You are to work on the following questions *alone*. Do not discuss these questions with anyone. Typeset your answers and submit as a `PDF` on Canvas. **Try to keep your answers short.**

1. An acceptor in Paxos maintains the highest accepted proposal (i.e., the proposal number and its associated value) or $\perp$, which indicates that the acceptor has not accepted any proposal. We use the notation A_i: $(20, x)$ to indicate that the highest proposal A_i has accepted is proposal numbered 20 and value x. Which of the following states are valid states that you might encounter in a single-instance Paxos with five acceptors? Justify your answer. (Note that each of the following parts relates to an independent execution sequence.)

   - A_1: $(8,x)$, A_2: $(9,y)$, A_3: $\perp$, A_4: $\perp$, A_5: $\perp$
   - A_1: $(8,x)$, A_2: $(9,y)$, A_3: $(10,z)$, A_4: $\perp$, A_5: $\perp$
   - A_1: $(8,x)$, A_2: $(9,y)$, A_3: $(10,z)$, A_4: $(11,w)$, A_5: $\perp$
   - A_1: $(8,x)$, A_2: $(11,y)$, A_3: $(14,z)$, A_4: $(13,y)$, A_5: $\perp$
   - A_1: $(8,x)$, A_2: $(11,y)$, A_3: $(14,z)$, A_4: $(13,y)$, A_5: $(15,x)$

2. Discuss why the Paxos protocol does not provide the liveness property in reaching consensus.

3. Assume that you want to support the fail-stop-restart model of fault-tolerance wherein a node can fail and subsequently reboot to join the distributed system using data stored in its stable storage (i.e., disks, SSDs, etc.). We want the recovering node to be considered as one of the non-failed nodes in the system when it is back online. The use of stable storage would allow, for instance, the entire Paxos group to fail simultaneously (say during a power failure) and then recover to operate as a replicated state machine without losing state on what has been agreed upon in the past. What state should a Multi-Paxos acceptor (i.e., a multiple instance Paxos node) maintain in stable storage to enable this form of fault tolerance?

4. Suppose you want to perform reconfiguration of a Paxos group, i.e., change the set of nodes that are part of the consensus group. For example, you might want to change the membership of a Paxos group from $\{A,B,C\}$ to $\{A,B,D\}$. In particular, you could use reconfiguration to swap out failed nodes with new nodes to achieve a higher degree of fault tolerance. Describe how reconfiguration can be performed in the context of Multi-Paxos under the constraint that your protocol should involve just the old or the new members of a Paxos group, i.e., you cannot use an additional separate service for performing the reconfiguration.

5. Consider the Chain Replication protocol. Discuss how you would extend the scheme to handle the simultaneous failure of two adjacent nodes in the chain. Describe what state is being maintained by the nodes and how the master could coordinate a transition to a new chain while preserving the correctness guarantees.