CSC 405
Writing Assembly and Binary Patching

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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**

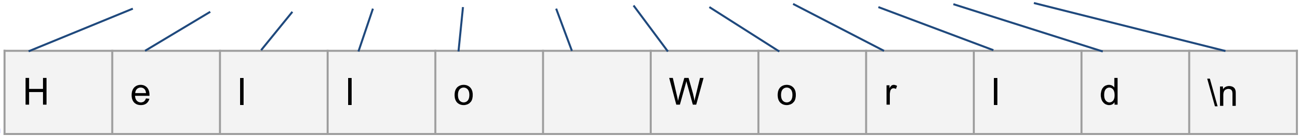
Without a newline character (10) the shell prompt is being displayed immediately after the string

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

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
                 oint for program

  _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
  g                                   progra

  _start:                   ; starting point
    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
  g                                  progra

  _start:                  ; starting point
    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
```

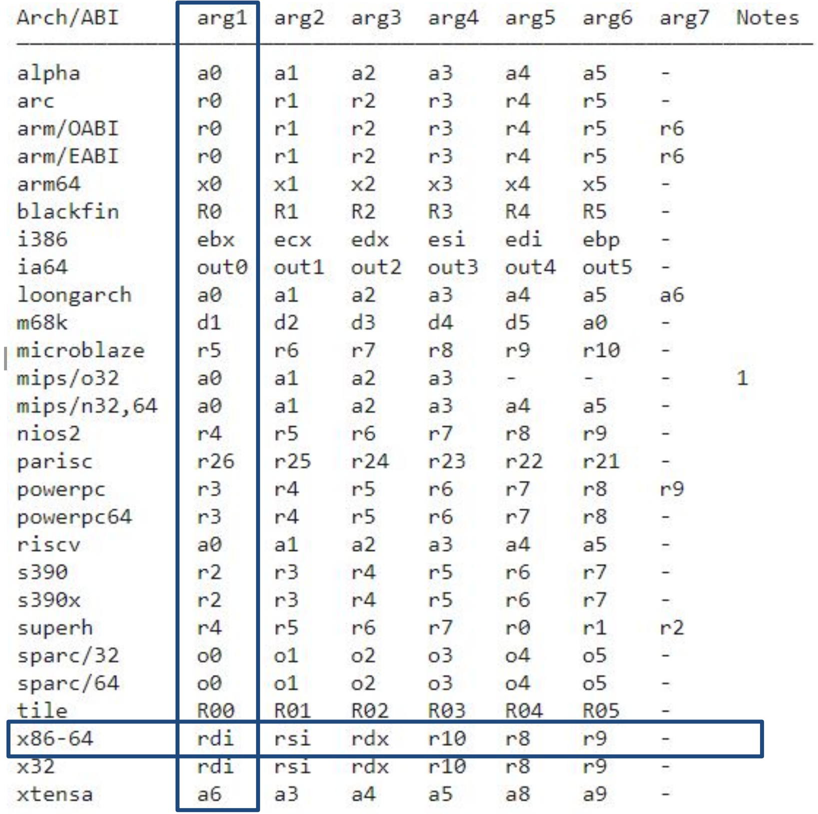
Then, we'll write **`1`** to the **`rdi`** general register

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
   g

   _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`



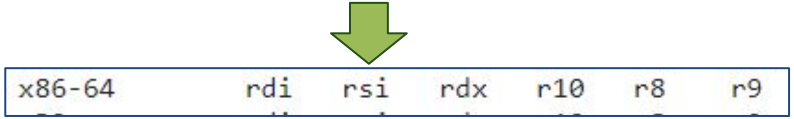
Arch/ABI	arg1	arg2	arg3	arg4	arg5	arg6	arg7	Notes
alpha	a0	a1	a2	a3	a4	a5	-	
arc	r0	r1	r2	r3	r4	r5	-	
arm/OABI	r0	r1	r2	r3	r4	r5	r6	
arm/EABI	r0	r1	r2	r3	r4	r5	r6	
arm64	x0	x1	x2	x3	x4	x5	-	
blackfin	R0	R1	R2	R3	R4	R5	-	
i386	ebx	ecx	edx	esi	edi	ebp	-	
ia64	out0	out1	out2	out3	out4	out5	-	
loongarch	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

  _

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

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



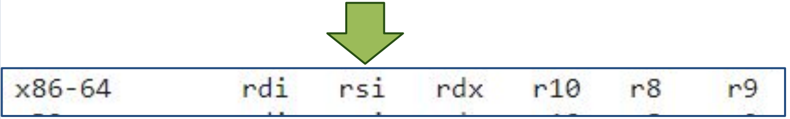
x86-64	rdi	rsi	rdx	r10	r8	r9

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)

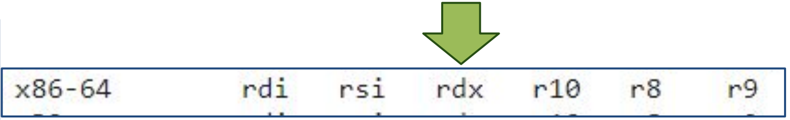


x86-64	rdi	rsi	rdx	r10	r8	r9

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



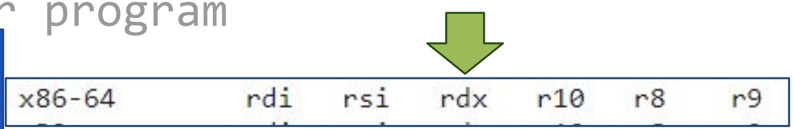
x86-64	rdi	rsi	rdx	r10	r8	r9

```
    mov        ello    ; message to write
    mov rdx, 12        ; message length
```

The Netwide Assembler (NASM)

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

sectio    text
   glob     start        ; entry point for program

    mov r               ; stdout
    mov rsi,   llo      ; message to write
    mov rdx, helloLen; message length
```

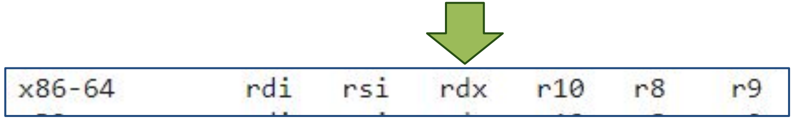
Some additional witchcraft could be done to calculate the length of a String by referencing the **current memory location** of `hello` (**$**) and calculating its **offset** (length) in memory (**-**)



x86-64	rdi	rsi	rdx	r10	r8	r9

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
```



x86-64	rdi	rsi	rdx	r10	r8	r9

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 Assembler (NASM)

```
.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

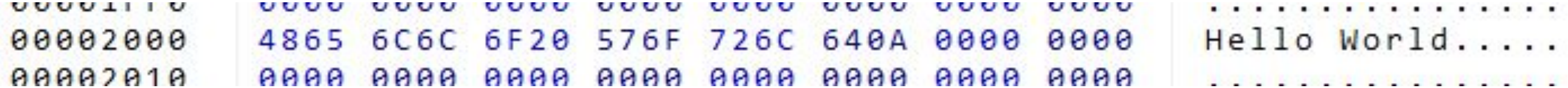
```
> gcc -c -no-pie hello.s -o hello.o
> ld -o hello hello.o
> ./hello
Hello World
```

`-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

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

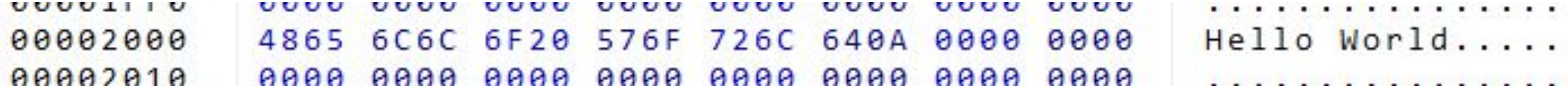


```
00002000    4865 6C6C 6F20 576F 726C 640A 0000 0000    Hello World.....
00002010    0000 0000 0000 0000 0000 0000 0000 0000    ................
```

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

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



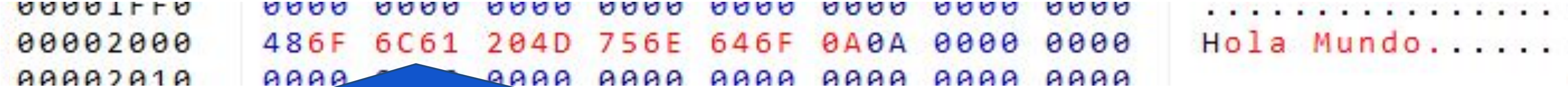
```
00002000    4865 6C6C 6F20 576F 726C 640A 0000 0000    Hello World.....
00002010    0000 0000 0000 0000 0000 0000 0000 0000    ................
```

```
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

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



```
00002000    486F 6C61 204D 756E 646F 0A0A 0000 0000    Hola Mundo......
```

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

```
00002000    486F 6C61 204D 756E 646F 0A0A 0000 0000    Hola Mundo......
```

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

Ensuring Program Integrity

This leads to a new question:

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

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Answer:

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

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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
— 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
```