Distributed Systems (DSy)

Classic Consensus

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21.04.2022

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Learning Goals

- Lecture 8 (Consistency)
  - How to achieve consistency in “classical” distributed systems?
  - Different algorithms to achieve consistency

Distributed Systems Categorization - L02S09

"Controlled" Distributed Systems

- Consistency
  - Leader election (Zookeeper, Paxos, Raft)
- Replication principles
  - More replicas: higher availability, higher reliability, higher performance, better scalability, but: requires maintaining consistency in replicas
- Transparency principles apply

"Fully" Decentralized Systems

- Consistency
  - Weak consistency: DHTs
  - Nakamoto consensus (aka proof of work)
  - Proof of stake – Leader election, PBFT protocols
    Is Bitcoin eventually consistent?
    - Some argue no, some argue it has even stronger guarantees [link]
- Replication principles apply to fully decentralized systems as well
- Transparency principles apply

Consensus

- Definition: Consensus decision-making is a group decision-making process in which group members develop, and agree to **support a decision in the best interest of the whole**.
- A Byzantine fault is an arbitrary fault that occurs during the execution of an algorithm by a distributed system
  - Not only crash, but lie or even collude to reach an advantage
- **“Controlled” Distributed Systems:** your own nodes, your control, no collusion
- Find consensus
  - Paxos, Raft, vDHT, Zookeeper

- Often: consensus defines leader
  - Leader creates block
  - Leader adds data
  - Leader creates version
- How to find a leader?

Arbitrary faults, but no collusion

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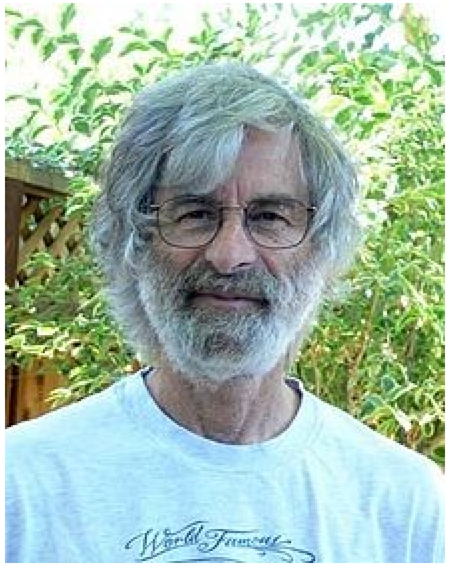
Paxos History

- Leslie Lamport discovered the Paxos algorithm in late 1980s
  - Attempt to prove that there was no such algorithm which can tolerate the failure of any number of its processes
  - Until he realized that he created working protocol



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- Wrote paper and submitted it to Transactions on Computer Systems (TOCS) in 1990
  - Reviewer: was mildly interesting, but needs significant improvement
  - Leslie Lamport: “so I did nothing with the paper”
- People started to using Paxos to solve problems in distributed systems
- Resubmitted in 1998 to TOCS
  - Accepted without any major changes
- Paxos paper won an ACM SIGOPS Hall of Fame Award in 2012
- Received Turing award in 2013 , also due to Paxos
  - “Turing Award is generally recognized as the highest distinction in computer science and the "Nobel Prize of computing”“ [link]

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Paxos Consensus

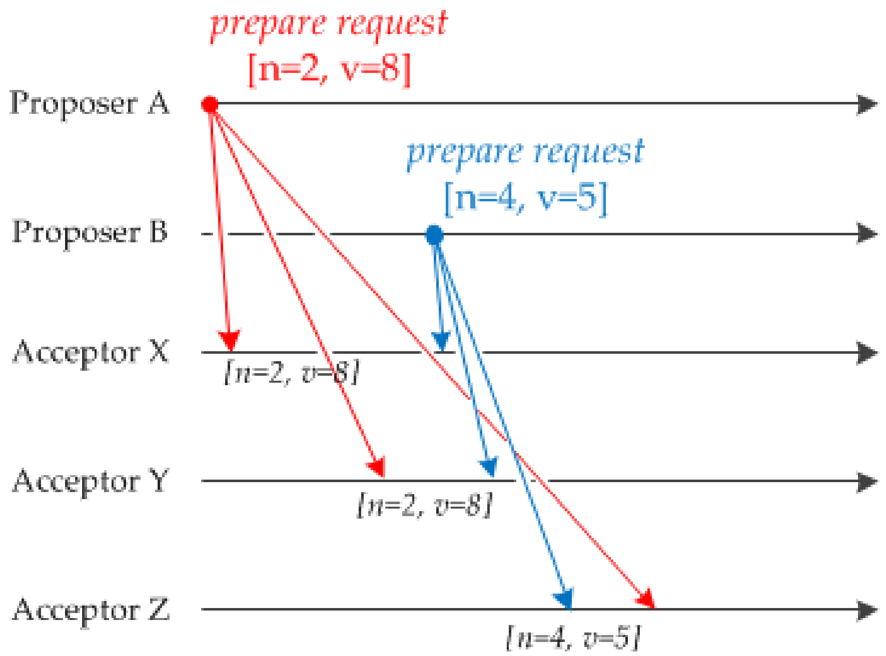
- Paxos: considered difficult to understand
  - “This website explains the infamously difficult to understand Paxos consensus protocol” [link]
  - “Paxos, a really beautiful protocol for distributed consensus” [link]
  - “Paxos is an algorithm whose entire behaviour is subtly difficult to grasp” [link]
- Problem: want reliable computing,
  - But: have unreliable components
- Due to unreliable components, run multiple components, i.e, multiple servers
  - Replica: inconsistent state

- Paxos guarantees that nodes will only ever choose a single value, but does not guarantee that a value will be chosen if a majority of nodes are unavailable
- Roles: proposer, acceptor, and learner
  - Proposer proposes a value that it wants agreement upon
  - Acceptor gets proposal, makes promises, sends result to learners
  - Learners: majority of acceptors must choose the same value
- 2 phases: prepare/promise phase, accept phase

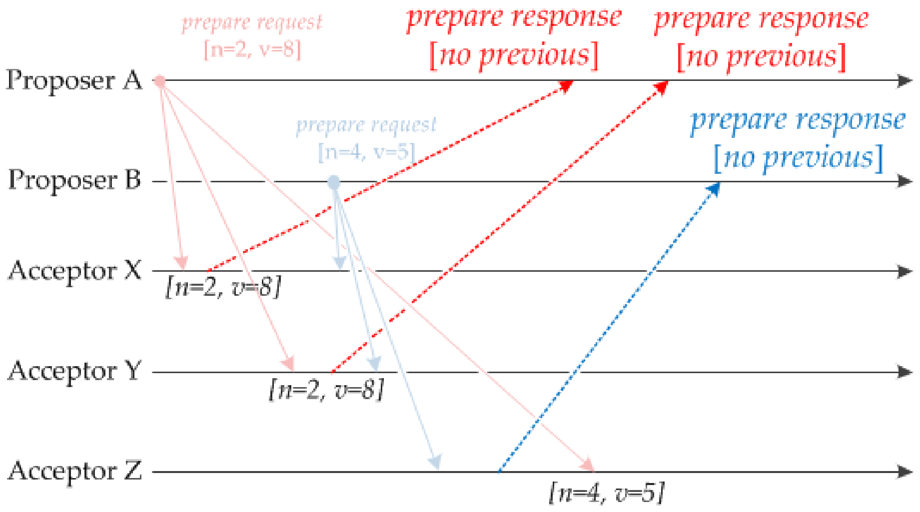
```
Client   Proposer      Acceptor     Learner
   |         |          |  |  |       |  |
   X-------->|          |  |  |       |  |  Request
   |         X--------->|->|->|       |  |  Prepare(1)
   |         |<---------X--X--X       |  |  Promise(1,{Va,Vb,Vc})
   |         X--------->|->|->|       |  |  Accept!(1,V)
   |         |<---------X--X--X------>|->|  Accepted(1,V)
   |<---------------------------------X--X  Response
   |         |          |  |  |       |  |
```

Paxos Example

- Proposer: prepare and accept requests, proposal number and value (n, v) [link]
  - Acceptor: already seen higher proposal number: ignore
  - Acceptor: seen lower proposal number: send back highest accepted n,v.

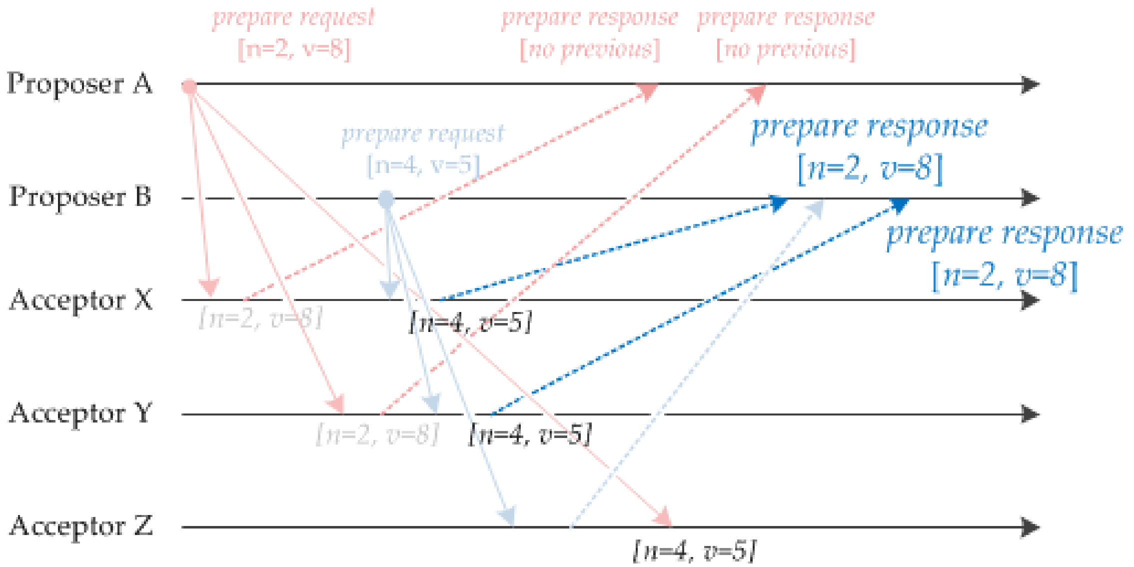


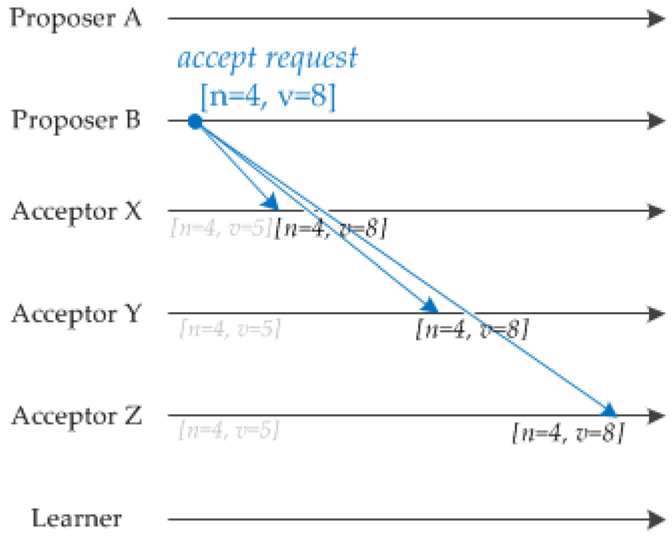
- Proposer A and proposer B
  - Acceptor Z receives B before A
- If acceptor receiving a prepare request for the first time
  - Acceptor responds with a prepare response
  - Promises never to accept another proposal with a lower proposal number



Paxos Consensus

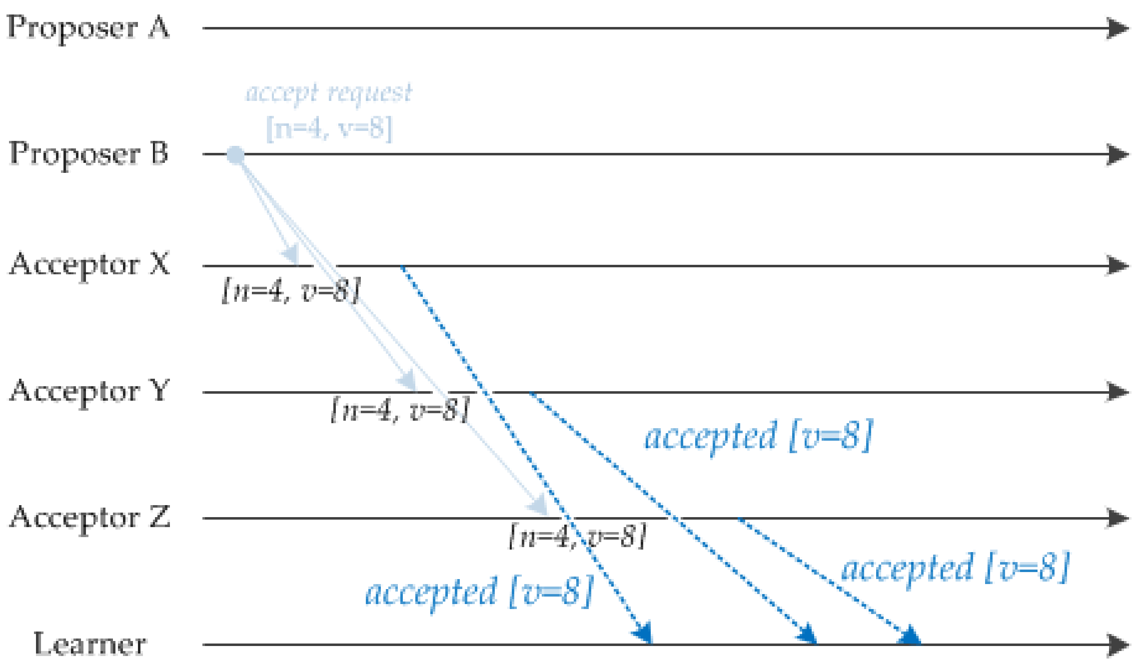
- Acceptor Z receives proposer A's request, and acceptors X and Y receive proposer B's request.
  - Only accept requests with higher number, Acceptor Z not sending response (or negative response) to B.
- Proposer B sends an accept request to each acceptor containing the proposal number it previously used (n=4) and the value associated with the highest proposal number among the prepare response messages it received (v=8)
- Proposer A sends its accept request before proposer B, but acceptor ignores them





Paxos Consensus

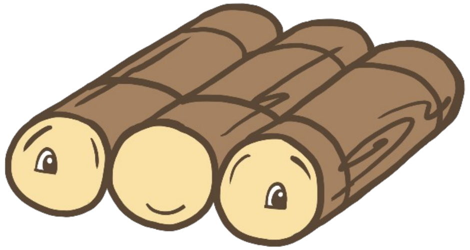
- If an acceptor receives an accept request for a higher or equal proposal number than it has already seen, it accepts and sends a notification to every learner node.
  - A value is chosen by the Paxos algorithm when a learner discovers that a majority of acceptors have accepted a value
  - Once a value is chosen by Paxos, communication with other proposers cannot change value
  - If another proposer, sends a higher proposal number than has previously been seen, with a different value (e.g., n=6, v=7), each acceptor responds with the previous highest proposal (n=4, v=8)
  - This requires the proposer to send an accept request containing [n=6, v=8], which confirms the value that has already been chosen



- Leader election: the leader is the node that has its data chosen by the Paxos instance [link] - youtube

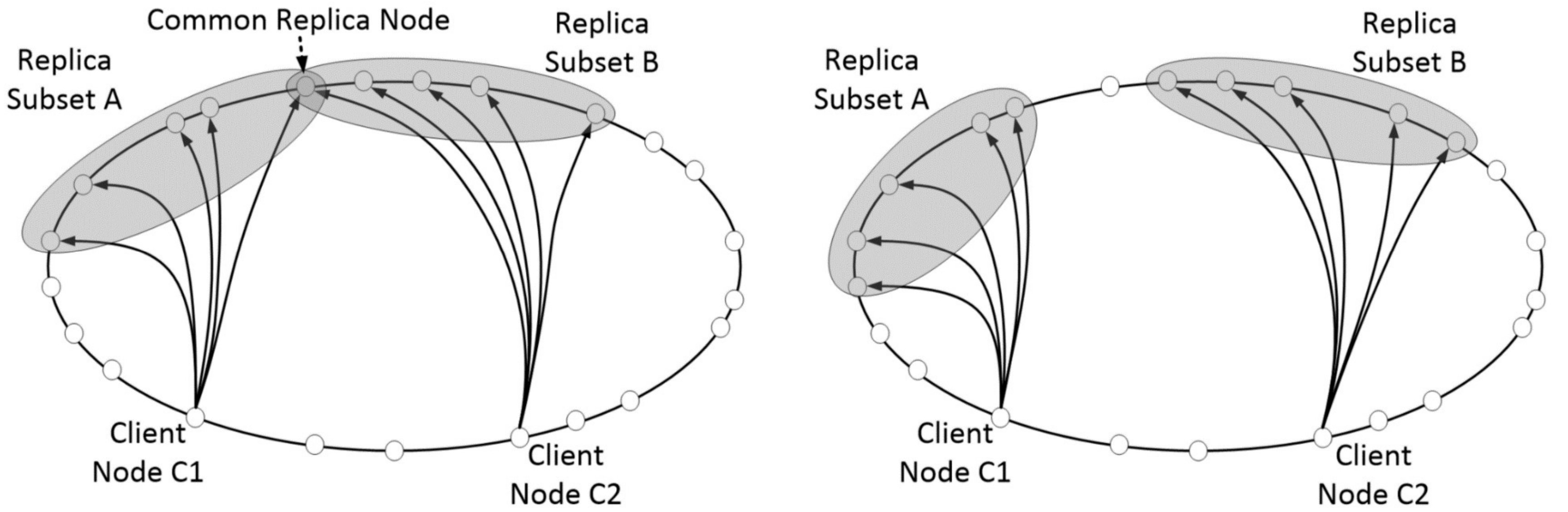
Raft (multi paxos)

- “this makes Raft more understandable than Paxos and also provides a better foundation for building practical systems.” [link]
- RAFT: Reliable, Replicated, Redundant, And Fault-Tolerant
- Follower, Candidate, Leader [link]
  - Raft implements leadership election,
  - Once a leader has been elected, all decision-making within the protocol will then be driven only by the leader
  - Only one leader can exist at a single time
- Each follower has a timeout (typically between 150 and 300 ms) in which it expects the heartbeat from the leader.
  - The system is only available when a leader has been elected and is alive
  - Otherwise, a new leader will be elected and the system will remain unavailable for the duration of the vote
  - Starts election by increasing term counter, voting for itself, and sending a message to all other servers requesting their vote
  - If a higher term is received, become follower, if not, leader



Consistency

- Consistency in DHTs – vDHT, similarities to Paxos
  - Number = versions, for doing updates
  - Simplified roles (peer)
  - No leader election, works well with churn (not heavy churn)
- CoW, software transactional memory (STM) → for consistent updates. Works for light churn



Consistency

- vDHT Basics
  - No locking, no timestamps
  - Every update – new version
    - 1. get() latest version, check if all replica peers have latest version, if not wait and try again
    - - may add delay
    - + wait until update is completed
    - 2. put() prepared with data and short TTL, if status is OK on all replica peers, go ahead, otherwise, remove the data and go to step 1.
      - Data can be either send now or with the confirm, if sent now we are optimistic
      - Peer marks the value as prepared, other put() fail on that key. If nothing happens, TTL
      - Value linked to previous version(s) (hash)
    - 3. put() confirmed, don't send the data, just remove the prepared flag and reset TTL
- In case of heavy churn, API user needs to resolve
  - Get latest version may return fork
  - Abort or resolve (join) manually