x86 Assembly

Chapter 4-5, Irvine

Jump Instruction

- The JMP instruction tells the CPU to "Jump" to a new location. This is essentially a goto statement. We should load a new IP and possibly a new CS and then start executing code at the new location.
- Basic format:

```
Label1: inc ax
        …
        … do processing
        jmp Label1
```

This is an infinite loop without some way to exit out in the "do processing" code

Jump Extras

- On the x86 we have actually have three formats for the JMP instruction:
  - JMP SHORT destination
  - JMP NEAR PTR destination
  - JMP FAR PTR destination
- Here, destination is a label that is either within +128 or –127 bytes (SHORT), a label that is within the same segment (NEAR), or a label that is in a different segment (FAR). By default, it is assumed that the destination is NEAR unless the assembler can compute that the jump can be short.
- Examples:

```
jmp near ptr L1
jmp short L2
jmp far ptr L3          ; Jump to different segment
```

- Why the different types of jumps?
  - Space efficiency
  - In a short jump, the machine code includes a 1 byte value that is used as a displacement and added to the IP. For a backward jump, this is a negative value. For a forward jump, this is a positive value. This makes the short jump efficient and doesn't need much space.
  - In the other types of jumps, we'll need to store a 16 or 32 bit address as an operand.
  - Assembler will pick the right type for you if possible

Loop

- For loops, we have a specific LOOP instruction. This is an easy way to repeat a block of statements a specific number of times. The ECX register is automatically used as a counter and is decremented each time the loop repeats. The format is:

```
LOOP destination
```

- Here is a loop that repeats ten times

```
        mov ecx, 10
        mov eax, 0
start:  inc eax
        ...
        loop start          ; Jump back to start
        ; When we exit loop, eax=10, ecx=0
```

Be careful not to change ecx inside the loop by mistake!
The LOOP instruction decrements ecx so you don't have to

Loop in real mode

- In Real Mode, the LOOP instruction only works using the CX register. Since CX is 16 bits, this only lets you loop 64K times.
- If you have a 386 or higher processor, you can use the entire ECX register to loop up to 4Gb times or more. LOOPD uses the ECX doubleword for the loop counter:

```
.386
    mov ecx, 0A0000000h
    L1      .
            .
            loopd L1            ; loop A0000000h times
```

Indirect Addressing

- An indirect operand is generally a register that contains the offset of data in memory.
  - The register is a pointer to some data in memory.
  - Typically this data is used to do things like traverse arrays.
- In real mode, only the SI, DI, BX, and BP registers can be used for indirect addressing.
  - By default, SI, DI, and BX are assumed to be offsets from the DS (data segment) register; e.g. DS:BX is the absolute address
  - By default, BP is assumed to be an offset from the SS (stack segment) register; e.g. SS:BP is the absolute address
- The format to access the contents of memory pointed to by an indirect register is to enclose the register in square brackets.
  - E.g., if BX contains 100, then [BX] refers to the memory at DS:100.
- Based on the real mode limitations, many programmers also typically use ESI, EDI, EBX, and EBP in protected mode, although we can also use other registers if we like.

Indirect Addressing

- Example that sums three 8 bit values

```
.data
aList byte 10h, 20h, 30h
sum byte 0

.code
mov ebx, offset aList          ; EBX points to 10h
mov al, [ebx]                  ; move to AL
inc ebx                        ; BX points to 20h
add al, [ebx]                  ; add 20h to AL
inc ebx
add al, [ebx]
mov esi, offset sum            ; same as MOV sum, al
mov [esi], al                  ; in these two lines
exit
```

Indirect Addressing

- Here instead we add three 16-bit integers:

```
.data
wordlist word 1000h, 2000h, 3000h
sum word ?

.code
mov ebx, offset wordlist
mov ax,[ebx]
add ax,[ebx+2]                 ; Directly add offset of 2
add ax,[ebx+4]                 ; Directly add offset of 4
mov [ebx+6], ax                ; [ebx+6] is offset for sum
```

Indirect Addressing

- Here are some examples in real mode:

```
        Include Irvine16.inc
        .data
        aString db “ABCDEFG”, 0

        .code
        mov ax, @data                   ; Set up DS for our data segment
        mov ds, ax                      ; Don’t forget to include this for
                                        ; real mode.  Not needed in protected/32
                                        ; bit mode.
        mov bx, offset aString          ; BX points to “A”
        mov cx, 7
L1:     mov dl, [bx]                    ; Copy char to DL
        mov ah, 2                       ; 2 into AH, code for display char
        int 21h                         ; DOS routine to display
        inc bx                          ; Increment index
        loop L1
```

Indirect Addressing

- Can you figure out what this will do?
  - Recall B800:0000 is where text video memory begins

```
        mov ax, 0B800h
        mov ds, ax
        mov cx, 80*25
        mov si, 0
L:      mov [si], word ptr 0F041h   ; need word ptr to tell masm
                                    ; to move just one byte worth
                                    ; (0F041h could use a dword)
        add si, 2
        loop L
```

Based and Indexed Operands

- Based and indexed operands are essentially the same as indirect operands.
- A register is added to a displacement to generate an effective address.
  - The distinction between based and index is that BX and BP are “base” registers, while SI and DI are “index” registers.
  - As we saw in the previous example, we can use the SI index like it were a base register.

Based Register Examples

- There are many formats for using the base and index registers. One way is to use it as an offset from an identifier much like you would use a traditional array in C or C++:

```
.data
string byte “ABCDE”,0
array byte 1,2,3,4,5

.code
mov ebx, 2
mov ah, array[ebx]          ; move offset of array +2 to AH
                            ; this is the number 3
mov ah, string[ebx]         ; move character C to AH
```

- Another technique is to add the registers together explicitly:

```
mov ah, [array + ebx]       ; same as mov ah, array[bx]
mov ah, [string + ebx]      ; same as mov ah, string[bx]
```

Based Register Examples

We can also add together base registers and index registers:

```
mov bx, offset string
mov si, 2
mov ah, [bx + si]          ; same as mov ah, string[si],
                           ; number 3 copied to ah
```

However we cannot combine two base registers and two index registers. This is just another annoyance of non-orthogonality:

```
mov ah, [si + di]          ; INVALID
mov ah, [bp + bx]          ; INVALID
```

Based Register Examples

- Finally, one other equivalent format is to put two registers back to back. This has the same effect as adding them:

```
.data
string byte “ABCDE”,0
array byte 1,2,3,4,5

.code
mov ebx, 1
mov esi, 2
mov ah, array[ebx][esi]      ; Moves number 4 to ah, offset+1+2
mov ah, [array+ebx+esi]      ; Also moves 4 to ah
```

- Sometimes this format is useful for representing 2D arrays, although not quite the same as in Java or C

Irvine Link Library

- Irvine's book contains a link library
- The Irvine link library contains several useful routines to input data, output data, and perform several tasks that one would normally have to use many operating system calls to complete.
  - In actuality, the Irvine library is simply an interface to these OS calls (e.g., it invokes either DOS calls or Windows 32 library routines).
- This library is called irvine32.lib (for 32 bit protected mode) and irvine16.lib (for 16 bit real mode) and should have been installed when you installed the CD-ROM from the Irvine book.
- Chapter 5 contains a full list of the library routines. We will only cover a few basic ones here.

Using the Library

- Most of what you will use in the Irvine link library are various procedures. To invoke a procedure use the format:

```
call procedureName
```

- The call will push the IP onto the stack, and when the procedure returns, it will be popped off the stack and continue executing where we left off, just like a normal procedure in C++ or Java.
- The procedures will handle saving and restoring any registers that might be used.
- It is important to keep in mind that these are all high-level procedures – they were written by Irvine. That is, an x86 machine does not come standard with the procedures available. Consequently, if you ever wish to use these routines in other settings, you might need to write your own library routines or import the Irvine library.

Irvine Procedures

- Parameters are passed to Irvine's procedures through registers (this makes recursion difficult). Here are some of the procedures available:

Clrscr	Clears the screen, moves the cursor to the upper-left corner
Crlf	Writes a carriage return / linefeed to the display
Gotoxy	Locates the cursor at the specified X/Y coordinates on the screen. DH = row (0-24), DL = column (0-79)
Writechar	Writes a single character to the current cursor location AL contains the ASCII character
DumpRegs	Display the contents of the registers
ReadChar	Waits for a keypress. AH = key scan code AL = ASCII code of key pressed

Irvine Example

```
Include Irvine32.inc
.code
main proc
        call Clrscr
        mov dh, 24
        mov dl, 79              ; bottom-right corner
        call Gotoxy             ; Move cursor there
        mov al, '*'
        call WriteChar          ; Write '*' in bottom right
        call ReadChar           ; Character entered by user is in AL
        mov dh, 10
        mov dl, 10
        call Gotoxy
        call WriteChar          ; Output the character entered at 10,10
        call CrLf               ; Carriage return to line 11

        call DumpRegs           ; Output registers
        ; output a row of '&'s to the screen, minus first column
        mov al, '&'
        mov cx, 79
        mov dh, 5               ; row 5
L1:     mov dl, cl
        call Gotoxy
        call WriteChar
        loop L1
        call CrLf
        exit
main endp
end main
```

More Irvine Procedures

Randomize	Initialize random number seed
Random32	Generate a 32 bit random integer and return it in eax
RandomRange	Generate random integer from 0 to eax-1, return in eax
Readint	Waits for/reads a ASCII string and interprets as a a 32 bit value. Stored in EAX.
Readstring	Waits for/reads a ASCII string. Input: EDX contains the offset to store the string ECX contains max character count Output: EAX contains number of chars input
Writeint	Outputs EAX as a signed integer
Writestring	Write a null-terminated string. Input: EDX points to the offset of the string

Additional Example

```
Include Irvine32.inc
.data
myInt DWORD ?
myChar BYTE ?
myStr BYTE 30 dup(0)
myPrompt BYTE "Enter a string:",0
myPrompt2 BYTE "Enter a number:",0

.code
main proc
        ; Output 2 random numbers
        call Randomize          ; Only call randomize once
        call Random32
        call WriteInt           ; output EAX as int
        call Crlf
        move ax, 1000
        call RandomRange
        call WriteInt           ; output EAX as int, will be 0-999
        call Crlf
        ; Get and display a string
        mov edx, offset myprompt
        call Writestring        ; Display prompt
        mov ecx, 30             ; Max length of 30
        mov edx, offset myStr
        call Readstring
        call Writestring        ; Output what was typed
        Call Crlf
        ; Get a number and display it
        mov edx, offset myprompt2
        call Writestring        ; Display prompt
        call ReadInt            Int stored in EAX
        call Crlf
        call WriteInt
        call Crlf

        exit
main endp
end main
```

Other Procedures

- There are other procedures for displaying memory, command line arguments, hex, text colors, and dealing with binary values.
- See Chapter 5 of the textbook for details.

Procedures and Interrupts

- As programs become larger and written by many programmers, it quickly becomes difficult to manage writing code in one big procedure.
  - Much more useful to break a problem up into many modules, where each module is typically a function or method or procedure.
  - This is the idea behind modular programming that you should have seen in CS201.
- When a procedure is invoked
  - The current instruction pointer is pushed onto the stack along with the Flags
  - The IP is loaded with the address of the procedure.
  - Procedure executes
  - When the procedure exits, the old instruction pointer is popped off the stack and copied into the instruction pointer. The flags are also popped and copied into the flags register.
  - We then continue operation from the next instruction after the procedure invocation.

The Stack

- The stack is serving as a temporary storage area for the instruction pointer and flags. Although the IP is pushed and popped off the stack automatically, you can also use the stack yourself to save your own variables.
- The instruction to push something on the stack is PUSH:

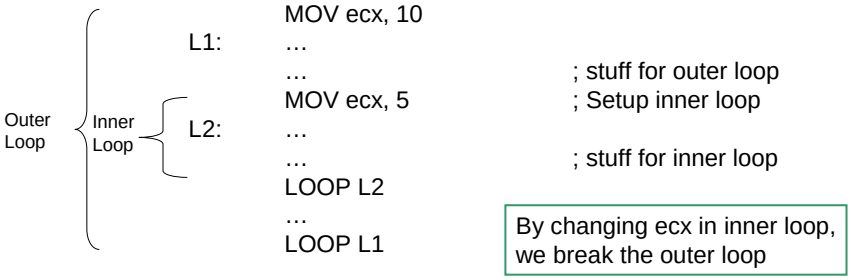
  PUSH register
  PUSH memval
- Two registers, CS and EIP, cannot be used as operands (why?)
- To get values off the stack, use POP:

  POP register ; top of stack goes into register
  POP memval ; top of stack goes into memval

Stack Example

- Essentially copies AX into BX by way of the stack.

  PUSH eax
  POP ebx
- A common purpose of the stack is to temporary save a value. For example, let's say that we want to make a nested loop, where the outer loop goes 10 times and the inner loop goes 5 times:



Fixed Loop with Stack

- An easy solution is to save the value in ECX before we execute the inner loop, and then restore it when we finish the inner loop

```
        MOV ecx, 10
L1:     …
        …                   ; stuff for outer loop
        PUSH ecx            ; Save ECX value in outer loop
        MOV ecx, 5          ; Setup inner loop
L2:     …
        …                   ; stuff for inner loop
        LOOP L2
        POP ECX             ; Restore ECX value in outer loop
        …
        LOOP L1
```

Make sure PUSH's always match the POP's

Other Uses of the Stack

- Another common place where values are pushed on the stack temporarily is when invoking a procedure call
  - If the procedure needs to use some registers to do its thing, prior values stored in these registers will be lost
  - Idea is to PUSH any registers that the procedure will change when the procedure first starts
  - Procedure then does its processing
  - POPs the registers off prior to returning to restore the original values
- Most high-level languages pass parameters to function by pushing them on the stack.
  - The procedure then accesses the parameters as offsets from the stack pointer.
  - This has the advantage that an arbitrary (up to the size of free space on the stack) number of parameters can be passed to the function.
  - In contrast, the Irvine Link Library and DOS interrupt routines pass parameters through registers. This has the disadvantage that a limited number of values can be passed, and we might also need to save the registers if the function changes them in some way. However, it is faster to pass parameters in registers than to pass them on the stack.

More Pushing and Popping

- One final PUSH and POP instruction is quite useful:

PUSHA	: Push ALL 16 bit registers on the stack, except for Flags Code Segment EIP, and Data Segment
POPA	: Pops ALL 16 bit registers off and restores them
PUSHAD	: Pushes all extended registers except above
POPAD	: Pops all extended registers

- If we want to save the flags registers, there is a special instruction for it:

PUSHF	: Push Flags
POPF	: Pop Flags

Writing Procedures

- You have already been using procedures; so far all code has gone into the “main” procedure. It is easy to define more:

```
<Procedure-Name> proc
        …
        …       ; code for procedure
        …
        ret     ; Return from the procedure
<Procedure-Name> endp
```

The keyword proc indicates the beginning of a procedure, and the keyword endp signals the end of the procedure. **Your procedure must use the RET instruction when the procedure is finished.** This causes the procedure to return by popping the instruction pointer off the stack.

Saving Registers

- Note that all other registers are not automatically pushed on the stack. Therefore, any procedures you write must be careful not to overwrite anything it shouldn't. You may want to push the registers that are used just in case, e.g.:

```
MyProc PROC
        Push EAX            ; If we use EAX, push it to save its value
        Push EBX
        …
        …                   ; Use EAX, EBX in here
        …
        POP EBX             ; Restore original value in EBX
        POP EAX             ; Restore original value in EAX
MyProc ENDP
```

Using Procedures

- To invoke a procedure, use call:

  call procedure-name

- Example:
  - This program uses a procedure to compute EAX raised to the EBX power (assuming EBX is a relatively small positive integer).
  - In this example we save all registers affected or used by the procedure, so it is a self-contained module without unknown side-effects to an outside calling program.

Power Procedure

```
Include Irvine32.inc
.data
.code
main proc
        mov eax, 3
        mov ebx, 9
        call Power ; Compute 3^9, result is stored in eax
        call WriteInt

        exit
main endp
power proc
        push ecx
        push edx   ; MUL changes EDX as a side effect
        push esi
        mov esi, eax
        mov ecx, ebx
        mov eax, 1
L1:     mul esi       ; EDX:EAX = EAX * ESI.
        loop L1
        pop esi
        pop edx
        pop ecx
        ret
power endp
end main
```

Procedures

- Note that we can also make recursive calls, just like we can in high-level languages.
- However, if we do so, we must push parameters on the stack so that there are separate copies of the variables for each invocation of the procedure instead of passing values through registers (equivalent of global variables)
- We can access these variables as offsets from the Stack Pointer; typically the Base Pointer is used for this purpose.
- Will see this later when we describe creating local variables

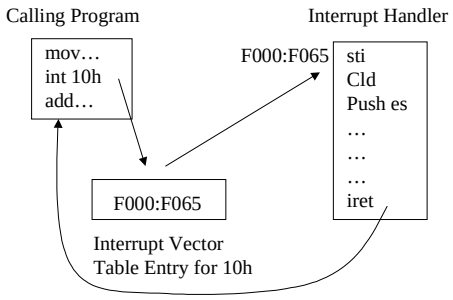
Software Interrupts

- Technically, a software interrupt is not really a "true" interrupt at all.
  - It is just a software routine that is invoked like a procedure when some hardware interrupt occurs.
  - However, we can use software interrupts to perform useful tasks, typically those provided by the operating system or BIOS.
- Here, we will look at software interrupts provided by MS-DOS.
  - A similar process exists for invoking Microsoft Windows routines (see Chapter 11).
  - Since we will be using MS-DOS, our programs must be constructed in real mode

Real Mode Interrupts

- Software interrupts in Real Mode are invoked with the INT instruction. The format is:

  INT <number>
- <Number> indicates which entry we want out of the interrupt vector table. For example:



Real Mode Interrupts

- The Real Mode interrupt handlers typically expect parameters to be passed in certain registers.
  - For example, DOS interrupt 21h with AH=2 indicates that we want to invoke the code to print a character.
- Here are some commonly used interrupt services

- INT 10h - Video Services
- INT 16h - Keyboard services
- INT 1Ah - Time of day
- INT 1Ch - User timer, executed 18.2 times per second
- INT 21h - DOS services

- See chapter 13, chapter 15, appendix C, and the web page linked from the CS221 home page for more information about all of these interrupts, particularly the DOS interrupt services.

BIOS Interrupts

- BIOS-Level Video Control (INT 10h) – Chapter 15.4-15.5
- INT 10h is used to set the video mode if we are in real mode
  - Early computers supported only monochrome, but later versions allowed for CGA, EGA, and VGA resolutions.
  - With the different modes we have different ways to display text (in various colors, for example), and different resolutions for graphics.

Video Modes

- Examples:

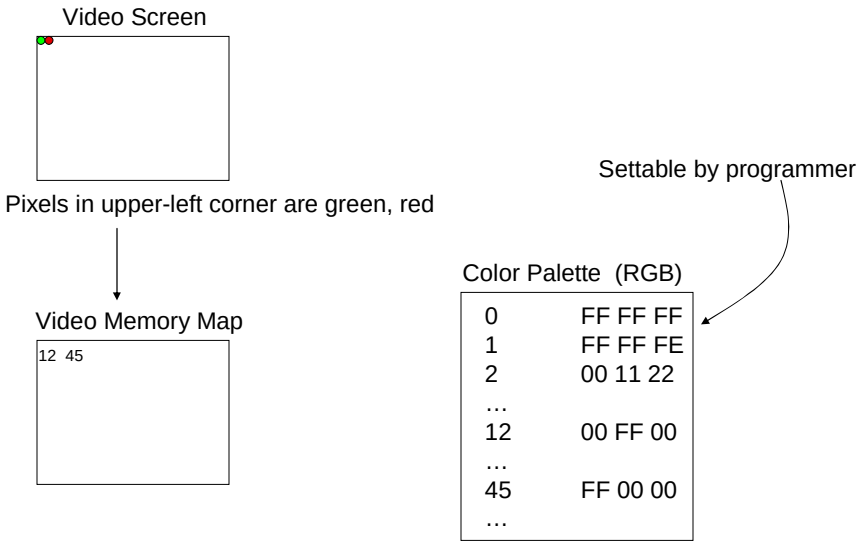
```
mov ah, 0          ; 0 in AH means to set video mode
mov al, 6          ; 640 x 200 graphics mode
int 10h

mov ah, 0
mov al, 3          ; 80x25 color text
int 10h

mov ah, 0
mov al, 13h        ; linear mode 320x200x256 color graphics
int 10h
```

Mode 13h sets the screen to graphics mode with a whopping 320x200 resolution and 256 colors. This means that each color is represented by one byte of data. There is a color palette stored on the video card that maps each number from 0-255 onto some color (e.g., 0=black, 1=dark grey, etc.). We can set these colors using the OUT instruction, but for our purposes we will just use the default palette.

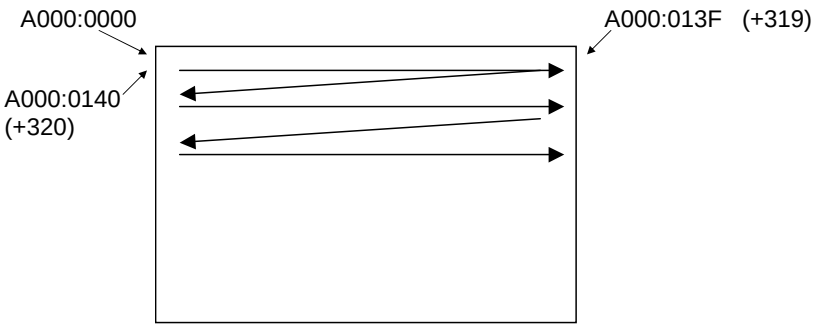
Palette Example



Mode 13h Video Memory Mapping

- Video memory begins at segment A0000:0000.
  - This memory location is mapped to the graphics video screen, just like we saw that memory at B800:0000 was mapped to the text video screen.
- The byte located at A000:0000 indicates the color of the pixel in the upper left hand corner (coordinate x=0,y=0).
  - If we move over one byte to A000:0001, this indicates the color of the pixel at coordinate (x=1, y=0).
  - Since this graphics mode gives us a total of 320 horizontal pixels, the very last pixel in the upper right corner is at memory address A000:013F, where 13F = 319 in decimal. The coordinate is (x=319, y=0).
  - The next memory address corresponds to the next row; A000:0140 is coordinate (x=0, y=1). The memory map fills the rows from left to right and columns from top to bottom.

Mode 13h Video Memory Mapping



Not only can we access pixels on the screen by referring to the memory address, but by storing data into those memory locations, we draw pixels on the screen.

Mode13h Example

- Can you figure out what this does?

```
Include Irvine16.inc
.data
mynum BYTE 3
.code
main proc
  mov ah, 0   ; Setup 320x200x256 graphics mode
  mov al, 13h
  int 10h

  mov ax, 0A000h  ; Move DS to graphics video buffer
  mov ds, ax

  mov ax, 128
  mov cx, 320
  mov bx, 0
L1:  mov [bx], al            ; Stores AL into DS:BX
  inc bx
  loop L1
  mov cx, 320
  mov ax, 120
  mov bx, 320*199
L2:  mov [bx], ax
  inc bx
  loop L2

  call Readchar
  mov ax, @data  ; Restore DS to our data segment
  mov ds, ax       ; Necessary if we want
                   ; to access any variables
                   ; since we changed DS to A000

  mov al, mynum   ; Stores DS:MyNum into AL
  mov ah, 0         ; Restore text video mode
  int 10h

  exit
main endp
end main
```

Offset from DS

- Notice how we must restore DS to @data (the location of our data segment) if we ever want to access variables defined in our segment.
  - This is because we changed DS to A000 to access video memory, and unless we change it back then we cannot access variables in our data segment.
  - If DS is set to A000, then
    mov myNum, 100
  - Would access some offset from video memory, not our data segment for myNum
- An alternate technique is to use the Extra Segment register. We can set ES to the segment we want, and then reference addresses relative to ES instead of the default of DS.

Mode 13h Example 2

```
Include Irvine16.inc
.data
.code
main proc
            mov ax, @data               ; set up DS register in case we
            mov ds, ax                  ; want to access any variables declared
                                        ; in .data.
            mov ah, 0                   ; Setup 320x200x256 graphics mode
            mov al, 13h
            int 10h

            mov ax, 0A000h              ; Move ES to graphics video buffer
            mov es, ax

            mov cx, 255                 ; Only loop up to 255 times
            mov bx, 0
L1:         mov es:[bx], bl             ; Move BL into [BX] instead of 128
            inc bx                      ; Note use of ES to override default DS
            loop L1

            call ReadChar

            mov ah, 0                   ; Restore text video mode
            mov al, 3
            int 10h

            exit
main endp
end main
```