CSC2/458 Parallel and Distributed Systems
More Clocks and Mutual Exclusion

Sreepathi Pai

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URCS

Outline

More on Total Order Multicast using Logical Clocks

Vector Clocks

Mutual Exclusion

Outline

Total-ordered multicast

- Each client multicasts a message to all replicas
  - Each message is timestamped according to local logical clock
  - Assume no loss of messages
  - Assume reliable ordering
- Each replica places received messages in a queue
- Each replica acknowledges receipt of messages using a multicast
- Each replica processes messages in order of their timestamps
  - Only when it has received acknowledgement for that message from all other replicas

This protocol ensures all processes see the same queue.

Invariants

- Process a message if:
  - it has been acknowledged by all other processes
- If multiple such messages exist:
  - process them in sender-timestamp order

Empty queue

Consider yourself to be a process.

- Your queue is empty
  - What do you do?

Queue with a message

- Your queue contains a single message
  - (or multiple messages)
- But no acknowledgements
  - What do you know?
  - What do you do?

Queue with acknowledgements

- Your queue contains only acknowledgements
- But no messages
  - What do you know?
  - What do you do?

Queue with message + all acknowledgements

- Your queue contains a message and all its acknowledgements
  - no other message (if any) has all its acknowledgements
  - What do you know?
  - What do you do?
- What if a message without its acknowledgements has a lower sender-timestamp?

Could it happen?

- Your queue contains a message A and all its acknowledgements
  - and no other message or acknowledgements
- Some other process contains a message B and all its acknowledgements
  - and no other message or acknowledgements

Checking all possible states of a finite state machine

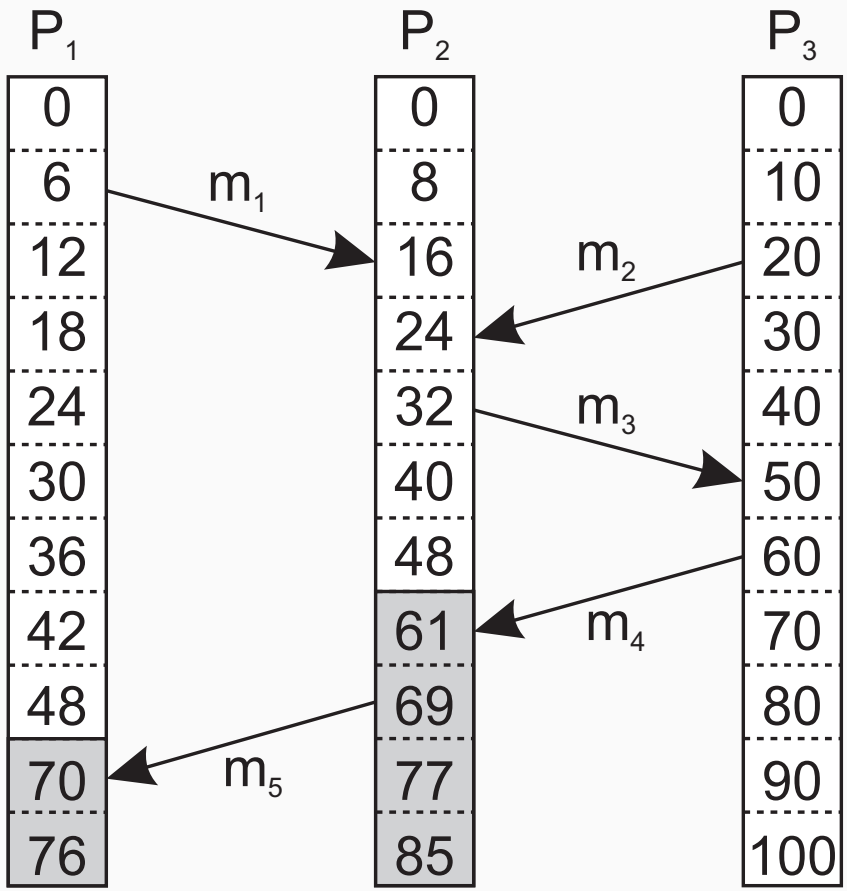
- A formal method called *model checking*
- Used by Amazon (among others)
    - How Amazon Web Services uses Formal Methods, CACM 48(4)
- Tools, TLA+ and TLC
    - The TLA home page

Outline

Causality

- Consider a messaging board where messages and replies are multicast (or broadcast)
- Messages must appear to everybody before their replies
- I.e. Replies are "caused by" messages
- In logical clocks:
  - $a \rightarrow b$ implies $C(a) < C(b)$
  - but $C(a) < C(b)$ does not imply $a \rightarrow b$

Example



- Are m_1 and m_2 causally related?
  - note: maybe better to read: did m_1 happen before m_2?

Easy way

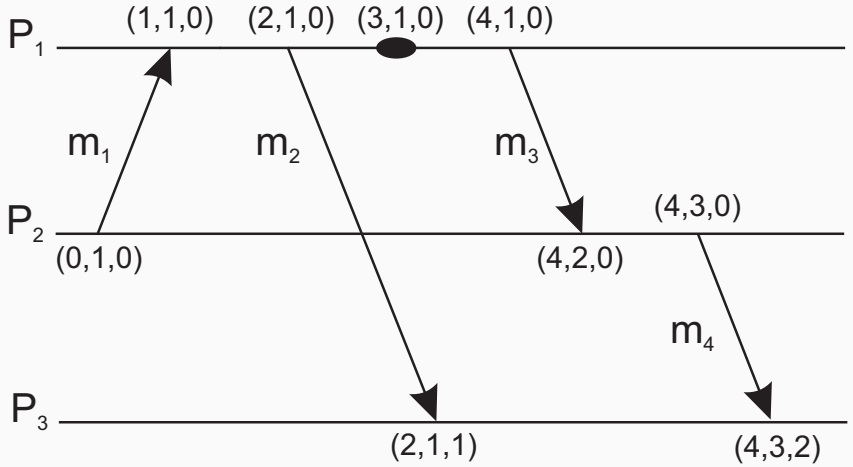
- Each message carries a list of all messages seen by sender
  - Causal history
- Easy to see when messages are not causally related
  - If *b* happened after *a*, it must have seen *a*
  - See textbook for formal definition

Vector Clocks

- Encode global knowledge into timestamps
- Each timestamp $ts(m)$ for message m is now a vector (i.e. an array)
  - Contains n items for n processes
  - $V_i[j]$ is vector clock at process i, containing last known timestamp at process j
  - $V_i[i]$ is incremented every time an event is generated (i.e. it is like i's local clock)
- Importantly, $V_i[j] = k$ means that process i knows k events have happened at process j
- Update:
  - $V_i[k] = \max\{V_i[k], ts(m)[k]\}$ for all k

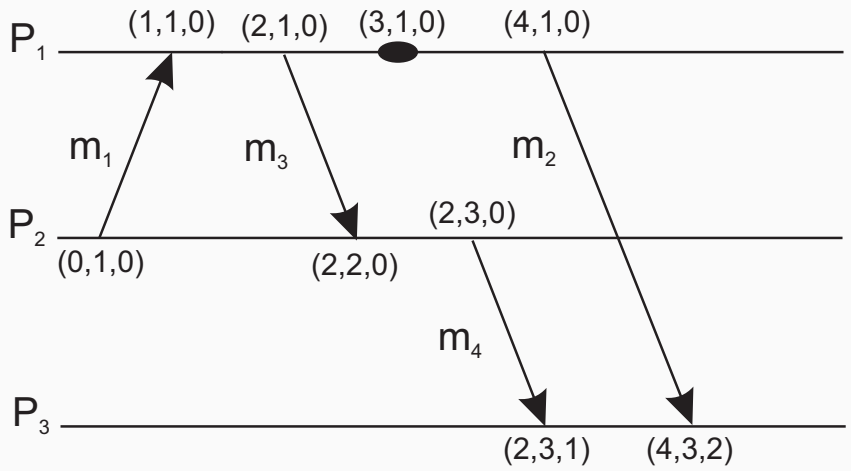
Example: Determining ordering

- Define $ts(a) < ts(b)$ for messages a and b if and only:
  - $ts(a)[k] \leq ts(b)[k]$ for all k
  - $ts(a)[k'] < ts(b)[k']$ for some k'
- Did m_2 happen before m_4?

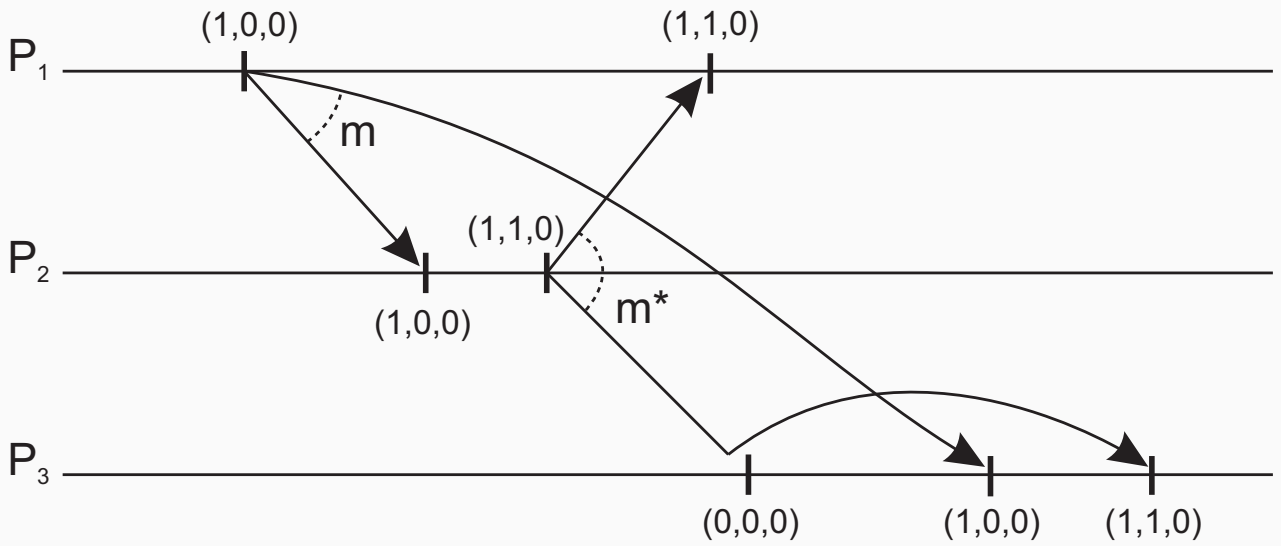


Example: Determining ordering – contd

- Did m_2 happen before m_4?



Causal-ordered Multicast Board



Outline

Centralized Mutual Exclusion

- One Coordinator
- All processes *Request* exclusive access from Coordinator
- Coordinator
  - *Grants* access if no other process is requesting the same resource
  - does not reply if another process is granted resource
  - places request in queue
- Process
  - blocks waiting for reply from Coordinator
  - accesses resource on grant from Coordinator
  - *Releases* resource by informing Coordinator
- Coordinator
  - on release, informs next process in queue that requested resource

Evaluating Centralized Mutual Exclusion

- Scalability
  - Single coordinator may become performance bottleneck
- Availability
  - Single coordinator may crash
  - What about process crashes?
- Number of messages
  - to enter critical section: 2

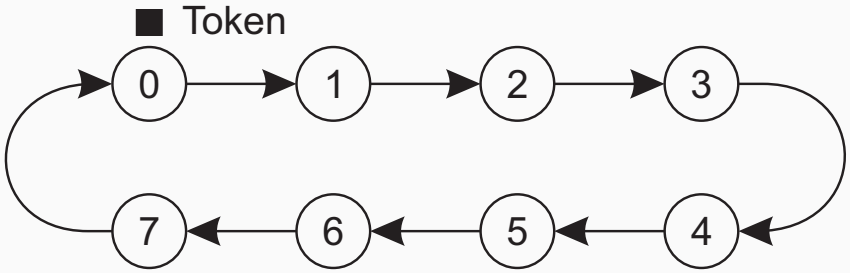
Mutual Exclusion using Totally ordered Multicasts

- Total ordered multicast produces a total order among all messages
- Can be used to implement mutual exclusion
- Messages:
  - ENTER: process multicasts that it wants to enter a critical section
  - ALLOW: process unicasts permission to ENTERing process
  - RELEASE: process multicasts that it has left a critical section

Evaluating Totally Ordered Multicasts

- Scalability
  - No single coordinator
  - But what about requiring permission from *everybody*?
- Availability
  - What if a process crashes?
- Number of Messages
  - to enter critical section?
- Multicasts and complexity
  - what if there is no multicast primitive?

Token Ring Mutual Exclusion



- Construct ring overlay (i.e. logical) network
  - Has no relation to physical network
  - how to construct this?
- Generate token
- On receiving token
  - Optionally, perform accesses to any shared resources
  - Pass token to neighbour

Evaluating Token Ring Mutual Exclusion

- Scalability
  - No centralized coordinator
- Availability
  - What if token is lost?
  - What if a process not holding a token crashes?
  - What if a process holding a token crashes?
- Number of messages
  - to enter critical section: $N - 1$ (max.)

Decentralized Mutual Exclusion using Voting

- Replicate resource N times
- Each replica controlled by different coordinator
- When a process requests access to a resource
  - It must get permission from more than $N/2$ coordinators (does it need to wait for all coordinators?)
  - Coordinators may refuse to give access if they've already given access
  - A process that is refused access sends releases to coordinators it got access from and will backoff and retry after some time
- Of interest, a coordinator may crash and "forget" it had given access
  - Incorrectly give access to a process
  - When will this cause a problem?

Evaluating Mutual Exclusion using Voting

- Scalability
  - Multiple centralized coordinators, only require majority
- Availability
  - Probabilistic arguments against all coordinators crashing
  - What about processes holding locks?
- Utilization
  - Does at least one process that competes for a resource get it?
- Number of messages
  - to enter a critical section: ?