Assembly Language

Lecture 4 – Data Transfers, Addressing, and Arithmetic

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Slides based on original lecture slides by Dr. Mahmoud Elgayyar

Outcomes of Lecture 3

- *Basic Elements of Assembly Language*
- *Example: Adding and Subtracting Integers*
- *Assembling, Linking, and Running Programs*
- *Defining Data*
- *Symbolic Constants*
- *Real-Address Mode Programming*

Outline

- *Data Transfer Instructions*
  - Operand types
  - MOV, MOVZX, MOVSX instructions
  - LAHF, SAHF instructions
  - XCHG instruction
- *Addition and Subtraction*
  - INC and DEC instructions
  - ADD, SUB instructions
  - NEG instruction
- *Data-Related Operators and Directives*
- *Indirect Addressing*
  - Arrays and pointers
- *JMP and LOOP instructions*

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Operand Types

- *Immediate – a constant integer (8, 16, or 32 bits)*
  - value is encoded within the instruction
- *Register – the name of a register*
- *Memory – reference to a location in memory*
  - memory address is encoded within the instruction, or a register holds the address of a memory location

```
.data
var1 BYTE 10h
;Suppose var1 were located at offset 10400h
mov AL,var1  → A0 00010400
```

Operand Notation

Operand	Description
reg8	8-bit general-purpose register: AH, AL, BH, BL, CH, CL, DH, DL
reg16	16-bit general-purpose register: AX, BX, CX, DX, SI, DI, SP, BP
reg32	32-bit general-purpose register: EAX, EBX, ECX, EDX, ESI, EDI, ESP, EBP
reg	Any general-purpose register
sreg	16-bit segment register: CS, DS, SS, ES, FS, GS
imm	8-, 16-, or 32-bit immediate value
imm8	8-bit immediate byte value
imm16	16-bit immediate word value
imm32	32-bit immediate doubleword value
reg/mem8	8-bit operand, which can be an 8-bit general register or memory byte
reg/mem16	16-bit operand, which can be a 16-bit general register or memory word
reg/mem32	32-bit operand, which can be a 32-bit general register or memory doubleword
mem	An 8-, 16-, or 32-bit memory operand

MOV Instruction

- *Move from source to destination*
- *Syntax:*

```
MOV destination, source
```

- *Both operands must be the* ***same size***
- *No more than* ***one memory operand*** *permitted*
- *CS, EIP, and IP* ***cannot*** *be the destination*
- *No* ***immediate*** *to segment registers moves*
- *Memory to Memory:*

```
.code
mov ax,var1
mov var2,ax
```

Direct Memory Operands

- *A direct memory operand is a named reference to storage in memory*
- *The named reference (label) is automatically dereferenced by the assembler*

```
.data
var1 BYTE 10h
.code
mov al,var1                     ; AL = 10h
mov al,[var1]                   ; AL = 10h
```

alternate format – Use consistently if you chose to use it

Use it only when an arithmetic expression is involved

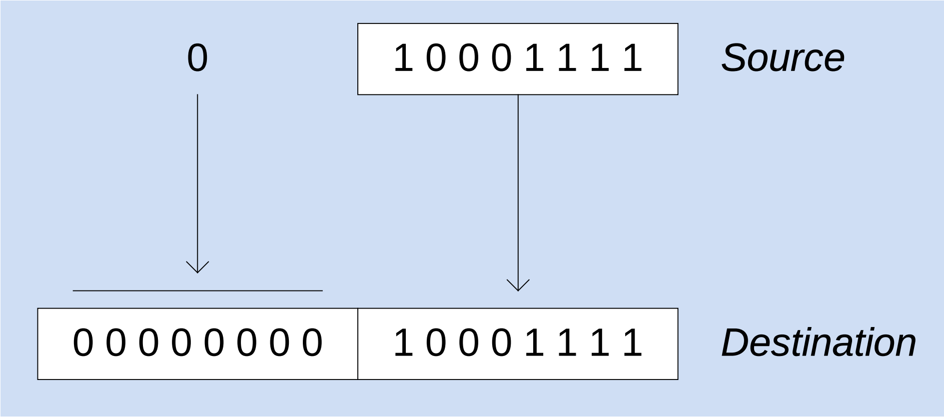
mov al, [var1 +5]

Mov Errors

```
.data

    bVal   BYTE    100
    bVal2  BYTE    ?
    wVal   WORD    2
    dVal   DWORD   5

.code

    mov al,wVal                 ; byte <- word
    mov ax,bVal                 ; word <- byte
    mov eax,bVal                ; dword <- byte
    mov ds,45                   ;immediate value not permitted
    mov eip,dVal                ;invalid destination (eip)
    mov 25,bVal                 ;invalid destination (25)
    mov bVal2,bVal              ;move in mem not permitted
```

Zero Extension

- *When you copy a smaller value into a larger destination, the MOVZX instruction fills (extends) the upper half of the destination with zeros*

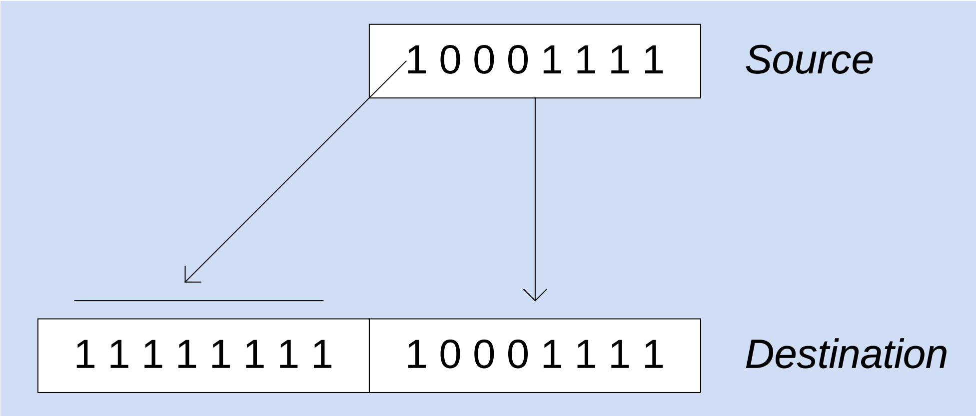



```
mov   bl,10001111b
movzx ax,bl                 ; zero-extension
```

The **destination** must be a **register**

Sign Extension

- *The MOVSX instruction fills the upper half of the destination with a copy of the source operand's sign bit*




```
mov   bl,10001111b
movsx ax,bl                ; sign extension
```

The **destination** must be a **register**

XCHG Instruction (swap)

- *XCHG exchanges the values of two operands*
- *At least **one operand** must be a register*
- *No immediate operands are permitted*

```
.data

   var1 WORD 1000h
   var2 WORD 2000h

.code
   xchg ax,bx          ; exchange 16-bit regs
   xchg ah,al          ; exchange 8-bit regs
   xchg var1,bx        ; exchange mem, reg
   xchg eax,ebx        ; exchange 32-bit regs

   xchg var1,var2      ; error: two memory operands
```

LAHF and SAHF Instructions

- *LAHF: loads status flags into AH*
  - Copies the low byte of the EFLAGS register including Sign, Zero, and Carry flags.
  - Save a copy of the flags in a variable for safekeeping

```
.data
    saveflags BYTE ?
.code
    lahf                    ; load flags into AH
    mov saveflags,ah        ; save them into a variable
```

- *SAHF: stores AH into status flags*
  - Copies AH into the low byte of the EFLAGS register
  - Retrieve the value of flags stored earlier

```
.code
    mov ah, saveflags       ; load save flags into AH
    sahf                    ; copy into flags register
```

Intel x86-16 bit flags

Bit #	Abbreviation	Description	Category
		FLAGS	
0	CF	Carry flag	Status
1	1	Reserved	
2	PF	Parity flag	Status
3	0	Reserved	
4	AF	Adjust flag	Status
5	0	Reserved	
6	ZF	Zero flag	Status
7	SF	Sign flag	Status
8	TF	Trap flag (single step)	Control
9	IF	Interrupt enable flag	Control
10	DF	Direction flag	Control
11	OF	Overflow flag	Status
12-13	IOPL	I/O privilege level (286+ only), always 1 on 8086 and 186	System
14	NT	Nested task flag (286+ only), always 1 on 8086 and 186	System
15	0	Reserved, always 1 on 8086 and 186, always 0 on later models	

Intel x86 flags

Bit #	Abbreviation	Description	Category
EFLAGS			
16	RF	Resume flag (386+ only)	System
17	VM	Virtual 8086 mode flag (386+ only)	System
18	AC	Alignment check (486SX+ only)	System
19	VIF	Virtual interrupt flag (Pentium+)	System
20	VIP	Virtual interrupt pending (Pentium+)	System
21	ID	Able to use CPUID instruction (Pentium+)	System
22	0	Reserved	
23	0	Reserved	
24	0	Reserved	
25	0	Reserved	
26	0	Reserved	
27	0	Reserved	
28	0	Reserved	
29	0	Reserved	
30	0	Reserved	
31	0	Reserved	
RFLAGS			
32-63	0	Reserved	

So Far…

1. *`mov`* *move, dest <- source*
2. *`movzx`* *move w. zero extend*
3. *`movsx`* *move w. sign extend*
4. *`xchg`* *swap a register with somewhere else*
5. *`lahf, sahf`* *loads/stores flag registers to/from AH*

- Don't move memory variables
- Match sizes

Direct-Offset Operands

- *A constant offset is added to a data label to produce an effective address (EA)*
  - that is ***de-referenced*** to get the value inside its memory location

```
.data

   arrayB BYTE 10h,20h,30h,40h

.code
   mov al,arrayB+1              ; AL = 20h
   mov al,[arrayB+1]            ; alternative notation
```

1. *Obtain address specified by label arrayB*
2. *Add 1 to address (to get second array element)*
3. *Dereference address to obtain value (20h)*

Examples

```
.data

    arrayW  WORD 1000h,2000h,3000h
    arrayD  DWORD 1,2,3,4

.code
    mov ax,[arrayW+2]               ; AX = 2000h
    mov ax,[arrayW+4]               ; AX = 3000h
    mov ax, [arrayW+6]              ; EAX = 00000002h
    mov eax,[arrayD+4]

                                    ; AX = 3000h
    mov eax,[arrayD-2]              ; Possible Seg Fault!
    mov eax,[arrayD+20]
```

There is no "range checking" – the address is calculated and used

Example 2

- *Write a program that adds the following three bytes:*

```
.data
    myBytes    BYTE    80h, 66h, 0A5h
```

- *Solution:*

```
mov al, myBytes
add al, [myBytes+1]
add al,[myBytes+2]
```

Find the error . . .

- *How about the following code. Is anything missing?*

```
.data
  myBytes     BYTE   80h,66h,0A5h

.code
        movzx ax,myBytes
        mov   bl,[myBytes+1]
        add   ax,bx
        mov   bl,[myBytes+2]
        add   ax,bx          ; AX = sum
```

What is in bx when we do the add? We loaded bl, what was in bh?

Review Questions

- *What are the three basic types of operands?*
- *(True/False): The destination operand of a MOV instruction cannot be a segment register.*
- *(True/False): In a MOV instruction, the second operand is known as the destination operand.*
- *(True/False): The EIP register cannot be the destination operand of a MOV instruction.*
- *In the operand notation used by Intel, what does reg/mem32 indicate?*
- *In the operand notation used by Intel, what does imm16 indicate?*

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INC and DEC Instructions

- *Add 1 or subtract 1 from operand*
  - operand may be <u>register or memory</u>
- *`INC` destination*
  - Logic: *destination* ← *destination* + 1

    (e.g., `destination++`)
- *DEC destination*
  - Logic: *destination* ← *destination* – 1

    (e.g., `destination--`)

INC and DEC Examples

```
.data

   myWord  WORD  1000h
   myDword DWORD 10000000h

.code
   inc myWord                    ; 1001h
   dec myWord                    ; 1000h
   inc myDword                   ; 10000001h

   mov ax,00FFh
   inc ax                        ; AX = 0100h
   mov ax,00FFh
   inc al                        ; AX = 0000h
```

ADD and SUB Instructions

- *ADD destination, source*
  - Logic: destination ← destination + source
- *SUB destination, source*
  - Logic: destination ← destination – source
- *Same operand rules as for the MOV instruction*

Examples

```
.data
   var1   DWORD 10000h
   var2   DWORD 20000h

.code
    mov eax,var1                ; 00010000h
    add eax,var2                ; 00030000h
    add ax,0FFFFh               ; 0003FFFFh
    add eax,1                   ; 00040000h
    sub ax,1                    ; 0004FFFFh
```

- ***Lesson***: *You can make yourself really confused and your code becomes garble if you keep using a register for different sized values (ax, al, eax, ah, ax, …)*
- *Pay attention to detail and know exactly what is in every part of a register*

NEG (negate) Instruction

- *Reverses the sign of an operand in a register or memory location (2nd complement)*

```
.data
   valB   BYTE -1
   valW   WORD +32767

.code
    mov al,valB             ; AL = -1
    neg al                  ; AL = +1
    neg valW                ; valW = -32767
```

- *Suppose AX contains –32,768 and we apply NEG to it. Will the result be valid? Remember, the max positive value is 32767   (**Try it**!!!)*

Performing Arithmetic

- *HLL compilers translate mathematical expressions into assembly language. You have to do it manually. For example:*

Rval = -Xval + (Yval – Zval)

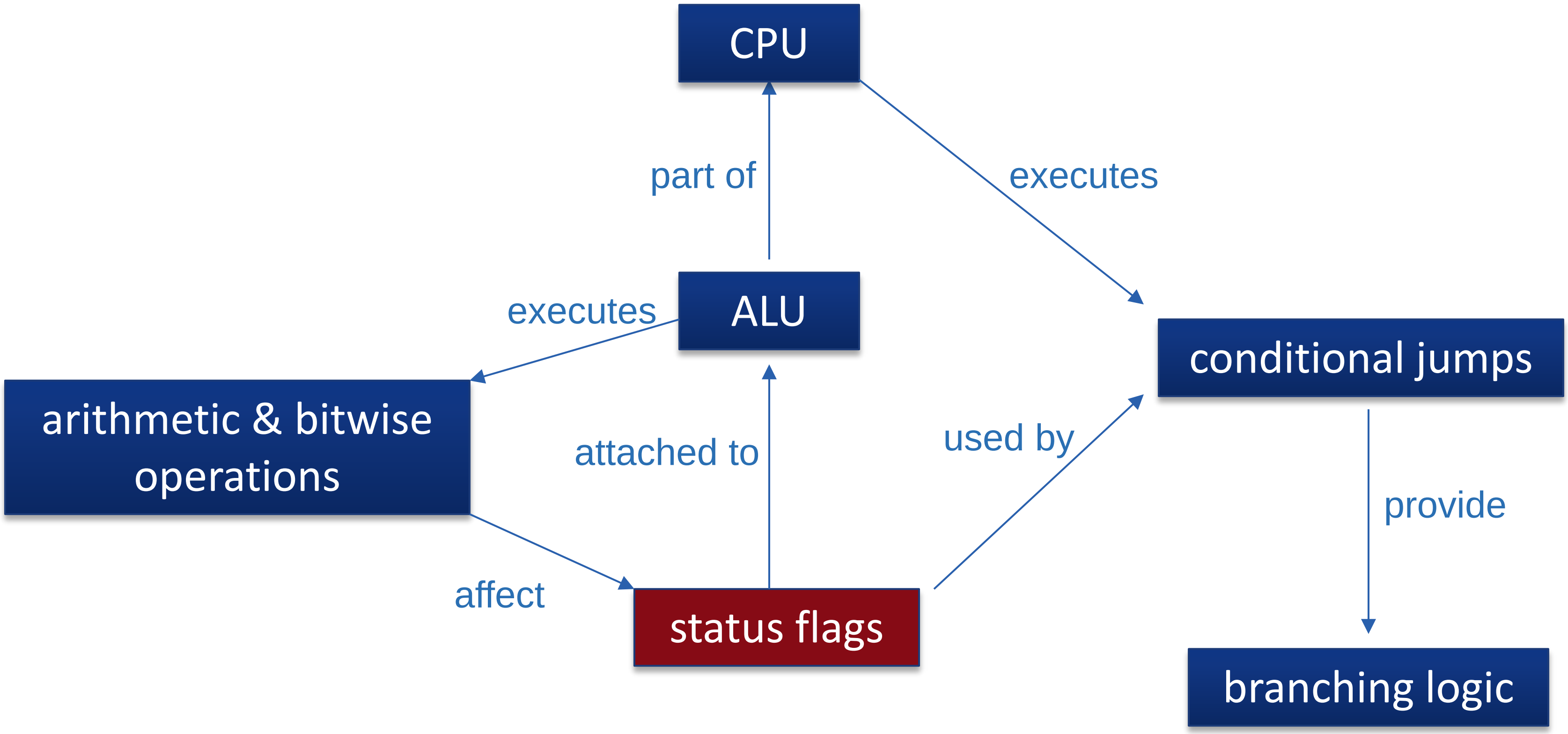
```
.data
    Rval DWORD ?
    Xval DWORD 26
    Yval DWORD 30
    Zval DWORD 40

.code
    ;first term :-Xval
    mov eax,Xval
    neg eax                     ; EAX = -26
    ;second term :Yval – Zval
    mov ebx,Yval
    sub ebx,Zval                ; EBX = -10
    ;add the terms and store the result
    add eax,ebx
    mov Rval,eax                ; -36
```

Flags Affected by Arithmetic

- *The ALU has a number of status flags that reflect the outcome of arithmetic (and bitwise) operations*
  - based on the contents of the ***destination operand*** after the operation
- *Essential flags:*
  - ***Zero flag –*** set when destination equals zero
  - ***Sign flag –*** set when destination is negative
  - ***Carry flag –*** set when unsigned value is out of range
  - ***Overflow flag –*** set when signed value is out of range.
- *The **MOV** instruction **never** affects the flags.*

Concept Map


CPU
part of
executes
ALU
executes
conditional jumps
arithmetic & bitwise operations
attached to
used by
provide
affect
status flags
branching logic

Zero Flag (ZF)

- *The Zero flag is set when the result of an operation* ***produces zero in the destination*** *operand*

```
mov cx,1
sub cx,1                ; CX = 0, ZF = 1
mov ax,0FFFFh
add ax,1                ; AX = 0, ZF = 1
add ax,1                ; AX = 1, ZF = 0
```

Remember...

- A flag is ***set*** when it equals 1
- A flag is ***clear*** when it equals 0

Sign Flag (SF)

- *The Sign flag is set when the destination operand is negative*

- *The flag is clear when the destination is positive*

```
mov cx,0
sub cx,1          ; CX = -1, SF = 1
add cx,2          ; CX =  1, SF = 0
```

- *The sign flag is a copy of the destination's highest bit*

```
mov al,0
sub al,1          ; AL = 11111111b, SF = 1
add al,2          ; AL = 00000001b, SF = 0
```

Signs on Integers

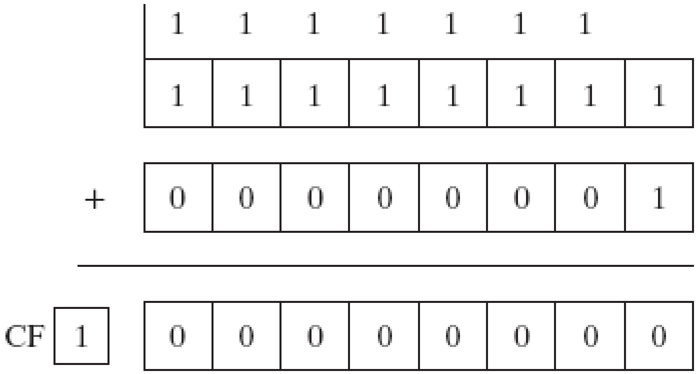
- *All CPU instructions operate exactly the same on signed and unsigned integers*
- *The CPU cannot distinguish between signed and unsigned integers*
- *YOU, the programmer, are solely responsible for using the correct data type with each instruction*

Carry Flag (CF)

- *The Carry flag is **concerned with the size error (unsigned arithmetic)***

```
mov al,0FFh
add al,1          ; CF = 1, AL = 00

mov ax,0FFh
add ax,1          ; CF = 0, AX = 0100h
```



More Examples

- *For each of the following marked entries, show the values of the destination operand and the Sign, Zero, and Carry flags:*

```
mov ax,00FFh

add ax,1          ; AX=0100h, SF=0 ZF=0 CF=0
sub ax,1          ; AX=00FFh, SF=0 ZF=0 CF=0
add al,1          ; AL=00h,   SF=0 ZF=1 CF=1

mov bh,6Ch
add bh,95h        ; BH=01h,   SF=0 ZF=0 CF=1

mov al,2
sub al,3          ; AL=FFh,   SF=1 ZF=0 CF=1
```

Overflow Flag (OF)

- *The Overflow flag is concerned with the **sign** error (signed **arithmetic**).*

```
mov al,+127
add al,1          ; OF = 1,   AL = -128

mov al,7Fh        ; OF = 1,   AL = 80h
add al,1
```

- *The two examples are identical at the binary level because*

7Fh = +127

80h = -128

- *To determine the value of the destination operand, it is often easier to calculate in hexadecimal*

Lesson: Work in one number system consistently (hex preferably)

Tricks

- *When adding two integers, remember that the Overflow flag is only set when . . .*
  - Two positive operands are added and their sum is negative
  - Two negative operands are added and their sum is positive

    The sign of the result is opposite the sign of the operands

```
What will be the values of the Overflow flag?
    mov al,80h                  ; (-128) + (-110)
    add al,92h                  ; OF = 1, al= 26

    mov al,-2
    add al,+127                 ; OF = 0
```

- Overflow never occurs when the signs of two addition operands are different.

  Sub a, b → add a, -b

A Rule of Thumb

- CF = (***carry out*** of the MSB)
- OF = Carry out ***XOR*** Carry in MSB

Add example:

mov al,01
add al,255

```
  0000 0001
+1111 1111
-----------------
  0000 0000
```

CarryIn=1
CarryOut=1

Then CF=1, OF=0

Sub Example:

mov al, 1
sub al, 128 ; al=1000 0001

In this example, the actual carry out= 0. However, the x86 processor invert this value and state the carry flag, then CF=1. Meanwhile, the Carry in of MSB=1 in the result of this operation. Thus:
if it's Carry flag xor MSB: then 1 xor 1 =0 (Wrong)
if it's Carry out xor Carry In of MSB: then 0 xor 1= 1 (Correct)

How it comes?

```
 0000 0001      0000 0001
-1000 0000 ->+0111 1111
                  +            1
----------------------------------
                   1000 0001
```

~~0000 0001~~
~~+ 1000 0000~~

CarryIn=1
CarryOut=0

Then CF=Inversion of CarryOut= 1
OF=CarryIn Xor Carryout=1

Flags Special Cases

- *INC and DEC instructions doesn't affect the Carry flag.*
- *Applying the NEG instruction to a nonzero operand always sets the Carry flag. (**sub 0, operand**)*

Warning

- *How does the CPU know whether an arithmetic operation is signed or unsigned?*
- *We can only give what seems a dumb answer: It doesn't!*
- *The CPU sets all status flags after an arithmetic operation using a set of Boolean rules,*
  - *regardless of which flags are relevant.*
  - You *(the programmer) decide which flags to interpret and which to ignore, based on your knowledge of the type of operation performed.*

Review Questions

1. *Implement the following expression in assembly language: AX = (-val2 + BX) - val4.*
2. *(Yes/No): Is it possible to set the Overflow flag if you add a positive integer to a negative integer?*
3. *(Yes/No): Is it possible for the NEG instruction to set the Overflow flag?*
4. *(Yes/No): Is it possible for both the Sign and Zero flags to be set at the same time?*
5. *Write a sequence of two instructions that set both the Carry and Overflow flags at the same time.*
6. *Write a sequence of instructions showing how the Zero flag could be used to indicate unsigned overflow (carry flag) after executing the INC instruction.*

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Align Directive

- *The ALIGN directive aligns a variable on a byte, word, doubleword, or paragraph boundary:*

```
.data
bVal    BYTE ?      ; 00404000
ALIGN 2
wVal    WORD ?      ; 00404002
bVal2   BYTE ?      ; 00404004
ALIGN 4
dVal    DWORD ?     ; 00404008
dVal2   DWORD ?     ; 0040400C
```

PTR Operator

- *Overrides the default type of a label (variable).*
- *Provides the flexibility to access part of a variable*
- *Requires a prefixed size specifier*

```
.data
   myDouble DWORD 12345678h
.code

   mov ax,myDouble                ;error! word<-dword

   mov ax,WORD PTR myDouble       ;loads 5678h

   mov WORD PTR myDouble,4321h    ;saves 4321h
```

Little Endian Order (again)

- *Little endian order refers to the way Intel stores integers in memory*
- *Multi-byte integers are stored in reverse order, with the* ***least significant byte stored at the lowest address***
- *For example, the DWORD 12345678h would be stored as:*

byte	offset
78	0000
56	0001
34	0002
12	0003

When integers are loaded from memory into registers, the bytes are automatically re-reversed into their correct positions

PTR Operator Examples

```
.data
   myDouble DWORD 12345678h
```

doubleword	word	byte	offset	
12345678	5678	78	0000	myDouble
		56	0001	myDouble + 1
	1234	34	0002	myDouble + 2
		12	0003	myDouble + 3

```
mov al,BYTE PTR  myDouble          ; AL = 78h
mov al,BYTE PTR [myDouble+1]       ; AL = 56h
mov al,BYTE PTR [myDouble+2]       ; AL = 34h
mov ax,WORD PTR  myDouble          ; AX = 5678h
mov ax,WORD PTR [myDouble+2]       ; AX = 1234h
```

Joining Words

- *PTR can also be used to combine elements of a smaller data type and move them into a larger operand*
- *The CPU will automatically reverse the bytes*

```
.data
    myBytes BYTE 12h,34h,56h,78h
.code
   mov ax,WORD PTR [myBytes]          ; AX = 3412h
    mov ax,WORD PTR [myBytes+2]       ; AX = 7856h
    mov eax,DWORD PTR myBytes         ; EAX = 78563412h
```

More Examples

```
.data
   varB BYTE 65h,31h,02h,05h
   varW WORD 6543h,1202h
   varD DWORD 12345678h

.code
     mov ax,WORD PTR [varB+2]          ; ax=0502h
     mov bl,BYTE PTR varD              ; bl=78h
     mov bl,BYTE PTR [varW+2]          ; bl=02h
     mov ax,WORD PTR [varD+2]          ; ax=1234h
     mov eax,DWORD PTR varW            ; eax=12026543h
```

TYPE Operator

- *The TYPE operator returns the size in bytes of a single element of a data declaration*

```
.data
    var1  BYTE ?
    var2  WORD ?
    var3  DWORD ?
    var4  QWORD ?

.code
     mov eax,TYPE var1      ; 1
     mov eax,TYPE var2      ; 2
     mov eax,TYPE var3      ; 4
     mov eax,TYPE var4      ; 8
```

LENGTHOF Operator

- *The LENGTHOF operator counts the number of elements in a single data declaration*

```
.data                                      LENGTHOF
   byte1    BYTE 10,20,30                    ; 3
   array1   WORD 30 DUP(?),0,0               ; 32
   array2   WORD 5 DUP(3 DUP(?))             ; 15
   array3   DWORD 1,2,3,4                    ; 4
   digitStr BYTE "12345678",0                ; 9
.code
    mov ecx,LENGTHOF array1                  ; 32
```

SIZEOF Operator

- *The SIZEOF operator is equivalent to multiplying:*

SIZEOF = LENGTHOF * TYPE

```
.data                                         SIZEOF
byte1    BYTE 10,20,30                        ; 3
array1   WORD 30 DUP(?),0,0                   ; 64
array2   WORD 5 DUP(3 DUP(?))                 ; 30
array3   DWORD 1,2,3,4                        ; 16
digitStr BYTE "12345678",0                    ; 9
.code
         mov ecx,SIZEOF array1                ; 64
```

Summary

- ***OFFSET:*** *Distance from beginning of data segment (i.e., a partial address)*
- ***PTR:*** *Changes the size of a value (i.e., a cast)*
- ***TYPE:*** *Size in bytes of a value*
- ***LENGTHOF:*** *Number of data elements*
- ***SIZEOF:*** *TYPE * LENGTHOF (i.e., total bytes used)*

Spanning Multiple Lines

- *A data declaration spans multiple lines if each line (except the last) ends with a comma*
- *The LENGTHOF and SIZEOF operators include all lines belonging to the declaration*

```
.data
array WORD  10,20,
            30,40,
            50,60

.code
            mov eax,LENGTHOF array   ; eax=6

            mov ebx,SIZEOF array     ; eax=12
```

Contrast: Anonymous Data

- *In the following example, array identifies only the first WORD declaration, with 2 values, even though the name can be used to access all 6 words*
- *SIZEOF/LENGTHOF are assembly directives, NOT runtime instructions*

```
.data
array  WORD 10,20     ; array ends here
       WORD 30,40     ; anonymous data, array+4
       WORD 50,60     ; array+8

.code
        mov eax,LENGTHOF array    ; 2

        mov ebx,SIZEOF array      ; 4
```

LABEL Directive

- *Assigns an alternate label name and type to an existing storage location*
- *LABEL* ***does not allocate any storage*** *of its own*
- *Avoids the need for the PTR operator*

```
.data
      dwList   LABEL DWORD
      wordList LABEL WORD
      byteList  BYTE 00h,10h,00h,20h
.code
      mov eax,dwList          ; 20001000h
      mov cx,wordList         ; 1000h
      mov dl,intList          ; 00h
```

dwList, wordList, intList are the same offset (address)

Review Questions

1. *(True/False): The PTR operator returns the 32-bit address of a variable.*
2. *(True/False): The TYPE operator returns a value of 4 for doubleword operands.*
3. *(True/False): The LENGTHOF operator returns the number of bytes in an operand.*
4. *(True/False): The SIZEOF operator returns the number of bytes in an operand.*

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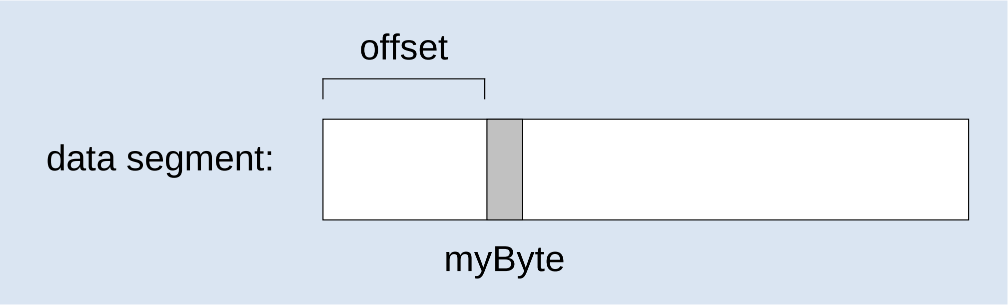
  - LAHF, SAHF instructions
  - XCHG instruction
- *Addition and Subtraction*
  - INC and DEC instructions
  - ADD, SUB instructions
  - NEG instruction
- *Data-Related Operators and Directives*
- ***Indirect Addressing***
  - Arrays and pointers
- *JMP and LOOP instructions*

OFFSET Operator

- *OFFSET returns the distance in bytes of a label from the beginning of its enclosing segment*
  - ***Protected mode: 32 bits***
  - Real mode: 16 bits



The Protected-Mode programs we write use only a single data segment due to the flat memory model

OFFSET Examples

- *Assume that bVal were located at offset 00404000h:*

```
.data
   bVal  BYTE ?
   wVal  WORD ?
   dVal  DWORD ?
   dVal2 DWORD ?

.code

   mov esi,OFFSET bVal  ; ESI = 00404000

   mov esi,OFFSET wVal  ; ESI = 00404001

   mov esi,OFFSET dVal  ; ESI = 00404003

   mov esi,OFFSET dVal2 ; ESI = 00404007
```

Indirect Operands (Register as a pointer)

- *An indirect operand holds the address of a variable, usually an array or string*
- *It can be de-referenced (just like a pointer) using [and]*
- *Works with OFFSET to produce the address to de-reference*

```
.data
   val1 BYTE 10h,20h,30h
.code
    mov esi,OFFSET val1    ; esi stores address of val1
    mov al,[esi]           ; dereference ESI (AL = 10h)

    inc esi
    mov al,[esi]           ; AL = 20h

    inc esi
    mov al,[esi]           ; AL = 30h
```

NOTE: We tend to use esi and edi to store addresses

Relating to C/C++

```
// C++ version:

char array[1000];
char * p = array;
```

```
; Assembly language:

.data
   array BYTE 1000 DUP(?)
.code
  mov esi,OFFSET array
```

Using PTR

- *Use PTR to clarify the size attribute of a memory operand*
- *When we have an address (offset) we don't know the size of the values at that offset and must specify them explicitly*

```
.data
   myCount WORD 0

.code
    mov esi,OFFSET myCount

    inc [esi]                 ; error: operand must have size
    inc WORD PTR [esi]        ; ok

    add [esi],20              ; error:..
    add ax, [esi]             ; ax or al specifies the size
    add WORD PTR [esi],20 ; ok
```

Array Sum Example

- *Indirect operands are ideal for traversing an array*
- *Note: the register in brackets must be incremented by a value that matches the array TYPE (i.e., 2 for WORD, 4 for DWORD, 8 for QWORD)*

```
.data
   arrayW WORD 1000h,2000h,3000h
.code
       mov esi,OFFSET arrayW
       mov ax,[esi]
       add esi,2
       ;or    add esi,TYPE arrayW     ; good clarity
       add ax,[esi]
       add esi,2
       add ax,[esi]               ; AX = sum of the array
```

Indirect operand (variable as a pointer)

- *Offsets are of size DWORD*
- *A variable of size DWORD can hold an offset*
- *i.e., you can declare a pointer variable that contains the offset of another variable.*

```
.data
   arrayW WORD  1000h,2000h,3000h
   ptrW   DWORD arrayW         ; ptrW = offset of arrayW
   ; Alternative – same as above
   ;ptrW  DWORD OFFSET arrayW

.code
       mov esi,ptrW

       mov ax,[esi]        ; AX = 1000h
```

Indexed Operands

- *An indexed operand adds an address and a register to generate an effective address*
- *There are two notational forms:*
  - [label + reg]
  - label[reg]

```
.data
    arrayW WORD 1000h,2000h,3000h
.code
    mov esi,0
    mov ax,[arrayW + esi]           ; AX = 1000h
    mov ax,arrayW[esi]              ; alternate format
    add esi,TYPE arrayW
    add ax,[arrayW + esi]
```

Index Scaling

- *You can scale an indirect or indexed operand to the offset of an array element by multiplying the index by the array's TYPE:*

```
.data
   arrayB  BYTE  0,1,2,3,4,5
   arrayW  WORD  0,1,2,3,4,5
   arrayD  DWORD 0,1,2,3,4,5

.code
    mov esi,4
    mov al,arrayB[esi*TYPE arrayB]            ; 04
    mov bx,arrayW[esi*TYPE arrayW]            ; 0004
    mov edx,arrayD[esi*TYPE arrayD]           ; 00000004
```

Review Questions

1. *(True/False): The OFFSET operator always returns a 16-bit value.*
2. *(True/False): Any 32-bit general-purpose register can be used as an indirect operand.*
3. *(True/False): The BX register is usually reserved for addressing the stack.*
4. *(True/False): The following instruction is invalid: inc [esi]*
5. *(True/False): The following is an indexed operand: array[esi]*

Outline

- *Data Transfer Instructions*
  - Operand types
  - MOV, MOVZX, MOVSX instructions
  - LAHF, SAHF instructions
  - XCHG instruction
- *Addition and Subtraction*
  - INC and DEC instructions
  - ADD, SUB instructions
  - NEG instruction
- *Data-Related Operators and Directives*
- *Indirect Addressing*
  - Arrays and pointers
- ***JMP and LOOP instructions***

JMP Instruction

- *Jumps are the basis of most control flow*
- *HLL compilers turn loops, if statements, switches etc. into some kind of jump*
- *JMP is an* ***unconditional jump*** *to a label that is usually within the same procedure.*
- *Syntax: JMP target*
- *Logic: EIP $\leftarrow$ target*

Example

```
top:
    .
    .
    jmp top
```

A jump outside the current procedure must be to a special type of label called a global label (which we will examine when we examine procedures)

LOOP Instruction

- *The LOOP instruction creates a **counted loop** using ECX*
- *Syntax: LOOP target*
- *target should precede the instruction*
  - ECX must contain the iteration count
- *Logic:*
  - ECX ← ECX – 1
  - if ECX != 0, jump back to target, else go to next instruction

```
    mov   ax,0
    mov   ecx,5

L1:
    add   ax,cx

    loop  L1
```

This loop calculates the sum:
5 + 4 + 3 +2 + 1

Examples

```
    mov ax,6
    mov ecx,4       ;Loop 4 times
L1:
    inc ax          ;Each iteration ax++ (7,8,9,10)
    loop L1
```

```
    mov ecx,0       ;ecx starts at 0! (an error)
X2:
    inc ax          ;ax++ until ecx holds 0
    loop X2         ;ecx– (-1,-2,-3, . . .)

;ax = 4294967296 when you exit the loop
```

Nested Loops

- *If you need to code a loop within a loop, you must save the outer loop counter's ECX value*
- *In this example, the outer loop executes 100 times, and the inner loop 20 times*

```
.data
   count DWORD ?
.code
    mov ecx,100            ; set outer loop count
L1:
      mov count,ecx        ; save outer loop count
      mov ecx,20           ; set inner loop count
L2: .
    .
      loop L2              ; repeat the inner loop
      mov ecx,count        ; restore outer loop count
      loop L1              ; repeat the outer loop
```

Summing an Array

```
.data
    intarray WORD 100h,200h,300h,400h
.code
    mov edi,OFFSET intarray        ; address of intarray
    mov ecx,LENGTHOF intarray      ; loop counter
    mov ax,0                       ; zero the accumulator
L1:

    add ax,[edi]                    ; add an integer
    add edi,TYPE intarray           ; point to next integer

    loop L1                         ; repeat until ECX = 0
```

Copying a String

```
.data
   source  BYTE  "This is the source string",0
   target  BYTE  SIZEOF source DUP(0)

.code
   mov  esi,0                     ; index register
   mov  ecx,SIZEOF source         ; loop counter
L1:
   mov  al,source[esi]            ; get char from source
   mov  target[esi],al            ; store it in the target
   inc  esi                       ; move to next character

   loop L1                        ; repeat for entire string
```

Review Questions

1. *(True/False): A JMP instruction can only jump to a label inside the current procedure.*
2. *(True/False): The LOOP instruction first checks to see whether ECX is not equal to zero; then LOOP decrements ECX and jumps to the destination label.*
3. *(Challenge): What will be the final value of EAX in this example?*

```
        mov eax,0
        mov ecx,10          ; outer loop counter
L1:
        mov eax,3
        mov ecx,5           ; inner loop counter
L2:
        add eax,5
        loop L2             ; repeat inner loop
        loop L1             ; repeat outer loop
```

4. *Revise the code from the preceding question so the outer loop counter is not erased when the inner loop starts.*

Summary

- *Data Transfer*
  - MOV – data transfer from source to destination
  - MOVSX, MOVZX, XCHG
- *Operand types*
  - direct, direct-offset, indirect, indexed
- *Arithmetic*
  - INC, DEC, ADD, SUB, NEG
  - Sign, Carry, Zero, Overflow flags
- *Operators*
  - OFFSET, PTR, TYPE, LENGTHOF, SIZEOF, TYPEDEF
- *JMP and LOOP – branching instructions*