Project #1 - Reverse Engineering

In this project, you will acquire hands-on experience in practical reverse engineering, developing a comprehensive understanding of ELF binary programs, their execution, and their interaction with the underlying software system.

You will be given several ELF binary files, which require a user to enter a password. Your primary task is to crack their passwords by performing reverse engineering on each binary.

Instructions

• Given that all binaries were built on a Thayer's Linux server, it is highly recommended to use one of these machines for this project (e.g., *babylon1.thayer.dartmouth.edu*). While alternative preferences are allowed, grading will be based on results obtained from Thayer's Linux machines.

• You will be given four binary files, *bin0*, *bin0-strip*, *bin1* and *bin2*, along with *bin0.c*. Each of these files requires a user to enter a correct password, but each binary file may have a different password and a distinct mechanism to validate it.

• You are NOT allowed to modify any of the files provided.

• For reverse engineering tools, it is recommended to use GNU debugging tools, such as readelf, gdb, and objdump if you do not have any preference.

• You might consider writing a python (or shell) script to automate your testing.

• Regardless of its difficulty, it may take some time. Start early!

(50 pts) Task 1

For the first task, you will examine a binary program, *bin0*, which was compiled from the source code *bin0.c*. Please answer the following questions.

1. (3 pts) Is the binary statically or dynamically linked? If it is statically linked, what is the size of the binary file? If dynamically linked, please list all externally used libraries.

- Using the `file` command followed by `bin0`, we know that the binary file, bin0, is dynamically linked.
- Using the `ldd` command followed by `bin0`, we know that all the externally used libraries in bin0 are
    - linux-vdso.so.1 (0x00007fff983b9000)
    - libc.so.6 => /lib/x86_64-linux-gnu/libc.so.6 (0x00007f6b13314000)
- And the dynamic linker/loader is
    - /lib64/ld-linux-x86-64.so.2 (0x00007f6b13570000)

2. (3 pts) List all the sections that are merged into a code segment (having an "execute" permission).

- Using the `objdump -h` command followed by `bin0`, it lists out all the different sections in the binary file with their properties. We are interested in the sections that have the `CODE` property because these are the ones that are merged into a code segment (i.e. having an "execute" permission). These sections are
    - .init
    - .plt
    - .text
    - .fini

3. (4 pts) What are the addresses of the program's entry point *before* and *after* execution?

- The address of the program's entry point before execution is 0x401060 and it's the same address after execution as well.
- I used the `info files` command in gdb to inspect the entry point of the program before and after execution.
- I run gdb on bin0, and before running the program, I use the `info files` command, and it states that the address of the entry point is 0x401060.

- I then run the program, and after the end of its execution, I use the `info files` command again, and the address of the entry point is still 0x401060.

4. (15 pts) Draw the layout of the stack frame corresponding to the function *check_password()* after its function prologue is done. For each element (e.g., local variables, function return address) on the stack, provide its address and size.

- In gdb, I set a breakpoint at the address of check_passwd. Then, after running the program, it stops at the check_passwd breakpoint.
- Afterwards, I used the `info frame` command to inspect some frame information. I got the following information:
    - The stack frame for check_passwd is at 0x7fffffffce80
    - rip = 0x40114a in check_passwd; saved rip = 0x4011ee
    - called by frame at 0x7fffffffcea0
    - Arglist at 0x7fffffffce70, args:
        - Locals at 0x7fffffffce70, Previous frame's sp is 0x7fffffffce80
    - Saved registers:
        - Saved rbp at 0x7fffffffce70, saved rip at 0x 7fffffffce78
- Now, I will disassemble the check_passwd frame to examine the stack frame further. The assembly code for check_passwd verifies our instinct, given the source code, that there are no local variables in the check_passwd stack frame because no values are being stored within a negative offset from %ebp.
- Putting all the information we acquired together, we get the following stack frame layout for check_passwd:

	addresses	values
	⋮	
	0xffffffffffff	
	⋮	previous frames
rbp →	0x7fffffffce80	return address = 0x4011ee
	0x7fffffffce78	saved rip = 0x4011ee
rsp →	0x7fffffffce70	saved rbp = 0x7fffffffcea0
	⋮	
	0x000000000000	

%rbp = 0x7fffffffce80
%rsp = 0x7fffffffce70
%rip = 0x40114a

- Now, the size of the function return address is 12 bytes long, the saved rip is also 12 bytes long, and the saved rbp is 24 bytes long.

5. (15 pts) In which segment(s) and address(es) would the password be located during program execution? (segment: heap, code, data, etc)

- It's stored in the code segment at the following addresses
    - 0x0000000000401183
        - This address has the character `T` stored in.
    - 0x000000000040118e
        - This address has the character `e` stored in.
    - 0x0000000000401199
        - This address has the character `S` stored in.
    - 0x00000000004011a4
        - This address has the character `t` stored in.

6. (10 pts) *bin0-strip* is a binary program compiled from the same source code, but with an additional *gcc -s* option. What's the difference between compiling with and without this option? Please describe as detail as possible using screenshot(s).

- Compiling a source code without the `-s` flag will produce a non-stripped ELF binary file. On the other hand, compiling a source code with the `-s` flag will produce a stripped ELF binary file.
- The main difference between a stripped ELF binary file and a non-stripped one is that stripped binaries don't preserve debugging symbols when compiled because the `-s` flag will tell the compiler when compiling to discard these debugging symbols, which are not needed for program execution. Unlike stripped binaries, non-stripped binaries preserve these debugging symbols when compiling. Some examples of debugging symbols include function names, variable names, line numbers, type information, stack frames, function parameters, and other pieces of information.
- Here are a few main consequences for this difference in terms of debugging symbols when it comes to ELF binary files.
    a. Stripping a binary reduces its size on the disk compared to a non-stripped one.

b. Stripping a binary file makes it a little more difficult to debug and reverse engineer compared to non-stripped ones because of the lack of the debugging symbols that gdb uses for example.
c. Stripping a binary file makes it harder, while not impossible, to read and analyze the binary file at hand and understand the logic behind it because of the lack of the debugging symbols.

(50 pts) Task 2

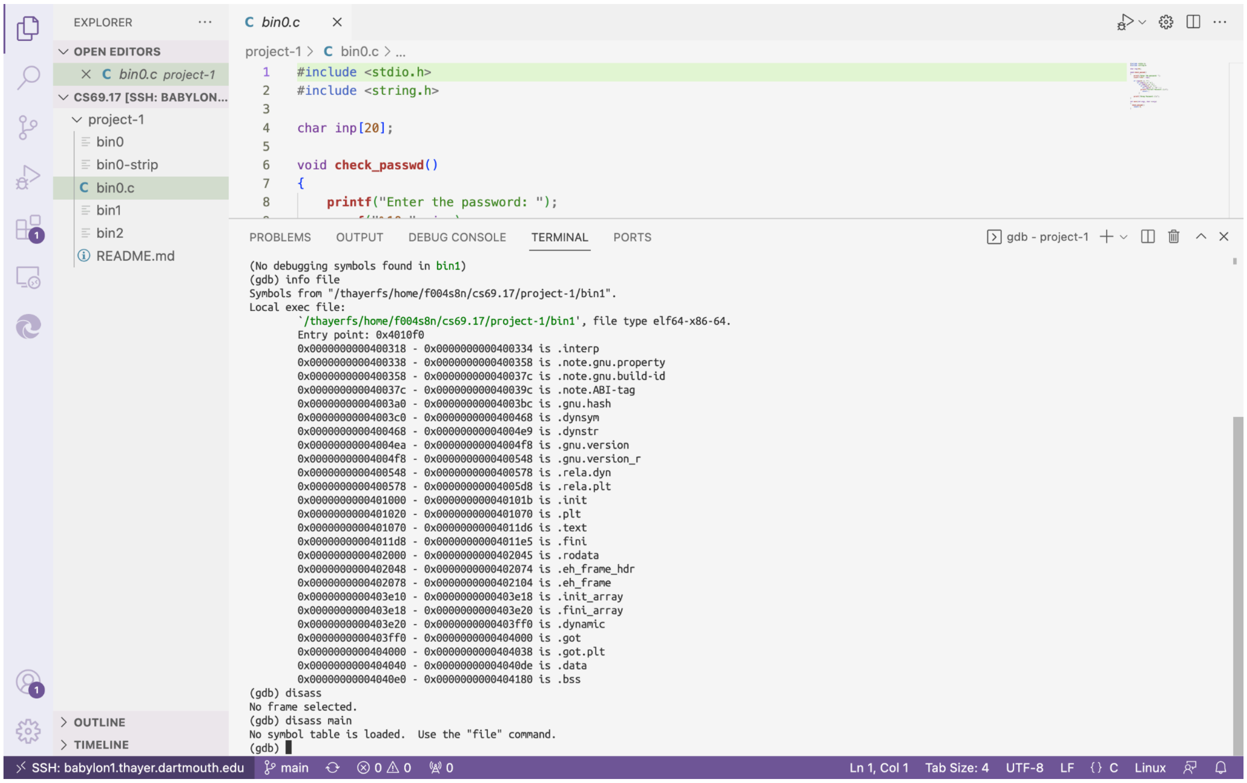
In this task, you will reverse engineer the two binary programs, *bin1*, and *bin2*, with no source code provided. Similar to Task 1, your goal is to crack the password for each binary. Note that the passwords can be located in any of the memory segments at runtime, such as stack segment, and the size of the password in each binary is variable.

1. (10 pts) What is the correct password for *bin1*?

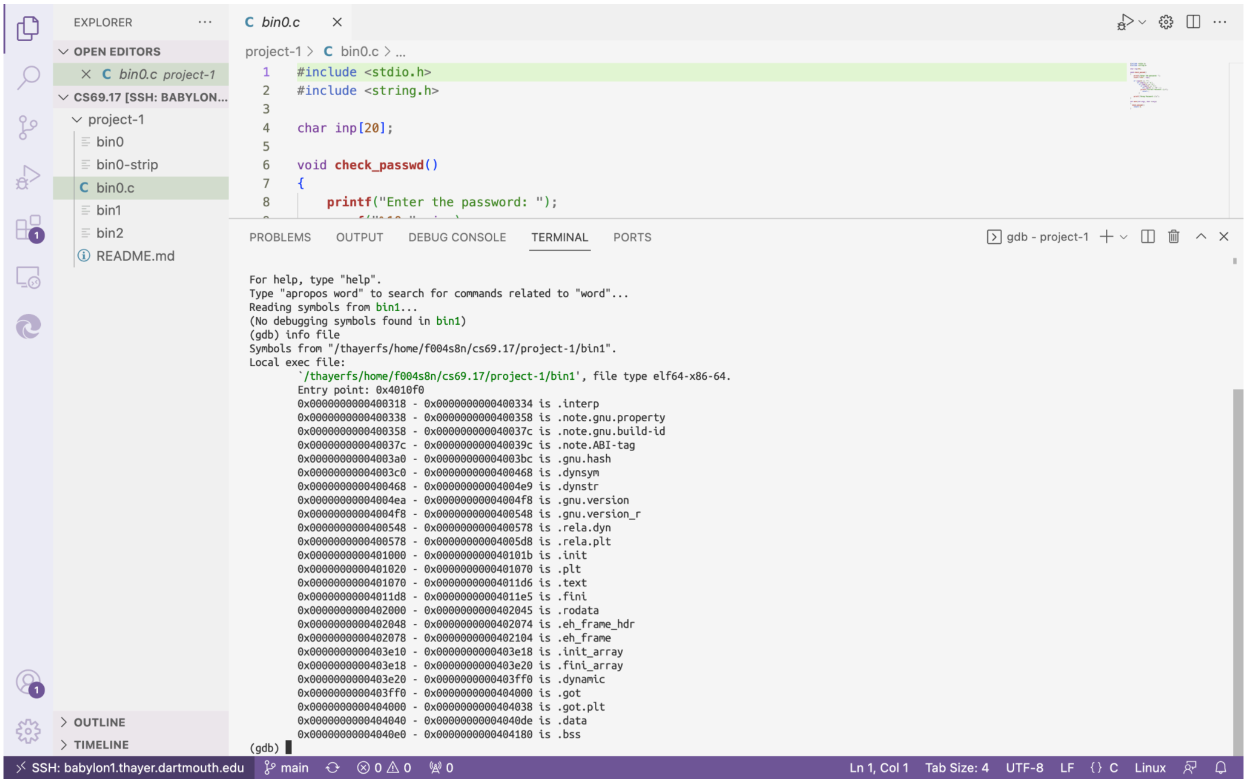
- The correct password for bin1 is `P0_y0u_l1Qe_Kr4bbY_pAt71ez?`.

2. (15 pts) Describe your strategy to crack the password of *bin1*. To receive full credit, explain how you determined the password. Explain all the steps. (screenshots may help.)

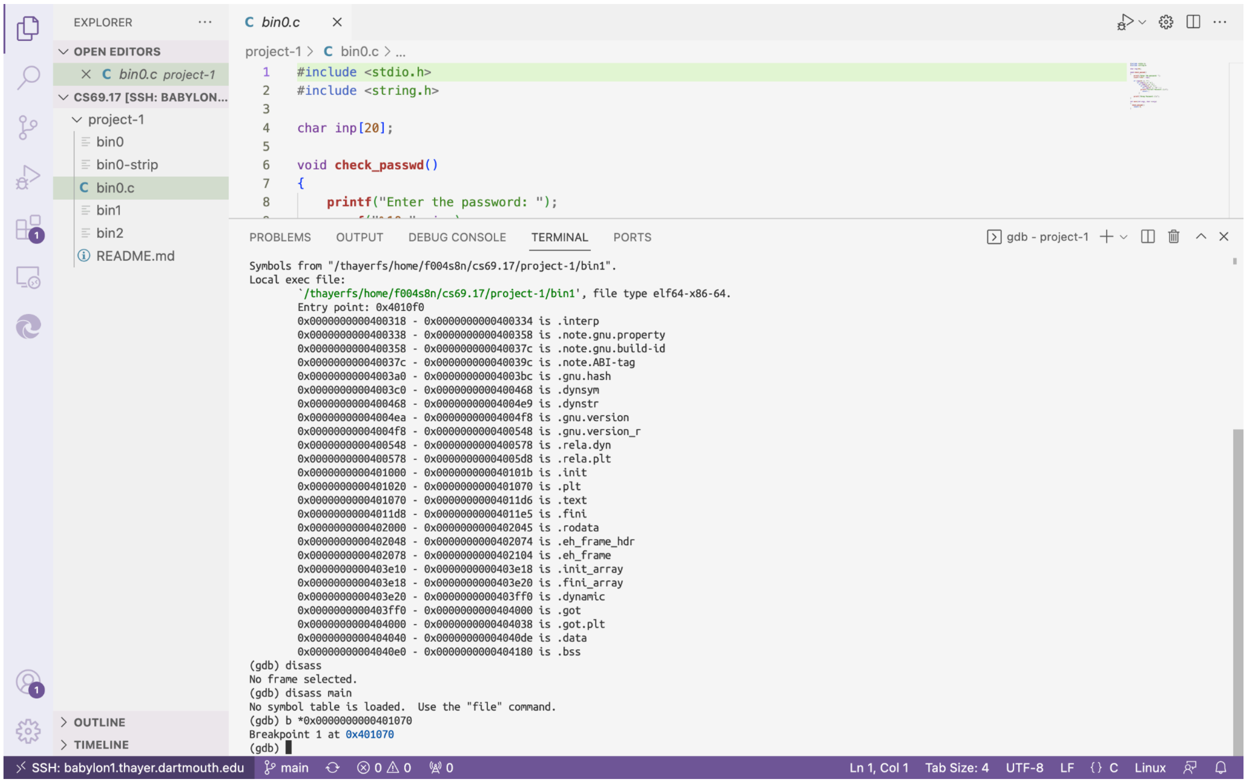
- Since bin1 is a stripped ELF binary, gdb has no idea where the address of the `main` function is when asked to disassemble the binary.



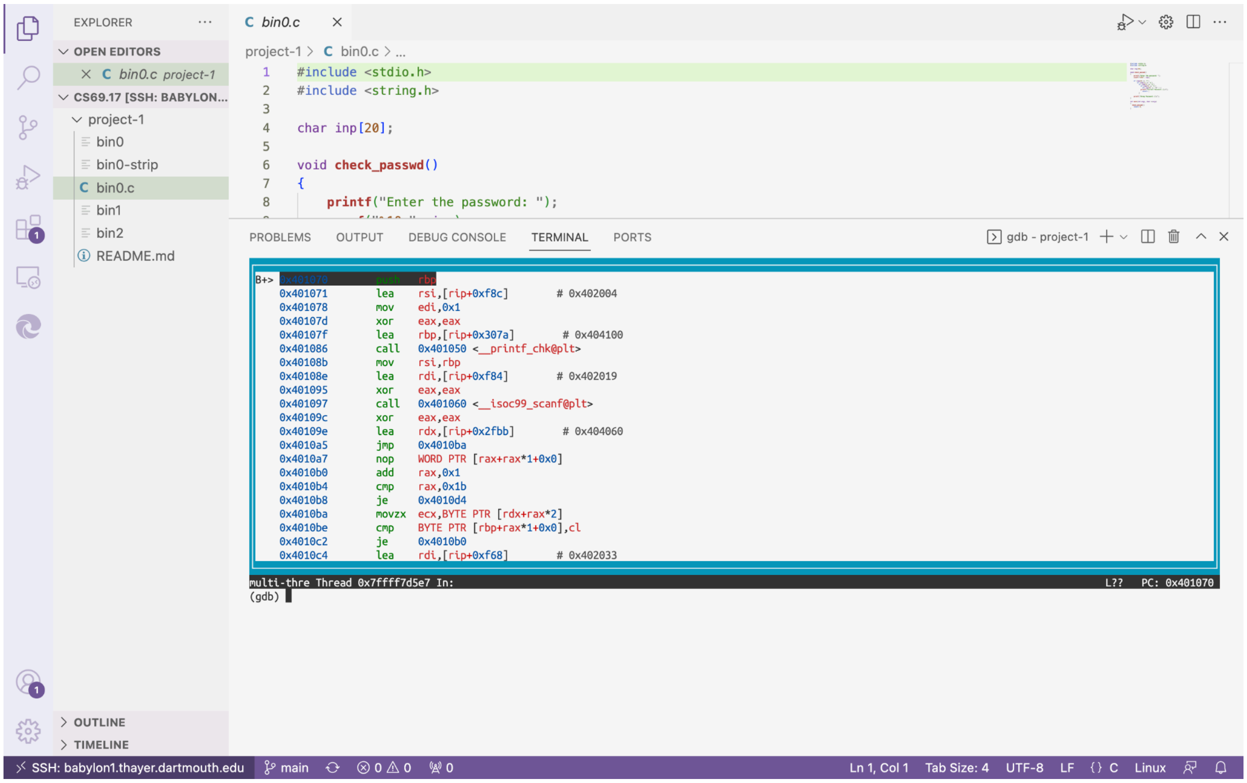
- Therefore, we have to figure out ourselves where the code starts and set a breakpoint at that address.
- To do that, I use the command `info files` in gdb to browse over some high level, but important, information about bin1 and the different sections in it.



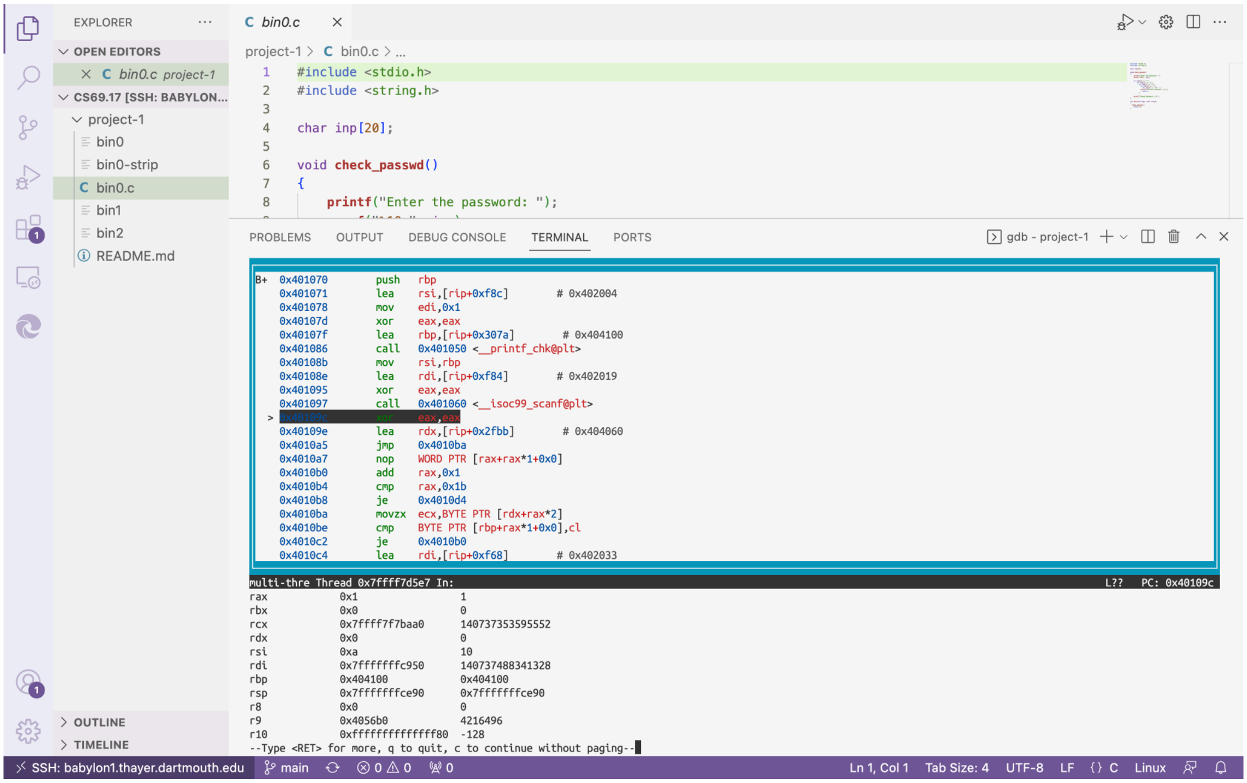
- When the `info files` command is run in gdb, it shows where the .text section starts and ends, that is, the addresses of which the executable code starts and ends. The beginning of this .text section is of interest to us because this is where the `main` function lies — or maybe within a few higher addresses.
- We then set a breakpoint at the beginning of the .text section, in our case, that would be the address 0x0000000000401070.



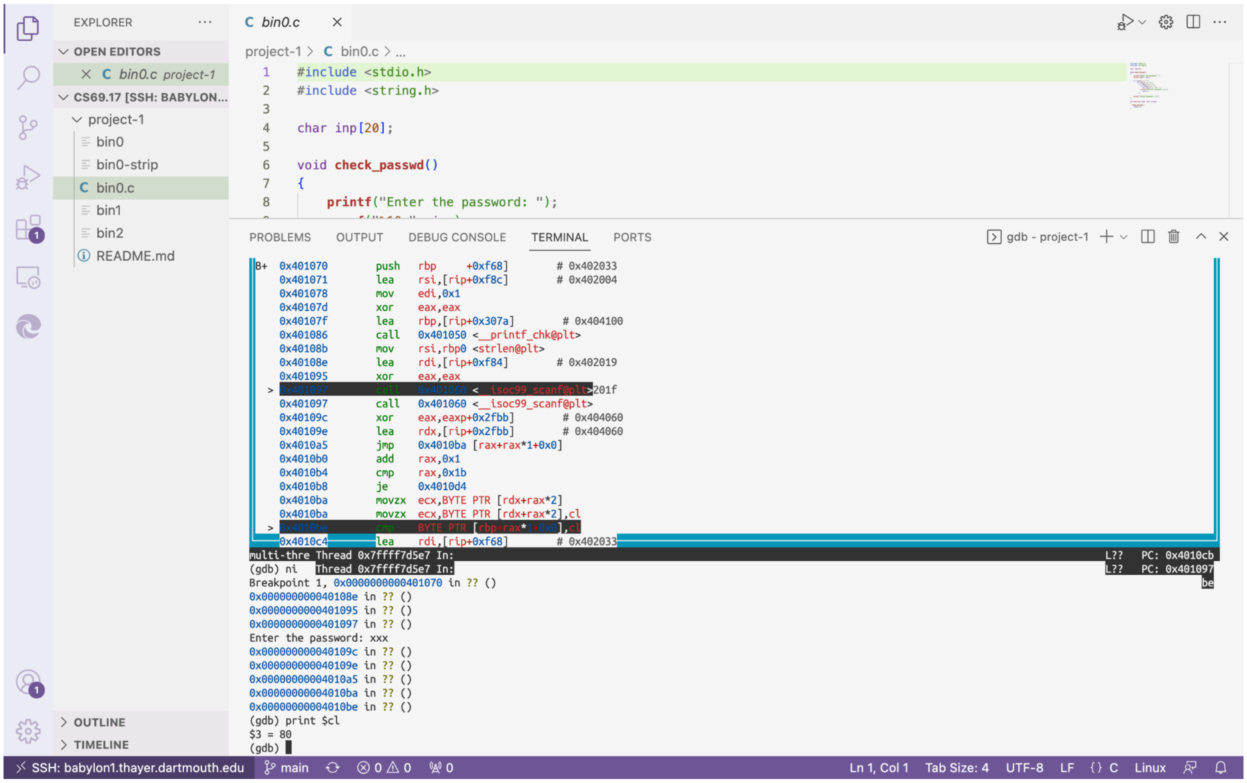
- Next, we run the program.
- After running the program, I will use the instruction `layout asm` to examine the assembly code as the program is running.



- After accessing the assembly, I try entering a few random passwords to try to understand the logic behind the assembly code. I keep doing this for a couple of few examples.
- I noticed that there is a counter running throughout the program that is being incremented after each character check. The counter is stored in %rax, and it’s being compared with the decimal value of 27 after each increment.
- While playing with different random examples at first, a few commands are of use to us to understand what is going on in the assembly code. One command is `info reg` where it lays out the different values of the registers at hand at the point of the program where the command was called. This is useful to observe how register values change when stepping through different assembly instructions in the program.



- Another useful command I used was `print $cl`. This command is of use to us in the case of bin1 because in the assembly code, in each loop the code makes while checking the user-input password, it compares each character from what the user entered with whatever value is stored in %cl, that is, the lower byte value of %rcx. This is an indicator that the correct password is actually being stored at each round in %cl since this is the register we use to verify whatever the user entered as a password.



- In total, after trying out different password examples and following the assembly code, we can understand the general logic behind the program. Essentially, the program compares the entered password character by character with the correct password it has already stored. If one comparison fails, i.e. the two compared characters are not the same, the loop breaks and then prints the string `Wrong Password :(`. Otherwise, it would just keep comparing the characters, character by character, until it reaches the end at 27-long characters, and then it prints `Correct Password :)`.
- My strategy to crack the correct password is the following. In the first round, I enter an arbitrary one-character long password. Then, as soon as the program reaches the compare instruction with %cl, i.e. the `cmp %cl,0x0(%rbp,%rax,1)` instruction, I print the value of %cl using the `print $cl` command in gdb, and then I write that value down because that is the first character of the correct password. Note that the printed value of %cl is in decimal value, that is, I have to look up the equivalent character value in ASCII of that decimal value. In our case, the first character of the correct password is `P`.

- In the next round, I enter an arbitrary two-character long password starting with P. I repeat the same strategy I used to crack the first character of the correct password to crack the second character of the correct password. In our case, that would be `0`.
- I keep repeating the same steps for 27 rounds to crack the 27 characters of the correct password.
- Overall, here are the characters stored in %cl that I got after each round.
    - First character is decimal 80 which is equivalent to` P` in ASCII
    - 48 = 0
    - 95 = _
    - 121 = y
    - 48 = 0
    - 117 = u
    - 95 = _
    - 108 = l (lowercase L)
    - 49 = 1 (number one)
    - 81 = Q
    - 101 = e
    - 95 = _
    - 75 = K
    - 114 = r
    - 52 = 4
    - 98 = b
    - 98 = b
    - 89 = Y
    - 95 = _
    - 112 = p
    - 65 = A
    - 116 = t
    - 55 = 7
    - 49 = 1 (number one)
    - 101 = e
    - 122 = z
    - Last character 63 = ?

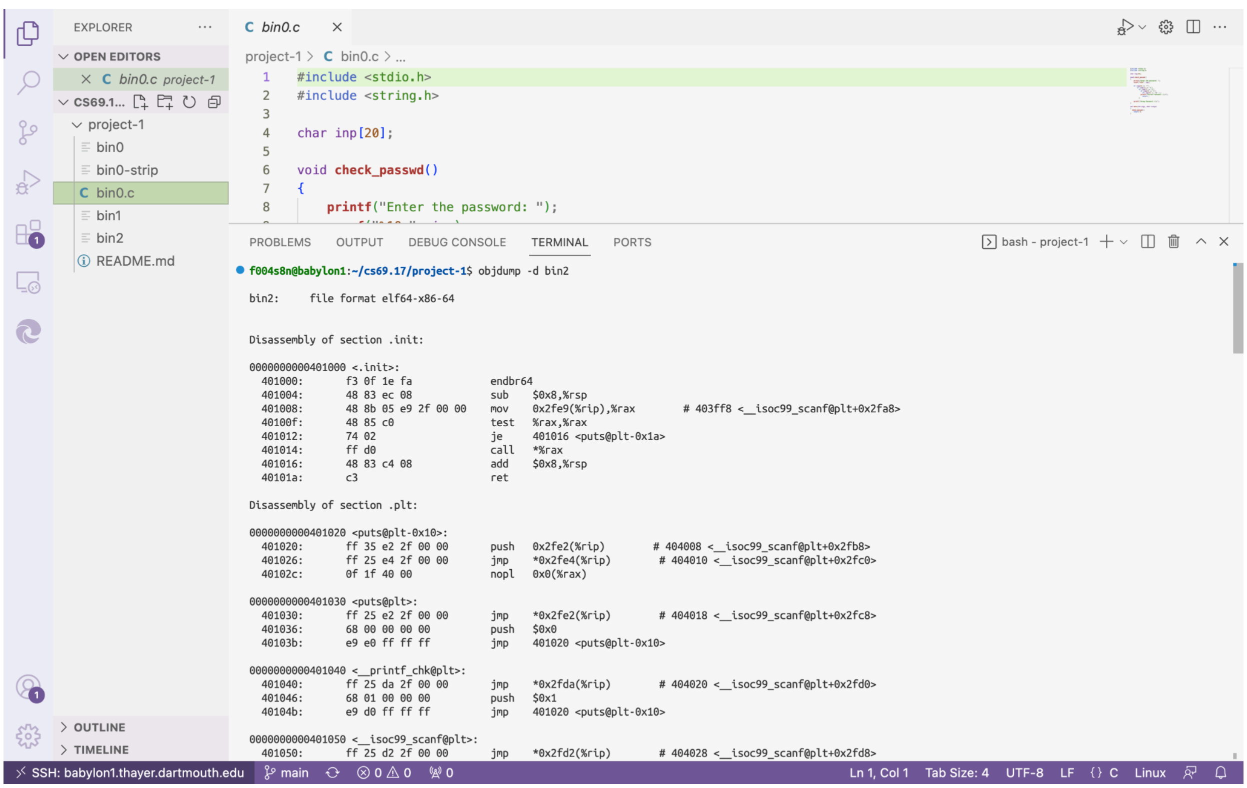
- At the end, I concatenate all the characters I got into one single 27-character long password, and that would be precisely` P0_y0u_l1Qe_Kr4bbY_pAt71ez?`.

3. (10 pts) What is the correct password for *bin2*?

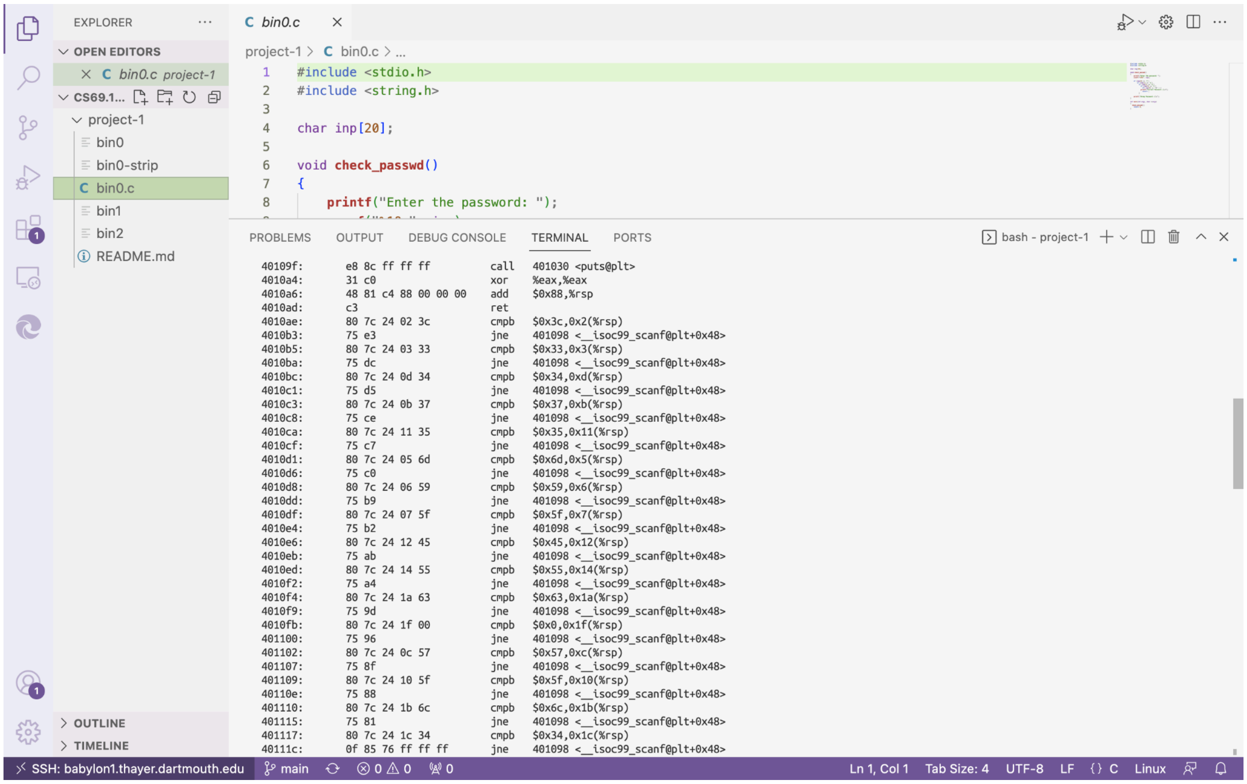
- The correct password for bin2 is ` K_<3_mY_s0F7W4re_5EcUR1tY_cl4sZ`.

4. (15 pts) Describe your strategy to crack the password of *bin2*. To receive full credit, explain how you determined the password. Explain all the steps. (screenshots may help.)

- Since bin2 is a stripped ELF binary, gdb has no idea where the address of the `main` function is when asked to disassemble the binary.
- An alternative to access the assembly code is by using the `objdump -d` command instruction. This instruction spits out the entire assembly code of bin2.



- After examining the assembly code we got from the object dump, we notice that there are a ton of `cmpb` instructions in the assembly. After a closer look, it appears that the program compares whatever the user entered as a password with all these hardcoded values in the different `cmpb` instructions.



- However, it is important to note that the comparisons are not being done in order. That is, the program compares the 13th character before it compares the 5th character for example, and the way to find out which character we are comparing precisely is by looking at the offset from %rsp in the `cmpb` instructions.
- Another thing to note is that the values we are comparing are in hex, so to find the character values we have to convert these hex values into characters by looking them up in an ASCII table.
- Overall, my strategy to crack the correct password is the following. Look into all the `cmpb` instructions where we compare a hard coded hex value with a value within a positive offset from the stack pointer. This hard coded hex value we are comparing it with a value being retrieved from the stack is one character from the correct password we are trying to hack. However, to find out which character exactly this value is from the correct

password, i.e. is it the 5th character vs the 23th character, we just keep note of the offset from the stack we are comparing its value with.

- Here are all the characters we compare with the password that the user inputs. I had written them in order for easier concatenation of the correct password.
    - Password[0] = K
    - Password[1] = _
    - Password[2] = <
    - Password[3] = 3
    - Password[4] = _
    - Password[5] = m
    - Password[6] = Y
    - Password[7] = _
    - Password[8] = s
    - Password[9] = 0 (zero)
    - Password[10] = F
    - Password[11] = 7
    - Password[12] = W
    - Password[13] = 4
    - Password[14] = r
    - Password[15] = e
    - Password[16] = _
    - Password[17] = 5
    - Password[18] = E
    - Password[19] = c
    - Password[20] = U
    - Password[21] = R
    - Password[22] = 1 (number one)
    - Password[23] = t
    - Password[24] = Y
    - Password[25] = _
    - Password[26] = c
    - Password[27] = l (lower case L)
    - Password[28] = 4

    - Password[29] = s
    - Password[30] = Z
    - Password[31] = Null
- At the end, I concatenate all the characters I got into one single 30-character long password, and that would be precisely` K_<3_mY_s0F7W4re_5EcUR1tY_cl4sZ`.