

The background of the slide is an abstract geometric pattern composed of numerous triangles of varying sizes. The color palette is a gradient of blues and greens, with darker blues at the bottom and lighter greens at the top. The triangles are arranged in a way that creates a sense of depth and movement.

COMPUTER SYSTEM ARCHITECTURE

Lecture Slides

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WHAT IS COMPUTER SYSTEM ARCHITECTURE

- Computer architecture is concerned with the structure and behavior of the various functional modules of the computer and how they interact to provide the processing needs of the user.
- Computer organization is concerned with the way the hardware components are connected together to form a computer system.
- Computer design is concerned with the development of the hardware for the computer taking into consideration a given set of specifications.

CHAPTER-1: DIGITAL LOGIC CIRCUITS

- Introduces the fundamental knowledge needed for the design of digital systems constructed with individual gates and flip-flops.
- It covers Boolean algebra, combinational circuits, and sequential circuits, providing necessary background for understanding the digital circuits.

- The digital computer is a digital system that performs various computational tasks.
- The word digital implies that the information in the computer is represented by variables that take a limited number of discrete values.
- For e.g., the decimal digits 0, 1, 2, ... , 9, for example, provide 10 discrete values.
- In practice, digital computers function more reliably if only two states are used. Because of the physical restriction of components, and because human logic tends to be binary (i.e., true/false, yes/no statements), digital components that are constrained to take discrete values are further constrained to take only two values and are said to be binary.

- Digital computers use the binary number system, which has two digits: 0 and 1. A binary digit is called a bit.
- Information is represented in digital computers in groups of bits.
- By using various coding techniques, groups of bits can be made to represent not only binary numbers but also other discrete symbols, such as decimal digits or letters of the alphabet.

- In contrast to the common decimal numbers that employ the base 10 system, binary numbers use a base 2 system with two digits: 0 and 1.
- For example, the binary number 1001011 represents a quantity that can be converted to a decimal number by multiplying each bit by the base 2 raised to an integer power as follows:

$$1 \times 2^6 + 0 \times 2^5 + 0 \times 2^4 + 1 \times 2^3 + 0 \times 2^2 + 1 \times 2^1 + 1 \times 2^0 = 75$$

- Hence, $(1001011)_2 = 75_{10}$

PROGRAM

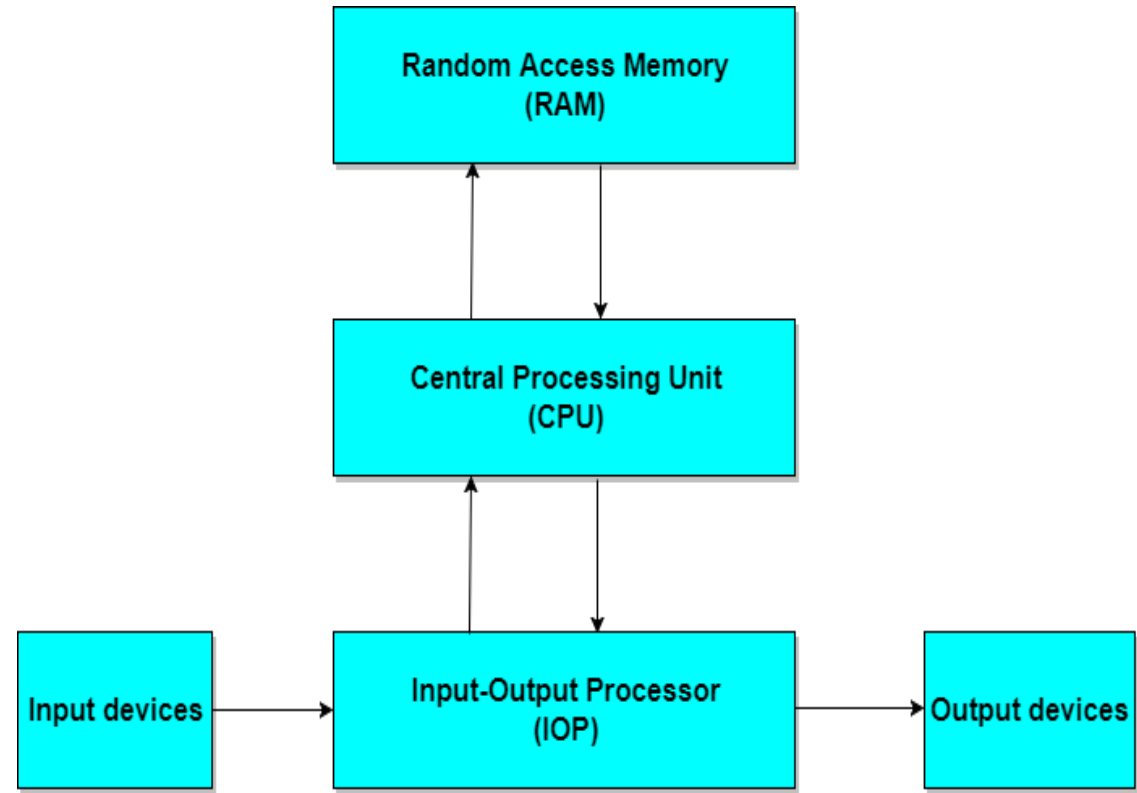
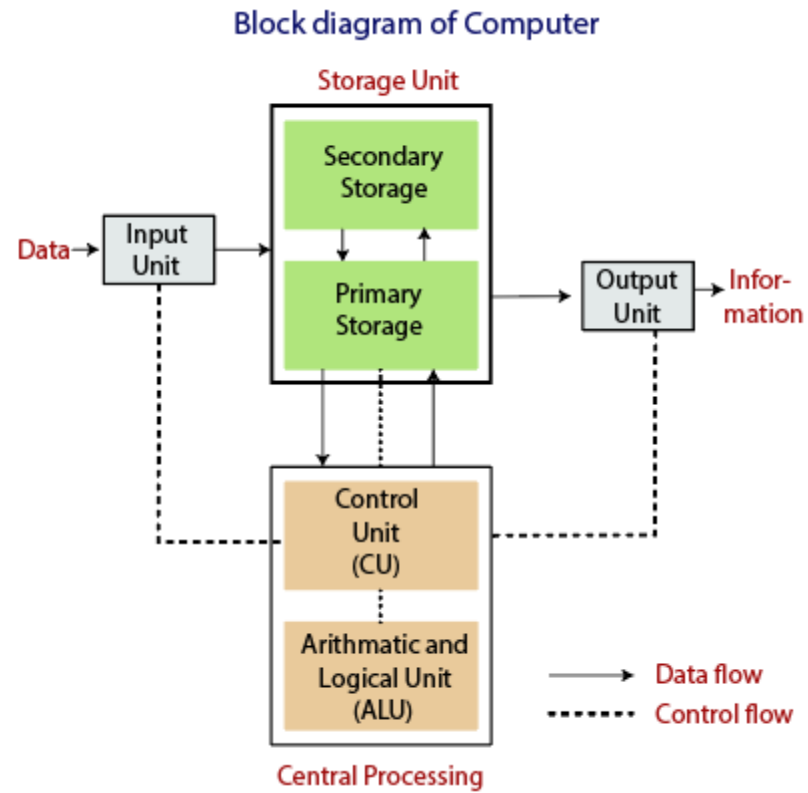
- A computer system is sometimes subdivided into two functional entities: hardware and software.
- The hardware of the computer consists of all the electronic components and electromechanical devices that comprise the physical entity of the device.
- Computer software consists of the instructions and data that the computer manipulates to perform various data-processing tasks.
- A sequence of instructions for the computer is called a program.
- The data that are manipulated by the program constitute the data base.

OPERATING SYSTEM

- The programs included in a systems software package are referred to as the operating system.
- They are distinguished from application programs written by the user for the purpose of solving particular problems.
- For example, a high-level language program written by a user to solve particular data-processing needs is an application program, but the compiler that translates the high-level language program to machine language is a system program.

COMPUTER HARDWARE

- The hardware of the computer is usually divided into three major parts:
- The **central processing unit (CPU)** contains an arithmetic and logic unit for manipulating data, a number of registers for storing data, and control circuits for fetching and executing instructions.
- The **memory** of a computer contains storage for instructions and data. It is called a random access memory (RAM) because the CPU can access any location in memory at random and retrieve the binary information within a fixed interval of time.
- The **input and output processor (IOP)** contains electronic circuits for communicating and controlling the transfer of information between the computer and the outside world. The input and output devices connected to the computer include keyboards, printers, terminals, magnetic disk drives, and other communication devices.



COMPUTER ORGANIZATION

- Computer organization is concerned with the way the hardware components operate and the way they are connected together to form the computer system.
- The various components are assumed to be in place and the task is to investigate the organizational structure to verify that the computer parts operate as intended.

COMPUTER DESIGN









- Computer design is concerned with the hardware design of the computer.
- Once the computer specifications are formulated, it is the task of the designer to develop hardware for the system.
- Computer design is concerned with the determination of what hardware should be used and how the parts should be connected. This aspect of computer hardware is sometimes referred to as computer implementation.

COMPUTER ARCHITECTURE

- Computer architecture is concerned with the structure and behavior of the computer as seen by the user.
- It includes the information formats, the instruction set, and techniques for addressing memory.
- The architectural design of a computer system is concerned with the specifications of the various functional modules, such as processors and memories, and structuring them together into a computer system.

LOGIC GATES

- Binary logic deals with binary variables and with operations that assume a logical meaning.
- It is used to describe, in algebraic or tabular form, the manipulation and processing of binary information.
- The manipulation of binary information is done by logic circuits called **gates** .
- Gates are blocks of hardware that produce signals of binary 1 or 0 when input logic requirements are satisfied.
- Each gate has a distinct graphic symbol and its operation can be described by means of an algebraic expression.
- The input-output relationship of the binary variables for each gate can be represented in tabular form by a **truth table**.

Name	Graphic symbol	Algebraic function	Truth table															
AND		$x = A \cdot B$ or $x = AB$	<table><tr><th>A</th><th>B</th><th>x</th></tr><tr><td>0</td><td>0</td><td>0</td></tr><tr><td>0</td><td>1</td><td>0</td></tr><tr><td>1</td><td>0</td><td>0</td></tr><tr><td>1</td><td>1</td><td>1</td></tr></table>	A	B	x	0	0	0	0	1	0	1	0	0	1	1	1
A	B	x																
0	0	0																
0	1	0																
1	0	0																
1	1	1																
OR		$x = A + B$	<table><tr><th>A</th><th>B</th><th>x</th></tr><tr><td>0</td><td>0</td><td>0</td></tr><tr><td>0</td><td>1</td><td>1</td></tr><tr><td>1</td><td>0</td><td>1</td></tr><tr><td>1</td><td>1</td><td>1</td></tr></table>	A	B	x	0	0	0	0	1	1	1	0	1	1	1	1
A	B	x																
0	0	0																
0	1	1																
1	0	1																
1	1	1																
Inverter		$x = A'$	<table><tr><th>A</th><th>x</th></tr><tr><td>0</td><td>1</td></tr><tr><td>1</td><td>0</td></tr></table>	A	x	0	1	1	0									
A	x																	
0	1																	
1	0																	
Buffer		$x = A$	<table><tr><th>A</th><th>x</th></tr><tr><td>0</td><td>0</td></tr><tr><td>1</td><td>1</td></tr></table>	A	x	0	0	1	1									
A	x																	
0	0																	
1	1																	
NAND		$x = (AB)'$	<table><tr><th>A</th><th>B</th><th>x</th></tr><tr><td>0</td><td>0</td><td>1</td></tr><tr><td>0</td><td>1</td><td>1</td></tr><tr><td>1</td><td>0</td><td>1</td></tr><tr><td>1</td><td>1</td><td>0</td></tr></table>	A	B	x	0	0	1	0	1	1	1	0	1	1	1	0
A	B	x																
0	0	1																
0	1	1																
1	0	1																
1	1	0																
NOR		$x = (A + B)'$	<table><tr><th>A</th><th>B</th><th>x</th></tr><tr><td>0</td><td>0</td><td>1</td></tr><tr><td>0</td><td>1</td><td>0</td></tr><tr><td>1</td><td>0</td><td>0</td></tr><tr><td>1</td><td>1</td><td>0</td></tr></table>	A	B	x	0	0	1	0	1	0	1	0	0	1	1	0
A	B	x																
0	0	1																
0	1	0																
1	0	0																
1	1	0																
Exclusive-OR (XOR)		$x = A \oplus B$ or $x = A'B + AB'$	<table><tr><th>A</th><th>B</th><th>x</th></tr><tr><td>0</td><td>0</td><td>0</td></tr><tr><td>0</td><td>1</td><td>1</td></tr><tr><td>1</td><td>0</td><td>1</td></tr><tr><td>1</td><td>1</td><td>0</td></tr></table>	A	B	x	0	0	0	0	1	1	1	0	1	1	1	0
A	B	x																
0	0	0																
0	1	1																
1	0	1																
1	1	0																
Exclusive-NOR or equivalence		$x = (A \oplus B)'$ or $x = A'B' + AB$	<table><tr><th>A</th><th>B</th><th>x</th></tr><tr><td>0</td><td>0</td><td>1</td></tr><tr><td>0</td><td>1</td><td>0</td></tr><tr><td>1</td><td>0</td><td>0</td></tr><tr><td>1</td><td>1</td><td>1</td></tr></table>	A	B	x	0	0	1	0	1	0	1	0	0	1	1	1
A	B	x																
0	0	1																
0	1	0																
1	0	0																
1	1	1																

AND Gate

- The AND gate produces the AND logic function: that is, the output is 1 if input A and input B are both equal to 1; otherwise, the output is 0.
- These conditions are also specified in the truth table for the AND gate. The table shows that output x is 1 only when both input A and input B are 1.
- The algebraic operation symbol of the AND function is the same as the multiplication symbol (\cdot) of ordinary arithmetic.
- AND gates may have more than two inputs, and by definition, the output is 1 if and only if all inputs are 1.

2 - input AND gate

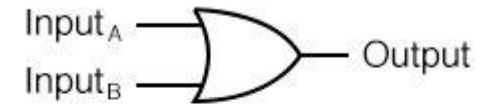


A	B	Output
0	0	0
0	1	0
1	0	0
1	1	1

OR Gate

- The OR gate produces the inclusive-OR function; that is, the output is 1 if input A or input B or both inputs are 1; otherwise, the output is 0.
- The algebraic symbol of the OR function is $+$, similar to arithmetic addition.
- OR gates may have more than two inputs, and by definition, the output is 1 if any input is 1.

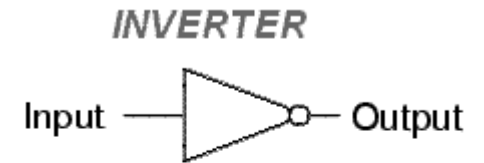
2 - input OR gate



A	B	Output
0	0	0
0	1	1
1	0	1
1	1	1

Inverter (NOT)

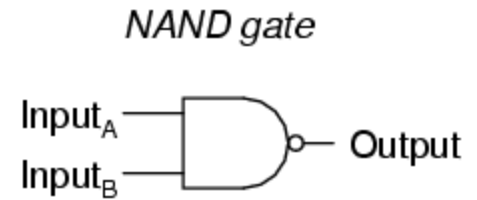
- The inverter circuit inverts the logic sense of a binary signal.
- It produces the NOT, or complement function.
- The algebraic symbol used for the logic complement is either a prime or a bar over the variable symbol.



Input	Output
1	0
0	1

NAND Gate

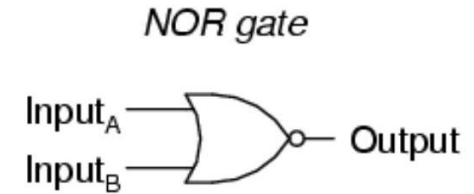
- This is a NOT-AND gate which is equal to an AND gate followed by a NOT gate.
- The outputs of all NAND gates are high if any of the inputs are low.
- The NAND function is the complement of the AND function, as indicated by the graphic symbol, which consists of an AND graphic symbol followed by a small circle.



A	B	Output
0	0	1
0	1	1
1	0	1
1	1	0

NOR Gate

- This is a NOT-OR gate which is equal to an OR gate followed by a NOT gate.
- The outputs of all NOR gates are low if any of the inputs are high.
- The NOR gate is the complement of the OR gate and uses an OR graphic symbol followed by a small circle.



A	B	Output
0	0	1
0	1	0
1	0	0
1	1	0

Exclusive-OR (XOR)

- It produces a high output if either, but not both, of its two inputs are high.
- The exclusive-OR gate has a graphic symbol similar to the OR gate except for the additional curved line on the input side.
- The output of this gate is 1 if any input is 1 but excludes the combination when both inputs are 1.

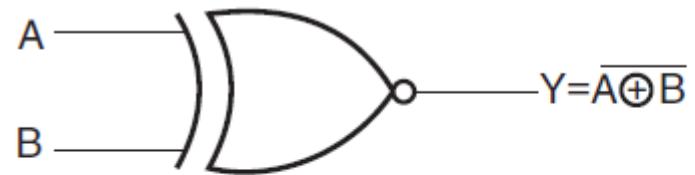
Exclusive-OR gate



A	B	Output
0	0	0
0	1	1
1	0	1
1	1	0

Exclusive-NOR (XNOR)

- The 'Exclusive-NOR' gate circuit does the opposite to the XOR gate.
- It will give a low output if either, but not both, of its two inputs are high.



$$Y = \overline{(A \oplus B)} = (A.B + \overline{A}.\overline{B})$$

A	B	Y
0	0	1
0	1	0
1	0	0
1	1	1

BOOLEAN ALGEBRA

- Boolean algebra is an algebra that deals with binary variables and logic operations.
- This forms the algebraic expression showing the operation of the logic circuit for each input variable either True or False that results in a logic “1” output.
- The three basic logic operations are AND, OR, and complement (NOT).
- The purpose of Boolean algebra is to facilitate the analysis and design of digital circuits. It provides a convenient tool to:
 - Express in algebraic form a truth table relationship between binary variables.
 - Express in algebraic form the input-output relationship of logic diagrams.
 - Find simpler circuits for the same function.

BOOLEAN FUNCTION

- Boolean function can be expressed algebraically with binary variables, the logic operation symbols, parentheses, and equal sign.
- For a given value of the variables, the Boolean function can be either 1 or 0.

E.g.,

$$F = x + y' z$$

The function F is equal to 1 if x is 1 or if both y' and z are equal to 1; F is equal to 0 otherwise. But saying that $y' = 1$ is equivalent to saying that $y = 0$ since y' is the complement of y . Therefore, we may say that F is equal to 1 if $x = 1$ or if $yz = 01$.

TRUTH TABLE

- The relationship between a function and its binary variables can be represented in a **truth table**.
- A truth table shows how the truth or falsity of a compound statement depends on the truth or falsity of the simple statements from which it's constructed.
- It defines the function of a logic gate by providing a concise list that shows all the output states in tabular form for each possible combination of input variable that the gate could encounter.
- To represent a function in a truth table we need a list of the 2^n combinations of the **n** binary variables.

LOGIC DIAGRAM

- Boolean function can be transformed from an algebraic expression into a logic diagram composed of AND, OR, and inverter/NOT gates.
- The logic diagram consists of gates and symbols that can directly replace an expression in Boolean arithmetic.
- This is a graphical representation of a logic circuit that shows the wiring and connections of each individual logic gate, represented by a specific graphical symbol that implements the logic circuit.

BOOLEAN ALGEBRA (REVISITED)

- A Boolean function specified by a truth table can be expressed algebraically in many different ways.
- **Boolean algebra** is the branch of algebra in which the values of the variables are the truth values true and false, usually denoted 1 and 0 respectively.
- By manipulating a Boolean expression according to Boolean algebra rules, one may obtain a simpler expression that will require fewer gates.
- It is used to analyze and simplify the digital (logic) circuits.

	AND Form	OR Form
Commutative Law	$A \cdot B = B \cdot A$	$A + B = B + A$
Associate Law	$(A \cdot B) \cdot C = A \cdot (B \cdot C)$	$(A + B) + C = A + (B + C)$
Distributive Law	$(A+B) \cdot C = (A \cdot C) + (B \cdot C)$	$(A + B) \cdot C = (A \cdot C) + (B \cdot C)$
Identity Law	$A \cdot 1 = A$	$A + 0 = A$
Zero and One Law	$A \cdot 0 = 0$	$A + 1 = 1$
Inverse Law	$A \cdot A' = 0$	$A + A' = 1$
Idempotent Law	$A \cdot A = A$	$A + A = A$
Absorption Law	$A(A+B) = A$	$A + A \cdot B = A$ $A + A' \cdot B = A + B$
DeMorgan's Law	$(A \cdot B)' = (A') + (B)'$	$(A + B)' = (A)' \cdot (B)'$
Double Complement Law	$\overline{\overline{X}} = X$	

Source: Google Search

NUMBER SYSTEM

- The number system is a way to represent or express numbers.
- Based on the different symbol used to represent numbers, there are various types of number systems:
 - The decimal number system
 - The binary number system
 - The octal number system and
 - The hexadecimal number system
 - Binary Coded Decimal or BCD Numbering System

CONVERTING FROM BINARY TO DECIMAL

- decimal = $d_0 \times 2^0 + d_1 \times 2^1 + d_2 \times 2^2 + \dots$
- Example

binary number:	1	1	1	0	0	1
power of 2:	2^5	2^4	2^3	2^2	2^1	2^0

$$111001_2 = 1 \cdot 2^5 + 1 \cdot 2^4 + 1 \cdot 2^3 + 0 \cdot 2^2 + 0 \cdot 2^1 + 1 \cdot 2^0 = 57_{10}$$

CONVERTING FROM DECIMAL INTEGER TO BINARY

- Conversion steps:
 - Divide the number by 2.
 - Get the integer quotient for the next iteration.
 - Get the remainder for the binary digit.
 - Repeat the steps until the quotient is equal to 0.
- Example

Convert 13_{10} to binary :

Division by 2	Quotient	Remainder	Bit #
13/2	6	1	0
6/2	3	0	1
3/2	1	1	2
1/2	0	1	3

$$13_{10} = 1101_2$$

SOURCE: INTERNET

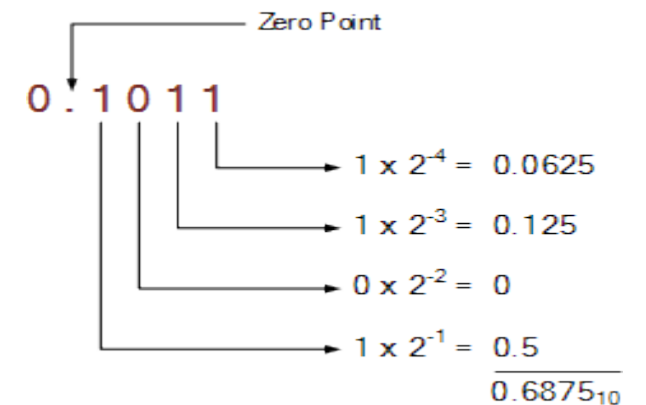
CONVERTING DECIMAL FRACTION TO BINARY

- Binary Fractions use the same weighting principle as decimal numbers except that each binary digit uses the base-2 numbering system.
- A decimal number representation of $(0.XY)_{10}$ can be converted into base of 2 and represented by $(0.a_1, a_2, a_3, \text{etc.})_2$.
- The fraction number is multiplied by 2, the result of integer part is a_1 and fraction part multiply by 2, and then separate integer part from fraction, the integer part represents a_1 ; this process continues until the fraction becomes 0.

Example: $(0.625)_{10}$

	Integer	Fraction	Coefficient
$0.625 * 2 =$	1	. 25	$a_1 = 1$
$0.25 * 2 =$	0	. 5	$a_2 = 0$
$0.5 * 2 =$	1	. 0	$a_3 = 1$

Answer: $(0.625)_{10} = (0.a_1 a_2 a_3)_2 = (0.101)_2$
 MSB LSB



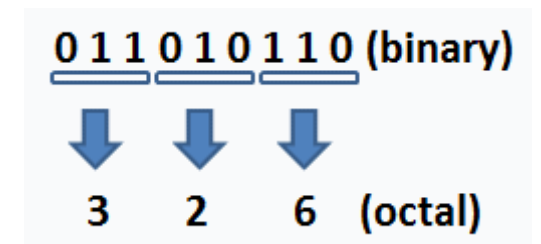
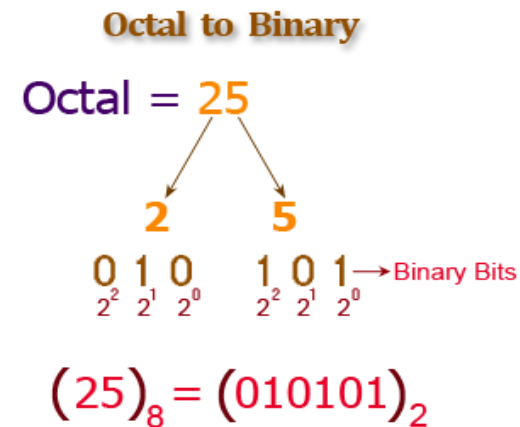
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CONVERTING FROM OCTAL TO BINARY

- The octal numeral system, or oct for short, is the base-8 number system, and uses the digits 0 to 7.
- Octal numerals can be made from binary numerals by grouping consecutive binary digits into groups of three (starting from the right).

Decimal	Octal	Binary
0	0	0
1	1	1
2	2	10
3	3	11
4	4	100
5	5	101
6	6	110
7	7	111

SOURCE: INTERNET



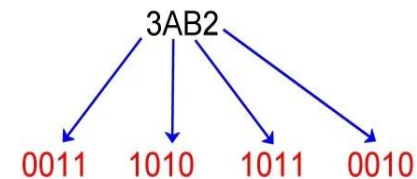
CONVERTING FROM HEX TO BINARY

- Hexadecimal (also base 16, or hex) is a positional numeral system with a radix, or base, of 16. It uses sixteen distinct symbols, most often the symbols 0–9 to represent values zero to nine, and A, B, C, D, E, F (or alternatively a, b, c, d, e, f) to represent values ten to fifteen.

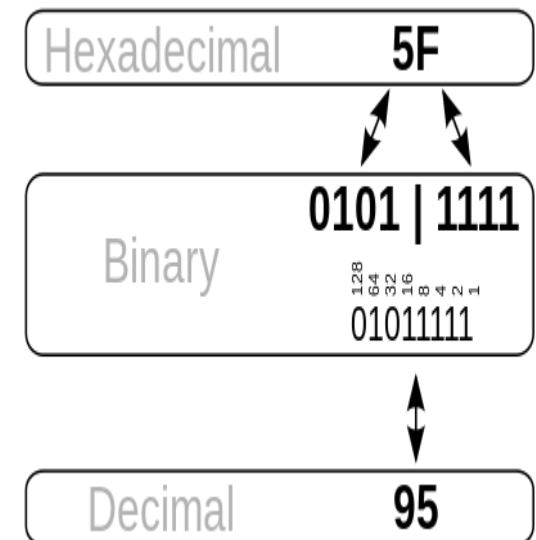
Decimal	Hexadecimal	Binary
0	0	0
1	1	1
2	2	10
3	3	11
4	4	100
5	5	101
6	6	110
7	7	111
8	8	1000
9	9	1001
10	A	1010
11	B	1011
12	C	1100
13	D	1101
14	E	1110
15	F	1111

SOURCE: INTERNET

Converting Hex to Binary



$$3AB2_{16} = 11101010110010_2$$



BINARY CODED DECIMAL (BCD)

- **BCD or Binary Coded Decimal** is that number system or code which has the binary numbers or digits to represent a decimal number where each digit is represented by a fixed number of binary bits, usually between four and eight.
- A decimal number contains 10 digits (0-9). Now the equivalent binary numbers can be found out of these 10 decimal numbers. In case of BCD the binary number formed by four binary digits, will be the equivalent code for the given decimal digits. In BCD we can use the binary number from 0000-1001 only, which are the decimal equivalent from 0-9 respectively.
- The BCD_{8421} code is so called because each of the four bits is given a 'weighting' according to its column value in the binary system. The least significant bit (lsb) has the weight or value 1, the next bit, going left, the value 2. The next bit has the value 4, and the most significant bit (msb) the value 8. E.g.,
 24_{10} in 8 bit binary would be 00011000 but in BCD_{8421} is 0010 0100.
 992_{10} in 16 bit binary would be 0000001111100000 but in BCD_{8421} is 1001 1001 0010.

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

} Unused

Binary-Coded Decimal vs. Binary to Decimal Conversion

Decimal Number	BCD				Binary			
0	0000	0000	0000	0000	0000	0000	0000	0000
1	0000	0000	0000	0001	0000	0000	0000	0001
2	0000	0000	0000	0010	0000	0000	0000	0010
3	0000	0000	0000	0011	0000	0000	0000	0011
4	0000	0000	0000	0100	0000	0000	0000	0100
5	0000	0000	0000	0101	0000	0000	0000	0101
6	0000	0000	0000	0110	0000	0000	0000	0110
7	0000	0000	0000	0111	0000	0000	0000	0111
8	0000	0000	0000	1000	0000	0000	0000	1000
9	0000	0000	0000	1001	0000	0000	0000	1001
⋮								
9620	1001	0110	0010	0000	0010	0101	1001	0100
120		0001	0010	0000	0000	0000	0111	1000
4568	0100	0101	0110	1000	0001	0001	1101	1000

REALPARS

Binary Base-2	Decimal Base-10	Hexa- Decimal Base-16	Octal Base-8	BCD Code
0000	0	0	0	0
0001	1	1	1	1
0010	2	2	2	2
0011	3	3	3	3
0100	4	4	4	4
0101	5	5	5	5
0110	6	6	6	6
0111	7	7	7	7
1000	8	8	10	8
1001	9	9	11	9
1010	10	A	12	---
1011	11	B	13	---
1100	12	C	14	---
1101	13	D	15	---
1110	14	E	16	---
1111	15	F	17	---

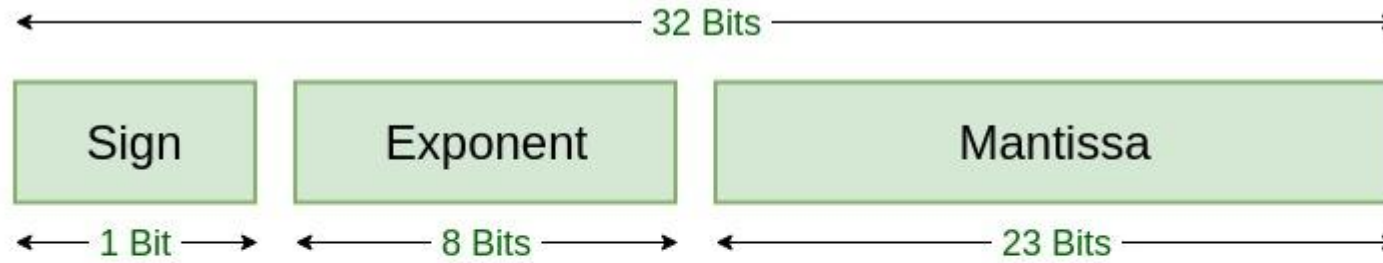
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FLOATING POINT REPRESENTATION

- Integers are whole numbers without fractional components. 1, 2, and 3 are integers, while 0.1, 2.2, and 3.0001 all have fractional components and are called floating point numbers.
- The floating point unit performs floating point operations. Floating point numbers have a sign, a mantissa, and an exponent.
- The central processing unit (CPU) typically consists of an arithmetic logic unit (ALU), floating point unit (FLU/FPU), registers, control unit, and the cache memory.
- The arithmetic logic unit performs integer arithmetic operations such as addition, subtraction, and logic operations such as AND, OR, XOR, etc.

IEEE STANDARD FOR FLOATING POINT REPRESENTATION

- The Institute of Electrical and Electronics Engineers (IEEE) developed a standard to represent floating point numbers, referred to as IEEE 754.
- This standard defines a format for both single (32-bit) and double (64-bit) precision floating point numbers.
- Floating point numbers in single precision are represented by 32 bits while in order to increase the accuracy of a floating point number, IEEE 745 offers double precision represented by 64 bits.
- Decimal floating points are represented by $M \times 10^E$, where M is the signed mantissa (normalized mantissa) and E is the exponent (biased exponent).



Single Precision IEEE 754 Floating-Point Standard



64-bit Double-Precision Floating-point Number

- **Biased Exponent** is the exponent + 127 $(01111111)_2$; therefore, the exponent is represented by a positive number.
- **Normalized Mantissa/mantissa** is represented by 1.M, where M is called normalized mantissa; if M = 00101, then mantissa is 1.00101.
- Example:

Find normalized mantissa and biased exponent of $(111.0000111)_2$.

111.0000111 can be written in the form of $1.110000111 * 2^{10}$

Where

$M = 110000111$

Biased exponent = $10 + 01111111 = 10000001$

The representation of 111.0000111 in single precision is

1bit	8 bits	23 bits
0	10000001	110000111000000000000000

- Convert the following single precision floating point to decimal number.

101111101 110010000000000000000000

$S = 1$ means mantissa is negative.

Biased exponent = 01111101.

Exponent = $01111101 - 01111111 = 00000010$.

Normalized mantissa = 110010000000000000000000.

Mantissa = $1.110010000000000000000000$.

Decimal number = $1.110010000000000000000000 * 2^{-10} = 0.01110011$.

- Represent 5.75 in IEEE 745 single precision.

$$-15.625 = (1111.101)_2$$

$$-1111.101 = -1.11101101 * 2^{11}$$

$$S = 1$$

$$\text{Normalized mantissa} = 0.11101101.$$

$$\text{Biased exponent} = 11 + 01111111 = 10000010.$$

IEEE745 single precision is

$$1 \ 10000010 \ 111011010000000000000000.$$

As examples, our 12-bit floating-point number with a binary representation of:

Sign Bit	Exponent				Mantissa						
1	0	0	0	0	1	0	0	0	0	0	1

converts to its decimal via $(-1)^1 \times 2^{1-7} \times 0.1000001 = -1 \times 2^{-6} \times 0.1000001 = -0.000001000001_2 = -(2^{-6} + 2^{-12})_{10} = -(1/64 + 1/4096) = -65/4096 = -0.015869140625$. While the floating-point number:

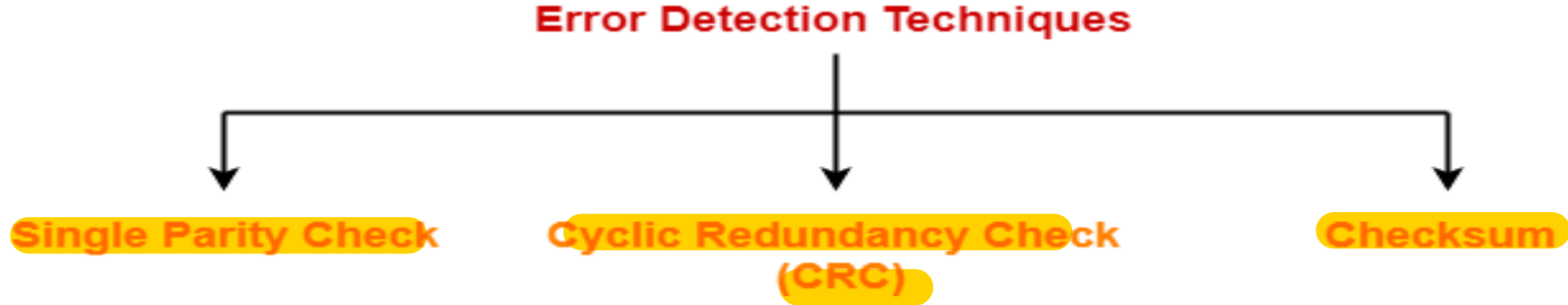
Sign Bit	Exponent				Mantissa						
0	0	1	1	0	1	0	1	0	1	0	1

converts to its decimal via $(-1)^0 \times 2^{6-7} \times 1.1010101 = (1 \times 2^{-1} \times 1.1010101)_2 = 0.11010101_2 = (2^{-1} + 2^{-2} + 2^{-4} + 2^{-6} + 2^{-8})_{10} = 1/2 + 1/4 + 1/16 + 1/64 + 1/256 = 213/256 = 0.83203125$.

ERROR DETECTION & CORRECTION CODES

ERROR

- The sequence of bits is called as “Data stream”.
- The change in position of single bit also leads to catastrophic (major) error in data output.
- The error detection and correction techniques are used to get the exact or approximate output.
- In a data sequence, if 1 is changed to zero or 0 is changed to 1, it is called “Bit error”.
- There are generally 3 types of errors occur in data transmission from transmitter to receiver. They are
 - **Single bit errors** (The change in one bit in the whole data sequence; occurs in parallel communication system)
 - **Multiple bit errors** (If there is change in two or more bits of data sequence of transmitter to receiver; occurs in both serial type and parallel type data communication networks)
 - **Burst errors** (The change of set of bits in data sequence; calculated in from the first bit change to last bit change; occurs in serial communication and they are difficult to solve)



PARITY (Vertical Redundancy Check (VRC))

A parity bit is used for error detection of information, since a bit or bits may be changed during the transmission of information from source to destination, a parity bit is an extra bit appended to the information. It represents whether the number of ones or zeroes is either even or odd in the original transmission and can alert the destination to a loss of information.

- Even Parity

The extra bit (0 or 1) is chosen such that the number of ones becomes even.

- Odd Parity

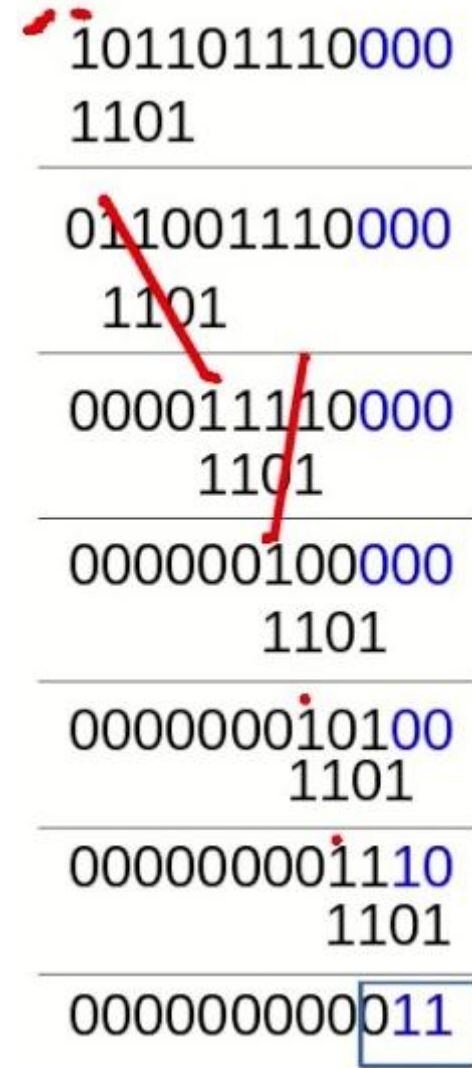
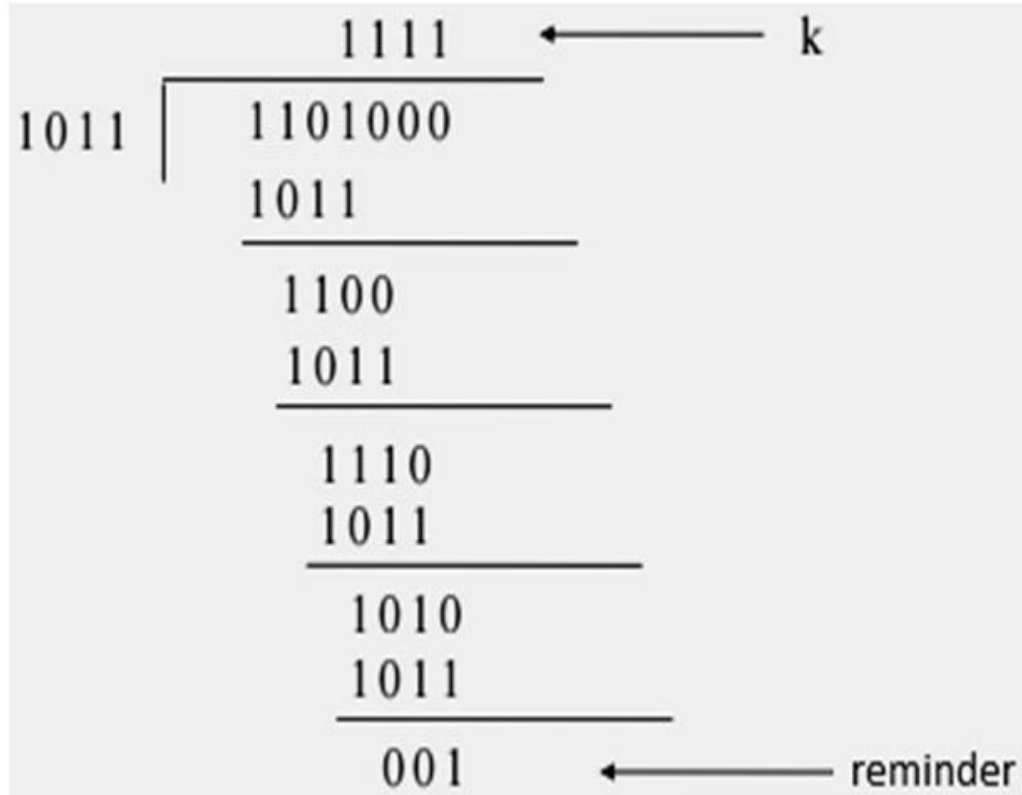
The extra bit (0 or 1) is chosen such that the number of ones becomes odd.

3 bit data			Message with even parity		Message with odd parity	
A	B	C	Message	Parity	Message	Parity
0	0	0	000	0	000	1
0	0	1	001	1	001	0
0	1	0	010	1	010	0
0	1	1	011	0	011	1
1	0	0	100	1	100	0
1	0	1	101	0	101	1
1	1	0	110	0	110	1
1	1	1	111	1	111	0

Original Data	Even Parity	Odd Parity
00000000	0	1
01011011	1	0
01010101	0	1
11111111	0	1
10000000	1	0
01001001	1	0

CYCLIC REDUNDANCY CHECK (CRC)

- CRC is commonly used to detect accidental changes to data transmitted via telecommunications networks and storage devices.
- A cyclic code is a linear (n, k) block code with the property that every cyclic shift of a codeword results in another code word. Here k indicates the length of the message at transmitter (the number of information bits). n is the total length of the message after adding check bits. (actual data and the check bits). n, k is the number of check bits. The codes used for cyclic redundancy check there by error detection are known as CRC codes (Cyclic redundancy check codes). Cyclic redundancy-check codes are shortened cyclic codes.
- CRC involves binary division of the data bits being sent by a predetermined divisor agreed upon by the communicating system. The divisor is generated using polynomials. So, CRC is also called polynomial code checksum.



Senders Side

$$\begin{array}{r}
 111101 \\
 1101 \overline{) 100100000} \\
 \oplus 1101 \\
 \hline
 01000 \\
 \oplus 1101 \\
 \hline
 01010 \\
 \oplus 1101 \\
 \hline
 001100 \\
 \oplus 1101 \\
 \hline
 0001
 \end{array}$$

CRC bits → 001

$$\begin{aligned}
 \text{Transmitted bits} &= \text{Original Message} + \text{CRC bits} \\
 &= 100100000 + 001 \\
 &= 100100001
 \end{aligned}$$

⊕ represents bitwise XOR

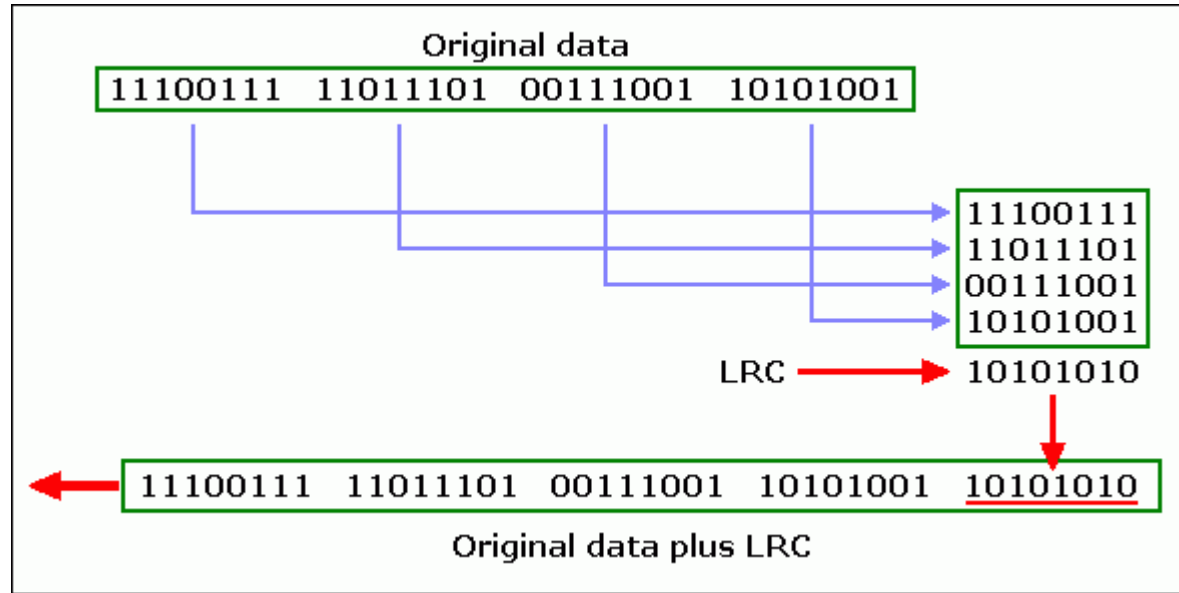
Receivers Side

$$\begin{array}{r}
 111101 \\
 1101 \overline{) 100100001} \\
 \oplus 1101 \\
 \hline
 01000 \\
 \oplus 1101 \\
 \hline
 01010 \\
 \oplus 1101 \\
 \hline
 01110 \\
 \oplus 1101 \\
 \hline
 001101 \\
 \oplus 1101 \\
 \hline
 0000
 \end{array}$$

Remainder is
zero, So data is
accepted

LONGITUDINAL REDUNDANCY CHECK (LRC)

- In longitudinal redundancy method, a BLOCK of bits are arranged in a table format (in rows and columns) and we will calculate the parity bit for each column separately.
- The set of these parity bits are also sent along with our original data bits.
- Longitudinal redundancy check is a bit by bit parity computation, as we calculate the parity of each column individually.
- LRC increases the likelihood of detecting burst error.
- However, if two bits in one data unit are damaged and two bits in exactly the same positions in another data unit are also damaged, the LRC checker will not detect an error.



10100011 00110011 11011101 11100111
10101010 (LRC)

Calculate the LRC for Data Received

10100011

00110011

11011101

11100111

→ LRC Calculated by Receiver 10101010

→ Compare with LRC Received 10101010

CHECKSUM

- A checksum number is appended to the packet sequence so that the sum of data plus checksum is zero.
- When received, the packet sequence may be added, along with the checksum, by a local microprocessor. If the sum is nonzero, an error has occurred.
- The checksum method includes parity bits, check digits and longitudinal redundancy check (LRC).

example: add two 16-bit integers

	1	1	1	0	0	1	1	0	0	1	1	0	0	1	1	0
	1	1	0	1	0	1	0	1	0	1	0	1	0	1	0	1
wraparound	1	1	0	1	1	1	0	1	1	1	0	1	1	1	0	1
sum	1	0	1	1	1	0	1	1	1	0	1	1	1	1	0	0
checksum	0	1	0	0	0	1	0	0	0	1	0	0	0	0	1	1

Note: when adding numbers, a carryout from the most significant bit needs to be added to the result

If $k = 4$, and $n = 8$ then

$k=4, n=8$
10110011
10101011
01011110
1
01011111
01011010
10111001
11010101
10001110
1
Sum : 10001111
Checksum 01110000

At sender side

10110011
10101011
01011110
1
01011111
01011010
10111001
11010101
10001110
1
10001111
01110000
Sum: 11111111
Complement = 00000000
Conclusion = Accept data

At receiver side

HAMMING CODES

- Hamming code is a set of error-correction codes that can be used to **detect and correct the errors** that can occur when the data is moved or stored from the sender to the receiver.
- Redundant bits: Redundant bits are extra binary bits that are generated and added to the information-carrying bits of data transfer to ensure that no bits were lost during the data transfer.

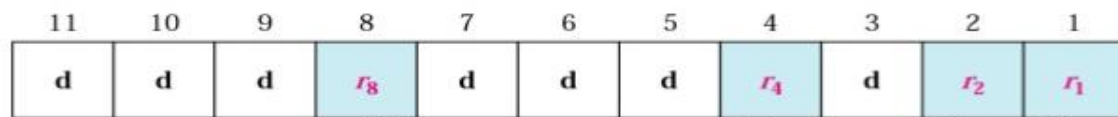
The number of redundant bits can be calculated using the following formula:

$$2^r \geq m + r + 1 \text{ where, } r = \text{redundant bit, } m = \text{data bit}$$

- Parity Bits: A parity bit is a bit appended to a data of binary bits to ensure that the total number of 1's in the data is even or odd.

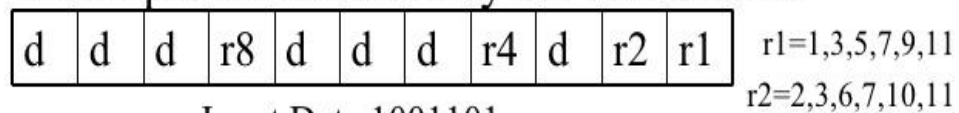
The key to the Hamming Code is the use of extra parity bits to allow the identification of a single error. Create the code word as follows:

1. Mark all bit positions that are powers of two as parity bits. (positions 1, 2, 4, 8, 16, 32, 64, etc.)
2. All other bit positions are for the data to be encoded. (positions 3, 5, 6, 7, 9, 10, 11, 12, 13, 14, 15, 17, etc.)
3. Each parity bit calculates the parity for some of the bits in the code word. The position of the parity bit determines the sequence of bits that it alternately checks and skips.
 - Position 1: check 1 bit, skip 1 bit, check 1 bit, skip 1 bit, etc. (1,3,5,7,9,11,13,15,...)
 - Position 2: check 2 bits, skip 2 bits, check 2 bits, skip 2 bits, etc. (2,3,6,7,10,11,14,15,...)
 - Position 4: check 4 bits, skip 4 bits, check 4 bits, skip 4 bits, etc. (4,5,6,7,12,13,14,15,20,21,22,23,...)
 - Position 8: check 8 bits, skip 8 bits, check 8 bits, skip 8 bits, etc. (8-15,24-31,40-47,...)
 - Position 16: check 16 bits, skip 16 bits, check 16 bits, skip 16 bits, etc. (16-31,48-63,80-95,...)
 - Position 32: check 32 bits, skip 32 bits, check 32 bits, skip 32 bits, etc. (32-63,96-127,160-191,...) etc.
4. Set a parity bit to 1 if the total number of ones in the positions it checks is odd. Set a parity bit to 0 if the total number of ones in the positions it checks is even.

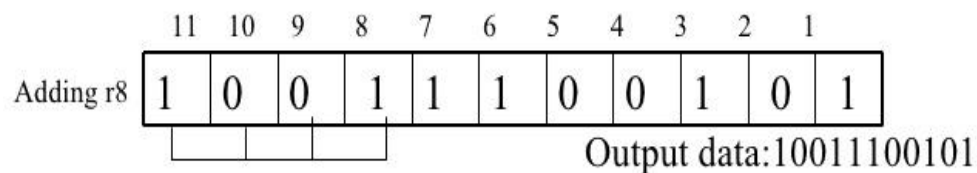
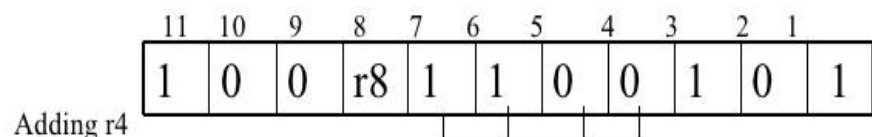
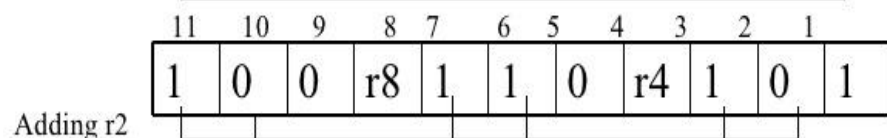
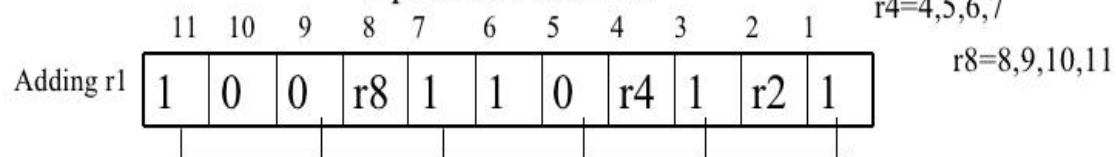


error-correcting bits

Example of redundancy bit calculation

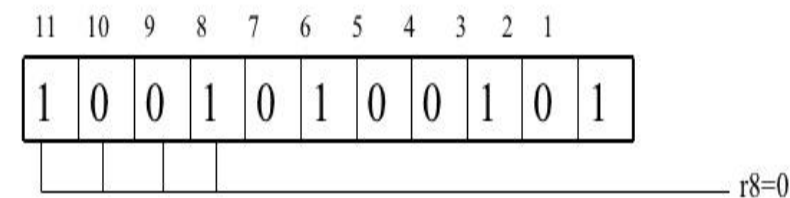
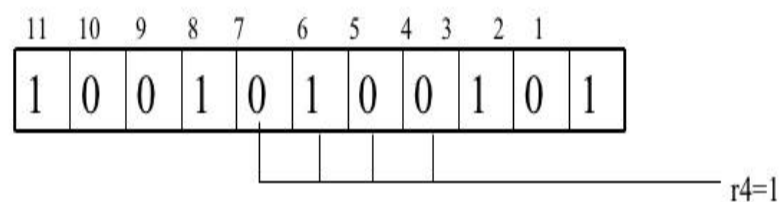
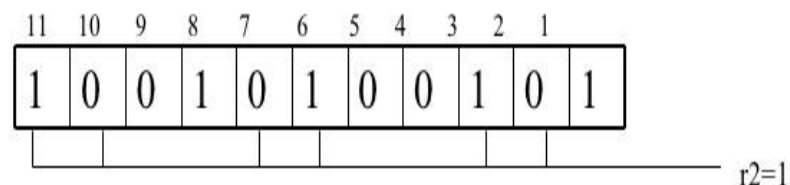
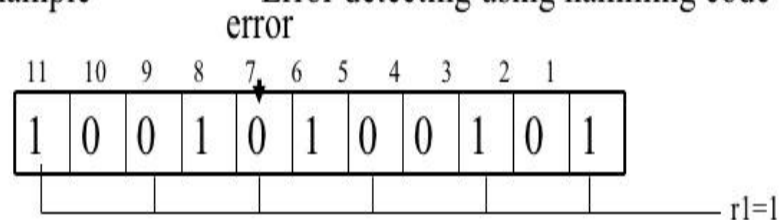


Input Data 1001101



Output data: 10011100101

example Error detecting using hamming code



If no.1,s is even 0

If no.1,s is odd 1

8 4 2 1

0 1 1 1

7

It mean the 7 bit is corrupted