Introduction to Assembly Language

CFOMSC 260

Outline

- Basic Elements of Assembly Language
- Flat Memory Program Template
- Example: Adding and Subtracting Integers
- Assembling, Linking, and Debugging 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 given, the integer constant is decimal
  - A hexadecimal beginning with a letter must 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 tell the processor what to do
2. Assembler Directives
    - Provide information to the assembler while translating 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 address of an instruction, must have a colon :
  - Used to transfer program execution to a labeled instruction

- Mnemonic

  - Identifies the operation (e.g. MOV, ADD, SUB, 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
call Clrscr   ; call procedure Clrscr
jmp  L1       ; jump to instruction with label 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 between 1 and 247 characters
- Not case sensitive
- First character must be a letter (A..Z, 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 instruction sequences and algorithms used
  - Application-specific explanations
- 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 memory configuration
  - For our purposes, the **FLAT** memory model will be used
    - Linear 32-bit address space (no segmentation)
  - **STDCALL** directive tells the assembler to use …
    - 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 stack can be optionally specified by this directive
  - The runtime stack is required for procedure calls
- **.DATA** directive
  - Defines an area in memory for the program data
  - 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, you should link **Irvine32.lib** to your programs

- **PROC** and **ENDP** directives
  - 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             ; EAX = 10000h
   add eax,40000h             ; EAX = 50000h
   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=00000101  EDX=FFFFFFFF
ESI=00000000  EDI=00000000  EBP=0012FFF0  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 reserved words, mnemonics and register names
  - Capitalize only directives and operators
  - MASM is NOT case sensitive: does not matter what 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** function is defined in the **kernel32** library
  - We can replace **exit** with the following:

```
push 0       ; push parameter 0 on stack
call ExitProcess  ; to terminate program
```

  - 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

; No need to include Irvine32.inc for exit function
ExitProcess PROTO, dwExitCode:DWORD

.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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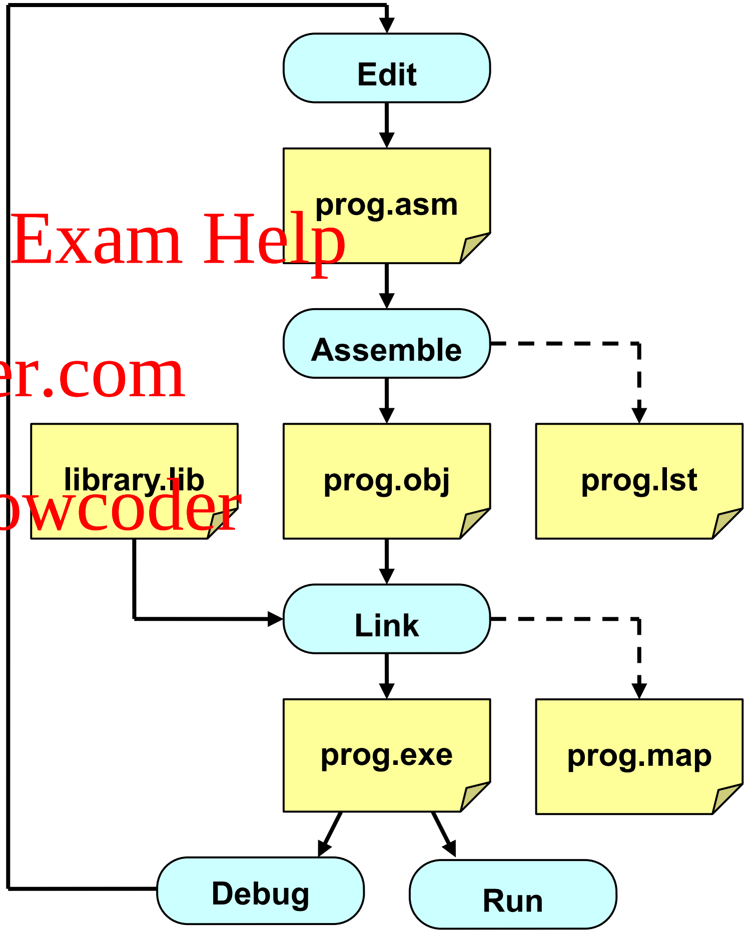
Assemble-Link-Debug Cycle

- Editor
  - Write new (.asm) programs
  - Make changes to existing ones
- Assembler: .lst file
  - Translate (.asm) file into object (.obj) file in machine language
  - 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



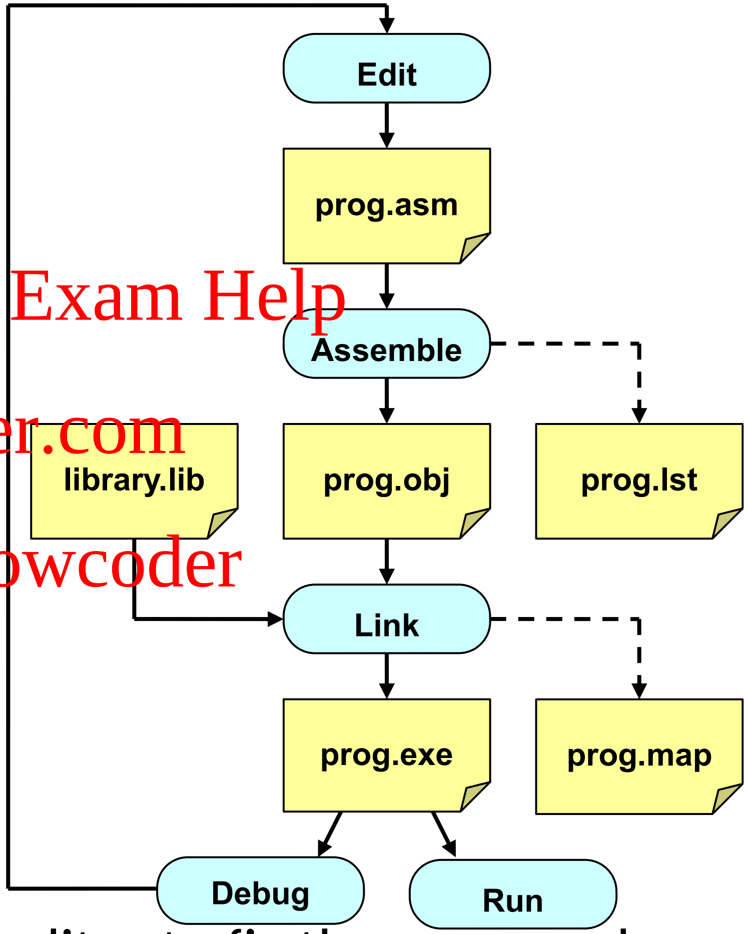
Assemble-Link-Debug Cycle – cont'd

– Trace program execution

- Either step-by-step, or
- Use breakpoints

– View

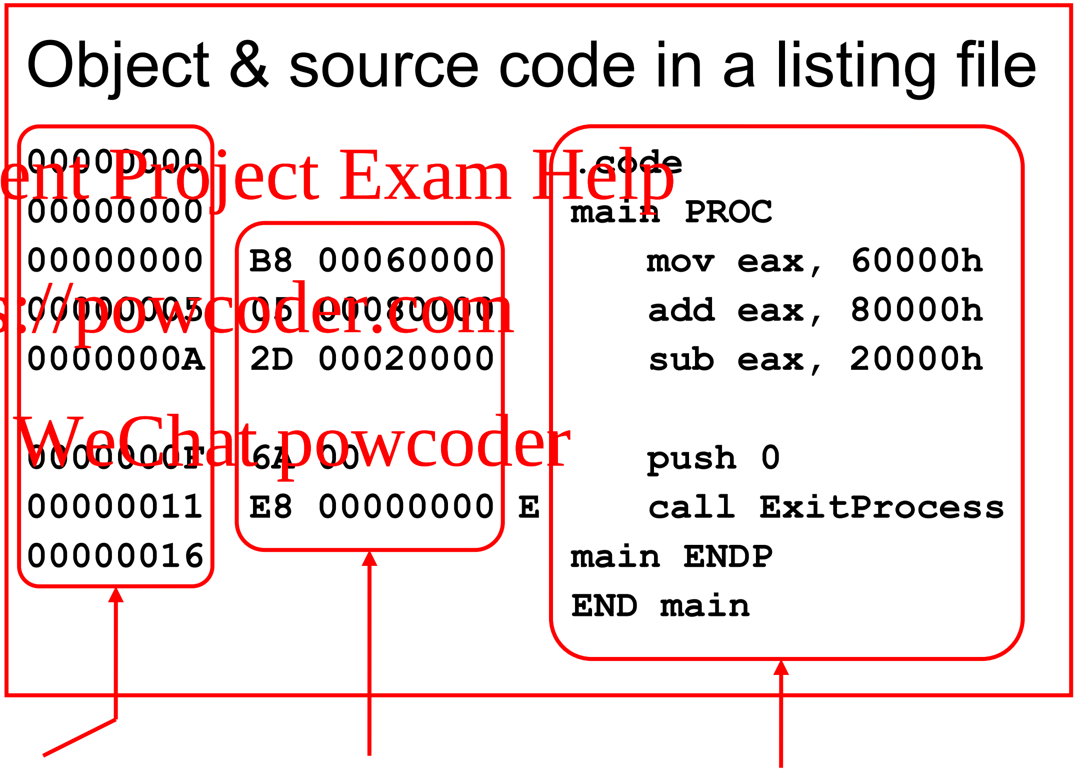
- Source (.asm) code
- Registers
- Memory by name & by address
- Modify register & memory content



– 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
00000000  B8 00060000              mov eax, 60000h
00000005  05 00080000              add eax, 80000h
0000000A  2D 00020000              sub eax, 20000h

0000000F  6A 00                    push 0
00000011  E8 00000000 E            call ExitProcess
00000016                       main ENDP
                               END main
```

Relative Addresses

object code (hexadecimal)

source code

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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 integer
- 16-bit signed integer

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

- IEEE double-precision
- Occupies 8 bytes

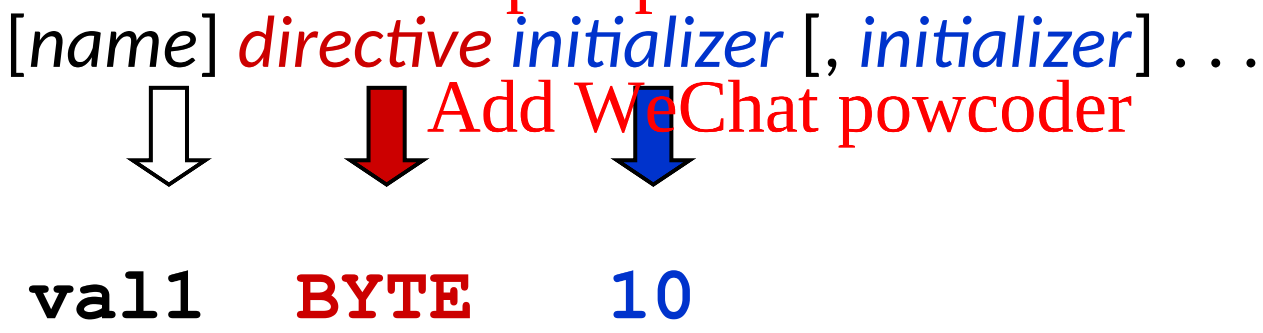
REAL10

- 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*] *directive* *initializer* [, *initializer*] . . .

```
val1   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 10,20,30,40
      BYTE 50,60,70,80
      BYTE 81,82,83,84
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 "Enter your name", 0
str2 BYTE 'Error: halting program', 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

```
menu BYTE "Checking Account",0dh,0ah,0dh,0ah,
    "1. Create a new account",0dh,0ah,
    "2. Open an existing account",0dh,0ah,
    "3. Credit the account",0dh,0ah,
    "4. Debit the account",0dh,0ah,
    "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 *argument* must be constants expressions
- The DUP operator may also be nested

```
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    65535          ; largest unsigned 16-bit value
word2   SWORD   -32768         ; smallest signed 16-bit value
word3   WORD    "AB"           ; two characters fit in a WORD
array1  WORD    1,2,3,4,5      ; array of 5 unsigned words
array2  SWORD   5 DUP(?)       ; array of 5 signed 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 integer or real
- DQ – 64 bit integer or real
- DT – define 80 bit integer

QWORD, TBYTE, and REAL Data

- QWORD and TBYTE
  - Define storage for 64-bit and 80-bit integers
  - Signed and Unsigned

- REAL4, REAL8, and REAL10

  - Defining storage for 32-bit, 64-bit, and 80-bit 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

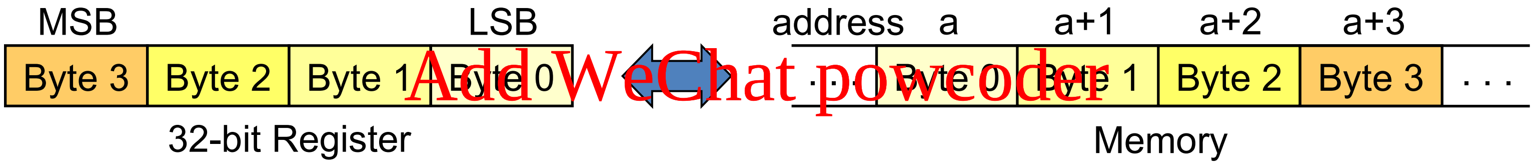
```
.DATA
value   WORD   0
sum     DWORD  0
marks   WORD   10 DUP (?)
msg     BYTE   'The grade is:',0
char1   BYTE   ?
```

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: Intel 80x86



MSB LSB

Byte 3 | Byte 2 | Byte 1 | Byte 0

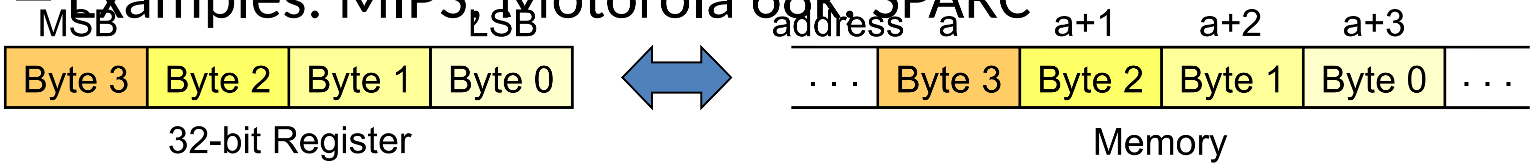
32-bit Register

address a a+1 a+2 a+3

. . . | Byte 0 | Byte 1 | Byte 2 | Byte 3 | . . .

Memory

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



MSB LSB

Byte 3 | Byte 2 | Byte 1 | Byte 0

32-bit Register

address a a+1 a+2 a+3

. . . | Byte 3 | Byte 2 | Byte 1 | Byte 0 | . . .

Memory

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 NOT allocate memory for symbolic constants
- Assembler provides three directives:
  - = 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

```
COUNT = 500     ; NOT a variable (NO memory allocation)
. . .
mov eax, COUNT  ; mov eax, 500
. . .
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 *<text>* Any text may appear within < …>

```
SIZE     EQU 10*10     ; Integer constant expression
PI       EQU <3.1416>      ; Real symbolic constant
PressKey EQU <"Press any key to continue...",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 %*constExpr constant integer expression

- *Name* can be redefined at any time (unlike EQU)

```
ROWSIZE = 5
COUNT     TEXTEQU   %(ROWSIZE * 2)  ; evaluates 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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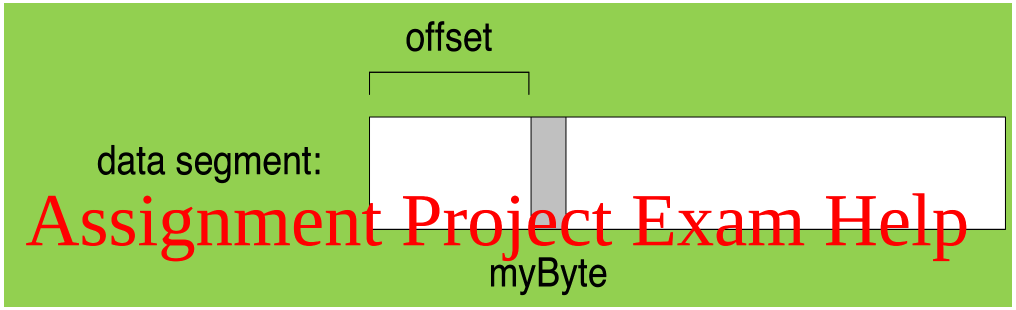
OFFSET Operator cont.

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



```
.DATA
bVal   BYTE   ?          ; Assume bVal 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++ version:

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

```
; Assembly language:

.data
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 variable should be a multiple of *bound*
- Assembler inserts empty bytes to enforce 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
```

<table>
<tr><td>40400C</td><td colspan="4">d2</td></tr>
<tr><td>404008</td><td colspan="4">d1</td></tr>
<tr><td>404004</td><td colspan="2">w2</td><td colspan="2"></td></tr>
<tr><td>404000</td><td>b1</td><td></td><td colspan="2">w1</td></tr>
</table>

TYPE Operator

- TYPE operator
  - 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    ; 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    DWORD   1,2,3,4
digitStr  BYTE    "12345678",0

.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
```

LENGHTOF returns   5

```
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      WORD    30 DUP(?),0,0
array2      WORD    5 DUP(3 DUP(?))
array3      DWORD   1,2,3,4
digitStr    BYTE   "12345678",0

.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 declaration

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

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

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

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

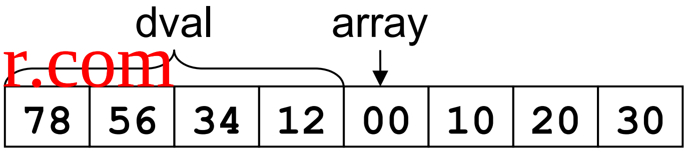
```
.DATA
array  WORD 10,20
       WORD 30,40
       WORD 50,60

.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  12345678h
array BYTE   00h,10h,20h,30h
```



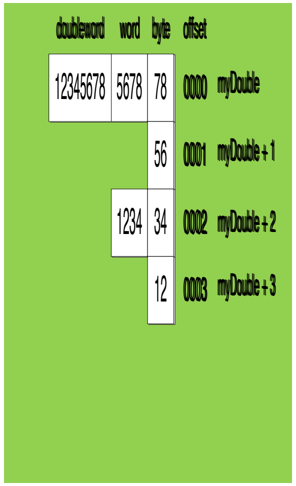
78	56	34	12	00	10	20	30

```
.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 doubleword 12345678h would be stored as:

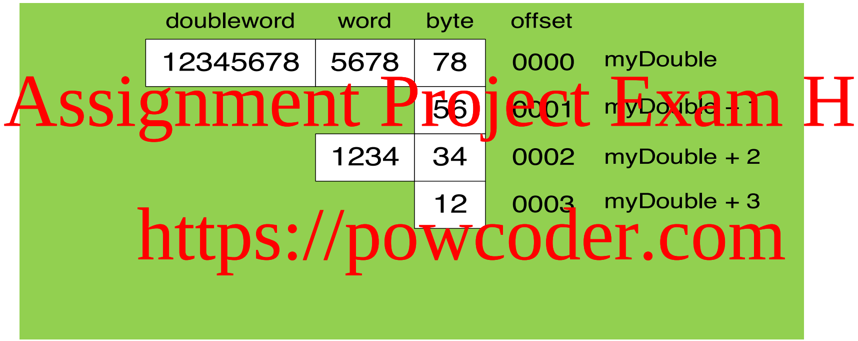


doubleword	word	byte	offset	
12345678	5678	78	0000	myDouble
		56	0001	myDouble + 1
	1234	34	0002	myDouble + 2
		12	0003	myDouble + 3

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
		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
```

Your turn . . .

Write down the value of each destination operand:

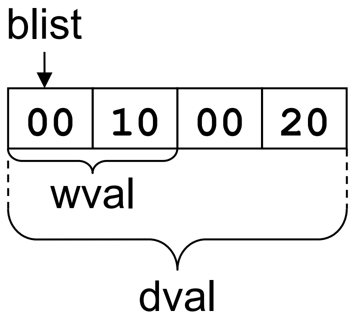
```
.data
varB BYTE 65h,31h,02h,05h
varW WORD 6543h,1202h
varD DWORD 12345678h

.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
```

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* LABEL *Type*

```
.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, data, and stack sections of a program
- Edit-Assemble-Link-Debug Cycle
- 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