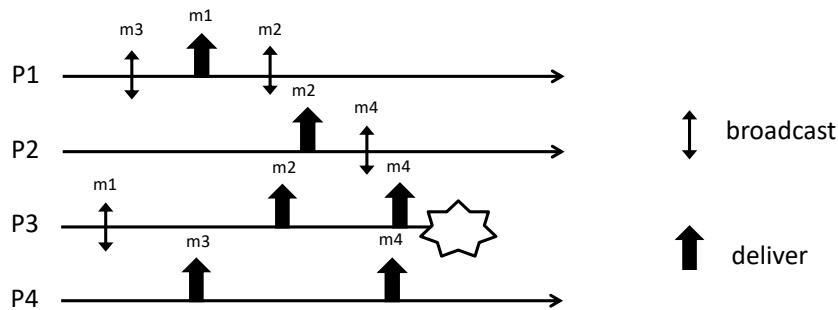


**Dependable Distributed Systems**  
**Master of Science in Engineering in Computer Science**

AA 2022/2023

**Week 7 – Exercises**  
**November 8<sup>th</sup>, 2023**

**Ex 1:** Consider the partial execution depicted in the Figure

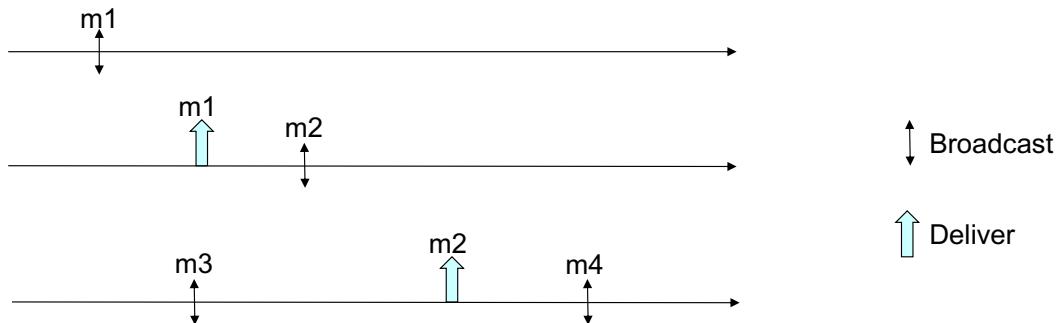


Answer to the following questions:

1. Provide ALL the possible delivery sequences that satisfies causal order and TO (UA, SUTO).
2. Complete the execution in order to have a run satisfying TO (UA WNUTO), FIFO order Broadcast but not Causal Order Broadcast.
3. Complete the execution in order to have a run satisfying Regular Reliable Broadcast but not Uniform Reliable Broadcast and not satisfying Total Order.

**NOTE:** In order to solve the exercise, you can only add broadcast, deliveries and failures.

**Ex 2:** Given the partial execution in Figure, provide all the delivery sequences such that both total order and causal order are satisfied



**Ex 3:** Let us consider the following algorithm implementing a (1, N) atomic register in synchronous system.

```

13 upon event { onar, Init } do
14   (ts, val) := (0, ⊥);
15   correct := Π;
16   writeset := ∅;
17   readval := ⊥;
18   reading := FALSE;

19 uponevent{P,Crash | p}do
20   correct := correct \ {p};

21 upon event { onar, Read } do
22   reading := TRUE;
23   readval := val;
24   trigger { beb, Broadcast | [WRITE, ts, val] };

25 upon event { onar, Write | v } do
  trigger { beb, Broadcast | [WRITE, ts + 1, v] };

```

```

1  upon event { beb, Deliver | p, [WRITE, ts', v'] } do
2    if ts' > ts then
3      (ts, val) := (ts', v');
4      trigger { pl, Send | p, [ACK] };

5  upon event { pl, Deliver | p, [ACK] } then
6    writeset := writeset ∪ {p};

7  upon correct ⊆ writeset do
8    writeset := ∅;
9    if reading = TRUE then
10      reading := FALSE;
11      trigger { onar, ReadReturn | readval };
12    else
13      trigger { onar, WriteReturn };

```

Assuming that messages are sent by using perfect point-to-point links and that the broadcast is best effort answer the following questions:

1. Discuss what does it happen to every atomic register property (i.e., termination, validity, and ordering) if the failure detector is eventually perfect and not perfect.
2. Discuss what does it happen to every atomic register property (i.e., termination, validity, and ordering) if we change line 12 with **trigger { beb, Broadcast | [WRITE, ts+1, val] };**

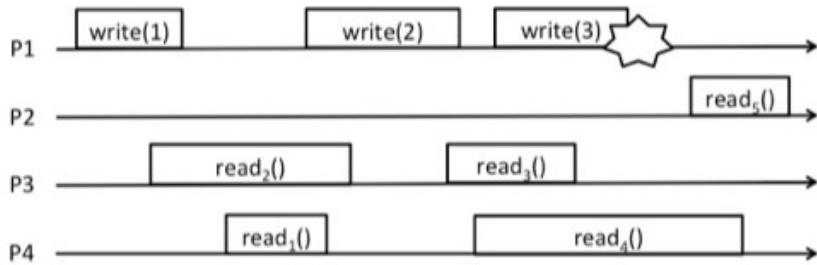
**Ex 4:** Consider a distributed system composed of n processes p1, p2, ..., pn connected through a ring topology. Initially, each process knows the list of correct processes and maintains locally a *next* variable where it stores the id of the following process in the ring.

Each process can communicate only with its next through FIFO perfect point-to-point channels (i.e. the process whose id is stored in the *next* variable).

Processes may fail by crash and each process has access to a perfect failure detector.

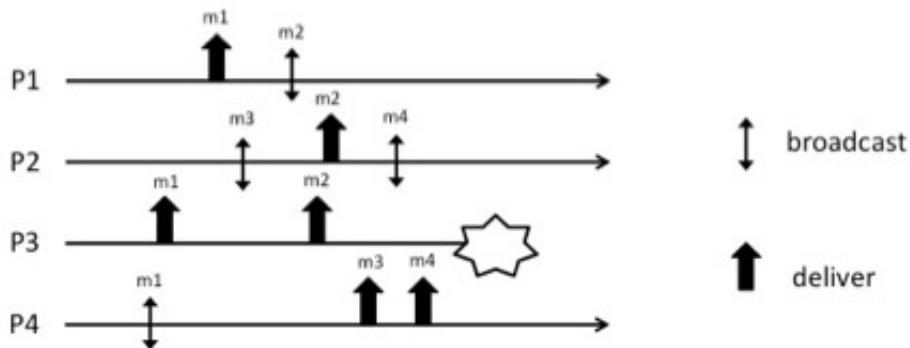
Write the pseudo-code of a distributed algorithm implementing a (1, N) atomic register.

**Ex 5:** Consider the execution depicted in the following figure and answer the questions



1. Define ALL the values that can be returned by read operations (Rx) assuming the run refers to a regular register.
2. Define ALL the values that can be returned by read operations (Rx) assuming the run refers to an atomic register.

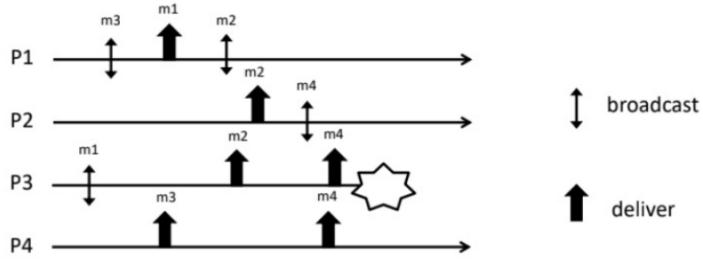
**Ex 6:** Let us consider the following partial execution



Answer the following points:

1. Provide the list of all the possible delivery sequences that satisfy both Total Order and Causal Order.
2. Complete the history (by adding the missing delivery events) to satisfy Total Order but not Causal Order.
3. Complete the history (by adding the missing delivery events) to satisfy FIFO Order but not Causal Order nor Total Order.

**Ex 1:** Consider the partial execution depicted in the Figure



Answer to the following questions:

- Provide ALL the possible delivery sequences that satisfies causal order and TO (UA, SUTO).
- Complete the execution in order to have a run satisfying TO (UA WNUTO), FIFO order Broadcast but not Causal Order Broadcast.
- Complete the execution in order to have a run satisfying Regular Reliable Broadcast but not Uniform Reliable Broadcast and not satisfying Total Order.

## 1) Causal and TO(UA, SUTO)

FIFO + local:  $m_3 \rightarrow m_2$   
 $m_1 \rightarrow m_2$   
 $m_2 \rightarrow m_4$

$\left. \begin{array}{l} m_3 \rightarrow m_2 \rightarrow m_4 \\ m_1 \rightarrow m_2 \rightarrow m_4 \end{array} \right\}$

TOTAL:  $m_3 \rightarrow m_4$  ( $r_4$ )  
 $m_2 \rightarrow m_4$  ( $r_3$ )

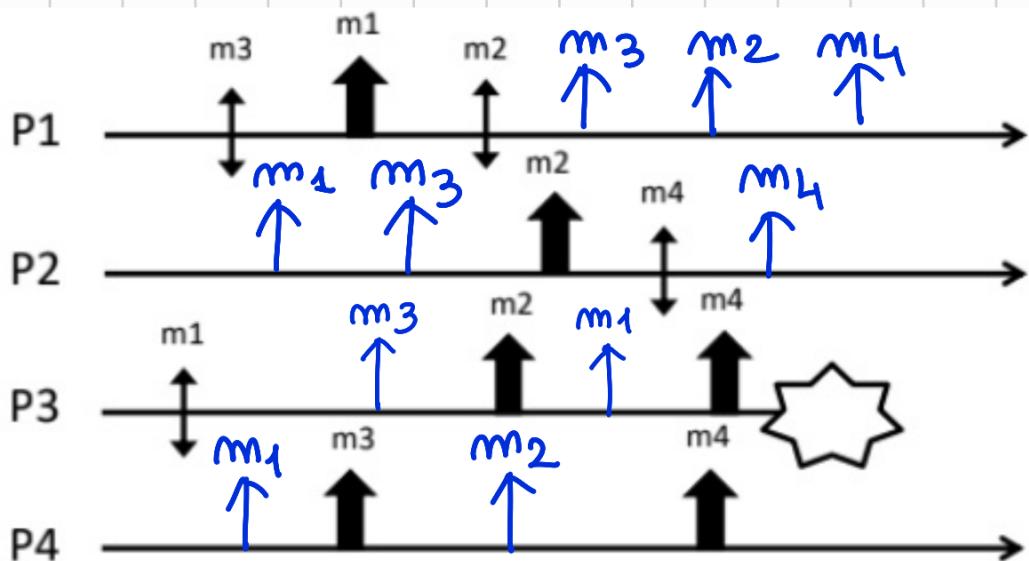
Sequences:  $m_1 \ m_3 \ m_2 \ m_4$

$m_3 \ m_1 \ m_2 \ m_4$

## 2) TO(UA, WNUTO), FIFO and not CAUSAL

FIFO:  $m_3 \rightarrow m_2$

NOT CAUSAL:  $m_1 \rightarrow m_2 \rightarrow m_4$

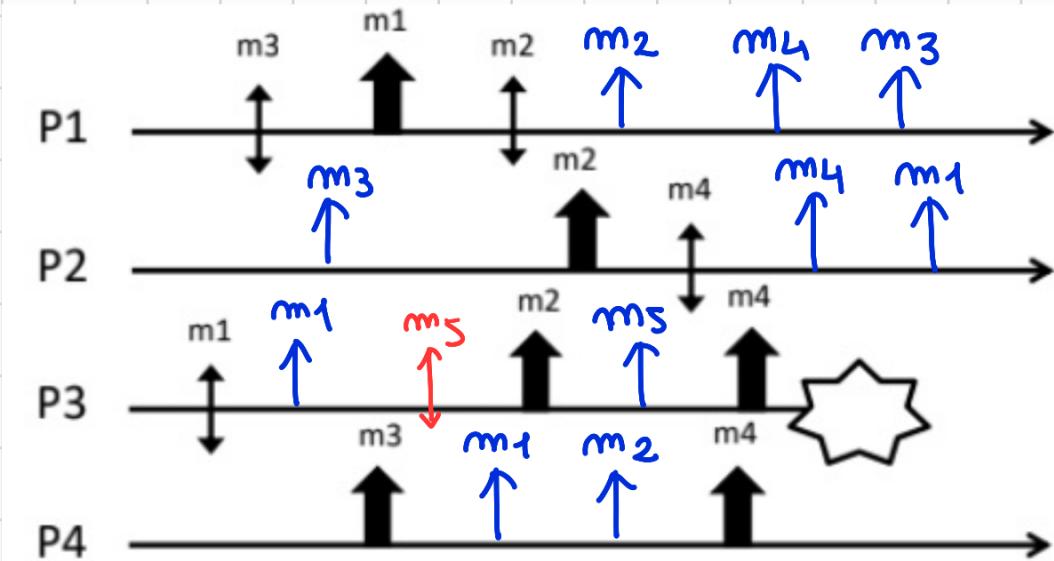


### 3) RB, mot URB and mot TOTAL

RB: same set (correct)

mot URB: faulty mot subset

mot TOTAL:  $m_3 \not\rightarrow m_4$ , same order same sequence



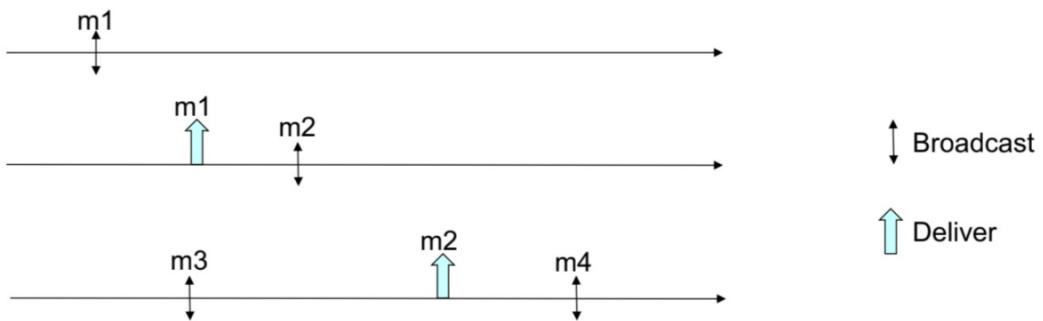
1243

3241

1524

3124

**Ex 2:** Given the partial execution in Figure, provide all the delivery sequences such that both total order and causal order are satisfied



FIFO + local:  $m_3 \rightarrow m_4$

$m_2 \rightarrow m_4$

$m_1 \rightarrow m_2$

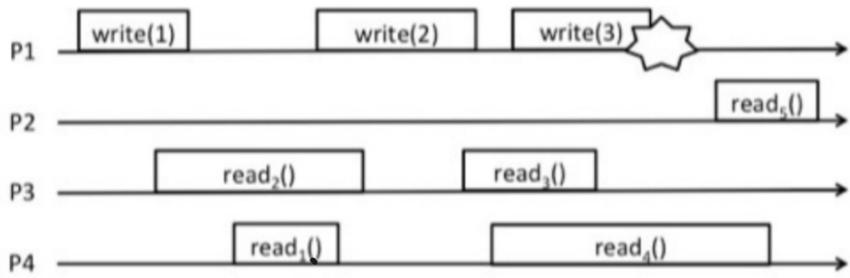
$m_3 \not\rightarrow m_1$

$\left. \begin{array}{l} m_2 \\ m_1 \end{array} \right\} \rightarrow m_4$

Sequences:  $m_1 \ m_2 \ m_3 \ m_4$

$m_1 \ m_3 \ m_2 \ m_4$

**Ex 5:** Consider the execution depicted in the following figure and answer the questions



1. Define ALL the values that can be returned by read operations (Rx) assuming the run refers to a regular register.
2. Define ALL the values that can be returned by read operations (Rx) assuming the run refers to an atomic register.

1) Regular register  $\Rightarrow$

$R_1 : 1, 2$   
 $R_2 : 0, 1, 2$   
 $R_3 : 1, 2, 3$   
 $R_4 : 2, 3$   
 $R_5 : 2, 3$

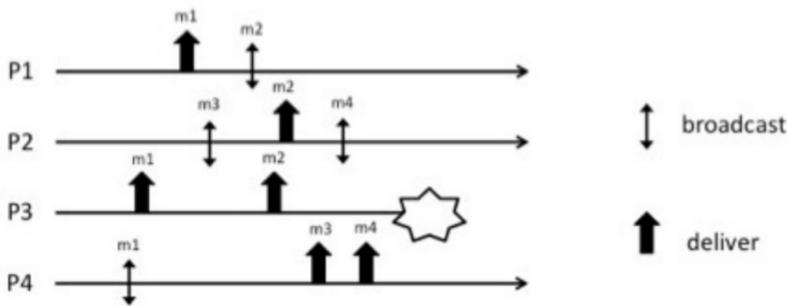
2) Atomic register  $\Rightarrow$

$R_1 : 1, 2$  (concurrent to  $R_2$ )  
 $R_2 : 0, 1, 2$   
 $R_3 : 2, 3$  or  $1, 2, 3$   
 $R_4 : 2, 3$   
 $R_5 : 2, 3$  or  $3$

$R_3$  depends on  $R_1$  and  $R_2$ : if  $R_2$  has  $(0, 1)$  then  $R_3$  can have  $(1, 2, 3)$ , otherwise  $(2, 3)$ . if  $R_1$  has  $(1)$  then  $R_3$  can have  $(1, 2, 3)$ , otherwise  $(2, 3)$

$R_5$  depends on  $R_1, R_2$  and  $R_3$ : if  $R_3$  has  $(2)$  then  $R_5$  can have  $(2, 3)$ , otherwise  $(3)$ .

**Ex 6:** Let us consider the following partial execution



Answer the following points:

- Provide the list of all the possible delivery sequences that satisfy both Total Order and Causal Order.
- Complete the history (by adding the missing delivery events) to satisfy Total Order but not Causal Order.
- Complete the history (by adding the missing delivery events) to satisfy FIFO Order but not Causal Order nor Total Order.

## 1) Total and causal

FIFO + Local:  $m_3 \rightarrow m_4$        $m_3 \cancel{\rightarrow} m_1$   
 $m_1 \rightarrow m_2$        $m_1 \rightarrow m_2 \rightarrow m_4$   
 $m_2 \rightarrow m_4$

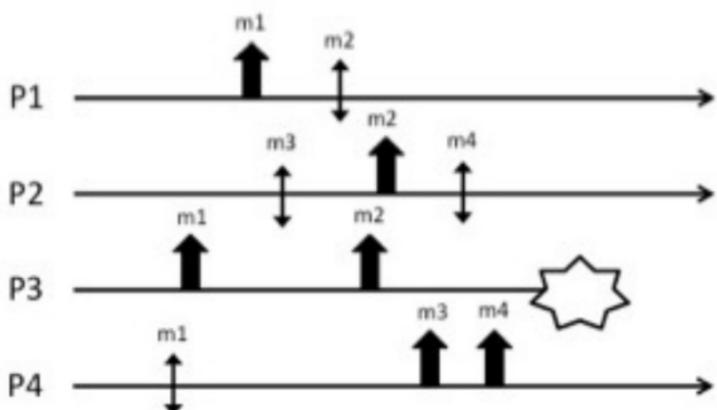
Sequences:  $m_1 m_2 m_3 m_4$   
 $m_1 m_3 m_2 m_4$

## 2) Total, not causal

not causal:  $m_3 \rightarrow m_4$   
 $m_1 \rightarrow m_2 \rightarrow m_4$

TOTAL: same sequence

$m_3 \rightarrow m_4$



It does not exist a sequence that have this specification

### 3) FIFO, not causal, not total

FIFO:  $m_3 \rightarrow m_4$       not Causal:  $m_1 \rightarrow m_2$   
 $m_2 \rightarrow m_4$

