3 Data Representation Methods in the Computer system

In this unit you will learn,

- computer data representation,
- Decimal, Binary, Octal and Hexadecimal number systems,
- most and least significant positional value of a number,
- converting decimal numbers to binary, octal numbers to hexadecimal numbers
- conversion among binary, octal, hexadecimal and decimal numbers,
- data storage capacity,
- coding systems in computers.

3.1 Computer Data Representation

Chanaka : Can you prepare this application using the computer Anjana?

Anjana : Sure, I’ll do it. You read this. Let us type it. "Application…"

Chanaka : When “A” on the keyboard is pressed, how does the computer identify it Anjana?

Sameera : Let us ask our teacher.

Janitha : Teacher, how is letter “A” represented in the computer?

Teacher : look at this picture children. (Figure 3.1)

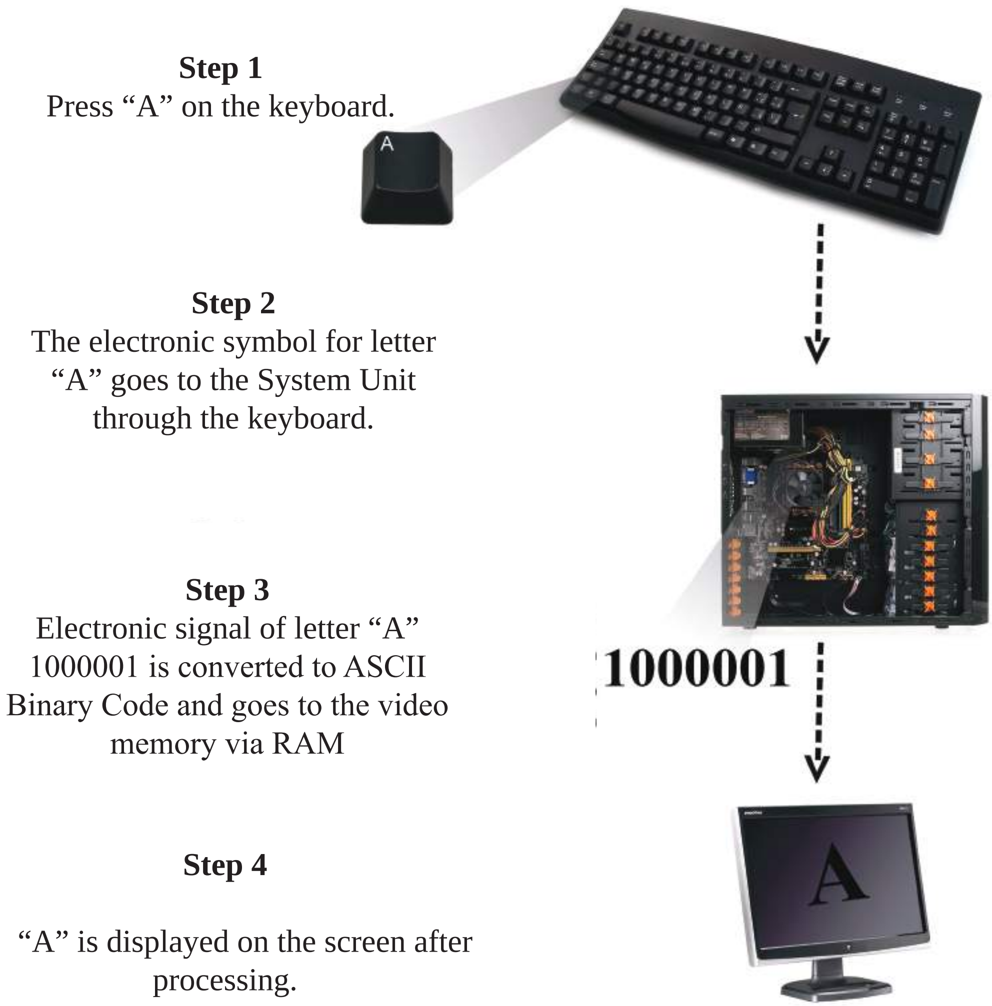


Figure 3.1 – Letter “A” representation on the computer.

Teacher : According to the figure above (Figure 3.1), when you type “A” on the keyboard, this electronic symbol goes to the Central Processing Unit. Then this letter “A” is sent to the CPU it is converted to an electronic symbol and is stored in Memory to process this pattern. After the process, the letter “A” is displayed on the screen.

3.1.1 Number System

When typing letters or words using the computer, these words or letters are represented by the computer as numbers it can understand. While this group of numbers that the computer can understand is called a 'Number System' the limited number of numerals in the number system called digits. The value of these numbers (numerals) depends on the position they occupy within the number.

While the concept of number system was present in the 'Abacus ' considered as the first calculating machine of the world, it has progressed up to the computer of today.

The number system used for the representation of data in the computer is as follows;

Table 3.1 - Numbers and Alphabetic characters used in the Number System

Number System	Base Value	Number and Alphabetic character used
1. Binary	2	0, 1
2. Octal	8	0, 1, 2, 3, 4, 5, 6, 7
3. Decimal	10	0, 1, 2, 3, 4, 5, 6, 7, 8, 9
4. Hexa - decimal	16	0, 1, 2, 3, 4, 5, 6, 7, 8, 9, A, B, C, D, E, F

3.1.2 Use of Binary Numbers in Computer Data Representation

Computer represents data in two signal states. There are two Voltage levels for these two symbols. One is named as the high voltage level and the other is named as low voltage level. "0" and "1" digits respectively represent these low and high voltage levels in a circuit. Thus, "1" and "0" status are equal to the “On” and “Off” states of an electronic circuit. Any data in the world can be represented on the computer using these two digits.

Figure 3.2 – A switch of an electronic circuit

According to the Figure 3.3 given below, when data stored in Secondary Storage is sent to the Main Memory and when it is sent to the Central Processing Unit from there, that data are converted to a binary code.

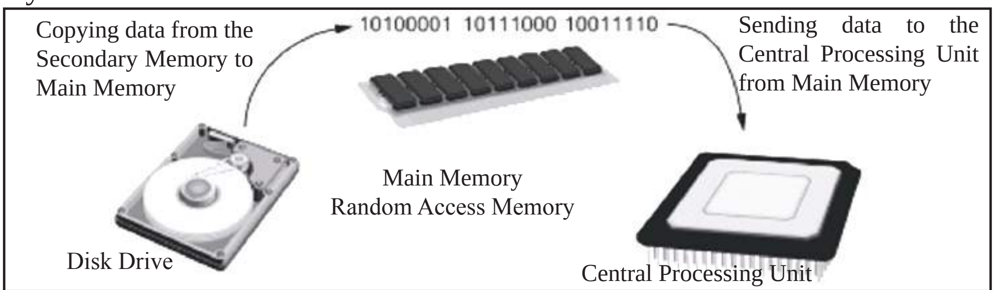


Figure 3.3 – How data is sent to the Central Processing Unit from the Secondary Storage

Let us consider the instance where Binary numbers are used for computer colours. Any colour can be made with the combination of different degrees of red, green and blue.

These can be represented as RGB (Red, Green, Blue) and the value of any colour ranges from 0 to 255.

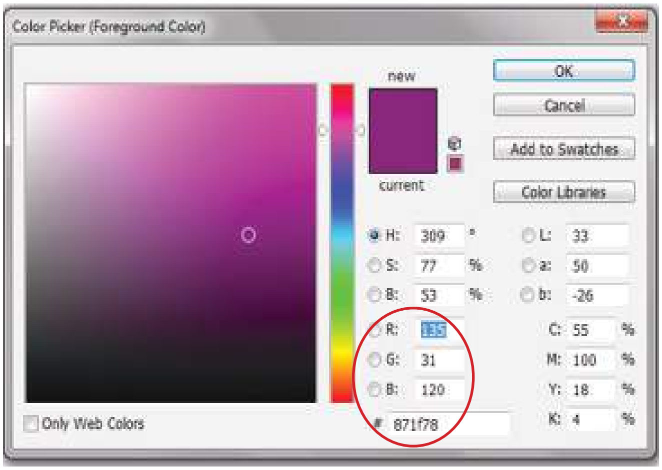


Figure 3.4 – Colour representation in computer

For instance, if you need to use dark purple for the background of a document, that colour can be represented in the computer as “135, 31, 120” (Figure 3.4). With these numbers, the colour combination for the above colour is represented in decimal numbers. Binary numbers for 135, 31 and 120 are 10000111_2, 11111_2, and 1111000_2.

3.2 Decimal, Binary, Octal and Hexa-Decimal Number Systems

3.2.1 Decimal Number System

Each number system is made of a Unit, Number and Base / Radix.

Unit

Unit is a single object. For instance, a mango, a Rupee, and a day can be considered a unit.

Number

A number is a symbol which represents a unit or quantity.

Base / Radix

A number of symbols used in a number system is called the base/radix. The base of any number system is indicated in decimal numbers.

From our childhood, we have learnt to perform calculations using decimal Number System which consists of digits from 0 to 9.

Normally, the base value of decimal numbers are not mentioned, but for the other numbers the base value has to be mentioned. The digits that are used in the decimal number system are as follows;

Table 3.2 – Digits of Decimal Number System

Number System	Decimal Number System or base 10 number system
Base / Radix	10
Digits used	0, 1, 2, 3, 4, 5, 6, 7, 8, 9

Let us study how a number included in the decimal number system is formed.

Example

Let us consider how the number 25 is formed.
25 is formed with the addition of 20 and 5.

$$
\begin{aligned}
25 &= 20 + 5 \\
&= (2 \times 10) + (5 \times 1) \\
&= (2 \times 10^1) + (5 \times 10^0)
\end{aligned}
$$

These positional values such as 10^0, 10^1, 10^2 are called Weighting Factors of decimal number system. This number can be shown on a counting frame (abacus). (Figure 3.5)

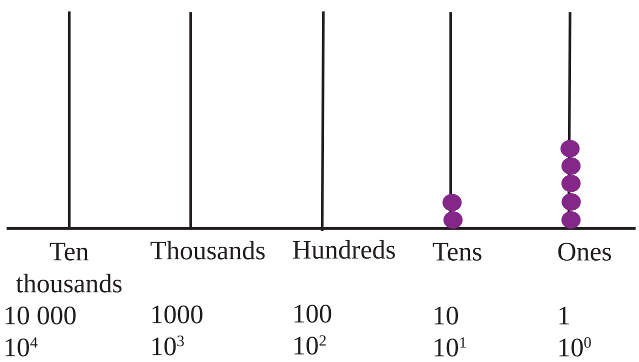


Figure 3.5 – Decimal number representation of 25

This can be shown as given below, as well.

$$\begin{array}{l l r} 2\ 5 & & \\ & 5 \times 10^0 = & 5 \\ & 2 \times 10^1 = & \underline{20} \\ & & \underline{\underline{25}} \end{array}$$

Example

Next, let us consider how a decimal number is formed.

$$\begin{array}{cccccl} 3 & 0 & 2. & 7 & 5 & \text{- decimal number} \\ \downarrow & \downarrow & \downarrow & \downarrow & \downarrow & \\ 10^2 & 10^1 & 10^0 & 10^{-1} & 10^{-2} & \text{- weighting factor} \end{array}$$

$$= (3\times10^2) + (0\times10^1) + (2\times10^0) + (7\times10^{-1}) + (5\times 10^{-2})$$

$$= 300 + 0 + 2 + \frac{7}{10} + \frac{5}{100}$$

$$= 300 + 0 + 2 + 0.7 + 0.05$$

$$= 302.75$$

$$\begin{array}{l l r} 302.75 & & \\ & 5 \times 10^{-2} = & 0.05 \\ & 7 \times 10^{-1} = & 0.7 \\ & 2 \times 10^{0} = & 2 \\ & 0 \times 10^{1} = & 0 \\ & 3 \times 10^{2} = & \underline{300} \\ & & \underline{\underline{302.75}} \end{array}$$

3.2.2 Binary Number System

Though we use the decimal number system when we input numbers as data or instructions, the computer represents these data as 0 and 1. The number system which consists of 0 and 1 is the binary number system.

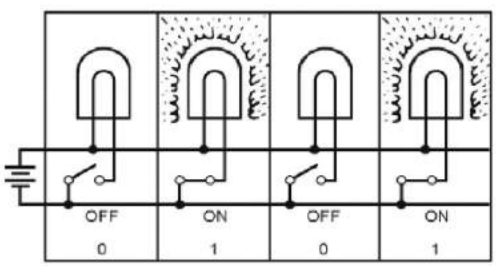


Figure 3.6 – Electronic circuit

The digits for the binary number system is given below. (Table 3.3)

Table 3.3 – Digits used in the Binary Number System

Number System	**Binary Number System**
Base	2
Digits used	0,1

For instance, let us consider 11101101_2.

1	1	1	0	1	1	0	1_2	- decimal number
↓	↓	↓	↓	↓	↓	↓	↓	
2^7	2^6	2^5	2^4	2^3	2^2	2^1	2^0	- weighting factor

The values such as 2^0, 2^1, 2^2, 2^3… are called the weighting factors of binary number system.

2^7	2^6	2^5	2^4	2^3	2^2	2^1	2^0
1	1	1	0	1	1	0	1

This number can be indicated in a binary base counting frame as given below. (Figure 3. 7)

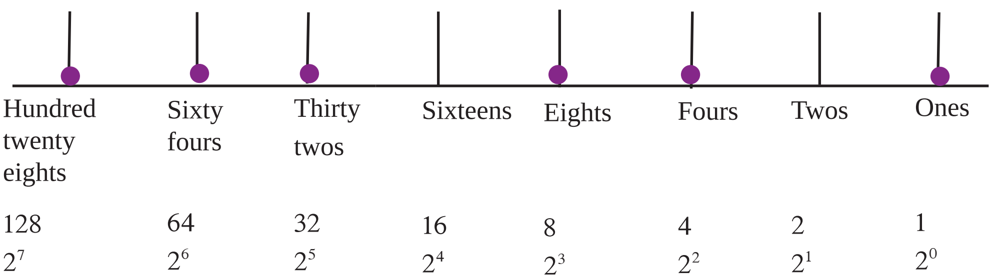


Figure 3.7 – Binary number representation.

The Binary number system is very important in computing and it contributes in the representation of a bit; the basic measuring unit of the computer. The smallest value and the highest value which can be seen in this number system is 0 or 1 respectively. This smallest value is called Bit Binary Digit

3.2.3 Octal Number System

The number system which uses eight digits: 0, 1, 2, 3, 4, 5, 6, 7 is called the octal number system.

Digits of the octal number system are given below. (Table 3.4)

Table 3.4 – Digits of Octal Number System

Number System	**Octal Number System**
Base	8
Digits used	0, 1, 2, 3, 4, 5, 6, 7

For instance, let us consider 236_8.

$$\begin{array}{cccl} 2 & 3 & 6 & \text{- octal number} \\ \downarrow & \downarrow & \downarrow & \\ 8^2 & 8^1 & 8^0 & \text{- weighting factor} \end{array}$$

The values such as 8^0, 8^1, 8^2, 8^3 … are called the weighting factors of the octal number system. This number can be represented as given below in a base eight counting frame. (Figure 3.7)

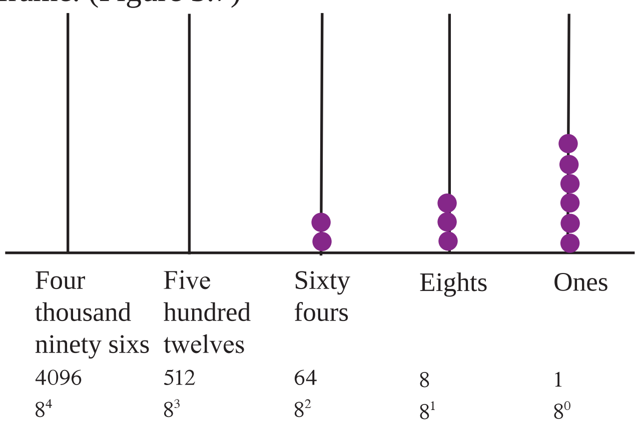


Figure 3.8 – Octal number representation

3.2.4 Hexa-Decimal Number System

The computer uses binary numbers and it is difficult for human beings to read them. Hence, the hexadecimal number system is used as it is easier for humans to use. Normally, calculations are performed using the ten fingers of the hands. Just imagine you have sixteen fingers on your hands. Then you can use sixteen numbers to count. In the hexadecimal number system, ten digits are used from 0 to 9 and for the other 6 digits, A, B, C, D, E and F symbols are used. Here, A, B, C, D, E and F are used to represent 10, 11, 12, 13, 14 and 15. (Table 3.5)

Table 3.5 – Comparison of Decimal and Hex-Decimal numbers

Decimal Number	0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
Hexa-Decimal Digit	0	1	2	3	4	5	6	7	8	9	A	B	C	D	E	F

The Digits of the hexadecimal number system are given in the table below. (Table 3.6)

Table 3.6 - Digits of Hexadecimal Number System

Number System	**Hexadecimal Number System**
Base	16
Digits Used	0, 1, 2, 3, 4, 5, 6, 7, 8, 9, A, B, C, D, E, F

When F the largest number of hexadecimal number system, is expressed in binary form, it can be indicated with 4 Bits. Thus, instead of using a binary number with 4 Bits, a single number in hexadecimal number system can be used. For example, Hexadecimal numbers are used to represent memory addresses of the computer.

You can see code “# 871F78” related to the dark purple colour shown in Figure 3.4. Here the value of the colour is started with “#” symbol. The colour value is indicated in the computer in hexa decimal numbers. Thus, the code for dark purple in the above example is “# 871F78”. R,G,B values of this can be indicated from 0 to 255 in decimal numbers. If “#’ or “&H” (ampersand) symbol is used in front of the value of any value, it is a hexa decimal number. Given below in Table 3.7 are the hexa decimal values and RGB values of dark purple colour.

Table 3.7 – Hexadecimal Value of Dark Purple Colour

Name of Colour	**Colour**	**Hexadecimal Value**	**R**	**G**	**B**
Dark Purple		# 871F78 &H 871F78	135	31	120

For instance, let us consider $15E_{16}$

$$\begin{array}{cccl} 1 & 5 & E_{16} & \text{- Hexa-decimal number} \\ \downarrow & \downarrow & \downarrow & \\ 16^2 & 16^1 & 16^0 & \text{- Weighting factor} \end{array}$$

$$\begin{array}{ccc} 16^2 & 16^1 & 16^0 \\ \searrow & \downarrow & \swarrow \\ & 15E_{16} & \end{array}$$

Here, $16^0, 16^1, 16^2, 16^3$….. values are called Hexadecimal Weighting Factors. This number can be represented on a sixteen base counting frame as below. (Figure 3.9)

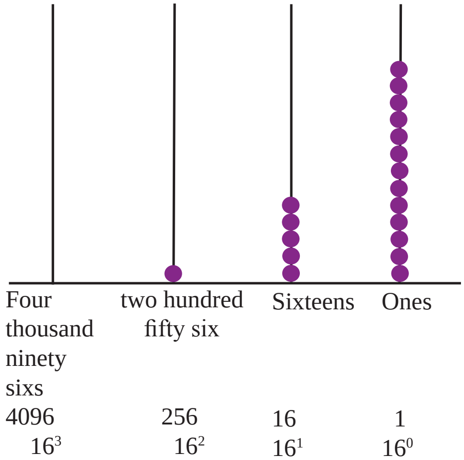


Figure 3.9 – Sixteen base number representation

Relationship among Decimal, Binary, Octal and Hexadecimal

Figure 3.8 - Relationship among Decimal, Binary, Octal and Hexadecimal

	Decimal	Binary	Octal	Hexadecimal	
	0	0	0	0	
2^0	1	1	1	1	$8^0, 16^0$
2^1	2	10	2	2	
	3	11	3	3	
	4	100	4	4	
	5	101	5	5	
	6	110	6	6	
	7	111	7	7	
2^3	8	1000	10	8	8^1
	9	1001	11	9	
	10	1010	12	A	
	11	1011	13	B	
	12	1100	14	C	
	13	1101	15	D	
	14	1110	16	E	
	15	1111	17	F	
2^4	16	10000	20	10	16^1
	17	10001	21	11	
	18	10010	22	12	
	19	10011	23	13	
	20	10100	24	14	
	21	10101	25	15	
	22	10110	26	16	
	23	10111	27	17	
	24	11000	30	18	

3.3 Most and Least Significant Positional Value of a Number

There are two seperate methods to find the most and least significant values of decimal numbers and whole numbers. When a whole number is read from left to right, the number in the right most end is the least significant positional value and the number in the left most end which is not 0 is the most significant positional value. (Figure 3.10)

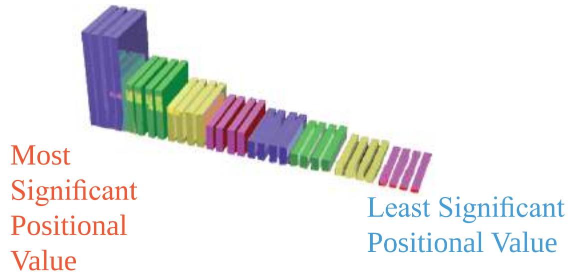


Figure 3.10 - Most and Least Significant Positional Values

In decimal numbers, the value in the right extreme after the decimal point which is not 0 becomes the least significant positional value and the number in the left extreme of the decimal point which is not 0 becomes the most significant positional value.

3.3.1 Most Significant Digit (MSD) and Least Significant Digit (LSD)

Given below in Table 3.9 are the most and least significant digits of a round figure or a decimal number.

Table 3.9 – The Most and Least Significant Positional Value of a number

Number	MSD	LSD
329	3	9
1237.0	1	7
58.32	5	2
0.0975	9	5
0.4	4	4

You can use the same method used for the decimal number system to find the most and least significant positional digits of binary, octal and hexadecimal numbers.

Activity

Find the most significant digit and the least significant digit of the following numbers.

(i) 56870_{10} (ii) 154.01_{10} (iii) 23.080_8 (iv) $AD\,239_{16}$

(v) 0.00110_2

3.3.2 Most Significant Bit (MSB) and Least Significant Bit (LSB)

Only the Binary Number System is used to find the most significant bit (MSB) and the least significant bit(LSB). There are two ways to find this using decimal numbers and whole numbers.

In a whole number, read from left to right, the value in the right extreme is the least significant bit and the value in the left extreme which is not 0 is the most significant bit. In binary decimal numbers, the value in the right extreme of the decimal point which is not 0 is the least significant bit and the value in the left extreme of the decimal point which is not 0 is the most significant bit.

Table 3.10 - The most significant bit and the least significant bit

Binary Number	MSB	LSB
1001	$1 = (2^3)$	$1 = (2^0)$
011.101	$1 = (2^1)$	$1 = (2^{-3})$

Activity

Find the most significant bit and the least significant bit of the following numbers.

(i) 1000_2 (ii) 011101_2 (iii) 0.11001_2 (iv) 1.0010_2

(v) 0.00110_2

3.4 Converting Decimal Numbers to Binary, Octal and Hexa-Decimal Numbers

3.4.1 Conversion of Decimal numbers to numbers of other bases

All the data we input to the computer is taken by it as digits of binary number system; 0 and 1. Hence, the knowledge to convert a base ten number to another base is important. Here in this chapter, conversion of a decimal number to a binary number, octal number and a hexadecimal number is discussed.

3.4.2 Conversion of Decimal Numbers to Binary Numbers

When a decimal number is converted to a binary number, the decimal number can be divided by two until the remainder is 0 and the remainder of the division can be written on the right side. After that, write all the remainders from the bottom to top to build the number.

Example

Converting number 12_{10} to a binary number.

➢ First, divide this number by 2 writing the remainders.

		Remainder
2	12	
2	6	0
2	3	0
2	1	1
	0	1

Quotient

➢ Secondly, write down all the remainders from bottom to top.

$12_{10} = \underline{\underline{1100_2}}$

Example

Converting 46_{10} to a binary number.

2 | 46		
2 | 23	—	0
2 | 11	—	1
2 | 5	—	1
2 | 2	—	1
2 | 1	—	0
0	—	1

$46_{10} = 101110_2$

Activity

Convert the following decimal numbers to binary numbers.

(i) 155_{10} (ii) 472_{10} (iii)1163_{10}

3.4.3 Converting Decimal Numbers to Octal Numbers

Here, divide the given number by 8 until the remainder is 0 and write the remainders from bottom to top.

Example

Converting 158_{10} to an octal number.

➢ Firstly, divide this number by 8 and write down the remainder.

8 | 158		
8 | 19	—	6
8 | 2	—	3
0	—	2

Remainders

Quotient

➢ Secondly, write down all the remainders from bottom to top.

$158_{10} = 236_8$

Activity

Convert the following decimal numbers to octal numbers.

(i) 155_{10} (ii) 472_{10} (iii) 1163_{10}

3.4.4 Converting Decimal Numbers to Hexadecimal Numbers

Here, divide the number by 16 until the remainder is 0 and write down the remainders from bottom to top.

Example

Converting number 38_{10} to a hexadecimal number.

- Firstly, divide this number by 16 and write down the remainders.

$$
\begin{array}{r|l}
16 & 38 \\ \hline
16 & 2 \quad — \ 6 \\ \hline
 & 0 \quad — \ 2
\end{array}
$$

remainders

Quotient

- Secondly, write down all the remainders from bottom to top.

$38_{10} = 26_{16}$

Example

Converting number 47_{10} to a hexadecimal number.

$$
\begin{array}{r|l}
16 & 47 \\ \hline
16 & 2 \quad — \ 15 \rightarrow F \\ \hline
 & 0 \quad — \ 2 \rightarrow 2
\end{array}
$$

$47_{10} = 2F_{16}$

Activity

Convert the following decimal numbers to hexadecimal numbers.

(i) 256_{10} (ii) 478_{10} (iii) 1963_{10}

3.5 Conversion among Binary, Octal, Hexadecimal and Decimal Numbers

We have converted decimal numbers (base ten) to binary, octal and hexadecimal numbers earlier. Now let us consider how to convert binary numbers to decimal numbers, octal numbers to decimal numbers and hexadecimal numbers to decimal numbers. (Figure 3.11)

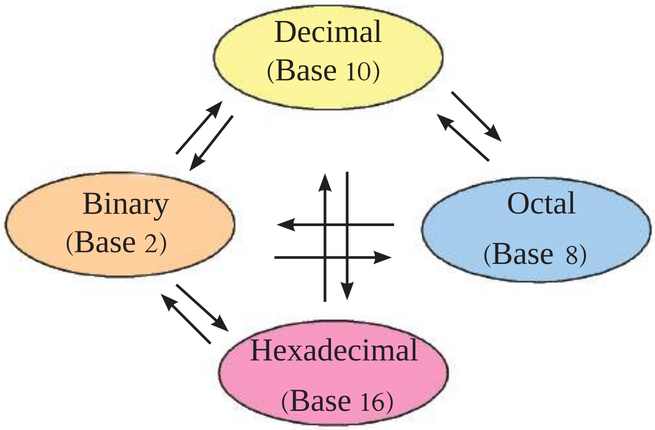


Figure 3.11 – Conversion between number systems

3.5.1 Converting Binary Numbers to Decimal Numbers

Example

Converting number 1101_2 to a decimal number.

$$\begin{array}{cccc} 1 & 1 & 0 & 1 \\ \downarrow & \downarrow & \downarrow & \downarrow \\ 2^3 & 2^2 & 2^1 & 2^0 \end{array}$$

$$\begin{aligned} 1101_2 &= (1\times2^3) + (1\times2^2) + (0\times2^1) + (0\times2^0) \\ &= (1\times8) + (1\times4) + (0\times2) + (1\times1) \\ &= 8 + 4 + 0 + 1 \end{aligned}$$

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

1101_2

$$\begin{aligned} &\rightarrow 1\times2^0 = 1 \\ &\rightarrow 0\times2^1 = 0 \\ &\rightarrow 1\times2^2 = 4 \\ &\rightarrow 1\times2^3 = 8 \\ & \qquad\qquad \underline{\underline{13}} \end{aligned}$$

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

Activity

Convert the following binary numbers to decimal numbers.

(i)101_2 (ii) 111010110_2 (iii)1010010111_2

3.5.2 Converting Octal Numbers to Decimal Numbers

Example

Converting number 1275_8 to a decimal number.

$$\begin{array}{cccc} 1 & 2 & 7 & 5 \\ \downarrow & \downarrow & \downarrow & \downarrow \\ 8^3 & 8^2 & 8^1 & 8^0 \end{array}$$

$$\begin{aligned} 1275_8 &= (1\times8^3) + (2\times8^2) + (7\times8^1) + (5\times8^0) \\ &= (1\times512) + (2\times64) + (7\times8) + (5\times1) \\ &= 512 + 128 + 56 + 5 \end{aligned}$$

$$\underline{\underline{1275_8 = 701_{10}}}$$

1275_8

$$\begin{aligned} 5\times8^0 &= 5 \\ 7\times8^1 &= 56 \\ 2\times8^2 &= 128 \\ 1\times8^3 &= 512 \\ & \overline{701} \end{aligned}$$

$$\underline{\underline{1275_8 = 701_{10}}}$$

Activity

Convert the following octal numbers to decimal numbers.

(i) 230_8 (ii) 745_8 (iii) 2065_8

3.5.3 Converting Hexadecimal Numbers to Decimal Numbers

Example

Converting number 329_{16} to a decimal number.

$$\begin{array}{ccc} 3 & 2 & 9 \\ \downarrow & \downarrow & \downarrow \\ 16^2 & 16^1 & 16^0 \end{array}$$

$$\begin{aligned} 329_{16} &= (3\times16^2) + (2\times16^1) + (9\times16^0) \\ &= (3\times256) + (2\times16) + (9\times1) \\ &= 768 + 32 + 9 \end{aligned}$$

$$\underline{\underline{329_{16} = 809_{10}}}$$

329_{16}

$$\begin{aligned} 9\times16^0 &= 9 \\ 2\times16^1 &= 32 \\ 3\times16^2 &= 768 \\ & \overline{809} \end{aligned}$$

$$\underline{\underline{329_{16} = 809_{10}}}$$

Example

Converting number $AB2_{16}$ to a decimal number.

$$\begin{array}{ccc} A & B & 2 \\ \downarrow & \downarrow & \downarrow \\ 16^2 & 16^1 & 16^0 \end{array}$$

$$\begin{aligned} AB2_{16} &= (A\times16^2) + (B\times16^1) + (2\times16^0) \\ &= (10\times256) + (11\times16) + (2\times1) \\ &= 2560 + 176 + 2 \\ AB2_{16} &= 2738_{10} \end{aligned}$$

$AB2_{16}$

$$\begin{aligned} 2\times16^0 &= 2 \\ 11\times16^1 &= 176 \\ 10\times16^2 &= 2560 \\ & \quad 2738 \end{aligned}$$

$AB2_{16} = 2738_{10}$

Activity

Convert the following hexadecimal numbers to decimal numbers

(i) $1A_{16}$ (ii) $7EF_{16}$ (iii) $A49_{16}$

3.5.4 Converting Binary Numbers to Octal Numbers

From the digits used in the octal number system; 0, 1, 2, 3, 4, 5, 6, and 7, the largest digit is 7. We can indicate digit 7 as 111_2 in binary form. Thus 7; the largest digit in the octal number system, can be indicated in a binary form with 3 digits. Likewise all the digits in the octal number system can be indicated in the three digit binary form. Given below in Table 3.11 are the binary forms of the digits used in eight base (octal) number system.

Table 3.11 – Indicating octal digits in decimal and binary numbers.

Decimal Number	Octal Number	Binary Number
0	0	000
1	1	001
2	2	010
3	3	011
4	4	100
5	5	101
6	6	110
7	7	111

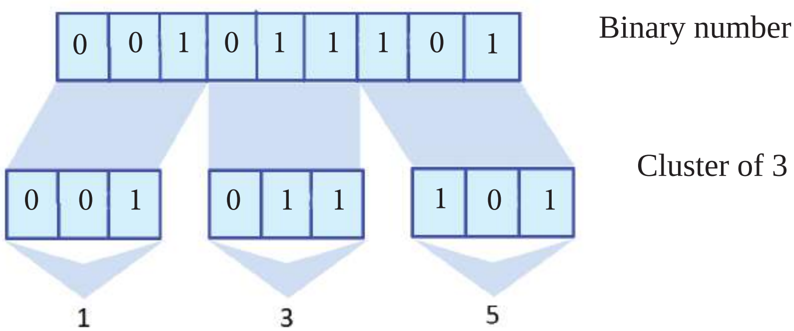
As per the above table, three bits are used when indicating an octal number in binary form. $(8 = 2^3)$

Let us consider how a binary number is converted to an octal number.

Example

Converting 1011101_2 to an octal number.

- ➢ First, divide the number into three bits from the right corner to the left corner. If the last cluster in the left corner does not consist of 3 bits, add 0s to complete.
- ➢ Write each octal number separately for each cluster.
- ➢ Then write these clusters in octal digits.
- ➢ Write these digits in order from the left corner to the right corner.



$$1011101_2 = 135_8$$

Activity

Convert the following binary numbers to octal numbers.

(i) 10011001_2 (ii) 111100111_2 (iii) 10101010110_2

3.5.5 Converting Binary Numbers to Hexadecimal Numbers

From the symbols used in the hexadecimal number system, the value represented by "F" possesses the largest numerical value. This can be indicated as a four-bit binary number; 1111_2. Thus, all the digits in the hexadecimal number system can be indicated as four-bit binary numbers. Given below in Table 3.12 are the binary numbers for the digits used in the hexadecimal number system.

Table 3.12 – Indicating hexadecimal digits in decimal and binary numbers.

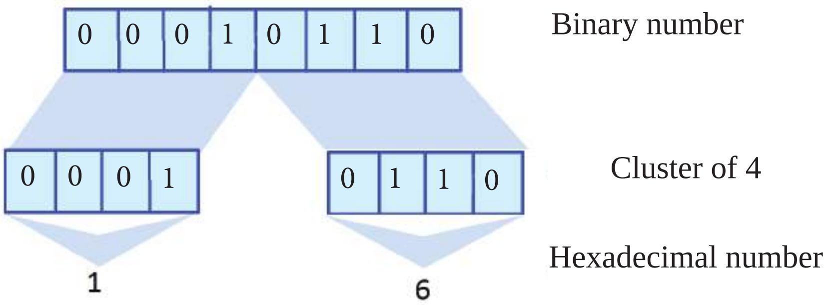
Decimal Number	Hexadecimal Number	Binary Number
0	0	0000
1	1	0001
2	2	0010
3	3	0011
4	4	0100
5	5	0101
6	6	0110
7	7	0111
8	8	1000
9	9	1001
10	A	1010
11	B	1011
12	C	1100
13	D	1101
14	E	1110
15	F	1111

As shown in the table above (Table 3.12), four bits are used to indicate a hexadecimal number in binary form. ($16 = 2^4$)

Example

Converting number 10110_2 to a hexadecimal number.

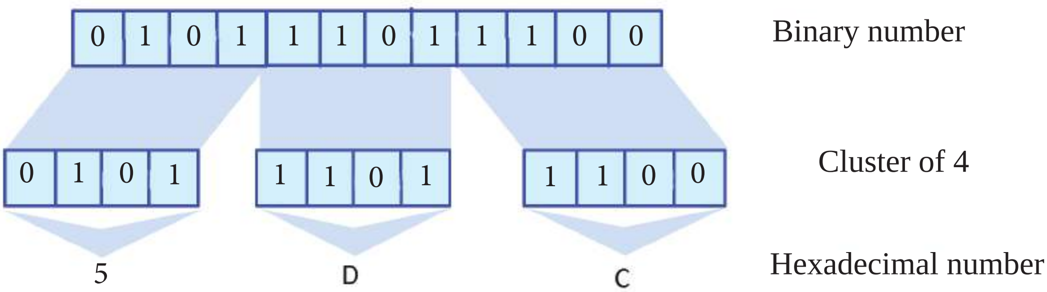
- First, divide the number into four-bit clusters from the right corner to the left corner.
- Write hexadecimal numbers separately for each cluster.
- Write these numbers in order from the left corner to the right corner and write down the base.



$$\underline{\underline{10110_2 = 16_{16}}}$$

Example

Converting number 10111011100_2 to a hexadecimal number.



$$\underline{\underline{10111011100_2 = 5DC_{16}}}$$

Activity

Convert the following binary numbers to hexadecimal numbers.

(i) 11011010_2 (ii) 11111001101_2 (iii) 10011100011_2

3.5.6 Converting Octal numbers to Binary Numbers

We have learned above that an octal number can be indicated in three digits when it is converted to a binary number.

Thus, each digit in octal numbers should be written in three digits when it is converted to base two.

Example

Converting number 457_8 to a binary number.

- Firstly, write each digit in octal number in three bits.
- Secondly, write down all the bits together to get the binary number for the octal number.

4	5	7
100	101	111

$457_8 = 100101111_2$

Activity

Convert the following octal numbers to binary numbers.

(i) 10_8 (ii) 245_8 (iii) 706_8

3.5.7 Converting Octal numbers to Hexadecimal Numbers

Example

Converting number 1057_8 to a hexadecimal number.

- First, write each digit in octal number in three bits.
- Divide the binary number you get into four-bit clusters from the right corner to the left corner.
- Write the related hexadecimal number for each cluster.

1	0	5	7
001	000	101	111

00 1 0	0 0 1 0	1111
2	2	15
2	2	F

$1057_8 = 22F_{16}$

Activity

Convert the following octal numbers to hexadecimal numbers

(i) 320_8 (ii) 475_8 (iii) 1673_8

3.5.8 Converting Hexadecimal Numbers to Binary Numbers

You have learnt earlier that any symbol in a hexadecimal number can be written in a four-bit binary number. Thus, when a hexadecimal number is converted to a binary number, each digit in that number should be indicated in a four-bit binary number.

Example

Converting number 74_{16} to a binary number.

7	4
0111	0100

$$74_{16} = 1110100_2$$

Converting number $2AE_{16}$ to a binary number.

2	*A*	*E*
0010	1 010	1110

$$2AE_{16} = 1010101110_2$$

Activity

Convert the following hexadecimal numbers to binary numbers.

(i) 78_{16} (ii) $B2C_{16}$ (iii) $4DEF_{16}$

3.5.9 Converting Hexadecimal Numbers to Octal Numbers

First, the hexadecimal number should be converted to a binary number and then it should be converted to an octal number.

Example

Converting number $23A_{16}$ to an octal number.

2	3	A
0010	0011	1010

001	0 0 0	1 1 1	010
1	0	7	2

$23A_{16} = 1072_8$

Activity

Convert the following hexadecimal numbers to octal numbers.

(i) 320_{16} (ii) $A7B_{16}$ (iii) $10ED_{16}$

Activity

1. Consider number "23_y". Here, 'y' is the base of the number system. From the number systems you have learned, as to which number system "23y" belongs.
2. Convert the decimal number 83_{10} to a binary number. Show steps.
3. Convert the binary number 10110111_2 to an octal number. Show steps.
4. Convert the hexadecimal number $23D_{16}$ to a binary number.

5. Fill in the blanks in the table given below.

Table 3.13 – Several colours and their RGB values and the hexadecimal values

Name of the Colour	Colour	Hexadecimal Value	R	G	B
Dark purple		# 871F78	135	31	120
Light pink			255	182	193
Sky blue			50	153	204
Green			0	255	0
Yellow			255	238	0

3.6 Data Storage Capacity

A certain space is needed to store data in the computer. Data storage capacity is measured by units such as bits, bytes, kilobytes, Megabytes, Gigabytes, Terabytes and Petabytes. Let us understand how to arrange these different data storage capacities in order from the small unit to the big unit and to define the relationships between these as well.

3.6.1 Units to Measure Data Storage

Bit

This is the smallest unit used in the computer to store data. This word is coined from the words Binary Digit. A bit is the two binary digits; 0 and 1.

Byte

1 byte is 8 bits.

Nibble

A nibble is half of a byte or 4 bits. This unit is not commonly used like bits and bytes.

kilobyte

This consists of 1024 bytes. ($1024 = 2^{10}$) Kilobyte is written as KB or kbyte.

Megabyte

This consists of 1024 kilobytes (1024 = 210) or 1048576 bytes. Megabyte is written as MB or mbyte.

Gigabyte

One Gigabyte is made of 1024 Megabytes. (1024 MB) Gigabyte is written as GB or gbyte. It is wrong to write 'Gb' as it indicates gigabit.

Terabyte

One Terabyte is made of 1024 Gigabytes (1024 GB). This is written as TB.

Petabyte

One Petabyte is made of 1024 Terabytes (1024 TB).

Observation

Following are the relationships between units which measure data storage capacity.

8 bits	=	1 byte
4 bits	=	1 nibble
1024 bytes	=	1 kilobyte (KB)
1024 kilobytes	=	1 Megabyte (MB)
1024 Megabytes	=	1 Gigabyte(GB)
1024 Gigabytes	=	1 Terabyte(TB)
1024 Terabytes	=	1 Petabyte(PB)

Consider the examples given below to get an idea about the units above.

Table 3.14 – Approximate data storage capacity as text pages.

Name	Abbreviation	Approximate Bytes	Exact Bytes	Approximate Text pages
Byte	B	One	1	One text
Kilobyte	KB (or K)	Thousand	1024	½ page
Megabyte	MB	One million	1,048,576	500 pages
Gigabyte	GB	One billion	1,073,741,824	500,000 pages
Terabyte	TB	One trillion	1,099,511,627,776	500,000,000 pages

3.6.2 Capacities of Data Storage Devices

Different storage devices possess different storage capacities. The tasks fulfilled by these devices are also different. Let us study these different storage devices. (Figure 3.12)

Register Memory
1 KB
Cache memory
3 MB – 32 MB
Compact Disk (CD)
650 – 900 MB
Digital Versatile Disc
4.7 – 9 GB
Random Access Memory
01 – 64 GB
Read Only Memory (ROM)
Flash Memory
1 – 64 GB
Hard Disk
100 GB – 6 TB
Magnetic Tape
1 TB – 185 TB

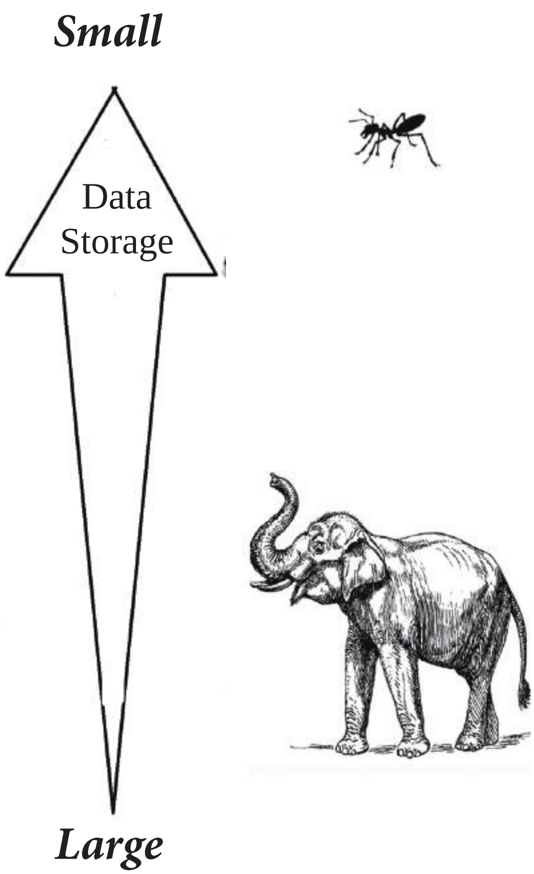


Figure 3.12 – Capacities of storage devices

When reading and writing data, the time spent to access the devices (access speed) is different. Consider the figure given below. (Figure 3.13)

3.6.3 Data Access Speed

Register Memory
Cache Memory
Random Access Memory
Read Only Memory
Flash Memory
Hard Disk
Digital Versatile Disc – DVD
Compact Disc (CD)
Magnetic Tape

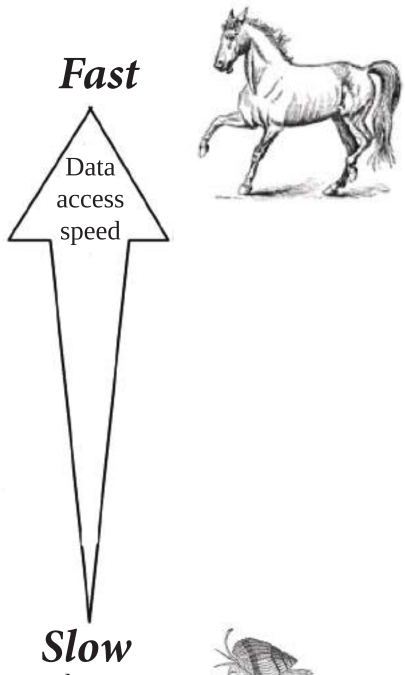


Figure 3.13 – Data access speed

3.6.4 Cost per unit Storage

For different storage devices, cost per a bit to store data is different. For instance, the cost is more for Register Memory and Cache Memory. The comparison is shown in the figure given below. (Figure 3.14)

Register Memory
Cache Memory
Random Access Memory
Read Only Memory
Magnetic Tape
Flash Memory
Hard Disk
Digital Versatile Disc – DVD

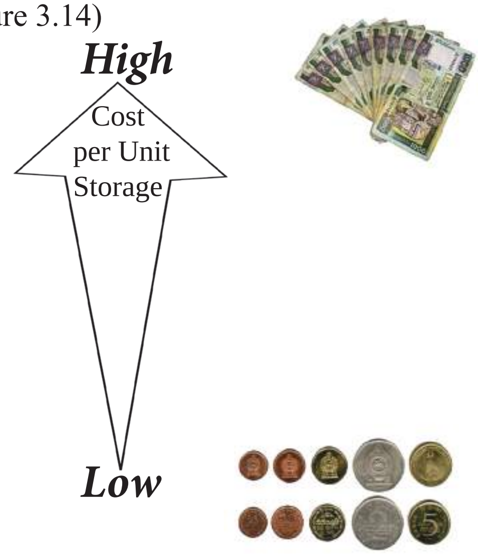


Figure 3.14 – Cost per unit storage

3.7 Coding Systems

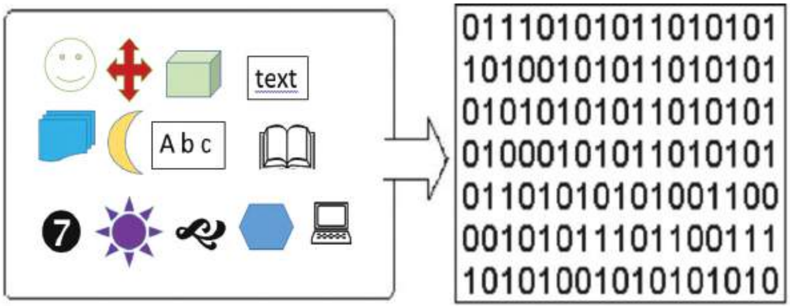


Figure 3.15 – Data you enter to the computer and computer data representation

According to the above figure (Figure 3.15), when you enter a data to the computer, it converts the data to different patterns made of 0 and 1. Thus, binary codes are used when storing numeric, alphabetic, special character, images and sounds in internal storage devices of computers.

In the beginning of the lesson, when you type ‘A’ on the keyboard, the code you get for ‘A’ is the bits pattern 1000001 (the binary code of letter ‘A’). The number of bits used is 7. Thus, a combination made of a bit pattern is used to represent each data and the bits used for each code is different. Following are different coding systems used.

1. BCD — Binary Coded Decimal
2. ASCII — American Standards Code for Information Interchange
3. EBCDIC — Extended Binary Coded Decimal Interchange Code
4. Unicode

3.7.1 BCD - Binary Coded Decimal

This coding system was used in the early stages of computing. In this system one digit is represented by 4 bits. This is used only to represent decimal numbers. Sixteen symbols ($2^4 = 16$) can be represented in this system. The table 3.15 shows the BCD codes for the 10 digits from 0 to 9.

Table 3.15 – Decimal Numbers and BCD Values

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

Example

Indicating number 37_{10} in BCD codes.

$3 \quad 7_{10}$

$0011 \quad 0111$

$37_{10} = 00110111$

Activity

Write the BCD values for the decimal values given below.

(i) 302 (ii) 2136 (iii) 17295

3.7.2 ASCII – American Standard Code for Information Interchange

Initially ASCII coding system used 7-bit binary digit. 128 characters can be represented using this coding system. ASCII is used to represent text. (Appendix - Table 3.17)

ASCII system is designed and approved by ANSI (American National Standard Institute).

Example

- **Text**

When the word ‘School’ is entered into the computer through the keyboard, write down how it is understood by the computer. (Use Appendix Table 3.7)

- First, write the decimal numbers for the symbols.

  S - 83 c - 99 h - 104 o - 111 l - 108

- Write binary numbers for each value.

  S - 1010011 c – 1100011 h - 1101000 o - 1101111
  l - 1101100

- Write the associated code

  S c h o o l
  101001111000111110100011011111101111101100

Activity

Write down the ASCII code of “ICT” in binary numbers.

3.7.3 EBCDIC – Extended Binary Coded Decimal Interchange Code

We can write only 128 characters using ASCII system, but the EBCDIC code system allows the use of 256 characters. Here, one symbol can be written with a binary number which consists of 8 bits. Hence, 256 characters can be represented using this system. This system was used in IBM main frame computers. The table below shows that there are different EBCDIC codes for the 26 different capital letters and 26 different EBCDIC codes for the 26 simple letters in this system.

Table 3.16 – EBCDIC values for English capital and simple letters

Uppercase			Lowercase		
	EBCDIC			**EBCDIC**	
Character	In Binary	In Hexa Decimal	Character	In Binary	In Hexa Decimal
A	1100 0001	C1	a	1000 0001	81
B	1100 0010	C2	b	1000 0010	82
C	1100 0100	C3	c	1000 0011	83
D	1100 0101	C4	d	1000 0100	84

3.7.4 Unicode System

Though 128 characters can be used in the ASCII system and 256 characters can be used in the EBCDIC system for data representation. For example, these systems cannot be used for Sinhala, Japanese, Chinese and Tamil languages as there are more than 256 characters. Hence Unicode system was designed according to a standard to represent 65536 different symbols of 16 bits ($2^{16} = 65536$).

As per the figure given below (Figure 3.16), shows the Unicode system can be used to represent Sinhala and Tamil letters, and special symbols and picture symbols.

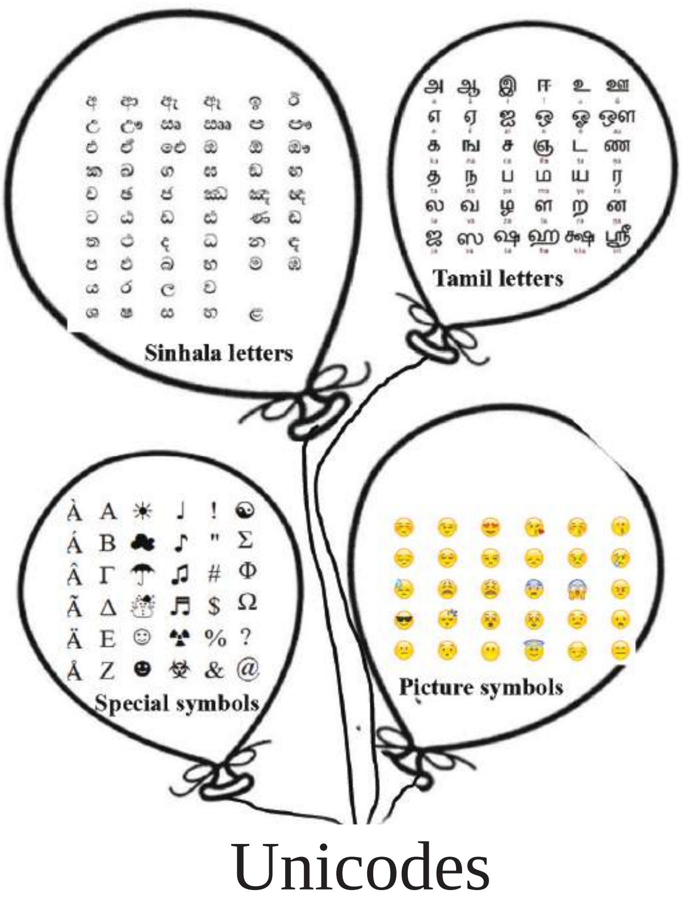


Figure 3.16 – Occasions Unicode are used

Unicode system uses unique number for each number, text or symbol in any or Operating System.

Example

- **Picture and Graphic Data**

Given below (Figure 3.17) is a close up or a highly enlarged image of photograph. A photograph consists of pixels (dots) made of different colours in big grid. Computer graphic data such as pictures, frames of a movie or frames of an animation consist of various colours. The picture given below consists of a number of different colours.

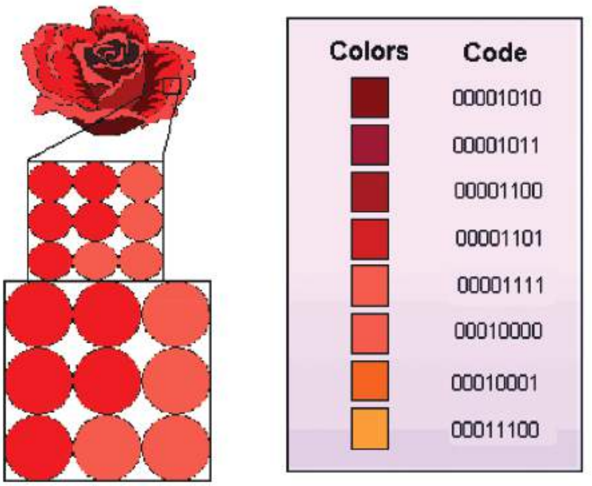


Figure 3.17 – Colours in a picture and their binary values.

- **Sound**

As shown in the figure below (Figure 3.17) is the sound emitted from a speaker is normally represented as analog waves. However, all data in computer are digital data and those are made of bytes. Hence, sound which comes as a analog data is converted to a digital data. Thus, a sound is also represented in a bits pattern made of 0s and 1s in a computer.

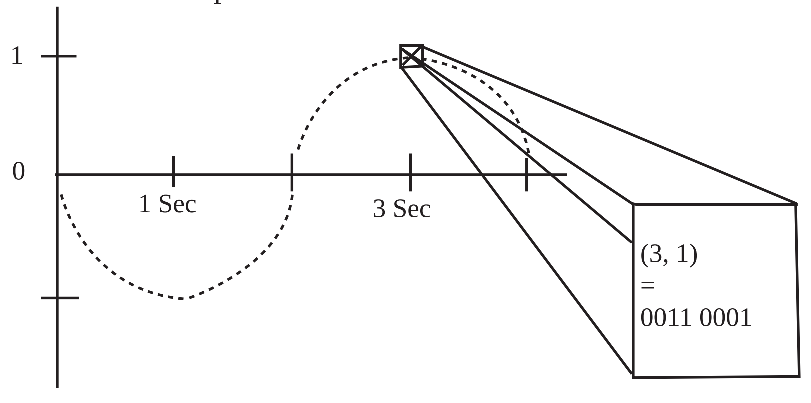


Figure 3.18 – Conversion of analog data of a sound to digital data

By this coding system, codes are classified to represent characters of all the international languages. The institution which initiated is the International Standard Institution and Unicode Consortium. Unicode is largely used in designing websites and newspapers. (Appendix - Table 3.18)

Activity

1. If ‘A’ character is represented as 1000001 in ASCII system, what is the ASCII code for letter ‘F’?

2. What is the largest number presented in BCD (Binary Coded Decimal)?

3. What is the minimum number of bits required to present a hexadecimal number?

4. If 1000010_2 represents “B” in ASCII code, what is the ASCII code for letter “L”?

5. What are the coding systems used in computers? Explain the need to use such coding systems.

Summary

Number systems used for data representation

Number Systems		
Number Systems	**Base**	**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

❖ Code systems used in computers

Code System	Number of Bits Used
BCD - Binary Coded Decimal	4
ASCII - American Standard Code for Information Interchange Code	7
EBCDIC- Extended Binary Coded Decimal Interchange Code	8
Unicode	16

Appendix

ASCII and EBCDIC codes for characters and related decimal, octal and hexadecimal numbers

Table 3.17 - ASCII and EBCDIC codes for characters and related decimal, octal and hexadecimal numbers

Decimal	Hex	Octal	EBCDIC Character	ASCII Character		Decimal	Hex	Octal	EBCDIC Character	ASCII Character
00	00	000	NUL	NUL		128	80	200		
001	01	001	SOH	SOH		129	81	201	a	
002	02	002	STX	STX		130	82	202	b	
003	03	003	ETX	ETX		131	83	203	c	
004	04	004	PF	EOT		132	84	204	d	
005	05	005	HT	ENQ		133	85	205	e	
006	06	006	LC	ACK		134	86	206	f	
007	07	007	DEL	BEL		135	87	207	g	
008	08	010		BS		136	88	210	h	
009	09	011		HT		137	89	211	i	
010	0A	012	SMM	LF		138	8A	212		
011	0B	013	VT	VT		139	8B	213		
012	0C	014	FF	FF		140	8C	214		
013	0D	015	CR	CR		141	8D	215		
014	0E	016	SO	SO		142	8E	216		
015	0F	017	SI	SI		143	8F	217		
016	10	020	DLE	DLE		144	90	220		
017	11	021	DC1	DCI		145	91	221	j	
018	12	022	DC2	DC2		146	92	222	k	
019	13	023	TM	DC3		147	93	223	l	
020	14	024	RES	DC4		148	94	224	m	

021	15	025	NL	NAK		149	95	225	n	
022	16	026	BS	SYN		150	96	226	o	
023	17	027	IL	ETB		151	97	227	p	
024	18	030	CAN	CAN		152	98	230	q	
025	19	031	EM	EM		153	99	231	r	
026	1A	032	CC	SUB		154	9A	232		
027	1B	033	CU1	ESC		155	9B	233		
028	1C	034	IFS	FS		156	9C	234		
029	1D	035	IGS	GS		157	9D	235		
030	1E	036	IRS	RS		158	9E	236		
031	1F	037	IUS	US		159	9F	237		
032	20	040	DS	Space		160	A0	240		
033	21	041	SOS	!		161	A1	241		
034	22	042	FS	"		162	A2	242	s	
035	23	043		#		163	A3	243	t	
036	24	044	BYP	$		164	A4	244	u	
037	25	045	LF	%		165	A5	245	v	
038	26	046	ETB	&		166	A6	246	w	
039	27	047	ESC	'		167	A7	247	x	
040	28	050		(		168	A8	250	y	
041	29	051		)		169	A9	251	z	
042	2A	052	SM	*		170	AA	252		
043	2B	053	CU2	+		171	AB	253		
044	2C	054		,		172	AC	254		
045	2D	055	ENQ	-		173	AD	255	[	
046	2E	056	ACK	.		174	AE	256		
047	2F	057	BEL	/		175	AF	257		
048	30	060		0		176	B0	260		
049	31	061		1		177	B1	261		
050	32	062	SYN	2		178	B2	262		
051	33	063		3		179	B3	263		
052	34	064	PN	4		180	B4	264		
053	35	065	RS	5		181	B5	265		
054	36	066	UC	6		182	B6	266		
055	37	067	EOT	7		183	B7	267		
056	38	070		8		184	B8	270		
057	39	071		9		185	B9	271		
058	3A	072		:		186	BA	272		

059	3B	073	CU3	;		187	BB	273		
060	3C	074	DC4	<		188	BC	274		
061	3D	075	NAK	=		189	BD	275	]	
062	3E	076		>		190	BE	276		
063	3F	077	SUB	?		191	BF	277		
064	40	100	Space	@		192	CO	300	{	
065	41	101		A		193	C1	301	A	
066	42	102		B		194	C2	302	B	
067	43	103		C		195	C3	303	C	
068	44	104		D		196	C4	304	D	
069	45	105		E		197	C5	305	E	
070	46	106		F		198	C6	306	F	
071	47	107		G		199	C7	307	G	
072	48	110		H		200	C8	310	H	
073	49	111		I		201	C9	311	I	
074	4A	112	CENT	J		202	CA	312		
075	4B	113	.	K		203	CB	313		
076	4C	114	<	L		204	CC	314		
077	4D	115	(	M		205	CD	315		
078	4E	116	+	N		206	CE	316		
079	4F	117	|	O		207	CF	317		
080	50	120	&	P		208	D0	320	}	
081	51	121		Q		209	D1	321	J	
082	52	122		R		210	D2	322	K	
083	53	123		S		211	D3	323	L	
084	54	124		T		212	D4	324	M	
085	55	125		U		213	D5	325	N	
086	56	126		V		214	D6	326	O	
087	57	127		W		215	D7	327	P	
088	58	130		X		216	D8	330	Q	
089	59	131		Y		217	D9	331	R	
090	5A	132	!	Z		218	DA	332		
091	5B	133	$	[		219	DB	333		
092	5C	134	*	\		220	DC	334		
093	5D	135	)	]		221	DD	335		
094	5E	136	;	^		222	DE	336		

095	5F	137		_		223	DF	337		
096	60	140	-	`		224	E0	340		
097	61	141	/	a		225	E1	341		
098	62	142		b		226	E2	342	S	
099	63	143		c		227	E3	343	T	
100	64	144		d		228	E4	344	U	
101	65	145		e		229	E5	345	V	
102	66	146		f		230	E6	346	W	
103	67	147		g		231	E7	347	X	
104	68	150		h		232	E8	350	Y	
105	69	151		i		233	E9	351	Z	
106	6A	152		j		234	EA	352		
107	6B	153	,	k		235	EB	353		
108	6C	154	%	l		236	EC	354		
109	6D	155	_	m		237	ED	355		
110	6E	156	>	n		238	EE	356		
111	6F	157	?	o		239	EF	357		
112	70	160		p		240	F0	360	0	
113	71	161		q		241	F1	361	1	
114	72	162		r		242	F2	362	2	
115	73	163		s		243	F3	363	3	
116	74	164		t		244	F4	364	4	
117	75	165		u		245	F5	365	5	
118	76	166		v		246	F6	366	6	
119	77	167		w		247	F7	367	7	
120	78	170		x		248	F8	370	8	
121	79	171		y		249	F9	371	9	
122	7A	172	:	z		250	FA	372		
123	7B	173	#	{		251	FB	373		
124	7C	174	@	|		252	FC	374		
125	7D	175	`	}		253	FD	375		
126	7E	176	=	~		254	FE	376		
127	7F	177	"	DEL		255	FF	377		

Table 3.18 – ASCII and EBCDIC values related to letters

Unicode for Sinhala and Tamil letters

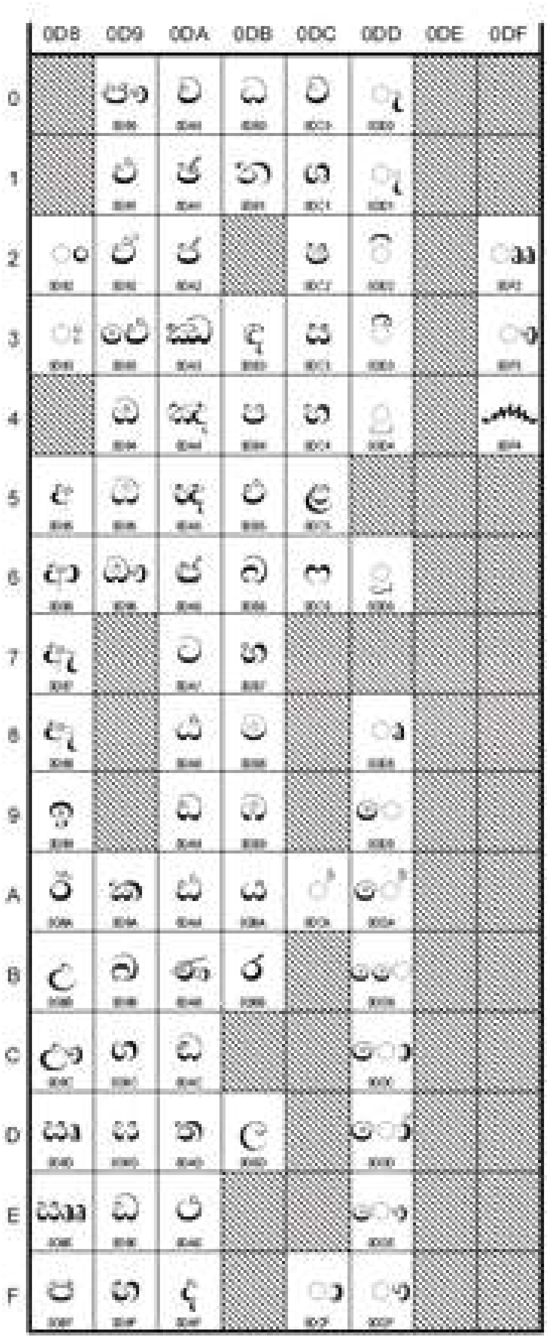


Table 3.18 – Sinhala Unicode

	0B8	0B9	0BA	0BB	0BC	0BD	0BE	0BF
0		ஐ		ர	ீ	ௐ		௰
1				ற	ு			௱
2	ஂ	ஒ		ல	ூ			௲
3	ஃ	ஓ	ண	ள				௳
4		ஔ	த	ழ				௴
5	அ	க		வ				௵
6	ஆ			ஶ	ெ		௦	௶
7	இ			ஷ	ே	ௗ	௧	௷
8	ஈ		ந	ஸ	ை		௨	௸
9	உ	ங	ன	ஹ			௩	௹
A	ஊ	ச	ப		ொ		௪	௺
B					ோ		௫	
C		ஜ			ௌ		௬	
D					்		௭	
E	எ	ஞ	ம	ா			௮	
F	ஏ	ட	ய	ி			௯	

Table 3.19 – Tamil Unicode