CSC 405
Writing Assembly and Binary Patching

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(Slides adapted from Dr. Kapravelos)

The Netwide Assembler (NASM)

```
section .text
  global _start

  _start:
```

As mentioned in our last lecture, Assembly level programs can be broken down into three distinct **sections**

`.text` contains the actual logic of the program

The Netwide Assembler (NASM)

```
section .text
  global _start

  _start:
```

One thing this section also includes is an entry point for where the code actually begins

This is handled with the global **`_start`**

The Netwide Assembler (NASM)

```
section .bss
  ; variables

section .text
  global _start        ; entry point for program

  _start:              ; starting point
```

Next the **block starting symbol** (`.bss`) section stores the variables that may / may not change during the execution of the program

The Netwide Assembler (NASM)

```
section .bss
  ; variables

section .data
  ; constants

section .text
  global _start       ; entry point for program

  _start:             ; starting point
```

Finally, the **.data** section handles constants that will not change

The Netwide Assembler (NASM)

Let's say we want to print "Hello World" in Assembly…

Our first task is to design a **label** for the String

```
section .data
  hello:

section .text
  global _start       ; entry point for program

  _start:             ; starting point
```

The Netwide Assembler (NASM)

We can use **define byte** (or **db**) to define the String into memory

The `10` afterwards refers to the decimal notation for a **new line**
Without a newline character (10) the shell prompt is being displayed immediately after the string

```
section
  hello: db "Hello World\n"

section .text
  global _start       ; entry point for program

  _start:             ; starting point
```

The Netwide Assembler (NASM)

We could have also omitted the **db** command and placed the characters of the String as raw hexadecimal values

```
section
  hello: 48 65 6C 6C 6F 20 57 6F 72 6C 64 0A

secti
  global _start        ; entry point for program

  _start:              ; starting point
```

The Netwide Assembler (NASM)

```
section .bss
  ; variables

section .data
  hello: db "Hello World", 10

section .text
  global _start ; must be declared for linker (ld)

_start:         ; starting point
```

Now it's time to actually print "Hello World"

The Netwide Assembler (NASM)

```
section .data
  hello: db "Hello World", 10

section .text
  g                                    r program
  _start:                    ; starting point
    mov rax, 1               ; sys_write
```

We'll start by moving **1** into the **rax** general register

1 corresponds in Linux to the **sys_write** command

The Netwide Assembler (NASM)

```
section .data
  hello: db "Hello World", 10

section .text
  global _start
_start:
  mov rax, 1        ; sys_write
```

Note, you'll often see `rax`, `eax`, and `ax` but they all refer to the same thing, only with a smaller bit space

rax	64-bit general register
eax	32-bit general register
ax	16-bit general register

The Netwide Assembler (NASM)

```
section .data
  hello: db "Hello World", 10

section .text
  global _start

_start:
  mov rax, 1        ; sys_write
```

Likewise, we can place other integers into rax to execute different system calls

0	sys_read
1	sys_write
2	sys_open
...	...
41	sys_socket
...	...

https://filippo.io/linux-syscall-table/

The Netwide Assembler (NASM)

```
section .data
  hello: db "Hello World", 10

section .text
  g                                          r program
  _start:                    ; starting point
    mov rax, 1               ; sys_write
    mov rdi, 1               ; stdout
```

Then, we'll write **1** to the **rdi** general register

This time, **1** in **rdi** corresponds to the terminal's standard output

The Netwide Assembler (NASM)

```
section .data
  hello: db "Hello World", 10

section .text
  global _start

_start:                 ; starting point
  mov rax, 1            ; sys_write
  mov rdi, 1            ; stdout
```

Since I'm using rax to establish sys_write, rdi can be viewed as the **argument** for sys_write

Arch/ABI	arg1	arg2	arg3	arg4	arg5	arg6	arg7	Notes
alpha	a0	a1	a2	a3	a4	a5	-	
arc	r0	r1	r2	r3	r4	r5	-	
arm/OABI	r0	r1	r2	r3	r4	r5	r6	
arm/EABI	r0	r1	r2	r3	r4	r5	r6	
arm64	x0	x1	x2	x3	x4	x5	-	
blackfin	R0	R1	R2	R3	R4	R5	-	
i386	ebx	ecx	edx	esi	edi	ebp	-	
ia64	out0	out1	out2	out3	out4	out5	-	
loongarch	a0	a1	a2	a3	a4	a5	a6	
m68k	d1	d2	d3	d4	d5	a0	-	
microblaze	r5	r6	r7	r8	r9	r10	-	
mips/o32	a0	a1	a2	a3	-	-	-	1
mips/n32,64	a0	a1	a2	a3	a4	a5	-	
nios2	r4	r5	r6	r7	r8	r9	-	
parisc	r26	r25	r24	r23	r22	r21	-	
powerpc	r3	r4	r5	r6	r7	r8	r9	
powerpc64	r3	r4	r5	r6	r7	r8	-	
riscv	a0	a1	a2	a3	a4	a5	-	
s390	r2	r3	r4	r5	r6	r7	-	
s390x	r2	r3	r4	r5	r6	r7	-	
superh	r4	r5	r6	r7	r0	r1	r2	
sparc/32	o0	o1	o2	o3	o4	o5	-	
sparc/64	o0	o1	o2	o3	o4	o5	-	
tile	R00	R01	R02	R03	R04	R05	-	
x86-64	rdi	rsi	rdx	r10	r8	r9	-	
x32	rdi	rsi	rdx	r10	r8	r9	-	
xtensa	a6	a3	a4	a5	a8	a9	-	

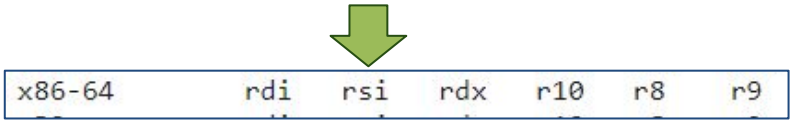
https://man7.org/linux/man-pages/man2/syscall.2.html

The Netwide Assembler (NASM)

```
section .data
  hello: db "Hello World", 10

section .text
  global _start       ; entry point for program
```

Next, we specify the message we intend to write to the terminal by using our label from **.data**




```
  mov r                ; stdout
  mov rsi, hello       ; message to write
```

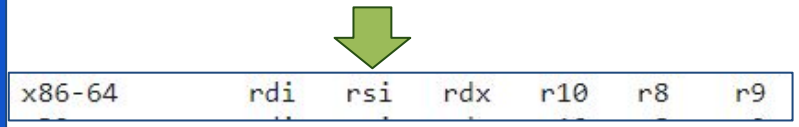
The Netwide Assembler (NASM)

```
section .data
  hello: db "Hello World", 10

section .text
  global  start        ; entry point for program
  mov r                ; stdout
  mov rsi, hello       ; message to write
```

However, Assembly isn't smart enough to know **how much** to print

All we said was **where to start printing from** (remember, variables are simply memory addresses)

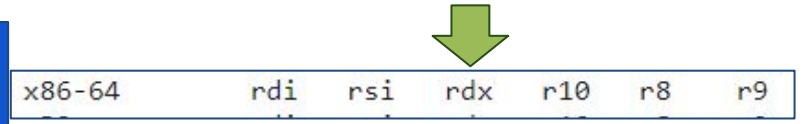


The Netwide Assembler (NASM)

```
section .data
  hello: db "Hello World", 10

section .text
  global _start       ; entry point for program
```

So, we need to specify to the program **how many bytes to read** from the memory address of **`hello`** by giving **`sys_write`** the memory address as a parameter



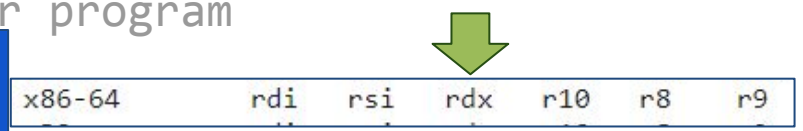

```
    mov r[illegible]ello    ; message to write
    mov rdx, 12             ; message length
```

The Netwide Assembler (NASM)

```
section .data
  hello: db "Hello World", 10
  helloLen: equ $-hello

section .text
  global _start          ; entry point for program
    mov r                ; stdout
    mov rsi, hello       ; message to write
    mov rdx, helloLen    ; message length
```

Some additional witchcraft could be done to calculate the length of a String by referencing the **current memory location** of `hello` (**$**) and calculating its **offset** (length) in memory (**-**)

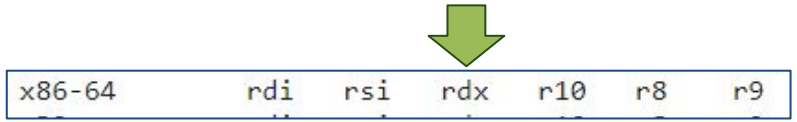


The Netwide Assembler (NASM)

```
section .data
  hello: db "Hello World", 10

section .text
  global _start       ; entry point for program

  _start:             ; starting point
    mov rax, 1        ; sys_write
    mov rdi, 1        ; stdout
    mov rsi, hello    ; message to write
    mov rdx, 12       ; message length
```



We don't need the rest of these registers for our application, but the Linux manual for **`syscall`** also notes where additional parameters can be found

The Netwide Assembler (NASM)

```
section .data
  hello: db "Hello World", 10

section .text
  global _start       ; entry point for program

  _start:             ; starting point
    mov rax, 1        ; sys_write
    mov rdi, 1        ; stdout
    mov rsi, hello    ; message to write
    mov rdx, 12       ; message length
    syscall           ; execute rax
```

Now that we've loaded everything needed into memory, we can finally tell the CPU to call `sys_write`

The Netwide Assembler (NASM)

```
_start:                 ; starting point
   mov rax, 1           ; sys_write
   mov rdi, 1           ; stdout
   mov rsi, hello       ; message to write
   mov rdx, 12          ; message length
   syscall              ; execute rax

   mov rax, 60          ; sys_exit
   mov rdi, 0           ; error code 0 (success)
   syscall              ; execute rax
```

This last bit of instruction is to "correctly" end our program, because the CPU expects a **sys_exit** system call

“Compiling” Assembly

Similar to other languages, Assembly needs to be translated into machine code

```
> nasm -f elf64 hello.asm
```

We can use NASM to generate our 64-bit binary (In `elf` format specifically, we'll talk more about it next lecture)

We need to do one final task: **link** our binary to an executable file

```
> ld -o hello hello.o
> ./hello
Hello World
```

~~The Netwide~~ GNU Assembler (GAS)

```
.data
  hello: .string "Hello World\n"

.text
.global _start          # entry point for program

  _start:               # starting point
    mov $1,      %rax   # sys_write
    mov $1,      %rdi   # stdout
    mov $hello,  %rsi   # message to write
    mov $12,     %rdx   # message length
    syscall             # execute rax

    mov $60,     %rax   # sys_exit
    mov $0,      %rdi   # error code 0 (success)
    syscall             # execute rax
```

Now in AT&T (Linux format)!

“Compiling” Assembly

If we're using AT&T syntax then NASM won't work!

However, we can utilize **`gcc`** to do the exact same thing

```
> gcc -c -no-pie hello.s -o hello.o
> ld -o hello hello.o
> ./hello
Hello World
```

`-c` = generate an object, but don't link

`-no-pie` = disable Position Independent Executable (PIE), which is a security feature that randomizes the base address of the program

In-class practice / Tooling check

- Write and assemble (compile) an x86 “Hello, World” binary
  - Ensure you have the right Linux setup
- What happens if you pass a 0 for $RSI?
- What happens if you pass a value greater than 12?
- How could you bypass the need to have a data section?

NR	syscall name	references	%rax	arg0 (%rdi)	arg1 (%rsi)	arg2 (%rdx)	arg3 (%r10)	arg4 (%r8)	arg5 (%r9)
1	write	man/ cs/	0x01	unsigned int fd	const char *buf	size_t count	-	-	-
60	exit	man/ cs/	0x3c	int error_code	-	-	-	-	-
62	kill	man/ cs/	0x3e	pid_t pid	int sig	-	-	-	-

In-class practice / Tooling check

- Write and assemble (compile) an x86 “Hello, World” binary
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  - Nothing. You could figure this out by looking at the source code but this is way easier!
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- What happens if you pass a value greater than 12?
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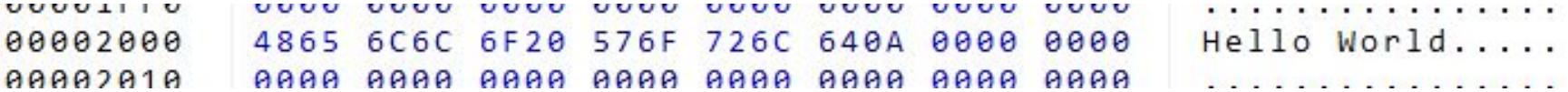
- How could you bypass the need to have a data section?
  - Put things on the stack!
  - Put things in the code!

Changing the World

Whether you used Intel or AT&T syntax, the end result is the same: a binary object that stores "Hello World" in binary




```
hello: 48 65 6C 6C 6F 20 57 6F 72 6C 64 0A
```

Changing the World

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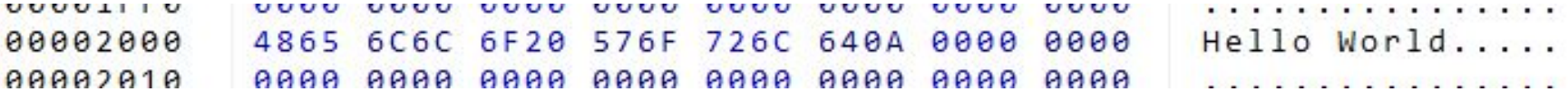


```
hello: 48 65 6C 6C 6F 20 57 6F 72 6C 64 0A
```

But that also means if we change this section in memory, we can **~change the world~**

Changing the World

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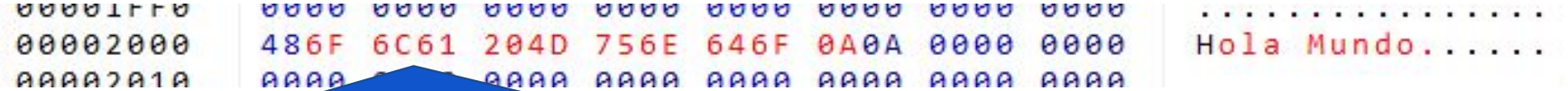
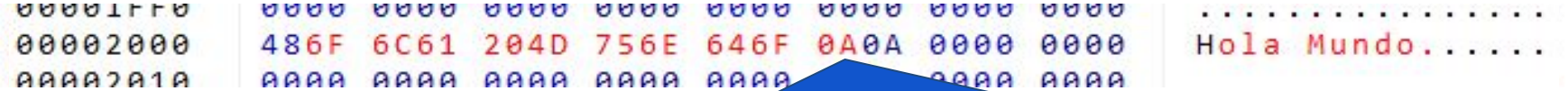


By directly manipulating the binary, we can replace "Hello World" with any text that fits into 12 bytes

Changing the World

Whether you used Intel or AT&T syntax, the end result is the same: a binary object that stores "Hello World" in binary



Note "Hola Mundo" is only 10 characters, so I also injected another new line character into the code

In-class practice

- You can use HexEd.it to patch binaries in your browser!
  - Go to https://go.ncsu.edu/csc405-s26-02
  - Try out changing “Hello World” with `./hello`
  - Get `./check` to print “Access Granted”

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    - Change Access Denied to Access Granted
    - Fix the bug of not having a null-terminated string

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    - Bypass the check! `75 27 (jne)` → `90 90 (nop nop)`

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    - Fix the bug of not having a null-terminated string
    - Bypass the check! `75 27 (jne)` → `90 90 (nop nop)`

```
alex@mithrun ~/A/c/02-assembly (main)> chmod +x check_nop
alex@mithrun ~/A/c/02-assembly (main)> ./check_nop
Enter password: isajdfoaisjdofijasdoifj
Access granted!
alex@mithrun ~/A/c/02-assembly (main)>
```

Ensuring Program Integrity

This leads to a new question:

How do I ensure a program has not been tampered with?

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We can calculate a **checksum** of the program's original binary

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```
> sha256sum hello
6688884c7518fb722e560c2b29866c5bbf97228e10d98966cd17fa4470da224c  hello
– or –
> md5sum hello
5c0499e5aec8b99a22e4723cbdc5c199  hello
```

We can then save this checksum to always ensure the program has not been tampered with

Ensuring Program Integrity

This leads to a new question:

How do I ensure a program has not been tampered with?

Answer:

We can calculate a **checksum** of the program's original binary

```
> sha256sum hello
6688884c7518fb722e560c2b29866c5bbf97228e10d98966cd17fa4470da224c  hello
— We edit the hello binary —
> sha256sum hello
6c2ff4ed235045a645f188630ac59ca3e826a94e0468b2f1896d6fe85ac350a6  hello
```

Security Zen - World's First MIDI Shellcode

https://psi3.ru/blog/swl01u/