Student's Token:
A. Knowledge (15 points)

1. Which of the following statements is true concerning 2-phase commit protocols in the context of transaction processing? Check all that apply:
   a. The participants in the protocol may block due to a synchronization-induced deadlock that occurs during the execution of the protocol.
   b. The participants in the protocol never block.
   c. The participants in the protocol may block under some failure scenarios.
   d. The participants in the protocol may record the outcome in a redo log.
   e. None of the above.

2. Which of the following is true about transactional memory? Check all that apply:
   a. Transactional memory is a mechanism that ensures the durability of the results of a transaction.
   b. Transactional memory is a mechanism to support optimistic concurrency control by exploiting the cache coherence protocol of a multiprocessor.
   c. Transactional memory is a memory system in which reads and writes to main memory are considered as transactions that satisfy the ACID properties.
   d. Transactional memory is a mechanism to support concurrency control; it can be implemented either in software or hardware.
   e. None of the above.

3. In-memory databases sacrifice which of the following? Check all that apply:
   a. Durability of a transaction’s result.
   b. Transaction performance.
   c. Database size.
   d. The isolation property of transactions.
   e. None of the above.

4. A monitor is a synchronization mechanism that features an object with methods that manipulate its private data structures. The monitor ensures mutual exclusion by acquiring an implicit lock for threads that enter into the object by invoking the methods. The Java “Synchronized” keyword is an example of a partial implementation of a monitor. Which of the following is true about monitors? Check all that apply:
   a. Two different threads can enter the monitor simultaneously via the invocation of two different methods, but no two threads can enter the monitor simultaneously via the invocation of the same method.
   b. A monitor is an excellent example of a wait-free synchronization primitive since a thread simply enters the monitor by invoking a method without having to enter a spinning loop or block on a lock.
   c. A thread can circumvent a monitor by accessing its data structures directly without having to invoke a method (demonic variables).
   d. Using monitors can prevent deadlocks.
   e. None of the above.
5. A log is a fundamental structure in many system applications. It is typically implemented using contiguous allocation on a disk, where appending the log does not generally require a disk seek. As we move increasingly toward semiconductor-based secondary storage, which of the following statements will be true? (Check all that apply):
   a. There will be no need for a redo log in the context of a database system.
   b. The read performance out of the log will improve.
   c. It will not be important to allocate the log using contiguous allocation of sectors.
   d. Wear-leveling sector allocation algorithms will influence which sectors will be allocated to a log.
   e. None of the above.

6. In the figure below, there are four processes that exchange messages (showed by the diagonal arrows). Which of the following is true about this system? Check all that apply.
   a. The system state identified by state 11 at $P_1$, state 21 at $P_2$, state 31 at $P_3$, and state 42 at $P_4$ is a consistent global state.
   b. There is a causal relation between state 30 and state 42.
   c. A system checkpoint consisting of states 11, 21, 31 and 41 can be used to recover from potential future failures.
   d. The content of the state 32 would be identical if message $m_5$ was received before $m_6$.
   e. None of the above.
7. Consider a cloud environment that implements a service with multiple servers. The service follows a client-server architecture. When a client sends a request, workload distributor assigns the request to one of the servers that offer the service. The distributor uses heuristics to try to balance the loads on the servers. Which of the following factors could be used by the distributor in the heuristics of assignment of a client request to a particular server? Check all that apply:
   a. The workload on each server.
   b. Previous assignments of requests by the same client.
   c. Physical proximity if the cloud environment is geographically distributed.
   d. The type of the request.
   e. None of the above.

8. Debugging multithreaded applications (Check all that apply)
   a. Can be effectively and efficiently done by rerunning the application and setting breakpoints at suspected program points.
   b. Can be effectively and efficiently done by inserting printf() statements to monitor the values of critical variables.
   c. Can be effectively and efficiently done by running each thread to completion in sequence.
   d. Can be effectively and efficiently done by inserting additional locks into the program.
   e. None of the above.

9. The availability of a computing service depends on which of the following? Check all that apply:
   a. Mean time to failure.
   b. Mean time to repair.
   c. Failure rate of components.
   d. Number of components.
   e. None of the above.

10. Which of the following is true about failure detection in a distributed computing system? Check all that apply.
    a. A heartbeat mechanism can detect failures with absolute certainty.
    b. It is mathematically impossible to design an algorithm to detect failures.
    c. A failure of a remote system cannot be distinguished from the failure of the network that connects us to the remote system.
    d. A quorum-based read and write protocol can mitigate the effects of network partitions.
    e. None of the above.
B. Analysis (15 points)

11. Let the notation $r_i(x)$ denote a read operation by transaction $i$ of data item $x$. Similarly, let the notation $w_i(x)$ denote a write operation by transaction $i$ of data item $x$. Consider the following schedule of operations:

$$r_1(x), r_3(x), r_1(y), r_2(x), w_3(x), w_1(y), w_3(z), r_4(u), w_4(u), r_5(x), w_5(x), w_5(z)$$

Enumerate, if any, all possible sequential schedules that yield the same results as the given schedule.
12. Assume $n$ processes that are connected by a network whose topology corresponds to a complete graph.
   
   a. What is the total number of links in the network?

   b. If no more than $n-1$ links can fail, prove or disprove that a network partition can exist.
13. Assume that you have a hypervisor that hosts multiple virtual machines by exporting an abstraction of the underlying hardware. Assume that the operating system in every virtual machine is oblivious to virtualization. Explain what happens when a user program issues a system call. Show the various transitions from user to supervisor mode and vice versa. Explain what should the operating system do during initialization, and how does the hardware and hypervisor react to the initialization requests of the operating system.
14. Consider the following code:

```c
for (i = 0; i < n; i++)
    c[i] = a[i] + b[i];
for (i = 0; i < n; i++)
    c[i] = c[i] * d[i];
```

Outline an equivalent solution to this code using Map-Reduce. Explain clearly the role of all the participants in the computation and explain what each component does. Assume you have 17 processors, and \( n \) is a power of 2. Your solution should be efficient.
15. Assume a transaction processing system that uses a “redo” log. Assume a transaction writes two data records, \( x \) and \( y \), commits, and immediately after committing and before \( x \) and \( y \) are written to their home locations from the cache, the entire system fails due to a power outage.
   a. Immediately upon restart, will the values of \( x \) and \( y \) reflect the committed value of the transaction that committed before the system crashed? If so, explain why, and if not, explain how the system can recover the missed values.

b. Consider the case of a transaction that commits in a system that uses an “undo log” then immediately fails after the commit operation the system fails due to a power outage. Immediately upon restart, will the values of \( x \) and \( y \) reflect the committed value of the transaction that committed before the system crashed? If so, explain why, and if not, explain how the system can recover the missed values.
C. Synthesis (15 points)

16. Consider a virtualization environment in which deduplication is used to reduce the storage requirements of the file systems pertaining to the virtual machines. Show how to extend the concept of deduplication from the file system into the management of main memory by the hypervisor. What processes would you exploit to maximize the savings? What mechanisms at the hypervisor level would you need to implement the sharing? What is the granularity of sharing? Give as much detail as you can.
17. Assume $n$ processes in a distributed system. The processes have access to an atomic broadcast protocol that delivers messages reliably in the same order to all processes. Design a leader election protocol.
18. You have access to RAID-6 storage system that provides 10PB of storage. You also have access to 2 small, fast disks that provide 1TB of storage each. Additionally you have 128 flash drives that provide 128TB of storage in the aggregate. The file system will likely consist of very large files, and the workload consists of 95% query operations and 5% update operations. Design the file system to ensure reliability, integrity, and high performance. Identify the role, if any, of each of the given components in your design. Does your design depend on the expected size of the files in the system?