Introduction to low-level software vulnerabilities

Lecture

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Whoami

Alexandre Thiroux

- CSIRT Manager at **Sectigo**
- Fields of interest : Forensics, Internet of Things, low level exploitation.
- **Defcon 11333** Organizer (https://dc11333.org)
- GCIH (SANS), OSCP & OSCE (Offensive Security) certified

Submodule introduction

This 8H submodule is composed with two parts:

- Reverse engineering (4H including a 15min break)
  - Lecture (45min)
  - Workshop (60min)
- Binary exploitation (4H including a 15min break)
  - Lecture (60min)
  - Workshop (45min)

Submodule requirements

To follow this lesson you will need the following pre-requisites:

- The Kali VM installed on your machine **4GB RAM (min)**
- Understanding C simple source code
- Python programming skills
- Basic knowledge in x32 ASM (reminders are planned)
- Basic knowledge in system architecture
- A notepad

Introduction to software exploitation

A software is potentially subjects to vulnerabilities or flaws introduced in the source code.
In this lesson you will discover the two main axis of the software exploitation:

- The reverse engineering
- The binary exploitation

Reverse engineering allows to understand the software logic and discover hidden functionalities after the program has been compiled. Depending of the program size and complexity, the process can be quite difficult.
Binary exploitation will allow you to find and exploit a vulnerability. This sometimes leads a full control of a host.

Reverse engineering

Reverse engineering: introduction

Reverse engineering use cases

lib/logos/.png

Reversing a program is used for many purposes. Here are some common use cases:

- Malware analysis
- Closed source program understanding
- Discover patent violations
- Discovering vulnerabilities

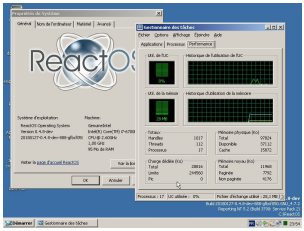


Figure 1: Reverse engineering example:
ReactOs a Windows clone

Reverse glossary

Some technical terms you have to know about:

- Disassembly
  Get the assembly code of a compiled program
- Decompile
  From assembly code, try to reproduce the original source code of the program
- Static analysis
  Analyse a software without executing it
- Dynamic analysis
  Analyse software interactions while running it

Compiling a code

lib/logos/.png

```
main:
        lea     ecx, [esp+4]
        and     esp, -16
        push    DWORD PTR [ecx-4]
        push    ebp
        mov     ebp, esp
        push    ebx
        push    ecx
        sub     esp, 64
        mov     ebx, ecx
        sub     esp, 12
        push    OFFSET FLAT:.LC0
        call    puts
        add     esp, 16
        cmp     DWORD PTR [ebx], 1
        jg      .L2
        sub     esp, 12
        push    OFFSET FLAT:.LC1
        call    puts
        add     esp, 16
        mov     eax, 1
        jmp     .L4
.L2:
        mov     eax, DWORD PTR [ebx+4]
        add     eax, 4
        mov     eax, DWORD PTR [eax]
        sub     esp, 8
        push    eax
        lea     eax, [ebp-58]
```

Figure 2: C code to x32 ASM

ASM x32 in a nutshell : basic instructions

There is two syntaxes for ASM instructions: Intel or AT&T.
The Intel one is add eax, ebx ; whereas the AT&T is addq %ebx, %eax ;.
In this course, we will only use the Intel syntax.

- MOV eax, 0x1 : move a value to a register
- PUSH 0x1 : push a value on the stack
- POP eax : remove a value from the stack and put it inside a register
- CALL eax : call a function with arguments
- SUB eax, 0x1 : substract a value from a register
- ADD eax, 0x1 : add value to a register
- JMP eax: jump to an instruction
- INT3 : place a breakpoint in the code
- INT80: System call
- RET: return to previous function (= POP RIP + JMP RIP)

Break: 5 minutes

lib/logos/.png

Break time. If you have any question, don't hesitate to ask it now. Otherwise, go to this website and try to play with it's functionalities:

- https://godbolt.org/

Don't forget the -m32 parameter.

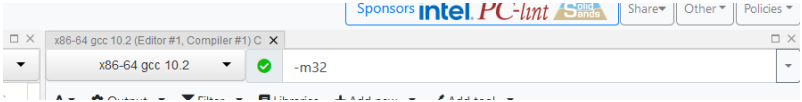


Figure 3: Compiler parameters

Different methods

There are different methods of reverse engineering:

- **Static analysis** is a method of computer program debugging, done by examining the code **without executing** the program.
- **Dynamic analysis** is the testing and evaluation of a **program by executing data in real-time**. The objective is to find errors in a program while it is running, rather than examining the code offline.

Reverse engineering: Tools and methods

Static analysis tools: Strings

lib/logos/.png

Figure 4: String command results

Strings command on linux will extract text strings from binary files. It can be useful to spot passwords or configuration paramaters.

Static analysis tools: Ghidra

lib/logos/.png

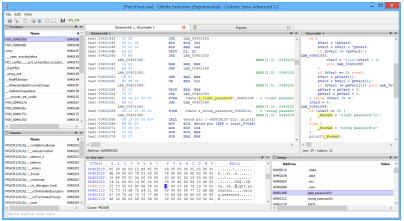


Figure 5: Ghidra's main interface

Ghidra is an all-in-one disassembly and decompiler software. It provides useful functionnalities like functions call tree.

> **Remark**
> Similar tools exists such as IDA (Paid) or Radare2.

Dynamic analysis tools: (S|L)trace

- Strace is a diagnostic, debugging and instructional userspace utility. It is used to monitor and tamper with interactions between processes and the Linux.
- Ltrace is a debugging utility, used to display the calls in a userspace application makes to shared libraries.

Dynamic analysis tools: Wireshark

- Wireshark is packet analyzer. It is used for network troubleshooting, analysis, software and communications protocol development.
- Often, programs are communicating with their environment. Using a packet analyser allows to analyse and track those communications.

Dynamic analysis tools: GDB

lib/logos/.png

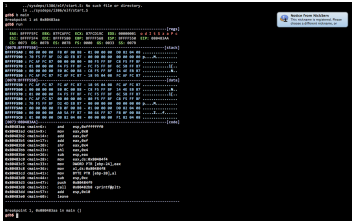


Figure 6: GDB's main interface

GDB is a debugger. A debugger is a software which helps developpers/or reversers to understand the program working. By setting breakpoints you can interrupt the execution to verify the environement at a given time.

> **Remark**
> On Windows you can use OllyDBG or WinDBG

Reverse engineering: Workshop

Workshop

- You will find exercices https://github.com/Hexliath/VA_RE
- I’m here to answer your questions

Information
Next lesson will be on Binary exploitation.
On your kali VM, please install gdb-peda (https://github.com/longld/peda) and have a look on how the stack is working.

Binary exploitation

Binary exploitation: introduction

Binary exploitation use cases

The principe of binary exploitation is to take advantage of bugs located inside a software in order to cause unintended or unanticipated behavior.
Here are some common use cases :

- Gaining privilege escalation
- Exploiting private devices (such as game consoles)
- Getting an unauthorized access on distant machine

Finding and exploiting such bugs is a long process. Thus, the researching part is almost never done during a pentest where already made exploits are preferred.

Exploit.db

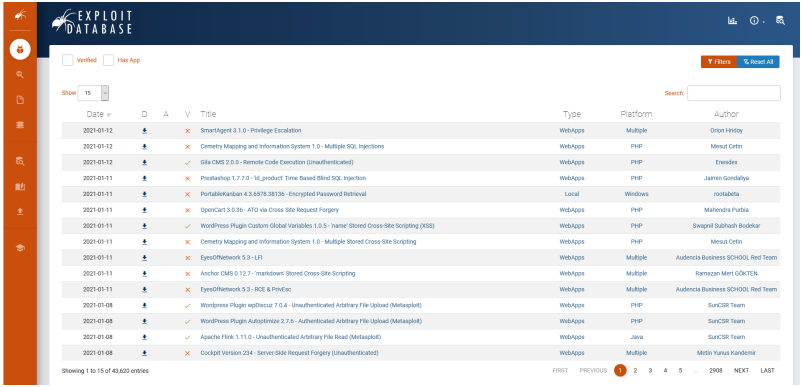


Figure 7: Exploit.db website

ELF binaries

In this course, we will study ELF binary file format which is the default Linux executable format. An executable is made of different sections. Here are the main ones (use **man elf** to see them all)

Name	Description	Flags
.text	Holds the executable instructions of the program	allocated & executable
.rodata	Holds the read only data	allocated
.data	Holds initialized data that contributes to program's memory	allocated & write
.bss	Holds unitialized data that contributes to program's memory	allocated & write

Table 1: ELF Sections

Memory

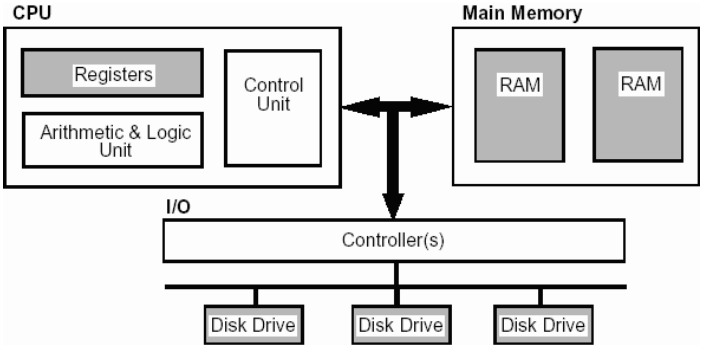
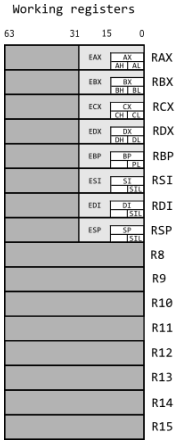


Figure 8: RISC architecture : the memory

Memory: The registers

Essential for data manipulation, registers are places where a program store temporary values during the execution. Registers also store information about the execution flow (EFLAGS).



RIP: Register Instruction Pointer
Points on the current instruction

RFLAGS: Flags register
Contains boolean values about the execution state

Memory : The stack and the heap

When it comes to store data, the stack and the heap are really useful. Stack is mainly use to store local data and variables with a known size whereas heap will be used when variable are declared through allocations (malloc,realloc...).

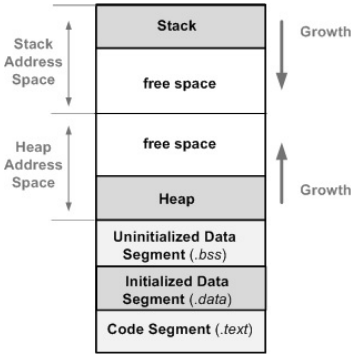


Figure 9: Memory layout

A stack frame

When you enter a new function using call instruction, the stack will create a new frame.
A stack frame will always contains the following elements:

- Return address : the next asm instruction right after the call
- Caller's EBP: the previous function EBP value
- Local variables and saved register content

A stack frame: exploit_me() function

To understand the stack working, we will study the exploit_me function. This function just take an argument input and copy it to a 50 bytes char array.

```
void exploit_me(char* arg){
   char buf[50];
   strcpy(buf,arg);
}
```

```
0x01    push    ebp
0x02    mov     ebp, esp
0x03    sub     esp,72

0x04    sub     esp,8
0x05    push    [ebp+8]
0x06    lea     eax, [ebp-58]
0x07    push    eax
0x08    call    strcpy
0x09    add     esp, 16

0x0A    mov     ebp,esp
0x0B    pop     ebp
0x0C    ret
```

Figure 10: C code and ASM disassembly

A stack frame: exploit_me() function

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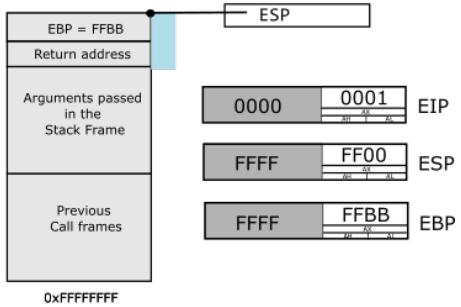

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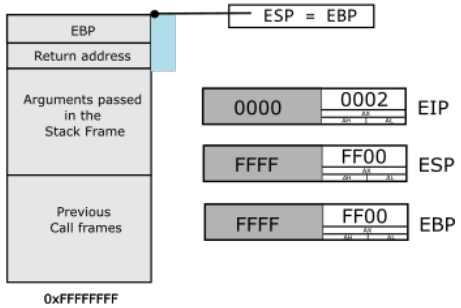

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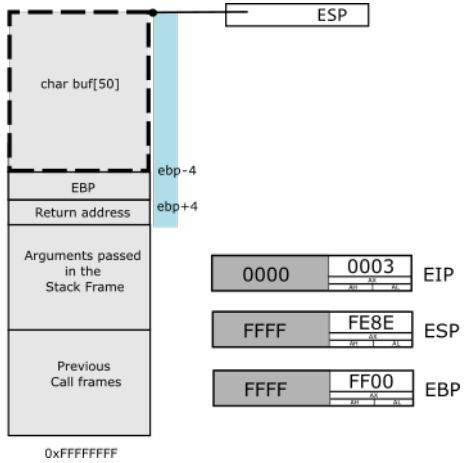

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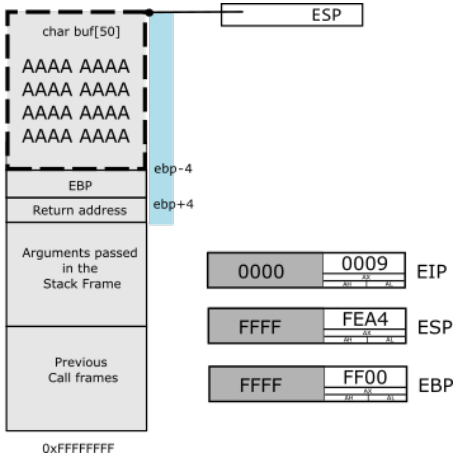

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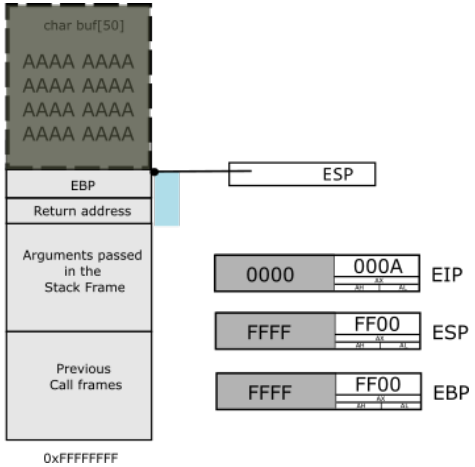

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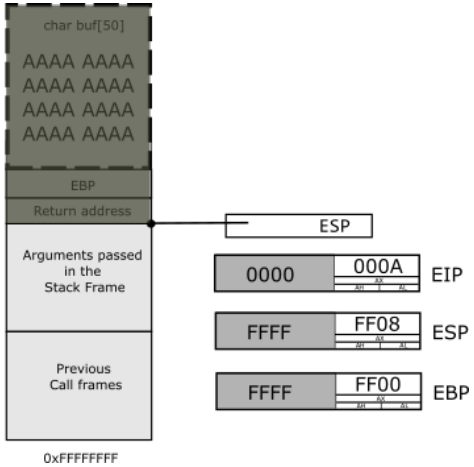


Break: 15 minutes

Break time.

- Open your VM
- Install gdb-peda (https://github.com/longld/peda)
- Download **https://cutt.ly/IjmnCJI**
- run gdb ./demo.exe, set breakpoints and inspect the registers

> **Remark**
> Basic commands for gdb are :
> disas <function name> : disassemble a function
> b * <breakpoint address>: set a breakpoint at a given address
> ni: go to next instruction **(EIP+1)**
> c: continue the execution until next breakpoint
> r: run or restart the program
> i r: inspect register
> x/xw <register or address>: see address content

Binary exploitation: buffer overflow

Software vulnerabilities

A lot of vulnerabilities exist in pentesting software field. Here are some of them you may have heard about :

- Stack-based buffer overflow
- Heap-based overflow
- Format string vulnerability
- Integer overflow

In the next slides, we will focus on "Stack-based buffer overflow" vulnerability which is probably the most known.

Buffer overflow: introduction

This type of vulnerability arises **when more data are inserted in a local variable** than the actual variable size. A stack-buffer overflow happen and data from the stack are overwrite by user input.
Let's reuse our previous exploit_me() function.

```
void exploit_me(char* arg){
   char buf[50];
   strcpy(buf,arg);
}
```

Figure 11: exploit_me() function

Buffer overflow: introduction

What does happen when an argument longer than 50 characters is passed to the function ? Let's say arg is 'A'x80 without any spaces.

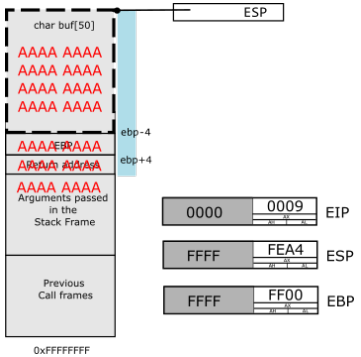


Figure 12: The stack frame is overwritten by the passed argument

Live demonstration

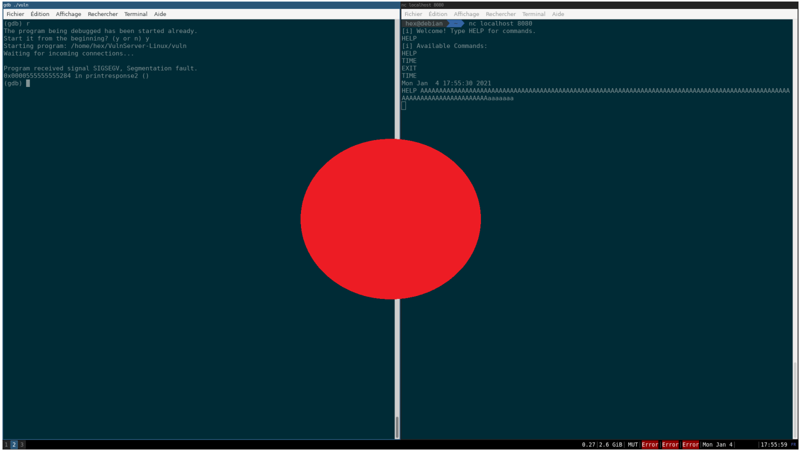


Figure 13: Do you wanna see an exploit ?

Buffer overflow: exploitation

A methodology exists to find and exploit a classic buffer overflow. This one consists in three parts : find, get control and exploit.
Here are the basics steps :

- Fuzzing
- Find a crash
- Find the EIP offset
- Jump to ESP
- Slide into the payload injection
- Get a shell

These steps will be covered in the next slides.

Fuzzing: explanations

Fuzzing is a testing technique that involves providing invalid, unexpected, or random data as inputs to a computer program. Using an automated fuzzer, or doing it manually, the goal is to find a crash while the program is running. After the crash has been find, a debugger should be used in order to identify where and when the program has crashed.

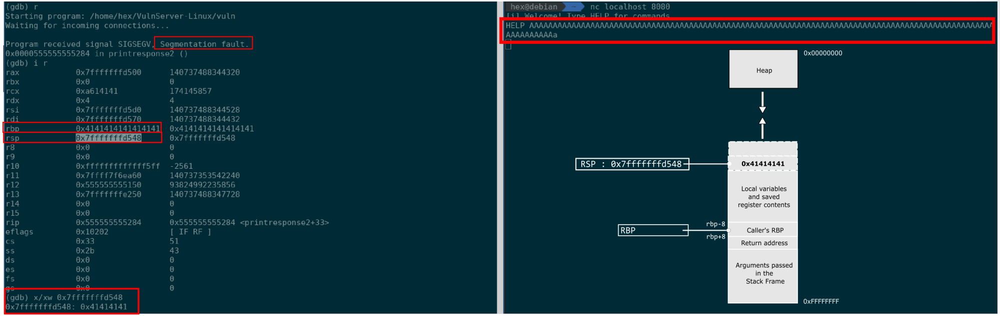
```
(gdb) r
Starting program: /home/hex/VulnServer-Linux/vuln
Waiting for incoming connections...

Program received signal SIGSEGV, Segmentation fault.
0x0000555555555284 in printresponse2 ()
```

Figure 14: Typical buffer overflow crash

Remark

Boofuzz is a Python library which is really useful to automate fuzzing proccess for online targets.
Pwn library and random inputs can also be useful.

Fuzzing: The segmentation fault



Controlling the execution flow: cyclic pattern

Now that we have found an entry point inside the program, the next step will be to redirect the execution flow of the program (EIP) where we want it.
First of all, we need to find and control EIP. For that a cyclic pattern can be used to determine the EIP's offset.

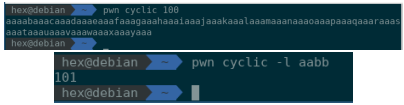


Figure 15: Cyclic pattern location

Once we have the offset, we can create a custom string using this length.
Characters right after this string will be considered as the new return address.

> **Remark**
> **pwn** can be installed using python3-pip : **pip3 install pwntools**

Controlling the execution flow: controlling EIP

EIP is now under control.

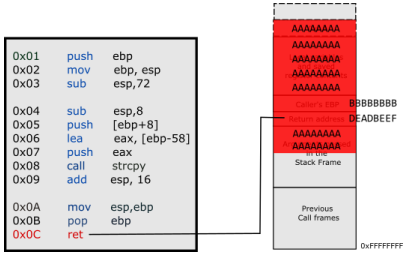


Figure 16: EIP points to 0xdeadbeef

Nevertheless, 0xdeadbeef is a false address. Let's find something we can really jump into.

Controlling the execution flow: jmp ESP

In our demonstration program, we are controlling ESP.
(you can see it using **x/xw $esp** in gdb-peda)
So we need to find a jmp ESP instruction inside the program.

Then, using this address we can redirect EIP to ESP thanks to this string:
"A"*offset + jmp esp address + "C"*a relatively big number

> **Remark**
> Using GDB-Peda you can type **jmpcall esp** to find one.

Controlling the execution flow: nop sliding

Let’s talk about the most useful instruction in ASM.
The NOP (x90) instruction.

This instruction does nothing.
But, it’s very useful to slide into another interesting place.

Controlling the execution flow: shellcode

At the end of the nop slide, you can insert a shellcode.
A shellcode is an ASM piece executing some useful functionalities such as a shell.

You can find a shellcode library here : **http://shell-storm.org/shellcode/**

Your string should look like this:
"A"*offset + jmp esp address + "NOP" slide + shellcode

Controlling the execution flow: shellcode

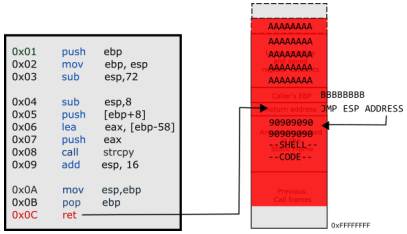


Figure 17: Sliding to shellcode

Once the shellcode has been read, it's executed.

Binary exploitation: workshop

Workshop

- You will find the exercices on https://github.com/Hexliath/VA_BE
- Your report has to be sent to alexandre.thiroux@xx before the next supervised work. It will be marked (1 coefficient).

Questions ?

x

Introduction to low-level software vulnerabilities

Lecture

Alexandre Thiroux[1]

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January & February 2022