Subprogram 101

ICS312

Machine-Level and Systems Programming

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Subprograms

- Subprograms (i..e, functions, procedures, methods) make programs modular, promoting code reuse
  - We use them a lot in high-level code
    - From a software engineering perspective, it’s bad practice to write long sequences of lines of code
    - So we end up putting a lot of code in subprograms
    - Some companies even require that subprograms be shorter than some fixed number of lines of code
- We are going to see how to define and call subprograms in assembly
  - Useful to write large(r) assembly programs
  - **More importantly,** will allow us to understand how subprograms work in higher-level languages
- But first, let’s just review the concept of indirection

Indirect Addressing

- Registers can hold “data” or “addresses”
  - mov eax, L   vs.   mov eax, [L]
  - Not keeping this straight leads to horrible bugs
    - You may already know this from programming assignments
  - The processor will happily apply whatever operation on whatever data as long as data sizes are correct
  - e.g., if you think that a register contains an integer, but in fact it stores the address of the integer in memory, then your arithmetic operations will return very strange results
- Since addresses are 32-bit, only the EAX, EBX, ECX, EDX, ESI, and EDI registers can be used to store addresses in a program
- Storing addresses into a register is what makes it possible to implement our first subprogram

What is a subprogram?

- A subprogram is a piece of code that starts at some address in the text segment
- The program can jump to that address to “call” the subprogram
- When the subprogram is done executing, it jumps back to the instruction after the call, and the execution resumes “as if nothing had happened”
- The subprogram can take parameters and return a value
- Let’s see how we can implement this using only what we know about x86 assembly as of now

Example Subprogram

- Say we want to write a subprogram that computes some numerical function of two operands and returns the result
  - e.g., because we need to compute that function often and code duplication is evil
- We will write the subprogram so that, when it is called, the first operand is in eax and the second in ebx, and when it returns the result is in eax
  - This is a convention that we make, and that should be documented in the code
- Calling the subprogram can then be done via a simple jmp instruction
- Let's look at the code…

“By hand” subprogram

```
    . . .
    mov  eax, 12        ; first operand = 12
    mov  ebx, 14        ; second operand = 14
    jmp  func           ; "call" the function
return_here:
    . . .
    . . .
func:
    add eax, ebx        ; eax = eax + ebx
    jmp return_here     ; "return" to the instruction
                        ; after the call
```

“By hand” subprogram

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                        ; after the call
```

Why is this not really a subprogram?

Multiple Calls?

- We want to be able to call a function from multiple places in a program
- The problem with the previous code is that the function always returns to a single label!

```
        . . .
        jmp   func          ; "call" the function
return_here_1:
        . . .
        jmp   func          ; "call" the function
return_here_2:
        . . .
func:
        . . .
        jmp   ???           ; where should we return???
```

A Better Function Call

- To fix our previous example, we need to remember the place where the function should return
- This could be done by storing the address of the instruction after the call in a register, say, register ecx
- The code for the function then can just return to whatever instruction ecx points to
  - Again, this is a convention that we decide as a programmer and that we must remember

Storing instruction addresses?

- A label in the code is just like a label in the .data / .bss segments: it's an address
- So, for instance we can do:

```
here:
        add   eax, ebx        ; some instruction
there:
        mov   eax, there      ; compute the difference
        sub   eax, here       ; between "there" and "here"
        call  print_int       ; prints the size of the instruction's
                              ; code in number of bytes!
```

A Better Function Call

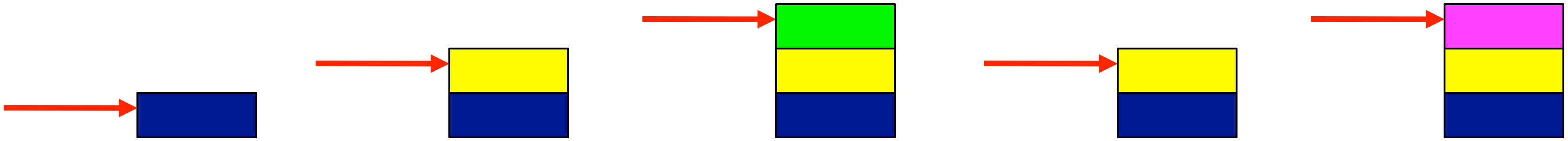
```
        . . .
        mov  ecx, return_here_1      ; store the return address
        jmp  func                    ; "call" the function
return_here_1:
        . . .
        mov  ecx, return_here_2      ; store the return address
        jmp  func                    ; "call" the function
return_here_2:
        . . .
func:
        . . .
        jmp  ecx                ; return
```

All Good, but ...

- So at this point, we can do any function call
- We just need to decide on and document a convention about which registers hold the
  - input parameters
  - return value
  - return address
- The problem is that this gets very cumbersome
  - It requires a bunch of “ret” labels all over the code
    - The textbook shows how the return address can be computed numerically, but it is very awkward
  - It forces the programmer to constantly keep track of registers and be careful to save and restore important values
    - We already have so few registers to begin with :(
- Solution:
  - A stack and two new instructions: CALL and RET

A Stack

- A stack is a Last-In-First-Out data structure
- It provides two operations
  - Push: puts something on the stack
  - Pop: removes something from the stack
- Defined by the address of the “element” at the top of the stack, which is stored in the so-called “stack pointer”
  - Push: puts an element on top of the stack and updates the stack pointer
  - Pop: gets the element from the top of the stack and updates the stack pointer
- The processor has “tools” (registers, instructions) to maintain one particular stack, the “runtime stack”



The Runtime Stack

- A stack in RAM that allows pushing/popping of 4-byte elements
  - Not “quite” true, but true in this course
- The stack pointer is always stored in the ESP register
- Initially the stack is empty and the ESP register has some value
- The stack grows downward (i.e., toward lower addresses)
- **Pushing an element:**
  - Decrease ESP by 4 and write 4 bytes at address ESP
  - Examples: push eax push dword 42
- **Popping an element:**
  - Get the value from the top of the stack into a register and increase ESP by 4
  - Examples: pop eax pop ebx
- **Accessing an element:**
  - Read the 4 bytes at address ESP
  - Example: mov eax, [esp]

Example Stack Instructions

- Assuming that ESP=00001000h

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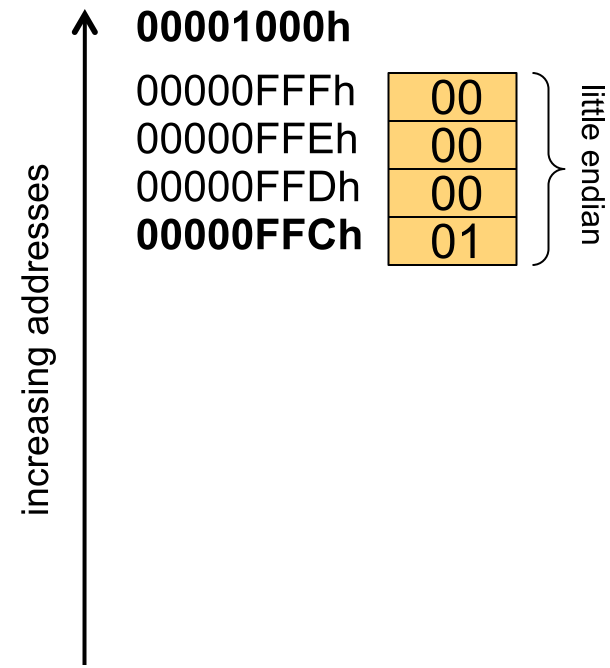
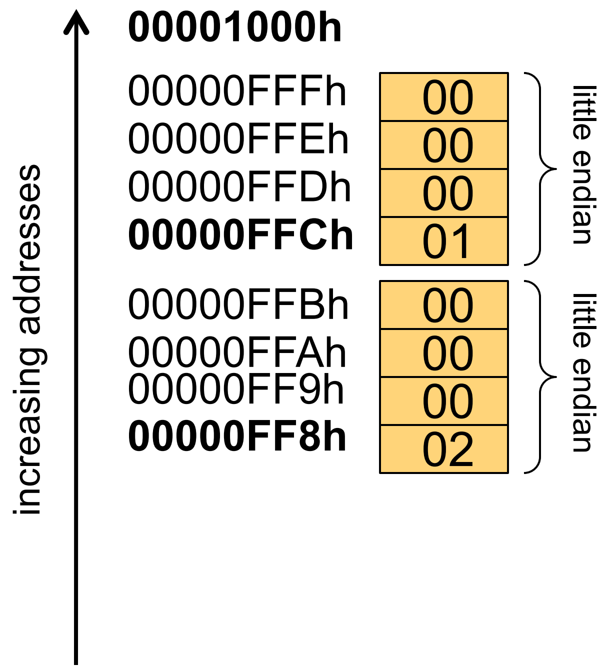
```
push    dword    1          ; ESP = 00000FFCh
```



Example Stack Instructions

- Assuming that ESP=00001000h

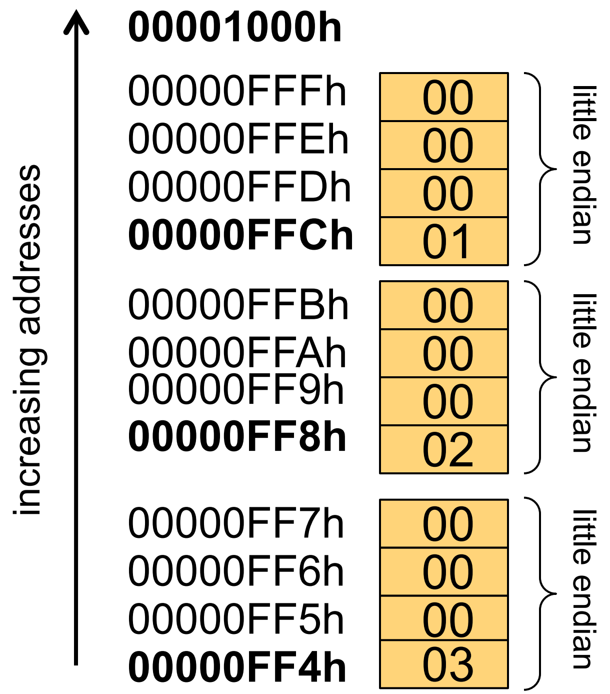
```
push    dword   1       ; ESP = 00000FFCh
push    dword   2       ; ESP = 00000FF8h
```



Example Stack Instructions

- Assuming that ESP=00001000h

push	dword	1	; ESP = 00000FFCh
push	dword	2	; ESP = 00000FF8h
push	dword	3	; ESP = 00000FF4h

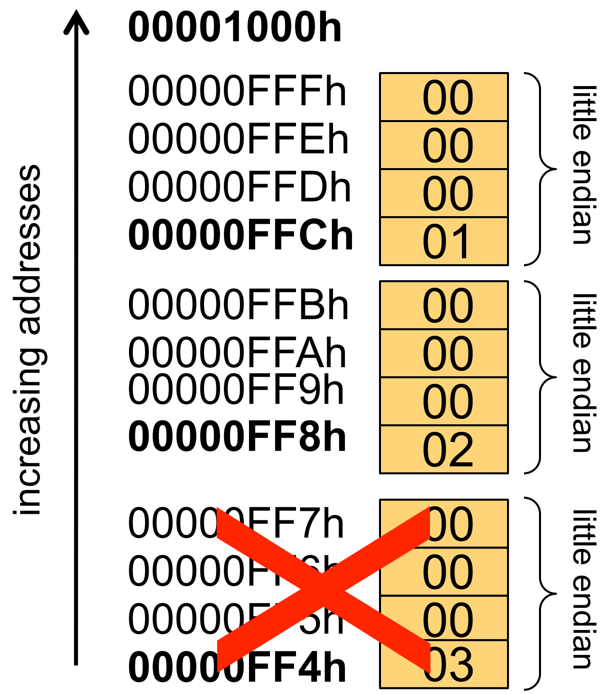


Example Stack Instructions

- Assuming that ESP=00001000h

```
push   dword   1        ; ESP = 00000FFCh
push   dword   2        ; ESP = 00000FF8h
push   dword   3        ; ESP = 00000FF4h

pop    eax              ; EAX = 3
```

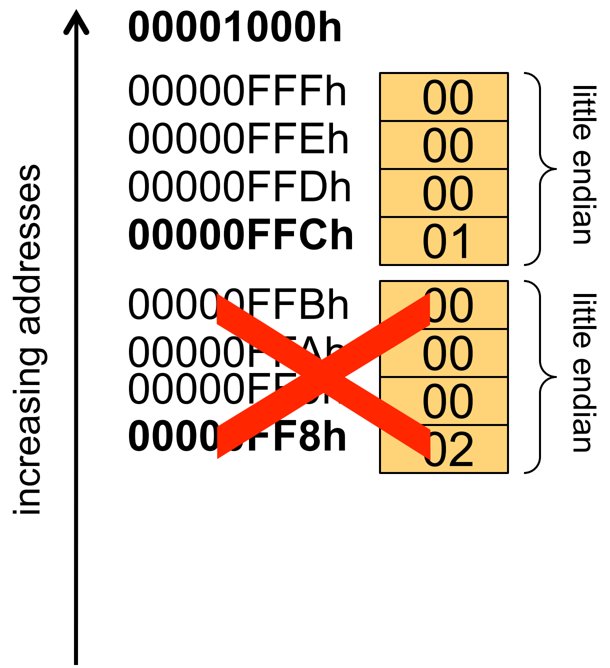


Example Stack Instructions

- Assuming that ESP=00001000h

```
push    dword   1          ; ESP = 00000FFCh
push    dword   2          ; ESP = 00000FF8h
push    dword   3          ; ESP = 00000FF4h

pop     eax                ; EAX = 3
pop     ebx                ; EBX = 2
```

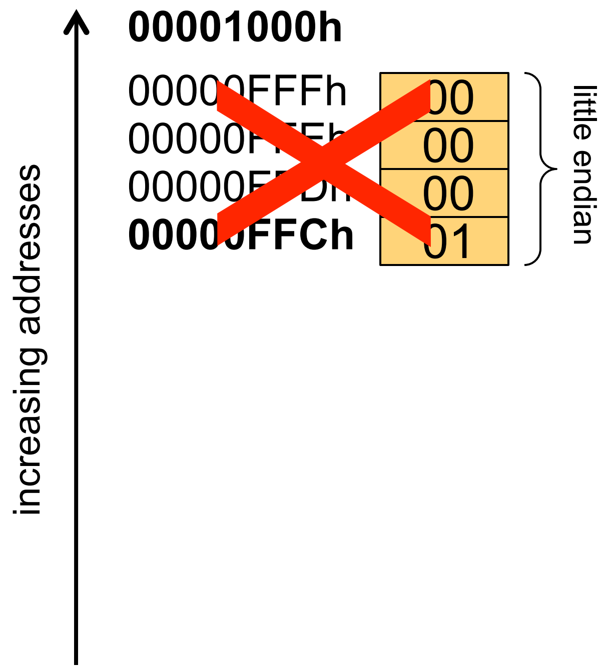


Example Stack Instructions

- Assuming that ESP=00001000h

```
push    dword   1        ; ESP = 00000FFCh
push    dword   2        ; ESP = 00000FF8h
push    dword   3        ; ESP = 00000FF4h

pop     eax              ; EAX = 3
pop     ebx              ; EBX = 2
pop     ecx              ; ECX = 1
```



The ESP Register

- The ESP register always contains the address of the element at the **top** of the stack
  - which is the "bottom" of the figure in the previous slide since the stack grows towards lower addresses
- IMPORTANT: Do not use ESP for anything else!
  - Even if you "run out" of registers, using ESP to store your data is not an option
- Its value is updated automatically by calls to push and pop, and a few other instructions
- In a few very specific and well-known cases we'll update it by hand
  - See this in a few slides

PUSHA and POPA

- For subprograms, the stack it used to save/restore register values
- Say your program uses ebx and calls a function written by somebody else
- You have no idea whether that function uses ebx, but if it does, your ebx will be corrupted
- One easy solution:
  - push ebx onto the stack
  - call the function and let it do its thing until it returns
  - pop the stack to restore the ebx value
- The x86 offers two convenient instructions
  - PUSHA: pushes EAX, EBX, ECX, EDX, ESI, EDI, and EBP onto the stack
  - POPA: pops the stack to restore them all
- We can say “save all my registers” and “restore all my registers”
  - Probably overkill, but safe and easy

Recall the NASM Skeleton

```
    ; 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
```

Save the registers since they may have been in use by the “driver” C program

Restore the registers so that the “driver” program will not be disrupted by the call to function asm_main

The CALL and RET Instructions

- One of the annoying things with our previous subprogram attempt was that we had to manage the return address
  - In our example we stored it into the ECX register
- Two convenient instructions can do this for us
- CALL:
  - Pushes the address of the next instruction on the stack
  - Unconditionally jumps to a label (calling a function)
- RET:
  - Pops the stack and gets the return address
  - Unconditionally jumps to that address (returning from a function)

Without CALL and RET

```
        . . .
        mov   ecx, return_here_1      ; store the return address
        jmp   func                    ; "call" the function
return_here_1:
        . . .
        mov   ecx, return_here_2      ; store the return address
        jmp   func                    ; "call" the function
return_here_2:
        . . .
func:
        . . .
        jmp   ecx                ; return
```

With CALL and RET

```
    . . .
    call   func             ; call the function
    . . .

    call   func             ; call the function
    . . .

func:
    . . .
    ret                     ; return
```

With CALL and RET

```
    . . .
    call  func          ; call the function
    . . .

    call  func          ; call the function
    . . .

func:
    . . .
    ret                 ; return
```

Looks almost like high-level code

Recall the NASM Skeleton

```
    ; 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
```

Returns from function asm_main

Nested Calls

- The use of the stack enables nested calls
  - Return addresses are popped in the reverse order in which they were pushed (Last-In-First-Out)
- Warning: one must be extremely careful to pop everything that's pushed on the stack inside a function
- Example of erroneous use of the stack:

```
func:
        mov   eax, 12       ; eax = 12
        push  eax           ; put eax on the stack
        ret                 ; pop eax and interpret
                            ; it as a return address!!
```

One example

- Let's write together a program in which the main program calls a function f that calls a function g
  - And try to see what happens if we "corrupt" the stack...

Conclusion

- The next set of lecture notes will talk about everything we can do with the stack
  - Much more than just storing return addresses!