Proseminar Distributed Systems
Summer Semester 2016

Paxos algorithm

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The Paxos algorithm

- Family of protocols for reaching consensus among distributed agents
- Agents may fail (and later recover)
- Messages may be delayed or lost

- Employed to achieve fault-tolerant state machine replication

The Paxos algorithm (contd.)

- A voting protocol by which a set of communicating agents (processes) agree on a value
- Messages are broadcast, they may be delayed or may be lost, but not corrupted
- Any agent may fail; if an agent fails, it must be able to re-start from a saved protocol state
- Values may be proposed by different agents at different times during the voting

Agent Roles

- Proposer
  - Initiates a voting round
  - Proposes a value to be agreed upon
- Acceptor
  - Acknowledges a proposer
  - Votes for a proposed value (accepts the value) or against (doesn‘t answer or disagrees)
- Learner
  - Detects when a value has been accepted by a majority of acceptors

Basic Paxos Algorithm – Phase 1

- A proposer *P* sends a *prepare* request with a proposal number *n* to a majority of acceptors
- An acceptor A checks if the requested n is greater than the maximum proposal number m whose value A has already **accepted** so far.
  - If so, then it sends *to P* an *ACK* message (A, m, v_m)
    - v_m is the accepted value of proposal number m
    - if A accepted no value so far then it responds with null values
  - Otherwise, it does not recognize ***P***'s request (no response or response with a *NACK* message)

Basic Paxos Algorithm – Phase 2a

- Proposer *P* receives a set **M** of *ACK* messages as response to its proposal number *n*. If these come from a majority of acceptors, then
  - It takes $m_{\max} = \max_{(A,m,v_m)\in\mathbf{M}} m$
  - It sets $v_n = \begin{cases} v_{m_{\max}}, & \text{if } m_{\max} \neq NULL \\ a, & \text{otherwise} \end{cases}$

    where a is some value chosen by P
  - It sends to each acceptor A, with $(A,m,v_m)\in\mathbf{M}$, an *accept* request for proposal number *n* with value v_n

Basic Paxos Algorithm – Phase 2b

- Upon receiving an *accept* request for proposal number *n*, an acceptor accepts v_n iff it has not already acknowledged a *prepare* request with number greater than *n*
- The acceptance message is sent to a set of learners
- When a learner receives acceptance messages from a majority of acceptors, it commits the accepted value

Basic Paxos Algorithm – Progress

- Proposer P completes phase 1 for proposal number n_1
- Then another proposer Q completes phase 1 for a proposal number $n_2 > n_1$
- Phase 2 of P fails
- P starts another phase 1 with number $n_3 > n_2$
- Phase 2 of Q fails
- And so on...

Basic Paxos Algorithm – Progress

- A distinguished proposer must be established
- Only the distinguished proposer may issue proposals
- The leader may fail, in which case a new leader is chosen
- Further reading about the Paxos algorithm
  - Links on the DS lecture website
  - Additional links on the PS website!

Multi-Paxos

- To agree on a *sequence* of values
- Each process runs multiple Paxos instances concurrently
- A message between processes includes, in addition to proposal number and value, the index of the Paxos instance to which the above data refers

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Distributed Clock Synchronization

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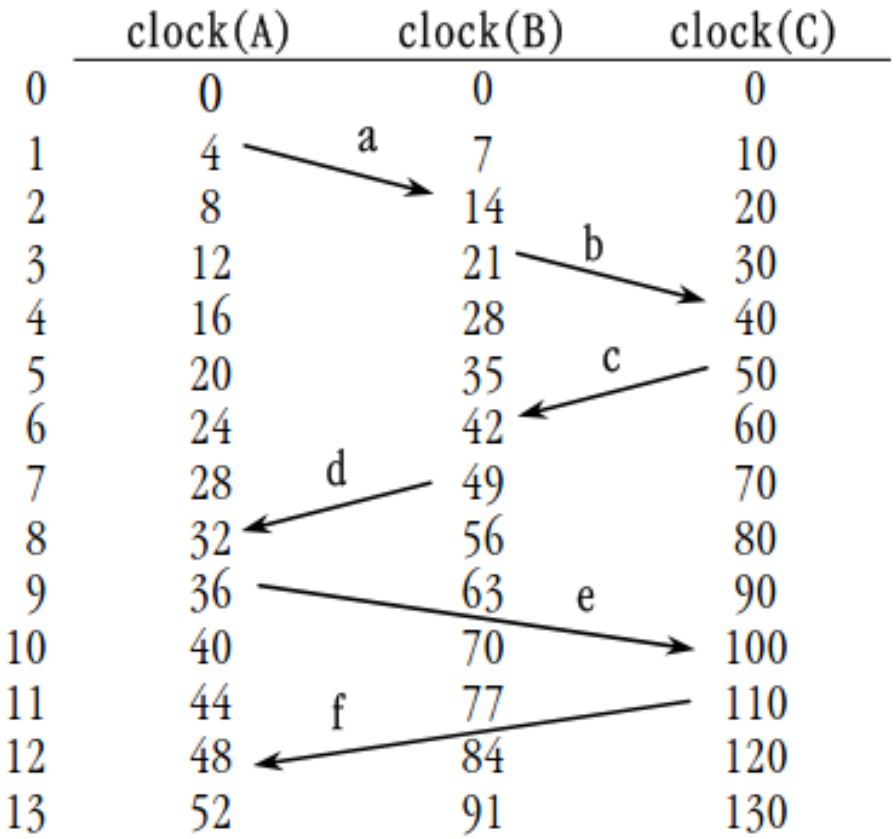
Logical clocks

- Interconnected DE nodes
  - Events are ordered using timestamps at each node
  - Timestamps are generated locally
  - The „time“ at a node is the timestamp of the last processed event
  - Nodes communicate via messages

- Global ordering of events must be ensured

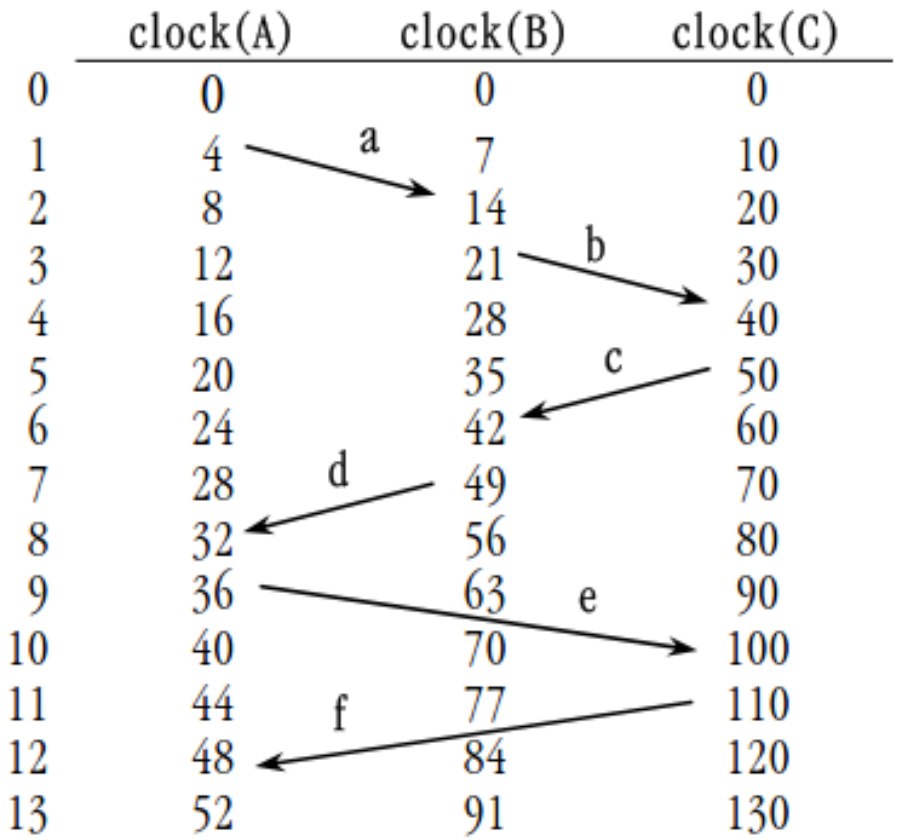
Logical clocks example

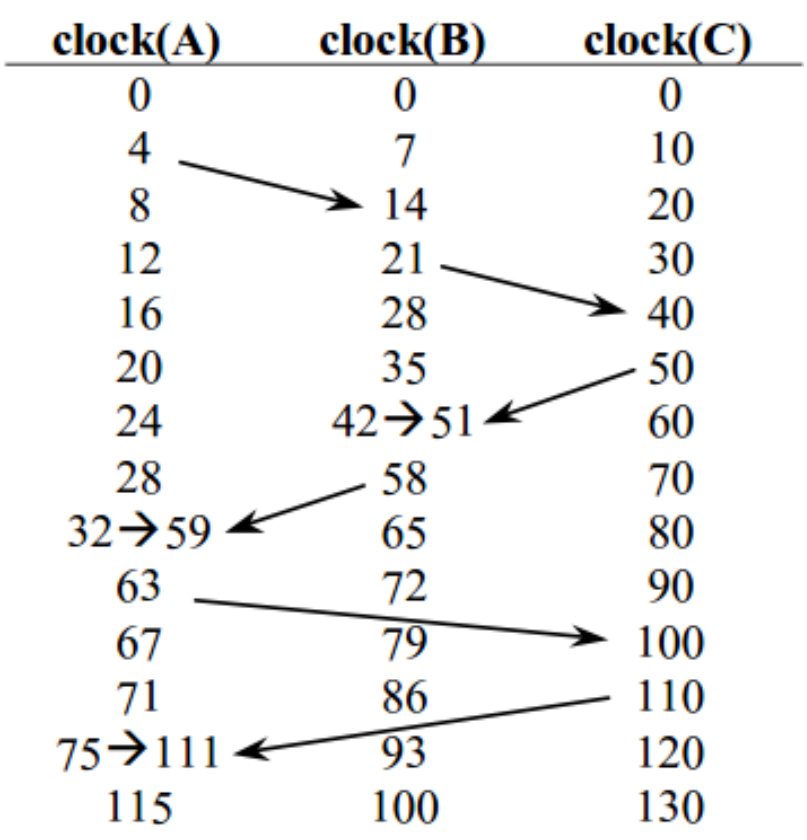


Lamport‘s algorithm

- Each message includes the sender‘s time *t*
- If the receiver‘s time is less than *t*, then the clock of the receiver is advanced to *t+1*
  - Otherwise, do nothing

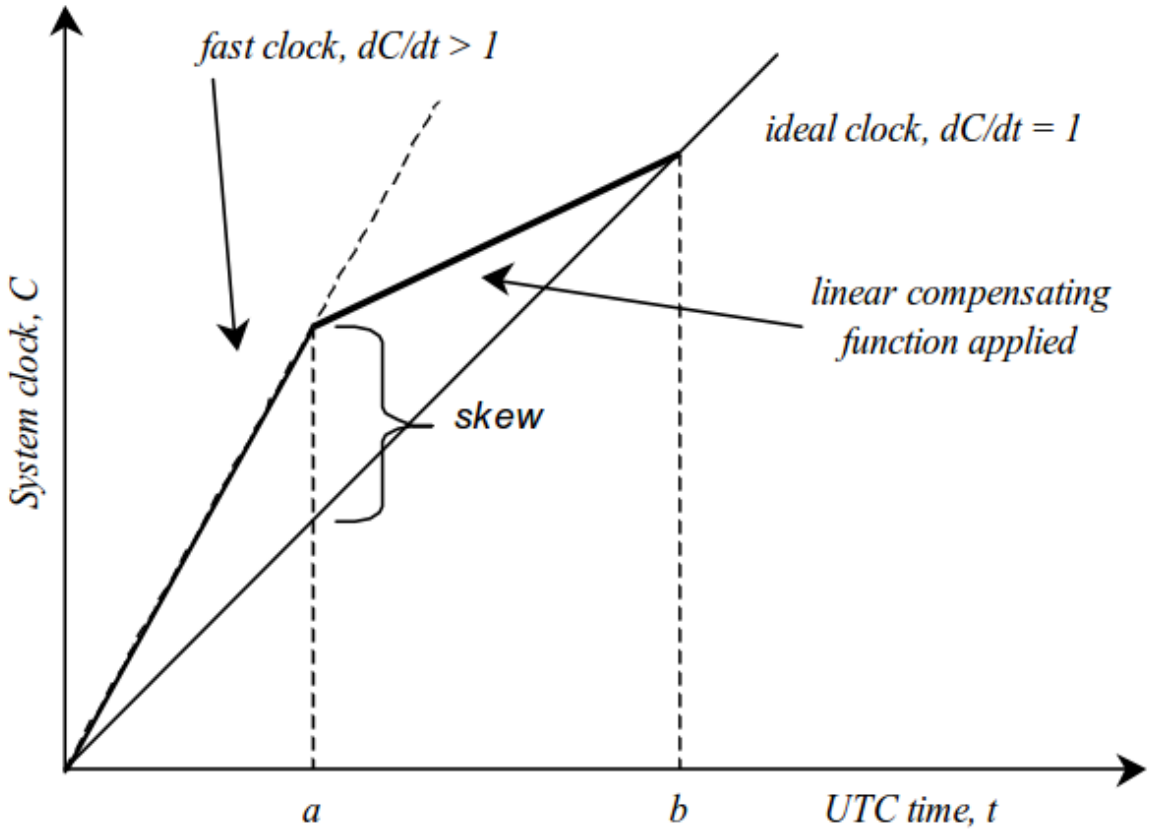
Lamport‘s algorithm example





Physical clocks

- Drift compensation



Christian‘s algorithm

- Reference time provided by server
- T_0: local time when client issues time request to server
- T_1: local time when server‘s reply arrives at client
- T_{server}: time value specified by server

$$T_{client} = T_{server} + (T_1 - T_0)/2$$

Berkeley algorithm

- Participating nodes synchronize to average time
- Master node:
  - periodically asks the others for their times
  - computes the average
  - sends back the offset for each slave node
  - adjusts its own time as well
- Example: