Name__________________ Lastname__________________ Student number

Distributed Systems
academic year 2011-2012

Rules

- This is a closed books exam.
- The operation of any electronic device is prohibited (e.g, no calculator, phone or PDA).
- Answer the questions being *precise, complete,* and *formal*.
- Write as *clearly* as possible, both in terms of handwriting and wording.

Questions

1. Illustrate the five phases executed when performing a client request in an active replication architecture, that is, without a primary back-up.
2. Consider the Hirschberg-Sinclair leader election algorithm discussed in the lectures, which applies to bidirectional rings. According to this algorithm, each p$_i$ tries to become a leader in phase k among its 2^k neighborhood, while the size of the neighborhood doubles in each phase. Illustrate how the algorithm operates in a ring with the following identifiers 8; 1; 5; 3; 7; 2; 6; 4 (in that order). What is the number of phases and how many messages are sent?

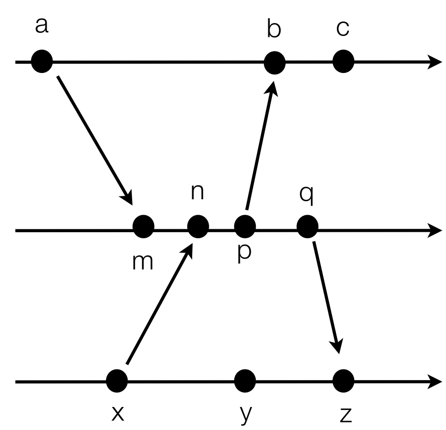

Figure 1: Events on three processes.

3. Consider three processes in a distributed system with the events depicted in Figure 1.
   (a) List all happened before relations among the 10 events.
   (b) List with which events is n parallel to, if any.
   (c) Provide the Vector clocks values for all the events.
   (d) Give two snapshots of the system, both containing the event n, one which is consistent and one which is not.

4. Consider a synchronous system with reliable FIFO channels where the processors try to reach consensus on a binary value.
   (a) How many byzantine faulty processors can the system tolerate in general so that consensus is correctly reached for the non-faulty processors?
   (b) How many in the asynchronous case?
   (c) Consider the case of five processors $\{P_0 \dots P_4\}$ exchanging 3 rounds of messages. Consider the possible three situations for process P_4 :

   Case A. At round 1, received 0 from P_0. At round 2, received 0 from $P_1 - P_0$, $P_2 - P_0$, $P_3 - P_0$. At round 3, received 0 from $P_2 - P_1 - P_0$, $P_3 - P_1 - P_0$, $P_1 - P_2 - P_0$, $P_3 - P_2 - P_0$, $P_1 - P_3 - P_0$, $P_2 - P_3 - P_0$.

   Case B. At round 1, received 0 from P_0. At round 2, received 1 from $P_1 - P_0$, and 0 from $P_2 - P_0$, $P_3 - P_0$. At round 3, received 1 from $P_2 - P_1 - P_0$, $P_3 - P_1 - P_0$, $P_1 - P_2 - P_0$, and 0 from $P_3 - P_2 - P_0$, $P_1 - P_3 - P_0$, $P_2 - P_3 - P_0$.

   Case B. At round 1, received 1 from P_0. At round 2, received 1 from $P_1 - P_0$, and 0 from $P_2 - P_0$, $P_3 - P_0$. At round 3, received 1 from $P_2 - P_1 - P_0$, $P_3 - P_1 - P_0$, $P_1 - P_2 - P_0$, and 0 from $P_3 - P_2 - P_0$, $P_1 - P_3 - P_0$, $P_2 - P_3 - P_0$.

   For each one of these three cases, what is the 'conclusion' reached by processor P_4 with respect to the agreed value? Is such value to be trusted? How many processors does he suspects to be faulty? Explain the answers. [1]

5. The GPS system works, in first approximation, in the following way. From any position on the earth, at least four satellites are visible and these emit messages at a constant rate of 50bits/second of 1500 bits in size. Each message includes a clock reading and information on the position of the satellite. A GPS receiver takes the messages sent from the satellites and considering that they travel at the speed of light, it computes its distance from all satellites. One can think of this as taking a sphere centered around the satellite on which the receiver must be located. Ideally, there will be one intersection point of all the spheres which provides the exact location of the receiver. Satellites are equipped with atomic clocks that tick every nanosecond. To be able to locate the receiver, one needs a reading of the time with at most 25 nanoseconds error. Due to relativity theory, satellite clocks will tick more rapidly by about 45.9 microseconds per day because they have a higher gravitational potential, but they will also tick more slowly by about 7.2 microseconds per day due to their relative speed to the earth.
   (a) How much time does a satellite need to emit one message (in seconds)?
   (b) What is the satellite clock resolution (seconds)?
   (c) What is the clocks drift rate due to the relativistic effect (seconds/second)?
   (d) Take clock A and B, synchronize them and assume their drift rate is null. What will be the skew after one day from the synchronization if one is placed on a GPS satellite and the other one is kept on earth (seconds)?
   (e) If with a 25 nanosecond error, a GPS receiver will provide its location with an accuracy of 6.46 meters, what will be the accuracy after one day if the relativistic effects are not compensated for (meters)?

[1] By $P_i - P_j$, we denote the value recorded by processor P_i of the value received from P_j in the previous round. By $P_i - P_j - P_k$, we denote the value recorded by processor P_i of the value received from P_j in turn received from P_k.