# Exploiting Software Vulnerabilities

## Advanced Exploitation Techniques

## Exploit Payloads



Dept. of Computer Science and Systems Engineering
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**Master's Degree in Informatics Engineering**

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*Seminar A.22, Ada Byron building*

# Outline

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# A little recap
## What is a exploit payload?

**Shellcode?**

- Shellcode: code that executes a shell
- Exploit payload: executable code in exploits

# A little recap

## What is a exploit payload?

**Shellcode?**

- Shellcode: code that executes a shell
- Exploit payload: executable code in exploits

**Exploit payload**

- Snippets of code that are injected into a running process and run from within that process
- It must keep the injected process running
  - Otherwise the process will terminate and thus the exploit will terminate as well

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# A little recap

## What is a exploit payload?

### Requirements

- Position-independent code
  - Facilitates execution, regardless of the memory address or the segment in which they are injected
- Size constraints: as compact as possible
  - The smaller the payload, the more generically useful it will be
- Avoid certain bytes that can be misinterpreted (e.g., NULL bytes)
- Cannot use library functions
  - Unless they resolve the shared libraries themselves or they are located in the same fixed memory location

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# A little recap

## System calls – syscalls

**Exploit payload manipulates the program to force it to make a syscall**

- Functions that allow access to specific functions of the OS
- Interface between protected kernel mode and user mode

# A little recap

## Syscalls on Linux

- Through software interrupts (`int 0x80`)
- Forces the switch to the kernel model and executes the appropriate syscall function
- Unlike other Unix syscall methods, Linux uses a fastcall convention (that is, it uses the CPU registers for higher performance)
  - The `eax` register contains the specific syscall number
  - The arguments of the syscall function are placed in other registers

# Outline

# Payload types
## Byte content

### Null-free payloads

- **Payloads that have NO null bytes**
- **Useful for string-based exploits**
- What if we need, for instance, a null value for the execution of the shellcode?
  - Example: we need to insert a 0 value in the stack
- **Solution**: ***look for equally semantic instructions in the ISA***

```
push 0 ; 0x6a00      →   xor eax, eax     ; 0x33c0
                         push eax         ; 0x50
```

```
mov eax, 0x00ddaa00 ; 0xb800aadd00   →   mov eax, 0x88DDAA88    ; 0xb888aadd88
                                         xor eax, 0x77FFFF77    ; 0x3577ffff77
```

# Payload types
## Byte content

### Alphanumeric

- **Only printable bits are valid**
  - For instance, ASCII bytes
- **Useful against certain filter functions**
- Further reading: *Writing IA32 alphanumeric shellcodes* (http://phrack.org/issues/57/15.html)

# Outline

# Filters

- **Some applications may incorporate a sanitized input filter into the code**
  - Remove printable chars
  - Delete certain bytes
  - ASCII input → UNICODE input
- **A filter can modify the payload and then becomes useless**

**Payload can be prepared to bypass these filters**

# Filters

## Alphanumeric filters

- **The filter only accepts printable ASCII characters of numbers and letters**
  - '0'...'9' (0x30...0x39)
  - 'a'...'z', 'A'...'Z' (0x61...0x7a – 0x41...0x5a)

```
call eax ; 0xffd0   →   push 0x50                ; 0x6a50
                        pop eax                  ; 0x58
                        xor al, 0x50             ; 0x3450
                        dec eax                  ; 0x48
                        xor eax, 0x47305757      ; 0x3557573047
                        xor eax, 0x68303838      ; 0x3538383068
                        push eax                 ; 0x50
```

After the last `xor` instruction, `eax` **will contain the value** `0xD0FF9090`

**How to use `eax`?**

- **From 2 bytes to 17 bytes** (+ extras, as the required value is in a register!)
- **Very tedious and error prone task**
- **There are automatic tools to create alphanumeric payloads**
  - Or algorithms, such as base64 encoding (if supported)

# Filters

## Skipping alphanumeric filters

### Base16 data encoding

- **Standard, case-insensitive hex encoding**
- **The 16-characters subset of US-ASCII is used**
  - 4 bits to represent a printable character
- Encoding process:
  - Represents input bit octets as 2-character encoded output strings
  - Each octet is divided into two parts (nibble)
  - Each nibble is translated to a single character in the base16 alphabet

**Further reading**: `https://tools.ietf.org/html/rfc4648`

# Filters

## Skipping alphanumeric filters

### Encoding algorithm

- For each input byte, divided it into its nibble parts
- For each nibble, add the value ’A’ (`0x41`)
  - The result will be in the range `0x41`...`0x50` (’A’...’P’)
- Mark the end of the payloads with some character greater than ’P’

### Decoding algorithm

- For each input byte, subtract the value ’A’ (`0x41`)
- Shift the result to the left
- Add the next input byte, after subtracting the value ’A’ (`0x41`)
- For each nibble, add the value ’A’ (`0x41`)

# Filters
## Skipping alphanumeric filters

```
INIT:
  8A07                    MOV AL,BYTE PTR DS:[EDI]
  2C 41                   SUB AL,0x41
  C0E0 04                 SHL AL,0x4
  47                      INC EDI
  0207                    ADD AL,BYTE PTR DS:[EDI]
  2C 41                   SUB AL,0x41
  8806                    MOV BYTE PTR DS:[ESI],AL
  46                      INC ESI
  47                      INC EDI
  803F 51                 CMP BYTE PTR DS:[EDI],0x51
  72 EB                   JB @INIT
```

- `edi`: encoded shellcode buffer
- `esi`: decoded shellcode buffer
  - **Can they both be the same buffer?**

*Note that these bytecodes* **are not** *alphanumerical. Some initial conversion is needed, as discussed before*

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# Filters

## Skipping alphanumeric filters

- How to achieve **execution of the decoded payload**?
- Can be **located just after the conditional jump of the previous code**
- **Question**: **how to configure `edi`/`esi` values properly?**

```
    EB 02           JMP B
A:
    EB 05           JMP C
B:
    E8 F9FFFFFF     CALL A
C:
    5F              POP EDI
    83C7 1C         ADD EDI,0x1C
    57              PUSH EDI
    5E              POP ESI
```

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# Filters

## UNICODE filters

- **UNICODE character set**
  - 16 bits (instead of 8) to represent characters
  - UNICODE characters equivalent to ASCII character are named *wide chars*
- **A wide character is its ASCII code plus the null byte**
  - In particular, from `0x01` to `0x7F`
- **This null byte is used for other alphabetic encodings**, such as Chinese, Russian, etc.

```
nop    ; 0x90
nop    ; 0x90          nop                                ; 0x90
nop    ; 0x90    →     add byte ptr ds:[eax + 90009000], dl   ; 0x009000900090
nop    ; 0x90
```

# Filters

## Skipping UNICODE filters

### Valid instructions

- **Single opcode**
- `0xNN 0x00 0xNN` **opcodes**
- `0x00 0xNN 0x00` **opcodes**
- `0xNN 0x00 0xNN 0x00 0xNN` **opcodes**

```
push eax            ; 0x50
pop ecx             ; 0x59
```

→

```
push eax                      ; 0x50
add byte ptr [ebp], ch        ; 0x006d00
pop ecx                       ; 0x59
add byte ptr [ebp], ch        ; 0x006d00
```

**NOTE**: ebp must point to a writable memory address (otherwise, it will crash)

# Filters

## Skipping UNICODE filters

### How to jump to the payload?

- **Find the payload in ASCII mode in memory**
- **Write a UNICODE-compliant payload manually**
- **Use a encoder**
  - `alpha2`
  - `vense`: Perl script

**Remember: you must first configure the EIP with a valid address**

**Further reading**: *Unicode – from 0x00410041 to calc*,

`https://www.corelan.be/index.php/2009/11/06/exploit-writing-tutorial-part-7-unicode-from-0x00410041-to-calc`

# Outline

# Encoders/decoders

## XOR encoders

- **Take advantage of XOR properties**
  - $a \otimes b = c; c \otimes b = a; c \otimes a = b$
- **XOR-based code obfuscation**: generally used by malware
- **Useful to get shellcodes without null bytes**
- Example: XOR 1-byte cipher

```
int encode(unsigned char xorKey, unsigned char *buf, int shellcodelen)
{
        for(int i = 0; i < shellcodelen; i++)
        if(xorKey != (unsigned char)shellcode[i])
            buf[i] = ((unsigned char)shellcode[i])^xorKey;
}
```

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# Encoders/decoders

## Assembler code for XOR decoder

```
   EB 02               JMP B
A:
   EB 05               JMP C
B:
   E8 F9FFFFFF         CALL A
C:
   5F                  POP EDI
   83C7 1A             ADD EDI,1A
   57                  PUSH EDI
   5E                  POP ESI
   33C0                XOR EAX,EAX
   33C9                XOR ECX,ECX
   B1 NN               MOV CL, NNh # shellcode size
DEC:
   8A07                MOV AL,BYTE PTR DS:[EDI]
   3C 41               CMP AL,41 # cipher key
   74 02               JE G
   34 41               XOR AL,41 # cipher key
G:
   8806                MOV BYTE PTR DS:[ESI],AL
   47                  INC EDI
   46                  INC ESI
   E2 F2               LOOPD DEC
```

# Encoders/decoders

- **Addition/subtraction encoder**
  - Uses `add`/`sub` instructions, instead of `xor`
  - *Example*: `https://github.com/h0mbre/Myth`
- **Shikata Ga Nai polymorphic XOR additive feedback encoder**
  - **Rotating key**: it changes the key in each round!
  - Helps prevent detection based on signatures (e.g., byte patterns)
- **Other variants**:
  - XOR-ROR additive feedback (`https://github.com/Re4son/slae-4`)
  - ...

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# Encoders/decoders

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  - ...

## Custom encoders/decoders

- **Customize your encoder/decoder!**
- **Always following these steps**:
  1. Choose an encoding mechanism
  2. Develop an encoder
  3. Develop a decoder
  4. Decoder must be located before the modified payload
- **Tedious manual work, but (almost) all filters can be skipped!**

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# Encoders/decoders

## *Encoders available in Metasploit*

```
Name                          Rank       Description
----                          ----       -----------
x86/add_sub                   manual     Add/Sub Encoder
x86/alpha_mixed               low        Alpha2 Alphanumeric Mixedcase Encoder
x86/alpha_upper               low        Alpha2 Alphanumeric Uppercase Encoder
x86/avoid_underscore_tolower  manual     Avoid underscore/tolower
x86/avoid_utf8_tolower        manual     Avoid UTF8/tolower
x86/bloxor                    manual     BloXor - A Metamorphic Block Based XOR Encoder
x86/bmp_polyglot              manual     BMP Polyglot
x86/call4_dword_xor           normal     Call+4 Dword XOR Encoder
x86/context_cpuid             manual     CPUID-based Context Keyed Payload Encoder
x86/context_stat              manual     stat(2)-based Context Keyed Payload Encoder
x86/context_time              manual     time(2)-based Context Keyed Payload Encoder
x86/countdown                 normal     Single-byte XOR Countdown Encoder
x86/fnstenv_mov               normal     Variable-length Fnstenv/mov Dword XOR Encoder
x86/jmp_call_additive         normal     Jump/Call XOR Additive Feedback Encoder
x86/nonalpha                  low        Non-Alpha Encoder
x86/nonupper                  low        Non-Upper Encoder
x86/opt_sub                   manual     Sub Encoder (optimised)
x86/service                   manual     Register Service
x86/shikata_ga_nai            excellent  Polymorphic XOR Additive Feedback Encoder
x86/single_static_bit         manual     Single Static Bit
x86/unicode_mixed             manual     Alpha2 Alphanumeric Unicode Mixedcase Encoder
x86/unicode_upper             manual     Alpha2 Alphanumeric Unicode Uppercase Encoder
x86/xor_dynamic               normal     Dynamic key XOR Encoder
```

### Steps to prepare an encoder/decoder that works

- **Recognize the filter in the vulnerable program**
- **Know (in detail) the underlying ISA**

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# Outline

# Payload components

## Restore privileges

- Useful on Unix-like systems: effective user ID vs real user ID
  - `eid` governs what access the process has
  - `uid` determines who the user really is
- Some programs may drop privileges before execution (e.g., `/etc/sh` in the latest versions of GNU/Linux and macOS)
- You can run `seteuid(0)` before the shellcode payload to get an elevated shell (in a +s program)

```
xor eax, eax
mov al, 70
xor ebx, ebx
xor ecx, ecx
int 0x80
```

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# Payload components

**Creation of new processes**

- Some systems (like macOS) may require your program to call `vfork()` beforehand to run a new process
  - Otherwise, `execve()` will return the error `ENOTSUP`
- `vfork()` is like `fork()`, except that the parent process is suspended until the child process executes the `execve()` system call or exits

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# Payload components

## Shell execution

- Minimal payload to run a shell
- You have worked with this payload before, see the previous topic slides (or lab workbooks)!
- Note that on some systems, a drop of privileges may occur by default as a good practice of security principles
- On remote, variants: *bind shell* and *reverse shell*

```
xor    eax, eax
push   eax
push   0x68732f2f
push   0x6e69622f
mov    ebx, esp
push   eax
push   ebx
mov    ecx, esp
mov    al, 0xb
int    0x80
```

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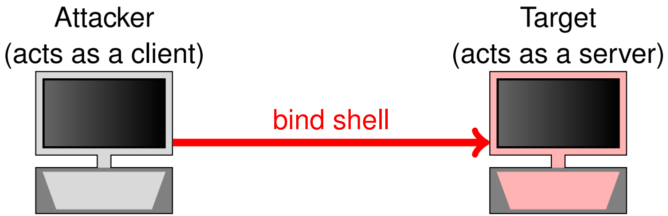
# Payload components

## Bind shell

- Payload that opens a listening port
- When the attacker connects, it automatically launches a shell
- Think of a **client/server architecture**:
  - **The attacker acts as a client, the target acts as a server**



# Payload components

## Reverse shell

- Payload that connects to a specific address
- When connecting to the address, it automatically launches a shell
- Think of a **client/server architecture**:
  - **The attacker acts as a server, the target acts as a client**
- **Useful to bypass firewalls or other port blocking procedures**

# Payload components

## Redirection of std to fds

- Duplicate a socket file descriptor (std) into standard input, standard output, and standard error file descriptors (fds)
- Useful to remotely interact with the target system through the socket

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## Staged payload

- Useful to avoid payload size constraints
- Each stage prepares the runtime environment for the next stage, allowing the next stage to run with fewer constraints
  - For instance, the first stage can search for the subsequent stage somewhere else in memory and decode it, or download it over the network, and then run it (or inject it into a running process)

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