INDIAN INSTITUTE OF TECHNOLOGY KHARAGPUR												
											Stamp / Signature of the Invigilator	
EXAMINATION (Mid Semester)									SEMESTER (Spring 2024)			
Roll Number									Section		Name	
Subject Number	C	S	6	0	0	0	2	Subject Name	Distributed Systems			
Department / Center of the Student									Additional sheets			

Important Instructions and Guidelines for Students

1. You must occupy your seat as per the Examination Schedule/Sitting Plan.
2. Do not keep mobile phones or any similar electronic gadgets with you even in the switched off mode.
3. Loose papers, class notes, books or any such materials must not be in your possession, even if they are irrelevant to the subject you are taking examination.
4. Data book, codes, graph papers, relevant standard tables/charts or any other materials are allowed only when instructed by the paper-setter.
5. Use of instrument box, pencil box and non-programmable calculator is allowed during the examination. However, exchange of these items or any other papers (including question papers) is not permitted.
6. Write on both sides of the answer script and do not tear off any page. **Use last page(s) of the answer script for rough work.** Report to the invigilator if the answer script has torn or distorted page(s).
7. It is your responsibility to ensure that you have signed the Attendance Sheet. Keep your Admit Card/Identity Card on the desk for checking by the invigilator.
8. You may leave the examination hall for wash room or for drinking water for a very short period. Record your absence from the Examination Hall in the register provided. Smoking and the consumption of any kind of beverages are strictly prohibited inside the Examination Hall.
9. Do not leave the Examination Hall without submitting your answer script to the invigilator. **In any case, you are not allowed to take away the answer script with you.** After the completion of the examination, do not leave the seat until the invigilators collect all the answer scripts.
10. During the examination, either inside or outside the Examination Hall, gathering information from any kind of sources or exchanging information with others or any such attempt will be treated as **'unfair means'**. Do not adopt unfair means and do not indulge in unseemly behavior.

Violation of any of the above instructions may lead to severe punishment.

Signature of the Student

To be filled in by the examiner

Question Number	1	2	3	4	5	6	7	8	9	10	Total
Marks Obtained											

Marks obtained (in words)	Signature of the Examiner	Signature of the Scrutineer

Write the answers in the boxes only. You can use the designated spaces for rough works. This question has 10 pages including the space for rough works.

1. Answer the following questions briefly. Marks will be deducted for unnecessary descriptions. No marks will be given if the answers are not explained and only Yes/No answer is given.

   [10x3=30 Marks]

   (a) Consider that π is a distributed knowledge for a Group G. Under the following conditions, state whether the group can use a Gossip-based protocol to make π a common knowledge? [State clearly, if you make any additional assumptions.]

   (i) The communication channel is asynchronous but reliable; there is no failure.

   (ii) The communication channel is synchronous but unreliable; there is no failure.

   (b) Define a *fair-loss* link. How can you convert a *fair-loss* link to a *reliable* link?

(c) Consider a network of processes with synchronous, bi-directional, and reliable communication channels. However, the processes in this network can fail (fail-stop) arbitrarily. Let the network has a common knowledge that at most 20% of the processes can fail in the network; however, the total number of processes in the network is not a common knowledge. Is it possible to elect a leader in this network through a distributed leader election algorithm? Explain your answer. If you think that a leader election is possible, give the outline of your algorithm.

(d) Consider a network of processes which communicate over synchronous, reliable, bi-directional communication channels. The processes and the communication channels represent a graph, where each node denotes a process, and an edge between two nodes denotes a bi-directional communication channel between the corresponding processes. You want to develop a Breadth First Search (BFS) Tree over this graph in a distributed way; however, the processes do not have a knowledge of the complete graph, and they just know their neighbours. Do the processes need any common knowledge at the beginning to run a distributed BFS algorithm successfully on this network of processes? Explain your answer.

(e) Assume a set of N agents divided into two groups G_1 and G_2. Consider two facts π_1 and π_2. π_1 is a common knowledge in G_1, and $\pi_1 \cup \pi_2$ is a common knowledge in G_2. Assume that there is at least one agent that belongs to both the groups G_1 and G_2. Is $\pi_1 \cap \pi_2$ a common knowledge for the agents in $G_1 \cup G_2$? Explain your answer.

(f) Consider four events e_1, e_2, e_3 and e_4. Say, $e_1 \rightarrow e_2$ and $e_3 \rightarrow e_4$. Say, $TL(e_2) < TL(e_3)$, where $TL(e)$ is the Lamport clock timestamp of an event. Then can we say, $e_1 \rightarrow e_4$? Explain your answer. Can we say, $e_1 \rightarrow e_4$, if $TV(e_2) < TV(e_3)$, where $TV(e)$ is the Vector clock timestamp of an event. Explain the answer.

(g) Consider that there are three processes P_1, P_2, and P_3. Say, the vector clock of two events $e(P_1)$ (triggered over P_1) and $e(P_3)$ (triggered over P_3) are $[2,5,3]$ and $[6,2,4]$ respectively. Which of the followings is true? (a) $e(P_1) \rightarrow e(P_3)$, (b) $e(P_3) \rightarrow e(P_1)$, (c) $e(P_1) || e(P_3)$, where $\rightarrow$ indicates the *happened-before* relation, and $||$ indicates that the two events are parallel. Explain your answer.

(h) Can vector clock generate a total ordering of the events in a distributed system? Explain your answer.

(i) Consider three processes P_1, P_2 and P_3 where every communication follows the causal delivery criteria. Let e be an event in P_1 and e' be an event in P_3. If $LC(e) < LC(e')$, where LC denote the Lamport's logical clock timestamp of an event, then can we say $e \rightarrow e'$? Explain your answer.

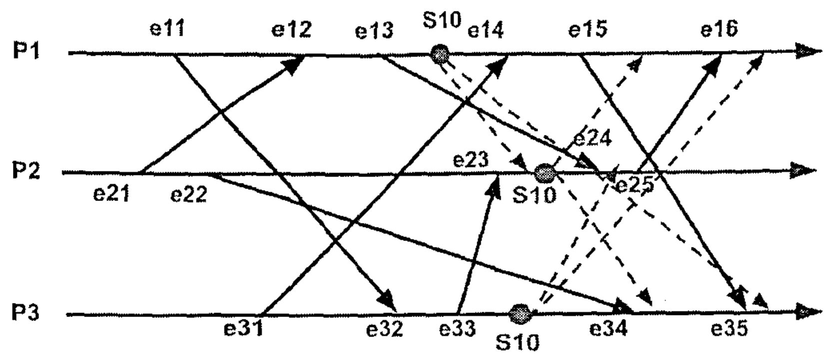
(j) Consider three processes P_1, P_2 and P_3, where the communication between any pair of processes always follows the FIFO delivery rule. Are the communications also causal? Explain your answer.

Space for Rough Works

2. **Common Knowledge and Distributed Snapshot** **[Total 15 Marks]**

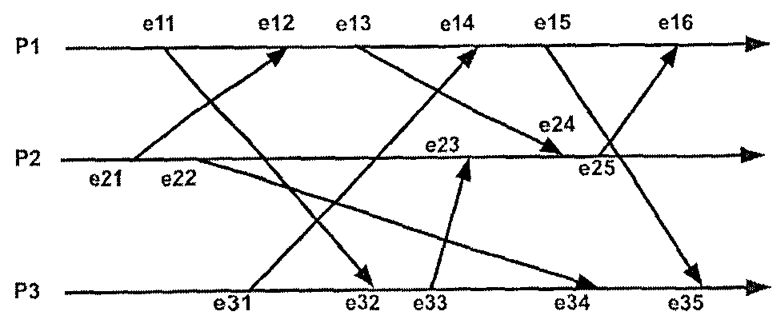
(a) Consider the Distributed Systems Class, where the instructor chooses two students – Student A and Student B. The instructor then announces the following:
Among the integers ranging from 2 to 7, including 2 and 7 themselves, I will choose two different numbers. I will whisper the sum to Student A and the least common multiple (LCM) to Student B. the LCM of two positive integers x and y is the smallest positive integer that is divisible by both x and y without any remainder; for example, LCM(3,6)=6 and LCM(5,7)=35.
The instructor then performs as promised. The following dialogues are then taken place among the students.
Student A: *I know that Student B does not know the numbers.*
Student B: *Okay, but now I do know them.*
Student C: *I now know them as well.*
Find out what are the numbers. Explain your answer with each steps. [Hint: Analyze what is the common knowledge gained after each of the above dialogues.] **[8 Marks]**

(b) Consider the following figure that shows three processes $P1$, $P2$ and $P3$, and the corresponding events and message transfers across the processes, mas shown through solid arrows.



Let the three processes start taking snapshot $S10$. The dots marked as $S10$ indicates when the markers are sent, and the dotted arrows indicate the transfer of the markers from one process to another. Answer the following questions.

(a) Following the notion of the Lamport's logical clock, write down the clock values for each of the events on the following diagram. **[3 Marks]**

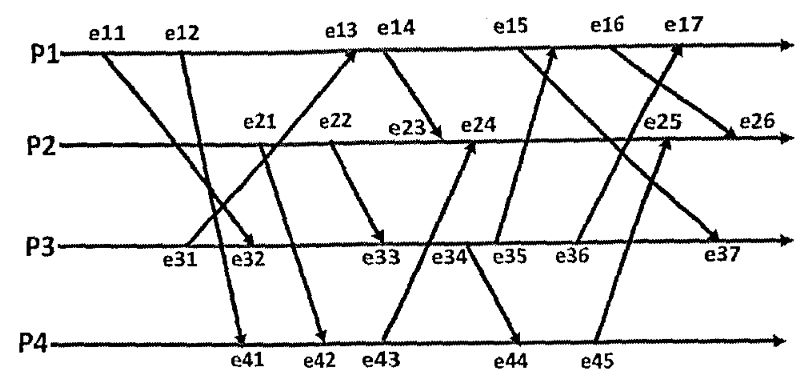


(b) Write down the events that will be recorded at each process, and for each channel, for the snapshot $S10$. Consider that $e11$, $e21$, and $e31$ were not recorded in a process or in a channel during the previous snapshot. **[4 Marks]**

3. **Vector Clocks and Distributed Leader Election** **[Total 15 Marks]**

(a) Consider the following sequence of message communications in a distributed system. Following the vector clock notation, write down the clock values for each of the events.

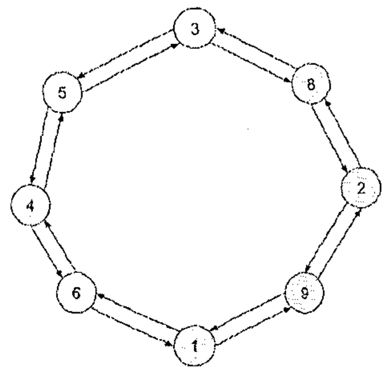
[4 Marks]



List down four events, one from each of the four processes, where those events are parallel as per the notion of the vector clocks. If no such parallel events exist, write it down. **[2 Marks]**

(b) What is meant by *pairwise inconsistent events*? Define with the notion of vector clocks, and explain with an example. **[3 Marks]**

(c) Execute the Hirschberg-Sinclair Algorithm for distributed leader election on the following ring. The number inside the nodes indicate the IDs of the node.



Show each step of the algorithm pictorially, and indicate the TTL values of the messages at each round. Indicate the output at the end of each round. **[3 Marks]**

Derive the average-case message complexity of the above algorithm. **[3 Marks]**

Space for Rough Works