Termination Detection in a Distributed System

Course: Distributed Computing

Faculty: Dr. Rajendra Prasath

About this topic

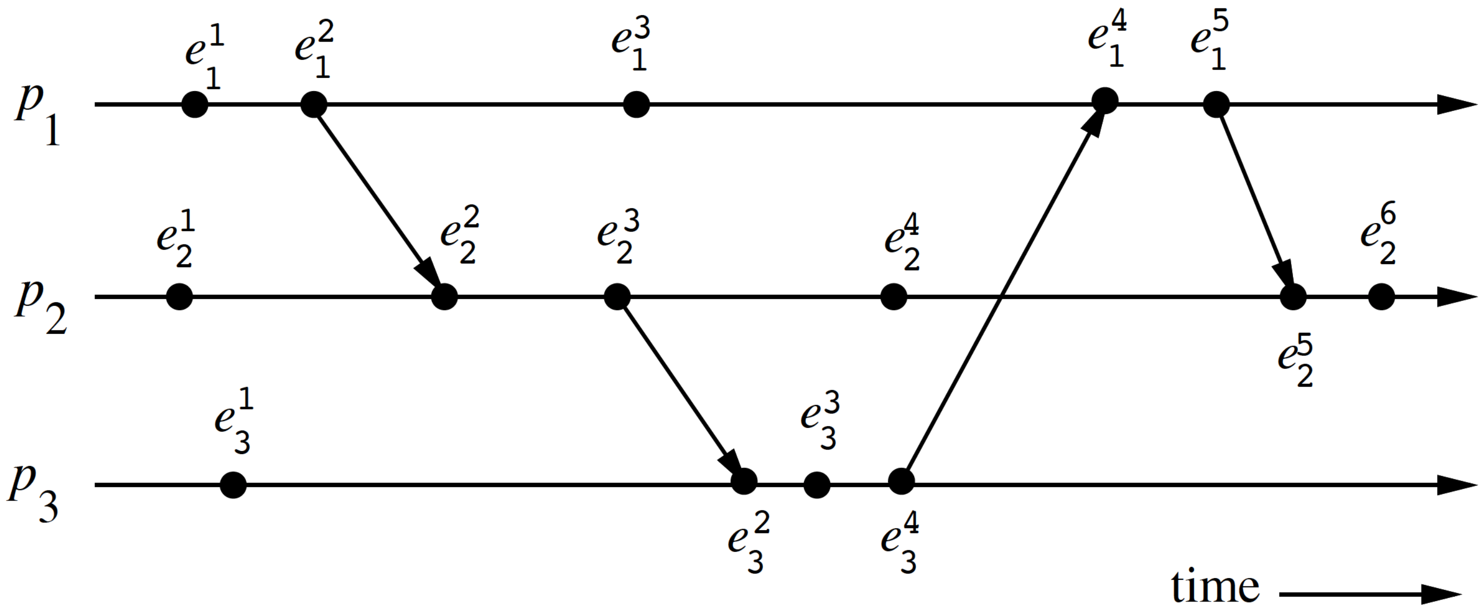
This course covers essential aspects of **Termination Detection in Distributed Systems and its related concepts**

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



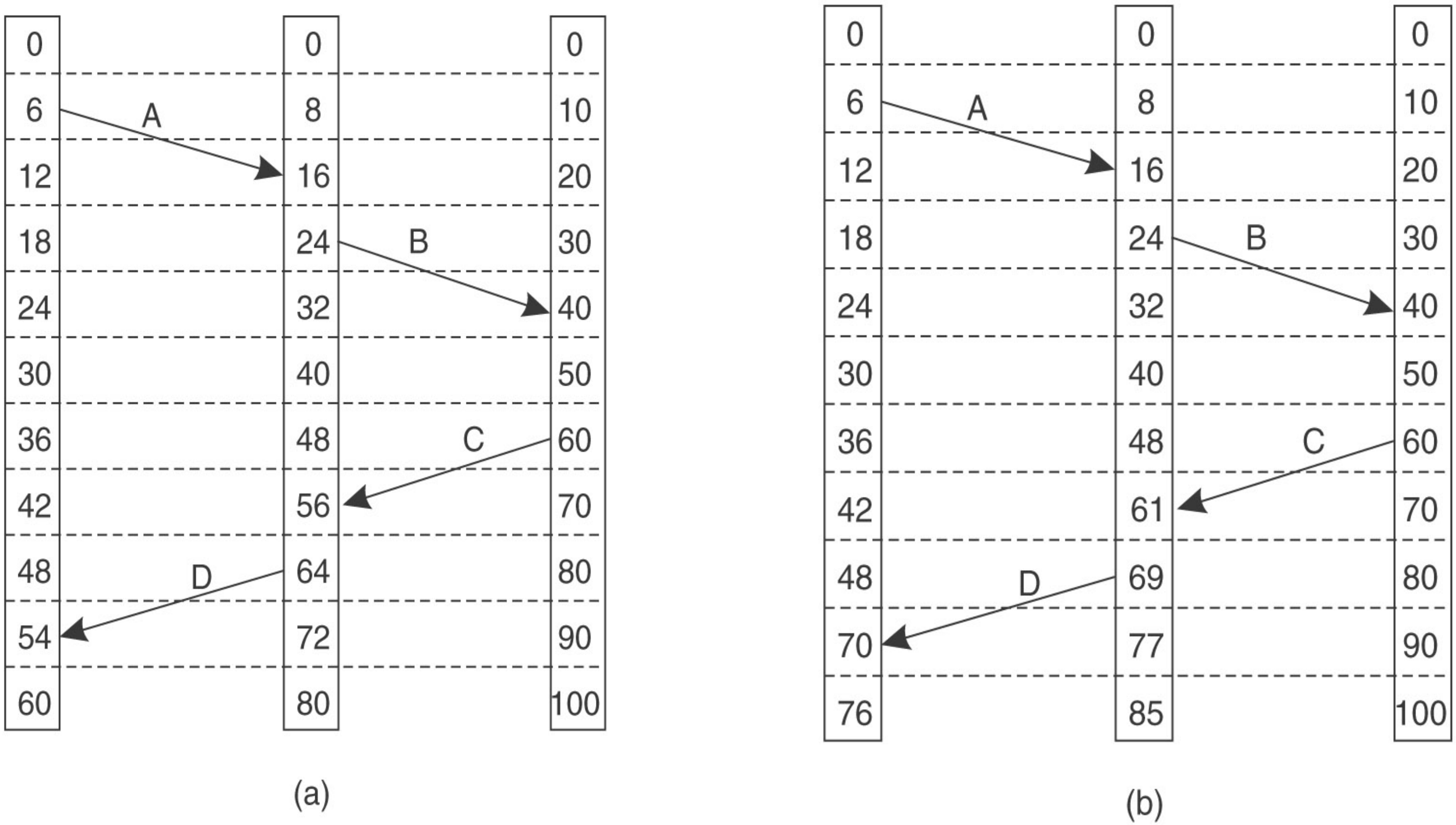
- **For Process P'_1:**

  Second event is a message send event

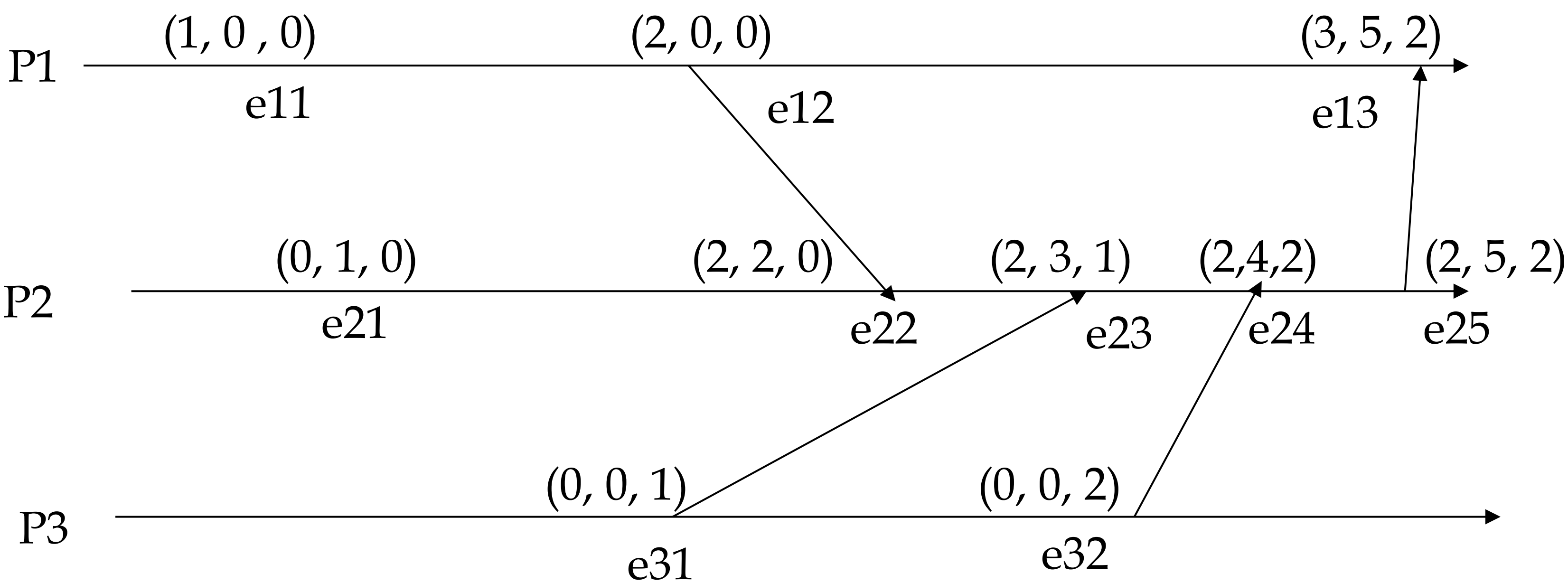
  First and Third events are internal events

  Fourth event is a message receive event

Logical Clocks - Correction of Clocks



Vector Clocks – An Example



Less than or equal:

- ➔ *ts(a)* ≤ *ts(b)* **if** *ts(a)[i]* ≤ *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* □ *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

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

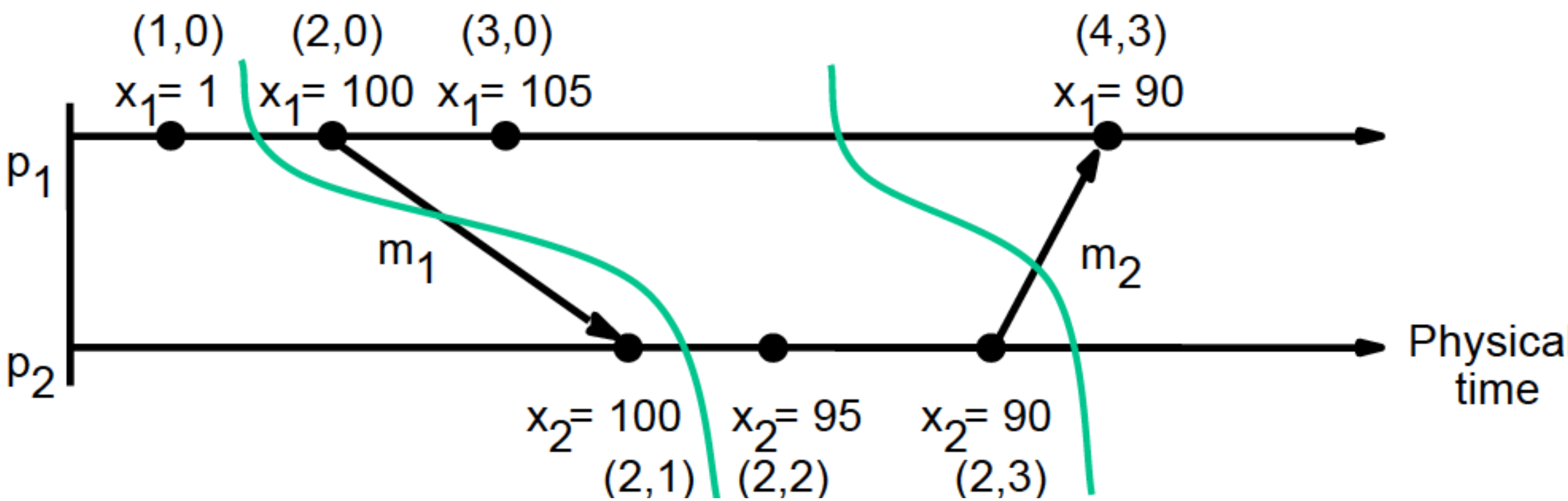
Where the global state is given by

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

- 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: Determine the termination status of a distributed computation
- 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:

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

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

- 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

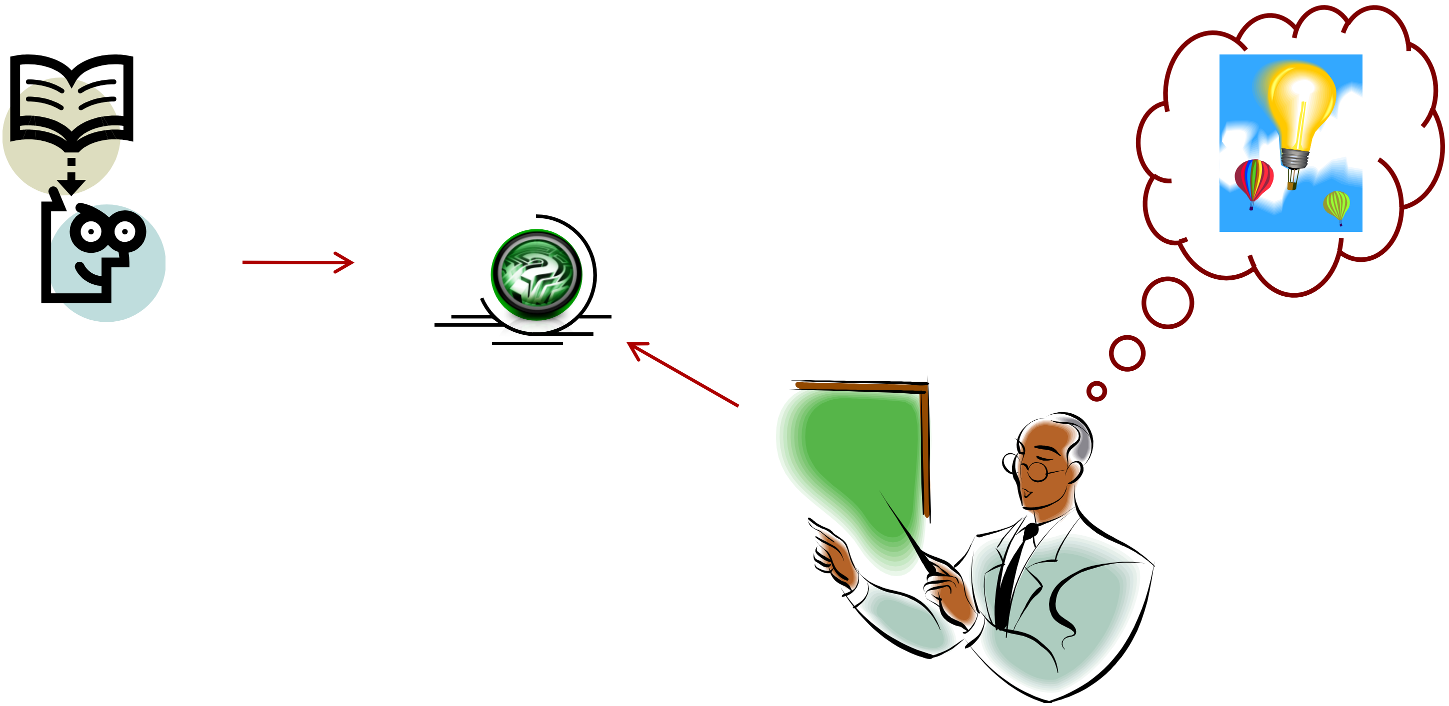
Help among Yourselves?

- **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 ???