SKEE 1223
DIGITAL ELECTRONICS

CHAPTER 2: NUMBER SYSTEMS & DIGITAL CODES

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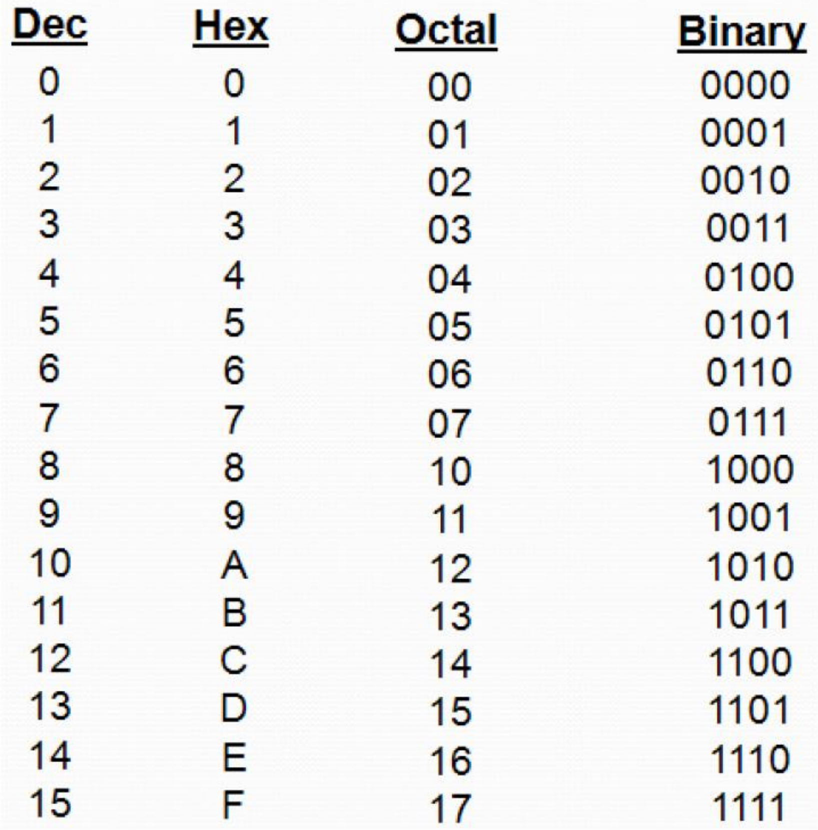
TIMETABLE (SECTION 13):
Sunday: 8 am -10 am (P07-411.2)
Tuesday: 8 am -10 am (P07-411.1)

DECIMAL, BINARY, HEXADECIMAL & OCTAL NUMBERS

NUMBER SYSTEMS
INTRODUCTION

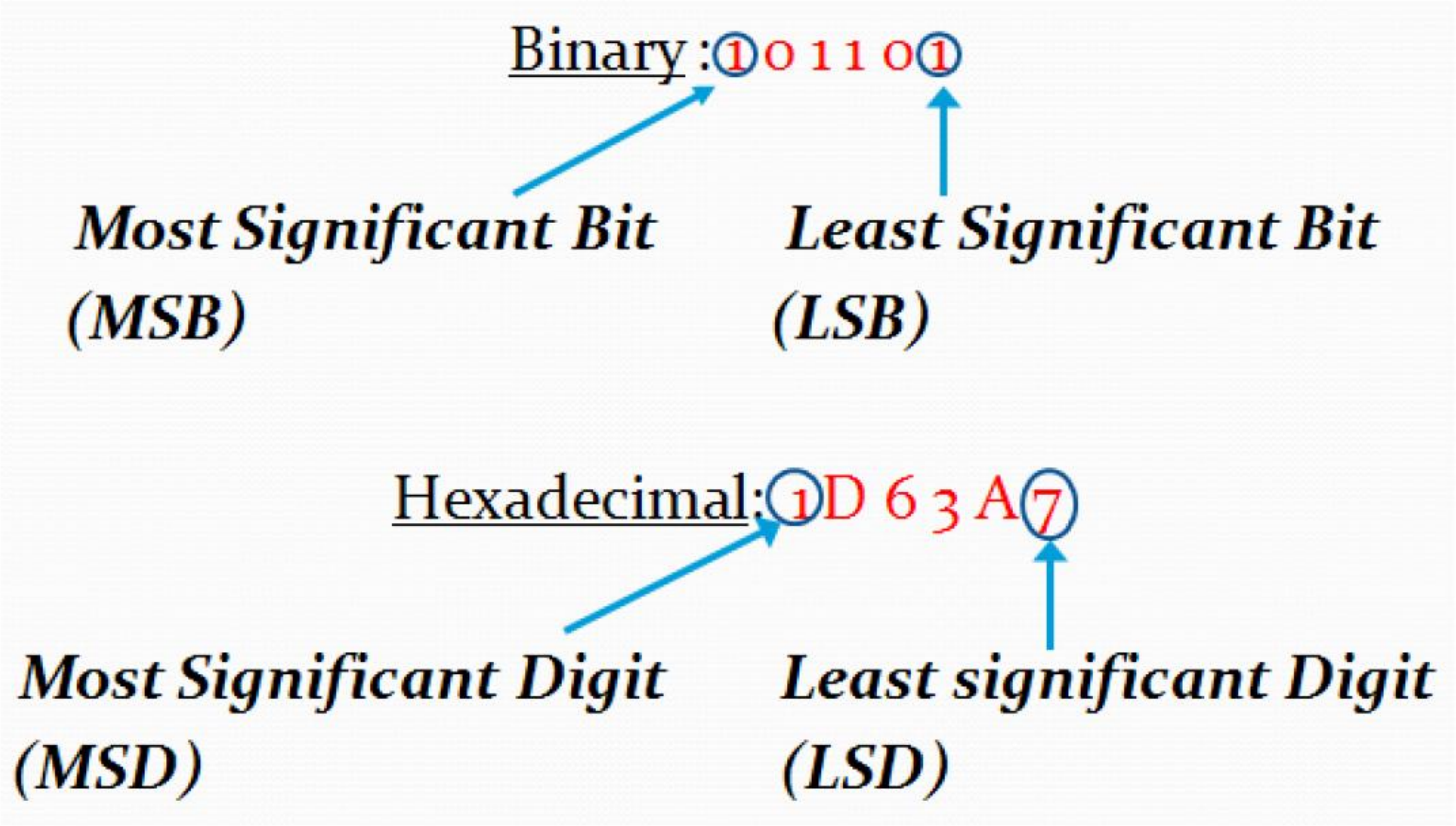
Number Systems	Examples
Decimal	0 ~ 9
Binary	0 ~ 1
Octal	0 ~ 7
Hexadecimal	0 ~ 9, A ~ F



Dec	Hex	Octal	Binary
0	0	00	0000
1	1	01	0001
2	2	02	0010
3	3	03	0011
4	4	04	0100
5	5	05	0101
6	6	06	0110
7	7	07	0111
8	8	10	1000
9	9	11	1001
10	A	12	1010
11	B	13	1011
12	C	14	1100
13	D	15	1101
14	E	16	1110
15	F	17	1111

NUMBER SYSTEMS

SIGNIFICANT BIT/DIGIT



Binary : ①0 1 1 0①

Most Significant Bit (MSB)

Least Significant Bit (LSB)

Hexadecimal: ①D 6 3 A⑦

Most Significant Digit (MSD)

Least significant Digit (LSD)

NUMBER SYSTEMS

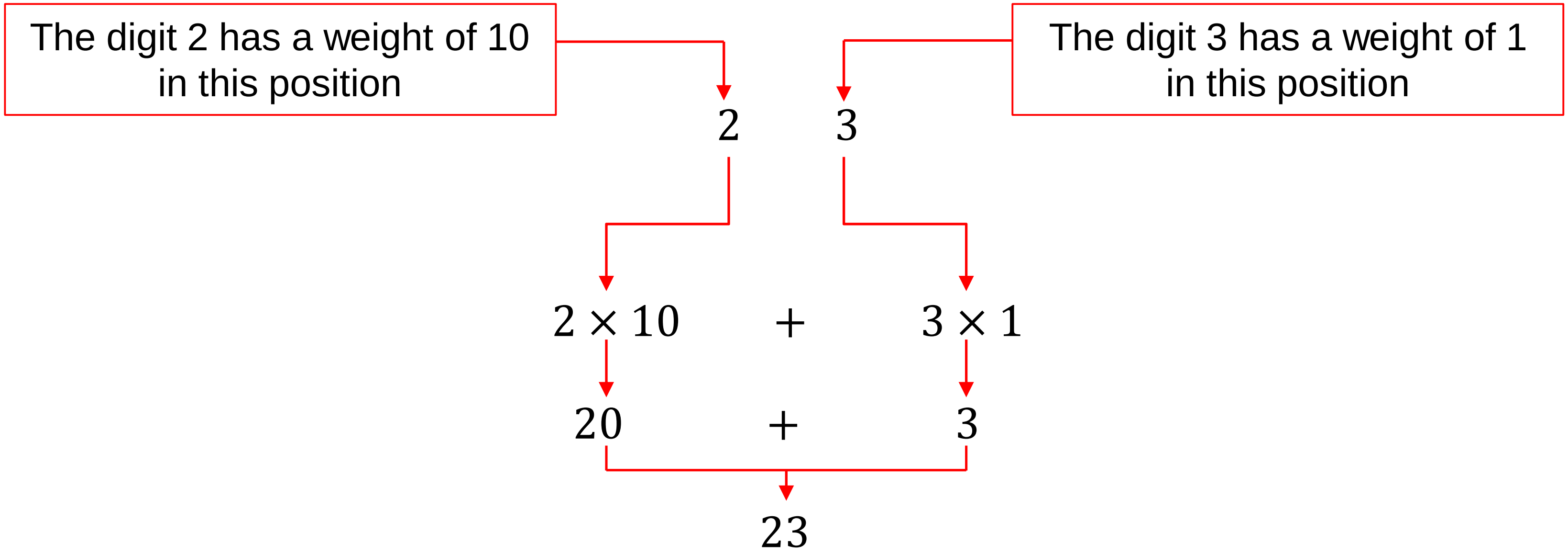
SIZE OF BIT/NIBBLE/BYTE/WORD

Unit	Size
Bit	One binary digit
Nibble	4 bit
Byte	8 bit
Word	16 bit

NUMBER SYSTEMS

DECIMAL NUMBERS: INTRODUCTION

- Use **Base-10** system.
- 10 digits/symbols: 0, 1, 2, 3, 4, 5, 6, 7, 8 and 9.
- The value of a digit is determined by its position in the number.
- For example, to express the quantity twenty three:



The digit 2 has a weight of 10 in this position

The digit 3 has a weight of 1 in this position

$$2 \quad 3$$

$$2 \times 10 \quad + \quad 3 \times 1$$

$$20 \quad + \quad 3$$

$$23$$

- The position of each digit indicates the magnitude of the quantity and can be assigned by a **weight**.

NUMBER SYSTEMS

DECIMAL NUMBERS: INTRODUCTION

- The weight of **whole numbers** are **positive powers of ten**, that increases from right to left, beginning from $10^0 = 1$.

$$\boxed{\ldots 10^5\ 10^4\ 10^3\ 10^2\ 10^1\ 10^0}$$

- The weight of **fraction numbers** are **negative powers of ten**, that decreases from left to right that begins with $10^{-1} = 0.1$.

$$\boxed{10^2\ 10^1\ 10^0 .\ 10^{-1}\ 10^{-2}\ 10^{-3} \ldots}$$

Decimal point

- The value of decimal number is a sum of the digits after each digits multiplied by its weight.

NUMBER SYSTEMS

DECIMAL NUMBERS: EXAMPLE

Example

Decimal number = 2745.214

Weights	10^3	10^2	10^1	10^0		10^{-1}	10^{-2}	10^{-3}
	2	7	4	5	.	2	1	4

$$2745.214 = (2 \times 10^3) + (7 \times 10^2) + (4 \times 10^1) + (5 \times 10^0) + (2 \times 10^{-1}) + (1 \times 10^{-2}) + (4 \times 10^{-3})$$

$$= (2 \times 1000) + (7 \times 100) + (4 \times 10) + (5 \times 1) + (2 \times 0.1) + (1 \times 0.01) + (4 \times 0.001)$$

$$= \mathbf{2000 + 700 + 40 + 5 + 0.2 + 0.01 + 0.004}$$

NUMBER SYSTEMS

BINARY NUMBERS: INTRODUCTION

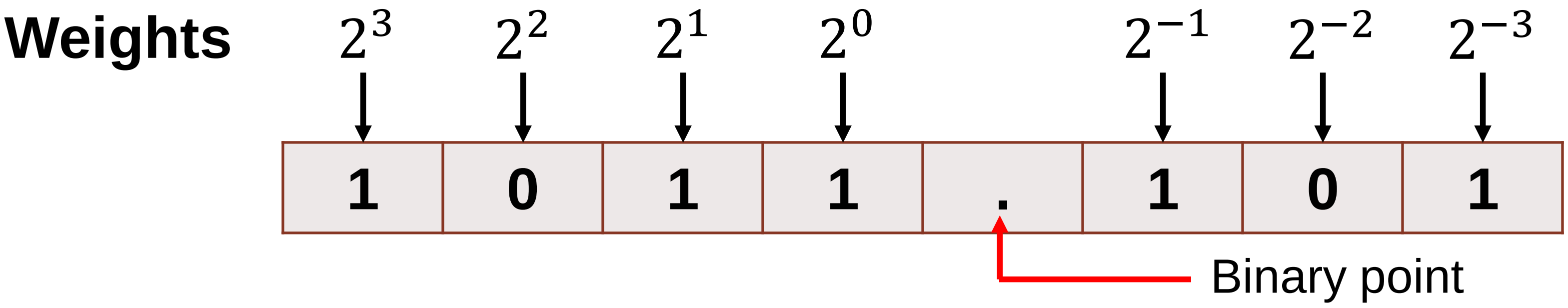
- Use **Base-2** system.
- 2 binary digits (bits)/symbols: 0 and 1.
- Example: 00, 01, 10, 11, 100, 101, 110, 111, …
- The value of a bit is determined by its position in the number.
- The position of 0 and 1 indicates its **weight**, or value within number.

Weights	2^3	2^2	2^1	2^0		2^{-1}	2^{-2}	2^{-3}
	↓	↓	↓	↓		↓	↓	↓
	1	**0**	**1**	**1**	**.**	**1**	**0**	**1**

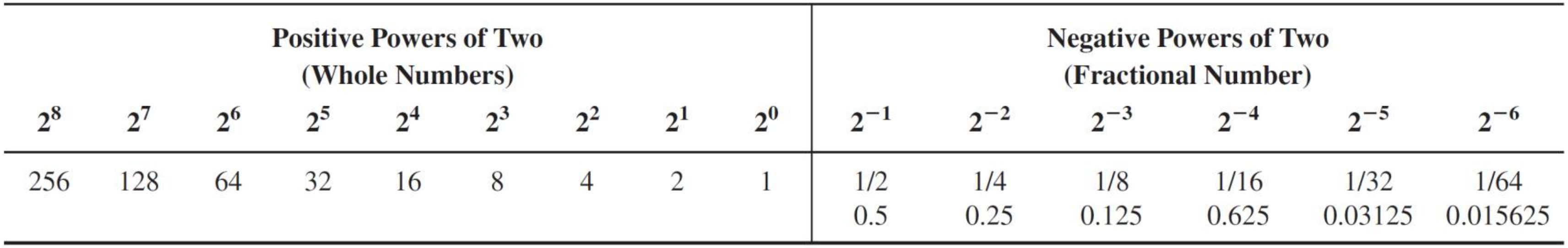
- The right-most bit is the **LSB** (least significant bit).
- The **binary whole number** has the weight of $2^0 = 1$.
- The weight increase from right to left by **power of two**.

NUMBER SYSTEMS

BINARY NUMBERS: INTRODUCTION



- The left most bit of binary number is the **MSB** (most significant bit).
- The **binary fraction number** has the weight of **negative powers of two** which decreases from left to right that begins with $2^{-1} = 0.5$.



Positive Powers of Two (Whole Numbers)									Negative Powers of Two (Fractional Number)					
2^8	2^7	2^6	2^5	2^4	2^3	2^2	2^1	2^0	2^{-1}	2^{-2}	2^{-3}	2^{-4}	2^{-5}	2^{-6}
256	128	64	32	16	8	4	2	1	1/2 0.5	1/4 0.25	1/8 0.125	1/16 0.625	1/32 0.03125	1/64 0.015625

NUMBER SYSTEMS

BINARY NUMBERS: BINARY TO DECIMAL CONVERSION

- The decimal value of any binary number can be found by **adding the weights of all bits that are 1** and **discarding the weights of all bits that are 0**.

Example 1

Convert the binary whole number 1101101 to decimal.

Solution

Determine the weight of each bit that is a 1, then calculates the sum of weights.

$$\boxed{\begin{array}{rccccccc} \mathit{Weight}: & 2^6 & 2^5 & 2^4 & 2^3 & 2^2 & 2^1 & 2^0 \\ \mathit{Binary\ Number}: & 1 & 1 & 0 & 1 & 1 & 0 & 1 \end{array}}$$

$$\begin{aligned} 1101101 &= 2^6 + 2^5 + 2^3 + 2^2 + 2^0 \\ &= 64 + 32 + 8 + 4 + 1 = \mathbf{109} \end{aligned}$$

NUMBER SYSTEMS

BINARY NUMBERS: BINARY TO DECIMAL CONVERSION

Example 2

Convert the fractional binary number 0.1011 to decimal.

Solution

Determine the weight of each bit that is a 1, then calculates the sum of weights.

$$\boxed{\begin{array}{rlllll} Weight: & 2^{-1} & 2^{-2} & 2^{-3} & 2^{-4} \\ Binary\ Number: & 0.1 & 0 & 1 & 1 \end{array}}$$

$$\begin{aligned} 0.1011 &= 2^{-1} + 2^{-3} + 2^{-4} \\ &= 0.5 + 0.125 + 0.00625 = \mathbf{0.6875} \end{aligned}$$

NUMBER SYSTEMS

BINARY NUMBERS: BINARY TO DECIMAL CONVERSION

Example 3

Convert the fractional binary number 1011.101 to decimal.

Solution

Determine the weight of each bit that is a 1, then calculates the sum of weights.

Weights	2^3	2^2	2^1	2^0		2^{-1}	2^{-2}	2^{-3}
	1	0	1	1	.	1	0	1

$$\begin{aligned} 1011.101 &= 2^3 + 2^1 + 2^0 + 2^{-1} + 2^{-3} \\ &= 8 + 2 + 1 + 0.5 + 0.125 = \mathbf{11.625_{10}} \end{aligned}$$

NUMBER SYSTEMS

BINARY NUMBERS: DECIMAL TO BINARY CONVERSION (WHOLE NUMBER)

Repeated Division-by-2 Method

- Dividing the decimal number by **2**.
- Repeating dividing each resulting **quotient** by **2** until there is **0** whole-number quotient.
- Take the **remainders** generated from the division and form the binary number.
- The first remainder is set as **LSB**, and the last remainder as **MSB**.

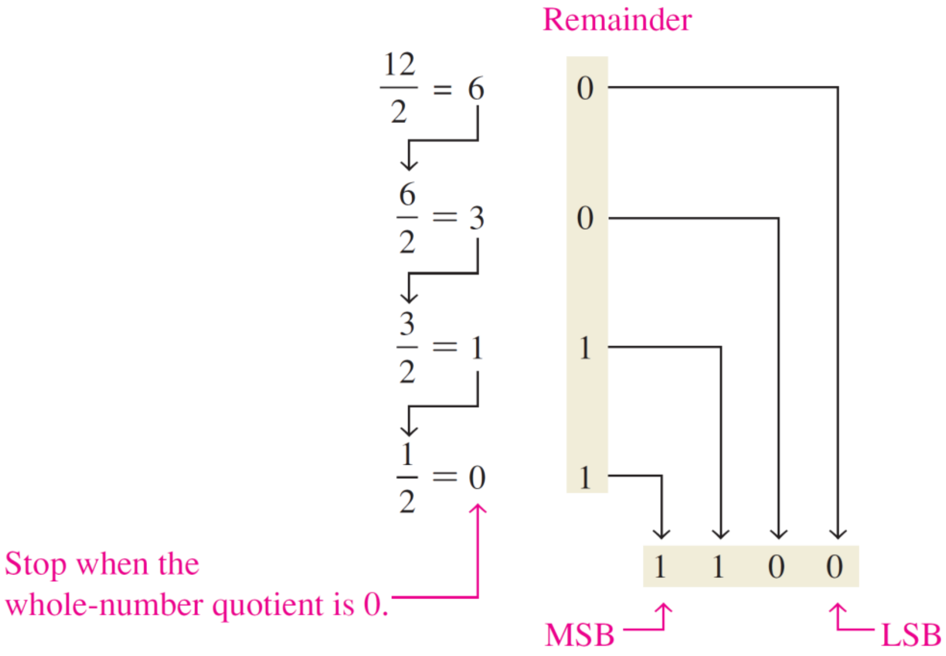
NUMBER SYSTEMS

BINARY NUMBERS: DECIMAL TO BINARY CONVERSION (WHOLE NUMBER)

Example

Convert the decimal number 12 to binary.

Solution



NUMBER SYSTEMS

BINARY NUMBERS: DECIMAL TO BINARY CONVERSION (FRACTIONAL NUMBER)

Repeated Multiplication-by-2 Method

- Multiplying the decimal number by **2**.
- Repeating multiplying each resulting **fractional** part by **2** until the **fractional product** is **0**.
- Take the **carries** generated by the multiplication to form the binary number.
- The first carry product is set as **MSB**, and the last carry as **LSB**.

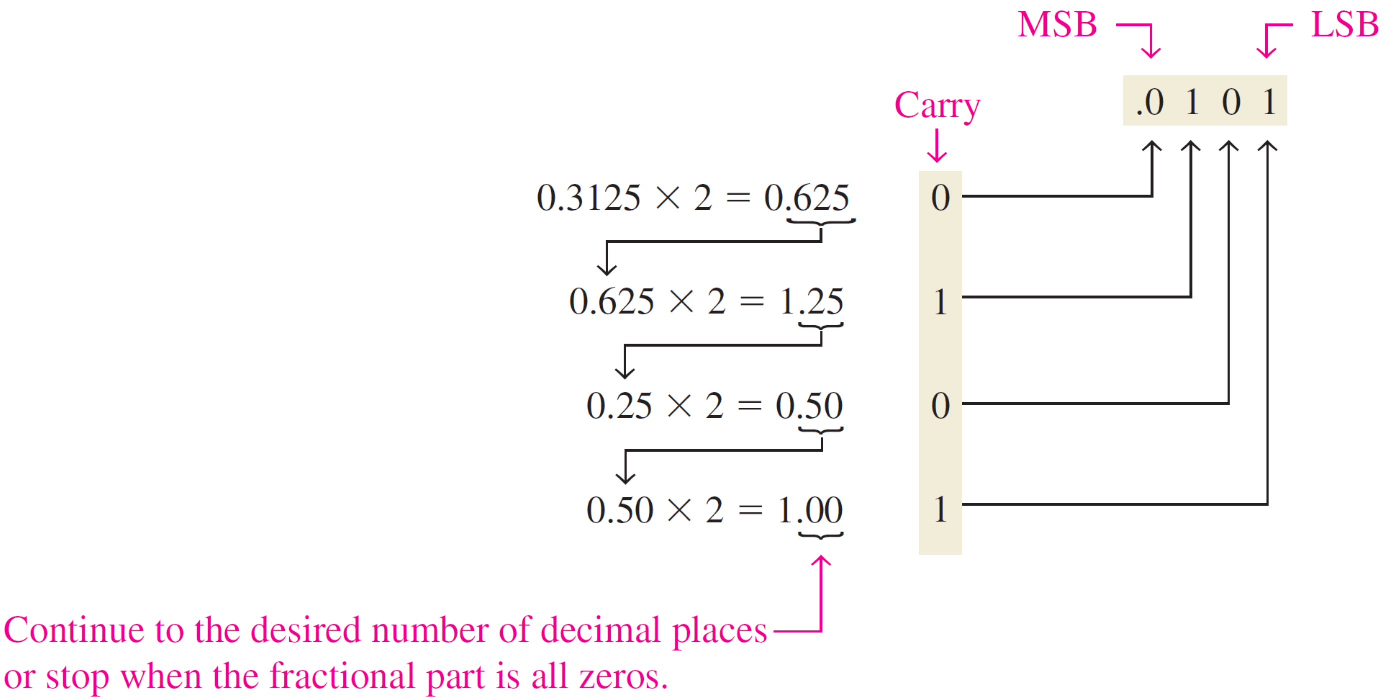
NUMBER SYSTEMS

BINARY NUMBERS: DECIMAL TO BINARY CONVERSION (FRACTIONAL NUMBER)

Example

Convert the fractional decimal number 0.3125 to binary.

Solution



Continue to the desired number of decimal places or stop when the fractional part is all zeros.

NUMBER SYSTEMS

OCTAL NUMBERS: INTRODUCTION

- Use **Base-8** system.
- 8 digits/symbols: 0, 1, 2, 3, 4, 5, 6 and 7.
- **Example**: 0, 1, 2, 3, 4, 5, 6, 7, 10, 11, 12, 13, 14, 15, 16, 17, 20, …
- The value of a digit is determined by its position in the number.
- The position of each digit indicates the magnitude of the quantity and can be assigned by a **weight**.

8^4	8^3	8^2	8^1	8^0	8^{-1}	8^{-2}	8^{-3}	8^{-4}	8^{-5}

●

Octal point

- In **octal whole number**, it has a weight of $8^0 = 1$. The weight increase from right to left by **power of eight**.

NUMBER SYSTEMS

OCTAL NUMBERS: INTRODUCTION

- In **octal fraction numbers**, the weight are **negative powers of eight**, that decreases from left to right beginning with $8^{-1} = 0.125$.
- Convenient way to express binary numbers and codes. Uses **3-bits binary boundary**.

Octal Digit	**0**	**1**	**2**	**3**	**4**	**5**	**6**	**7**
Binary Equivalent	000	001	010	011	100	101	110	111

Example Convert the binary 100111010 to octal numbers.

$$\underbrace{1\quad 0\quad 0}_{4}\quad \underbrace{1\quad 1\quad 1}_{7}\quad \underbrace{0\quad 1\quad 0}_{2_8}$$

NUMBER SYSTEMS

OCTAL NUMBERS: OCTAL TO DECIMAL CONVERSION

- The decimal equivalent can be accomplished by **multiplying** each digit by its **weight** and summing the products.

Example

Convert the octal whole number 2374_8 to decimal.

Solution

Multiply each digit by its weight, then calculates the sum of the products.

$Weight$:	8^3	8^2	8^1	8^0
$Octal\ Number$:	2	3	7	4

$$\begin{aligned} 2374_8 &= (2 \times 8^3) + (3 \times 8^2) + (7 \times 8^1) + (4 \times 8^0) \\ &= (2 \times 512) + (3 \times 64) + (7 \times 8) + (4 \times 1) \\ &= 1024 + 192 + 56 + 4 \\ &= \mathbf{1276_{10}} \end{aligned}$$

NUMBER SYSTEMS

OCTAL NUMBERS: DECIMAL TO OCTAL CONVERSION (WHOLE NUMBER)

Repeated Division-by-8 Method

- Dividing the decimal number by **8**.
- Repeating dividing each resulting **quotient** by **8** until there is **0** whole-number quotient.
- Take the **remainders** generated from the division and form the octal number.
- The first remainder is set as **LSD**, and the last remainder as **MSD**.

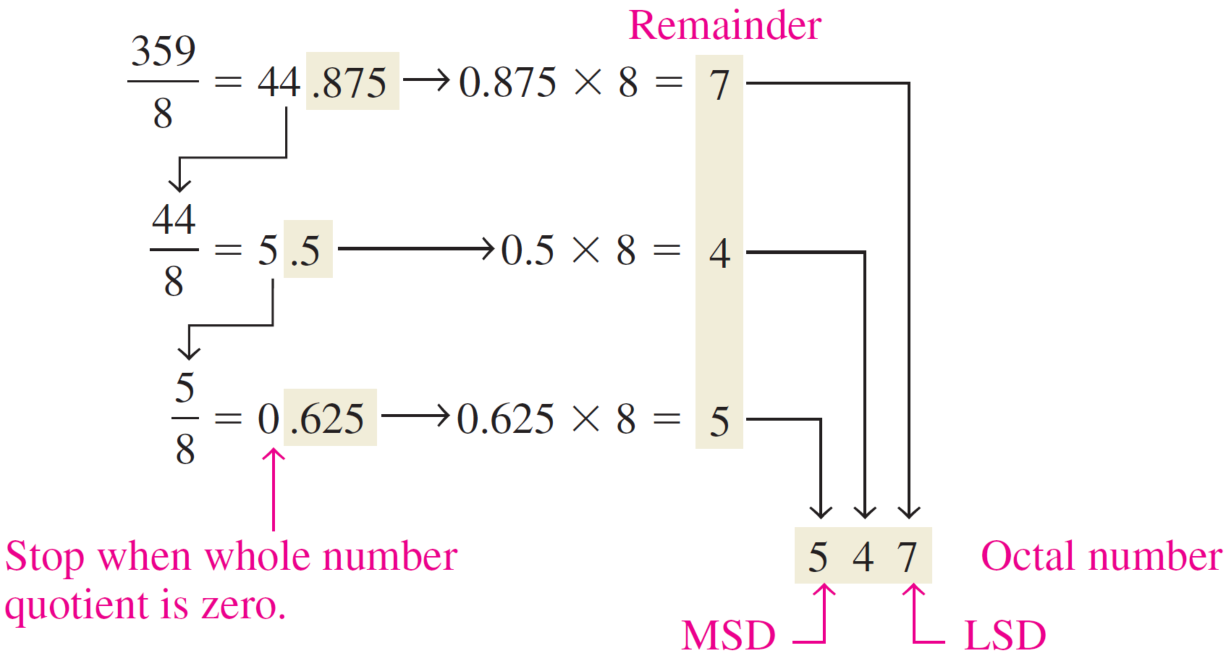
NUMBER SYSTEMS

OCTAL NUMBERS: DECIMAL TO OCTAL CONVERSION (WHOLE NUMBER)

Example

Convert the decimal number 359 to octal.

Solution



Remainder

$$\frac{359}{8} = 44.875 \longrightarrow 0.875 \times 8 = 7$$

$$\frac{44}{8} = 5.5 \longrightarrow 0.5 \times 8 = 4$$

$$\frac{5}{8} = 0.625 \longrightarrow 0.625 \times 8 = 5$$

5 4 7 Octal number

MSD LSD

Stop when whole number quotient is zero.

$$Answer = 547_8$$

NUMBER SYSTEMS

OCTAL NUMBERS: DECIMAL TO OCTAL CONVERSION (FRACTIONAL NUMBER)

Repeated Multiplication-by-8 Method

- Multiplying the decimal number by **8**.
- Repeating multiplying each resulting **fractional** part by **8** until the fractional product is **0**.
- Take the **carries** generated by the multiplication to form the octal number.
- The first carry product is set as **MSD**, and the last carry as **LSD**.

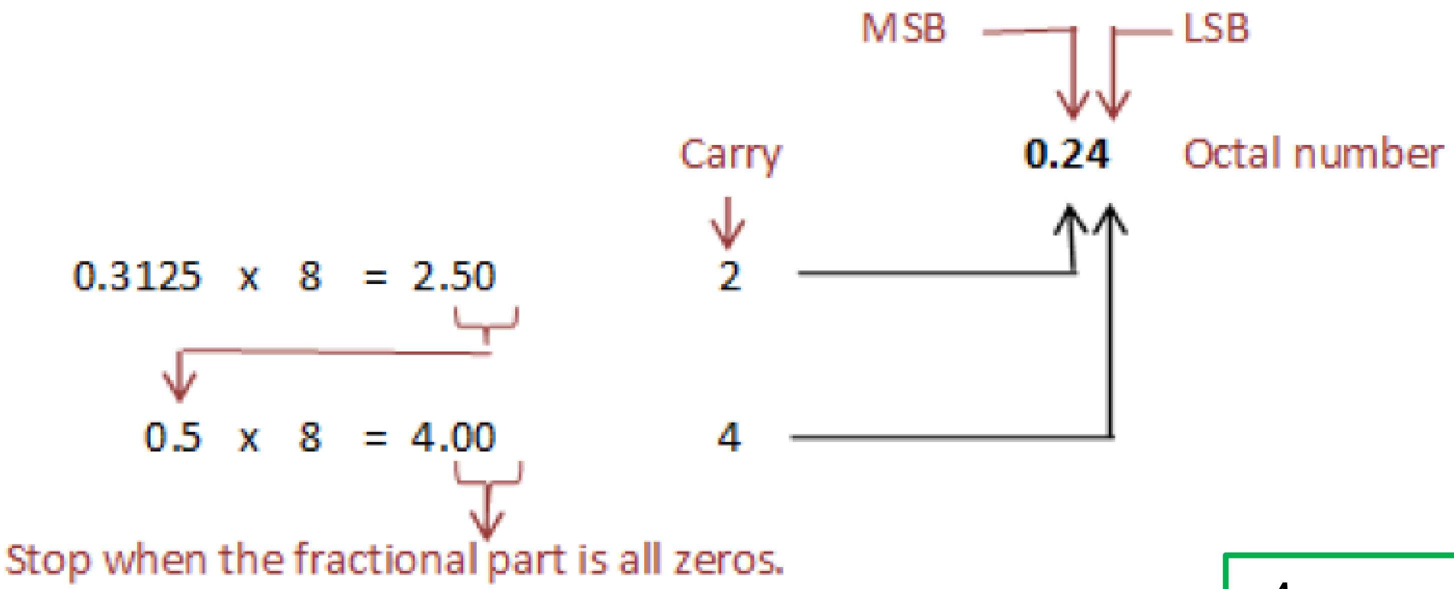
NUMBER SYSTEMS

OCTAL NUMBERS: DECIMAL TO OCTAL CONVERSION (FRACTIONAL NUMBER)

Example

Convert the fractional decimal number 0.3125 to octal.

Solution



MSB LSB

Carry 0.24 Octal number

0.3125 x 8 = 2.50 2

0.5 x 8 = 4.00 4

Stop when the fractional part is all zeros.

$$\boxed{Answer = 0.24_8}$$

NUMBER SYSTEMS

OCTAL NUMBERS: BINARY TO OCTAL CONVERSION

To convert binary to octal, simply:

Step 1

Break the binary number into **3-bits group (3-bits boundary)**, starting from LSD.

Step 2

Replace each **3-bits group** with the value equivalent to the octal number

Octal Digit	**0**	**1**	**2**	**3**	**4**	**5**	**6**	**7**
Binary Equivalent	000	001	010	011	100	101	110	111

NUMBER SYSTEMS

OCTAL NUMBERS: BINARY TO OCTAL CONVERSION

Example 1

Convert the binary number 110101 to octal.

Solution

$Binary:$	110	101
$Octal:$	6	5

$$\boxed{Answer = 65_8}$$

Example 2

Convert the binary number 1010011 to octal.

Solution

$Binary:$	001	010	011
$Octal:$	1	2	3

$$\boxed{Answer = 123_8}$$

NUMBER SYSTEMS

OCTAL NUMBERS: OCTAL TO BINARY CONVERSION

To convert octal to binary number, simply replace octal digit with the appropriate 3-bits group **(3-bits boundary)**.

Example 1

Convert the octal number 13_8 to binary.

Solution

$$\begin{array}{rcc} Octal: & 1 & 3 \\ Binary: & 001 & 011 \end{array}$$

$$\boxed{Answer = 001011_2}$$

Example 2

Convert the octal number 7526_8 to binary.

Solution

$$\begin{array}{rcccc} Octal: & 7 & 5 & 2 & 6 \\ Binary: & 111 & 101 & 010 & 110 \end{array}$$

$$\boxed{Answer = 111101010110_2}$$

NUMBER SYSTEMS

HEXADECIMAL NUMBERS

- Use **Base-16** system.
- 16 symbols consists of 10 **numeric digits** and 6 **alphabetic characters**: 0, 1, 2, 3, 4, 5, 6, 7, 8, 9, A, B, C, D, E and F.
- The value of a digit is determined by its position in the number.
- The position of each digit indicates the magnitude of the quantity and can be assigned by a **weight**.
- The weight of hexadecimal whole numbers are **positive powers of sixteen**, that increases from right to left, beginning from $16^0 = 1$.

16^{4}	16^{3}	16^{2}	16^{1}	16^{0}	16^{-1}	16^{-2}	16^{-3}	16^{4}	16^{-5}

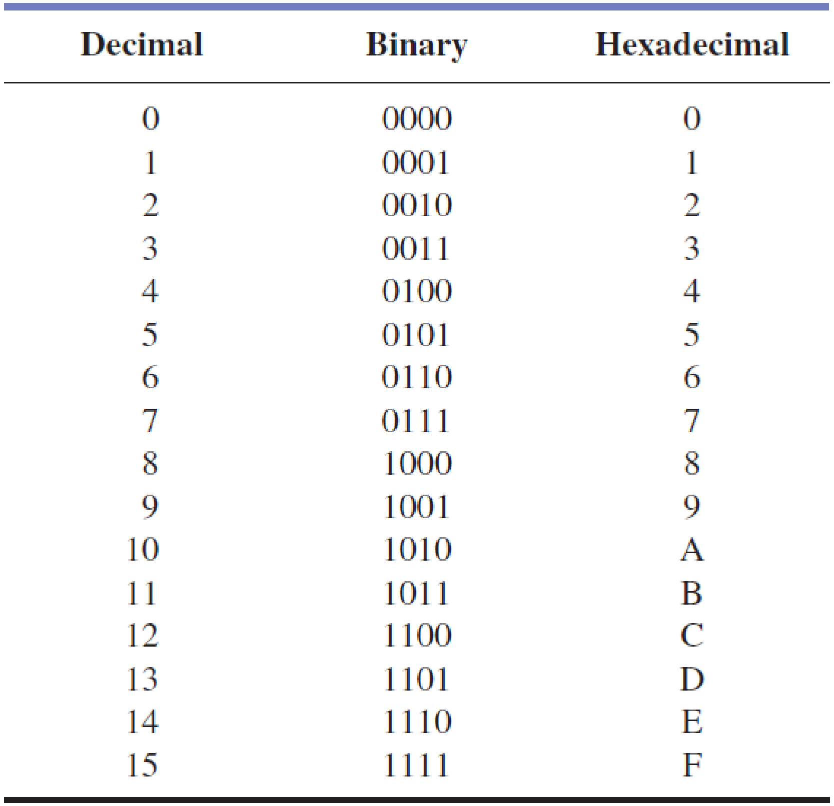
●

Hexadecimal point

NUMBER SYSTEMS

HEXADECIMAL NUMBERS

- The weight of hexadecimal fraction numbers are **negative powers of sixteen**, that decrease from left to right beginning with $16^{-1} = 0.0625$.
- Compact way to express binary numbers and codes. Uses **4-bits binary boundary**.



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

NUMBER SYSTEMS

HEXADECIMAL NUMBERS: HEXADECIMAL TO DECIMAL CONVERSION

- The decimal equivalent can be accomplished by **multiplying** each **hexadecimal digit** by its **weight** and summing the products.

Example

Convert the hexadecimal number $B2F8_{16}$ to decimal.

Solution

Multiply each digit by its weight, then calculates the sum of products.

$$\begin{array}{rcccc} Weight: & 16^3 & 16^2 & 16^1 & 16^0 \\ Hexadecimal\ Number: & B & 2 & F & 8 \end{array}$$

$$\begin{aligned} B2F8_{16} &= (B \times 16^3) + (2 \times 16^2) \\ &\quad +(F \times 16^1) + (8 \times 16^0) \\ &= (11 \times 4096) + (2 \times 256) \\ &\quad +(15 \times 16) + 8 \\ &= \mathbf{45816_{10}} \end{aligned}$$

NUMBER SYSTEMS

HEXADECIMAL NUMBERS: DECIMAL TO HEXADECIMAL CONVERSION (WHOLE NUMBER)

Repeated Division-by-16 Method

- Dividing the decimal number by **16**.
- Repeating dividing each resulting **quotient** part by **16** until the whole-quotient number is **0**.
- Take the **remainders** generated by the division to form the hexadecimal number.
- The first remainder is set as **LSD**, and the last remainder as **MSD**.

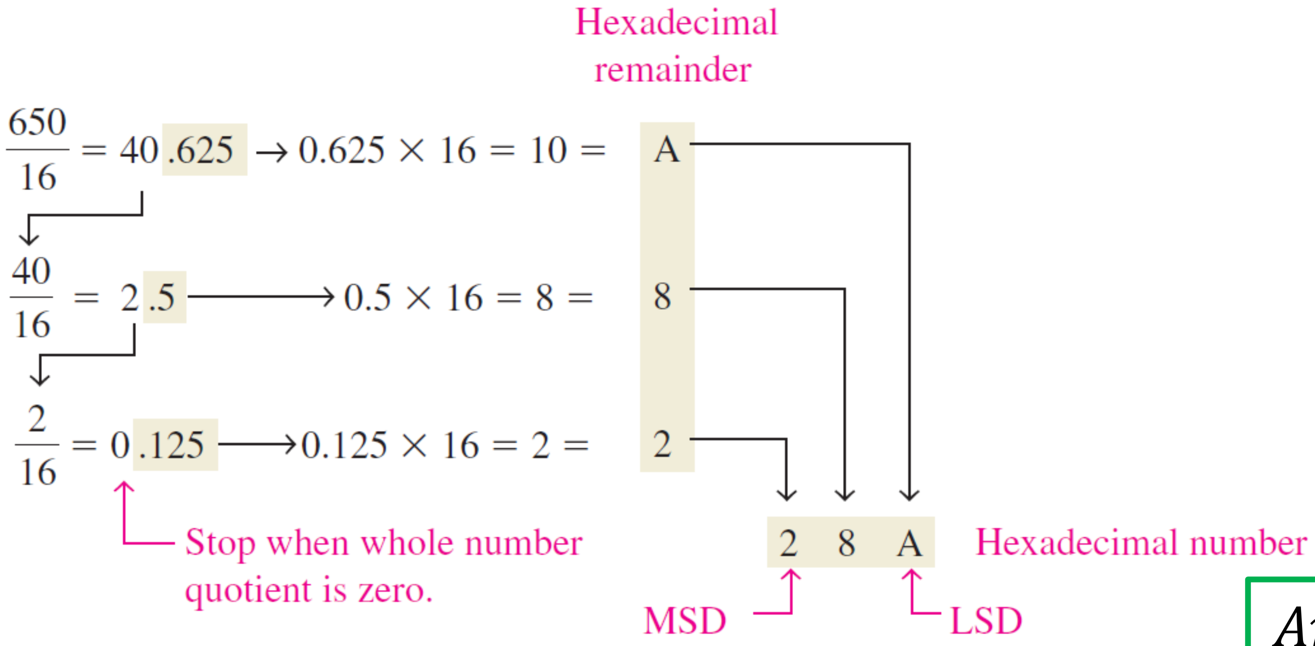
NUMBER SYSTEMS

HEXADECIMAL NUMBERS: DECIMAL TO HEXADECIMAL CONVERSION (WHOLE NUMBER)

Example

Convert the decimal number 650 to hexadecimal.

Solution



Hexadecimal remainder

$$\frac{650}{16} = 40.625 \rightarrow 0.625 \times 16 = 10 = \text{A}$$

$$\frac{40}{16} = 2.5 \longrightarrow 0.5 \times 16 = 8 = 8$$

$$\frac{2}{16} = 0.125 \longrightarrow 0.125 \times 16 = 2 = 2$$

Stop when whole number quotient is zero.

2 8 A Hexadecimal number

MSD

LSD

$$Answer = 28A_{16}$$

NUMBER SYSTEMS

HEXADECIMAL NUMBERS: DECIMAL TO HEXADECIMAL CONVERSION (FRACTIONAL NUMBER)

Repeated Multiplication-by-16 Method

- Multiplying the decimal number by **16**.
- Repeating multiplying each resulting **fractional** part by **16** until the fractional product is **0**.
- Take the **carries** generated by the multiplication to form the hexadecimal number.
- The first carry product is set as **MSD**, and the last carry as **LSD**.

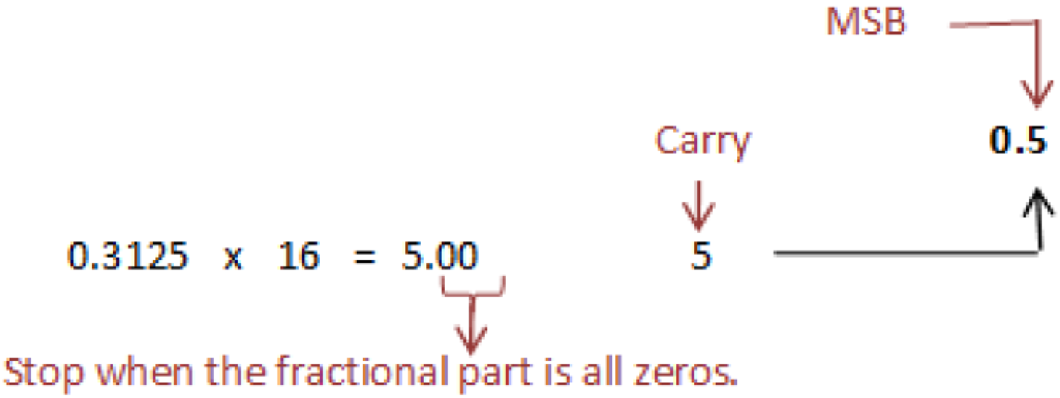
NUMBER SYSTEMS

HEXADECIMAL NUMBERS: DECIMAL TO HEXADECIMAL CONVERSION (FRACTIONAL NUMBER)

Example

Convert the decimal number 0.3125 to hexadecimal.

Solution



MSB

Carry

0.5

0.3125 x 16 = 5.00

5

Stop when the fractional part is all zeros.

$$Answer = 0.5_{16}$$

NUMBER SYSTEMS

HEXADECIMAL NUMBERS: BINARY TO HEXADECIMAL CONVERSION

To convert binary to hexadecimal, simply:

Step 1

Break the binary number into **4-bits group (4-bits boundary)**, starting from LSD.

Step 2

Replace each **4-bits group** with the value equivalent to the hexadecimal number.

NUMBER SYSTEMS

HEXADECIMAL NUMBERS: BINARY TO HEXADECIMAL CONVERSION

Example 1

Convert the binary number 1100101001010111 to hexadecimal.

Solution

$Binary$:	1100	1010	0101	0111
$Hexadecimal$:	C	A	5	7

$Answer = CA57_{16}$

Example 2

Convert the binary number 11111000101101001 to hexadecimal.

Solution

$Binary$:	0011	1111	0001	0110	1001
$Hexadecimal$:	3	F	1	6	9

$Answer = 3F169_{16}$

NUMBER SYSTEMS

HEXADECIMAL NUMBERS: HEXADECIMAL TO BINARY CONVERSION

- To convert hexadecimal to binary number, simply replace hexadecimal digit with the appropriate **4-bits group (4-bits boundary)**.

Example 1

Convert the hexadecimal number $10A4_{16}$ to binary.

Solution

$Hexadecimal$	:	1	0	A	4
$Binary$	:	0001	0000	1010	0100

$$\boxed{Answer \;=\; 0001000010100100_2}$$

NUMBER SYSTEMS

HEXADECIMAL NUMBERS: HEXADECIMAL TO BINARY CONVERSION

Example 2

Convert the hexadecimal number $CF8E_{16}$ to binary.

Solution

$Hexadecimal:$	C	F	8	E
$Binary \quad :$	1100	1111	1000	1110

$$\boxed{Answer \ = \ 1100111110001110_2}$$

NUMBER SYSTEMS

ASSESSMENT 1

Fill in the blanks:

Decimal	Binary	Octal	Hexadecimal
	1101.011_2		
	10101.11_2		
245.625_{10}			
703_{10}			
			$A85_{16}$

NUMBER SYSTEMS

ASSESSMENT 1

Fill in the blanks:

Decimal	Binary	Octal	Hexadecimal
13.375_{10}	1101.011_2	15.3_8	$D.6_{16}$
21.75_{10}	10101.11_2	25.6_8	$15.C_{16}$
245.625_{10}	11110101.101_2	365.5_8	$F5.A_{16}$
703_{10}	1010111111_2	1277_8	$2BF_{16}$
2693_{10}	101010000101_2	5205_8	$A85_{16}$

BINARY ARITHMETIC

BINARY ARITHMETIC

BINARY ADDITION: INTRODUCTION

- The four rules for adding binary digits (bits) are:

Rules	Definition
$0 + 0 = 0$	Sum of **0** with carry of **0**
$0 + 1 = 1$	Sum of **1** with carry of **0**
$1 + 0 = 1$	Sum of **1** with carry of **0**
$1 + 1 = 10$	Sum of **0** with carry of **1**

- When binary numbers are added, the last condition creates a sum of 0 in a given column and carry of 1 in the next column to the left.

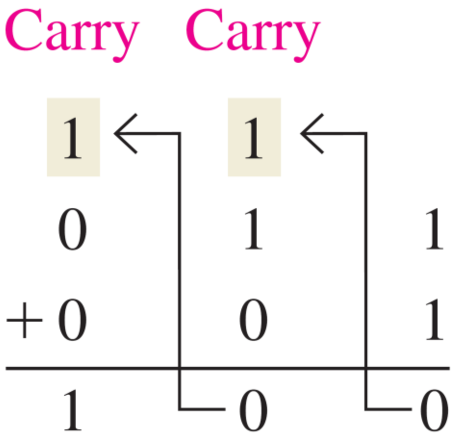
BINARY ARITHMETIC

BINARY ADDITION: EXAMPLE

Example

Find 11 + 1?

Solution



BINARY ARITHMETIC

BINARY SUBTRACTION: INTRODUCTION

- The four rules for subtracting binary digits (bits) are:

Rules
$0 - 0 = 0$
$1 - 1 = 0$
$1 - 0 = 1$
$10 - 1 = 1$
$0 - 1$ with a borrow of 1

- When subtracting numbers, needs to borrow from the next column to the left if try to subtract 1 from 0.
- When one is borrowed from the next column to the left, a 10 is created in the column being subtracted.

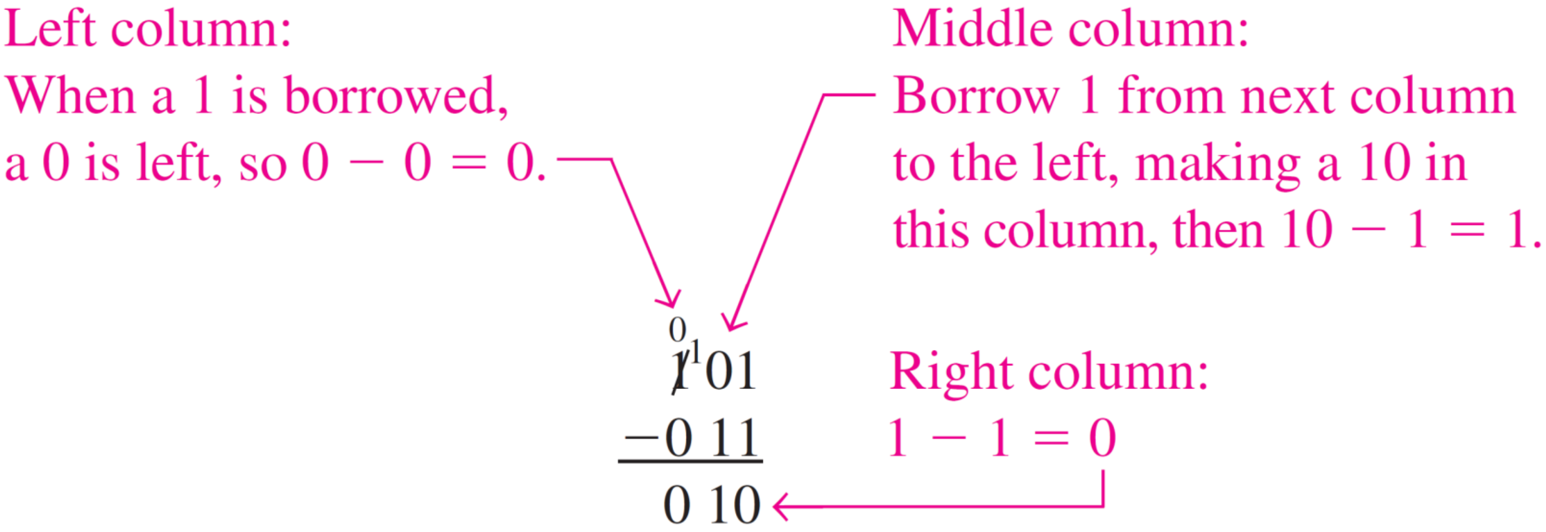
BINARY ARITHMETIC

BINARY SUBTRACTION: EXAMPLE

Example

Find 101 – 011?

Solution



Left column:
When a 1 is borrowed,
a 0 is left, so 0 − 0 = 0.

Middle column:
Borrow 1 from next column
to the left, making a 10 in
this column, then 10 − 1 = 1.

$$\begin{array}{r} \overset{0}{\cancel{1}}{}^{1}01 \\ -0\,11 \\ \hline 0\,10 \end{array}$$

Right column:
1 − 1 = 0

BINARY ARITHMETIC

BINARY MULTIPLICATION: INTRODUCTION

- The four rules for multiplying binary digits (bits) are:

Rules
$0 \times 0 = 0$
$0 \times 1 = 0$
$1 \times 0 = 0$
$1 \times 1 = 1$

- Same manner as with decimal number
- Involves performing partial product, shifting each successive partial product one place, then adding all the partial products.

BINARY ARITHMETIC

BINARY MULTIPLICATION: EXAMPLE

Example

Find 101 × 111?

Solution

$$\begin{array}{rr} & 111 \\ & \times\ 101 \\ \cline{2-2} \text{Partial products} \left\{ \begin{array}{r} \\ \\ \\ \end{array} \right. & \begin{array}{r} 111 \\ 000 \\ +111 \end{array} \\ \cline{2-2} & \mathbf{100011} \end{array} \qquad \begin{array}{r} 7 \\ \times\ 5 \\ \hline 35 \end{array}$$

BINARY ARITHMETIC

BINARY DIVISION: INTRODUCTION AND EXAMPLE

- The procedure is same as with decimal number.

Example

Find 110 ÷ 11?

Solution

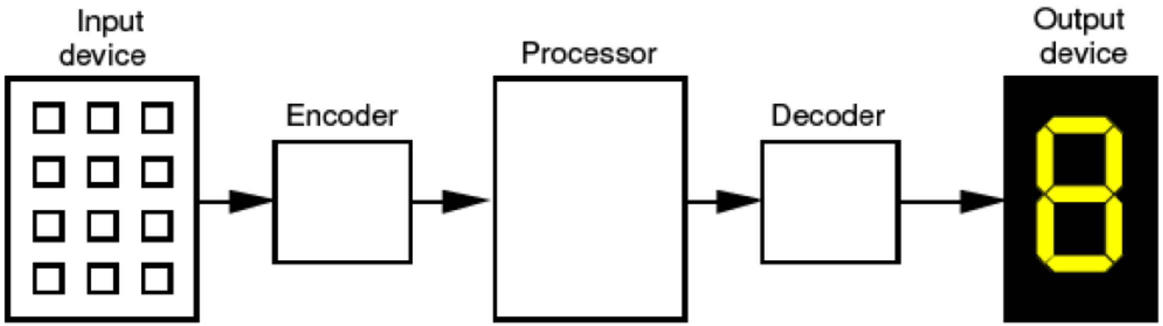
$$\begin{array}{r} \mathbf{10} \\ 11\overline{)110} \\ \underline{11} \\ 000 \end{array} \qquad\qquad \begin{array}{r} 2 \\ 3\overline{)6} \\ \underline{6} \\ 0 \end{array}$$

DIGITAL CODES

DIGITAL CODES

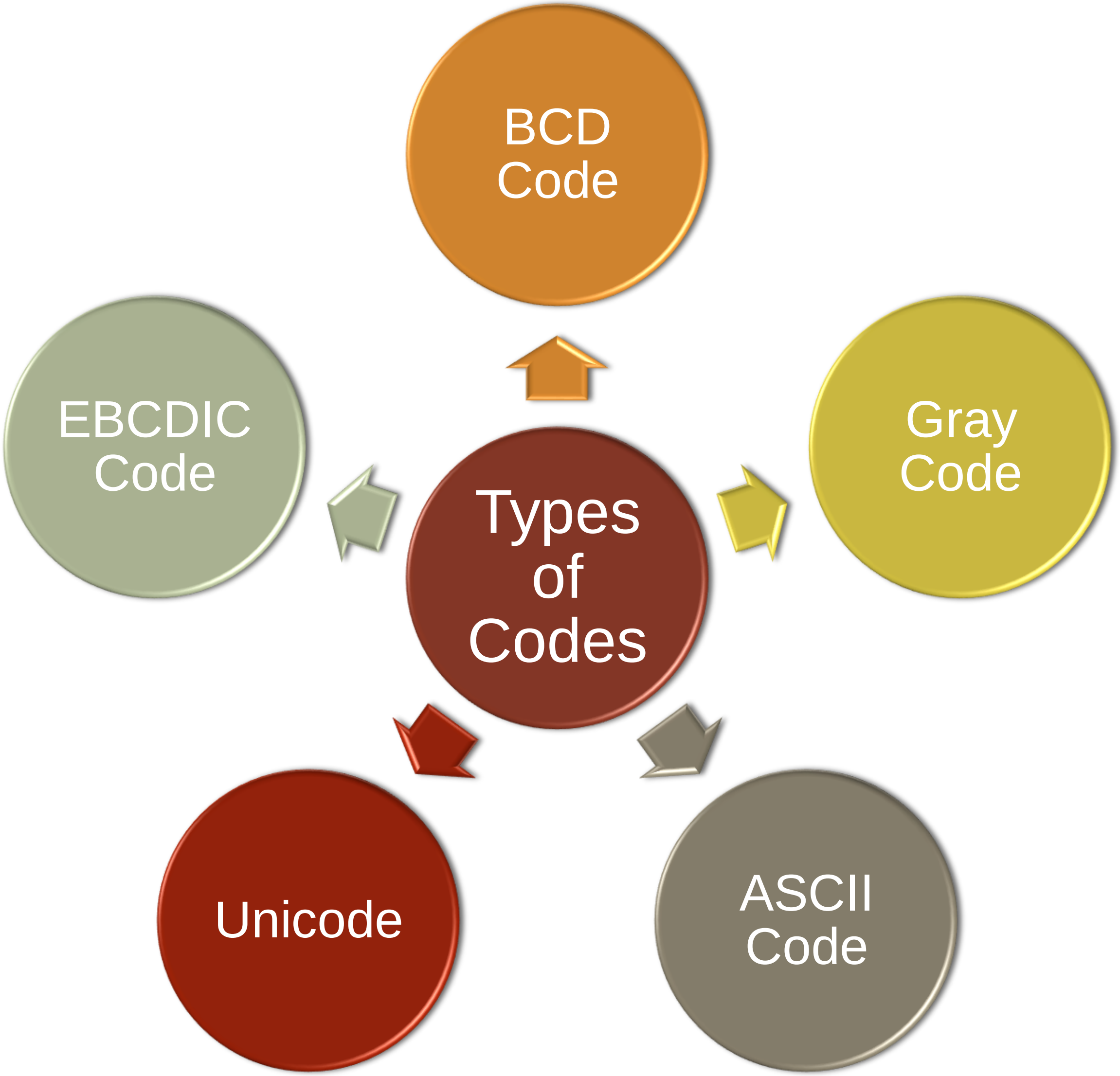
INTRODUCTION

- Many digital devices interact with humans.
- Information is entered from the **input device** to digital system and the results will be displayed through the **output device**.
- As human prefer the decimal system, information often has to be converted from decimal to binary **(encoding)** for processing, and binary to decimal **(decoding)** for presentation.
- Special circuit called **encoder** and **decoder** are required to perform data conversion.



Application of encoder and decoder in a calculator

DIGITAL CODES
INTRODUCTION


Types of Codes

BCD Code

Gray Code

ASCII Code

Unicode

EBCDIC Code

DIGITAL CODES

BINARY CODED DECIMAL (BCD) CODE: INTRODUCTION

- The simplest interface between binary and digital system.
- Each decimal digit uses **4-bits**.
- Each **4-bit groups** is treated as separate binary number.

Decimal Digit	**0**	**1**	**2**	**3**	**4**	**5**	**6**	**7**
BCD	0000	0001	0010	0011	0100	0101	0110	0111

- Also known as **BCD 8421 code** because the numbers indicate as the weight of each bits.

DIGITAL CODES

BINARY CODED DECIMAL (BCD) CODE: BCD TO DECIMAL CONVERSION

To convert BCD to decimal, simply:

Step 1

Break the BCD into **4-bits group**, starting from **LSB**.

Step 2

Replace each **4-bits group** with the value equivalent to the decimal number.

DIGITAL CODES

BINARY CODED DECIMAL (BCD) CODE: BCD TO DECIMAL CONVERSION

Example

Convert BCD code 001101010001 to decimal

Solution

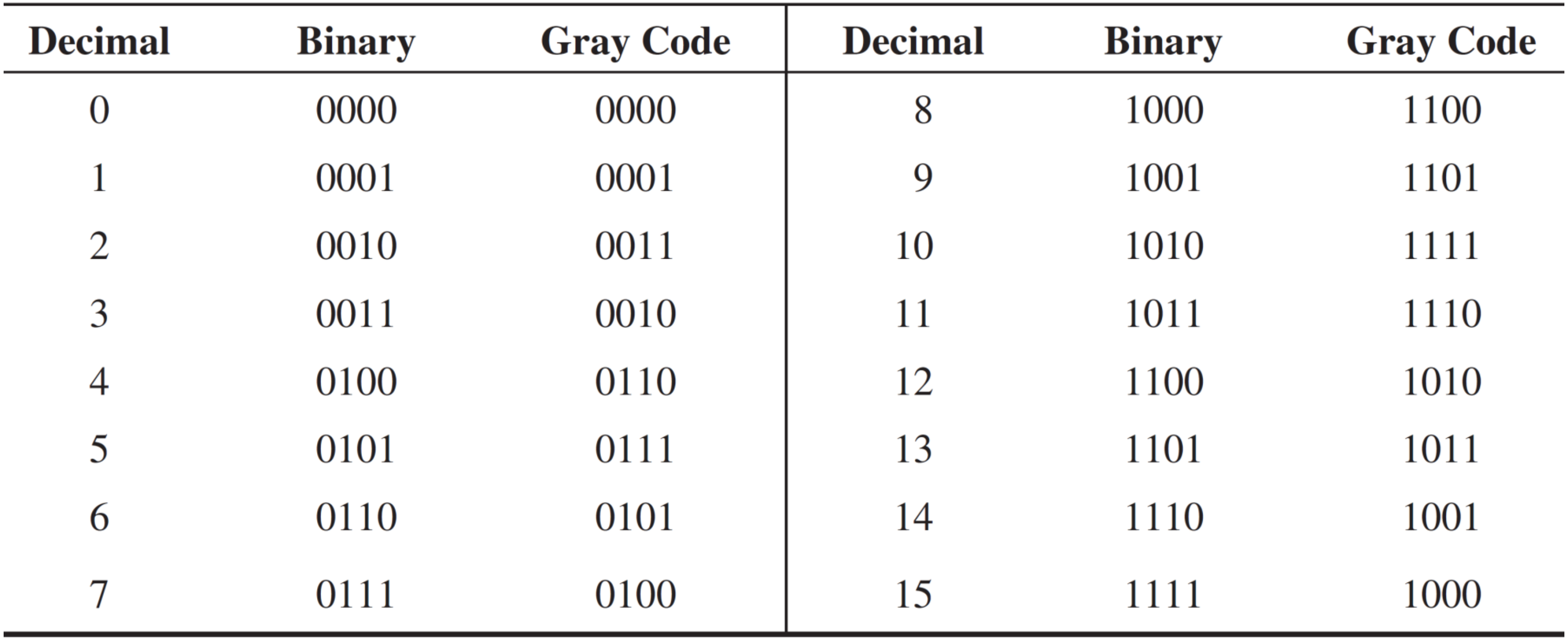
4-bit grouping	0011	0101	0001
Decimal number	3	5	1

$$\boxed{Answer\ =\ 351_{10}}$$

DIGITAL CODES

GRAY CODE: INTRODUCTION

- Is a **non-weighted** code.
- Only a single bit change from one code word to the next sequence.
- Good – to minimize the chance of error.



Decimal	Binary	Gray Code	Decimal	Binary	Gray Code
0	0000	0000	8	1000	1100
1	0001	0001	9	1001	1101
2	0010	0011	10	1010	1111
3	0011	0010	11	1011	1110
4	0100	0110	12	1100	1010
5	0101	0111	13	1101	1011
6	0110	0101	14	1110	1001
7	0111	0100	15	1111	1000

DIGITAL CODES

GRAY CODE: BINARY TO GRAY CODE CONVERSION

To convert binary to Gray Code, simply:

Step 1

The most significant bit (left-most) in the Gray Code is the same as the corresponding **MSB** in the binary number.

Step 2

Going from left to right, add each adjacent pair of binary code to get next gray code. Discard carries.

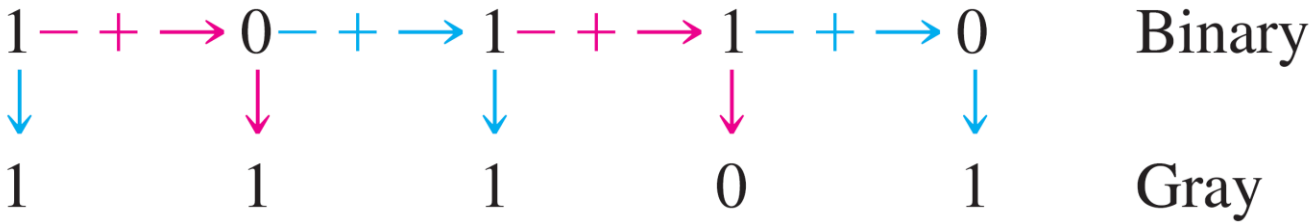
DIGITAL CODES

GRAY CODE: BINARY TO GRAY CODE CONVERSION

Example

Convert the binary number 10110 to Gray Code.

Solution



$$\boxed{Answer\ = 11101}$$

DIGITAL CODES

GRAY CODE: GRAY CODE TO BINARY CONVERSION

To convert Gray Code to binary, simply:

Step 1

The most significant bit (left-most) in the binary number is the same as the corresponding **bit** in the Gray Code.

Step 2

Add each binary number bit generated to the Gray Code bit in the next adjacent position. Discard carries.

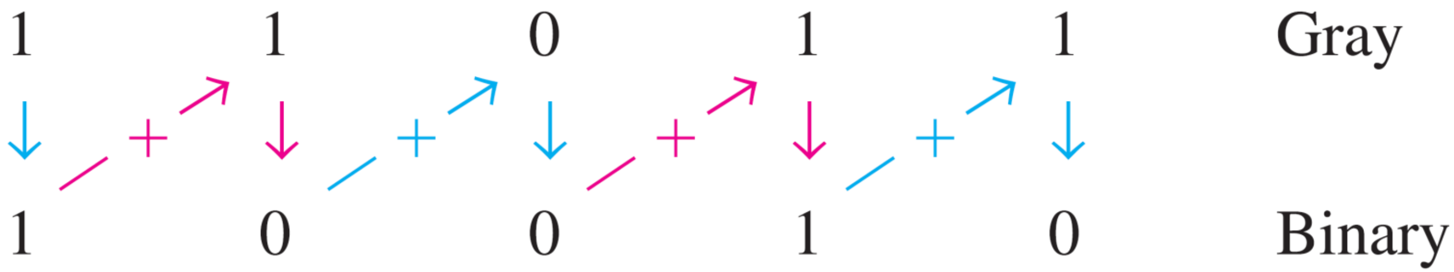
DIGITAL CODES

GRAY CODE: GRAY CODE TO BINARY CONVERSION

Example

Convert the Gray Code 11011 to binary.

Solution



$$\boxed{Answer\ = 10010}$$

DIGITAL CODES

ALPHANUMERIC CODE

- In complex digital system, such computers must process not only numeric data, but also alphabets, punctuation marks and other symbols.
- Thus, to represent numbers and alphabet characters (letters), a code called **alphanumeric code** is needed.
- At minimum, the code must represents 10 digit decimal numbers (0-9) and 26 letters (A-Z) with a total of 36 items.
- 6-bits are needed in the code that represents the numbers and letters because 5-bits is not enough $(2^5 = 32)$.
- **ASCII** is the most common alphanumeric code.

DIGITAL CODES

ASCII CODE

- **ASCII** is the abbreviation of **American Standard Code for International Interchange**.
- Used in computers and electronic equipment.
- Most computer keyboards are standardized with ASCII code.
- When entering a letter, a number or control command, the corresponding ASCII code goes to the computer.
- ASCII has **128 characters**, represents by **7-bit** binary code.
- Can be considered as 8-bit with MSB = 0.
- ASCII can be divided into:
  - **Non-graphic commands:** The first 32 ASCII characters are only for control purpose. *E.g. Null, line feed, start of text, escape and etc*.
  - **Graphic symbols:** Letter of alphabet (lowercase and uppercase), 10 decimal digits, punctuation signs and other commonly used symbols.

DIGITAL CODES

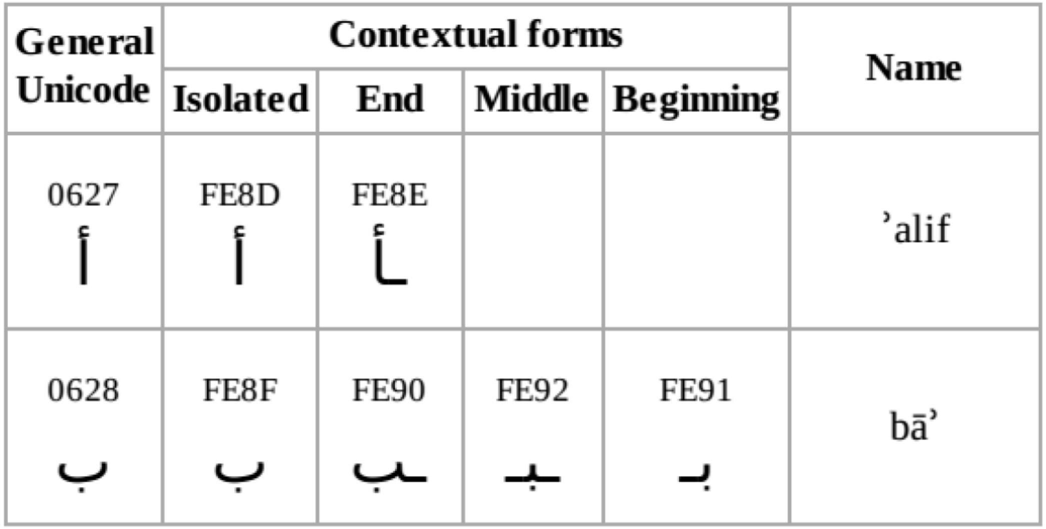
ASCII CODE

Bits 3-0	Bits 6-4							
	000	**001**	**010**	**011**	**100**	**101**	**110**	**111**
0000	NUL	DLE	SP	0	@	P	‘	p
0001	SOH	DC1	!	1	A	Q	a	q
0010	STX	DC2	"	2	B	R	b	r
0011	ETX	DC3	#	3	C	S	c	s
0100	EOT	DC4	$	4	D	T	d	t
0101	ENQ	NAK	%	5	E	U	e	u
0110	ACK	SYN	&	6	F	V	f	v
0111	BEL	ETB	’	7	G	W	g	w
1000	BS	CAN	(	8	H	X	h	x
1001	HT	EM	)	9	I	Y	i	y
1010	LF	SUB	*	:	J	Z	j	z
1011	VT	ESC	+	;	K	[	k	{
1100	FF	FS	,	<	L	\	l	|
1101	CR	GS	-	=	M	]	m	}
1110	SO	RS	.	>	N	ˆ	n	
1111	SI	US	/	?	O	_	o	DEL

DIGITAL CODES

UNICODE

- **ASCII** code is sufficient for using computers in United States, but not for other regions. (i.e, currency sign €, £, ¥)
- **Unicode** is 31 bit standards that allows more than **110000 characters**, for most language in the world.
- Each character is assigned a code point written in hexadecimal.
- Unicode is constantly changing as more characters get added.



General Unicode	Contextual forms				Name
	Isolated	End	Middle	Beginning	
0627 أ	FE8D أ	FE8E ـأ			’alif
0628 ب	FE8F ب	FE90 ـب	FE92 ـبـ	FE91 بـ	bā’

DIGITAL CODES

EBCDIC ALPHANUMERIC CODE

- Extended Binary Coded Decimal Interchange Code (EBCDIC).
- 8-bit character encoding.

Character or Number	ASCII-8 Binary	EBCDIC Binary
A	01000001	11000001
E	01000101	11000101
Z	01011010	11101001
0	0000	0000
1	0001	0001
5	0101	0101

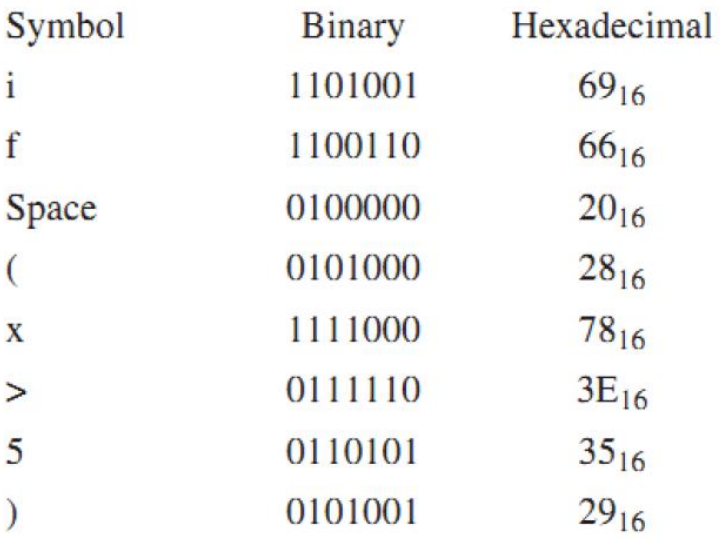
DIGITAL CODES

ASSESSMENT 2

Determine the binary ASCII codes that are entered from the computer’s keyboard when the following C language program statement is typed in. Also express each code in hexadecimal and decimal.

```
if (x>5)
```

Solution



Symbol	Binary	Hexadecimal
i	1101001	69_{16}
f	1100110	66_{16}
Space	0100000	20_{16}
(	0101000	28_{16}
x	1111000	78_{16}
>	0111110	$3E_{16}$
5	0110101	35_{16}
)	0101001	29_{16}