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# EE213 COMPUTER ORGANIZATION AND ASSEMBLY LANGUAGE

Spring 2018

# DATA TRANSFERS, ADDRESSING, AND ARITHMETIC

# OUTLINES

- Data Transfer Instructions
- Addition and Subtraction
- Data-Related Operators and Directives
- Indirect Addressing
- JMP and LOOP Instructions

# 4.1 DATA TRANSFER INSTRUCTIONS

## Operand Types

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



- 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

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

```
mov al var1
```

```
A0 00010400
```

## 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*



.data

```
count BYTE 100
wVal  WORD 2
```

.code

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

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

## Zero Extension

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

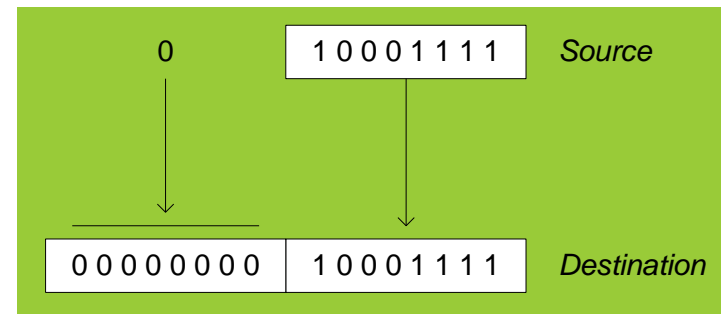
```
mov bl,10001111b
```


```
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
```





.data

byte1 BYTE 9Bh

word1 WORD 0A69Bh

.code

movzx eax,word1 ; EAX = 0000A69Bh

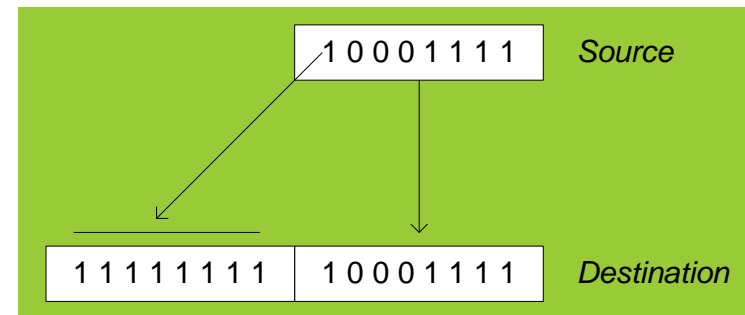
movzx edx,byte1 ; EDX = 0000009Bh

movzx cx,byte1 ; CX = 009Bh

## 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
```

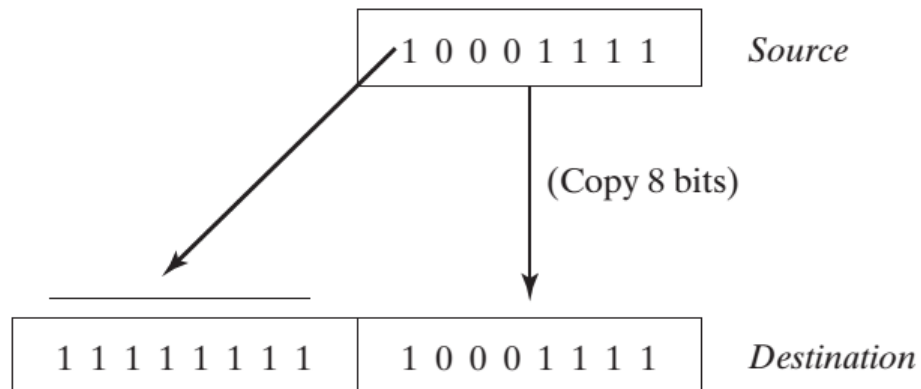


.data

byteVal BYTE 10001111b

.code

**movsx** ax,byteVal ; AX = 1111111110001111b






**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
```



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



## 4.2 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           ; 1001h
    dec myWord           ; 1000h
    inc myDword          ; 10000001h

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



## **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



.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 reverses the sign of a number by converting the number to its two's complement

NEG *reg*

NEG *mem*

## Implementing Arithmetic Expressions

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

$$\text{Rval} = -\text{Xval} + (\text{Yval} - \text{Zval})$$

```
Rval  DWORD ?  
Xval  DWORD 26  
Yval  DWORD 30  
Zval  DWORD 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



```
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
```

## Addition and the Carry Flag

```
mov al,0FFh
```

```
add al,1 ; AL = 00, CF = 1
```

	1	1	1	1	1	1	1
	1	1	1	1	1	1	1
+	0	0	0	0	0	0	1
<hr/>							
CF	1	0	0	0	0	0	0



```
mov  al,1
```

$$\text{sub } a1,2 \quad ; \quad \text{AL} = \text{FFh}, \quad \text{CF} = 1$$

$$\begin{array}{ccccccccc}
0 & 0 & 0 & 0 & 0 & 0 & 0 & 1 \\
+ & 1 & 1 & 1 & 1 & 1 & 1 & 1 & 0 \\
\hline
CF \quad 1 & 1 & 1 & 1 & 1 & 1 & 1 & 1 & 1
\end{array}
\begin{matrix}
(1) \\
(-2) \\
\\
(FFh)
\end{matrix}$$

## Signed Operations: 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
```

- The NEG instruction produces an invalid result if the destination operand cannot be stored correctly.

```
mov al,-128 ; AL = 10000000b
```

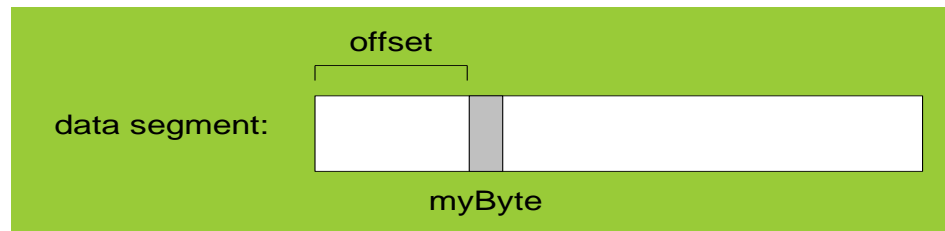
```
neg al      ; AL = 10000000b, OF = 1
```

The Overflow flag is set, indicating that AL contains an invalid value:

## 4.3 DATA-RELATED OPERATORS AND DIRECTIVES

- **OFFSET** Operator
- **PTR** Operator
- **TYPE** Operator
- **LENGTHOF** Operator
- **SIZEOF** Operator
- **LABEL** Directive

- The **OFFSET** operator returns the offset of a data label.
  - returns the distance (in bytes) of a variable from the beginning of its enclosing segment.



Assuming, data segment begins at 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

- 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.

- 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



- 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
```


.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, <b>LENGTHOF</b> array1	; 32

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

	SIZEOF
.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
.code	
mov ecx, <b>SIZEOF</b> array1	; 64



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

## 4.4 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
```

- The size of an operand may not be evident from the context of an instruction.

```
inc [esi] ; error: operand must have size
```

- Because the assembler does not know whether ESI points to a byte, word, doubleword, or some other size. The PTR operator confirms the operand size:

```
inc BYTE PTR [esi]
```

## 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]**

## 4.5 JMP AND LOOP INSTRUCTIONS

- By default, the CPU loads and executes programs sequentially, however, control may be transferred to a new location in the program.
- A *transfer of control*, or *branch*, is a way of altering the order in which statements are executed, there are two basic types:
  1. **Unconditional Transfer:** No condition is involved, control is transferred to a new location in all cases.
  2. **Conditional Transfer:** The program branches if a certain condition is true (based on status of flags).

## JMP Instruction

The JMP instruction causes an unconditional transfer to a destination, identified by a code label.

JMP *destination*

offset of *destination* is moved into the instruction pointer, causing execution to continue at the new location

```
top:    INC  AX
        MOV  BX, AX
        jmp top
```

## LOOP Instruction

The `LOOP` instruction, formally known as *Loop According to ECX Counter*, repeats a block of statements a specific number of times.

- `ECX` is automatically used as a counter and is decremented each time the loop repeats.

`LOOP destination`

The loop destination must be within -128 to +127 bytes of the current location counter.

- -128 bytes is the largest backward jump from current instruction +127 bytes is the largest forward jump.

The execution of the LOOP instruction involves two steps:

1. First, it subtracts 1 from ECX.
2. Next, it compares ECX to zero. If ECX is not equal to zero, a jump is taken to the label identified by *destination*. Otherwise, no jump takes place, and control passes to the instruction following the loop.

```
mov ax,0
mov ecx,5

L1:   inc ax
      loop L1
      mov bx,ax
```

# YOUR TURN . . .

What will be the value of BX?

```
        mov ax, 6
        mov ecx, 4
L1:     inc ax
        loop L1
        mov bx, ax
```

# NESTED LOOPS

- When creating a loop inside another loop, special consideration must be given to the outer loop counter in ECX. You can save it in a variable:

```
.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
```

# 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, LABEL

## JMP and LOOP – branching instructions