

Assembly Language for x86 Processors

7th Edition

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Chapter 3: Assembly Language Fundamentals

Slides prepared by the author

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Chapter Overview

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

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)

Labels

- Act as place markers
 - marks the address (offset) of code and data
- Follow identifier 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

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
- Defining Data
- Symbolic Constants
- 64-Bit Programming

Example: Adding and Subtracting Integers

```
; AddTwo.asm - adds two 32-bit integers
```

```
.386
```

```
.model flat,stdcall
```

```
.stack 4096
```

```
ExitProcess PROTO, dwExitCode:DWORD
```

```
.code
```

```
main PROC
```

```
    mov     eax,5        ; move 5 to the EAX register
```

```
    add     eax,6        ; add 6 to the EAX register
```

```
    INVOKE  ExitProcess,0
```

```
main ENDP
```

```
END main
```

Example Output

Showing registers and flags in the debugger:

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

Required Coding Standards

- (to be filled in by the professor)

Program Template

```
; Program Template                (Template.asm)

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

.386
.model flat,stdcall
.stack 4096
ExitProcess PROTO, dwExitCode:DWORD
.data
; declare variables here
.code
main PROC
    ; write your code here
    INVOKE ExitProcess,0
main ENDP
; (insert additional procedures here)
END main
```

What's Next

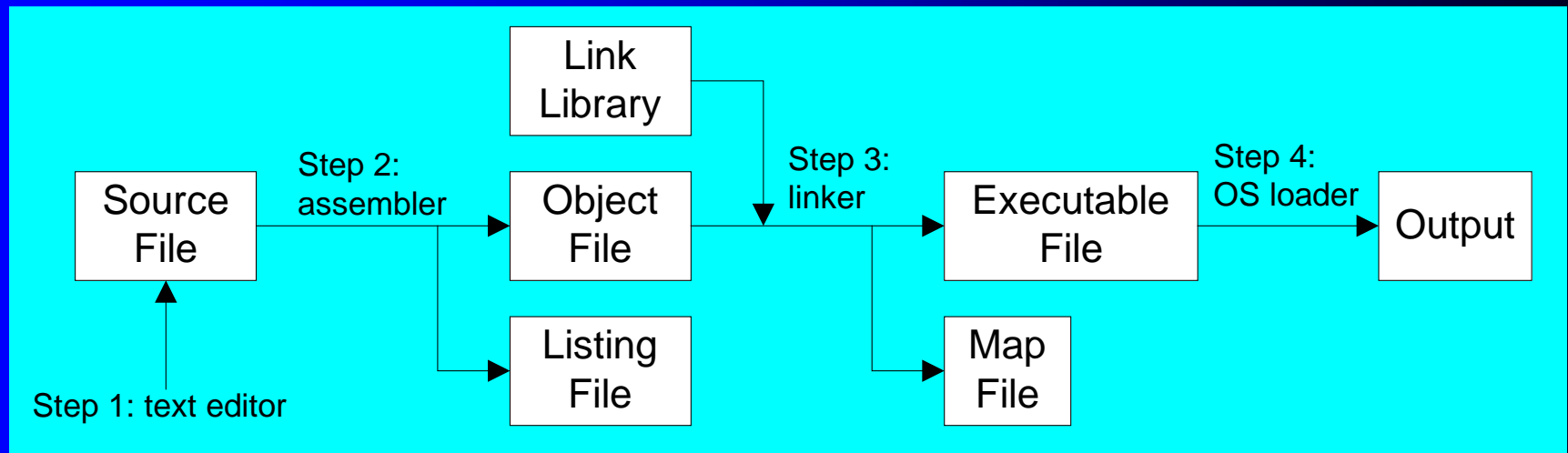
- Basic Elements of Assembly Language
- Example: Adding and Subtracting Integers
- **Assembling, Linking, and Running Programs**
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- Symbolic Constants
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Assembling, Linking, and Running Programs

- 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.



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)

What's Next

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

- 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.

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

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

Defining WORD and SWORD Data

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

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

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 uninitialized data segment:

```
.data?
```

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

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

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

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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"
```

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64-Bit Programming

- MASM supports 64-bit programming, although the following directives are not permitted:
 - INVOKE, ADDR, .model, .386, .stack
 - (Other non-permitted directives will be introduced in later chapters)

64-Bit Version of AddTwoSum

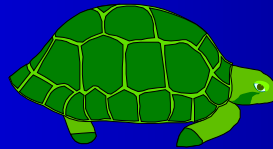
```
1: ; AddTwoSum_64.asm - Chapter 3 example.
3: ExitProcess PROTO
5: .data
6: sum DWORD 0
8: .code
9: main PROC
10:     mov     eax,5
11:     add     eax,6
12:     mov     sum,eax
13:
14:     mov     ecx,0
15:     call    ExitProcess
16: main ENDP
17: END
```

Things to Notice About the Previous Slide

- The following lines are not needed:
 `.386`
 `.model flat,stdcall`
 `.stack 4096`
- INVOKE is not supported.
- CALL instruction cannot receive arguments
- Use 64-bit registers when possible

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



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