Termination Detection in a Distributed System

Course: Distributed Computing

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About this topic

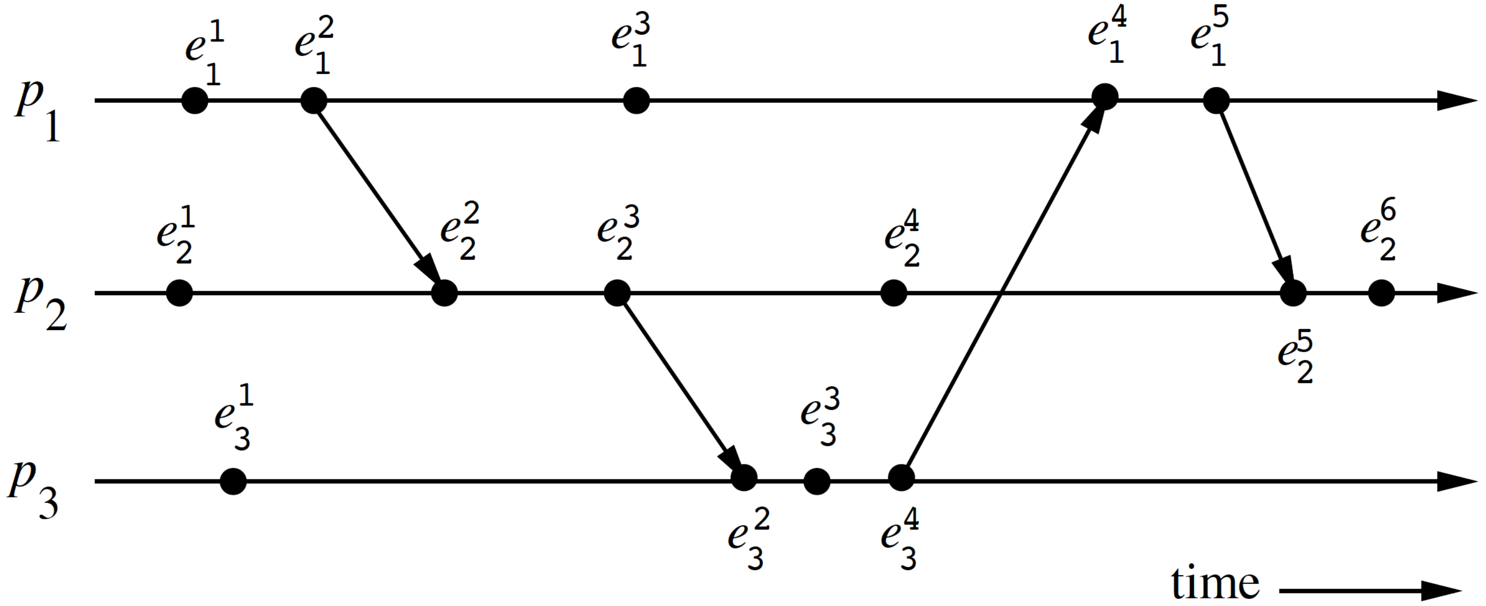
This course covers essential aspects of **Termination Detection in a Distributed System and its related concepts**

RECAP

What did you learn so far?

- Challenges in Message Passing systems
- Distributed Sorting
- Space-Time Diagram
- Partial Ordering / Total Ordering
- Causal Ordering
- Causal Precedence Relation
  - Happens Before
- Concurrent Events
- Local Clocks and Vector Clocks
- Distributed Snapshots

A State-Time diagram – An Example



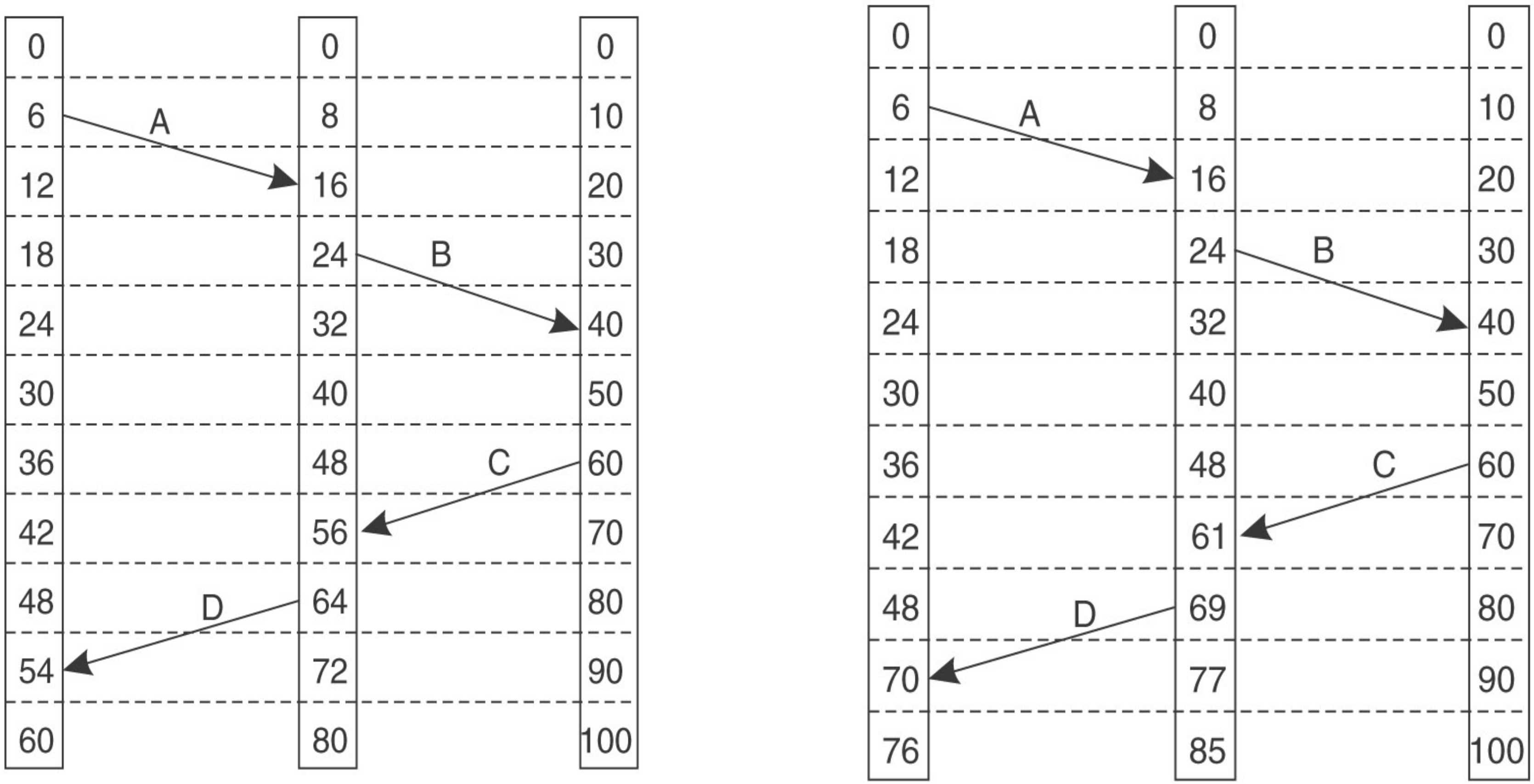
➔ **For Process P'_1:**

Second event is a message send event

First and Third events are internal events

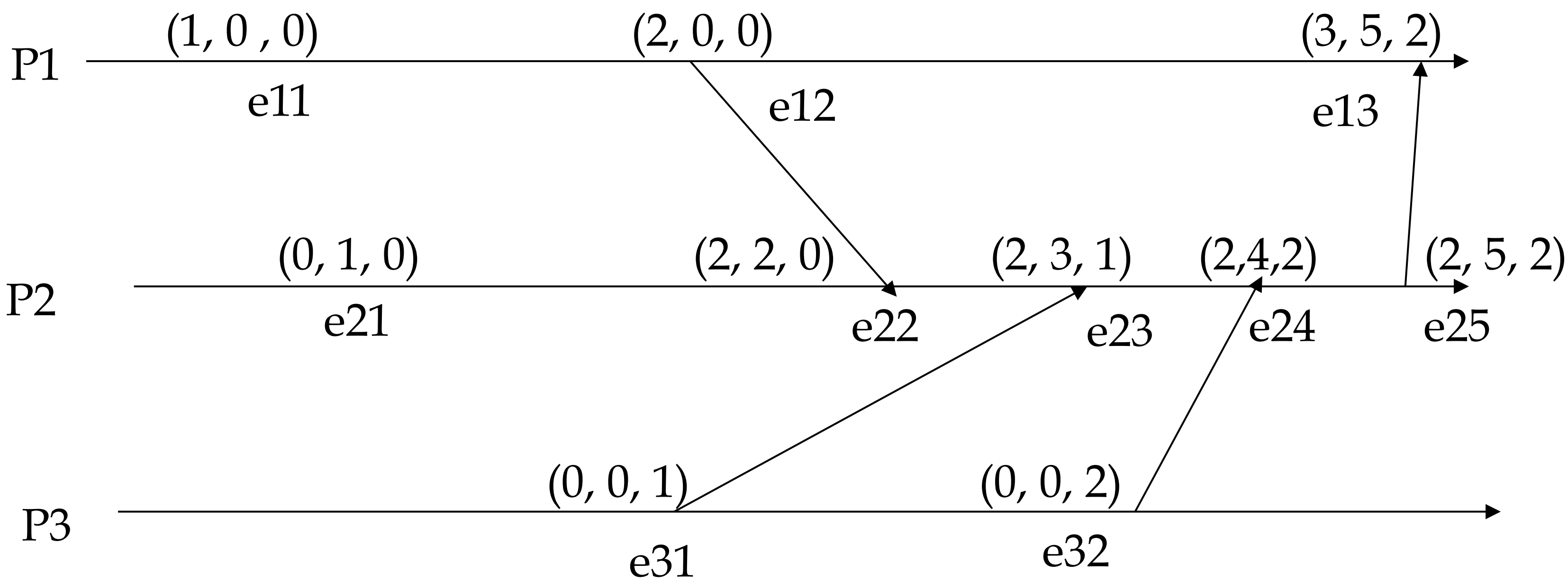
Fourth event is a message receive event

Logical Clocks - Correction of Clocks



(a) (b)

Vector Clocks – An Example



Less than or equal:

- $ts(a) \leq ts(b)$ **if** $ts(a)[i] \leq ts(b)[i]$ **for all** i

  (3,3,5) ≤ (3,4,5)

- $ts(e11) = (1, 0, 0)$ **and** $ts(e22) = (2, 2, 0)$

  This implies $e11 \rightarrow e22$

Global State

- The global state of a distributed system is a collection of the local states of the processes and the channels.

A global state GS is defined as,

$$GS = \{\bigcup_i LS_i^{x_i}, \bigcup_{j,k} SC_{jk}^{y_j, z_k}\}$$

- For a global state to be meaningful, the states of all the components of the distributed system must be recorded at the same instant
- Two important situations (Impossible !!):
  - local clocks at processes were perfectly synchronized
  - there were a global system clock that can be instantaneously read by the processes

A Consistent Global State

Definition:

➔ A global state is a consistent global state iff

$$\forall m_{ij} : \; send(m_{ij}) \not\preceq LS_i^{x_i} \; \Leftrightarrow \; m_{ij} \notin SC_{ij}^{x_i, y_j} \bigwedge rec(m_{ij}) \not\preceq LS_j^{y_j}$$

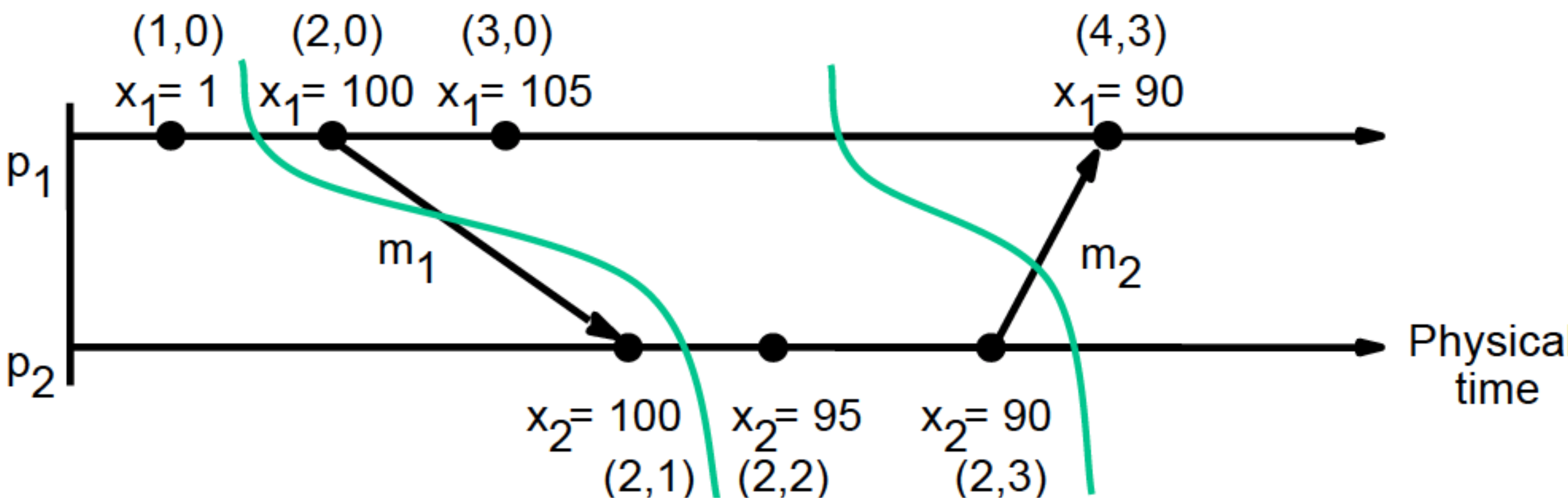
Where the global state is given by

$$GS = \{ \bigcup_i LS_i^{x_i}, \bigcup_{j,k} SC_{jk}^{y_j, z_k} \}$$

➔ This implies that the channel state and process state must not include any message that process P_i sent after executing event

Consistent Global State

- Let $V(s_i)$ be the vector timestamp of state s_i received from P_i.
- S is a consistent global state if and only if: $V(s_i)[i] >= V(s_j)[i]$ for all i,j in $[1, N]$



Reachable

When is a state said to be reachable?

- A state S′ is reachable from a state S if there exists a consistent run (Ordering of events satisfies all happened-before relations) from S to S′.

- May exist more than one consistent run, since the ordering from happened-before relation is a partial order

Data Sensitive Applications

Banking Example

- ➔ A Few Banking Operations
  - deposit(amount)
    - deposit amount in the account
  - withdraw(amount)
    - withdraw amount from the account
  - getBalance() → amount
    - return the balance of the account
  - setBalance(amount)
    - set the balance of the account to amount

Termination Detection

- A fundamental problem: To determine if a distributed computation has terminated
- A non-trivial task: NO process has complete knowledge of the global state, and global time does not exist
- A distributed computation is globally terminated if every process is locally terminated and there is no message in transit between any processes
- "Locally terminated" state is a state in which a process has finished its computation and will not restart any action unless it receives a message
- In the termination detection problem, a particular process (or all of the processes) must infer when the underlying computation has terminated

Important aspects

- Messages used in the underlying computation are called **basic messages**, and messages used for the purpose of termination detection are called **control messages**

- A termination detection (TD) algorithm must ensure the following:
  - Execution of a TD algorithm cannot indefinitely delay the underlying computation
  - The termination detection algorithm must not require addition of new communication channels between processes

System Model

- At any given time, a process can be in only one of the two states: active where it is doing local computation and idle otherwise and will be reactivated only on the receipt of a message from another process.
- An active process can become idle at any time but an idle process can become active only on the receipt of a message from another process
- Only active processes can send messages
- A message can be received by a process when it is in one of two states: active or idle. On receipt of a message, an idle process becomes active
- The sending of a message and the receipt of a message occur as atomic actions

Termination Detection - Definition

- Let $P_i\ (t)$ denote the state (active or idle) of process P_i at instant t
- Let $c_{i,\ j}\ (t)$ denote the number of messages in transit in the channel at instant t from process P_i to process P_j
- A distributed computation is said to be **terminated** at time instant t_k iff:

$$\textit{for all } i\ ,$$

$$(P_i\ (t_k) = \textit{idle})\ \wedge\ (\textit{for all } i, j \textit{ such that } c_{i,j}\ (t_k)\ ) = 0$$

- Thus, a distributed computation has terminated iff all processes have become idle and there is no message in transit in any channel

TD using Distributed Snapshots

- **Assumption:** There is a logical bidirectional communication channel between every pair of processes
- Communication channels are reliable
- Message delay is arbitrary but finite

TD using Distributed Snapshots

Main idea:

- When a process goes from active to idle state, it issues a request to all other processes to take a local snapshot, and also requests itself to take a local snapshot
- When a process receives the request, if it agrees that the requester became idle before itself, it grants the request by taking a local snapshot for the request
- A request is successful if all processes have taken a local snapshot
- The requester or any external agent may collect all the local snapshots of a request
- If a request is successful, a global snapshot of the request can thus be obtained and the recorded state will indicate termination of the computation

A Formal Description

- Each P_i has a logical clock x initialized to zero at t_0
- A process increments its x by one each time it becomes idle
- A basic message sent by a process at its logical time x is of the form $B(x)$
- A control message that requests processes to take local snapshot issued by P_i at its logical time x is of the form $R(x, i)$
- Each process synchronizes its logical clock x loosely with the logical clocks x's on other processes in such a way that it is the maximum of clock values ever received or sent in messages
- A process also maintains a variable k such that when the process is idle, (x,k) is the maximum of the values (x, k) on all messages $R(x, k)$ ever received or sent by the process
- Logical time is compared as follows: $(x, k) > (x', k')$ *iff* $(x > x')$ *or* $((x=x')$ *and* $(k>k'))$ i.e., a tie between x and x' is broken by the process identification numbers k and k'

Algorithm

➔ **Four Rules:**

(R1): When process i is active, it may send a basic message to process j at any time by doing

send a $B(x)$ *to* j.

(R2): Upon receiving a $B(x')$, process i does

let $x{:=}x'+1$;

if (i is idle) $\longrightarrow$ go active.

(R3): When process i goes idle, it does

let $x{:=}x+1;$

let $k{:=}i;$

send message $R(x,\ k)$ to all other processes;

take a local snapshot for the request by $R(x,\ k)$.

(R4): Upon receiving message $R(x',\ k')$, process i does

$[((x',\ k') > (x,k)) \wedge$ (i is idle)$\longrightarrow$ let $(x,k){:=}\ (x',\ k');$

take a local snapshot for the request by $R(x',\ k')$;

$\square$

$((x',\ k') \leq (x,k)) \wedge (i \text{ is idle}) \longrightarrow$ do nothing;

$\square$

(i is active)$\longrightarrow$ let $x{:=}\max(x',\ x)$].

➔ **The last process to terminate will have the largest clock value.**

Summary

- ➔ Global Snapshots
  - ➔ Global State of a DS
  - ➔ Chandy – Lamport's GS Recording Algorithm
    - ➔ Initiating / Propagating / Terminating the Snapshot Algorithm
- ➔ Termination Detection
  - ➔ Definition
  - ➔ A Formal Description
  - ➔ TD using Global Snapshots

➔ Many more to come up … stay tuned in !!

How to reach me?

- Please leave me an email:

  rajendra [DOT] prasath [AT] iiits [DOT] in

- Visit my homepage @

  - http://www.iiits.ac.in/FacPages/index-rajendra.html

  OR

  - http://rajendra.2power3.com

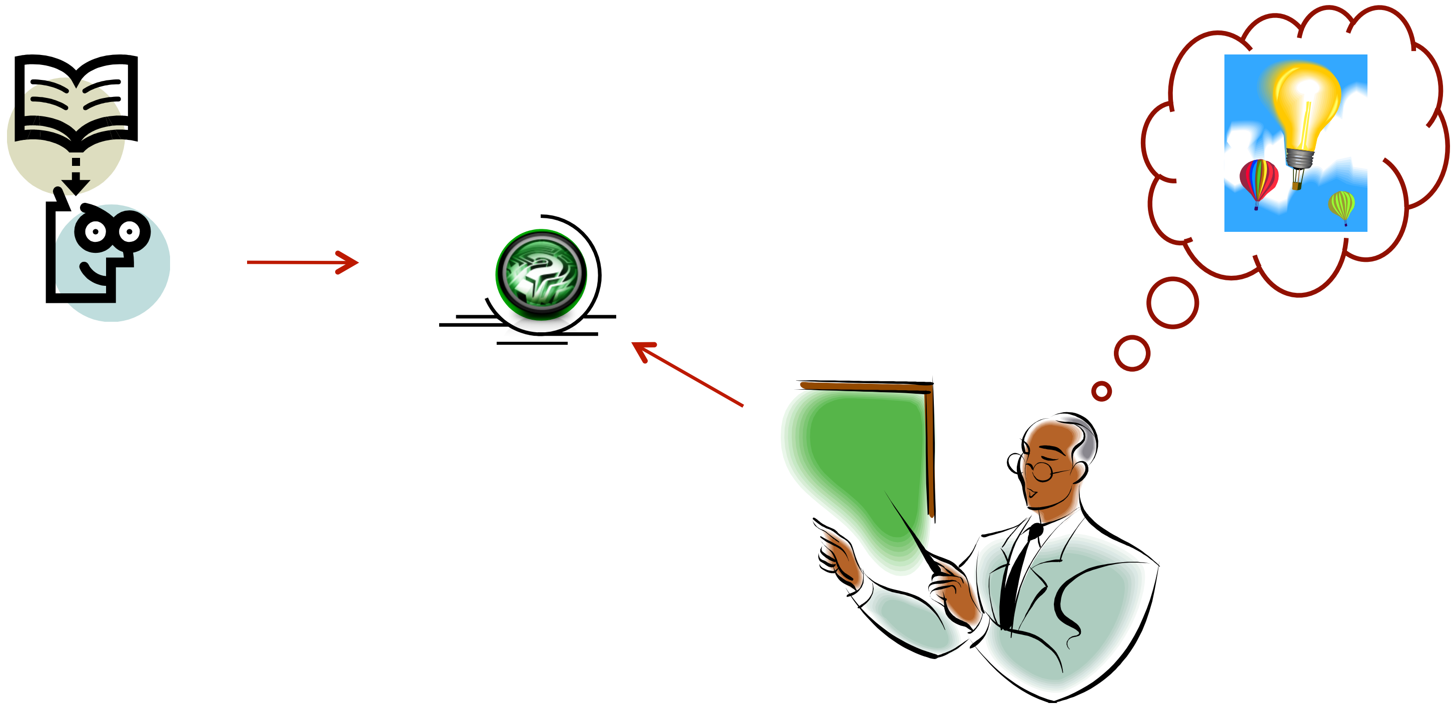
Help among Yourselves?

- **Perspective Students** (having CGPA above 8.5 and above)
- **Promising Students** (having CGPA above 6.5 and less than 8.5)

- **Needy Students** (having CGPA less than 6.5)
  - Can the above group help these students? (Your work will also be rewarded)

- You may grow a culture of **collaborative learning** by helping the needy students

Thanks …



… Questions ???