Computer Organization & Assembly Languages

Assembly Language Fundamentals

Pu-Jen Cheng

Adapted from the slides prepared by Kip Irvine for the book, Assembly Language for Intel-Based Computers, 5th Ed.

Chapter Overview

- Basic Elements of Assembly Language
- Example: Adding and Subtracting Integers
- Assembling, Linking, and Running Programs
- Defining Data
- Symbolic Constants
- Real-Address Mode Programming

Basic Elements of Assembly Language

- Integer constants
- Integer expressions
- Character and string constants
- Reserved words and identifiers
- Directives and instructions
- Labels
- Mnemonics and Operands
- Comments
- Examples

Integer Constants

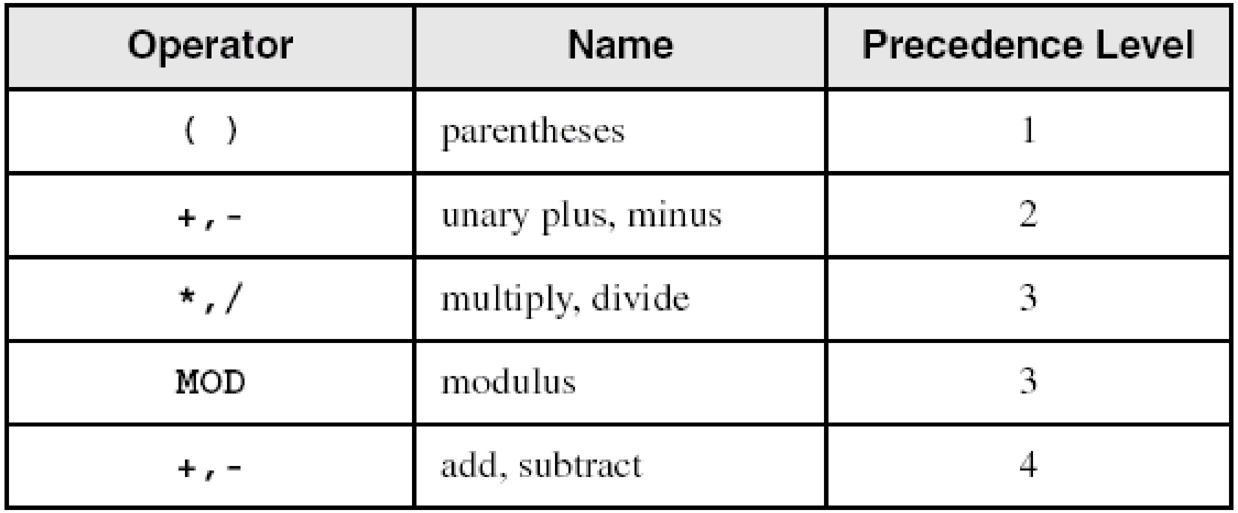
- [{+|-}] *digits* [*radix*]
- Optional leading + or – sign
- Binary, decimal, hexadecimal, or octal digits
- Common radix characters:
  - h – hexadecimal
  - d – decimal
  - b – binary
  - r – encoded real

Examples: 30d, 6Ah, 42, 1101b

Hexadecimal beginning with letter: 0A5h

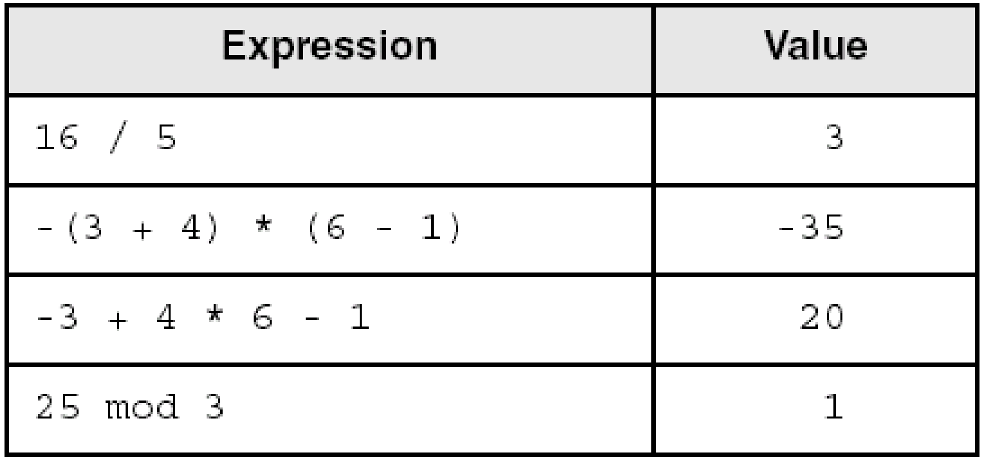
Integer Expressions

- Operators and precedence levels:



Operator	Name	Precedence Level
( )	parentheses	1
+, -	unary plus, minus	2
*, /	multiply, divide	3
MOD	modulus	3
+, -	add, subtract	4

- Examples:



Expression	Value
16 / 5	3
-(3 + 4) * (6 - 1)	-35
-3 + 4 * 6 - 1	20
25 mod 3	1

Real Number Constants

- [{+|-}] *integer*.[*integer*] [*exponent*]
- Exponent: E[{+|-}]*integer*

Examples: 2., +3.0, -44.2E+05

- Encoded Reals
  - IEEE floating-point format (e.g. 3F800000r)

Character and String Constants

- Enclose character in single or double quotes
  - 'A', "x"
  - ASCII character = 1 byte
- Enclose strings in single or double quotes
  - "ABC"
  - 'xyz'
  - Each character occupies a single byte
- Embedded quotes:
  - “This isn’t a test"
  - 'Say "Goodnight," Gracie'

Reserved Words and Identifiers

- Reserved words cannot be used as identifiers
  - Instruction mnemonics (MOV), directives (.code), type attributes (BYTE, WORD), operators (=), predefined symbols (@data)
  - See MASM reference in Appendix A
- Identifiers
  - 1-247 characters, including digits
  - not case sensitive
  - first character must be a letter, _, @, ?, or $

  Examples: var1, Count, $first, _main, @@myfile

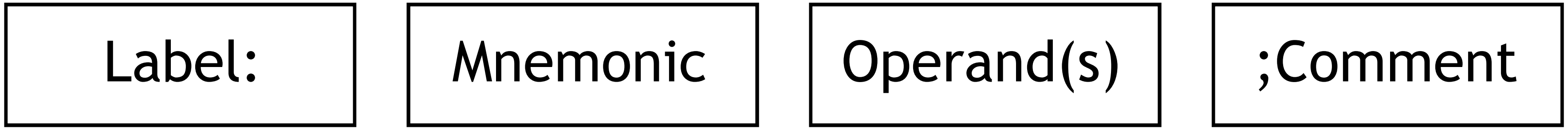
Directives

- Commands that are recognized and acted upon by the assembler
  - Not part of the Intel instruction set
  - Used to declare code, data areas, select memory model, declare procedures, etc.
  - not case sensitive
- Different assemblers have different directives
  - NASM not the same as MASM, for example

Examples: `.data, .code`

Instructions

- Assembled into machine code by assembler
- Executed at runtime by the CPU
- We use the Intel IA-32 instruction set
- An instruction contains:
  - Label (optional)
  - Mnemonic (required)
  - Operand (depends on the instruction)
  - Comment (optional)



Labels

- Act as place markers
  - marks the address (offset) of code and data
- Follow identifer rules
- Data label
  - must be unique
  - example: **count DWORD 100** (not followed by colon)
- Code label
  - target of jump and loop instructions
  - example: **target:** (followed by colon)

```
target:
....
jmp target
```

Mnemonics and Operands

- Instruction Mnemonics
  - memory aid
  - examples: MOV, ADD, SUB, MUL, INC, DEC
- Operands
  - constant (immediate value), **96**
  - constant expression, **2+4**
  - Register, **eax**
  - memory (data label), **count**

Constants and constant expressions are often called immediate values

Comments

- Comments are good!
  - explain the program's purpose
  - when it was written, and by whom
  - revision information
  - tricky coding techniques
  - application-specific explanations
- Single-line comments
  - begin with semicolon (;)
- Multi-line comments
  - begin with COMMENT directive and a programmer-chosen character
  - end with the same programmer-chosen character

```
COMMENT !
  This is a comment
  and this line is also a comment
!
```

Instruction Format Examples

- No operands
  - stc ; set Carry flag
- One operand
  - inc eax ; register
  - inc myByte ; memory
- Two operands
  - add ebx, ecx ; register, register
  - sub myByte, 25 ; memory, constant
  - add eax, 36 * 25 ; register, constant-expression
- NOP Instruction
  - Used by compilers and assemblers to align codes

What's Next

- Basic Elements of Assembly Language
- **Example: Adding and Subtracting Integers**
- Assembling, Linking, and Running Programs
- Defining Data
- Symbolic Constants
- Real-Address Mode Programming

Example: Adding and Subtracting Integers

```
TITLE Add and Subtract              (AddSub.asm)

; This program adds and subtracts 32-bit integers.

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 Output

Program 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, including instruction mnemonics and register names
  - capitalize only directives and operators
- Other suggestions
  - descriptive identifier names
  - spaces surrounding arithmetic operators
  - blank lines between procedures

Suggested Coding Standards (cont.)

- Indentation and spacing
  - code and data labels – no indentation
  - executable instructions – indent 4-5 spaces
  - comments: begin at column 40-45, aligned vertically
  - 1-3 spaces between instruction and its operands
    - ex: `mov  ax,bx`
  - 1-2 blank lines between procedures

Alternative Version of AddSub

```
TITLE Add and Subtract              (AddSubAlt.asm)

; This program adds and subtracts 32-bit integers.
.386
.MODEL flat,stdcall
.STACK 4096

ExitProcess PROTO, dwExitCode:DWORD
DumpRegs PROTO

.code
main PROC
    mov eax,10000h              ; EAX = 10000h
    add eax,40000h              ; EAX = 50000h
    sub eax,20000h              ; EAX = 30000h
    call DumpRegs
    INVOKE ExitProcess,0
main ENDP
END main
```

Program Template

```
TITLE Program Template           (Template.asm)

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

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

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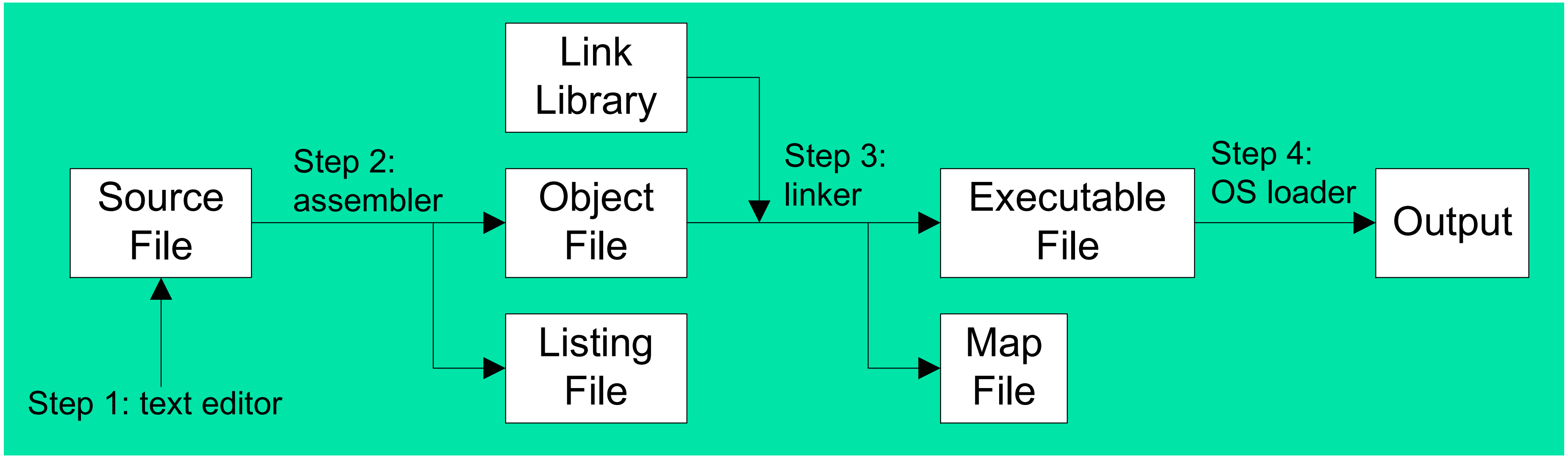
Assembling, Linking, and Running Programs

- Assemble-Link-Execute Cycle
- make32.bat
- Listing File
- Map File

Assemble-Link Execute Cycle

- The following diagram describes the steps from creating a source program through executing the compiled program.
- If the source code is modified, Steps 2 through 4 must be repeated.



make32.bat

- Called a batch file
- Run it to assemble and link programs
- Contains a command that executes ML.EXE (the Microsoft Assembler)
- Contains a command that executes LINK32.EXE (the 32-bit Microsoft Linker)
- Command-Line syntax:

```
make32  progName
```

(*progName* includes the .asm extension)

(use make16.bat to assemble and link Real-mode programs)

Listing File

- Use it to see how your program is compiled
- Contains
  - source code
  - addresses
  - object code (machine language)
  - segment names
  - symbols (variables, procedures, and constants)
- Example: addSub.lst

Map File

- Information about each program segment:
  - starting address
  - ending address
  - size
  - segment type
- Example: addSub.map (16-bit version)

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- **Defining Data**
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Defining Data

- Intrinsic Data Types
- Data Definition Statement
- Defining BYTE and SBYTE Data
- Defining WORD and SWORD Data
- Defining DWORD and SDWORD Data
- Defining QWORD Data
- Defining TBYTE Data
- Defining Real Number Data
- Little Endian Order
- Adding Variables to the AddSub Program
- Declaring Uninitialized Data

Intrinsic Data Types (1 of 2)

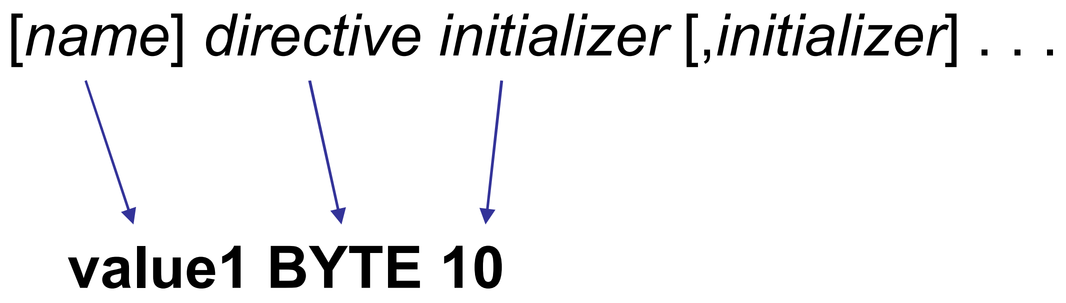
- BYTE, SBYTE
  - 8-bit unsigned integer; 8-bit signed integer
- WORD, SWORD
  - 16-bit unsigned & signed integer
- DWORD, SDWORD
  - 32-bit unsigned & signed integer
- QWORD
  - 64-bit integer
- TBYTE
  - 80-bit integer

Intrinsic Data Types (2 of 2)

- REAL4
  - 4-byte IEEE short real
- REAL8
  - 8-byte IEEE long real
- REAL10
  - 10-byte IEEE extended real

Data Definition Statement

- A 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*] . . .

value1 BYTE 10

- All initializers become binary data in memory

Defining BYTE and SBYTE Data

Each of the following defines a single byte of storage:

```
value1 BYTE 'A'            ; character constant
value2 BYTE 0              ; smallest unsigned byte
value3 BYTE 255            ; largest unsigned byte
value4 SBYTE -128          ; smallest signed byte
value5 SBYTE +127          ; largest signed byte
value6 BYTE ?              ; uninitialized byte
```

- A variable name is a data label that implies an offset (an address).
- If you declare a SBYTE variable, the Microsoft debugger will automatically display its value in decimal with a leading sign.

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 (1 of 3)

- A string is implemented as an array of characters
  - For convenience, it is usually enclosed in quotation marks
  - It often will be null-terminated
- Examples:

```
str1 BYTE "Enter your name",0
str2 BYTE 'Error: halting program',0
str3 BYTE 'A','E','I','O','U'
greeting  BYTE "Welcome to the Encryption Demo program "
          BYTE "created by Kip Irvine.",0
greeting2 \
          BYTE "Welcome to the Encryption Demo program "
          BYTE "created by Kip Irvine.",0
```

Defining Strings (cont.)

- 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
```

Defining Strings (cont.)

- End-of-line character sequence:
  - 0Dh = carriage return
  - 0Ah = line feed

```
str1 BYTE "Enter your name:    ",0Dh,0Ah
     BYTE "Enter your address: ",0

newLine BYTE 0Dh,0Ah,0
```

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

Using the DUP Operator

- Use DUP to allocate (create space for) an array or string. Syntax: *counter* DUP (*argument*)
- *Counter* and *argument* must be constants or constant expressions

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

Defining WORD and SWORD Data

- Define storage for 16-bit integers
  - or double characters
  - single value or multiple values

```
word1  WORD   65535          ; largest unsigned value
word2  SWORD -32768          ; smallest signed value
word3  WORD   ?              ; uninitialized, unsigned
word4  WORD   "AB"           ; double characters
myList WORD   1,2,3,4,5      ; array of words
array  WORD   5 DUP(?)       ; uninitialized array
```

Defining DWORD and SDWORD Data

Storage definitions for signed and unsigned 32-bit integers:

```
val1 DWORD  12345678h         ; unsigned
val2 SDWORD -2147483648       ; signed
val3 DWORD  20 DUP(?)         ; unsigned array
val4 SDWORD -3,-2,-1,0,1      ; signed array
```

Defining QWORD, TBYTE, Real Data

Storage definitions for quadwords, tenbyte values, and real numbers:

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

Little Endian Order

- All data types larger than a byte store their individual bytes in reverse order.
- The least significant byte occurs at the first (lowest) memory address.
- Example:

val1 DWORD 12345678h

0000:	78
0001:	56
0002:	34
0003:	12

Adding Variables to AddSub

```
TITLE Add and Subtract, Version 2            (AddSub2.asm)
; This program adds and subtracts 32-bit unsigned
; integers and stores the sum in a variable.
INCLUDE Irvine32.inc
.data
val1 DWORD 10000h
val2 DWORD 40000h
val3 DWORD 20000h
finalVal DWORD ?
.code
main PROC
    mov eax,val1              ; start with 10000h
    add eax,val2              ; add 40000h
    sub eax,val3              ; subtract 20000h
    mov finalVal,eax          ; store the result (30000h)
    call DumpRegs             ; display the registers
    exit
main ENDP
END main
```

Declaring Uninitialized Data

- Use the .data? directive to declare an unintialized data segment:

  .data?

- Within the segment, declare variables with "?" initializers:

  smallArray DWORD 10 DUP(?)

Advantage: the program's EXE file size is reduced.

```
.data
  smallArray DWORD 10 DUP(0)
.data?
  bigArray   DWORD 5000 DUP(?)
```

Mixing code and data

```
.code
mov eax, ebx
.data
temp DWORD ?
.code
mov temp, eax
```

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Symbolic Constants

- Equal-Sign Directive
- Calculating the Sizes of Arrays and Strings
- EQU Directive
- TEXTEQU Directive

Equal-Sign Directive

- *name* = *expression*
  - expression is a 32-bit integer (expression or constant)
  - may be redefined
  - *name* is called a symbolic constant
- good programming style to use symbols
  - Easier to modify
  - Easier to understand, **`ESC_key`**
  - **`Array DWORD COUNT DUP(0)`**
  - `COUNT=5`

```
 Mov al, COUNT
 COUNT=10
 Mov al, COUNT
```

```
COUNT = 500
.
.
mov al,COUNT
```

Calculating the Size of a Byte Array

- Current location counter: $
  - subtract address of list
  - difference is the number of bytes

```
list BYTE 10,20,30,40
     BYTE 100 DUP(0)
ListSize = ($ - list)
```

Calculating the Size of a Word Array

Divide total number of bytes by 2 (the size of a word)

```
list WORD 1000h,2000h,3000h,4000h
ListSize = ($ - list) / 2
```

Calculating the Size of a Doubleword Array

Divide total number of bytes by 4
(the size of a doubleword)

```
list DWORD 1,2,3,4
ListSize = ($ - list) / 4
```

EQU directive

- name EQU expression

  name EQU symbol

  name EQU <text>
- Define a symbol as either an integer or text expression.
- Can be useful for non-integer constant
- Cannot be redefined

EQU directive

```
PI EQU <3.1416>
pressKey EQU <"Press any key to continue...",0>
.data
prompt BYTE pressKey
```

```
matrix1 EQU 10*10
matrix2 EQU <10*10>
.data
M1 WORD matrix1            ; M1 WORD 100
M2 WORD matrix2            ; M2 WORD 10*10
```

TEXTEQU Directive

- Define a symbol as either an integer or text expression.
- Called a text macro
- Can be redefined

```
continueMsg TEXTEQU <"Do you wish to continue (Y/N)?">
rowSize = 5
.data
prompt1 BYTE continueMsg
count TEXTEQU %(rowSize * 2)      ; evaluates the expression
setupAL TEXTEQU <mov al,count>

.code
setupAL                           ; generates: "mov al,10"
```

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Real-Address Mode Programming

- Generate 16-bit MS-DOS Programs
- Advantages
  - enables calling of MS-DOS and BIOS functions
  - no memory access restrictions
- Disadvantages
  - must be aware of both segments and offsets
  - cannot call Win32 functions (Windows 95 onward)
  - limited to 640K program memory

Real-Address Mode Programming (cont.)

- Requirements
  - INCLUDE Irvine16.inc
  - Initialize DS to the data segment:

```
mov ax,@data
mov ds,ax
```

Add and Subtract, 16-Bit Version

```
TITLE Add and Subtract, Version 2        (AddSub2r.asm)
INCLUDE Irvine16.inc
.data
val1 DWORD 10000h
val2 DWORD 40000h
val3 DWORD 20000h
finalVal DWORD ?
.code
main PROC
    mov ax,@data                 ; initialize DS
    mov ds,ax
    mov eax,val1                 ; get first value
    add eax,val2                 ; add second value
    sub eax,val3                 ; subtract third value
    mov finalVal,eax             ; store the result
    call DumpRegs                ; display registers
    exit
main ENDP
END main
```

Summary

- Integer expression, character constant
- directive – interpreted by the assembler
- instruction – executes at runtime
- code, data, and stack segments
- source, listing, object, map, executable files
- Data definition directives:
  - BYTE, SBYTE, WORD, SWORD, DWORD, SDWORD, QWORD, TBYTE, REAL4, REAL8, and REAL10
  - DUP operator, location counter ($)
- Symbolic constant
  - EQU and TEXTEQU