Sentinel

by Nicolas A. Economou

CORE SECURITY

Intro

- Why Sentinel ?
  - Hundreds of 0-day **binary bugs** appear per year
  - Many Antivirus can’t stop 0-day exploits
  - **AntiXploit tools** are relativity new
  - The best **knowledge** comes from exploit writers

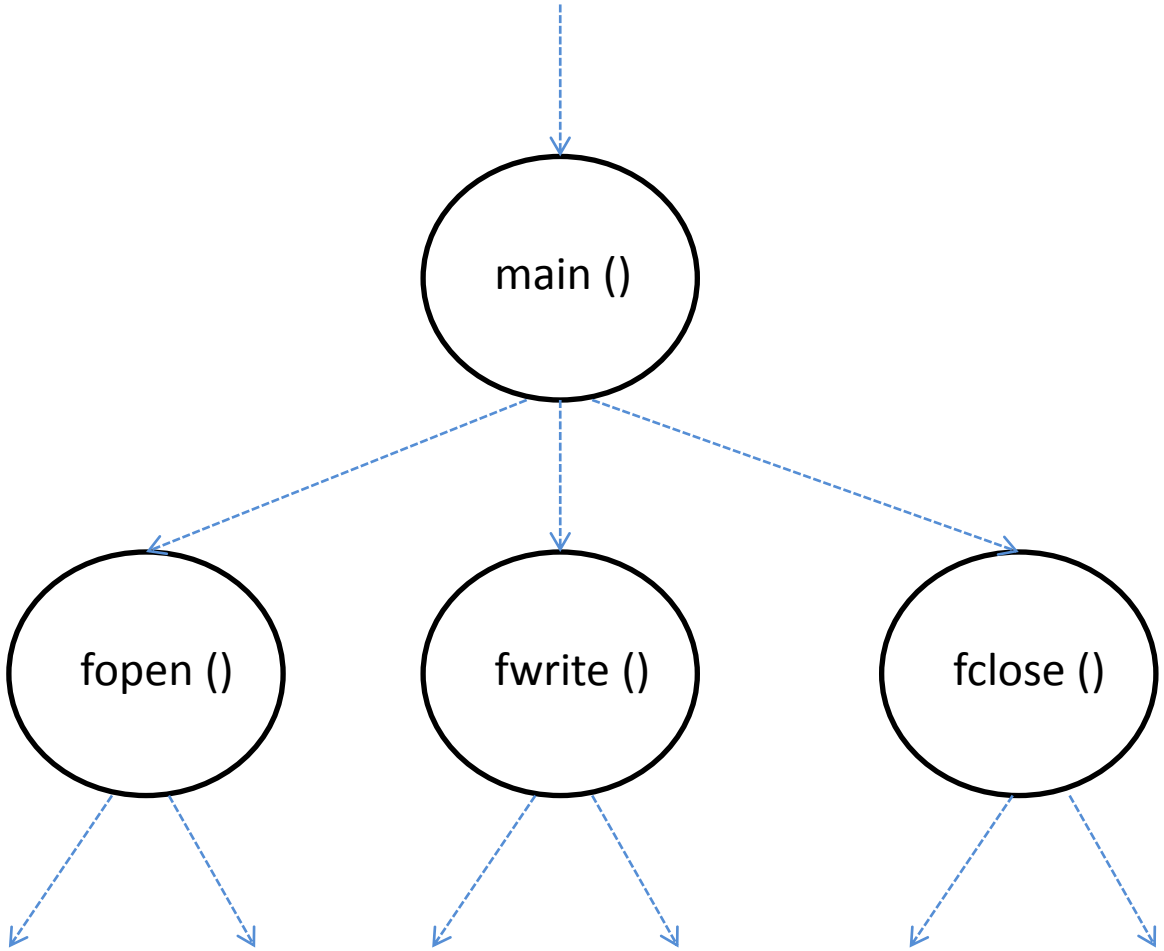
Let’s start …

Calling functions

- E.g. a “C” program

```
main ( … )
{
   printf ( … );
   fopen ( … );
   fwrite ( … );
   fclose ( … );
}
```

Callgraph



Calling functions

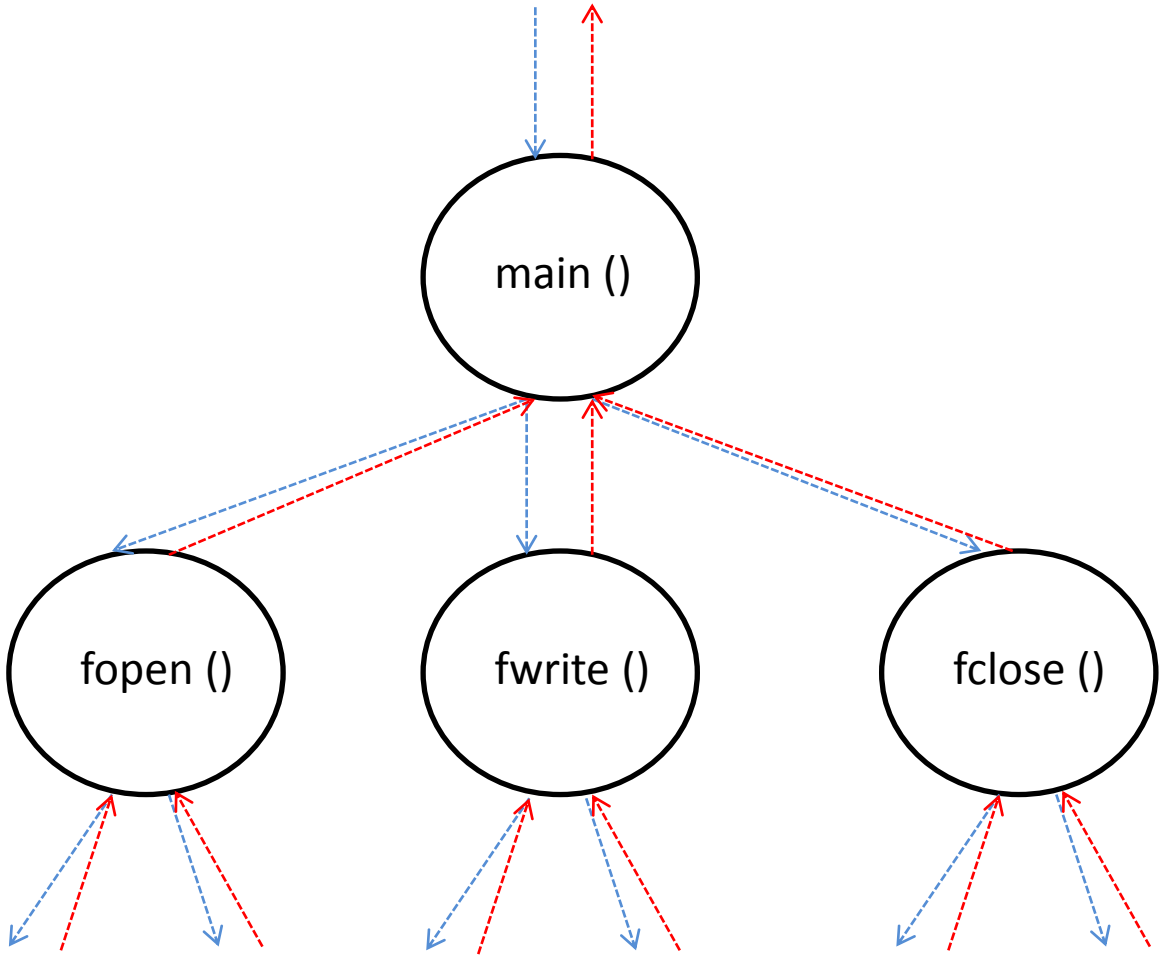
- E.g. a “C” program

→ main ()

- → printf ()
- ← printf ()
- → fopen ()
- ← fopen ()
- → fwrite ()
- ← fwrite ()
- → fclose ()
- ← fclose ()

← main ()

Callgraph



Breaking rules

- E.g. a “C” program

→ main ()

→ printf ()

← printf ()

→ fopen ()

← fopen ()

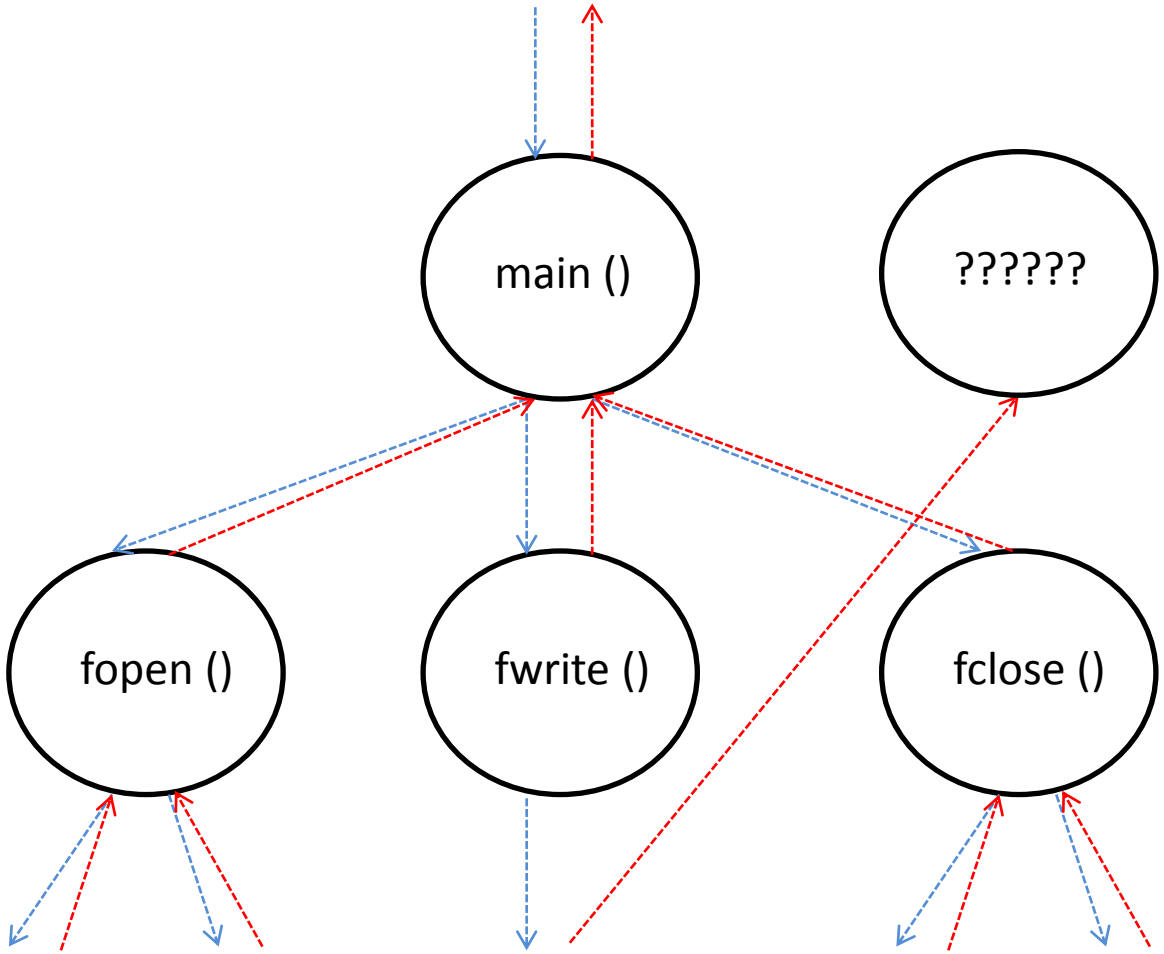
→ fwrite ()

← system () or WinExec () or 0x41414141 ??????????????

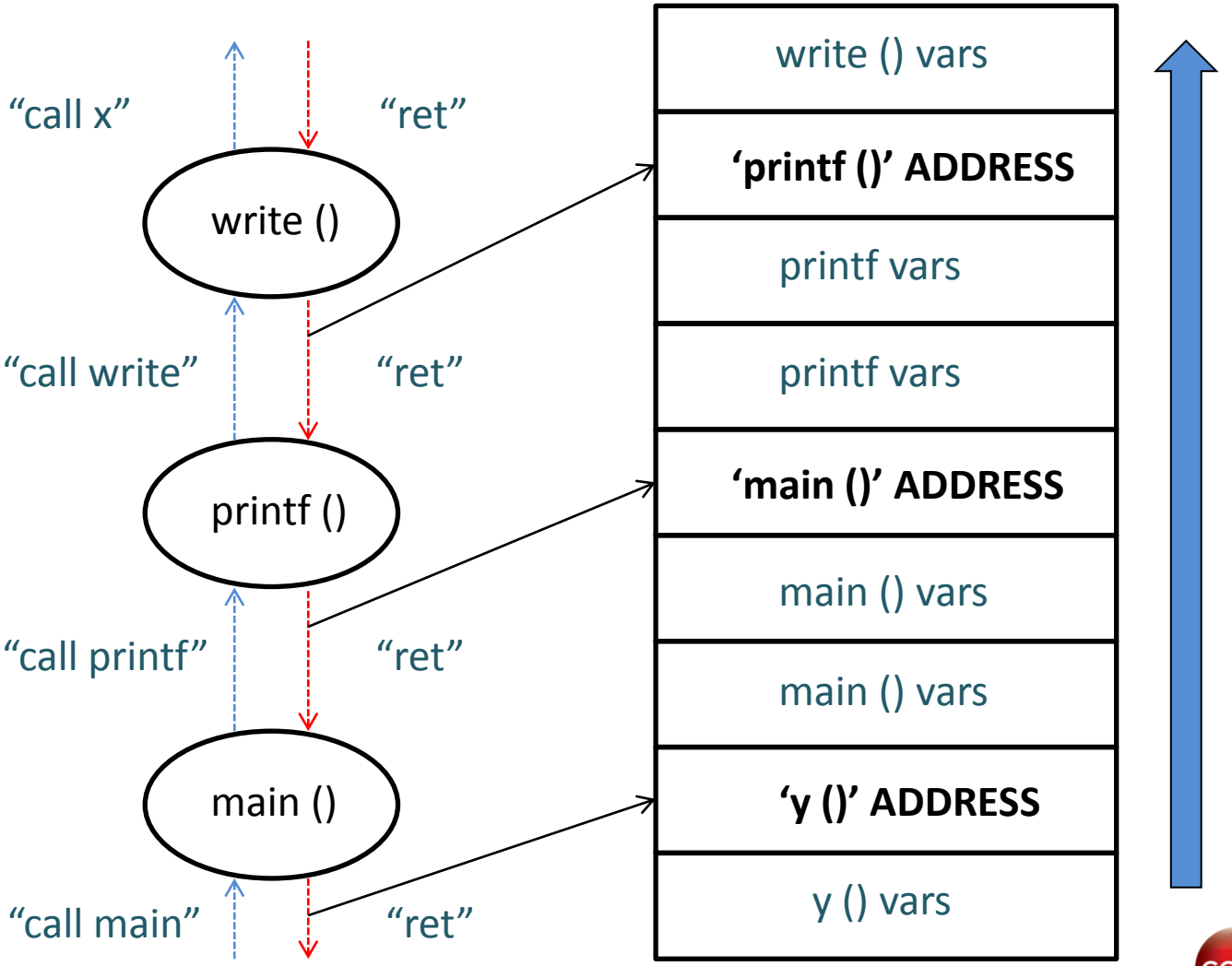
→ …

← main ()

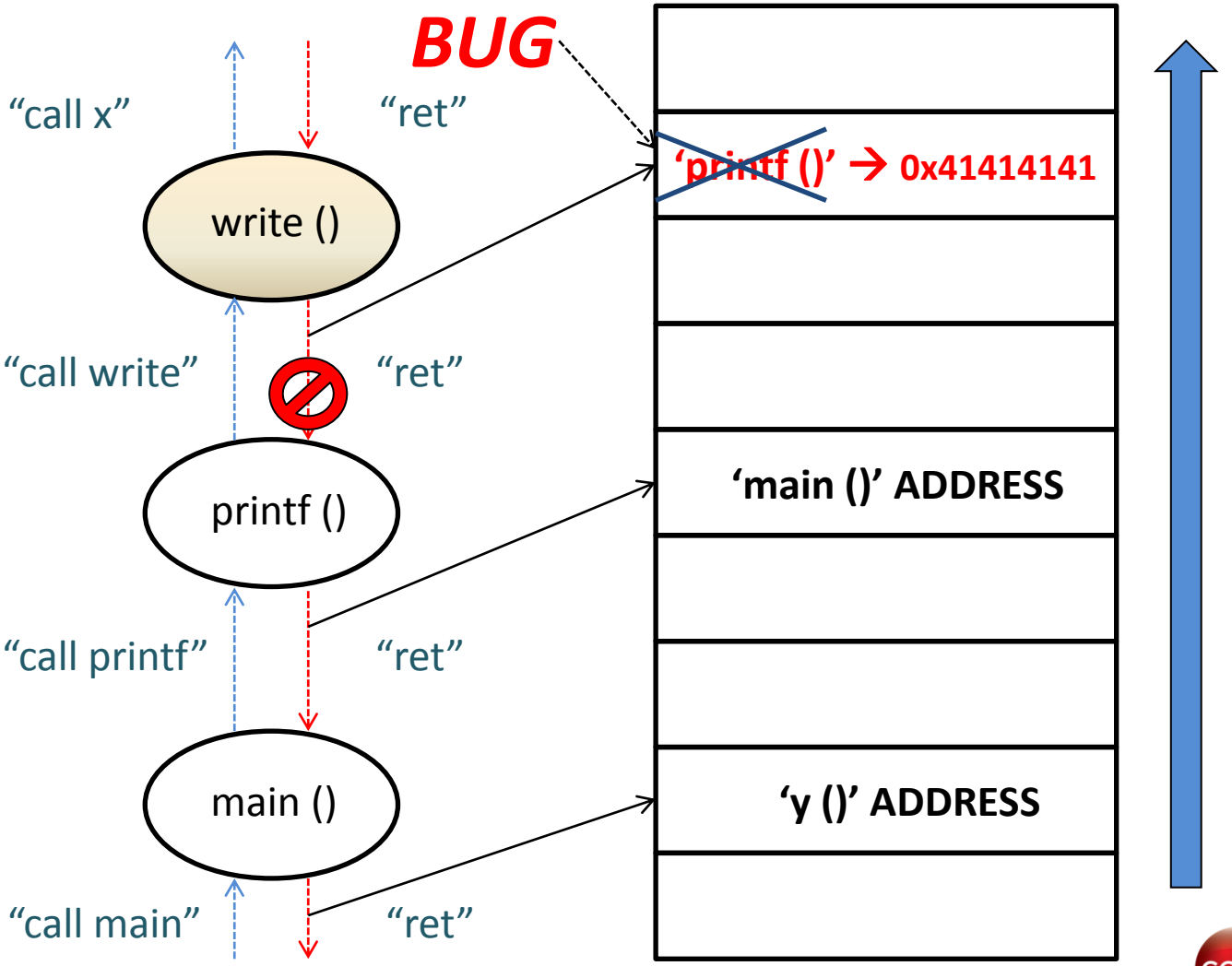
Breaking rules



Stack working



Return address modified



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ROP

- Return-oriented programming

- Used by the most current exploits

- It needs **HARDCODED addresses** or **offsets**

- Usually the STACK is used to **reach** code execution

ROP

- The idea is to:
  - Bypass protection mechanisms (**unprotect** stack or heap)
  - Execute a new program (e.g. “\\myip\rootkit.exe”)

Targeted functions:

- VirtualProtect – VirtualProtectEx - ZwProtectVirtualMemory
- VirtualAlloc - VirtualAllocEx - ZwAllocateVirtualMemory
- ZwSetInformationProcess
- CreateProcess – CreateProcessEx
- LoadLibrary

-Final target:

- **Code execution** (to take control of the target)

ROP

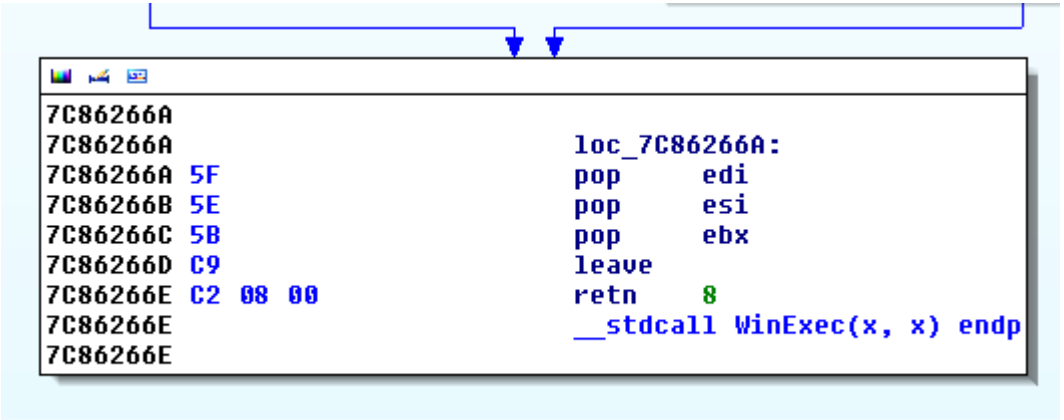
- In most cases, the "**RET**" instruction is required in each step

- Generally, "**RET**" instructions are located in function **EPILOGUES**.

- An **EPILOGUE** is the last part of a function
  - It's used to:
    - Check the canary (if it exists)
    - Restore some registers
    - Return to the **PARENT** function

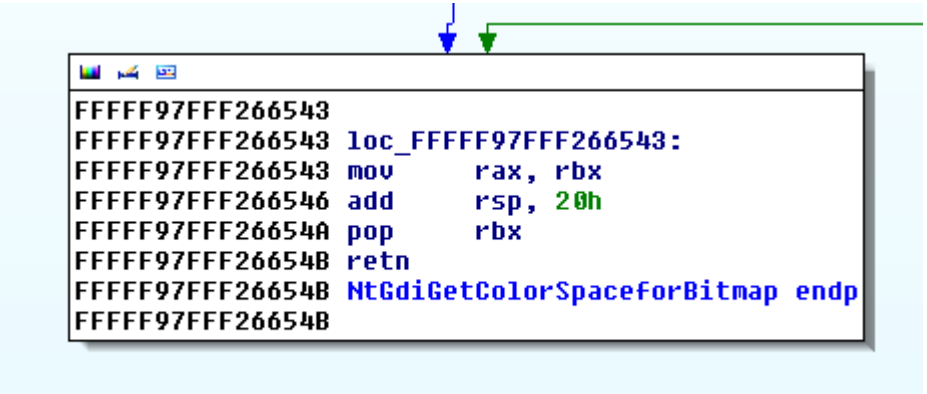
ROP

- Epilogue example:
  - Intel 32 bits - Windows



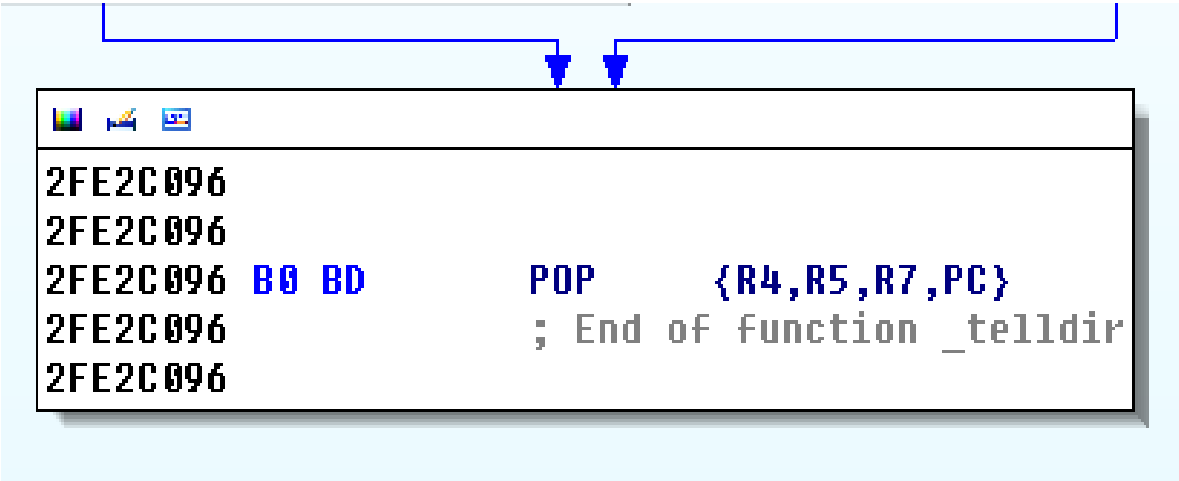
ROP

- Epilogue example:
  - Intel 64 bits - Windows



ROP

- Epilogue example:
  - ARM - iPhone



ROP

- A “subgroup” of the instructions contained in an **EPILOGUE** can be called **GADGET**

- **GADGETS** are little operations used to set register/memory values

- Sometimes it’s necessary to **chain** many GADGETS to reach the final target

ROP

- GADGET examples:
  - “xchg eax,ebx”
  - “pop esi”
  - “pop edi”
  - “**ret**”

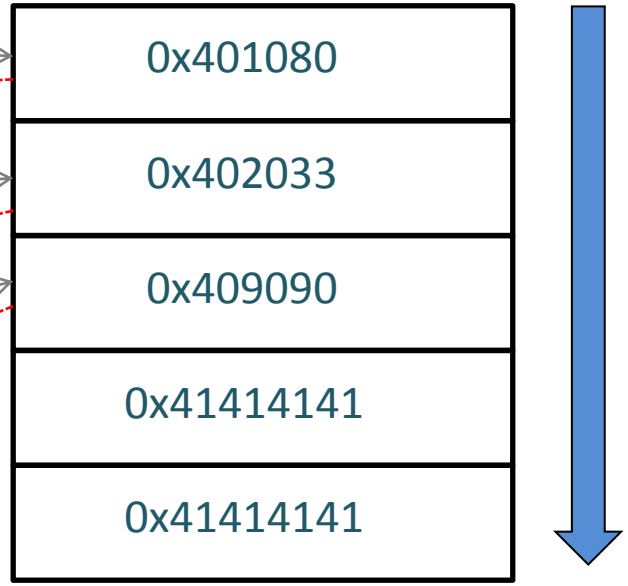
  - “xor eax,eax”
  - “leave”
  - “**ret** 4”

ROP example

0x123456:
“pop eax”
“pop ebx”
“ret”

Objective: EAX=1, EBX=2, ECX=3

CONTROLABLE STACK



0x401080:
“mov eax,1”
“ret”

0x402033:
“mov ebx,2”
“ret”

0x409090:
“mov ecx,3”
“ret”

The Sentinel Project

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Sentinel

- Command line **TOOL** able to **INTERCEPT exploit attacks** (usually with ROP activity)

- It can **protect**:
  - **Running** programs
  - Launch a program and protect it

- It **RUNS** completely in **USER MODE**

Sentinel

- It **doesn't need feedback** about the module to protect

- It has 2 level protections:
  - Default: Minimal (only "critical" functions)
  - Custom: Default + targeted modules

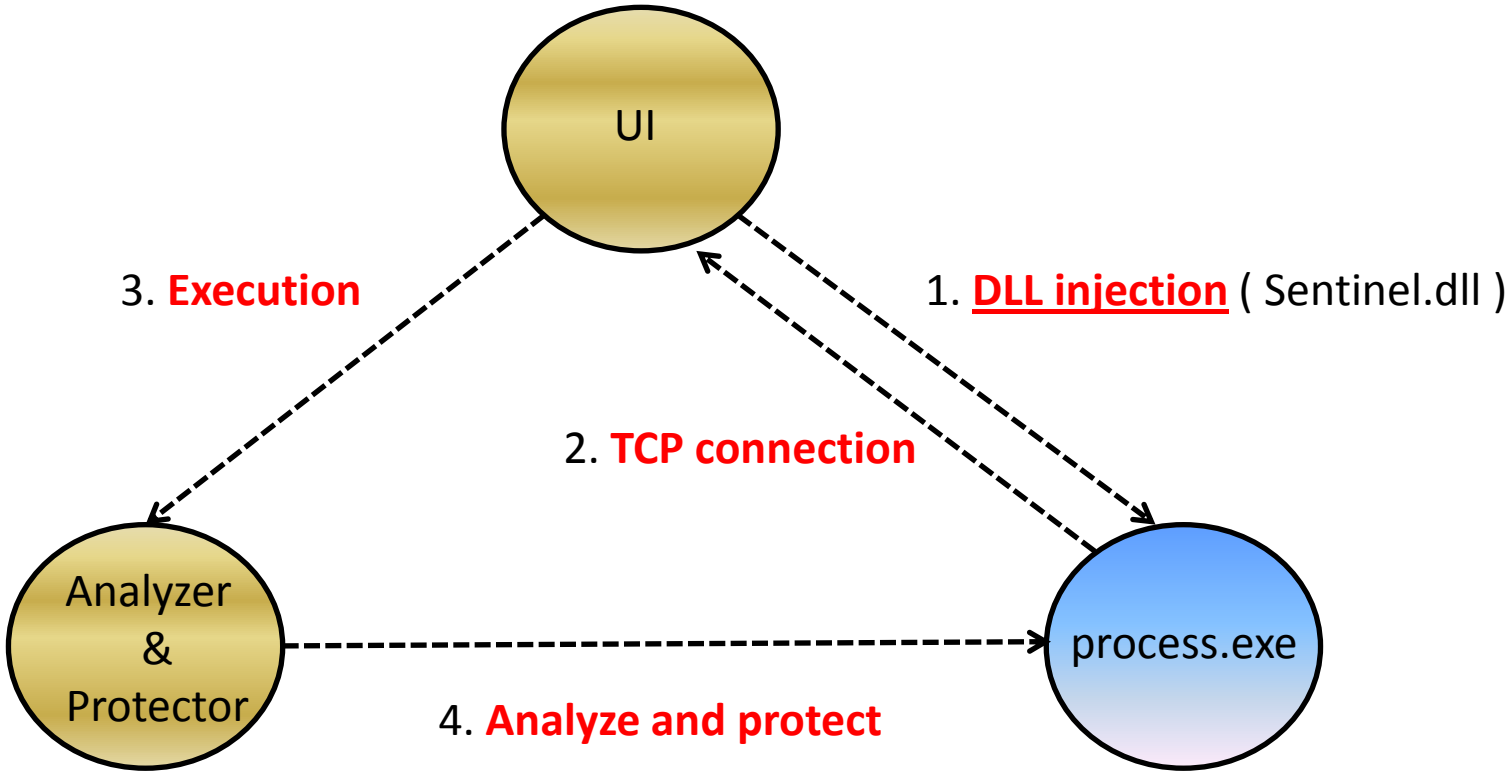
- Written in C/C++/ASM

- Download: http://corelabs.coresecurity.com (find Sentinel)

Similar Projects

- EMET ('Enhanced Mitigation Experience Toolkit')
  - Author: Microsoft
- Anti-Exploit
  - Author: Malwarebytes

Sentinel working scheme



Sentinel analyzer

- Read the process memory
  - Using “ReadProcessMemory” function
- Disassemble the “.text” section
  - Using “Distorm” lib
- Program function detection
  - Identifying **CALLs** to functions
  - Identifying function **prologues**
  - Listing **exported** functions

Sentinel analyzer

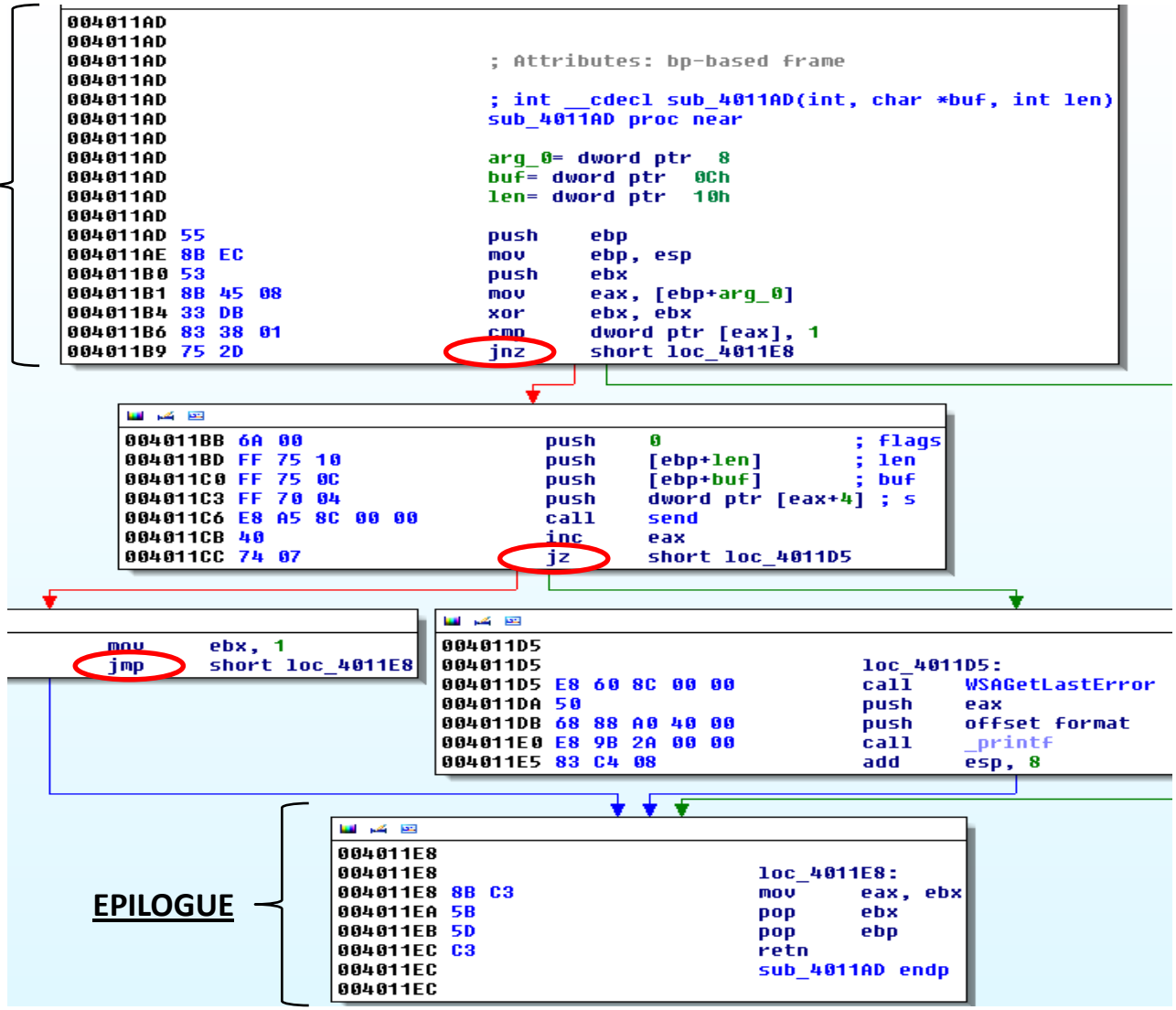
- Function analysis
  - Detect **prologues** and **epilogues**

- Basic block detection:
  - Conditional JUMPs (“je”, “jne”, “jg”, “ja”, etc)
  - Unconditional JUMPs (“jmp”)
  - Jump tables (“jmp [addr+reg*4]”)

Disassembled function

```
004011AD ; int __cdecl sub_4011AD(int, char *buf, int len)
004011AD sub_4011AD      proc near               ; CODE XRE
004011AD                                         ; funcion_
004011AD
004011AD arg_0           = dword ptr  8
004011AD buf             = dword ptr  0Ch
004011AD len             = dword ptr  10h
004011AD
004011AD                 push    ebp
004011AE                 mov     ebp, esp
004011B0                 push    ebx
004011B1                 mov     eax, [ebp+arg_0]
004011B4                 xor     ebx, ebx
004011B6                 cmp     dword ptr [eax], 1
004011B9                 jnz     short loc_4011E8
004011BB                 push    0               ; flags
004011BD                 push    [ebp+len]       ; len
004011C0                 push    [ebp+buf]       ; buf
004011C3                 push    dword ptr [eax+4] ; s
004011C6                 call    send
004011CB                 inc     eax
004011CC                 jz      short loc_4011D5
004011CE                 mov     ebx, 1
004011D3                 jmp     short loc_4011E8
004011D5 ; ---------------------------------------------------------
004011D5
004011D5 loc_4011D5:                            ; CODE XRE
004011D5                 call    WSAGetLastError
004011DA                 push    eax
004011DB                 push    offset format   ; "El codi
004011E0                 call    _printf
004011E5                 add     esp, 8
004011E8
004011E8 loc_4011E8:                            ; CODE XRE
004011E8                                         ; sub_4011
004011E8                 mov     eax, ebx
004011EA                 pop     ebx
004011EB                 pop     ebp
004011EC                 retn
004011EC sub_4011AD      endp
```

Flowchart function



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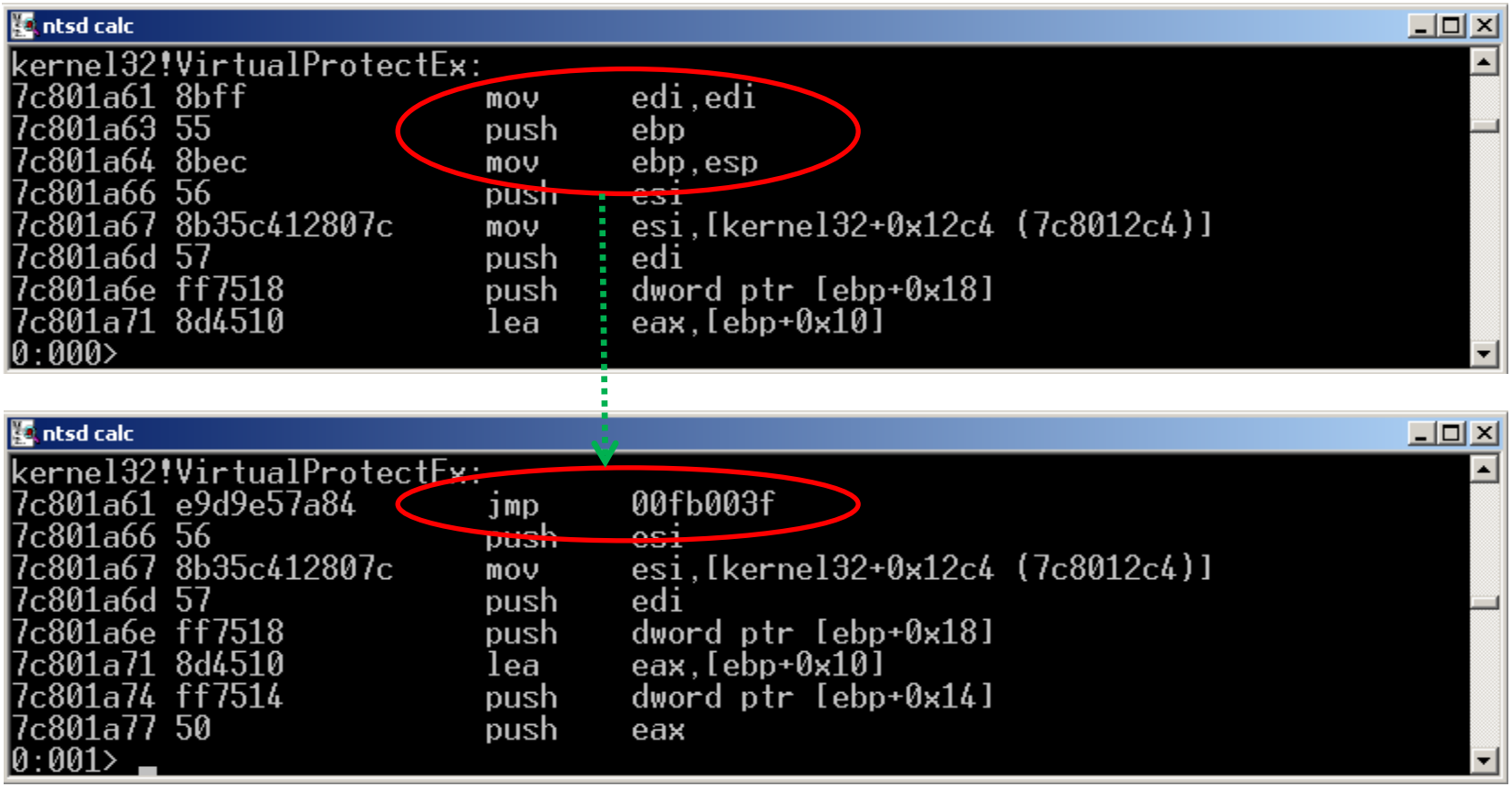
Sentinel protector

- Protect the **chosen** module/modules
  - Using “WriteProcessMemory” function
- Use the analyzer information
- Choose **PATCHABLE** functions
- Create the **STUB** area

Sentinel protector

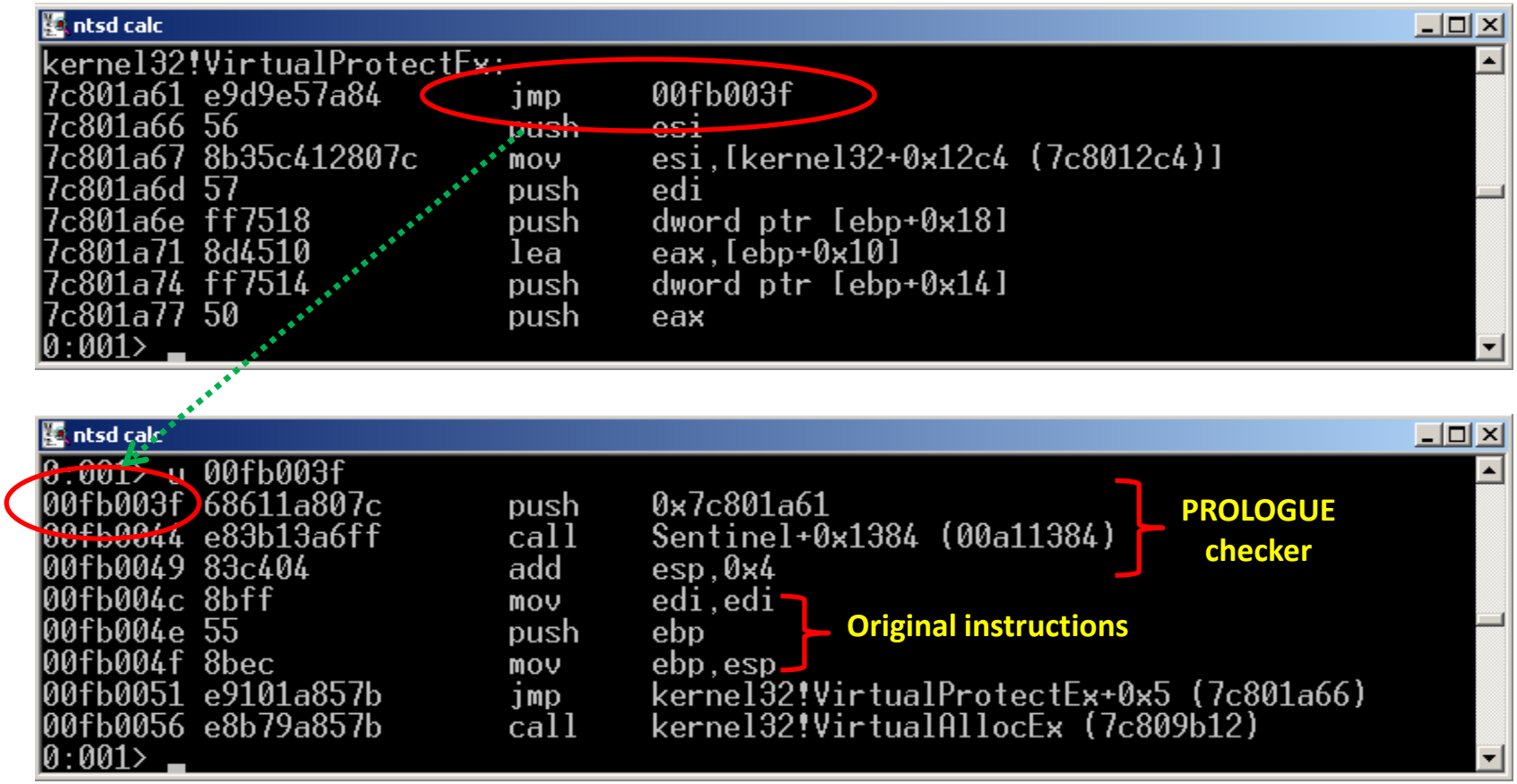
- Patchable function requirements:
  - Prologue >= 5 bytes
  - All Epilogues >= 5 bytes
  - **Shared** epilogues only with **VALID prologues**
  - Epilogues only finishing with "**RET/RET n**" instruction
  - more …

E.g. Patched Prologue



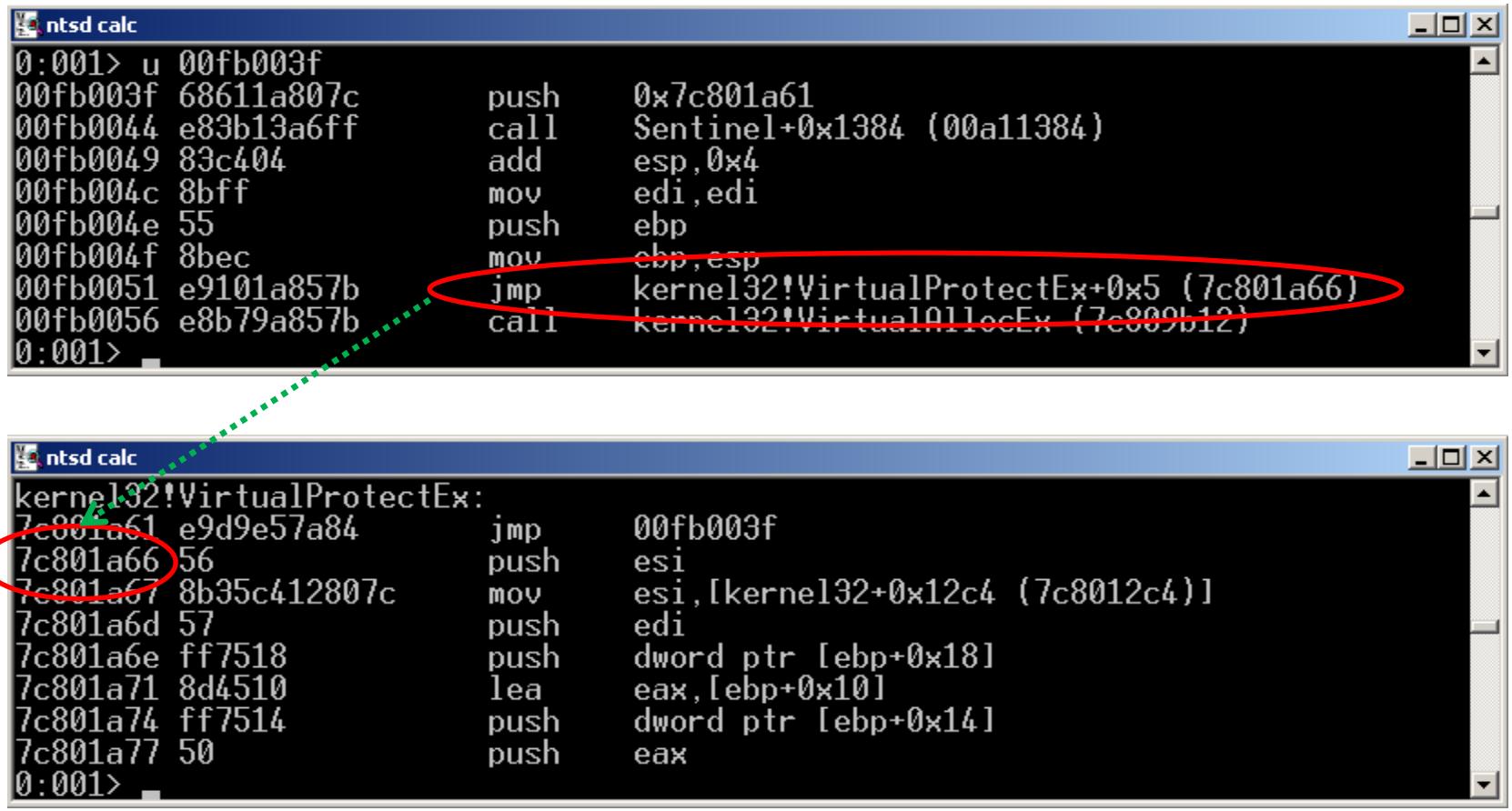
CORE SECURITY

E.g. Patched Prologue



CORE SECURITY

E.g. Patched Prologue



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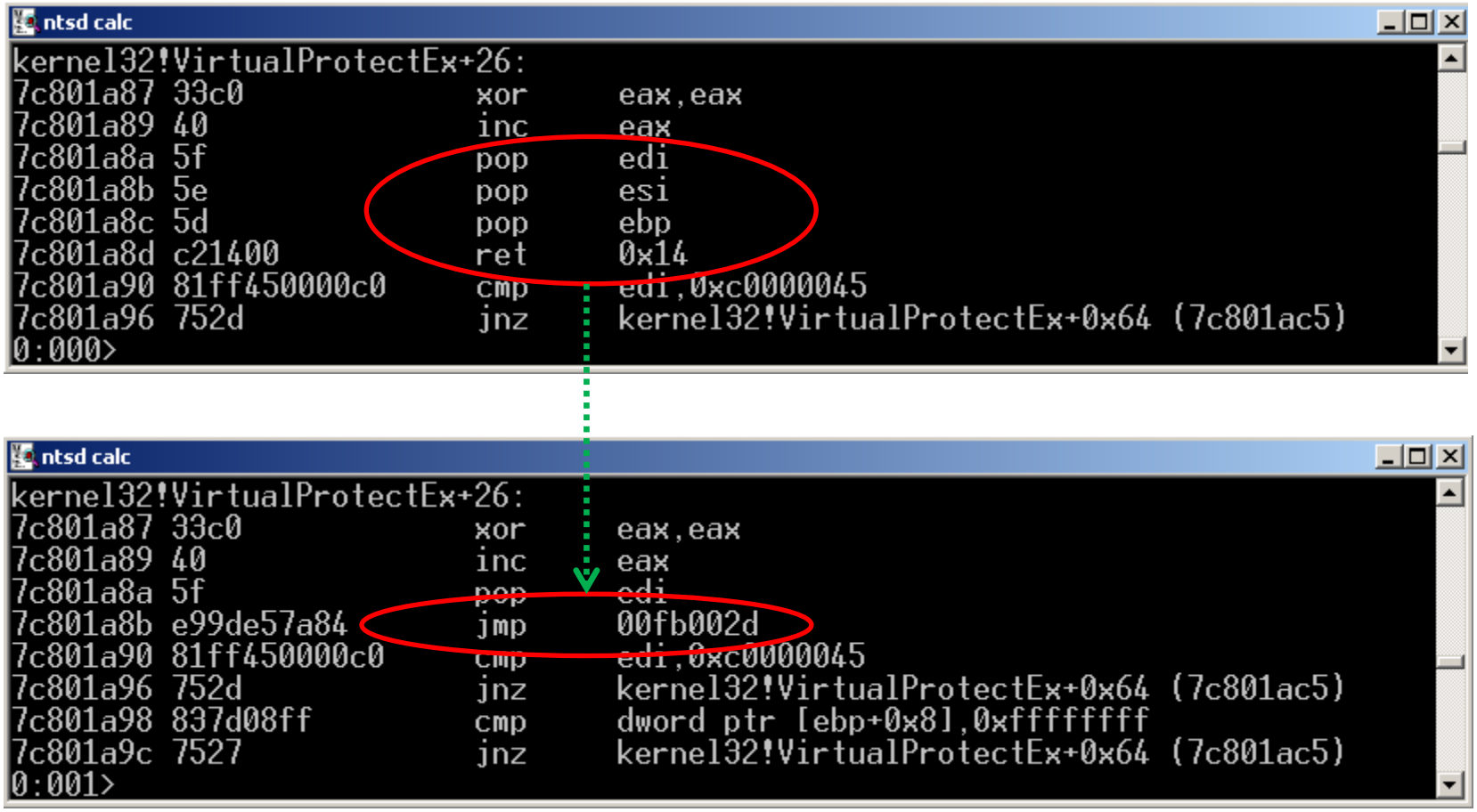
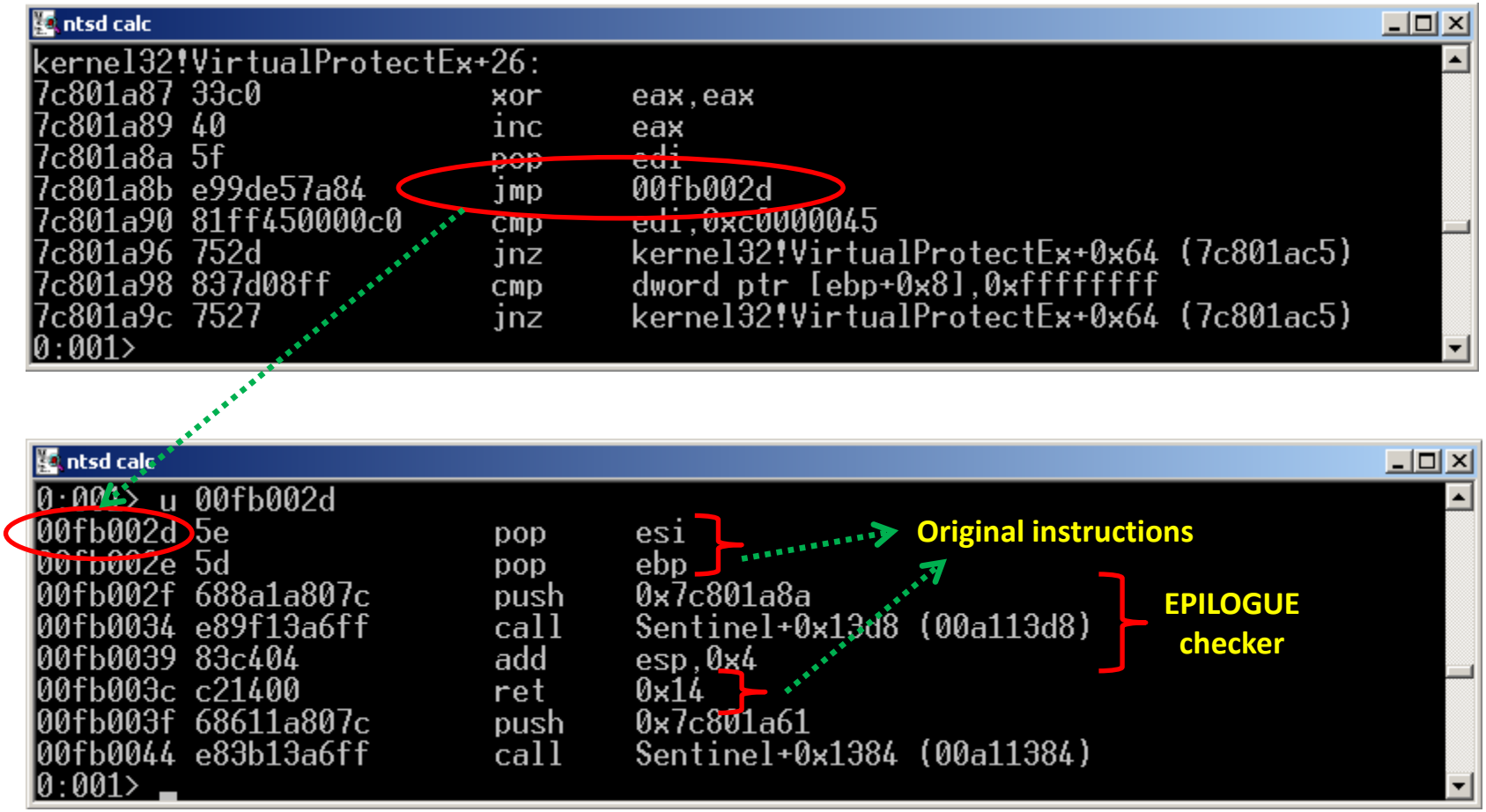
E.g. Patched Epilogue



E.g. Patched Epilogue



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Intercepting exploit attacks

Sentinel check mechanisms

- Parallel STACK
- PARENT CALL checker
- STACK checker
- EPILOGUE replacing …

Mechanism: Parallel STACK

- Inspired on **CANARY** checking

- When a protected function is **called**
  - Some values are **saved** in the function **PROLOGUE**

- When a protected function is **ending**
  - The **saved** values are **compared** with the **CURRENT VALUES** in the **EPILOGUE**

Mechanism: Parallel STACK

- If a **difference** exists, it could be:
  - STACK OVERFLOW
  - MEMORY CORRUPTION
  - **ROP activity !!!!!!!**
  - Problematic functions:
    - “SEH handling”, “canary checks”, “alloca_probe”, etc

Mechanism: Parallel STACK

- Details:
  - Area allocated by **VirtualAlloc**
  - 4 kb per **THREAD** (to be improved)
  - Support up to 256 **logs** (entries)
  - Pointer to the area located in the **TEB**

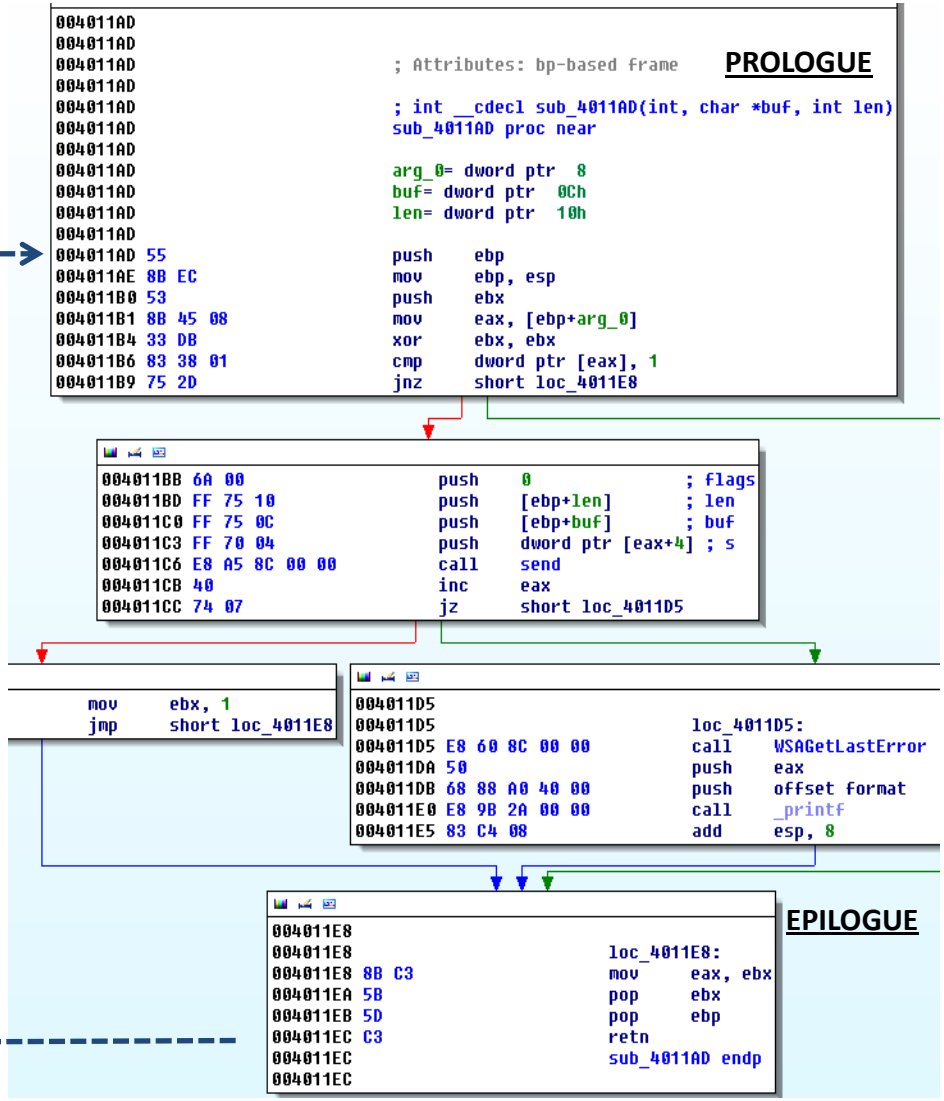
Mechanism: Parallel STACK

- Values to **save** and **check** (entry):
  - **Base pointer** register (EBP)
  - **Stack pointer** register (ESP)
  - **Return address**

Mechanism: Parallel STACK

“call 0x4011ad”

Regular working



“ret caller_function“

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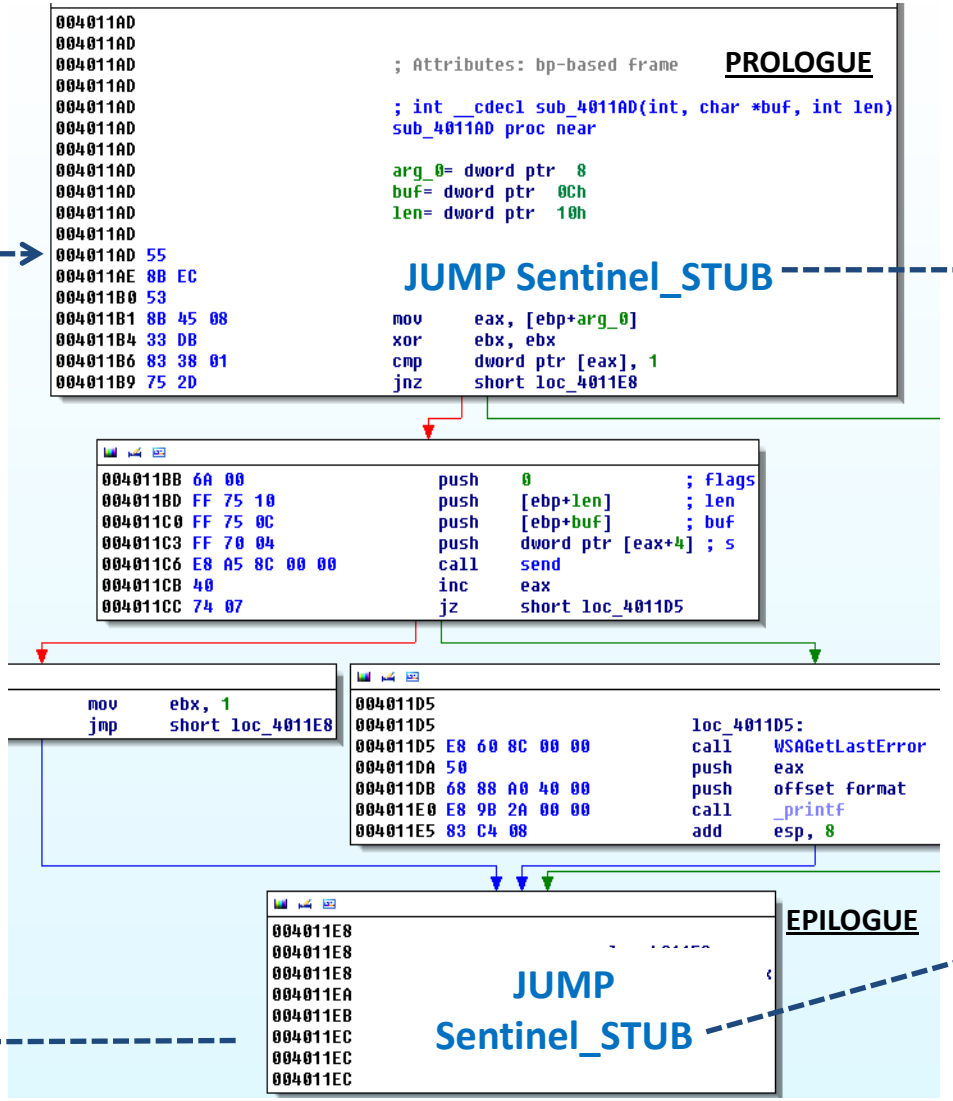
Mechanism: Parallel STACK



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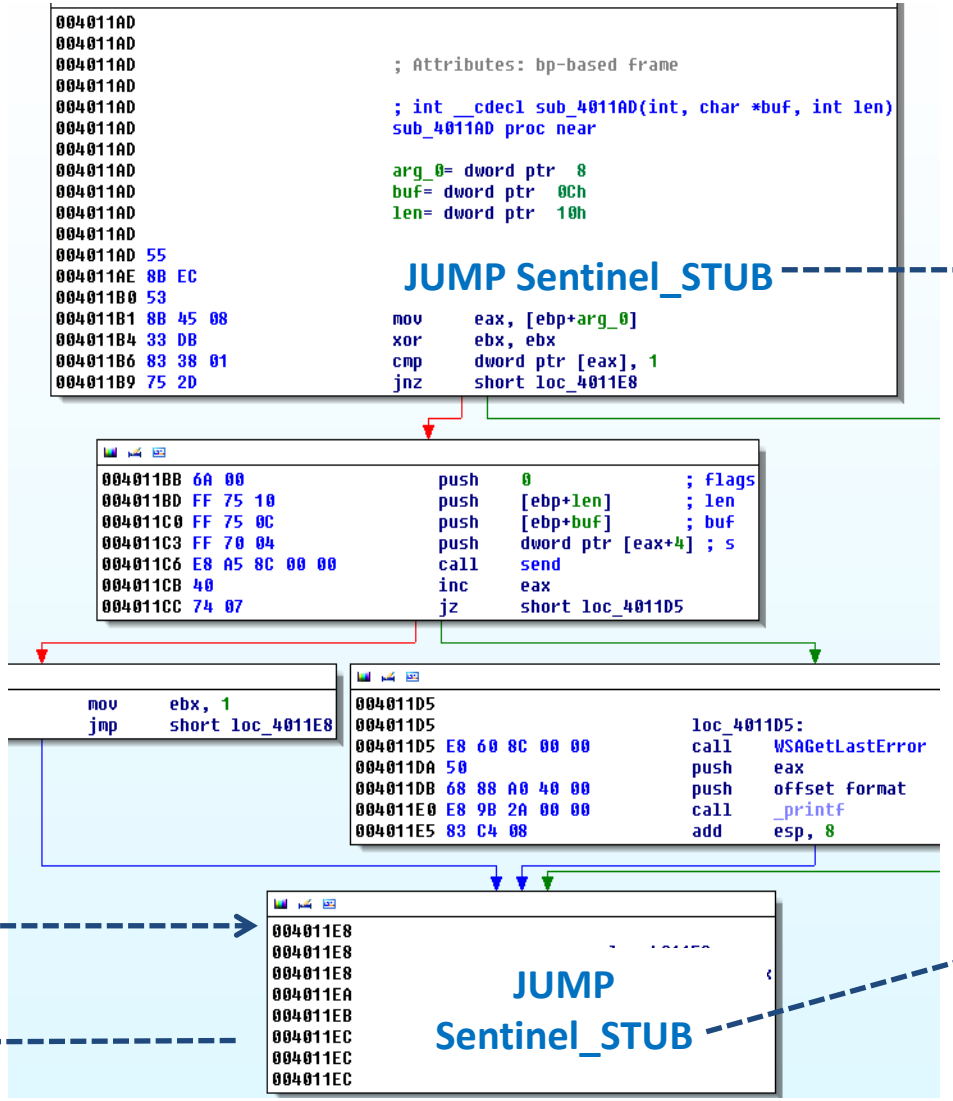
Mechanism: Parallel STACK

With
Sentinel working
&
ROP activity !



NON SAVED VALUES

COMPARE AGAINST WHAT ???

ROP to EPILOGUE

"ret caller_function"

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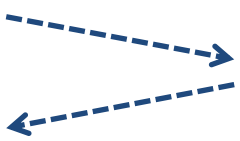
Mechanism: CALLER checker

Caller point of view:

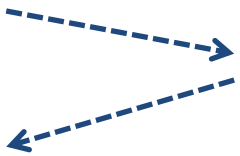
1. "**call** function_A"
2. "mov eax, value"
3. …



function_A ()

Function point of view (like a linked LIST !):

1. "????????????"
2. "mov eax, value"
3. …



function_A ()

Mechanism: CALLER checker

- **Idea:**
  - **Check** if the **CALLER instruction** is **VALID**
- Why ?
  - Usually, **ROP doesn't use CALL instructions**
- Looking **BACK**
  - Using ~~**BRANCH TRACING**~~ (**BlueHat winner !**)
  - Using **CALLER checking** (**BlueHat 2nd !**)

Mechanism: CALLER checker

- Idea:
  - Backwards Disassembling from 2 to 8/9 bytes
- If a **VALID** CALL exists
  - The check is **passed**
- Problems:
  - False positives/negatives
  - Slow down the speed of checking performance

Mechanism: STACK checker

- Stack pivoting:
  - When **ESP** is out of the **VALID STACK RANGE** (check against the TEB)
  - Usually ESP is pointed to the HEAP
  - It’s very common in **browser exploitations**

Mechanism: STACK checker

- Return address checking:
  - **Detect** if the **RETURN ADDRESS** is in the **STACK** (last **ROP** step or stack execution)
- Stack execution prevention:
  - Set **NX** for each intercepted **THREAD** (useful OLD OSs/OLD applications)

Mechanism: Epilogue replacing

- Idea (not implemented yet !):
  - Replace **ALL VALID epilogues** by:
    - A **JUMP** to the rellocated **EPILOGUE**
    - **Fill** the rest of the bytes with **BREAKPOINTS**
    - Check rellocated **EPILOGUES** as well
- When **ROP** is working:
  - A **breakpoint** will be **executed**
  - Or it will **CRASH** (executing a part of the **new JUMP**)

Bypassing ?

- Parallel stack:
  - **ROP** to **OUT OF PHASE** gadgets
- Caller check:
  - **ROP** to **VALID CALL** instructions
  - Return address – 1 inst. = **VALID CALL**
- Stack check:
  - **Not** to **return directly** to the **STACK**
  - **Not** to do **CALLs** from the **STACK**

Bypassing ?

- Stack pivoting:
  - Try to **revert** it and came back to the **VALID STACK** (very tricky !)
- Epilogue replacing:
  - **ROP** to **OUT OF PHASE** gadgets

Demo Time

Demo 1

- **Performance Test**
  - Program: “vlc.exe” (Media player)
- **Adding protections to:**
  - Modules: “vlc.exe”, “kernel32.dll” and “user32.dll”

Demo 2

- **Jumping to 0x41414141:**
  - Program: “bug.exe”
  - Vector: Remote attack
  - Vulnerability: **STACK OVERFLOW**

- **Objective:**
  - Stop the attack protecting “bug.exe” module

Demo 2 bis

- **Bypassing EMET v4.0:**
  - Program: “bug.exe”
  - Vector: Remote attack
  - Vulnerability: **STACK OVERFLOW**

- **Objective:**
  - Execute remotely “calc.exe”

Demo 3

- **Exploiting:**
  - Program: “svchost.exe” (Server service)
  - CVE: 2008-4250
  - Vector: Remote attack
  - Vulnerability: **STACK OVERFLOW**

- **Special comments:**
  - Used by **Win32/Conficker** (WORM)

- **Adding protections to:**
  - Modules: **“acgenral.dll” … ???** (**netapi32.dll** is vuln !)

Demo 4

- **Exploiting:**
  - Program: “Adobe Reader v9.5” (**PDF files**)
  - CVE: 2013-0640 and 2013-0641
  - Vector: Client Side attack (Remote)
  - Vulnerability: **HEAP OVERFLOW**

- **Special comments:**
  - Filename: “Visaform Turkey.pdf”
  - In later versions the **Adobe Sandbox** **protects** the application

- **Adding protections to:**
  - Modules: **only patching critical functions used by exploits !!!**

Demo 5

- **Exploiting:**
  - Program: “Internet Explorer 8.0”
  - CVE: 2013-2551
  - Vector: Client Side attack (Remote)
  - Vulnerability: **USER AFTER FREE**

- **Special comments:**
  - 0-day used in **Pwn2own 2013** competition
  - **Used together** with a **kernel** privilege escalation **exploit**

- **Adding protections to:**
  - Modules: **only patching critical functions used by exploits !!!**

Questions ?