

# Distributed systems

## Total Order Broadcast

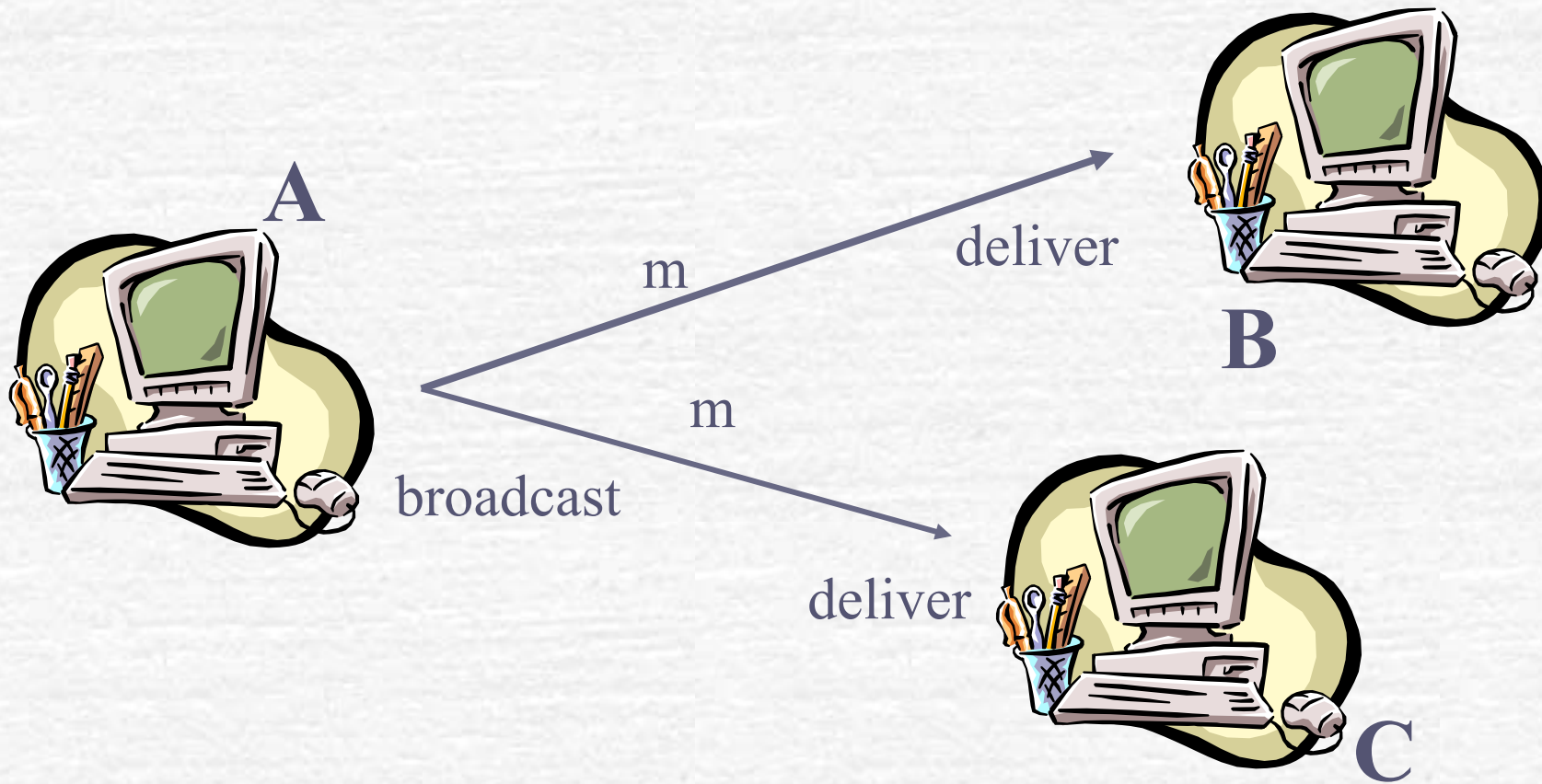
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# Overview

- **Intuitions:** what is total order broadcast?
- **Specifications** of *total order broadcast*
- **Consensus**-based total order algorithm

# Broadcast

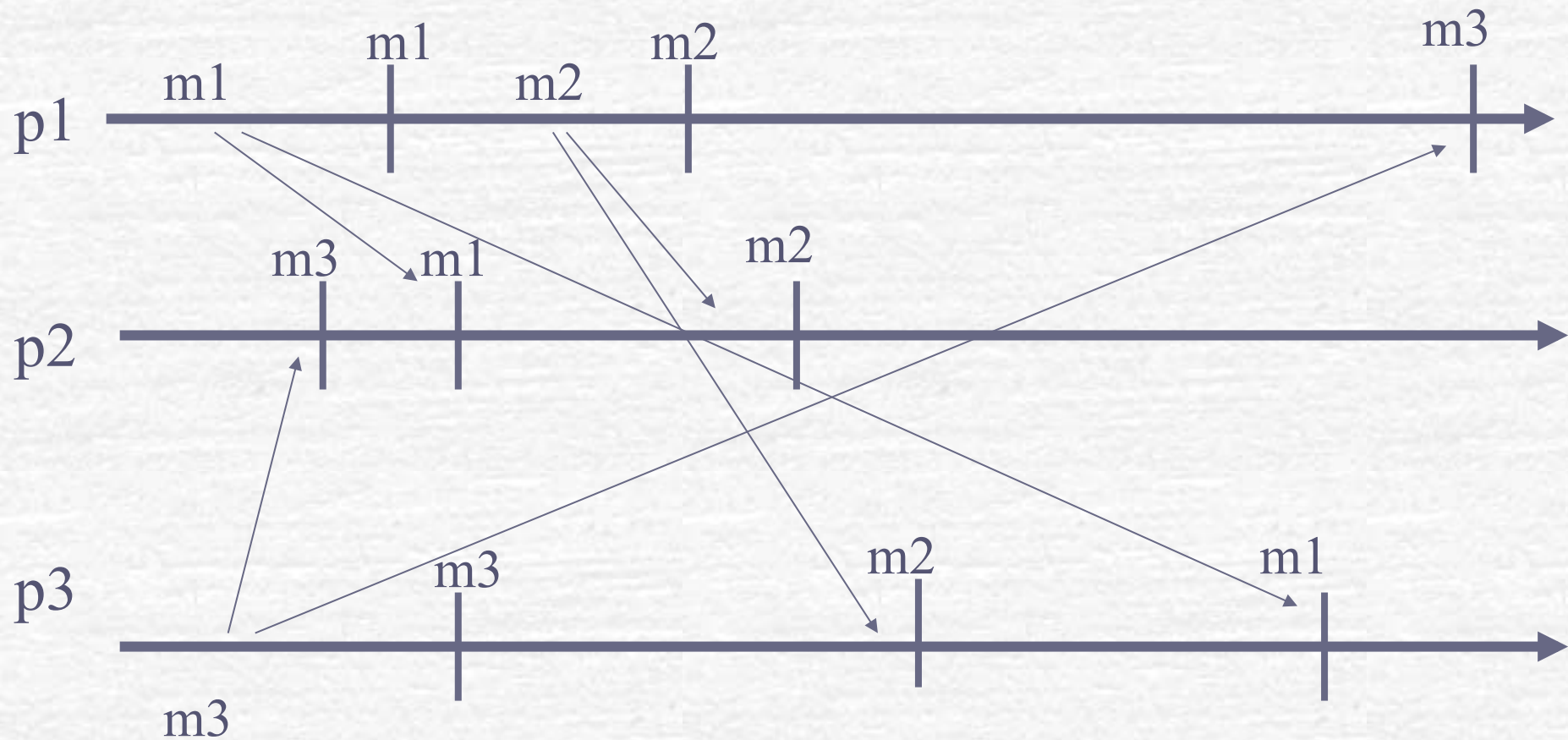


# Intuitions (1)

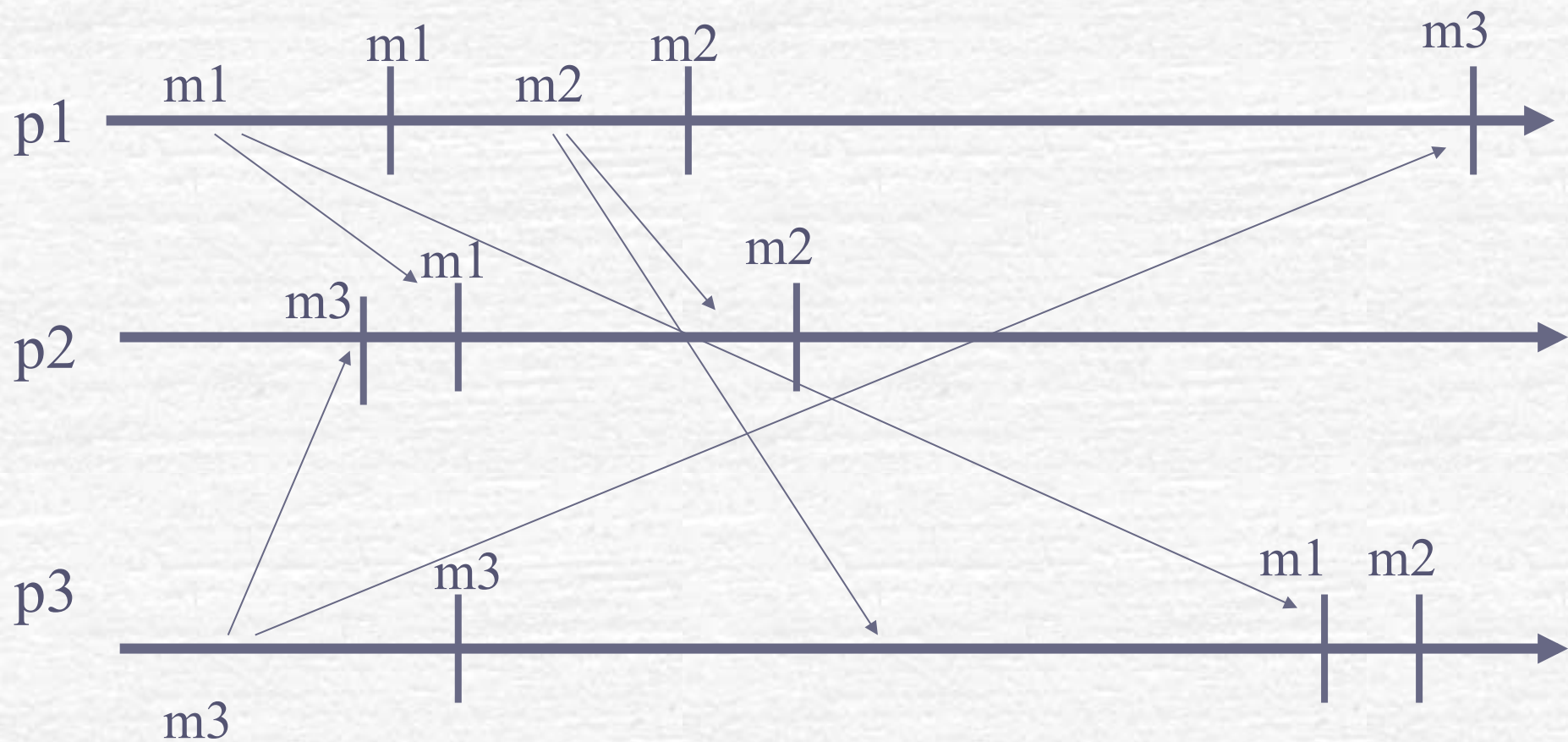
- In **reliable** broadcast, the processes are free to deliver messages in any order they wish
- In **causal** broadcast, the processes need to deliver messages according to some order (causal order)
- The order imposed by causal broadcast is however partial: some messages might be delivered in different order by the processes



# Reliable Broadcast



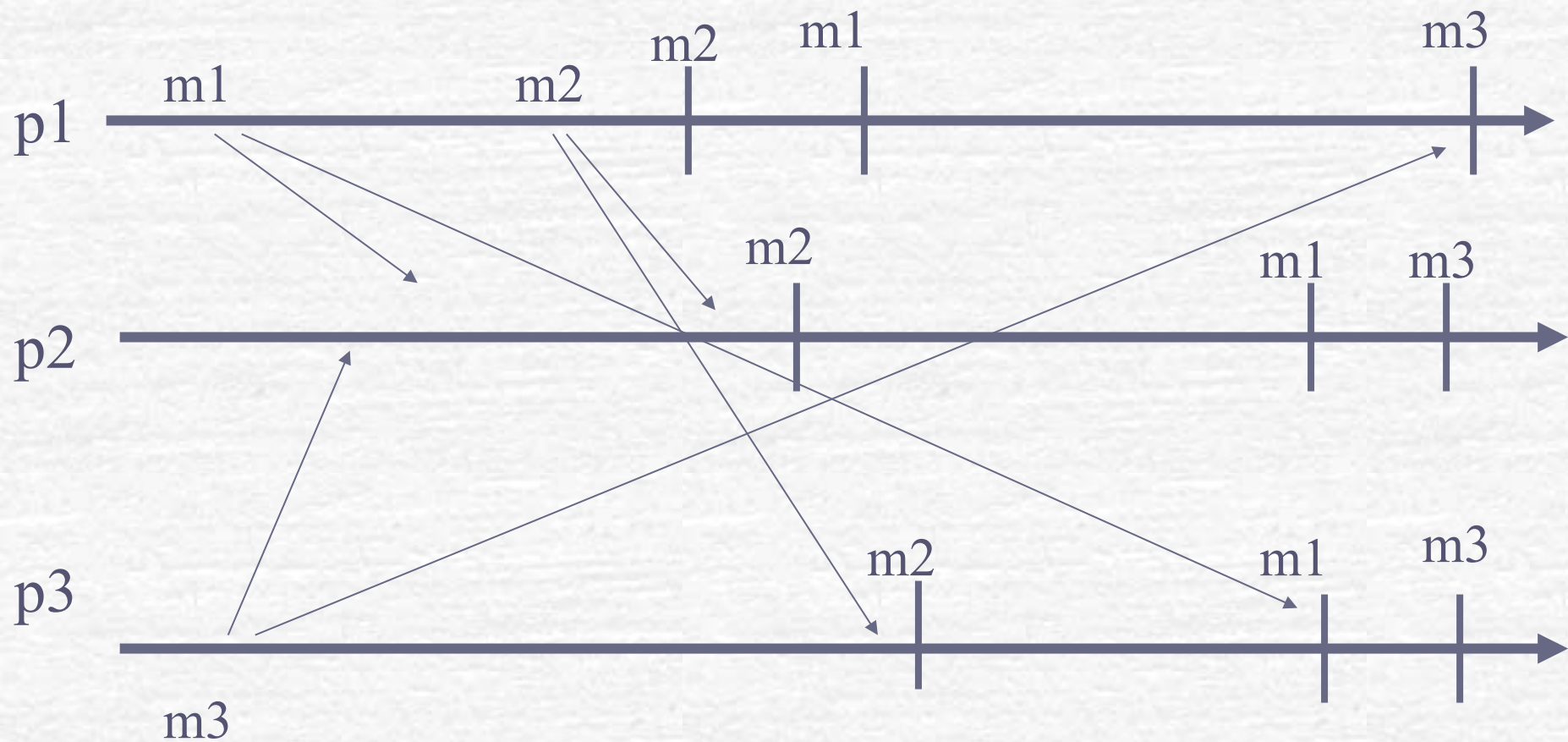
# Causal Broadcast



## Intuitions (2)

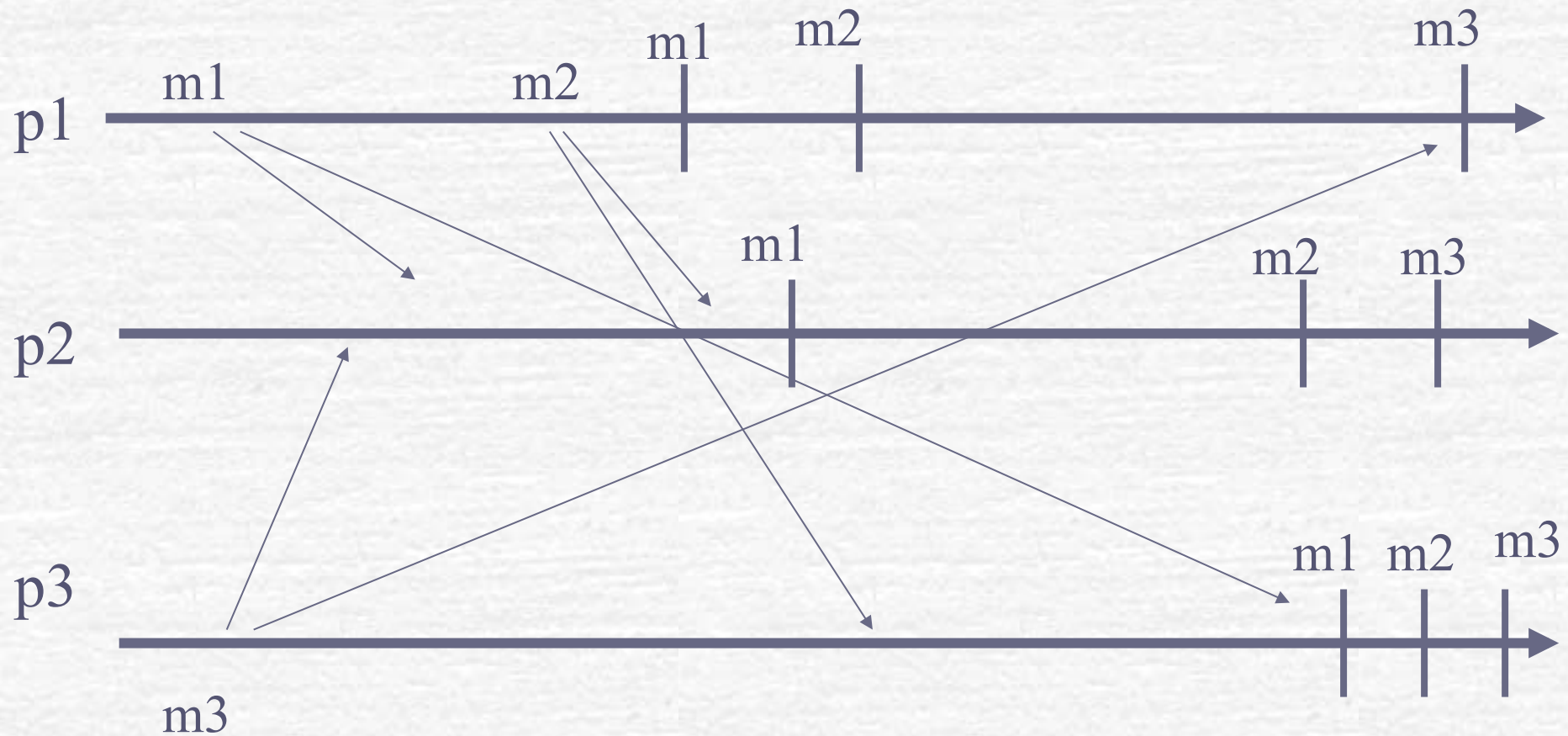
- In ***total order*** broadcast, the processes must deliver all messages according to the same order (i.e., the order is now total)
- Note that this order does not need to respect causality (or even FIFO ordering)
- Total order broadcast can be made to respect causal (or FIFO) ordering

# Total Order Broadcast (I)





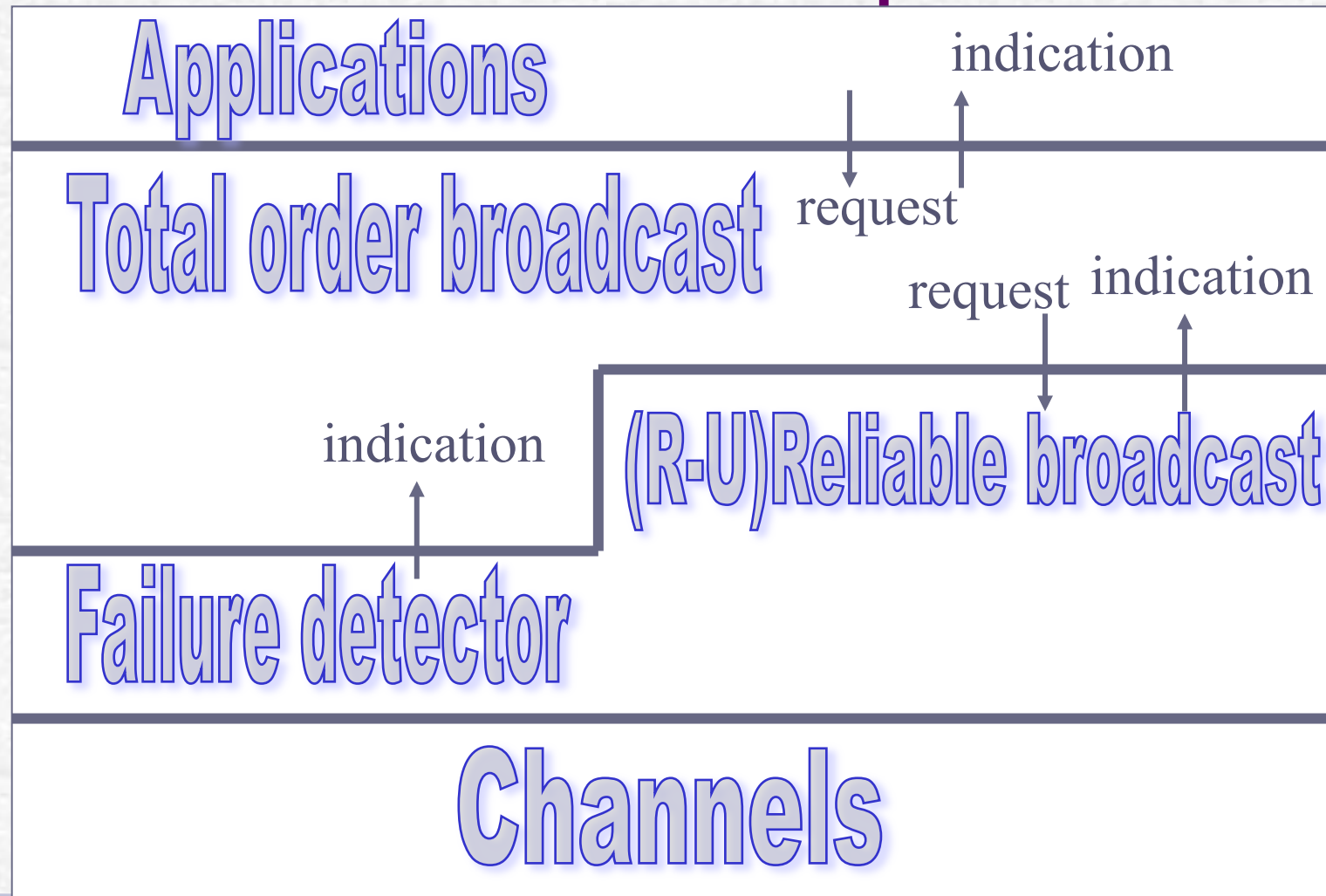
# Total Order Broadcast (II)



## Intuitions (3)

- A replicated service where the replicas need to treat the requests in the ***same order*** to preserve consistency  
(we talk about state machine replication)
- A notification service where the subscribers need to get notifications in the same order

# Modules of a process



# Overview

- **Intuitions:** what is total order broadcast?
- **Specifications** of *total order broadcast*
- **Consensus**-based algorithm



# Total order broadcast (tob)

## • ***Events***

- Request:  $\langle \text{toBroadcast}, m \rangle$
- Indication:  $\langle \text{toDeliver}, \text{src}, m \rangle$

## • ***Properties:***

- ***RB1, RB2, RB3, RB4***
- ***Total order property***

# Specification (I)

**Validity:** If  $p_i$  and  $p_j$  are correct, then every message broadcast by  $p_i$  is eventually delivered by  $p_j$

**No duplication:** No message is delivered more than once

**No creation:** No message is delivered unless it was broadcast

**(Uniform) Agreement:** For any message  $m$ . If a correct (any) process delivers  $m$ , then every correct process delivers  $m$

# Specification (II)

## ***(Uniform) Total order.***

Let  $m$  and  $m'$  be any two messages.

Let  $p_i$  be any (correct) process that delivers  $m$  without having delivered  $m'$

Then no (correct) process delivers  $m'$  before  $m$

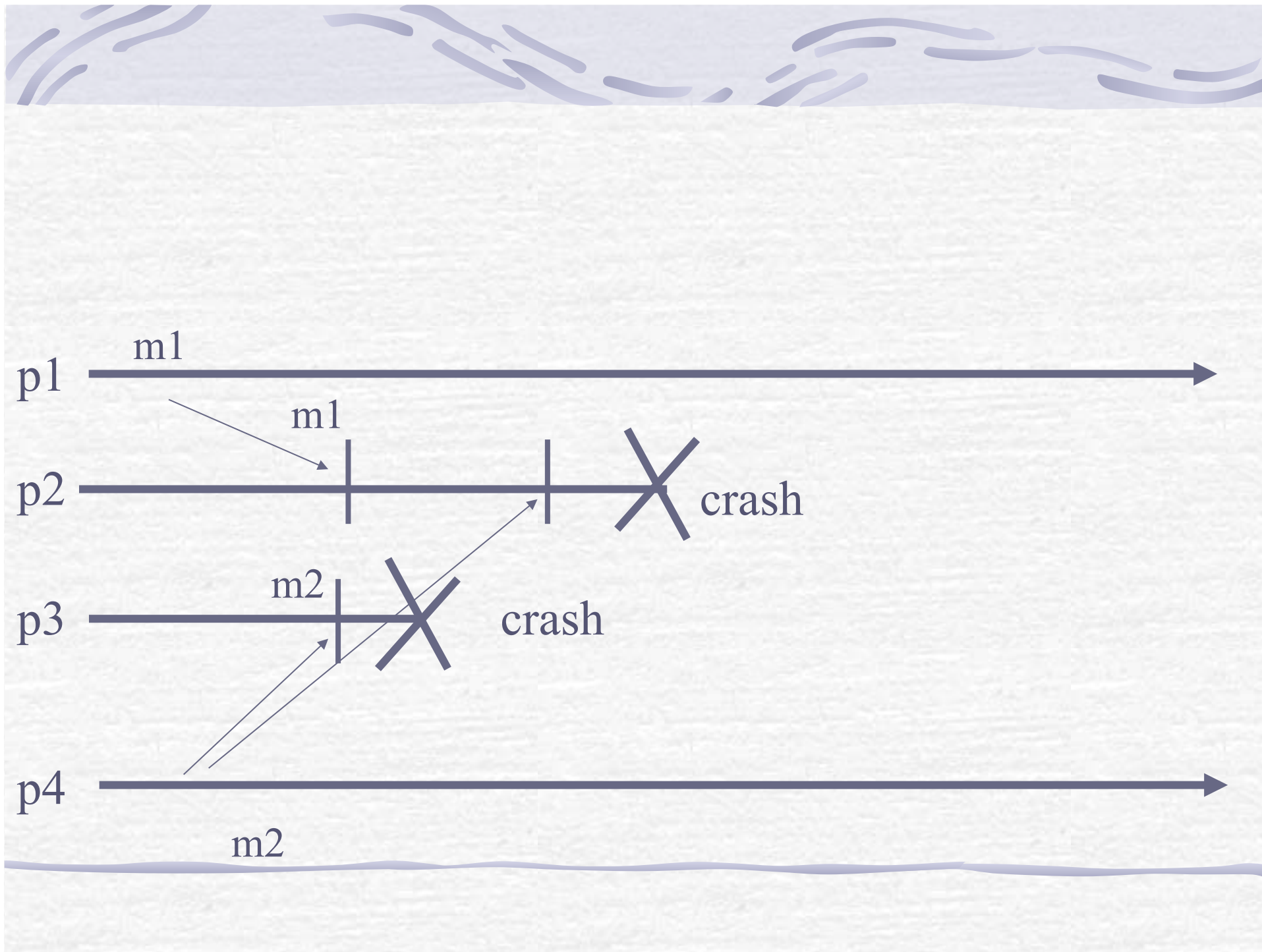
# Specifications

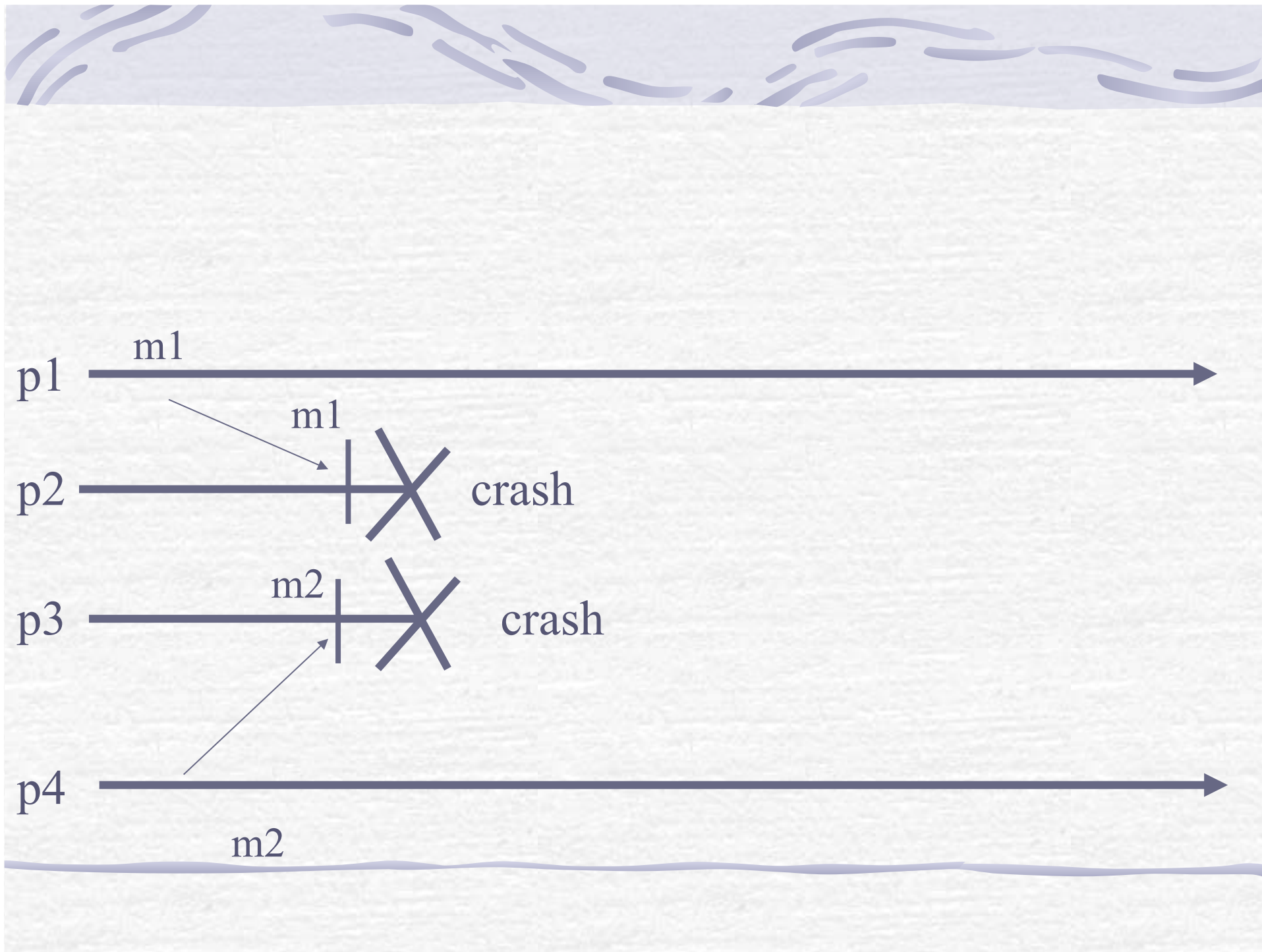
***Note the difference with the following properties:***

Let  $p_i$  and  $p_j$  be any two correct (any) processes that deliver two messages  $m$  and  $m'$ . If  $p_i$  delivers  $m'$  before  $m$ , then  $p_j$  delivers  $m'$  before  $m$ .

Let  $p_i$  and  $p_j$  be any two (correct) processes that deliver a message  $m$ . If  $p_i$  delivers a message  $m'$  before  $m$ , then  $p_j$  delivers  $m'$  before  $m$ .







# Overview

- **Intuitions:** what total order broadcast can bring?
- **Specifications** of *total order broadcast*
- **Consensus**-based algorithm

# (Uniform) Consensus

In the (uniform) consensus problem, the processes propose values and need to agree on one among these values

**C1. Validity:** Any value decided is a value proposed

**C2. (Uniform) Agreement:** No two correct (any) processes decide differently

**C3. Termination:** Every correct process eventually decides

**C4. Integrity:** Every process decides at most once



# Consensus

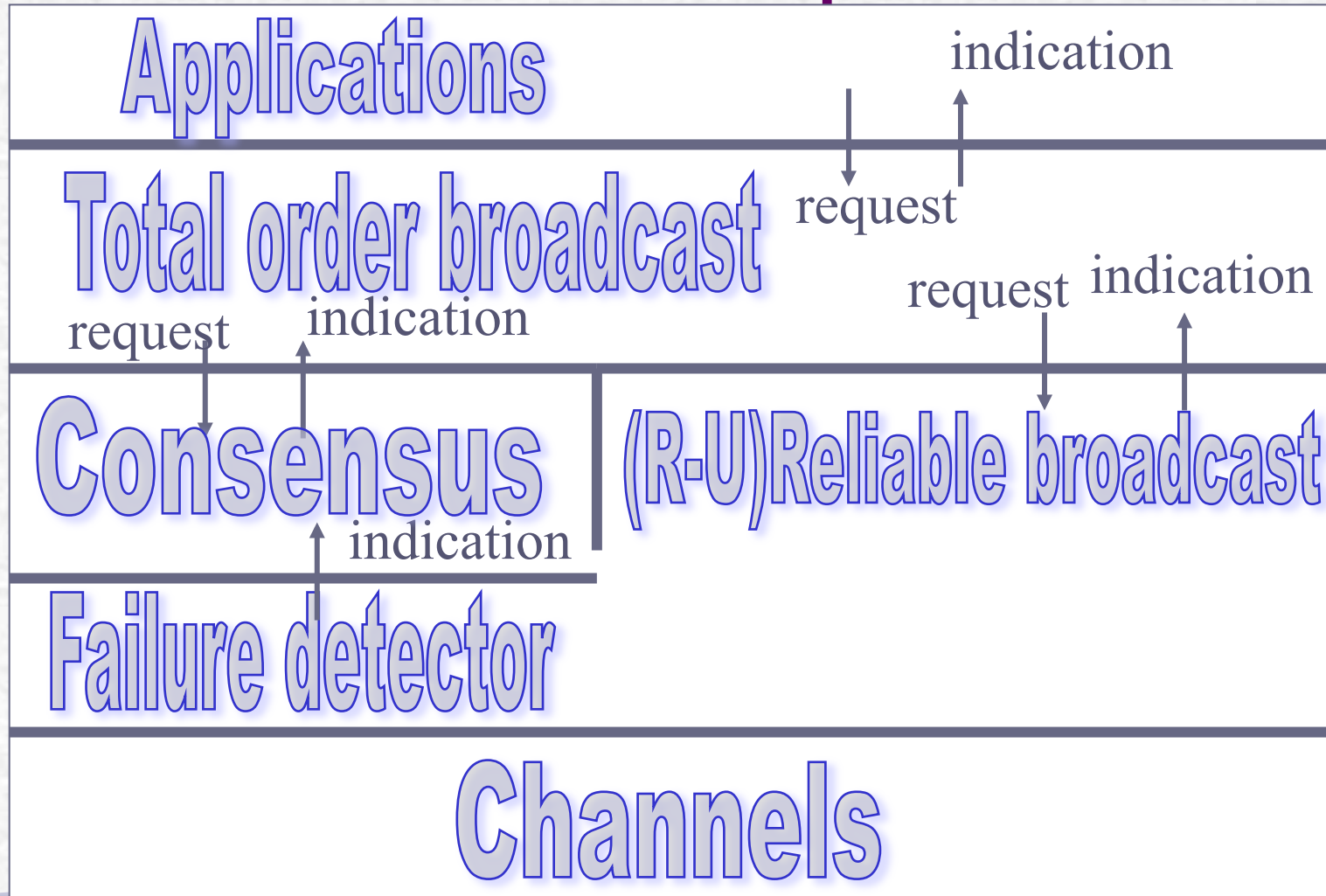
## • ***Events***

- Request:  $\langle \text{Propose}, v \rangle$
- Indication:  $\langle \text{Decide}, v' \rangle$

## • ***Properties:***

- ***C1, C2, C3, C4***

# Modules of a process



# Algorithm

- **Implements:** TotalOrder (to).

- **Uses:**

  - ReliableBroadcast (rb).

  - Consensus (cons);

- **upon event** < Init > **do**

  - unordered: = delivered: =  $\emptyset$ ;

  - wait := false;

  - sn := 1;

# Algorithm (cont'd)

- **upon event**  $\langle \text{toBroadcast}, m \rangle$  **do**
  - **trigger**  $\langle \text{rbBroadcast}, m \rangle$ ;
- **upon event**  $\langle \text{rbDeliver}, sm, m \rangle$  and  $(m \notin \text{delivered})$  **do**
  - $\text{unordered} := \text{unordered} \cup \{(sm, m)\}$ ;
- **upon**  $(\text{unordered} \neq \emptyset)$  and  $\text{not}(\text{wait})$  **do**
  - $\text{wait} := \text{true}$ ;
  - **trigger**  $\langle \text{Propose}, \text{unordered} \rangle_{sn}$ ;



# Algorithm (cont'd)

- **upon event**  $\langle \text{Decide}, \text{decided} \rangle_{sn}$  **do**
  - $\text{unordered} := \text{unordered} \setminus \text{decided};$
  - $\text{ordered} := \text{deterministicSort}(\text{decided});$
  - for all  $(sm, m)$  in  $\text{ordered}$ :
    - **trigger**  $\langle \text{toDeliver}, sm, m \rangle;$
    - $\text{delivered} := \text{delivered} \cup \{m\};$
  - $sn := sn + 1;$
  - $\text{wait} := \text{false};$

# Equivalences

1. One can build consensus with total order broadcast
2. One can build total order broadcast with consensus and reliable broadcast

***Therefore, consensus and total order broadcast are equivalent problems in a system with reliable channels***