Digital Logic & Design

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Lecture 01

Analogue Quantities

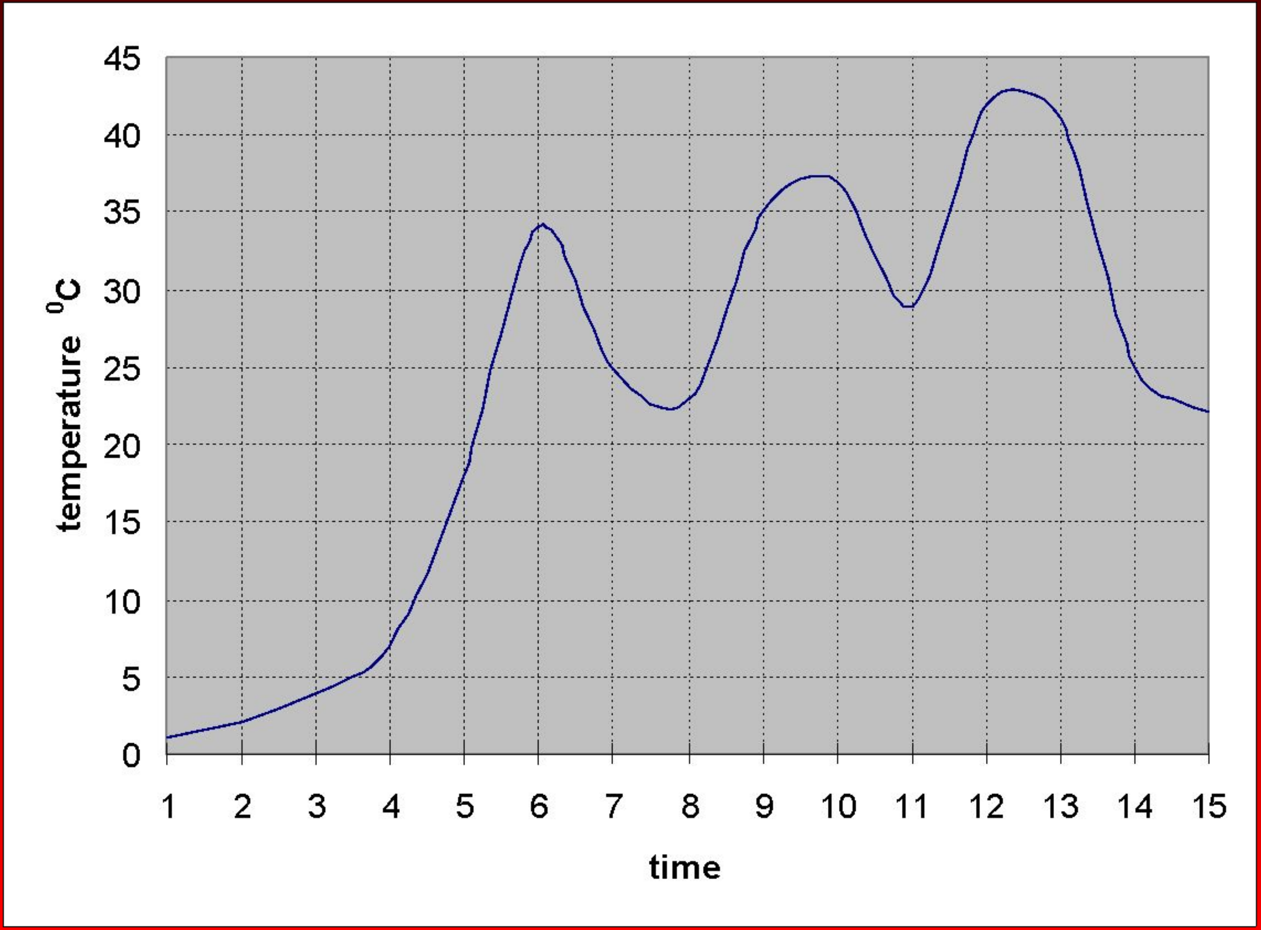
- Most of the quantities in nature that we can measure are continuous,
- for example the intensity of light, temperature, velocity all change continuously.
- Temperature for example never rises in discrete steps like 37, 39, 43. The rise in temperature is continuous.

Digital Values

- Digital values on the other hand are a discrete set of values which represent the actual Continuous Signal.
- Consider the continuous signal shown in the diagram.

Continuous Signal

- The diagram shows a plot of temperature continuously varying with time.
  - The continuous signal can be represented digitally by taking samples at regular but fixed intervals.

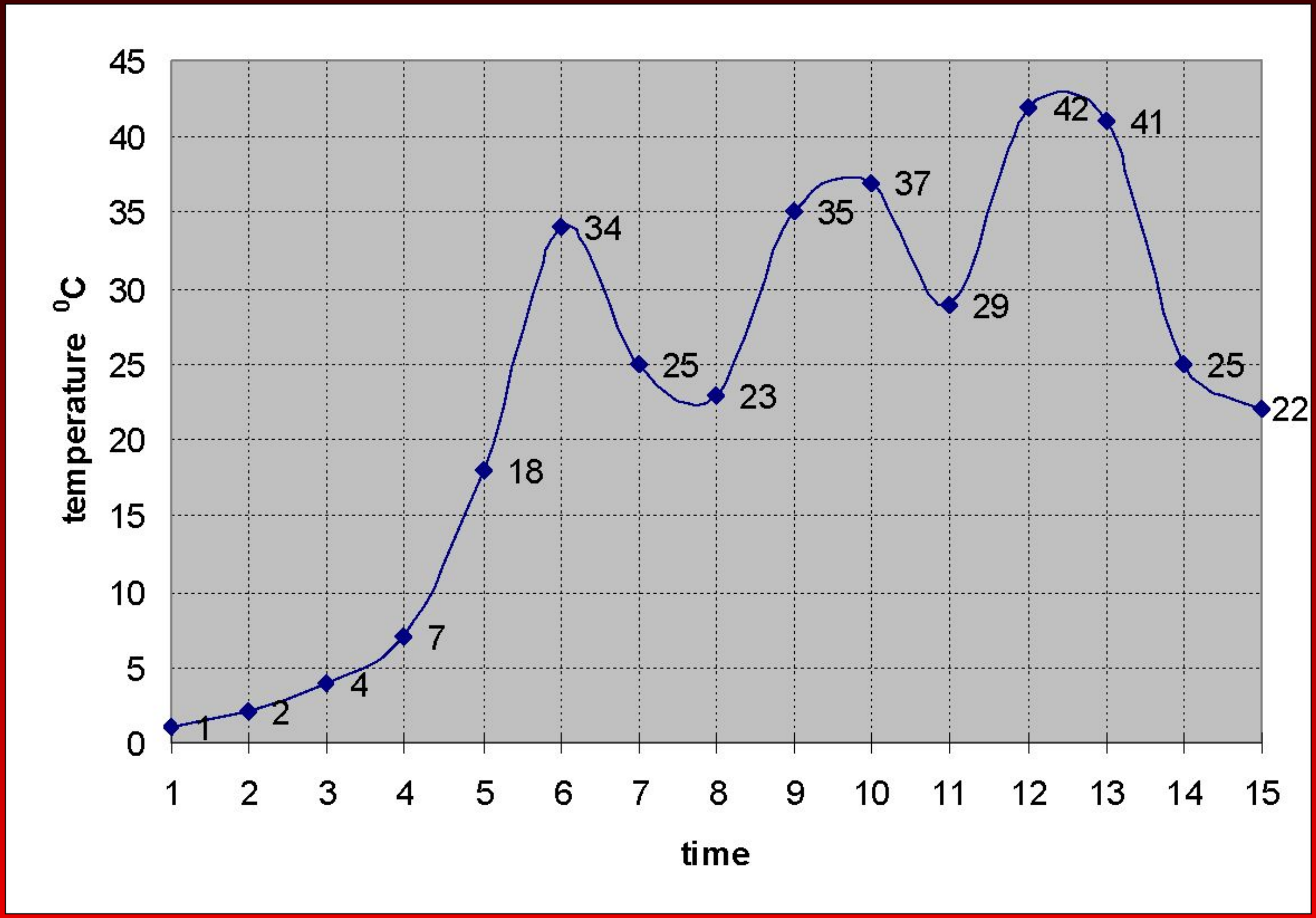


Continuous Signal

- In this case 15 samples at regular time intervals are collected.
- The 15 samples having the values 1, 2,4,7,18,34,25,23,35,37,29,42,41,25 and 22 represent the continuous signal digitally.
- The digital representation of the continuous signal only approximates the original signal and does not truly represent the original signal as can be seen by plotting the digital values.

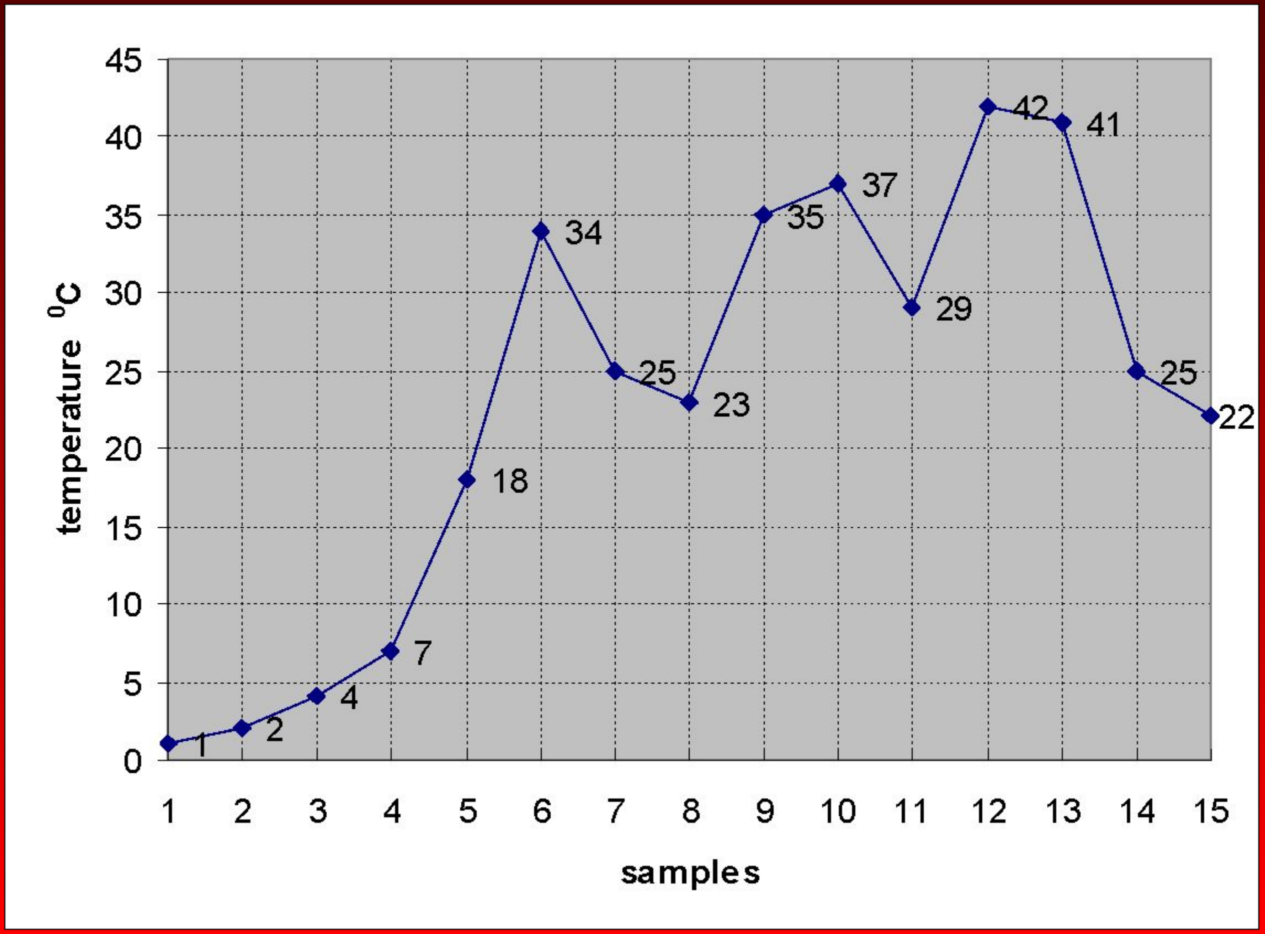
- Graph in next slide

Continuous Signal



Digital Representation

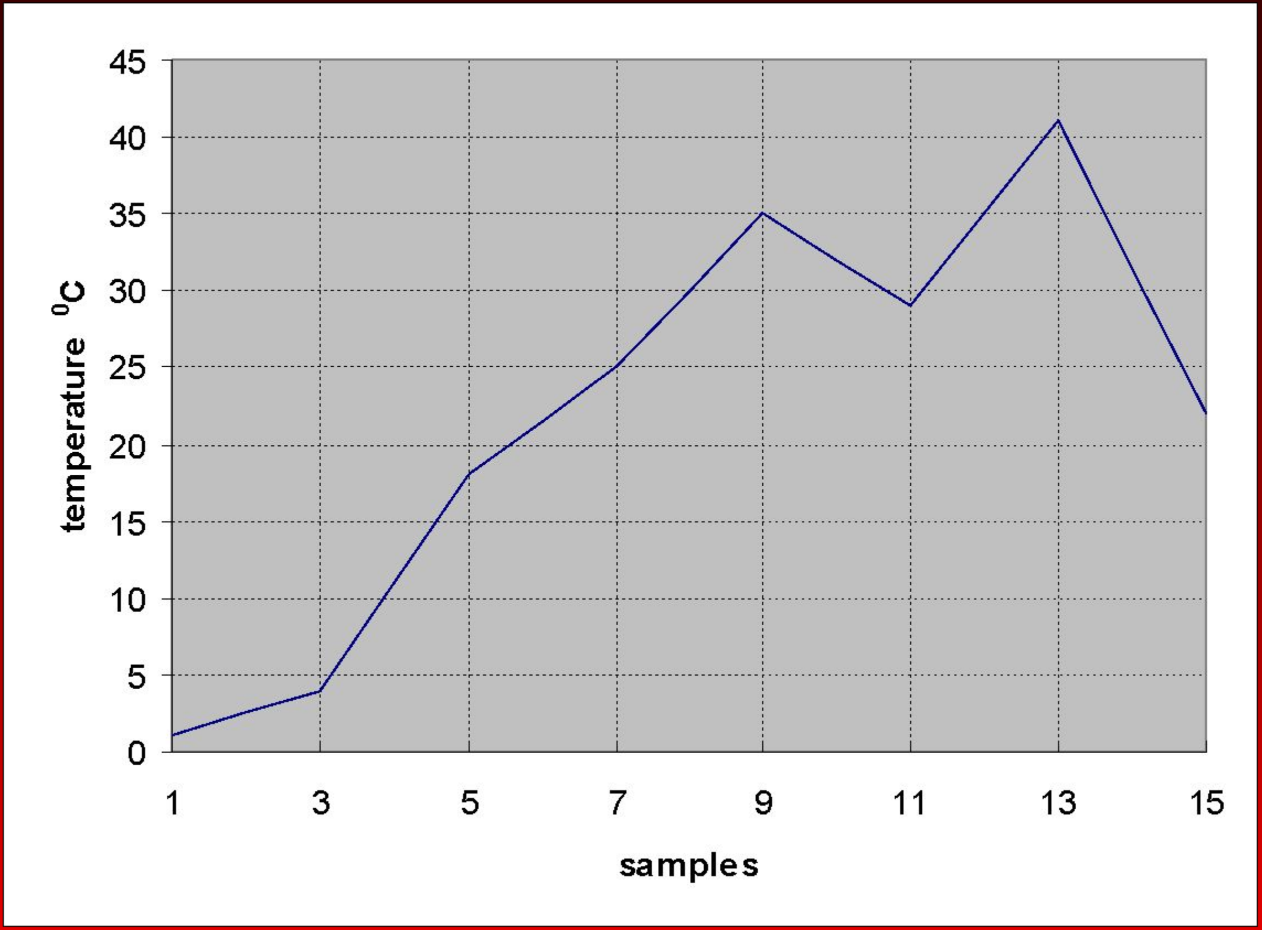
- The reconstructed continuous signal does not give an exact replica of the original.
- The reconstructed signal has sharp edges and corners in contrast to the original signal which has smooth curves.



Under Sampling

- If the number of samples that are collected are reduced by half, that is samples are collected at every odd interval of time, the resulting reconstructed signal is very different from the original signal.
- The peak in the continuous signal at 34 ^{0}C and the dip at 23 ^{0}C are all together missing from the reconstructed signal.
- This is due to the small number of samples taken.
- A better approximation of the original signal can be obtained by increasing the number of samples.
- An infinite number of samples very accurately represent the original continuous signal.

Under Sampling



Electronic Processing

- Electronic processing of these continuous and digital quantities requires that these quantities be converted into and represented in term of voltages.
- Analogue Electronic Systems deal with electronic signals or voltages that are continuous and represent continuous quantities.

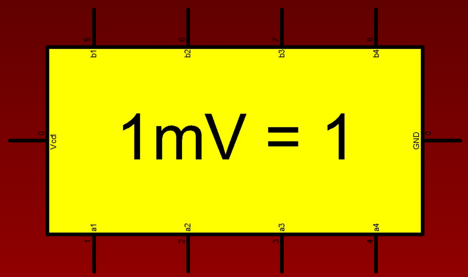
Electronic Processing

- Thus a temperature transducer converts a continuous temperature of 39 ^{0}C into 39 mVs and 42.75 ^{0}C into 42.75 mVs.
- Digital Electronic Systems on the other hand deal with discrete electronic signals or voltages that represent discrete or digital values.
- How does a digital system such as a calculator process the number 39? Do the Digital systems represent discrete values in terms of voltages? Lets have a look.

Representing Digital Values

39 ^{0}C ?

Digital System



39mV

6.25 x 10^{18} ?

6.25 x 10^{15} V !!

Digital Systems

- Digital systems use electronic circuitry that only works with two voltage levels. The two voltage levels represent two states. A voltage level of 5v represents logic high or logic 1 state and a voltage level of 0v represents logic low or logic 0 state.
- The two states in a digital system can represent any two quantities, the numbers 0/1, on/off, black/white, hot/cold, moving/stationary and similar other quantities.
- How does one represent more than two states in a digital system?
- Such as the different shades of grey in between the colours black and white or the temperature 39 or the velocity of a moving object.

Binary Number System

- The two states of the Digital circuits are based on the Binary number system which allows only two numbers 0 and 1.
- The Binary digit is called a bit.
- To represent more than two states a combination of binary bits is used.
- In the decimal number system a single digit can represent 10 values from 0 to 9.
- voltage levels 5, 0, 0, 5, 5 and 5 volts

Binary Number System

- To represent more than 10 values a combination of two digits is used which allows up to 100 values to be represented.
- In a binary number system a combination of 2 bits allows 4 different values to be represented.
- For example the four shades are represented by two bits, 00, 01, 10, 11.
- A temp of 39 is represented by a combination of six bits 100111.
- The number 39 is represented in a digital system by a combination of voltage levels 5, 0, 0, 5, 5 and 5 volts

Merits of Digital Systems

- Efficient Processing & Data Storage
- Efficient & Reliable Transmission
- Detection and Correction of Errors
- Precise & Accurate Reproduction
- Easy Design and Implementation
- Occupy minimum space

Information Processing

- A computer which is a digital system can process different types of information
  - It can handle numbers and perform arithmetic operations on the numbers
  - It can handle text and perform editing operations on text
  - It can handle mathematical and scientific formulas
  - It can handle drawings and pictures
  - It can process sound and music

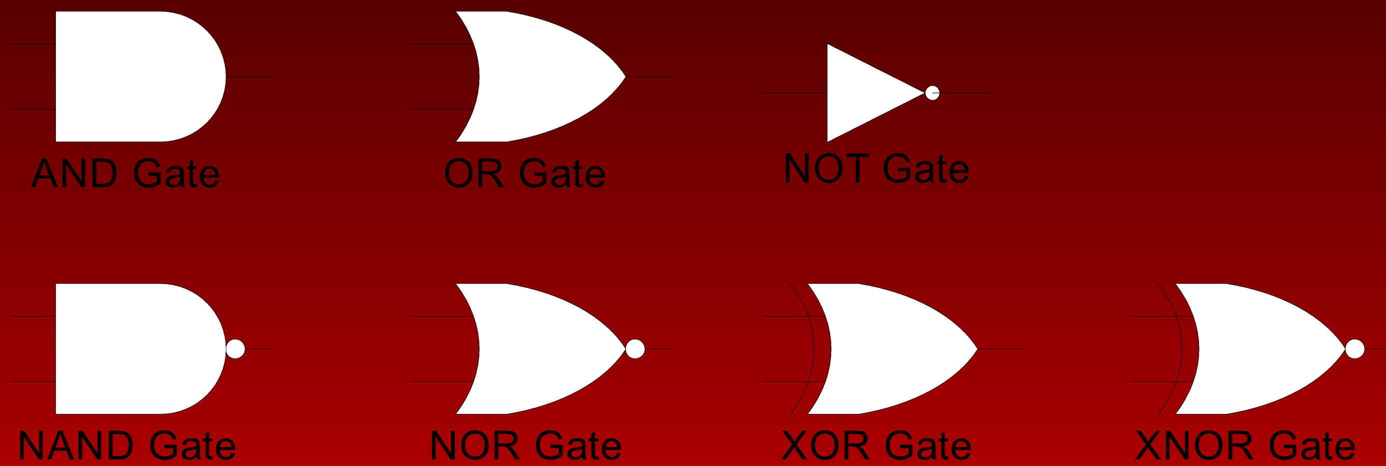
Logic Gates

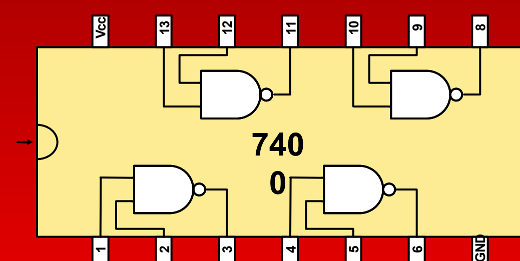
- How does the digital circuit process the binary information?
- As mentioned earlier, the digital circuits are designed to work with binary numbers.
- Logic Gates which are the Basic building blocks of a complex digital system which perform simple but unique operations on the binary or digital information.
- The basic Logic Gates are the AND Gate, OR Gate and the NOT Gate.

Logic Gates

- Each of these three gates performs unique logical operations on the information applied at the outputs. The result of the operation is available on the output of the gate.
- Other gates that are also frequently used are NAND, NOR, XOR and XNOR. The four gates are symbolically represented in the diagram.
- All these gates are available in the form of Integrated Circuits (ICs)

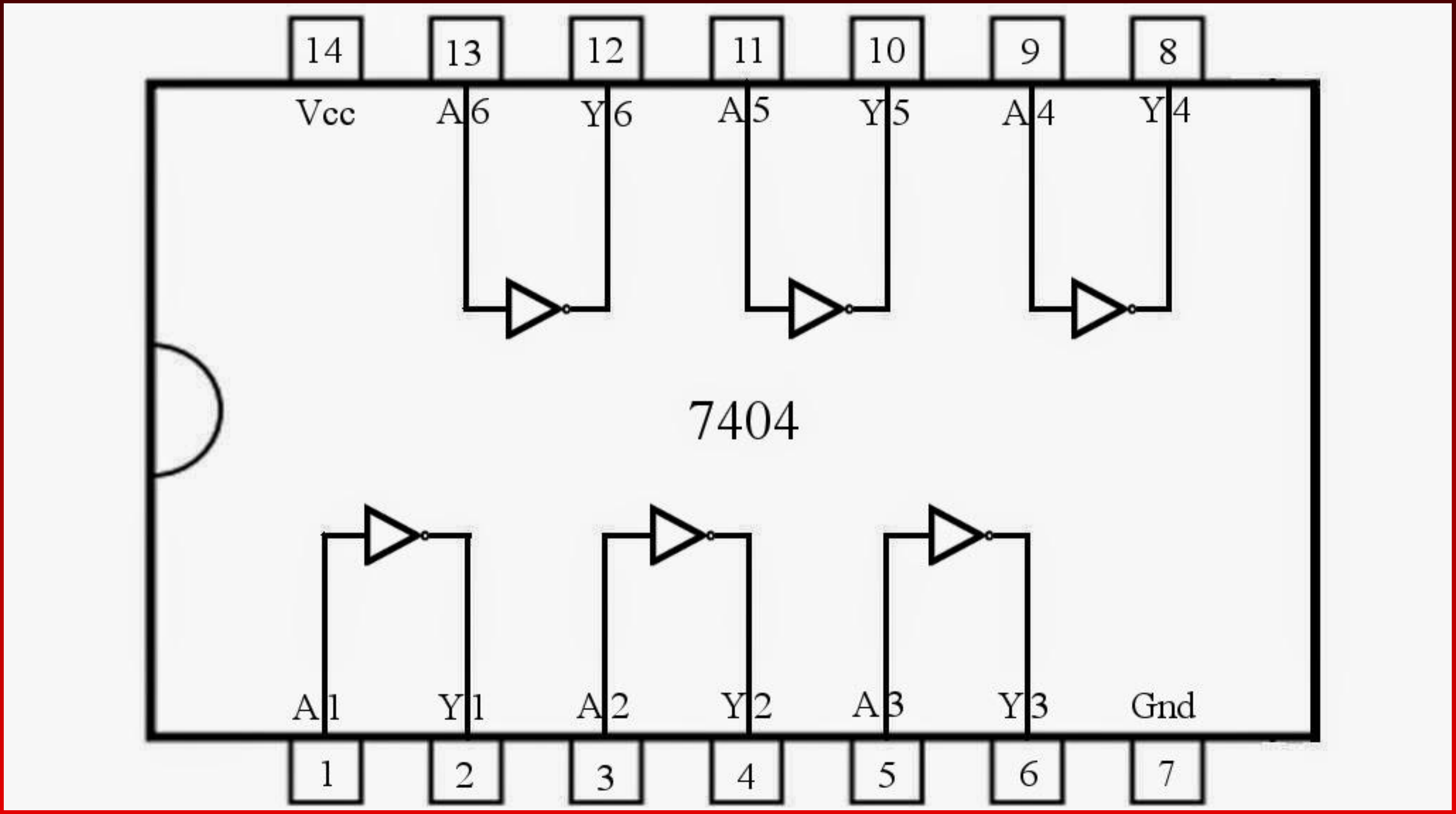
Logic Gate Symbol and ICs





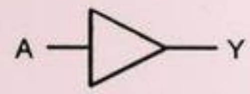
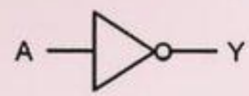
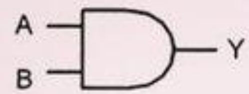
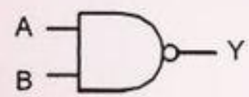
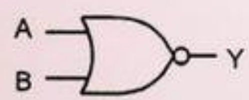
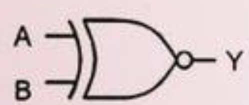
NAND Gate IC

Not Gate IC



14
13
12
11
10
9
8
Vcc
A 6
Y 6
A 5
Y 5
A 4
Y 4
7404
A 1
Y 1
A 2
Y 2
A 3
Y 3
Gnd
1
2
3
4
5
6
7

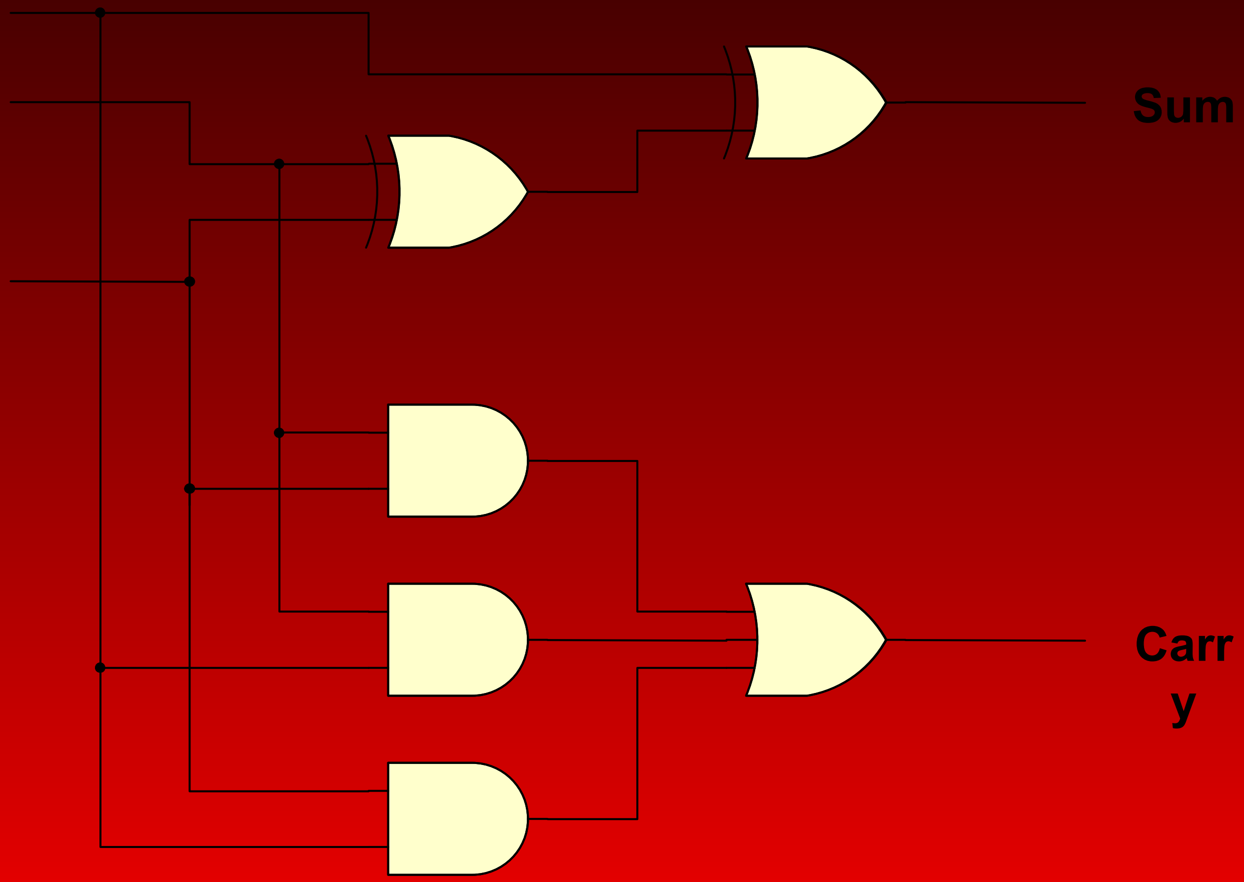
Truth Table

Gate	Symbol	Truth table	Expression
Buffer		A Y 0 0 1 1	$Y = A$
Inverter (NOT gate)		A Y 0 1 1 0	$Y = \overline{A}$
2-input AND gate		A B Y 0 0 0 0 1 0 1 0 0 1 1 1	$Y = A \bullet B$
2-input NAND gate		A B Y 0 0 1 0 1 1 1 0 1 1 1 0	$Y = \overline{A \bullet B}$
2-input OR gate		A B Y 0 0 0 0 1 1 1 0 1 1 1 1	$Y = A + B$
2-input NOR gate		A B Y 0 0 1 0 1 0 1 0 0 1 1 0	$Y = \overline{A + B}$
2-input EX-OR gate		A B Y 0 0 0 0 1 1 1 0 1 1 1 0	$Y = A \oplus B$
2-input EX-NOR gate		A B Y 0 0 1 0 1 0 1 0 0 1 1 1	$Y = \overline{A \oplus B}$

Combinational Circuits

- A circuit formed by the combination of logic gates is known as a combinational circuit.
- An Adder combination circuit is shown in the diagram

Adder Combinational Circuit



Functional Devices

- Commonly used functional ICs are
  - Adders
  - Comparators
  - Encoders/Decoders
  - Multiplexers/ Demultiplexers

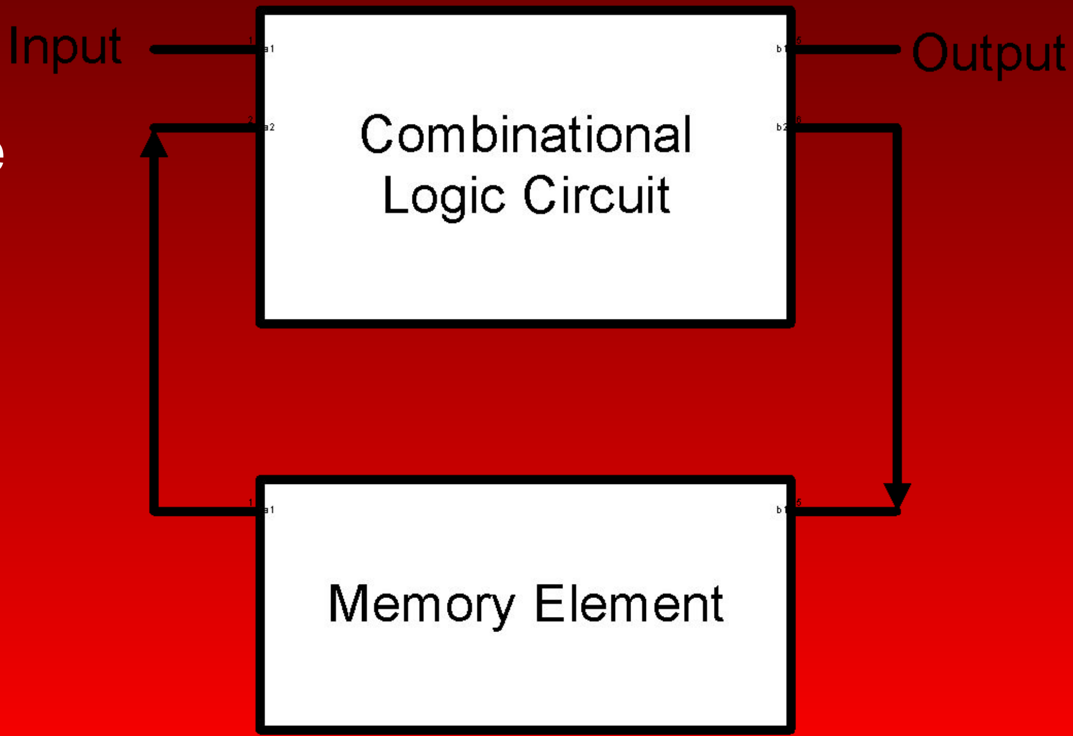
Sequential Circuits

- A large number of these digital systems generate an output based on not only the current information but some previously stored information.
- Consider a timer circuit, counting in reverse from 10 to 0. The timer circuit decrements the count by 1 each time it receives an input signal.
- Flip-Flops
- Counters & Registers

Block Diagram of a Sequential Circuit

- The Sequential circuit consists of a Combinational part and a memory element.
- Consider the timer of a microwave oven. You key in the time to cook your favourite dish.

- The microwave display unit displays the cooking time.
- The memory element of the microwave oven sequential circuit stores the cooking time.
- The cooking time is decremented by 1 after every second when a new input signal is received



Block Diagram of a Sequential Circuit

- A traffic signal controller operates in a similar manner. It switches between the green, amber and red signal in a sequence on the basis of current and previous information.

Programmable Logic Devices (PLDs)

- A modern trend in implementing digital systems is through Programmable Logic Devices or PLDs.
- PLDs provide the user with a general purpose circuitry which the user can configure or program to form any combinational or Sequential functional unit.
- The adder circuit discussed earlier is a combinational circuit that uses AND, OR and XOR Gates. Thus three different ICs have to be used to implement an adder.

Memory

- Memory is an important requirement of a digital system. Besides its use to implement sequential circuits, large memory is required to store information in computer systems. Essentially memory is of two types.
- RAM (Random Access Memory) which also stored information to be read or modified.
- RAMs are volatile, that is if the power is turned off, the contents stored in the memory are lost.
- ROM (Read-Only Memory) as the name specifies allows only read operations. No new information is allowed to be written into the memory.
- ROMs are non-volatile and retain the information even if the power is turned off.

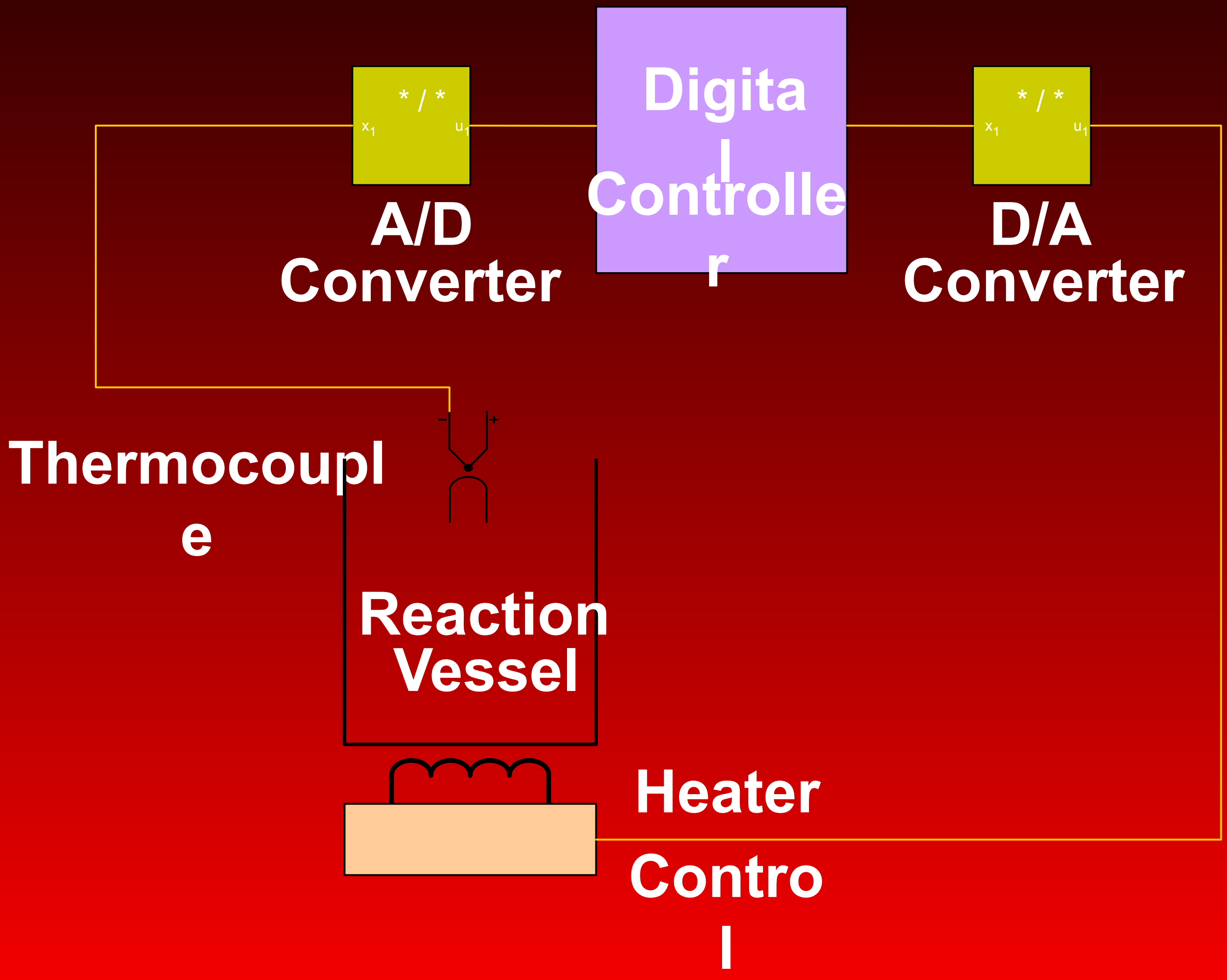
A/D & D/A Converters

- Real-world quantities as mention earlier are continuous in nature and have widely varying ranges. Processing of real-world information can be efficiently and reliably done in the digital domain.
- This requires real-world quantities to be read and converted into equivalent digital values which can be processed by a digital system. In most cases the processed output needs to be converted back into real-world quantities.

A/D & D/A Converters

- Two conversions are required, one from the real-world to the digital domain and then back from the digital domain to the real-world.
- Modern digitally controlled industrial units extensively use Analogue to Digital (A/D) and Digital to Analogue (D/A) converters to covert quantities represented as an analogue voltage into an equivalent digital representation and vice versa.
- The diagram shows a chemical reaction vessel being heated to expedite the chemical reaction.

Digital Industrial Control



Summary

- Continuous Signals
- Digital Representation in Binary
- Information Processing
- Logic Gates

Summary

- Combinational & Sequential Circuits
- Programmable Logic Devices (PLDs)
- Memory (RAM & ROM)
- A/D & D/A Converters

Number Systems and Codes

- Decimal Number System
- Binary Number System
- Hexadecimal Number System
- Octal Number System

Decimal Number System

- Ten unique numbers 0,1..9
- Combination of digits
- Positional Number System
- $275 = 2 \times 10^2 + 7 \times 10^1 + 5 \times 10^0$
  - Base 10
  - Weight 1, 10, 100, 1000 ….

Representing Fractions

- Fractions can be represented in decimal number system in a manner

  $= 3 \times 10^2 + 8 \times 10^1 + 2 \times 10^0 + 9 \times 10^{-1}$

  $+ 1 \times 10^{-2}$

  $= 300 + 80 + 2 + 0.9 + 0.01$

  $= 382.91$

Binary Number System

- Two unique numbers 0 and 1
- Base – 2
- A binary digit is a bit
- Combination of bits to represent larger values

Binary Number System

Decimal Number	Binary Number	Decimal Number	Binary Number
0	0	10	1010
1	1	11	1011
2	10	12	1100
3	11	13	1101
4	100	14	1110
5	101	15	1111
6	110	16	10000
7	111	17	10001
8	1000	18	10010
9	1001	19	10011

Combination of Binary Bits

- Combination of Bits
- $10011_2 = 19_{10}$
  $= (1 \times 2^4) + (0 \times 2^3) + (0 \times 2^2) + (1 \times 2^1)$
  $+ (1 \times 2^0)$
  $= (1 \times 16) + (0 \times 8) + (0 \times 4) + (1 \times 2)$
  $+ (1 \times 1)$
  $= 16 + 0 + 0 + 2 + 1$
  $= 19$

Fractions in Binary

- Fractions in Binary
- $1011.101_2 = 11.625$
  $= (1 \times 2^3) + (0 \times 2^2) + (1 \times 2^1) + (1 \times 2^0)$
  $+ (1 \times 2^{-1}) + (0 \times 2^{-2}) + (1 \times 2^{-3})$
  $= (1 \times 8) + (0 \times 4) + (1 \times 2) + (1 \times 1)$
  $+ (1 \times 1/2) + (0 \times 1/4) + (1 \times 1/8)$
  $= 8 + 0 + 2 + 1 + 0.5 + 0 + 0.125$
  $= 11.625$
- Floating Point Notations

Decimal-Binary Conversion

- Binary to Decimal Conversion
  - Sum-of-Weights
  - Adding weights of non-zero terms
- Decimal to Binary Conversion
  - Sum-of-Weights (in reverse)
  - Repeated Division by 2

Decimal to binary conversion using Sum of weight

Number	Weight	Result after subtraction	Binary
392	256	392-256=136	1
136	128	136-128=8	1
8	54		0
8	32		0
8	16		0
8	8	8-8=0	1
0	4		0
0	2		0
0	1		0

Decimal-Binary Conversion

- Binary to Decimal Conversion
  - Sum-of-Weights
  - Adding weights of non-zero terms

$$10011_2$$

$$(1\times 2^4)+(0\times 2^3)+(0\times 2^2)+(1\times 2^1)$$

$$+(1\times 2^0)$$

Terms 16,0,0.2 and 1

19

Decimal-Binary Conversion

- Binary to Decimal Conversion
  - Sum-of-Weights
  - Adding weights of non-zero terms

Decimal-Binary Conversion

- Binary to Decimal Conversion
  - Sum-of-Weights
  - Adding weights of non-zero terms

$$10011_2 = 16 + 2 + 1 = 19$$

$$1011.101_2 = 8 + 2 + \frac{1}{2} + \frac{1}{8}$$

$$= 11 + \frac{5}{8}$$

$$= 11.625$$

Lecture No. 1

Number Systems

A Summary