Computer Organization & Assembly Language - EE2003

Lecture 05

Week 03

Chapter Overview

- General Concepts
- IA-32 Processor Architecture
- IA-32 Memory Management
- Components of an IA-32 Microcomputer
- Input-Output System

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

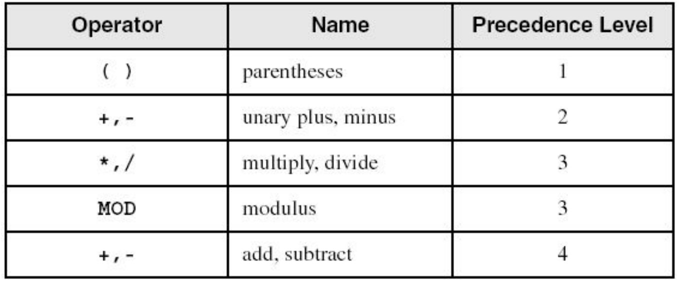
- Optional leading + or – sign
- binary, decimal, hexadecimal, or octal digits
- Common radix characters:
  - h – hexadecimal
  - d – decimal
  - b – binary
  - r – encoded real

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

Hexadecimal beginning with letter: 0A5h

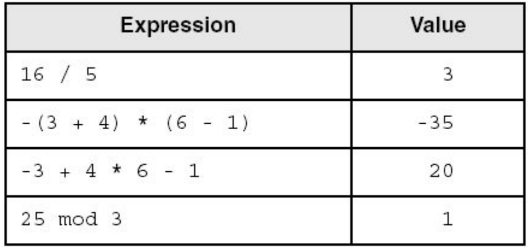
Integer Expressions

- 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

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'

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 $

Reserved Words

- Have special meaning and can only be used in correct context
  - Instruction mnemonics like MOV, ADD, SUB, INT etc.
  - Register Names like AX, BX, DL, DH etc.
  - Directives like .DATA, .CODE etc.
  - Attributes like BYTE, WORD etc.
  - Operators used in constant expressions
  - Predefined symbols

Identifiers

- Name of a variable, constant, procedure or a code label selected by programmer
- Some rules to follow while choosing identifier names
  - From 1 to 247 number of characters
  - Names are not case sensitive
  - An identifier cannot be the same as an assembler reserved word
  - First character must be a letter (a-z, A-Z), underscore(_), @, ? Or $. Subsequent characters may also contain digits
- Examples are `var1`, `CounT`, `_name`, `_1344`

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

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)

Instructions

- A statement that becomes executable when a program is assembled
- Translated by assembler into machine language
- An Instruction contains four basic parts
  - Label (optional)
  - Instruction Mnemonic (required)
  - Operand(s) (usually required)
  - Comment (optional)
- Basic syntax is

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

Labels

- Act as place markers
  - marks the address (offset) of code and data
- Follow identifer rules
- Data label
  - must be unique
  - example: myArray (not followed by colon)
- Code label
  - target of jump and loop instructions
  - example: L1: (followed by colon)

Mnemonics and Operands

- Instruction Mnemonics
  - memory aid
  - examples: MOV, ADD, SUB, MUL, INC, DEC
- Operands
  - constant
  - constant expression
  - register
  - memory (data label)

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

NOP (No Operation) Instruction

- The safest and even most useless instruction in assembly language
- Does not do anything except occupying 1 byte of program storage
- Sometimes used by assemblers to align code to even-address boundaries

```
00000000 66 8B C3 MOV AX, BX
00000003 90       NOP
00000004 8B D1    MOV EDX, ECX
```

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

What's Next

- Basic Elements of Assembly Language
- Example: Adding and Subtracting Integers
- Assembling, Linking, and Running Programs
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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 (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
- 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: right side of page, 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
```

What's Next

- Basic Elements of Assembly Language
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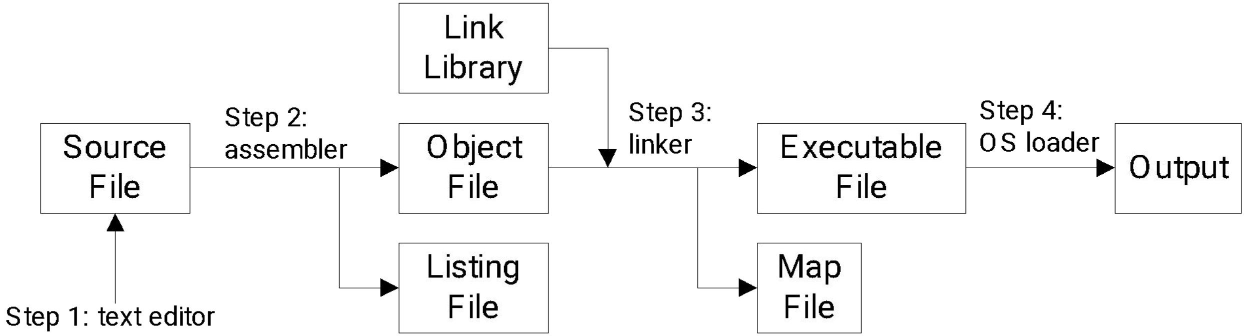
Assembling, Linking, and Running Programs

- Assemble-Link-Execute Cycle
- Listing File
- Map File

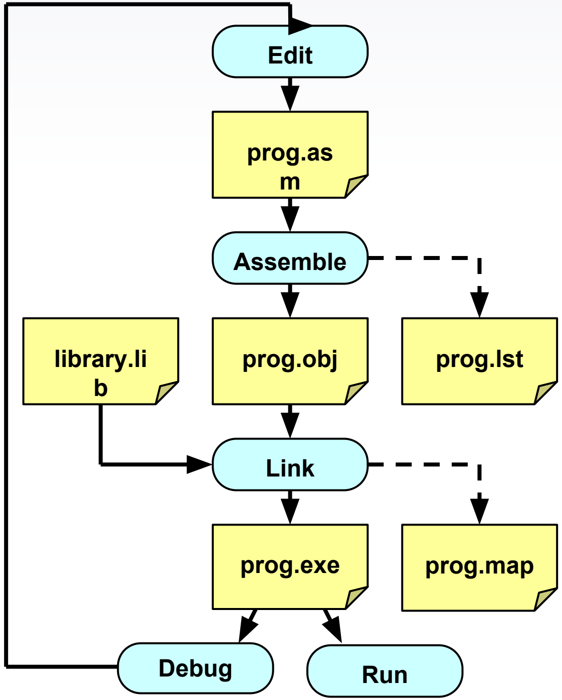
Assemble-Link Execute Cycle

- 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.



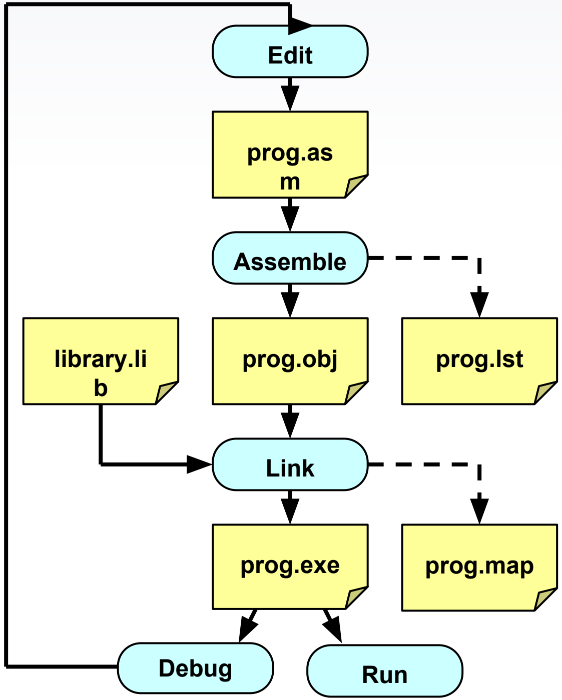
Assemble-Link-Debug Cycle (2/3)

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



Assemble-Link-Debug Cycle (3/3)

- Debugger
  - 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



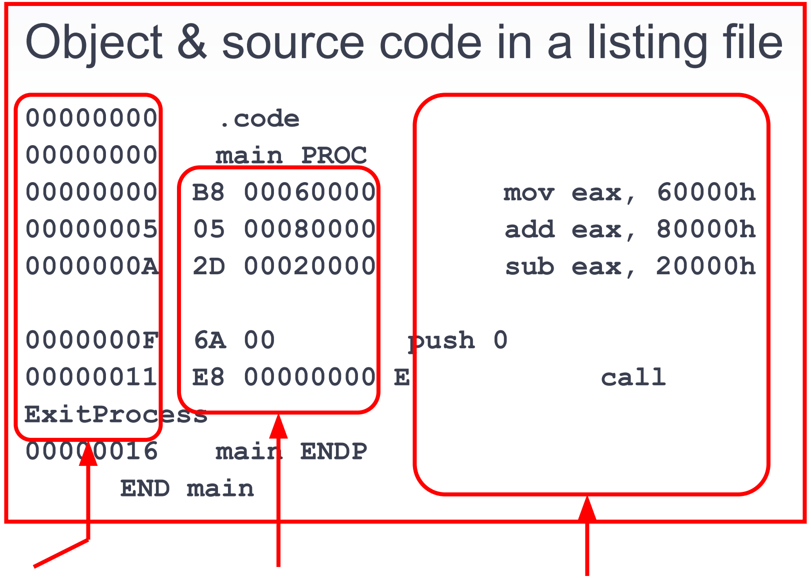
Listing File

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

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

Map File

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

THANKS!

Any questions?

You can find me at:

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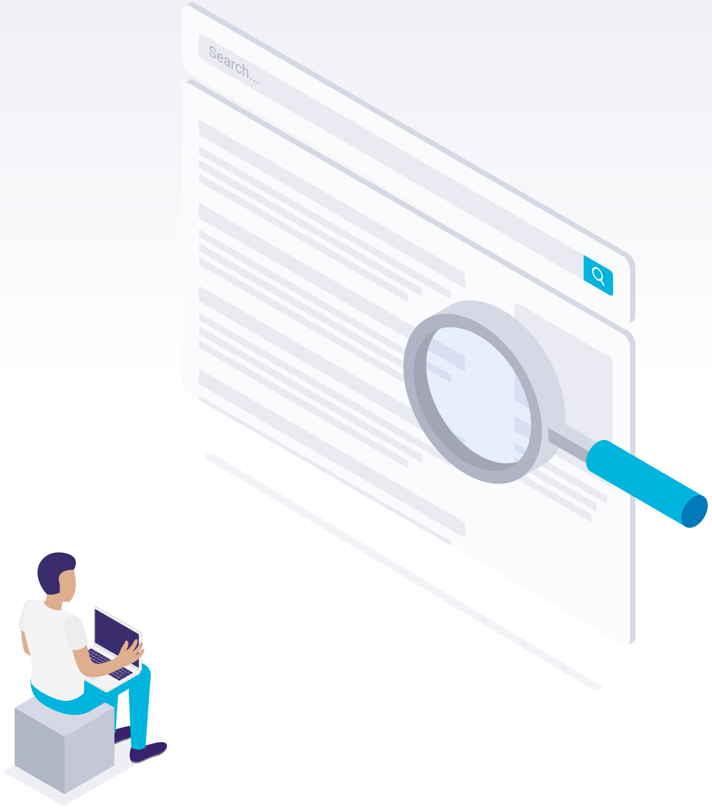
- Office #213, Visiting Hours Only



Lecture 06

Week 03

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

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 (1/2)

- Assigns storage in memory for a variable
- Syntax for a data definition statement is

```
[name] directive initializer [,initializer]
```

- Name is optional and must follow the rules of naming the identifiers
- At least one initializer is required
- Question mark (?) can be used as initializer if uninitialized variable

Data Definition Statement (2/2)

- Directive can be any of the following

Directive	**Description**	**Usage**
DB	**D**efine **B**yte	8-bit Integer
DW	**D**efine **W**ord	16-bit Integer
DD	**D**efine **D**oubleword	32-bit Integer
DQ	**D**efine **Q**uadword	64-bit Integer
DT	**D**efine **T**enbytes	80-bit Integer

DB Directive

- Defines an 8-bit signed or unsigned variable
- The initializer must fit into 8-bits either signed or unsigned
- `name` shows the offset from the beginning of its segment
- Syntax is like this

```
              [name] DB initializer
```

- Examples are

```
val1 DB 255  ; largest unsigned value
val2 DB +127 ; largest signed value
```

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
```

- MASM does not prevent you from initializing a BYTE with a negative value, but it's considered poor style.
- If you declare a SBYTE variable, the Microsoft debugger will automatically display its value in decimal with a leading sign.

Multiple Initializers

- If multiple initializers are used in the same data definition statement
  - … its label refers only to the offset of first initializer

```
[name] Directive initializer ,initializer
```

- Also called Array
- Example is

```
vals1 DB 10, -20, 30
vals2 DW 0Ah, 10, 00111100b
```

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
```

Defining Strings (2 of 3)

- 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 (3 of 3)

- 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
```

DW Directive

- Defines a 16-bit signed or unsigned integer
- The initializer must fit into 16-bits either signed or unsigned
- `name` shows the offset from the beginning of its segment
- Syntax is like this

```
[name] DW initializer
```

- Examples are

```
val1 DW 65535  ;largest unsigned value
val2 DW -32768 ;smallest signed value
```

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
```

DD Directive

- Defines a 32-bit signed or unsigned integer
- The initializer must fit into 32-bits either signed or unsigned
- `name` shows the offset from the beginning of its segment
- Syntax is like this

```
[name] DD initializer
```

- Examples are

```
val1 DD FFFFFFFFh ;largest unsigned value
val2 DD 80000000h ;smallest signed value
```

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
```

DQ Directive

- Defines a 64-bit signed or unsigned integer
- The initializer must fit into 64-bits either signed or unsigned
- `name` shows the offset from the beginning of its segment
- Syntax is like this

```
[name] DQ initializer
```

- Examples are

```
val1 DQ 10001010h
val2 DQ 10001010b
```

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

- x86 processors store and retrieve data from memory using Little Endian Order
- Least significant byte is stored at the first memory address allocated for data
- Remaining bytes are stored in the next consecutive memory locations
- Example, consider 2-bytes value 1234h
  - If placed in memory at offset 0000, 34h would be stored in first byte
  - 12h would be stored in the second byte

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

Big Endian Order

- Some other processors store and retrieve data from memory using Big Endian Order
- Most significant byte is stored at the first memory address allocated for data
- Remaining bytes are stored in the next consecutive memory locations
- Example, consider 2-bytes value 1234h
    - If placed in memory at offset 0000, 12h would be stored in first byte
    - 34h would be stored in the second byte

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:

```
    smallArray DWORD 10 DUP(?)
```

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

What's Next

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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

```
COUNT = 500
.
.
mov ax,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 = ($ - 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

- Define a symbol as either an integer or text expression.
- Cannot be redefined

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

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"
```

What's Next

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Real-Address Mode Programming (1 of 2)

- 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 (2 of 2)

- 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

THANKS!

Any questions?

You can find me at:

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