Assembly Language

Lecture 3 – Assembly Fundamentals

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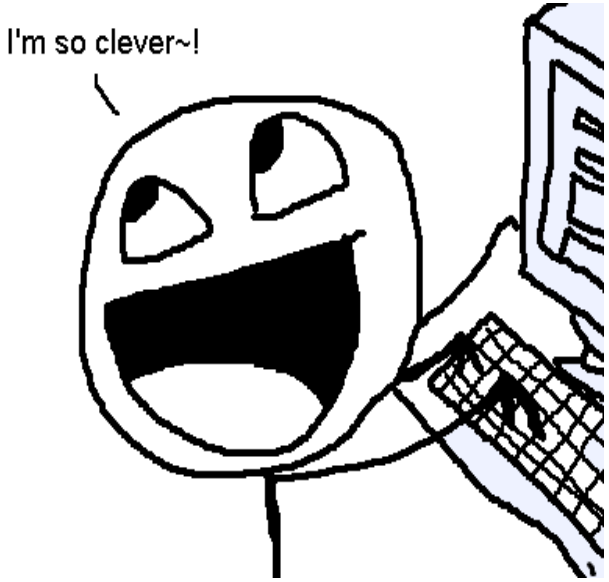
Slides based on original lecture slides by Dr. Mahmoud Elgayyar

Outcomes of Lecture 2

- *General Concepts*
  - CPU Design, Instruction execution cycle
- *IA-32 Processor Architecture*
  - Modes of operations, CPU Registers & Flags, Intel CPU History
- *IA-32 Memory Management*
  - Real address mode, segmented memory, paging
- *Input-Output System*
  - Levels of input / output system

Outline

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



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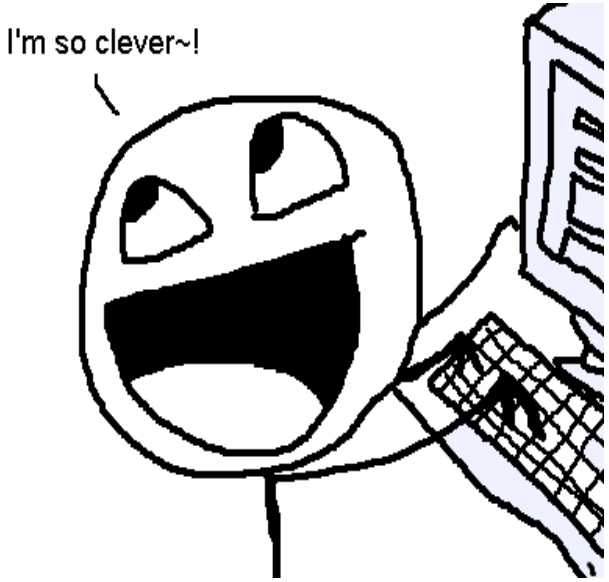
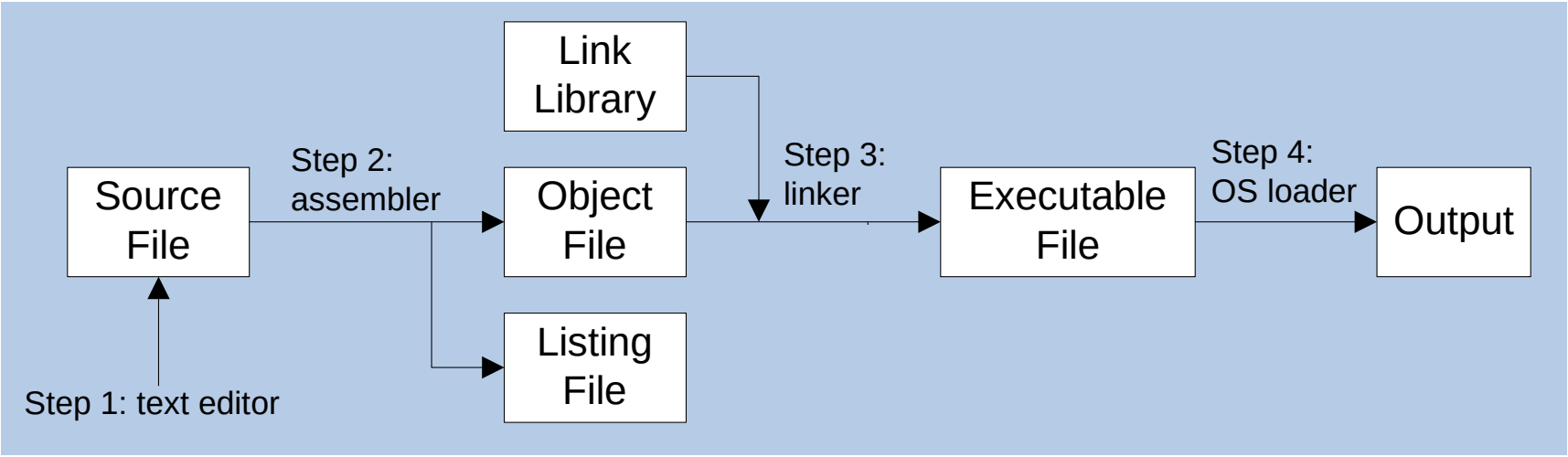


Assemble-Link Execute Cycle

- *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.*



Listing File

- *Use it to see how your program is compiled*
- *Named after the project, e.g.,* `project.lst`
- *Suitable for printing*
- *Contains:*
  - source code
  - addresses
  - object code (machine language)
  - segment names
  - symbols (variables, procedures, and constants)
- ***Example on pages 72-74 with detailed explanation – PLEASE READ!***

Review Questions

- *What types of files are produced by the assembler?*
- *(True/False): The linker extracts assembled procedures from the link library and inserts them in the executable program.*
- *Which operating system component reads and executes programs?*

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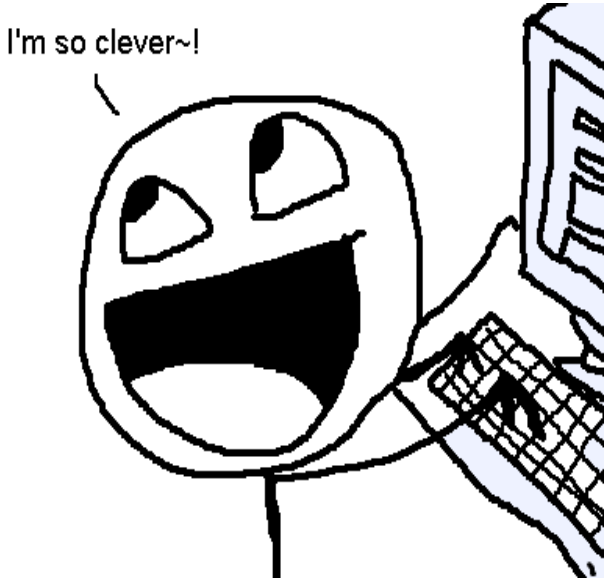

Basic Elements

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

Integer Constants

[{+|-} digits [radix]

- *Optional leading + or – sign*
- *Binary, decimal, hexadecimal*
- *Common radix characters:*
  - h – hexadecimal — Use as much as possible
  - d – decimal — When hex makes no sense
  - b – binary — For bitwise clarity
  - r – encoded real — Real

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

Hexadecimal can't begin with a letter: 0A5h

Integer Expressions

- *Evaluated at assembly time*

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

Characters and Strings

- *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 are allowed:*
  - 'Say "Goodnight," Gracie'
  - "This isn't a test"

Reserved Words and Identifiers

- *Reserved words cannot be used as identifiers*
  - Instruction mnemonics, directives, type attributes, operators, predefined symbols
  - See MASM reference in Appendix A
- *Identifiers*
  - 1-247 characters, including digits
  - not case sensitive
  - first character must be a letter, _, @, ?, or $
  - used for labels (procedure names, variables), constants

Directives

- *Instructions on how to assemble (not @ runtime)*
- *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, variables etc.
  - not case sensitive (.data, .DATA, and .Data)
- *Different assemblers have different directives*
  - GNU assembler, netwide assembler not the same as MASM

Directives: Defining Segments

- *One important function of assembler directives is to define program sections, or segments*

```
.data

.code

.stack 100h
```

Intel Instructions

- *Assembled into machine code by assembler*
- *Executed at runtime by the CPU*
- *An instruction contains:*
  - Label (optional)
  - Mnemonic (required)
  - Operand(s) (depends on the instruction)
  - Comment (optional) – begins with ';'

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

```
loop1:    mov    eax,32    ;count of array elements
```

Labels

- *Act as place markers*
  - marks the address (offset) of code and data
- *Follow identifier rules*
- *Data label (Variable names)*
  - must be unique
  - example: **count DWORD 100** (not followed by colon)
- *Code label*
  - target of jump and loop instructions
  - example: **L1:** (followed by colon)

Instruction Formats

- *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 ; reg, const-expr`

NOP Instruction

- *No Operation*
  - The safest and most useless instruction
- *Uses 1 byte of storage*
- *CPU: Reads it, Decodes it, Ignores it*
- *Usually used to align code to even-address boundaries (multiple of 4):*

```
00000000 66 8B C3 mov ax,bx
00000003 90 nop ; align next instruction
00000004 8B D1 mov edx,ecx
```

- *x86 processors are designed to load code and data more quickly from even doubleword addresses.*

Review Questions

- *(Yes/No): Is A5h a valid hexadecimal constant?*
- *(Yes/No): Must string constants be enclosed in single quotes?*
- *What is the maximum length of an identifier?*
- *(True/False): Assembler directives execute at runtime.*

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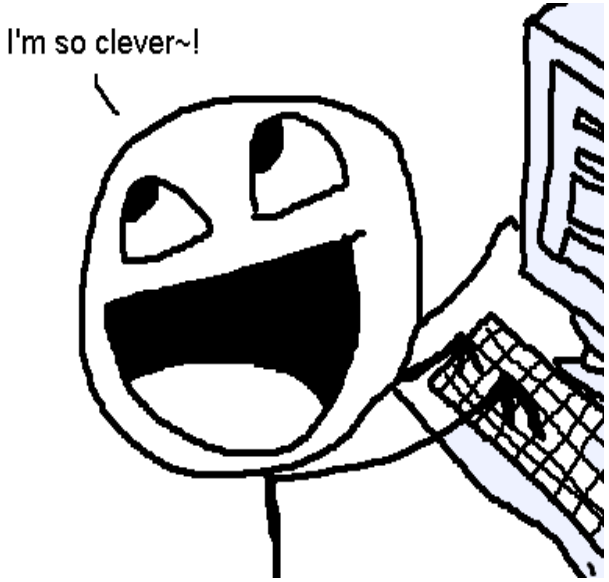

Program Template

```
TITLE Program Template                (Template.asm)

.data

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

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
```

Possible Coding Standards

- *Capitalization*
  - Capitalize reserved words, including mnemonics and register names
  - Capitalize nothing
  - Capitalize initial letters
- *Use descriptive identifier names*
- *Indentation and spacing*
  - code and data labels – no indentation
  - executable instructions – indent 4-5 spaces (1 tab)
  - comments: right side of page, aligned vertically
  - 1-3 spaces between instruction and its operands (1 tab)
  - 1-2 blank lines between procedures

Example: Adding and Subtracting Integers

2nd version

```
TITLE Add and Subtract                (AddSub2.asm)

; This program adds and subtracts 32-bit integers.
; Without include
.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               ; display registers
    INVOKE ExitProcess, 0
main ENDP

END main
```

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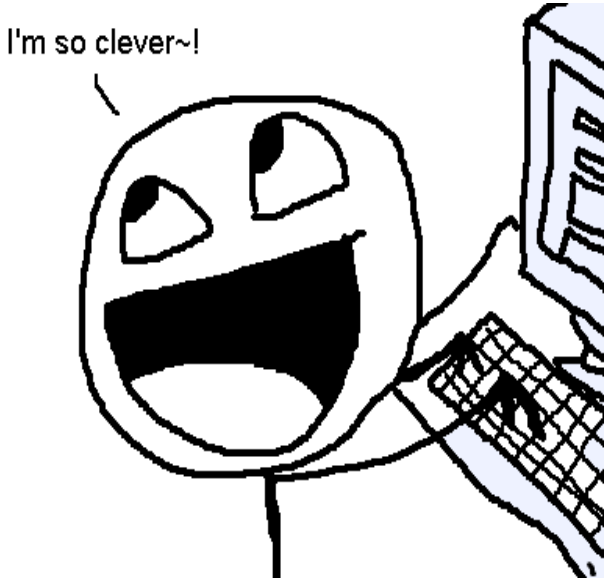


Basic Data Types

- *BYTE, SBYTE: 8-bit unsigned & signed integers*
- *WORD, SWORD: 16-bit unsigned & signed integers*
- *DWORD, SDWORD: 32-bit unsigned & signed integers*
- *QWORD: 64-bit integer*
  - Note: Not signed/unsigned
- *TBYTE: 80-bit (ten byte) integer*
- *REAL4, REAL8: 4-byte short & 8-byte long reals*
- *REAL10: 10-byte IEEE extended real*

Legacy Data Directives

Directive	Usage
DB	8-bit integer
DW	16-bit integer
DD	32-bit integer or real
DQ	64-bit integer or real
DT	80-bit (10 bytes) integer

supported also by the *Netwide Assembler* (NASM) and *Turbo Assembler* (TASM)

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
```

- *Use the **?** Symbol for undefined variables*
- *All initializers become binary data in memory*
  - 00110010b, 32h, and 50d all end up being having the same binary value

Defining BYTE, SBYTE Data

- *Each of the following defines a single byte of storage:*

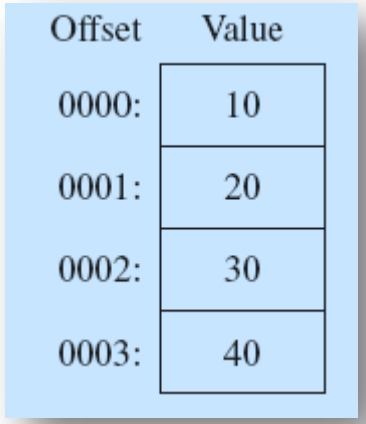
```
value1 BYTE 'A'                ; character constant
value2 BYTE 0                  ; smallest unsigned byte
value3 BYTE 255                ; largest unsigned byte
value4 SBYTE -128              ; smallest signed byte
value5 SBYTE +127              ; largest signed byte
value6 BYTE ?             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

- *The optional name is a label marking the variable's offset from the beginning of its enclosing segment.*
  - if value1 is located at offset 0000 in the data segment and consumes 1 byte of storage, value2 is automatically located at offset 0001
- *MASM allow you from initializing a BYTE with a negative value (poor style)*
- *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
```



Offset	Value
0000:	10
0001:	20
0002:	30
0003:	40

- *An array is simply a set of sequential memory locations*
- *The **directive (BYTE)** indicates the offset needed to get to the next array element*
- *No length, no termination flag, no special properties*

Defining Strings

- *A string is implemented as a sequence of characters*
  - For convenience, it is usually enclosed in quotation marks
  - It is usually null terminated
  - Characters are bytes
  - Hex characters `0Dh` (CR) and `0Ah` (LF) are useful
- *Examples:*

```
str1     BYTE "Enter your name: ",0
str2     BYTE 'ERROR!',0Dh,0Ah,'Halting program',0Dh,0Ah,0
str3     BYTE 'A','E','I','O','U'
newLine  BYTE 0Dh,0Ah,0
greet    BYTE "A string in"
         BYTE " two parts.",0
menu     BYTE "1. Create a new account",0dh,0ah,
              "2. Open an existing account",0dh,0ah,
              "3. Exit",0ah,0ah,
              "Choice> ",0
```

DUP Operator

- *Use DUP to allocate space for data*
- *Syntax: repetitions DUP (argument)*
- *repetitions 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 Other Types

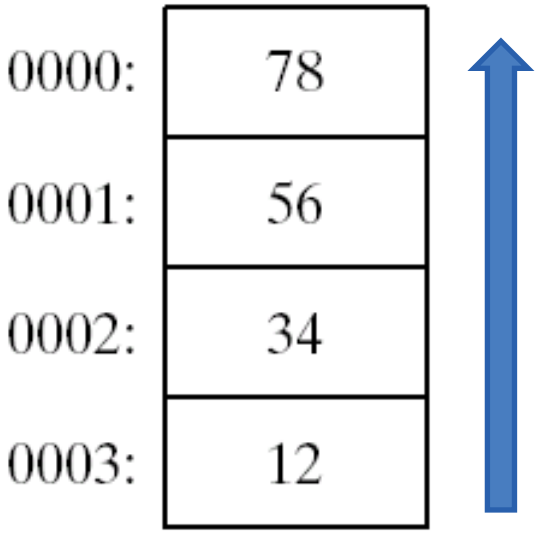
```
val1    WORD    65535               ; largest unsigned value
val2    SWORD   -32768              ; smallest signed value
word3   WORD    ?                   ; uninitialized, unsigned
word4   DWORD    "ABCD"             ; four characters
myList  WORD    1,2,3,4,5           ; array of words
array   WORD    5 DUP(?)            ; uninitialized array
val5    DWORD   0FFFF0000h          ; unsigned
val6    SDWORD  -2147483648         ; signed
dwd7    SDWORD  -2,-1,0,1,2           ; signed array
qwd8    QWORD   1234567812345678h
rVal1   REAL4   -2.1
rVal2   REAL8   3.2E-260
```

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
```



Example: Using Variables

```
TITLE Add and Subtract, Version 3                (AddSub3.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
```

Segment Control

- *.code*
  - all that follows goes in the code segment
- *.data*
  - all that follows goes in the data segment
- *.data?*
  - uninitialized data segment
  - allocated at runtime to store data
  - no space needed in stored .exe (since no values to store)
- *If intermixed they are separated by the assembler*

Declaring Uninitialized Data

- *Use the .data? directive to declare an uninitialized data segment*
  - .DATA? directive reduces the size of a compiled program.

```
.data?
array1 DWORD 5000 DUP (?)
```

- *No space is allocated to array1 until the program is loaded for execution (.exe is 20KB smaller)*

```
.data
array2 DWORD 5000 DUP (?)
```

- *array2, even though empty, has 20KB saved in .exe to store its non-existent values*

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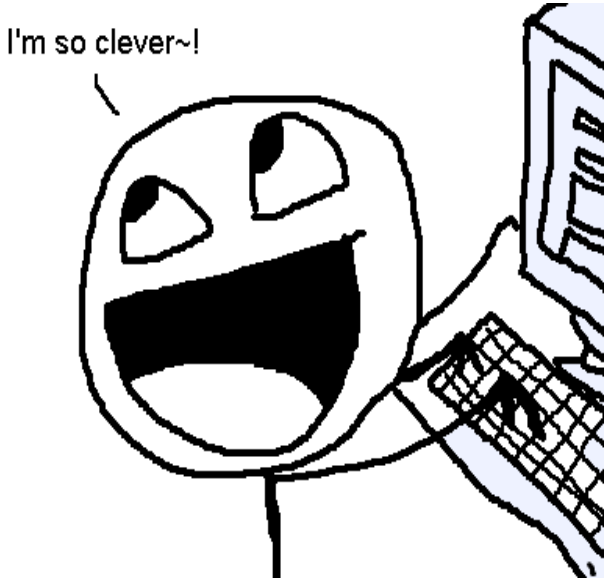

Integer Symbolic Constants

name = expression

- expression is a **32-bit integer** (expression or constant)
- may be redefined (but not good form to do so!)
- *name* is called a ***symbolic constant***
- Directives: No runtime impact, not part of .exe

- *good programming style to use symbols*

```
COUNT = 500
...
mov ax,COUNT
```

Array Size

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

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

- *Divide by element size if bigger than a byte (i.e., 2 for WORD, 4 for DWORD, 8 for QWORD)*
- *Example:*

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

EQU Directive

- *Define a symbol as either an integer or text expression*
- *= directive only permitted integers*
- *Cannot be redefined*
- *Example:*

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

TEXTEQU Directive

- *Define a textual symbol as either an integer or text expression*
- *Called a* **text macro**
- *Can be redefined*
- *% turns an integer into text*

```
;macros
msg TEXTEQU <"Do you wish to continue (Y/N)?">
rowSize = 5
count TEXTEQU %(rowSize * 2)       ; eval & store as text
setupAL TEXTEQU <mov al,count>     ; macro for a mov instr
.data
prompt1 BYTE msg
.code
setupAL                            ; creates "mov al,10"
```

Real-Address Programming

- *Make your computer look, act, and feel like one built in the 80s*
- *Generate 16-bit MS-DOS Programs (Why?)*
- *"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

Requirements

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

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

X64

- x64 extends x86's 8 general-purpose registers to be 64-bit, and adds 8 new 64-bit registers. The 64-bit registers have names beginning with "r", so for example the 64-bit extension of **eax** is called **rax**. The new registers are named **r8** through **r15**.

64-bit register	Lower 32 bits	Lower 16 bits	Lower 8 bits
rax	**eax**	**ax**	**al**
rbx	**ebx**	**bx**	**bl**
rcx	**ecx**	**cx**	**cl**
rdx	**edx**	**dx**	**dl**
rsi	**esi**	**si**	**sil**
rdi	**edi**	**di**	**dil**
rbp	**ebp**	**bp**	**bpl**
rsp	**esp**	**sp**	**spl**
r8	**r8d**	**r8w**	**r8b**
r9	**r9d**	**r9w**	**r9b**
r10	**r10d**	**r10w**	**r10b**
r11	**r11d**	**r11w**	**r11b**
r12	**r12d**	**r12w**	**r12b**
r13	**r13d**	**r13w**	**r13b**
r14	**r14d**	**r14w**	**r14b**
r15	**r15d**	**r15w**	**r15b**

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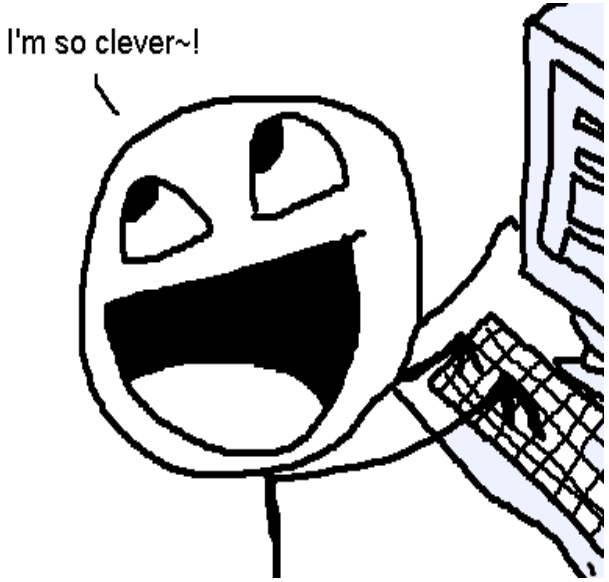

Summary

- *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, REAL4, REAL8
  - TBYTE, REAL10 – Obscure and rarely used instructions (becoming obsolete)
  - DUP operator, location counter ($)
- *Symbolic constants*
  - =, EQU and TEXTEQU