

Distributed systems

Reliable Broadcast

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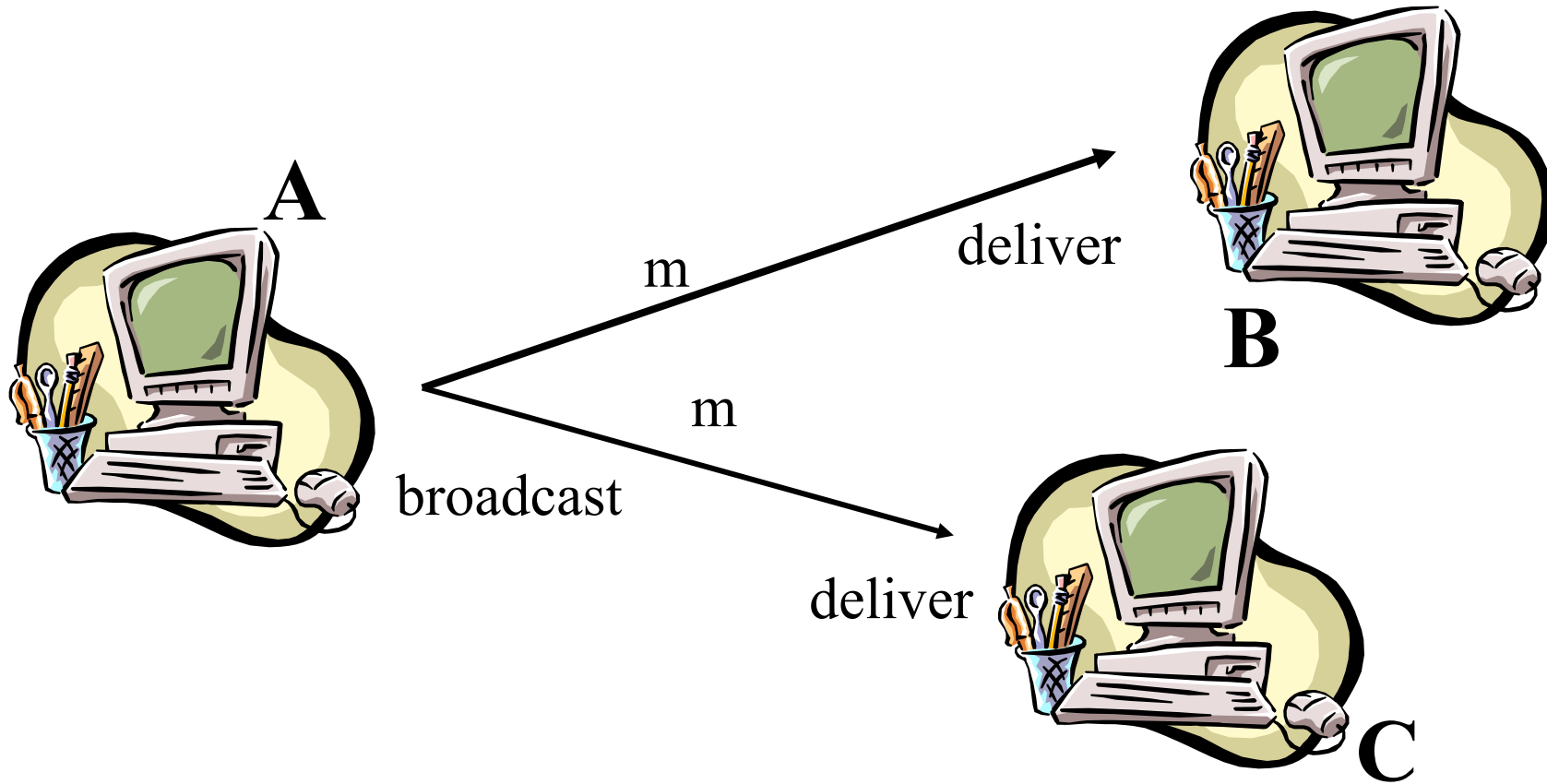


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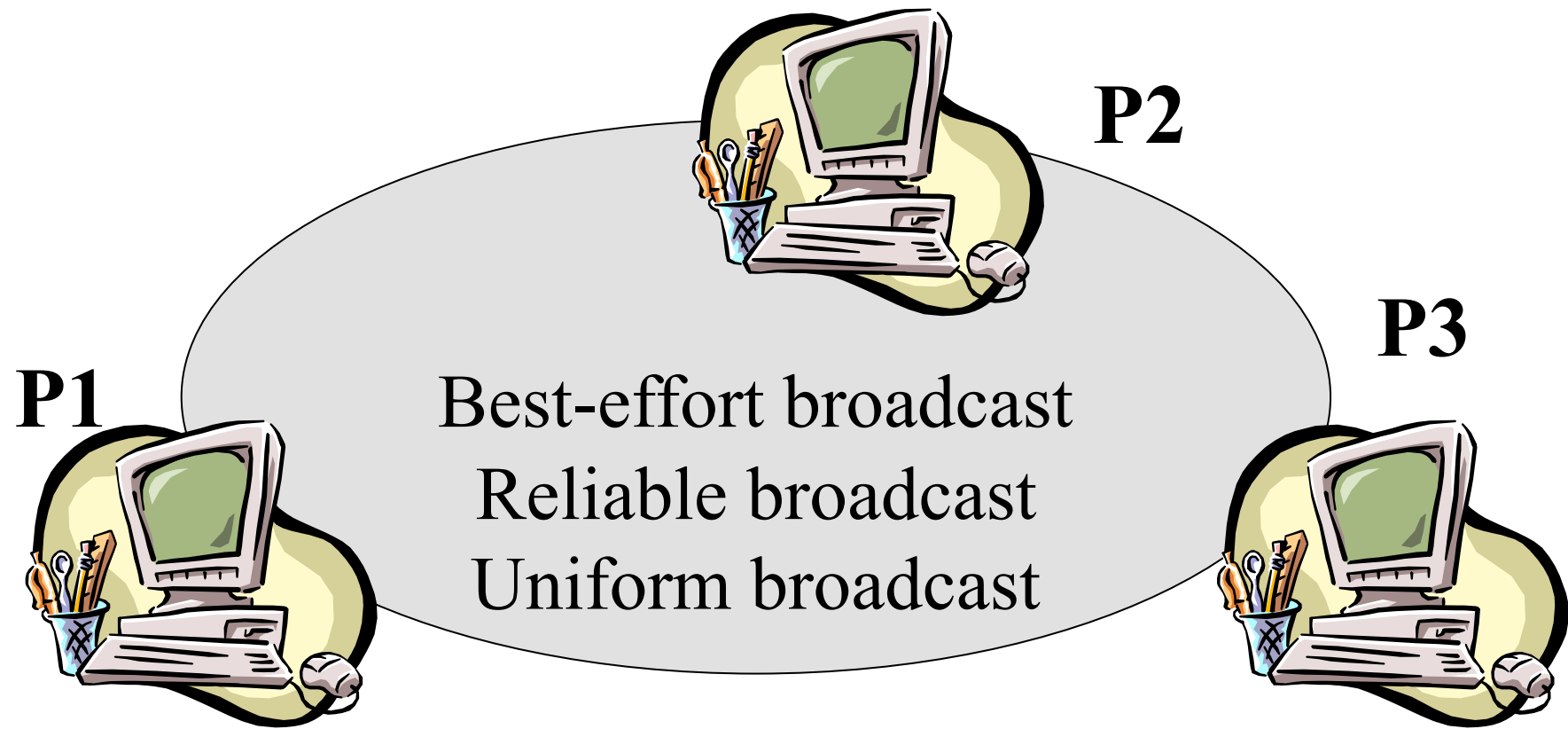
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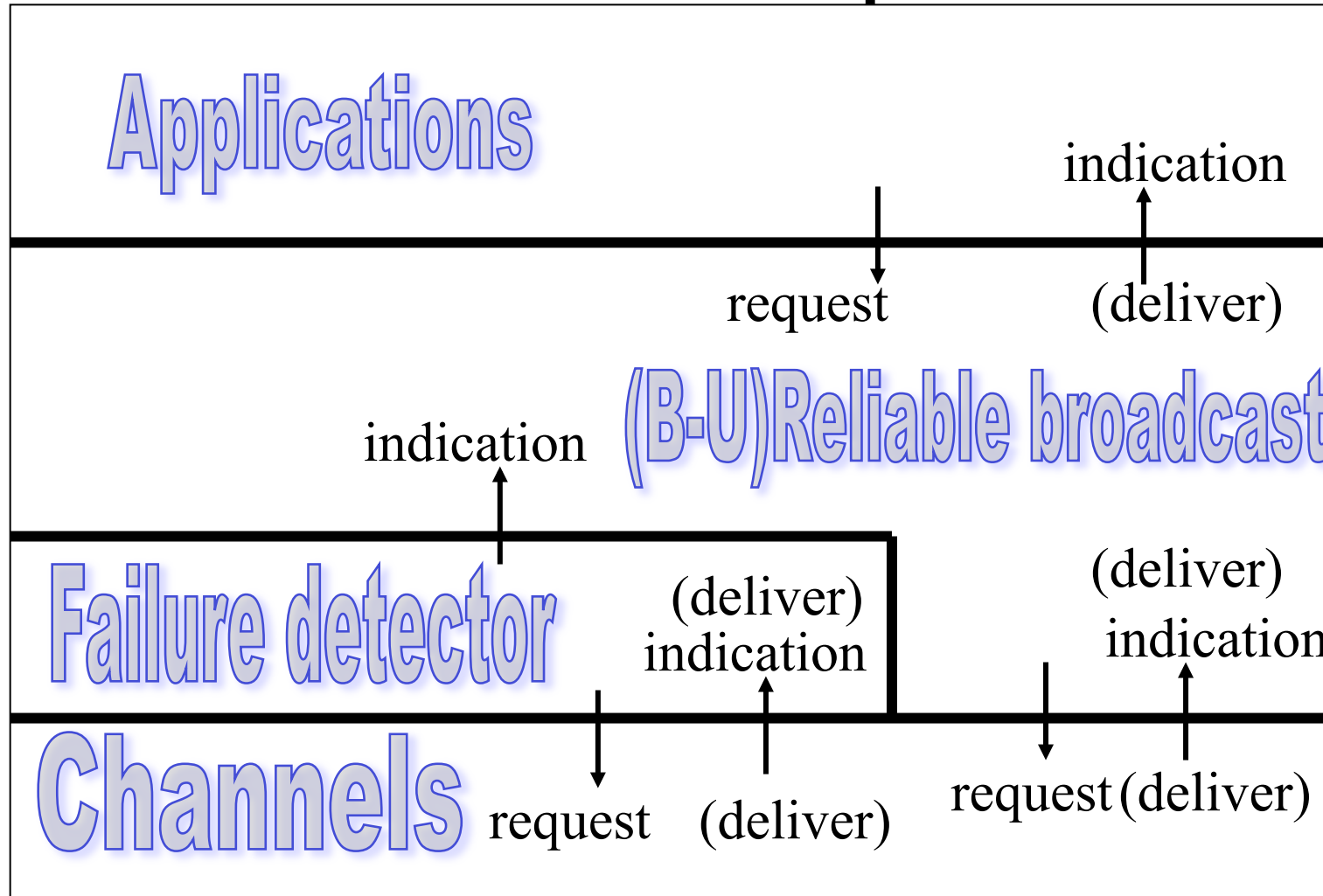
Broadcast



Broadcast abstractions



Modules of a process



Intuition

- Broadcast is useful for instance in applications where some processes subscribe to events published by other processes (e.g., stocks)
- The subscribers might require some **reliability** *guarantees* from the broadcast service (we say sometimes *quality of service* – *QoS*) that the underlying network does not provide

Overview

- ☛ We shall consider three forms of reliability for a broadcast primitive
- ☛ **(1) *Best-effort broadcast***
- ☛ **(2) *(Regular) reliable broadcast***
- ☛ **(3) *Uniform (reliable) broadcast***
- ☛ We shall give first ***specifications*** and then *algorithms*

Best-effort broadcast (beb)

• *Events*

• Request: <bebBroadcast, m>

• Indication: <bebDeliver, src, m>

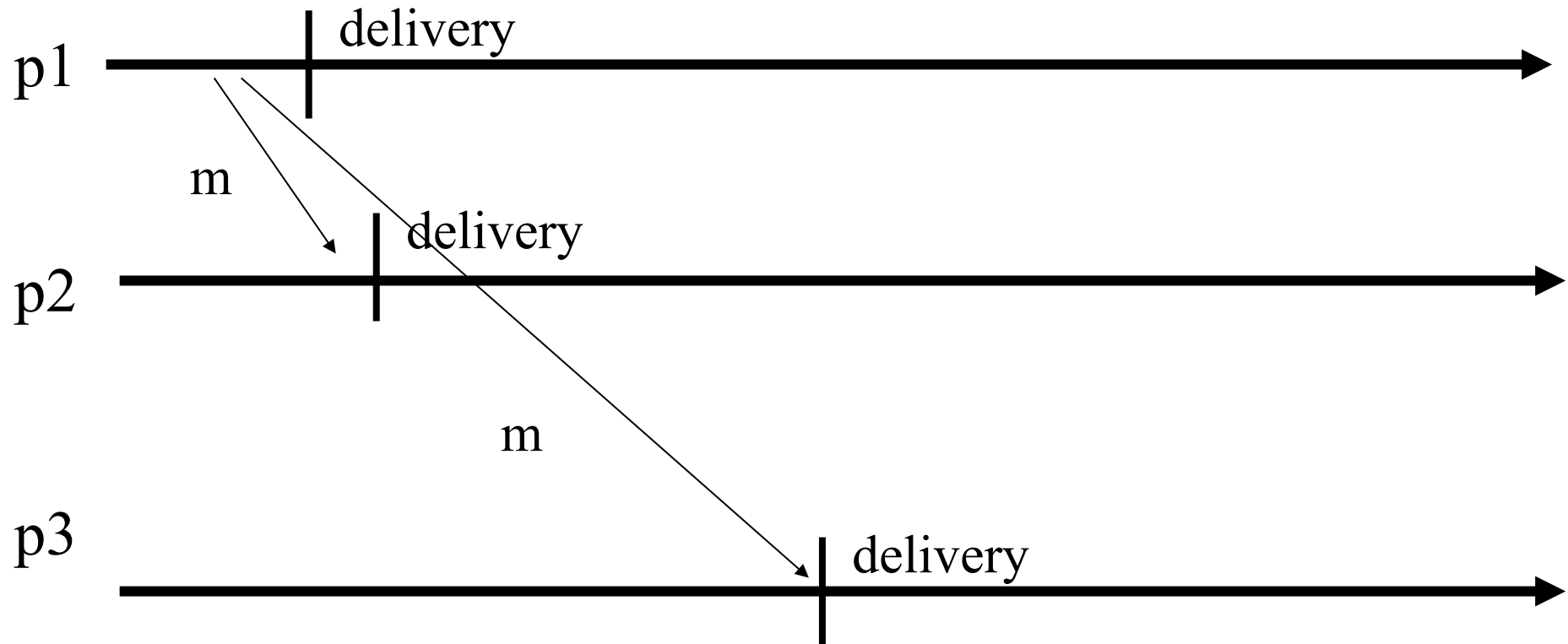
• *Properties: BEB1, BEB2, BEB3*

Best-effort broadcast (beb)

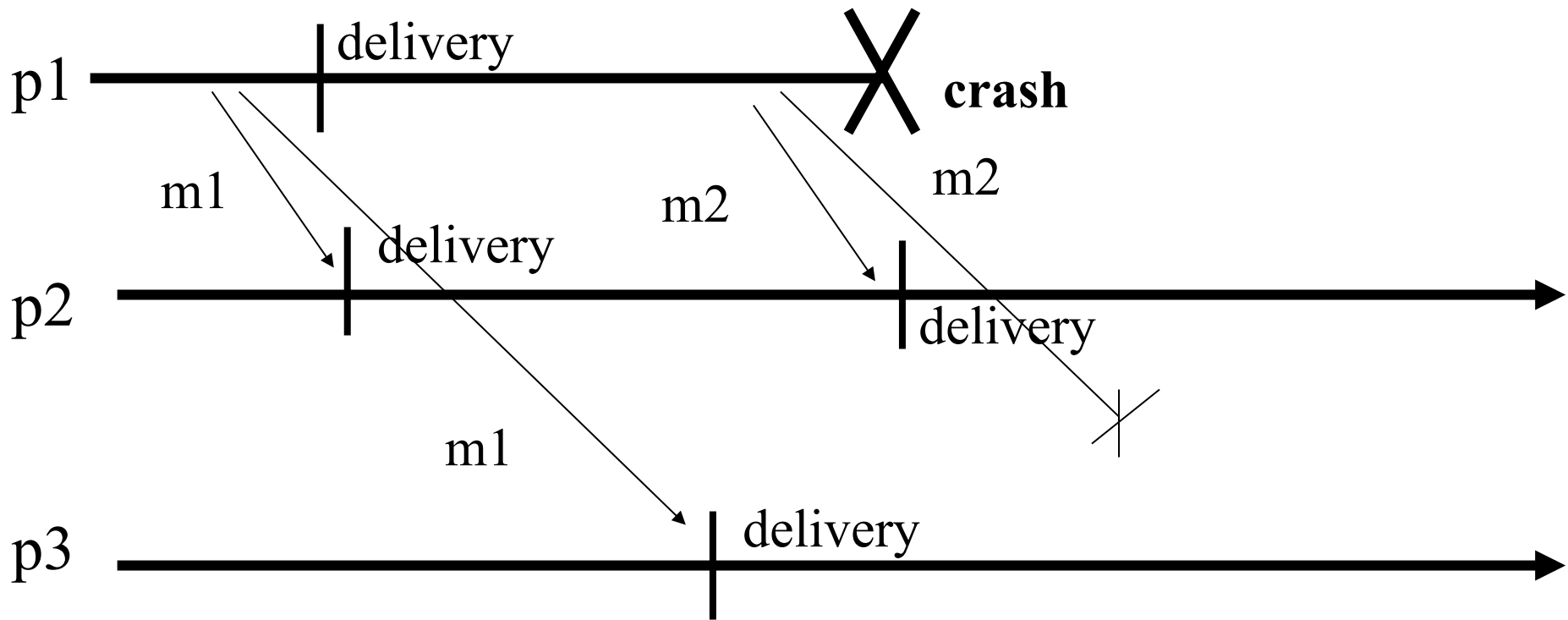
☛ *Properties*

- ☛ ***BEB1. Validity:*** If p_i and p_j are correct, then every message broadcast by p_i is eventually delivered by p_j
- ☛ ***BEB2. No duplication:*** No message is delivered more than once
- ☛ ***BEB3. No creation:*** No message is delivered unless it was broadcast

Best-effort broadcast



Best-effort broadcast



Reliable broadcast (rb)

• ***Events***

- Request: $\langle \text{rbBroadcast}, m \rangle$
- Indication: $\langle \text{rbDeliver}, \text{src}, m \rangle$

- ***Properties: RB1, RB2, RB3, RB4***

Reliable broadcast (rb)

☛ *Properties*

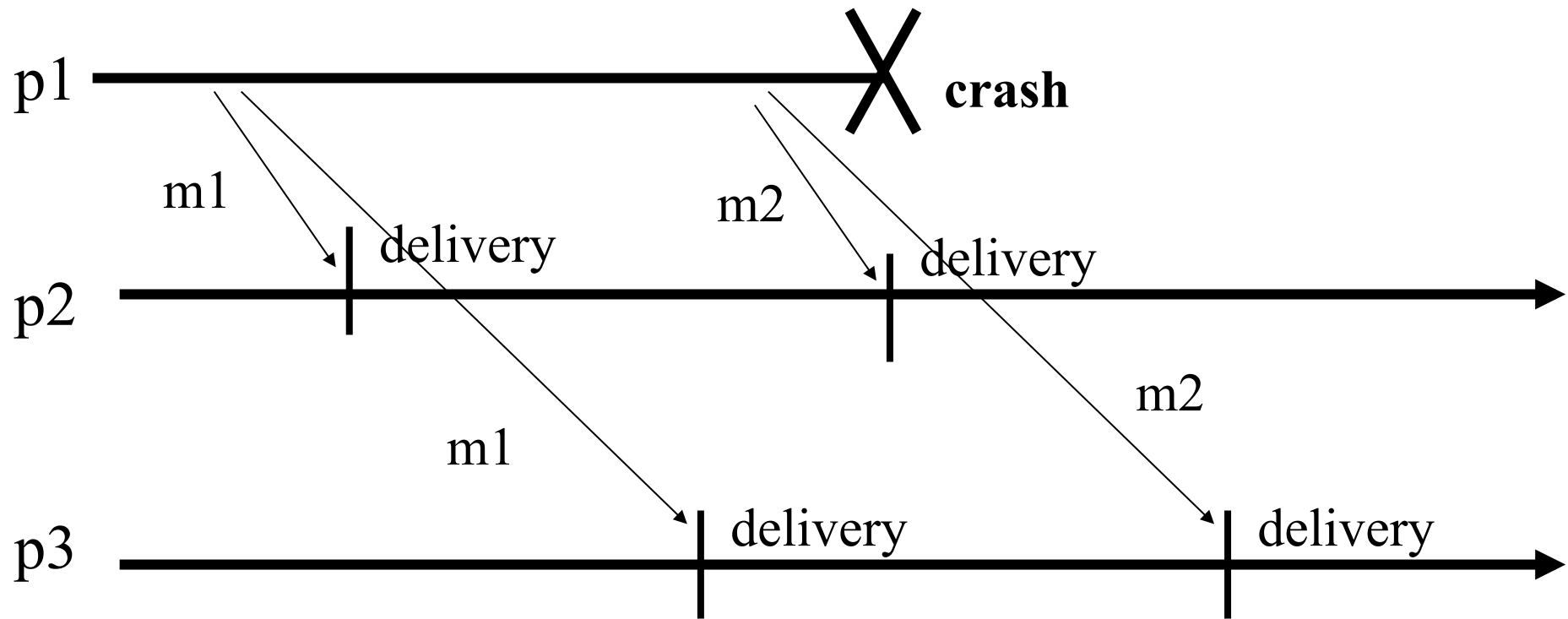
☛ ***RB1 = BEB1.***

☛ ***RB2 = BEB2.***

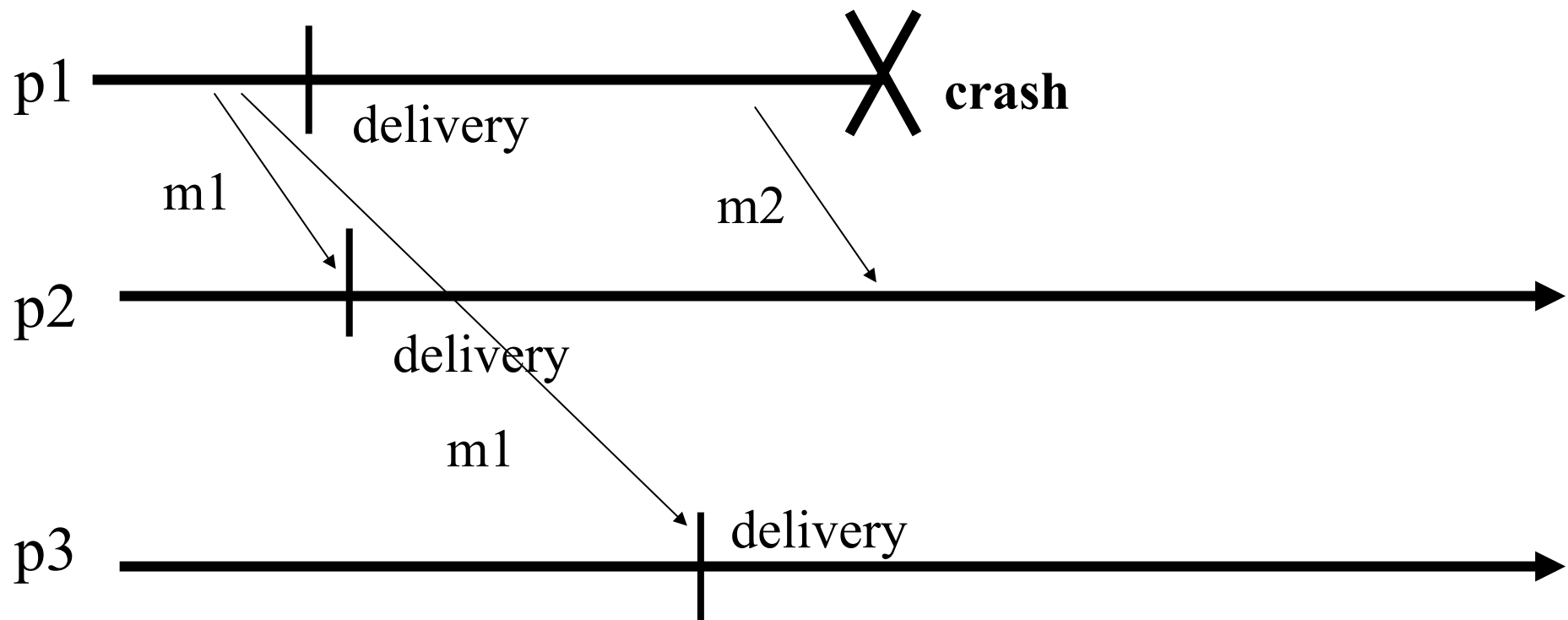
☛ ***RB3 = BEB3.***

☛ ***RB4. Agreement:*** For any message m , if a correct process delivers m , then every correct process delivers m

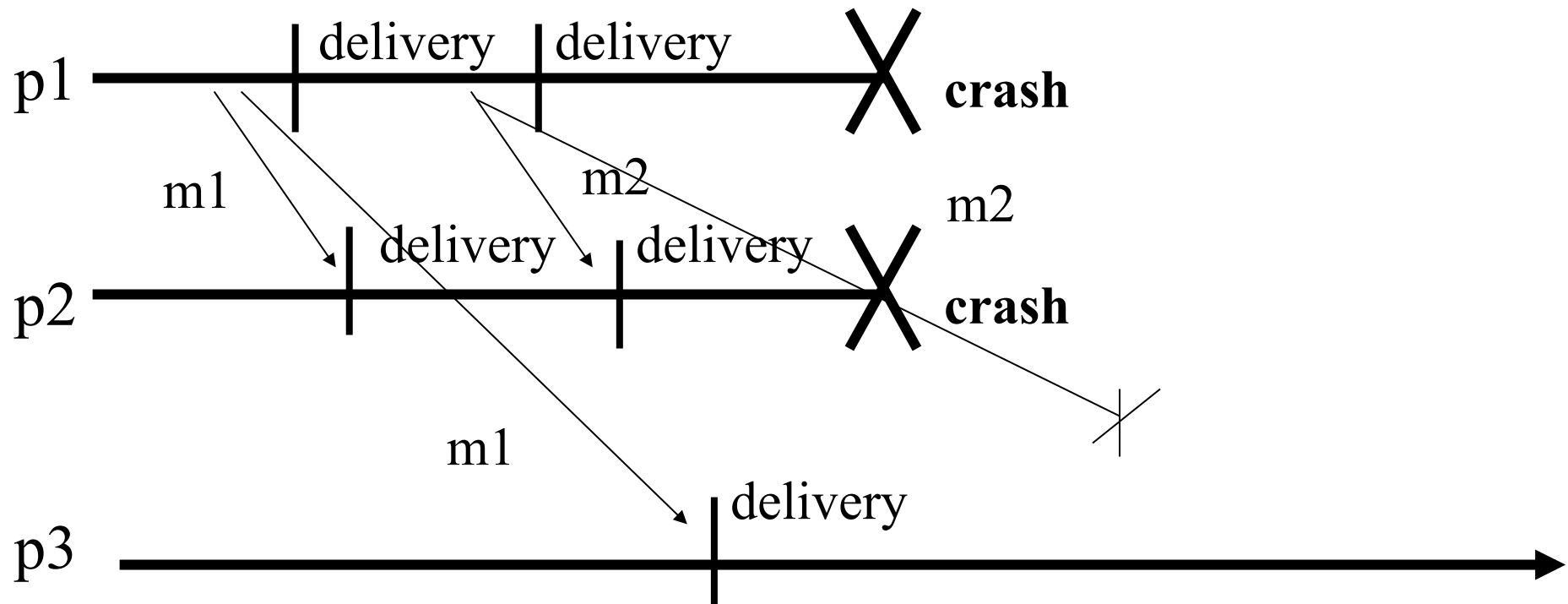
Reliable broadcast



Reliable broadcast



Reliable broadcast



Uniform broadcast (urb)

☛ **Events**

☛ Request: <urbBroadcast, m>

☛ Indication: <urbDeliver, src, m>

- ***Properties: URB1, URB2, URB3, URB4***

Uniform broadcast (urb)

☛ *Properties*

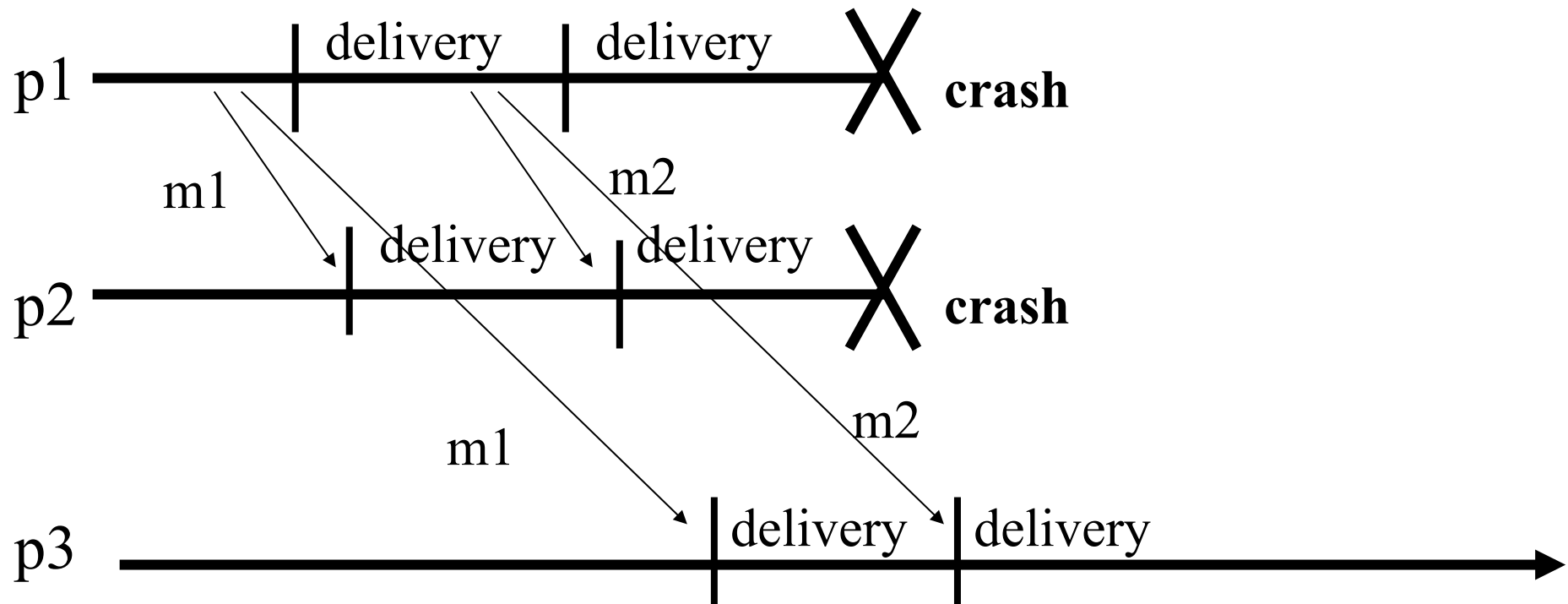
☛ ***URB1 = BEB1.***

☛ ***URB2 = BEB2.***

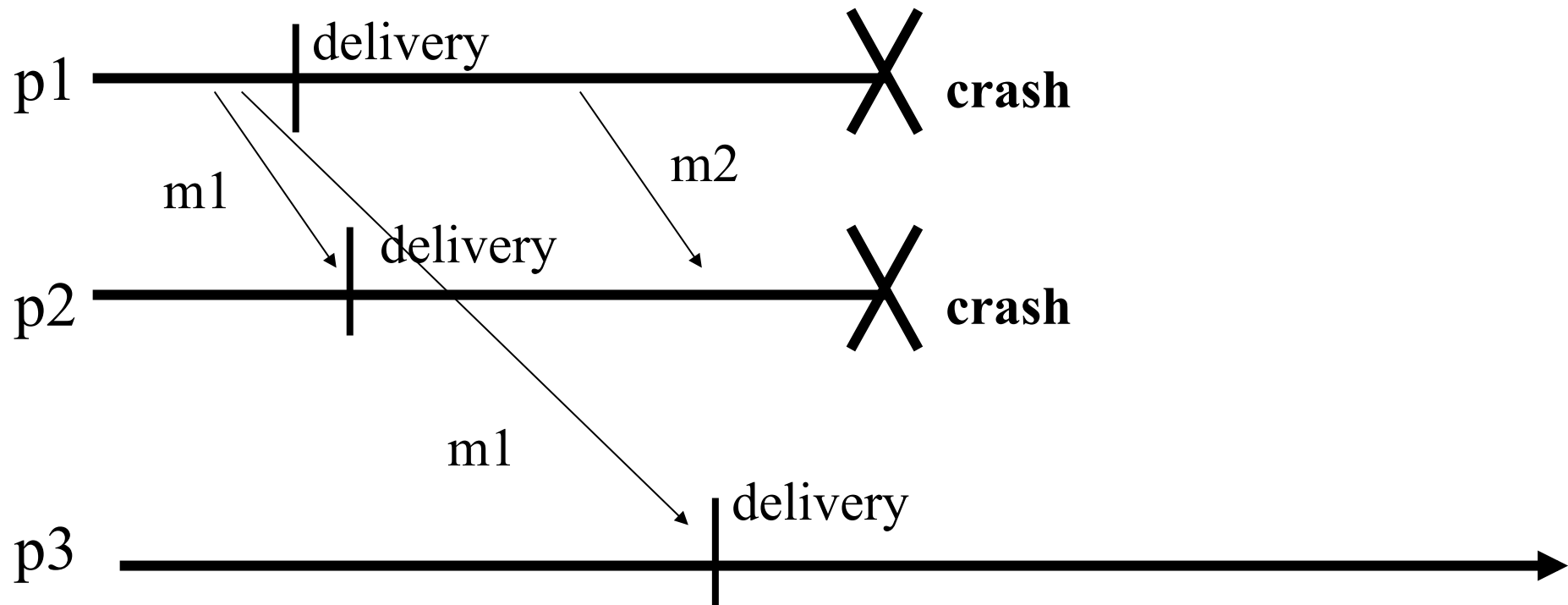
☛ ***URB3 = BEB3.***

☛ ***URB4. Uniform Agreement:*** For any message m , if a process delivers m , then every correct process delivers m

Uniform reliable broadcast



Uniform reliable broadcast



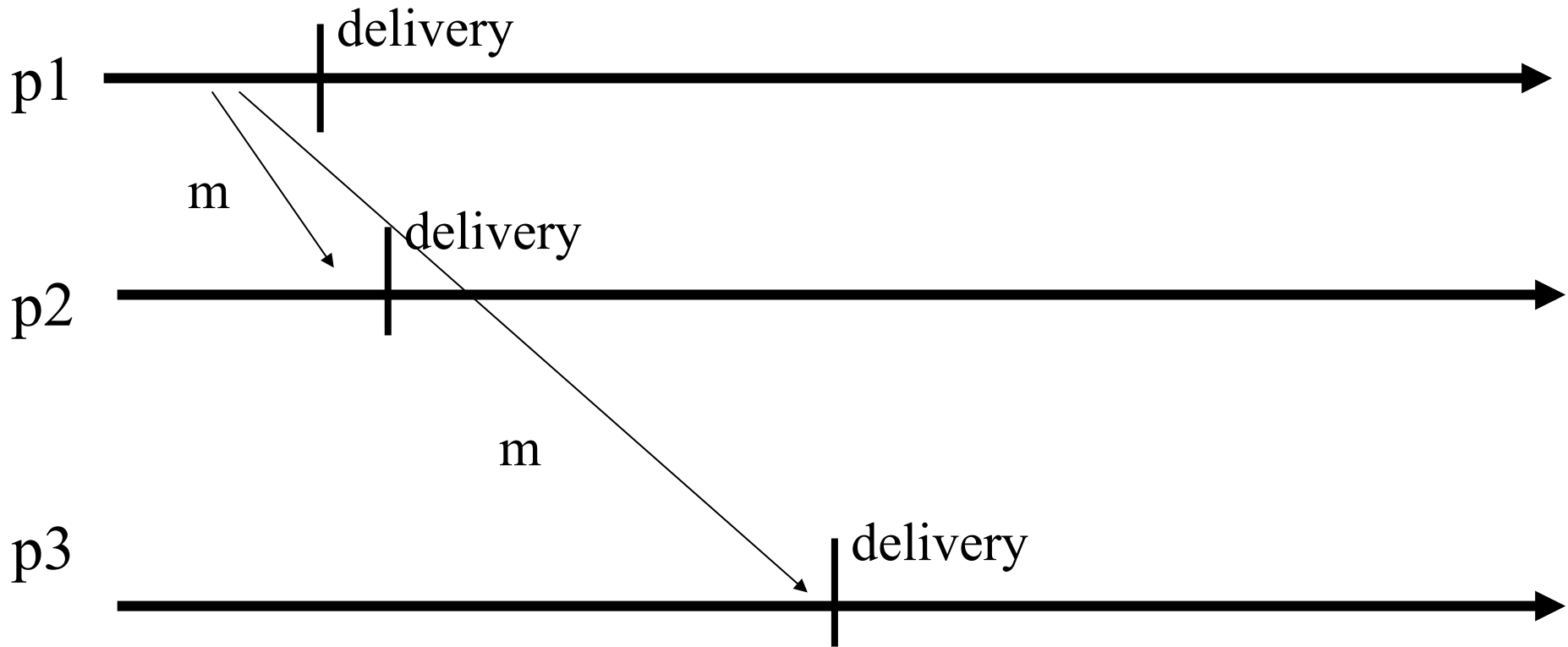
Overview

- ☛ We consider three forms of reliability for a broadcast primitive
- ☛ **(1) *Best-effort broadcast***
- ☛ **(2) *(Regular) reliable broadcast***
- ☛ **(3) *Uniform (reliable) broadcast***
- ☛ We give first *specifications* and then ***algorithms***

Algorithm (beb)

- ☛ **Implements:** BestEffortBroadcast (beb).
- ☛ **Uses:** PerfectLinks (pp2p).
- ☛ **upon event** $\langle \text{bebBroadcast}, m \rangle$ **do**
 - ☛ **forall** $p_i \in S$ **do**
 - ☛ **trigger** $\langle \text{pp2pSend}, p_i, m \rangle$;
- ☛ **upon event** $\langle \text{pp2pDeliver}, p_i, m \rangle$ **do**
 - ☛ **trigger** $\langle \text{bebDeliver}, p_i, m \rangle$;

Algorithm (beb)

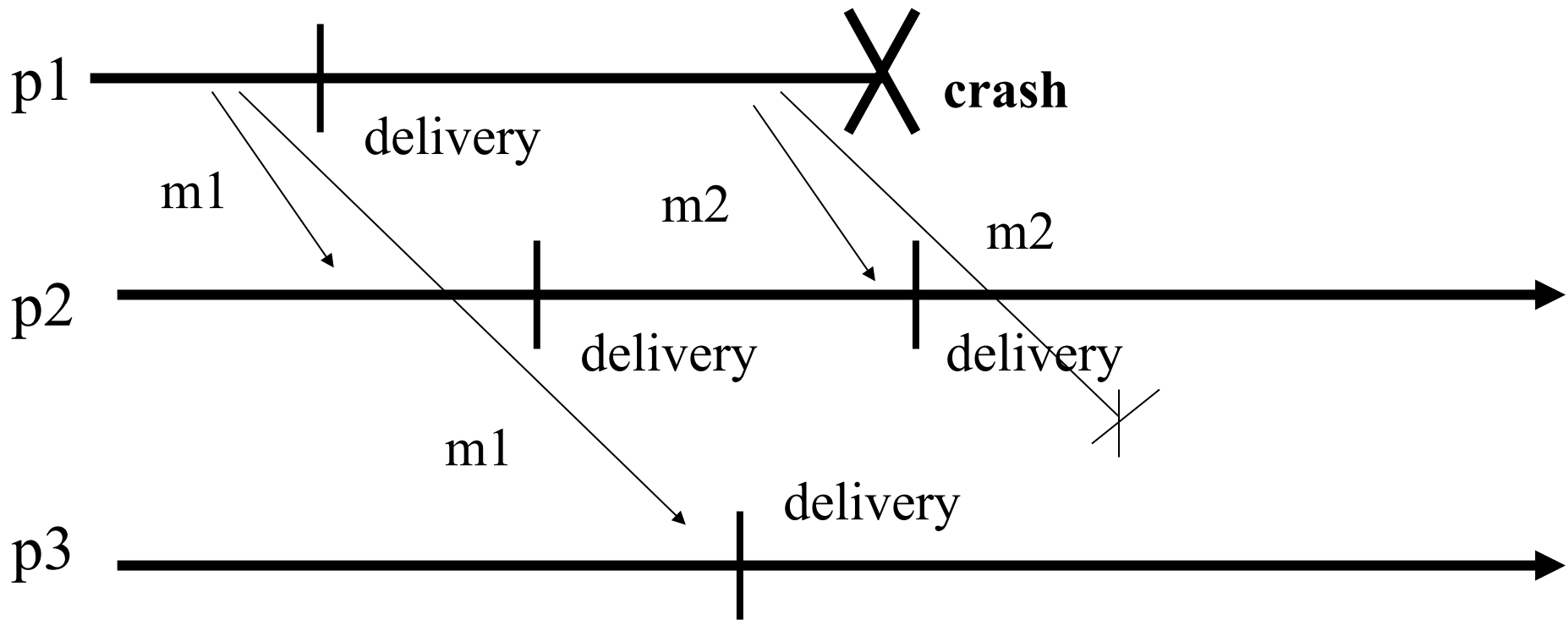


Algorithm (beb)

☛ *Proof (sketch)*

- ☛ ***BEB1. Validity:*** By the validity property of perfect links and the very facts that (1) the sender sends the message to all and (2) every correct process that pp2pDelivers a message bebDelivers it
- ☛ ***BEB2. No duplication:*** By the no duplication property of perfect links
- ☛ ***BEB3. No creation:*** By the no creation property of perfect links

Algorithm (beb)



Algorithm (rb)

- ☛ **Implements:** ReliableBroadcast (rb).
- ☛ **Uses:**
 - ☛ BestEffortBroadcast (beb).
 - ☛ PerfectFailureDetector (P).
- ☛ **upon event** < Init > **do**
 - ☛ delivered := \emptyset ;
 - ☛ correct := S;
 - ☛ **forall** $p_i \in S$ **do** from[p_i] := \emptyset ;

Algorithm (rb – cont'd)

- **upon event** < rbBroadcast, m > **do**
 - delivered := delivered U {m};
 - **trigger** < rbDeliver, self, m >;
 - **trigger** < bebBroadcast, [Data,self,m] >;

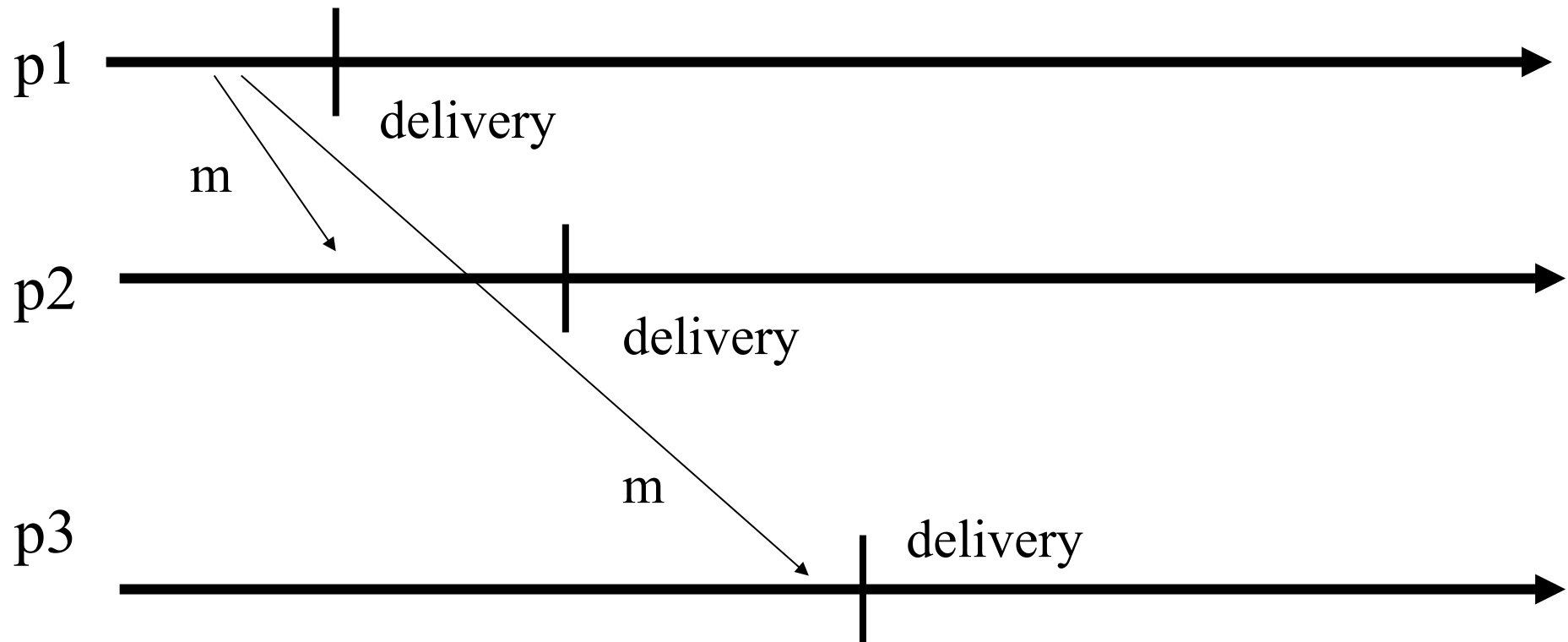
Algorithm (rb – cont'd)

- ☛ **upon event** $\langle \text{crash}, p_i \rangle$ **do**
 - ☛ $\text{correct} := \text{correct} \setminus \{p_i\};$
 - ☛ **forall** $[p_j, m] \in \text{from}[p_i]$ **do**
 - ☛ **trigger** $\langle \text{bebBroadcast}, [\text{Data}, p_j, m] \rangle;$

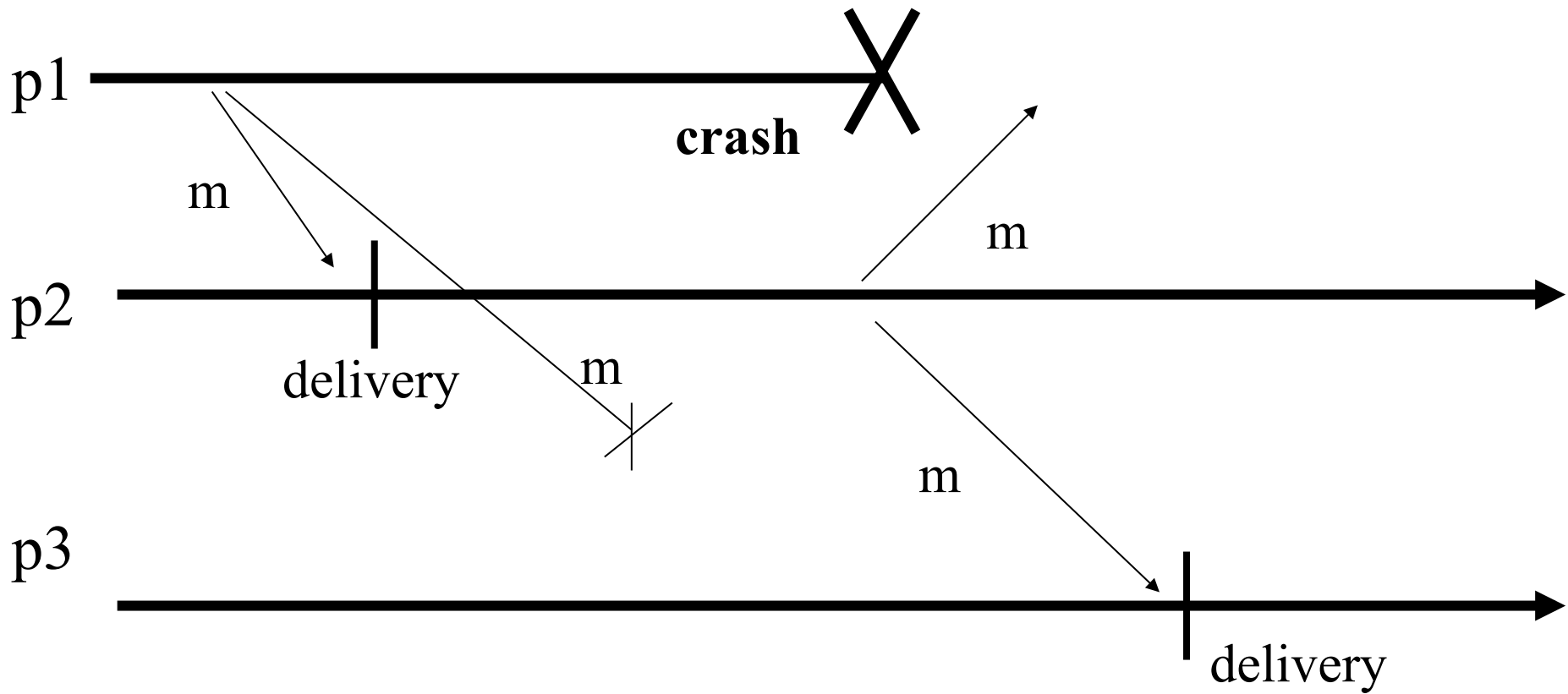
Algorithm (rb – cont'd)

- ☛ **upon event** $\langle \text{bebDeliver}, p_i, [\text{Data}, p_j, m] \rangle$ **do**
 - ☛ **if** $m \notin \text{delivered}$ **then**
 - ☛ $\text{delivered} := \text{delivered} \cup \{m\};$
 - ☛ **trigger** $\langle \text{rbDeliver}, p_j, m \rangle;$
 - ☛ **if** $p_i \notin \text{correct}$ **then**
 - ☛ **trigger** $\langle \text{bebBroadcast}, [\text{Data}, p_j, m] \rangle;$
 - ☛ **else**
 - ☛ $\text{from}[p_i] := \text{from}[p_i] \cup \{[p_j, m]\};$

Algorithm (rb)



Algorithm (rb)



Algorithm (rb)

☛ *Proof (sketch)*

- ☛ **RB1. RB2. RB3:** as for the 1st algorithm
- ☛ **RB4. Agreement:** Assume some correct process p_i `rbDelivers` a message m `rbBroadcast` by some process p_k . If p_k is correct, then by property BEB1, all correct processes `bebDeliver` and then `rebDeliver` m . If p_k crashes, then by the completeness property of P , p_i detects the crash and `bebBroadcasts` m to all. Since p_i is correct, then by property BEB1, all correct processes `bebDeliver` and then `rebDeliver` m .

Algorithm (urb)

- ☛ **Implements:** uniformBroadcast (urb).
- ☛ **Uses:**
 - ☛ BestEffortBroadcast (beb).
 - ☛ PerfectFailureDetector (P).
- ☛ **upon event** < Init > **do**
 - ☛ correct := S;
 - ☛ delivered := forward := \emptyset ;
 - ☛ ack[Message] := \emptyset ;

Algorithm (urb – cont'd)

- **upon event** $\langle \text{crash}, \text{pi} \rangle$ **do**
 - $\text{correct} := \text{correct} \setminus \{\text{pi}\};$
- **upon event** $\langle \text{urbBroadcast}, \text{m} \rangle$ **do**
 - $\text{forward} := \text{forward} \cup \{[\text{self}, \text{m}]\};$
 - **trigger** $\langle \text{bebBroadcast}, [\text{Data}, \text{self}, \text{m}] \rangle;$

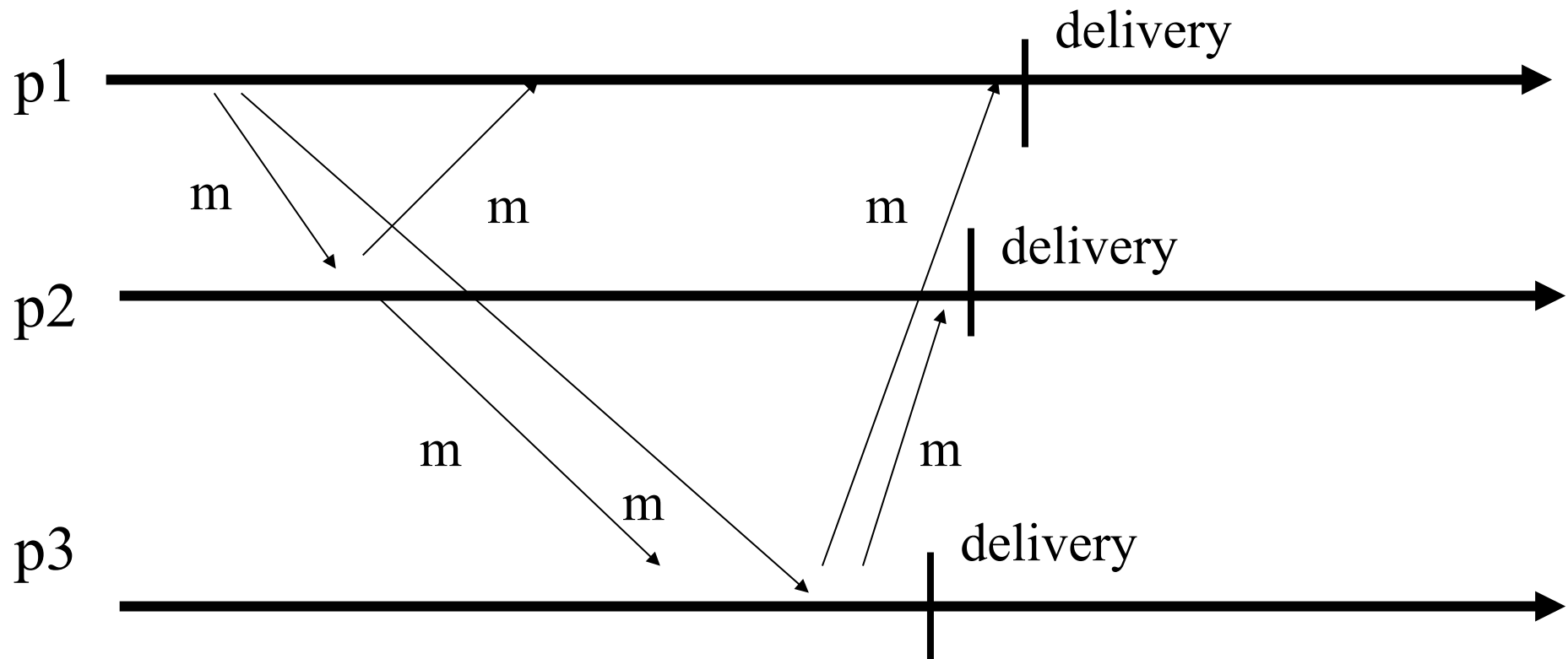
Algorithm (urb – cont'd)

- **upon event** $\langle \text{bebDeliver}, p_i, [\text{Data}, p_j, m] \rangle$ **do**
 - $\text{ack}[m] := \text{ack}[m] \cup \{p_i\};$
 - **if** $[p_j, m] \notin \text{forward}$ **then**
 - $\text{forward} := \text{forward} \cup \{[p_j, m]\};$
 - **trigger** $\langle \text{bebBroadcast}, [\text{Data}, p_j, m] \rangle;$

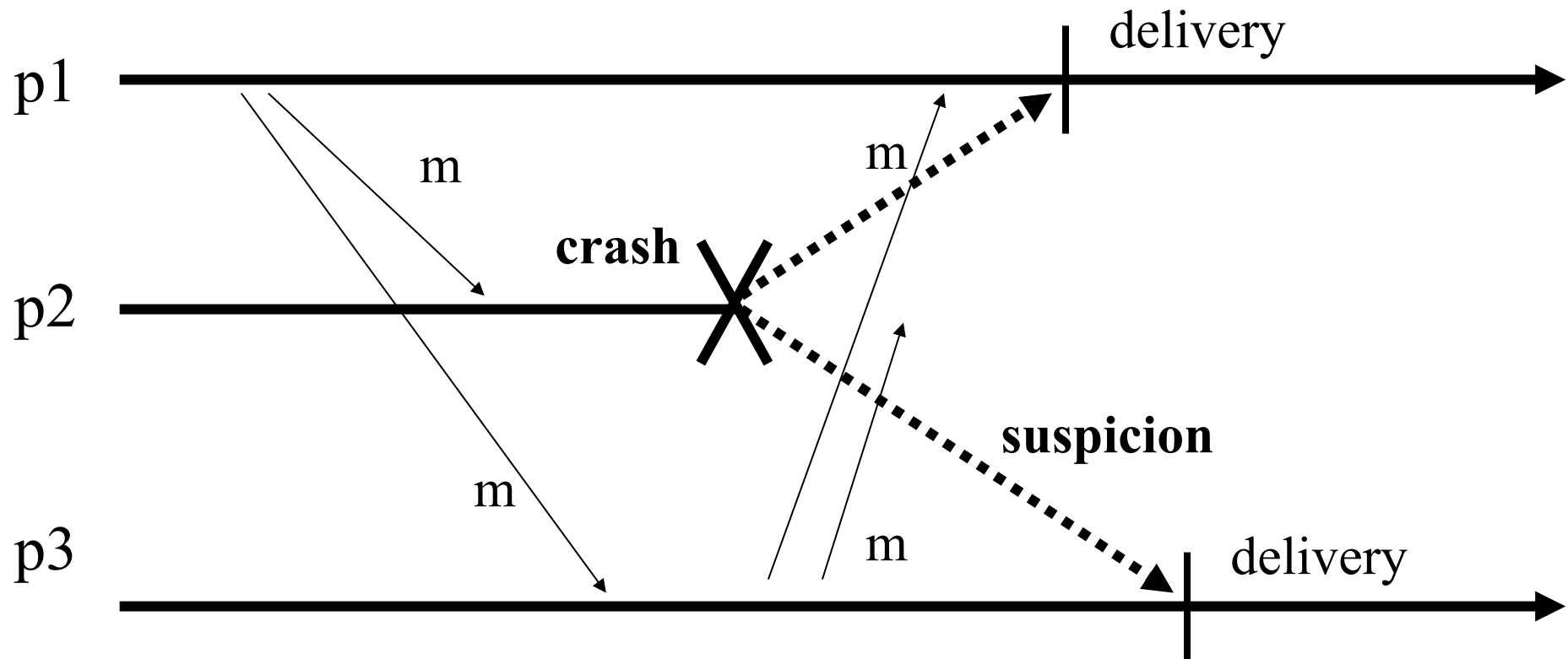
Algorithm (urb – cont'd)

- **upon event** (for any $[pj, m] \in \text{forward}$)
 $\langle \text{correct} \subseteq \text{ack}[m] \rangle$ **and** $\langle m \notin \text{delivered} \rangle$ **do**
 - $\text{delivered} := \text{delivered} \cup \{m\};$
 - **trigger** $\langle \text{urbDeliver}, pj, m \rangle;$

Algorithm (urb)



Algorithm (urb)



Algorithm (urb)

• ***Proof (sketch)***

- ***URB2. URB3:*** follow from BEB2 and BEB3
- ***A simple lemma:*** *If a correct process p_i bebDelivers a message m , then p_i eventually urbDelivers m .*
- Any process that bebDelivers m bebBroadcasts m . By the completeness property of the failure detector and property BEB1, there is a time at which p_i bebDelivers m from every correct process and hence urbDelivers m .

Algorithm (urb)

• ***Proof (sketch)***

- ***URB1. Validity:*** If a correct process p_i urbBroadcasts a message m , then p_i eventually bebBroadcasts and bebDelivers m : by our lemma, p_i urbDelivers m .
- ***URB4. Agreement:*** Assume some process p_i urbDelivers a message m . By the algorithm and the completeness and accuracy properties of the failure detector, every correct process bebDelivers m . By our lemma, every correct process will urbDeliver m .