CSE530 Distributed Systems - Mid-semester Exam (Winter 2023) - February 26, 2023
Max. Time: (60 mins) Max. Marks: 40

Important Note:

1. Please ensure that the question paper consists of **two printed sides [1 page].**
2. Before starting to answer any question, please read it completely.
3. Exam is fully closed-book. No cheat sheet etc. is allowed.
4. Calculator is allowed although not required. Sharing of calculators is not allowed.

Question 1: Theory questions [5 marks]:

1. What is the most important difference between default RPC and ZeroMQ? [1 mark]
2. What is the primary reason for performing parameter marshaling and unmarshaling in RPC? [1 mark]
3. List the major steps in the centralized algorithm for ensuring mutual exclusion. [2 marks]
4. Which process is elected as the leader in the bully algorithm? [1 mark]

Question 2: Vector Clocks [10 marks]

Consider a distributed system with four processes: P1, P2, P3, and P4. Assume that all the processes have an agreement on physical time at any moment. Each process has a vector clock with four entries, initialized to all zeros. The following events occur in the system: [T refers to the timestamp according to physical time.]

- Event A: At T = 1, P1 sends a message M1 to P2
- Event B: At T = 2, P2 sends a message M2 to P3
- Event C: At T = 4, P1 sends another message M3 to P2
- Event D: At T = 2, P3 sends a message M4 to P4
- Event E: At T = 3, P2 receives the message M1 from P1
- Event F: At T = 5, P3 receives the message M2 from P2
- Event G: At T = 4, P4 receives the message M4 from P3
- Event H: At T = 6, P4 sends a message M5 to P1
- Event I: At T = 10, P2 receives the message M3 from P1
- Event J: At T = 8, P1 receives the message M5 from P4

Assume that the messages are sent or received by any process based on the specified **T**. Compute the vector clock values associated with **EACH** of the above events. **[1 mark for each event]**

Question 3: Lamport's Logical clocks/timestamp [10 marks]

Consider a distributed system with four processes: P1, P2, P3, and P4. Assume that all the processes have an agreement on physical time at any moment. Each process has a Lamport's logical timestamp initialized to zero. The following events occur in the system: [T refers to the timestamp according to the physical time.]

- Event A: At T = 1, P1 sends a message M1 to P4
- Event B: At T = 2, P3 sends a message M2 to P2
- Event C: At T = 3, P2 receives the message M2 from P3
- Event D: At T = 4, P4 receives the message M1 from P1
- Event E: At T = 5, P4 sends a message M3 to P3
- Event F: At T = 6, P2 sends a message M4 to P3
- Event G: At T = 7, P1 sends a message M5 to P2
- Event H: At T = 8, P2 receives the message M5 from P1
- Event I: At T = 9, P3 receives the message M4 from P2
- Event J: At T = 10, P3 receives the message M3 from P4

Assume that the messages are sent or received by any process based on the specified **T**. Compute the Lamport's timestamp values associated with **EACH** of the above events. **[1 mark for each event]**

Question 4: Consistency Models [10 marks]

Consider a distributed system with four processes: $\mathbf{P_1}$, $\mathbf{P_2}$, $\mathbf{P_3}$, and $\mathbf{P_4}$. Assume that all the four processes are accessing a distributed data store having three replicas. Any process can access any replica for read and write operations. Assume that all the processes have an agreement on physical time at any moment. $\mathbf{T_k}$ refers to a timestamp based on physical time. $\mathbf{T_k}$ is used for describing read and write operations below.

$\mathbf{R_i(x)a\ [T_s, T_c]}$ denotes a read operation on data item **x** by process $\mathbf{P_i}$ where

1. **a** is the result of this read operation
2. Read operation was issued at $\mathbf{T_s}$ by process $\mathbf{P_i}$
3. Read operation completed at $\mathbf{T_c}$ (i.e. $\mathbf{P_i}$ got the result **a** of read operation at $\mathbf{T_c}$)

$\mathbf{W_i(x)b\ [T_s, T_c]}$ denotes a write operation on data item **x** by process $\mathbf{P_i}$ where

1. **b** is the value written to the data store for data item **x**
2. Write operation was issued at $\mathbf{T_s}$ by process $\mathbf{P_i}$
3. Write operation completed at $\mathbf{T_c}$ (i.e. Until $\mathbf{T_c}$, $\mathbf{P_i}$ was blocked waiting for the write request to return. At $\mathbf{T_c}$, $\mathbf{P_i}$ was notified of the completion of the write request. Note that this does not necessarily mean that the write operation completed on all the replicas.)

Consider the following operations being performed on the distributed data store:

1. $\mathbf{W_1(x)a\ [1, 4]}$
2. $\mathbf{W_1(x)b\ [5, 9]}$
3. $\mathbf{W_2(x)c\ [3, 6]}$
4. $\mathbf{W_2(x)d\ [8, 12]}$
5. $\mathbf{R_3(x)?\ [7, 10]}$
6. $\mathbf{R_3(x)?\ [11, 13]}$
7. $\mathbf{R_4(x)?\ [2, 4.5]}$
8. $\mathbf{R_4(x)?\ [14, 15]}$

Answer the following questions:

a. Provide a possible scenario for all the read operations (marked as ?) which is allowed by **strict** consistency **[2 marks]**
b. Provide a possible scenario for all the read operations (marked as ?) which is allowed by **linearizability** consistency but **not by strict** consistency **[2 marks]**
c. Provide a possible scenario for all the read operations (marked as ?) which is allowed by **sequential** consistency but **not by strict consistency and linearizability [2 marks]**
d. Provide a possible scenario for all the read operations (marked as ?) which is allowed by **causal** consistency but **not by sequential** consistency **[2 marks]**
e. Provide a possible scenario for all the read operations (marked as ?) which is allowed by **eventual** consistency but **not by causal** consistency **[2 marks]**

Question 5: Network Time Protocol [5 marks]

1. Network time protocol (**NTP**) assumes that the network delay from client to server ($\mathbf{D_{c\text{-}s}}$) and network delay from server to client ($\mathbf{D_{s\text{-}c}}$) is approximately the same. Consider a simple variant of **NTP** (we name this variant as **NTP-V**) where the assumption is that the network delay from client to server ($D_{c\text{-}s}$) is approximately half the network delay from server to client ($\mathbf{D_{s\text{-}c}}$). That is, $\mathbf{D_{c\text{-}s} = 0.5 * D_{s\text{-}c}}$ Using the simple variant of **NTP** as described above, solve the following problem: An **NTP-V** client sends a request to an **NTP-V** server with a originate timestamp of **T1** and a receive timestamp of **T2**. The server responds with a transmit timestamp of **T3** and a receive timestamp of **T4**. Calculate the round-trip delay and offset for the client in terms of **T1, T2, T3** and **T4**.