A Brief History of Exploitation Techniques & Mitigations on Windows

By Matt Miller

leviathan security group

Agenda

- Introduction
  - What are exploit mitigations?
- Evolution of exploit mitigations on Windows
  - /GS, SafeSEH, DEP, ASLR
- A look toward the future

Overview

- Software vulnerabilities are common
- Reliable exploitation techniques exist
  - Stack-based buffer overflows
  - Heap overflows (not covered due to time)
- Exploit mitigations act as countermeasures to these techniques

What are exploit mitigations?

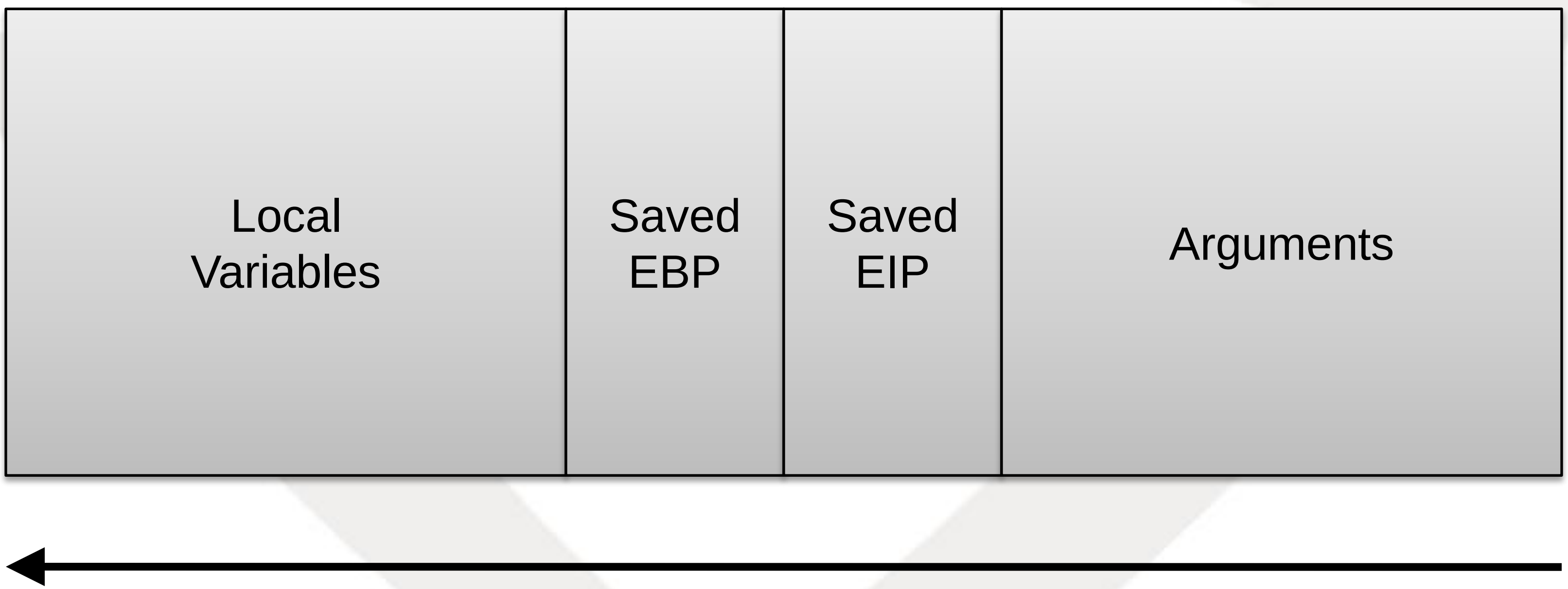
- Prevent or impede exploitation
- Patching the vulnerability
  - The only guaranteed mitigation (if done right)
- Workarounds
  - Disabling the vulnerable service
- Generic mitigations
  - Buffer overflow prevention

Exploit techniques & mitigations

THE LOGICAL EVOLUTION

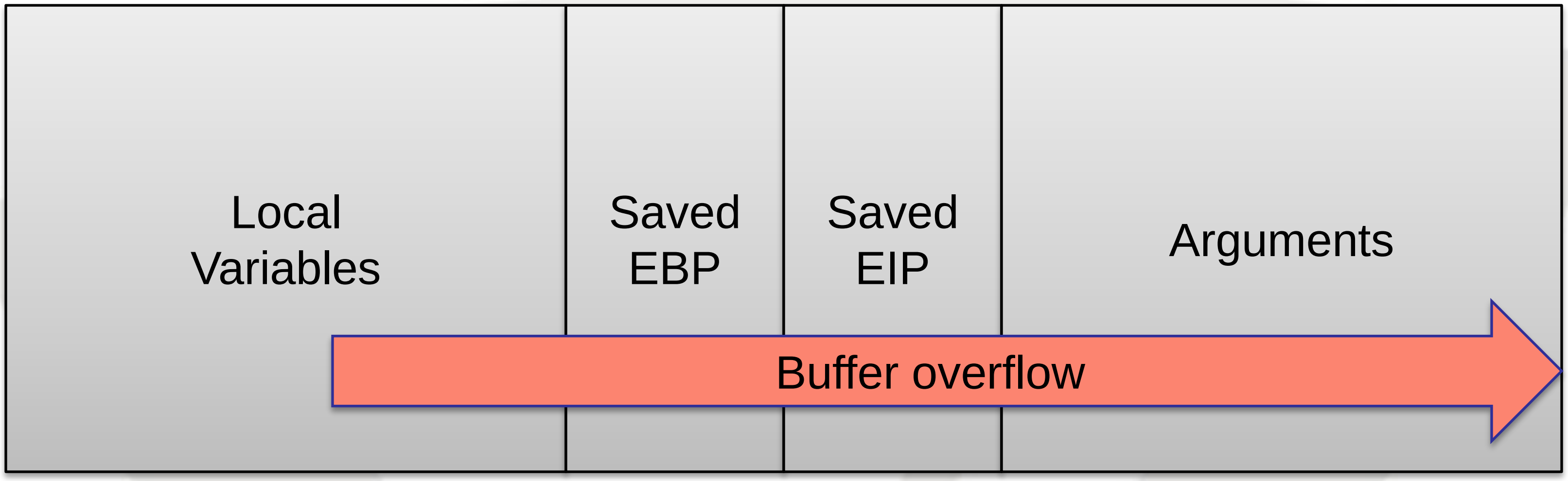
Starting from the beginning

Common structure of an x86 stack frame



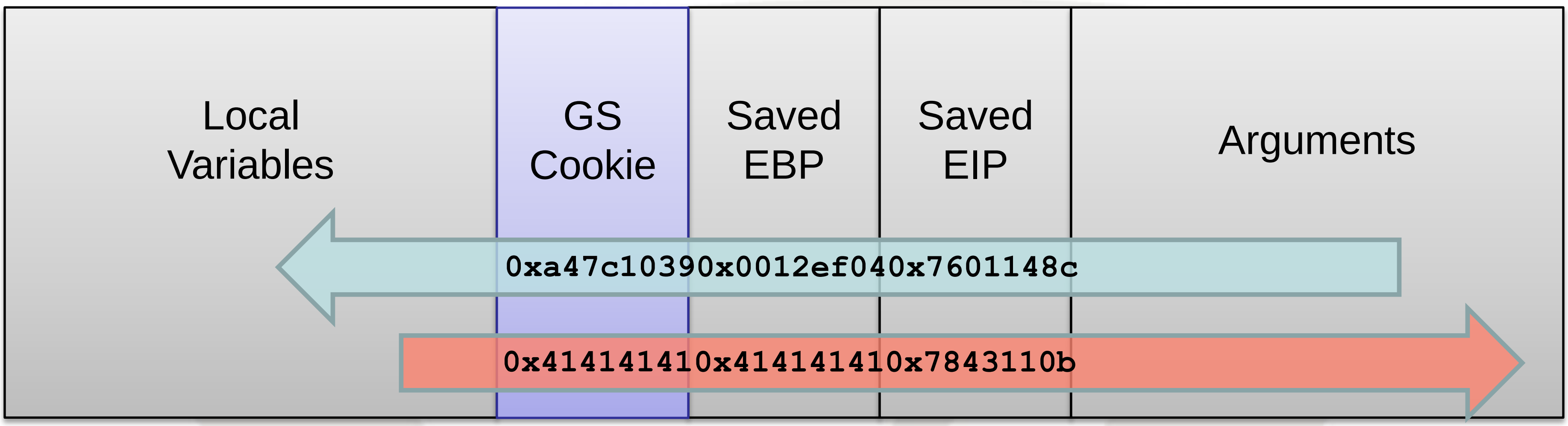
Stack grows toward lower addresses

Exploit: Overwrite saved EIP



- Common stack-based buffer overflow [7]
- Return address is overwritten with address of shellcode

Mitigation: Stack canaries (/GS)



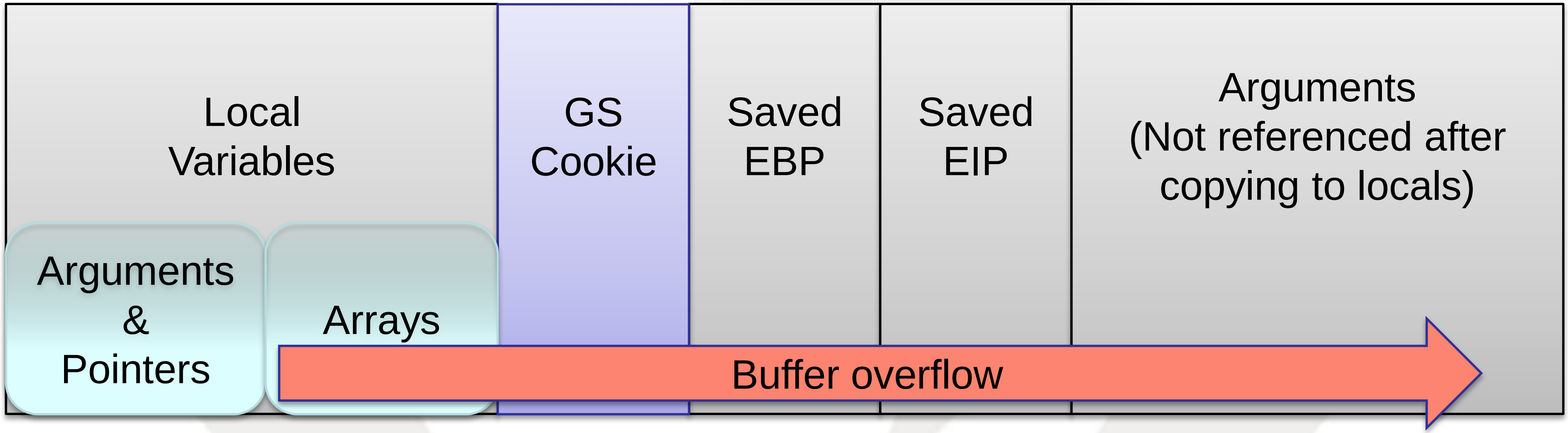
- Compiler change introduced in VS2002 [7]
- Canary is validated before a function returns
- Mismatching canary leads to process termination

Exploit: Overwrite variables

```
void vulnerable(char *in, char *out) {
    char buf[256];
    strcpy(buf, in);    // overflow!
    strcpy(out, buf);   // out is corrupt
    return;             // canary checked
}
```

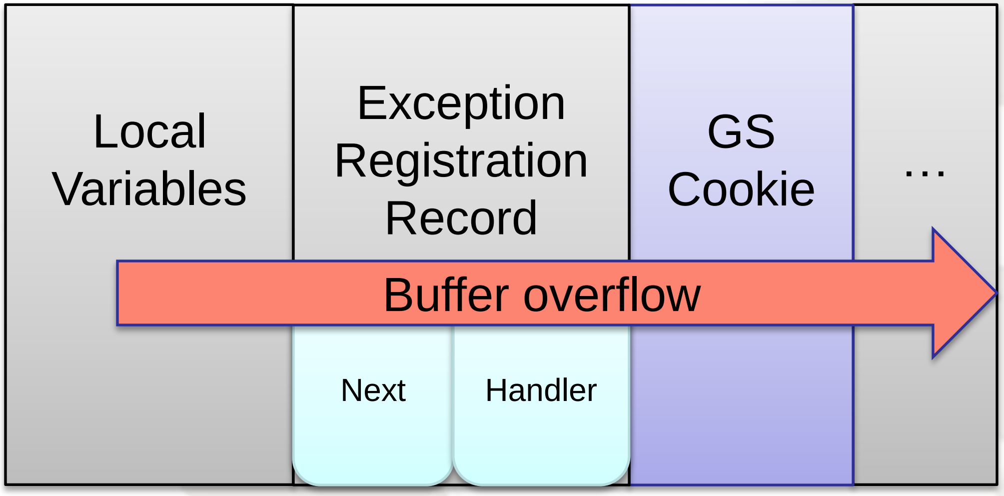
- Canary is only checked at function return
- Corrupt arguments or locals may be used before return
- Attacker could overwrite canary or other memory [2,8]

Mitigation: /GS improvements



- “Safe” copies of arguments made as locals
- Arrays positioned directly adjacent to GS cookie
- Corruption of dangerous locals and arguments is less likely

Exploit: SEH Overwrite



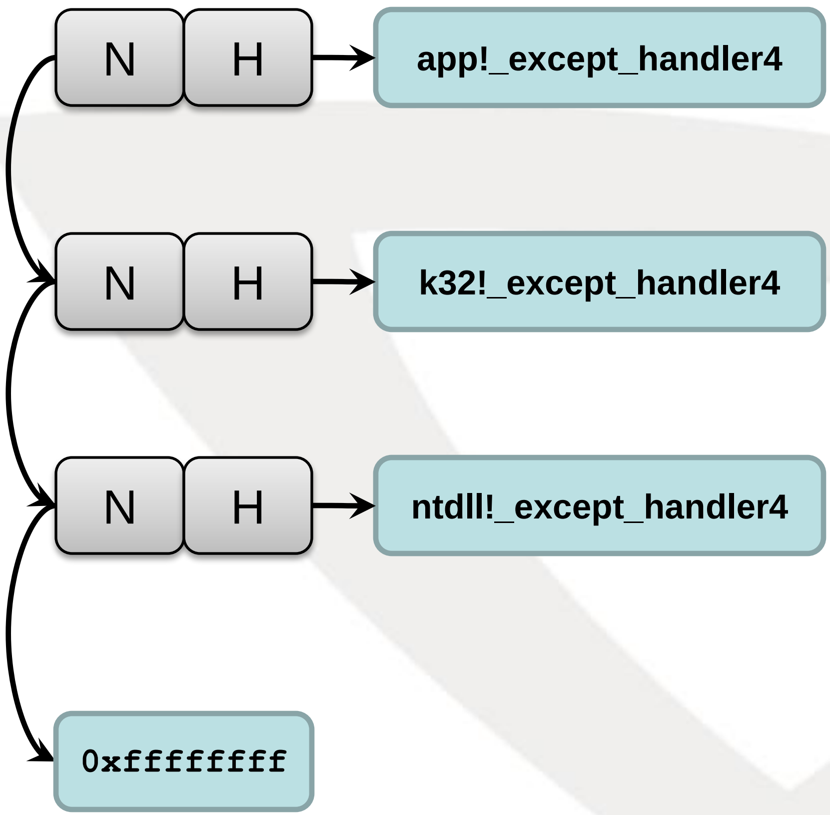

```
void vulnerable(char *ptr){
    char buf[128];
    try {
        strcpy(buf, ptr);
        … exception …
    } except(…) { }
}
```

- *Structured Exception Handler* (SEH) overwrite [1]
  - `Handler` overwritten during overflow
  - Called when an exception is generated

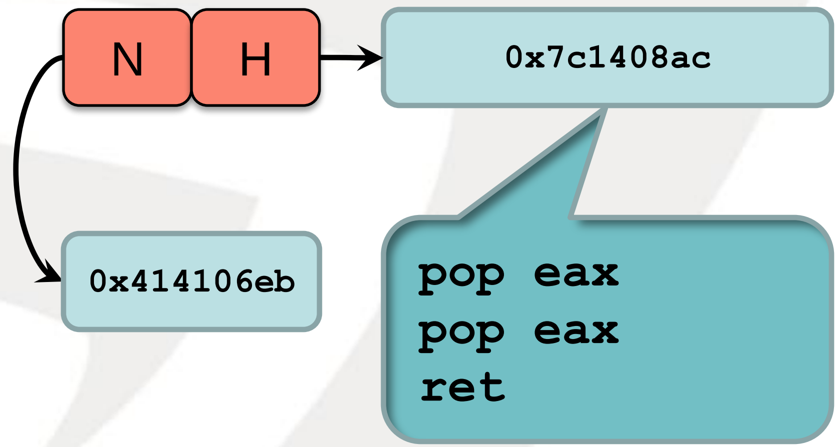
- Exception can be generated before the canary is checked

Exploit: SEH Overwrite (cont'd)

Normal SEH Chain



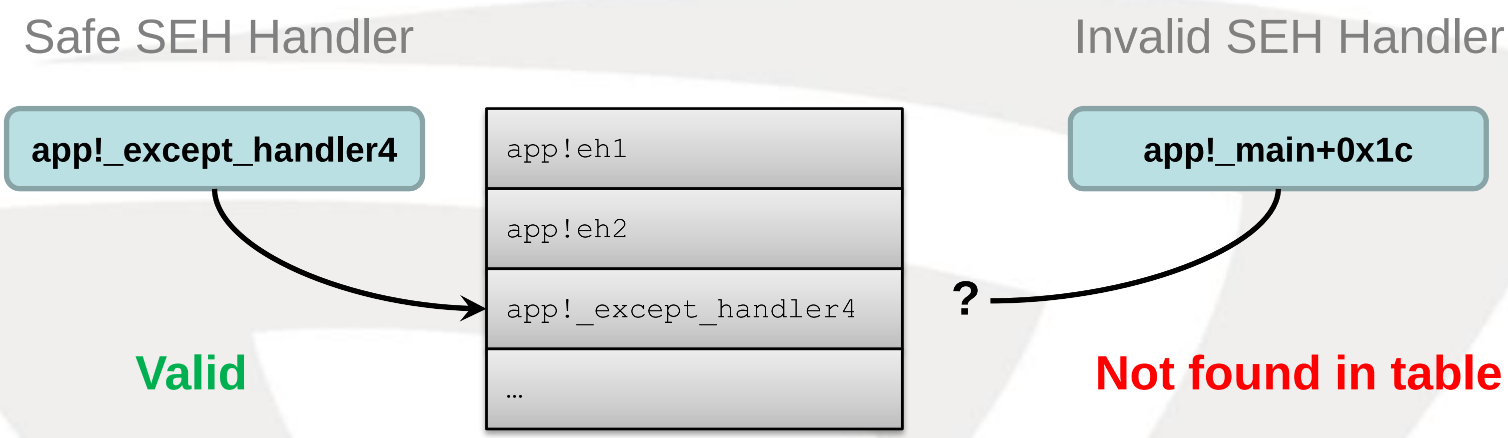
Corrupt SEH Chain



An exception will cause 0x7c1408ac to be called as an exception handler as:

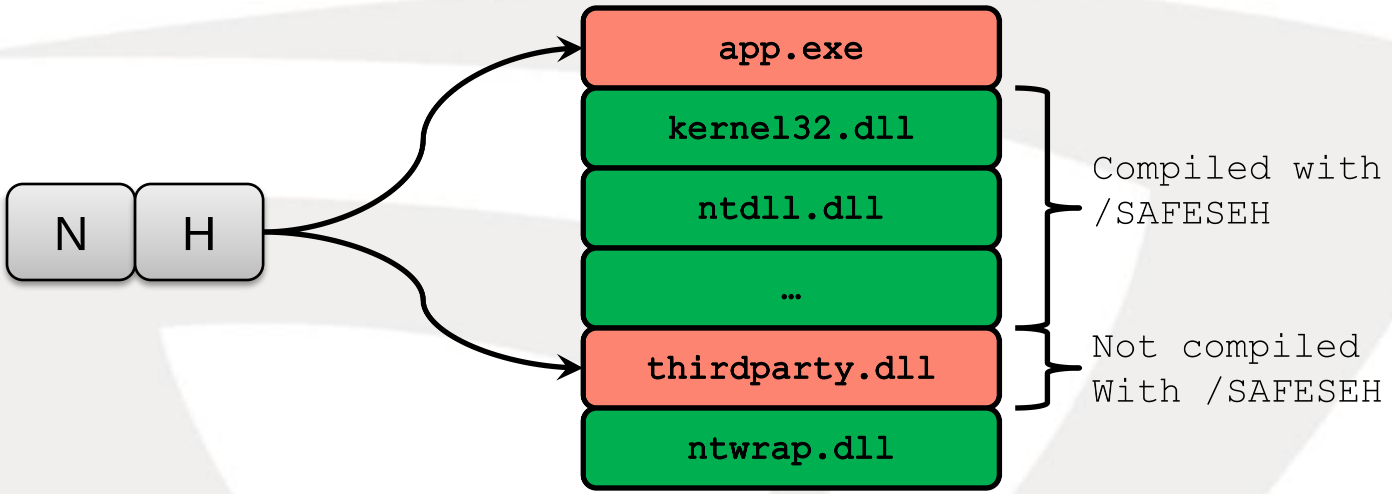
```
EXCEPTION_DISPOSITION Handler(
    PEXCEPTION_RECORD Exception,
    PVOID EstablisherFrame,
    PCONTEXT ContextRecord,
    PVOID DispatcherContext);
```

Mitigation: SafeSEH



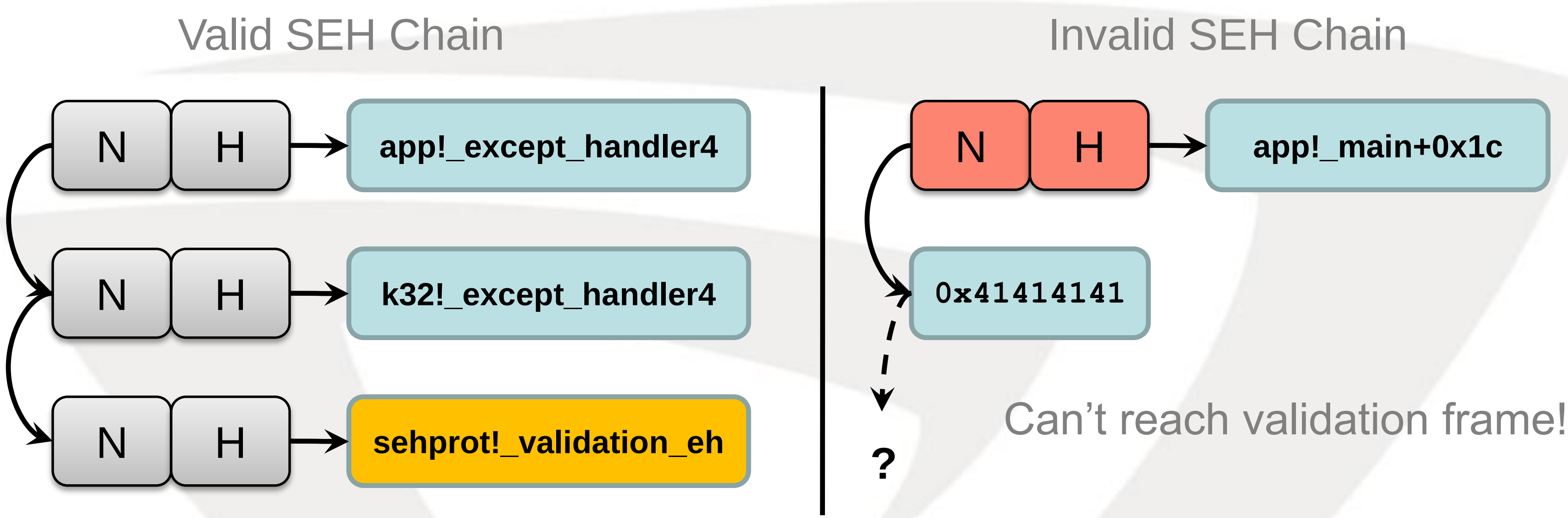
- VS2003 compiler change (/SafeSEH) [9]
- Binaries are compiled with a table of safe exception handlers
- Exception dispatcher checks if handlers are safe before calling

Exploit: SEH Overwrite Part II



- SafeSEH only works if all binaries in a process are compiled with it [4]
- `Handler` can be pointed into a binary that does not have a safe exception handler table

Mitigation: Dynamic SafeSEH

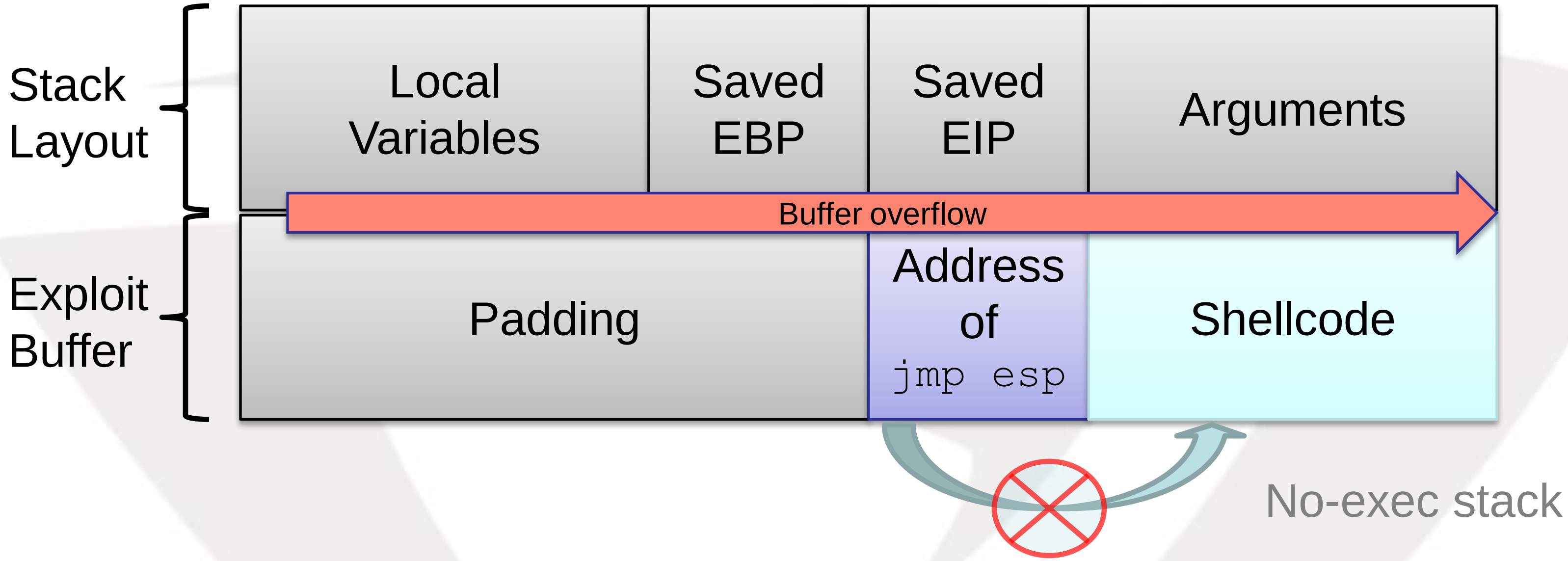


- Dynamic protection against SEH overwrites [4]
  - No compile time hints required
- Symbolic *Validation frame* inserted as final entry in chain
- Corrupt `Next` pointers prevent traversal to validation frame

Recap: GS and SafeSEH

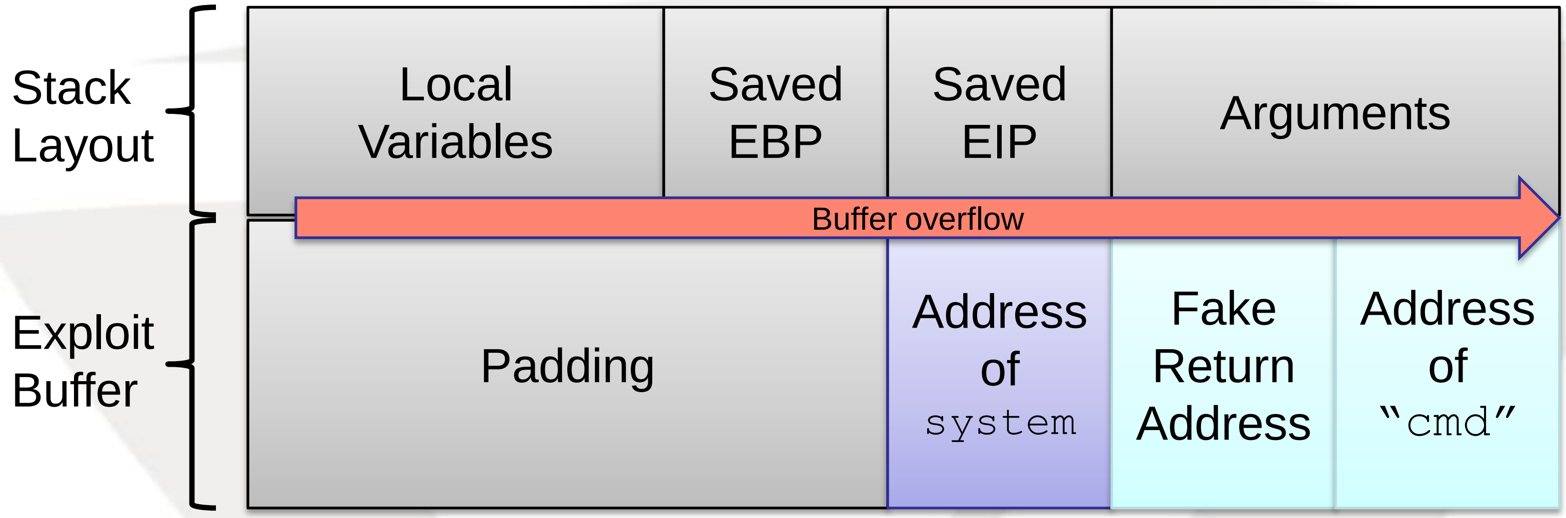
- GS and SafeSEH are solid mitigations for stack-based buffer overflows
- Applications must be recompiled
  - With the exception of dynamic SafeSEH
- Additional runtime mitigations are needed
  - Protection for legacy & 3rd party applications

Mitigation: Hardware DEP (NX)



- Exploits typically attempt to run shellcode stored in writable memory regions [10]
- Enforcing non-executable pages prevents execution of arbitrary shellcode
    - Binary must indicate support, VS2005 sets flag

Exploit: ret2libc



- NX stack and heap prevents arbitrary code execution
- Library code is executable and can be abused [11]
- Example: return into a library function with a fake call frame

Exploit: ret2libc (cont'd)

Address of `VirtualProtect`	Address of `jmp esp`	Address of shellcode	Size of shellcode	RWX	Writable address	shellcode

1 Return from vulnerable function

2 Entry to `VirtualProtect`

3 Return from `VirtualProtect`

- Windows makes extensive use of `stdcall`
  - Caller pushes arguments
  - Callee pops arguments with `retn`
- Allows multiple functions to be chained in ret2libc

Exploit: ret2libc (cont'd)

- Returning to `VirtualProtect` requires the ability to use NULL bytes
  - Often impossible (string-related overflows)

- Windows has an API to disable NX for an entire process
  - `NtSetInformationProcess`[0x22]

- `ntdll` calls this API & we can abuse it [3]

Exploit: NtSetInformationProcess

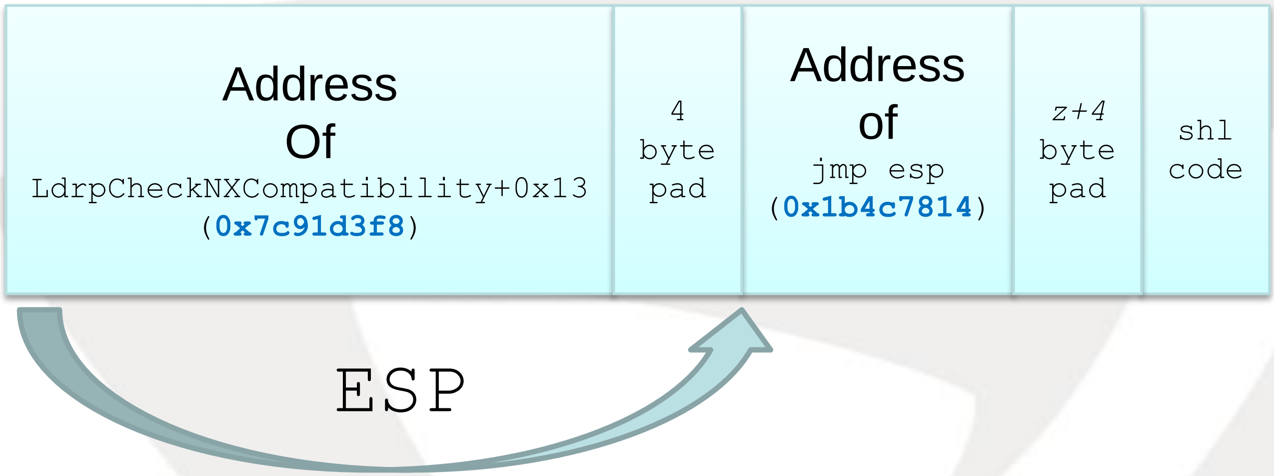
Address of `NtdllOkayToLockRoutine` (**0x7c952080**)	*n* byte pad	Address Of `LdrpCheckNXCompatibility+0x13` (**0x7c91d3f8**)	4 byte pad	Address of `jmp esp` (**0x1b4c7814**)	*z+4* byte pad	shl code

ESP

```
app!vulnerable+0x1c:
104713a4 c20400   retn 4
```

← **Return to** `NtdllOkayToLockRoutine` **and add 4 to esp (*n*=4)**

Exploit: NtSetInformationProcess




```
ntdll!NtdllOkayToLockRoutine:
7c952080 b001     mov al,0x1
7c952082 c20400   ret 0x4
```

← **Set al to 1**

← **Return to** LdrpCheckNxCompatibility+0x13

Exploit: NtSetInformationProcess

Address of jmp esp (0x1b4c7814)	z+4 byte pad	shl code

```
ntdll!LdrpCheckNXCompatibility+0x13:
7c91d3f8 3c01         cmp al,0x1             ← al is equal to 1
7c91d3fa 6a02         push 0x2               ← Set esi to 2
7c91d3fc 5e           pop esi
7c91d3fd 0f84b72a0200 je 7c93feba            ← ZF=1, jump
…
7c93feba 8975fc       mov [ebp-0x4],esi      ← Set [ebp-4] to 0x2
7c93febd e941d5fdff   jmp 7c91d403
…
7c91d403 837dfc00     cmp [ebp-0x4],0x0      ← [ebp-4] is not 0
7c91d407 0f8560890100 jne 7c935d6d           ← ZF=0, jump
```

Exploit: NtSetInformationProcess

Address of jmp esp (0x1b4c7814)	z+4 byte pad	shl code

ESP

```
ZwSetInformationProcess(
  NtCurrentProcess(), ProcessExecuteFlags,
  &ExecuteFlags, sizeof(ULONG));
```

```
7c935d6d 6a04        push 0x4                        ← Length := 4
7c935d6f 8d45fc      lea eax,[ebp-0x4]
7c935d72 50          push eax                        ← &[ebp-4] (0x2)
7c935d73 6a22        push 0x22                       ← ProcessExecuteFlags
7c935d75 6aff        push 0xff                       ← NtCurrentProcess()
7c935d77 e8b188fdff  call ntdll!ZwSetInformationProcess  ← Invoke
7c935d7c e9c076feff  jmp 7c91d441                    ← NX is now disabled
…
7c91d441 5e          pop esi
7c91d442 c9          leave
7c91d443 c20400      ret 0x4                         ← Return to jmp esp then
                                                       jump into shellcode
```

Mitigation: Permanent flag

- Boot flag can force all applications to run with NX enabled (AlwaysOn)[10]
- Processes can prevent future updates to execute flags
  - `NtSetInformationProcess`[22] with flag 0x8
- Does not mitigate return into VirtualProtect

Recap: DEP (NX)

- Memory segments can be marked non-executable with hardware support
  - Stacks, heaps, etc
- Ret2libc can run malicious code without using shellcode
- It can also be used to disable NX and run shellcode
  - `VirtualProtect`
  - `NtSetInformationProcess`

A common thread

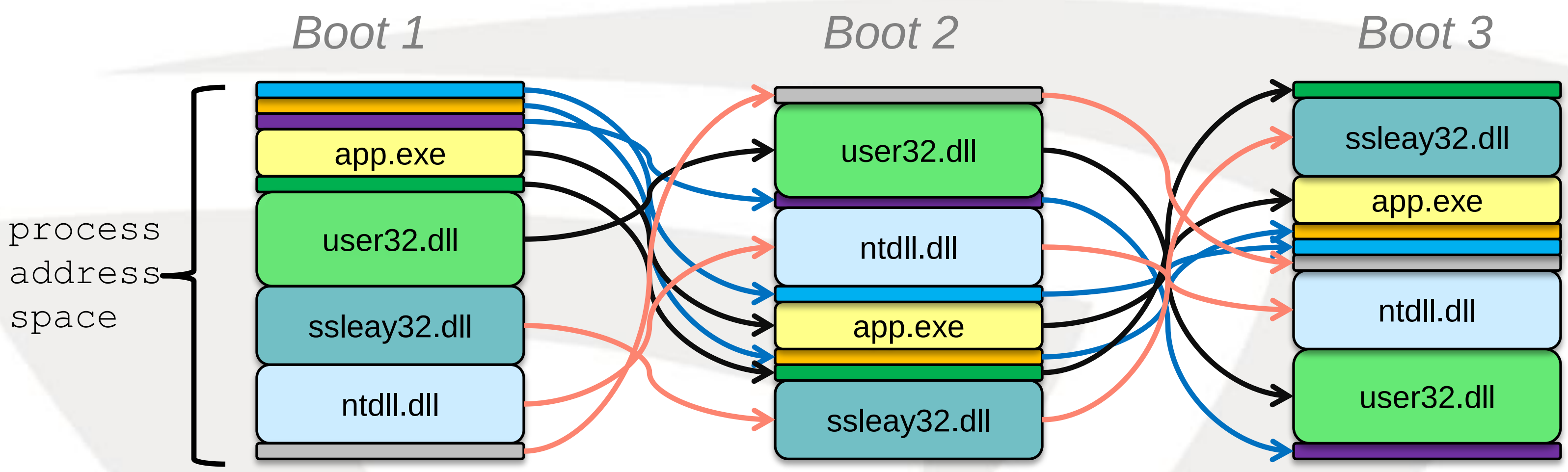
What is common about all of the exploitation techniques discussed so far?

A common thread

- Each technique generally relies on address space knowledge
  - Address used for a return address
  - Address used for an SEH handler
  - Address used for a library routine (ret2libc)

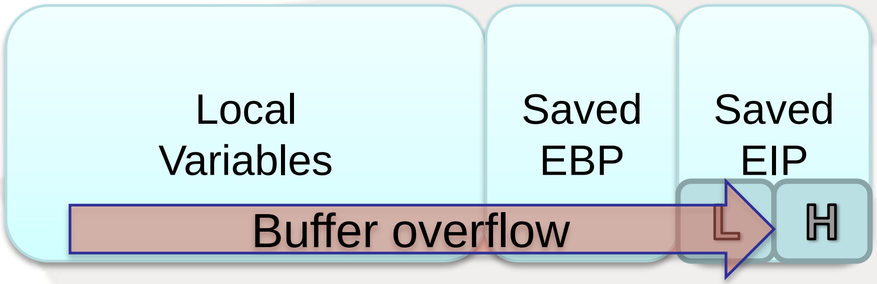
- What if the address space was unpredictable?

Mitigation: ASLR



- *Address Space Layout Randomization* (ASLR) [12]
  - Images must be compiled with */dynamicbase*
- Randomizes memory locations
  - Addresses are no longer predictable

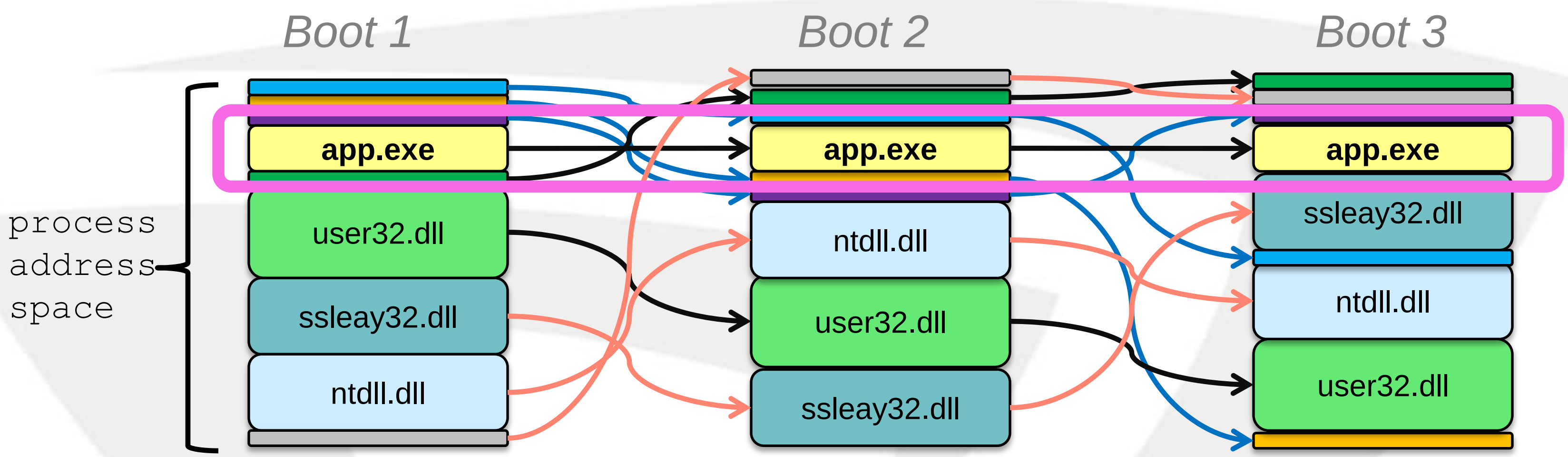
Exploit: Partial overwrite




```
memcpy(
   dest,      ← Stack buf
   src,       ← Controlled
   length);   ← Controlled
```

- Only the high-order two bytes are randomized in image mappings
- Low-order two bytes can be overwritten to return into another location within a mapping
  - Overwriting `0x1446`**`047c`** with `0x1446`**`1846`**
- Target address can be used to pivot

Exploit: non-reloc executables



- Not all binaries are compiled with relocation information
  - Executables often don't have relocations (/fixed:yes)

- ASLR is only effective if all regions are randomized

Exploit: Brute force

- Vista ASLR randomizes most DLLs once per-boot
- Brute forcing addresses may be possible
  - No “forking” daemons in Windows
  - Vista service restart policy limits this
- Not as effective against Windows ASLR in most cases

Exploit: Information disclosure

- Application bugs may leak address space information
- Can be used to construct reliable return addresses
- Knowledge of image file version is all that is needed

Recap: ASLR

- Address space becomes unpredictable
- Exploits cannot assume the location of opcodes and other values
- Still, it has its weaknesses
  - Partial overwrite
  - Brute force
  - Information disclosure

Exploit techniques & mitigations

THE CHRONOLOGICAL EVOLUTION

Chronology on Windows

- Attack: Smashing the stack (Aug, 1996)
- Mitigation: Visual Studio 2002 (Feb, 2002)
  - First release of /GS [7]
- Attack: Overwrite variables [2] (Feb, 2002)
- Attack: SEH Overwrite [1] (Sep, 2003)

Chronology on Windows

- Mitigation: Visual Studio 2003 (Nov, 2003)
  - Arrays placed adjacent to GS cookie
  - /SAFESEH added [9]
- XP SP2 released (Aug, 2004)
  - Windows compiled with /GS and /SAFESEH
  - DEP
- Attack: Bypass NX [3] (Sep, 2005)

Chronology on Windows

- Mitigation: Visual Studio 2005 (Nov, 2005)
  - Arguments copied to safe locals for /GS
- Mitigation: ASLR (Nov, 2006)
  - Included with Windows Vista
  - Attacks against ASLR already existed
- Attack: Weak GS entropy [5] (May, 2007)

Exploit techniques & mitigations

WRAP UP

Looking toward the future

- Vista has formidable mitigations
  - GS, SafeSEH, Heap cookies, DEP, ASLR
- Easily exploitable issues have been found
  - Alexander Sotirov’s write-up on ANI
- Third parties have been slow to adopt
- Unlikely Vista will have a wormable flaw

Questions?

References

[1] Litchfield, David. *Defeating the Stack Based Buffer Overflow Prevention Mechanism of Microsoft Windows 20003 Server.* http://www.ngssoftware.com/papers/defeating-w2k3-stack-protection.pdf.

[2] Ren, Chris et al. *Microsoft Compiler Flaw Technical Note*. http://www.cigital.com/news/index.php?pg=art&artid=70.

[3] skape, Skywing. *Bypassing Windows Hardware-enforced DEP*. http://www.uninformed.org/?v=2&a=4&t=sumry.

[4] skape. *Preventing the Exploitation of SEH Overwrites*. http://www.uninformed.org/?v=5&a=2&t=sumry.

[5] skape. *Reducing the Effective Entropy of GS Cookies*. http://www.uninformed.org/?v=7&a=2&t=sumry.

[6] Aleph1. *Smashing the Stack for Fun and Profit*. http://www.phrack.org/issues.html?issue=49&id=14#article.

[7] Microsoft. */GS Compiler Switch*. http://msdn2.microsoft.com/en-us/library/8dbf701c(VS.80).aspx.

[8] Whitehouse, Ollie. *Analysis of GS Protections in Microsoft Windows Vista.* http://www.symantec.com/avcenter/reference/GS_Protections_in_Vista.pdf.

[9] Microsoft. */SAFESEH Compiler Switch*. http://msdn2.microsoft.com/en-us/library/9a89h429(VS.80).aspx.

[10] Microsoft. *A detailed description of DEP.* http://support.microsoft.com/kb/875352.

[11] Wikipedia. *Return-to-libc attack*. http://en.wikipedia.org/wiki/Return-to-libc_attack.

[12] Wikipedia. *Address Space Layout Randomization (ASLR)*. http://en.wikipedia.org/wiki/ASLR.