Assembly Language for x86 Processors
7th Edition

Kip Irvine

Chapter 1: Basic Concepts

Slides prepared by the author –

slightly modified by the Instructor

Revision date: 2/15/2016

Chapter Overview

- **Welcome to Assembly Language**
- Virtual Machine Concept
- Data Representation
- Boolean Operations

Welcome to Assembly Language

- Some Good Questions to Ask
- Assembly Language Applications

Questions to Ask

- Why am I learning Assembly Language?
- What background should I have?
- What is an assembler?
- What hardware/software do I need?
- What types of programs will I create?
- What do I get with this book?
- What will I learn?

Welcome to Assembly Language *(cont)*

- How does assembly language (AL) relate to machine language?
- How do C++ and Java relate to AL?
- Is AL portable?
- Why learn AL?

Assembly Language Applications

- **Some representative types of applications:**
  - Business application for single platform
  - Hardware device driver
  - Business application for multiple platforms
  - Embedded systems & computer games

(see next panel)

Comparing ASM to High-Level Languages

Type of Application	High-Level Languages	Assembly Language
Business application software, written for single platform, medium to large size.	Formal structures make it easy to organize and maintain large sections of code.	Minimal formal structure, so one must be imposed by programmers who have varying levels of experience. This leads to difficulties maintaining existing code.
Hardware device driver.	Language may not provide for direct hardware access. Even if it does, awkward coding techniques must often be used, resulting in maintenance difficulties.	Hardware access is straightforward and simple. Easy to maintain when programs are short and well documented.
Business application written for multiple platforms (different operating systems).	Usually very portable. The source code can be recompiled on each target operating system with minimal changes.	Must be recoded separately for each platform, often using an assembler with a different syntax. Difficult to maintain.
Embedded systems and computer games requiring direct hardware access.	Produces too much executable code, and may not run efficiently.	Ideal, because the executable code is small and runs quickly.

Irvine, Kip R. Assembly Language for Intel-Based Computers 7/e, 2015.

What's Next

- Welcome to Assembly Language
- **Virtual Machine Concept**
- Data Representation
- Boolean Operations

Virtual Machine Concept

- **Virtual Machines**
- **Specific Machine Levels**

Virtual Machines

- Tanenbaum: Virtual machine concept
- **Programming Language analogy:**
  - Each computer has a native machine language (language L0) that runs directly on its hardware
  - A more human-friendly language is usually constructed above machine language, called Language L1
- **Programs written in L1 can run two different ways:**
  - **Interpretation** – L0 program interprets and executes L1 instructions one by one
  - **Translation** – L1 program is completely translated into an L0 program, which then runs on the computer hardware

Translating Languages

English: Display the sum of A times B plus C.

↓

C++: cout << (A * B + C);

↓

Assembly Language:

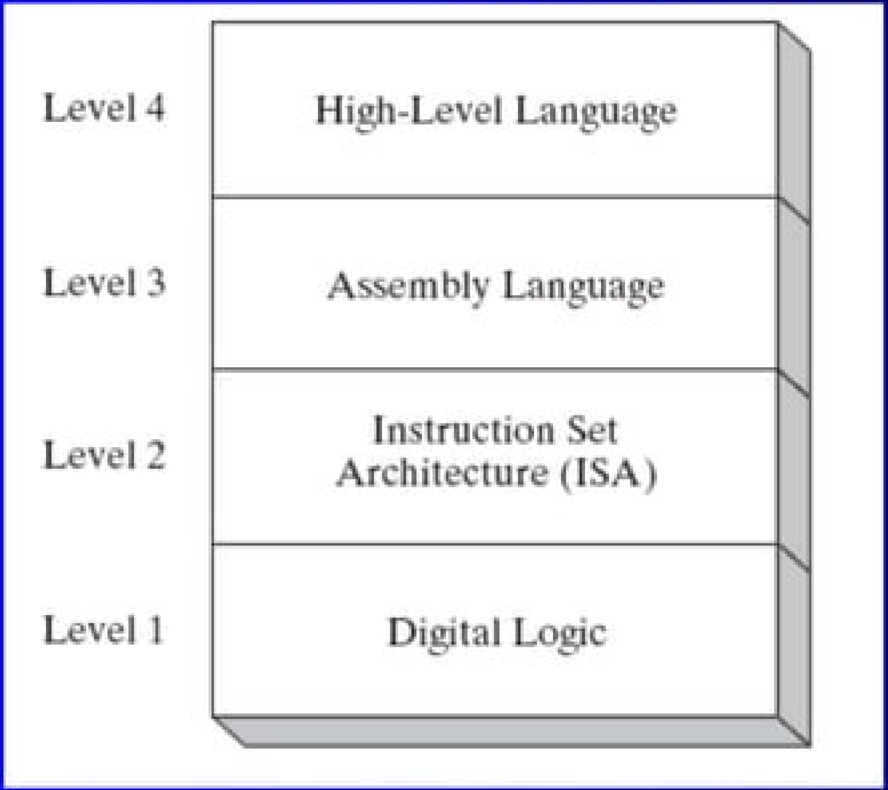
```
mov eax,A
mul B
add eax,C
call WriteInt
```

→

Intel Machine Language:

```
A1 00000000
F7 25 00000004
03 05 00000008
E8 00500000
```

Specific Machine Levels



(descriptions of individual levels follow . . .)

High-Level Language

- Level 4
- Application-oriented languages
  - C++, Java, Pascal, Visual Basic . . .
- Programs compile into assembly language (Level 4)

Assembly Language

- Level 3
- Instruction mnemonics that have a one-to-one correspondence to machine language
- Programs are translated into Instruction Set Architecture Level - machine language (Level 2)

Instruction Set Architecture (ISA)

- Level 2
- Also known as conventional machine language
- Executed by Level 1 (Digital Logic)

Digital Logic

- **Level 1**
- CPU, constructed from digital logic gates
- System bus
- Memory
- Implemented using bipolar transistors

next: Data Representation

What's Next

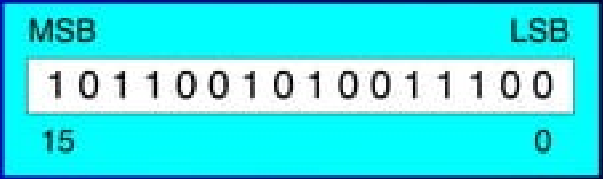
- Welcome to Assembly Language
- Virtual Machine Concept
- **Data Representation**
- Boolean Operations

Data Representation

- Binary Numbers
  - Translating between binary and decimal
- Binary Addition
- Integer Storage Sizes
- Hexadecimal Integers
  - Translating between decimal and hexadecimal
  - Hexadecimal subtraction
- Signed Integers
  - Binary subtraction
- Character Storage

Binary Numbers

- Digits are 1 and 0
  - 1 = true
  - 0 = false
- MSB – most significant bit
- LSB – least significant bit
- Bit numbering:



Big Endian和Little Endian的比較

endian指的是當物理上的最小單元比邏輯上的最小單元小時，邏輯單元對映到物理單元的排布關係。

如果你在文件上看到一個雙字組的data，
Ex: long MyData=0x12345678，要寫到從0x0000開始的記憶體位址時。

實際的例子
如果你在文件上看到一個雙字組的data，Ex: long MyData=0x12345678，要寫到從0x0000開始的記憶體位址時。

如果是Big Endian的系統，
存到記憶體會變成 0x12 0x34 0x56 0x78，最高位元組在位址最低位元，最低位元組在位址最高位元，依次排列。

如果是Little Endian的系統，
存到記憶體會變成 0x78 0x56 0x34 0x12，最低位元組在最低位元，最高位元組在最高位元，反序排列。

Big Endian和Little Endian的比較

如果你在文件上看到一個雙字組的data，Ex: long MyData=0x12345678，要寫到從0x0000開始的記憶體位址時。

如果是Big Endian的系統，

存到記憶體會變成 0x12 0x34 0x56 0x78，最高位元組在位址最低位元，最低位元組在位址最高位元，依次排列。

如果是Little Endian的系統，

存到記憶體會變成 0x78 0x56 0x34 0x12，最低位元組在最低位元，最高位元組在最高位元，反序排列。

Big Endian和Little Endian的比較

如果你在文件上看到一個雙字組的data，Ex: long MyData=0x12345678，要寫到從0x0000開始的記憶體位址時。

比較的結果就是這樣：	big-endian	little-endian
0x0000	0x12	0x78
0x0001	0x34	0x56
0x0002	0x56	0x34
0x0003	0x78	0x12

Big Endian和Little Endian的比較

這有什麼差別呢？

以目前常見的CPU為例：
INTEL X86、DEC VAX 使用 LITTLE-ENDIAN 設計；

HP、IBM、MOTOROLA 68K 系列使用 BIG-ENDIAN 設計；

POWERPC 同時支援兩種格式，稱為 BI-ENDIAN。

Program to Test the Machine for endianness

```
#include <stdio.h>
typedef union { long l; unsigned char c[4]; } EndianTest;
int main(int argc, char* argv[]) {
EndianTest a;
a.l=0x12345678;
int i=0;
if(a.c[0]==0x78 && a.c[1]==0x56 && a.c[2]==0x34 && a.c[3]==0x12) {
printf("This system is 'Little Endian'.\n"); }
else if(a.c[0]==0x12 && a.c[1]==0x34 && a.c[2]==0x56 && a.c[3]==0x78)
{
printf("This system is 'Big Endian'.\n");
}
else {
printf("This system is 'Unknown Endian'.\n");
}
printf("for a long variable value is 0x%lX\n",a.l);
printf("and its storage order in memory :\n");
for(i=0;i<4;i++) printf("%p : 0x%02X\n",&a.c[i],a.c[i]);
// getchar(); // wait for a key .. ◦
return 0;
}
```

Irvine, Kip R. Assembly Language for Intel-Based Computers 7/e, 2015.

Binary Numbers

- Each digit (bit) is either 1 or 0
- Each bit represents a power of 2:

Every binary number is a sum of powers of 2

Table 1-3 Binary Bit Position Values.

2^n	Decimal Value	2^n	Decimal Value
2^0	1	2^8	256
2^1	2	2^9	512
2^2	4	2^{10}	1024
2^3	8	2^{11}	2048
2^4	16	2^{12}	4096
2^5	32	2^{13}	8192
2^6	64	2^{14}	16384
2^7	128	2^{15}	32768

Translating Binary to Decimal

Weighted positional notation shows how to calculate the decimal value of each binary bit:

$$dec = (D_{n-1} \times 2^{n-1}) + (D_{n-2} \times 2^{n-2}) + ... + (D_1 \times 2^1) + (D_0 \times 2^0)$$

D = binary digit

binary 00001001 = decimal 9:

$(1 \times 2^3) + (1 \times 2^0) = 9$

Translating Unsigned Decimal to Binary

- Repeatedly divide the decimal integer by 2. Each remainder is a binary digit in the translated value:

Division	Quotient	Remainder
37 / 2	18	1
18 / 2	9	0
9 / 2	4	1
4 / 2	2	0
2 / 2	1	0
1 / 2	0	1

37 = 100101

Binary Addition

- Starting with the LSB, add each pair of digits, include the carry if present.

carry:					1				
	0	0	0	0	0	1	0	0	(4)
+	0	0	0	0	0	1	1	1	(7)
	0	0	0	0	1	0	1	1	(11)
bit position:	7	6	5	4	3	2	1	0	

Integer Storage Sizes

Standard sizes:

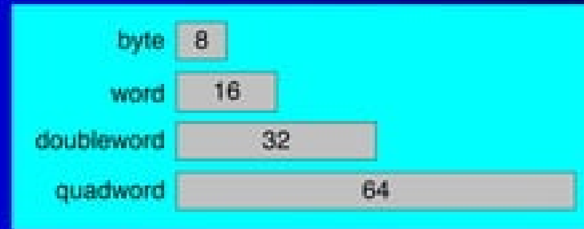


Table 1-4 Ranges of Unsigned Integers.

Storage Type	Range (low–high)	Powers of 2
Unsigned byte	0 to 255	0 to $(2^8 - 1)$
Unsigned word	0 to 65,535	0 to $(2^{16} - 1)$
Unsigned doubleword	0 to 4,294,967,295	0 to $(2^{32} - 1)$
Unsigned quadword	0 to 18,446,744,073,709,551,615	0 to $(2^{64} - 1)$

What is the largest unsigned integer that may be stored in 20 bits?

Hexadecimal Integers

Binary values are represented in hexadecimal.

Table 1-5 Binary, Decimal, and Hexadecimal Equivalents.

Binary	Decimal	Hexadecimal	Binary	Decimal	Hexadecimal
0000	0	0	1000	8	8
0001	1	1	1001	9	9
0010	2	2	1010	10	A
0011	3	3	1011	11	B
0100	4	4	1100	12	C
0101	5	5	1101	13	D
0110	6	6	1110	14	E
0111	7	7	1111	15	F

Translating Binary to Hexadecimal

- Each hexadecimal digit corresponds to 4 binary bits.
- Example: Translate the binary integer 000101101010011110010100 to hexadecimal:

1	6	A	7	9	4
0001	0110	1010	0111	1001	0100

Converting Hexadecimal to Decimal

- Multiply each digit by its corresponding power of 16:

  $$dec = (D_3 \times 16^3) + (D_2 \times 16^2) + (D_1 \times 16^1) + (D_0 \times 16^0)$$

- Hex 1234 equals $(1 \times 16^3) + (2 \times 16^2) + (3 \times 16^1) + (4 \times 16^0)$, or decimal 4,660.

- Hex 3BA4 equals $(3 \times 16^3) + (11 * 16^2) + (10 \times 16^1) + (4 \times 16^0)$, or decimal 15,268.

Powers of 16

Used when calculating hexadecimal values up to 8 digits long:

16^n	Decimal Value	16^n	Decimal Value
16^0	1	16^4	65,536
16^1	16	16^5	1,048,576
16^2	256	16^6	16,777,216
16^3	4096	16^7	268,435,456

Converting Decimal to Hexadecimal

Division	Quotient	Remainder
422 / 16	26	6
26 / 16	1	A
1 / 16	0	1

decimal 422 = 1A6 hexadecimal

Hexadecimal Addition

- Divide the sum of two digits by the number base (16). The quotient becomes the carry value, and the remainder is the sum digit.

		1	1
36	28	28	6A
42	45	58	4B
78	6D	80	B5

21 / 16 = 1, rem 5

Important skill: Programmers frequently add and subtract the addresses of variables and instructions.

Hexadecimal Subtraction

- When a borrow is required from the digit to the left, add 16 (decimal) to the current digit's value:

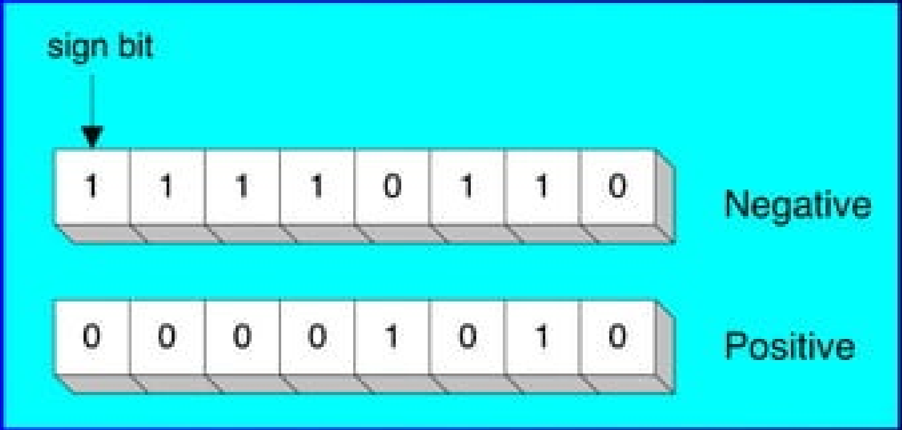
$\boxed{16 + 5 = 21}$

$$\begin{array}{cc} & -1 \\ \mathrm{C6} & 75 \\ \mathrm{A2} & 47 \\ \hline 24 & \mathrm{2E} \end{array}$$

Practice: The address of **var1** is 00400020. The address of the next variable after var1 is 0040006A. How many bytes are used by var1?

Signed Integers

The highest bit indicates the sign. 1 = negative, 0 = positive



If the highest digit of a hexadecimal integer is > 7, the value is negative. Examples: 8A, C5, A2, 9D

Forming the Two's Complement

- Negative numbers are stored in two's complement notation
- Represents the additive Inverse

Starting value	00000001
Step 1: reverse the bits	11111110
Step 2: add 1 to the value from Step 1	11111110 +00000001
Sum: two's complement representation	11111111

Note that 00000001 + 11111111 = 00000000

Binary Subtraction

- When subtracting A – B, convert B to its two's complement
- Add A to (–B)

```
  0 0 0 0 1 1 0 0            0 0 0 0 1 1 0 0
– 0 0 0 0 0 0 1 1   ──→      1 1 1 1 1 1 0 1
  ---------------            ---------------
                             0 0 0 0 1 0 0 1
```

Practice: Subtract 0101 from 1001.

Learn How To Do the Following:

- Form the two's complement of a hexadecimal integer
- Convert signed binary to decimal
- Convert signed decimal to binary
- Convert signed decimal to hexadecimal
- Convert signed hexadecimal to decimal

Ranges of Signed Integers

The highest bit is reserved for the sign. This limits the range:

Storage Type	Range (low–high)	Powers of 2
Signed byte	−128 to +127	-2^7 to $(2^7 - 1)$
Signed word	−32,768 to +32,767	-2^{15} to $(2^{15} - 1)$
Signed doubleword	−2,147,483,648 to 2,147,483,647	-2^{31} to $(2^{31} - 1)$
Signed quadword	−9,223,372,036,854,775,808 to +9,223,372,036,854,775,807	-2^{63} to $(2^{63} - 1)$

Practice: What is the largest positive value that may be stored in 20 bits?

Character Storage

- Character sets
  - Standard ASCII (0 – 127)
  - Extended ASCII (0 – 255)
  - ANSI (0 – 255)
  - Unicode (0 – 65,535)
- Null-terminated String
  - Array of characters followed by a *null byte*
- Using the ASCII table
  - back inside cover of book

Numeric Data Representation

- pure binary
  - can be calculated directly
- ASCII binary
  - string of digits: "01010101"
- ASCII decimal
  - string of digits: "65"
- ASCII hexadecimal
  - string of digits: "9C"

next: Boolean Operations

Boolean Algebra

- Based on symbolic logic, designed by George Boole
- Boolean expressions created from:
  - NOT, AND, OR

Expression	Description
$\neg X$	NOT X
$X \wedge Y$	X AND Y
$X \vee Y$	X OR Y
$\neg X \vee Y$	(NOT X) OR Y
$\neg(X \wedge Y)$	NOT (X AND Y)
$X \wedge \neg Y$	X AND (NOT Y)

What's Next

- Welcome to Assembly Language
- Virtual Machine Concept
- Data Representation
- **Boolean Operations**

Boolean Operations

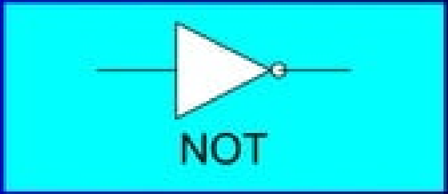
- NOT
- AND
- OR
- Operator Precedence
- Truth Tables

NOT

- Inverts (reverses) a boolean value
- Truth table for Boolean NOT operator:

X	¬X
F	T
T	F

Digital gate diagram for NOT:

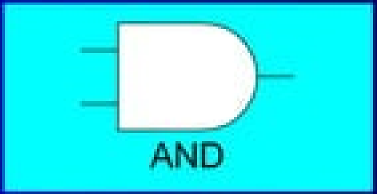


AND

- Truth table for Boolean AND operator:

X	Y	$X \wedge Y$
F	F	F
F	T	F
T	F	F
T	T	T

Digital gate diagram for AND:

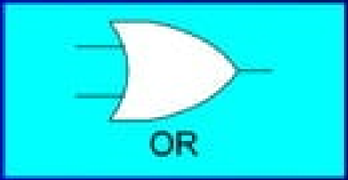


OR

- **Truth table for Boolean OR operator:**

X	Y	$X \vee Y$
F	F	F
F	T	T
T	F	T
T	T	T

Digital gate diagram for OR:



Operator Precedence

- Examples showing the order of operations:

Expression	Order of Operations
$\neg X \vee Y$	NOT, then OR
$\neg(X \vee Y)$	OR, then NOT
$X \vee (Y \wedge Z)$	AND, then OR

Truth Tables (1 of 3)

- A Boolean function has one or more Boolean inputs, and returns a single Boolean output.
- A truth table shows all the inputs and outputs of a Boolean function

Example: $\neg X \vee Y$

X	$\neg$X	Y	$\neg X \vee Y$
F	T	F	T
F	T	T	T
T	F	F	F
T	F	T	T

Truth Tables (2 of 3)

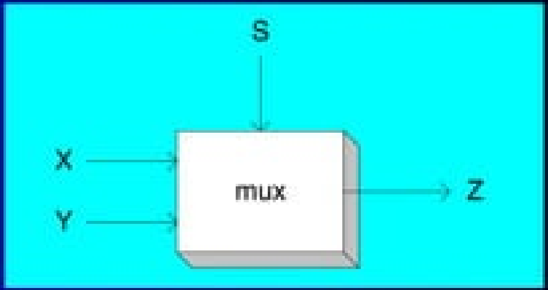
- Example: $X \wedge \neg Y$

X	Y	$\neg$Y	$X \wedge \neg Y$
F	F	T	F
F	T	F	F
T	F	T	T
T	T	F	F

Truth Tables (3 of 3)

- Example: $(Y \wedge S) \vee (X \wedge \neg S)$

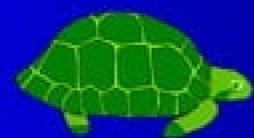
X	Y	S	$Y \wedge S$	$\neg S$	$X \wedge \neg S$	$(Y \wedge S) \vee (X \wedge \neg S)$
F	F	F	F	T	F	F
F	T	F	F	T	F	F
T	F	F	F	T	T	T
T	T	F	F	T	T	T
F	F	T	F	F	F	F
F	T	T	T	F	F	T
T	F	T	F	F	F	F
T	T	T	T	F	F	T



Two-input multiplexer

Summary

- Assembly language helps you learn how software is constructed at the lowest levels
- Assembly language has a one-to-one relationship with machine language
- Each layer in a computer's architecture is an abstraction of a machine
  - layers can be hardware or software
- Boolean expressions are essential to the design of computer hardware and software



54 68 65 20 45 6E 64

What do these numbers represent?

END of chapter 1