Figure 10.1 Skew between computer clocks in a distributed system

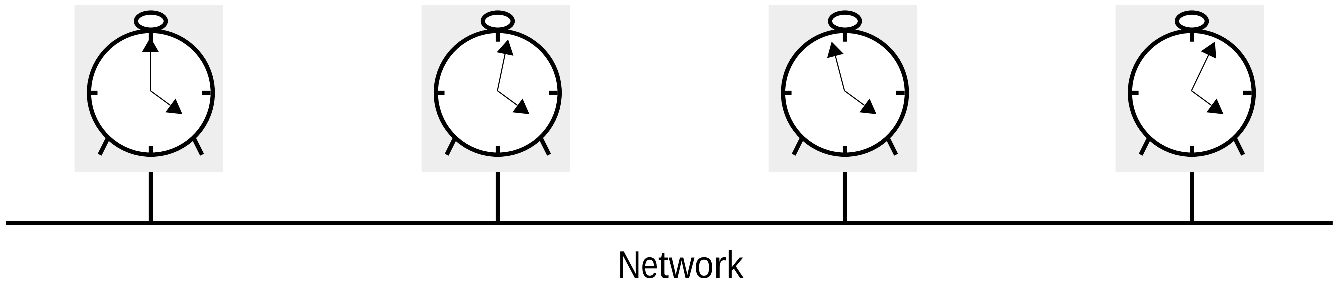


Figure 10.2 Clock synchronization using a time server

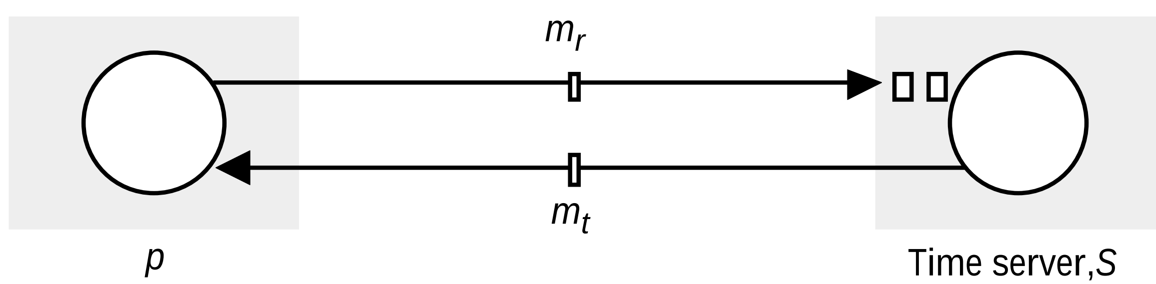
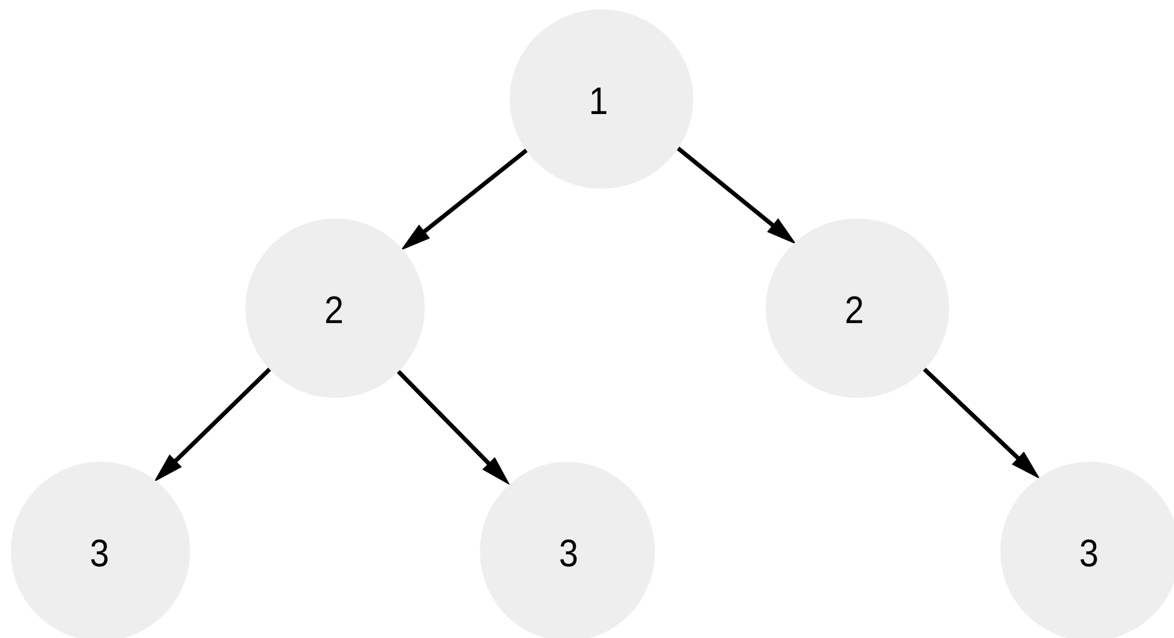


Figure 10.3 An example synchronization subnet in an NTP implementation



Note: Arrows denote synchronization control, numbers denote strata.

Figure 10.4 Messages exchanged between a pair of NTP peers

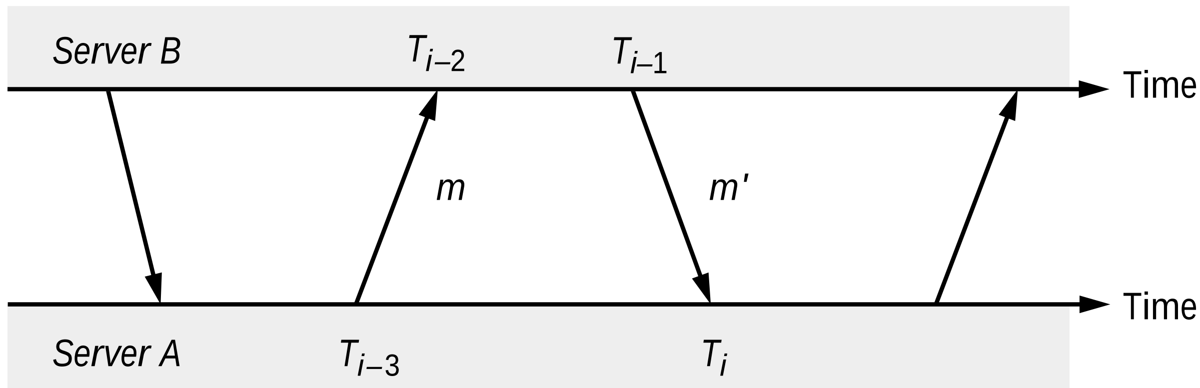


Figure 10.5 Events occurring at three processes

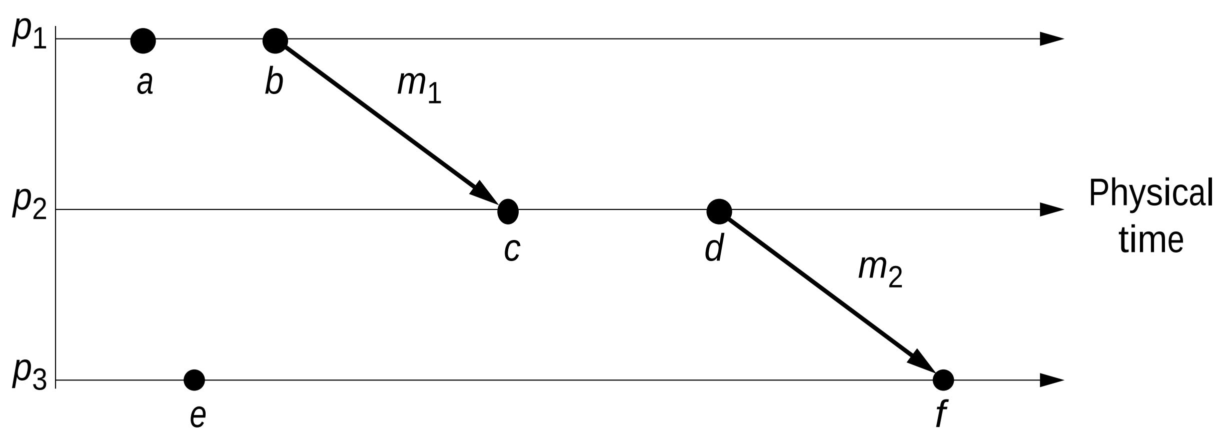


Figure 10.6 Lamport timestamps for the events shown in Figure 10.5.

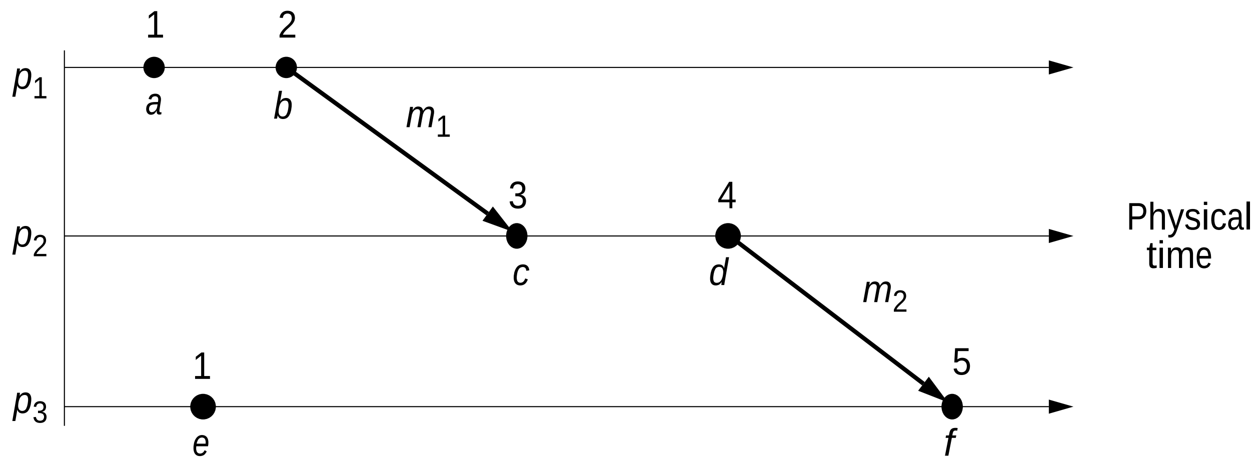


Figure 10.7 Vector timestamps for the events shown in Figure 10.5

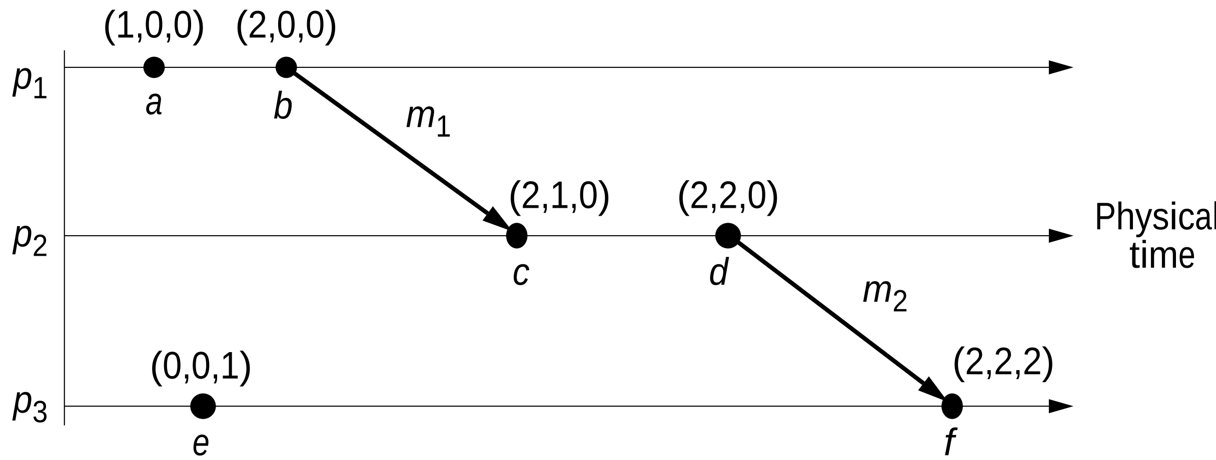


Figure 10.8 Detecting global properties

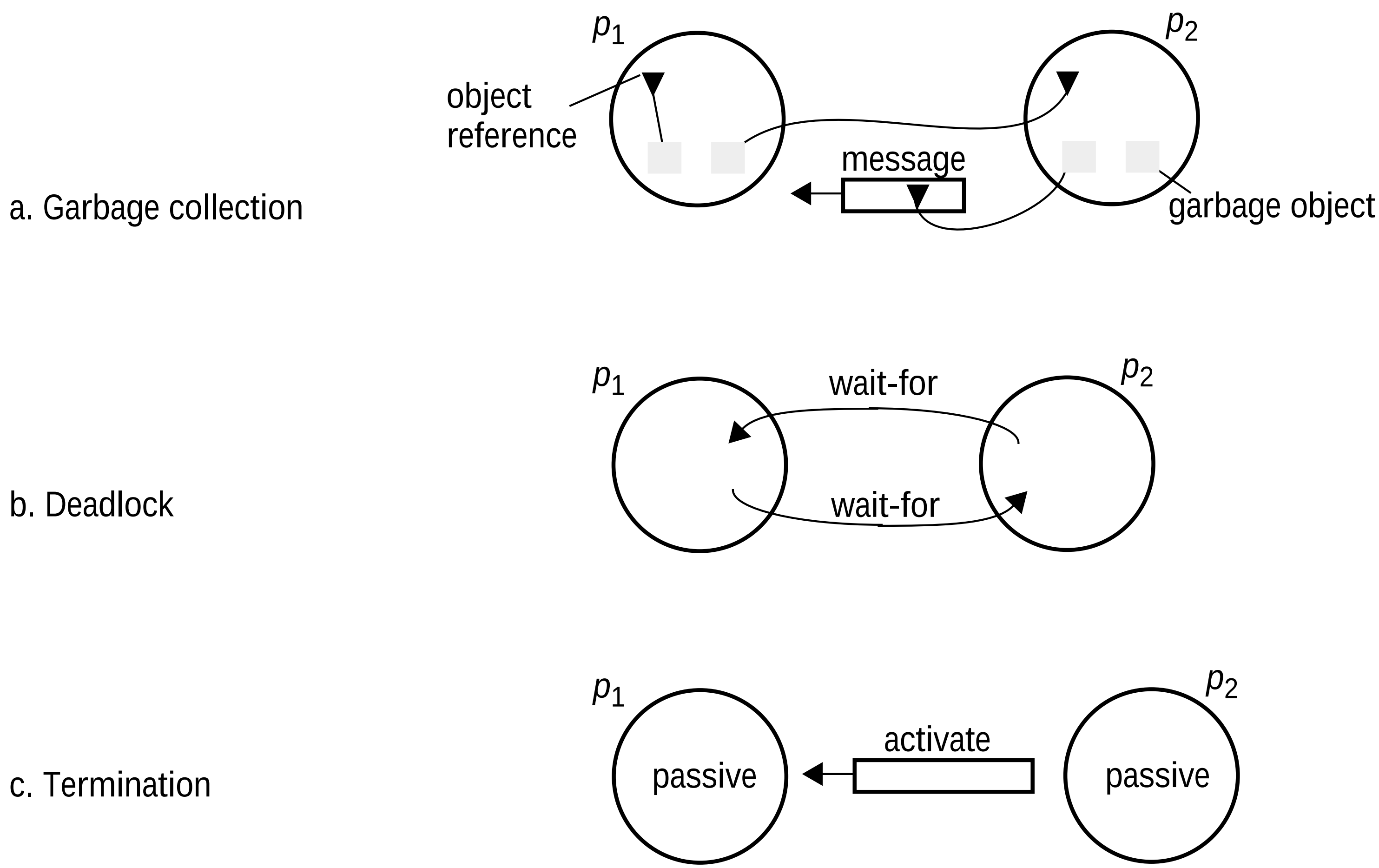


Figure 10.9 Cuts

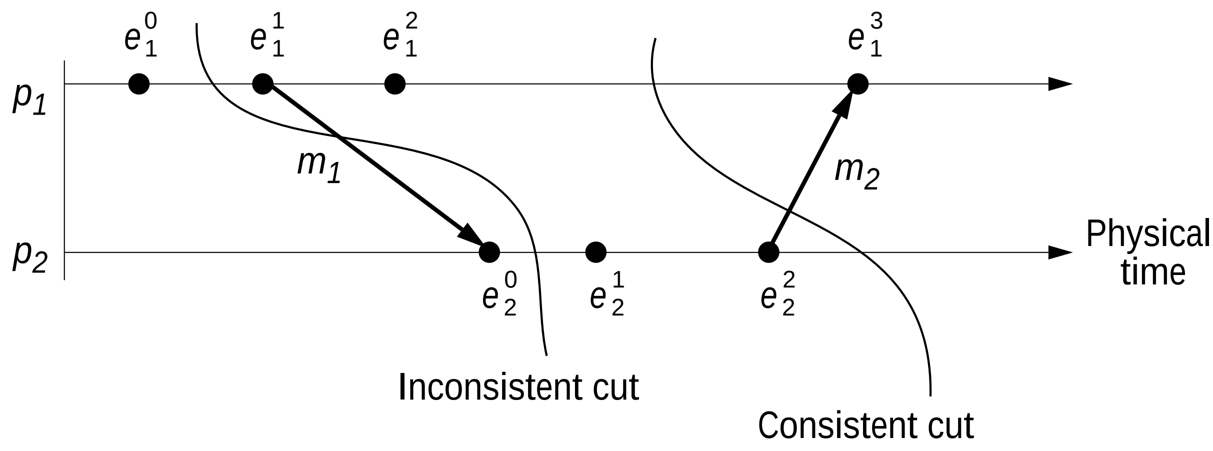


Figure 10.10 Chandy and Lamport's 'snapshot' algorithm

Marker receiving rule for process p_i

On p_i's receipt of a *marker* message over channel *c*:

if (p_i has not yet recorded its state) it

records its process state now;

records the state of *c* as the empty set;

turns on recording of messages arriving over other incoming channels;

else

p_i records the state of *c* as the set of messages it has received over *c* since it saved its state.

end if

Marker sending rule for process p_i

After p_i has recorded its state, for each outgoing channel *c*:

p_i sends one marker message over *c* (before it sends any other message over *c*).

Figure 10.11 Two processes and their initial states

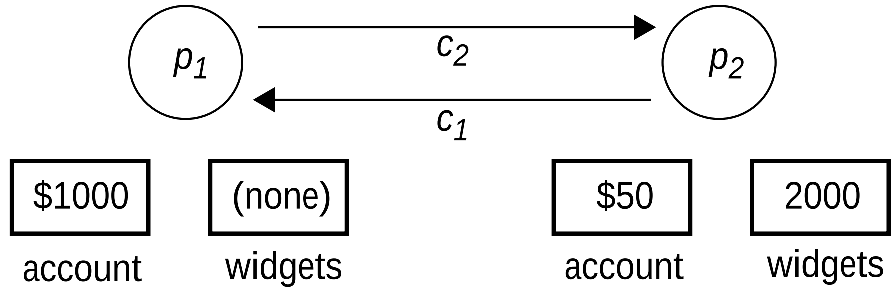


Figure 10.12 The execution of the processes in Figure 10.11

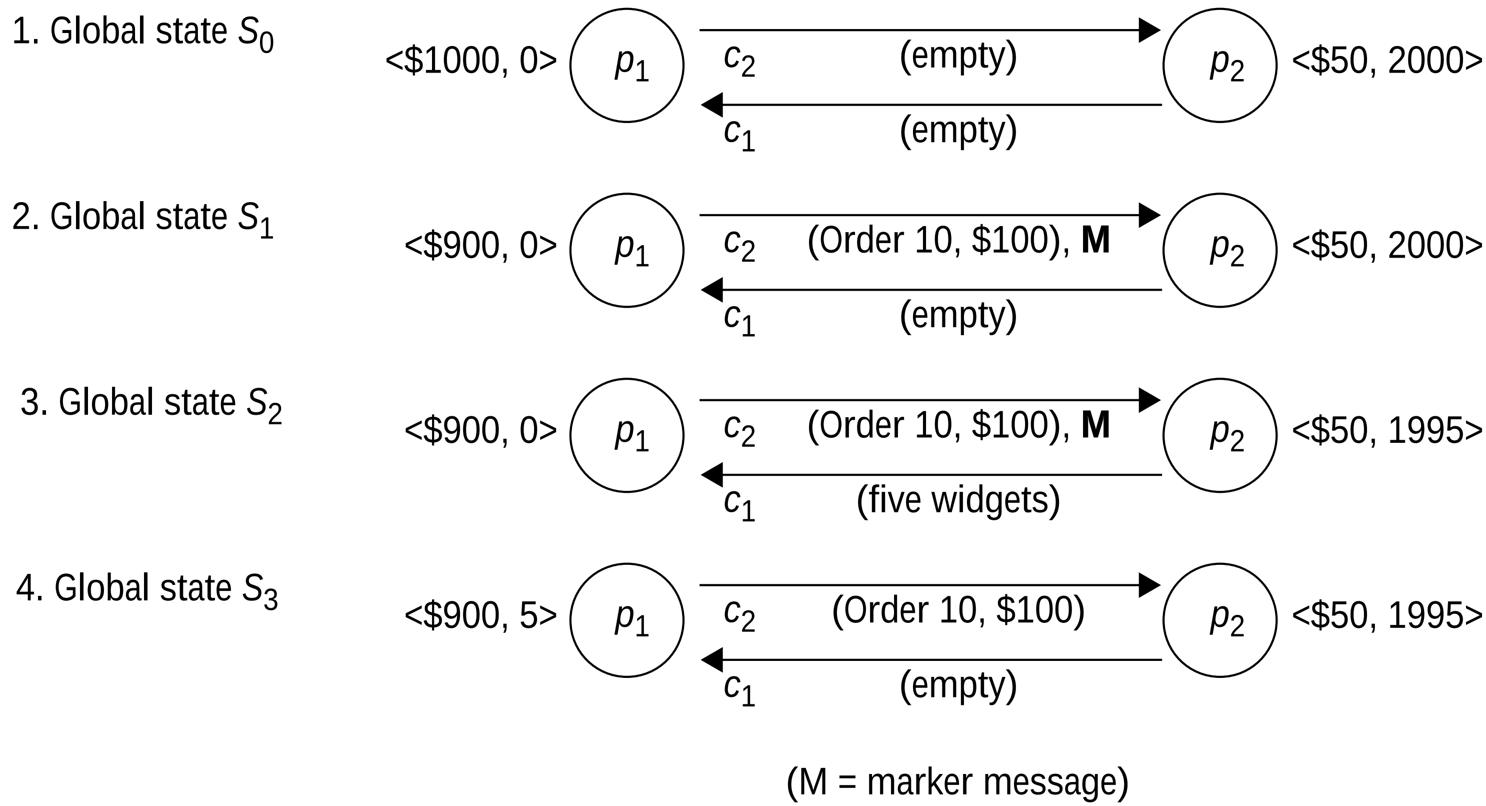


Figure 10.13 Reachability between states in the snapshot algorithm

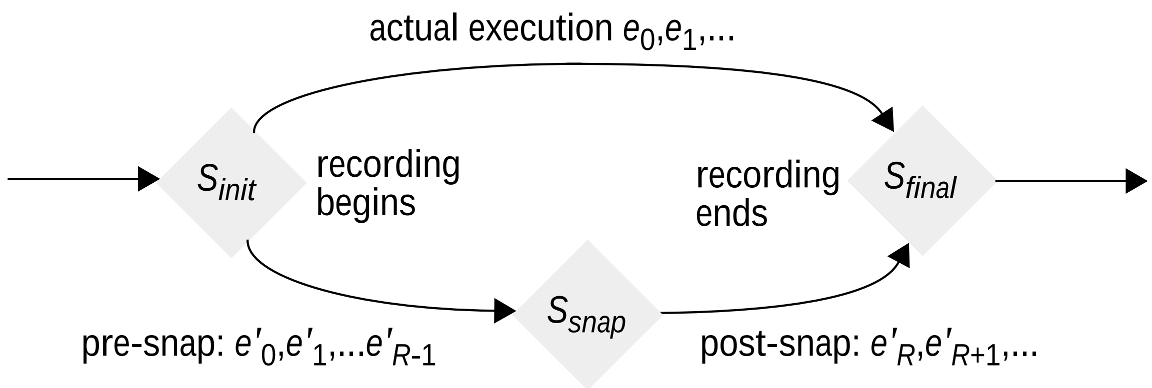


Figure 10.14 Vector timestamps and variable values for the execution of Figure 10.9

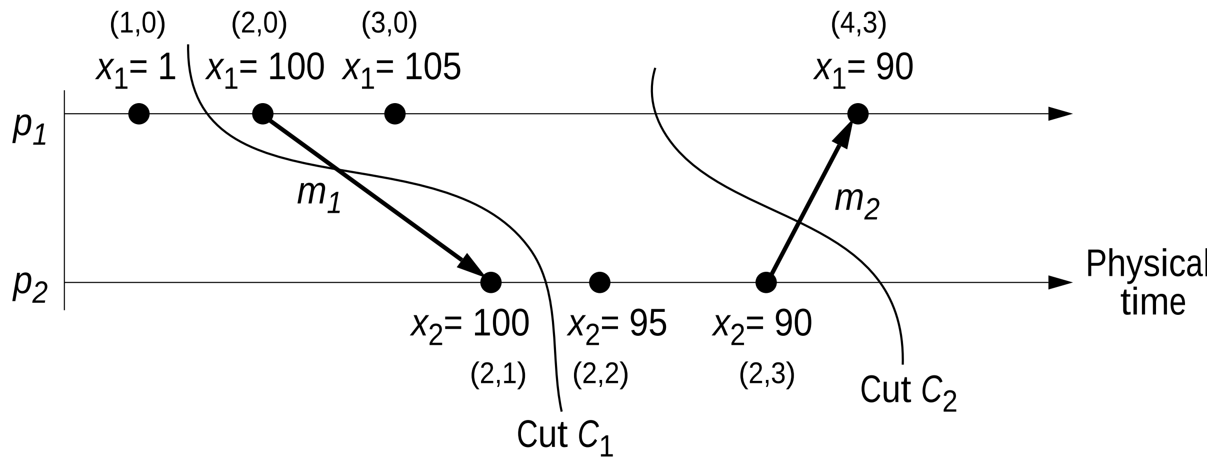


Figure 10.15 The lattice of global states for the execution of Figure 10.14

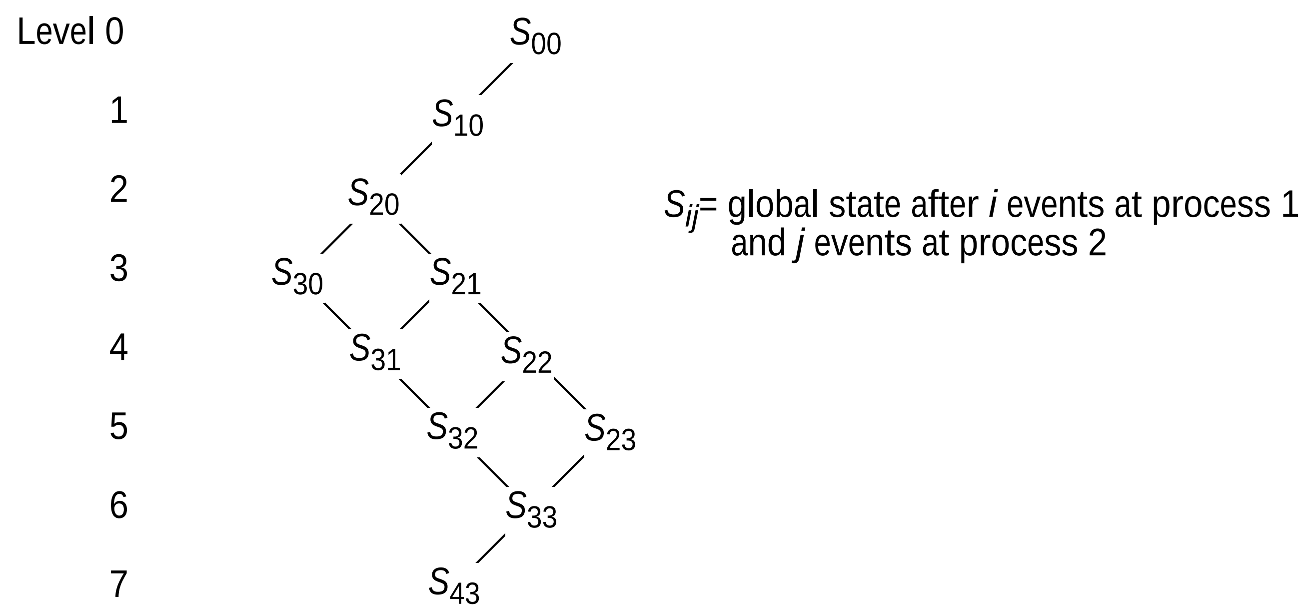


Figure 10.16 Algorithms to evaluate *possibly* ϕ and *definitely* ϕ

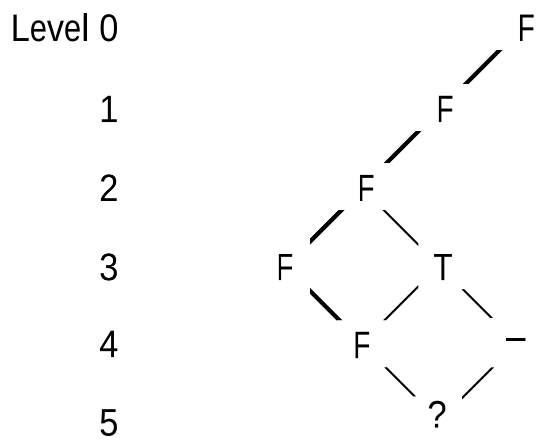
1. *Evaluating possibly ϕ for global history H of N processes*

$L := 0;$
$States := \{ (s_1^0, s_2^0, \ldots, s_N^0) \};$
while $(\phi(S) = False$ for all $S \in$ States$)$
$\quad L := L + 1;$
$\quad Reachable := \{S' : S'$ reachable in H from some $S \in$ States $\wedge$ level$(S') = $ L$\};$
$\quad States := Reachable$
end while
output "*possibly* ϕ";

2. *Evaluating definitely ϕ for global history H of N processes*

$L := 0;$
if $(\phi(s_1^0, s_2^0, \ldots, s_N^0))$ *then* $States := \{\}$ *else* $States := \{ (s_1^0, s_2^0, \ldots, s_N^0) \};$
while $(States \neq \{\})$
$\quad L := L + 1;$
$\quad Reachable := \{S' : S'$ reachable in H from some $S \in$ States $\wedge$ level$(S') = $ L$\};$
$\quad States := \{S \in Reachable : \phi(S) = False\}$
end while
output "*definitely* ϕ";

Figure 10.17 Evaluating *definitely* ϕ



F = ($\phi(S)$ = False); T = ($\phi(S)$ = True)