CSC 3210

Computer Organization and Programming

Chapter 4: Data Transfers, Addressing, and Arithmetic

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Outline

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

Data Transfer Instructions

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

Data Transfer 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

Listing File

```
00000000   .data
00000000 00000000  sum DWORD 0
00000000   .code
00000000   main proc
00000000   B8 00000008       mov eax, 8
00000005   83 C0 04          add  eax, 4
00000008   A3 00000000 R     mov sum, eax
```

Data Transfer Instructions: 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

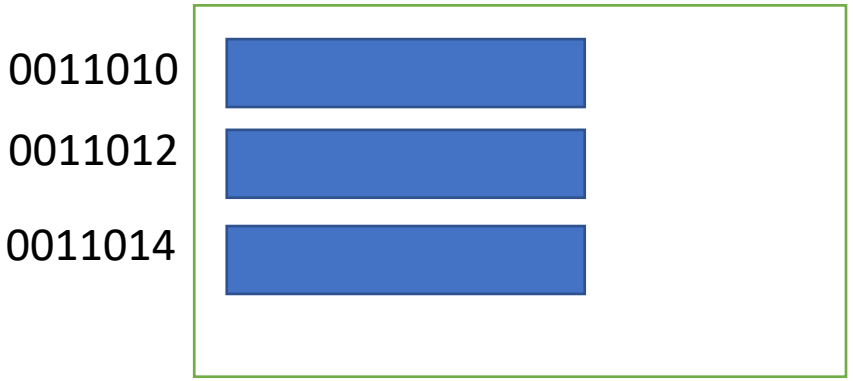
MOV **reg,reg**
MOV **mem,reg**
MOV **reg,mem**
MOV **mem,imm**
MOV **reg,imm**

```
MOVZX   reg32,reg/mem8
MOVZX   reg32,reg/mem16
MOVZX   reg16,reg/mem8
```

Data Transfer Instructions

- Register to Register

- Register to Memory , Vice versa



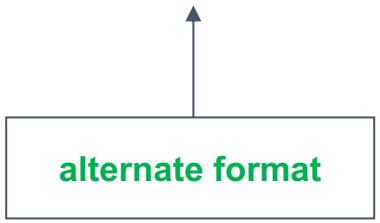
How to see variables in VS

Data Transfer Instructions: Direct Memory Operands

- A **direct memory operand** is a named reference to storage in memory

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

```
mov al,[var1] ; AL = 10h
```



Data Transfer Instructions: Direct Memory Operands

- The **named reference (label)** is automatically dereferenced by the **assembler**

```
.data
var1 BYTE 10h
```

  - Suppose **var1** were located at offset 10400h.
  - The following instruction copies its **value** into the AL register:

```
mov al, var1
```

    - It would be **assembled** into the following machine instruction:

```
A0 00010400
```

Data Transfer Instructions: Direct Memory Operands

- The **named reference (label)** is automatically dereferenced by the **assembler**

A0 00010400

Listing File

- The **first byte** in the machine instruction is the **opcode**.
- The **remaining part** is the **32-bit hexadecimal address of var1**.

```
00000000   .data

00000000 00000000  sum DWORD 0

00000000   .code

00000000   main proc
00000000   B8 00000008       mov eax, 8
00000005   83 C0 04          add  eax, 4
00000008   A3 00000000 R     mov sum, eax
```

Data Transfer Instructions: MOV Instruction

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

  MOV *destination*, *source*

- MOV instruction **formats**:

  MOV **reg,reg**
  MOV **mem,reg**
  MOV **reg,mem**
  MOV **mem,imm**
  MOV **reg,imm**

  - Both operands must be the same size.
  - Both operands cannot be memory operands.
  - The (IP, EIP, or RIP) cannot be a destination operand.

Ex:

```
.data
count BYTE 100
wVal  WORD 2
.code
    mov bl,count
    mov ax,wVal
    mov count,al

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

Data Transfer Instructions: MOV Instruction

- 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 eax,wVal
        mov eip,dVal
        mov 25,bVal
        mov bVal2,bVal
```

- Both operands must be the same size.
- Both operands cannot be memory operands.
- The (IP, EIP, or RIP) cannot be a destination operand.

Data Transfer Instructions: MOV Instruction

- **Memory to Memory (problem):**
  - A single MOV instruction cannot be used to move data directly from one memory location to another.
  - Instead, you must move
    - the source operand's value to a register
    - before assigning its value to a memory operand:

Ex:

```
.data
var1 WORD ?
var2 WORD ?
.code
mov ax,var1
mov var2,ax
```

Data Transfer Instructions: MOV Instruction

- Overlapping Values
  - The same 32-bit register **can be modified** using differently sized data.
    - When oneWord is moved to AX, it **overwrites** the existing value of AL.
    - When oneDword is moved to EAX, it **overwrites** AX.
    - When 0 is moved to AX, it **overwrites** the lower half of EAX.

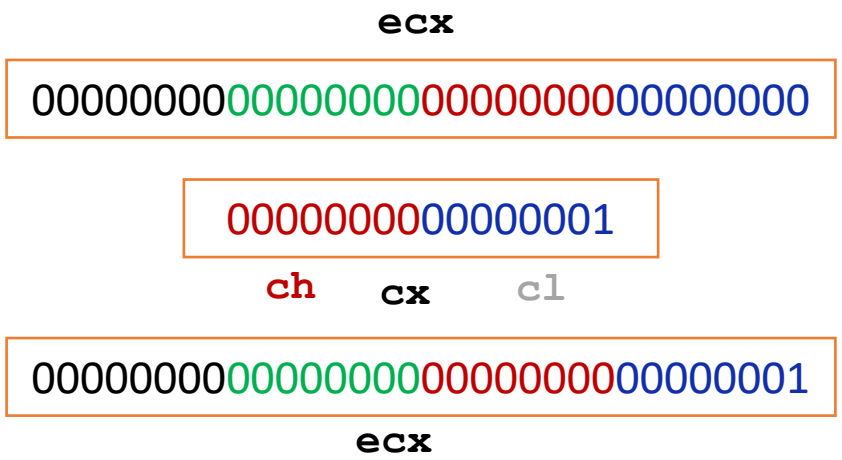
```
.data
oneWord WORD 1234h
oneDword DWORD 12345678h
```

```
.code
mov eax, 0
mov ax, oneWord          ; EAX = 00001234h
mov eax, oneDword        ; EAX = 12345678h
mov ax, 0                ; EAX = 12340000h
```

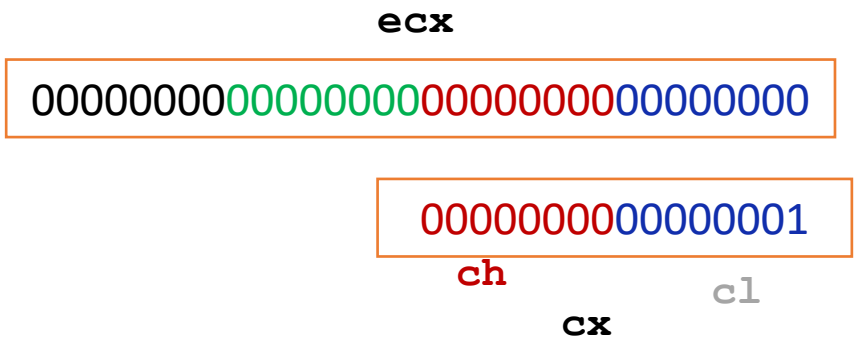
Data Transfer Instructions: Zero & Sign Extension

- **Sign extension problem:**
  - MOV cannot directly copy data from a **smaller** operand to a **larger** one
  - **Workarounds**:
    - Suppose **count** (**unsigned**, **16 bits**) must be moved to **ECX** (32 bits).
    - **Trick**: Set **ECX** to **zero** and move **count** to **CX**:

```
.data
count WORD 1
.code
mov ecx,0
mov cx,count
```



  - What happens if we try the same approach with a signed integer equal to -16?


ecx
00000000000000000000000000000000
0000000000000001
ch
cl
cx

Data Transfer Instructions: Zero & Sign Extension

- **Sign extension problem:**
  - What happens if we try the same approach with a signed integer equal to -16?

```
.data
signedVal SWORD -16              ; FFF0h (-16)
.code
mov ecx,0
mov cx,signedVal                 ; ECX = 0000FFF0h (+65,520)
```

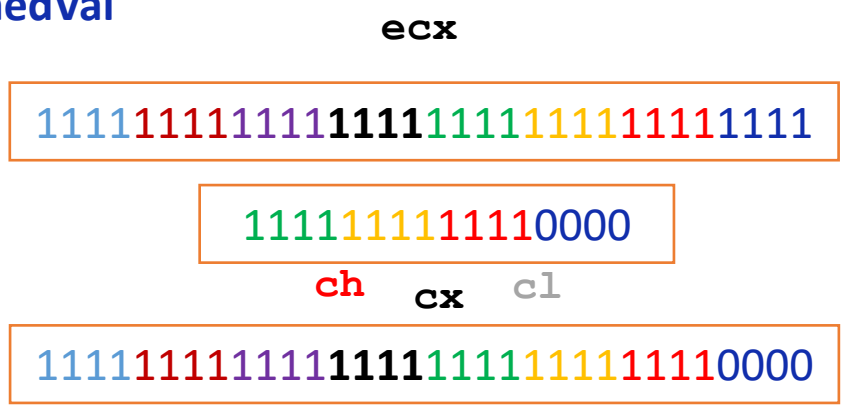
Data Transfer Instructions: Zero & Sign Extension

- **Sign extension problem:**

```
.data
signedVal SWORD -16             ; FFF0h (-16)
.code
mov ecx,0
mov cx,signedVal                ; ECX = 0000FFF0h (+65,520)
```

  - If we had filled **ECX** first with FFFFFFFFh and then copied **signedVal** to **CX**:

```
mov  ecx,FFFFFFFFh
mov  cx,signedVal          ; ECX = FFFFFFF0h (-16)
```



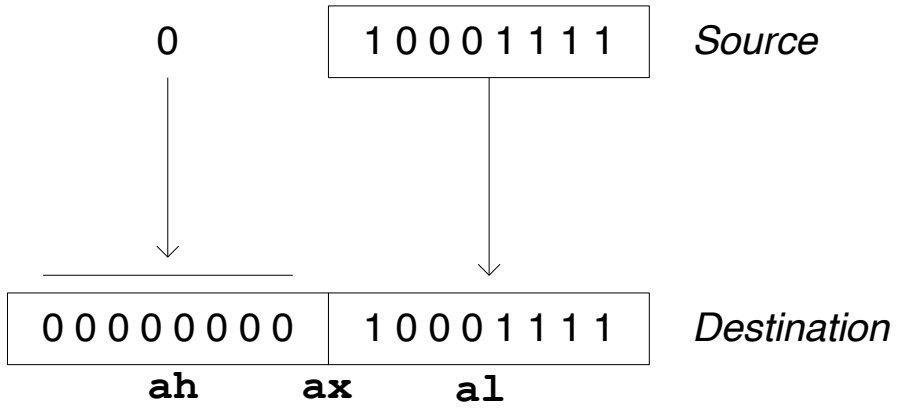
- **MOVZX** and **MOVSX** instructions to deal with both unsigned and signed integers.

Data Transfer Instructions: Zero Extension (MOVZX)

- The MOVZX instruction
- 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
```

```
MOVZX   reg32,reg/mem8
MOVZX   reg32,reg/mem16
MOVZX   reg16,reg/mem8
```



The destination must be a register.

Data Transfer Instructions: Zero Extension (MOVZX)

The following examples use registers for all operands, showing all the size variations:

```
mov    bx,0A69Bh
movzx  eax,bx                  ; EAX = 0000A69Bh
movzx  edx,bl                  ; EDX = 0000009Bh
movzx  cx,bl                   ; CX  = 009Bh
```

The following examples use memory operands for the source and produce the same results:

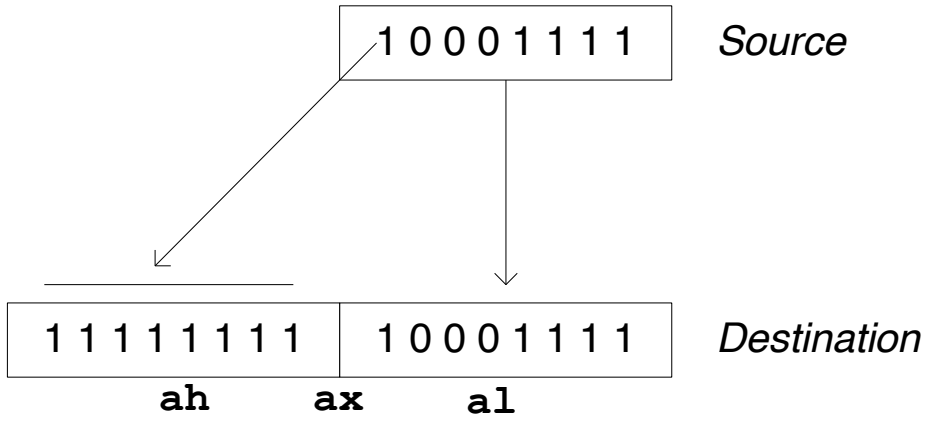
```
.data
byte1  BYTE 9Bh
word1  WORD 0A69Bh
.code
movzx  eax,word1               ; EAX = 0000A69Bh
movzx  edx,byte1               ; EDX = 0000009Bh
movzx  cx,byte1                ; CX  = 009Bh
```

Data Transfer Instructions: **Sign Extension (MOVSX)**

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

```
MOVSX  reg32,reg/mem8
MOVSX  reg32,reg/mem16
MOVSX  reg16,reg/mem8
```

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



The destination must be a register.

Data Transfer Instructions: **Sign Extension (MOVSX)**

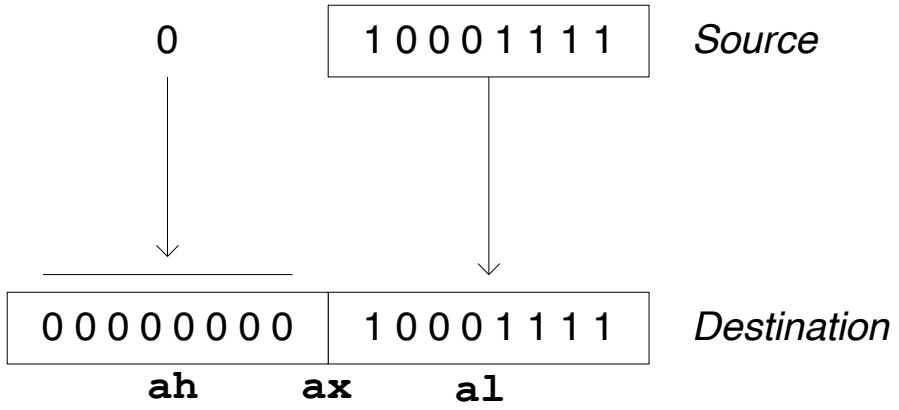
- In the following example,
  - the hexadecimal value moved to BX is A69B,
  - so the leading "A" digit tells us that the highest bit is set.

```
mov     bx, A69Bh
movsx eax,bx            ; EAX = FFFFA69Bh
movsx edx,bl            ; EDX = FFFFFF9Bh
movsx cx,bl             ; CX = FF9Bh
```

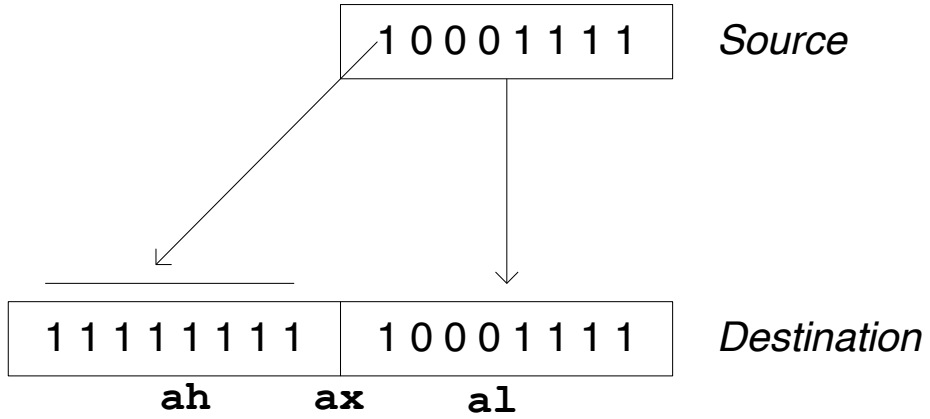
Data Transfer Instructions: Zero & Sign Extension

- MOVZX vs. MOVSX

MOVZX



MOVSX



Data Transfer Instructions: XCHG Instruction

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

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

```
xchg ah,al          ; exchange 8-bit regs
xchg ax,bx          ; exchange 16-bit regs
xchg eax,ebx        ; exchange 32-bit regs
xchg var1,bx ; exchange 16-bit mem op with BX
```

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

Xchange items

Data Transfer Instructions: **XCHG Instruction**

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

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

```
.data
var1 WORD 1000h
var2 WORD 2000h
.code
mov ax,val1
xchg ax,val2
mov val1,ax
```

Data Transfer Instructions: **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                    ; AL = 10h
mov al,arrayB+1                  ; AL = 20h

  mov al,[arrayB+1]        ; alternative notation
```

Why doesn't arrayB+1 produce 11h?

Data Transfer Instructions: **Direct-Offset Operands**

```
.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]        ; ??
```

Data Transfer Instructions: **Direct-Offset Operands**

```
.data
arrayW  WORD 1000h,2000h,3000h
arrayD  DWORD 1,2,3,4
.code
mov ax, [arrayD+0]              ; AX = 2000h
mov ax, [arrayD+4]              ; AX = 3000h
mov eax,[arrayD+8]              ; EAX = 00000002h
```

Will the following statements assemble?

```
mov ax,[arrayW-2]          ; ??
mov eax,[arrayD+16]        ; ??
```

Data Transfer Instructions: Direct-Offset Operands

- Write a program that rearranges the values of three doubleword values in the following array as:

1,2,3 ----------→ 3, 1, 2.

LAB

```
.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]
```

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

- **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
```

Data Transfer Instructions: Direct-Offset Operands

- 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?

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

- Any other possibilities?

Data Transfer Instructions: Direct-Offset Operands

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

```
.data
myBytes BYTE 80h,66h,0A5h
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- What is your evaluation of the following code?

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mov al,myBytes
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- What is your evaluation of the following code?

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movsx ax, myBytes
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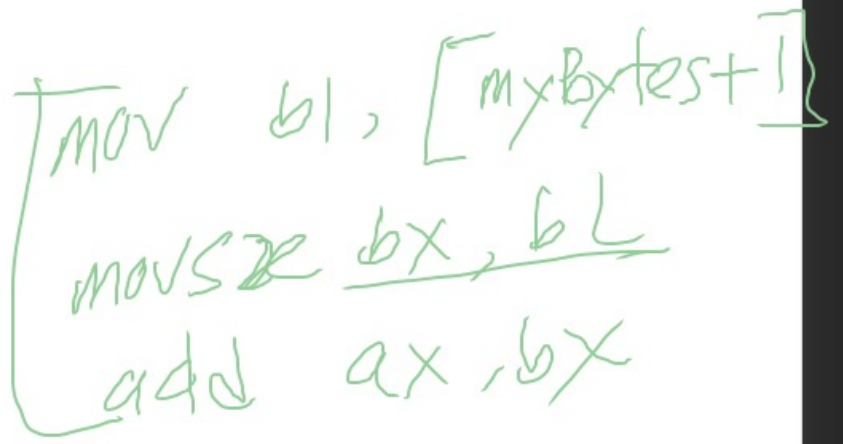

- Any other possibilities?

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Outline

- 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

Addition and Subtraction: INC and DEC Instructions

- Add 1, subtract 1 from destination operand
  - operand may be register or memory
- The **Syntax**:

```
INC reg/mem
DEC reg/mem
```

- INC *destination*
  - Logic: *destination* ← *destination* + 1
- DEC *destination*
  - Logic: *destination* ← *destination* – 1

Addition and Subtraction: INC and DEC Examples

```
.data
myWord  WORD 1000h
myDword DWORD 10000000h
.code
        inc myWord
        dec myWord
        inc myDword

        mov ax,00FFh
        inc ax
        mov ax,00FFh
        inc al
```

Addition and Subtraction: INC and DEC Examples

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

```
.data
myByte BYTE FFh, 0

.code
    mov al,myByte
    mov ah,[myByte+1]
    dec ah
    inc al
    dec ax
```

Addition and Subtraction

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

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

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

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
```

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

Can you add registers of different sizes?

add eax,bx

Can you add mem to mem?

add var1,var2

Addition and Subtraction

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

NEG (negate) Instruction

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

```
NEG reg
NEG mem
```

Ex.

```
.data
valB SBYTE -1                    ;valB BYTE -1 is also acceptable, why?
valW WORD +32
.code
    mov al,valB                  ; AL = -1
    neg al                       ; AL = +1
    neg valW                     ; valW = -32
```

- Suppose **AX** contains **–32,768** and we apply **NEG** to it.
- **Will** the **result be valid**?

Addition and Subtraction

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

Implementing **Arithmetic Expressions**

- **HLL compilers** translate mathematical expressions into **assembly language**.
- You can do it also.
- For example: **Do not permit** Xval, Yval, or Zval to be modified

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
```

Implementing **Arithmetic Expressions**

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

Rval = Xval - (-Yval + Zval)

Previous Example:

Rval = -Xval + (Yval – Zval)

  - Assume that all values are signed doublewords.

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

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

Addition and Subtraction

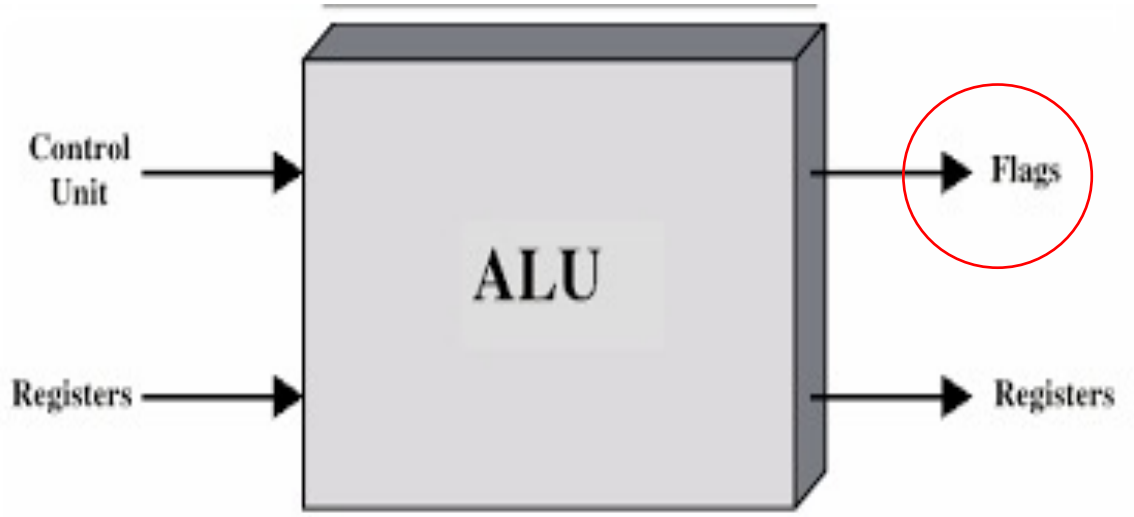
- INC and DEC Instructions
- ADD and SUB Instructions
- NEG Instruction
- Implementing Arithmetic Expressions
- Flags Affected by Arithmetic
  - Zero
  - Sign
  - Carry
  - Overflow

Flags: Why?

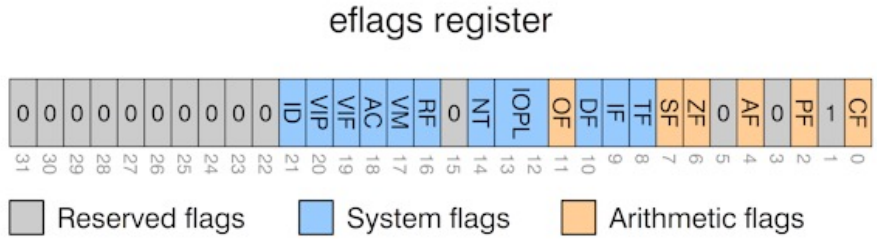
- When executing **arithmetic instructions**, we often want to know something about the result:
  - Is it negative, positive, or zero?
  - Is it **too large** or **too small** to fit into the destination operand?
- Answers to such questions can help detect calculation errors that might otherwise cause erratic program behavior.
- The values of CPU status flags is used to check the outcome of arithmetic operations.
  - Status flag values are also used to activate **conditional branching instructions**, the basic tools of program logic.

Flags: **Flags** Affected by **Arithmetic/Bitwise**

- The **ALU** has a number **of status flags** that reflect the outcome of
  - arithmetic operations
  - bitwise operations
- **based** on the contents of the
- destination operand



Flags: **Flags** Affected by **Arithmetic/Bitwise**



- 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

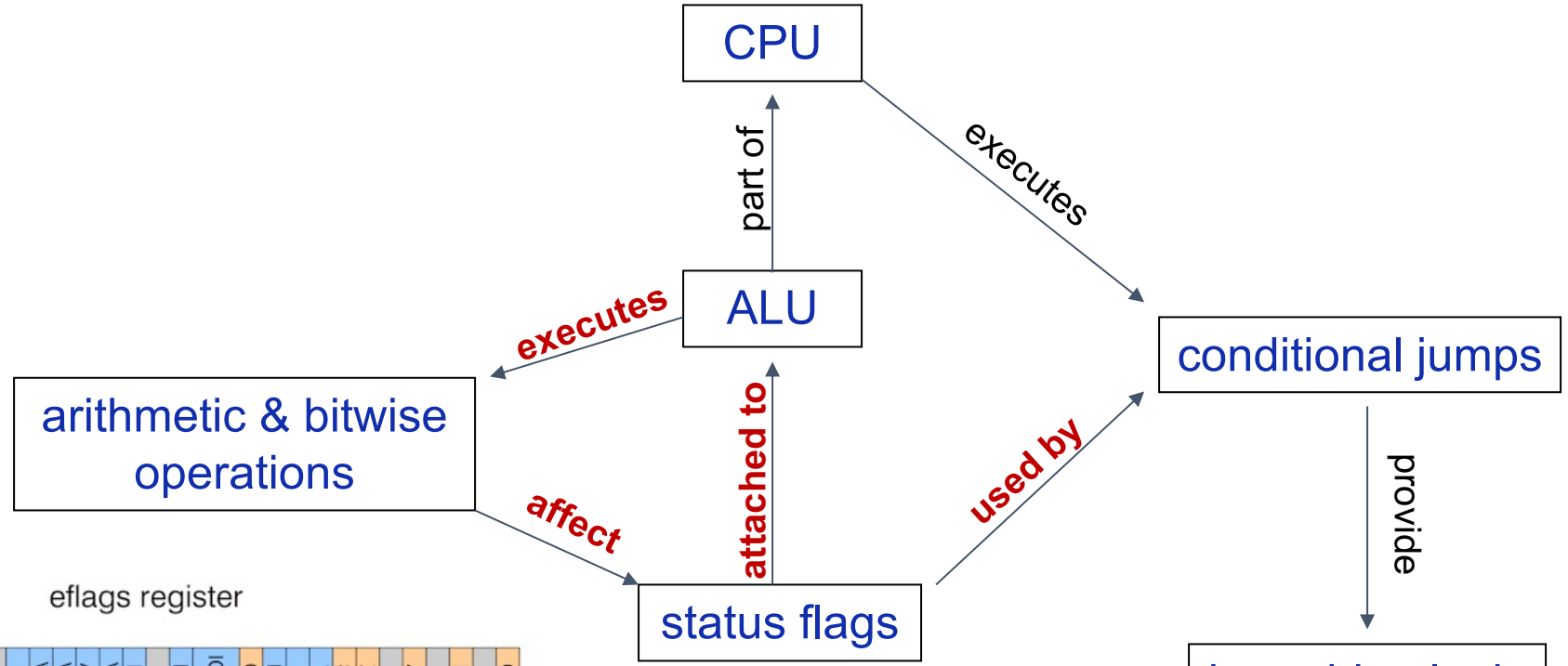
- **Visual Studio Flags?**

Flag Name	Overflow	Direction	Interrupt	Sign	Zero	Aux Carry	Parity	Carry
Symbol	OV	UP	EI	PL	ZR	AC	PE	CY

The **MOV** instruction never affects the flags. (**Why?**)

Flags: **Map**

- The **ALU** has a number **of status flags** that reflect the outcome of **arithmetic** operations and **bitwise** operations.



Flags: **Displaying CPU Flags in Visual Studio**

- **You must be currently debugging a program in order to see these menu options.**
- To display the CPU status flags **during a debugging session**,
  - select Windows from the Debug menu,
  - then select Registers from the Windows menu.
  - Inside the Registers window, right-click and select Flags from the dropdown list.

Each flag is assigned a value of 0 (clear) or 1 (set).

Flags: **Unsigned and Signed Integers Operations**

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

CF vs. OF

Flags: Unsigned Operations, Zero flag (ZF)

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

```
mov ecx,1
sub ecx,1          ; ECX = 0, ZF = 1
mov eax,FFFFFFFFh
inc eax            ; EAX = 0, ZF = 1
inc eax            ; EAX = 1, ZF = 0
```

Based on the contents of the **destination operand**

Remember...

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

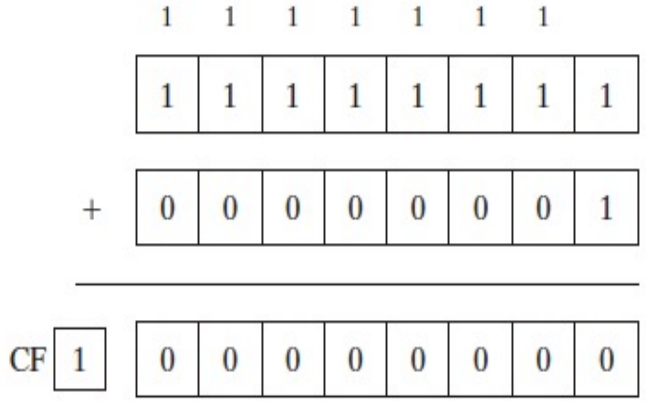
Flags: Unsigned Operations, **Carry flag (CF)**

- The **Carry flag (CF)** 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**).
- Addition .Vs Subtraction (**borrow**)

- **Addition** and the Carry Flag

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

FIGURE 4–3 Adding 1 to 0FFh sets the Carry flag.

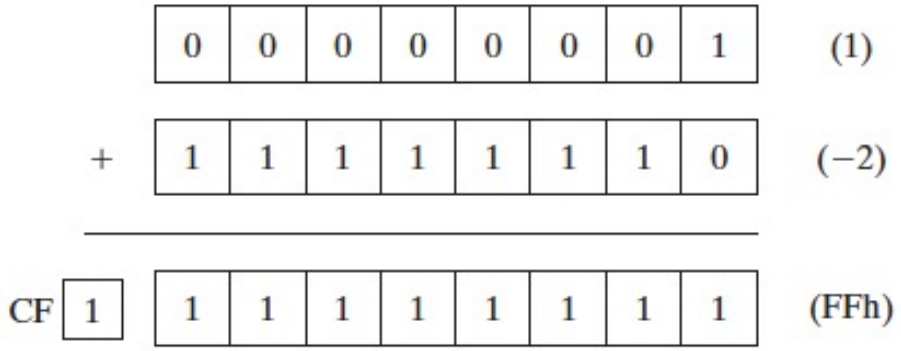


Flags: Unsigned Operations, **Carry flag (CF)**

- **Subtraction** and the Carry (and **borrow**) Flag
- A subtract operation sets the Carry flag when
  - a larger unsigned integer is **subtracted** from a smaller one.

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

FIGURE 4–4 Subtracting 2 from 1 sets the Carry flag.



Flags: Unsigned Operations, **Carry flag (CF)**

- **Subtraction** and the Carry (and **borrow**) Flag
- A subtract operation sets the Carry flag when
  - a larger unsigned integer is **subtracted** from a smaller one.

```
; Try to go below zero:

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

Flags: Unsigned Operations, Parity

- **Parity**
  - **The Parity flag (PF)** is set when
    - The least significant byte of the **destination** has an **even number of 1 bits**.
  - The following ADD and SUB instructions alter the parity of AL:

```
mov al,10001100b
add al,00000010b ; AL = 10001110, PF = 1
sub al,10000000b ; AL = 00001110, PF = 0
```

Flags: Signed Operations, **Sign Flag (SF)**

- The **Sign flag (SF)** 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
```

Flags: Signed Operations, **Sign Flag (SF)**

- The **Sign flag (SF)** is set when the destination operand is negative.

- 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
```

Flags: Signed Operations, **Overflow Flag (OF)**

The **Overflow flag (OF)** 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.

Flags: **Unsigned and Signed Integers Operations**

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

```
mov ax,7ff0h
add al,10h          ; AX=       SF=   ZF=   CF=    OF=
add ah,1            ; AX=       SF=   ZF=   CF=    OF=
add ax,2            ; AL=       SF=   ZF=   CF=    OF=
```

8000 → 32768

Flags: Unsigned and Signed Integers Operations

Use the following data for Questions 4-5:

```
.data
val2 WORD 8000h
val4 WORD 7FFFh
```

1. If **val2** is incremented by 1 using the ADD instruction, what will be the values of the Carry and Sign flags?
2. If **val4** is incremented by 1 using the ADD instruction, what will be the values of the Overflow and Sign flags?

Flags: Unsigned and Signed Integers Operations

- **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
```

Flags: Unsigned and Signed Integers Operations

- **Overflow and Carry Flags**
  - What will be the values of the given **flags** after each operation?

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

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

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

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

a larger signed integer is **subtracted** from a **smaller** one

Flags: NEG Instruction

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

Ex1.
- If we move 128 to AL and try to negate it, the correct value (128) will not fit into AL.
- The Overflow flag is set, indicating that AL contains an invalid value:

```
mov al,-128        ; AL = 10000000b
neg al             ; AL = 10000000b, OF = 1
```

Flags: NEG Instruction

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

Ex2.

- If 127 is negated, the result is valid and the Overflow flag is clear:

```
mov al,+127          ; AL = 01111111b
neg al               ; AL = 10000001b, OF = 0
```

Flags: NEG Instruction

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

Ex2.

- If 127 is negated, the result is valid and the Overflow flag is clear:

```
mov al,+127          ; AL = 01111111b
neg al               ; AL = 10000001b, OF = 0
```

Outline

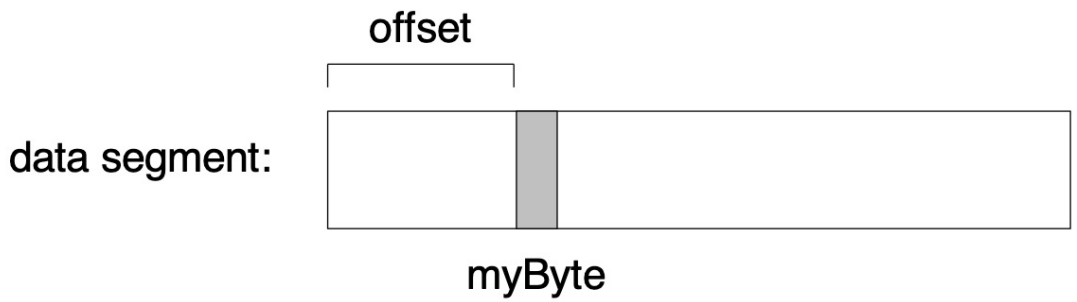
- Data Transfer Instructions
- Addition and Subtraction
- **Data-Related Operators and Directives**
- Indirect Addressing
- JMP and LOOP Instructions
- 64-Bit Programming

Operators and Directives

- **Operators** and **directives** are not executable instructions;
  - They are interpreted by the assembler.
    - OFFSET Operator
    - PTR Operator
    - TYPE Operator
    - LENGTHOF Operator
    - SIZEOF Operator

OFFSET Operator

- **OFFSET returns** ~~the offset of the data label~~, address of a variable
  it represents the distance in **bytes**, of a label from the **beginning** of its enclosing segment
  - **Protected mode**: **32 bits**
  - **Real mode**: **16 bits**



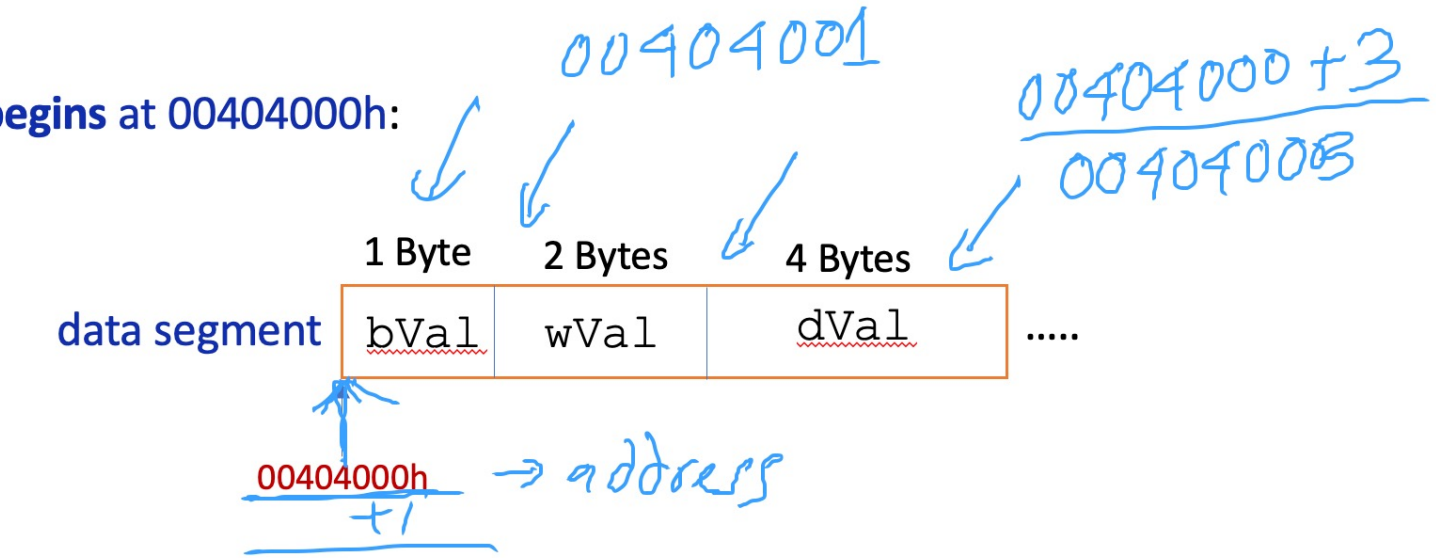
The **Protected-mode programs** we **use only a single segment** (**flat** memory model).

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
```



This is a memory address not a memory value

OFFSET: Examples

- OFFSET can also be applied to a direct-offset operand
- Suppose myArray contains five 16-bit words
- The following MOV instruction
  - **Obtains the offset of myArray,**
  - Adds 4,
  - Moves the resulting address to ESI.
  - We can say that ESI points to the third integer in the array:

```
.data
myArray WORD 1,2,3,4,5

.code
mov esi,OFFSET myArray + 4      ESI = 00404000 + 4
```

OFFSET: **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

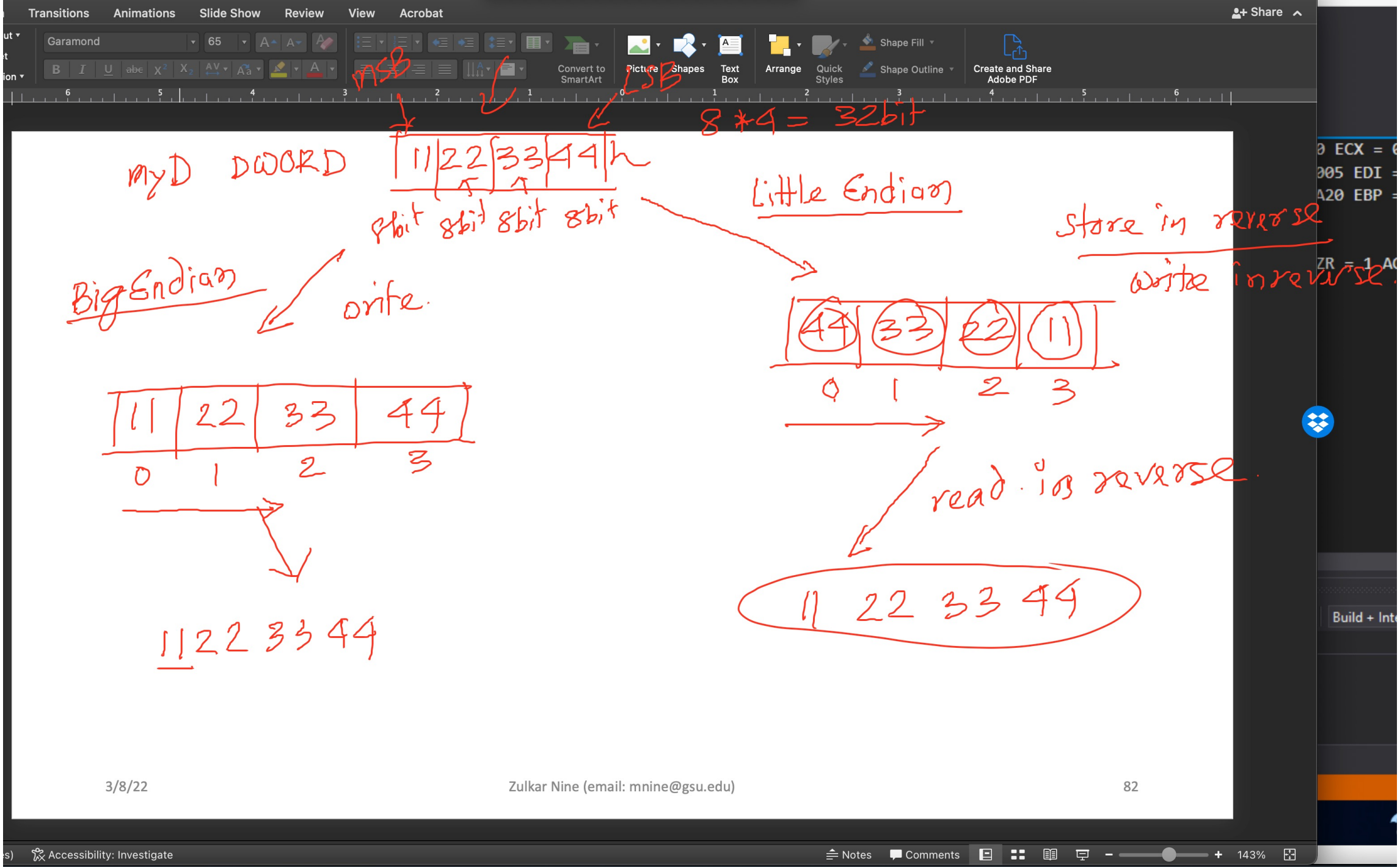
- **Overrides** the **default type** of a **label** (variable).
- Provides the flexibility to **access PART of a variable**.
- Used in combination with BYTE, SBYTE, WORD, SWORD, DWORD, SDWORD, FWORD, QWORD, or TBYTE
- **Ex.** PTR operator makes it possible to move the **low-order**

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

- But the **WORD PTR operator** makes it possible to move the low-order word (**5678h**) to AX:

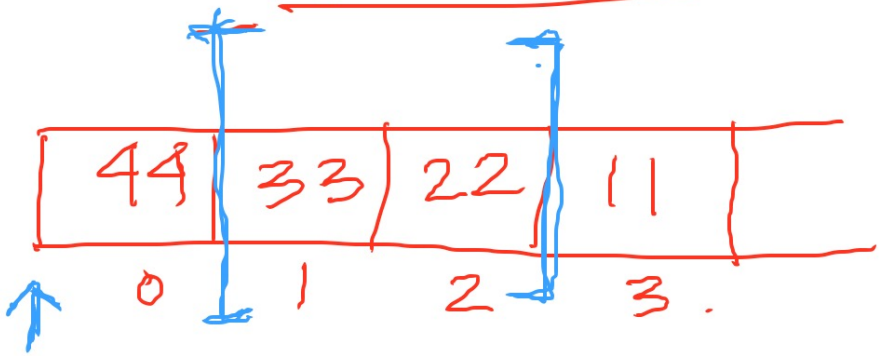
```
mov  ax,WORD PTR myDouble
```

Why wasn't 1234h moved into **AX**?


Transitions
Animations
Slide Show
Review
View
Acrobat
Share
Garamond
65
Convert to SmartArt
Picture
Shapes
Text Box
Arrange
Quick Styles
Shape Fill
Shape Outline
Create and Share Adobe PDF
MSB
LSB
8*4 = 32bit
myD DWORD 11223344h
8bit 8bit 8bit 8bit
Little Endian
store in reverse
write in reverse.
BigEndian
write.
11 22 33 44
0 1 2 3
read in reverse.
11 22 33 44
11223344
3/8/22
Zulkar Nine (email: mnine@gsu.edu)
82
Accessibility: Investigate
Notes
Comments
143%

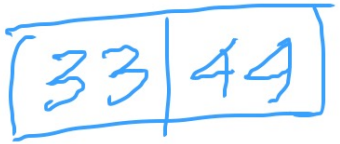
myD DWORD 11223344h

Little Endian



MOV AL BYTE PTR myD = 44

WORD PTR myD = ~~4433~~ ?



WORD PTR myD+1 = 22 33

WORD PTR myD+2 = 11 22

PTR Operator

Why wasn't 1234h moved into **AX**?

- **x86 processors** use the **little endian storage format**

- **low-order byte is stored at the variable's starting address**

- For example, the **doubleword 12345678h** would be stored as:

```
mov  ax,WORD PTR myDouble
```

(**5678h**)

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: Example1

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

Memory Layout

```
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: **Example2**

- PTR can also be used to **combine elements of a smaller data type** and move them into a larger operand.

```
.data
wordList WORD 5678h,1234h
.code
mov eax, DWORD PTR wordList          ; EAX = 12345678h
```

PTR Operator: **Exercise**

- Use the following data definitions for Questions 6:

```
myBytes      BYTE 10h,20h,30h,40h
myWords      WORD 8Ah,3Bh,72h,44h,66h
myDoubles DWORD 1,2,3,4,5
myPointer    DWORD myDoubles
```

6. Fill in the requested register values on the right side of the following instruction sequence:

```
mov  esi,OFFSET myBytes
mov  ax,[esi]                    ; a. AX =
mov  eax,DWORD PTR myWords       ; b. EAX =
mov  esi,myPointer
mov  ax,[esi+2]                  ; c. AX =
mov  ax,[esi+6]                  ; d. AX =
mov  ax,[esi-4]                  ; e. AX =
```

myWords WORD 8Ah,3Bh,72h,44h,66h

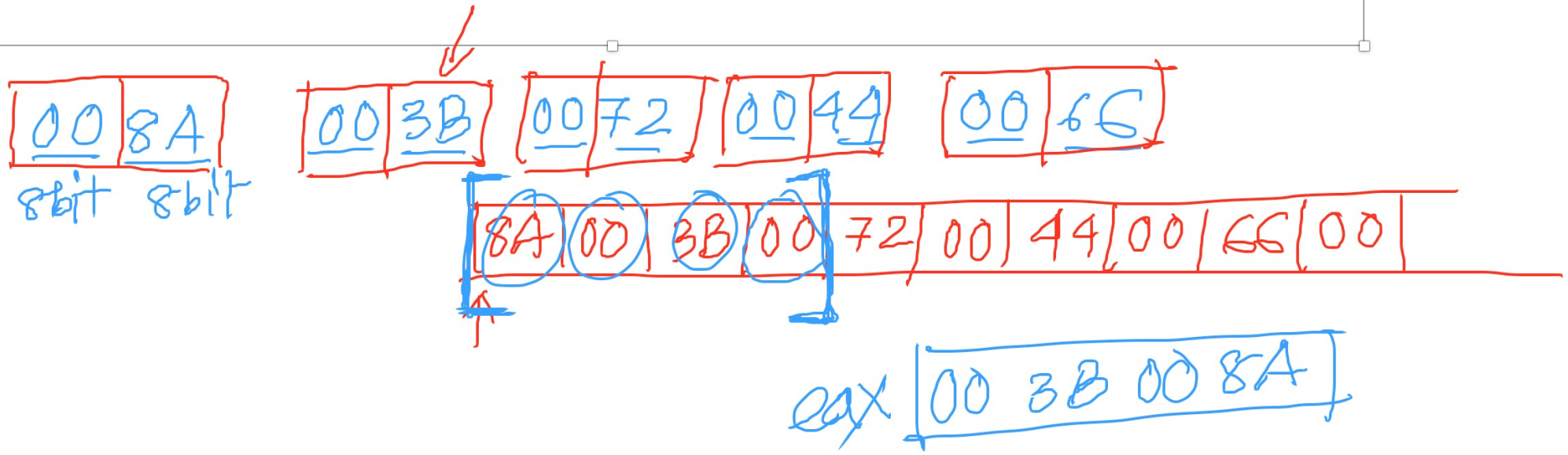
6. Fill in the requested register values on the right side of the following instruction sequence:

```
mov  esi,OFFSET myBytes
mov  ax,[esi]                    ; a. AX =
mov  eax,DWORD PTR myWords       ; b. EAX =
mov  esi,myPointer
mov  ax,[esi+2]                  ; c. AX =
mov  ax,[esi+6]                  ; d. AX =
mov  ax,[esi-4]                  ; e. AX =
```

myWords WORD 8Ah,3Bh,72h,44h,66h

6. Fill in the requested register values on the right side of the following instruction sequence:

```
mov  esi,OFFSET myBytes
mov  ax,[esi]                ; a. AX =
mov  eax,DWORD PTR myWords   ; b. EAX =
mov  esi,myPointer
mov  ax,[esi+2]              ; c. AX =
mov  ax,[esi+6]              ; d. AX =
mov  ax,[esi-4]              ; e. AX =
```



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
```

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
```

SIZEOF Operator (in byte) = lengthof * Type

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

```
.data                                          3 * 1 byte →  SIZEOF
byte1   BYTE 10,20,30                                    ; 3
array1  WORD 30 DUP(?),0,0                    32*2 byte  ; 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
```

Outline

- 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
- Pointers

Indirect Addressing (1)

- Direct addressing becomes infeasible for array access.
- Mov eax, arrayD
- Mov eax, [arrayD+4]
- Mov eax, [arrayD+8]

- There is no way to parameterize the constant offset (e.g. 4)

Indirect Addressing (1)

- Direct addressing becomes infeasible for array access.
- Mov eax, arrayD
- Mov eax, [arrayD+4]
- Mov eax, [arrayD+8]

- There is no way to parameterize the constant offset (e.g. 4)

Indirect Addressing (2)

- Indirect addressing can solve the issue
- Consider the example.

```
.data
Val1 BYTE 11h, 33h, 55h
```

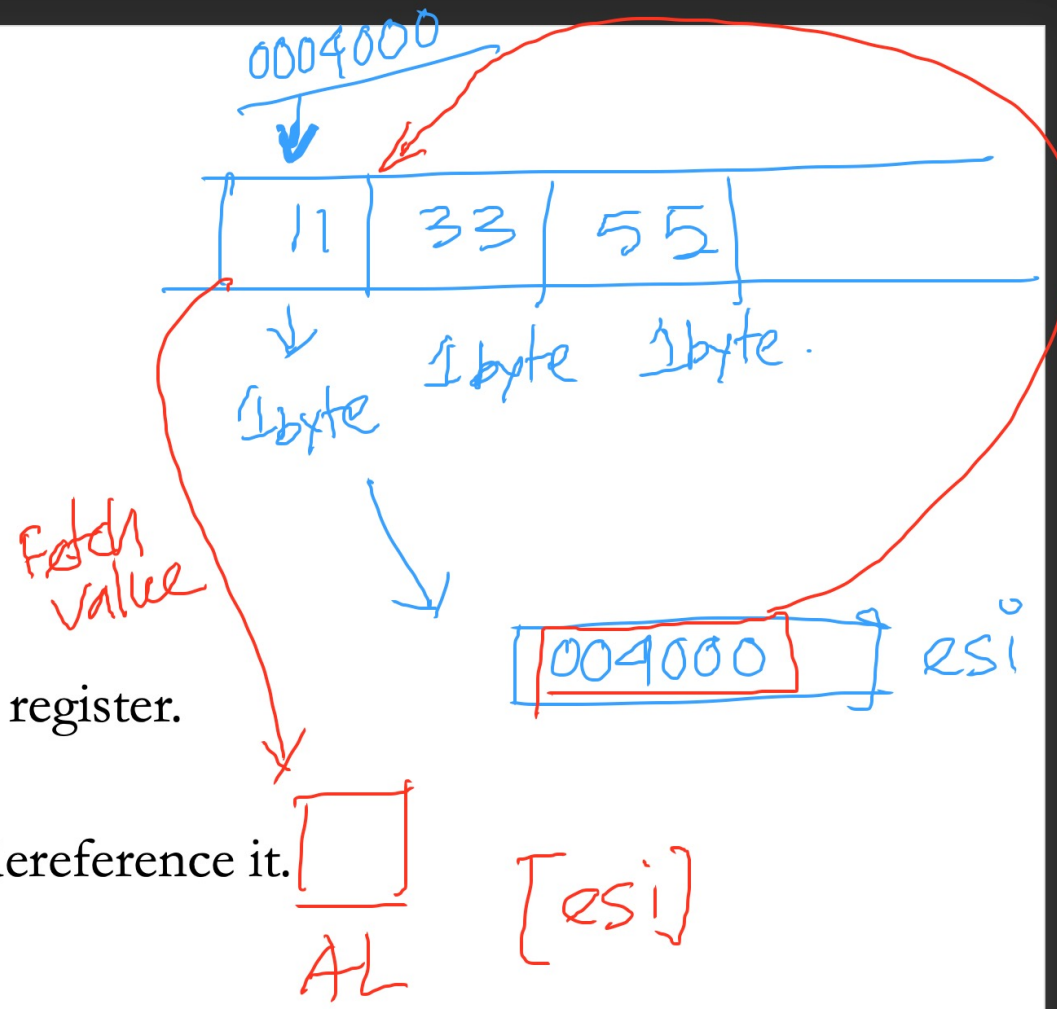
- Store the address of the array in any 32-bit register.
  - **mov esi, OFFSET val1**
- The put that register inside the bracket to dereference it.
  - **mov al, [esi]**
  - Now Al contains 11h

Indirect Addressing (2)

- Indirect addressing can solve the issue
- Consider the example.

```
.data
Val1 BYTE 11h, 33h, 55h
```

- Store the address of the array in any 32-bit register.
  - **mov esi, OFFSET val1**
- The put that register inside the bracket to dereference it.
  - **mov al, [esi]**
  - Now Al contains 11h

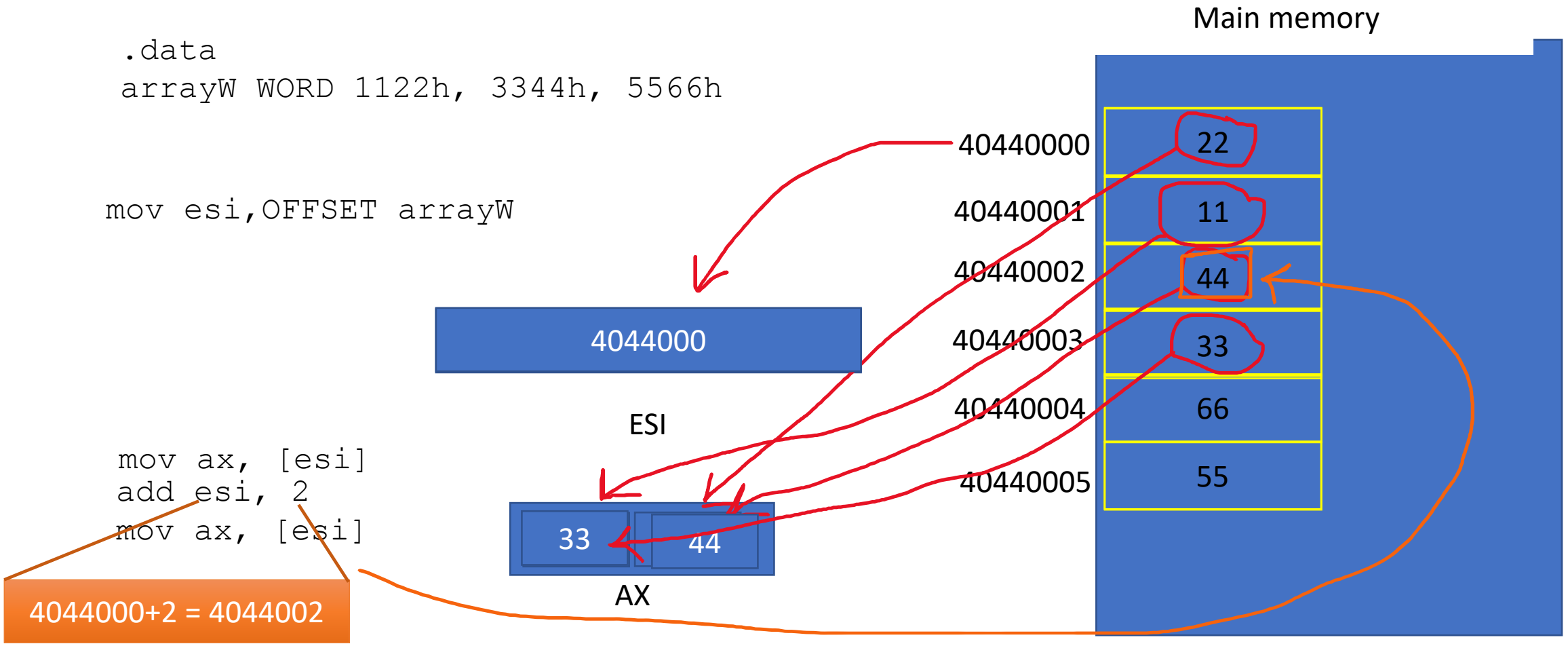


Indirect Addressing

```
.data
arrayW WORD 1122h, 3344h, 5566h

mov esi,OFFSET arrayW

mov ax, [esi]
add esi, 2
mov ax, [esi]
```



Attendance!

Indirect Addressing: **Indirect Operands**

- 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 Addressing: **Indirect Operands**

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

```
.data
myCount WORD 7,3,2

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

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

Indirect Addressing: **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.

Indirect Addressing

- Indirect Operands
  - Array Sum Example
- **Indexed Operands**
- Pointers

Indexed Operands

- Instead of storing the address in ESI register (or any 32-bit register)
  - You can use these registers as counter.
- An **indexed operand** adds a constant to a register to generate an **effective address.**
- There are two notational forms:

  [*label* + *reg*] **_label_[*reg*]**

- [var1 + esi] OR var1[esi]

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**.

Indirect Addressing

- Indirect Operands
- Array Sum Example
- Indexed Operands
- **Pointers**

Pointers

- You can declare a pointer variable that contains the offset of **another variable**.

```
.data
arrayW WORD 1000h,2000h,3000h
myptrW  DWORD  arrayW
.code
    mov esi,myptrW
    mov ax,[esi]              ; AX = 1000h
```

Alternate format:

myptrW DWORD OFFSET arrayW

Outline

- 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 and LOOP Instructions

- **CPU** loads and executes programs **sequentially**
- Current **instruction** might be a one that **transfer control** to a different **memory address**

offset	machine code	source code
00000000	B8 00000000	mov eax,0
00000005	EB 03	**jmp** addone
00000007	83 C0 02	add eax,2
0000000A		addone:
0000000A	40	inc eax
0000000B	83 C0 01	add eax,4294967295

- **Assembly language** programs use **conditional instructions** to implement high-level statements
  - IF statements and Loops.

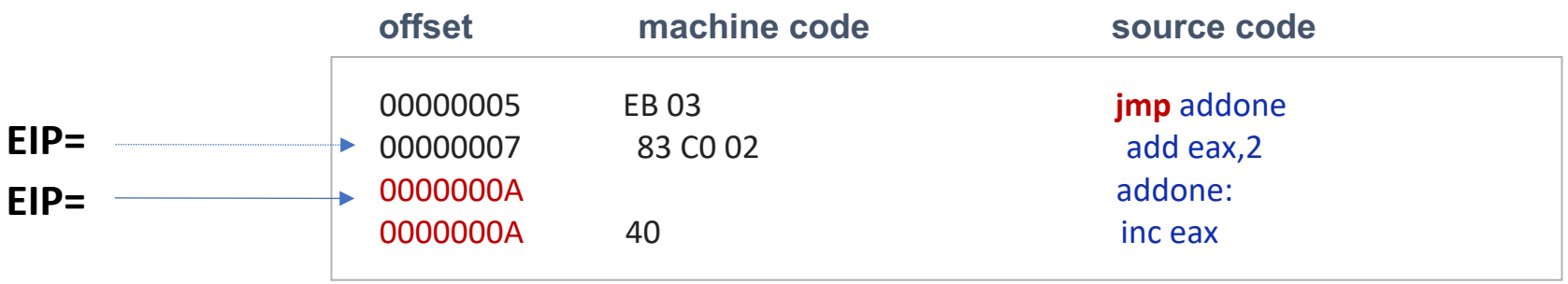
JMP and **LOOP** Instructions

- There are two basic **types of transfers**:
  - **Unconditional Transfer**
  - **Conditional Transfer**

- **Unconditional Transfer**: Control is transferred to a new location **in all cases**
  - New address is loaded into **the instruction pointer, EIP**,
    - causing execution to **continue at the new address**.
  - The JMP instruction does this.

JMP Instruction (Unconditional Transfer)

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



JMP Instruction (Unconditional Transfer)

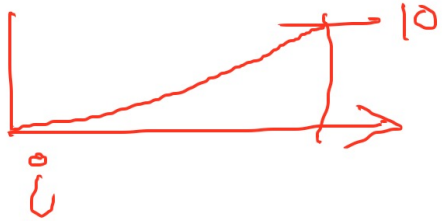
- JMP is **an unconditional jump** to **a label** that is **usually** within the same procedure.
- **Example**:

```
mov eax,0
Jmp addone
add eax,2
addone:
inc eax
add eax, 4294967295          ;2^32 = 4294967296
```

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).

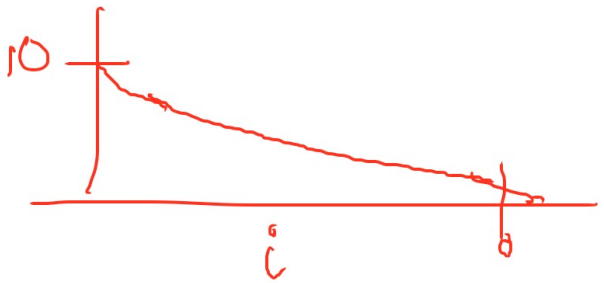
Try Visual Studio

```
for(i=0; i<10; i++){
    a = a+1;
}
```



increasing for loop

```
for(i=10; i>0; i--){
    a = a+1;
}
```



decreasing for loop

LOOP Instruction (**Conditional Transfer**)

- **Conditional Transfer**: The program branches **if a certain condition is true**
  - A wide **variety** of conditional transfer **instructions** can be combined to create **conditional logic structures.**

- The **LOOP** instruction creates a **counting loop**
- Syntax: LOOP *target*

- Logic:
  1. ECX ← ECX – 1
  2. **if ECX != 0**, jump to *target*

The CPU interprets true/false conditions based on the contents of the ECX and Flags registers.

LOOP: Example

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

```
mov   ax,0
mov   ecx,5
L1:   add   ax,cx
loop L1
```

Logic: ECX ← ECX – 1
if ECX != 0, jump to *target*

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		

How assembler calculates FB?

LOOP: Example (Conditional Transfer)

- The **assembler calculates the distance**, in bytes, between
  - the **offset** of the **following instruction** and
  - the **offset** of **the target label**.

offset	machine code	source code
00000009	66 03 C1	L1: add ax,cx
0000000C	E2 FB	loop L1
0000000E		

LOOP: **Example** (Conditional Transfer)

- When LOOP is assembled,
    1. The current location = 0000000E (offset of the **next** instruction)
    2. Distance is
        - -5 (**FBh**)
        - **FBh** is added to the the current location,
        - causing a jump to location **00000009**:

          Target Label location address = Offset of the **next** instruction + Distance

          00000009 ← 0000000E + **FB**
    3. The relative offset is added to **EIP** = 00000009

LOOP: **Example**

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

LOOP: Example

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?

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

A common programming error is to inadvertently **initialize ECX to zero** before beginning a loop.

LOOP: **Nested LOOP**

LOOP: 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 **3** times, and **the inner loop 2 times**.

```
.data
count DWORD ?
.code
    mov ecx,3              ; set outer loop count
L1:
    mov count,ecx          ; save outer loop count
    mov ecx,2              ; set inner loop count
L2: .
    .
    loop L2                ; repeat the inner loop
    mov ecx,count          ; restore outer loop count
    loop L1                ; repeat the outer loop
```

JMP and **LOOP** Instructions

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

Array: 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
1       mov edi,OFFSET intarray     ; address of intarray
2       mov ecx,LENGTHOF intarray   ; loop counter
3       mov ax,0                    ; zero the accumulator
4   L1:
5       add ax,[edi]                ; add an integer
6       add edi,TYPE intarray       ; point to next integer
7       loop L1                     ; repeat until ECX = 0
```

1. **Assign** the array's **address** to a register that will serve as an indexed operand.
2. **Initialize** the loop counter to the **length** of the array.
3. **Assign** zero to the register that **accumulates** the sum.
4. **Create** a label to mark the **beginning** of the loop.
5. In the loop body, **add** a single array element to the sum.
6. **Point** to the next array element.
7. **Use** a LOOP instruction to repeat the loop.

Array: Summing an Integer Array

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

```
intarray WORD 100h,200h,300h,400h

mov ax,0
add ax,[edi]
```

JMP and **LOOP** Instructions

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

Copying a **String**

- Use a loop to **copy** a string, represented as an **array of bytes** with **a null terminator value**.

```
source  BYTE  "This is the source string",0
```

- The target string must **have enough available space** to receive the copied characters, including the null byte at the end 🤔:

```
target  BYTE  SIZEOF source DUP(0)
```

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

- **Indexed addressing** works well for this type of operation because the same index register references both strings.

```
mov  esi,0              ; index register
mov  al,source[esi]     ; get char from source
mov  target[esi],al
```

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

Copying a **String**

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
- JMP and LOOP – branching instructions