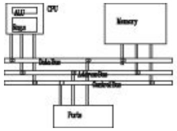
# Assembly Fundamentals

## ***Computer Organization and Assembly Languages***

*with slides by Kip Irvine*

# Announcements



- Homework#1 assigned, due on 10/27
- Next week’s class (10/20) will be taught by TAs
- Midterm examination will be held on the week of 11/10

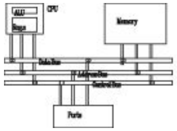
# Chapter Overview

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

# 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



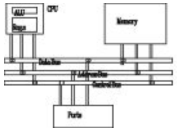
- [{+|-}] *digits* [*radix*]
- Optional leading + or – sign
- binary, decimal, hexadecimal, or octal digits
- Common radix characters:
  - **`h`** – hexadecimal
  - **`d`** – decimal (default) t Decimal (alternate)
  - **`b`** – binary y Binary (alternate)
  - **`r`** – encoded real
  - **`o`** – octal q/o Octal

Examples: **`30d, 6Ah, 42, 42o, 1101b`**

Hexadecimal beginning with letter: **`0A5h`**

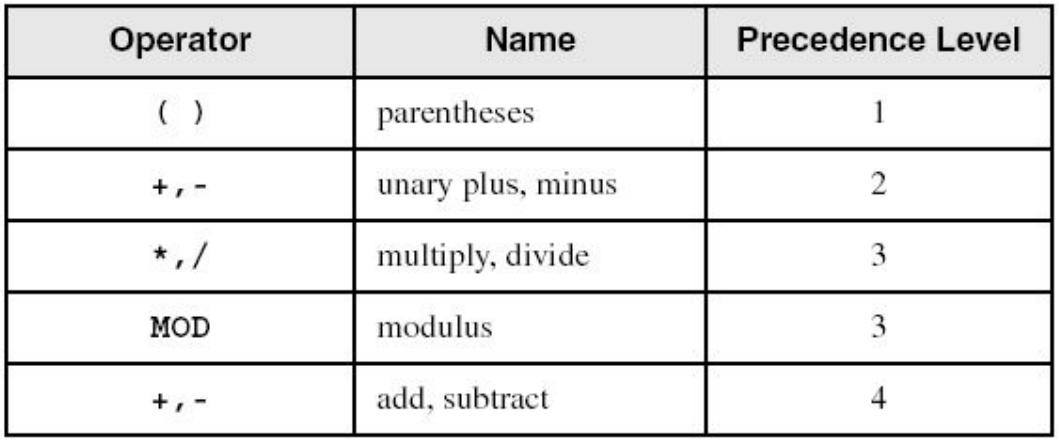
A hexadecimal constant beginning with a letter must have a leading zero to prevent the assembler from interpreting it as an identifier

# Integer expressions



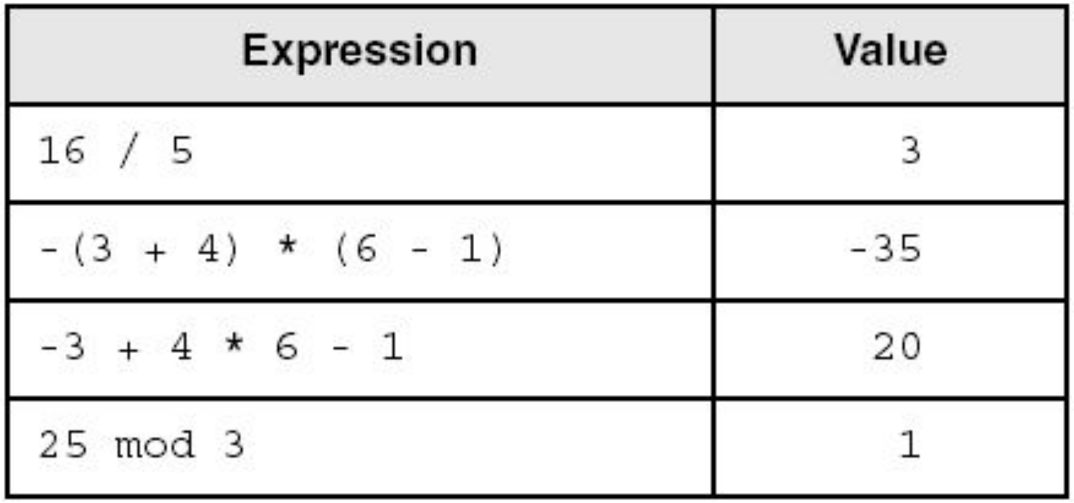
- Operators and precedence levels:

PEMM DAS



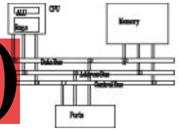
| Operator | Name | Precedence Level |
|---|---|---|
| ( ) | parentheses | 1 |
| +, - | unary plus, minus | 2 |
| *, / | multiply, divide | 3 |
| MOD | modulus | 3 |
| +, - | add, subtract | 4 |

- Examples:



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

# Real number constants (encoded reals)



- Fixed point v.s. floating point

| 1 | 8 | 23 |
|---|---|---|
| S | E | M |

-44.2E+0

$\pm 1.bbbb \times 2^{(E-127)}$

Real number constants are represented as decimal reals or encoded (hexadecimal) reals

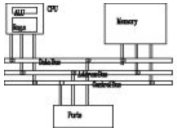
- Example

**3F800000r=+1.0,37.75=42170000r**

- double

| 1 | 11 | 52 |
|---|---|---|
| S | E | M |

# Real number constants (decimal reals)



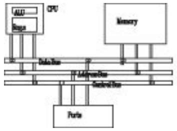
- [*sign*]*integer*.[*integer*][*exponent*]

  sign → {+|-}

  exponent → E[{+|-}]integer
- Examples:

```
2.
+3.0
-44.2E+05
26.E5
```

# Character and string constants



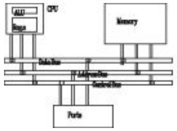
- Enclose character in single or double quotes
  - **`'A', "x"`**
  - ASCII character = 1 byte
- Enclose strings in single or double quotes
  - **`"ABC"`**
  - **`'xyz'`**
  - Each character occupies a single byte
- Embedded quotes:
  - **`‘Say "Goodnight," Gracie’`**
  - **`"This isn't a test"`**

# Reserved words and identifiers

- Reserved words (Appendix D) cannot be used as identifiers
  - Instruction mnemonics, directives, type attributes, operators, predefined symbols
- Identifiers
  - 1-247 characters, including digits
  - case insensitive (by default)
  - first character must be a letter, `_`, `@`, or `$`
  - examples:

```
var1    Count      $first
  _main     MAX      open_file
@@myfile  xVal     _12345
```

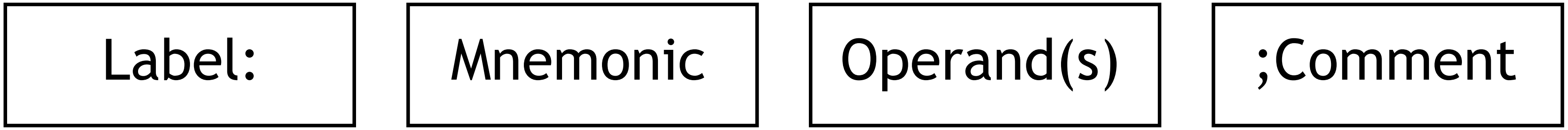
# Directives



- Commands that are recognized and acted upon by the assembler
  - Part of assembler's syntax but not part of the Intel instruction set
  - Used to declare code, data areas, select memory model, declare procedures, etc.
  - case insensitive
- Different assemblers have different directives
  - NASM != MASM, for example
- Examples: **`.data`** **`.code`** **`PROC`**

# Instructions

- Assembled into machine code by assembler
- Executed at runtime by the CPU
- Member of the Intel IA-32 instruction set
- Four parts
  - Label (optional)
  - Mnemonic (required)
  - Operand (usually required)
  - Comment (optional)



Label: Mnemonic Operand(s) ;Comment

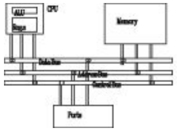
# Labels

- Act as place markers
  - marks the address (offset) of code and data
- Easier to memorize and more flexible

  `mov ax, [0020]` → `mov ax, val`
- Follow identifier rules
- Data label
  - must be unique
  - example: `myArray  BYTE  10`
- Code label
  - target of jump and loop instructions
  - example:

```
L1: mov ax, bx
    ...
    jmp L1
```

# Mnemonics and operands



- Instruction mnemonics
  - "reminder"
  - examples: **`MOV, ADD, SUB, MUL, INC, DEC`**
- Operands
  - constant (immediate value), **`96`**
  - constant expression, **`2+4`**
  - Register, **`eax`**
  - memory (data label), **`count`**
- Number of operands: 0 to 3
  - **`stc       ; set Carry flag`**
  - **`inc ax      ; add 1 to ax`**
  - **`mov count, bx ; move BX to count`**

# Comments

- Comments are good!
  - explain the program's purpose
  - tricky coding techniques
  - application-specific explanations
- Single-line comments
  - begin with semicolon (;)
- block comments
  - begin with COMMENT directive and a programmer-chosen character and end with the same programmer-chosen character

```
COMMENT &
 This line is a comment.
 This line is also a comment.
 &
```

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

# Example: adding/subtracting integers

directive marks comment

```
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
```

comment

copy definitions from Irvine32.inc

code segment. 3 segments: code, data, stack

beginning of a procedure

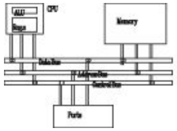
source

destination

defined in Irvine32.inc to end a program

mark the last line and startup procedure

# Example output



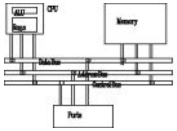
Program output, showing registers and flags:

```
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 (1 of 2)

- Some approaches to capitalization
  - capitalize nothing
  - capitalize everything
  - capitalize all reserved words, including instruction mnemonics and register names
  - capitalize only directives and operators (used by the book)
- Other suggestions
  - descriptive identifier names
  - spaces surrounding arithmetic operators
  - blank lines between procedures

# Suggested coding standards (2 of 2)



- 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
```

ExitProcess is
an MS-Windows function that halts the current program

# 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
```

The INCLUDE directive copies necessary definitions and setup information from a text file named Irvine32.inc, located in the assembler's INCLUDE directory.

The .code directive marks the beginning of the code segment, where all executable statements in a program are located.

The PROC directive identifies the beginning of a procedure. The name chosen for the only procedure in our program is main

call DumpRegs ; display registers

PROTO directives declare prototypes for procedures used by the program

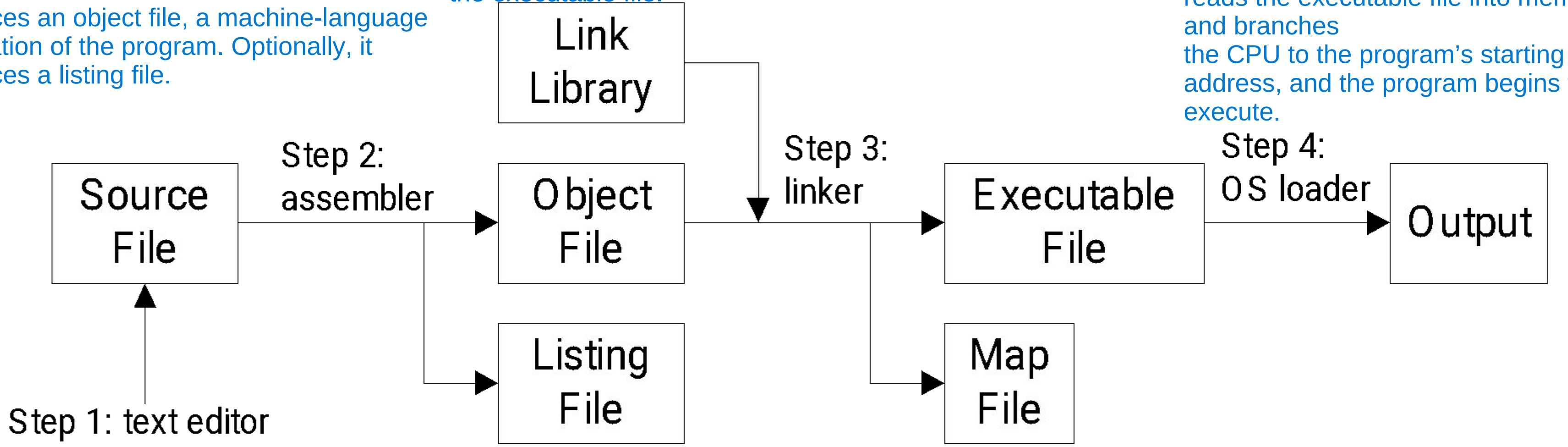
# Assemble-link execute cycle

- 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.

The assembler reads the source file and produces an object file, a machine-language translation of the program. Optionally, it produces a listing file.

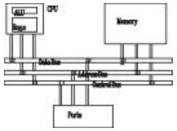
The linker reads the object file and checks to see if the program contains any calls to procedures in a link library. The linker copies any required procedures from the link library, combines them with the object file, and produces the executable file.

The operating system loader utility reads the executable file into memory and branches
the CPU to the program’s starting address, and the program begins to execute.



A listing file contains a copy of the program’s source code, with line numbers, the numeric address of each instruction, the machine code bytes of each instruction (in hexadecimal), and a symbol table.

# make32.bat



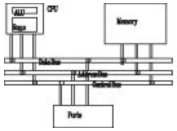
- Called a batch file
- Run it to assemble and link programs
- Contains a command that executes ML.EXE (the Microsoft Assembler)
- Contains a command that executes LINK32.EXE (the 32-bit Microsoft Linker)
- Command-Line syntax:

  **make32** ***progName***

  (*progName* includes the .asm extension)

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

# Listing file

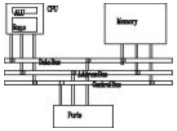


- Use it to see how your program is compiled
- Contains
  - source code
  - addresses
  - object code (machine language)
  - segment names
  - symbols (variables, procedures, and constants)
- Example: addSub.lst

# Defining data

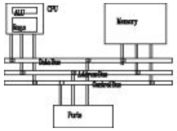
- Intrinsic data types
- Data Definition Statement
- Defining BYTE and SBYTE Data
- Defining WORD and SWORD Data
- Defining DWORD and SDWORD Data
- Defining QWORD Data
- Defining TBYTE Data
- Defining Real Number Data
- Little Endian Order
- Adding Variables to the AddSub Program
- Declaring Uninitialized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

# Intrinsic data types (1 of 2)



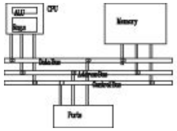
- **`BYTE`**, **`SBYTE`**
  - 8-bit unsigned integer; 8-bit signed integer
- **`WORD`**, **`SWORD`**
  - 16-bit unsigned & signed integer
- **`DWORD`**, **`SDWORD`**
  - 32-bit unsigned & signed integer
- **`QWORD`**
  - 64-bit integer
- **`TBYTE`**
  - 80-bit integer

# 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

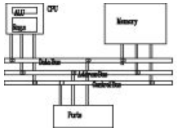


- A data definition statement sets aside storage in memory for a variable.
- May optionally assign a name (label) to the data
- Syntax:

  [*name*] *directive initializer* [,*initializer*] . . .

  At least one initializer is required, can be **?**
- 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).

# Defining multiple bytes

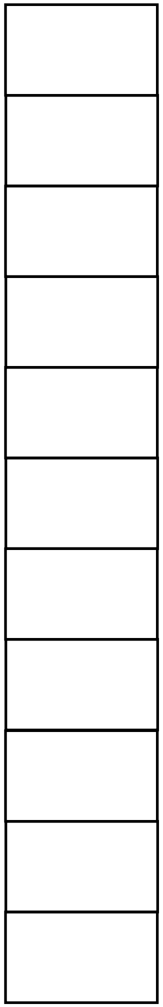
Examples that use multiple initializers:

```
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 2)

- A string is implemented as an array of characters
  - For convenience, it is usually enclosed in quotation marks
  - It usually has a null byte at the end
- Examples:

```
str1 BYTE "Enter your name",0
str2 BYTE 'Error: halting program',0
str3 BYTE 'A','E','I','O','U'
greeting1 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 (2 of 2)

- 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.
- 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
```

# 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:

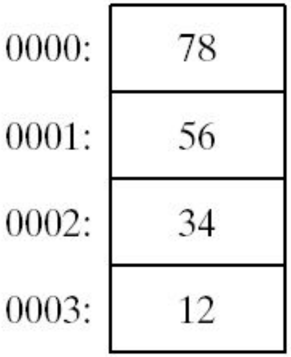
```
quad1 QWORD  1234567812345678h
val1  TBYTE  1000000000123456789Ah
rVal1 REAL4  -2.1
rVal2 REAL8  3.2E-260
rVal3 REAL10 4.6E+4096
ShortArray REAL4 20 DUP(0.0)
```

# 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 unitialized data

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

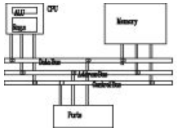
```
.data?
```

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

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
```

# 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

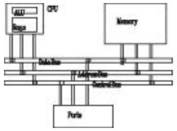
```
list BYTE 10,20,30,40
ListSize = 4
```

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

```
list BYTE 10,20,30,40
Var2 BYTE 20 DUP(?)
ListSize = ($ - list)
```

```
myString BYTE “This is a long string.”
myString_len = ($ - myString)
```

# Calculating the size of a word array

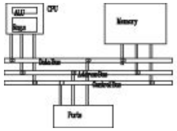


- current location counter: $
  - subtract address of list
  - difference is the number of bytes
  - divide by 2 (the size of a word)

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

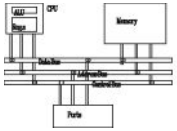
```
list DWORD 1,2,3,4
ListSize = ($ - list) / 4
```

# 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
```

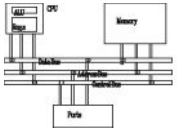
```
Matrix1 EQU 10*10
matrix1 EQU <10*10>
.data
M1 WORD matrix1  ; M1 WORD 100
M2 WORD matrix2  ; M2 WORD 10*10
```

# TEXTEQU directive

- name TEXTEQU <text>
  name TEXTEQU textmacro
  name TEXTEQU %constExpr
- 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
move TEXTEQU <mov>
setupAL TEXTEQU <move al,count>
.code
setupAL    ; generates: "mov al,10"
```

# Chapter recap



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