Graphical Approach to the Learning of Inter-conversion of Various Number Systems

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ABSTRACT

The number is a symbol or a word used to represent a numeral, while a system is a functionally related group of elements, so as whole, a number is set/group of symbols to represent numbers/numerals. In other words, any system that is used for naming or representing numbers is a number system, also known as numeral system. Almost everyone is familiar with decimal number system using ten digits. However digital devices and computers use binary number system instead of decimal number system, having only two digits i.e. 0 and 1. Binary number system is based on the same fundamental concept of decimal number system. Various other number systems also use the same fundamental concept of decimal number system, e.g. octal number system (using eight digits) and hexadecimal number systems (using sixteen digits). The knowledge of number systems, their limitations, data formats, arithmetic, inter conversion and other related terms is essential for understanding of computers and successful programming for digital devices. Understanding all these number systems and particularly their inter conversion (such process in which things are each converted into the other) of number system requires allot of time and a large number of techniques to expertise. In this particular paper the intercom version of four well-known number systems is taken under the consideration in tabulated as well as graphical form. It is simply a shorthand to the inter conversion of these number systems to understand as well as memorise it. The well-known number systems to be discussed are binary, octal, decimal and hexadecimal.

Index terms

Number Systems, Graphical learning, Data Communication, Microprocessor, Digital Logic and Computer Design

Keywords

Computers, Binary, octal, hexadecimal, bases or radix, inter conversion

1. INTRODUCTION

Modern civilization is so familiar with decimal number system that they do not experience a need to think about other number systems. This is so, because they perform the computations since childhood, using the numbers 0 - 9, the digits of the decimal number system. However when we deals with digital technology i.e. computers and other digital devices we necessitate to be familiar with other number systems as well.

In the digital world, most commonly computer science and information technology, normally we requires a working knowledge of various number systems, four basic and most common of these are binary, octal, decimal and hexadecimal. More specifically, the use of the microprocessor requires a working knowledge of binary, decimal and hexadecimal number system [1, 2]. Computers communicate and operate in binary digits 0 and 1; on the other hand human beings generally use the decimal systems with ten digits 0-9. Other number systems used in digital systems are octal with eight digits i.e. 0 through 7 and hexadecimal system with digits from 0 through 15. These all number systems use unique and distinct symbols. Some of these numeral system use only numeric digits (0, 1, 2... 9), while other use alphabets as well along the numeric digits. In case of hexadecimal system, digits 10-15 are designated as A through F to avoid confusion with the decimal numbers, 10 to 15 [3].

In data communication we need that a simple signal must be manipulated so that it contains certain changes that are recognizable to the sender and receiver as representing the information intended. First the information must be translates into agreed-upon patterns of 0s and 1s, for example, using ASCII. Also, data stored in the computer are in the form of 0s and 1s. To be carried from one place to another, data are usually converted to digital signals. Some times we need to convert an analog signal (such as voice in a telephone conversation) into a digital signal and vice versa [4]. So, in many applications we deal with the inter conversion of number systems. Remember, all number systems are inter-convertible. But each conversion i.e. from one number system to another often takes place in a different way, using different techniques [5]. So it becomes very tedious for beginners to overcome this difficulty and understand these conversions in short time. There are various techniques that are used for these inter conversions.

In this particular paper, we introduce a tabulated format and a graphical approach for these conversions. It covers all these interconversions in only three steps, further explained with graphs, taking approximately one contact hour of the lecture. Each step consists of two parts having graphical illustration. While, in earlier approaches we have to use more than 20 steps to perform understand and all these conversions.

This paper is organized in such a way that it consist of five sections. Section one covers the brief introduction of the number systems, need of various number systems, their inter conversion and easy approach for inter conversion of these systems. Section two is the overview of the number systems their limitations and representations. Section three describes all the conversion techniques (both for integral and fractional part of the numbers) frequently used so far. Section four contains the proposed tabulated form for interconversion processes along the graphical representations of each step, while last one section concludes the paper.

2. OVERVIEW OF NUMBER SYSTEMS

Humans are speaking to one another in a particular language made of words and letters. While we type words and letters in the computer, the computer does not understand the words and letters. Rather, those words and letters are translated into numbers. It means that computers “talk” and understand in numbers. Although many students know the decimal (base 10) system, and are very comfortable with performing operations using this system, it is too important for students to understand that the decimal system is not the only system. By studying other number systems such as binary (base 2) quaternary (base 4), octal (base 8), hexadecimal (base 16) and so forth, students will gain a better understanding of how number systems work in general.

2.1 Digits

Before the conversion concepts of numbers from one number system to another, the digit of a number system must be understood. The first digit in any numbering system is always a zero. For example, a base 2 (binary) numbers contains 2 digits: 0 and 1, a base 8 (octal) numbers contains 8 digits: 0 through 7 and so on. Note that a base 10 (decimal) numbers does not contain the digit 10, similarly base 8 numbers does not contain a digit 8, and same is the case for the other number systems. Once the digits of a number system are understood, larger numbers can be constructed using positional notation or place-value notation method. According to the positional notation method, in decimal numbers the first right most digit (integer) has a unit's position. Further, to the left of the units position is the ten's position, the position to the left of the ten's position is the hundred's position and so forth. Here, the units position has a weight of 10^0, or 1; the tens position has a weight of 10^1, or 10; and the hundreds position has a weight of 10^2, or 100. The exponential powers of the positions are critical for understanding numbers in other numbering systems. Remember the position to the left of the radix point is always the unit's position in any number system. For example the position to the left of the binary point is always 2^0, or 1; the position to the left of the octal point is always 8^0, or 1 and so on.
The position to the left of the unit's position is always the number whose base is raised to the first power; i.e. 2^1, 8^1 and so on. These concepts can be extended to each and every number system.

2.2 Number representation

A number in any base system can be represented in a generalized format as follows:

$N = A_n B^n + A_{n-1} B^{n-1} + - - - + A_1 B^1 + A_0 B^0$, where
N = Number, B=Base, A= any digit in that base

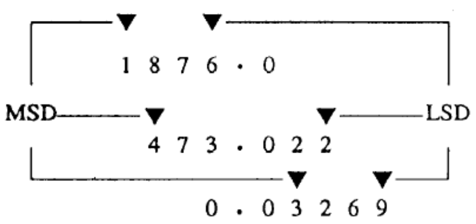
For example number 154 can be represented in various number systems as follows:

Table: 2.1 Number representations in various number systems

Decimal	154	$1\times10^2 + 5\times10^1 + 4\times10^0$ = 100 + 50 + 4	154
Binary	1001101 0	$1\times2^7 + 0\times2^6 + ... + 0\times2^0$ = 128+0+0+16+8+0+2+0	154
Octal	232	$2\times8^2 + 3\times8^1 + 2\times8^0$ = 128 + 24 + 2	154
Hexa-decimal	9A	$9\times16^1 + A\times16^0$ = 144 + 10	154

2.3 Most Significant Digit and Least Significant Digit

The MSD in a number is the digit that has the greatest effect on that number, while The LSD in a number is the digit that has the least effect on that number.
Look at the following examples:



You can easily see that a ch ange in the MSD will increase or decrease the value of the number in the greatest amount, while changes in the LSD will have the smallest effect on the value.

2.4 Counting

When the symbols for the first digit are exhausted, the next-higher digit (to the left) is incremented, and counting starts over at 0. For example in decimal number system, counting proceeds like that: 00, 01, 02 ... 07, 08, and 09 (rightmost digit starts over, and next digit is incremented) **1**0, 11, 12 ... 19 ... 90, 91, 92 ... 97, 98, and 99 (rightmost two digits start over, and next digit is incremented) **1**00, 101, 102 ... and so on. After a digit reaches 9, an increment resets it to 0 but also causes an increment of the next digit to the left. In binary, counting is the same except that only the two symbols 0 and 1 are used. Thus after a digit reaches 1 in binary, an increment resets it to 0 but also causes an increment of the next digit to the left: 0, 1, 10, 11, 100, 101, 110 … and so on. The same counting procedure is applicable on all number systems.

2.5 Decimal Number System

The decimal number system is known as international system of numbers [6]. It is also called base ten or occasionally denary number system. It has ten as its base. It is the numerical base most widely used by modern civilization [7].
Decimal notation often refers to a b ase-10 positional notation; however, it can also be used more generally to refer to non-positional systems. Positional decimal systems include a zero and use symbols (called digits) for the ten values (0, 1, 2, 3, 4, 5, 6, 7, 8, and 9) to represent any number, no matter how large or how small.

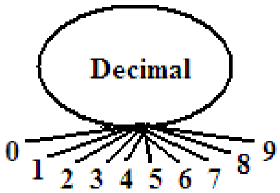
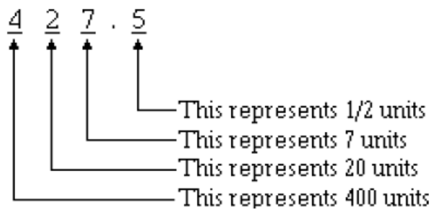
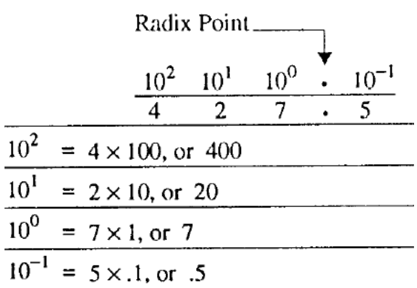


Figure: 1. Symbols used in decimal number system

Let's examine the decimal (base 10) value of 427.5. You know that this value is four hundred twenty-seven and one-half. Now examine the position of each number:



Each digit has its own value (weight) as described in the above figure. Now let's look at the value of the base 10 number 427.5 with the positional notation line graph:



You can see that the power of the base is multiplied by the number in that position to determine the value for that position. All numbers to the left of the decimal point are whole numbers or integers, and all numbers to the right of the decimal point are fractional numbers.

2.5 Binary Number System

The number system with base (or radix) 2, is known as the binary number system. Only two symbols are used to represent numbers in this system and these are 0 and 1, these are known as bits. It is a positional system i.e. every position is assigned a specific weight. Moreover, it has two parts the Integral part or integers and the fractional part or fractions, set a part by a radix point. For example $(1101.101)_2$

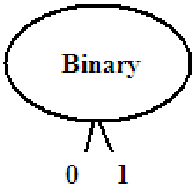


Figure: 2. Symbols used in binary number system

In binary number system the left–most bit is known as most significant bit (MSB) and the right–most bit is known as the least significant bit (LSB), similar to decimal number system. The following graph shows the position and the power of the base (2 in this case):

$$2^3 \; 2^2 \; 2^1 \; 2^0 . \; 2^{-1} \; 2^{-2} \; 2^{-3}$$

The arithmetic operations such as addition, subtraction, multiplication and division of decimal numbers can be also performed on binary numbers. Also binary arithmetic is much simpler than decimal arithmetic because here only two digits, 0 and 1 are involved.

2.6 Octal Number System

As its name reveal (octal = 8), the number system with base 8 is known as the octal number system. In this system eight symbols, 0, 1, 2, 3, 4, 5, 6, and 7 are used to represent the number. Hence, any octal number can not have any digit greater than 7 [8].

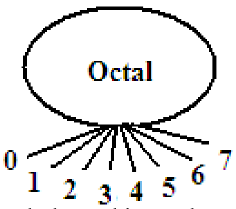


Figure: 3. Symbols used in octal number system

Similar to decimal and binary number systems, it is also a positional system; the octal number system uses power of 8 to determine the value of a number's position. The following graph shows the positions and the power of the base (8 in this case):

$$8^3 \; 8^2 \; 8^1 \; 8^0 \bullet 8^{-1} \; 8^{-2} \; 8^{-3}$$

Octal number has also two parts: Integral and fractional, set a part (separated) by a radix point, for example $(6327.4051)_8$

The main advantage of using the octal number system is that, in any digital transmission system it is highly tedious to handle long strings of binary numbers. It may also cause errors. Therefore, octal numbers are used for entering binary data and displaying certain information in short.

2.7 Hexadecimal Numbering System

Hexadecimal number system is very popular in computer uses. The base for hexadecimal number system is 16 which require 16 distinct symbols to represent the number. These are numerals 0 through 9 and alphabets A through F [9]. This is an alphanumeric number system because its uses both alphabets and numerical to represent a hexadecimal number. Hexadecimal number system use 0, 1, 2, 3, 4, 5, 6, 7, 8, 9, A, B, C, D, E, and F.

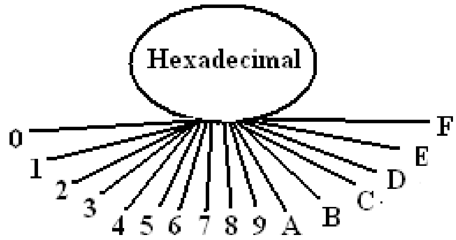


Figure: 4. Symbols and alphabets used in hexadecimal number system

Any number in hexadecimal number system can be represented as $(B52.AC3)_{16}$. It has also two parts i.e. integral and fractional. Like the binary, octal, and decimal systems, the hexadecimal number system is a positional system. Powers of 16 are used for the positional values of a number. The following graph shows the positions and power of the base (16 in this case):

$$16^3 \; 16^2 \; 16^1 \; 16^0 \, \blacksquare \; 16^{-1} \; 16^{-2} \; 16^{-3}$$

The most significant and least significant digits will be determined in the same manner as the other number systems.

3 CONVERSION BETWEEN NUMBER SYSTEMS

As we have discussed so far, the most common and well-known number systems are the decimal, binary, octal and hexadecimal. Now let we check that how any number can be converted from one to another number system. Number systems are given in the ascending order as,

Binary
Octal
Decimal
Hexadecimal

A given number in any of the above number systems may consist of two parts i.e. the integral part and the fractional part. Each part some times, required a different technique for conversion. In other words, in case of fractions the conversion process requires additional techniques. So as a whole, more than 20 steps and various techniques are required to complete the conversion process. Some of these steps are enlisted below.

Integral part of a numbers

Binary – to – octal
Octal – to – binary
Binary – to – decimal
Decimal – o – binary
Binary- to – hexadecimal
Hexadecimal – to – binary
Octal – to – decimal
Decimal –to – octal
Octal –to – hexadecimal
Hexadecimal –to- octal
Decimal – to – hexadecimal
Hexadecimal –to – decimal

Fractions

Binary fraction – to – octal
Octal fraction– to – binary
Binary fraction – to – decimal
Decimal fraction – to – binary
Binary fraction - to – hexadecimal
Hexadecimal fraction – to – binary

Octal fraction – to – decimal
Decimal fraction –to – octal
Octal fraction –to- hexadecimal
Hexadecimal fraction –to- octal
Decimal fraction – to – hexadecimal
Hexadecimal fraction –to – decimal

It is obvious, that the beginners will be very depress and frustrated to use such a lot of techniques for the conversion in short time of one contact hour or so. To overcome this problem we present a very easy approach to the complete inter conversion of numbers as given under.

4 TABULATED FORMAT AND GRAPHICAL REPRESENTATION

We know that the decimal number system is the most common of the above mentioned number systems, because it is widely used in mathematics and our daily life calculations. So we start the conversion from the decimal number system to the remaining systems. Here a w ord "other" is used for those number systems which are other than the consider one.
We can perform the conversion between different number systems in three steps,

Step: 1 A) From Decimal number system → to → other number systems [Binary, Octal, Hexadecimal]
B) From Other number systems [Binary, Octal, Hexadecimal] → to → Decimal number system

In step: 1 all the conversion processes related to decimal number system is covered. So we will not use the conversion from/to decimal number system to/from others, anymore.

Step: 2 A) From Binary number system → to → other [Octal, Hexadecimal] number systems
B) From Other [Octal, Hexadecimal] number systems → to → Binary number system

In step: 2 all the conversion processes related to binary number system are covered. So we will not use the conversion from/to binary number system to/from others, anymore.

Step: 3 A) From octal number system → to → hexadecimal number system
B) From hexadecimal number system → to → octal number system

Step: 1

A) Conversion from Decimal number system → to → other number systems [Binary, Octal, Hexadecimal]

To convert a given number from decimal number system to any other number system, follow these steps:
1. Divide the decimal number by r i.e. base of the other system (2, 8, or 16). Remember the quotient and the remainder of this division.
2. After that, divide the quotient (from the first division) by r, again remembering the quotient and the remainder.
3. Keep dividing your new quotient by r until you get a quotient of 0. After each division, keep track of the remainder.
4. When you reach a quotient of 0, the remainders of all the divisions (written in reverse order) will be the equivalent number in base r number system. [Reverse order mean that, the first remainder that you got in step-1 will be the least significant digit (LSD) of the number in base r number system].
In case of the fractions or the fractional part in a given number the repeated multiplication method is used. In this method the fractional part of the number is multiplied by the base. Here is given a simple, step-by-step technique for computing the expansion on the right-hand side of the radix point.

1. Start with the decimal fraction given in a number (say .625) and multiply by base (2, 8 or 16). The whole number part of the result is the first binary digit to the right of the point. I.e. 0.625 x 2 = 1.25 So now we have .625 = .1--- (in base 2).
2) Next without involving the whole number part of the previous result (the 1 in this case) and multiply by 2 once again. The whole number part of this new result is the second digit to the right of the point.
3) Continue this process until we get a zero as our decimal part or up to required number beyond the radix point. Hence the representation of .625 = .101 (in base 2)
This whole process can be summarized as,

Step No:	Part-A
Step1	Decimal - to - others [binary, octal, hexadecimal] $(==)_{10} \rightarrow (==)_{2,8,16}$ **Integer:** repeated division method **Fraction:** repeated multiplication method

The procedure discussed earlier in step 1, part A can be illustrated graphically as,

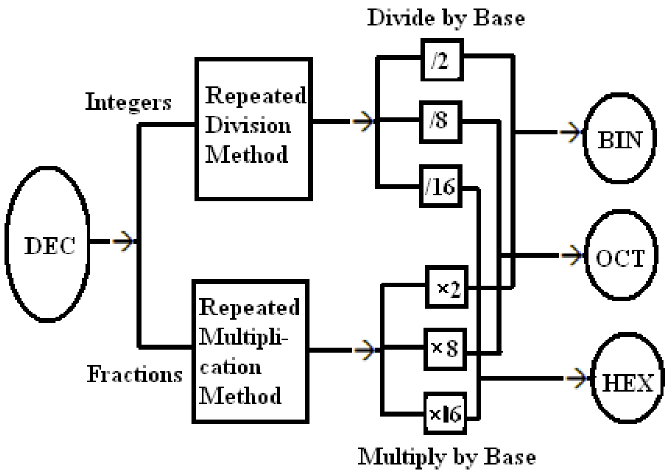


Figure: 5. Graphical illustration of step 1, part A

B) Conversion from Other number systems [binary, octal, hexadecimal] → to → decimal number system

The conversion process from other number systems [i.e. binary, octal, and hexadecimal] to decimal number system has the same procedure. Here any given number can be converted into its equivalent decimal number using the weights assigned to each bit position. Incase of binary the weights are 2^0 (Units), 2^1 (twos), 2^2 (fours), 2^3 (eights), 2^4 (sixteen) and so on. Similarly in case of octal the weights are 8^0, 8^1, 8^2, 8^3, 8^4 and so on. For hexadecimal the weights are 16^0, 16^1, 16^2, 16^3, 16^4 and so on. Here few steps are given which are helpful in faster and easy conversion of other systems to decimal number system.
1. Write the given (i.e. 2, 8, or 16) base number
2. Write the corresponding weight x^0, x^1, x^2, x^3… under each digit.
3. Cross out any weight under a 0 (means that any 0 involve in given number).
4. Add the remaining weights.
In case of converting the fractions or the fractional part in a given number to the decimal representation, same procedure is used as mentioned above. The only difference is that the negative weights are assigned to each bit position instead of positive weights. For example

in case of binary the weights are 2^{-1}, 2^{-2}, 2^{-3}, 2^{-4}, and so on. Similarly in case of octal the weights are 8^{-1}, 8^{-2}, 8^{-3}, 8^{-4}, and so on.
This whole process can be summarized as,

Step No:	Part-B
Step1	Others [binary, octal, hexadecimal] - to - decimal $(==)_{2,8,16} \rightarrow (==)_{10}$ **Integer:** sum of [(+ve weights) × (integer)] **Fraction:** sum of [(-ve weights) × (fraction)]

The procedure discussed in step 1, part B can be illustrated graphically as,

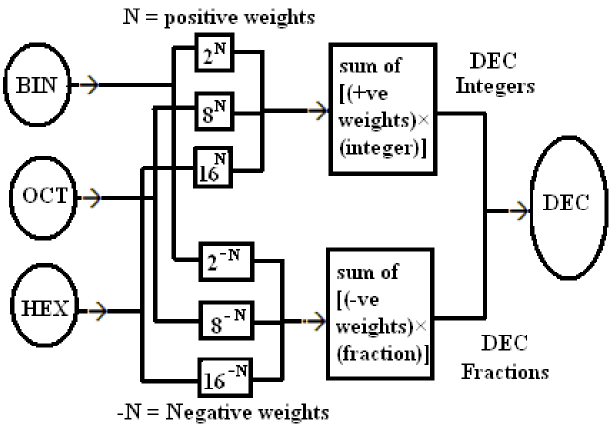


Figure: 6. Graphical illustration of step 1, part B

Step: 2

A) Conversion from Binary number system → to → other [Octal, Hexadecimal] number systems

A binary number can be converted to octal number and hexadecimal number by replacing method. The binary digits are grouped by threes (in case of converting to octal) and fours (in case of converting to hexadecimal) respectively by starting from the decimal point and proceeding to the left and to the right. Add leading 0s (or trailing zeros to the right of decimal point) to fill out the last group of three or four if needed. Then replace group of three or group of four with the equivalent octal or hexadecimal digit accordingly. A fraction of binary is converted to both octal and hexadecimal numbers in the same manner. This above process can be summarized as,

	Part-A
Step2	binary to other [octal, hexadecimal] $(==)_2 \rightarrow (==)_{8,16}$ **To octal:** replace group of 3-binary bits by octal digit **To hex:** replace group of 4-binary bits hexadecimal digit (same method for both integral and fraction part)

The procedure discussed in step 2, part A can be illustrated graphically as

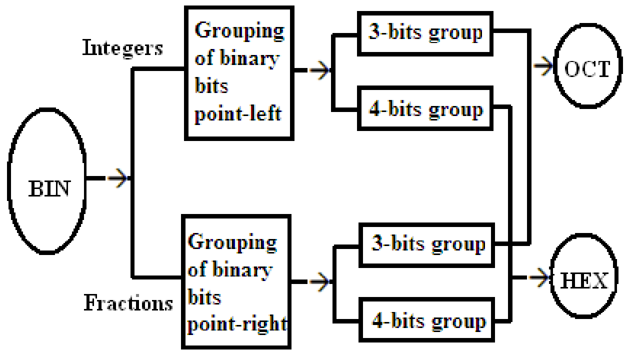


Figure: 7. Graphical illustration of step 2, part A

B) Conversion from Other [Octal, Hexadecimal] number systems → to → Binary number system

For some computers to accept octal or hexadecimal data, the octal or hexadecimal digits must be converted to binary. This process is the reverse of binary to octal and hexadecimal conversion. To convert a given (octal or hexadecimal) number to binary, write out the number and then write below each digit the corresponding three-digit binary-coded octal equivalent (in case of converting from octal) or four-digit binary-coded hexadecimal equivalent (in case of converting from hexadecimal). A fraction in both octal and hexadecimal is converted to binary in the same manner. The above process can be summarized as,

Step2	Part-B
	Other [octal, hexadecimal] to binary $(==)_{8,16} \rightarrow (==)_2$ **From octal:** replace each octal digit by 3-bit binary **From hex:** replace each hexa-decimal digit by 4-bit binary (same method for both integral and fraction part)

The procedure discussed in step 2, part B can be illustrated graphically as,

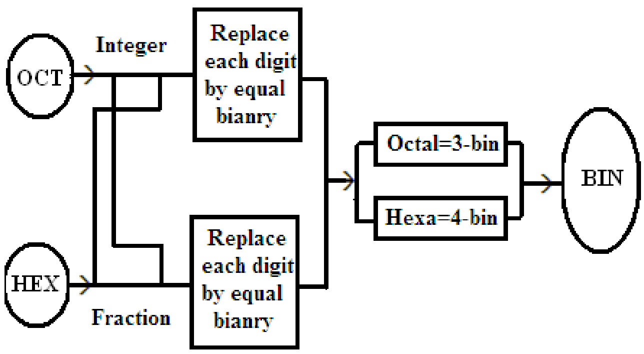


Figure: 8. Graphical illustration of step 2, part B

The below table relates the all four number systems and also shows the equivalence of binary in other number system of first 16 (0 through 15) decimal numbers:
(Note that each octal and hexadecimal digit is equivalent to 3-bit and 4-bit binary number respectively).

Table: 3.1 conversion table- Decimal, Hexadecimal, Octal, Quaternary to Binary

Decimal	Hexadecimal	Octal
1= 0001	1= 0001	1= 001
2 = 0010	2 = 0010	2 = 010
3 = 0011	3 = 0011	3 = 011
4 = 0100	4 = 0100	4 = 100
5 = 0101	5 = 0101	5 = 101
6 = 0110	6 = 0110	6 = 110
7 = 0111	7 = 0111	7 = 111
8 = 1000	8 = 1000	10 = 001000
9 = 1001	9 = 1001	11 = 001001
10 = 1010	A = 1010	12 = 001010
11 = 1011	B = 1011	13 = 001011
12 = 1100	C = 1100	14 = 001100
13 = 1101	D = 1101	15 = 001101
14 = 1110	E = 1110	16 = 001110
15 = 1111	F = 1111	17 = 001111

Step: 3

A) Conversion from Octal number system → to → Hexadecimal number system

The conversion from octal number system to hexadecimal number system is a two-step procedure using decimal as an intermediate base. In first step Octal number is converted to decimal number using the technique illustrated in step1 part B, then this decimal number is further converted into hexadecimal number using the technique illustrated in step1 part A. The result will be hexadecimal number.
In case of converting the fractions or fractional part of the given octal number to hexadecimal number system the same procedure i.e. used for the integral part, will be used. (Binary can also be used as the intermediate base). The above process can be summarized as,

Step No:	Part-A
Step3	octal to hexadecimal $(==)_8$ → $(==)_{16}$ Direct conversion not applicable Octal → Decimal → Hexadecimal

The procedure discussed above can be illustrated graphically as,

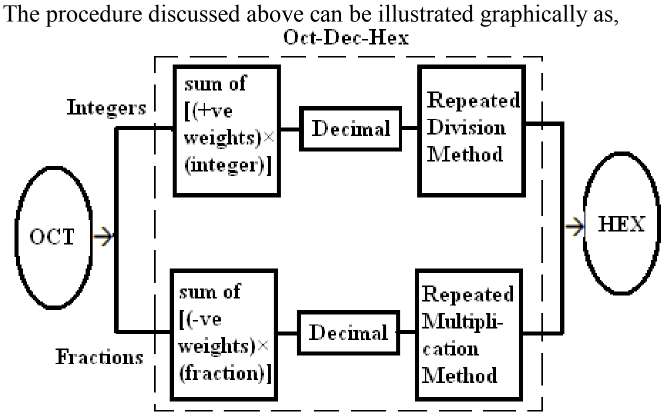


Figure: 9. Graphical illustration of step 3, part A

B) Conversion from Hexadecimal number system → to → Octal number system

The conversion from hexadecimal number system to octal number system is the reversal of the same algorithm as declared in first part of step-3. Reverse the previous algorithm to achieve the conversion. The reverse process can be summarized as,

Step No:	Part-B
Step3	hexadecimal to octal $(==)_{16}$ → $(==)_8$ Direct conversion not applicable Hexadecimal → Decimal → Octal

The procedure discussed in step 3, part B can be illustrated graphically as,

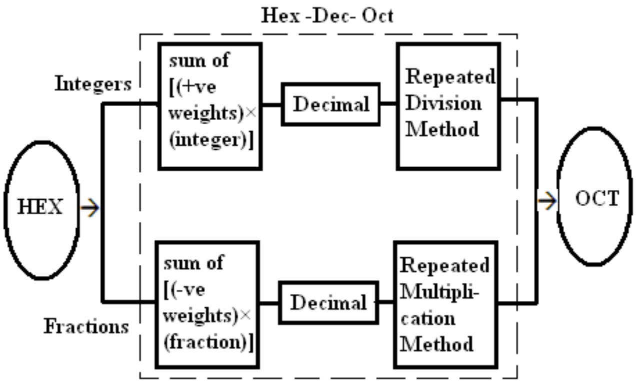


Figure: 10. Graphical illustration of step 3, part B

Table

The following table reveals the conversion between the four number systems in three steps along the methods of conversion (for integers and fractions). Remember, in step 2 and 3 conversion technique (method) for integral and fractional part is not mentioned in the table. It is so, because in both steps, same technique is used for both integers and fractions conversion.

Table: 3.2 conversions between Decimal, Binary, Octal and Hexadecimal along the conversion techniques

Step No:	Part-A	Part-B
Step1	Decimal - to - others [binary, octal, hexadecimal] $(==)_{10} \rightarrow (==)_{2,8,16}$ **Integer:** repeated division method **Fraction:** repeated multiplication method	Others [binary, octal, hexadecimal] - to - decimal $(==)_{2,8,16} \rightarrow (==)_{10}$ **Integer:** sum of [(+ve weights) × (integer)] **Fraction:** sum of [(-ve weights) × (fraction)]
Step2	binary to other [octal, hexadecimal] $(==)_{2} \rightarrow (==)_{8,16}$ **To octal:** replace group of 3-binary bits by octal digit **To hex:** replace group of 4-binary bits by hexadecimal digit (same method for both integral and fraction part)	Other [octal, hexadecimal] to binary $(==)_{8,16} \rightarrow (==)_{2}$ **From octal:** replace each octal digit by 3-bit binary **From hex:** replace each hexa-decimal digit by 4-bit binary (same method for both integral and fraction part)
Step3	octal to hexadecimal $(==)_{8} \rightarrow (==)_{16}$ Direct conversion not applicable Octal → Decimal → Hexadecimal	hexadecimal to octal $(==)_{16} \rightarrow (==)_{8}$ Direct conversion not applicable Hexadecimal → Decimal → Octal

CONCLUSION

In this particular paper we propose an easy, short and trouble-free approach, using a single table along the graphical illustrations, to the complete interconversion of various numbers from the four most common number systems used in the digital world specially computer technology. Keep in mind that, these four number systems are not the only number systems used in digital world, but are the very common and frequently used number systems in most of the digital technologies and devices.

The concept of these number systems and especially the complete inter conversion takes a lot of time to understand and memorize all the processes and techniques involved. From this paper we conclude that this is simply a shorthand to the well-known number systems and their inter conversion (also applicable to all other number systems), used in digital technology providing a rapid practice and simplicity to the understanding and memorizing the inter conversion between various number systems and all the techniques involved (used for these conversions so far). It will be very help full for those people who are new in the field of computer science or digital electronics. As a future work, the conversion table and graphical approach proposed in this paper may be enhanced by including more number systems and graphical illustration for their representation, arithmetic, and compliments along their interconversions. Also, newer conversion techniques can be added in it to make it valuable. Moreover, Software (simulator) and hardware (calculating device) can be implemented with the help of this proposed work.

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