Distributed Systems

CS425/ECE428

Feb 19 2021

Instructor: Radhika Mittal

Acknowledgements for some of materials: Indy Gupta and Nikita Borisov

Logistics

- HW1 is due tonight at 11:59pm.
- HW2 has been released.
  - You should be able to solve the first two questions right away.
  - You should (hopefully) be able to solve all questions after Wednesday's class.
- MP1 will be released on Wednesday (Feb 24th).
  - Please reach out to me if you are changing groups for MP1, so that we can accordingly reassign the VM clusters.

Logistics

- Midterm on March 8th, Monday, 7pm-8:50pm.
  - CBTF will proctor the exam via Zoom.
- Please sign up with CBTF if you have not already done so.
- Conflict and DRES accommodation requests will be dealt with using the CBTF portal.
- It is a closed-book exam (no websites, no textbooks).
  - You are allowed one physical double-sided cheat sheet (could be typed or hand-written).
- Your answers can be hand-written or typed.
  - If you are typing your answers, use of any online editors (e.g. Google Docs) is **not** allowed.
  - You can use offline text editors (e.g. Microsoft Word, textEdit, vim, notepad, etc).
- You must submit your responses on Gradescope within 1 hour 50 mins of the start of your exam.
- Syllabus includes everything covered up to (and including) "Multicast".

Recap: Global snapshot

- State of each process (and each channel) in the system at a given instant of time.
- Difficult to capture global state at same instant of time.
- Capture consistent global state.
    - If captured state includes an event **e**, it includes all other events that *happened before* **e**.
- Chandy-Lamport algorithm captures consistent global state.

Recap: Global snapshot

- **Global system properties (or predicates):** defined for a captured global state. Two categories:
  - Liveness, e.g. has the algorithm terminated?
    - Must be true for some state reachable from initial state for all linearizations.
  - Safety, e.g. the system is not deadlocked.
    - Must be true for all states reachable from initial state for all linearizations.

- Chandy-Lamport algorithm can capture **stable global properties**:
  - once true, stays true forever afterwards (for stable liveness)
  - once false, stays false forever afterwards (for stable non-safety)

Today’s agenda

- **Multicast**
  - Chapter 15.4
- **Goal:** reason about desirable properties for message delivery among a group of processes.

Communication modes

- **Unicast**
  - Messages are sent from exactly <u>one</u> process <u>to</u> <u>one</u> process.
- **Broadcast**
  - Messages are sent from exactly <u>one</u> process <u>to</u> <u>all</u> processes on the network.
- **Multicast**
  - Messages broadcast within a group of processes.
  - A multicast message is sent from any <u>one</u> process <u>to</u> a <u>group</u> of processes on the network.

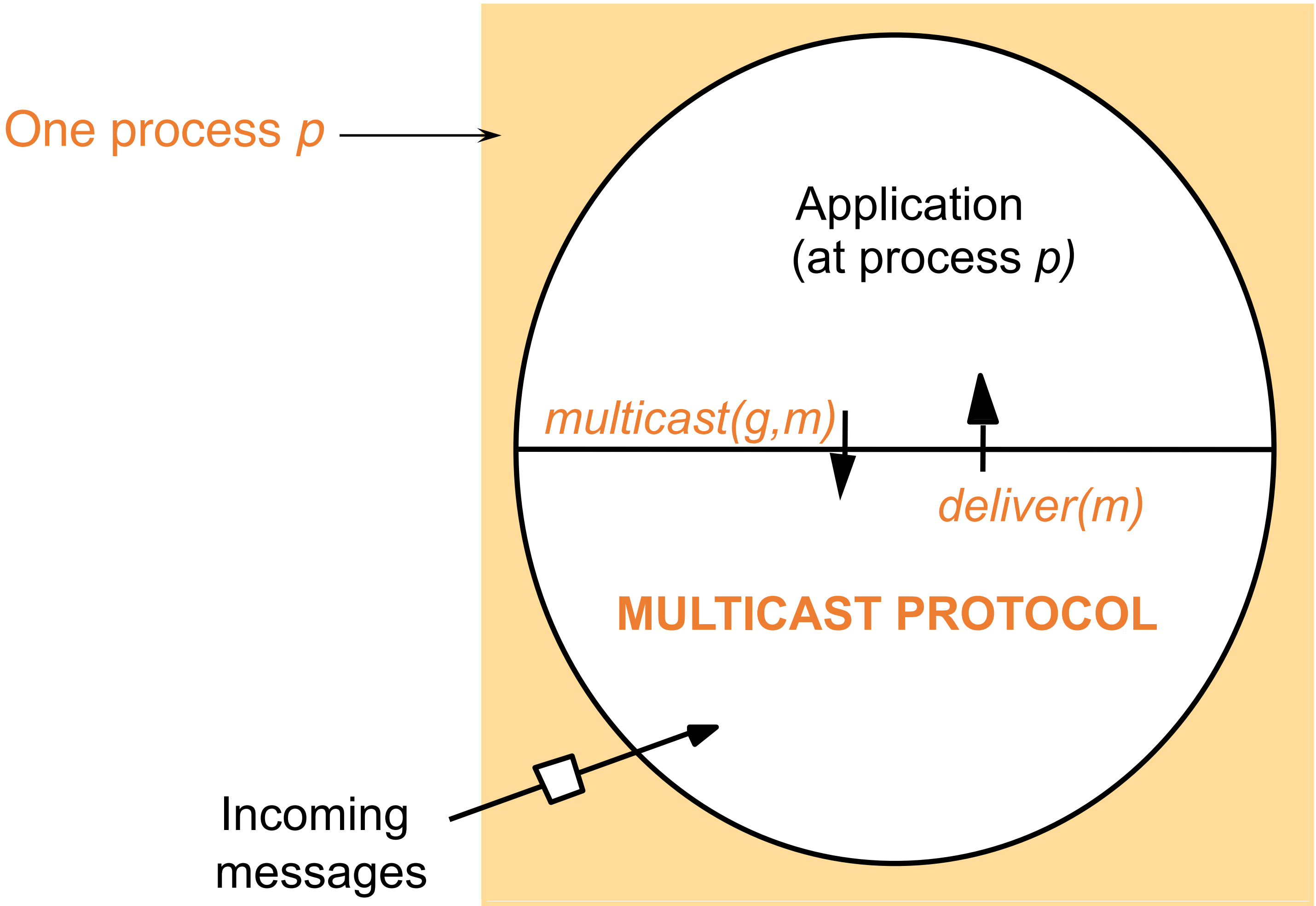
Where is multicast used?

- Distributed storage
  - Write to an object are multicast across replica servers.
  - Membership information (e.g., heartbeats) is multicast across all servers in cluster.
- Online scoreboards (ESPN, French Open, FIFA World Cup)
  - Multicast to group of clients interested in the scores.
- Stock Exchanges
  - Group is the set of broker computers.
- ……

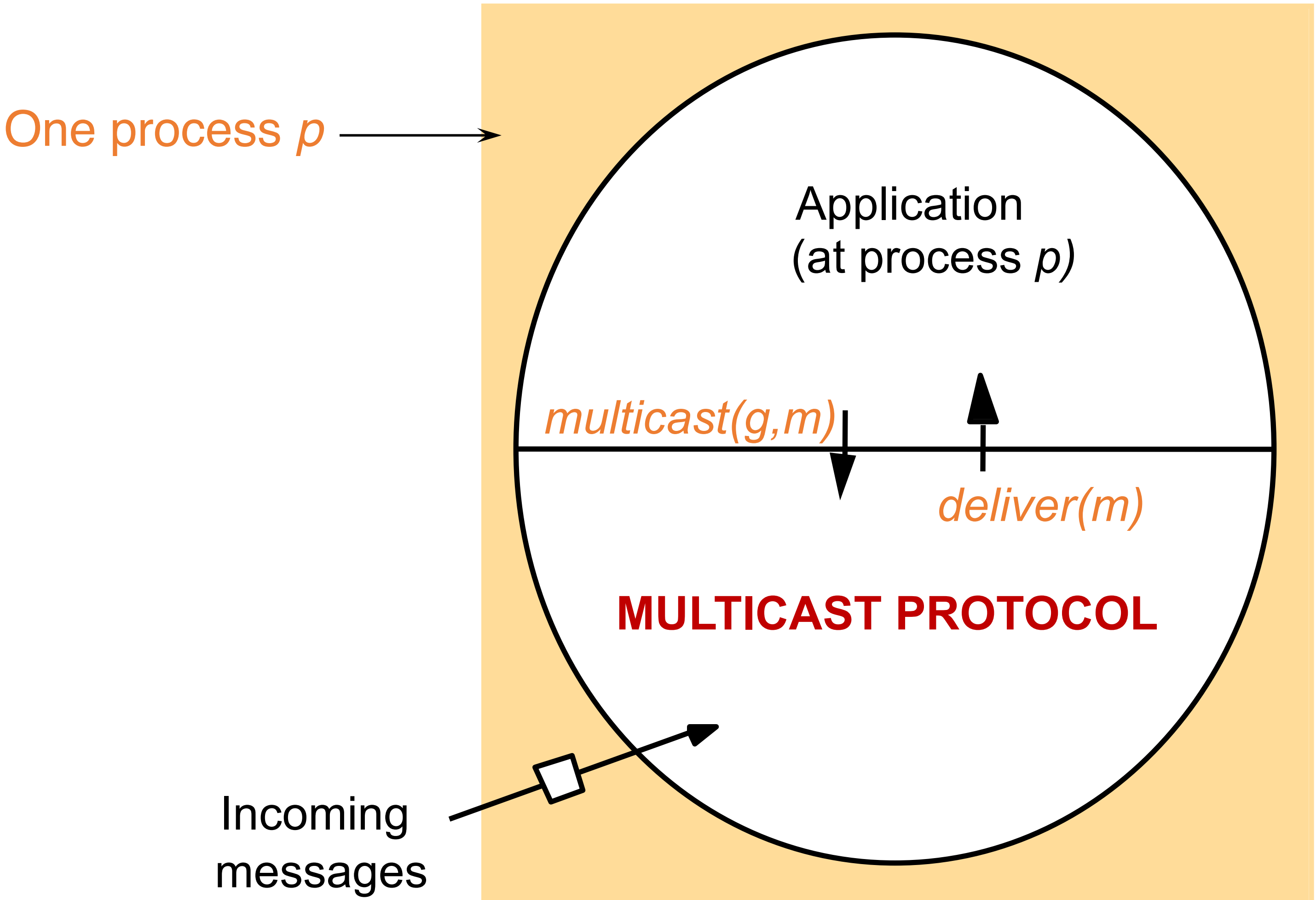
Communication modes

- **Unicast**
  - Messages are sent from exactly <u>one</u> process <u>to</u> <u>one</u> process.
    - *Best effort:* if a message is delivered it would be intact; no reliability guarantees.
    - *Reliable:* guarantees delivery of messages.
    - *In order:* messages will be delivered in the same order that they are sent.
- **Broadcast**
  - Messages are sent from exactly <u>one</u> process <u>to</u> <u>all</u> processes on the network.
- **Multicast**
  - Messages broadcast within a group of processes.
  - A multicast message is sent from any <u>one</u> process <u>to</u> the <u>group</u> of processes on the network.
  - *How do we define (and achieve) reliable or ordered multicast?*

What we are designing in this class?



What we are designing in this class?



Basic Multicast (B-Multicast)

- Straightforward way to implement B-multicast:
  - use a reliable one-to-one send (unicast) operation:

    B-multicast(group g, message m):

    for each process p in g, send (p,m).

    receive(m): B-deliver(m) at p.
- Guarantees: message is eventually delivered to the group if:
  - Processes are non-faulty.
  - The unicast "send" is reliable.
  - *Sender does not crash.*
- *Can we provide reliable delivery even after sender crashes?*
  - *What does this mean?*

Reliable Multicast (R-Multicast)

- **Integrity**: A *correct* (i.e., non-faulty) process *p* delivers a message *m* at most once.
  - *Assumption: no process sends **exactly** the same message twice*
- **Validity**: If a *correct* process multicasts (sends) message *m*, then it will eventually deliver *m* itself.
  - *Liveness for the sender.*
- **Agreement**: If a *correct* process delivers message *m*, then all the other *correct* processes in group(*m*) will eventually deliver *m*.
  - *All or nothing.*
- Validity and agreement together ensure overall liveness: if some correct process multicasts a message *m*, then, all correct processes deliver *m* too.

Reliable Multicast (R-Multicast)

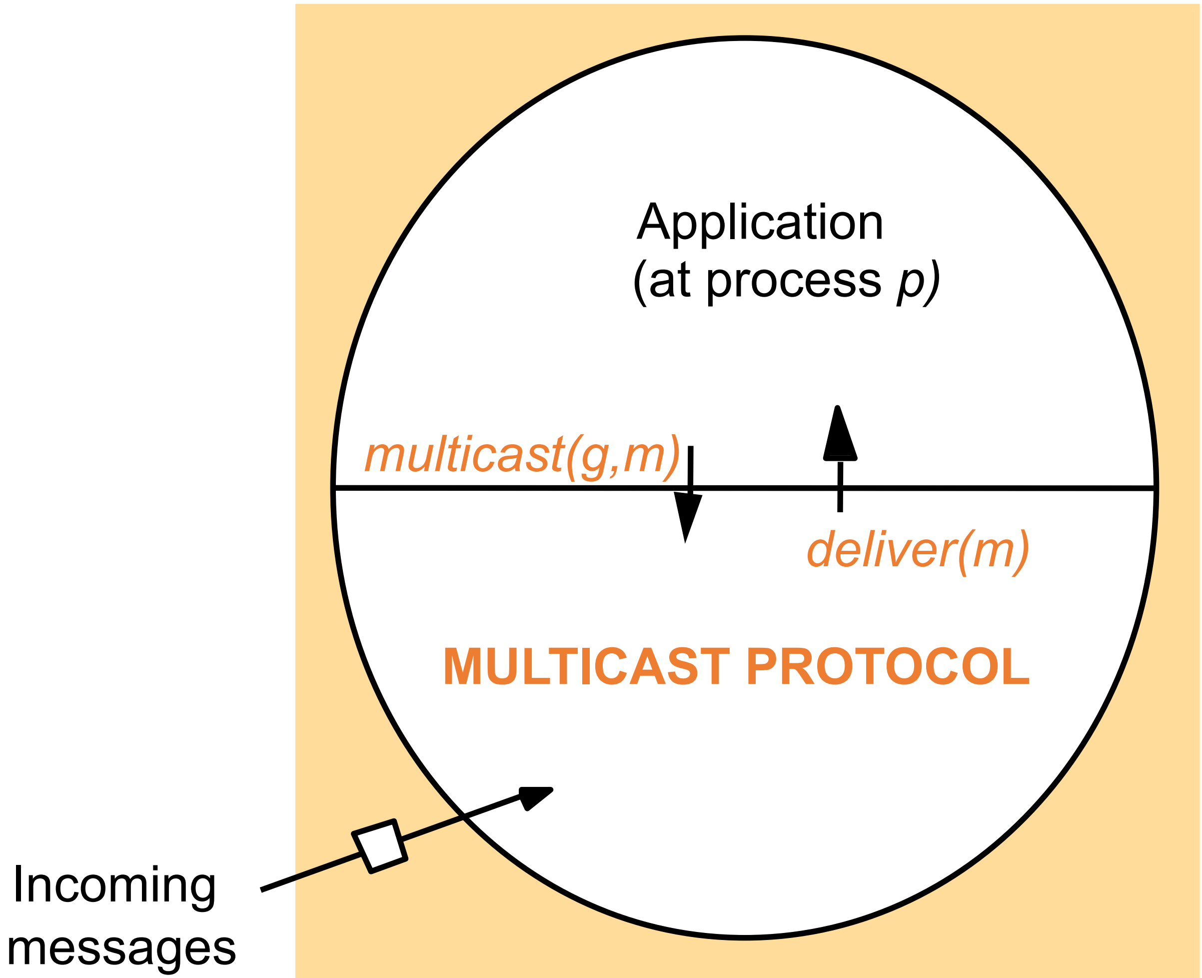
- **Integrity**: A *correct* (i.e., non-faulty) process *p* delivers a message *m* at most onc
  - *Assur* *wice*
- **Validity**: I hen it will eventuall
  - *Livene*
- **Agreeme** the other *correct* pr
  - *All or*

What happens if a process initiates B-multicasts of a message but fails after unicasting to a subset of processes in the group?

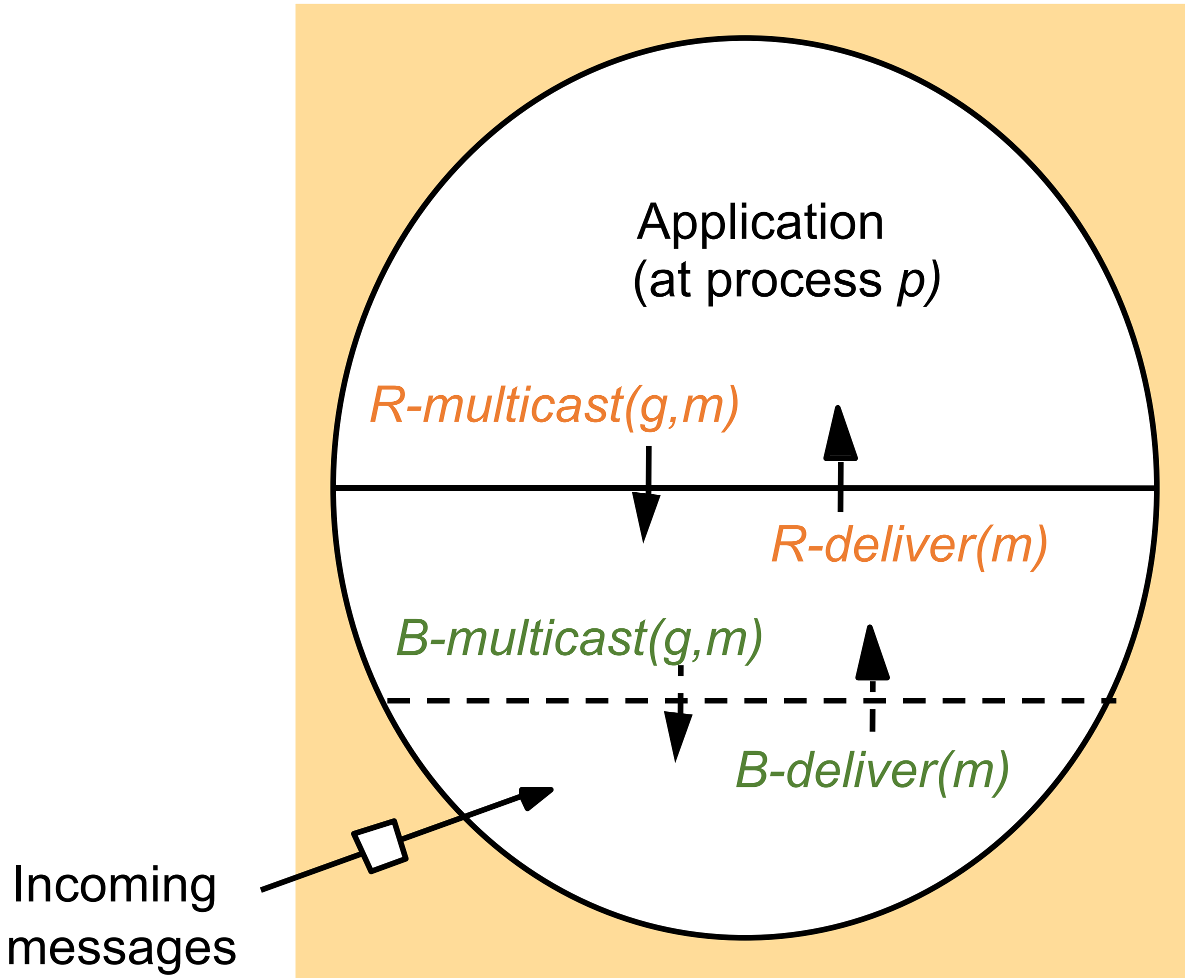
Agreement is violated! R-multicast not satisfied.

- Validity and agreement together ensure overall liveness: if some correct process multicasts a message *m*, then, all correct processes deliver *m* too.

Implementing R-Multicast



Implementing R-Multicast



Implementing R-Multicast

On initialization

    Received := {};

For process p to R-multicast message m to group g

    B-multicast(g,m); (p $\in$ g is included as destination)

On B-deliver(m) at process q in g = group(m)

    if (m $\notin$ Received):

        Received := Received $\cup$ {m};

        if (q $\neq$ p): B-multicast(g,m);

        R-deliver(m)

Reliable Multicast (R-Multicast)

- **Integrity**: A *correct* (i.e., non-faulty) process *p* delivers a message *m* at most once.
  - *Assumption: no process sends **exactly** the same message twice*
- **Validity**: If a *correct* process multicasts (sends) message *m*, then it will eventually deliver *m* itself.
  - *Liveness for the sender.*
- **Agreement**: If a *correct* process delivers message *m*, then all the other *correct* processes in group(*m*) will eventually deliver *m*.
  - *All or nothing.*
- Validity and agreement together ensure overall liveness: if some correct process multicasts a message *m*, then, all correct processes deliver *m* too.

Ordered Multicast

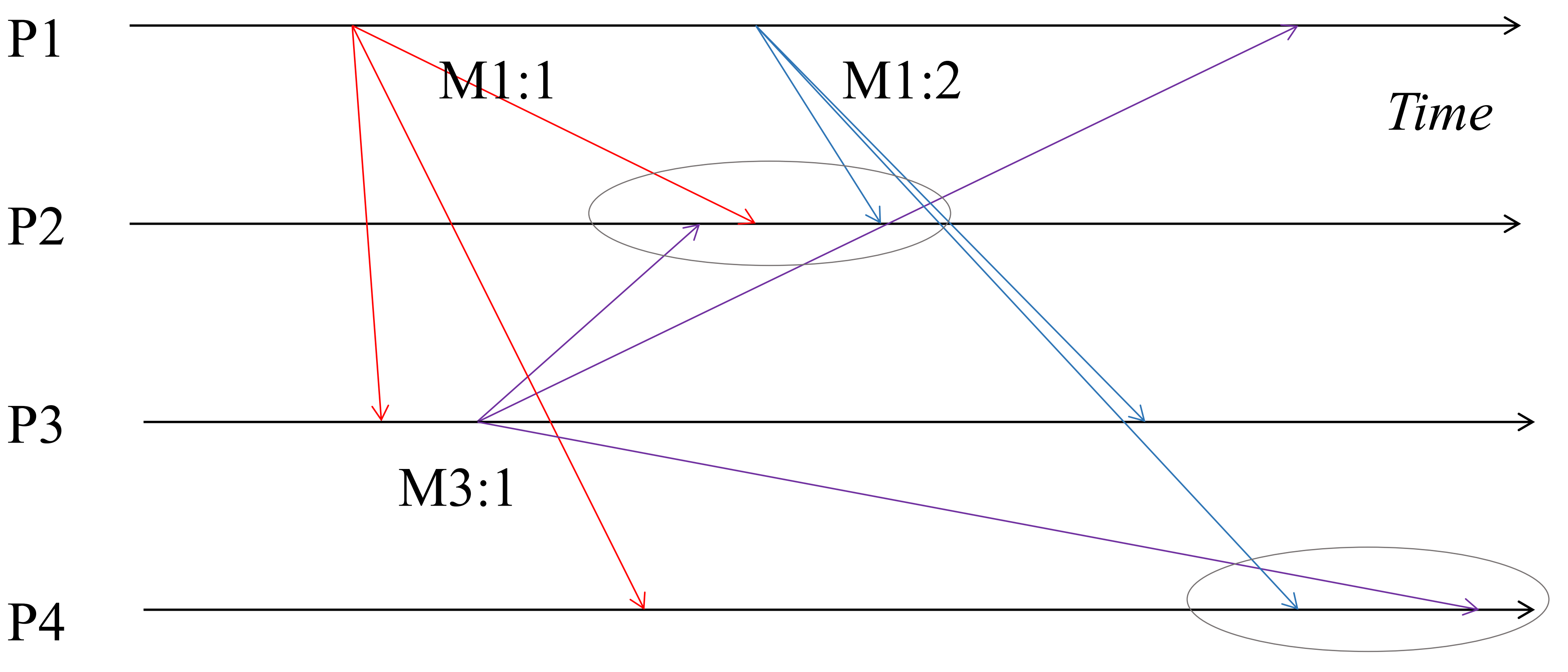
- Three popular flavors implemented by several multicast protocols:
  1. FIFO ordering
  2. Causal ordering
  3. Total ordering

1. FIFO Order

- Multicasts from each sender are delivered in the order they are sent, at all receivers.
- Don't care about multicasts from different senders.

- More formally
  - *If a correct process issues multicast(g,m) and then multicast(g,m'), then every correct process that delivers m' will have already delivered m.*

FIFO Order: Example



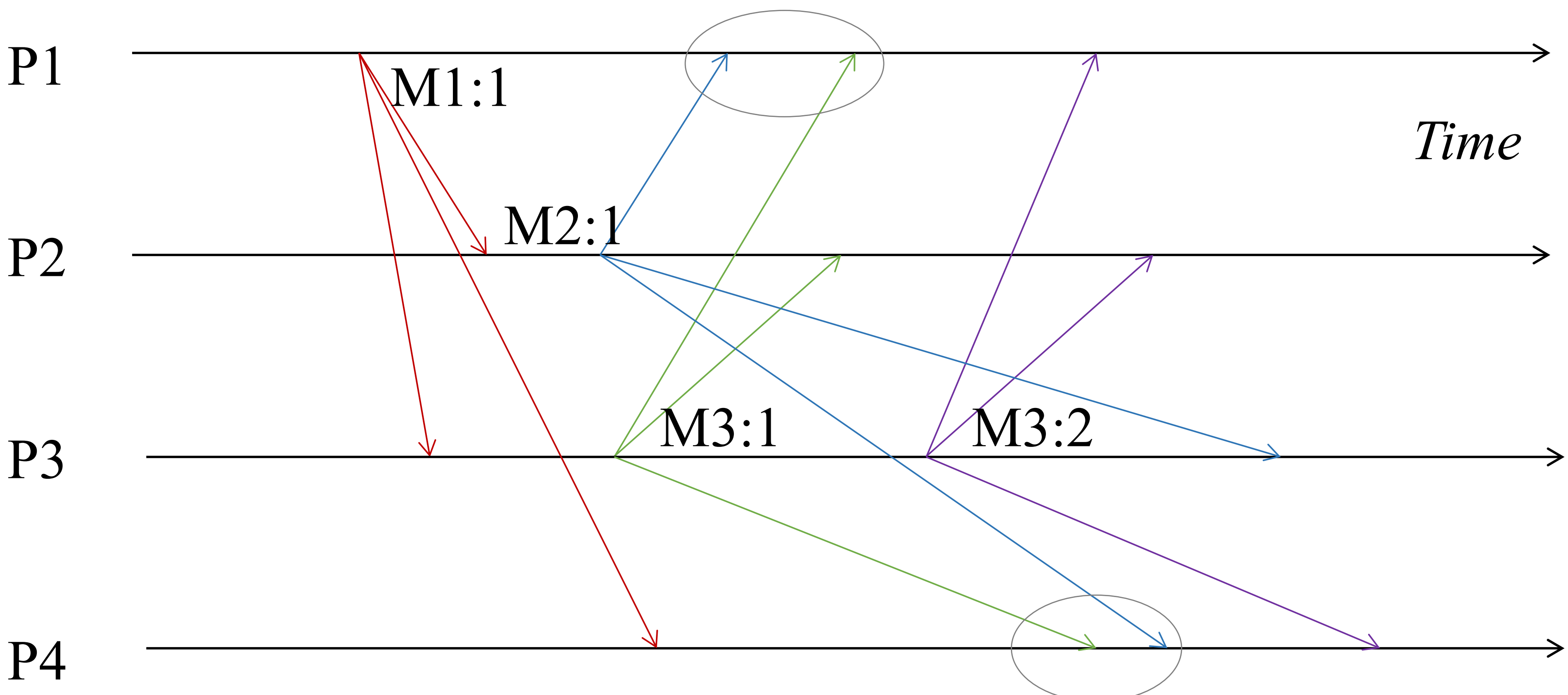
M1:1 and M1:2 should be delivered in that order at each receiver.
Order of delivery of M3:1 and M1:2 could be different at different receivers.

2. Causal Order

- Multicasts whose send events are causally related, must be delivered in the same causality-obeying order at all receivers.

- More formally
  - *If multicast(g,m) $\rightarrow$ multicast(g,m') then any correct process that delivers m' will have already delivered m.*
  - $\rightarrow$ *is Lamport's happens-before*
  - $\rightarrow$ is induced only by multicast messages in group g, and when they are **delivered** to the application, rather than all network messages.

Causal Order: Example



M3:1 → M3:2, M1:1 → M2:1, M1:1 → M3:1 and so should be delivered in that order at each receiver.

M3:1 and M2:1 are concurrent and thus ok to be delivered in any (and even different) orders at different receivers.

To be continued in next class

- More on causal ordering
- Total ordering
- Implementing of FIFO/Causal/Total ordering

Summary

- Multicast is an important communication mode in distributed systems.
- Applications may have different requirements:
  - Reliability
  - Ordering: FIFO, Causal, Total
  - Combinations of the above.