

NANYANG TECHNOLOGICAL UNIVERSITY**SEMESTER 2 EXAMINATION 2023-2024****CE4013/CZ4013/SC4051 – DISTRIBUTED SYSTEMS**

Apr/May 2024

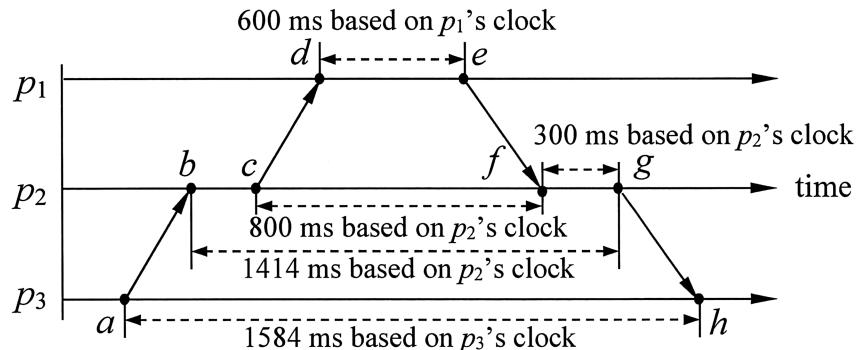
Time Allowed: 2 hours

INSTRUCTIONS

1. This paper contains 6 questions and comprises 5 pages.
 2. Answer **ALL** questions.
 3. This is a closed-book examination.
 4. Questions do not carry equal marks.
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1. (a) In a distributed banking system, the server keeps the transaction records of credit cards and provides two services. The first service is for customers to query the available credit limit (a floating-point value) by specifying the credit card number (an integer). The second service is to keep customers informed of their new transactions through callback. To use this service, a customer must register his interest by specifying the credit card number. A callback from the server includes the transaction description (a string) and the amount used (a floating-point value). Design Java remote interfaces for the server and the customer. (6 marks)
- (b) Let A and B be two different idempotent operations on the same object. Let C be a compound operation that first executes A and then executes B . Analyze whether operation C is idempotent and briefly explain your answer. (6 marks)
- (c) Briefly explain one-copy update semantics and session update semantics. What update semantics do the local UNIX file system, the Network File System and the Andrew File System implement respectively? (5 marks)

2. In a peer-to-peer file sharing system based on Chord routing, the identifier circle ranges from 0 to 127 (i.e., $2^7 - 1$). There are 10 nodes in the system: N0, N6, N25, N38, N45, N58, N67, N73, N88 and N94, where the numbers behind ‘N’ denote the node identifiers on the identifier circle.
- What is the route of a query issued by node N88 for the location information of file K71 (the number behind ‘K’ denotes the key identifier of the file on the identifier circle)? (5 marks)
 - When a new node joins the system, it changes the route of the query in Q2(a). What are the possible node identifiers of this new node? (5 marks)
3. Three processes p_1 , p_2 and p_3 are running on different computers in an asynchronous distributed system. Each process has a local clock. Figure Q3 shows four messages sent between the processes, where events a to h represent the sending and receiving events of these messages. Let t_e be the reading of p_1 's clock at event e , and t_g be the reading of p_2 's clock at event g . Suppose that p_3 knows t_e and t_g , as well as the lengths of the time intervals measured by the respective clocks as shown in Figure Q3.

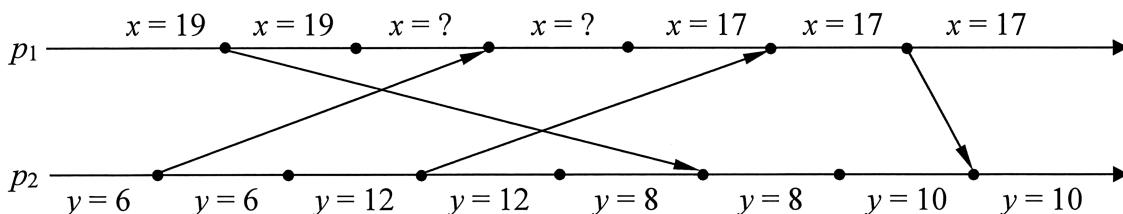
**Figure Q3**

- Assume that the clock drifts are negligible. If p_3 would like to synchronize its clock with p_2 's clock as accurately as possible, what time should p_3 set its clock to when it receives the message at event h ? What is the accuracy of this setting? (4 marks)
- Assume that the clock drifts are negligible. If p_3 would like to synchronize its clock with p_1 's clock as accurately as possible, what time should p_3 set its clock to at event h ? What is the accuracy of this setting? (4 marks)

Note: Question No. 3 continues on Page 3

- (c) Suppose that the drift rate of each clock is bounded by 10 ms per second (the drift rate of a clock is defined as the change in the offset between the clock and a perfect reference clock per unit of time measured by the perfect reference clock). If p_3 would like to synchronize its clock with p_2 's clock as accurately as possible, what time should p_3 set its clock to at event h ? What is the accuracy of this setting? (6 marks)
- (d) List all the events that happened-before event e in causal ordering. (2 marks)
- (e) Assume that message delivery on each unidirectional point-to-point channel follows FIFO order. Suppose that p_1 initiates the Chandy-and-Lamport algorithm immediately after event e to record a snapshot of the system. What are the possible snapshots finally recorded? In your answer, if needed, use S_1 , S_2 and S_3 to represent the initial states of p_1 , p_2 and p_3 respectively, and use S_x to represent the state of the process immediately after event x occurs (for example, S_a is the state of p_3 immediately after event a occurs, and S_c is the state of p_2 immediately after event c occurs). (6 marks)

4. Figure Q4 shows the execution of two processes p_1 and p_2 in an asynchronous distributed system, where the dots represent the events occurring in the processes, and the arrows represent the messages sent between the processes. Process p_1 contains a variable x , and process p_2 contains a variable y . The values of x and y at the different process states are shown in Figure Q4.

**Figure Q4**

- (a) Draw the lattice of consistent global states. In the lattice, use S_{ij} to denote the global state after i events at process p_1 and j events at process p_2 . (6 marks)

Note: Question No. 4 continues on Page 4

- (b) If it can be inferred that the constraint $|x - y| > 6$ must be broken in the execution, what is the possible range of x 's values in the two states shown by “ $x = ?$ ” (note that these two states have the same x value)?
- (7 marks)
5. (a) Suppose that the Ricart and Agrawala algorithm is used for distributed mutual exclusion among n processes p_1, p_2, \dots, p_n . Below is the partial pseudocode of the algorithm executed by a process p_i . Complete the algorithm by filling in the boxes A to F with the appropriate pseudocode. Each box other than D is for one statement, and D is a logical condition.

On initialization

state := RELEASED;

To enter the critical section

state := WANTED;

A

$T :=$ the timestamp of the request by the logical clock;

B

C

On receipt of a request $\langle T_j, p_j \rangle$ from another process p_j ($j \neq i$)

if D

D

then

E

else

queue request from p_j without replying;

end if

To exit the critical section

state := RELEASED;

F

(6 marks)

- (b) In the Ricart and Agrawala algorithm, suppose the statement “ $T :=$ the timestamp of the request by the logical clock” is changed to “ $T := i$ ” (i.e., the timestamp is set to the process index). Does the algorithm still guarantee that at most one process may execute in the critical section at any time? Briefly explain your answer.
- (7 marks)
- (c) Suppose that we would like to modify the Ricart and Agrawala algorithm to coordinate p_1, p_2, \dots, p_n for accessing a shared resource that can be accessed by at most two processes at any time. Which box (or boxes) in Q5(a) need to be amended and how it (or they) should be amended to achieve this goal?
- (5 marks)

6. Consider a replicated shared object service hosting an integer object x whose initial value is 0. Table Q6 shows the operations performed by two clients on x . For example, $\text{read}(x) \rightarrow a$ denotes a read operation on x returning a value a , and $\text{write}(x \leftarrow x + 50)$ denotes a write operation increasing the value of x by 50. The operations of each client are listed in the order that they are performed by the client.

Table Q6

| Program order | Client A | Client B |
|---------------|---|--|
| ↓ | $\text{write}(x \leftarrow x + 6)$ $\text{read}(x) \rightarrow a$ $\text{write}(x \leftarrow x + 50)$ $\text{read}(x) \rightarrow b$ | $\text{read}(x) \rightarrow c$ $\text{write}(x \leftarrow x + 400)$ $\text{read}(x) \rightarrow d$ |

- (a) If $a = 406$ and the object service is sequentially consistent, what are the possible combinations of the values c and d ? (4 marks)
- (b) If the object service is FIFO consistent, what are the possible combinations of the values a and b ? (4 marks)
- (c) If $a = 400$ and the object service is monotonic-read consistent, what are the possible values of b ? (4 marks)
- (d) If $a = 406$ and the object service is read-your-writes consistent, what are the possible values of b ? (4 marks)
- (e) If $a = 400$ and the object service is both monotonic-write consistent and writes-follow-reads consistent, what are the possible values of b ? (4 marks)

END OF PAPER

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Please read the following instructions carefully:

- 1. Please do not turn over the question paper until you are told to do so. Disciplinary action may be taken against you if you do so.**
2. You are not allowed to leave the examination hall unless accompanied by an invigilator. You may raise your hand if you need to communicate with the invigilator.
3. Please write your Matriculation Number on the front of the answer book.
4. Please indicate clearly in the answer book (at the appropriate place) if you are continuing the answer to a question elsewhere in the book.