Computer Organization & Assembly Language - EE2003

Lecture 07

Week 04

Data Transfer Instructions

- Operand Types
- Instruction Operand Notation
- Direct Memory Operands
- MOV Instruction
- Zero & Sign Extension
- XCHG Instruction
- Direct-Offset Instructions

Operand Types

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

Instruction 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

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

MOV Instruction

- Move from source to destination. Syntax:

  { MOV *destination,source* }
- No more than one memory operand permitted
- CS, EIP, and IP cannot be the destination
- No immediate to segment moves

```
.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
```

MOV Instruction (2/2)

- Some rules to follow when using `MOV`
  - Both operands must have same size
  - Both operands cannot be memory operands
  - `CS`, `EIP`, `IP` cannot be destination operands
  - An immediate value cannot be moved to a segment register
- Some useful variants of `MOV`

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

Zero/Sign Extension of Integers (1/4)

- `MOV` cannot copy data directly from a smaller operand to a larger one
- Suppose we want to move a *byte* variable `var` into a 16-bit register `ax`

```
.data
var DB 10h
.code
MOV ax, 0
MOV al, var
```

Zero/Sign Extension of Integers (2/4)

- What happens if same approach is followed to copy a negative number?
- What is the value in `ax` after this code is assembled?

```
.data
svar DB -8
.code
MOV ax, 0
MOV al, svar
```

0	0	0	0	0	0	0	0	1	1	1	1	1	0	0	0

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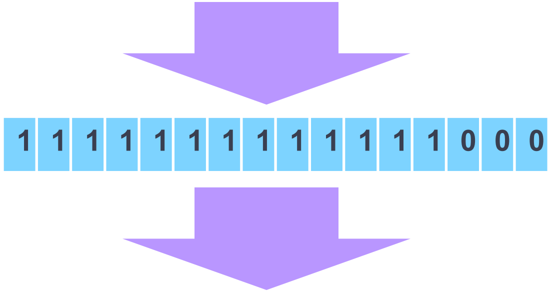
- What happened to -8?

Zero/Sign Extension of Integers (3/4)

- How about doing like this?

```
.data
svar DB -8
.code
MOV ax, 0FFFFFFFFh
MOV al, svar
```



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Zero/Sign Extension of Integers (4/4)

- These examples show different approaches for signed and unsigned number
  - In case of unsigned numbers, a zero is extended to all higher order bits of the destination operand
  - In case of signed numbers, the sign-bit is extended to all higher order bits of the destination operand

Your turn . . .

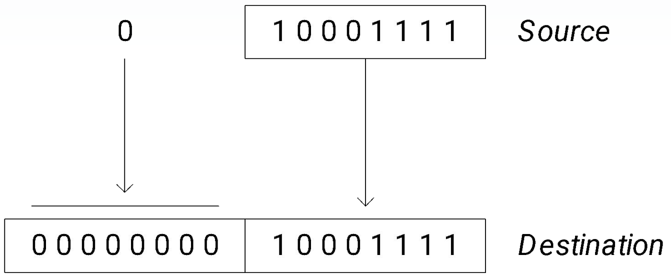
Explain why each of the following MOV statements are invalid:

```
.data
bVal   BYTE    100
bVal2  BYTE    ?
wVal   WORD    2
dVal   DWORD   5
.code
     mov ds,45
     mov esi,wVal
     mov eip,dVal
     mov 25,bVal
     mov bVal2,bVal
```

```
immediate move to DS not permitted
size mismatch
EIP cannot be the destination
immediate value cannot be destination
memory-to-memory move 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
```

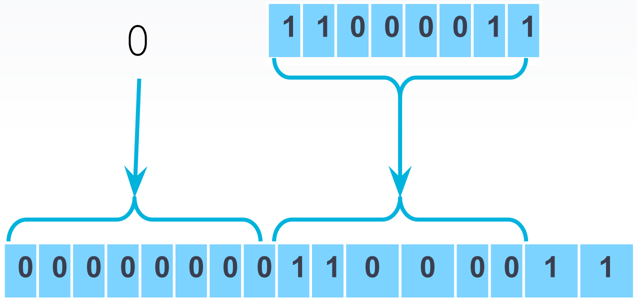
The destination must be a register.

MOVZX Instruction (1/2)

- `MOVZX` (MOVe with Zero-eXtend) copies the source operand into destination operand and extends zeroes in the remaining higher order bits of destination operand
- It has three variants
  - `MOVZX reg32, reg/mem8`
  - `MOVZX reg32, reg/mem16`
  - `MOVZX reg16, reg/mem8`

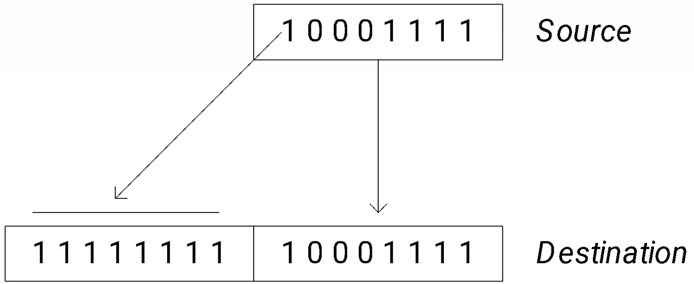
MOVZX Instruction (2/2)

```
.data
val DB 11000011b
.code
MOVZX ax, val
```



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
```

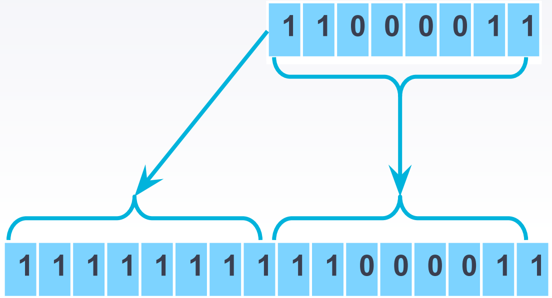
The destination must be a register.

MOVSX Instruction (1/2)

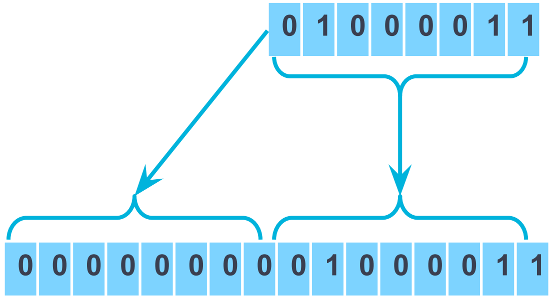
- `MOVSX` (MOVe with Sign-eXtend) copies the source operand into destination operand and extends the sign-bit in remaining higher order bits in destination operand
- It has three formats
  - `MOVSX reg32, reg/mem8`
  - `MOVSX reg32, reg/mem16`
  - `MOVSX reg16, reg/mem8`

MOVSX Instruction (2/2)

```
.data
val DB 11000011b
.code
MOVSX ax, val
```




```
.data
val DB 01000011b
.code
MOVSX ax, val
```



LAHF and SAHD Instructions

- `LAHF` (Load `AH` from status Flags) instruction copies lower byte of EFLAGS register into `AH`
- Sign, Zero, Auxiliary Carry, Parity and Carry flags are copied
- `SAHF` (Store `AH` into status Flags) instruction copies `AH` into lower byte of EFLAGS register

XCHG Instruction

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
```

XCHG Instruction

- `XCHG` instruction exchanges the contents of two operands
- This instruction has three different variants
  - `XCHG` reg, reg
  - `XCHG` reg, mem
  - `XCHG` mem, reg
- To exchange two memory operands, a register is used as temporary container

```
XCHG al, ah
```

Direct-Offset Operands

- Adding a displacement or offset to the name of a variable
- This technique makes it possible to access memory locations which do not have explicit labels
- For example, to access individual elements of an array

Direct-Offset Operands

A constant offset 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
```

Q: Why doesn't arrayB+1 produce 11h?

Direct-Offset Operands (cont)

A constant offset 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
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 eax,[arrayD+4]        ; EAX = 00000002h
```

```
; Will the following statements assemble?
mov ax,[arrayW-2]     ; ??
mov eax,[arrayD+16]       ; ??
```

What will happen when they run?

Your turn. . .

Write a program that rearranges the values of three doubleword values in the following array as: 3, 1, 2.

```
.data
arrayD DWORD 1,2,3
```

- Step1: copy the first value into EAX and exchange it with the value in the second position.

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

- Step 2: Exchange EAX with the third array value and copy the value in EAX to the first array position.

```
xchg eax,[arrayD+8]
mov  arrayD,eax
```

Evaluate this . . .

- We want to write a program that adds the following three bytes:

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

- What is your evaluation of the following code?

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

- What is your evaluation of the following code?

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

- Any other possibilities?

Evaluate this . . . (cont)

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

- How about the following code. Is anything missing?

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

Yes: Move zero to BX before the MOVZX instruction.

THANKS!

Any questions?

You can find me at:

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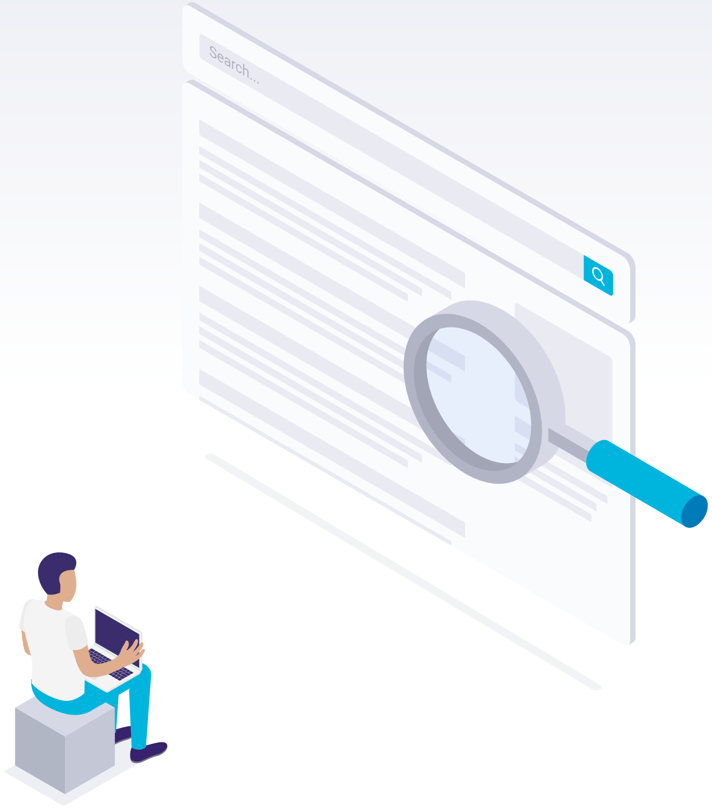
- Office #213, Visiting Hours Only



Lecture 08

Week 04

What's Next

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

Addition and Subtraction

- INC and DEC Instructions
- ADD and SUB Instructions
- NEG Instruction
- Implementing Arithmetic Expressions
- Flags Affected by Arithmetic
  - Zero
  - Sign
  - Carry
  - Overflow

INC and DEC Instructions

- Add 1, subtract 1 from destination operand
  - operand may be register or memory
- INC *destination*
  - Logic: *destination* $\longleftarrow$ *destination* + 1
- DEC *destination*
  - Logic: *destination* $\longleftarrow$ *destination* – 1

INC and DEC Instructions

- `INC` instruction increments 1 in a single operand
- `DEC` instruction decrements 1 from a single operand
- Syntax is
  - `INC` reg/mem
  - `DEC` reg/mem
- Flags affected
  - OF, SF, ZF, AF, PF

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
```

Your turn...

Show the value of the destination operand after each of the following instructions executes:

```
.data
myByte BYTE 0FFh, 0
.code
    mov al,myByte ; AL =                    FFh
    mov ah,[myByte+1] ; AH =                00h
    dec ah    ; AH =                        FFh
    inc al    ; AL =                        00h
    dec ax    ; AX =                        FEFF
```

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

ADD Instruction

- Adds a source operand into a destination operand
- Both operands must have the same size
- Sum is stored in the destination operand
- Syntax is

```
ADD dest, src
```

- Flags affected
  - CF, ZF, SF, OF, AF, PF

SUB Instruction

- Subtracts a source operand from a destination operand
- Both operands must have the same size
- Result is stored in the destination operand
- Syntax is `SUB dest, src`
- Flags affected
  - CF, ZF, SF, OF, AF, PF

ADD and SUB Examples

```
.data
var1 DWORD 10000h
var2 DWORD 20000h
.code     ; ---EAX---
    mov eax,var1  ; 00010000h
    add eax,var2  ; 00030000h
    add ax,0FFFFh ; 0003FFFFh
    add eax,1     ; 00040000h
    sub ax,1 ; 0004FFFFh
```

NEG (negate) Instruction

Reverses the sign of an operand. Operand can be a register or memory operand.

```
.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?

NEG Instruction

- Reverses the sign of a number by taking its 2's complement
- Syntax is
  - NEG reg
  - NEG mem
- Flags affected
  - CF, ZF, SF, OF, AF, PF

NEG Instruction and the Flags

The processor implements NEG using the following internal operation:

```
SUB 0,operand
```

Any nonzero operand causes the Carry flag to be set.

```
.data
valB BYTE 1,0
valC SBYTE -128
.code
    neg valB ; CF = 1, OF = 0
    neg [valB + 1]     ; CF = 0, OF = 0
    neg valC ; CF = 1, OF = 1
```

Implementing Arithmetic Expressions

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

```
Rval = -Xval + (Yval – 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
```

Your turn...

Translate the following expression into assembly language.
Do not permit Xval, Yval, or Zval to be modified:

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

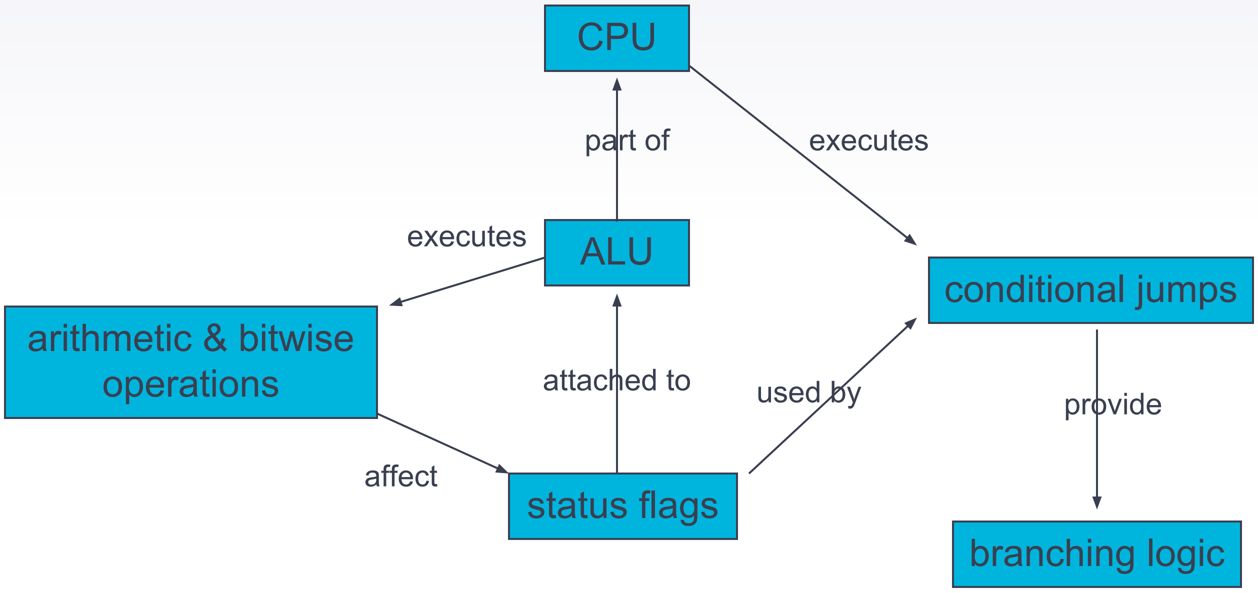
Assume that all values are signed doublewords.

```
mov  ebx,Yval
neg  ebx
add  ebx,Zval
mov  eax,Xval
sub  eax,ebx
mov  Rval,eax
```

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
- 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



You can use diagrams such as these to express the relationships between assembly language concepts.

Zero Flag (ZF)

- ZF is set when the result of an operation produces zero in the destination operand

```
MOV al, 1        ;no flag affected
SUB al, 1        ;al=0 □ ZF=1
MOV bl, 0FFh     ;no flag affected
INC bl           ;bl=0 □ ZF=1
INC bl           ;bl=1 □ ZF=0
```

- Remember that
  - A flag is set when it equals 1
  - A flag is clear when it equals 0

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
inc ax     ; AX = 0, ZF = 1
inc ax     ; AX = 1, ZF = 0
```

Remember...

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

Sign Flag (SF)

- SF is set when destination operand is –ve
- SF is clear when destination is +ve

```
MOV al, 0      ;no flag affected
SUB al, 1      ;al=-1 □ SF=1
ADD al, 2      ;al=1 □ SF=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
```

Signed and Unsigned Integers
A Hardware Viewpoint

- 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

Overflow and Carry Flags
A Hardware Viewpoint

- How the ADD instruction affects OF and CF:
  - CF = (carry out of the MSB)
  - OF = CF XOR MSB
- How the SUB instruction affects OF and CF:
  - CF = INVERT (carry out of the MSB)
  - negate the source and add it to the destination
  - OF = CF XOR MSB

MSB = Most Significant Bit (high-order bit)
XOR = eXclusive-OR operation
NEG = Negate (same as SUB 0,operand)

Carry Flag (CF)

The Carry flag is set when the result of an operation generates an unsigned value that is out of range (too big or too small for the destination operand).

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

; Try to go below zero:

mov al,0
sub al,1 ; CF = 1, AL = FF
```

Your turn . . .

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=       SF=   ZF=   CF=   0100h    0   0   0
sub ax,1 ; AX=       SF=   ZF=   CF=   00FFh    0   0   0
add al,1 ; AL=       SF=   ZF=   CF=   00h      0   1   1
mov bh,6Ch
add bh,95h    ; BH=       SF=   ZF=   CF=   01h    0   0   1

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

Overflow Flag (OF)

The Overflow flag is set when the signed result of an operation is invalid or out of range.

```
; Example 1
mov al,+127
add al,1 ; OF = 1,   AL = ??

; Example 2
mov al,7Fh    ; OF = 1,   AL = 80h
add al,1
```

The two examples are identical at the binary level because 7Fh equals +127. To determine the value of the destination operand, it is often easier to calculate in hexadecimal.

A Rule of Thumb

- 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

```
What will be the values of the Overflow flag?
     mov al,80h
     add al,92h    ; OF =                    1

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

Your turn . . .

What will be the values of the given flags after each operation?

```
mov al,-128
neg al    ; CF =      OF =              1        1

mov ax,8000h
add ax,2 ; CF =    OF =                 0              0

mov ax,0
sub ax,2 ; CF =    OF =                 1              0

mov al,-5
sub al,+125   ; OF =                    1
```

What's Next

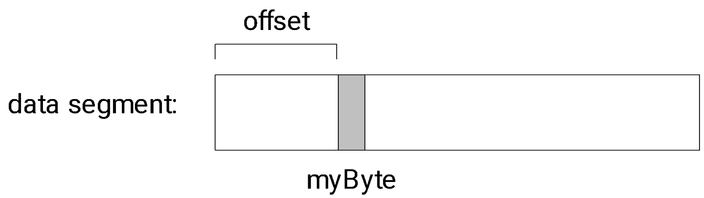
- Data Transfer Instructions
- Addition and Subtraction
- Data-Related Operators and Directives
- Indirect Addressing
- JMP and LOOP Instructions

Data-Related Operators and Directives

- OFFSET Operator
- PTR Operator
- TYPE Operator
- LENGTHOF Operator
- SIZEOF Operator

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 segment (flat memory model).

OFFSET Examples

Let's assume that the 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
```

Relating to C/C++

The value returned by OFFSET is a pointer. Compare the following code written for both C++ and assembly language:

```
// C++ version:

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

```
; Assembly language:

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

PTR Operator

Overrides the default type of a label (variable). Provides the flexibility to access part of a variable.

```
.data
myDouble DWORD 12345678h
.code
mov ax,myDouble                ; error – why?

mov ax,WORD PTR myDouble                ; loads 5678h

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

Little endian order is used when storing data in memory (see Section 3.4.9).

Little Endian Order

- 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 doubleword 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
```

PTR Operator (cont)

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
```

Your turn . . .

Write down the value of each destination operand:

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

.code
mov ax,WORD PTR [varB+2]   ; a.                 0502h
mov bl,BYTE PTR varD   ; b.                     78h
mov bl,BYTE PTR [varW+2]   ; c.                 02h
mov ax,WORD PTR [varD+2]   ; d.                 1234h
mov eax,DWORD PTR varW ; e.                     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 returns a value that is equivalent to multiplying LENGTHOF by 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
```

THANKS!

Any questions?

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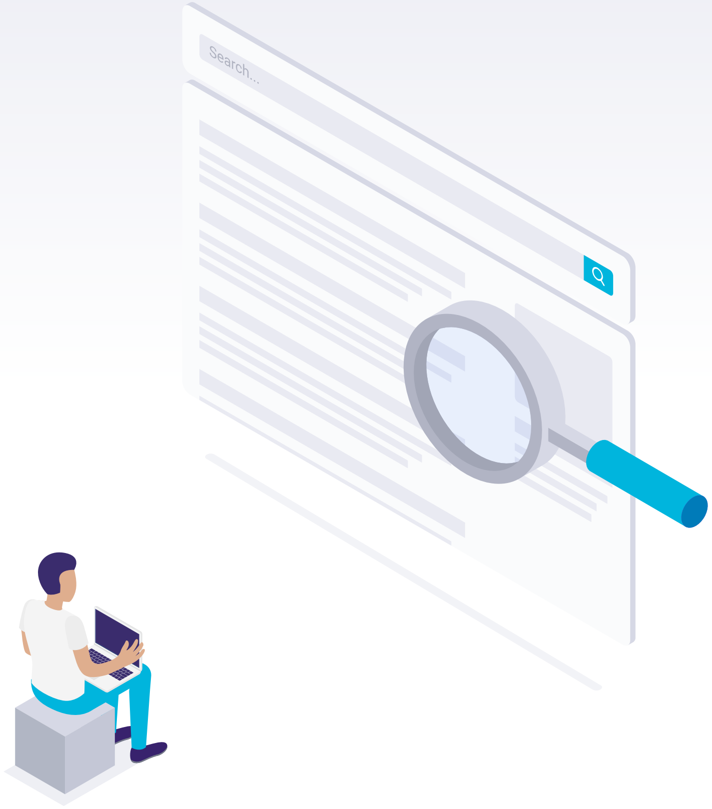

Lecture 09

Week 05

What's Next

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

Indirect Addressing

- Indirect Operands
- Array Sum Example
- Indexed Operands

Indirect Operands (1/3)

- In Protected Mode
  - A 32-bit general purpose register can be used as an indirect operand surrounded by square brackets
  - The register contains the address of variable
- In Real-Address Mode
  - A 16-bit register holds the offset of variable
  - Any of SI, DI, BX or BP can be used
- Indirect Operands are useful to step through arrays

Indirect Operands (2/3)

- Protected Mode

```
.data
val DB 10h, 20h, 30h
.code
MOV esi, OFFSET val
MOV al, [esi]
INC esi
MOV bl, [esi]
```

Indirect Operands (3/3)

- Real-Address Mode

```
.data
val DB 10h, 20h, 30h
.code
MOV si, OFFSET val
MOV al, [si]
INC si
MOV bl, [si]
```

Pointer

- A pointer can be declared in the following way

```
.data
val DW 10h
vptr DW val
.code
MOV si, vptr
MOV al, [si]
```

Indirect Operands (1 of 2)

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
```

Indirect Operands (2 of 2)

Use PTR to clarify the size attribute of a memory operand.

```
.data
myCount WORD 0

.code
mov esi,OFFSET myCount
inc [esi]      ; error: ambiguous
inc WORD PTR [esi]     ; ok
```

Should PTR be used here?

```
add [esi],20
```

yes, because [esi] could point to a byte, word, or doubleword

Array Sum Example

Indirect operands are ideal for traversing an array. Note that the register in brackets must be incremented by a value that matches the array type.

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

ToDo: Modify this example for an array of doublewords.

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]
    etc.
```

ToDo: Modify this example for an array of doublewords.

Index Scaling

You can scale an indirect or indexed operand to the offset of an array element. This is done 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
```

What's Next

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

JMP and LOOP Instructions

- JMP Instruction
- LOOP Instruction
- LOOP Example
- Summing an Integer Array
- Copying a String

JMP Instruction

- JMP is an unconditional jump to a label that is usually within the same procedure.
- Syntax: JMP *target*
- Logic: EIP ← *target*
- Example:

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

A jump outside the current procedure must be to a special type of label called a global label (see Section 5.5.2.3 for details).

LOOP Instruction

- The LOOP instruction creates a counting loop
- Syntax: LOOP *target*
- Logic:
  - ECX ← ECX – 1
  - if ECX != 0, jump to *target*
- Implementation:
  - The assembler calculates the distance, in bytes, between the offset of the following instruction and the offset of the target label. It is called the relative offset.
  - The relative offset is added to EIP.

LOOP Example

The following loop calculates the sum of the integers
5 + 4 + 3 +2 + 1:

Offset machine code source code

```
00000000  66 B8 0000          mov  ax,0
00000004  B9 00000005         mov  ecx,5

00000009  66 03 C1       L1:  add  ax,cx
0000000C  E2 FB          loop L1
0000000E
```

When LOOP is assembled, the current location = 0000000E (offset of the next instruction). –5 (FBh) is added to the the current location, causing a jump to location 00000009:

00000009 ← 0000000E + FB

Your turn . . .

If the relative offset is encoded in a single signed byte,

(a) what is the largest possible backward jump?

(b) what is the largest possible forward jump?

(a) -128

(b) $+127$

Your turn . . .

What will be the final value of AX?

10

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

How many times will the loop execute?

4,294,967,296

```
      mov ecx,0
X2:
      inc ax
      loop X2
```

Nested Loop

If you need to code a loop within a loop, you must save the outer loop counter's ECX value. In the following 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 Integer Array

The following code calculates the sum of an array of 16-bit integers.

```
.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
```

Your turn . . .

What changes would you make to the program on the previous slide if you were summing a doubleword array?

Copying a String

The following code copies a string from source to target:

```
.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
```

good use of SIZEOF

Your turn . . .

Rewrite the program shown in the previous slide, using indirect addressing rather than indexed addressing.

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

THANKS!

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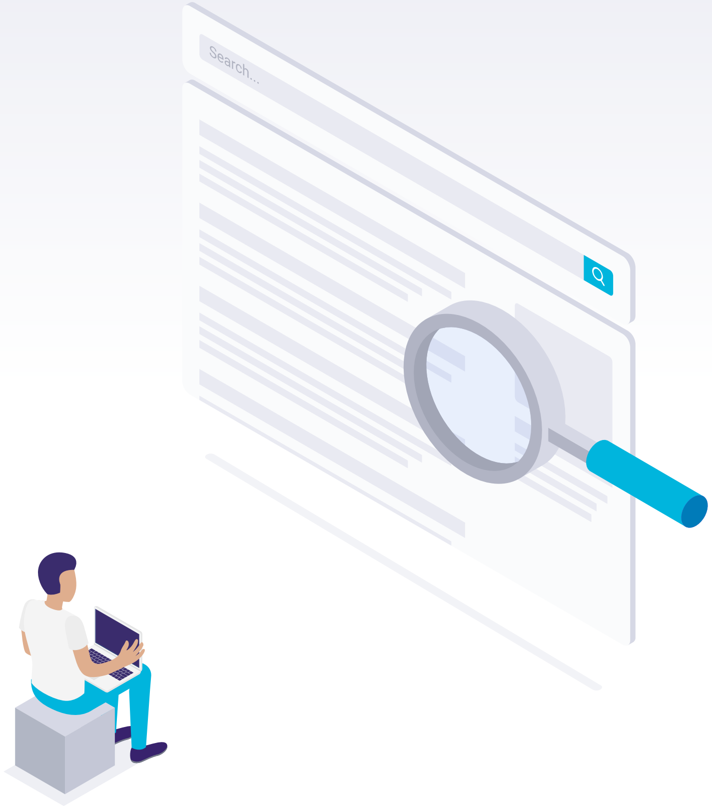
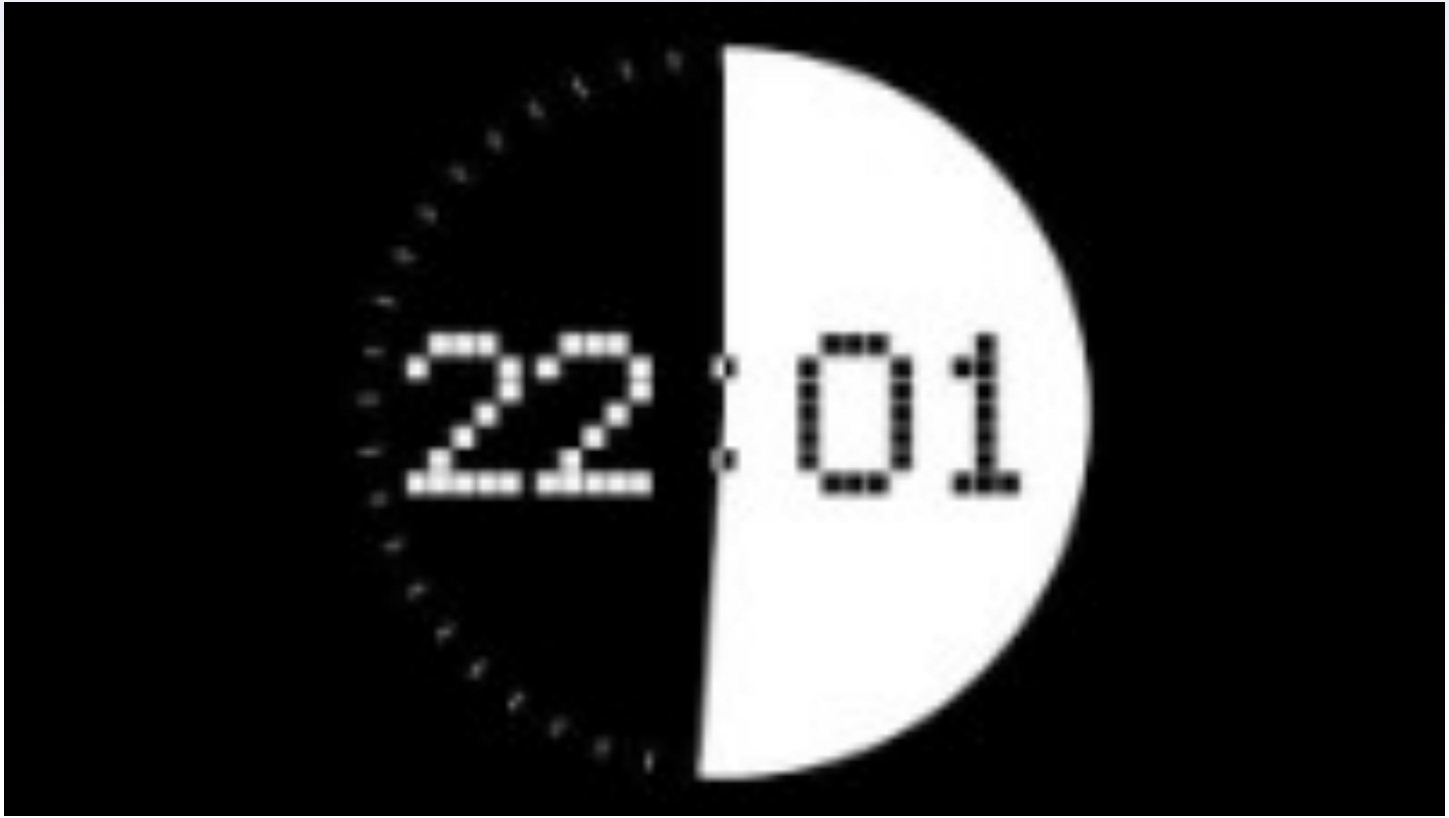


Lecture 10

Week 05

Quiz...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Let's Revise!

THANKS!

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