CSE 486/586 Distributed Systems
Reliable Multicast --- 2

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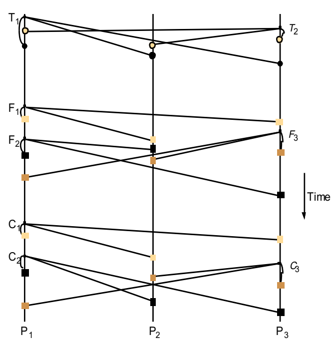
Last Time

- How do a group of processes communicate?
- Multicast
  – One-to-many: "Local" broadcast within a group *g* of processes
- What are the issues?
  – Processes crash (we assume crash-stop)
  – Messages get delayed
- B-multicast
- R-Multicast
  – Properties: integrity, agreement, validity
- Ordering
  – Why do we care about ordering?

Recap: Ordering

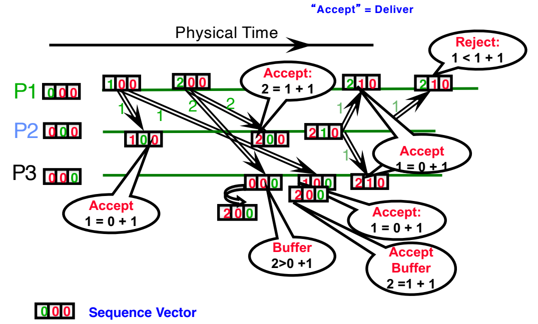
- •Totally ordered messages T_1 and T_2.
- •FIFO-related messages F_1 and F_2.
- •Causally related messages C_1 and C_3
- •Total ordering does not imply causal ordering.
- • Causal ordering implies FIFO ordering
- • Causal ordering does not imply total ordering.
- • Hybrid mode: causal-total ordering, FIFO-total ordering.



Example: FIFO Multicast

*(do **NOT** be confused with vector timestamps)*

"Accept" = Deliver



Totally Ordered Multicast

- Using a sequencer
  – One dedicated "sequencer" that orders all messages
  – Everyone else follows.
- ISIS system
  – Similar to having a sequencer, but the responsibility is distributed to each sender.

Total Ordering Using a Sequencer

Sequencer = Leader process

1. Algorithm for group member *p*

On initialization: $r_g := 0$;

To TO-multicast message m to group g
  B-multicast$(g \cup \{sequencer(g)\}, <m, i>)$; *i*: unique message id

On B-deliver$(<m, i>)$ *with* $g = group(m)$
  Place $<m, i>$ in hold-back queue;

On B-deliver$(m_{order} = <\text{“order”}, i, S>)$ *with* $g = group(m_{order})$
  wait until $<m, i>$ in hold-back queue and $S = r_g$;
  TO-deliver m; // (after deleting it from the hold-back queue)
  $r_g = S + 1$;

2. Algorithm for sequencer of *g*

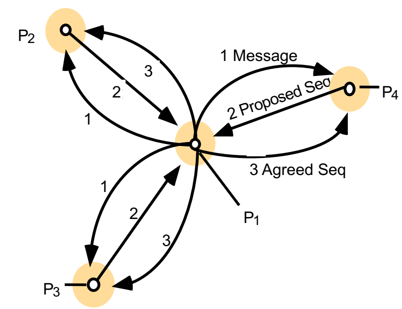
On initialization: $s_g := 0$;

On B-deliver$(<m, i>)$ *with* $g = group(m)$
  B-multicast$(g, <\text{“order”}, i, s_g>)$;
  $s_g := s_g + 1$;

ISIS algorithm for total ordering

- No central sequencer
  - Achieves decentralization
  - *Distributed* doesn't mean *decentralized*.
- Every sender acts as a sequencer.
- Since there is no single sequencer that determines a number, it requires *agreement* on sequence numbers.
  - Agreement is very important for decentralization.
- Thus, each sender does not pick a sequence number alone.
  - Otherwise, two different senders can pick the same number.
- Each sender receives proposals for a sequence number every time.
  - Among the proposals, the sender picks a number.

ISIS algorithm for total ordering



ISIS algorithm for total ordering

- Sequence number requirement
  - It should always be strictly increasing (otherwise, there's no ordering).
  - I.e., a sequence number should always be greater than the previous sequence number.
- How do we ensure that?
  - Reminder: a sequence number is picked among proposals.
  - Each receiver proposes a higher number that it has never proposed or agreed to use as a sequence number.
  - A sender picks the highest number among all proposals.
- How to always propose a higher number?
  - A receiver looks at two things.
  - The last agreed sequence number assigned to a message
  - The last proposed number by the receiver
  - A receiver takes the max of the two, adds one, and proposes that number.

A Walk-Thru with Two Processes

- Assume:
  - P1 has proposed up to 8 so far.
  - P2 has proposed up to 5 so far.
  - The last message's sequence number was 4.
- Q: why would something like this happen?
  - Multiple messages sent around the same time and network delays.
- P1 sends a message to P1 & P2.
- P1 proposes 9 (to P1).
- P2 proposes 6 (to P1).
- P1 picks 9 as the sequence number.
- P1 announces that the sequence number is 9.
- Sequence numbers of the last two messages: 4 & 9

ISIS algorithm for total ordering

- Sender multicasts message to everyone
- Reply with proposed priority (sequence no.)
  - Larger than all observed *agreed* priorities
  - Larger than any previously proposed (by self) priority
- Store message in priority queue
  - Ordered by priority (proposed or agreed)
  - Mark message as undeliverable
- Sender chooses agreed priority, re-multicasts message with agreed priority
  - Maximum of all proposed priorities
- Upon receiving agreed (final) priority
  - Mark message as deliverable
  - Reorder the delivery queue based on the priorities
  - Deliver any deliverable messages at the front of priority queue
- Notice any (small) issue?

CSE 486/586 Administrivia

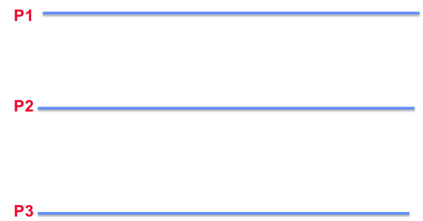
- PA2-B is due on 3/13.
  - Right before Spring break
- PA1 re-grading office hours
  - Tuesdays 1pm - 4pm
  - Wednesdays 2pm - 5pm
  - Thursdays 9 am - 12 pm
  - Fridays 9am - 12pm
- Midterm is on 3/11.
  - During class, not in the evening

Problematic Scenario

- Two processes P1 & P2 at their initial state.
- P1 sends M1 & P2 sends M2.
- P1 receives M1 (its own) and proposes 1. P2 does the same for M2.
- P2 receives M1 (P1's message) and proposes 2. P1 does the same for M2.
- P1 picks 2 for M1 & P2 also picks 2 for M2.
- Same sequence number for two different msgs.
- How do you want to solve this?
  - Use process numbers as a tie-breaker.
  - For a proposal, always use the following format: X.Y
    - » X is the proposed number and Y is the process id.
  - P1 has proposed 2 for M1 → The proposal for M1 is now 2.1.

Example: ISIS algorithm

We don't dictate when events are happening



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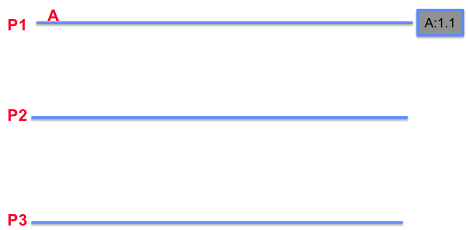

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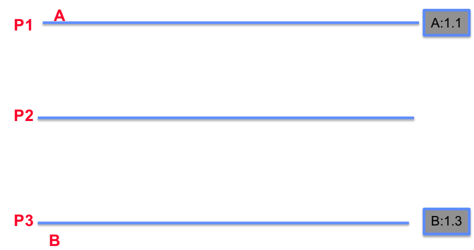

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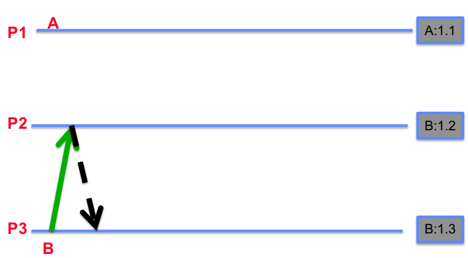

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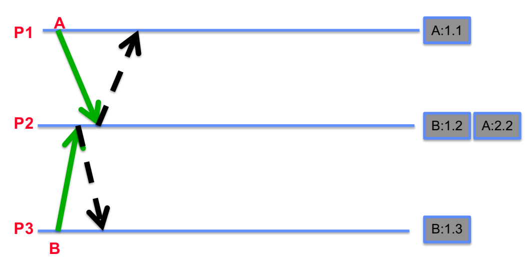

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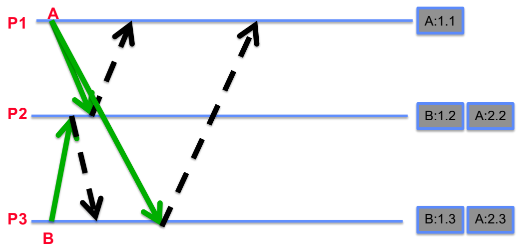

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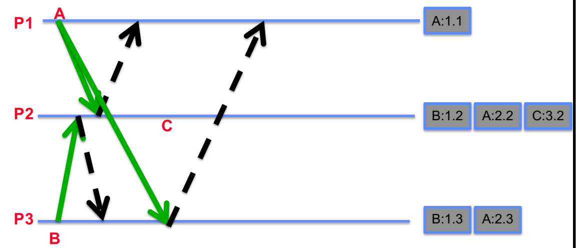

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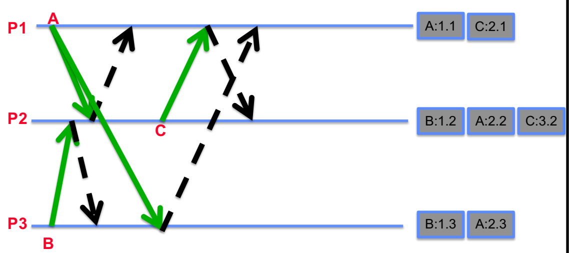

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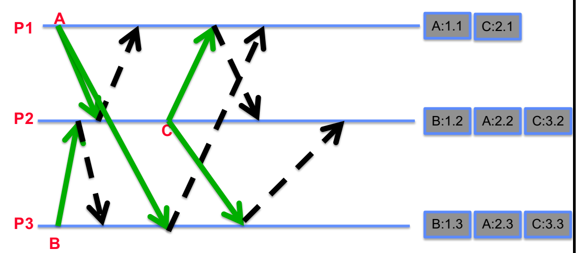

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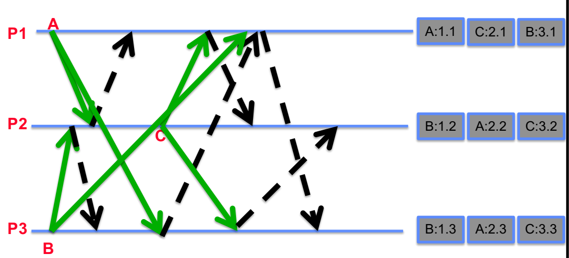

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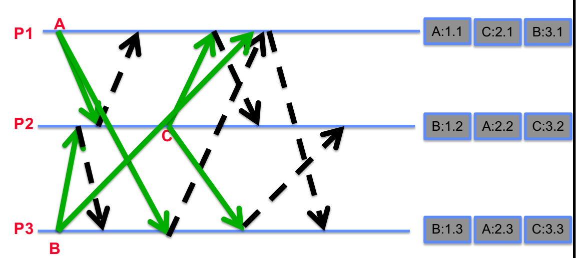

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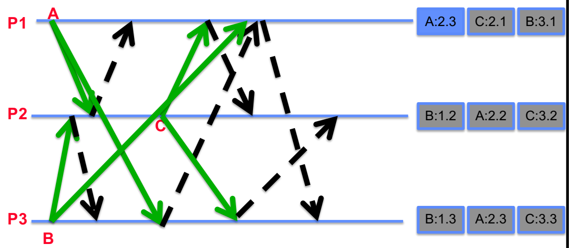

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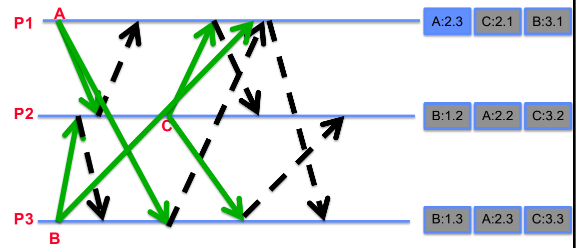

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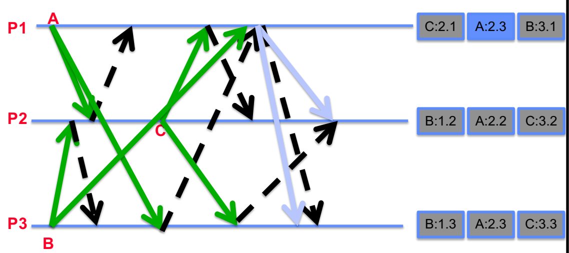

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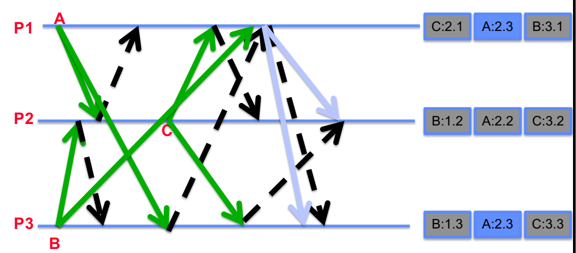

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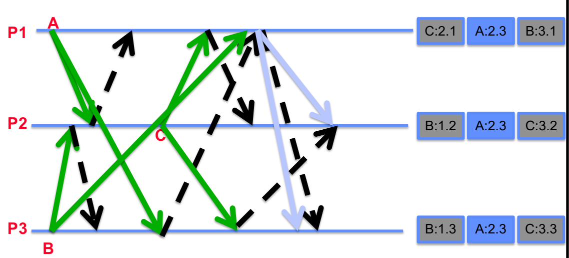

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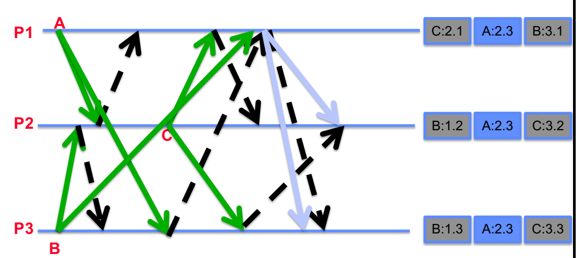

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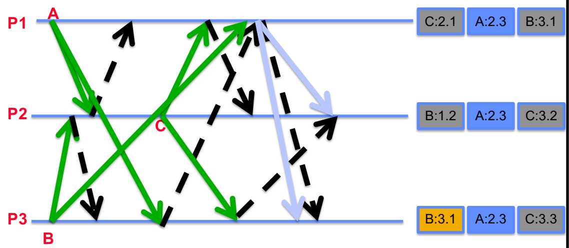

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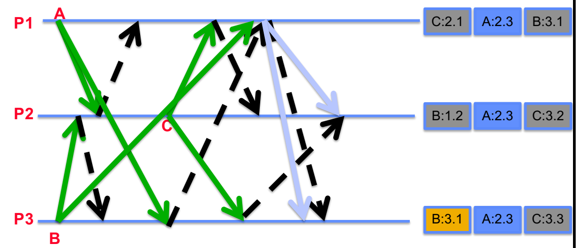

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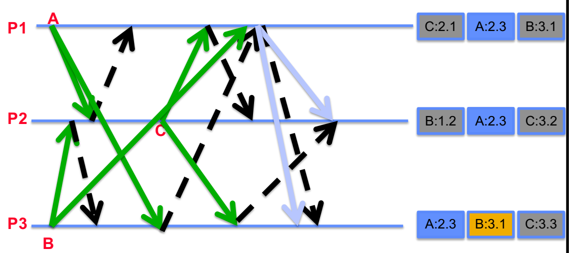

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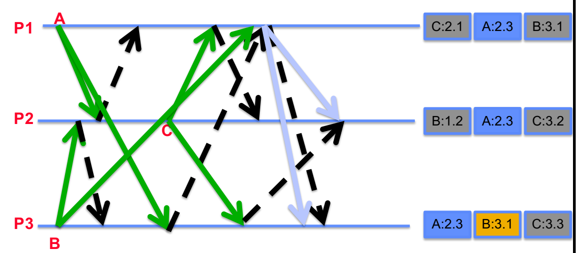

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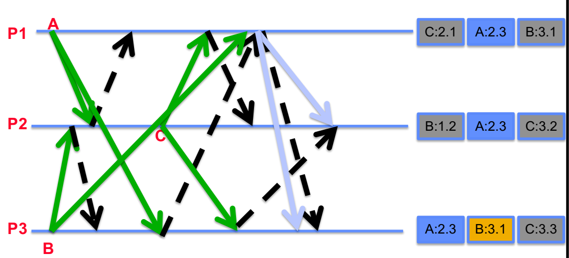

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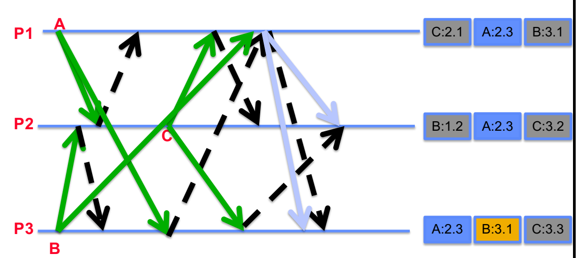

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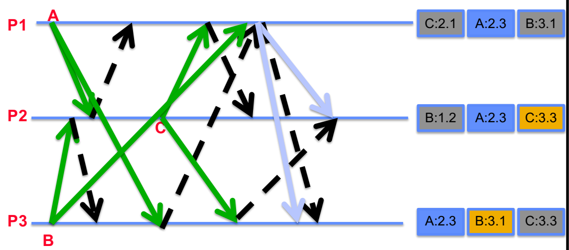

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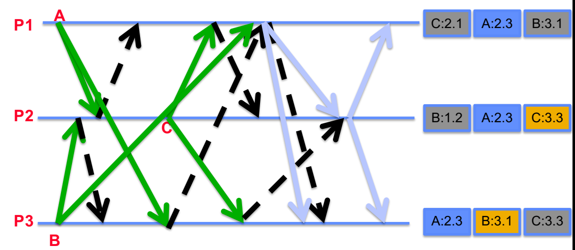

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Example: ISIS algorithm

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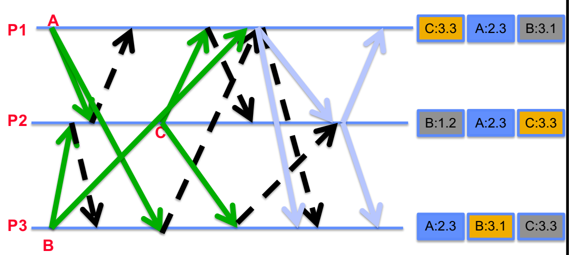

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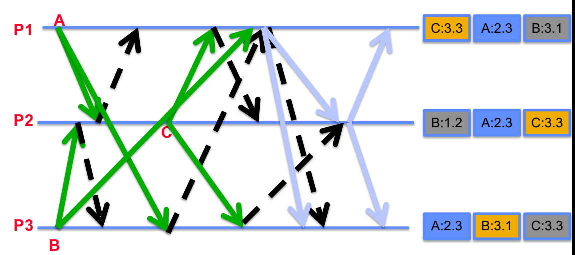

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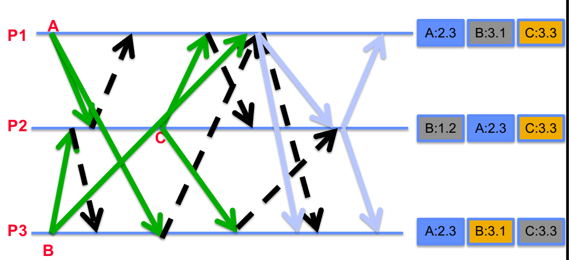

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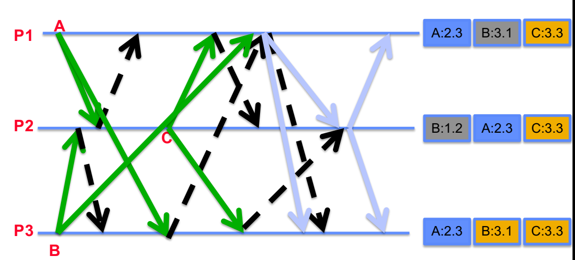

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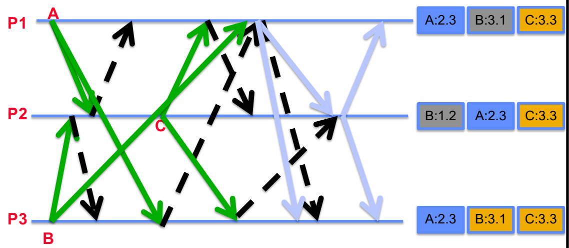

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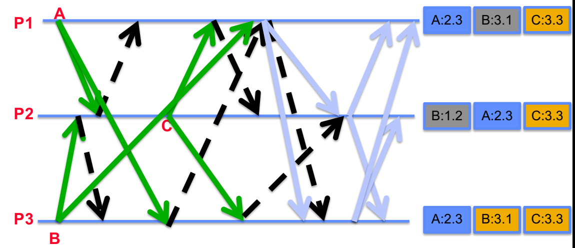

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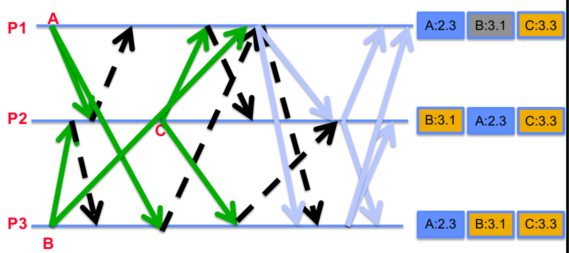

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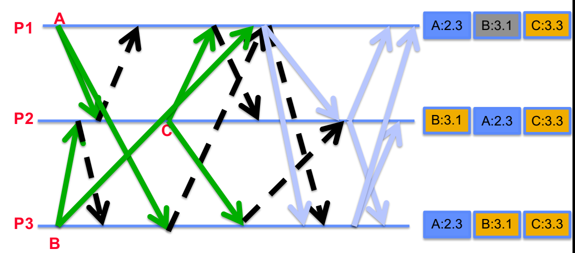

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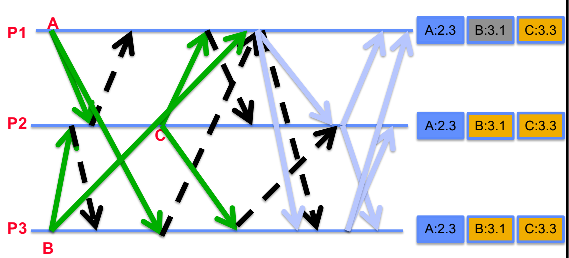

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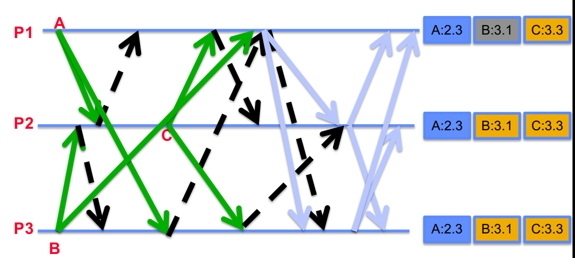

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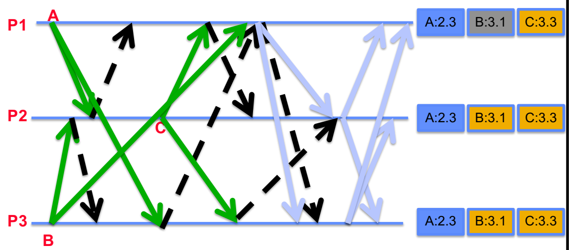

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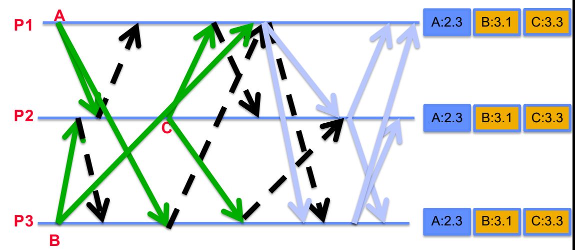

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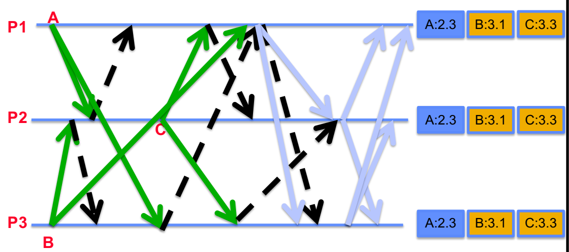

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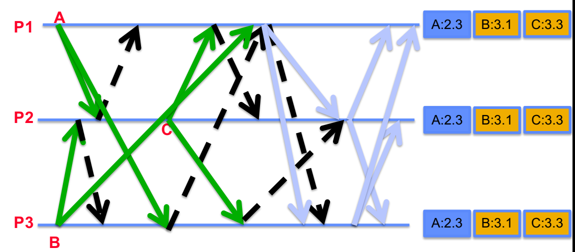


Proof of Total Order

- For a message m_1, consider the first process *p* that delivers m_1
- At *p*, when message m_1 is at head of priority queue and has been marked deliverable, let m_2 be another message that has not yet been delivered (i.e., is on the same queue or has not been seen yet by *p*)

  finalpriority(m_2) >= Due to "max" operation at sender

  proposedpriority(m_2) > Since queue ordered by increasing priority

  finalpriority(m_1)
- Suppose there is some other process *p'* that delivers m_2 before it delivers m_1. Then at *p'*,

  finalpriority(m_1) >= Due to "max" operation at sender

  proposedpriority(m_1) > Since queue ordered by increasing priority

  finalpriority(m_2)
- **a contradiction**!

Causally Ordered Multicast

- Each process keeps a vector of message clocks.
  - Each counter represents the number of messages received from each of the other processes.
  - This works just like vector clocks, but with messages.
- When multicasting a message, the sender process increments its own counter and attaches its vector clock.
- Upon receiving a multicast message, the receiver process waits until it can preserve causal ordering, i.e., until it has delivered all the messages that have happened before:
  - It has delivered all the messages from the sender.
  - It has delivered all the messages that the sender had delivered before the multicast message.

Causal Ordering

Algorithm for group member p_i $(i = 1, 2..., N)$

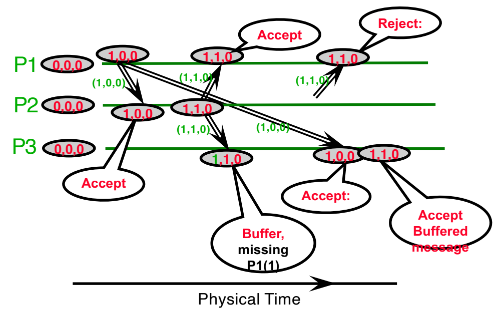
On initialization
$V_i^g[j] := 0$ $(j = 1, 2..., N)$;

The number of group-g messages from process j that have been seen at process i so far

To CO-multicast message m to group g
$V_i^g[i] := V_i^g[i] + 1$;
B-multicast$(g, < V_i^g, m >)$;

On B-deliver$(< V_j^g, m >)$ *from* p_j, *with* $g = group(m)$
place $< V_j^g, m >$ in hold-back queue;
wait until $V_j^g[j] = V_i^g[j] + 1$ and $V_j^g[k] \le V_i^g[k]$ $(k \ne j)$;
CO-deliver m; // after removing it from the hold-back queue
$V_i^g[j] := V_i^g[j] + 1$;

Example: Causal Ordering Multicast



Summary

- Two multicast algorithms for total ordering
  - Sequencer
  - ISIS
- Multicast for causal ordering
  - Uses vector timestamps

Acknowledgements

- These slides contain material developed and copyrighted by Indranil Gupta (UIUC).