Introduction to NASM Programming

ICS312

Machine-Level and Systems Programming

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Machine code

- Each type of CPU understands its own machine language
- Instructions are numbers that are stored in bytes in memory
- Each instruction has its unique numeric code, called the opcode
- Instruction of x86 processors vary in size
  - Some may be 1 byte, some may be 2 bytes, etc.
- Many instructions include operands as well

opcode	operands

- Example:
  - On x86 there is an instruction to add the content of EAX to the content of EBX and to store the result back into EAX
  - This instruction is encoded (in hex) as: 03C3
- Clearly, this is not easy to read/remember

Assembly code

- An assembly language program is stored as text
- Each assembly instruction corresponds to exactly one machine instruction
  - Not true of high-level programming languages
  - E.g.: a function call in C corresponds to many, many machine instructions
- The instruction on the previous slides (EAX = EAX + EBX) is written simply as:

```
add    eax, ebx
```

mnemonic

operands

Assembler

- An assembler translates assembly code into machine code
- Assembly code is NOT portable across architectures
  - Different ISAs, different assembly languages
- In this course we use the **N**etwide **A**ssembler (NASM) assembler to write 32-bit Assembler
  - See Homework #0 for getting NASM installed/running
- Note that different assemblers for the same processor may use slightly different syntaxes for the assembly code
  - The processor designers specify machine code, which must be adhered to 100%, but not assembly code syntax

Comments

- Before we learn any assembly, it's important to know how to insert comments into a source file
  - Uncommented code is a really bad idea
  - Uncommented assembly is a really, really bad idea
  - In fact, commenting assembly is necessary
- With NASM, comments are added after a '**;**'
- Example:

```
add eax, ebx     ; y = y + b
```

Assembly directives

- Most assembler provides “directives”, to do things that are not part of the machine code but are convenient
- Defining immediate constants
  - Say your code always uses the number 100 for a specific thing, say the “size” of an array
  - You can just put this in the NASM code:

    %define SIZE 100
  - Later on in your code you can do things like:

    mov eax, SIZE
- Including files
  - %include “some_file”
- If you know the C preprocessor, these are the same ideas as
  - #define SIZE 100 or #include “stdio.h”
- Use %define whenever possible to avoid “code duplication”
  - Because code duplication is evil

NASM Program Structure

```
; include directives

segment .data
    ; DX directives

segment .bss
    ; RESX directives

segment .text
    ; instructions
```

C Driver for Assembly code

- Creating a *whole* program in assembly requires a lot of work
  - e.g., set up all the segment registers correctly
- You will rarely write something in assembly from scratch, but rather only pieces of programs, with the rest of the programs written in higher-level languages like C
- In this class we will “call” our assembly code from C
  - The main C function is called a driver

```
int main()   // C driver
{
  int ret_status;
  ret_status = asm_main();
  return ret_status;
}
```

```
...
add eax, ebx
mov ebx, [edi]
...
```

So what's in the text segment?

- The text segment defines the asm_main symbol:

```
global    asm_main   ; makes the symbol visible
asm_main:            ; marks the beginning of asm_main
    ; all instructions go here
```

- On Windows, you need the '_' before asm_main although in C the call is simply to "asm_main" not to "_asm_main"
- On Linux you do not need the '_'
- I'll assume Linux from now on (e.g., in all the .asm files on the course's Web site)

NASM Program Structure

```
; include directives

segment .data
    ; DX directives

segment .bss
    ; RESX directives

segment .text
    global asm_main
    asm_main:
        ; instructions
```

More on the text segment

- Before and after running the instructions of your program there is a need for some “setup” and “cleanup”
- We’ll understand this later, but for now, let’s just accept the fact that your text segment will always looks like this:

```
enter   0,0
pusha
;
; Your program here
;
popa
mov     eax, 0
leave
ret
```

NASM Skeleton File

```
    ; include directives

segment .data
    ; DX directives

segment .bss
    ; RESX directives

segment .text
    global asm_main
    asm_main:
        enter   0,0
        pusha
        ; Your program here
        popa
        mov     eax, 0
        leave
        ret
```

Our First Program

- Let's just write a program that adds two 4-byte integers and writes the result to memory
  - Yes, this is boring, but we have to start somewhere
- The two integers are initially in the .data segment, and the result will be written in the .bss segment

Our First Program

```
segment .data
    integer1    dd      15              ; first int
    integer2    dd      6               ; second int
segment .bss
    result      resd    1               ; result
segment .text
    global asm_main
    asm_main:
        enter   0,0
        pusha
        mov     eax, [integer1]         ; eax = int1
        add     eax, [integer2]         ; eax = int1 + int2
        mov     [result], eax           ; result = int1 + int2
        popa
        mov     eax, 0
        leave
        ret
```

File ics312_first_v0.asm on the Web site

I/O?

- This is all well and good, but it's not very interesting if we can't "see" anything
- We would like to:
  - Be able to provide input to the program
  - Be able to get output from the program
- Also, debugging will be difficult, so it would be nice if we could tell the program to print out all register values, or to print out the content of some zones of memory
- Doing all this requires quite a bit of assembly code and requires techniques that we will not see for a while
- The author of our textbook provides a nice I/O package that we can just use, without understanding how it works for now

asm_io.asm and asm_io.inc

- The "PC Assembly Language" book comes with many add-ons and examples
  - Downloadable from the course's Web site
- A very useful one is the I/O package, which comes as two files:
  - asm_io.asm   (assembly code)
  - asm_io.inc   (macro code)
- Simple to use:
  - Assemble asm_io.asm into asm_io.o
  - Put "%include asm_io.inc" at the top of your assembly code
  - Link everything together into an executable

Simple I/O

- Say we want to print the result integer in addition to having it stored in memory
- We can use the print_int “macro” provided in asm_io.inc/asm
- This macro prints the content of the eax register, interpreted as an integer
- We invoke print_int as:

```
call   print_int
```

- Let’s modify our program

Our First Program

```
%include "asm_io.inc"

segment .data
    integer1        dd    15       ; first int
    integer2        dd     6       ; second int
segment .bss
    result          resd  1        ; result
segment .text
            global asm_main
    asm_main:
        enter       0,0
        pusha
        mov         eax, [integer1]         ; eax = int1
        add         eax, [integer2]         ; eax = int1 + int2
        mov         [result], eax           ; result = int1 + int2
        call        print_int               ; print result
        popa
        mov         eax, 0
```

File ics312_first_v1.asm on the Web site

How do we run the program?

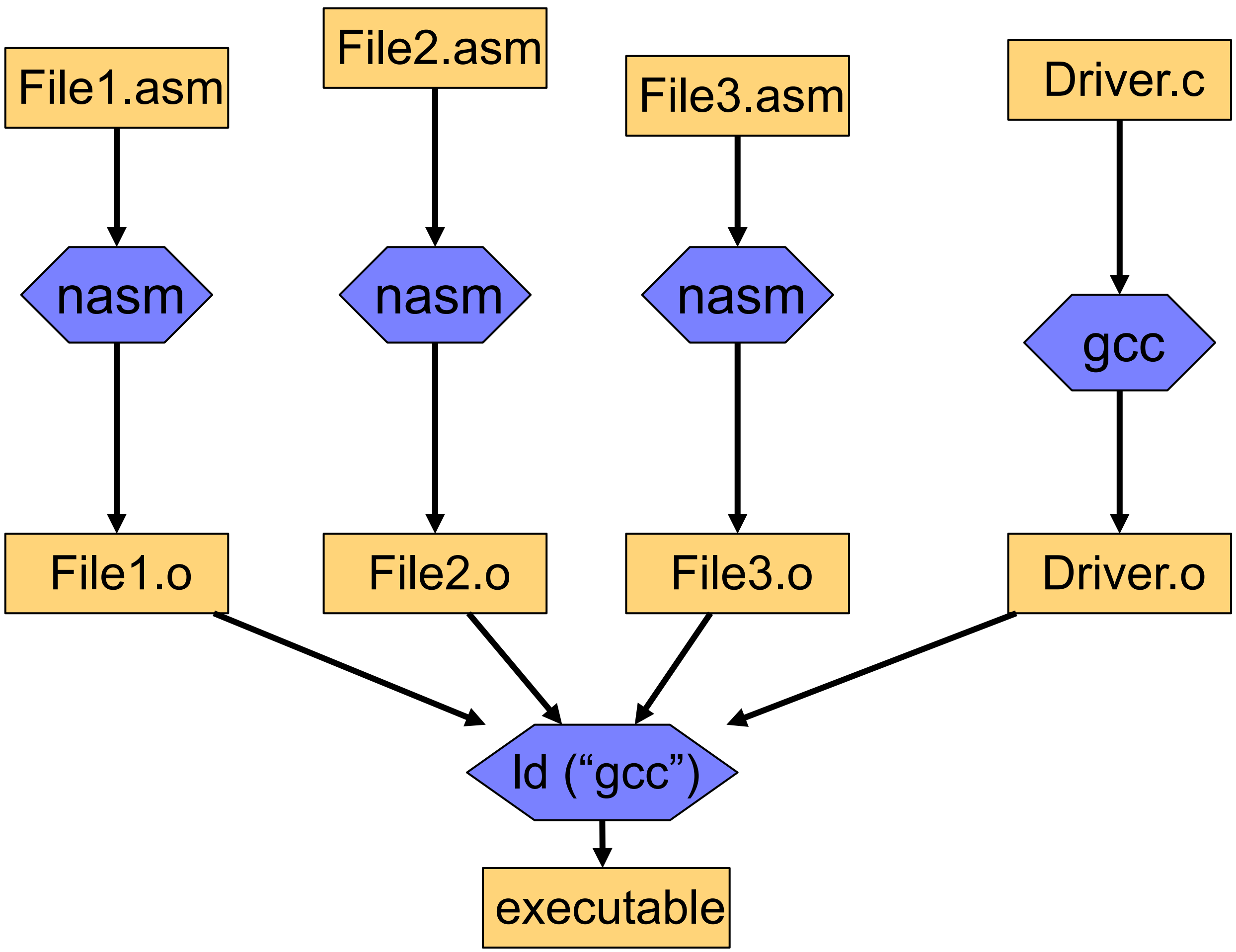
- Now that we have written our program, say in file ics312_first_v1.asm using a text editor, we need to assemble it
- When we assemble a program we obtain an object file (a .o file)
- We use NASM to produce the .o file:

  % nasm **-f elf** ics312_first_v1.asm **-o** ics312_first_v1.o
- So now we have a .o file, that is a machine code translation of our assembly code
- We also need a .o file for the C driver:

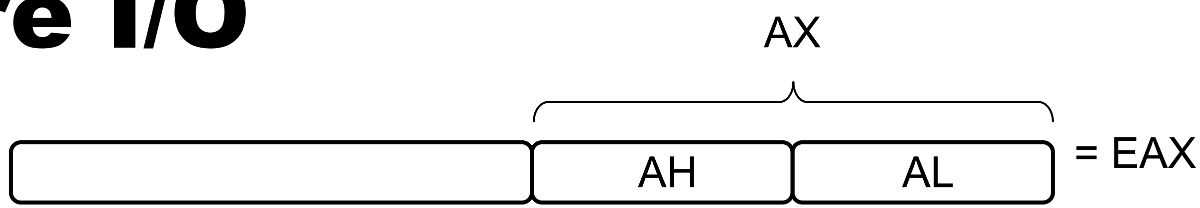
  % gcc -m32 -c driver.c -o driver.o
  - We generate a 32-bit object (our machines are likely 64-bit)
- We also create asm_io.o by assembling asm_io.asm
- Now we have three .o files.
- We link them together to create an executable:

  % gcc driver.o ics312_first_v1.o asm_io.o -o ics312_first_v1
- And voila... right?

The Big Picture



More I/O



- print_char: prints out the character corresponding to the ASCII code stored in AL
- print_string: prints out the content of the string stored at the address stored in eax
  - The string must be null-terminated (last byte = 00)
- print_nl: prints a new line
- read_int: reads an integer from the keyboard and stores it into eax
- read_char: reads a character from the keyboard and stores it into AL
- Let us modify our code so that the two input integers are read from the keyboard, so that there are more convenient messages printed to the screen

Our First Program

```
%include "asm_io.inc"

segment .data
      msg1    db          "Enter a number: ", 0
      msg2    db          "The sum of ", 0
      msg3    db          " and ", 0
      msg4    db          " is: ", 0
segment .bss
      integer1   resd   1     ; first integer
      integer2   resd   1     ; second integer
      result      resd   1    ; result
segment .text
      global asm_main
asm_main:
      enter    0,0
      pusha
      mov      eax, msg1          ; note that this is a pointer!
      call     print_string
      call     read_int           ; read the first integer
      mov      [integer1], eax   ; store it in memory
      mov      eax, msg1          ; note that this is a pointer!
      call     print_string
      call     read_int           ; read the second integer
      mov      [integer2], eax   ; store it in memory
```

```
      mov     eax, [integer1]   ; eax = first integer
      add     eax, [integer2]   ; eax += second integer
      mov     [result], eax     ; store the result
      mov     eax, msg2         ; note that this is a pointer
      call    print_string
      mov     eax, [integer1]   ; note that this is a value
      call    print_int
      mov     eax, msg3         ; note that this is a pointer
      call    print_string
      mov     eax, [integer2]   ; note that this is a value
      call    print_int
      mov     eax, msg4         ; note that this is a pointer
      call    print_string
      mov     eax, [result]     ; note that this is a value
      call    print_int
      call    print_nl
      popa
      mov     eax, 0
      leave
      ret
```

File ics312_first_v2.asm
on the Web site... let's compile/run it

Our First Program

- In the examples accompanying our textbook there is a very similar example of a first program (called first.asm)
- So, this is great, but what if we had a bug to track?
  - We will see that writing assembly code is very bug-prone
- It would be _very_ cumbersome to rely on print statements to print out all registers, etc.
- So asm_io.inc/asm also provides two convenient macros for debugging!

dum_regs and dump_mem

- The macro dump_regs prints out the bytes stored in all the registers (in hex), as well as the bits in the FLAGS register (only if they are set to 1)

  dump_regs 13

  - '13' above is an arbitrary integer, that can be used to distinguish outputs from multiple calls to dump_regs
- The macro dump_memory prints out the bytes stored in memory (in hex). It takes three arguments:
  - An arbitrary integer for output identification purposes
  - The address at which memory should be displayed
  - The number minus one of 16-byte segments that should be displayed
  - for instance

  dump_mem 29, integer1, 3

  - prints out "29", and then (3+1)*16 bytes

Using dump_regs and dump_mem

- To demonstrate the usage of these two macros, let's just write a program that highlights the fact that the Intel x86 processors use Little Endian encoding
- We will do something ugly using 4 bytes
  - Store a 4-byte hex quantity that corresponds to the ASCII codes: "live"
    - "l" = 6Ch
    - "i" = 69h
    - "v" = 76h
    - "e" = 65h
  - Print that 4-byte quantity as a string

Little-Endian Exposed

```
%include "asm_io.inc"

segment .data
      bytes   dd          06C697665h  ; "live"
      end     db          0               ; null

segment .text
      global asm_main
asm_main:
      enter               0,0
      pusha
      mov                 eax, bytes      ; note that this is an address
      call                print_string    ; print the string at that address
      call                print_nl        ; print a new line
      mov                 eax, [bytes]    ; load the 4-byte value into eax
      dump_mem            0, bytes, 1     ; display the memory
      dump_regs           0               ; display the registers
      pusha
      popa
      mov                 eax, 0
      leave
      ret
```

File ics312_littleendian.asm on the site...let's run it

Output of the program

The program prints "evil" and not "live"

The address of "bytes" is 0804A020"

"bytes" starts here

```
evil
Memory Dump # 0 Address = 0804A020
0804A020 65 76 69 6C 00 00 00 00 25 69 00 25 73 00 52 65 "evil????%i?%s?Re"
0804A030 67 69 73 74 65 72 20 44 75 6D 70 20 23 20 25 64 "gister Dump # %d"
Register Dump # 0
EAX = 6C697665 EBX = B7747FF4 ECX = BFBCB2C4 EDX = BFBCB254
ESI = 00000000 EDI = 00000000 EBP = BFBCB208 ESP = BFBCB1E8
EIP = 080484A4 FLAGS = 0282        SF
```

and yes, it's "evil"

The "dump" starts at address 0804A020 (a multiple of 16)

bytes in eax are in the "live" order

Conclusion

- It is paramount for the assembly language programmer to understand the memory layout precisely
- We have seen the basics for creating an assembly language program, assembling it with NASM, linking it with a C driver, and running it