History graphs record dependencies between individual atomic operations within sequences of events associated with specific schedules of more complex transactions.

(a) (i) What do edges in a history graph represent? [1 mark]

(ii) What graph property holds if a bad schedule is present? [1 mark]

(iii) Which ACID properties may be violated by a bad schedule? [2 marks]

(iv) Define serial and serialisable executions. Explain whether (and if so, how) one is a superset of the other. [3 marks]

(b) Two transactions, \( T_1 \) and \( T_2 \), consist of operations on two objects, \( A \) and \( B \):

\[
T_1: \{
    a = A.\text{getbalance}();
    b = B.\text{getbalance}();
    \text{return} \ (a + b);
\}
\]

\[
T_2 (v): \{
    \text{A.debit}(v);
    \text{B.credit}(v);
\}
\]

(i) Explain how a dirty read might be experienced through concurrent executions of \( T_1 \) and \( T_2 \). [2 marks]

(ii) Draw and label a history graph illustrating this bad schedule. [2 marks]

(c) A programmer designs a transaction system that uses history graphs to detect bad schedules. After an operation is performed, and before its containing transaction is allowed to commit, the history graph is updated and a graph analysis is run. If a bad schedule is detected, affected transactions will be aborted and rolled back.

(i) Will this scheme always make progress? Explain your answer. [2 marks]

(ii) Time Stamp Ordering (TSO) will sometimes reject good schedules, which could lead to unnecessary transaction aborts. Does the scheme described here accept or reject more schedules than TSO? Explain why. [3 marks]

(iii) Explain one way in which this scheme may perform better than TSO. Explain one way in which it may perform worse. [4 marks]