# Distributed systems

# Reliable Broadcast

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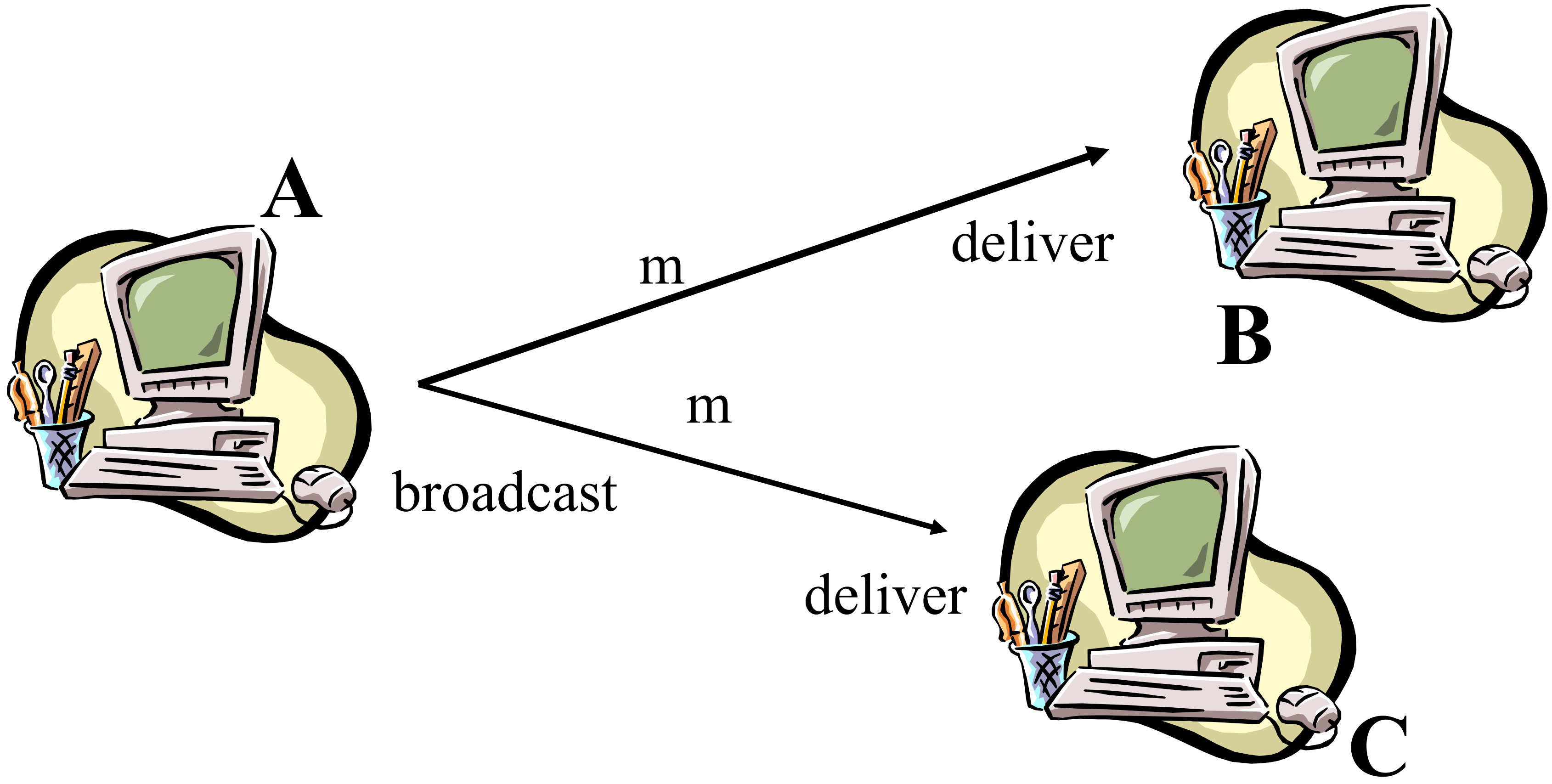
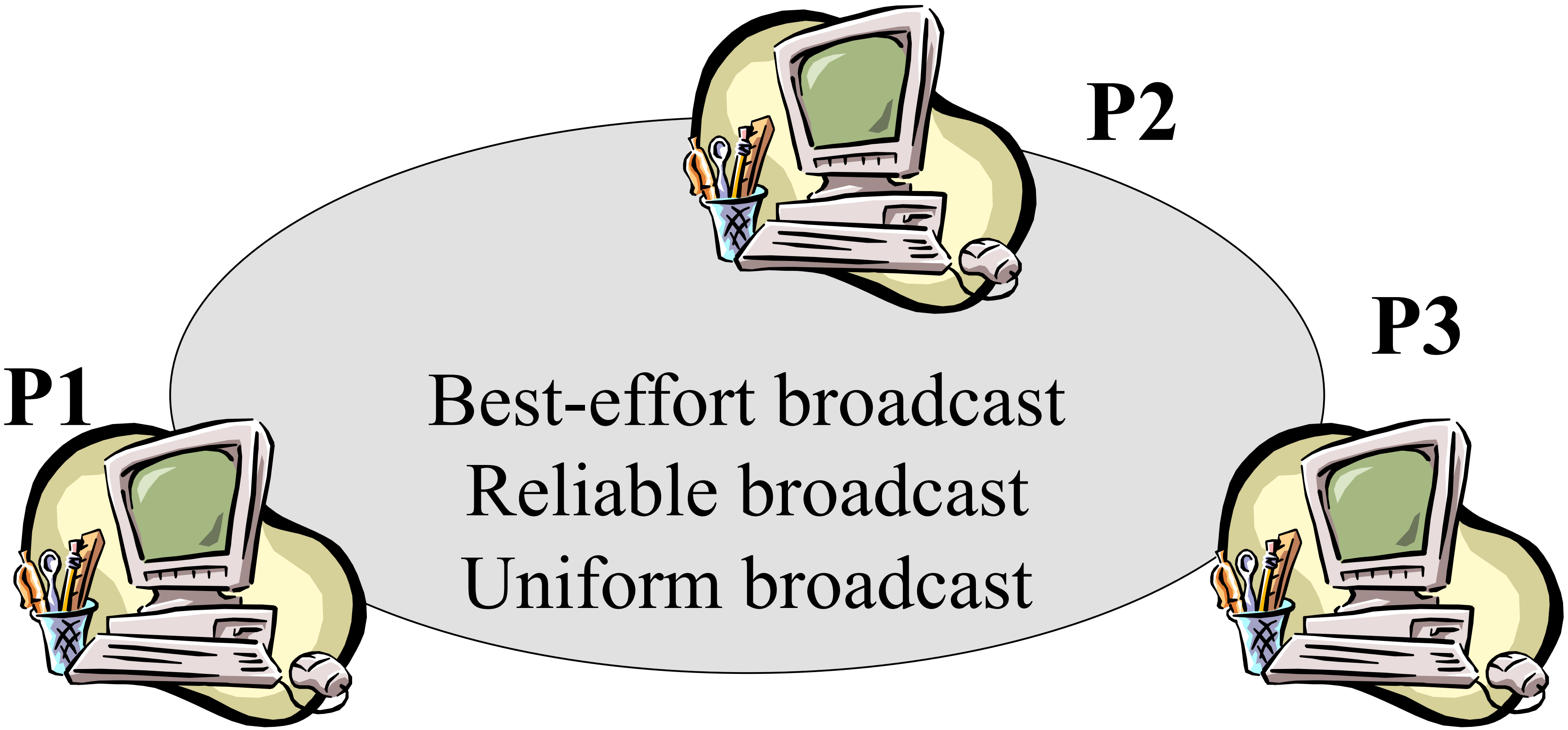
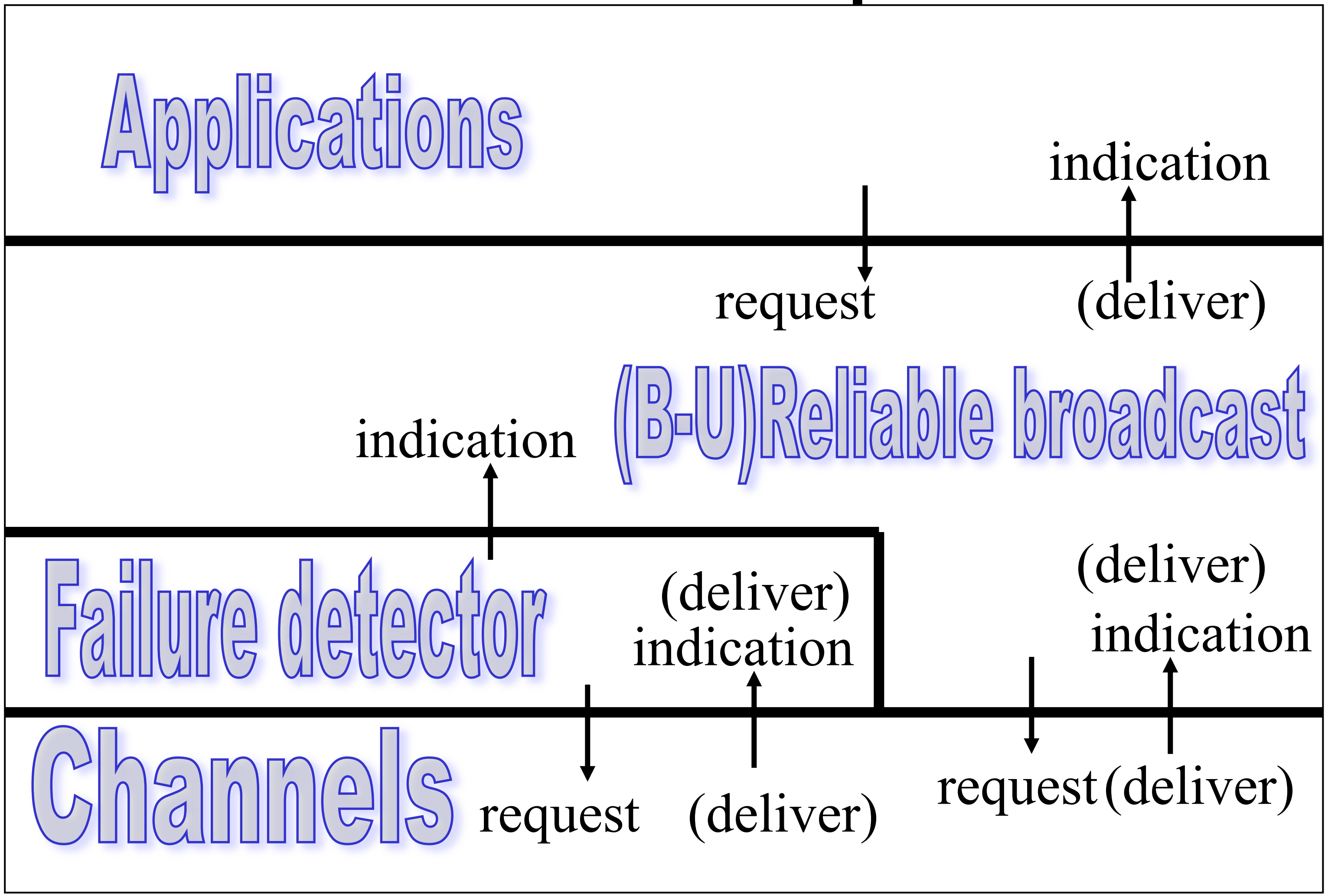
# Broadcast



# 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)

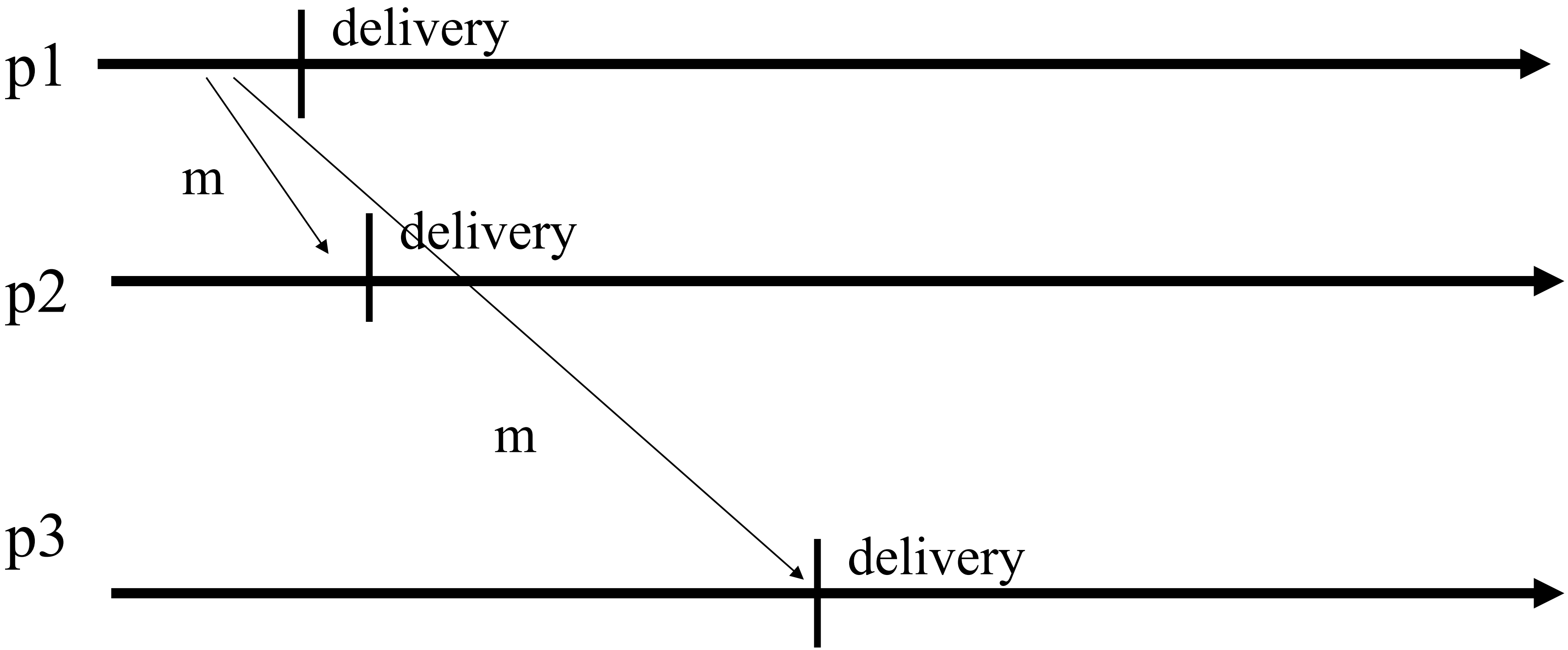
- ***Events***
  - Request: <bebBroadcast, m>
  - Indication: <bebDeliver, src, m>

- ***Properties: BEB1, BEB2, BEB3***

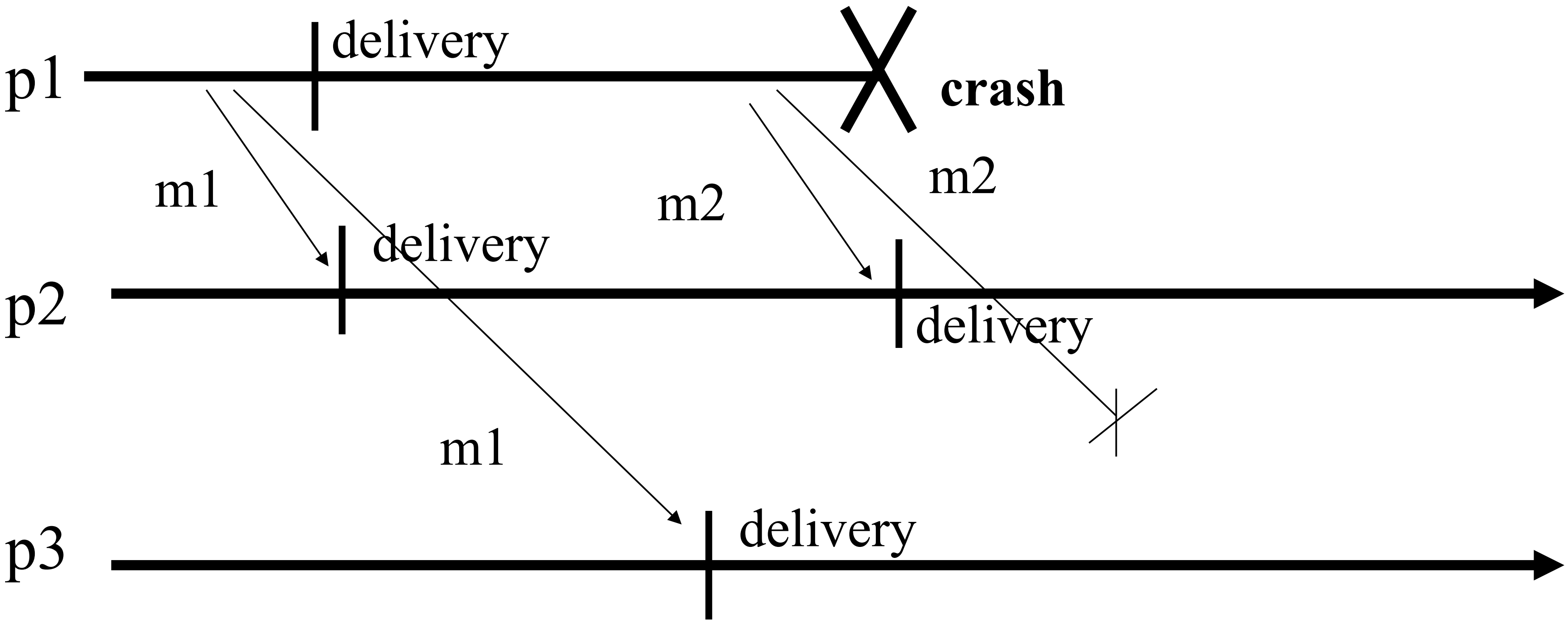
# Best-effort broadcast (beb)

- ***Properties***
  - ***BEB1. Validity***: If pi and pj are correct, then every message broadcast by pi is eventually delivered by pj
  - ***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)

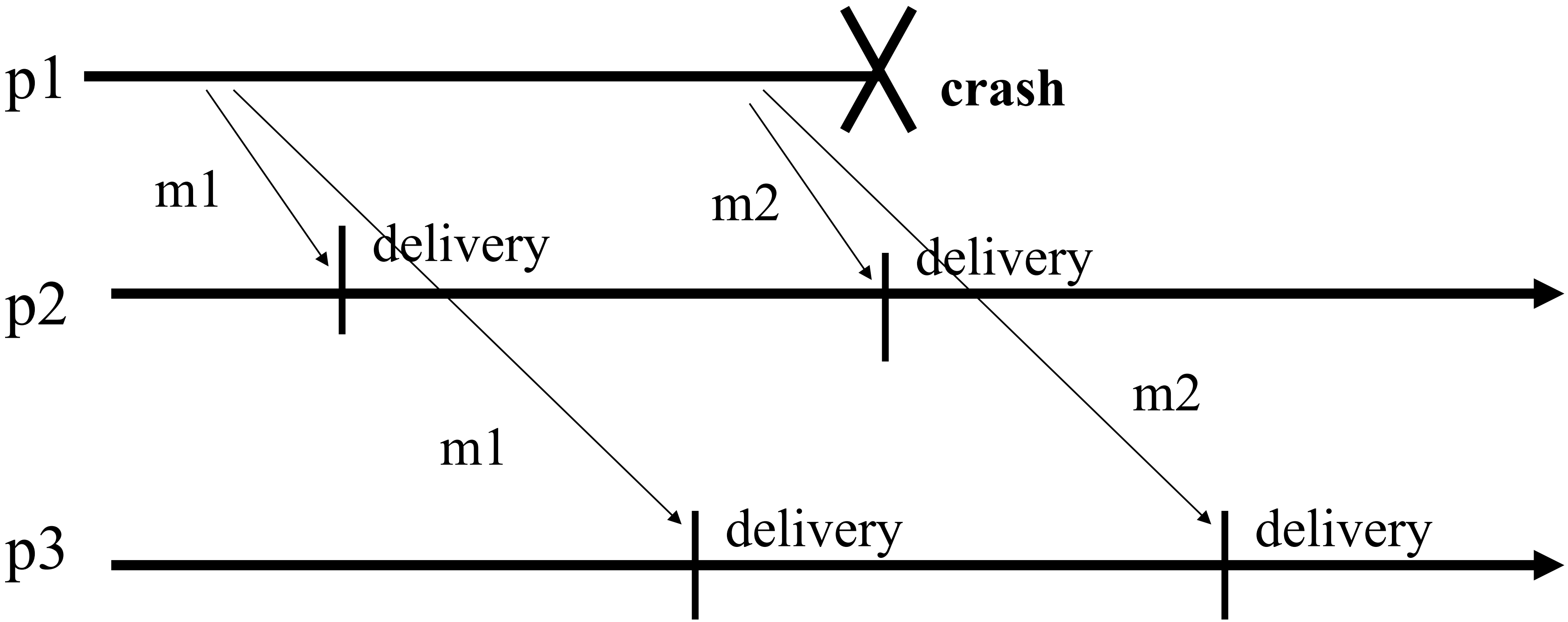
- ***Events***
  - Request: <rbBroadcast, m>
  - Indication: <rbDeliver, src, m>

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

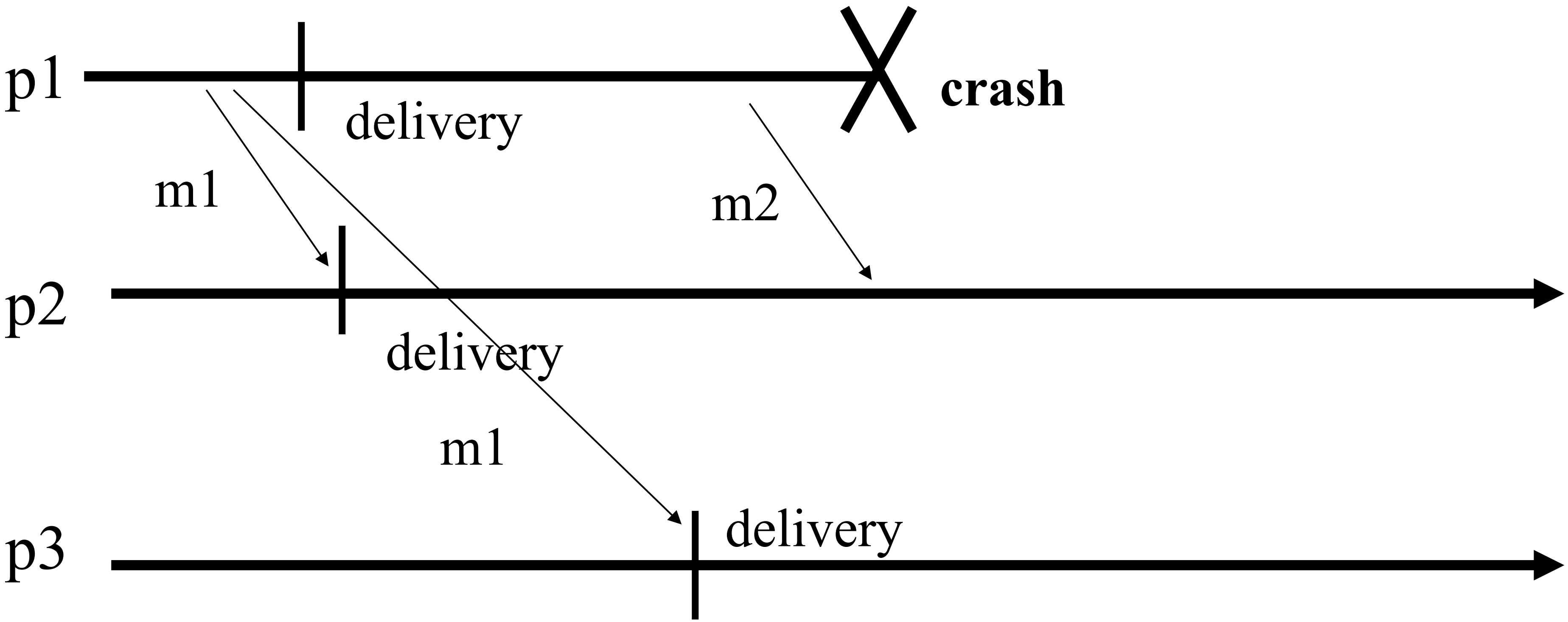
# Reliable broadcast (rb)

- ***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

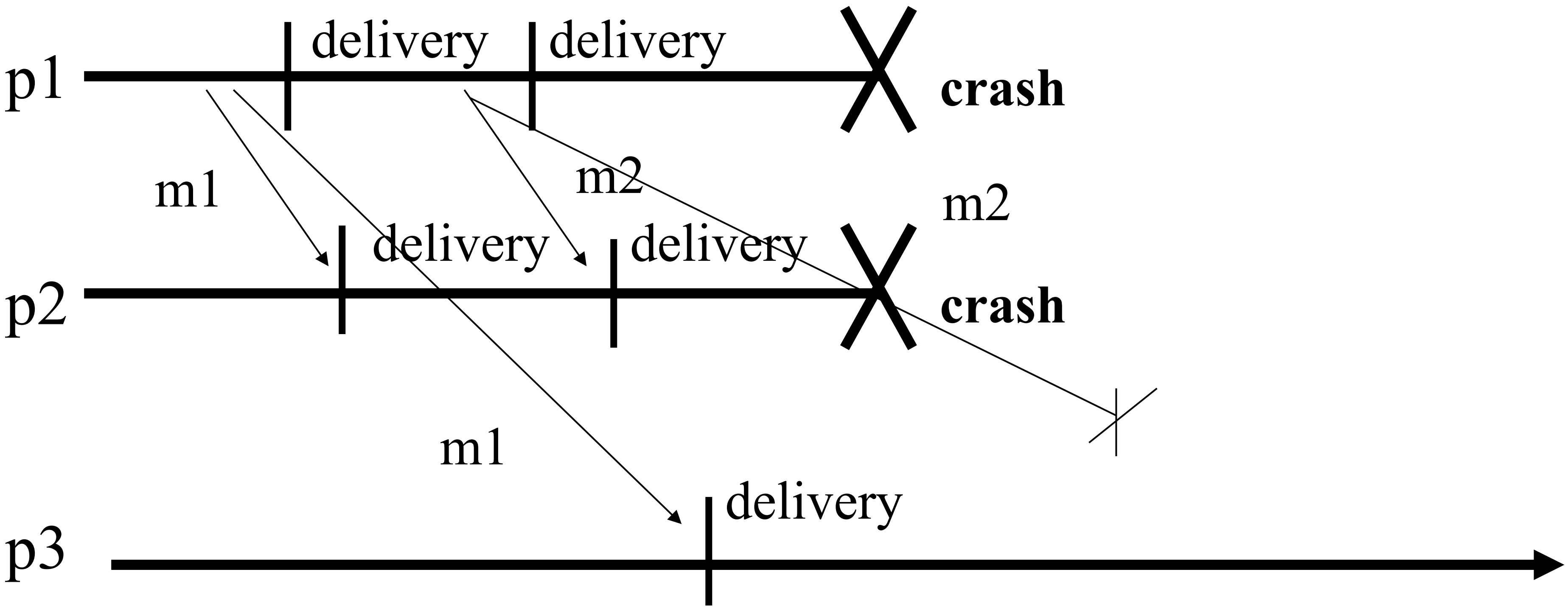
# Reliable broadcast



# Reliable broadcast



# Reliable broadcast



# Uniform broadcast (urb)

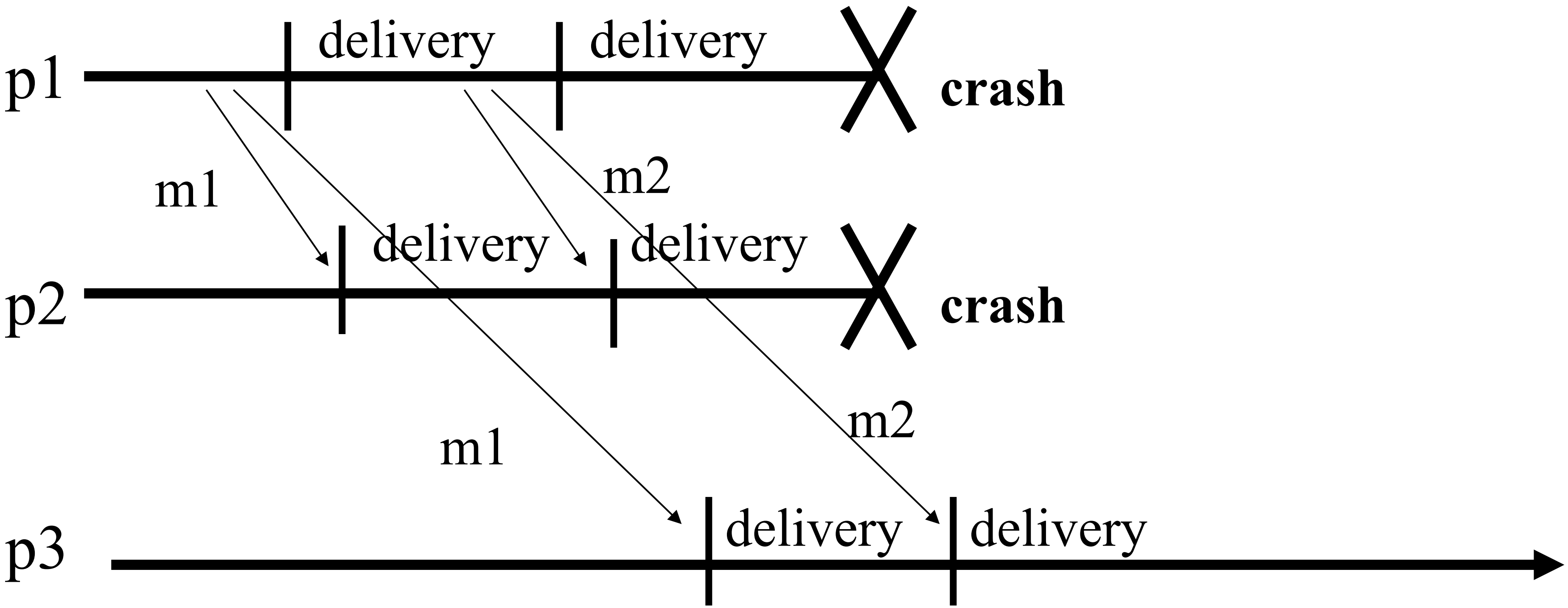
- ***Events***
  - Request: <urbBroadcast, m>
  - Indication: <urbDeliver, src, m>

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

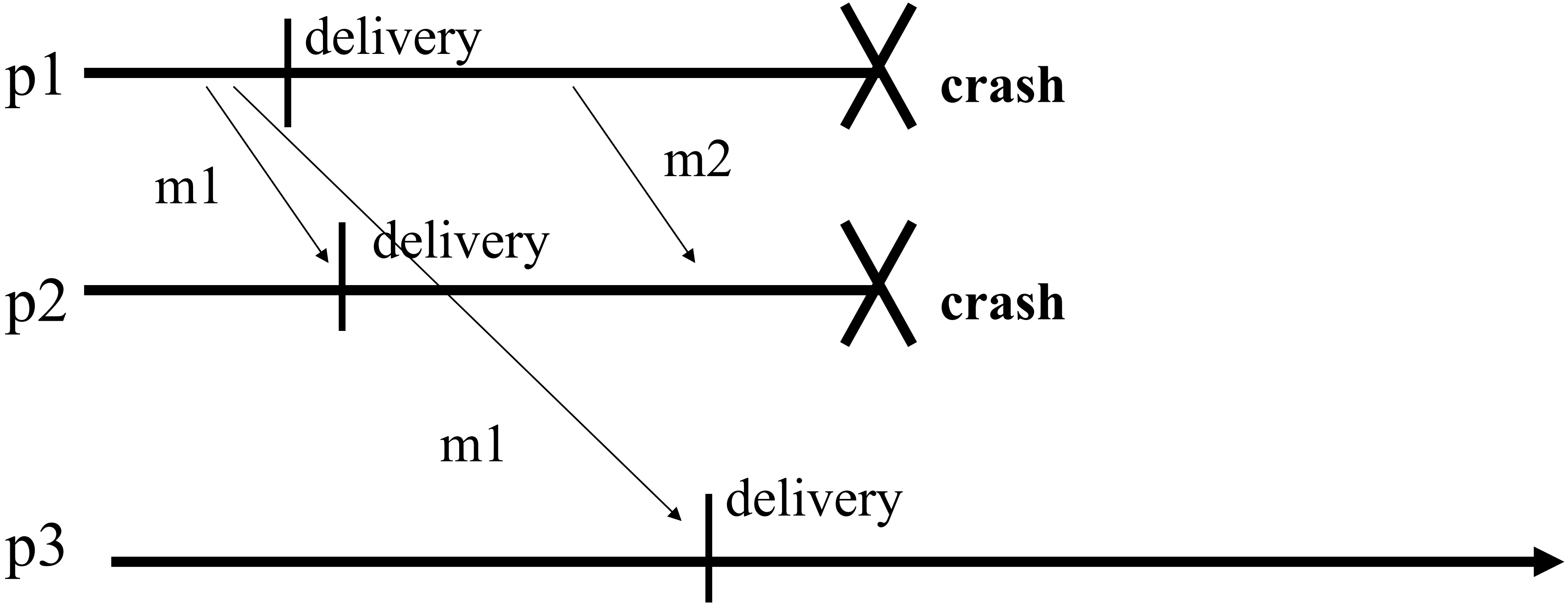
# Uniform broadcast (urb)

- ***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



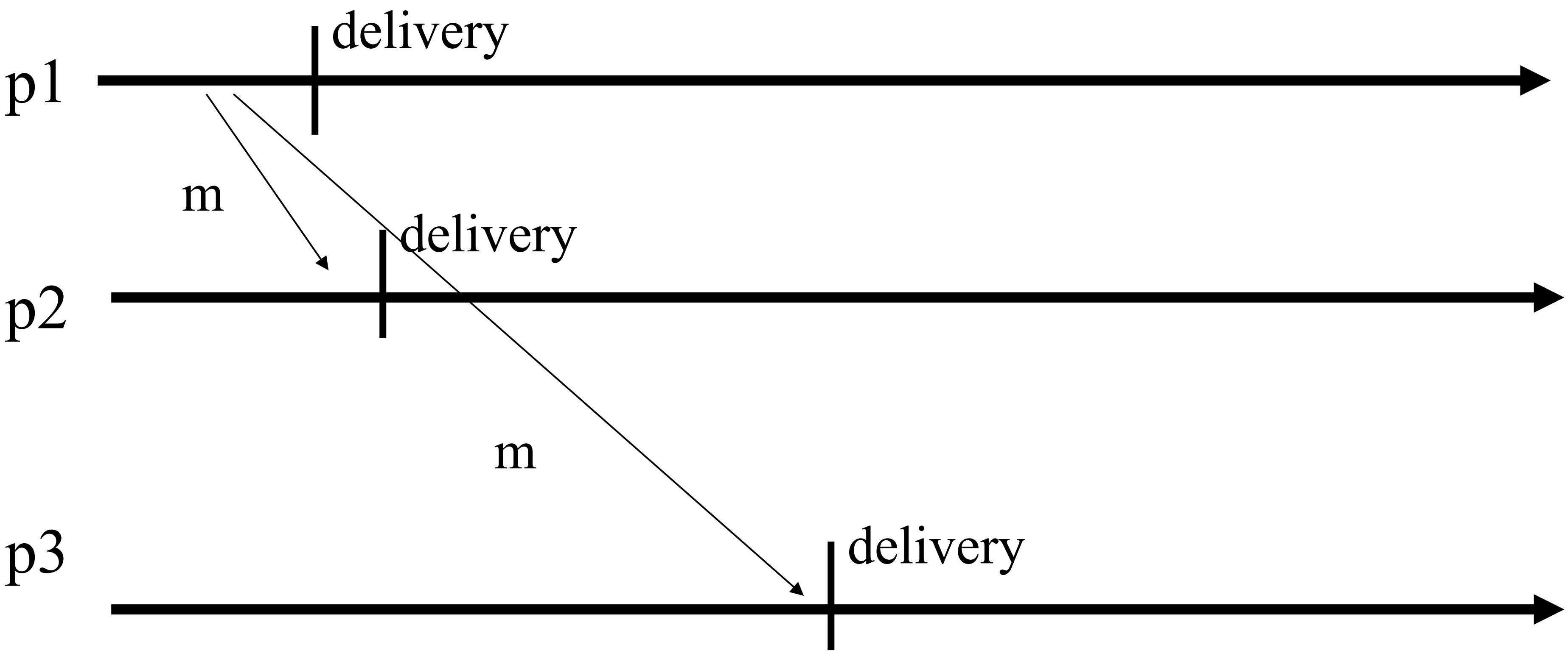
# Overview

- 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** < bebBroadcast, m> **do**
  - **forall** pi ∈ S **do**
    - **trigger** < pp2pSend, pi, m>;
- **upon event** < pp2pDeliver, pi, m> **do**
  - **trigger** < bebDeliver, pi, m>;

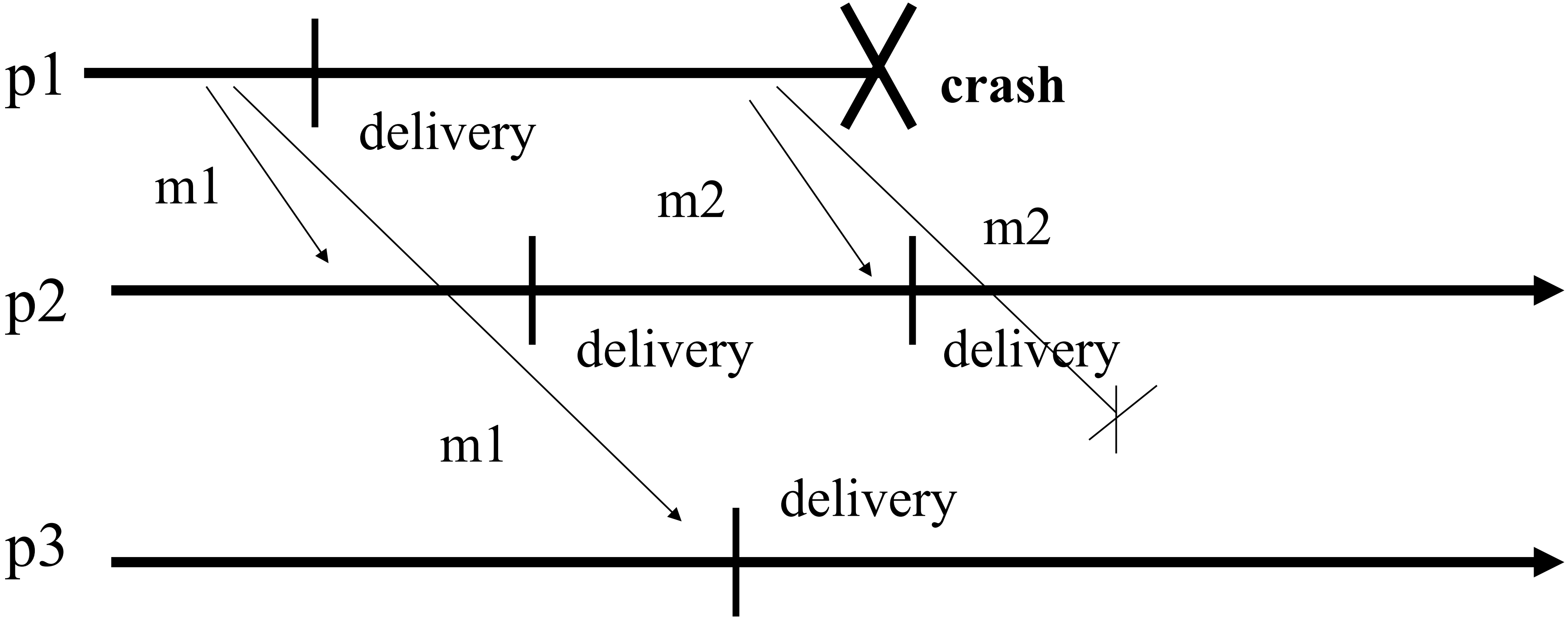
# Algorithm (beb)



# 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 := ∅;
  - correct := S;
  - **forall** pi ∈ S **do** from[pi] := ∅;

# Algorithm (rb – cont’d)

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

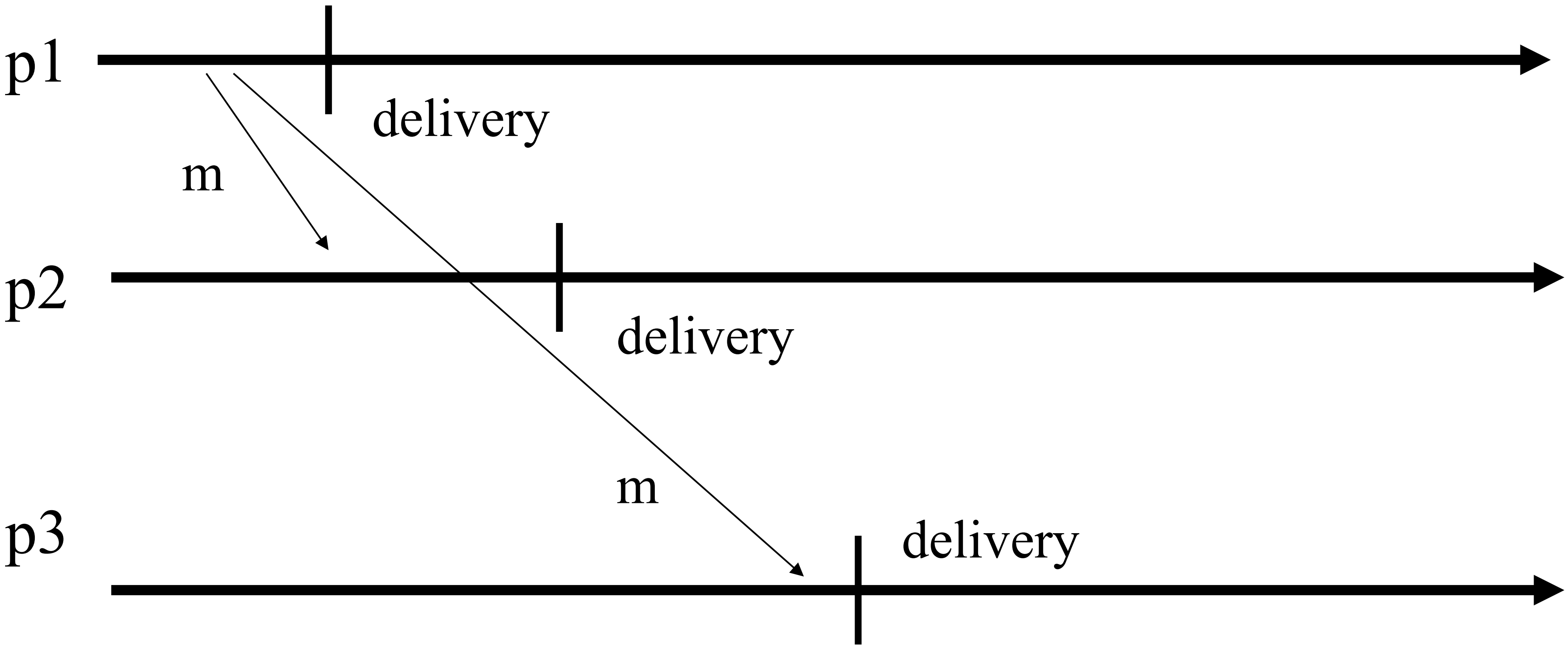
# Algorithm (rb – cont'd)

- **upon event** < crash, pi > **do**
  - correct := correct \ {pi};
  - **forall** [pj,m] $\in$ from[pi] **do**
    - **trigger** < bebBroadcast,[Data,pj,m]>;

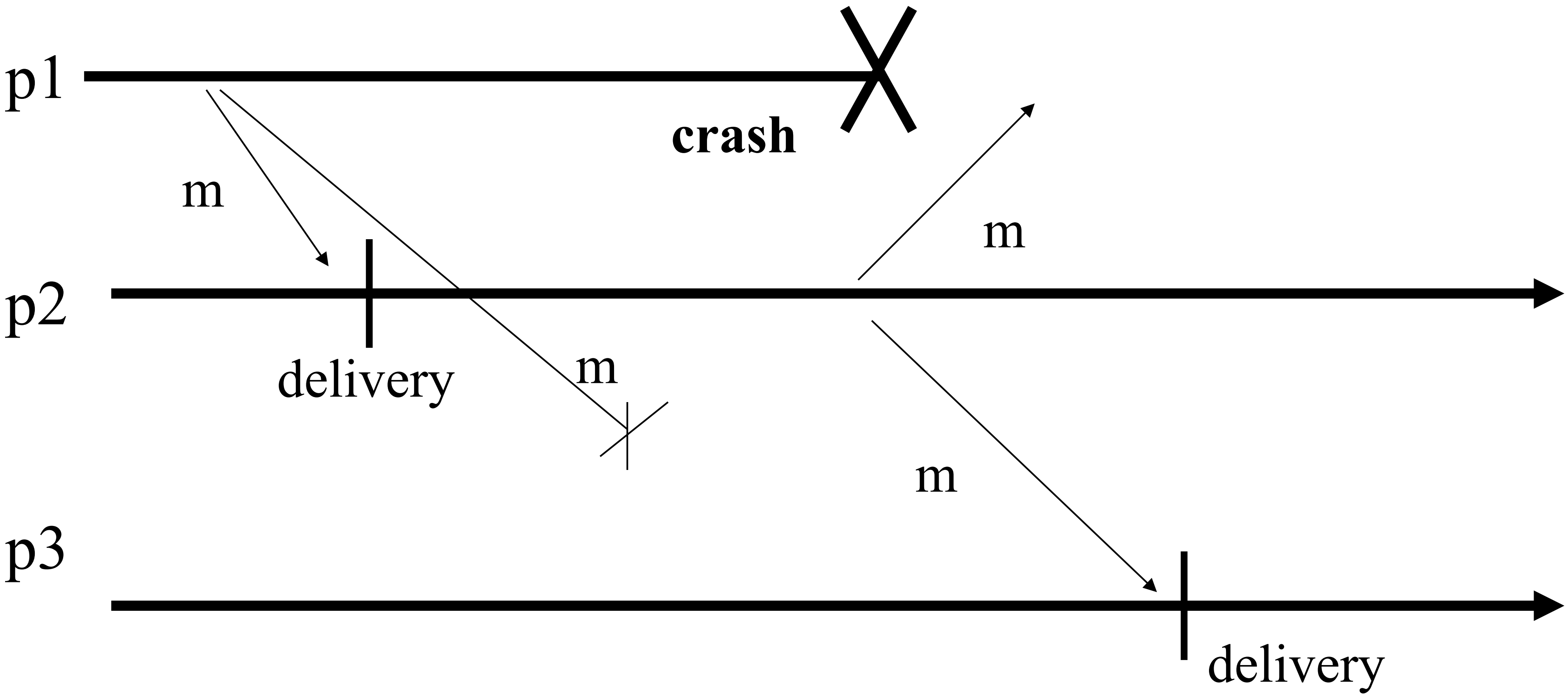
# Algorithm (rb – cont'd)

- **upon event** < bebDeliver, pi, [Data,pj,m]> **do**
  - **if** m $\notin$ delivered **then**
  - delivered := delivered U {m};
  - **trigger** < rbDeliver, pj, m>;
  - **if** pi $\notin$ correct **then**
  - **trigger** < bebBroadcast,[Data,pj,m]>;
  - **else**
  - from[pi] := from[pi] U {[pj,m]};

# Algorithm (rb)



# Algorithm (rb)



# Algorithm (rb)

- ***Proof (sketch)***
  - ***RB1. RB2. RB3:*** as for the 1st algorithm
  - ***RB4. Agreement:*** Assume some correct process pi rbDelivers a message m rbBroadcast by some process pk. If pk is correct, then by property BEB1, all correct processes bebDeliver and then rebDeliver m. If pk crashes, then by the completeness property of P, pi detects the crash and bebBroadcasts m to all. Since pi 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** < crash, pi > **do**
  - correct := correct \  {pi};

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

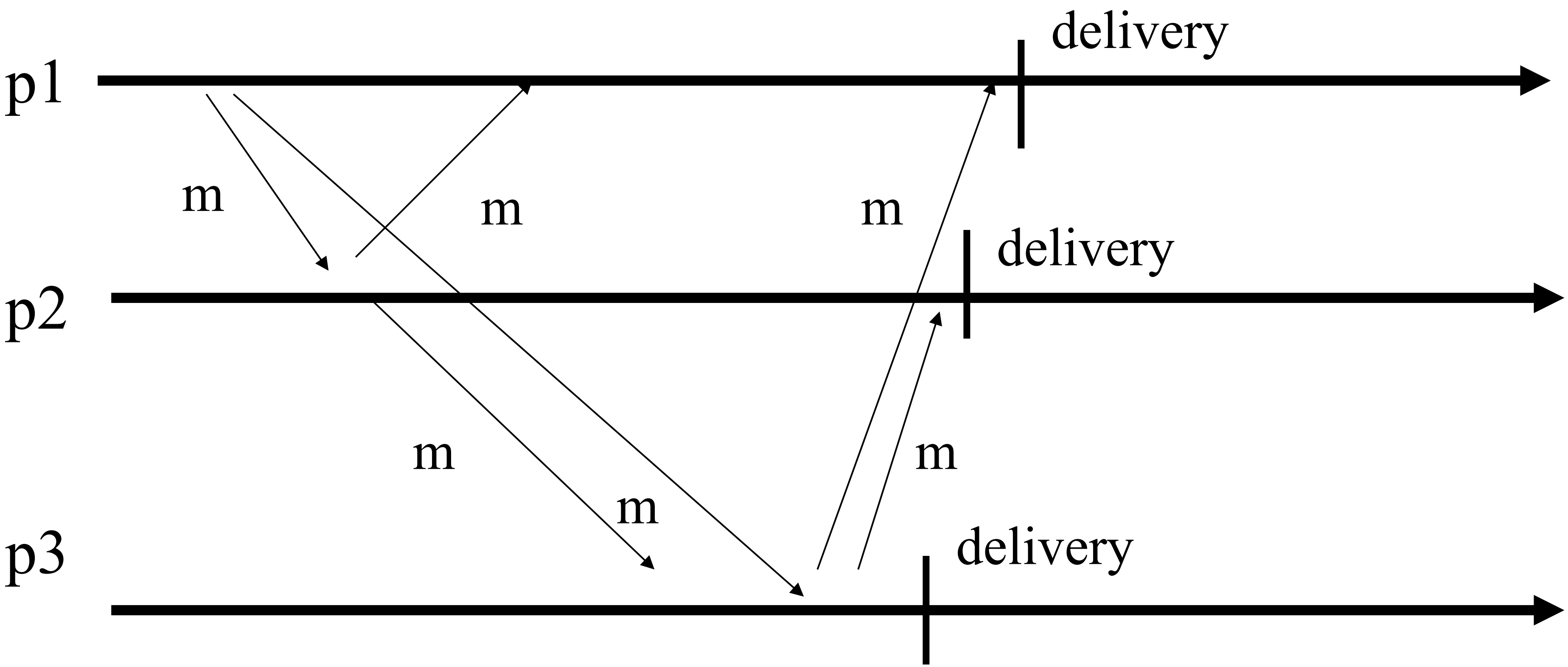
# Algorithm (urb – cont'd)

- **upon event** <bebDeliver, pi, [Data,pj,m]> **do**
  - ack[m] := ack[m] U {pi};
  - **if** [pj,m] $\notin$ forward **then**
    - forward := forward U {[pj,m]};
    - **trigger** < bebBroadcast,[Data,pj,m]>;

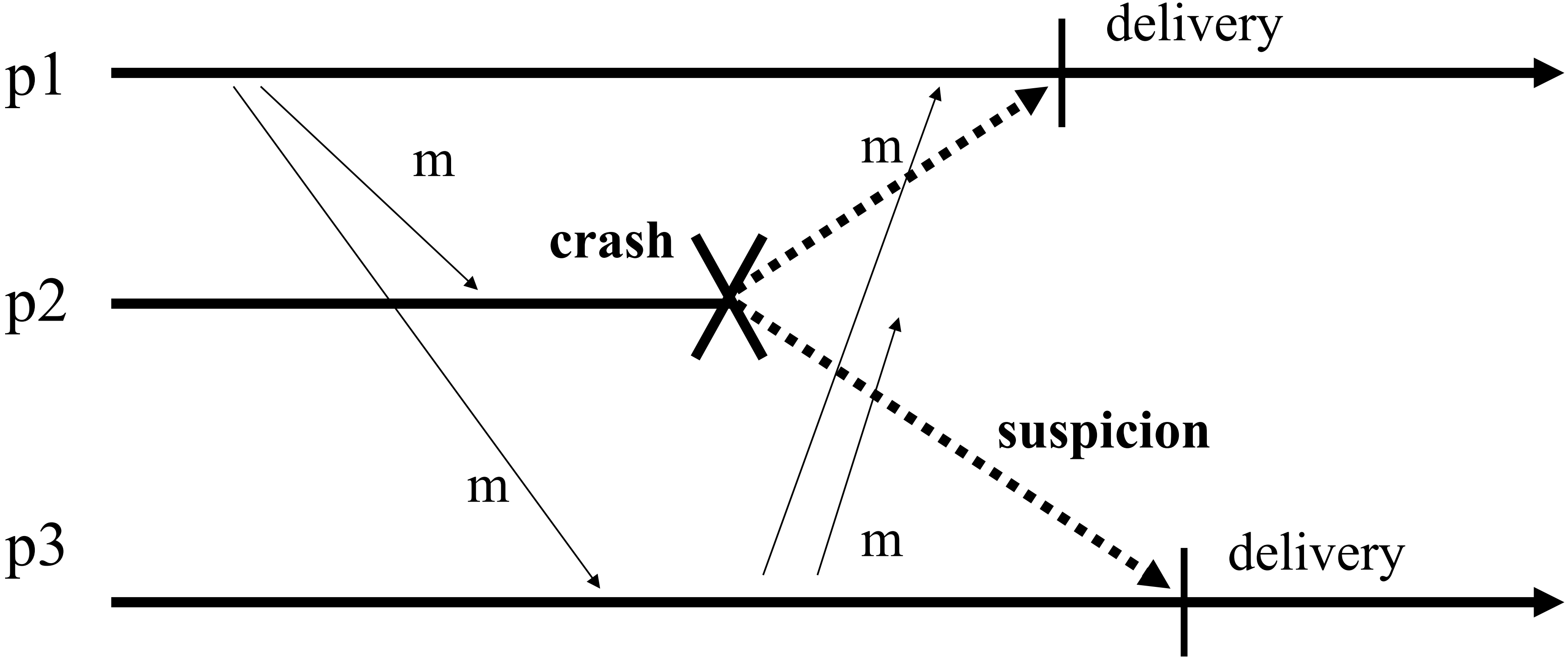
# Algorithm (urb – cont’d)

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

# Algorithm (urb)



# Algorithm (urb)



# Algorithm (urb)

- ***Proof (sketch)***
  - ***URB2. URB3:*** follow from BEB2 and BEB3
  - ***A simple lemma***: *If a correct process pi bebDelivers a message m, then pi 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 pi bebDelivers m from every correct process and hence urbDelivers m.

# Algorithm (urb)

- ***Proof (sketch)***
  - ***URB1. Validity:*** If a correct process pi urbBroadcasts a message m, then pi eventually bebBroadcasts and bebDelivers m: by our lemma, pi urbDelivers m.
  - ***URB4. Agreement:*** Assume some process pi 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.