

CLOUD COMPUTING CONCEPTS

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TIME AND ORDERING

Lecture E

VECTOR CLOCKS

VECTOR TIMESTAMPS

- Used in key-value stores like Riak
- Each process uses a vector of integer clocks
- Suppose there are N processes in the group $1 \dots N$
- Each vector has N elements
- Process i maintains vector $V_i[1 \dots N]$
- j th element of vector clock at process i , $V_i[j]$, is i 's knowledge of latest events at process j

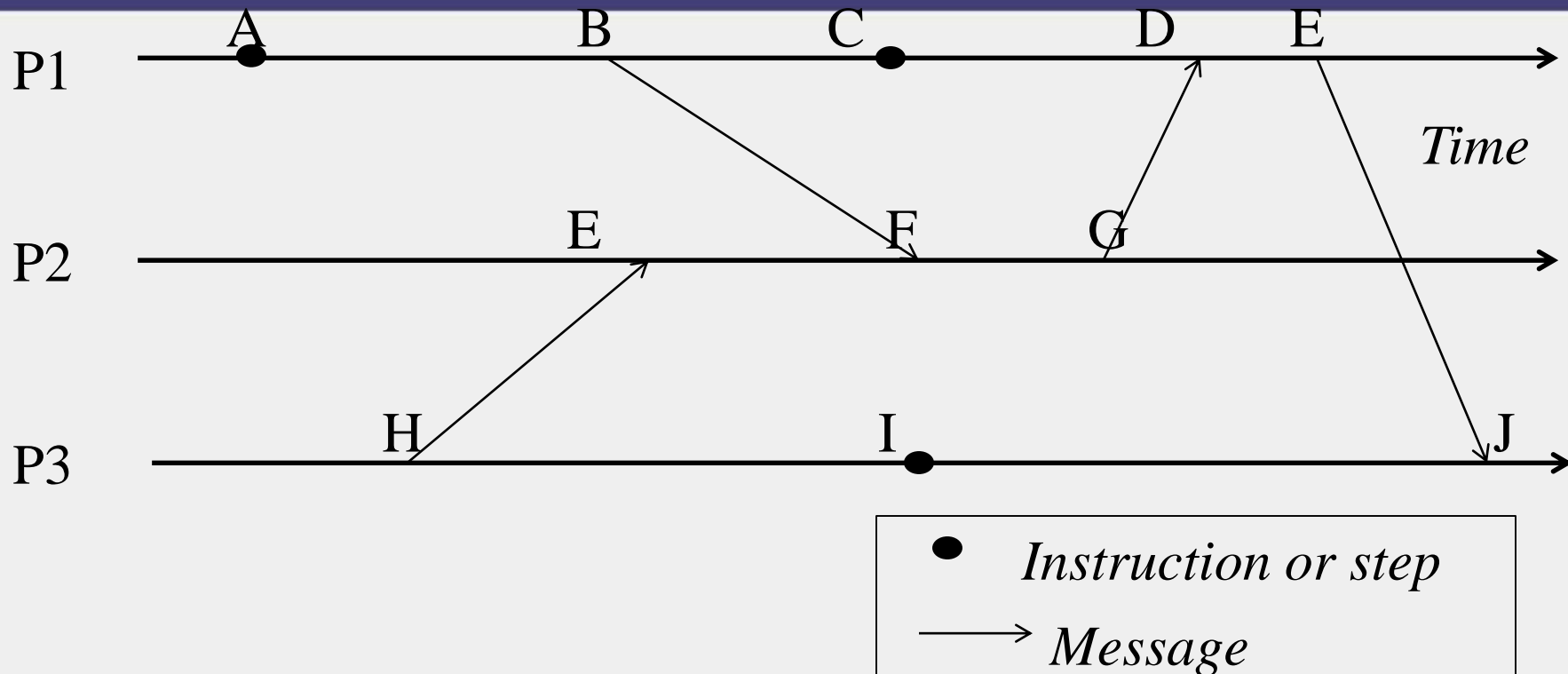
ASSIGNING VECTOR TIMESTAMPS

- Incrementing vector clocks
 1. On an instruction or send event at process i , it increments only its i th element of its vector clock
 2. Each message carries the send-event's vector timestamp $V_{\text{message}}[1 \dots N]$
 3. On receiving a message at process i :

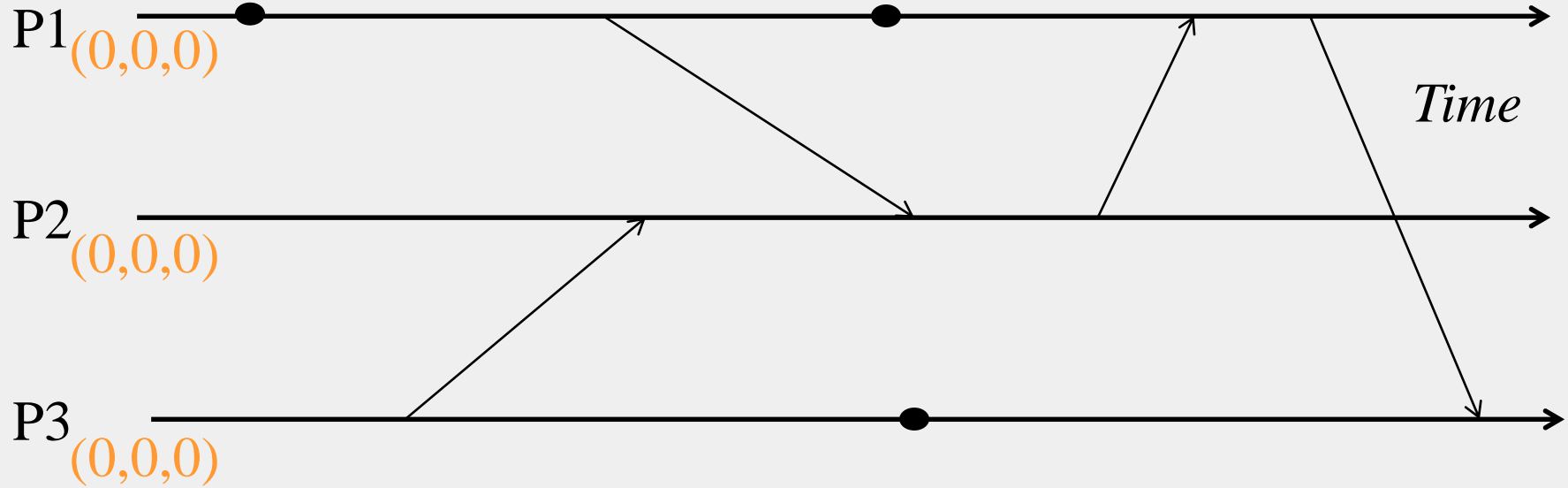
$$V_i[i] = V_i[i] + 1$$

$$V_i[j] = \max(V_{\text{message}}[j], V_i[j]) \text{ for } j \neq i$$

EXAMPLE

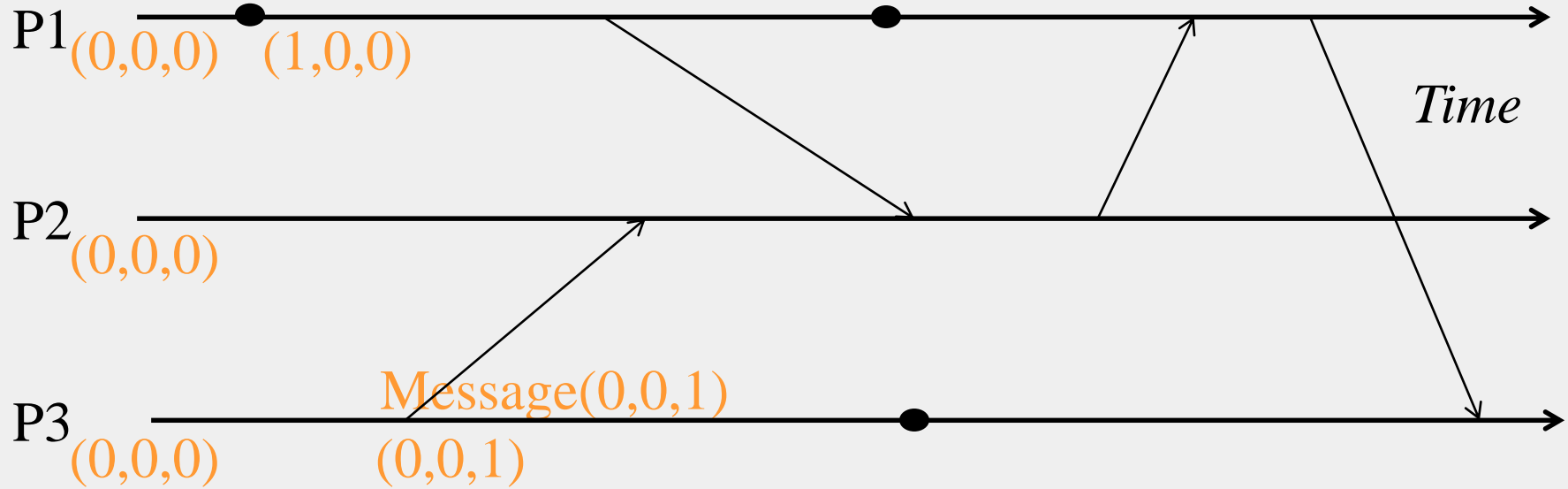


VECTOR TIMESTAMPS

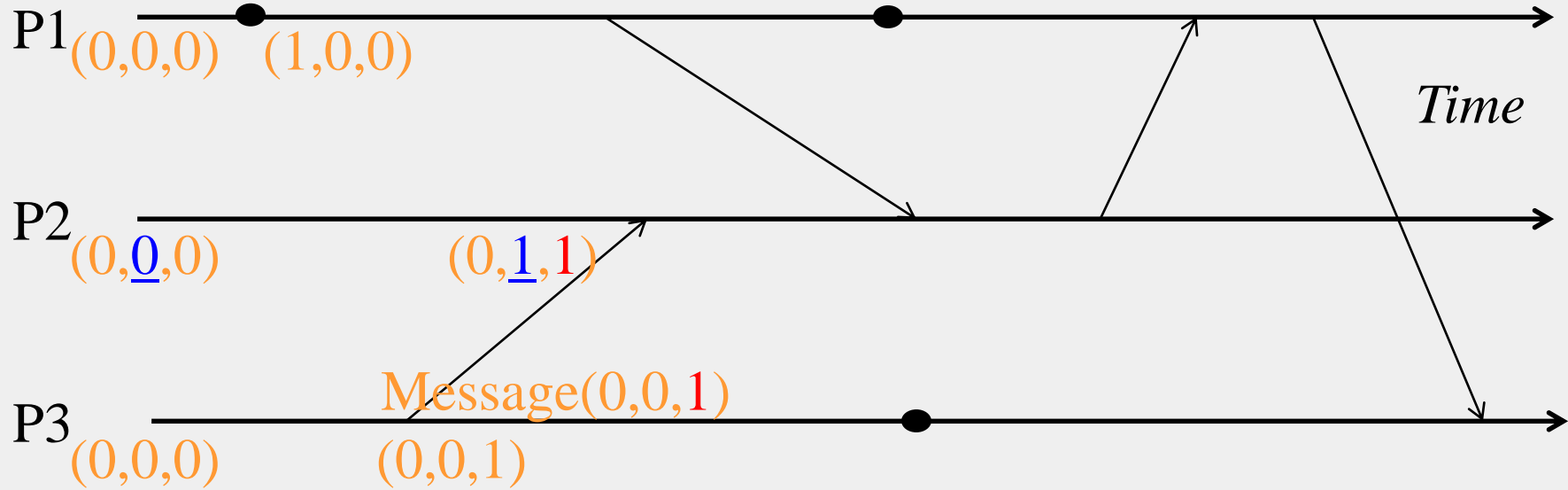


Initial counters (clocks)

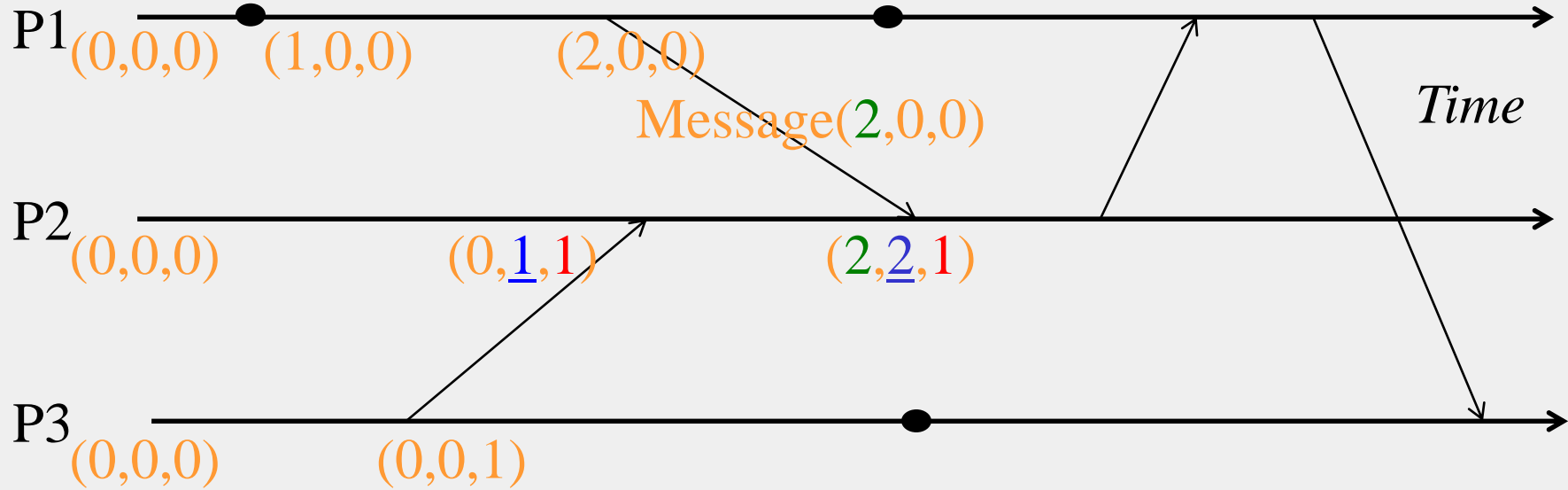
VECTOR TIMESTAMPS



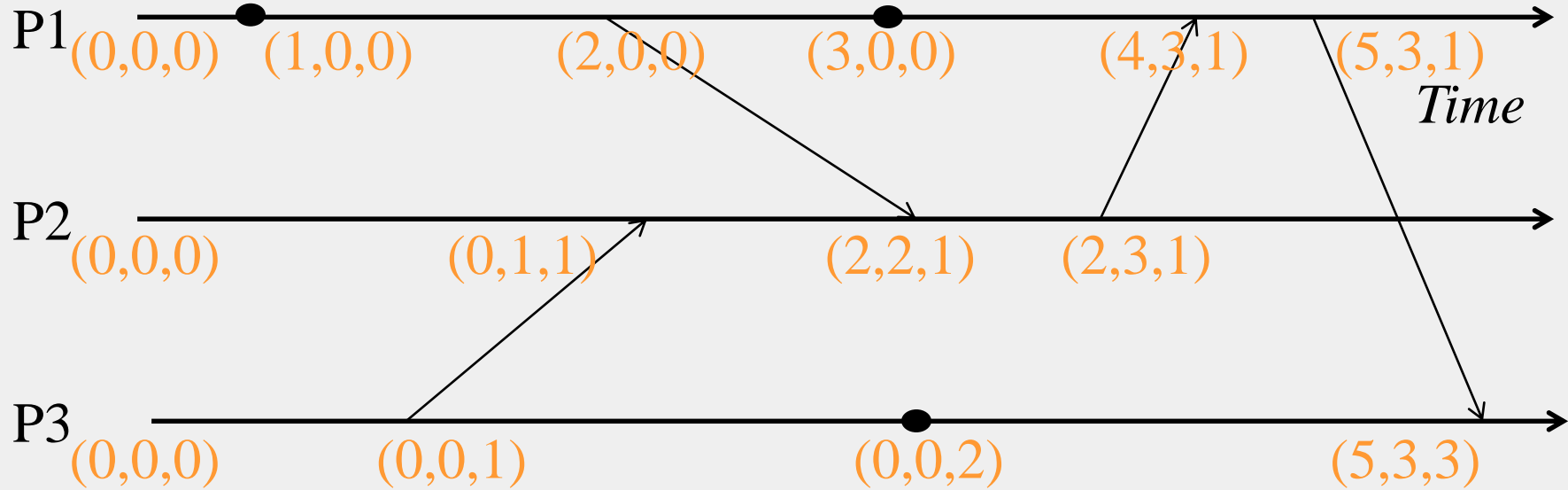
VECTOR TIMESTAMPS



VECTOR TIMESTAMPS



VECTOR TIMESTAMPS



CAUSALLY-RELATED ...

- $VT_1 = VT_2$,
iff (if and only if)
 $VT_1[i] = VT_2[i]$, for all $i = 1, \dots, N$
- $VT_1 \leq VT_2$,
iff $VT_1[i] \leq VT_2[i]$, for all $i = 1, \dots, N$
- Two events are **causally related** *iff*
 $VT_1 < VT_2$, i.e.,
iff $VT_1 \leq VT_2$ &
there exists j such that
 $1 \leq j \leq N$ & $VT_1[j] < VT_2[j]$

... OR NOT CAUSALLY-RELATED

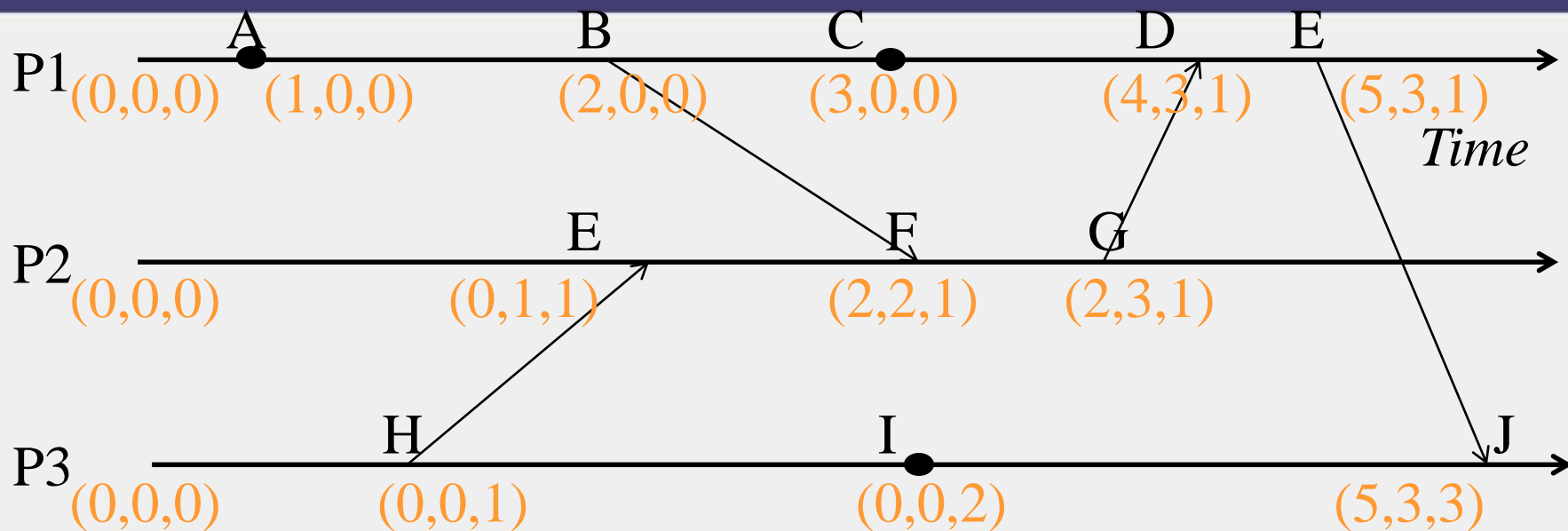
- Two events VT_1 and VT_2 are **concurrent**

iff

$$\text{NOT } (VT_1 \leq VT_2) \text{ AND NOT } (VT_2 \leq VT_1)$$

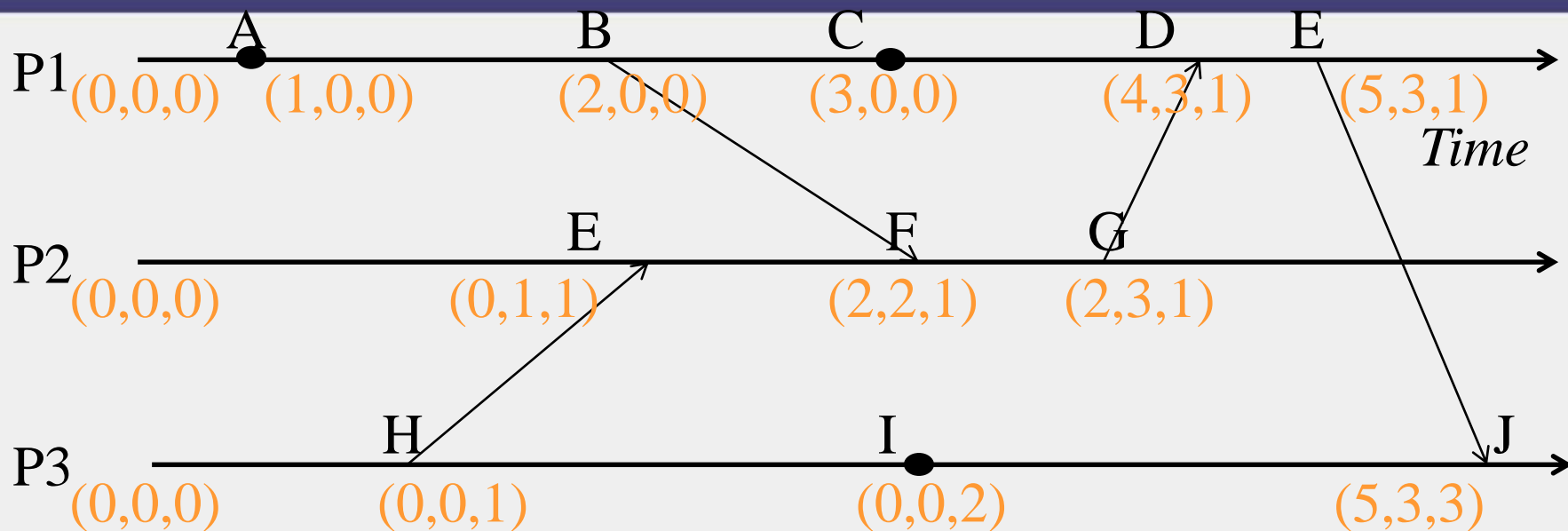
We'll denote this as $VT_2 \parallel VT_1$

OBEYING CAUSALITY



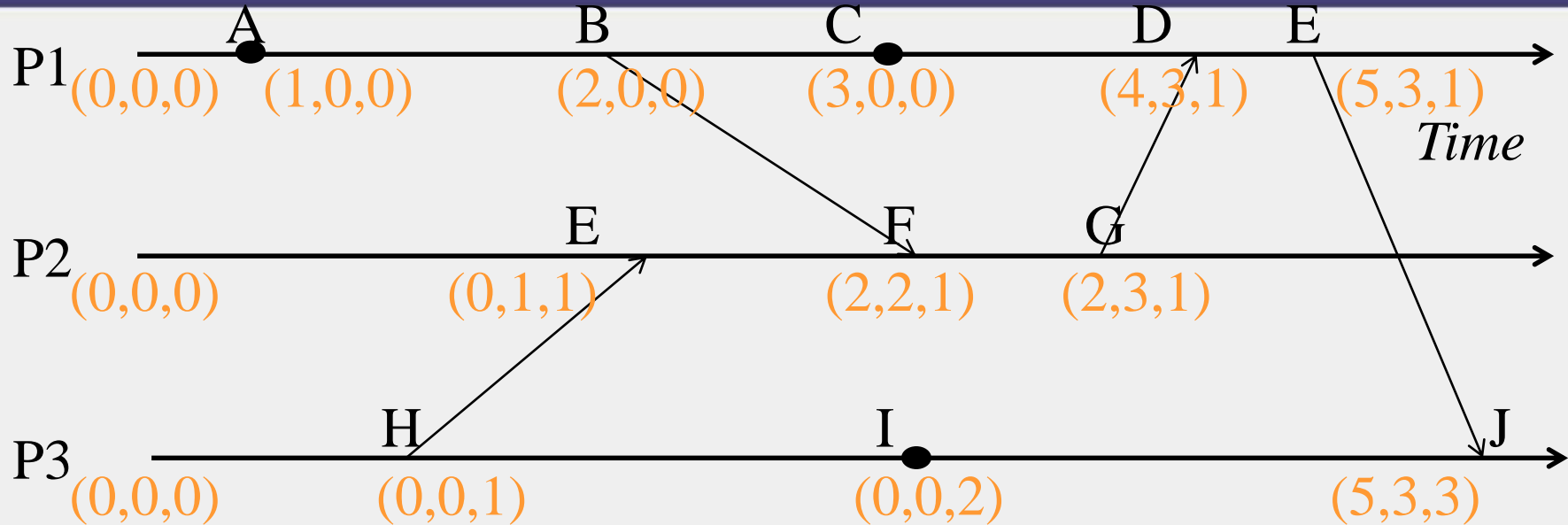
- $A \rightarrow B :: (1,0,0) < (2,0,0)$
- $B \rightarrow F :: (2,0,0) < (2,2,1)$
- $A \rightarrow F :: (1,0,0) < (2,2,1)$

OBEYING CAUSALITY (2)



- $H \rightarrow G :: (0,0,1) < (2,3,1)$
- $F \rightarrow J :: (2,2,1) < (5,3,3)$
- $H \rightarrow J :: (0,0,1) < (5,3,3)$
- $C \rightarrow J :: (3,0,0) < (5,3,3)$

IDENTIFYING CONCURRENT EVENTS



- C & F :: $(\underline{3},0,0) \parallel (2,2,\underline{1})$
- H & C :: $(0,0,\underline{1}) \parallel (\underline{3},0,0)$
- (C, F) and (H, C) are pairs of concurrent events

LOGICAL TIMESTAMPS: SUMMARY

- **Lamport timestamps**
 - Integer clocks assigned to events
 - Obey causality
 - Cannot distinguish concurrent events
- **Vector timestamps**
 - Obey causality
 - By using more space, can also identify concurrent events

TIME AND ORDERING: SUMMARY

- **Clocks are unsynchronized in an asynchronous distributed system**
- **But need to order events, across processes!**
- **Time synchronization**
 - Cristian's algorithm
 - NTP
 - Berkeley algorithm
 - But error a function of round-trip-time
- **Can avoid time sync altogether by instead assigning logical timestamps to events**