(Re)introduction to x86 Assembly

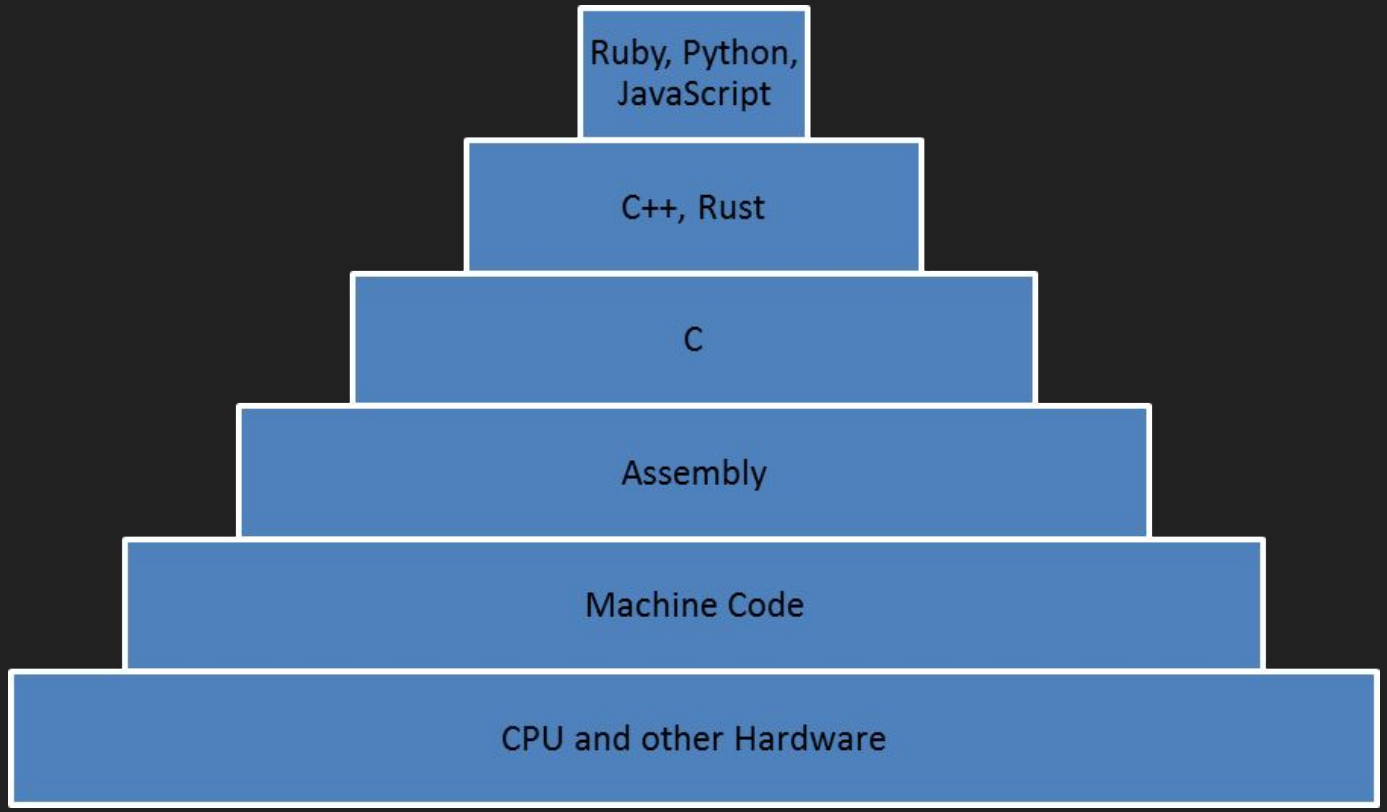
MST - 1/26

What is Assembly?

What and why

- Lowest level language we're concerned about directly writing
- Translates almost 1:1 into machine code for the CPU
- We focus on 32-bit **x86 assembly** in this class, common on Intel and AMD processors
  - Many other variants including ARM, RISC, AVR, etc
- Understanding assembly will help you learn what your computer is really doing
- Initial learning curve can be difficult, but stick with it

What is Assembly?



Basic Syntax

x86 Key Concepts

- Understanding assembly is crucial to low-level exploitation
- **Instructions** are the main unit of code
- Many instructions use **registers**, which are built-in named temporary variables
- Two main forms: **Intel** and **AT&T** syntax

```
Intel: mov eax, 12345

AT&T: movl $12345, %eax
```

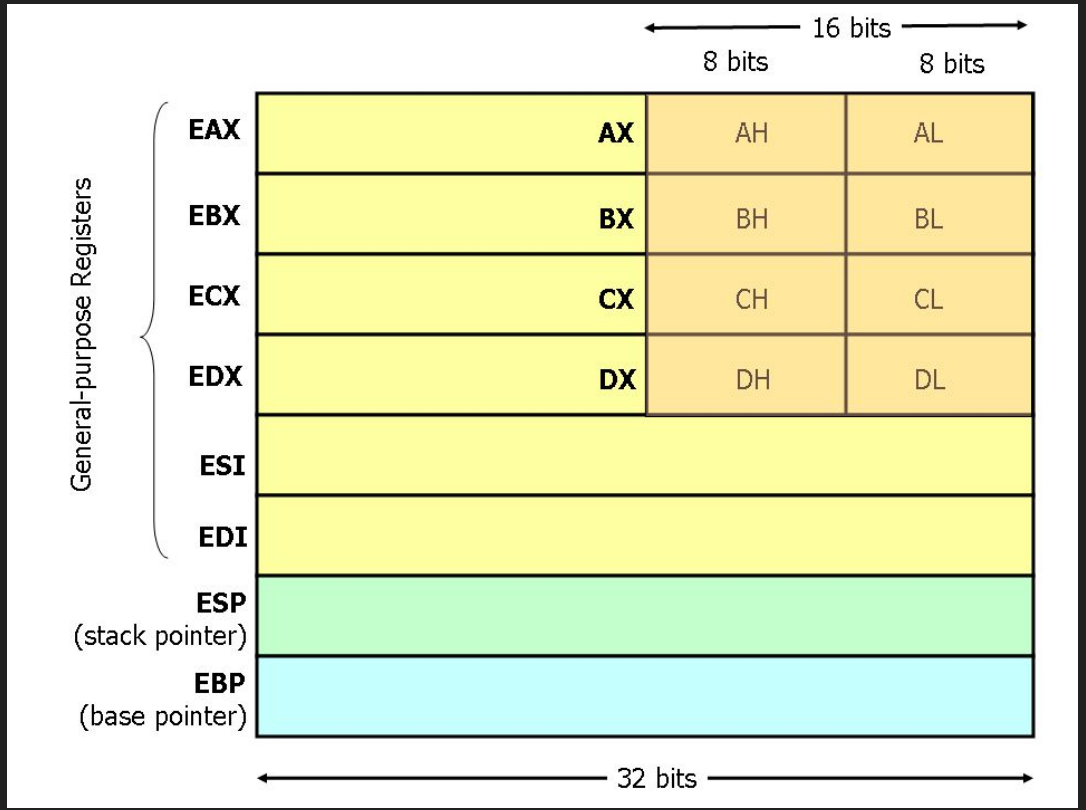
- May take multiple instructions to perform one higher-level “operation"

```
000000000040057d <main>:
55                      push   rbp
48 89 e5                mov    rbp,rsp
48 83 ec 10             sub    rsp,0x10
bf 44 06 40 00          mov    edi,0x400644
e8 c1 fe ff ff          call   400450 <puts@plt>
c7 45 fc 05 00 00 00    mov    DWORD PTR [rbp-0x4],0x5
83 45 fc 01             add    DWORD PTR [rbp-0x4],0x1
8b 45 fc                mov    eax,DWORD PTR [rbp-0x4]
89 c6                   mov    esi,eax
bf 50 06 40 00          mov    edi,0x400650
b8 00 00 00 00          mov    eax,0x0
e8 b2 fe ff ff          call   400460 <printf@plt>
b8 00 00 00 00          mov    eax,0x0
c9                      leave
c3                      ret


$ gcc hello.c
$ ./a.out
Hello World
6
```

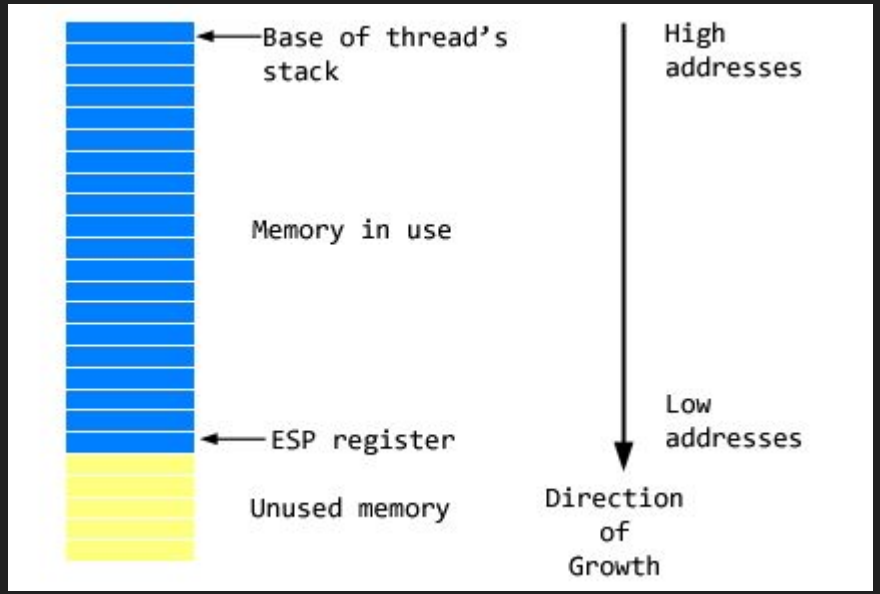
Registers

- **EAX**, **EBX**, **ECX**, **EDX**
  - Common general purpose registers
- **ESP**
  - Points to the “top” of the current stack frame
- **EBP**
  - Stack base pointer, points to the “bottom” of the current stack frame
- **EIP**
  - Points to the location of the current instruction in memory
- **EFLAGS**
  - Contains **flag bits** (zero flag, carry flag, sign flag, etc)



The Stack

- LIFO data structure used for local variables and function calls
- A **stack frame** is the portion of the stack used by the current function
- ESP stores the lowest address, which is the top of the stack
- EBP stores the highest address, which is the bottom of the current stack frame

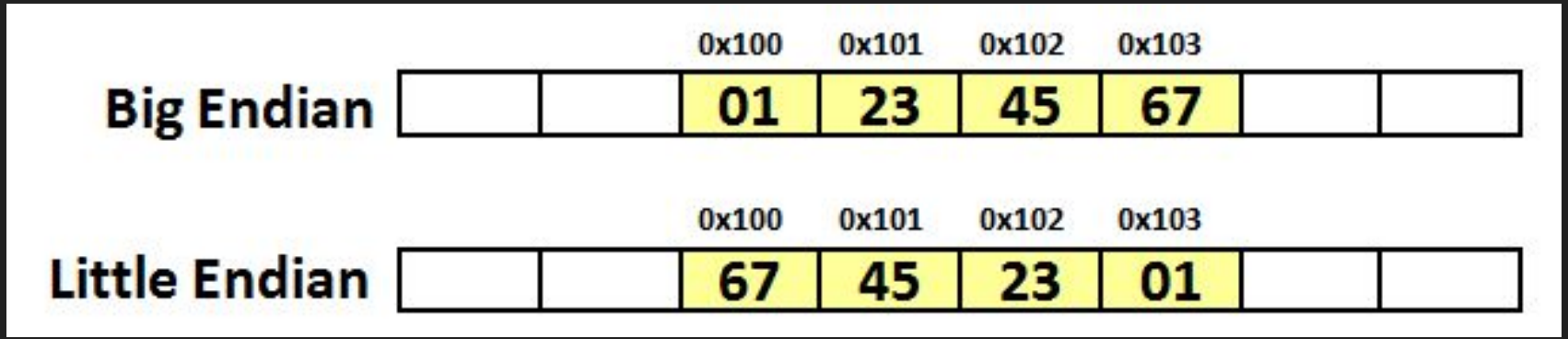


Side note: Hexadecimal and Binary

- Both hex and binary are widely used in assembly and low-level exploitation
- Addresses are almost always expressed in hexadecimal
  - 134524739 = 0x0804af43
- Useful to know ASCII representation of common characters in hex as well
  - ‘A’ = 0x41, ‘B’ = 0x42, ….
- Understanding binary operations quickly can also be helpful
  - AND, OR, XOR, NOT, etc

Side note: Little Endian vs Big Endian

- x86 is a **little endian** architecture, which refers to the order of bytes in memory for multi-byte data
- This matters only if you access specific bytes of a larger data type - otherwise, it will be transparently handled for you



Common Instructions

Arithmetic Instructions

- `add eax, 0x123`
  - `eax = eax + 0x123`
- `sub eax, 0x456`
  - `eax = eax - 0x456`
- `and eax, ebx`
  - `eax = eax | ebx`
- `not ecx`
  - `ecx = ~ecx`
- `inc edx`
  - `edx++`
- `shl ecx, al`
  - `ecx = ecx << al`
- `mul ecx`
  - `(edx:eax) = ecx * eax`
- `div ecx`
  - `eax = (edx:eax) / ecx`
  - `edx = (edx:eax) % ecx`

MOV Instructions

- `mov eax, ebx`
  - `eax = ebx`
- `mov eax, 123`
  - `eax = 123`
- `mov eax, DWORD PTR [0x123456]`
  - `eax = *(0x123456)`
- `mov eax, DWORD PTR [edx+esi*4]`
  - `eax = *(edx + esi * 4)`
- `lea esi, [ebp - 16]`
  - `esi = ebp - 16`
  - Commonly used for pointer manipulations

Addressing Modes

```
[ebx]
[ebx - 4]
[ebx + eax]
[ebx + eax*4]
[ebx-eax] ; Invalid
     (Can only add registers)
[ebx + eax + ecx] ; Invalid
     (Can only use 2 registers)
```

Size Directives

```
BYTE PTR [edx]
WORD PTR [edx]
DWORD PTR [edx]
```

Control Flow Instructions

- `jmp eax`
  - Unconditional jump
- `jz $my_location`
  - Jump if zero flag set
- `jnz $my_location`
  - Jump if zero flag not set
- `jg $my_location`
  - Jump if greater
- `jb $my_location`
  - Jump if below

EFLAGS register

- Stores bit flags to indicate the results of operations
  - **Carry Flag**
  - **Zero Flag**
  - **Sign Flag**
- Implicitly set after certain instructions

```
mov eax, 5
cmp eax, 4
jg $cool_place
```

```
mov eax, 5
cmp eax, 5
jz $also_cool
```

PUSH, POP, CALL, RET

- Mainly used for calling functions and saving registers
- `push ebp`
  - Puts `EBP` on the top of the stack and decrements `ESP`
- `pop ebp`
  - Loads the top of the stack into `ESP` and increments `ESP`
- `call 400460 <printf@plt>`
  - Pushes the address of the next instruction to the stack and jumps to `400460`
- `ret`
  - Pulls the top of the stack into `EIP` and continues execution

Calling Conventions

- When compilers generate x86 from C, they use the **cdecl** calling convention
- cdecl specifies what to do with registers and the stack
  - Which registers have to be saved before calling a function?
  - How are arguments passed?
  - How do we handle saving and updating EBP and ESP?
  - Which function should handle cleanup?
- Since all relevant C compilers for x86 use cdecl, their code can interoperate

cdecl

- Function arguments are pushed to the stack in reverse order before the call
- EBP is set to the top of the stack at the beginning of the function
- EBP is restored at the bottom of a function
- Caller is responsible for
  - Cleaning up the stack after a call
  - Saving EAX, ECX, and EDX registers
- Callee is responsible for
  - Putting the return value in EAX
  - Preserving all other registers

callee(1, 2, 3);

```
caller:
    . . .
    ; push call arguments
    push    3
    push    2
    push    1
    ; call subroutine 'callee'
    call    callee
    ; remove arguments from frame
    add     esp, 12
    ; use subroutine result
    cmp     eax, 6
    . . .
```

```
callee:
    ; make new call frame
    push    ebp
    mov     ebp, esp
    ; use arguments to set result
    mov eax, [ebp+0x8]
    mov edx, [ebp+0xc]
    mov ecx, [ebp+0x10]
    add eax, edx
    add eax, ecx
    ; restore old call frame
    pop     ebp
    ; return to caller
    ret
```

Calling Conventions

- You **don’t** have to use cdecl when writing in assembly…
- ...but you won’t be able to call 32-bit C library functions!
- Also, it’s good to get practice for later when we are reading compiler-generated assembly

Basic x86 example

What does this code do?

```
my_function:
    push ebp
    mov ebp, esp
    mov eax, [ebp+0x4]
    mov edx, [ebp+0x8]
body:
    mov ecx, [eax]
    cmp ecx, edx
    jz found
    cmp ecx, 0
    jz notfound
    inc eax
    jmp body
```

```
found:
    mov ecx, [ebp+0x4]
    sub eax, ecx
    jmp done
notfound:
    xor eax, eax
done:
    pop ebp
    ret
```

What does this code do?

```
my_function:
    push ebp ; function prologue
    mov ebp, esp
    mov eax, [ebp+0x4]
    mov edx, [ebp+0x8]
body: ; loop body
    mov ecx, [eax]
    cmp ecx, edx ; what is ecx? edx?
    jz found
    cmp ecx, 0
    jz notfound
    inc eax
    jmp body
```

```
found: ; success case
    mov ecx, [ebp+0x4]
    sub eax, ecx
    jmp done
notfound: ; error case
    xor eax, eax
done: ; function epilogue
    pop ebp
    ret
```

x86 -> C

```
my_function:
    push ebp
    mov ebp, esp
    mov eax, [ebp+0x4]
    mov edx, [ebp+0x8]
body:
    mov ecx, [eax]
    cmp ecx, edx
    jz found
    cmp ecx, 0
    jz notfound
    inc eax
    jmp body
( rest omitted )
```

```
int my_function(char *d, char ch)
{
    int x = 0;
    while (d[x] != 0) {
        if (d[x] == ch)
            return x;
        x++;
    }
    return 0;
}
```

Creating Executables

Use GCC as an assembler

```
$ gcc -m32 -o simple simple.s

$ ./simple

$ echo $?
1
```

```
.intel_syntax noprefix

.globl main
main:
mov eax, 1
ret
```

Calling C functions

```
$ gcc -m32 -o hello hello.s

$ ./hello
Hello World!
```

```
.intel_syntax noprefix

.data
message:
.string “Hello World!”

.text
.globl main
main:
mov ecx, offset message
push ecx
call puts
pop ecx
mov eax, 0
ret
```

Homework

Homework: Print out a file backwards

- Write a script that accepts a filename, reads in the file, and prints it out backwards

```
$ cat hello_world.txt
Hello World!
$ ./your_program hello_world.txt
!dlroW olleH
```

- Write code only in 32-bit x86 assembly, but no other restrictions

Homework grading

- Submit your assembly code file to cm7bv@virginia.edu with the subject “MST Assignment 1 - <YOUR_UVA_ID>”
  - eg: “MST Assignment 1 - cm7bv”
- Also, include a brief (1-paragraph) description of what you did and how it went
- We’ve included a simple grading script you can test your program against in the GitHub repository (check the folder for today’s class)

Homework tips

- You will need to use dynamic memory management (with malloc/free) handle command line arguments
- Don’t overthink it or worry about performance. Only consider correctness
- You can use gcc to assemble your code into a program
  - eg: `gcc my_code.s`
- Become familiar with man pages, they are invaluable
- Syscalls may be easier than the C standard library in many cases
- Don’t be afraid to ask questions either via Slack or email!

Good Resources

Resources

https://en.wikibooks.org/wiki/X86_Assembly

https://www.nayuki.io/page/a-fundamental-introduction-to-x86-assembly-programming

https://www.cs.virginia.edu/~evans/cs216/guides/x86.html

General bash and terminal practice: http://overthewire.org/wargames/bandit/