Distributed Systems

ECE428

Lecture 7

Adopted from Spring 2021

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

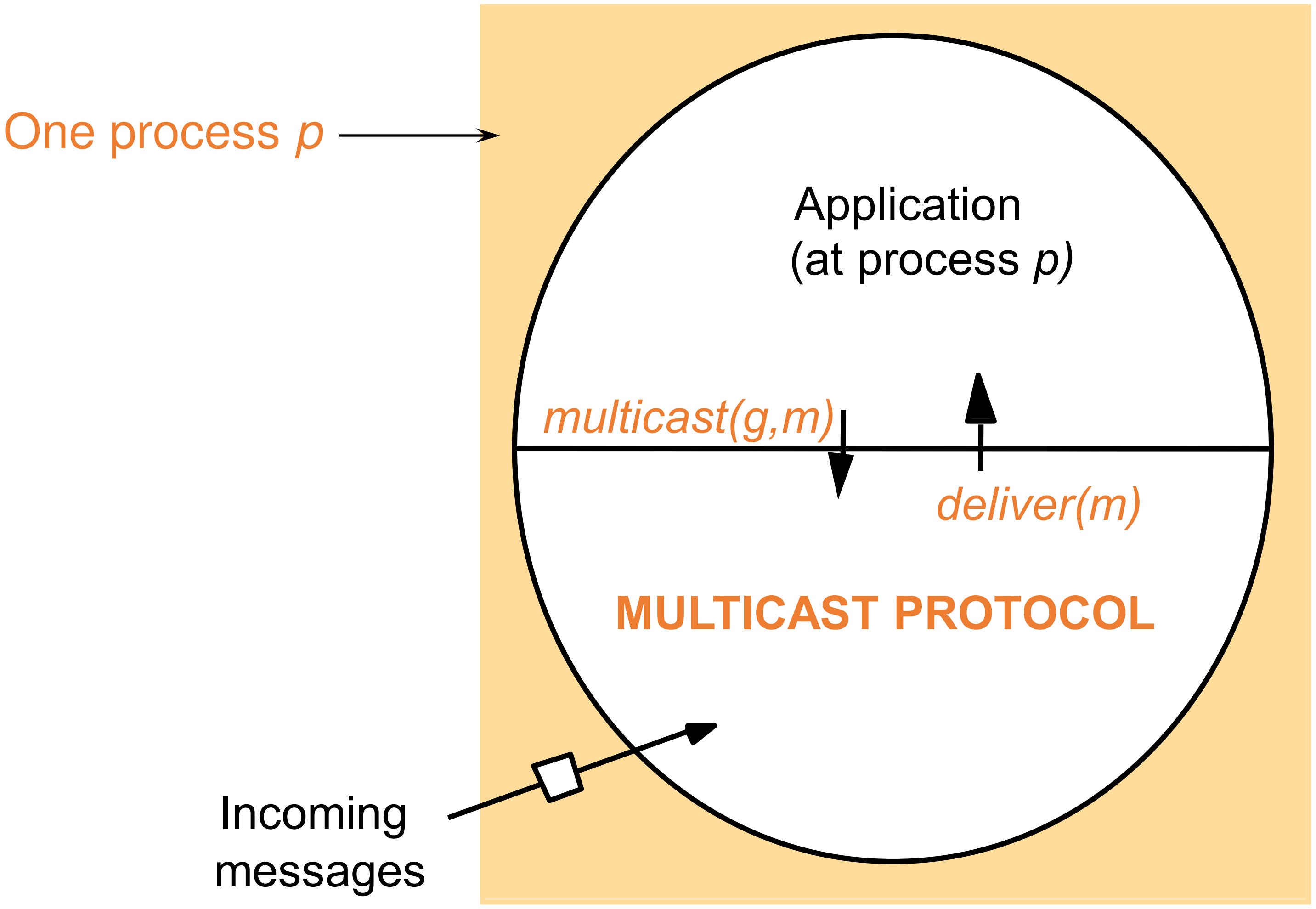
Where is multicast used?

- 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 sent from exactly one process to one process.
    - *Best effort:* if a message is delivered it would be intact; no reliability guarantees.
    - *Reliable:* guarantees delivery of messages.
    - *In order:* messages delivered in same order that they were sent.
- Broadcast
  - Msgs sent from exactly one process to all other processes.
- Multicast
  - Messages broadcast within a group of processes.
  - A multicast message is sent from any one process to a group of processes.
  - *How to define and achieve a reliable & ordered multicast?*

What are we designing in this class?



One process *p*

Application
(at process *p*)

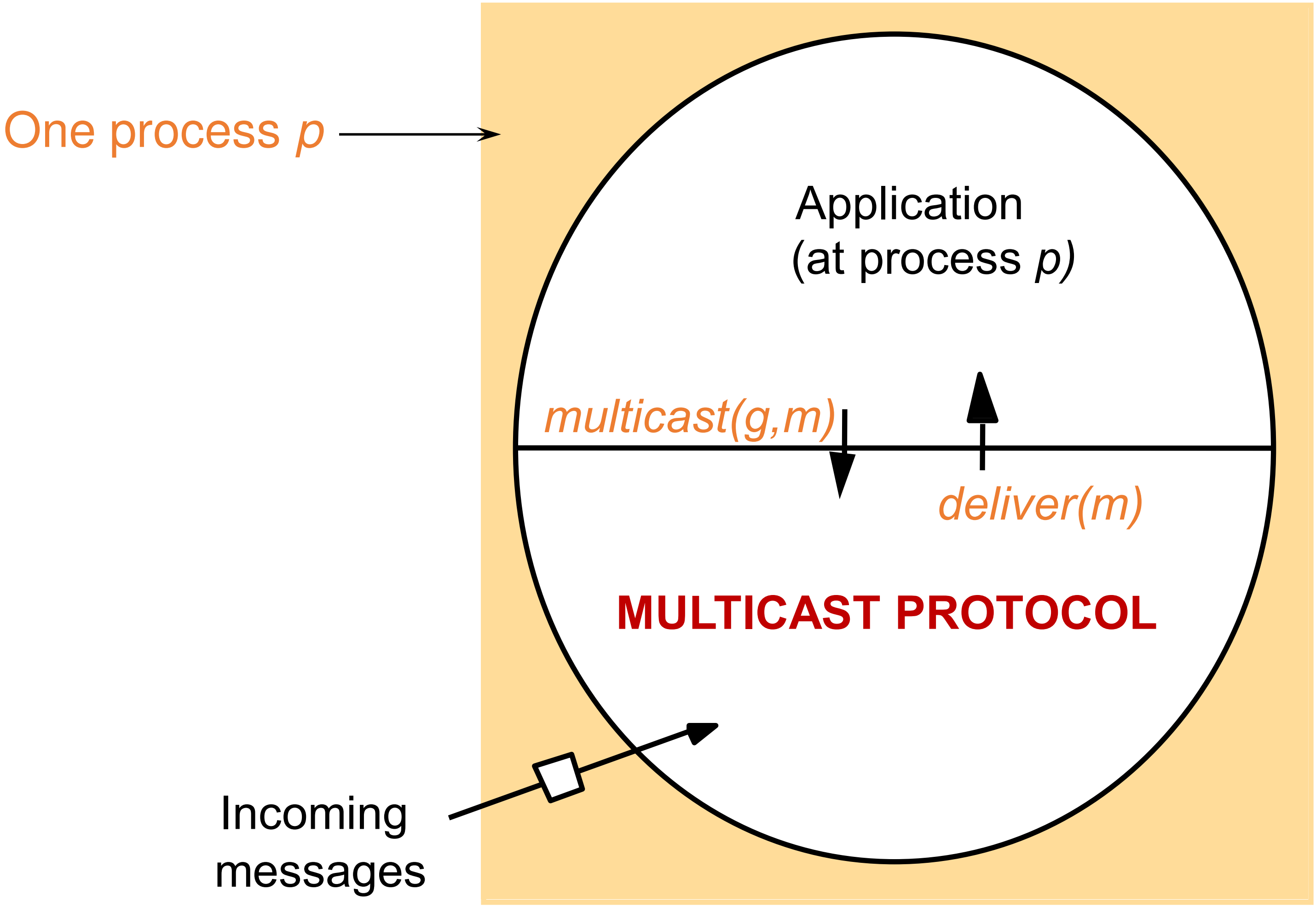
multicast(g,m)

deliver(m)

MULTICAST PROTOCOL

Incoming
messages

What are we 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 eventually delivered to 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 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 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.

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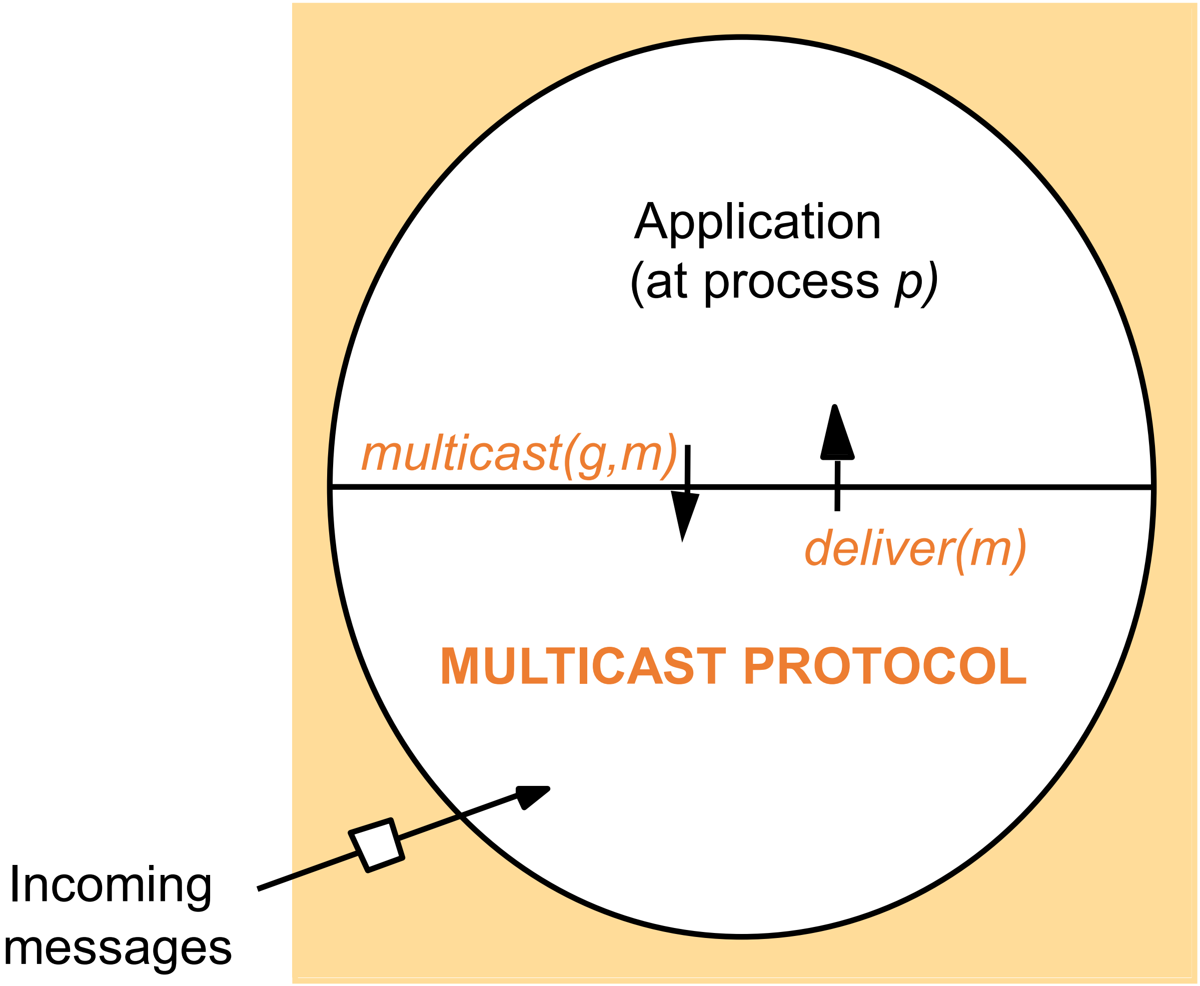
What happens if a process initiates B-multicasts of a message but fails after unicasting to a subset of processes in the group?

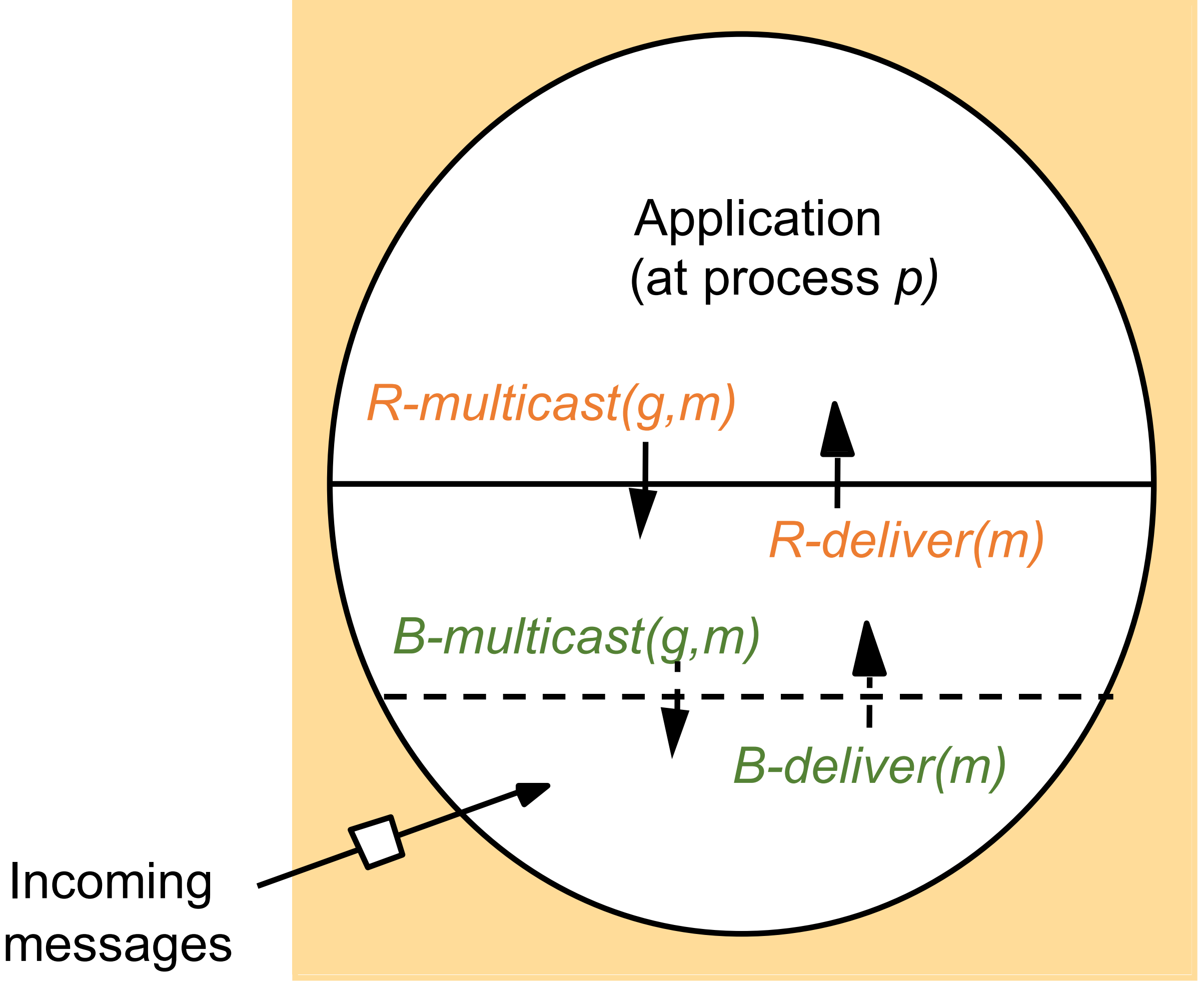
Agreement is violated! R-multicast not satisfied.

- 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)
```

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Ordered Multicast

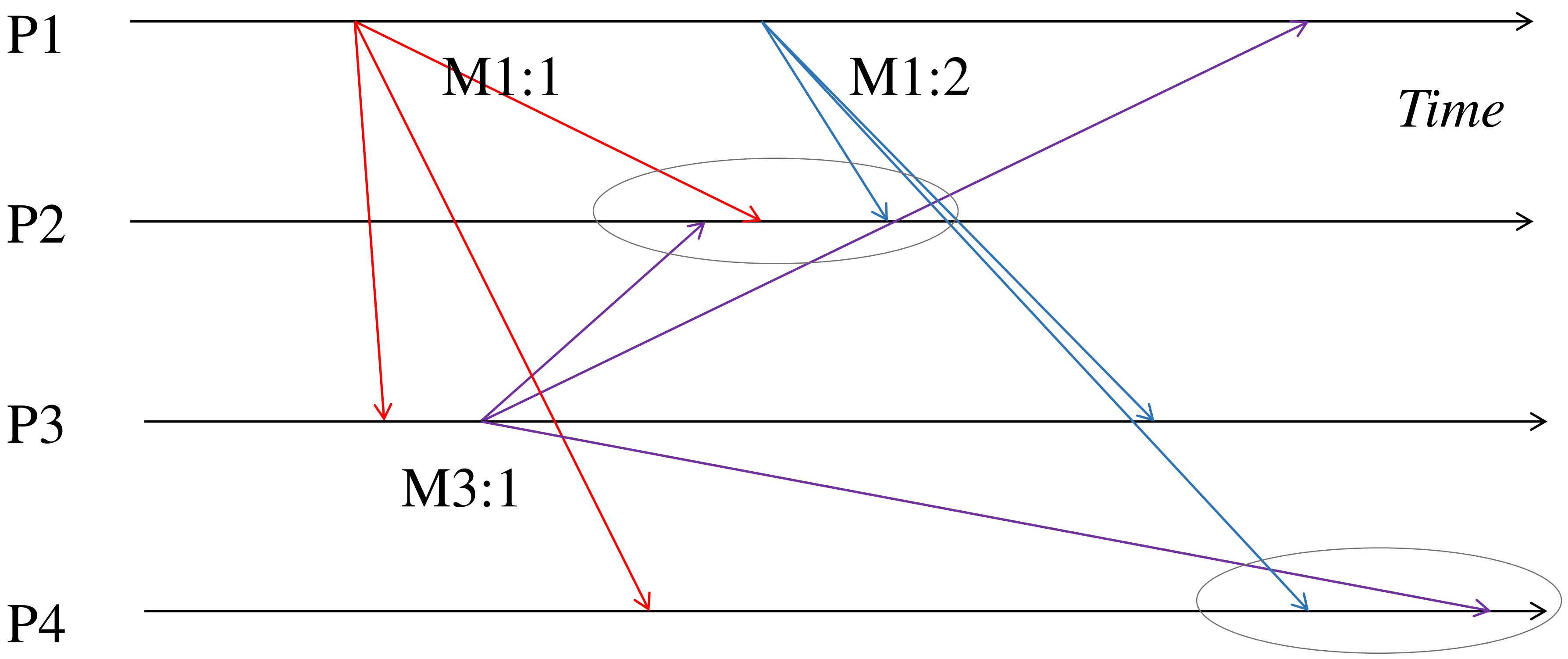
- Three popular flavors implemented by several multicast protocols:
  1. FIFO ordering
  2. Causal ordering
  3. Total ordering

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

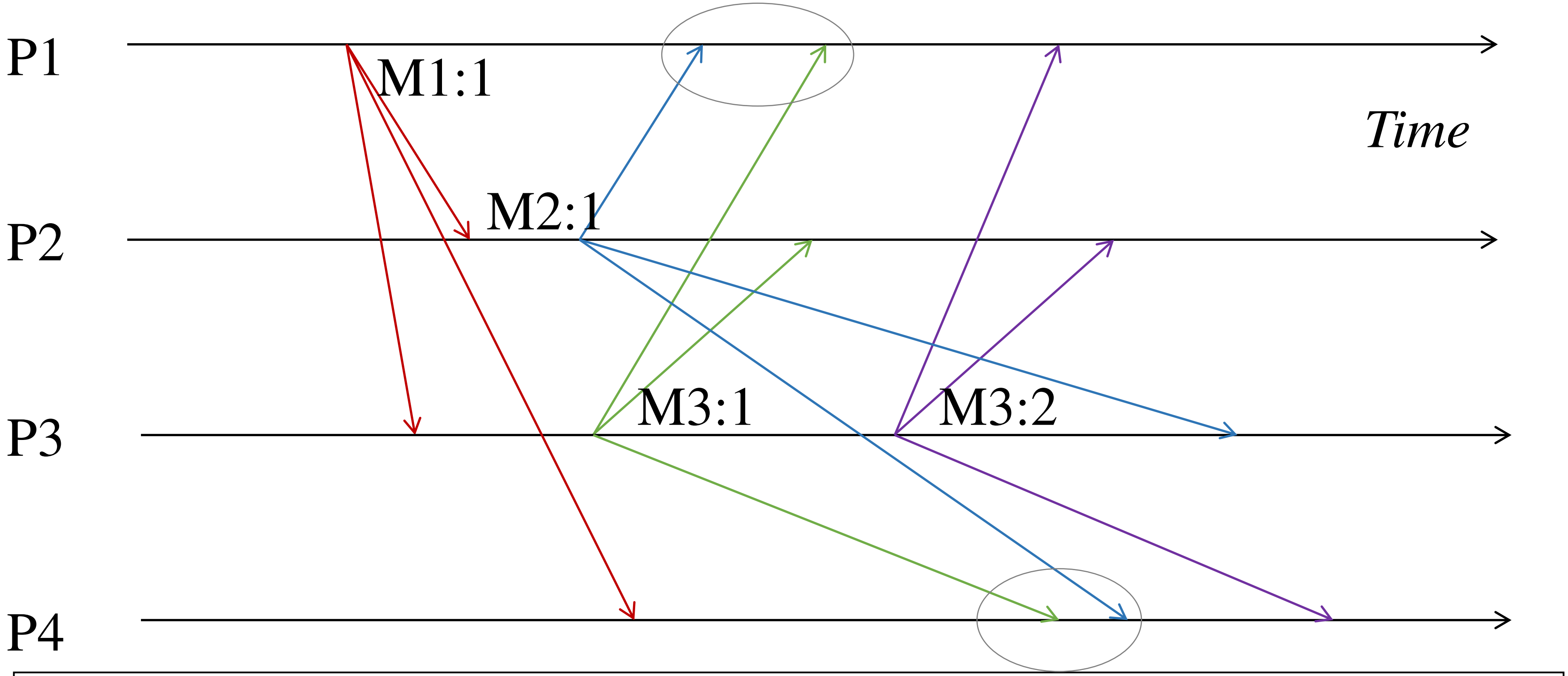


M1:1 and M1:2 should be delivered in that order at each receiver.
Order of delivery of M3:1 and M1:2 could be different at different receivers.

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) → multicast(g,m') then any correct process that delivers m' will have already delivered m.*
  - *→ is Lamport's happens-before*
  - → 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.