Distributed systems

Causal Broadcast

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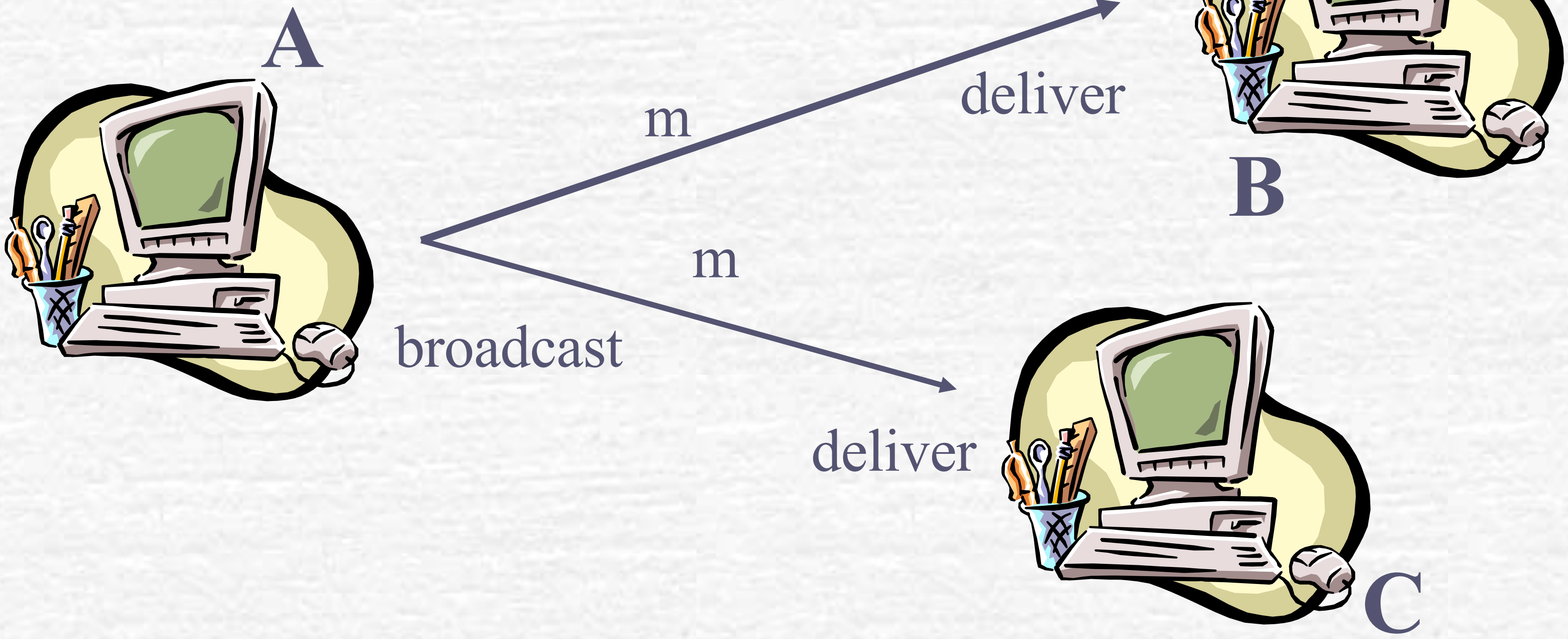
Distributed Programming Laboratory

Overview

- **Intuitions:** why causal broadcast?
- **Specifications** of ***causal broadcast***
- **Algorithms:**
  - A ***non-blocking*** algorithm using the ***past*** and
  - A ***blocking*** algorithm using ***vector clocks***

Broadcast



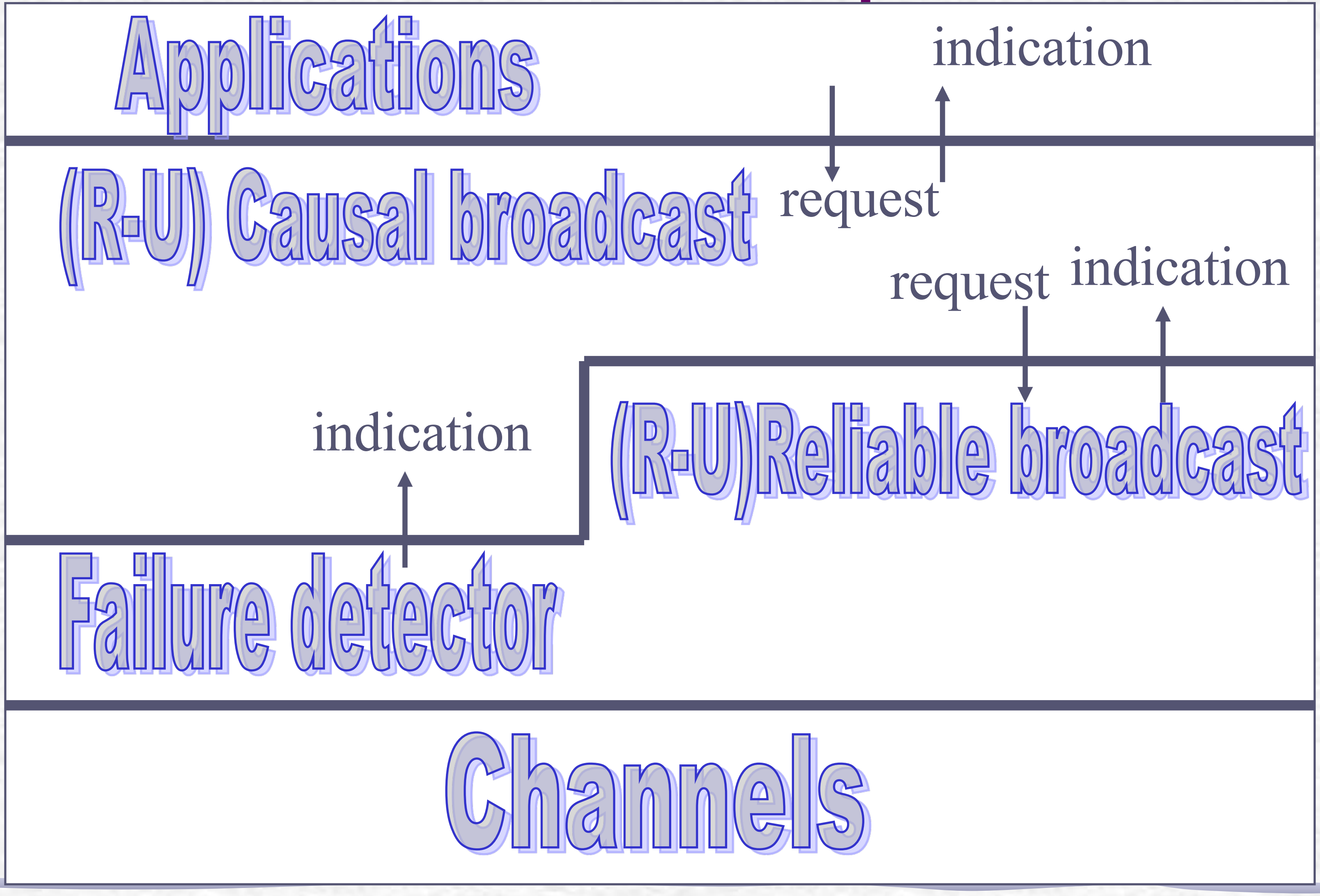
Intuitions (1)

- So far, we did not consider ordering among messages; In particular, we considered messages to be independent
- Two messages from the same process might not be delivered in the order they were broadcast
- A message m1 that causes a message m2 might be delivered by some process after m2

Intuitions (2)

- Consider a system of news where every new event that is displayed in the screen contains a reference to the event that caused it, e.g., a comment on some information includes a reference to the actual information
- Even uniform reliable broadcast does not guarantee such a dependency of delivery
- Causal broadcast alleviates the need for the application to deal with such dependencies

Modules of a process



Applications

indication

request

(R-U) Causal broadcast

request

indication

indication

(R-U)Reliable broadcast

Failure detector

Channels

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Causal broadcast

- ***Events***
  - Request: <coBroadcast, m>
  - Indication: <coDeliver, src, m>

- ***Property:***
  - ***Causal Order (CO)***

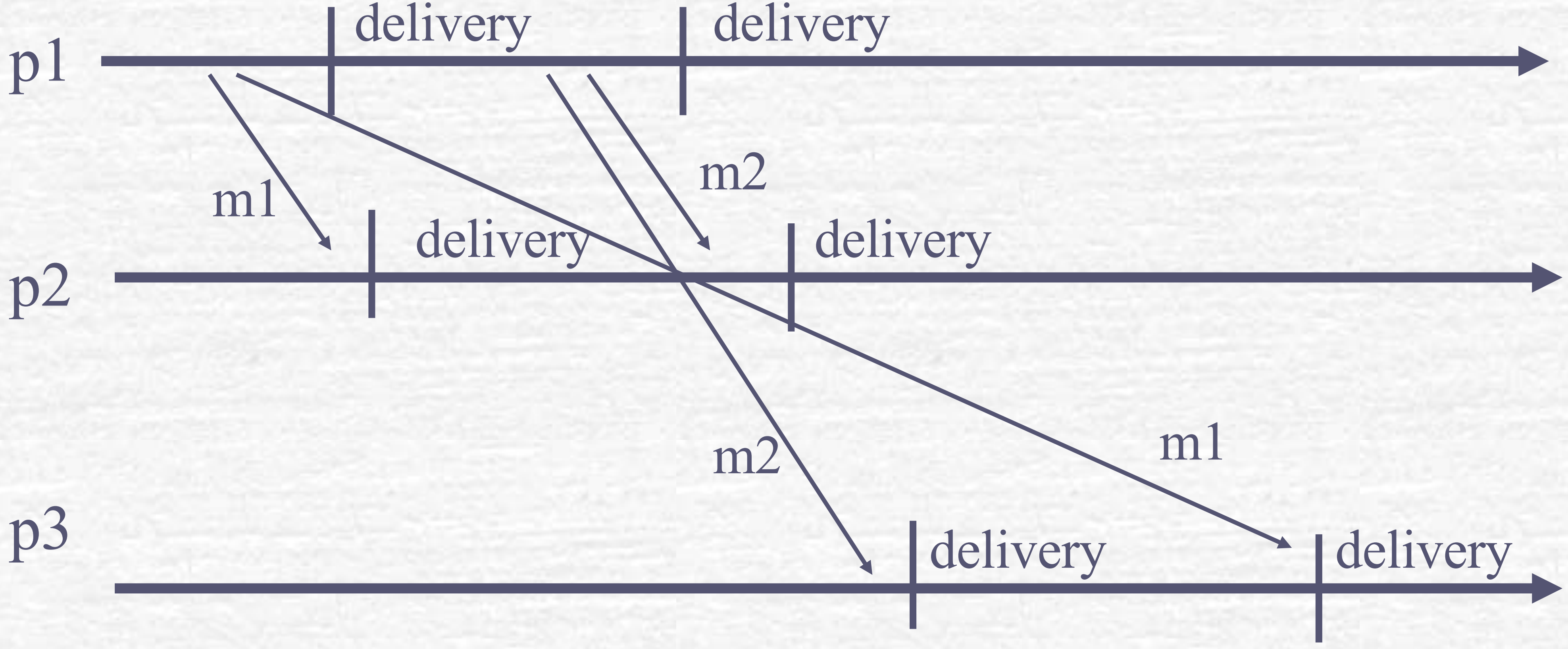
Causality

- ***Let m1 and m2 be any two messages: m1 -> m2 (m1 causally precedes m2) iff***
  - **C1 (FIFO order).** Some process pi broadcasts m1 before broadcasting m2
  - **C2 (Local order).** Some process pi delivers m1 and then broadcasts m2
  - **C3 (Transitivity).** There is a message m3 such that m1 -> m3 and m3 - > m2

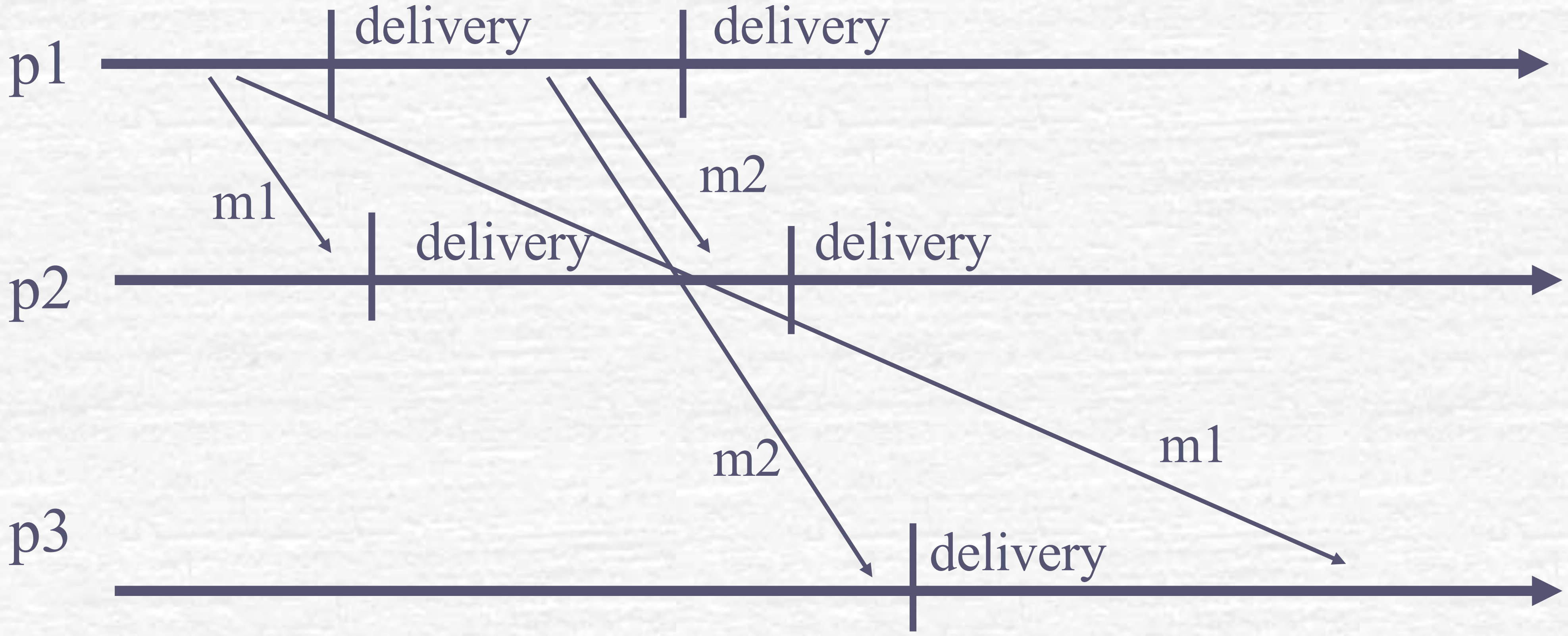
Causal broadcast

- ***Events***
  - Request: <coBroadcast, m>
  - Indication: <coDeliver, src, m>
- ***Property:***
  - ***CO***: If any process pi delivers a message m2, then pi must have delivered every message m1 such that m1 -> m2

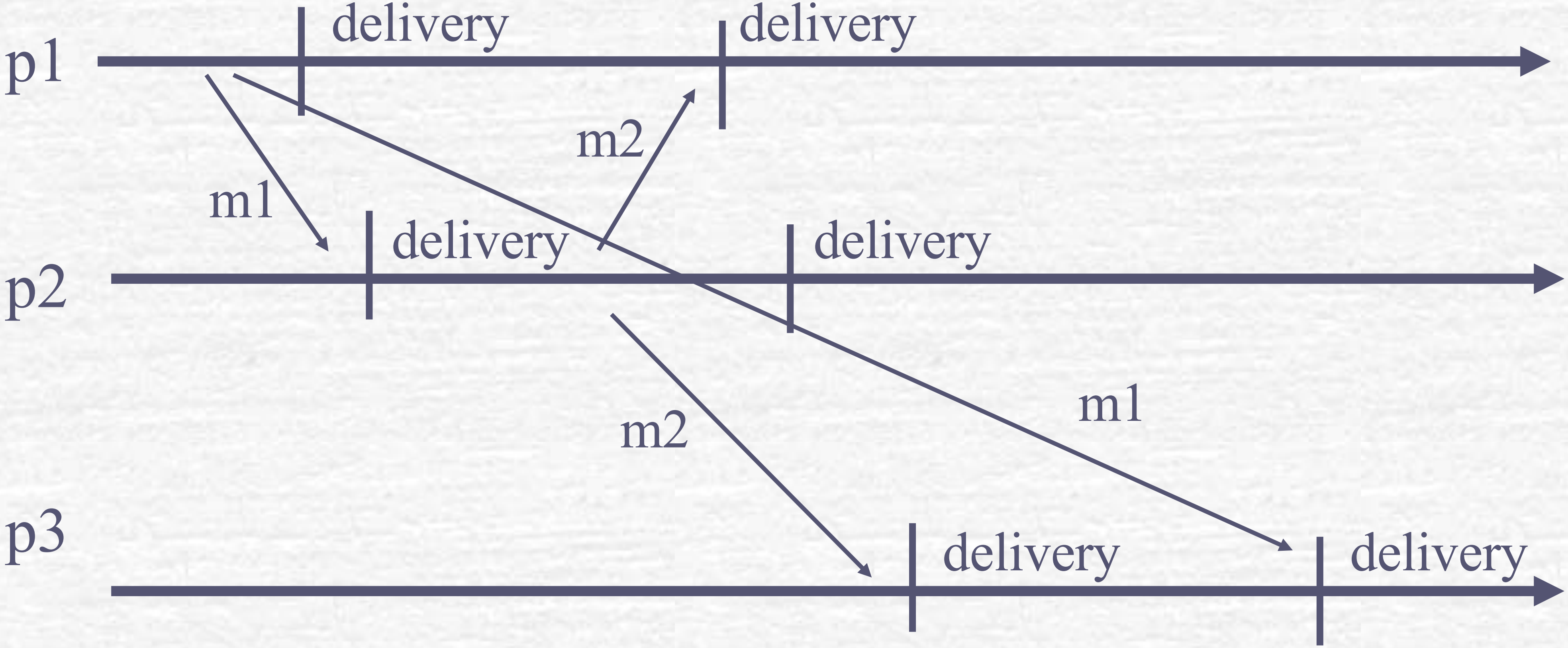
Causality ?


p1
delivery
delivery
m1
m2
p2
delivery
delivery
m2
m1
p3
delivery
delivery

Causality ?


p1
delivery
delivery
m2
m1
delivery
delivery
p2
m2
m1
p3
delivery

Causality ?


p1
delivery
delivery
m2
m1
delivery
delivery
p2
m2
m1
p3
delivery
delivery

Reliable causal broadcast (rcb)

- ***Events***
  - Request: <rcoBroadcast, m>
  - Indication: <rcoDeliver, src, m>
- ***Properties:***
  - ***RB1, RB2, RB3, RB4 +***
  - ***CO***

Uniform causal broadcast (ucb)

- ***Events***
  - Request: <ucoBroadcast, m>
  - Indication: <ucoDeliver, src, m>
- ***Properties:***
  - ***URB1, URB2, URB3, URB4 +***
  - ***CO***

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Algorithms

- We present **reliable causal broadcast** algorithms using **reliable broadcast**

- We obtain **uniform causal broadcast** algorithms by using instead an underlying **uniform reliable broadcast**

Algorithm 1

```
Implements: ReliableCausalOrderBroadcast (rco).
Uses: ReliableBroadcast (rb).
upon event < Init > do
    delivered := past := $\emptyset$;
upon event < rcoBroadcast, m> do
    trigger < rbBroadcast, [Data,past,m]>;
    past := past U {[self,m]};
```

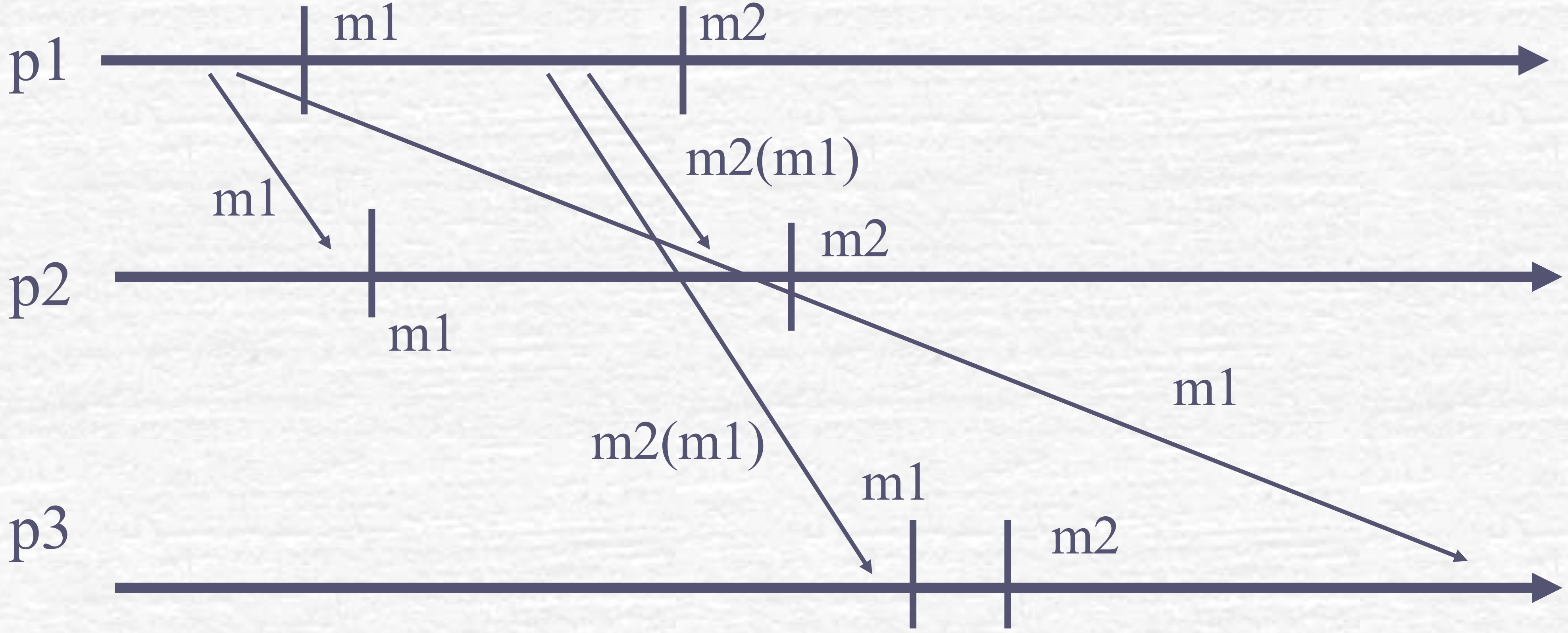
Algorithm 1 (cont’d)

```
upon event <rbDeliver,pi,[Data,past$_m$,m]> do
    if m $\notin$ delivered then
        (*) forall [sn, n] in past$_m$ do
            if n $\notin$ delivered then
                trigger < rcoDeliver,sn,n>;
                delivered := delivered U {n};
                past := past U {[sn, n]};
```

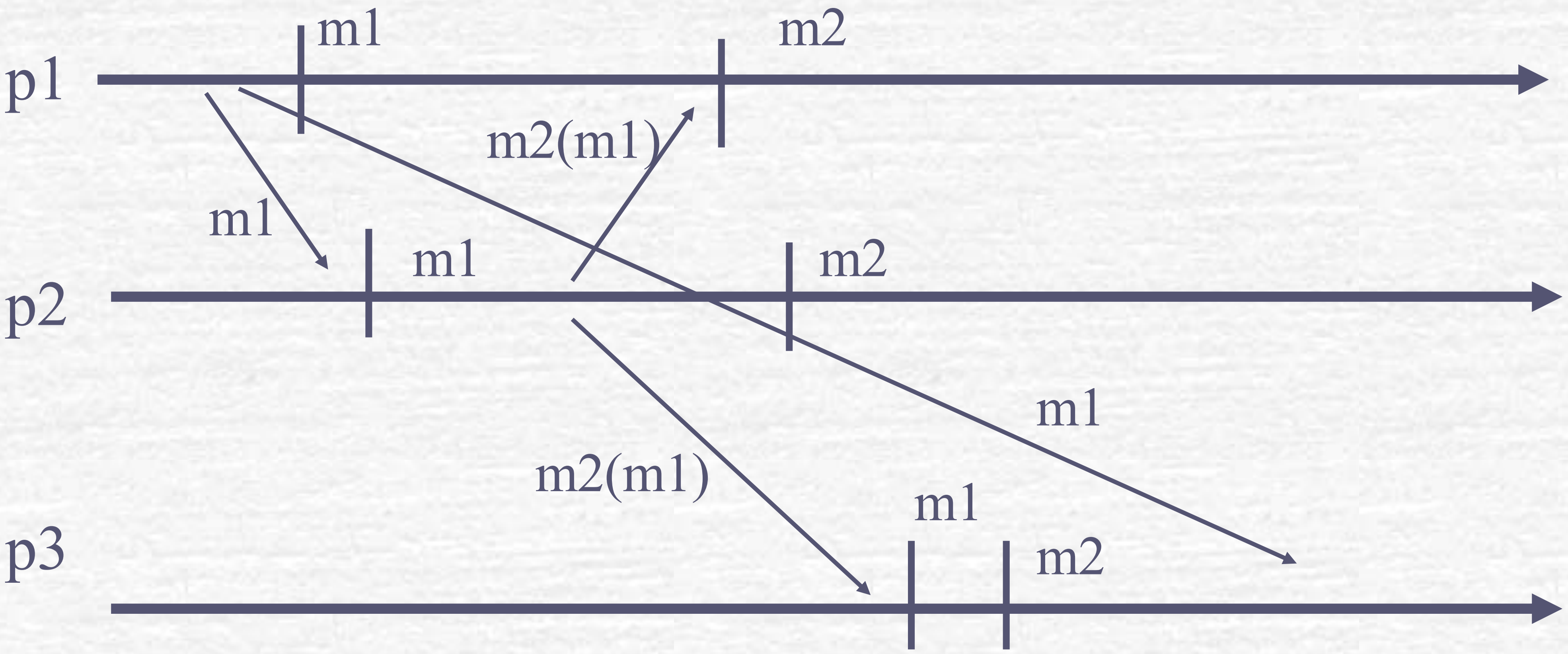
Algorithm 1 (cont’d)

- **(*)**
  - **…**
  - **…**
  - **…**
- **trigger** <rcoDeliver,pi,m>;
- delivered := delivered U {m};
- past := past U {[pi,m]};

Algorithm 1



Algorithm 1



Uniformity

- Algorithm 1 ensures causal reliable broadcast

- If we replace reliable broadcast with uniform reliable broadcast, Algorithm 1 would ensure uniform causal broadcast

Algorithm 1’ (gc)

- **Implements:** GarbageCollection (+ Algo 1).
- **Uses:**
  - ReliableBroadcast (rb).
  - PerfectFailureDetector(P).
- **upon event** < Init > **do**
  - delivered := past := ∅;
  - correct := S;
  - ack_m := ∅ (for all m);

Algorithm 1’ (gc – cont’d)

```
upon event < crash, pi > do
    correct := correct \ {pi}

upon for some $m \in$ delivered: self $\notin ack_m$ do
    $ack_m := ack_m \cup \{self\}$;
    trigger < rbBroadcast, [ACK,m]>;
```

Algorithm 1’ (gc – cont’d)

```
upon event <rbDeliver,pi,[ACK,m]> do
    $ack_m$ := $ack_m$ U {pi};
    if forall pj $\in$ correct: pj $\in$ $ack_m$ do
        past := past \ {[sm, m]};
```

Algorithm 2

- **Implements:** ReliableCausalOrderBroadcast (rco).
- **Uses:** ReliableBroadcast (rb).

- **upon event** < Init > **do**
  - **for all** pi ∈ S: VC[pi] := 0;
  - pending := ∅

Algorithm 2 (cont'd)

```
upon event < rcoBroadcast, m> do
    trigger < rcoDeliver, self, m>;
    trigger < rbBroadcast, [Data,VC,m]>;
    VC[self] := VC[self] + 1;
```

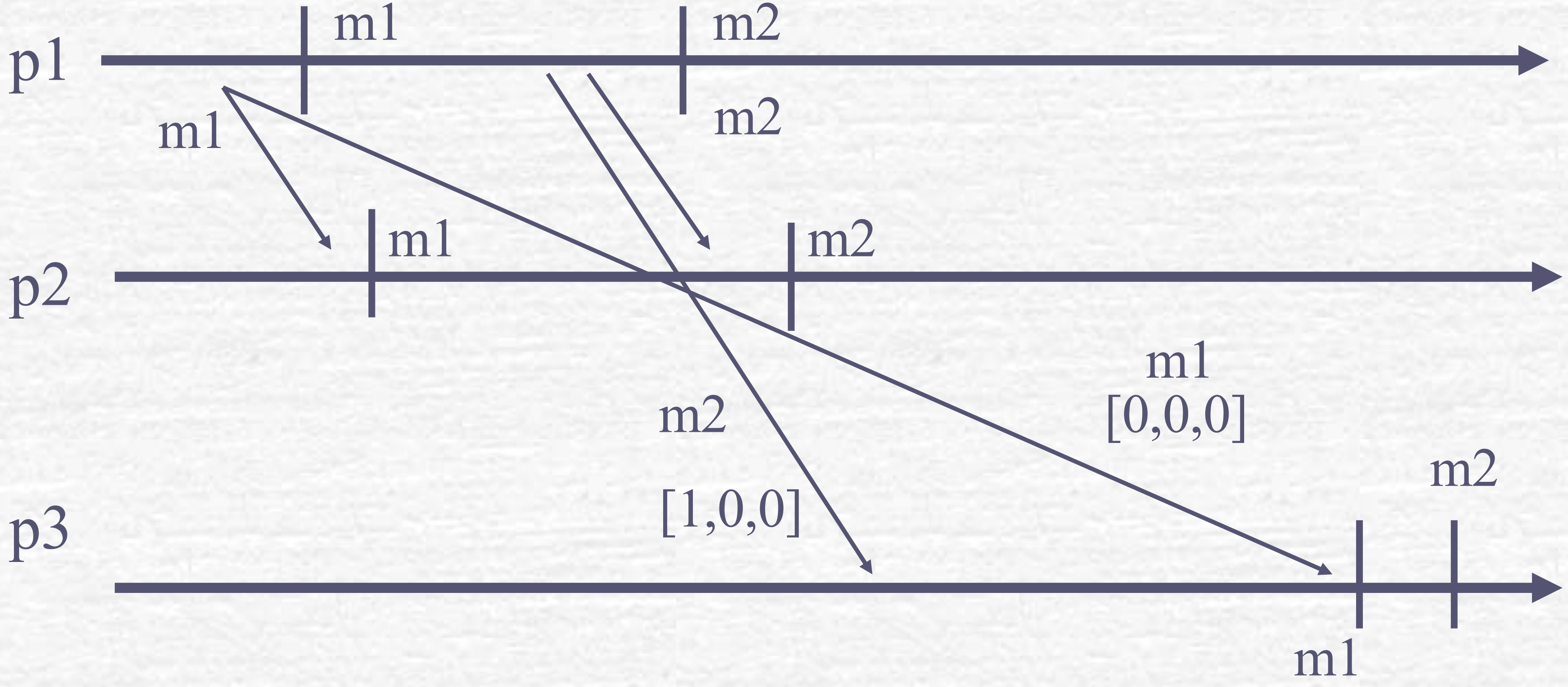
Algorithm 2 (cont’d)

```
upon event <rbDeliver, pj, [Data,VCm,m]> do
    if $pj \neq self$ then
        pending := $pending \cup (pj, [Data,VCm,m])$;
        deliver-pending.
```

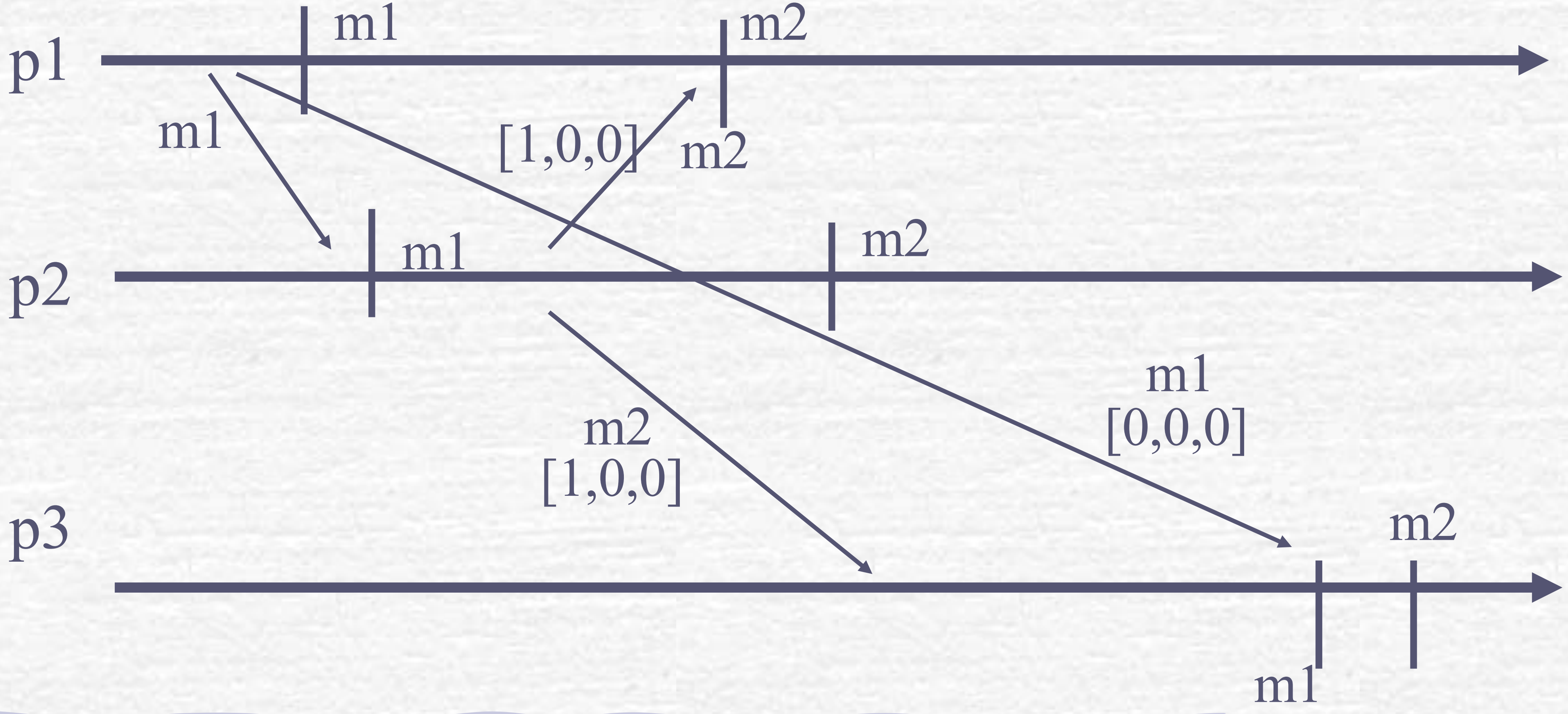
Algorithm 2 (cont’d)

```
procedure deliver-pending is
  While (s, [Data,VCm,m]) ∈ pending s.t.
    for all pk: (VC[pk] ≥ VCm[pk]) do
      pending := pending – (s, [Data,VCm,m]);
      trigger < rcoDeliver, self, m>;
      VC[s] := VC[s] + 1.
```

Algorithm 2



Algorithm 2


m1
m2
p1
m1
[1,0,0]
m2
m1
m2
p2
m1
[0,0,0]
m2
[1,0,0]
p3
m2
m1