# Homework 1 (20+5 points)

Due 02/25/21 before class

Note: (1) Clearly justify your answer to each of the following questions. (2) The starred problems are required for graduate students only.

1. **(5 points)** A client attempts to synchronize with a time server. It records the round-trip times and timestamps returned by the server in the table below. Which of these times should it use to set its clock? To what time should it set it? If it is known that the time between sending and receiving a message in the system concerned is at least 8 ms, what is the accuracy of the setting with respect to the server's clock?

Round-trip (ms)	Time (hr:min:sec)
22	10:54:23.674
25	10:54:25.450
20	10:54:28.342

2. **(3 points)** We say that event e is concurrent with event f if they are not related by the happened-before relation. Show that "concurrent with" is **not** a transitive relation.

3. **(5 points)** Calculate the vector clock values of the events a-j in the figure below. Use these vector clock values to show that (d, h) are concurrent events, but f happened before e.
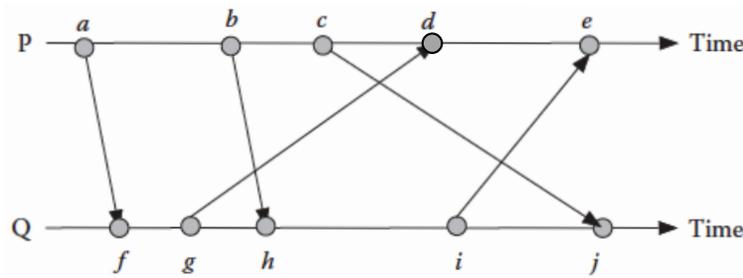
4. **(7 points)** In the vector clock algorithm we discussed in class, each process needs to include a copy of its vector clock in every outgoing message. Suppose that the underlying communication system guarantees first-in, first-out (FIFO) ordering of messages. How will you exploit this feature to reduce the communication complexity of the vector clock algorithm? Clearly describe your solution and its overhead savings.

5* **(5 points)** Prove the following for vector clocks: for any two events e and f occured at two processes i and j respectively, we have $e \to f$ iff

$$(\forall k : VC(e)[k] \leq VC(f)[k]) \wedge (VC(e)[j] < VC(f)[j])$$