Nick Weaver
Fall 2018

CS 161
Computer Security

Midterm 1

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

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.

SIGN your name: ______________________

PRINT your class account login: `cs161-`______________________ and SID: ______________________

Name of the person sitting to your left: ______________________

Name of the person sitting to your right: ______________________

You may consult one sheet of paper of notes. You may not consult other notes, textbooks, etc. Calculators, computers, and other electronic devices are not permitted. We use Gradescope for grading so please write your answers in the space provided.

If you think a question is ambiguous, please come up to the front of the exam room to the staff. If we agree that the question is ambiguous we will add clarifying assumptions to the central document projected in the exam rooms.

You have 110 minutes. There are 11 questions, of varying credit (134 points total). The questions are of varying difficulty, so avoid spending too long on any one question.

Some of the test may include interesting technical asides as footnotes. You are not responsible for reading the footnotes.

Do not turn this page until your instructor tells you to do so.

Problem 1 ***Cryptography True/False*** **(18 points)**

Answer the following cryptography questions true or false.

(a) Let E_k be a secure block cipher. TRUE or FALSE: It is impossible to find two messages m and m' such that $m \neq m'$ and $E_k(m) = E_k(m')$, even if the attacker knows k.

● TRUE ○ FALSE

> **Solution:** Yes, no such m and m' exist as E_k is injective.

(b) Let E_k be a secure block cipher. TRUE or FALSE: It is computationally difficult to find two pairs (m, k) and (m', k') such that $m \neq m'$, $k \neq k'$ and $E_k(m) = E_{k'}(m')$.

○ TRUE ● FALSE

> **Solution:** No. Let $k' \neq k$ and $m' = D_{k'}(E_k(m))$. W.h.p. we have $m' \neq m$ as desired.

(c) Let MAC_k be a secure MAC. TRUE or FALSE: It is computationally difficult to find messages m and m' such that $m \neq m'$ and $\text{MAC}_k(m) = \text{MAC}_k(m')$, even if the attacker knows k.

○ TRUE ● FALSE

> **Solution:** It depends on the MAC: In particular, AES-MAC is secure but does not have this property. You can have multiple messages all with the same MAC, because you just take the intermediate values: you mac a message M, and then "roll back" a single block. HMAC does have this property however. And this is why HMAC-accept-no-substitutes!

(d) Let H be a cryptographic hash function. TRUE or FALSE: $H(M)$ provides confidentiality for the message M.

○ TRUE ● FALSE

> **Solution:** No, this leaks if the same message is sent twice. Also an attacker can try confirmation attacks on the message.

(e) HMAC-DRBG does not have rollback resistance.

○ TRUE ● FALSE

(f) Diffie/Hellman is secure in the presence of an active adversary.

○ TRUE ● FALSE

(g) Properly constructed RSA Signatures provide both integrity and authenticity.

● True ○ False

> **Solution:** Integrity and Authentication.

(h) El Gamal encryption provides confidentiality but it does not provide integrity or authentication.

● True ○ False

> **Solution:** True. El Gamal provides only confidentiality.

(i) In examining a certificate we need to consider how we obtained the certificate as well as the certificate's contents and signatures.

○ True ● False

Problem 2 ***Potpourri*** **(18 points)**

(a) Instead of storing user input on the stack, you decide to create a new section of memory (separate from code, static, heap, and stack) for storing user input. You also put a 64-bit canary at the top (largest memory address) of the section. Name one memory-safety vulnerability that this prevents.

> **Solution:** This prevents a simple buffer overflow attack from changing return addresses on the stack.

(b) Name one memory-safety issue that the scheme from part (a) fails to prevent.

> **Solution:** This does not prevent buffer overflows from overwriting other user input stored in the section. Format string vulnerabilities can still allow the attacker to read arbitrary parts of memory. Programmer sloppiness is also a possibility as copying user input into a local variable stored in the stack (through strcpy etc.) can still cause buffer overflows to overwrite the return address.

(c) TRUE or FALSE: In a threat detection systems, false negatives can be catastrophic, but false positives are always harmless.

○ TRUE ● FALSE

> **Solution:** False, false positives can take time, money, and other resources to address. False positives can make a good detector/alarm unusable even if it has a very low false negative rate.

(d) Which of the following are recommended ways to protect a password database? (Select all that apply.)

■ Salting Passwords ☐ Using a Fast Hashing Function

☐ Encrypting Passwords ■ Using a Slow Hashing Function

(e) A heap overflow or use-after-free vulnerability can allow the attacker to overwrite the `vtable` pointer of an object (that is, the pointer at the start of a C++ object that points to the actual methods for the function, basically a pointer to an array of function pointers). Can this bypass stack canaries without additional information?

● Yes ○ No

(f) At what rank did Grace Hopper retire?

○ Lieutenant Colonel ○ Captain

● Rear Admiral ○ Brigadier General

> **Solution:** No. MACs provide integrity and can provide authentication if used by only one party.

(g) Alice generates a MAC on her homework answers that she stores with her homework answers in a secret remote server. When she needs to submit her homework, she uses the MAC to check that her answers have not been tampered with. Only she has the key needed to generate the MAC. Which of the following apply in this scenario?

- ○ Integrity and Confidentiality
- ○ Authentication and Confidentiality
- ● Integrity and Authentication
- ○ Only Integrity

(h) Which of the following attacks can be used against a crypto system? (Select all that apply.)

- ■ Side-Channel
- ☐ Rolling-regression
- ■ Chosen-plaintext
- ■ Chosen-ciphertext
- ■ Rubber-Hose Cryptanalysis

Solution: See selected.

(i) "Crypto" means:

- ■ Cryptography
- ☐ Cryptocurrency
- ☐ Kryptonite
- ☐ CryptoKitties

(j) The Magic Word is:

- ☐ Adava Kedavra
- ☐ Windgardium Leviosa
- ■ Stupify
- ☐ Crucio

Problem 3 ***Security Principles*** **(12 points)**

Write the best match for which security principle each situation.

Four CS 161 students, Chiyo, Habiba, Mr. Anderson, and Not Outis, decided that after learning about security principles and buffer overflows, they could implement their own distributed database (a database across multiple machines) with a focus on security!

(a) Mr. Anderson suggests code their database in a higher-level programming language since they could avoid common security problems later on. Which security principle did he to use here?

> **Solution:** Design in Security from the Start

(b) Let's say they start coding their database and realized that a malicious user on one machine could corrupt their database. As a result, Habiba wants permission from at least 50% database users before a machine can be taken down. Which security principle is she using here?

> **Solution:** Division of Trust

(c) The database the students built was password-protected for modification and they use a snippet (like the following) everywhere to check passwords:

```
String password = getPassword("user");
if (!password.equals(enteredPassword)) error();
```

Not Outis eventually forgets to put this snippet to check the passwords. What security principle does this violate?

> **Solution:** Ensure Complete Mediation

(d) To encrypt the data, Not Outis decides to take each piece of data and rotate the bytes in it by a fixed amount. It figured that since their database was closed source, no one would figure out how they were encrypting things. What security principle does this violate?

> **Solution:** Shannon's Maxim or Kerckhoff's Principle

(e) Mr. Anderson decides that new users should automatically get privileged access in order to set up their account to access whatever items they needed. After 1 hour, they would be dropped back to regular permissions, an administrator would be notified of changes, and they could revert changes if necessary. What security principle says this is not a good idea?

> **Solution:** Fail-Safe Defaults

(f) After fixing all previous problems, Chiyo decides to refactor their encryption code into its own module since a lot of it was spread across multiple modules. She also put all non-encryption code in a sandbox so that no vulnerabilities in those modules could effect the overall security of the database. What security principle is she trying to follow? What is she trying to minimize the size of?

> **Solution:** Privilege Separation, TCB

Problem 4 *Go With The Control Flow* (14 points)

The code below runs on a 32-bit Intel architecture. No defenses against buffer overflows are enabled. The code was not compiled to produce a position independent executable. No optimizations are enabled, and the compiler does not insert padding or reorder stack variables, which means `buffer` is at a lower address than `fp`.

```c
1  int run_command(char *cmd) {
2      return system(cmd);
3  }
4  int print_hello(char *msg) {
5      printf("Hello %s!\n", msg);
6      return 0;
7  }
8  int main() {
9      int (*fp)(char *) = &print_hello;
10     char buffer[8];
11     gets(buffer);
12     fp(buffer);
13 }
```

Note that the syntax `int (*fp)(char *)` indicates that `fp` is a pointer to a function which takes in a `char *` and returns an `int`.

(a) What line contains a memory vulnerability? What is this vulnerability called?

> **Solution:** Line 11. Buffer overflow!

(b) At line 12, we have that `%ebp = 0xbfdead20` and `&print_hello = 0x08cafe13`. Fill in the Python egg below to give an input which will **overwrite the return address of `main`**, causing the execution of the shellcode after the program returns from `main`.

`print 'A' * _____ + '_________________' + 'AAAA' + '_________________' + SHELLCODE`

> **Solution:** `print 'A' * 8 + '\x13\xfe\xca\x08AAAA\x28\xad\xde\xbf' + SHELLCODE`

(c) Which of the following would sometimes or always prevent the code that you gave in part (b) from working? (Select all that apply.)

■ ASLR (same as part 5 on the project)

■ Selfrando

■ W^X

■ Using a memory-safe language instead of C

(d) "I know," says Louis Reasoner, "let's add stack canaries to make this impossible to exploit!" Obviously this doesn't work. Fill in the Python egg below to give an input which will cause the execution of `run_command("/bin/sh")`. At line 12, we have that `%ebp = 0xbfdead20` and `&run_command = 0x08c0de42`. HINT: Note that `gets` can read in a `NUL` byte (\x00), even in the middle of its input.

`print '_____________________________________________________________________________'`

> **Solution:** `print '/bin/sh\x00\x42\xde\xc0\x08'`

(e) Which of the following would sometimes or always prevent the code that you gave in part (d) from working? (Select all that apply.)

- ☐ ASLR (same as part 5 on the project)
- ■ Selfrando
- ☐ W^X
- ■ Using a memory-safe language instead of C

Problem 5 ***Ben Bitdiddle's Preconditions*** **(8 points)**

Ben Bitdiddle did not do a good job at coming up with a set of preconditions for some functions. For each code block, explain why with a short example the given preconditions are **not** sufficient to ensure memory safety by giving a small example.

(a)

```c
/*   array_of_strings != NULL
     n <= size(array_of_strings)
     max_size > 0
     for all i . 0 <= i < n ==>
          array_of_strings[i] != NULL and is a NUL-terminated string */
char *
concat_all(char *array_of_strings[], size_t n, size_t max_size) {
    char *concat = calloc(max_size, sizeof(char));
    if (!concat) return NULL;
    size_t space_used = 0;
    for (size_t i = 0; i < n; i++) {
        char *s = array_of_strings[i];
        size_t len = strlen(s);
        strncpy(concat + space_used, s, max_size - space_used - 1);
        space_used += len;
    }
    return concat;
}
```

Explanation:

Solution: Consider `concat_all({"abcde", "fghi"}, 2, 5)`. After the first loop iteration, we will have `space_used = 5, max_size = 5`, and `concat = "abcd\0"`. Then because of integer overflow, we have `max_size - space_used - 1 = (size_t) -1` (which is really big!) On the next iteration we write out-of-bounds, and this is a heap buffer overflow.

(b)

```c
/*   arr != NULL
     n <= size(arr)
     for all i . 0 <= i < n ==> 0 <= arr[i] < n */
int solve_interview_question(int *arr, size_t n) {
    for (size_t i = 0; i < n; i++)
        arr[arr[i]] *= -1;
    for (size_t i = 0; i < n; i++)
        if (arr[i] < 0)
            return i;
    return 0;
}
```

Explanation:

Solution:

Consider `arr = {1, 1}`. Then all of the preconditions are met, but this accesses `arr[-1]` (in the second loop iteration) which may not be defined.

Problem 6 *Greetings Professor Falken!* (9 points)

Consider the code below.

```
1  void launch_nuclear_missiles() {
2      puts("Launching the nukes...");
3      /* code to launch nuclear missiles here */
4      exit(1);
5  }
6
7  #define MAX_INPUT 8
8  int main() {
9      char *correct_password = malloc(MAX_INPUT * sizeof(char));
10     strcpy(correct_password, "S3creT\n");
11     while (!feof(stdin)) {
12         char *user_password = malloc(MAX_INPUT * sizeof(char));
13         fgets(user_password, MAX_INPUT, stdin);
14         if (strcmp(user_password, correct_password) == 0)
15             launch_nuclear_missiles();
16         free(user_password);
17         free(correct_password);
18         puts("Wrong password, try again!");
19     }
20 }
```

All compiler optimizations are disabled, and both the source and binary are not available to David Lightman, who's trying to log in to play a game. Consider the following (buggy) interaction:

1. David inputs "Hello" followed by a newline.
2. The program outputs "Wrong password, try again!".
3. David inputs "Joshua" followed by a newline.
4. The program outputs "Launching the nukes...", and then the nukes are launched.[1]

(a) Which memory safety vulnerability is present in this code?

> **Solution:** Use after free.

(b) Explain why this issue leads to the behavior David observes.

> **Solution:** Occurs since the memory for `correct_password` is reused by the next malloc for `user_password`. Therefore the second input is always correct as `correct_password == user_password`.

(c) How could you fix this issue in the code?

> **Solution:** Delete line 17.

[1] This immediately vaporizing millions of humans and wildlife on impact, beginning World War III and eventually wiping out most of the world due to an extended nuclear winter. This is why you don't hack into systems without permission. If you want to understand more how nuclear command, control, and decision making works, the two books to read are Command and Control: Nuclear Weapons, the Damascus Accident, and the Illusion of Safety by Eric Schlosser, and The 2020 Commission Report on the North Korean Nuclear Attacks Against the United States (A Speculative Novel) by Jeffrey Lewis.

Problem 7 ***Fail Caesar*** **(12 points)**

A student at a well known Junior University decided to write their own Caesar Cipher after learning about them in their computer security class. Unfortunately for the student, they fell asleep during the lecture on memory safety. (Note: The `atoi()` function converts the initial portion of the string to an integer, returning 0 in case of an error.)

```
1  #include <stdio.h>
2  #include <stdlib.h>
3  void encrypt(int offset, char plaintext[]) {
4      char ciphertext[64];
5      memset(ciphertext, 0, 64);
6      int i = 0;
7      fgets(plaintext, 64, stdin);
8      while (plaintext[i]){
9          ciphertext[i] = plaintext[i] + offset;
10         i++;
11     }
12     printf(ciphertext);
13 }
14
15 int main(int argc, char *argv[]){
16     char buffer[64];
17     int offset = 0;
18     if (argc > 1) offset = atoi(argv[1]) % 26;
19     while (!feof(stdin)){
20         memset(buffer, 0, 64);
21         encrypt(offset, buffer);
22     }
23     return 0;
24 }
```

(a) What line contains a memory vulnerability? What is this vulnerability called?

> **Solution:** The vulnerable code is on line 12. This is a format string vulnerability.

(b) Give a file that, when input to the command `failcaesar` with no arguments, will cause the program to crash.

> **Solution:** Either a lot of %s or %n items...

(c) How would you change the line to fix the vulnerability?

> **Solution:** Change `printf(ciphertext)` to `printf("%s", ciphertext)` or `fputs(ciphertext, stdout)`. Also accept `puts(ciphertext)` or `printf("%s\n", ciphertext)` although they add a trailing newline.

(d) The student's friend who was awake for the memory safety lecture tells them to enable stack canaries to make their code more secure. If an attacker does not have time to perform a bruteforce attack, does enabling stack canaries prevent this code from being exploited? Explain why or why not.

Solution: No, in a format string vulnerability a malicious user can write directly to a desired address in memory without making consecutive writes up the stack. As such, Mallory can write around the stack canary to overwrite the return instruction pointer.

Problem 8 *A Lack of Integrity...* (9 points)

Alice and Bob want to communicate. They have preshared a symmetric key k. In order to send a message M to Bob, Alice encrypts it using AES-CBC, and sends the encryption to Bob. (You may assume that M's length is divisible by the AES-CBC block length and that characters are 8 bits, so no padding is necessary.) Recall that the actual message sent is $IV||E(M)$, that is, the IV is prepended to the message and sent all as a single stream of bytes. Alice uses a random IV for each message.

In order to make sure that Bob is listening, they agree to using *pingback* messages. If Alice sends a message whose plaintext begins with the two bytes "PB", then Bob sends back the rest of the message *in plaintext*. For example, if Alice sends AES-CBC$_k$("PBI Love CS 161!"), then Bob responds "I Love CS 161!" without any encryption.

Alice uses the protocol to communicate some message M to Bob. Assume M is not a pingback message. Mallory, a man-in-the-middle attacker, decides to attempt to trick Bob into generating a pingback message. She thus sends the message $IV'||IV||E(M)$, where IV' is a random 128b string.

(a) With what probability will Mallory's message trigger a pingback message?

> **Solution:** 1 in 2^{16}.

(b) If Mallory's message triggers a pingback message, what does Mallory receive?

> **Solution:** 14 bytes of garbage prepended to the real message sent

(c) How can Alice and Bob change their protocol to prevent this attack?

> **Solution:** Use a MAC!

Problem 9 ***Screwups in Inserting an IV*** **(15 points)**

Alice encrypts two messages, M_1 and M_2 using the same IV/nonce and a deterministic padding scheme (when appropriate for the particular mode) using AES (a 128b block cipher). Eve, the Eavesdropper, knows the plaintext of M_1, that each block of M_1 is different, that M_1 is 120 *bytes*, and that Alice never sends any bytes she doesn't have to. Unbeknownst to Eve, it turns out that the messages differ only in the 21st byte of the two messages but are otherwise identical.

Yes, Alice screwed up. But how badly? For each possibility, select *all* which apply.

(a) If Alice used AES-ECB (Electronic Code Book), Eve is able to determine which of the following about M_2:

- ■ That M_2 is exactly 120B long
- □ The entire plaintext for M_2
- ■ The entire plaintext for M_2 except for the 2nd block
- □ That M_2 is less than 129B long but not the exact length
- □ The plaintext for only the first two blocks of M_2
- □ The plaintext for only the first block of M_2

(b) If Alice used AES-CTR (Counter), Eve is able to determine which of the following about M_2:

- ■ That M_2 is exactly 120B long
- ■ The entire plaintext for M_2
- □ The entire plaintext for M_2 except for the 2nd block
- □ That M_2 is less than 129B long but not the exact length
- □ The plaintext for only the first two blocks of M_2
- □ The plaintext for only the first block of M_2

(c) If Alice used AES-CBC (Cipher Block Chaining), Eve is able to determine which of the following about M_2:

- □ That M_2 is exactly 120B long
- □ The entire plaintext for M_2
- □ The entire plaintext for M_2 except for the 2nd block
- ■ That M_2 is less than 129B long but not the exact length
- □ The plaintext for only the first two blocks of M_2
- ■ The plaintext for only the first block of M_2

(d) If Alice used AES-CFB (Ciphertext Feedback), Eve is able to determine which of the following about M_2:

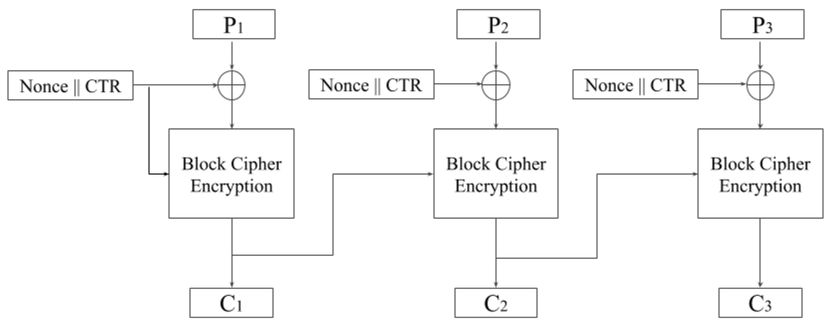
- ■ That M_2 is exactly 120B long
- □ The entire plaintext for M_2
- □ The entire plaintext for M_2 except for the 2nd block
- □ That M_2 is less than 129B long but not the exact length
- ■ The plaintext for only the first two blocks of M_2
- □ The plaintext for only the first block of M_2

(e) If Alice did *not* screw up, which modes allow Eve to determine the exact length of a third message M_3 that is completely different from M_1 and M_2.

- □ AES-ECB
- ■ AES-CTR
- □ AES-CBC
- ■ AES-CFB

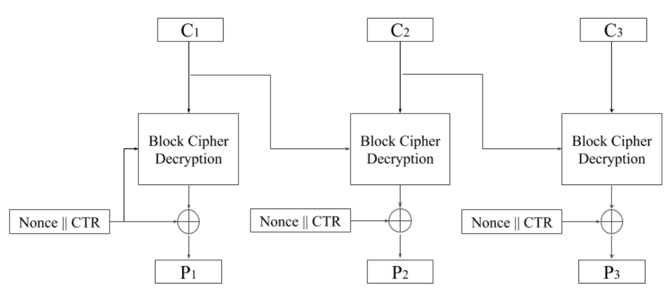
Problem 10 ***No More Keys*** **(7 points)**

Frustrated by your newfound love of encryption schemes, your partner decides to throw away all of your secret keys. As a student in CS 161, you decide to make the best of a bad situation. You decide to design your own encryption scheme!



(a) Design the Decryption scheme.

Solution:



(b) This is IND-CPA:

○ True ● False

Solution: Of course not!

(c) The encryption is parallelizeable:

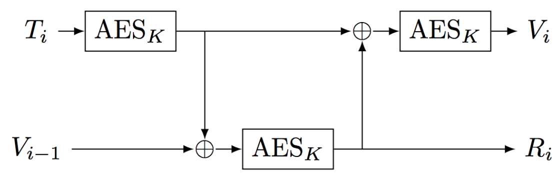
○ True ● False

(d) The decryption is parallelizeable:

● True ○ False

Problem 11 ***Like Water off a DUHK's Back*** **(12 points)**

The ANSI X9.17/X9.31 is a fairly simple pRNG that was widely used based on a block cipher (commonly AES). The internal state V and key K are combined with the current time T to update the state and produce a "random" value.



The current time is measured in microseconds as that is what the common operating system routines return. This is a strong pRNG as long as the initial state V_0 and the key K are both high entropy and secret, and the block cipher is secure.

Unfortunately this scheme can fail badly when common mistakes are made. The standard never specified how to select K. So some implementations, rather than using a high-entropy source to seed a secret K, used a hardcoded key. The result is a catastrophic failure[2].

(a) If the attacker exactly knows K, T_1, and R_1, the attacker can then recover V_0. How?

Solution: $V_0 = D(R_1) \oplus E(T_1)$

(b) Since one can then use this to calculate R_0 given T_0, what design principle for a good pRNG does this fail to implement?

Solution: Rollback Resistance

(c) If the attacker knows T_0 and T_1 with just millisecond resolution, the attacker can check to see if a possible candidate for T_0 and T_1 is consistent with guesses for R_0 and thereby know they found V_0. How many possible combinations of T_0 and T_1 may potentially need to be checked to determine V_0?

Solution: 1,000,000

[2]This was analyzed as the DUHK ("Don't Use Hardcoded Keys") attack, and it worked against FortiGate VPNs. For more details see https://duhkattack.com. This catastrophic failure mode is why it is no longer part of the standard suite of pRNGs.

Foot-Shooting Prevention Agreement

I, ______________, promise that once
Your Name

I see how simple AES really is, I will **not** implement it in production code even though it would be really fun.

This agreement shall be in effect until the undersigned creates a meaningful interpretive dance that compares and contrasts cache-based, timing, and other side channel attacks and their countermeasures.

X______________________________ __________
Signature Date