1.0 Introduction to Computer Organization

Computer architecture is the conceptual design and fundamental operational structure of a computer system. It is a blueprint and functional description of requirements and design implementations for the various parts of a computer, focusing largely on the way by which the central processing unit (CPU) performs internally and accesses addresses in memory. It may also be defined as the science and art of selecting and interconnecting hardware components to create computers that meet functional, performance and cost goals.

Computer architecture can be classified into three main categories:

Instruction Set Architecture, or ISA, is the image of a computing system that is seen by a machine language programmer. It includes the instruction set, word size, memory address modes, processor registers, and address and data formats.

Computer Organization is a lower level and detailed description of the system that involves how the different parts of the system are interconnected and how they interoperate in order to implement the ISA.

System Design which includes all of the other hardware components within a computing system such as:

- Computer buses and switches
- Memory controllers
- Direct Memory Access (DMA)
- Issues like multi-processing

Overview

In the modern world of electronics, the term Digital is generally associated with a computer because the term Digital is derived from the way computers perform operations, by counting digits. For many years, the application of digital electronics was only in the computer system. But now-a-days, digital electronics is used in many other applications. Following are some of the examples in which Digital electronics is heavily used.

- Industrial process control
- Military system
- Television
- Communication system
- Medical equipment
- Radar
- Navigation

Signal

Signal can be defined as a physical quantity, which contains some information. It is a function of one or more than one independent variables. Signals are of two types.

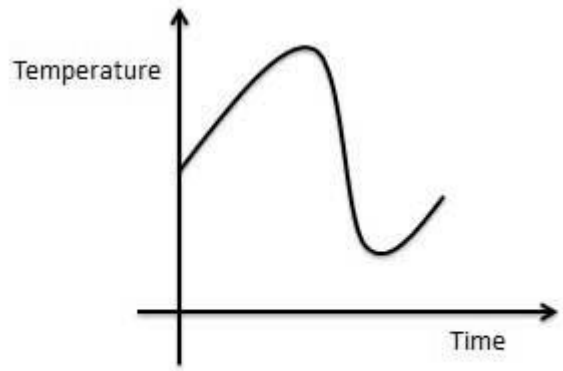
- Analog Signal
- Digital Signal

Analog Signal

An analog signal is defined as the signal having continuous values. Analog signal can have infinite number of different values. In real world scenario, most of the things observed in nature are analog. Examples of the analog signals are following.

- Temperature
- Pressure
- Distance
- Sound
- Voltage
- Current
- Power

Graphical Representation of Analog Signal (Temperature)



Analog Signal

The circuits that process the analog signals are called as analog circuits or system. Examples of the analog system are following.

- Filter
- Amplifiers
- Television receiver
- Motor speed controller

Disadvantage of Analog Systems

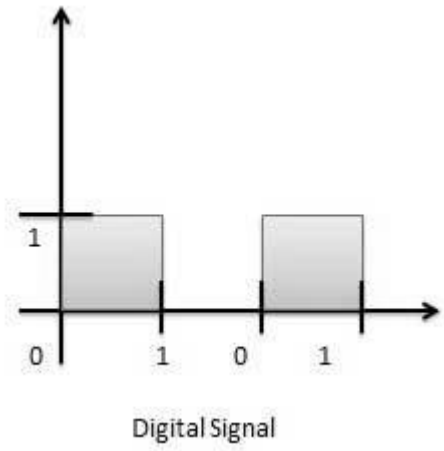
- Less accuracy
- Less versatility
- More noise effect
- More distortion
- More effect of weather

Digital Signal

A digital signal is defined as the signal which has only a finite number of distinct values. Digital signals are not continuous signals. In the digital electronic calculator, the input is given with the help of switches. This input is converted into electrical signal which have two discrete values or levels. One of these may be called low level and another is called high level. The signal will always be one of the two levels. This type of signal is called digital signal. Examples of the digital signal are following.

- Binary Signal
- Octal Signal
- Hexadecimal Signal

Graphical Representation of Digital Signal (Binary)



Digital Signal

The circuits that process the digital signals are called digital systems or digital circuits. Examples of the digital systems are following.

- Registers
- Flip-flop
- Counters
- Microprocessors

Advantage of Digital Systems

- More accuracy
- More versatility
- Less distortion
- Easy communicate
- Possible storage of information

Comparison of Analog and Digital Signal

S.N.	Analog Signal	Digital Signal
1	Analog signal has infinite values.	Digital signal has a finite number of values.
2	Analog signal has a continuous nature.	Digital signal has a discrete nature.
3	Analog signal is generated by transducers and signal generators.	Digital signal is generated by A to D converter.
4	Example of analog signal: sine wave, triangular waves.	Example of digital signal: Binary signal.

2.0 DIGITAL NUMBER SYSTEMS

A digital system can understand positional number system only where there are a few symbols called digits and these symbols represent different values depending on the position they occupy in the number.

A value of each digit in a number can be determined using

- The digit
- The position of the digit in the number
- The base of the number system (where base is defined as the total number of digits available in the number system).

Decimal Number System

The number system that we use in our day-to-day life is the decimal number system. Decimal number system has base 10 as it uses 10 digits from 0 to 9. In decimal number system, the successive positions to the left of the decimal point represents units, tens, hundreds, thousands and so on.

Each position represents a specific power of the base (10). For example, the decimal number 1234 consists of the digit 4 in the units position, 3 in the tens position, 2 in the hundreds position, and 1 in the thousands position, and its value can be written as

$(1x1000)+ (2x100)+ (3x10)+ (4xl)$ $(1x10^3)+ (2x10^2)+ (3x10^1)+ (4xl0^0)$

1000 + 200 + 30 + 1

1234

As a computer programmer, IT professional or a mathematician, you should understand the following number systems which are frequently used in computers.

S.N.	Number System & Description
1	**Binary Number System** Base 2. Digits used: 0, 1
2	**Octal Number System** Base 8. Digits used: 0 to 7
3	**Hexa Decimal Number System** Base 16. Digits used: 0 to 9, Letters used: A- F

Binary Number System

Characteristics

- Uses two digits, 0 and 1.
- Also called base 2 number system
- Each position in a binary number represents a 0 power of the base (2).
- Example: 20
- Last position in a binary number represents an x power of the base (2).
- Example: 2x where x represents the last position - 1.

Example

Binary Number: 10101_2

Calculating Decimal Equivalent:

Step	Binary Number	Decimal Number
Step 1	10101_2	$((1 \times 24) + (0 \times 23) + (1 \times 22) + (0 \times 21) + (1 \times 20))_{10}$
Step 2	10101_2	$(16 + 0 + 4 + 0 + 1)_{10}$
Step 3	10101_2	21_{10}

Note: 10101_2 is normally written as 10101.

Octal Number System

Characteristics

- Uses eight digits, 0,1,2,3,4,5,6,7.
- Also called base 8 number system
- Each position in an octal number represents a 0 power of the base (8).
  Example: 80
- Last position in an octal number represents an x power of the base (8).

Example: 8x where x represents the last position - 1.

Example

Octal Number: 12570_8

Calculating Decimal Equivalent:

Step	Octal Number	Decimal Number
Step 1	12570_8	$((1 \times 8^4) + (2 \times 8^3) + (5 \times 8^2) + (7 \times 8^1) + (0 \times 8^0))_{10}$
Step 2	12570_8	$(4096 + 1024 + 320 + 56 + 0)_{10}$
Step 3	12570_8	5496_{10}

Note: 12570_8 is normally written as 12570.

Hexadecimal Number System

Characteristics

- Uses 10 digits and 6 letters, 0,1,2,3,4,5,6,7,8,9,A,B,C,D,E,F.
- Letters represents numbers starting from 10. A = 10, B = 11, C = 12, D = 13, E = 14, F = 15.
- Also called base 16 number system.
- Each position in a hexadecimal number represents a 0 power of the base (16). Example 160.
- Last position in a hexadecimal number represents an x power of the base (16).

Example: 16x where x represents the last position - 1.

Example:

Hexadecimal Number: 19FDE16
Calculating Decimal Equivalent:

Step	Hexadecimal Number	Decimal Number
Step 1	$19FDE_{16}$	$((1 \times 16^4) + (9 \times 16^3) + (F \times 16^2) + (D \times 16^1) + (E \times 16^0))_{10}$
Step 2	$19FDE_{16}$	$((1 \times 16^4) + (9 \times 16^3) + (15 \times 16^2) + (13 \times 16^1) + (14 \times 16^0))_{10}$
Step 3	$19FDE_{16}$	$(65536+ 36864 + 3840 + 208 + 14)_{10}$
Step 4	$19FDE_{16}$	106462_{10}

Note: 19FDE16 is normally written as 19FDE.

3.0 NUMBER SYSTEM CONVERSION

There are many methods or techniques which can be used to convert numbers from one base to another. We'll demonstrate here the following:

- Decimal to Other Base System
- Other Base System to Decimal
- Other Base System to Non-Decimal
- Shortcut method - Binary to Octal
- Shortcut method - Octal to Binary
- Shortcut method - Binary to Hexadecimal
- Shortcut method - Hexadecimal to Binary

Decimal to Other Base System

Steps

Step 1 - Divide the decimal number to be converted by the value of the new base.

Step 2 - Get the remainder from Step 1 as the rightmost digit (least significant digit) of new base number.

Step 3 - Divide the quotient of the previous divide by the new base.

Step 4 - Record the remainder from Step 3 as the next digit (to the left) of the new base number.

Repeat Steps 3 and 4, getting remainders from right to left, until the quotient becomes zero in Step 3.

The last remainder thus obtained will be the Most Significant Digit (MSD) of the new base number.

Example:

Decimal Number: 29_{10}

Calculating Binary Equivalent:

Step	Operation	Result	Remainder
Step 1	29 / 2	14	1
Step 2	14 / 2	7	0
Step 3	7 / 2	3	1
Step 4	3 / 2	1	1
Step 5	1 / 2	0	1

As mentioned in Steps 2 and 4, the remainders have to be arranged in the reverse order so that the first remainder becomes the Least Significant Digit (LSD) and the last remainder becomes the Most Significant Digit (MSD).

Decimal Number: 29_{10} = Binary Number: 11101_2.

Other Base System to Decimal System

Steps

Step 1 - Determine the column (positional) value of each digit (this depends on the position of the digit and the base of the number system).

Step 2 - Multiply the obtained column values (in Step 1) by the digits in the corresponding columns.

Step 3 - Sum the products calculated in Step 2. The total is the equivalent value in decimal.

Example

Binary Number: 11101_2

Calculating Decimal Equivalent:

Step	Binary Number	Decimal Number
Step 1	11101_2	$((1 \times 24) + (1 \times 23) + (1 \times 22) + (0 \times 21) + (1 \times 20))_{10}$
Step 2	11101_2	$(16 + 8 + 4 + 0 + 1)_{10}$
Step 3	11101_2	29_{10}

Binary Number: 11101_2 = Decimal Number: 29_{10}

Other Base System to Non-Decimal System

Steps

Step 1 - Convert the original number to a decimal number (base 10).

Step 2 - Convert the decimal number so obtained to the new base number.

Example

Octal Number: 25_8

Calculating Binary Equivalent:

Step 1: Convert to Decimal

Step	Octal Number	Decimal Number
Step 1	25_8	$((2 \times 81) + (5 \times 80))_{10}$
Step 2	25_8	$(16 + 5)_{10}$

Step 3	25_8	21_{10}

Octal Number: 25_8 = Decimal Number: 21_{10}

Step 2 : Convert Decimal to Binary

Step	Operation	Result	Remainder
Step 1	21 / 2	10	1
Step 2	10 / 2	5	0
Step 3	5 / 2	2	1
Step 4	2 / 2	1	0
Step 5	1 / 2	0	1

Decimal Number: 21_{10} = Binary Number: 10101_2

Octal Number: 25_8 = Binary Number: 10101_2

Shortcut method - Binary to Octal

Steps

Step 1 - Divide the binary digits into groups of three (starting from the right).

Step 2 - Convert each group of three binary digits to one octal digit.

Example

Binary Number: 10101_2

Calculating Octal Equivalent:

Step	Binary Number	Octal Number
Step 1	10101_2	010 101
Step 2	10101_2	2_8 5_8
Step 3	10101_2	25_8

Binary Number: 10101_2 = Octal Number: 25_8

Shortcut method - Octal to Binary

Steps

Step 1 - Convert each octal digit to a 3 digit binary number (the octal digits may be treated as decimal for this conversion).

Step 2 - Combine all the resulting binary groups (of 3 digits each) into a single binary number.

Example

Octal Number: 25_8

Calculating Binary Equivalent:

Step	Octal Number	Binary Number
Step 1	25_8	210 510
Step 2	25_8	010_2 101_2
Step 3	25_8	010101_2

Octal Number: 25_8 = Binary Number: 10101_2

Shortcut method - Binary to Hexadecimal

Steps

Step 1 - Divide the binary digits into groups of four (starting from the right).

Step 2 - Convert each group of four binary digits to one hexadecimal symbol.

Example

Binary Number: 10101_2

Calculating hexadecimal Equivalent:

Step	Binary Number	Hexadecimal Number
Step 1	10101_2	0001 0101
Step 2	10101_2	1_{16} 5_{16}
Step 3	10101_2	15_{16}

Binary Number: 10101_2 = Hexadecimal Number: 15_{16}

Shortcut method - Hexadecimal to Binary

Steps

Step 1 - Convert each hexadecimal digit to a 4 digit binary number (the hexadecimal digits may be treated as decimal for this conversion).

Step 2 - Combine all the resulting binary groups (of 4 digits each) into a single binary number.

Example

Hexadecimal Number: 15_{16}

Calculating Binary Equivalent:

Step	Hexadecimal Number	Binary Number
Step 1	15_{16}	1_{16} 5_{16}
Step 2	15_{16}	0001_2 0101_2
Step 3	15_{16}	00010101_2

Hexadecimal Number: 15_{16} = Binary Number: 10101_2

4.0 BINARY CODES

In the coding, when numbers, letters or words are represented by a specific group of symbols, it is said that the number, letter or word is being encoded. The group of symbols is called as a code. The digital data is represented, stored and transmitted as group of binary bits. This group is also called as binary code. The binary code is represented by the number as well as alphanumeric letter.

Advantages of Binary Code

Following is the list of advantages that binary code offers.

- Binary codes are suitable for the computer applications.
- Binary codes are suitable for the digital communications.
- Binary codes make the analysis and designing of digital circuits if we use the binary codes.
- Since only 0 & 1 are being used, implementation becomes easy.

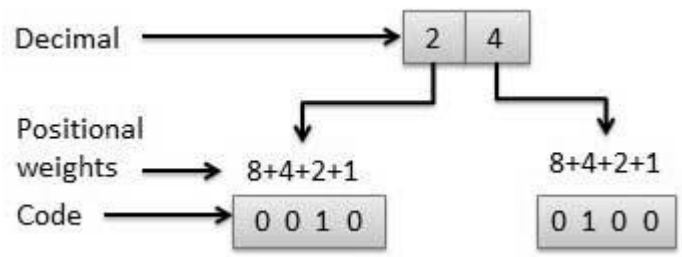
Classification of binary codes

The codes are broadly categorized into following four categories.

- Weighted Codes
- Non-Weighted Codes
- Binary Coded Decimal Code
- Alphanumeric Codes
- Error Detecting Codes
- Error Correcting Codes

Weighted Codes

Weighted binary codes are those binary codes which obey the positional weight principle. Each position of the number represents a specific weight. Several systems of the codes are used to express the decimal digits 0 through 9. In these codes each decimal digit is represented by a group of four bits.

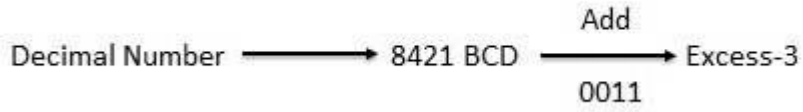


Non-Weighted Codes

In this type of binary codes, the positional weights are not assigned. The examples of non-weighted codes are Excess-3 code and Gray code.

Excess-3 code

The Excess-3 code is also called as XS-3 code. It is non-weighted code used to express decimal numbers. The Excess-3 code words are derived from the 8421
BCD code words adding $(0011)_2$ or $(3)_{10}$ to each code word in 8421. The excess-3 codes are obtained as follows:



Example

Decimal	BCD 8 4 2 1	Excess-3 BCD + 0011
0	0 0 0 0	0 0 1 1
1	0 0 0 1	0 1 0 0
2	0 0 1 0	0 1 0 1
3	0 0 1 1	0 1 1 0
4	0 1 0 0	0 1 1 1
5	0 1 0 1	1 0 0 0
6	0 1 1 0	1 0 0 1
7	0 1 1 1	1 0 1 0
8	1 0 0 0	1 0 1 1
9	1 0 0 1	1 1 0 0

Gray Code

It is the non-weighted code and it is not arithmetic codes. That means there are no specific weights assigned to the bit position. It has a very special feature that, only one bit will change each time the decimal number is incremented as shown in fig. As only one bit changes at a time, the gray code is called as a unit

distance code. The gray code is a cyclic code. Gray code cannot be used for arithmetic operation.

Decimal	BCD	Gray
0	0 0 0 0	0 0 0 0
1	0 0 0 1	0 0 0 1
2	0 0 1 0	0 0 1 1
3	0 0 1 1	0 0 1 0
4	0 1 0 0	0 1 1 0
5	0 1 0 1	0 1 1 1
6	0 1 1 0	0 1 0 1
7	0 1 1 1	0 1 0 0
8	1 0 0 0	1 1 0 0
9	1 0 0 1	1 1 0 1

Application of Gray code

- Gray code is popularly used in the shaft position encoders.
- A shaft position encoder produces a code word which represents the angular position of the shaft.

Binary Coded Decimal (BCD) code

In this code each decimal digit is represented by a 4-bit binary number. BCD is a way to express each of the decimal digits with a binary code. In the BCD, with four bits we can represent sixteen numbers (0000 to 1111). But in BCD code only first ten of these are used (0000 to 1001). The remaining six code combinations i.e. 1010 to 1111 are invalid in BCD.

Decimal	0	1	2	3	4	5	6	7	8	9
BCD	0000	0001	0010	0011	0100	0101	0110	0111	1000	1001

Advantages of BCD Codes

- It is very similar to decimal system.
- We need to remember binary equivalent of decimal numbers 0 to 9 only.

Disadvantages of BCD Codes

- The addition and subtraction of BCD have different rules.
- The BCD arithmetic is little more complicated.
- BCD needs more number of bits than binary to represent the decimal number. So BCD is less efficient than binary.

Alphanumeric codes

A binary digit or bit can represent only two symbols as it has only two states '0' or '1'. But this is not enough for communication between two computers because there we need many more symbols for communication. These symbols are required to represent 26 alphabets with capital and small letters, numbers from
0 to 9, punctuation marks and other symbols.

The alphanumeric codes are the codes that represent numbers and alphabetic characters. Mostly such codes also represent other characters such as symbol and various instructions necessary for conveying information. An alphanumeric code should at least represent 10 digits and 26 letters of alphabet i.e. total 36 items. The following three alphanumeric codes are very commonly used for the data representation.

- American Standard Code for Information Interchange (ASCII).
- Extended Binary Coded Decimal Interchange Code (EBCDIC).
- Five bit Baudot Code.

ASCII code is a 7-bit code whereas EBCDIC is an 8-bit code. ASCII code is more commonly used worldwide while EBCDIC is used primarily in large IBM computers.

Error Codes

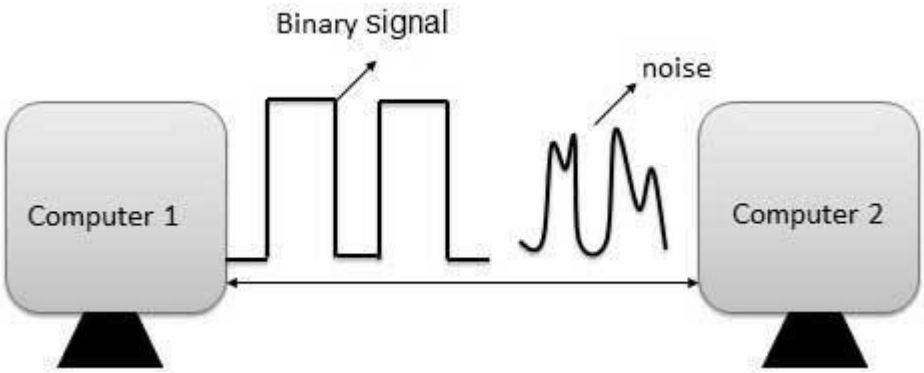
There are binary code techniques available to detect and correct data during data transmission.

Error Code	Description
Error Detection and Correction	Error detection and correction code techniques

5. Error detection and correction

What is Error?

Error is a condition when the output information does not match with the input information. During transmission, digital signals suffer from noise that can introduce errors in the binary bits travelling from one system to other. That means a 0 bit may change to 1 or a 1 bit may change to 0.



Error-Detecting Codes

Whenever a message is transmitted, it may get scrambled by noise or data may get corrupted. To avoid this, we use error-detecting codes which are additional data added to a given digital message to help us detect if an error occurred during transmission of the message. A simple example of error-detecting code is **parity check**.

Error-Correcting Codes

Along with error-detecting code, we can also pass some data to figure out the original message from the corrupt message that we received. This type of code is called an error-correcting code. Error-correcting codes also deploy the same strategy as error-detecting codes but additionally, such codes also detect the exact location of the corrupt bit.

In error-correcting codes, parity check has a simple way to detect errors along with a sophisticated mechanism to determine the corrupt bit location. Once the corrupt bit is located, its value is reverted (from 0 to 1 or 1 to 0) to get the original message.

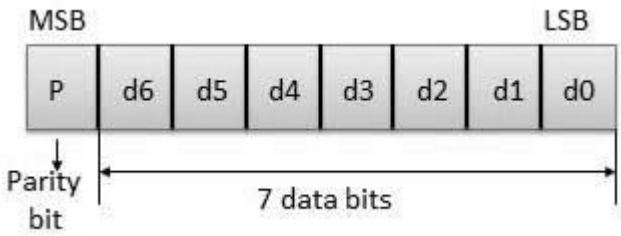
How to Detect and Correct Errors?

To detect and correct the errors, additional bits are added to the data bits at the time of transmission.

- The additional bits are called parity bits. They allow detection or correction of the errors.
- The data bits along with the parity bits form a code word.

Parity Checking of Error Detection

It is the simplest technique for detecting and correcting errors. The MSB of an 8- bits word is used as the parity bit and the remaining 7 bits are used as data or message bits. The parity of 8-bits transmitted word can be either even parity or odd parity.



Even parity -- Even parity means the number of 1's in the given word including the parity bit should be even (2, 4, 6,....).

Odd parity -- Odd parity means the number of 1's in the given word including the parity bit should be odd (1, 3, 5,....).

Use of Parity Bit

The parity bit can be set to 0 and 1 depending on the type of the parity required.

- For even parity, this bit is set to 1 or 0 such that the no. of "1 bits" in the entire word is even. Shown in fig. (a).
- For odd parity, this bit is set to 1 or 0 such that the no. of "1 bits" in the entire word is odd. Shown in fig. (b).

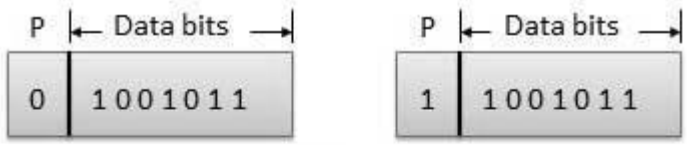


Fig. (a)

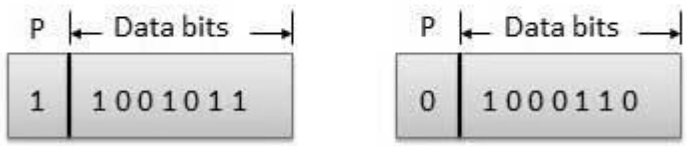


Fig. (b)

How Does Error Detection Take Place?

Parity checking at the receiver can detect the presence of an error if the parity of the receiver signal is different from the expected parity. That means, if it is known that the parity of the transmitted signal is always going to be "even" and if the received signal has an odd parity, then the receiver can conclude that the received signal is not correct. If an error is detected, then the receiver will ignore the received byte and request for retransmission of the same byte to the transmitter.