awsum-quotes

The program is a collection of quotations, each composed of two strings: the actual text of the quotation and the author.

The collection is implemented as a structure which contains:

- number of stored quotations, as an integer
- array of quotations (length 8)

Each quotation is also a structure:

- text (length 80)
- author (length 30)

The main menu allows the following operations:

1. Show all the quotations
2. Show a specific quotation
3. Add a new quotation to the collection

During the inital setup, the program fills 5 out of the 8 elements available in the quotations array, so the user can add only 3 more quotations. If it tries to add more, the program will terminate.

Some of the default quotations may give small hints on the solution of the challenge.

Build

Compiled with gcc 7.5.0 (Ubuntu 18.04)

```
gcc -o awsum_quotes awsum_quotes.c
```

Writeup

An unexpected gadget

`checksec` shows that the binary has all the security options in place, so some kind of ROP will probably be necessary. We run `ropper` to see if there are some useful gadgets:

```
0x00000000000010dc: pop r12; pop r13; pop r14; pop r15; ret;
0x00000000000010de: pop r13; pop r14; pop r15; ret;
0x00000000000010e0: pop r14; pop r15; ret;
0x00000000000010e2: pop r15; ret;
0x0000000000000983: pop rbp; jmp rax;
0x00000000000010db: pop rbp; pop r12; pop r13; pop r14; pop r15; ret;
0x00000000000010df: pop rbp; pop r14; pop r15; ret;
0x0000000000000990: pop rbp; ret;
0x0000000000000994: pop rdi; xor rax, rax; mov al, 0x3b; syscall;
0x00000000000010e3: pop rdi; ret;
0x00000000000010e1: pop rsi; pop r15; ret;
0x00000000000010dd: pop rsp; pop r13; pop r14; pop r15; ret;
0x0000000000000aff: push rax; add dword ptr [rax - 0x75], ecx; call 0xfffffffc9901b92; ret;
0x0000000000000902: ret 0x2016;
0x0000000000000a9a: ret 0xfffd;
```

Well, that's unusual: at 0x994 there is a gadget that seems to be preparing the registers for the syscall *SYS_EXECVE*. Why should the program execute those instructions? Checking with Ghidra, we see that the instructions are not recognized by the disassembler and they are not reached by any flow of execution:

```
                         LAB_00100990                                XREF
00100990 5d                  POP        RBP
00100991 c3                  RET
00100992 0f                  ??         0Fh
00100993 1f                  ??         1Fh
00100994 5f                  ??         5Fh    _
00100995 48                  ??         48h    H
00100996 31                  ??         31h    1
00100997 c0                  ??         C0h
00100998 b0                  ??         B0h
00100999 3b                  ??         3Bh    ;
0010099a 0f                  ??         0Fh
0010099b 05                  ??         05h
0010099c 90                  ??         90h
0010099d 00                  ??         00h
0010099e 00                  ??         00h
0010099f 00                  ??         00h

                         **************************************************
                         *                    FUNCTION
                         **************************************************
                         undefined register_tm_clones()
       undefined           AL:1           <RETURN>
                         register_tm_clones                          XREF
001009a0 48 8d 3d            LEA        RDI,[__TMC_END__]
         69 16 20 00
```

The area of code in which the gadget resides is actually *padding code* that the compiler adds so that the beginning of some functions are aligned at nibble level (4 bits). Normally in x64 this padding code is a [*multi-byte NOP*](multi-byte NOP) (or a sequence of them):

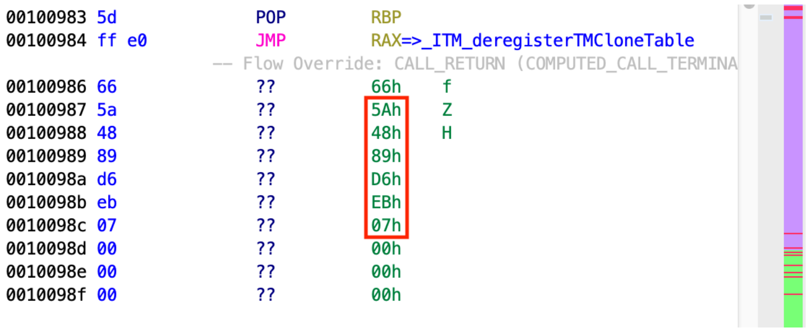
```
bytes  sequence                encoding

 1      90H                         NOP
 2      66 90H                      66 NOP
 3      0F 1F 00H                   NOP DWORD ptr [EAX]
 4      0F 1F 40 00H                NOP DWORD ptr [EAX + 00H]
 5      0F 1F 44 00 00H             NOP DWORD ptr [EAX + EAX*1 + 00H]
 6      66 0F 1F 44 00 00H          NOP DWORD ptr [AX + AX*1 + 00H]
 7      0F 1F 80 00 00 00 00H       NOP DWORD ptr [EAX + 00000000H]
 8      0F 1F 84 00 00 00 00 00H    NOP DWORD ptr [AX + AX*1 + 00000000H]
 9      66 0F 1F 84 00 00 00 00 00H NOP DWORD ptr [AX + AX*1 + 00000000H]
```

In this case, the multi-byte NOP has been partially overwritten with the instructions of the gadget. That's interesting.

Let's go back to the list of gadgets and see if there is everything we need to prepare the registers for the *SYS_EXECVE*: we need to set RAX, RDI, RSI and RDX. The gadget mentioned takes care of RDI and RAX, there is another gadget that pops RSI but there is nothing for RDX. RDX will point to the environment of the execve so it can't be a random value (the easiest way is to make it a pointer to NULL), but there is no gadget that gives us control over it.

But wait, let's think about what we saw until now: somebody put instructions that seem like a backdoor inside some padding code. Maybe there is other padding code that has been altered in the same fashion?



Ha-ha! Just before the bytes of the backdoor gadget there is another strange padding sequence. Disassembling those bytes we find:

```
pop rdx
mov rsi, rdx
jmp <+0x7>
```

This small block jumps to the backdoor gadget, so they are actually a single magic gadget that pops everything that is needed to call *SYS_EXECVE*. With this gadget we will only need to somehow prepare the stack with a pointer to NULL (8 null bytes) and a pointer to the string "/bin/sh". The latter can be found in *.rodata* because it is used as the author string for one of the default quotations.

At this point we have a clear idea of what to do: find some way to hijack the flow of the program and execute the magic gadget. Let's see what vulns we can find.

Buffer overflow

There is an evident buffer overflow in the `get_new_quote()` function, both in the text of the quotation and in the author buffers. The program calls two `read()` of 0x90 bytes for buffers of length 80 (text) and 30 (author).

Also, the text buffer is printed to stdout before reading the the author, so... what about overflowing the buffer until we reach the canary, so that the canary itself is printed as part of the text buffer?

Leaking stuff

Let's look at the stack we get before sending our input:

```
0x7fff13087cc0:     esp     0x00007f0bf3e14a00  0x00005624b3dfe260
0x7fff13087cd0:             0x000000000000000a  0x0000000000000000
0x7fff13087ce0:             0x00007f0bf3e14a00  0x00007f0bf3ab73f2
0x7fff13087cf0:     author  0x0000000000000000  0x0000000000000000
0x7fff13087d00:             0x0000000000000000  0x0000000000000000
0x7fff13087d10:     text    0x0000000000000000  0x0000000000000000
0x7fff13087d20:             0x0000000000000000  0x0000000000000000
0x7fff13087d30:             0x0000000000000000  0x0000000000000000
0x7fff13087d40:             0x0000000000000000  0x0000000000000000
0x7fff13087d50:             0x0000000000000000  0x0000000000000000
0x7fff13087d60:             0x0000000000000000  0x07b8f36c3cac6e00      canary
0x7fff13087d70:     ebp     0x00007fff13087da0  0x00005624b2a1203d      saved IP
0x7fff13087d80:             0x00000003b2a12080  0x00005624b3dfe260
0x7fff13087d90:             0x00000a3313087e80  0x07b8f36c3cac6e00
```

Highlighted in blue and green are the beginning of the text and author buffers, respectively.

Our end goal is to overwrite the **saved IP** with the address of the magic gadget. Since the binary is PIE, a leak of the *.text* section is needed in order to calculate that addres. Can we leak the saved IP?

Yes, but it's a bit convoluted. We can't leak it directly because the **canary** would be modified in the process; then the program would exit before returning from `get_new_quote()`. What we can do is to leak the canary first, together with the **saved BP**, and only then, leak the saved IP.

It's time to add some quotes.

Quote #1

leak canary + saved BP

The idea is to write enough bytes in the text buffer to reach the canary. We need 0x58 bytes (writing into memory goes towards the higher addresses). Since `printf` prints until the character terminator (null byte `\x00` for C programs), we need to overwrite also the least significan byte of the canary - notice that the canary is implemented so that it always has a null byte at the end.

Since the program performs a substitution of the first `\n` (newline) character in the buffer with a null byte, we must make sure that also the newline byte `\x0a` is not in our buffer.

Can we? Well, the we control the payload of 0x58 + 1 bytes, so no problem for that, but don't forget that also the canary itself will be part of our buffer and we have no control on it whatsoever: it is a random number generated at the beginning of the execution. From now on we assume that the canary does not contain any newline or null characters, besides the least significant byte that is always `\x00`, as we said. We'll discuss the other case later. This reasoning applies for all the values that we will leak in this exploit.

Together with the canary, the printf will print also the saved BP. It won't print further than that because the 2 most significant bytes of the saved BP are always `\x00`.

After the leak, we can restore the least significant byte of the canary with the overflow of the author buffer. This time the payload will be 0x78 + 1 bytes long, with the last byte set to `\x00`. This way the program won't detect any change on the canary upon return form `get_new_quote()`.

Quote #2

leak saved IP

At this point we know the canary and the saved BP. We can leak the saved IP following the same process described for the first quote:

1. write enough bytes to reach the value to leak (text buffer overflow)
2. restore values on the stack to let the execution go on (author buffer overflow)

For the first part 0x68 bytes are needed. For the second, we must restore both the canary and the saved BP.

Quote #3

final trigger

Now we know where to jump. After finding the addresses of "/bin/sh" and of 8 `\x00` bytes in the executable, let's send everything in the text buffer *(from low to high addresses)*:

- padding bytes
- canary
- saved BP
- address of the gadget
- address of null bytes
- address of "/bin/sh"

After sending a short author string, we get the shell.

```
> cat flag
```

Issues

Throughout the exploit, we assumed that the leaked values didn't have any `\x00` or `\x0a` bytes. They are all random values: the **canary** is random by implementation, the addresses of the stack (**saved BP**) and the .text segment (**saved IP**) are randomized by ASLR. There is nothing that can be done about that, that's why this exploit is not always succesful.

Testing 30 runs gave a success rate of ~*75%*.

Hosting

The challenge can be hosted on a system with the latest libc-2.31. The exploit does not make use of libc addresses.