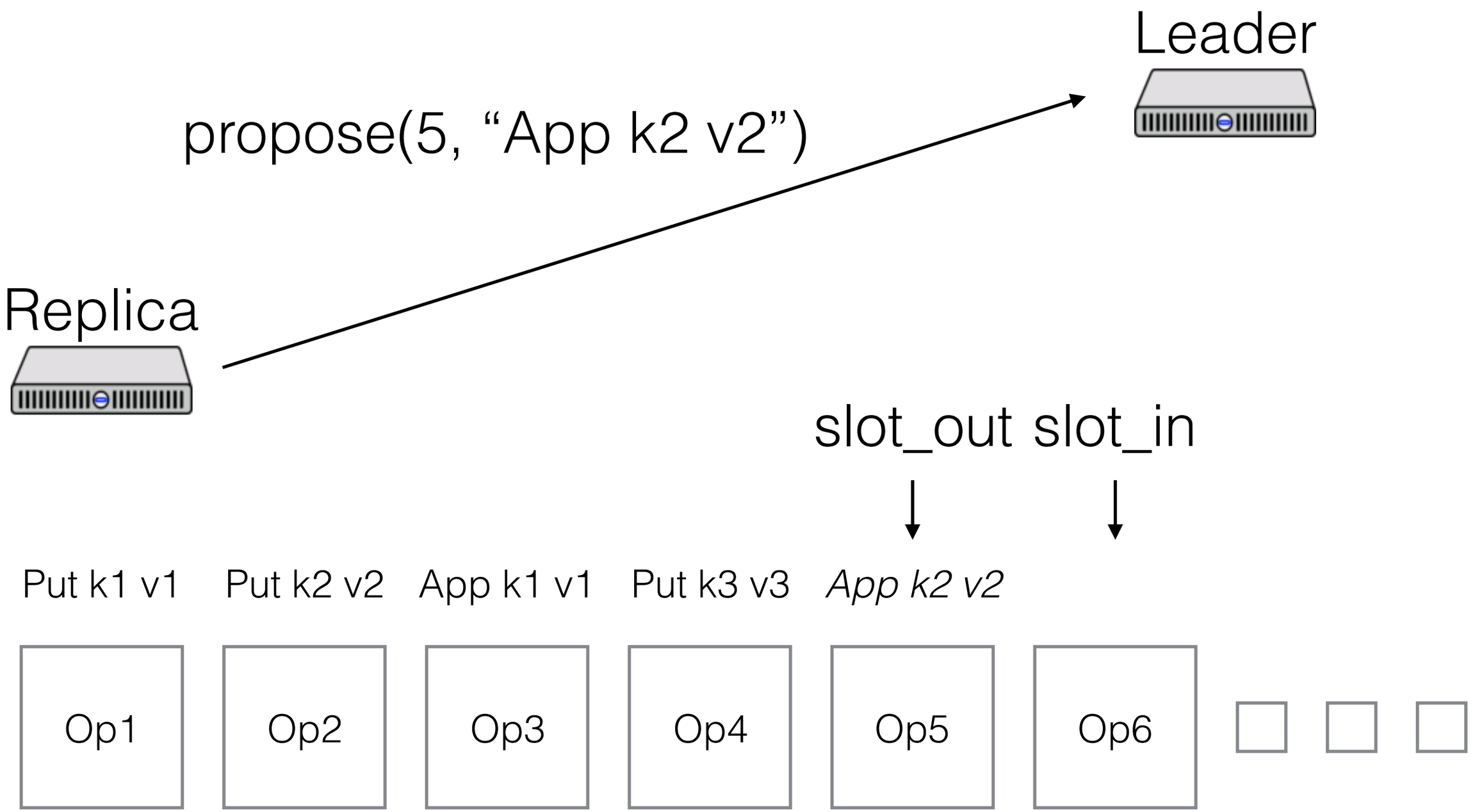
Put k1 v1 | Put k2 v2 | App k1 v1 | *App k2 v2*

Op1	Op2	Op3	Op4	Op5	Op6			

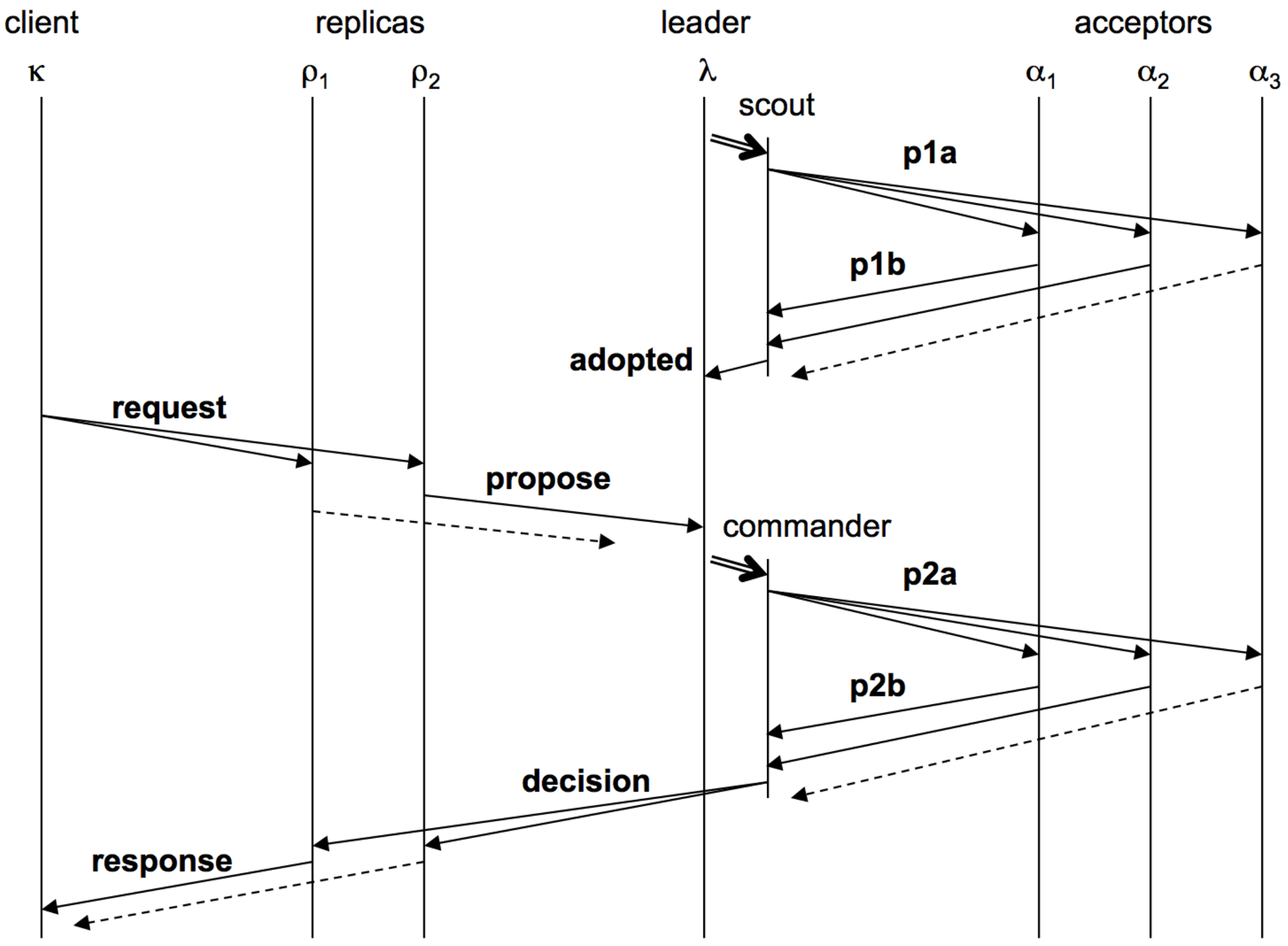
Replicas


Leader
decision(4, “Put k3 v3”)
Replica
slot_out
slot_in
Put k1 v1
Put k2 v2
App k1 v1
App k2 v2
Op1
Op2
Op3
Op4
Op5
Op6

Replicas


Leader
propose(5, “App k2 v2”)
Replica
slot_out
slot_in
Put k1 v1
Put k2 v2
App k1 v1
Put k3 v3
App k2 v2
Op1
Op2
Op3
Op4
Op5
Op6

Paxos Made Moderately Complex Made Simple



Reconfiguration

All replicas *must* agree on who the leaders and acceptors are

How do we do this?

Reconfiguration

All replicas *must* agree on who the leaders and acceptors are

How do we do this?

- Use the log!
- Commit a special reconfiguration command
- New config applies after WINDOW slots

Reconfiguration

What if we need to reconfigure *now* and client requests aren't coming in?

Reconfiguration

What if we need to reconfigure *now* and client requests aren’t coming in?

- Commit no-ops until WINDOW is cleared

Other complications

State simplifications

- Can track much less information, esp. on replicas

Garbage collection

- Unbounded memory growth is bad
- Lab 3: track finished slots across all instances, garbage collect when everyone has learned result

Read-only commands

- Can’t just read from replica (why?)
- But, don’t need their own slot

Questions

What should be in stable storage?

Question

What are the costs to using Paxos? Is it practical enough?