Department of Electrical Engineering and Computer Science

MASSACHUSETTS INSTITUTE OF TECHNOLOGY

6.033 Computer Systems Engineering: Spring 2016

Quiz 2

There are **21 questions** and **14 pages** in this quiz booklet. Answer each question according to the instructions given. You have two hours to answer the questions.

- The questions are organized (roughly) by topic. They are not ordered by difficulty nor by the number of points they are worth.
- **If you find a question ambiguous, write down any assumptions you make.** Be neat and legible.
- Some students will be taking a make-up exam at a later date. **Do not** discuss this quiz with anyone who has not already taken it.
- You may use the back of the pages for scratch work, but **do not** write anything on the back that you want graded. We will not look at the backs of the pages.
- Write your name in the space below. Write your initials at the bottom of each page.

This is an open-book, open-notes, open-laptop quiz, but you may **NOT** use your laptop, or any other device, for communication with any other entity (person or machine).

Turn all network devices, including your phone, off.

CIRCLE your recitation section:

10:00	1. Matei/Cathie	7. Mark/CK	8. Michael/Pratheek	15. Karen/Jacqui
11:00	9. Matei/Cathie	10. Mark/CK	11. Michael/Pratheek	16. Karen/Jacqui
12:00	12. Asaf/Anubhav			
1:00	2. Mike/Steven	5. Peter/Sumit	13. Mark/Jodie	14. Asaf/Anubhav
2:00	3. Mark/Jodie	4. Peter/Sumit	6. Mike/Steven	

Name:

I Reliability

1. [6 points]: RAID-033 is a new addition to the family of RAID schemes. A RAID-033 array consists of N data disks ($D_1, D_2, \ldots, D_N$) and an additional parity disk. Block i on the parity disk is equal to the `xor` of all blocks of disk D_i.

You are considering whether to use RAID-033, or to stick with the time-tested RAID-4. For each of the scenarios below, specify whether RAID-4 or RAID-033 is more resilient to the failure described. In all cases, you can assume that no additional failures occur.

A. Total failure of the parity disk.

(a) RAID-4 is more resilient to this failure.
(b) RAID-033 is more resilient to this failure.
(c) The two schemes are equally resilient to this failure.

B. Concurrent failure of multiple blocks on the same disk.

(a) RAID-4 is more resilient to this failure.
(b) RAID-033 is more resilient to this failure.
(c) The two schemes are equally resilient to this failure.

C. Concurrent failure of block i on multiple (different) disks.

(a) RAID-4 is more resilient to this failure.
(b) RAID-033 is more resilient to this failure.
(c) The two schemes are equally resilient to this failure.

2. [2 points]: True / False GFS does not allow for concurrent writes to the same file (i.e., writes from multiple distinct users at the same time).

3. [4 points]: Inspired by the first two questions on this exam, you decide to combine the ideas of GFS and RAID into a single system, D-RAID ("D" for distributed).

In D-RAID, files are broken into three chunks—F_1, F_2, F_3—and a parity block $P = F_1 \oplus F_2 \oplus F_3$ is calculated. F_1, F_2, F_3, and P are stored on four separate machines.

Circle True or False for each of the following. In all below, by "GFS" we mean the default configuration of GFS, with a replication factor of three.

A. True / False In general, D-RAID requires less storage space per file than GFS.

B. True / False Both GFS and D-RAID can recover from any single-disk failure.

C. True / False Both GFS and D-RAID can recover from any two-disk failure.

D. True / False In general, D-RAID has better performance for concurrent reads to the same file than GFS.

Initials:

II Atomicity

4. [4 points]: Consider the following **portion** of a write-ahead log. In this log, `UPDATE` records are of the form `UPDATE <var>=<old_value>; <var>=<new_value>`.

Log Entry	Transaction ID	Record
	...	
229	100	UPDATE A=0; A=10
230	100	UPDATE B=0; B=10
231	100	COMMIT
232	101	BEGIN
233	101	UPDATE A=10; A=25
234	101	UPDATE B=10; B=20
235	102	BEGIN
236	102	UPDATE C=0; C=30
237	102	UPDATE D=0; D=40
238	102	COMMIT
239	101	UPDATE D=40; D=55
240	101	UPDATE B=20; B=60
241	103	BEGIN
242	103	UPDATE C=30; C=70
	/** CRASH **/	

The system crashed after log entry 242; no further entries were written.

A. After recovery, what are the values of A, B, C, and D? If it is impossible to determine the value for any of these variables, write "None" in the corresponding space.

Value of A: __________ Value of C:__________

Value of B: __________ Value of D:__________

B. True / False The log portion shown is consistent with a transaction processing system that is using two-phase locking.

Initials:

5. [6 points]: Consider a write-ahead logging system that uses non-volatile cell storage. Writes go to the log and then to cell storage. A write is complete once it has been written to the log and to cell storage. Reads are done directly from cell storage.

You decide to modify the system to improve the performance of **writes**. Which of the following three modifications will result in a new logging system with improved write performance **that still guarantees atomicity**?

(Circle True if the modification satisfies this property, and False otherwise.)

A. True / False

- Send writes to the log and cell storage in parallel instead of sequentially. A write is complete when both writes have returned.

B. True / False

- Add a volatile cache. Assume that the cache is large enough to hold all data.
- Send writes to the cache after writing to the log the log. Delay updating cell storage until the cache is flushed (in which case all cache updates will be written to cell storage). A write is complete once it has been written to the cache and to the log.
- Reads go directly to the cache.

C. True / False

- Add a volatile cache. Assume that the cache is large enough to hold all data.
- Send writes to the cache. Delay updating the log and cell storage until the cache is flushed (in which case all cache updates will be written to the log and to cell storage). A write is complete once it has been written to the cache.
- Reads go directly to the cache.

6. [4 points]: Answer the following True/False questions about LFS.

A. True / False LFS's garbage collection mechanism will occasionally copy data from its original location to elsewhere on the disk in order to minimize fragmentation.

B. True / False Given two segments, one with k dead blocks and one with ℓ dead blocks ($k > \ell$), LFS's garbage collection mechanism will clean the one with k dead blocks first.

7. [8 points]: A coordinator C is running a two-phase commit protocol with two servers, X and Y. During this process, you observe X's and Y's logs, specifically the entries for transaction ID 78. These logs use the same format as those in Question 4:

- The three entries in each row are the log entry number, the transaction ID, and the record.
- UPDATE records are of the form UPDATE <var>=<old_value>; <var>=<new_value>.

For each of the following log snippets, specify whether it is consistent with a correct two-phase commit protocol. In each case, we have shown you all of the log entries that have been written thus far pertaining to transaction 78; it is possible that more entries will be written in the future.

A. Consistent / Not Consistent

X's log

```
141   78   UPDATE A=10; A=20
142   78   PREPARE
```

Y's log

```
159   78   UPDATE B=70; B=80
160   78   PREPARE
```

B. Consistent / Not Consistent

X's log

```
141   78   UPDATE A=10; A=20
142   78   PREPARE
143   78   COMMIT
```

Y's log

```
159   78   UPDATE B=70; B=80
```

C. Consistent / Not Consistent

X's log

```
141   78   UPDATE A=10; A=20
142   78   PREPARE
143   78   COMMIT
```

Y's log

```
159   78   UPDATE B=70; B=80
160   78   PREPARE
161   78   COMMIT
```

D. Consistent / Not Consistent

X's log

```
141   78   PREPARE
142   78   UPDATE A=10; A=20
143   78   COMMIT
```

Y's log

```
159   78   PREPARE
160   78   UPDATE B=70; B=80
161   78   COMMIT
```

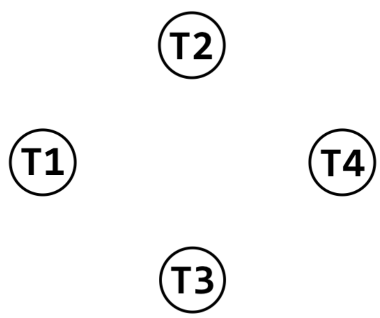
Initials:

III Isolation

8. [8 points]: A transaction processing system runs the steps of transactions T1, T2, T3, and T4 in the order shown (time goes downwards; step i runs before step $i+1$). All transactions commit after step 7 below.

T1	T2	T3	T4
1. `write(x)`			
	2. `read(x)`		
			3. `read(y)`
		4. `write(y)`	
			5. `read(y)`
			6. `read(x)`
	7. `write(y)`		

A. Draw the conflict graph corresponding to this schedule of steps.



B. In order to make this schedule conflict serializable, we would need to do which of the following? Circle the **best** answer.

(a) Nothing; this schedule is already conflict serializable.

(b) Swap the order of **exactly one** pair of operations (i.e., run B before A instead of A before B).

(c) Swap the order of **more than one** pair of operations.

(d) It is impossible to alter this schedule such that it is conflict serializable.

C. In order to make this schedule final-state serializable, we would need to do which of the following? Circle the **best** answer.

(a) Nothing; this schedule is already final-state serializable.

(b) Swap the order of **exactly one** pair of operations (i.e., run B before A instead of A before B).

(c) Swap the order of **more than one** pair of operations.

(d) It is impossible to alter this schedule such that it is final-state serializable.

Initials:

9. [4 points]: Consider a workload of $N + 1$ transactions, $T_0, T_1, \ldots, T_N$, all of which access a shared variable x.

- T_0 writes to x (but does not read its value)
- $T_1, T_2, \ldots, T_N$ read x (but do not write to it)

Ben is using two-phase locking to provide isolation, and is considering using reader-/writer-locks ("R/W locks") to improve performance.

Circle True or False for each of the following.

A. True / False R/W locks could improve performance because they will allow $T_1, T_2, \ldots, T_N$ to execute in parallel.

B. True / False R/W locks could improve performance because they will allow *all* transactions ($T_0, T_1, \ldots, T_N$) to execute in parallel.

C. True / False R/W locks could improve performance, but only if the read locks can be safely released early (i.e., before the commit point of the transaction).

D. True / False R/W locks will not improve performance because all accesses are to the same variable.

IV Availability

10. [6 points]: Consider the following traces of requests and responses made by a single client process in PNUTS (responses to read requests contain the result along with a version number; responses to write requests return a version number on success). For each, indicate whether a client could observe this behavior on PNUTS. Assume that there are no failures (either servers or network). Assume that there can be other concurrent clients.

A. Could Observe / Could Not Observe

```
Read-latest(‘‘foo’’) → (‘‘bar’’, 2.8)
Read-any(‘‘foo’’) → (‘‘bar’’, 2.6)
```

B. Could Observe / Could Not Observe

```
Read-latest(‘‘foo’’) → (‘‘bar’’, 2.8)
Read-any(‘‘foo’’) → (‘‘bar’’, 2.6)
Read-critical(‘‘foo’’, 3.6) → (‘‘bar’’, 2.7)
```

C. Could Observe / Could Not Observe

```
Read-any(‘‘foo’’) → (‘‘bar’’, 2.6)
Write(‘‘foo’’, ‘‘baz’’) → 2.8
Read-any(‘‘foo’’) → (‘‘bar’’, 2.7)
```

11. [4 points]: Consider a replicated state machine (RSM) where each view has a single primary server P and *two* backup servers, B_1 and B_2.

A. In order to correctly provide single-copy consistency, which of the following must be true? Circle all that apply.

(a) There must also be two view servers.
(b) Only P will communicate with the view server(s).
(c) P must receive acknowledgments from both B_1 and B_2 before acknowledging an update to the coordinator.
(d) P must always communicate with B_1 before B_2 (or vice versa).
(e) None of the above.

B. Compared to an RSM where each view has only a single backup, what does the two-backup RSM improve? Circle the **best** answer.

(a) Atomicity
(b) Availability
(c) Consistency
(d) Isolation

Initials:

12. [4 points]: Consider five machines using RAFT. The current log of each machine is given below. Log entries are specified as <term number>.<update ID>; we do not give the specific contents of the updates.

Leader's log:	1.1	1.2	1.3	2.1	2.2	3.1	3.2	3.3
F1's log:	1.1	1.2	1.3	2.1				
F2's log:	1.1	1.2	1.3	2.1	2.2			
F3's log:	1.1	1.2	1.3	2.1	2.2	3.1		
F4's log:	1.1	1.2	1.3	2.1	2.2	3.1	3.2	

A. Which of the log entries are *not* guaranteed to be committed? If they are all guaranteed to be committed, write "None".

B. Which of the followers (F1 through F4) could potentially lead the next election term, assuming that multiple other nodes may fail? If none of the followers could possibly lead the next term, write "None".

Initials:

V Authentication

13. [6 points]: Ben is working on a scheme to store salted passwords. For each user, he generates a salt s and sends that to the user. On his server, he stores three things:

- The user's ID (e.g., their username).
- $H(s)$, where H is a cryptographically-secure hash function.
- The result of $f(p)$, where f is a currently-unspecified function of the user's password p.

These are the only three things Ben stores for each user. He does not, for instance, store s.

Ben's authentication scheme is the following:

1. The client sends their username and password $p_{inputted}$ to Ben's server.
2. Ben calculates $f(p_{inputted})$ and compares it to the stored value of $f(p)$.
3. If the values are equal, the client is authenticated.

Consider a server-side adversary Eve who has the ability to read the data stored on the server. Eve has no other access to the server. Eve also **cannot** perform rainbow-table attacks, or any other brute-force attacks. Eve would like to be able to masquerade as a valid client (i.e., to be authenticated as a valid client despite not being one).

A. Which of the following values of f can Ben use on his server such that his authentication mechanism is resistant to this server-side adversary? Circle all that apply.

(a) $f(x) = x$
(b) $f(x) = H(x)$
(c) $f(x) = H(s \mid x)$
(d) $f(x) = H(H(s) \mid x)$

Having chosen a proper function f (one that is resistant to server-side attacks), Ben turns his attention to network adversaries who can observe and tamper with network packets. These adversaries do not have infinite computational resources, and they cannot launch any other types of attacks (e.g., they cannot DDoS Ben's server).

Instead of having clients send their password across the network in plaintext, he decides to have the clients send $H(p)$ instead.

B. True / False Because users now send the hash of their password, Ben's system is secure against these network adversaries.

Initials:

14. [8 points]: In Katrina's Amazing Web Suite (KAWS), users make requests to the server to purchase cars. There are only two models of cars, and thus only two valid requests:

- `BUY BATMOBILE`
- `BUY JOKERMOBILE`

Each request r is tied to a unique ID, seq_r, which is sent along with the request itself (see below).

Four months after its launch, KAWS is adding some security features. After authenticating users with their passwords, KAWS uses session cookies for quick authentication.

The KAWS developers have a few proposals for how to construct their session cookies. Below, | implies string concatenation, H is a cryptographically-secure hash function, and p refers to the user's password.

Proposal 1. $\{username,\ request,\ seq_{request},\ H(p \mid request \mid seq_{request})\}$

Proposal 2. $\{username,\ request,\ seq_{request},\ H(p \mid seq_{request})\}$

Proposal 3. $\{username,\ request,\ seq_{request},\ H(p \mid request)\}$

The KAWS developers are not concerned with an adversary that has access to the server, and so store passwords in plaintext on the server.[1] They are, however, very concerned about a network adversary between the client and server. This adversary does not know the user's password p, nor do they have infinite computational power. They are able to **observe**, **tamper** with, and **replicate** packets sent between the client and server.

Suppose a user U sends a request to buy a Batmobile (i.e., `BUY BATMOBILE`) as part of a cookie. The unique ID for this request is 186950.

A. Which of the proposed cookies prevent a network adversary from buying multiple Batmobiles on behalf of U? Circle all that apply.

(a) Proposal 1
(b) Proposal 2
(c) Proposal 3
(d) None of the proposals

B. Which of the proposed cookies prevent a network adversary from tampering with U's packet, causing U to buy a Jokermobile instead of a Batmobile without the KAWS server noticing that something is amiss? Circle all that apply.

(a) Proposal 1
(b) Proposal 2
(c) Proposal 3
(d) None of the proposals

[1] This is a terrible idea, of course, but we truly are not concerned with their password-storage method for this problem.

15. [2 points]: Which of the following **best** describes the job of a certificate authority? (Circle only one answer.)

(a) To generate and disseminate key pairs to users.
(b) To store name-to-key mappings.
(c) To authenticate name-to-key mappings.

VI Secure Channels and Network Security

16. [6 points]: Alice is getting ready to communicate a message m to Bob using a shared symmetric key k. Both Alice and Bob know k; no one else does. Alice and Bob have many operations at their disposal:

- `MAC(k, m)`, which outputs the message authentication code of m using key k.
- `ENC(k, m)`, which outputs the encryption of m using key k.
- `DEC(k, c)`, which outputs the decryption of c using key k.

You can assume that the network is reliable: no packets will be dropped or corrupted by the network.

A. Consider a network adversary Eve who can **intercept** Alice's transmission and observe the contents. Eve does not have infinite computational power, nor can she tamper with packets; she can only passively observe.

Alice transmits `MAC(k, m)` to Bob (and nothing else).

(a) **True / False** Upon intercepting Alice's transmission, Eve cannot determine m.
(b) **True / False** Upon intercepting Alice's transmission, Eve canotn determine k.

B. After sending `MAC(k, m)` to Bob, Alice then sends `ENC(k, m)`. Unfortunately, Eve has now gained the ability to tamper with packets.

(a) **True / False** Upon intercepting Alice's transmission (of `ENC(k, m)`), Eve can tamper with it in a way that Bob will not be able to detect.

C. **True / False** If Eve had not gained the ability to tamper with packets, Alice could have communicated m to Bob securely by sending only `ENC(k, m)` (assume Eve is the only adversary in the network).

17. [2 points]: True / False Without chains of trust, DNSSEC would be open to man-in-the-middle attacks.

18. [2 points]: True / False The reason Torpig uses domain flux is so that potential victims have a harder time blocking the bots that are sending traffic to their machines.

19. [6 points]: Eve has rented a botnet, but has found it to have one flaw: the bots cannot spoof their IP addresses. This means that any traffic sent from bot B will have, as its source address, B's IP address.

Alice has her computer set up to drop all packets that have a source IP address from Eve's botnet. She's concerned about two attacks on her network:

- An **HTTP-flooding attack**, where Eve's bots send large, valid requests to her machine, preventing other non-malicious requests from getting through.
- A **DNS-reflection attack**, where Eve's bots send requests to DNS nameservers who then respond to Alice's machine.

A. True / False Alice is protected against the HTTP-flooding attack.

B. True / False Alice is protected against the DNS-reflection attack.

VII Anonymity

20. [6 points]: Alice is using Tor with three proxies—P_1, P_2, and P_3—and is concerned about an adversary who has access to the proxy servers, and thus may be able to learn the state stored on each proxy.

To combat this adversary, Alice decides to use more proxies in her Tor circuit: instead of just P_1, P_2, and P_3, she sends traffic through $P_1, P_2, \ldots, P_N$, $N > 3$ (and then the traffic goes to its ultimate destination, S).

Answer True or False for each of the following questions about Alice's new technique.

A. True / False The latency of Alice's packets will increase (compared to her original three-proxy technique).

B. True / False The size of Alice's packets will be roughly N times as large as her original data packet.

C. True / False Eve will now have to work harder (access more state on more servers) to determine that Alice is communicating with S.

21. [2 points]: Consider a Sybil attack, where a user creates multiple online identities in order to undermine a system. What aspect of Bitcoin is used to mitigate Sybil attacks? Circle the **best** answer.

(a) Cryptographic signatures

(b) Peer-to-peer networking

(c) Proofs of work

(d) None of the above

End of Quiz 2

Please double check that you wrote your name on the front of the quiz,
circled your recitation section, and initialed each page.

Initials: