Question 1:

This question relates to quorum replication (of R/W registers).

a) Show an example why removing line 4 from the client's read protocol (but keeping all other code as is) results only in a regular register semantics rather than atomic register.

b) Suppose the protocol is executed over a quorum system rather than bi-quorum system. Describe an optimization that enables skipping line 4 (sometimes) without violating the atomic register semantics.

Question 2:

Suppose you have access to a fault tolerant distributed compare&swap (CAS) service.

A CAS(obj,old,new) operation accepts an object obj, an expected value old and atomically stores the value new in obj if its value just prior to invoking the CAS was old.

a) Show how it can be used to implement a Consensus protocol, i.e., provide the missing code in the following:

```plaintext
obj Consensus(my_init_val) {
    obj decision = nil;
    CAS(_______________________);
    return decision;
}
```

b) What can you conclude about the ability to implement a CAS in a fault tolerant manner in an asynchronous distributed environment? Explain.

Question 3:

In this question we will prove the agreement property of Paxos. We will use the version of the protocol in which acceptors send ACCEPTED message only to the leader and then the leader sends the COMMIT message.

Lemma: Let p be a leader of a round r that gather (ACCEPTED,r,ACK) messages from a quorum. Then no leader with a round number r1>r would send an (ACCEPT,r1,v1) message with v1≠v.
**Proof:** Assume by way of contradiction that the lemma does not hold, and let q be the leader with minimal r1 that sends an (ACCEPT,r1,v1) message with v1≠v. Hence, q receives at least one (PROMISE,r1,ACK,r',v') message such that r' was maximal among received PROMISE messages and v'=v1.

Due to the quorum intersection property, at least one of the PROMISE messages received by q was from a process that sent an (ACCEPTED,r,ACK) message to p, adopted v as its value in round r, and set last_good_round to r.

Due to the minimality of r1 and the code, all r' values in the (PROMISE,r1,ACK,r',v') messages received by q for which v1≠v must be smaller than r. A contradiction to the assumption that q chose v1≠v for its (ACCEPT,r1,v1) message.

**Theorem:** Paxos satisfies the agreement property of consensus.

**Proof:** Assume, by way of contradiction, that the theorem does not hold.

*Complete the proof from here.*

Hint, think of a minimality argument for two leaders trying to decide different values v and v1.

**Question 4:**

a) Show a simple transformation from Ω to $\downarrow$S. Explain your construction. An unnecessarily complex construction will receive a lower grade than a simple one.

b) Explain the **fundamental** differences between the safety properties of Non-Blocking Atomic Commit and Consensus.

**Submission instructions:**

You should solve this exercise alone – submissions are individual. Solutions must be submitted through the course web site – either printed or a high-resolution scan of handwriting. Solutions must be written in Hebrew unless you get an authorization from Prof. Friedman to submit in English.

Try to be brief. If your answer is very lengthy, it could be a sign that it is wrong.

The submission date is Thursday 30/11/2014 before midnight.

**Good luck!**