Homework 2 Challenge Writeup

Reverse Engineering Part 2

Lindsay Von Tish
lmv9443@nyu.edu
02/14/2024

Table of Contents

Challenge Details

Bridge of Death

Overview

Bridge of Death		
150 Points	Flag Value	flag{@_W1tch_W3'v3_G0t_@_W1tch!!!!!!!!!}
	Location	offsec-chalbroker.osiris.cyber.nyu.edu 8005
	Lore	Monty Python and the Holy Grail

Details

The program asks the user a series of questions that anyone familiar with Monty Python and the Holy Grail should recognize. On the first run of `bridge_of_death`, I fell to my death.

```
gdb ./bridge_of_death
...omitted for brevity...
Reading symbols from ./bridge_of_death...
(No debugging symbols found in ./bridge_of_death)
(gdb) r
Starting program: /home/kali/Desktop/2-Week/bridge_of_death
What is your name?
Juneau
What is your quest?
Pass this class!

kek
kek
kek
kek
Auuuuuuuugh!
[Inferior 1 (process 5082) exited normally]
(gdb) q
```

I Fall to my Death

The `bridge_of_death main()` method, shown below after decompilation with *Ghidra*, calls three different "question" methods. Each method returns a boolean value that the method uses to determine whether the program continues or throws the user into the Gorge of Eternal Peril.

```
undefined8 main(EVP_PKEY_CTX *param_1)
{
  int iVar1;

  init(param_1);
  puts(
      "Stop! Who would cross the Bridge of Death must answer me these questions
three, ere the other  side he see.\n\nWhat is your name?"
      );
  iVar1 = question1();
  if (iVar1 == 0) {
    throw_into_gorge_of_eternal_peril();
  }
  puts("What is your quest?");
  iVar1 = question2();
  if (iVar1 != 0) {
```

```
    throw_into_gorge_of_eternal_peril();
  }
  puts("What is the air-speed velocity of an unladen swallow?");
  iVar1 = question3();
  if (iVar1 != 0) {
    throw_into_gorge_of_eternal_peril();
  }
  puts("Right. Off you go.");
  print_flag();
  return 0;
}
```

Main Method

Question 1: What is your name?

The `bridge_of_death` binary stores the answer to question 1 in plaintext.

```
strings bridge_of_death| grep -i "Lancelot"
My name is Sir Lancelot of Camelot.
```

Strings

The `question1()` method compares the user-entered text to the string `"My name is Sir Lancelot of Camelot."`

```
void question1(void)
{
  long in_FS_OFFSET;
  char guess [136];
  long local_10;

  local_10 = *(long *)(in_FS_OFFSET + 0x28);
  fgets(guess,0x80,stdin);
  strcmp("My name is Sir Lancelot of Camelot.",guess);
  if (local_10 != *(long *)(in_FS_OFFSET + 0x28)) {
                    /* WARNING: Subroutine does not return */
    __stack_chk_fail();
  }
  return;
}
```

Question 1

However, subsequent testing showed that `question1()` would return true regardless of the name entered.

```
nc offsec-chalbroker.osiris.cyber.nyu.edu 8005
Stop! Who would cross the Bridge of Death must answer me these questions three, ere
the other side he see.

What is your name?
My name is Sir Lancelot of Camelot.
What is your quest?
...omitted for brevity...

nc offsec-chalbroker.osiris.cyber.nyu.edu 8005
```

```
Stop! Who would cross the Bridge of Death must answer me these questions three, ere
the other side he see.
What is your name?
Juneau
What is your quest?
```

Name Demonstration

Question 2: What is your quest?

The `question2()` function uses `get_number()` to take in two user-entered integers. The `get_number()` function will return `0` if the entered value is not a valid integer. It is the same function used in Postage, shown for reference in Appendix C.

```
bool question2(void)

{
  undefined4 uVar1;
  int iVar2;
  int iVar3;

  uVar1 = get_number();
  iVar2 = get_number();
  iVar3 = func2(uVar1,0,0x14);
  return iVar2 != iVar3;
}
```

Question 2

After reading in the numbers, the function calls `func2()` and checks to see if the return value is equal to the second user-entered integer. The method takes three inputs: the user-entered guess (`p1`) and two other numbers.

```
int func2(int p1,int p2,int p3)
{
  int v1;
  int v2;
  puts("kek");
  v1 = p2 + (p3 - p2) / 2;
  if (p1 < v1) {
    v2 = func2(p1,p2,v1 + -1);
    v1 = v2 + v1;
  }
  else if (v1 < p1) {
    v2 = func2(p1,v1 + 1,p3);
    v1 = v2 + v1;
  }
  return v1;
}
```

Func2

The recursion in `func2()` is a red herring; the important part of the problem is the math used to calculate `v1`. If `p1` is equal to `v1`, then `func2()` skips the recursion entirely and returns the value of `v1`. The last two parameters `func2()` receives are hardcoded by `question2()`, making it easy to solve for the correct value of `p1`.

```
a = Int('a')
b, c = Reals('b, c')
#g = Int('g')
s = Solver()
s.add(b == 0)
s.add(c == 20)
s.add(a == b + (c-b)/2)
print(s.check())
print(s.model())

>> sat
>> [a = 10, c = 20, b, = 0]
```

Solver Script

The correct value of `p1` is `10`, which should be entered for both guesses to answer question 2.

```
What is your name?
Juneau
What is your quest?
10
10
kek
What is the air-speed velocity of an unladen swallow?
I have no clue

Auuuuuuuugh!
```

Success

Question 3

The `question3()` function is much longer and more complex than the previous questions.

```
undefined8 question3(void)

{
  long lVar1;
  uint guess1;
  uint guess2;
  undefined8 flag;
  long in_FS_OFFSET;
  int counter;

  lVar1 = *(long *)(in_FS_OFFSET + 0x28);
  counter = 1;
  do {
    if (9 < counter) {
      flag = 0;
LAB_0010159d:
      if (lVar1 != *(long *)(in_FS_OFFSET + 0x28)) {
                    /* WARNING: Subroutine does not return */
        __stack_chk_fail();
      }
      return flag;
    }
    guess1 = get_number();
    guess2 = get_number();
    if ((0xff < guess1) || (0xff < guess2)) {
      flag = 1;
      goto LAB_0010159d;
    }
    if (counter != (char)forestOfEwing[(ulong)guess2 + (ulong)guess1 * 0x100]) {
      flag = 1;
      goto LAB_0010159d;
    }
    counter = counter + 1;
  } while( true );
}
```

Question 3

The important part of the code is in the highlighted if statement.

At each iteration of the loop, `question3()` compares the number of the current iteration (`counter`) to a character in the array `forestOfEwing`. The character's position is determined using two user-entered integers (`guess1` and `guess2`).

The `question3()` disassembly gives more insight into how `bridge_of_death` calculates the character's location in `forestOfEwing`.

```
   0x000055555555554b <+98>:    mov    -0x94(%rbp),%edx
   0x0000555555555551 <+104>:   mov    -0x98(%rbp),%eax
   0x0000555555555557 <+110>:   shl    $0x8,%rax
   0x000055555555555b <+114>:   add    %rax,%rdx
   0x000055555555555e <+117>:   lea    0x2abb(%rip),%rax #0x555555558020
<forestOfEwing>
   0x0000555555555565 <+124>:   add    %rdx,%rax
   0x0000555555555568 <+127>:   movzbl (%rax),%eax
   0x000055555555556b <+130>:   movsbl %al,%eax
   0x000055555555556e <+133>:   cmp    %eax,-0x9c(%rbp)
   0x0000555555555574 <+139>:   je     0x555555555584 <question3+155>
```

Question 3 Disassembly

The program calculates the index in the array using the two guesses and then adds it to the address of `forestOfEwing`. After saving the address in `RAX`, the program uses it to load the character value into the `EAX` register before the comparison. Setting the value of `RAX` to the address of the counter will ensure that the values are equal.

```
gdb ./bridge_of_death
(gdb) break *0x0000555555555568
Breakpoint 4 at 0x555555555568
(gdb) c
...omitted for brevity...
What is the air-speed velocity of an unladen swallow?
1
2

...omitted for brevity...
Breakpoint 4, 0x0000555555555568 in question3 ()
(gdb) info registers rax
rax            0x555555558122      93824992248098
(gdb) set $rax=$rbp-0x9c
(gdb) info registers rax
rax            0x7fffffffdd24      140737488346404
(gdb) c
Continuing.
1
2
...omitted for brevity...
Breakpoint 4, 0x0000555555555568 in question3 ()
(gdb) info registers rax
rax            0x555555558122      93824992248098
(gdb) set $rax=$rbp-0x9c
(gdb) info registers rax
rax            0x7fffffffdd24      140737488346404
(gdb) c
Continuing.
Right. Off you go.
ERROR: no flag found.
```

Debugging Solution

Unfortunately, this method only works on a local instance of the program. Because of the size limitations on the guesses, the address used must point to a character in `forestOfEwing`. The program code contains the `forestOfEwing` array, which is 65535 characters long.

After exporting the `forestOfEwing` data from the `bridge_of_death` disassembly in *Ghidra*, I put it in a Python list and used a script to search for characters matching each possible counter value.

```
def question3(p):
	i = 0
	index = [[0,0],[0,0],[0,0],[0,0],[0,0],[0,0],[0,0],[0,0],[0,0]]
	for value in f0e:
		if value == 0x1:
			index[0][0] = i//256
			index[0][1] = i%256
		elif value == 0x2:
			index[1][0] = i//256
			index[1][1] = i%256
		elif value == 0x3:
			index[2][0] = i//256
			index[2][1] = i%256
		elif value == 0x4:
			index[3][0] = i//256
			index[3][1] = i%256
		elif value == 0x5:
			index[4][0] = i//256
			index[4][1] = i%256
		elif value == 0x6:
			index[5][0] = i//256
			index[5][1] = i%256
		elif value == 0x7:
			index[6][0] = i//256
			index[6][1] = i%256
		elif value == 0x8:
			index[7][0] = i//256
			index[7][1] = i%256
		elif value == 0x9:
			index[8][0] = i//256
			index[8][1] = i%256
		i +=1
	i = 0
	while i < 9:
		msg = str(index[i][0]).encode()
		p.sendline(msg)
		msg = str(index[i][1]).encode()
		p.sendline(msg)
		i += 1
	return index
```

Solver Script

The script uses the location of each matching value to calculate the integer values for both guesses.

```
python3 Q3-search.py
[[64, 234], [4, 44], [132, 146], [14, 148], [41, 138], [170, 133], [173, 99], [12,
9], [73, 199]]
```

Results

```
gdb ./bridge_of_death
GNU gdb (Debian 13.2-1) 13.2
...omitted for brevity...
Stop! Who would cross the Bridge of Death must answer me these questions three, ere
the other side he see.

What is your name?
l
What is your quest?
10
10
kek
What is the air-speed velocity of an unladen swallow?
64
234
4
44
132
146
14
148
41
138
170
133
173
99
12
9
73
199
Right. Off you go.
ERROR: no flag found.
```

Local Success

Attempt

After verifying the results locally, I attempted the remote challenge. The solver script is available in Appendix D.

```
python3 BoD_Remote.py
[+] Opening connection to offsec-chalbroker.osiris.cyber.nyu.edu on port 8005: Done
Answering Question 1
Juneau
Answering Question 2
['10', '10']
Answering Question 3
[[64, 234], [4, 44], [132, 146], [14, 148], [41, 138], [170, 133], [173, 99], [12,
9], [73, 199]]
b"@_W1tch_W3'v3_G0t_@_W1tch!!!!!!!!!}\n"
[*] Closed connection to offsec-chalbroker.osiris.cyber.nyu.edu port 8005
```

Results

Dora

Overview

Bridge of Death		
150 Points	Flag Value	flag{mmaped_some_fresh_pages}
	Location	offsec-chalbroker.osiris.cyber.nyu.edu 1250`
	Lore-*a*	Dora the Explorer

Details

The first run of `Dora` made it clear that the wrong input would cause a segmentation error.

```
gdb ./dora
What's the key?
13
Program received signal SIGILL, Illegal instruction.
0x00007ffff7fc2000 in ?? ()
(gdb) q

gdb ./dora
What's the key?
111
Program received signal SIGSEGV, Segmentation fault.
0x00007ffff7fc2001 in ?? ()
(gdb) q
```

First Run

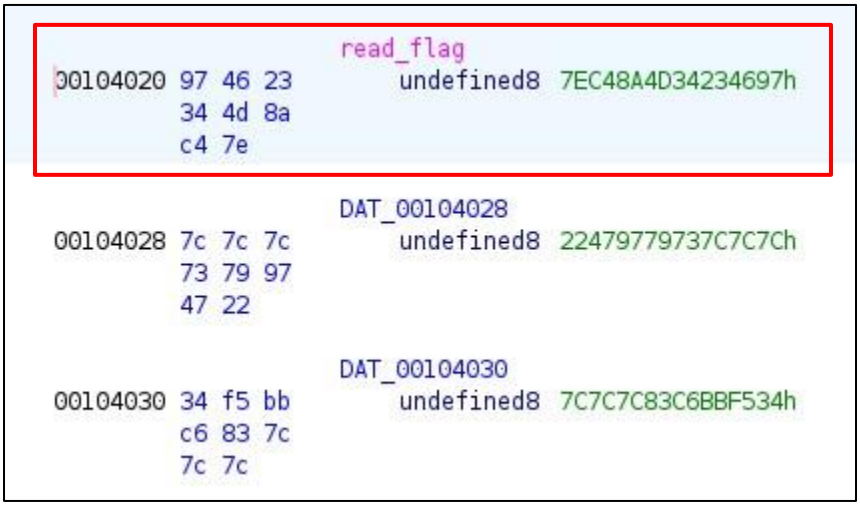
The decompiled `Dora main()` method is complex but provides valuable insight into the program's operations.

```
undefined8 main(EVP_PKEY_CTX *param_1)

{
  undefined8 *puVar1;
  long lVar2;
  undefined8 uVar3;
  ulong counter;

  init(param_1);
  puVar1 = (undefined8 *)mmap((void *)0x0,0x1000,7,0x22,-1,0);
  uVar3 = DAT_00104028;
  *puVar1 = read_flag;
  puVar1[1] = uVar3;
  ...omitted for brevity...
  puVar1[8] = DAT_00104060;
  puVar1[9] = uVar3;
  puts("What\'s the key?");
  lVar2 = get_number();
  if ((lVar2 < 0) || (0xff < lVar2)) {
    puts("That key is out of range :( Try again?");
    uVar3 = 1;
  }
  else {
    for (counter = 0; counter < 0x50; counter = counter + 1) {
```

```
      *(byte *)(counter + (long)puVar1) = *(byte *)(counter + (long)puVar1) ^
(byte)lVar2;
    }
    (*(code *)puVar1)();
    uVar3 = 0;
  }
  return uVar3;
}
```

Main Method

The program creates a memory map (mmap) in the calling process's virtual address space. Then, it adds data to the mmap from different locations in the program memory before taking in and validating a user-input integer.



Stored Data

After this setup, the program iterates through the saved data, performing an exclusive or (XOR) operation on each byte and the user-entered guess and saving the output.

The `main()` method disassembly reveals the registers containing the guess and mmap byte, which are stored in `ESI` and `EDX`, respectively.

```
   0x000055555555538d <+275>:   mov    -0x28(%rbp),%rcx
   0x0000555555555391 <+279>:   mov    -0x30(%rbp),%rax
   0x0000555555555395 <+283>:   add    %rcx,%rax
   0x0000555555555398 <+286>:   xor    %esi,%edx
   0x000055555555539a <+288>:   mov    %dl,(%rax)
   0x000055555555539c <+290>:   addq   $0x1,-0x30(%rbp)
```

Disassembly

Using a debugger, we can see the values in each register before the XOR operation, revealing the mmap data character by character. Initially, the mmap data appears to match the data stored in `read_flag`.

```
(gdb) break *0x0000555555555398
Breakpoint 2 at 0x555555555398
...omitted for brevity...
(gdb) c
Continuing.
What's the key?
23

Breakpoint 2, 0x0000555555555398 in main ()
(gdb) info registers edx
edx            0x97                151
(gdb) info registers esi
esi            0x17                23
(gdb) c
Continuing.

Breakpoint 3, 0x000055555555539a in main ()
(gdb) info registers edx
edx            0x80                128
(gdb) c
Continuing.

Breakpoint 2, 0x0000555555555398 in main ()
(gdb) info registers edx
edx            0x46                70
(gdb) c
Continuing.

Breakpoint 3, 0x000055555555539a in main ()
(gdb) info registers edx
edx            0x51                81
(gdb) c
Continuing.

Breakpoint 2, 0x0000555555555398 in main ()
(gdb) info registers edx
edx            0x23                35
(gdb) c
Continuing.

Breakpoint 3, 0x000055555555539a in main ()
(gdb) info registers edx
edx            0x34                52
(gdb) q
```

Disassembly

To get more information about the stored data, I wrote a script to extract every value from EDX.

```
def main():
	# Start gdb session
	p =  process('/bin/bash')
	p.sendline('gdb ./dora -q')
	p.sendline('break _start')
	p.recv() # GDB response with one line indicating that the breakpoint is set
	p.sendline('r')
	p.sendline('break *0x0000555555555398')
	p.recv()
	p.sendline('clear _start')
	p.recv()
	p.sendline('c')
	p.recvuntil(b'What\'s the key?')
	p.sendline(b'23')
	p.sendline('c')

	data = []

	for i in range(80):
		p.recvuntil(b'Breakpoint 2')
		p.recvline()
		p.sendline('info registers edx')
		c = cleanLine(p.recvline())
		r = re.split("\s+", c)
		data.append(r[2])
		p.sendline('c')

	print(data)
```

Extraction Script

```
['0x97', '0x46', '0x23', '0x34', '0x4d', '0x8a', '0xc4', '0x7e', '0x7c', '0x7c',
'0x7c', '0x73', '0x79', '0x97', '0x47', '0x22', '0x34', '0xf5', '0xbb', '0xc6',
'0x83', '0x7c', '0x7c', '0x7c', '0xc4', '0x7c', '0x7c', '0x7c', '0x7c', '0x73',
'0x79', '0xc3', '0x7d', '0x7c', '0x7c', '0x7c', '0xc6', '0x83', '0x7c', '0x7c',
'0x7c', '0xc4', '0x7d', '0x7c', '0x7c', '0x7c', '0x73', '0x79', '0xc3', '0x7c',
'0x7c', '0x7c', '0x7c', '0xc4', '0x40', '0x7c', '0x7c', '0x7c', '0x73', '0x79',
'0x94', '0xbd', '0x83', '0x83', '0x83', '0x1a', '0x10', '0x1d', '0x1b', '0x52',
'0x8', '0x4', '0x8', '0x7c', '0x94', '0xbc', '0x83', '0x83', '0x83', '0x0']
```

Data

After extracting the data, I attempted to brute force the solution by looping through each possible guess and performing a XOR between the guess integer and each byte in the extracted data.

```
def bruteForceMagic():
    for i in range(256):
        data = bytes(c ^ i for c in test_chars)
        print(data)
    return 0
```

Brute Force Script

Initially, the results appeared to be nonsense data, but after using *grep* to search for common terms, I discovered the string **"flag.txt"** in the script output.

```
python3 Dora_BF.py | grep -i "flag"
b'\xcb\x1a\x7fh\x11\xd6\x98"   /%\xcb\x1b~h\xa9\xe7\x9a\xdf   \x98    /%\x9f!
\x9a\xdf   \x98!   /%\x9f    \x98\x1c   /%\xc8\xe1\xdf\xdf\xdfFLAG\x0eTXT
\xc8\xe0\xdf\xdf\xdf\\'
b'\xeb:_H1\xf6\xb8\x02\x00\x00\x00\x0f\x05\xeb;^H\x89\xc7\xba\xff\x00\x00\x00\xb8\x
00\x00\x00\x00\x0f\x05\xbf\x01\x00\x00\x00\xba\xff\x00\x00\x00\xb8\x01\x00\x00\x00\
x0f\x05\xbf\x00\x00\x00\x00\xb8<\x00\x00\x00\x0f\x05\xe8\xc1\xff\xff\xfflag.txt\x0
0\xe8\xc0\xff\xff\xff|'
```

Script Output

An update to the script revealed which input value resulted in the useable data.

```
def bruteForceMagic():
    for i in range(256):
        data = bytes(c ^ i for c in test_chars)
        if 'flag'.encode() in data:
            return i
    return 0

>> python3 Dora_BF.py
>> 124
```

Brute Force Script

The full solver script for this challenge is available in Appendix E.

Attempt

After discovering a possible input value using good old-fashioned brute force, I validated the guess against a local instance of Dora.

```
$ gdb ./dora
...omitted for brevity...
(gdb) r
What's the key?
124
|[Inferior 1 (process 90978) exited normally]
(gdb) q
```

Local Success

This value also worked for the remote instance, which revealed the flag.

```
nc offsec-chalbroker.osiris.cyber.nyu.edu 1250
What's the key?
124
flag{mmaped_some_fresh_pages}
```

Flag

Appendix A: Student Information

Lindsay Von Tish	
Email	lmv9443@nyu.edu

Appendix B: Tools

Name	URL
EDB	https://www.kali.org/tools/edb-debugger/
GDB	https://www.gnu.org/software/gdb/gdb.html
Ghidra	https://ghidra-sre.org/
Netcat	https://netcat.sourceforge.net/
PwnTools	https://github.com/Gallopsled/pwntools

Appendix C: Postage

Overview

Postage		
200 Points	Flag Value	flag{i_hope_ur_ready_4_some_pwning_in_a_few_weeks}
	Location	offsec-chalbroker.osiris.cyber.nyu.edu 1247

Details

After downloading the postage binary, its execution results in a text prompt awaiting user input. The first execution resulted in a segmentation fault, shown in the following figure:

```
gdb ./postage
(gdb) r
Starting program: /home/kali/Desktop/1-Week/postage
Can you tell me where to mail this postage?
No

Program received signal SIGSEGV, Segmentation fault.
0x000000000040195e in main ()
```

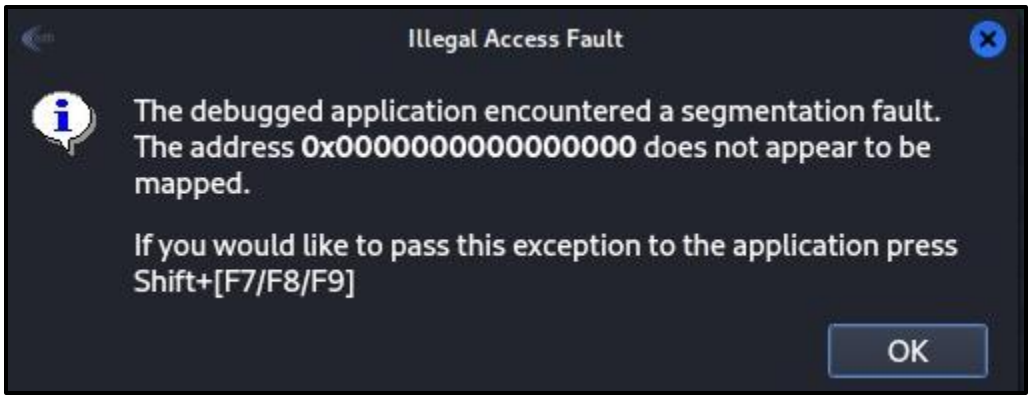
Segmentation Fault

The program's `main` method reveals its base functionality, making it useful for discovering the source of the error. The code below was disassembled using *Ghidra*, and the variable names have been changed for clarity. After printing a message asking for user input, `postage` uses the `get_number` function to save that number as a pointer value. Essentially, the user input is a memory address. Next, the program takes the data stored at that address and saves it in the `val` variable. Finally, the program compares `val` to the hardcoded value `0xd000dfaceee` and prints either the flag or a "try again" message based on whether or not the values match.

```
bool main(EVP_PKEY_CTX *param_1)
{
  long *pointer;
  long val;

  init(param_1);
  puts("Can you tell me where to mail this postage?");
  pointer = (long *)get_number();
  val = *pointer;
  if (val != 0xd000dfaceee) {
    puts("That doesn\'t look right... try again later, friend!");
  }
  else {
    puts("Got it! That\'s the right number!");
    print_flag();
  }
  return val != 0xd000dfaceee;
}
```

Main Method

Running `postage` with another debugger, such as *edb*, as shown in the following figure, reveals more information about the segmentation fault. The segfault occurred when the program attempted to access memory at the address `0x0000000`.



Segmentation Fault Data

A memory address of `0` is outside of the program's memory space; attempting to read data from it results in a segmentation fault. Based on the `postage main` method, the error most likely occurred when the program attempted to save the data at the user-input address in the `val` variable.

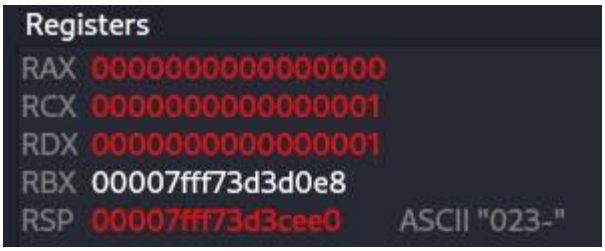
The `get_number` function, shown decompiled below, gives more insight into acceptable user input. The function uses `fgets` to save the user input as a string. Then it calls `strtol`, a C function that converts that user input string to a base ten long. If the string data cannot be converted, like if it has non-numerical ASCII characters, `strtol` will return `0`.

```
void get_number(void)

{
  long in_FS_OFFSET;
  char input [136];
  long check;

  check = *(long *)(in_FS_OFFSET + 0x28);
  fgets(input,0x80,(FILE *)stdin);
  strtol(input,(char **)0x0,10);
  if (check != *(long *)(in_FS_OFFSET + 0x28)) {
                    /* WARNING: Subroutine does not return */
    __stack_chk_fail();
  }
  return;
}
```

Get_number

Although `get_number` appears to be a void function that does not return any data, it essentially returns the result of `strtol`. When a function runs, the `RAX` register holds its return data. When `get_number` returns, the data returned by `strtol` remains in the `RAX` register, which, in turn, is saved as a pointer in the `val` variable. If the user enters a base-ten number, it will be stored in `RAX` as hexadecimal. Otherwise, `RAX` will equal `0`, the `strtol` error code.

In the following example, the user entered the number `4200836`. The value of `RAX` will change before and after the call to `get_number`.



RAX Before Call

RAX After Call

Program Output

`RAX` holds a value of `0000000000401984` after `get_number` runs. This number is the Hexadecimal notation of the user-entered decimal number, `4200836`. The memory at `0x401984` is accessible to the program, so it runs without a segmentation error, as illustrated below:

Although the program ran without error, the value the user entered was not correct. To successfully complete the challenge, the player must enter a decimal number corresponding to a program-accessible memory address that stores the "secret" value `0xD00DFACEEE`.

Challenge Attempt

Completing the challenge requires the user to enter an address of memory that is not only accessible to the `postage` program but also contains specific data. An attacker has two options: finding a memory location containing the target data or bypassing the comparison entirely.

Bypass Comparison

In the decompiled main method, postage sets the variable pointer to the user-entered address using `get_number`. This call is also visible at line `0x00401949` of the assembly code. Then, it saves the data stored at that address in the `val` variable before the if statement. These operations are performed by lines `0x0040194E` through `0x0040195E` of the assembly code.

```
puts("Can you tell me where to mail this postage?");
pointer = (long *)get_number();
val = *pointer;
if (val != 0xd000dfaceee) {
puts("That doesn\'t look right... try again later, friend!");
}
else {
puts("Got it! That\'s the right number!");
print_flag();
}
```

Main Method

```
00401949 e8 69 ff        CALL       get_number
         ff ff
0040194e 48 89 45 f0     MOV        qword ptr [RBP + local_18],RAX
00401952 48 8b 45 f0     MOV        RAX,qword ptr [RBP + local_18]
00401956 48 89 45 f8     MOV        qword ptr [RBP + local_10],RAX
0040195a 48 8b 45 f8     MOV        RAX,qword ptr [RBP + local_10]
0040195e 48 8b 00        MOV        RAX,qword ptr [pointer]
00401961 48 ba ee        MOV        RDX,0xd000dfaceee
         ce fa 0d
         00 0d 00 00
0040196b 48 39 d0        CMP        RAX,RDX
0040196e 75 20           JNZ        LAB_00401990
00401970 48 8d 05        LEA        RAX,[s_Got_it!_That's_the_right_number!_00   =
         d1 67 09 00
00401977 48 89 c7        MOV        RDI=>s_Got_it!_That's_the_right_number!_
0040197a e8 e1 12        CALL       puts                    int puts(char * __s)
         01 00
0040197f b8 00 00        MOV        RAX,0x0
         00 00
00401984 e8 5c fe        CALL       print_flag              undefined print_flag()
         ff ff
00401989 b8 00 00        MOV        RAX,0x0
         00 00
0040198e eb 14           JMP        LAB_004019a4
                     LAB_00401990                                    XREF[1]:
0040196e(j)
00401990 48 8d 05        LEA        RAX,[s_That_doesn't_look_right..._
         d9 67 09 00
```

Main Method Assembly

Once the values are set, the `MOV` command at `0x00401961` places the hexadecimal data `0xD00DFACEEE` in the `RDX` register in preparation for the comparison (`CMP`) at `0x0040196B`. If the `CMP` operation returns `True`, the program will continue into `0x00401970` to print the success message before calling `print_flag` at `0x00401984`. Otherwise, it will jump to `LAB_00401990` and begin the "incorrect" response at `0x00401990`.

By copying the data stored in `RDX` at `0x00401961` into `RAX` before the `CMP` at `0x0040196B`, an attacker can get the "success" message without entering a correct answer. Using a debugger, they can set a

breakpoint at **0x0040196B** and copy the data from **RDX** into **RAX** before the **CMP** operation runs. The following example uses *GDB*:

The attacker must use an input value consistent with a decimal notation of the address space postage can access.

```
gdb ./postage
       ...omitted for brevity...
Reading symbols from ./postage...
(No debugging symbols found in ./postage)
(gdb) break _start
Breakpoint 1 at 0x4016c0
(gdb) r
Starting program: /home/kali/Desktop/1-Week/postage

Breakpoint 1, 0x00000000004016c0 in _start ()
(gdb) disas main
Dump of assembler code for function main:
...omitted for brevity...
   0x000000000040195e <+63>:    mov    (%rax),%rax
   0x0000000000401961 <+66>:    movabs $0xd000dfaceee,%rdx
   0x000000000040196b <+76>:    cmp    %rdx,%rax
   0x000000000040196e <+79>:    jne    0x401990 <main+113>
...omitted for brevity...
End of assembler dump.
(gdb) break *0x000000000040196b
Breakpoint 2 at 0x40196b
(gdb) c
Continuing.
Can you tell me where to mail this postage?
4200836

Breakpoint 2, 0x000000000040196b in main ()
(gdb) info registers rax
rax            0xb8fffffe5ce8      203409651031272
(gdb) info registers rdx
rdx            0xd000dfaceee       14293885701870
(gdb) set $rax = $rdx
(gdb) info registers rax
rax            0xd000dfaceee       14293885701870
(gdb) info registers rax
rax            0xd000dfaceee       14293885701870
(gdb) c
Continuing.
Got it! That's the right number!
ERROR: no flag found.
```

Successful Bypass

Although this example successfully bypasses the program secret, it did not reveal the flag because the necessary debugging was done using a local copy of postage. To get the flag, the attacker must enter the correct value to attack the remote program.

The Right Answer

To get the flag, an attacker must input a memory address in decimal notation that holds the data `0xD00DFACEEE`. As shown in the disassembled main method, postage does not store the secret string in a variable. The hardcoded value is only stored in `RDX` at line `0x00401961`, right before the `CMP` at line `0x0040196B`, as shown below:

```
00401961 48 ba ee        MOV        RDX,0xd000dfaceee
         ce fa 0d
         00 0d 00 00
0040196b 48 39 d0        CMP        RAX,RDX
0040196e 75 20           JNZ        LAB_00401990
00401970 48 8d 05        LEA        RAX,[s_Got_it!_That's_the_right_number!_00   =
         d1 67 09 00
```

Secret Stored

The program itself stores the secret value. The line starts at `0x00401961`, the first two bytes of data detail the operation, and then the secret value is stored at `0x00401963`. The following table shows each byte in memory and the corresponding address.

Address	Value
0x00401961	48
0x00401962	ba
0x00401963	ee
0x00401964	ce
0x00401965	fa
0x00401966	0d
0x00401967	00
0x00401968	0d
0x00401969	00
0x0040196A	00

Secret in Memory

The address where the secret data begins, `0x00401963`, can be written as `4200803` in decimal notation. This is the correct address to enter, as shown below:

```
$ nc offsec-chalbroker.osiris.cyber.nyu.edu 1247
Can you tell me where to mail this postage?
4200803
Got it! That's the right number!
Here's your flag, friend: flag{i_hope_ur_ready_4_some_pwning_in_a_few_weeks}
```

Success

Appendix D: BoD_Remote.py

```
from pwn import *
import re

# Array with data from forestsOfEwing
f0e = […omitted for brevity…]
# Host and port for the remote challenge
HOST = 'offsec-chalbroker.osiris.cyber.nyu.edu'
PORT = 8005

# A function to send a name to the remote challenge
#      Input: Connection
#      Output: Message
def question1(p):
       msg = 'Juneau'
       p.sendline(msg)
       return msg

# A function to send a the answer to question 2
#      Input: Connection
#      Output: Array with both answers
def question2(p):
       msg = '10'
       p.sendline(msg.encode())
       p.sendline(msg.encode())
       ans = [msg, msg]
       return ans

# A function to send a the answer to question 3
#      Input: Connection
#      Output: Array with all nine answers
def question3(p):
       i = 0
       index = [[0,0],[0,0],[0,0],[0,0],[0,0],[0,0],[0,0],[0,0],[0,0]]
       for value in f0e:
              if value == 0x1:
                     index[0][0] = i//256
                     index[0][1] = i%256
              elif value == 0x2:
                     index[1][0] = i//256
                     index[1][1] = i%256
              elif value == 0x3:
                     index[2][0] = i//256
                     index[2][1] = i%256
              elif value == 0x4:
                     index[3][0] = i//256
                     index[3][1] = i%256
              elif value == 0x5:
                     index[4][0] = i//256
                     index[4][1] = i%256
              elif value == 0x6:
                     index[5][0] = i//256
                     index[5][1] = i%256
              elif value == 0x7:
```

```
                    index[6][0] = i//256
                    index[6][1] = i%256
             elif value == 0x8:
                    index[7][0] = i//256
                    index[7][1] = i%256
             elif value == 0x9:
                    index[8][0] = i//256
                    index[8][1] = i%256
             i +=1
      i = 0
      while i < 9:
             msg = str(index[i][0]).encode()
             p.sendline(msg)
             msg = str(index[i][1]).encode()
             p.sendline(msg)
             i += 1
      return index

def main():
    p = remote(HOST, PORT)
    p.recvuntil(b'What is your name?')
    print("Answering Question 1")
    print(question1(p))
    p.recvuntil(b'What is your quest?')
    print("Answering Question 2")
    print(question2(p))
    p.recvuntil(b'What is the air-speed velocity of an unladen swallow?')
    print("Answering Question 3")
    print(question3(p))
    p.recvuntil(b'flag{')
    print(p.recvline())
    p.close()
    return 0

if __name__ == "__main__":
    main()
```

Appendix E: Dora_BF.py

```
# Characters taken from the Dora memory map
test_chars = bytes([...omitted for brevity...])
# A function to xor all 255 characters with every byte in the array to see if we
get usable data
#   Input: N/A
#   Output: The value that creates data with the word "flag" in it
def bruteForceMagic():
    for i in range(256):
        data = bytes(c ^ i for c in test_chars)
        if 'flag'.encode() in data:
            return i
    return -13

print(bruteForceMagic())
```