UNIVERSITI TEKNOLOGI MALAYSIA

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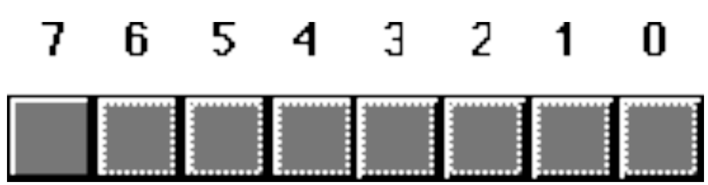
# SCSR1013 DIGITAL LOGIC

## MODULE 2b:
## DATA ORGANIZATION (CODES)

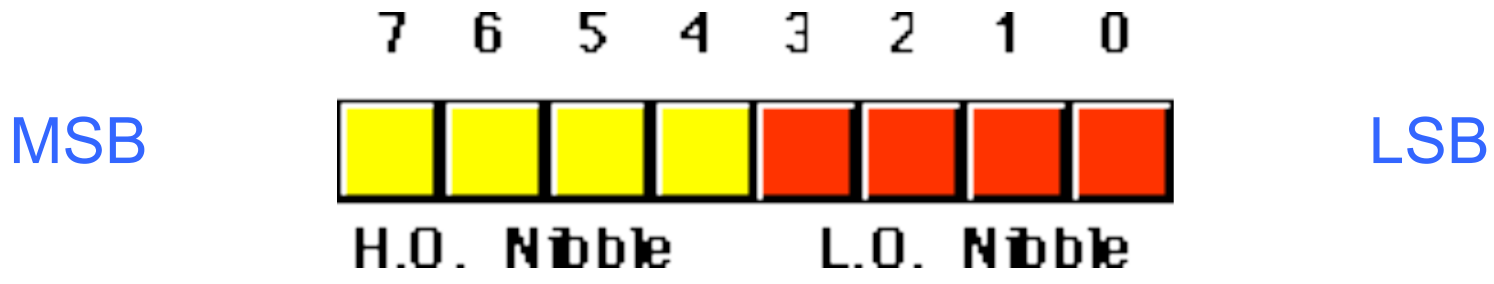
FACULTY OF COMPUTING

# Data Organization

- A value may take an arbitrary number of bits.
- Common collections are single bits
  - smallest "unit" of data on a binary computer is a single bit
  - groups of four bits called nibbles
  - groups of eight bits called bytes
  - groups of 16 bits called words
- The bits in a byte are normally numbered from zero to seven.



- Bit 0 is the low order bit (rightmost) or least significant bit (LSB) bit 7 is the high order bit (leftmost) or most significant bit (MSB) of the byte.
  Note 1 byte also contains exactly 2 nibbles:



# Nibbles

- 4 bits


- **Major uses**:
  - BCD (Binary Coded Decimal)
  - Hexadecimal numbers

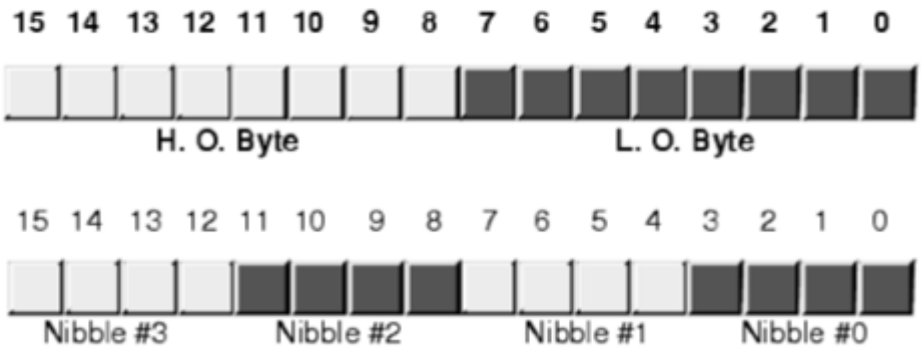
Example: 0111, 1011 and 1111.

$7_{16}$, $B_{16}$, $F_{16}$

# Bytes


- 8 bits
- Total values: $2^8 = 256$

- **Major uses**:
  - Numeric values ($0 \ldots 2^8-1 = 0 \ldots 255$)
  - Signed numbers: (-128 to +127)




- 16 bits = 2 bytes
- Bit 0 to 15
- **Total values**:
  - $2^{16} = 65{,}536$

- **Major uses of word**:
  - signed integer (-32,768 … +32,767)
  - unsigned integer (0 … $2^{16}$-1) = 0 … 65,535)
  - UNICODE characters

# What are codes?

- Code is a representation of information generated by following a certain rules.
- In general, we need code because:
  - Code is unique
  - Codes are easy to process
  - Code is easy to represent
  - Codes enable communication in place where ordinary spoken or written language is difficult or impossible, eg Morse Code
- Due to this, code can simplify the process (such as manipulation and arithmetic operations) of the information in the digital system.

**We will learn:**

i. BCD codes
ii. Gray Codes
iii. ASCII codes
iv. Parity codes/bit

# Binary Coded Decimal (BCD)

- BCD is a way to express each of the decimal digits with a binary code.
- There are only 10 code groups in the BCD system, one for every digit (0000 – 1001)

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

Invalid codes are 1010, 1011, 1100, 1101, 1110, 1111

Example 1: Convert 3245 to BCD

3 2 4 5

3245 = 0011 0010 0100 0101

Example 2: Convert 7848 to BCD

7 8 4 8

7848 = 0111 1000 0100 1000

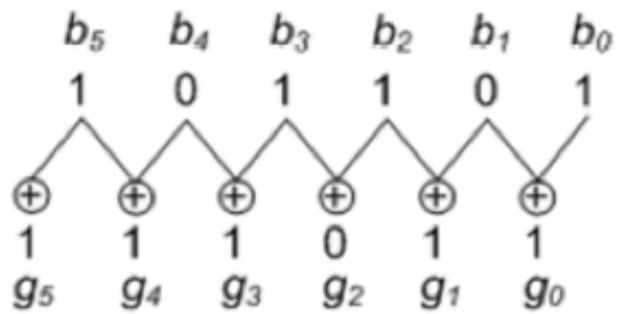
# Gray Codes

Electromechanical switches


- Designed to prevent false output from electromechanical switches.
- Are widely used to facilitate error correction in digital communications such as digital terrestrial television and some cable TV systems.
- In modern digital communications, Gray codes play an important role in error correction.
- It is arranged so that every transition from one value to the next value involves only one bit change.
- Sometimes referred to as reflected because the first eight values compare with those of the last 8 values, but in reverse order.

# Conversion of Gray Code ←→ Binary

To convert **binary → Gray code**




where $b_{i+1}, b_i, b_{i-1}, \ldots, b_0$ is the binary number while $g_{i+1}, g_i, g_{i-1}, \ldots, g_0$ gray code.

To convert **Gray code → binary:**

- $b_i = g_i$ if no. of 1's preceding $g_i$ is even
- $b_i = \overline{g_i}$ if no. of 1's preceding $g_i$ is odd

# Example:

Convert 100110 to its equivalent gray code value

| $b_7$ | $b_6$ | $b_5$ | $b_4$ | $b_3$ | $b_2$ | $b_1$ | $b_0$ |
|---|---|---|---|---|---|---|---|
| 1 | 0 | 0 | 1 | 1 | 0 | 1 | 0 |

(Maintain MSB)

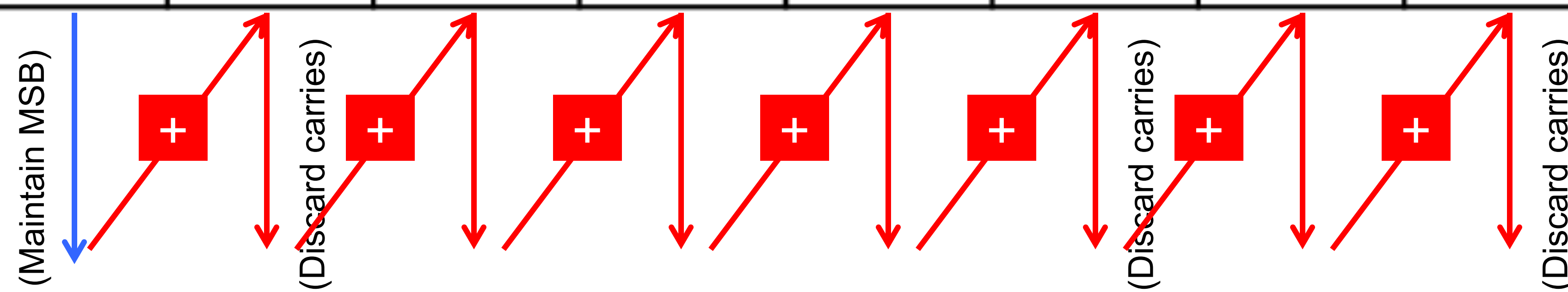
(Discard carries)

| | | | | | | | |
|---|---|---|---|---|---|---|---|
| | | | | | | | |
| $g_7$ | $g_6$ | $g_5$ | $g_4$ | $g_3$ | $g_2$ | $g_1$ | $g_0$ |

# Example:

Convert the Gray code 11010111 to binary.

| | | | | | | | |
|---|---|---|---|---|---|---|---|
| 1 | 1 | 0 | 1 | 0 | 1 | 1 | 1 |
| $g_7$ | $g_6$ | $g_5$ | $g_4$ | $g_3$ | $g_2$ | $g_1$ | $g_0$ |




| | | | | | | | |
|---|---|---|---|---|---|---|---|
| 1 | 0 | 0 | 1 | 1 | 0 | 1 | 0 |
| $b_7$ | $b_6$ | $b_5$ | $b_4$ | $b_3$ | $b_2$ | $b_1$ | $b_0$ |

## Exercise 2b.1:

Convert $11010100_2$ to its equivalent gray code value.

# Parity Code

Parity bit

- Parity bit used for bit error detection
  - Even parity – total number of 1s even $\boxed{0}$
  - Odd parity – total number of 1s odd $\boxed{0}$
- Parity bit is append to the code at the leftmost position (MSB) .

A parity bit is a bit that is added to ensure that the number of bits with value of 1's in a given set of bits is always even or odd. Parity bits are used as the simplest error detecting code.

Extra

## Examples:

**1** 1 0 1 0 0 1 1 1

Even Parity bit

**0** 1 0 1 0 0 1 1 1

Odd Parity bit

| Number 1s | Even Parity | Odd Parity |
|---|---|---|
| Even | 0 | 1 |
| Odd | 1 | 0 |

(Remember these basic rule)

| 7 bits of data (number of 1s) | 8 bits including parity | |
|---|---|---|
| | even | odd |
| 0000000 (0) | 00000000 | 10000000 |
| 1010001 (3) | 11010001 | 01010001 |
| 1101001 (4) | 01101001 | 11101001 |
| 1111111 (7) | 11111111 | 01111111 |

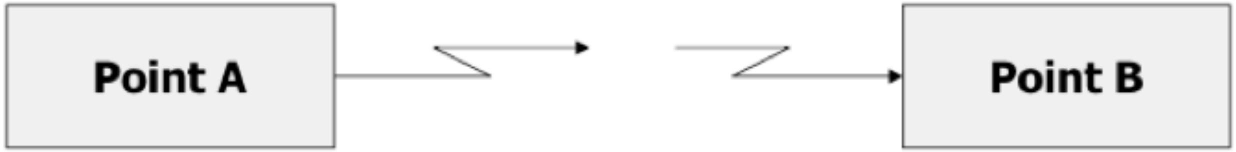
Parity bit

- Example: Calculate the parity bit for the codes below.

| Code | Number of 1s | Even/Odd | Even Parity | Odd Parity |
|---|---|---|---|---|
| 110010 | 3 | Odd | **1** 110010 | **0** 110010 |
| 101110 | 4 | Even | **0** 101110 | **1** 101110 |
| 101000 | 2 | Even | **0** 101000 | **1** 101000 |
| 110111 | 5 | Odd | **1** 110111 | **0** 110111 |
| 111111 | 6 | Even | 0 111111 | 1 111111 |
| 100000 | 1 | Odd | 1 100000 | 0 100000 |

# Error Detection by Parity Checking

- Assume that data = 0101
- It uses even parity.
- Therefore the appended parity bit is 0.
- The data with parity bit: 0 0101
- The data is transmitted.
- The data is received as 00001 → odd no. of 1, not even!!




Data: 0 0101
(even parity)

Data: 0 0001
(even parity)
but does not conform
to even parity

# American Standard Code for Information Interchange (ASCII)

- It has 128 characters and symbols represented in 7-bit binary code
- Example :
- A = $1000001_2$
- a = $1100001_2$
- A parity bit is added so that the total number of bits is 8 → a byte.

| Decimal | Hex | ASCII | Decimal | Hex | ASCII | Decimal | Hex | ASCII | Decimal | Hex | ASCII |
|---|---|---|---|---|---|---|---|---|---|---|---|
| 0 | 00 | NUL | 32 | 20 | (blank) | 64 | 40 | @ | 96 | 60 | ` |
| 1 | 01 | SOH | 33 | 21 | ! | 65 | 41 | A | 97 | 61 | a |
| 2 | 02 | STX | 34 | 22 | " | 66 | 42 | B | 98 | 62 | b |
| 3 | 03 | ETX | 35 | 23 | # | 67 | 43 | C | 99 | 63 | c |
| 4 | 04 | EOT | 36 | 24 | $ | 68 | 44 | D | 100 | 64 | d |
| 5 | 05 | ENQ | 37 | 25 | % | 69 | 45 | E | 101 | 65 | e |
| 6 | 06 | ACK | 38 | 26 | & | 70 | 46 | F | 102 | 66 | f |
| 7 | 07 | BEL | 39 | 27 | ' | 71 | 47 | G | 103 | 67 | g |
| 8 | 08 | BS | 40 | 28 | ( | 72 | 48 | H | 104 | 68 | h |
| 9 | 09 | HT | 41 | 29 | ) | 73 | 49 | I | 105 | 69 | i |
| 10 | 0A | LF | 42 | 2A | * | 74 | 4A | J | 106 | 6A | j |
| 11 | 0B | VT | 43 | 2B | + | 75 | 4B | K | 107 | 6B | k |
| 12 | 0C | FF | 44 | 2C | , | 76 | 4C | L | 108 | 6C | l |
| 13 | 0D | CR | 45 | 2D | - | 77 | 4D | M | 109 | 6D | m |
| 14 | 0E | SO | 46 | 2E | . | 78 | 4E | N | 110 | 6E | n |
| 15 | 0F | SI | 47 | 2F | / | 79 | 4F | O | 111 | 6F | o |
| 16 | 10 | DLE | 48 | 30 | 0 | 80 | 50 | P | 112 | 70 | p |
| 17 | 11 | DC1 | 49 | 31 | 1 | 81 | 51 | Q | 113 | 71 | q |
| 18 | 12 | DC2 | 50 | 32 | 2 | 82 | 52 | R | 114 | 72 | r |
| 19 | 13 | DC3 | 51 | 33 | 3 | 83 | 53 | S | 115 | 73 | s |
| 20 | 14 | DC4 | 52 | 34 | 4 | 84 | 54 | T | 116 | 74 | t |
| 21 | 15 | NAK | 53 | 35 | 5 | 85 | 55 | U | 117 | 75 | u |
| 22 | 16 | SYN | 54 | 36 | 6 | 86 | 56 | V | 118 | 76 | v |
| 23 | 17 | ETB | 55 | 37 | 7 | 87 | 57 | W | 119 | 77 | w |
| 24 | 18 | CAN | 56 | 38 | 8 | 88 | 58 | X | 120 | 78 | x |
| 25 | 19 | EM | 57 | 39 | 9 | 89 | 59 | Y | 121 | 79 | y |
| 26 | 1A | SUB | 58 | 3A | : | 90 | 5A | Z | 122 | 7A | z |
| 27 | 1B | ESC | 59 | 3B | ; | 91 | 5B | [ | 123 | 7B | { |
| 28 | 1C | FS | 60 | 3C | < | 92 | 5C | \ | 124 | 7C | \| |
| 29 | 1D | GS | 61 | 3D | = | 93 | 5D | ] | 125 | 7D | } |
| 30 | 1E | RS | 62 | 3E | > | 94 | 5E | ^ | 126 | 7E | ~ |
| 31 | 1F | US | 63 | 3F | ? | 95 | 5F | _ | 127 | 7F | (delete) |

*Resource: http://www.s4a.us/support/cimco_faq.htm*

Extra

$b_7$
$b_6$
$b_5$

| $b_7$ → | | | | | 0 | 0 | 0 | 0 | 1 | 1 | 1 | 1 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| $b_6$ → | | | | | 0 | 0 | 1 | 1 | 0 | 0 | 1 | 1 |
| $b_5$ → | | | | | 0 | 1 | 0 | 1 | 0 | 1 | 0 | 1 |
| Bits: $b_4$ ↓ | $b_3$ ↓ | $b_2$ ↓ | $b_1$ ↓ | Column → / Row ↓ | 0 | 1 | 2 | 3 | 4 | 5 | 6 | 7 |
| 0 | 0 | 0 | 0 | 0 | NUL | DLE | SP | 0 | @ | P | ` | p |
| 0 | 0 | 0 | 1 | 1 | SOH | DC1 | ! | 1 | A | Q | a | q |
| 0 | 0 | 1 | 0 | 2 | STX | DC2 | " | 2 | B | R | b | r |
| 0 | 0 | 1 | 1 | 3 | ETX | DC3 | # | 3 | C | S | c | s |
| 0 | 1 | 0 | 0 | 4 | EOT | DC4 | $ | 4 | D | T | d | t |
| 0 | 1 | 0 | 1 | 5 | ENQ | NAK | % | 5 | E | U | e | u |
| 0 | 1 | 1 | 0 | 6 | ACK | SYN | & | 6 | F | V | f | v |
| 0 | 1 | 1 | 1 | 7 | BEL | ETB | ' | 7 | G | W | g | w |
| 1 | 0 | 0 | 0 | 8 | BS | CAN | ( | 8 | H | X | h | x |
| 1 | 0 | 0 | 1 | 9 | HT | EM | ) | 9 | I | Y | i | y |
| 1 | 0 | 1 | 0 | 10 | LF | SUB | * | : | J | Z | j | z |
| 1 | 0 | 1 | 1 | 11 | VT | ESC | + | ; | K | [ | k | { |
| 1 | 1 | 0 | 0 | 12 | FF | FC | , | < | L | \ | l | \| |
| 1 | 1 | 0 | 1 | 13 | CR | GS | - | = | M | ] | m | } |
| 1 | 1 | 1 | 0 | 14 | SO | RS | . | > | N | ^ | n | ~ |
| 1 | 1 | 1 | 1 | 15 | SI | US | / | ? | O | _ | o | DEL |

7-bits binary$_2$ ASCII code

**Examples:**

$B_7b_6b_5$ $b_4b_3b_2b_1$

110 1101

is represent as 'm'

Resource: *http://en.wikipedia.org/wiki/File:ASCII_Code_Chart-Quick_ref_card.png*

# Exercise 2b.2:

Convert the string SCR1013 to its ASCII hexadecimal value.

SCR1013 = 53 43 52 31 30 31 33

By using even parity coding, calculate the parity bit and insert this bit at the MSB position. Recalculate the ASCII value in its hexadecimal representation.

Extra

## Exercise 2b.3:

Given a string (character) UTM1435.

a) Convert the string to its ASCII hexadecimal value.

b) Calculate the odd parity bit and insert as MSB.

a) Recalculate the ASCII value in hexadecimal.

| Number 1s | Even Parity | Odd Parity |
|---|---|---|
| Even | 0 | 1 |
| Odd | 1 | 0 |

Extra

| Character (ASCII) | ASCII (Hex) | Binary | Odd parity bit + Binary | New ASCII (Hex) |
|---|---|---|---|---|
| U | | | | |
| T | | | | |
| M | | | | |
| 1 | | | | |
| 4 | | | | |
| 3 | | | | |
| 5 | | | | |
| h | | | | |

| Decimal | Hex | ASCII | Decimal | Hex | ASCII | Decimal | Hex | ASCII | Decimal | Hex | ASCII |
|---|---|---|---|---|---|---|---|---|---|---|---|
| 0 | 00 | NUL | 32 | 20 | (blank) | 64 | 40 | @ | 96 | 60 | ` |
| 1 | 01 | SOH | 33 | 21 | ! | 65 | 41 | A | 97 | 61 | a |
| 2 | 02 | STX | 34 | 22 | " | 66 | 42 | B | 98 | 62 | b |
| 3 | 03 | ETX | 35 | 23 | # | 67 | 43 | C | 99 | 63 | c |
| 4 | 04 | EOT | 36 | 24 | $ | 68 | 44 | D | 100 | 64 | d |
| 5 | 05 | ENQ | 37 | 25 | % | 69 | 45 | E | 101 | 65 | e |
| 6 | 06 | ACK | 38 | 26 | & | 70 | 46 | F | 102 | 66 | f |
| 7 | 07 | BEL | 39 | 27 | ' | 71 | 47 | G | 103 | 67 | g |
| 8 | 08 | BS | 40 | 28 | ( | 72 | 48 | H | 104 | 68 | h |
| 9 | 09 | HT | 41 | 29 | ) | 73 | 49 | I | 105 | 69 | i |
| 10 | 0A | LF | 42 | 2A | * | 74 | 4A | J | 106 | 6A | j |
| 11 | 0B | VT | 43 | 2B | + | 75 | 4B | K | 107 | 6B | k |
| 12 | 0C | FF | 44 | 2C | , | 76 | 4C | L | 108 | 6C | l |
| 13 | 0D | CR | 45 | 2D | - | 77 | 4D | M | 109 | 6D | m |
| 14 | 0E | SO | 46 | 2E | . | 78 | 4E | N | 110 | 6E | n |
| 15 | 0F | SI | 47 | 2F | / | 79 | 4F | O | 111 | 6F | o |
| 16 | 10 | DLE | 48 | 30 | 0 | 80 | 50 | P | 112 | 70 | p |
| 17 | 11 | DC1 | 49 | 31 | 1 | 81 | 51 | Q | 113 | 71 | q |
| 18 | 12 | DC2 | 50 | 32 | 2 | 82 | 52 | R | 114 | 72 | r |
| 19 | 13 | DC3 | 51 | 33 | 3 | 83 | 53 | S | 115 | 73 | s |
| 20 | 14 | DC4 | 52 | 34 | 4 | 84 | 54 | T | 116 | 74 | t |
| 21 | 15 | NAK | 53 | 35 | 5 | 85 | 55 | U | 117 | 75 | u |
| 22 | 16 | SYN | 54 | 36 | 6 | 86 | 56 | V | 118 | 76 | v |
| 23 | 17 | ETB | 55 | 37 | 7 | 87 | 57 | W | 119 | 77 | w |
| 24 | 18 | CAN | 56 | 38 | 8 | 88 | 58 | X | 120 | 78 | x |
| 25 | 19 | EM | 57 | 39 | 9 | 89 | 59 | Y | 121 | 79 | y |
| 26 | 1A | SUB | 58 | 3A | : | 90 | 5A | Z | 122 | 7A | z |
| 27 | 1B | ESC | 59 | 3B | ; | 91 | 5B | [ | 123 | 7B | { |
| 28 | 1C | FS | 60 | 3C | < | 92 | 5C | \ | 124 | 7C | \| |
| 29 | 1D | GS | 61 | 3D | = | 93 | 5D | ] | 125 | 7D | } |
| 30 | 1E | RS | 62 | 3E | > | 94 | 5E | ^ | 126 | 7E | ~ |
| 31 | 1F | US | 63 | 3F | ? | 95 | 5F | _ | 127 | 7F | (delete) |

*Resource: http://www.s4a.us/support/cimco_faq.htm*