# Introduction to As [illegible] age

CFOMS

# Outline

- Basic Elements of Assembly Language
- Flat Memory Program Template

- Example: A g Integers

- Assembling, ging Programs

- Defining Data
- Defining Symbolic Constants
- Data-Related Operators and Directives

# Constants

- Integer Constants
  - Examples: –10, 42d, 10001101b, 0FF3Ah, 777o
  - Radix: b = binary, d = decimal, h = hexadecimal, and o = octal

  - If no radix is giv [illegible] ecimal

  - A hexadecimal [illegible] have a leading 0

- Character and String Constants
  - Enclose character or string in single or double quotes
  - Examples: 'A', "d", 'ABC', "ABC", '4096'
  - Embedded quotes: "single quote ' inside", 'double quote " inside'
  - Each ASCII character occupies a single byte

# Assembly Language Statements

- Three types of statements in assembly language

1. Executable Instructions

   - Generate machine code for the processor to execute at runtime
   - Instructions

2. Assembler Directives

   - Provide information to the assem lating a program
   - Used to define data, select memory model, etc.
   - Non-executable: directives are not part of instruction set

3. Macros
   - Shorthand notation for a group of statements
   - Sequence of instructions, directives, or other macros

# Instructions

- Assembly language instructions have the format:

```
[label:]    mnemonic    [operands]    [;comment]
```

- Instruction Label (optional)

  - Marks the addr ave a colon :
  - Used to transfe beled instruction

- Mnemonic

  - Identifies the operation (e.g. MO , JMP, CALL)
- Operands
  - Specify the data required by the operation
  - Executable instructions can have zero to three operands
  - Operands can be registers, memory variables, or constants

# Instruction Examples

- No operands

```
stc              ; set carry flag
```

- One operand

```
inc  eax               ; increment register eax
```

```
scr     call Clrscr
n with label L1
        jmp  L1
```

- Two operands

```
add  ebx, ecx ; register ebx = ebx + ecx
sub  var1, 25 ; memory variable var1 = var1 - 25
```

- Three operands

```
imul eax,ebx,5         ; register eax = ebx * 5
```

# Identifiers

- Identifier is a programmer chosen name
- Identifies variable, constant, procedure, code label
- May contain haracters
- Not case sen
- First character must be a l , a..z), underscore(_), @, ?, or $.
- Subsequent characters may also be digits.
- Cannot be same as assembler reserved word.

# Comments

- Comments are very important!
  - Explain the program's purpose
  - When it was written, revised, and by whom
  - Explain data used in the program
  - Explain instr[illegible]rithms used
  - Application-specific explana[illegible]
- Single-line comments
  - Begin with a semicolon ; and terminate at end of line
- Multi-line comments
  - Begin with **COMMENT** and chosen character
  - End with the same chosen character

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# Flat Memory Program Template

```
TITLE Flat Memory Program Template    (Template.asm)

; Program Description:
; Author:                             Creation Date:
; Modified by:                        Modification Date:

.386
.MODEL FLAT, STDCALL
.STACK

INCLUDE Irvine32.inc
.DATA
    ; (insert variables here)
.CODE
main PROC
    ; (insert executable instructions here)
    exit
main ENDP
    ; (insert additional procedures here)
END main
```

# TITLE and .MODEL Directives

- **TITLE** line (optional)
  - Contains a brief heading of the program and the disk file name
- **.MODEL** directive
  - Specifies the mem
  - For our purposes, t used
    - Linear 32-bit address space (no segmentation)
  - **STDCALL** directive tells the assembler
    - Standard conventions for names and procedure calls
- **.386** processor directive
  - Used **before** the **.MODEL** directive
  - The CPU architecture that the program can use
  - At least the **.386** directive should be used with the **FLAT** model

# .STACK, .DATA, & .CODE Directives

- **.STACK** directive
  - Tells the assembler to define a runtime stack for the program
  - The size of the st d by this directive
  - The runtime stac lls

- **.DATA** directive
  - Defines an area in memory for the
  - The program's variables should be defined under this directive
  - Assembler will allocate and initialize the storage of variables
- **.CODE** directive
  - Defines the code section of a program containing instructions
  - Assembler will place the instructions in the code area in memory

# INCLUDE, PROC, ENDP, and END

- **INCLUDE** directive
  - Causes the assembler to include code from another file
  - We will include **Irvine32.inc** provided by the author Kip Irvine
    - Declares procedures implemented in the **Irvine32.lib** library
    - To use this library, yo

- **PROC** and **ENDP**
  - Used to define procedures
  - As a convention, we will define ***main*** as the first procedure
  - Additional procedures can be defined after ***main***
- **END** directive
  - Marks the end of a program
  - Identifies the name (***main***) of the program's startup procedure

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# Adding and Subtracting Integers

```
TITLE Add and Subtract           (AddSub.asm)
; This program adds and subtracts 32-bit integers.
.386
.MODEL FLAT, STDCALL
.STACK
INCLUDE Irvine32.inc

.CODE
main PROC
   mov eax,10000h                          000h
   add eax,40000h                          000h
   sub eax,20000h             ; EAX = 30000h
   call DumpRegs              ; display registers
   exit
main ENDP
END main
```

# Example of Console Output

Procedure **DumpRegs** is defined in **Irvine32.lib** library

It produces the following console output,

showing registers and flags:

```
EAX=00030000  EBX=7FFDF000  ECX            EDX=FFFFFFFF
ESI=00000000  EDI=00000000  EBP            ESP=0012FFC4
EIP=00401024  EFL=00000206  CF=0  SF=0  ZF=0  OF=0
```

# Suggested Coding Standards

- Some approaches to capitalization
  - Capitalize nothing
  - Capitalize everything
  - Capitalize all rese [illegible] gister names
  - Capitalize only dir [illegible]
  - MASM is NOT case sensitive: does n [illegible] t case is used
- Other suggestions
  - Use meaningful identifier names
  - Use blank lines between procedures
  - Use indentation and spacing to align instructions and comments
    - Use tabs to indent instructions, but do not indent labels
    - Align the comments that appear after the instructions

# Understanding Program Termination

- The **exit** at the end of main procedure is a **macro**
  - Defined in **Irvine32.inc**
  - Expanded into a call to **ExitProcess** that terminates the program
  - **ExitProcess** functio ry
  - We can replace **exi**

```
push 0      ; push parameter            k
call ExitProcess  ; to term           ram
```

  - You can also replace **exit** with: `INVOKE ExitProcess, 0`
- **PROTO** directive (Prototypes)
  - Declares a procedure used by a program and defined elsewhere

```
ExitProcess PROTO, dwExitCode:DWORD
```

  - Specifies the parameters and types of a given procedure

# Modified Program

```
TITLE Add and Subtract                    (AddSubAlt.asm)
; This program adds and subtracts 32-bit integers

.386
.MODEL flat,stdcall
.STACK 4096

; functNonneed to incl
ExitProcess PROTO

.code
main PROC
   mov  eax,10000h              ; EAX = 10000h
   add  eax,40000h              ; EAX = 50000h
   sub  eax,20000h              ; EAX = 30000h

   push 0
   call ExitProcess             ; to terminate program
main ENDP
END main
```

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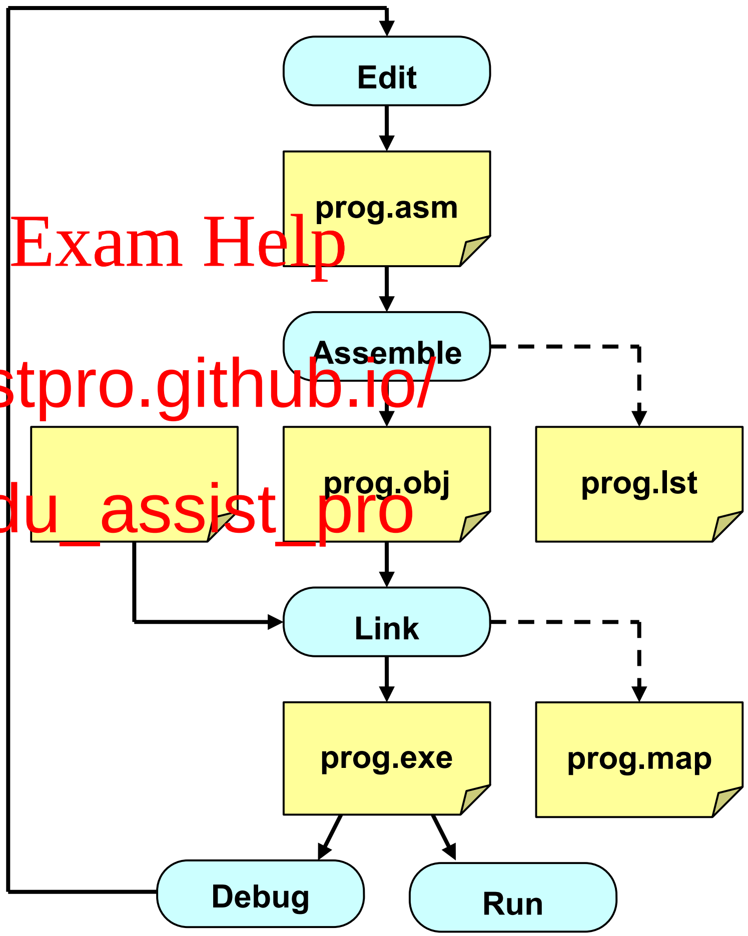
# Assemble-Link-Debug Cycle

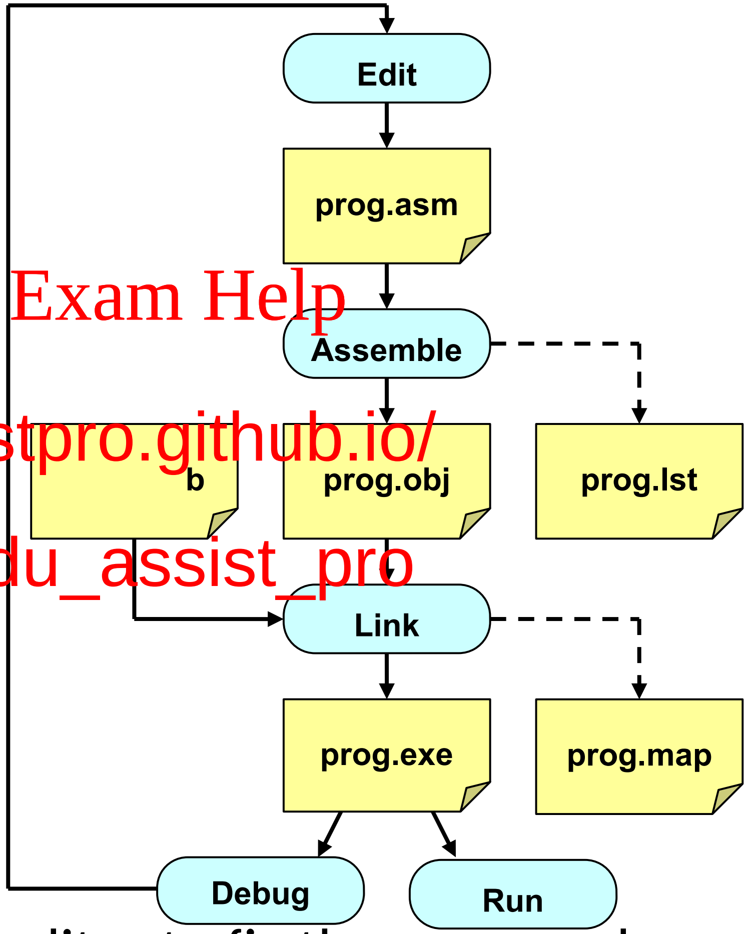
- Editor
  - Write new (**.asm**) programs
  - Make changes to existing ones
- Assembler: **.lst** file
  - Translate (**.asm**) file in machine la
  - Can produce a listing (**.lst**) file that shows the work of assembler
- Linker: **.exe** program
  - Combine object (**.obj**) files with link library (**.lib**) files
  - Produce executable (**.exe**) file
  - Can produce  (**.map**) file



# Assemble-Link-Debug Cycle – cont'd

– Trace program execution
  - Either step-by-step, or
  - Use breakpoints

– View
  - Source (.asm) code
  - Registers
  - Memory by name & by address
  - Modify register & memory content

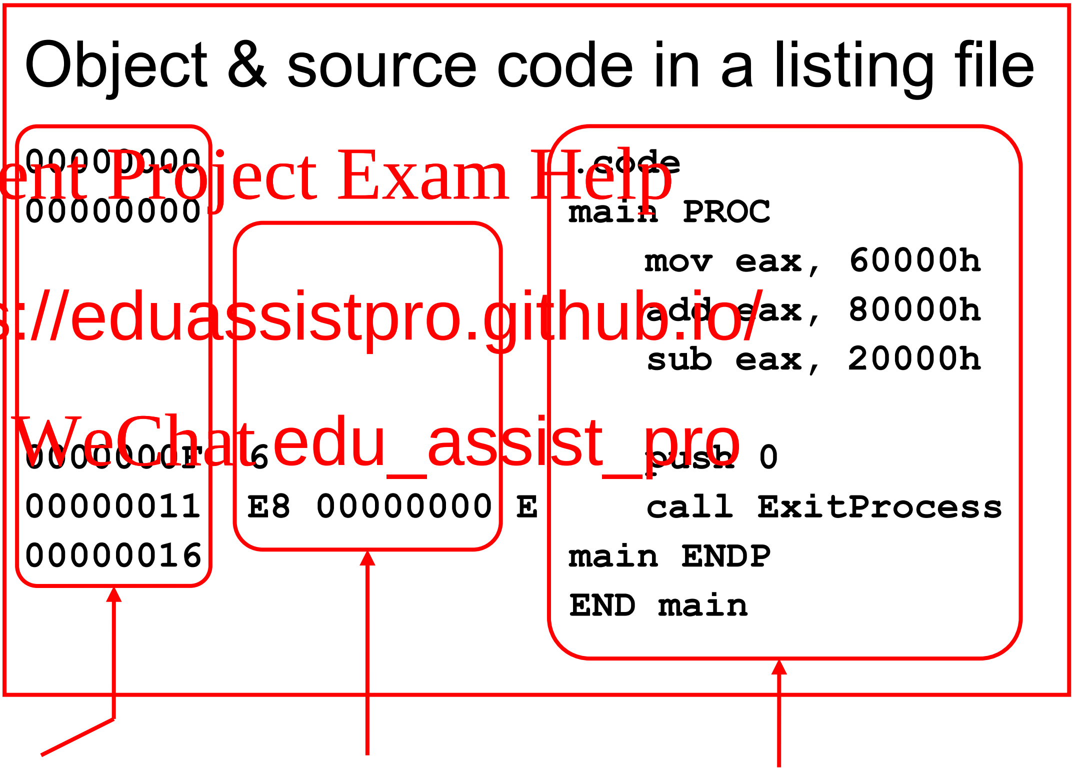


– Discover errors and go back to the editor to fix the program bugs

# Listing File

- Use it to see how your program is assembled

- Contains
  - Source code
  - Object code
  - Relative addresses
  - Segment names
  - Symbols
    - Variables
    - Procedures
    - Constants



Object & source code in a listing file

```
00000000                        .code
00000000                        main PROC
                                    mov eax, 60000h
                                    add eax, 80000h
                                    sub eax, 20000h

0000000F  6                         push 0
00000011  E8 00000000 E             call ExitProcess
00000016                        main ENDP
                                END main
```

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# Intrinsic Data Types(pre defined and always accessible)

**BYTE, SBYTE**

8-bit unsigned integer

8-bit signed integer

**WORD, SWORD**

16-bit unsigned in

16-bit signed inte

**DWORD, SDWORD**

32-bit unsigned integer

32-bit signed integer

**QWORD, TBYTE**

– 64-bit integer

– 80-bit integer

**REAL4**

IEEE single-precision float

Occupies 4 bytes

**REAL8**

ble-precision

s 8 bytes

**R**

IEEE extended-precision

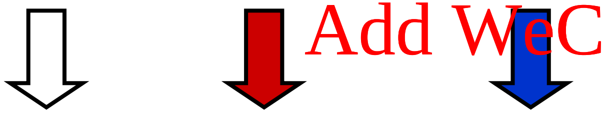
Occupies 10 bytes

IEEE stands for
Institute of Electrical and Electronics Engineers

# Data Definition Statement

- Sets aside storage in memory for a variable
- May optionally assign a name (label) to the data
- Syntax:

[*name*] *directi* *er*] . . .



**vall BYTE 10**

- **All initializers become binary data in memory**

# Defining Byte Arrays

Examples that use multiple initializers

```
list1 BYTE 10,20,30,40
list2


      BYTE 81,82,8
list3 BYTE ?,32,41h,00100010b
list4 BYTE 0Ah,20h,'A',22h
```

# Defining Strings

- A string is implemented as an array of characters
  - For convenience, it is usually enclosed in quotation marks
  - It is often terminated with a NULL char (byte value = 0)
- Examples:

```
str1 BYTE "E
str2 BYTE 'Error: halting              0
str3 BYTE 'D','V','C'
greeting  BYTE "Welcome to the Encryption "
          BYTE "Demo Program", 0
```

# Defining Strings – cont'd

- To continue a single string across multiple lines, end each line with a comma

ah,

```
menu BYTE "Checking Account",0dh,0ah,0dh,0ah,
    "1. Create a new account",0dh,0ah,
    "2. Open a
    "3. Credit
    "4. Debit
    "5. Exit",0ah,0ah,
    "Choice> ",0
```

End-of-line character sequence:

**0Dh = 13 = carriage return**

**0Ah = 10 = line feed**

**Idea:** Define all strings used by your program in the same area of the data segment

# Using the DUP Operator

- Use DUP to allocate space for an array or string
  - Advantage: more compact than using a list of initializers
- Syntax

  ***counter* DUP ( *argument* )**

  *Counter* and *ar* [illegible] expressions

- The DUP operator may also [illegible]

```
var1 BYTE 20 DUP(0)             ; 20 bytes, all equal to zero
var2 BYTE 20 DUP(?)             ; 20 bytes, all uninitialized
var3 BYTE 4 DUP("STACK")        ; 20 bytes: "STACKSTACKSTACKSTACK"
var4 BYTE 10,3 DUP(0),20        ; 5 bytes: 10, 0, 0, 0, 20
var5 BYTE 2 DUP(5 DUP('*'), 5 DUP('!')) ; '*****!!!!!*****!!!!!'
```

# Defining 16-bit and 32-bit Data

- Define storage for 16-bit and 32-bit integers
  - Signed and Unsigned
  - Single or multiple initial values

```
word1  WORD   65 igned 16-bit value
word2  SWORD  -3 gned 16-bit value
word3  WORD   "A ers fit in a WORD
array1 WORD   1,2,3,4,5     ; ar            signed words
array2 SWORD  5 DUP(?)      ; ar            gned words
dword1 DWORD  0ffffffffh    ; largest unsigned 32-bit
value
dword2 SDWORD -2147483648   ; smallest signed 32-bit value
array3 DWORD  20 DUP(?)     ; 20 unsigned double words
array4 SDWORD -3,-2,-1,0,1 ; 5 signed double words
```

# LEGACY DATA DIRECTIVES

- DB – 8-bit integer
- DW – 16 bit integer
- DD – 32 bit i
- DQ – 64 bit
- DT – define 80 bit integ

# QWORD, TBYTE, and REAL Data

- QWORD and TBYTE
  - Define storage for 64-bit and 80-bit integers
  - Signed and Unsigned
- REAL4, REAL8, a
  - Defining stora floating-point data

```
quad1 QWORD  1234567812345678h
val1  TBYTE  1000000000123456789Ah
rVal1 REAL4  -2.1
rVal2 REAL8  3.2E-260
rVal3 REAL10 4.6E+4096
array REAL4  20 DUP(0.0)
```

# Symbol Table

- Assembler builds a symbol table
  - So we can refer to the allocated storage space by name
  - Assembler keeps track of each name and its offset
  - Offset of a variable is relative to the address of the first variable

- Example

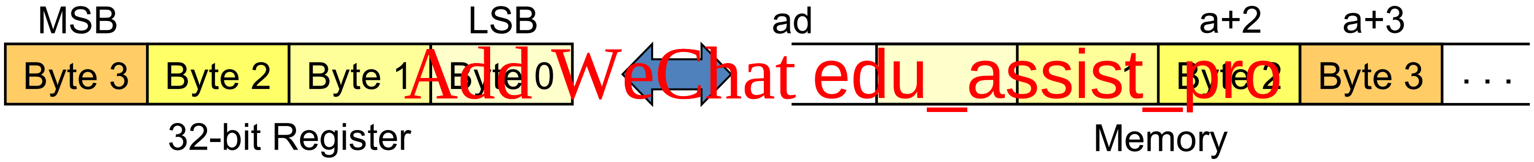
```
.DATA
value   WORD   0
sum     DWORD  0
marks   WORD   10 DUP (?)
msg     BYTE   'The grade is:',0
char1   BYTE   ?
```

Symbol Table

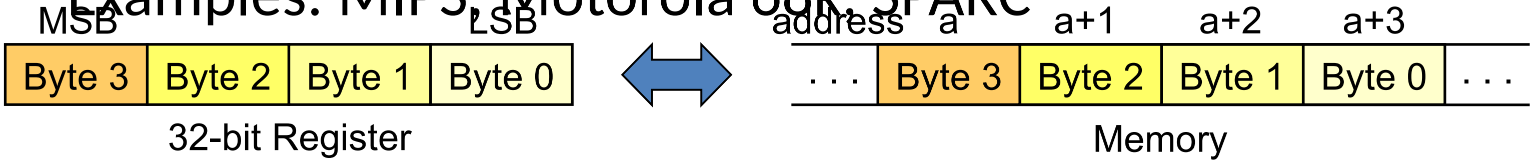
| Name | Offset |
|---|---|
| value | 0 |
| sum | 2 |
| marks | 6 |
| msg | 26 |
| char1 | 40 |

# Byte Ordering and Endianness

- Processors can order bytes within a word in two ways
- Little Endian Byte Ordering
  - Memory address = Address of **least significant byte**
  - Examples: Int



- Big Endian Byte Ordering
  - Memory address = Address of **most significant byte**
  - Examples: MIPS, Motorola 68k, SPARC



# Adding Variables to AddSub

```
TITLE Add and Subtract, Version 2            (AddSub2.asm)
.686
.MODEL FLAT, STDCALL
.STACK
INCLUDE Irvine32.inc
.DATA
val1   DWORD 10000h
val2   DWORD 40000h
val3   DWORD 20000h
result DWORD ?
.CODE
main PROC
    mov  eax,val1                ; start with 10000h
    add  eax,val2                    ; add 40000h
    sub  eax,val3                    ; subtract 20000h
    mov  result,eax                  ; store the result (30000h)
    call DumpRegs                    ; display the registers
    exit
main ENDP
END main
```

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# Defining Symbolic Constants

- Symbolic Constant
  - Just a name used in the assembly language program
  - Processed by the assembler ⇒ pure text substitution
  - Assembler does [illegible] mbolic constants
- Assembler provi [illegible]
  - = directive
  - EQU directive
  - TEXTEQU directive
- Defining constants has two advantages:
  - Improves program readability
  - Helps in software maintenance: changes are done in one place

# Equal-Sign Directive

- *Name = Expression*
  - *Name* is called a symbolic constant
  - *Expression* is an integer constant expression
- Good programming style to use symbols

```
emory allocation)
COUNT = 500
. . .
mov eax, COUNT   ; mov eax, 50
. . .
COUNT = 600      ; Processed by the assembler
. . .
mov ebx, COUNT   ; mov ebx, 600
```

- *Name* can be redefined in the program

# EQU Directive

- Three Formats:

  *Name* EQU *Expression* Integer constant expression

  *Name* EQU *Symbol* Existing symbol name

  *Name* EQU <*t* Any text may appear within < …>

```
SIZE     EQU 10 onstant expression
PI       EQU <3.1416>      ;              ic constant
PressKey EQU <"Press any key            ...",0>
.DATA
prompt BYTE PressKey
```

- No Redefinition: *Name* cannot be redefined with EQU

# TEXTEQU Directive

- TEXTEQU creates a text macro. Three Formats:

  ***Name* TEXTEQU <*text*>** assign any text to *name*

  ***Name* TEXTEQU *textmacro*** assign existing text macro

  ***Name* TEXTEQU %c** nt integer expression

- *Name* can be redefi

```
ROWSIZE = 5
COUNT      TEXTEQU   %(ROWSIZE *           ates to 10
MOV        TEXTEQU   < mov>
setupAL    TEXTEQU   <mov al,COUNT>
Greating   TEXTEQU   <“Welcome to Assembly Language”>
.DATA
prompt  BYTE     Greating
.CODE
setUpAL                            ; generates: mov al,10
```

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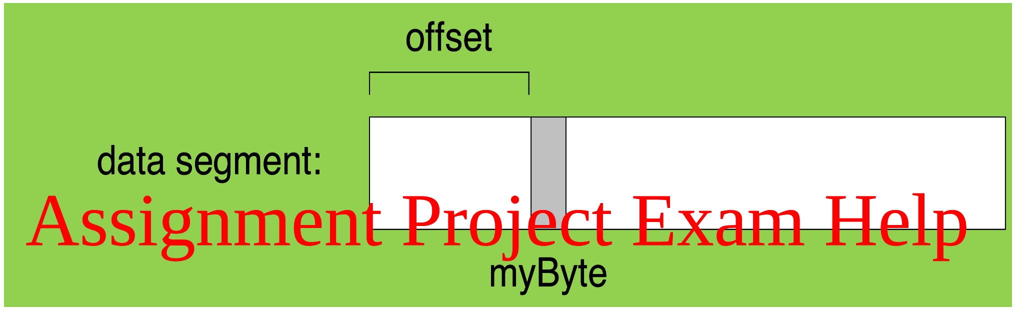
# OFFSET Operator cont.

- **OFFSET** = address of a variable within its segment



```
.DATA
bVal   BYTE   ?          ; A          is at 00404000h
wVal   WORD   ?
dVal   DWORD ?
dVal2 DWORD ?

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

# Relating to C/C++

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

```
// C++ versionguage:

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

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

# ALIGN Directive

- ALIGN directive aligns a variable in memory
- Syntax: ALIGN *bound*
  - Where *bound* can be 1, 2, 4, or 16
- Address of a ultiple of *bound*
- Assembler ins nforce alignment

```
.DATA            ; Assume that
b1  BYTE   ?     ; Address of b1 = 00404000h
ALIGN 2          ; Skip one byte
w1  WORD   ?     ; Address of w1 = 00404002h
w2  WORD   ?     ; Address of w2 = 00404004h
ALIGN 4          ; Skip two bytes
d1  DWORD  ?     ; Address of d1 = 00404008h
d2  DWORD  ?     ; Address of d2 = 0040400Ch
```

| | | | |
|---|---|---|---|
| 40400C | d2 | | |
| 404008 | d1 | | |
| 404004 | w2 | | |
| 404000 | b1 | | w1 |

# TYPE Operator

- TYPE operator
  - Size, in bytes, of a single element of a data declaration

```
.DATA
var1
var2
var3 DWORD ?
var4 QWORD ?

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

# LENGTHOF Operator

Counts **the number of elements** in a single data declaration

```
.DATA
array1     WORD     30 DUP(?),0,0
array2     WORD     5 DUP(3 DUP(?))
array3
digitSt

.code
mov ecx, LENGTHOF array1             ; ecx = 32
mov ecx, LENGTHOF array2             ; ecx = 15
mov ecx, LENGTHOF array3             ; ecx = 4
mov ecx, LENGTHOF digitStr           ; ecx = 9
```

# LENGTHOF Operator

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

LEN

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

LENGHTOF returns 10

# SIZEOF Operator

- Counts the **number of bytes** in a data declaration
- SIZEOF returns  TYPE * LENGHTOF

```
.DATA
array1
array2       WORD     5 DUP(
array3       DWORD    1,2,3,
digitStr     BYTE    "123456

.CODE
mov ecx, SIZEOF array1                 ; ecx = 64
mov ecx, SIZEOF array2                 ; ecx = 30
mov ecx, SIZEOF array3                 ; ecx = 16
mov ecx, SIZEOF digitStr               ; ecx = 9
```

# Multiple Line Declarations

A data declaration spans multiple lines if each line (except the last) ends with a comma

The LENGTHOF and SIZEOF operators include all lines belonging to the

In the following example, array identifies the first line WORD declaration only

Compare the values returned by LENGTHOF and SIZEOF here to se on the left

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

.CODE
mov eax, LENGTHOF array ; 6
mov ebx, SIZEOF array   ; 12
```

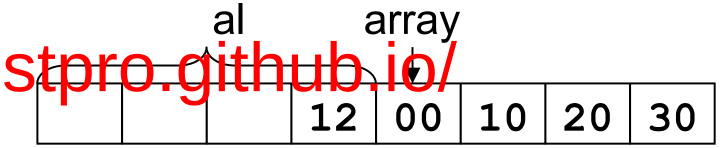
```
.
a               10,20
           WORD 30,40
           WORD 50,60

.CODE
mov eax, LENGTHOF array ; 2
mov ebx, SIZEOF array   ; 4
```

# PTR Operator

- PTR Provides the flexibility to access part of a variable
- Can also be used to combine elements of a smaller type
- Syntax: *Type* PTR (Overrides default type of a variable)

```
.DATA
dval  DWORD 1234
array BYTE  00h,
```

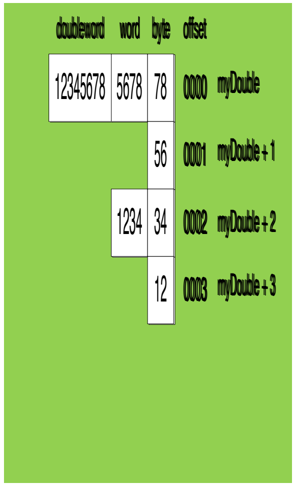


```
.CODE
mov al,  dval              ; error – why?
mov al,  BYTE PTR dval     ; al = 78h
mov ax,  dval              ; error – why?
mov ax,  WORD PTR dval     ; ax = 5678h
mov eax, array             ; error – why?
mov eax, DWORD PTR array   ; eax = 30201000h
```

# Little Endian Order

- Little endian order refers to the way Intel stores integers in memory.
- Multi-byte integers are stored in an order, thaT the least significant byte IS stored at the lowest address

- For example, the ld be stored as:

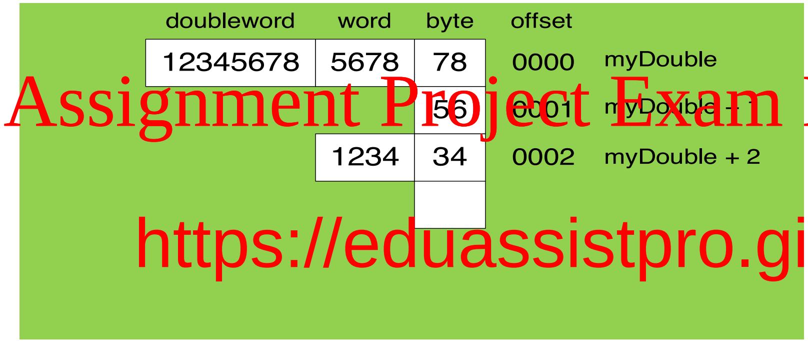


| doubleword | word | byte | offset | |
|---|---|---|---|---|
| 12345678 | 5678 | 78 | 0000 | myDouble |
| | | 56 | 0001 | myDouble + 1 |
| | 1234 | 34 | 0002 | myDouble + 2 |
| | | 12 | 0003 | myDouble + 3 |

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 |
| | | | | |

```
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
```

# Your turn . . .

Write down the value of each destination operand:

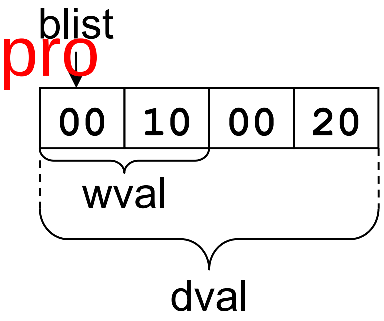
```
.data
varB BYTE 65h,31h,02h,05h
varW WORD 6543h,1202h
varD DWORD 12345678h

.code
mov ax,WORD PTR                                0502h
mov bl,BYTE PTR                                  h
mov bl,BYTE PTR [varW+2]                         h
mov ax,WORD PTR [varD+2]                         34h
mov eax,DWORD PTR varW             ; e.    12026543h
```

# LABEL Directive

- Assigns an alternate name and type to a memory location
- LABEL does not allocate any storage of its own
- Can remove the need for the PTR operator
- Format: *Name* L

```
.DATA
dval    LABEL DWORD
wval    LABEL WORD
blist   BYTE 00h,10h,00h,20h
.CODE
mov eax, dval        ; eax = 20001000h
mov cx,  wval        ; cx  = 1000h
mov dl,  blist       ; dl  = 00h
```



# Summary

- Instruction ⇒ executed at runtime
- Directive ⇒ interpreted by the assembler
- .STACK, .DATA, and .CODE
  - Define the code, dat m
- Edit-Assemble-Link-
- Data Definition
  - BYTE, WORD, DWORD, QWORD, etc.
  - DUP operator
- Symbolic Constant
  - =, EQU, and TEXTEQU directives
- Data-Related Operators
  - OFFSET, ALIGN, TYPE, LENGTHOF, SIZEOF, PTR, and LABEL