Introduction to NASM Programming

ICS312

Machine-Level and Systems Programming

Henri Casanova (henric@hawaii.edu)

Machine code

- Each type of CPU understands its own machine language
- Instructions are (binary) numbers stored as bytes in memory
- Each instruction has an opcode and possible operand

opcode	operand

- The opcode is a set of bits that specify what the instruction does
- The operand is a set of bits that specify which registers or memory locations the instruction applies to

- Let’s see two example binary encoding of simple instructions…

Machine code

- Example #1: **`add EAX, EBX`**
  - This x86 instruction adds the content of EAX to the content of EBX and stores the result back into EAX
  - This instruction is encoded in hex as: 03C3
    - 03 is the opcode, C3 is the operand
- Example #2: **`add ECX, EAX`**
  - This x86 instruction adds the content of ECX to the content of EAX and stores the result back into ECX
  - This instruction is encoded in hex as: 03C8
    - 03 is the opcode, C8 is the operand
- Clearly, such binary codes (even if we write/read them in hex) are not easy to remember at all
- Way back when, programmers had to learn them
- But now, we have assembly….

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, as we'll see
- Rather than writing 03C3, we instead will write

```
add     eax, ebx
```

opcode 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 x86 Assembly
- Note that different assemblers for the same processor may use different syntaxes for the assembly code
  - The processor designers specify machine code, which must be adhered to 100%, but not assembly code syntax
  - NASM uses one popular syntax, another popular syntax is the ATT syntax (easily recognized as is has many '$' and '%' characters in the code)
  - It would take about one hour to learn a different syntax, because instructions are so basic
  - Learning a new assembly syntax is NOT as hard as learning a new high-level programming language

Comments

- Before we learn assembly, let's learn how to insert comments into a source file
  - Uncommented code is a really bad idea
  - Uncommented assembly code is a really, really bad idea
  - In fact, commenting assembly is necessary
- With NASM, comments are added after a semicolon (';')
- 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, e.g., 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 “some_file”
- 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
```

NASM Program Structure

```
  ; include directives

segment .data
  ; DX directives

segment .bss
  ; RESX directives

segment .text
  ; instructions
```

- I am using red for pieces of the program you have to write “creatively”
- Other colors are for pieces of the program that you have to write but that are always there and always the same

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/C++/whatever
- In this class we “call” assembly code from C
  - We use a main C function as 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 a '_' before asm_main, even though 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)
  - If you want to do everything on Windows and then retro-fit it on Linux, that's great, but you'll get no help from us
- We can now augment our program a bit…

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”
  - This is so that the C can “call” the assembly correctly
- We’ll understand this later, but for now, let’s just accept the fact that your text segment will always look 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

- Let's do it "from scratch" right now before looking at the next slide…

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 a decimal integer
  - yes, it’s very limited: only prints eax
- We invoke **`print_int`** as:

```
call    print_int
```

- Let’s modify our program live…

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
        leave
        ret
```

File ics312_first_v1.asm on the Web site

How do we run the program?

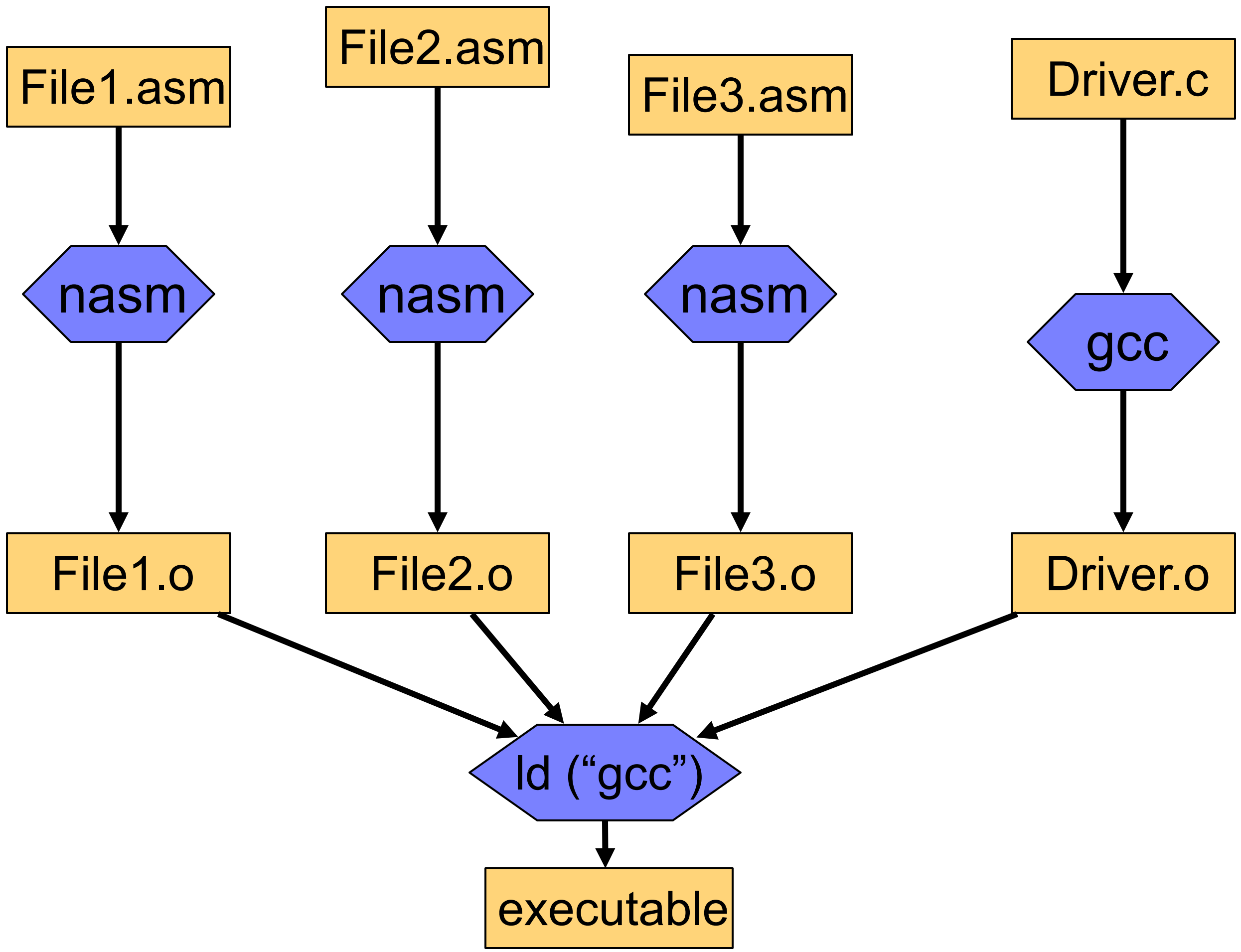
- Now that we have written our program, say in file ics312_first_v1.asm using a text editor, we need to assemble it
- I used a Makefile a minute ago… but what does it do?
- Assembling a program means building an object file (a .o file)
- We use NASM to produce the .o file:

  % 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 all 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

The Big Picture (three .asm files)

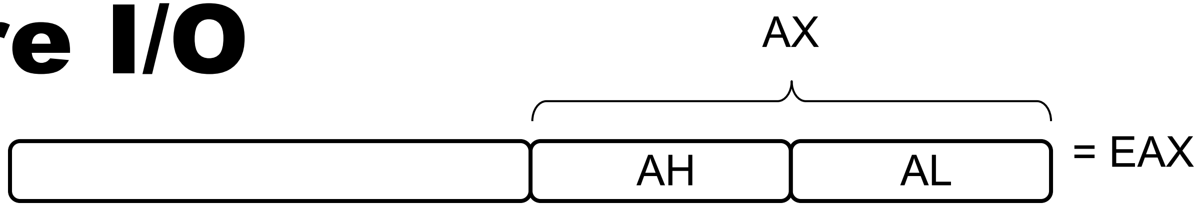


NASM HowTo

- I have created a “NASM how to” reading as part of this module on the course’s Web site
- Let’s look at it now and compile/run our sample program

- This is all based on the **`nasm_check.tar`** archive that is used in Homework #0

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 as a 4-byte value into eax
- read_char: reads a character from the keyboard and stores its ASCII code into EAX as follows: 00 00 00 xx (AL is the 1-byte ASCII code)
- Let us modify our code so that the two input integers are read from the keyboard, and 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
        integer2    resd    1
        result      resd    1
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
                                  e that this is a value
                                  e that this is a pointer
                                  e that this is a value
        call    print_int
        call    print_nl
        popa
        mov     eax, 0
        leave
        ret
```

In the examples accompanying our textbook there is a very similar example of a first program (called first.asm)

File ics312_first_v2.asm on the Web site...

Debugging???

- What if we have a bug to track?
  - Initially, assembly code is very bug-prone
- One option: rely on print statements to print out all registers, etc.
  - **This can be a huge waste of time**
  - Part of the course is to actually look at bytes in RAM and registers to figure out bugs
  - Otherwise, it's basically like debugging C with print statements, but with the difference that:
    - Our print statements are very weak
    - Our bugs can be even weirder (or as weird as if you write the most terrible/insane C code)
- So asm_io 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 a meaningless integer, that you can use 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:
  - A meaningless integer for distinguishing outputs
  - 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
  - Declare in the data segment a 4-byte hex quantity whose bytes are the ASCII codes: "live"
    - "l" = 6Ch, "i" = 69h, "v" = 76h, "e" = 65h
  - Print that 4-byte quantity as if it where a string
  - Then load it into a register
  - Use dump_mem and dump_reg to check out byte values
- Let's do it live again…

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 Web site

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

Word of Caution

- Each time I teach assembly I says “using print for debugging is a waste of time” and “debugging is done by looking at registers and RAM using dump_regs and dump_mem”
- Each time, a large fraction of students strongly resist and still use print, desperately clinging to the delusion that we’re using a high-level language
  - But even for high-level languages using print statements is very limiting for debugging!
- You will save hours if you let go of that delusion (and you will learn a lot and feel empowered in the process)
  - And you will avoid the “I spend 4 hours tracking a bug, then at office hours the prof/TA added a dump_mem statement and found it in 10 seconds” embarrassment

Another program?

- Should we do another program “live” in class?
- Any ideas of what the program could do?
  - We’re pretty limited right now, but I am game…

Livecoding Poll

- Let’s do a poll about “live coding” in this class…

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
- We have seen some convenient macros/ functions provided by the textbook author
- Time for you to start playing around with the sample programs and with...

- But first: Homework #3