Introduction

About me

- Course Instructors
  - Mr. Abdul Qadeer Bilal
  - Ms. Ayesha Inam

Teacher Info.

- Name: Abdul Qadeer Bilal
- E-mail: a.qadeer@nu.edu.pk
- Office #: 2nd Floor. #213
- Visiting Hours: (Please Follow it Strictly)

Day	Time
Monday	10:30 AM to 12:00 PM
Tuesday	01:30 PM to 03:00 PM
Thursday	10:30 AM to 12:00 PM

Course Info.

- Code: EE-213
- Credit Hours: 3+1
- Two lectures per week each of duration 1.5 hour
- Lab class each week

Text Books

- Text Books
  - Assembly Language for x86 Processors
    - by Kip R. Irvine
    - 6th Edition

Grading Policy

Class	
Assignments	5%
Quizzes	15%
Midterm Exams	(15+15)%
Class Participation	5%
Final Exam	45%
Total	100%

Grading Policy

- All deadlines will be hard
- Re-grading can be requested after grade reporting, within following time limits:
  - Midterm: Same day
  - Assignments: 2 working days
  - Quizzes: 2 working days
  - Everything will be final on 3rd day

General Guidelines

- Start work on project/assignment right from the first day
- No assignment will be accepted after due date
- Assignments copied from others will be marked zero
- No excuse will be accepted for a missed assignment or quiz
- Unannounced quizzes, so come prepared in the class

Lecture 01

Week 01

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

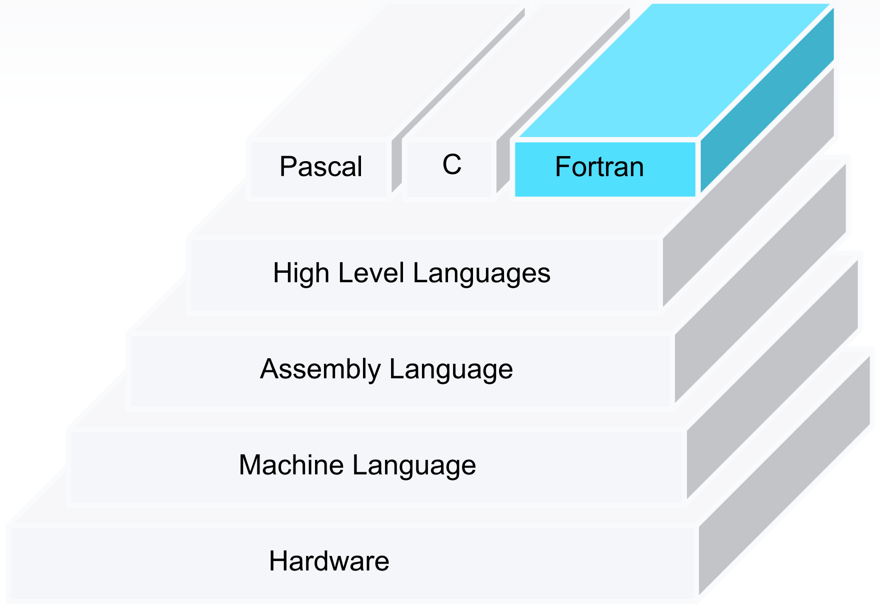
- Why am I learning Assembly Language?
- What background should I have?
- What is an assembler?
- What hardware/software do I need?
- What types of programs will I create?
- What do I get with this book?
- What will I learn?

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?

Hierarchy of Computer Languages



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

High Level Language

- Called High Level because closer to human language and farther from machine language
- Independent of a particular type of processor
- Easier to read, write and understand because uses natural language elements
- Hides implementation details
- Must be translated to machine language

Assembly Language

- Low level programming language
- Used to interact with computer hardware
- Specific to a particular computer architecture
- The instructions in assembly language may directly match the computer's architecture or they may be translated during execution by a program inside the processor known as a *microcode interpreter*
- Focuses on programming microprocessors
- Used to program
  - Embedded system
  - Device driver programming
  - Computer viruses and bootloaders

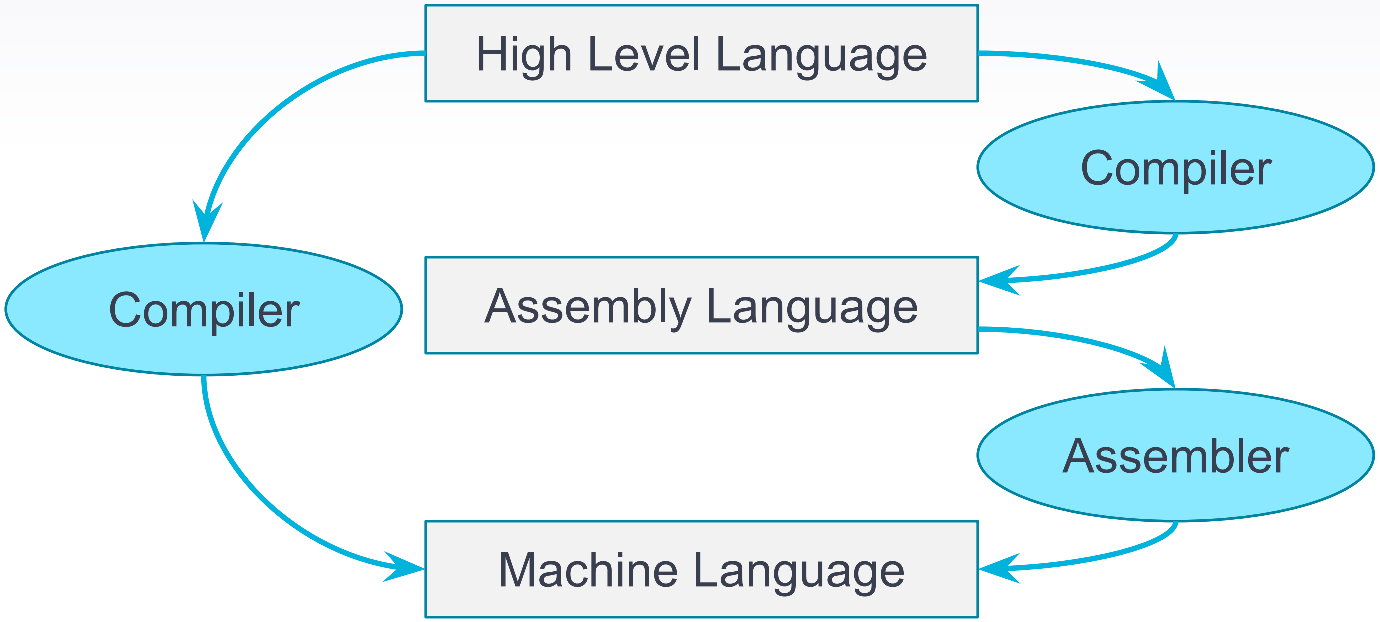
Machine Language

- Lowest level programming language
- Sequence of 1s and 0s
- Easily understood by computers
- Almost impossible for humans to use
- Each CPU has its own unique machine language

Conversion from High Level (HL) to Low Level (LL) Language

- From Assembly to Machine Language
  - Assembler is used
- From High Level to Machine Level Language
  - Compiler converts High Level Language to Object Code
  - Assembler is used to convert Assembly Language code to Machine Code

Compiler and Assembler



Assembly Language Portability

- Can be compiled and run on a wide variety of computers
- Assembly is designed for a specific processor family
- Motorola 68x00, x86, SUN Sparc, Vax, IBM-370 are different processor architectures

Conversion from HL to LL Language

Natural Language: Add 5 into 3 and store the result into X

High Level Language: int X = 5 + 3;

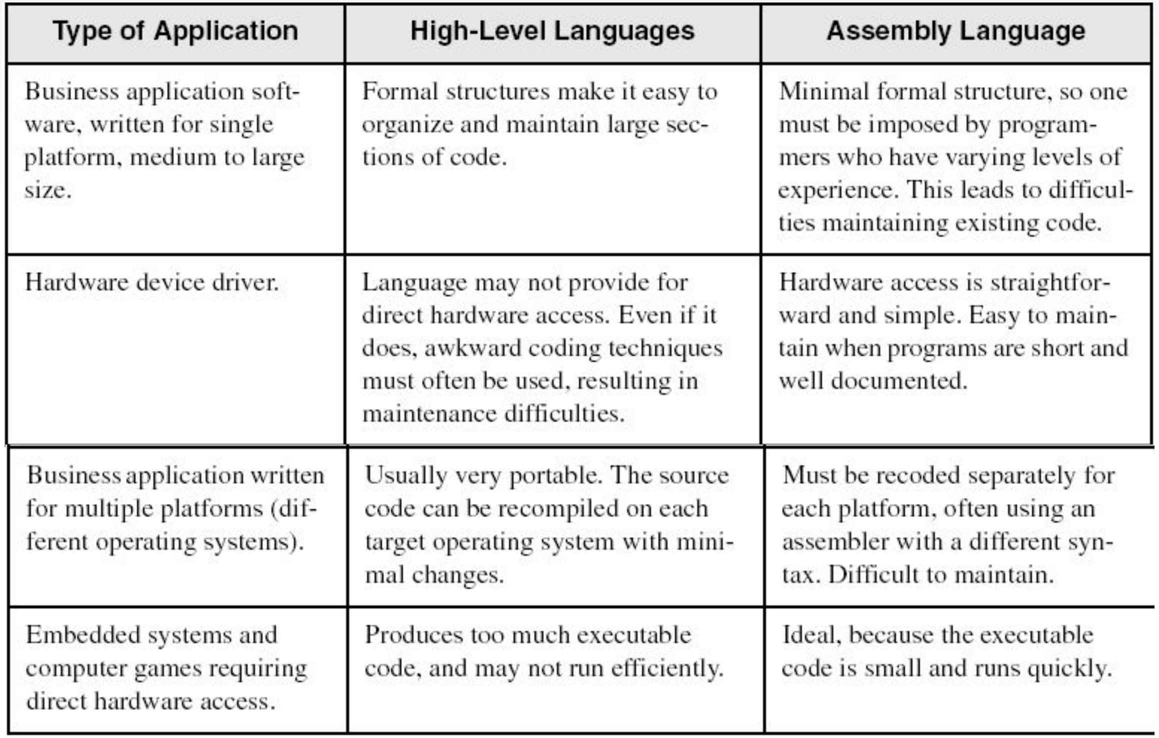
Assembly Language:

```
mov ax, 5
mov bx, 3
add ax, bx
mov X, ax
```

Advantages of HL Languages

- Program development is faster
  - High level statements: fewer instructions to code
- Program maintenance is easier
  - For the same above reasons
- Programs are portable
  - Contains less machine dependent details
    - Can be used with little or no modifications on different machines
  - Compiler translates to the target machine language

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.

What's Next

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

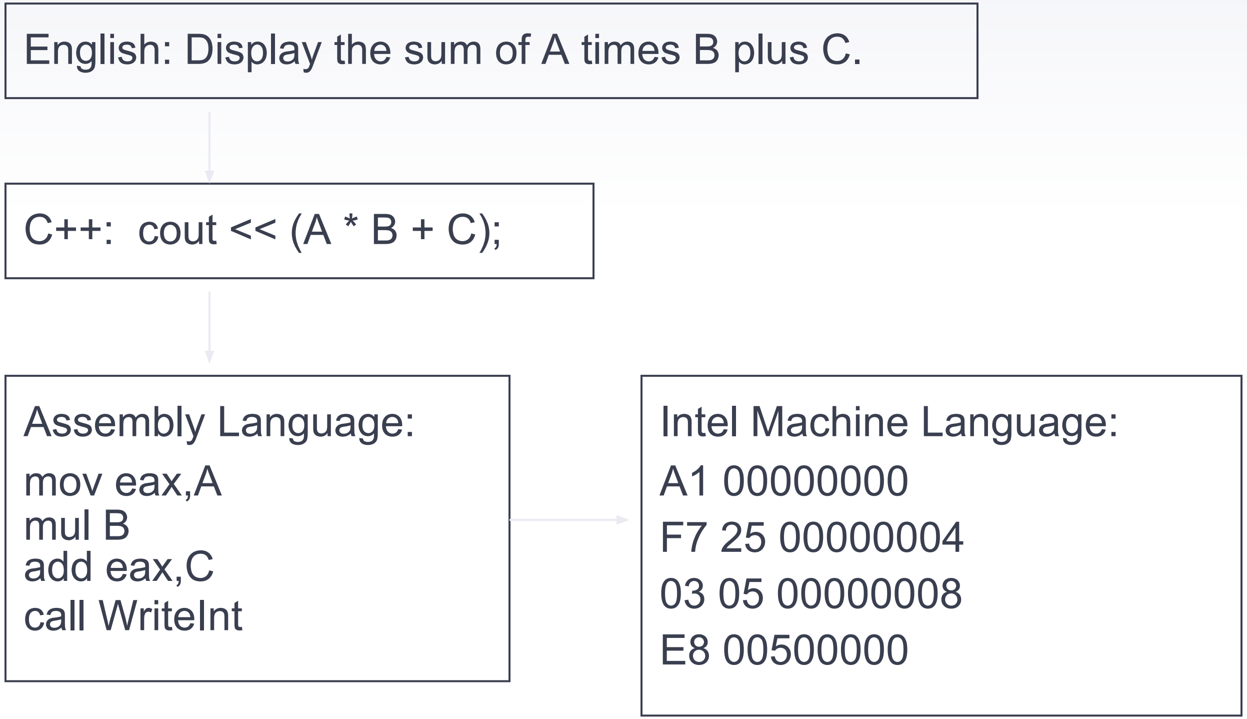
Virtual Machine Concept

- 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);
```

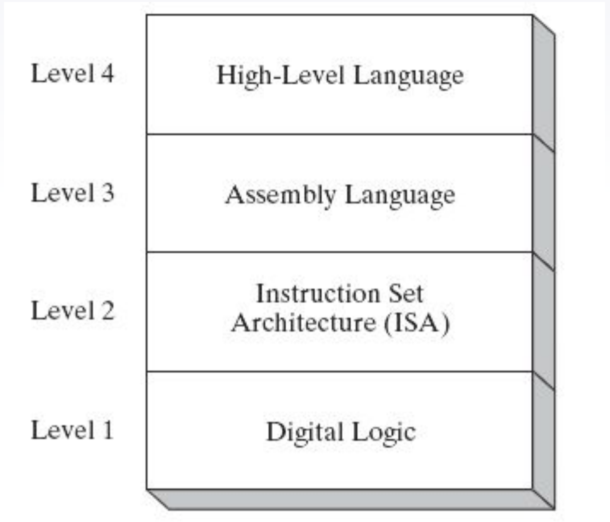
Assembly Language:

```
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

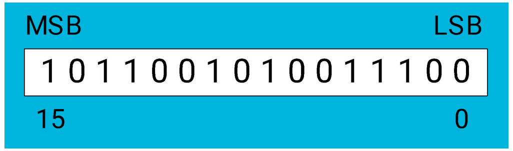
Data Representation

- Four basic data representation techniques
  - Binary (base 2)
  - Octal (base 8)
  - Decimal (base 10)
  - Hexadecimal (base 16)

System	Base	Possible Digits
Binary	2	0 1
Octal	8	0 1 2 3 4 5 6 7
Decimal	10	0 1 2 3 4 5 6 7 8 9
Hexadecimal	16	0 1 2 3 4 5 6 7 8 9 A B C D E F

Binary Numbers

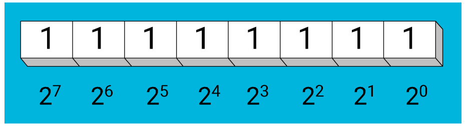
- Digits are 1 and 0
  - 1 = true
  - 0 = false
- MSB – most significant bit
- LSB – least significant bit
- Bit numbering:



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



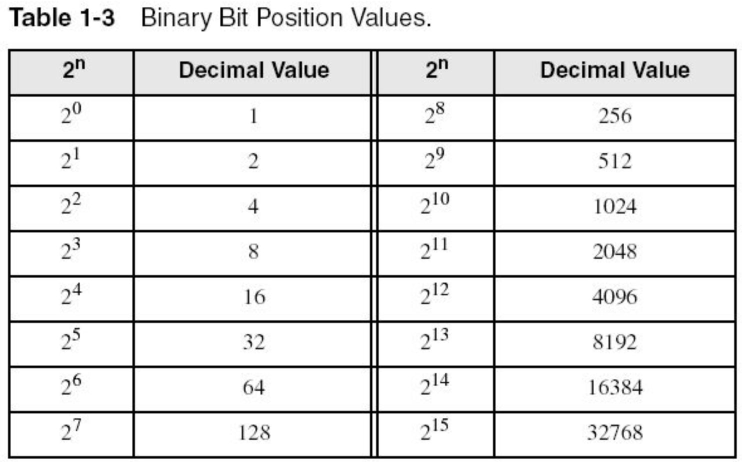


Table 1-3 Binary Bit Position Values.

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:

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

D = binary digit

binary 00001001 = decimal 9:

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

Binary to Decimal (1/2)

$$\text{Dec} = (D_{n-1} \times 2^{n-1}) + (D_{n-2} \times 2^{n-2}) + \ldots + (D_1 \times 2^1) + (D_0 \times 2^0)$$

- Weighted Positional Notation method
  - D = binary digit
  - n = bit position number in binary number

Binary to Decimal (2/2)

$0\,1\,1\,1_2 \Rightarrow$ 4-bit number so $n = 4$

$D_0 = 1$

$D_1 = 1$

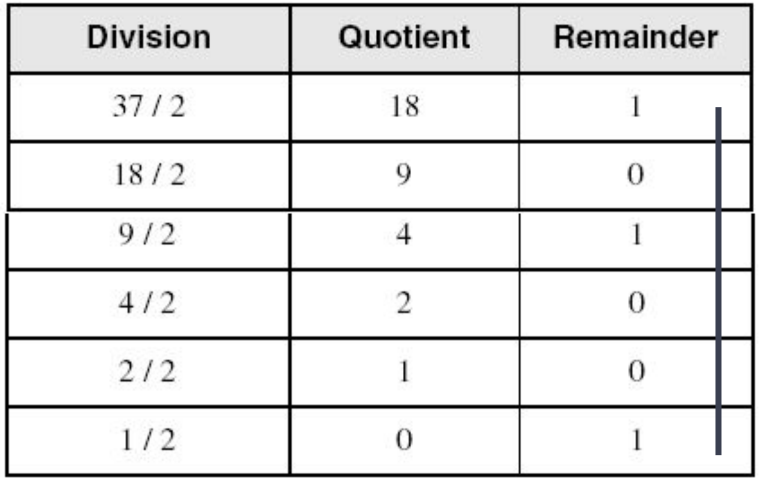
$D_2 = 1$

$D_3 = 0$

$$\begin{aligned}
\text{Dec} &= (D_{n-1} \times 2^{n-1}) + (D_{n-2} \times 2^{n-2}) + \ldots + (D_1 \times 2^1) + (D_0 \times 2^0) \\
&= (D_{4-1} \times 2^{4-1}) + (D_{4-2} \times 2^{4-2}) + \ldots + (D_1 \times 2^1) + (D_0 \times 2^0) \\
&= (D_3 \times 2^3) + (D_2 \times 2^2) + \ldots + (D_1 \times 2^1) + (D_0 \times 2^0) \\
&= (0 \times 2^3) + (1 \times 2^2) + (1 \times 2^1) + (1 \times 2^0) \\
&= 7
\end{aligned}$$

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

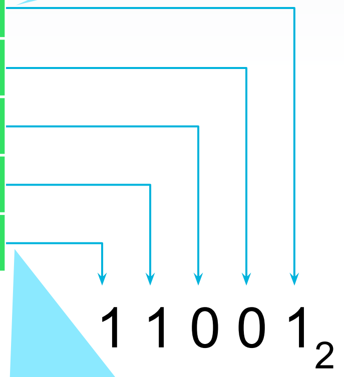
37 = 100101

Decimal to Binary (2/2)

- Convert 25_{10} into binary

Division	Quotient	Remainder
25 / 2	12	1
12 / 2	6	0
6 / 2	3	0
3 / 2	1	1
1 / 2	0	1

First remainder goes to LSB position

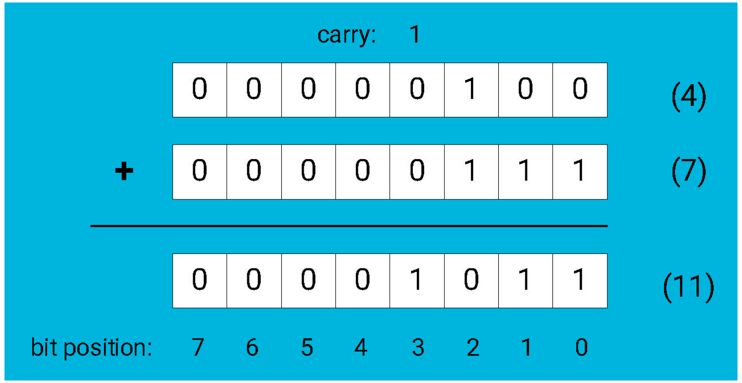


- Final result is **0001 1001**

When quotient is 0, remainder goes at MSB position

Binary Addition

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



Integer Storage Sizes

Standard sizes:

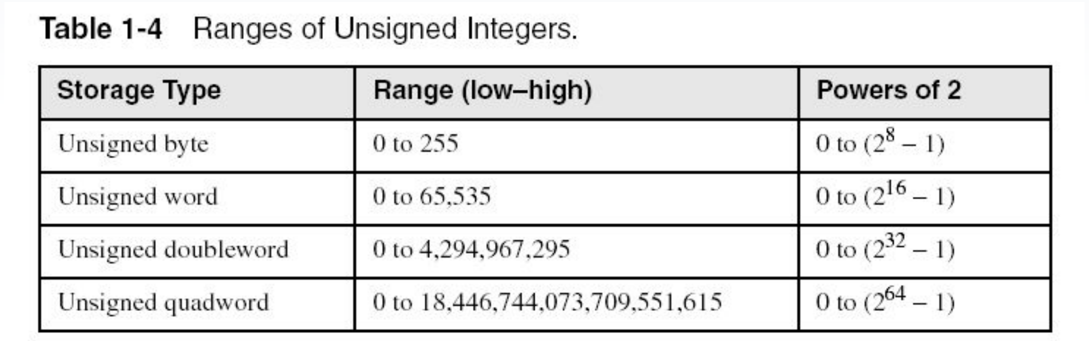
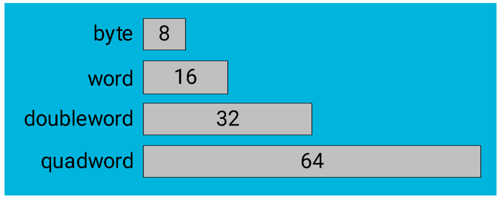


Table 1-4 Ranges of Unsigned Integers.

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.

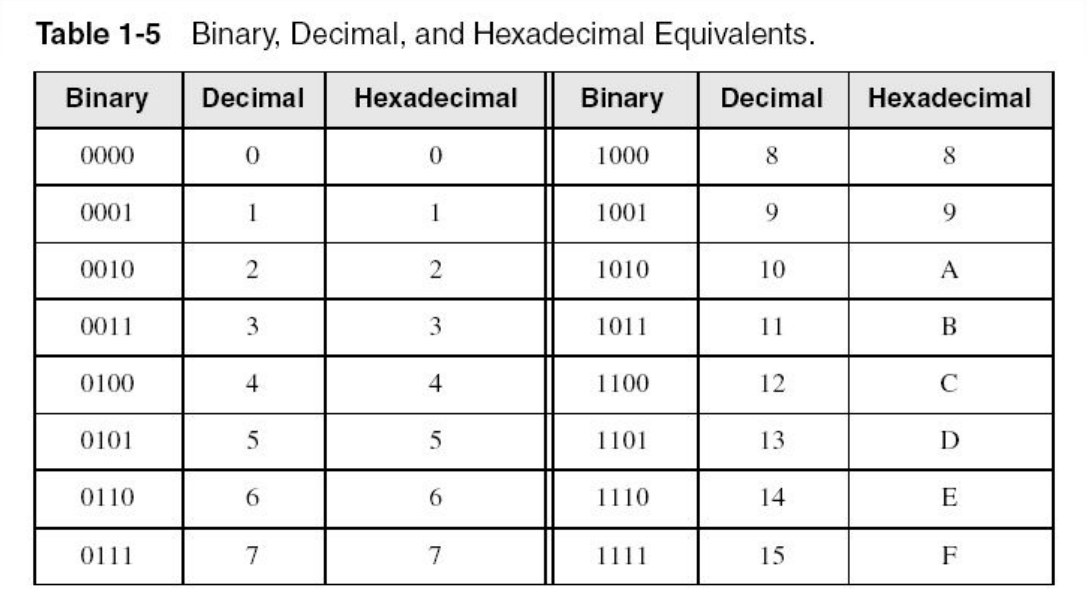
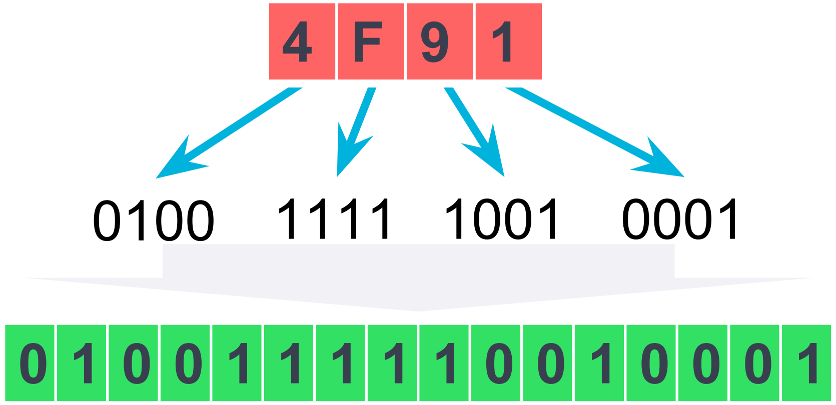


Table 1-5 Binary, Decimal, and Hexadecimal Equivalents.

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

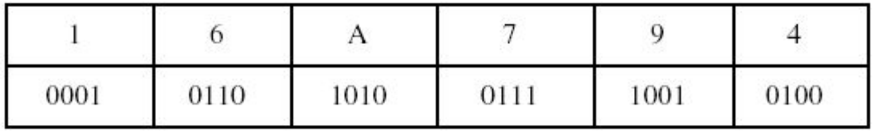
Hexadecimal to Binary

- Each hexadecimal integer corresponds to 4 binary bits
- Convert each hexadecimal number to corresponding binary number



Translating Binary to Hexadecimal

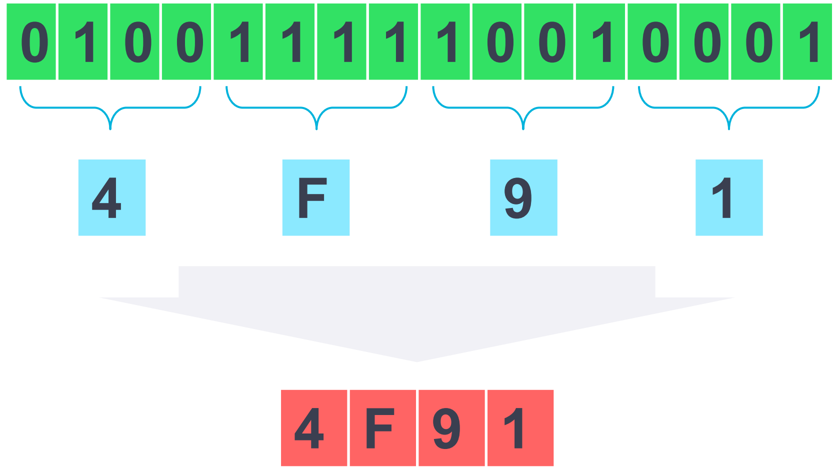
- Each hexadecimal digit corresponds to 4 binary bits.
- Example: Translate the binary integer 000101101010011110010100 to hexadecimal:



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

Binary to Hexadecimal

- Convert each 4 bits of binary into its corresponding hexadecimal



Lecture 02

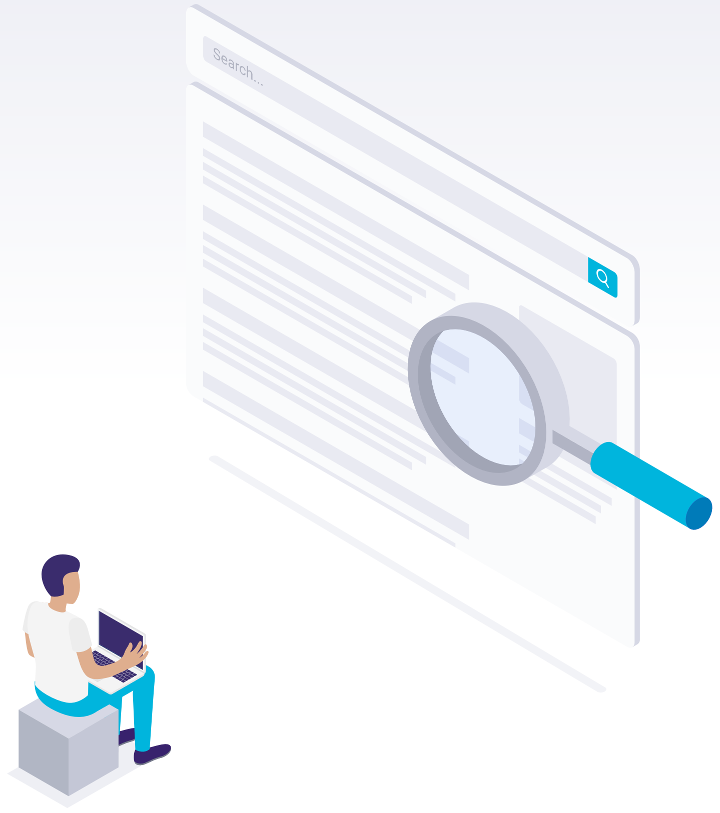
Week 01

THANKS!

Any questions?

You can find me at:

- A.qadeer@nu.edu.pk
- Office #213, Visiting Hours Only



Converting Hexadecimal to Decimal

- Multiply each digit by its corresponding power of 16:

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

- 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.

Hexadecimal to Decimal (2/2)

3 B A 4 ➡ 4-digit number so $n = 4$

$D_0 = 4$

$D_1 = \text{A}$

$D_2 = \text{B}$

$D_3 = 3$

$$= (D_{4-1} \times 16^{4-1}) + (D_{4-2} \times 16^{4-2}) + (D_1 \times 16^1) + (D_0 \times 16^0)$$

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

$$= (3 \times 4096) + (11 \times 256) + (10 \times 16) + (4 \times 1)$$

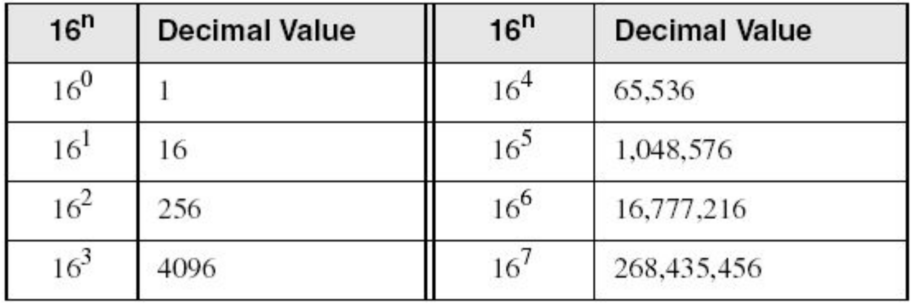
$$= (12288 + 2816 + 160 + 4) \quad = \mathbf{15268}$$

Decimal to Hexadecimal (1/2)

- Repeatedly divide the decimal integer by 16 until last quotient is 0
- Each remainder is a hex digit
- First remainder goes at least significant position and last remainder goes at most significant position

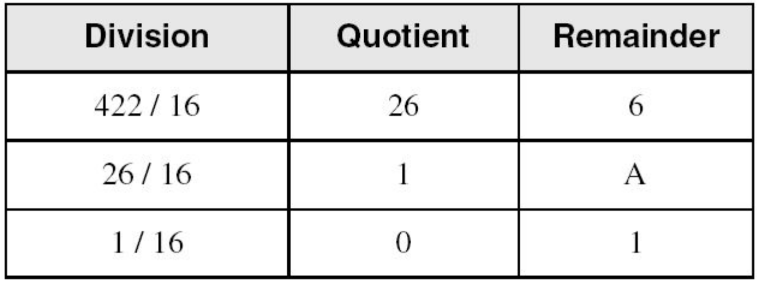
Powers of 16

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

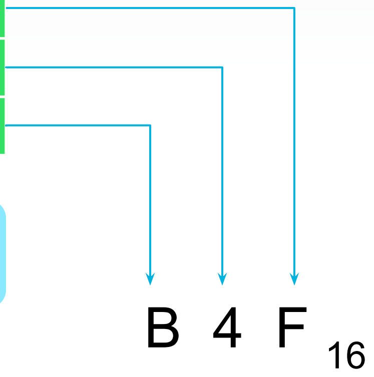
Decimal to Hexadecimal (2/2)

- Convert 2895_{10} into hexadecimal

Division	Quotient	Remainder
2895 / 16	180	F
180 / 16	11	4
11 / 16	0	B

First remainder goes to LS position

When quotient is 0, remainder goes at MS position



- So 2895_{10} = **B 4 F**$_{16}$

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:

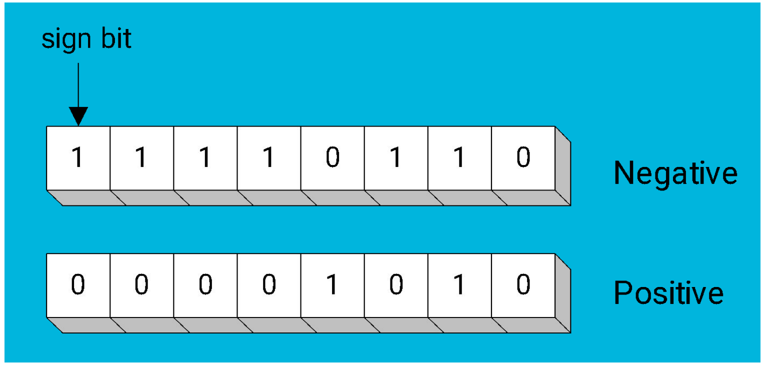
$\boxed{16 + 5 = 21}$

```
       −1
C6   75
A2   47
24   2E.
```

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



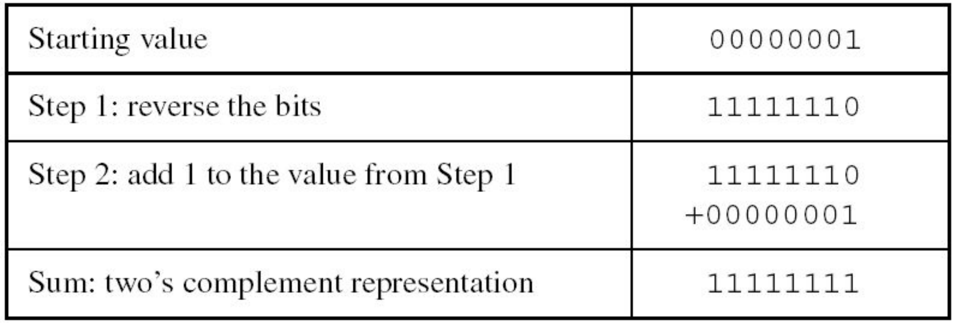
If the highest digit of a hexadecimal integer is > 7, the value is negative. Examples: 8A, C5, A2, 9D

Signed Integers

- Signed integers are either positive or negative
- Not possible to stick negative sign to a number in binary numbers
- When explicitly mentioned as signed integer, then MSB decides the +ve and –ve sign
- In signed binary/octal/hex integers
  - MSB = 1 □ integers is negative
  - MSB = 0 □ integers is positive
- Negative integers are represented using 2's complement notation

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

Range of Signed Numbers

- A certain number of bits can store only a fixed number of signed integers

Bits	Range	Total Numbers
8	-128 to +127	256
16	-32768 to +32767	65,536
32	-2,147,483,648 to +2,147,483,647	4,294,967,296
64	-9,223,372,036,854,775,808 to +9,223,372,036,854,775,807	18,446,744,073,709,551,616

Range of Unsigned Numbers

- Total numbers in signed integers is exactly equal to the total numbers in unsigned integers in the same size of bits

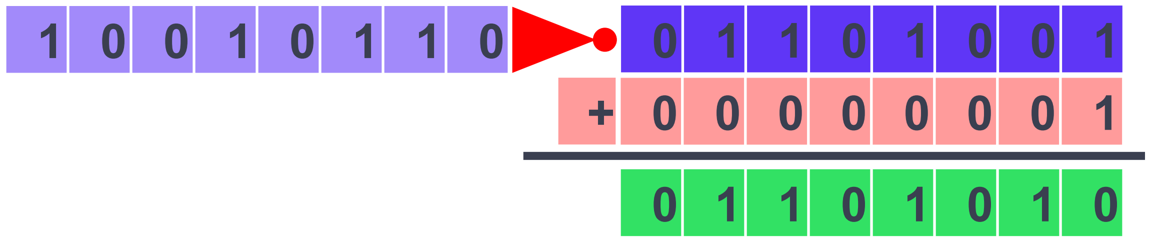
Bits	Range	Total Unsigned Numbers
8	0 to 255	256
16	0 to 65,535	65,536
32	0 to 4,294,967,295	4,294,967,296
64	0 to 18,446,744,073,709,551,615	18,446,744,073,709,551,616

2’s Complement Notation

- Useful for processors to perform subtraction with addition operation
- A fixed number of bits are used to represent the numbers
- The leftmost bit is called sign bit
- 2’s complement notation is used to represent both +ve and –ve numbers

How to calculate 2's complement

- How to get 2's complement of a binary number?
  - Take 1's complement of that number(invert all its bits)
  - Add 1 into the inverted binary number
  - ... and the result is 2's complement of that number



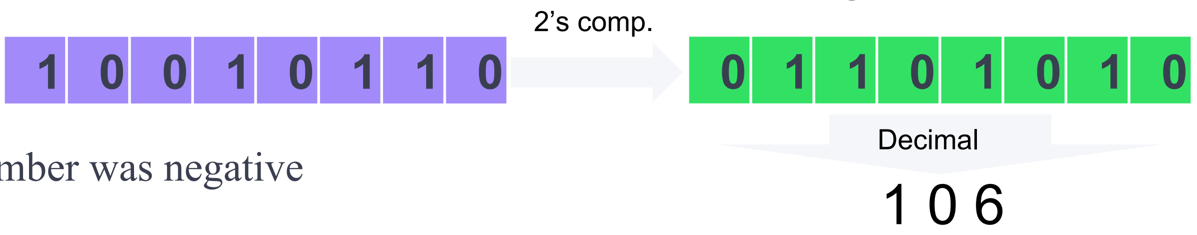
2’s Complement of Hexadecimal

- Invert all bits of hex number
- All bits of hex numbers can be inverted simply by subtracting the number from F_{16}
- Add 1 into the inverted hex number and the result is the 2’s complement
- Calculate 2’s complement of $(B\ 4\ F)_{16}$

$$\begin{array}{r} F\ F\ F \\ -\ B\ 4\ F \\ \hline 4\ B\ 0 \end{array} \Rightarrow 4\ B\ 0 \Rightarrow \begin{array}{r} 4\ B\ 0 \\ +\qquad 1 \\ \hline \mathbf{4\ B\ 1} \end{array}$$

Converting Signed Binary to Decimal

- If MSB is 0, then number is +ve and convert it into decimal in usual way
- If MSB is 1, then the number is in 2's complement notation and follow these steps
  - Calculate its 2's complement again
  - Convert this new number into decimal and add a –ve sign with it

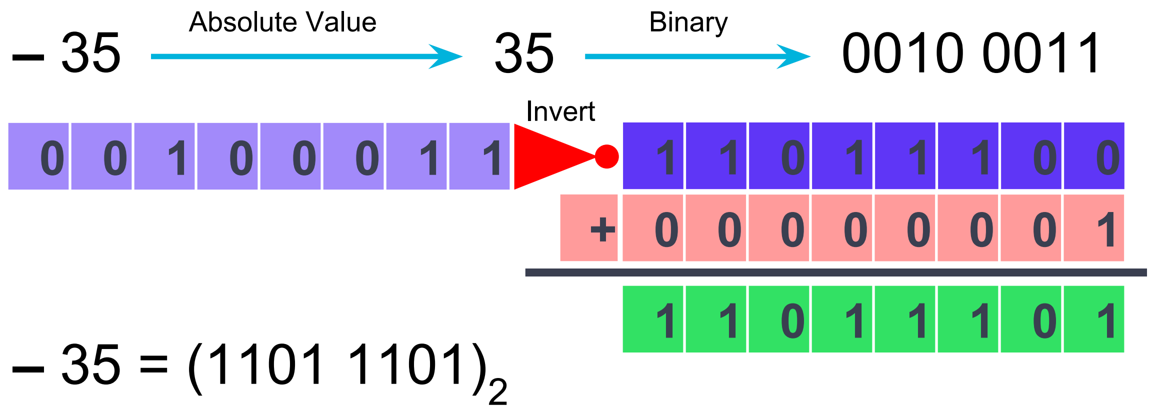


- As the number was negative
  - So in decimal it is

– 1 0 6

Converting Signed Decimal to Binary

- Convert absolute value of decimal into binary
- If original decimal number is –ve, calculate 2's complement of the binary number
- Convert -35 to binary



Convert Signed Decimal to Hexadecimal

- Convert absolute value of decimal to hex
- If decimal integer is –ve, create 2’s complement of hexadecimal integer
- Convert -2895 to hexadecimal

$$\begin{tikzcd}
-2895 \arrow[r, "\text{Absolute Value}"] & 2895 \arrow[r, "\text{Hexadecimal}"] & \text{B 4 F}
\end{tikzcd}$$

$$\begin{tikzcd}
\text{B 4 F} \arrow[r, "\text{Bit Inversion}"] & \text{4 B 0} \arrow[r, "\text{Add 1}"] & \text{4 B 1}
\end{tikzcd}$$

2’s Complement

Converting Signed Hex to Decimal (1/3)

- In signed hex number, if MSB=1, the number is –ve
- To convert it into decimal, follow these steps
  - Create its 2's complement
  - Convert the 2's complemented hex to decimal
  - Attach –ve sign to the decimal number

Converting Signed Hex to Decimal (2/3)

- Determine if Signed $8C_{16}$ is +ve or –ve
- By converting into binary
  - If MSB = 1, then number is –ve
  - $8C_{16} = (1000\ 1100)_2$
  - Since MSB = 1, so $8C_{16}$ is –ve
- Another method
  - If leftmost digit > 7, then number is –ve
  - Since leftmost digit i.e. 8 > 7

Converting Signed Hex to Decimal (3/3)

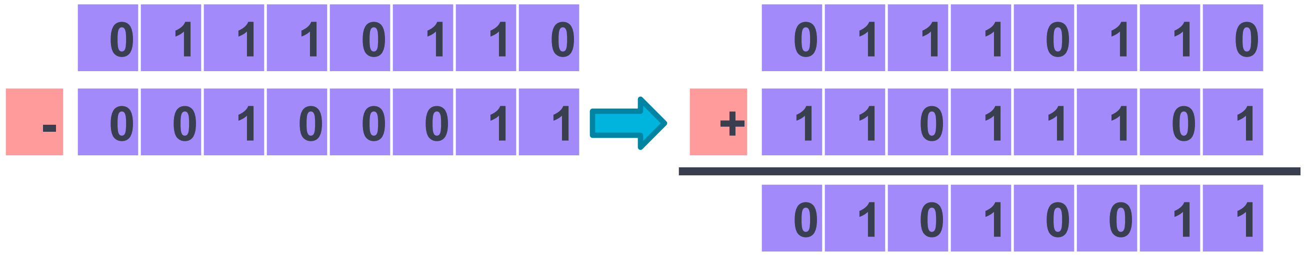
- Convert Signed $A3_{16}$ into decimal

$$\begin{tikzcd}\boxed{A\ 3} \arrow[d] \\ A > 7 \Rightarrow A3 \text{ is } -ve\end{tikzcd}$$

2's complement of A3 = 5D

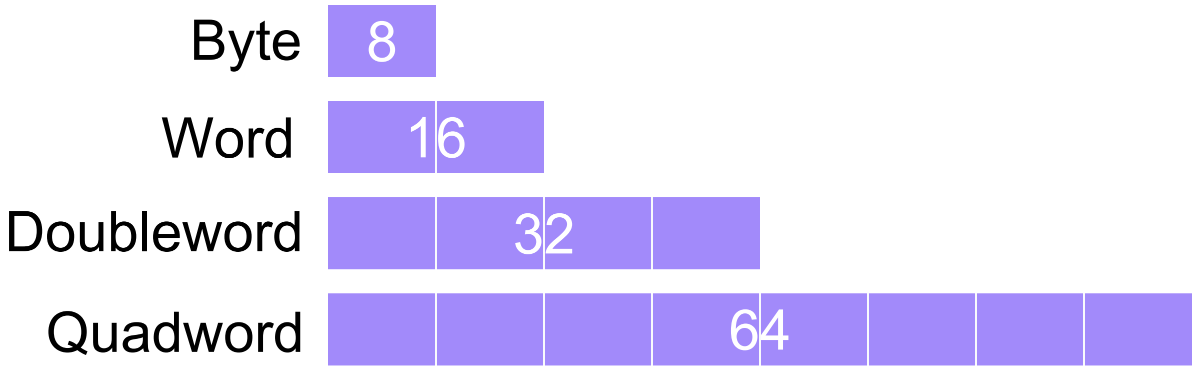
Binary Subtraction

- Big advantage of signed number is to use same circuit for addition and subtraction
- To perform A – B
  - Calculate –B by taking 2’s complement of B
  - Perform A+(-B)



Integer Storage System (1/2)

- Byte is the basic storage unit in x86 architecture
- Byte is composed of 8 bits



Integer Storage System

- Some larger measurements units
  - One kilobyte = 2^{10} bytes = 1024 bytes
  - One megabyte = 2^{20} bytes = 1,048,576 bytes
  - One gigabyte = 2^{30} bytes = 1,073,741,824 bytes
  - One terabyte = 2^{40} bytes = 1,099,511,627,776 bytes
  - One petabyte = 2^{50} bytes = 2^{40} kilobytes
  - One exabyte = 2^{60} bytes = 2^{10} petabytes
  - One zettabyte = 2^{70} bytes = 2^{30} terabytes
  - One yottabyte = 2^{80} bytes = 2^{20} exabytes

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

What's Next

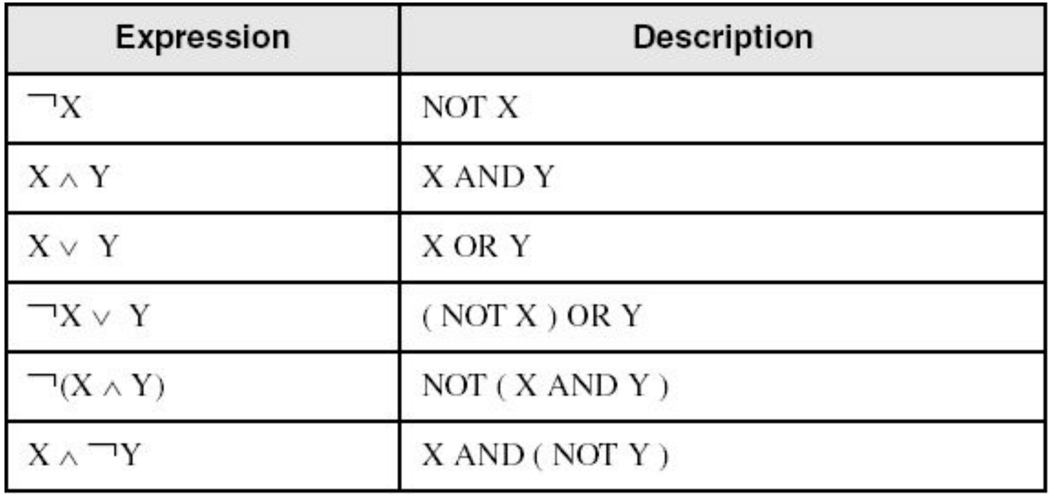
- Welcome to Assembly Language
- Virtual Machine Concept
- Data Representation
- Boolean Operations

Boolean Operations

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

Boolean Algebra

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



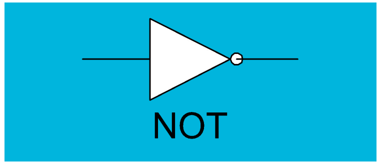
Expression	Description
$\neg X$	NOT X
$X \wedge Y$	X AND Y
$X \vee Y$	X OR Y
$\neg X \vee Y$	(NOT X) OR Y
$\neg(X \wedge Y)$	NOT (X AND Y)
$X \wedge \neg Y$	X AND (NOT Y)

NOT

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

X	¬X
F	T
T	F

Digital gate diagram for NOT:

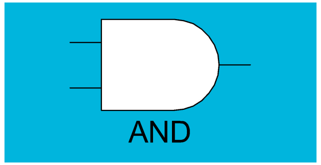


AND

- Truth table for Boolean AND operator:

X	Y	X ∧ Y
F	F	F
F	T	F
T	F	F
T	T	T

Digital gate diagram for AND:

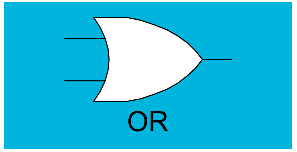


OR

- Truth table for Boolean OR operator:

X	Y	X ∨ Y
F	F	F
F	T	T
T	F	T
T	T	T

Digital gate diagram for OR:



Operator Precedence

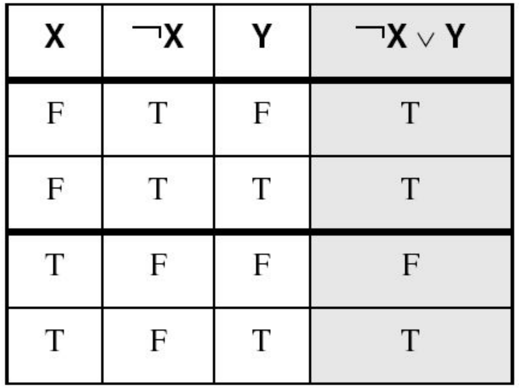
- Examples showing the order of operations:

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

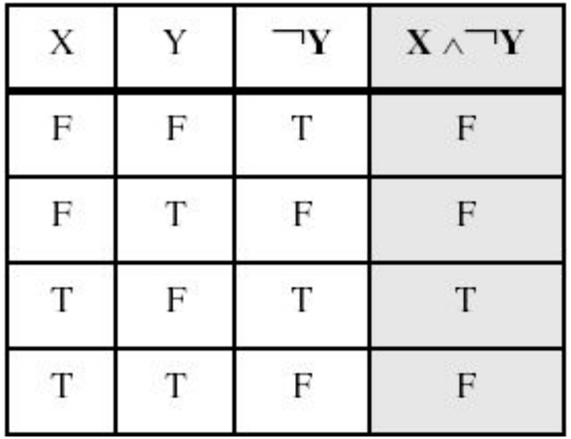
Example: ¬X ∨ Y



X	¬X	Y	¬X ∨ Y
F	T	F	T
F	T	T	T
T	F	F	F
T	F	T	T

Truth Tables (2 of 3)

- Example: $X \wedge \neg Y$

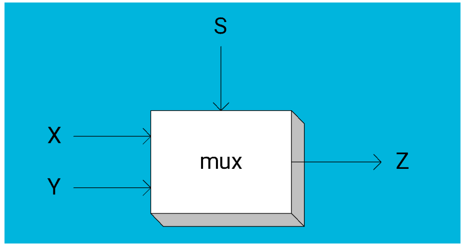


X	Y	$\neg Y$	$X \wedge \neg Y$
F	F	T	F
F	T	F	F
T	F	T	T
T	T	F	F

Truth Tables (3 of 3)

- Example: (Y ∧ S) ∨ (X ∧ ¬S)

X	Y	S	**Y ∧ S**	**¬S**	**X ∧ ¬S**	**(Y ∧ S) ∨ (X ∧ ¬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

THANKS!

Any questions?

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