Quorum Replication (Paxos)

Feb 12, 2016
CPSC 416

Goal

- Provide a service
- Survive the failure of up to *f* replicas
- Provide identical service as a non-replicated version (except more reliable, and perhaps different performance)

(A lot like your assignment 4 (where f = r-1) except without durable storage)

We'll cover

- Primary-backup
  - Operations handled by primary, it streams copies to backup(s)
  - Replicas are "passive"
  - Good: Simple protocol. Bad: Clients must participate in recovery.
- quorum consensus
  - Designed to have fast response time even under failures
  - Replicas are "active" - participate in protocol; there is no master, per se.
  - Good: Clients don't even see the failures. Bad: More complex.

Problems with p-b

- Not a great solution if you want very tight response time even when something has failed: Must wait for failure detector
- For that, *quorum* based schemes are used
- As name implies, different result:
  - To handle f failures, must have $2f + 1$ replicas. Why? so that a majority is still alive

Paxos [Lamport]

- quorum consensus usually boils down to the Paxos algorithm.
- *Very* useful functionality in big systems/clusters.
- Some notes in advance:
  - Paxos is painful to get right, particularly the corner cases. Steal an implementation if you can. See Yahoo's "Zookeeper" as a starting point.
  - There are lots of optimizations to make the common / no or few failures cases go faster; if you find yourself implementing, research these.
  - Paxos is *expensive*, as we'll see. Usually, used for critical, smaller bits of data and to coordinate cheaper replication techniques such as primary-backup for big bulk data.

Paxos requirement

- Correctness (safety):
  - All nodes agree on the same value
  - The agreed value X has been proposed by some node
- Fault-tolerance:
  - If less than N/2 nodes fail, the rest should reach agreement *eventually w.h.p*
  - Liveness is not *guaranteed*

Paxos: general approach

- Elect a replica to be the Leader
- Leader proposes a value and solicits acceptance from others
- If a majority ACK, the leader then broadcasts a commit message.

- This process may be repeated many times, as we'll see.

Paxos slides adapted from Jinyang Li, NYU; some terminology from "Paxos Made Live" (Google)

Why is agreement hard?

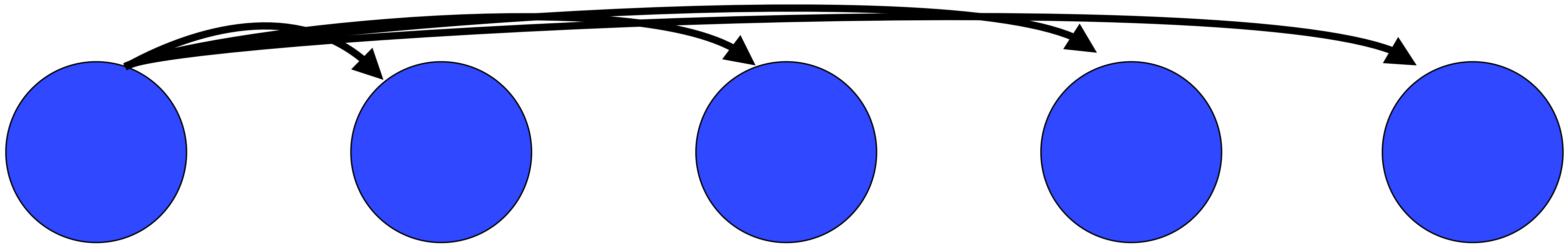
- What if >1 nodes think they're leaders simultaneously?
- What if there is a network partition?
- What if a leader crashes in the middle of solicitation?
- What if a leader crashes after deciding but before broadcasting commit?
- What if the new leader proposes different values than already committed value?

Basic two-phase commit

- Coordinator tells replicas: "Value V"
- Replicas ACK
- Coordinator broadcasts "Commit!"

- This isn't enough
  - What if some of the nodes or the coordinator fails during the communication?
  - What if there's more than 1 coordinator at the same time? (let's solve this first)

Combined leader election and two-phase



Propose(N) -- dude, I'm the master

if N >= Nh, Promise(N) -- ok, you're the boss. (I haven't seen anyone with a higher N, the highest N that I observed was Nh)

if majority promised: Accept(V, N) -- please agree on the value V

if N >= Nh,   ACK(V, N) -- Ok!
if majority ACK: Commit(V)

Multiple coordinators

- The value N is basically a lamport clock.
- Nodes that want to be the leader generate an N higher than any they've seen before
- If you get NACK'd on the propose, back off for a while - someone else is trying to be leader
- Have to check N at later steps, too, e.g.:
- Leader1: N = 5 --> propose --> promise
- Leader2: N = 6 --> propose --> promise
- Leader1: N = 5 --> accept(V1, ...)
- Replicas: NACK! Someone beat you to it.
- Leader2: N = 6 --> accept(V2, ...)
- Replicas: Ok!

But...

- What happens if there's a failure? Let's say the coordinator crashes before sending the commit message
- Or if only one or two of the replicas received the commit message

Paxos solution

- Proposals are ordered by proposal #
- Each acceptor may accept multiple proposals
  - If a proposal with value v is chosen, all higher proposals must have value v
- 3-round protocol (complex!)

Paxos operation: node state

- Each node maintains:
  - n_a, v_a: highest proposal # and its corresponding accepted value for round a
  - n_h: highest proposal # seen (for round a)
  - my_n: my proposal # in Paxos round a (leader's state when proposing in this round)

Paxos operation: 3-phase protocol

- Phase 1 (Prepare)
  - A node decides to be leader (and proposes)
  - Leader choose $my_n > n_h$
  - Leader sends <prepare, my_n> to all nodes
  - Upon receiving <prepare, n>

    If $n < n_h$

        reply <prepare-reject>

    Else

        $n_h = n$

        reply <prepare-ok, n_a,v_a>

This node will not accept any proposal lower than n

See the relation to lamport clocks?

Paxos operation

- Phase 2 (Accept):
  - If leader gets prepare-ok from a majority

    V = non-empty value corresponding to the highest n_a received

    If V= null, then leader can pick any V

    Send <accept, my_n, V> to all nodes
  - If leader fails to get majority prepare-ok
    - Delay and restart Paxos
  - Upon receiving <accept, n, V>

    If $n < n_h$

    reply with <accept-reject>

    else

    $n_a = n$; $v_a = V$; $n_h = n$

    reply with <accept-ok>

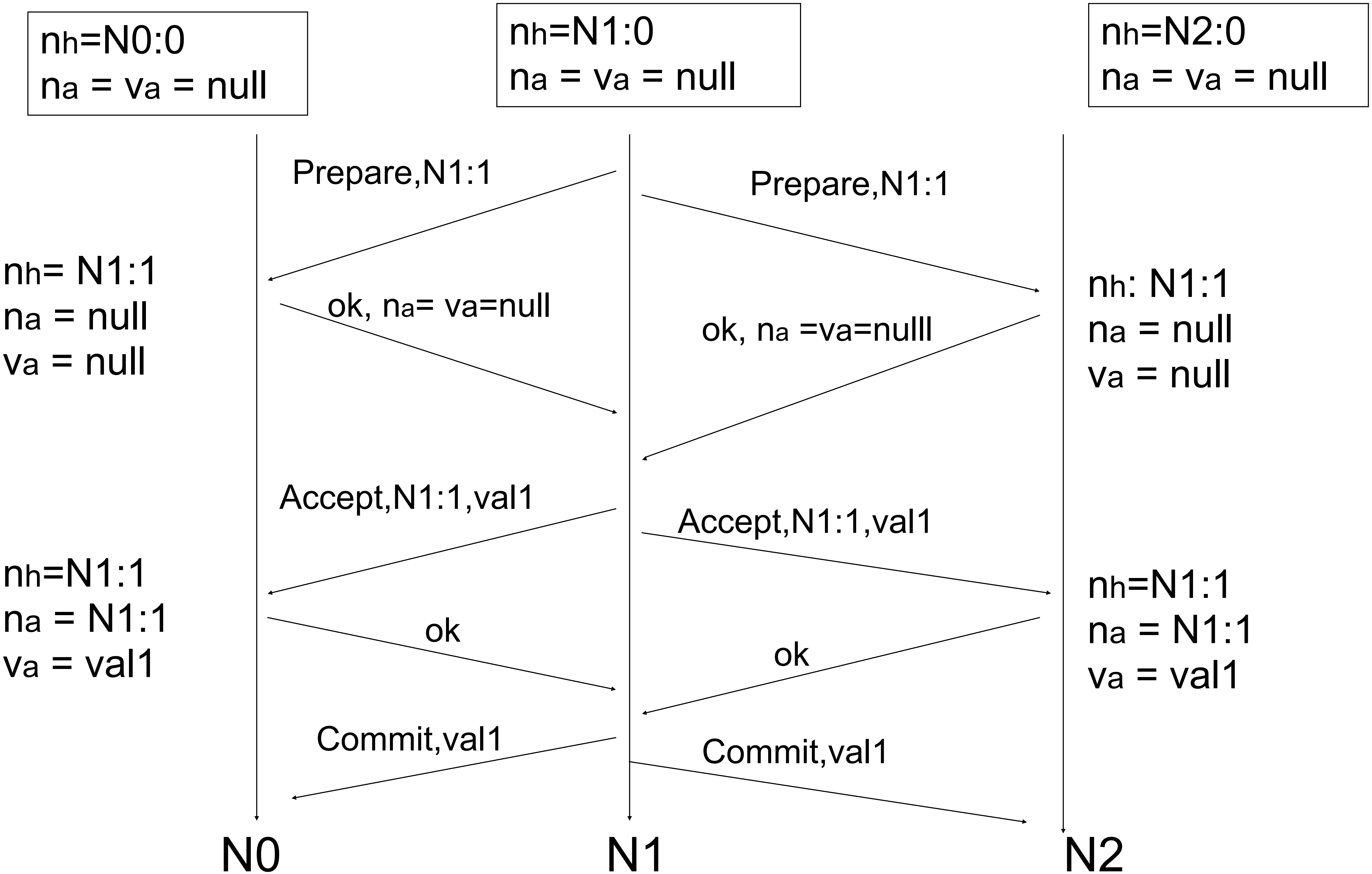
Paxos operation

- Phase 3 (Commit)
  - If leader gets accept-ok from a majority
    - Send <commit, v_a> to all nodes
  - If leader fails to get accept-ok from a majority
    - Delay and restart Paxos

Paxos Examples

- Failure after getting 1 node to accept the value
  - One example where the master hears the value from one of the nodes
  - One example where a new value wins
- Failure after getting > 1/2 nodes to accept the value
- Simultaneous failure of master and the 1 node that accepted in a 5 node system

Paxos operation: an example



Replication Wrap-Up

- Primary/Backup quite common, works well, introduces some time lag to recovery when you switch over to a backup. Doesn't handle as large a set of failures. f+1 nodes can handle f failures.
- Paxos is a general, quorum-based mechanism that can handle lots of failures, and quick response time. 2f+1 nodes to handle f failures