EE-2003
Computer Organization & Assembly Language

Chapter No: 04

Data Transfers, Addressing, and Arithmetic

OUTLINE

- DATA TRANSFER INSTRUCTIONS
- ADDITION AND SUBTRACTION
- DATA RELATED OPERATORS AND DIRECTIVES
- INDIRECT ADDRESSING
- JMP AND LOOP INSTRUCTIONS

DATA TRANSFER INSTRUCTION

Operand Types

- •Instructions in assembly language can have zero, one, two, or three operands.
- •mnemonic
- •mnemonic [destination]
- •mnemonic [destination],[source]
- •mnemonic [destination],[source1],[source2]

DATA TRANSFER INSTRUCTION

- The three types of operands are:

1. **Immediate:** a numeric literal expression /a constant integer (8, 16, or 32 bits), value is encoded within the instruction.

2. **Register:** the name of a register, register name is converted to a number and encoded within the instruction.

3. **Memory:** references a location in memory, memory address is encoded within the instruction, or a register holds the address of a memory location.

```
mov al var1
 A0 00010400
```

DATA TRANSFER INSTRUCTION

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

DATA TRANSFER INSTRUCTION

- **Direct Memory Operands**

  - Variable names are references to offsets within the data segment.

  - 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

MOV INSTRUCTION

- The MOV instruction copies data from a source operand to a destination operand. Known as a data transfer instruction.

MOV destination,source

- Both operands must be the same size.
- Both operands cannot be memory operands.
- The instruction pointer register (IP, EIP) and CS cannot be a destination operand.

```
MOV reg,reg
MOV mem,reg
MOV reg,mem
MOV mem,imm
MOV reg,imm
```

MOV INSTRUCTION

```
.data
     count BYTE 100
     wVal  WORD 2
```

```
.code
     mov bl,count
     mov ax,wVal
     mov count,al
```

ABOVE INSTRUCTIONS ARE CORRECT??

```
mov al,wVal
mov ax,count
mov eax,count
```

ABOVE INSTRUCTIONS ARE CORRECT??

Mistakes??

MOVZX INSTRUCTION

- **Zero Extension**

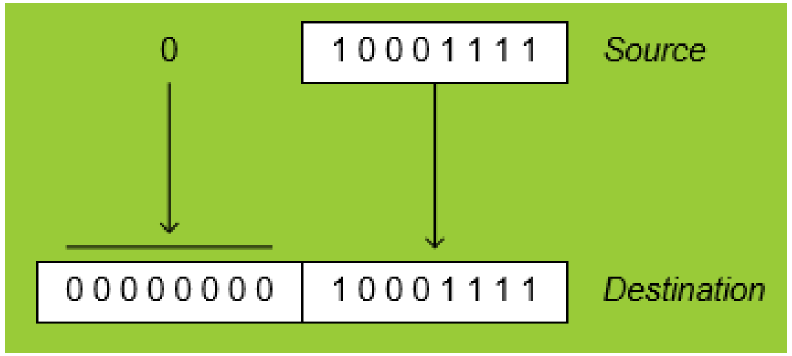
•MOV instruction cannot directly copy data from a smaller operand to a larger one.

mov bl,10001111b

mov ax,bl ; error

•**MOVZX (move with zero-extend) instruction** fills (extends) the upper half of the destination with zeros.

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



EXERCISE

```
.data
        byte1  BYTE  9Bh
        word1  WORD  0A69Bh
```

```
.code
        movzx eax,word1
        movzx edx,byte1
        movzx cx,byte1
```

Write down values of registers

```
EAX = 0000A69Bh
EDX = 0000009Bh
CX = 009Bh
```

EXERCISE

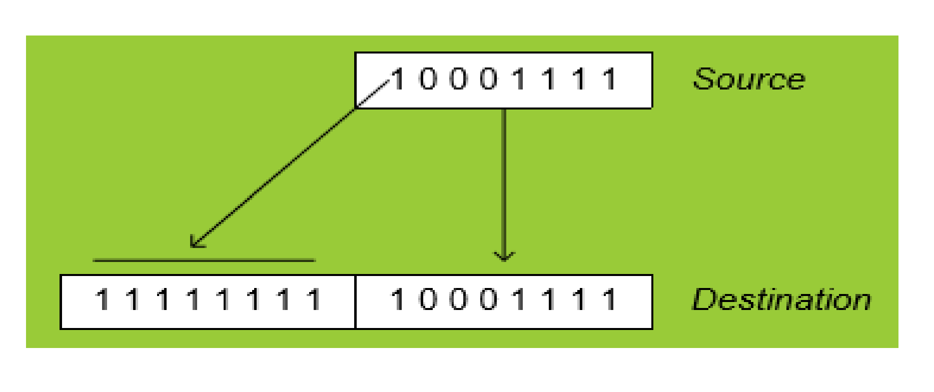
Write down values of registers

```
.data
oneByte BYTE 78h
oneWord WORD 1234h
oneDword DWORD 12345678h
.code
mov   eax,0           ; EAX = 00000000h
mov   al,oneByte      ; EAX = 00000078h
mov   ax,oneWord      ; EAX = 00001234h
mov   eax,oneDword    ; EAX = 12345678h
mov   ax,0            ; EAX = 12340000h
```

MOVSX INSTRUCTION

- The **MOVSX instruction (move with sign-extend)** copies the contents of a source operand into a destination operand and 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
```



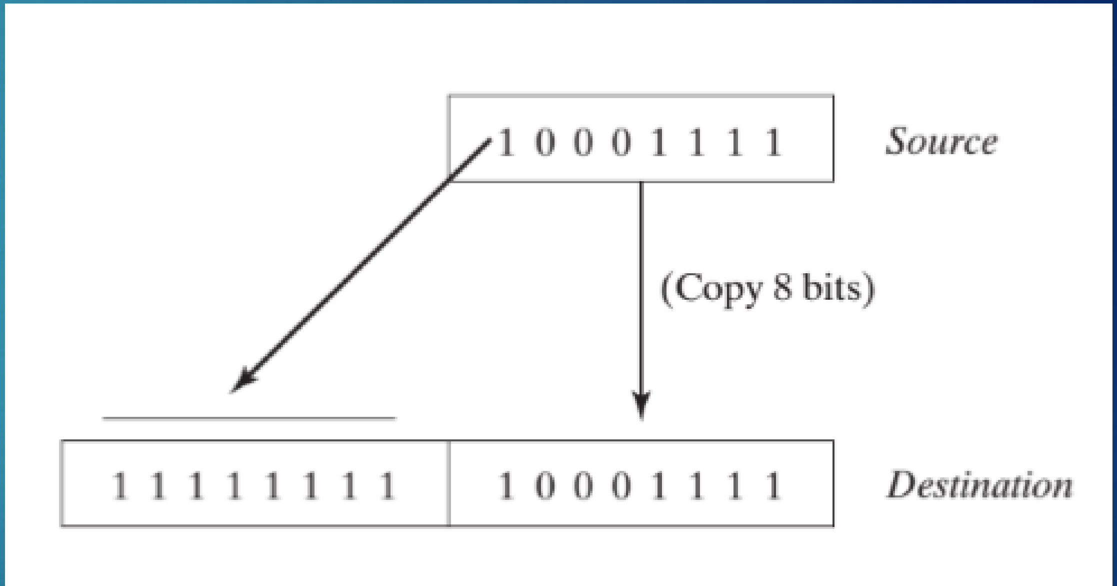
EXERCISE

```
.data
        byteVal BYTE 10001111b
```

```
.code
        movsx  ax,byteVal
```

Write down values ax.

AX = 1111111110001111b



XCHG INSTRUCTION

- The XCHG (exchange data) instruction exchanges the contents of two operands.

- There are three variants:

```
XCHG reg, reg
XCHG reg, mem
XCHG mem, reg
```

- You can exchange data between registers or between registers and memory, **but not from memory to memory**:

```
xchg    ax, bx         ; Put AX in BX and BX in AX
xchg    memory, ax     ; Put "memory" in AX and AX in "memory"
xchg    mem1, mem2     ; Illegal, can't exchange memory locations!
```

XCHG INSTRUCTION

- The rules for operands in the XCHG instruction are the same as those for the MOV instruction...

  ...except that XCHG does not accept immediate operands.

- In array sorting applications, XCHG provides a simple way to exchange two array elements.

```
xchg  ax,  bx  ; exchange 16-bit regs
xchg  ah,  al  ; exchange 8-bit regs
xchg  eax, ebx ; exchange 32-bit regs
xchg  [response], cl  ; exchange 8-bit mem op with CL
xchg  [total],    edx ; exchange 32-bit mem op with EDX
```

EXERCISE

```
.DATA
    val1  WORD 1000h
    val2  WORD 2000h
```

Write down contents of ax
And memory locations after
Execution of each instruction.

```
.CODE
    mov   ax,   [val1]
    xchg  ax,   [val2]
    mov   [val1], ax
```

Direct-Offset Operands

- lets you access memory locations that may not have explicit labels.

- A constant is added to a data label to produce an effective address (EA). The address is dereferenced to get the value inside its memory location.

```
.data
   arrayB BYTE 10h,20h,30h,40h
```

```
.code
    mov  al,arrayB+1
    mov  al,[arrayB+1]
```

Direct-Offset Operands

- **WORD Arrays**; In an array of 16-bit words, the offset of each array element is 2 bytes beyond the previous one.
- That's why 2 is added as offset in Array (for each next element of an array)

```
 .data
 arrayW WORD 100h,200h,300h
 .code
mov  ax,arrayW                    ; AX = 100h
mov  ax,[arrayW+2]                ; AX = 200h
```

- **DWORD Arrays**; In an array of 32-bit words, the offset of each array element is 4 bytes beyond the previous one.
- That's why 4 is added as offset in Array (for each next element of an array)

```
 .data
 arrayD DWORD 10000h,20000h
 .code
mov  eax,arrayD                   ; EAX = 10000h
mov  eax,[arrayD+4]               ; EAX = 20000h
```

EXAMPLE PROGRAM (MOVES)

```
.data
val1 WORD 1000h
val2 WORD 2000h
arrayB BYTE 10h,20h,30h,40h,50h
arrayW WORD 100h,200h,300h
arrayD DWORD 10000h,20000h
```

```
.code
main PROC

    mov bx,0A69Bh
    movzx eax,bx
    movzx edx,bl
    movzx cx,bl

    mov bx,0A69Bh
    movsx eax,bx
    movsx edx,bl
    movsx bl,7Bh
    movsx cx,bl

    mov ax,val1
    xchg ax,val2
    mov val1,ax
```

```
mov al,arrayB
mov al,[arrayB+1]
mov al,[arrayB+2]

mov ax,arrayW
mov ax,[arrayW+2]

mov eax,arrayD
mov eax,[arrayD+4]
mov eax,[arrayD+4]
```

ADDITION AND SUBTRACTION

- **INC and DEC Instructions**

•The INC (increment) and DEC (decrement) instructions, respectively, add 1 and subtract 1 from a register or memory operand.

```
.data
    myWord  WORD 1000h
    myDword DWORD 10000000h
```

```
.code
    inc myWord
    dec myWord
    inc myDword

    mov ax,00FFh
    inc ax
```

```
; 1001h
; 1000h
; 10000001h


; AX = 0100h
```

ADDITION AND SUBTRACTION

ADD Instruction

The ADD instruction adds a source operand to a destination operand of the same size.

```
ADD dest,source
```

SUB Instruction

The SUB instruction subtracts a source operand from a destination operand.

```
SUB dest,source
```

- The set of possible operands is the same as for the MOV instruction

ADDITION AND SUBTRACTION

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

```
.code
    mov eax,var1
    add eax,var2
    add ax,0FFFFh
    add eax,1
    sub ax,1
```

```
; ---EAX---
; 00010000h
; 00030000h
; 0003FFFFh
; 00040000h
; 0004FFFFh
```

NEG Instruction

- The neg (negate) instruction takes the two's complement of a byte or word.

- It takes a single (destination) operation and negates it. The syntax for this instruction is:

```
NEG reg
NEG mem
```

- Neg always updates the A, S, P, and Z flags as though you were using the sub instruction.

Implementing Arithmetic Expressions

- HLL compilers translate mathematical expressions into assembly language. You can do it also. For example:

```
Rval = -Xval + (Yval - Zval)
```

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

```
.code
 mov eax, Xval
 neg eax            ;EAX=-26

 mov ebx,Yval
 sub ebx,Zval       ;EBX = -10

 add eax,ebx
 mov Rval,eax       ; -36
```

Flags Affected by Addition and Subtraction

- 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.

- We use the values of CPU status flags to check the outcome of arithmetic operations and to activate conditional branching instructions.
- **Essential flags:**
- Zero flag – set when destination equals zero
- Sign flag – set when destination is negative; if the MSB of the destination operand is set,
- Carry flag – set when unsigned value is out of range.
- Overflow flag – set when signed value is out of range .

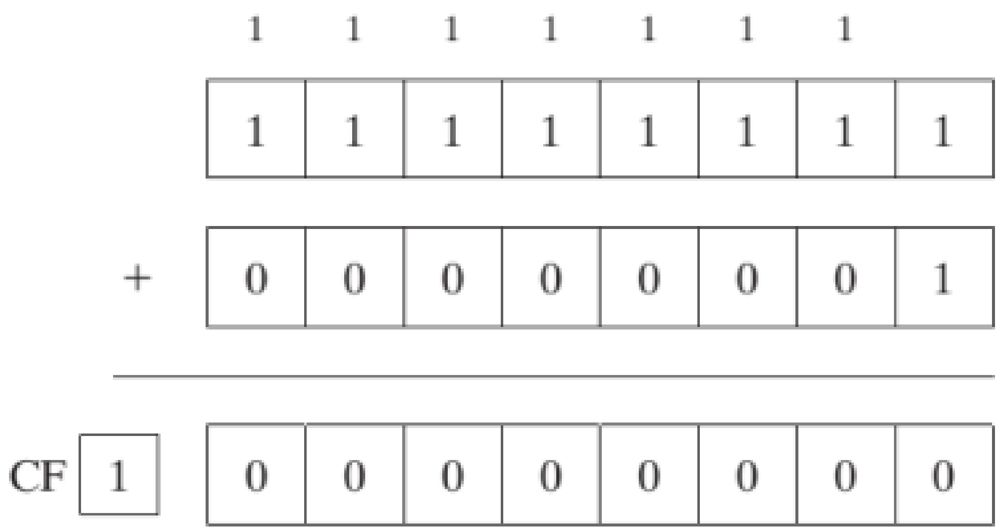
Flags Affected by Addition and Subtraction

```
mov cx,1
sub cx,1                ; CX = 0, ZF = 1

mov ax,0FFFFh
inc ax                  ; AX = 0, ZF = 1
inc ax                  ; AX = 1, ZF = 0

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

ADD & SUB Instructions

- Example:

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



ADD & SUB Instructions

- Example:

```
mov al,1
sub al,2                    ; AL = FFh, CF = 1
```

		0	0	0	0	0	0	0	1	(1)
	+	1	1	1	1	1	1	1	0	(−2)
CF	1	1	1	1	1	1	1	1	1	(FFh)

ADD & SUB Instructions

Sign and Overflow Flags:

- The Sign flag is set when the result of a signed arithmetic operation is negative.

```
mov eax,4
sub eax,5                ; EAX = -1, SF = 1
```

- The Overflow flag is set when the result of a signed arithmetic operation overflows or underflows the destination operand.

```
mov al,127
add al,1                 ; OF = 1
```

```
mov al,-128
sub al,1                 ; OF = 1
```

LAHF/SAHF (load/store status flag from/to AH)

- LAHF instruction loads lower byte of the EFLAGS register into AH register.

- The lowest 8 bits of the flags are transferred:
  - Sign
  - Zero
  - Auxiliary Carry
  - Parity
  - Carry

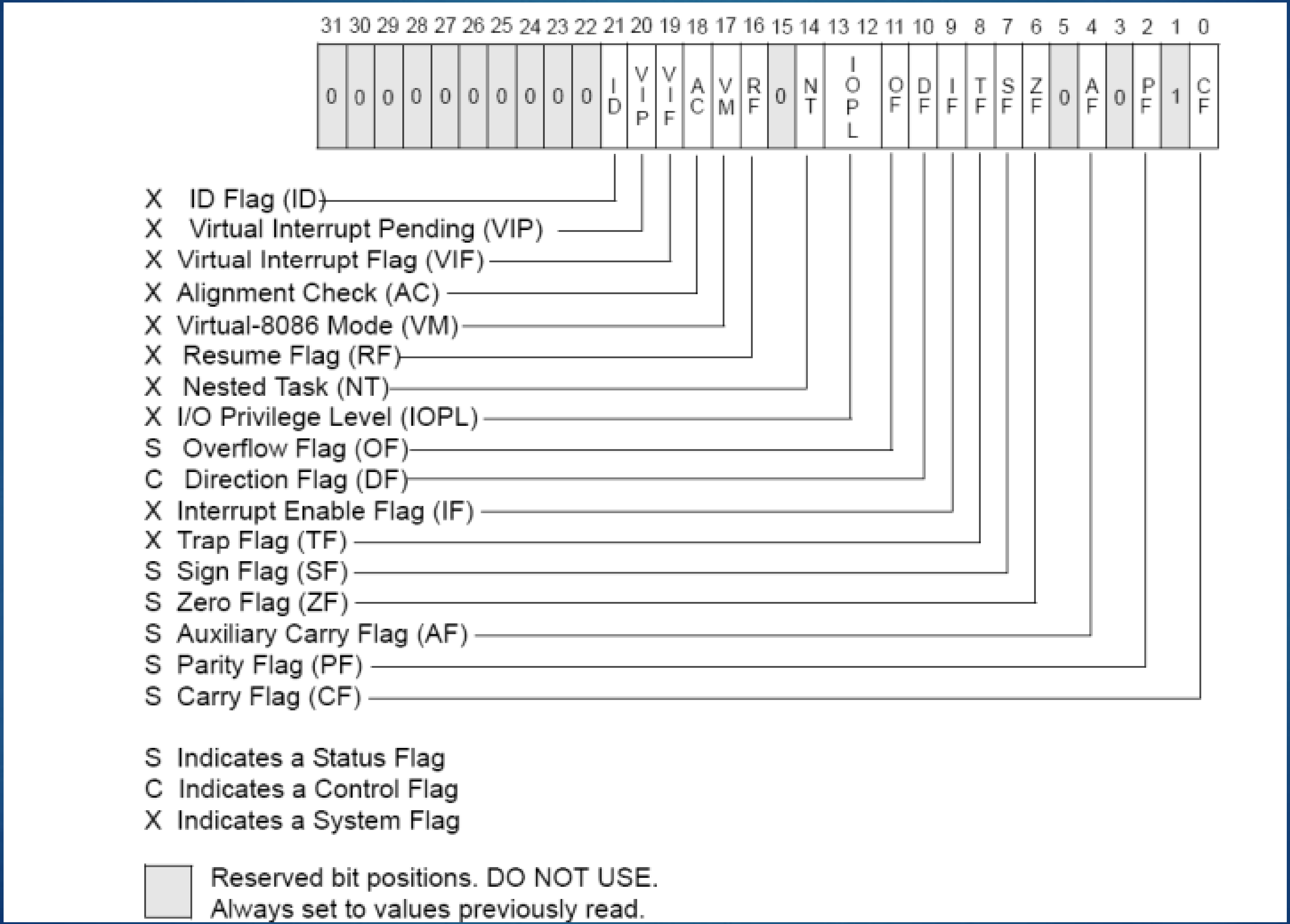
```
.data
saveflags BYTE ?
.code
lahf                    ; load flags into AH
mov  saveflags,ah       ; save them in a variable
```

LAHF/SAHF (load/store status flag from/to AH)

- **SAHF restores the value of lower byte flags.**
- **This instruction copies, AH into low byte of EFLAGS Register.**

```
mov  ah,saveflags                  ; load saved flags into AH
sahf                               ; copy into Flags register
```

EFLAGS



31 30 29 28 27 26 25 24 23 22 21 20 19 18 17 16 15 14 13 12 11 10 9 8 7 6 5 4 3 2 1 0
0 0 0 0 0 0 0 0 0 0 ID VIP VIF AC VM RF 0 NT IOPL OF DF IF TF SF ZF 0 AF 0 PF 1 CF
X ID Flag (ID)
X Virtual Interrupt Pending (VIP)
X Virtual Interrupt Flag (VIF)
X Alignment Check (AC)
X Virtual-8086 Mode (VM)
X Resume Flag (RF)
X Nested Task (NT)
X I/O Privilege Level (IOPL)
S Overflow Flag (OF)
C Direction Flag (DF)
X Interrupt Enable Flag (IF)
X Trap Flag (TF)
S Sign Flag (SF)
S Zero Flag (ZF)
S Auxiliary Carry Flag (AF)
S Parity Flag (PF)
S Carry Flag (CF)
S Indicates a Status Flag
C Indicates a Control Flag
X Indicates a System Flag
Reserved bit positions. DO NOT USE.
Always set to values previously read.

ALIGN DIRECTIVE

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

ALIGN bound

- Bound can be 1, 2, 4, 8, or 16. A value of 1 aligns the next variable on a 1- byte boundary (the default).
- If bound is 2, the next variable is aligned on an even-numbered address. If bound is 4, the next address is a multiple of 4. If bound is 16, the next address is a multiple of 16, a paragraph boundary.

ALIGN DIRECTIVE

- The assembler can insert one or more empty bytes before the variable to fix the alignment.
- Why bother aligning data?
- Because the CPU can process data stored at even-numbered addresses more quickly than those at odd-numbered addresses.

ALIGN DIRECTIVE

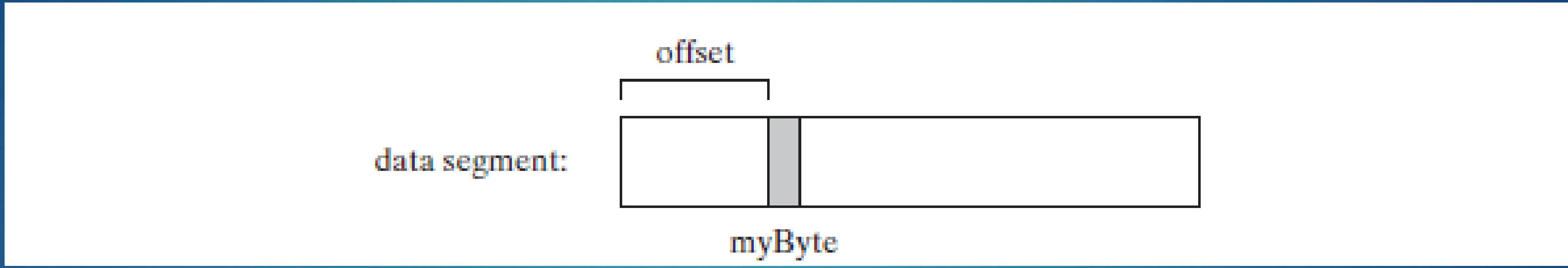
- In the following example, bVal is arbitrarily located at offset 00404000. Inserting the ALIGN 2 directive before wVal causes it to be assigned an even-numbered offset:

```
bVal   BYTE   ?                    ; 00404000h
ALIGN 2
wVal   WORD   ?                    ; 00404002h
bVal2  BYTE   ?                    ; 00404004h
ALIGN 4
dVal   DWORD ?                     ; 00404008h
dVal2  DWORD ?                     ; 0040400Ch
```

- Note that dVal would have been at offset 00404005, but the ALIGN 4 directive bumped it up to offset 00404008.

OFFSET Operator

- The OFFSET operator return the offset of a data label
- The offset represents the distance, in bytes, of the label from beginning of the data segment
- Figure shows a variable named myByte inside the data segment



OFFSET Operator

- Example:
- Declaration of different types:

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

- If bVal were located at offset 00404000 (hexa-decimal), the OFFSET operator would return the following values:

```
mov  esi,OFFSET bVal                  ; ESI = 00404000
mov  esi,OFFSET wVal                  ; ESI = 00404001
mov  esi,OFFSET dVal                  ; ESI = 00404003
mov  esi,OFFSET dVal2                 ; ESI = 00404007
```

PTR Operator

- You can use the PTR operator to override the declared size of an operand.

```
.data
        myDouble DWORD 12345678h
.code
        mov ax,myDouble                 ;error - why?
        mov ax,WORD PTR myDouble        ; loads 5678h
```

- Why wasn't 1234h moved into AX?
- x86 processors use the little endian storage format in which the low-order byte is stored at the variable's starting address.

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 ?
```

Expression	Value
TYPE var1	1
TYPE var2	2
TYPE var3	4
TYPE var4	8

LENGTHOF Operator

- The LENGTHOF operator counts the number of elements in an array, defined by the values appearing on the same line as its label.

```
.data
        byte1 BYTE 10,20,30
        array1 WORD 30 DUP(?),0,0
        array2 WORD 5 DUP(3 DUP(?))
        array3 DWORD 1,2,3,4
        digitStr BYTE "12345678",0
```

Expression	Value
LENGTHOF byte1	3
LENGTHOF array1	30 + 2
LENGTHOF array2	5 * 3
LENGTHOF array3	4
LENGTHOF digitStr	9

- If you declare an array that spans multiple program lines, LENGTHOF only regards the data from the first line as part of the array (here LENGTHOF myArray returns 5).

```
myArray BYTE 10,20,30,40,50
        BYTE 60,70,80,90,100
```

SIZEOF Operator

- The SIZEOF operator returns a value that is equivalent to multiplying LENGTHOF by TYPE.

```
.data
    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
```

SIZEOF

```
.code
    mov ecx, SIZEOF array1            ; 64
```

LABEL Directive

- **The LABEL directive assigns an alternate label name and type to an existing storage location. LABEL does not allocate any storage of its own.**

  • A common use of LABEL is to provide an alternative name and size attribute for the variable declared next in the data segment.

```
.data
        val16 LABEL WORD
        val32 DWORD 12345678h
.code
        mov ax,val16                ; AX = 5678h
        mov dx,[val16+2]            ; DX = 1234h
```

```
.data
        LongValue LABEL DWORD
        val1 WORD 5678h
        val2 WORD 1234h
.code
        mov eax,LongValue ; EAX = 12345678h
```

INDIRECT ADDRESSING

- Direct addressing is rarely used for array processing because it is impractical to use constant offsets to address more than a few array elements.
- An indirect operand holds the address of a variable, usually an array or string. It can be dereferenced (just like a pointer).

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

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

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

Arrays

- Indirect operands are ideal tools for stepping through arrays.

```
.data
        arrayB BYTE 10h,20h,30h
.code
        mov esi,OFFSET arrayB
        mov al,[esi]                    ; AL = 10h

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

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

Indexed Operands

- **An indexed operand adds a constant to 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,2
    add ax,[arrayW + esi]
```

Scale Factors in Indexed Operands

- Indexed operands must take into account the size of each array element when calculating offsets.
- Using an array of doublewords, as in the following example, we multiply the subscript (3) by 4 (the size of a doubleword) to generate the offset of the array element containing 400h:

```
.data
arrayD DWORD 100h, 200h, 300h, 400h
.code
mov esi,3 * TYPE arrayD                ; offset of arrayD[3]
mov eax,arrayD[esi]                    ; EAX = 400h
```

Scale Factors in Indexed Operands

- The x86 instruction set provides a way for offsets to be calculated, using a scale factor .
- The scale factor is the size of the array component (WORD=2, DWORD=4 or QWORD=8).

```
.data
arrayD DWORD 1,2,3,4
.code
mov esi,3                       ; subscript
mov eax,arrayD[esi*4]           ; EAX = 4
```

```
mov esi,3                       ; subscript
mov eax,arrayD[esi*TYPE arrayD] ; EAX = 4
```

EXERCISE

- **What will be the value of EAX after each of the following instructions execute?**

```
.data
myBytes   BYTE    10h,20h,30h,40h
myWords   WORD    3 DUP(?),2000h
myString  BYTE   "ABCDE"
```

```
mov   eax,TYPE myBytes                ; a.
mov   eax,LENGTHOF myBytes            ; b.
mov   eax,SIZEOF myBytes              ; c.
mov   eax,TYPE myWords                ; d.
mov   eax,LENGTHOF myWords            ; e.
mov   eax,SIZEOF myWords              ; f.
mov   eax,SIZEOF myString             ; g.
```

EXERCISE

Write down values of destination registers

```
.data
arrayB  BYTE    20, 40, 60, 80
arrayW  WORD    100, 150, 250, 300
.code
mov si, 1
mov al, arrayB[si]
mov al, [arrayB + 3]
mov si, 2
mov cx, arrayW[si]
mov cx, [arrayW + 4]
```

```
;       SI = 0001
;       AL = 40
;       AL = 80
;       SI = 2
;       CX = 150
;       CX = 250
```

EXERCISE

Use following array declarations:

arrayB BYTE 60, 70, 80

arrayW WORD 150, 250, 350

arrayD DWORD 600, 1200, 1800

For each array, add its 1st and last element using scale factors and display the result in a separate register.

Solution

```
main PROC
mov eax,0
mov esi,0
mov al,arrayB[esi *TYPE arrayB]
mov esi,2
add al,arrayB[esi*TYPE arrayB]

mov eax,0
mov esi,0
mov ax,arrayW[esi *TYPE arrayw]
mov esi,2
add ax,arrayW[esi*TYPE arrayw]
mov eax,0
mov esi,0
mov eax,arrayD[esi *TYPE arrayD]
mov esi,2
add  eax,arrayD[esi*TYPE arrayD]
call DumpRegs
exit
main ENDP
END main
```