Exercise 1

- By considering a chain of zero or more messages connecting events **e** and **e'** and using induction on the length of any sequence of events relating **e** and **e'**, show that **$e \rightarrow e' \Rightarrow L(e) < L(e')$**.

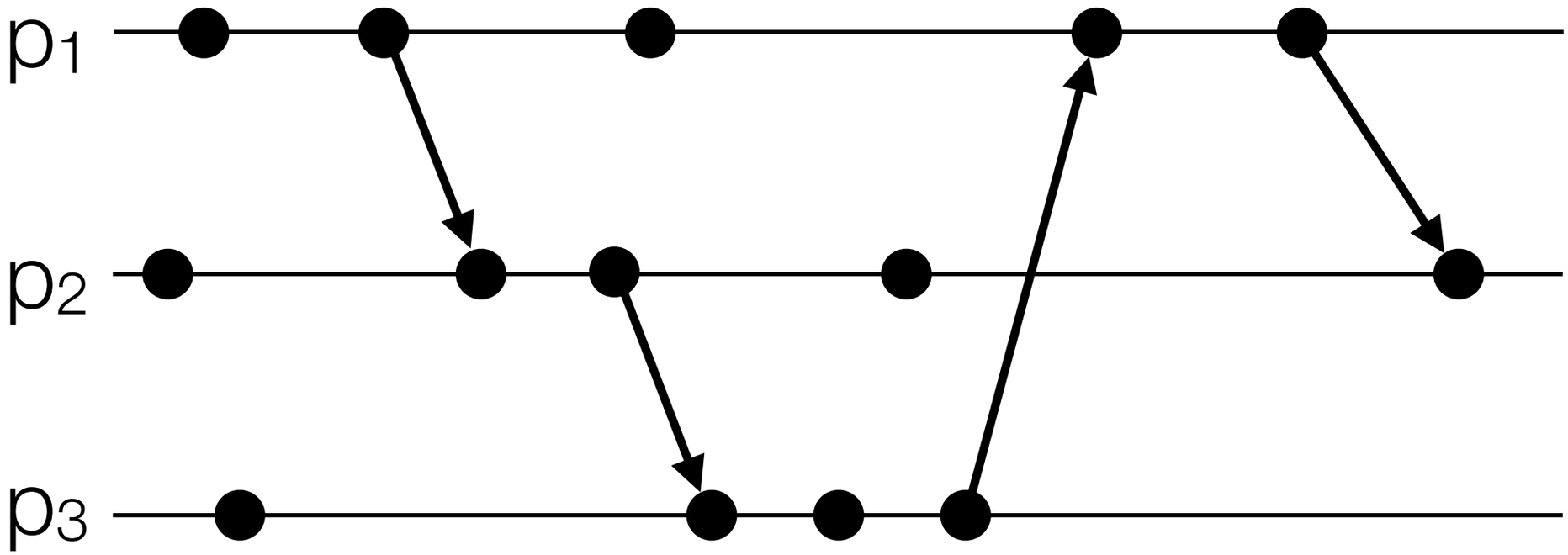
Exercise 2

- The $\rightarrow$ relation is an IRREFLEXIVE PARTIAL ORDERING on the set of all events in the distributed system.
  - Irreflexivity: $\neg(a \rightarrow a)$.
  - Partial ordering: not all the events can be related by $\rightarrow$.

  Extend the definition of the $\rightarrow$ relation to create a total ordering $\Rightarrow$ on events (that is, one for which all pairs of distinct events are ordered).

Exercise 3

- Timestamp the following events by means of vector clocks values.



Exercise 4

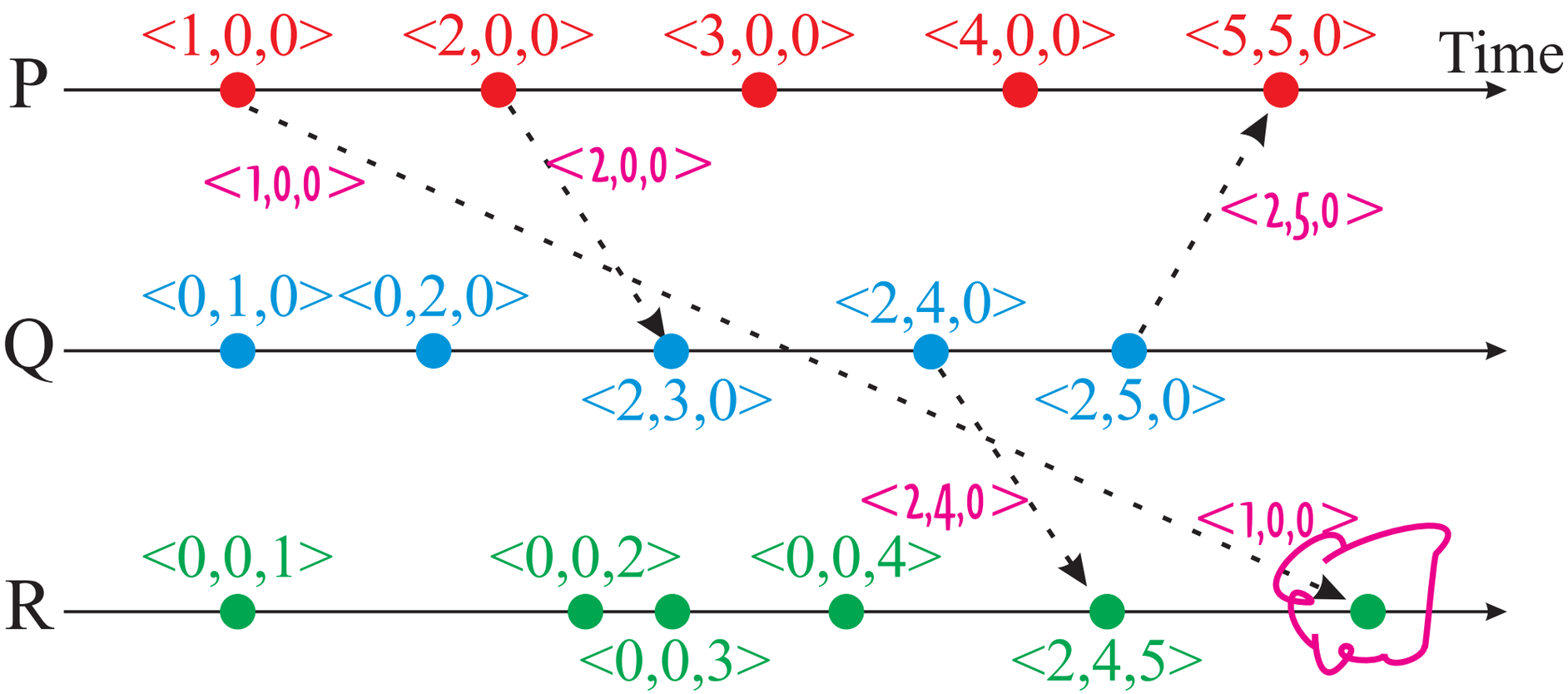
1) Discuss why $V_j[i] \leq V_i[i]$, for any **j** and **i**.

2) Show that $e \rightarrow e' \Rightarrow V(e) < V(e')$.

3) Using the result of Exercise 4.1), discuss why if events **e** and **e'** are concurrent then neither $V(e) \leq V(e')$ nor $V(e') \leq V(e)$.
Hence discuss why if $V(e) < V(e')$ then $e \rightarrow e'$.

Exercise 5

- Violation of causal ordering of messages occurs if msg **m** arrives with $V_m < V_i$.



- Show that it is impossible to capture this violation if we use Lamport clocks.

Exercise 6

- Singhal and Kshemkalyani's technique cuts down the storage overhead at each process from **$O(n^2)$** to ...

- Explain why.