# Logic for IT

*Combinational and sequential circuits*

SUPINFO

# *Course Objectives*

- Understand complex circuits
- Learn where and how they are used
- Basic knowledge of sequential circuits

# *Course Plan*

1. Combinational circuits

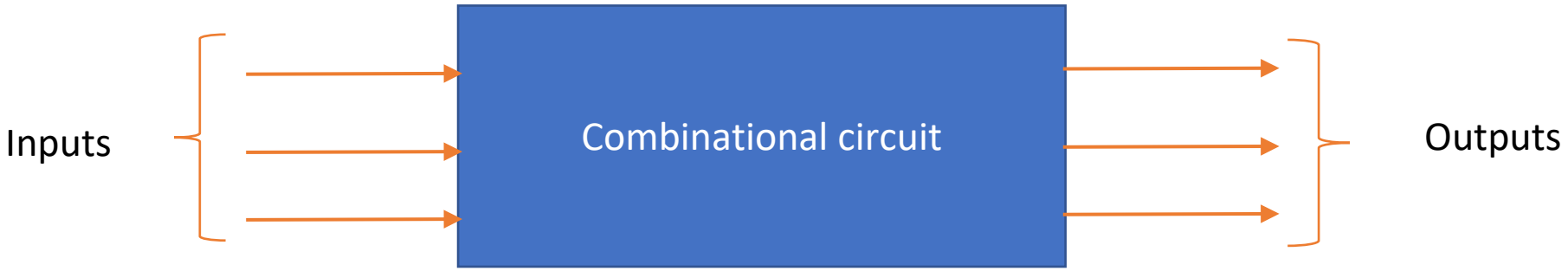
2. Sequential circuits

# 1. Combinational circuits

# 1. Combinational circuits

## Definitions

- A combinational logic circuit is one whose output solely depends on its current inputs.

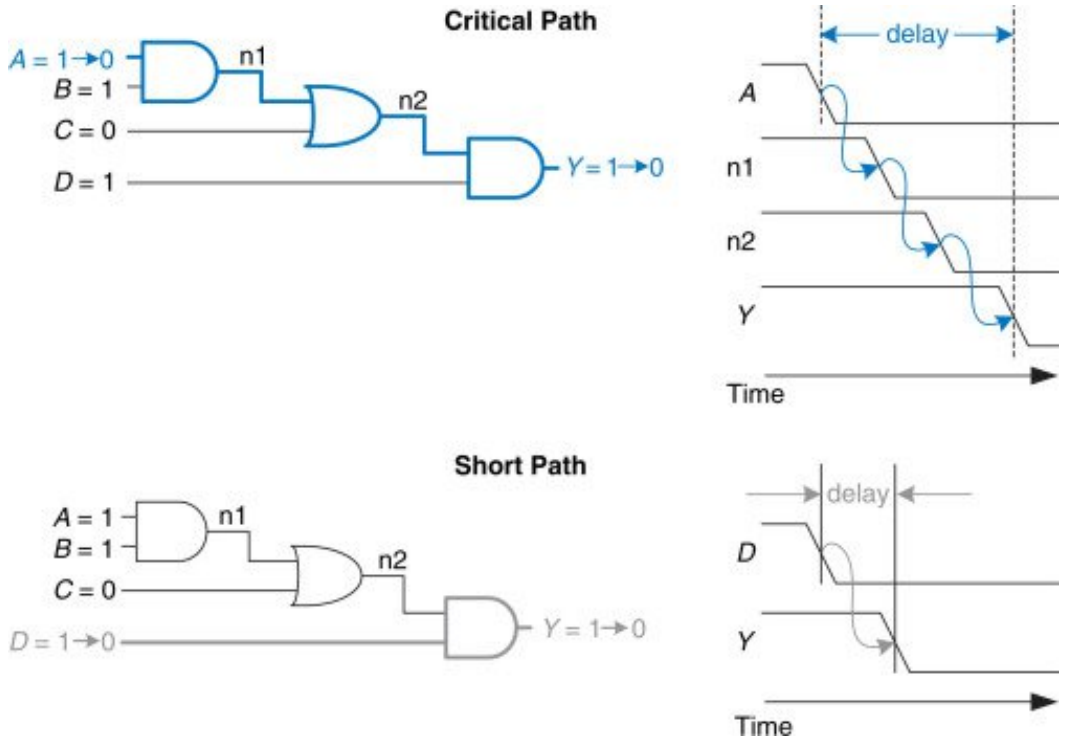


# 1. Combinational circuits

## Definitions

A combinational logic circuit is not perfect. Each gate has an inner propagation delay, that is when the input changes, the result output change is not immediate

The propagation delay of a combinational circuit is the sum of the propagation delays through each element on the critical pat



# 1. Combinational circuits

## Example of combinational circuits

- Adders
- Multiplexers, demultiplexers
- Encoders and decoders
- Transcoders
- Comparators
- Arithmetic and Logic Units (ALU)

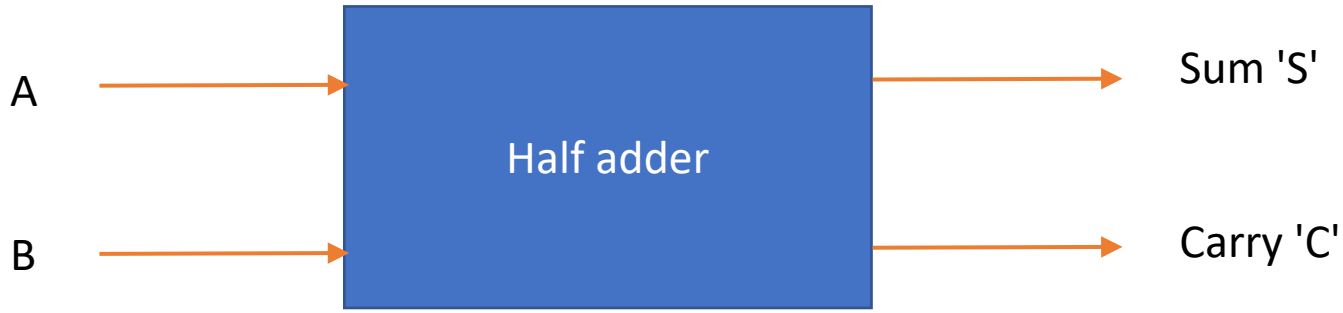
All these circuits are the basis of CPUs and complex digital circuits

# 1. Combinational circuits

## Half adder

An adder is a digital circuit that performs addition of numbers.
Half adder has only two inputs and two outputs.

The half adder adds two binary digits and produces two outputs as sum and carry.

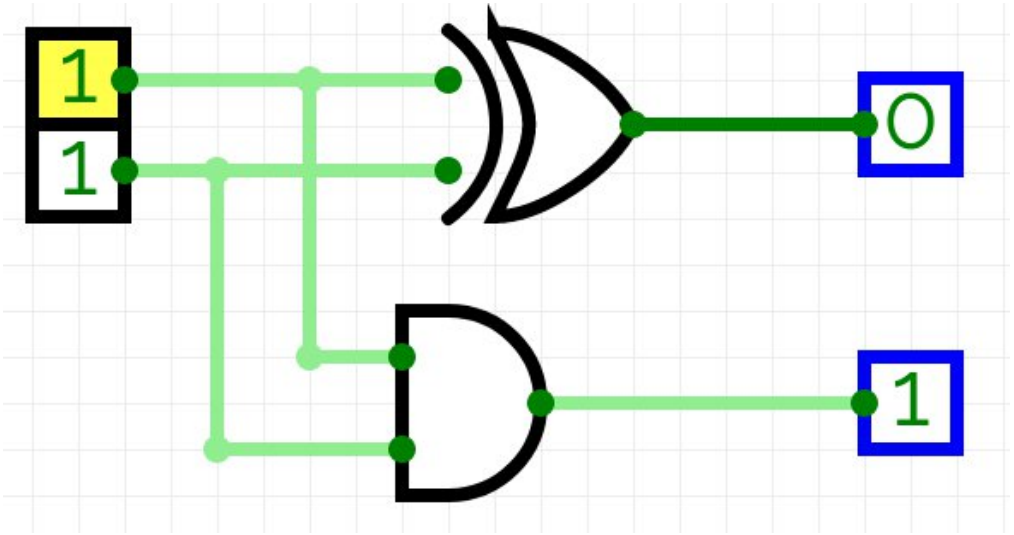


# 1. Combinational circuits

## Half adder

The half adder produces one output bit as the result of the addition but does not take as input any carry, only A and B.

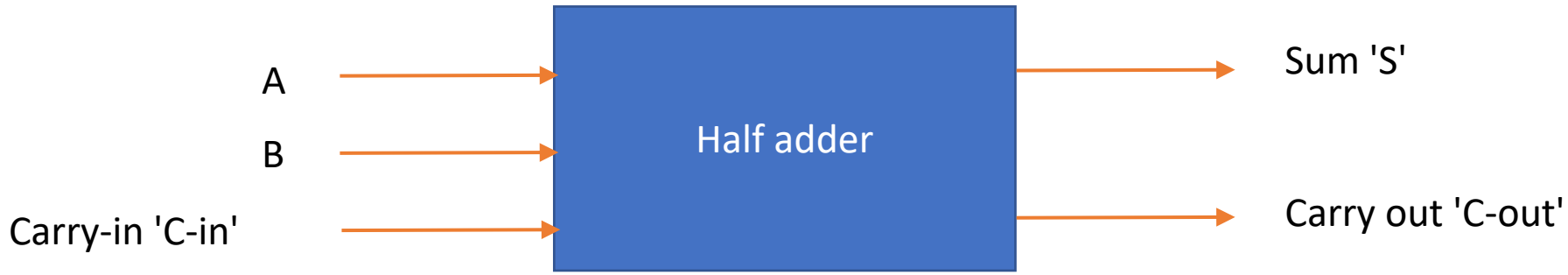
| a | b | Sum | Carry |
|---|---|---|---|
| 0 | 0 | 0 | 0 |
| 0 | 1 | 1 | 0 |
| 1 | 0 | 1 | 0 |
| 1 | 1 | 0 | 1 |



# 1. Combinational circuits

## Full adder

A full adder adds one input to the half adder to compute a real addition with a carry.
The input carry comes from another adder for instance.

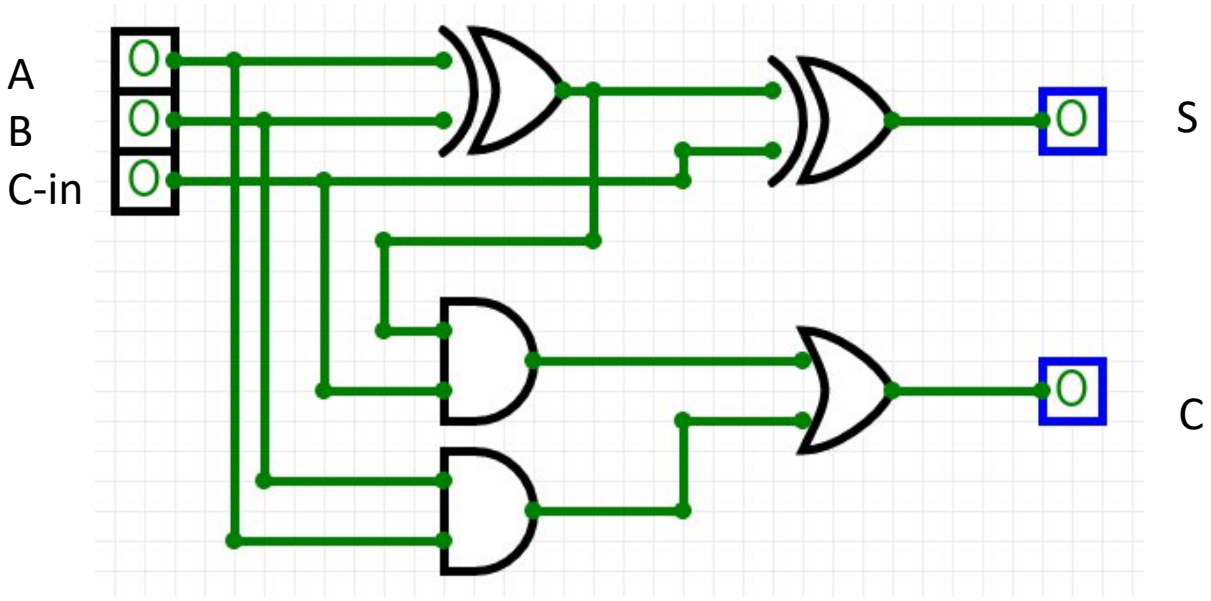


# 1. Combinational circuits

## Full adder

The half adder produces one output bit as the result of the addition but does not take as input any carry, only A and B.

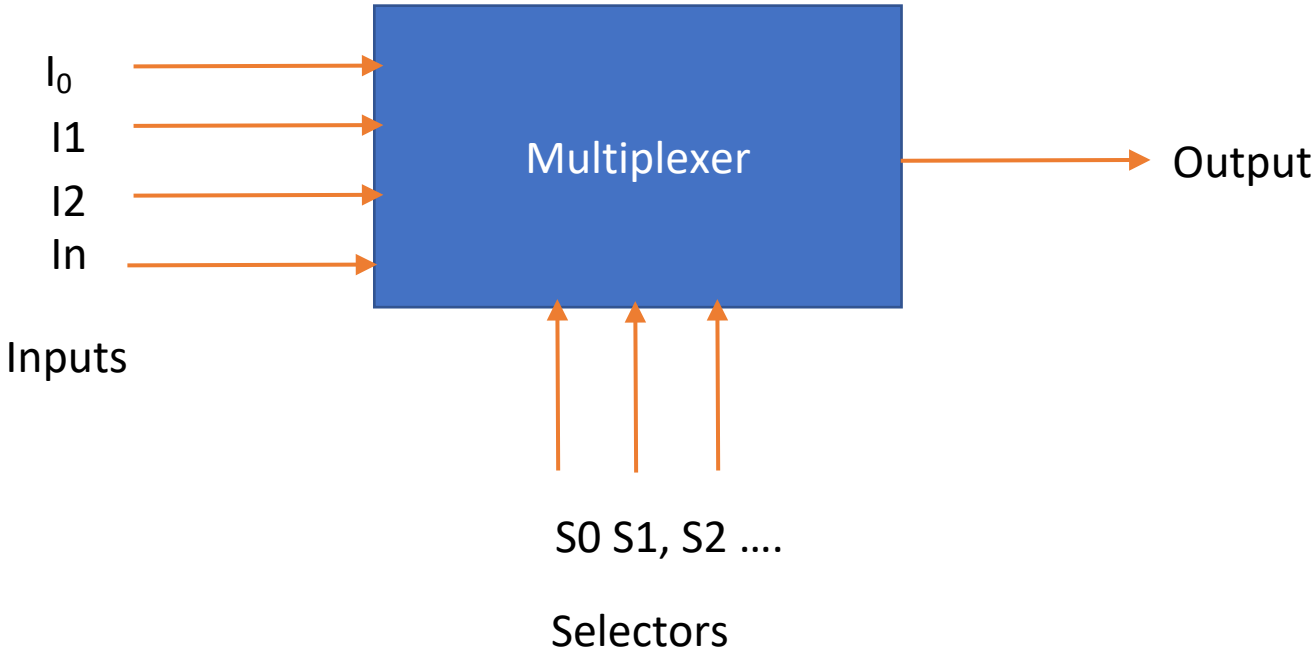
| a | b | C-in | Sum | C-out |
|---|---|---|---|---|
| 0 | 0 | 0 | 0 | 0 |
| 0 | 0 | 1 | 1 | 0 |
| 0 | 1 | 0 | 1 | 0 |
| 0 | 1 | 1 | 0 | 1 |
| 1 | 0 | 0 | 1 | 0 |
| 1 | 0 | 1 | 0 | 1 |
| 1 | 1 | 0 | 0 | 1 |
| 1 | 1 | 1 | 1 | 1 |

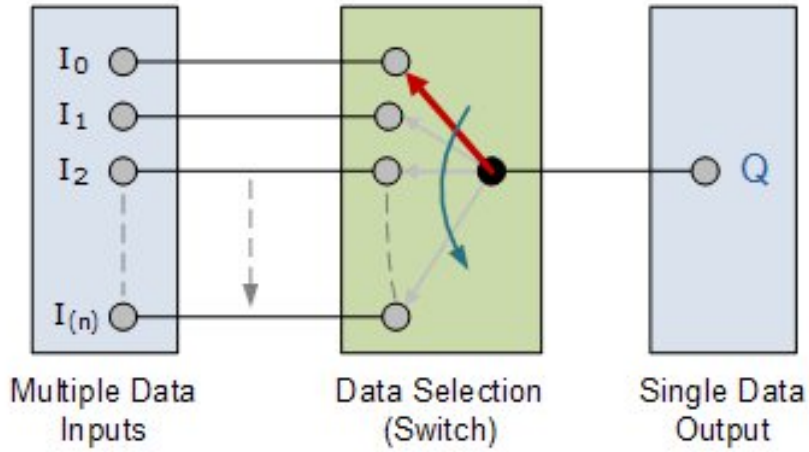


# 1. Combinational circuits

## Multiplexer (and opposite, a demultiplexer)

A multiplexer is a logic circuit that select and route any number of inputs to a single output.
Applications: telecommunications, computer memory...

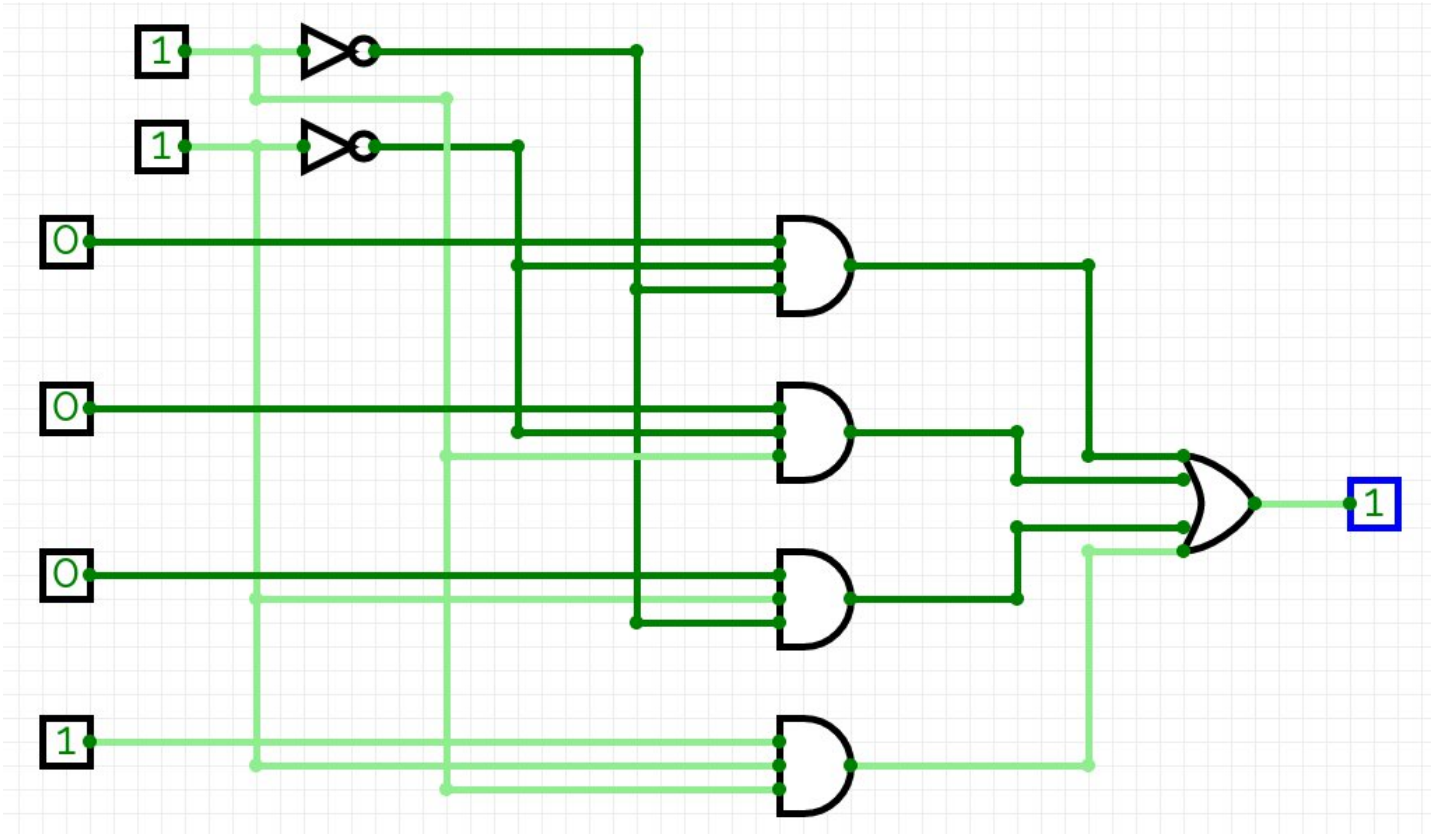



Example for a rotary switch

# 1. Combinational circuits

## Multiplexer (and opposite, a demultiplexer)

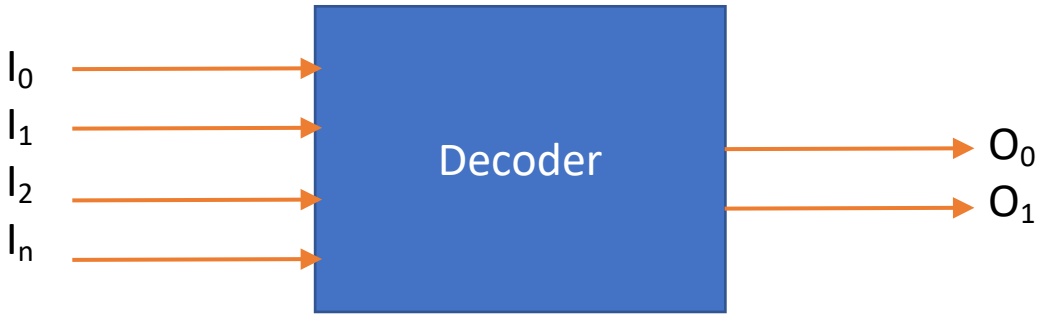


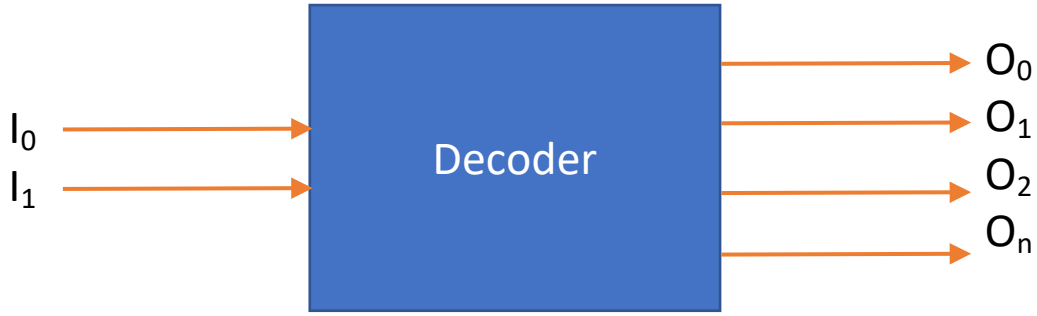

*Example of multiplexer using only basic gates*

# 1. Combinational circuits

## Encoder and decoder

An **Encoder** is a combinational circuit that generates a binary representation of the input lines. It encodes $2^n$ input lines into *n* output lines.
A decoder performs the inverse operation, with *n* input lines and $2^n$ output lines.



# 1. Combinational circuits

## Encoder and decoder

**Examples of Encoder are,**

1.Digital Keyboard Driver
2.Touchpad Driver
3.Biometric Converter
4.Modem
5.Digital Signal Processing Device or Circuit
6.Analog to Digital Converter Circuit
7.Transmitter Circuit in Optical Fiber Communication System

**Examples of Decoder are,**

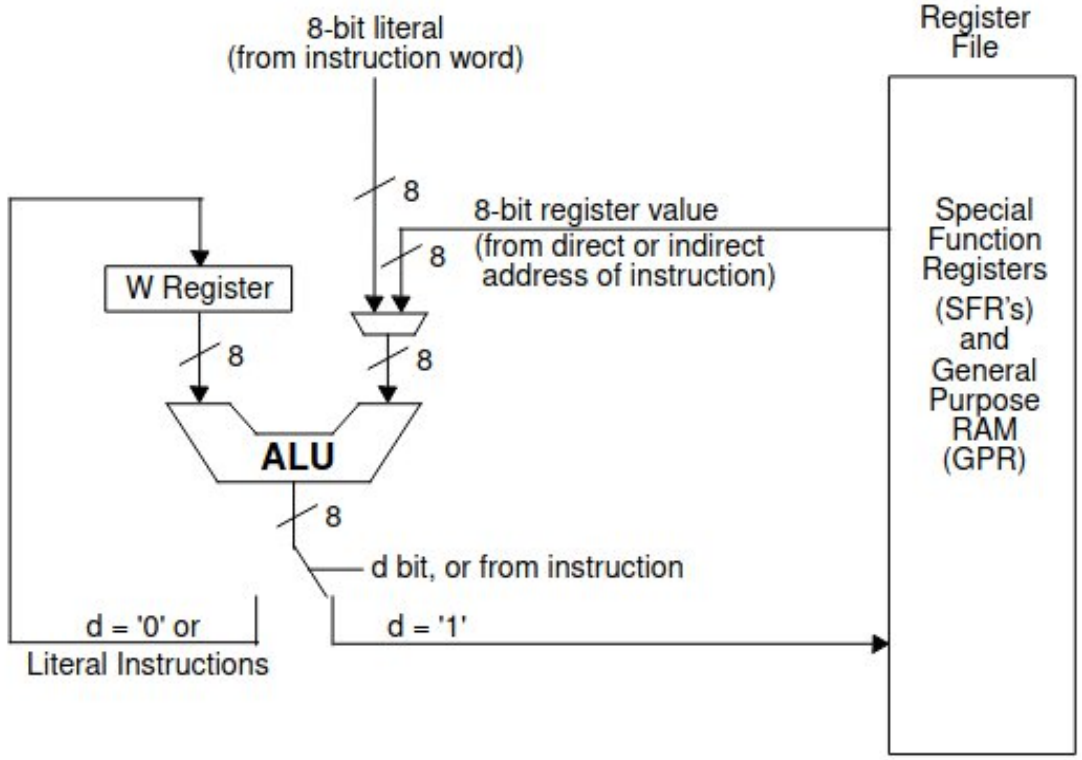
1.Led Driver
2.Digital Display Driver Circuit or IC
3.Modem
4.Digital to Analog Converter Circuit
5.Receiver in Optical Fiber Communication System
6.Seven Segment Display Driver

# 1. Combinational circuits

## Arithmetic and Logic Unit (ALU)

The ALU is a central part integrated in a Central Processing Unit (CPU). It is responsible for using the information in the program memory (instructions) to control the operation of a device.

Example of an 8-bit ALU Integrated in a Microchip microcontroller

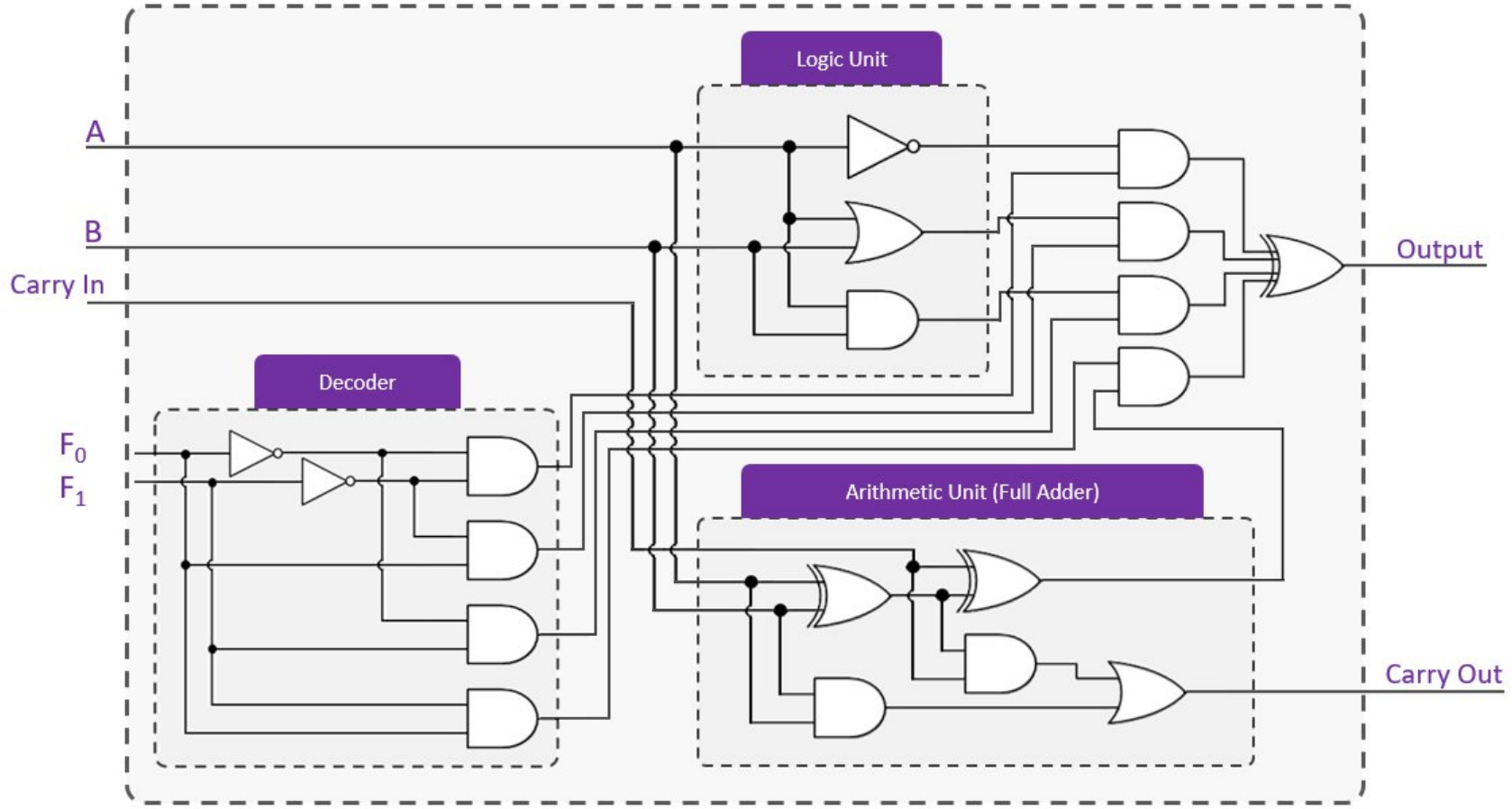


# 1. Combinational circuits

## Arithmetic and Logic Unit (ALU)

Example of implementation of an ALU using only basic gates

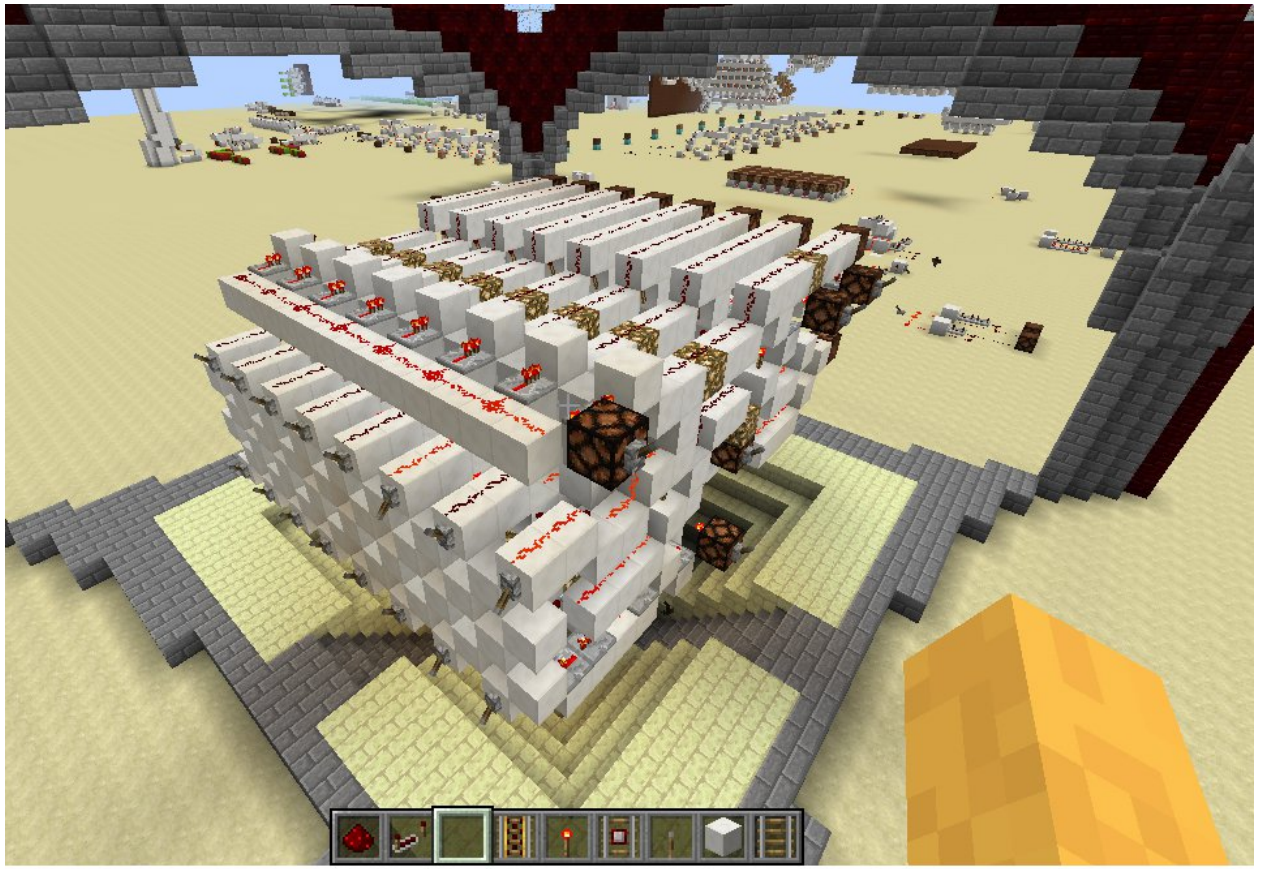
The F inputs choose the logical function to execute



# 1. Combinational circuits

## Arithmetic and Logic Unit (ALU)

An 8-bit ALU in Minecraft



# 1. Combinational circuits

**Exercises:**

- **8-bit adder/substractor**
- **ALU**
- **Multiplier**
- **7-segments display**

# 1. Combinational circuits

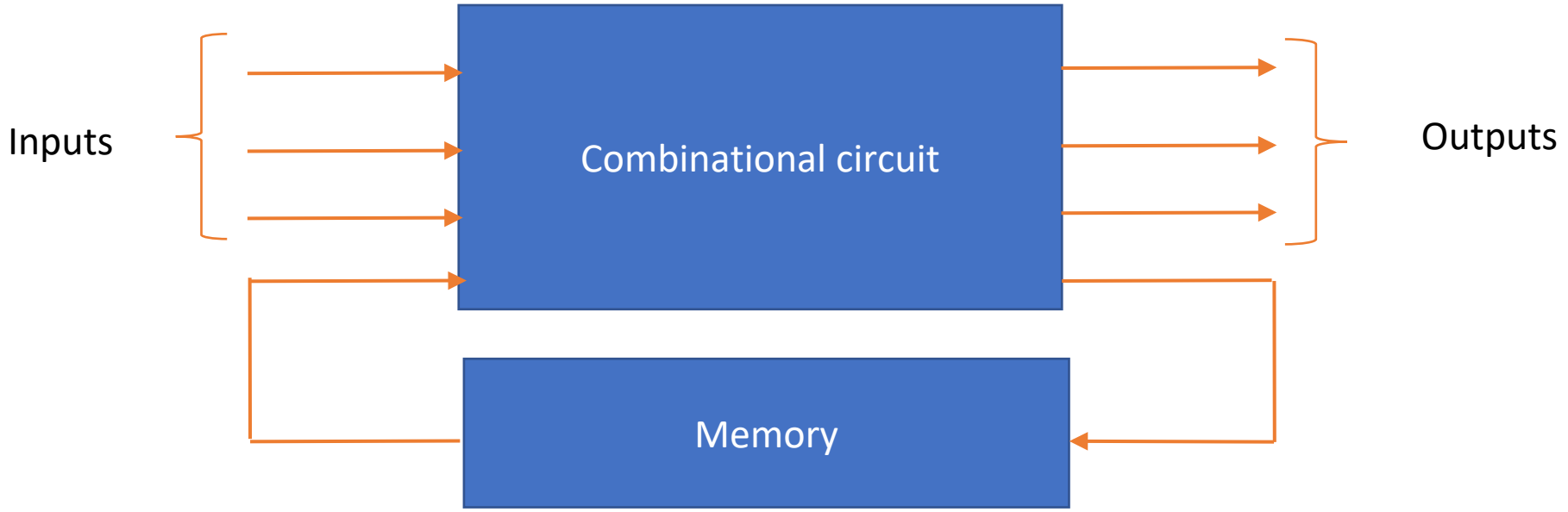
**Questions**

# 2. Sequential circuits

# 2. Sequential circuits

## Definitions

- A sequential circuit is built using combinational circuits and memory elements. These circuits generate output that depends on the current and previous states.

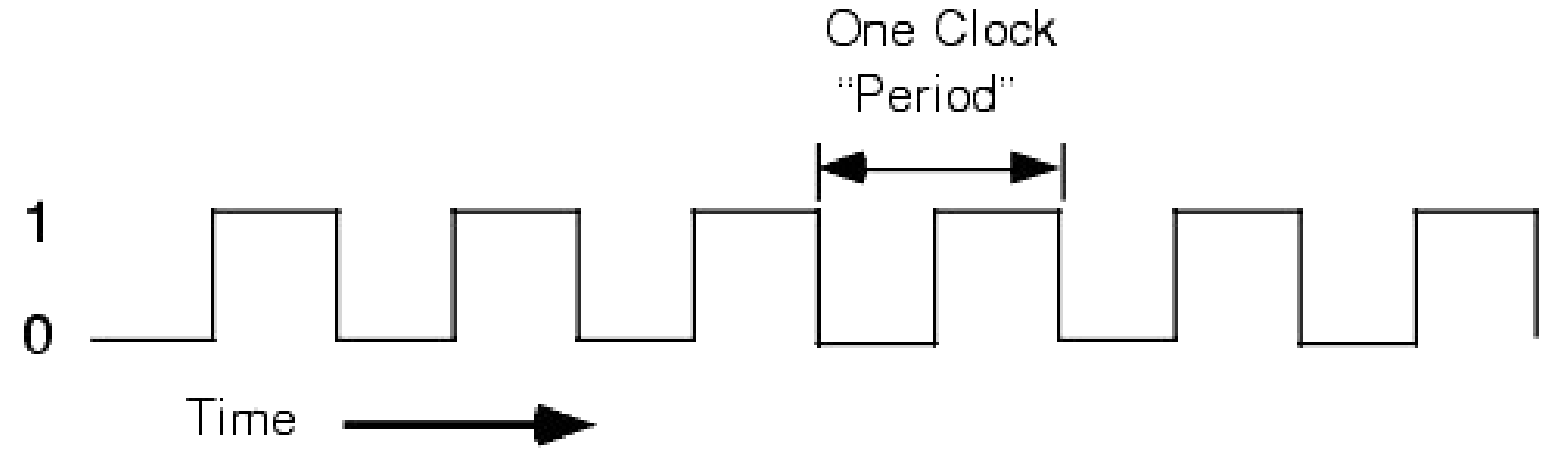


# 2. Sequential circuits

## Definitions: clock signal

- In a sequential circuit, a clock signal can be used to synchronize the sequential behavior on a certain periodicity and event
- A clock signal is a square waveform with a specific periodicity and duty cycle
- There is a relationship between the period (seconds) and frequency (Hz)

Logical 1 is usually 5V, 3.3V, 1.27V

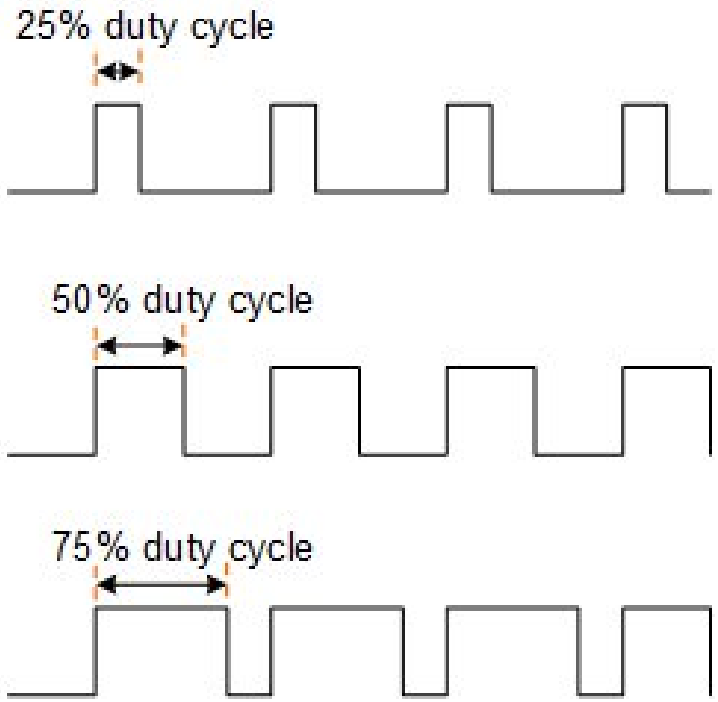



$$f = \frac{1}{T} = \frac{1}{10ms} = 100Hz$$

# 2. Sequential circuits

## Definitions: clock signal

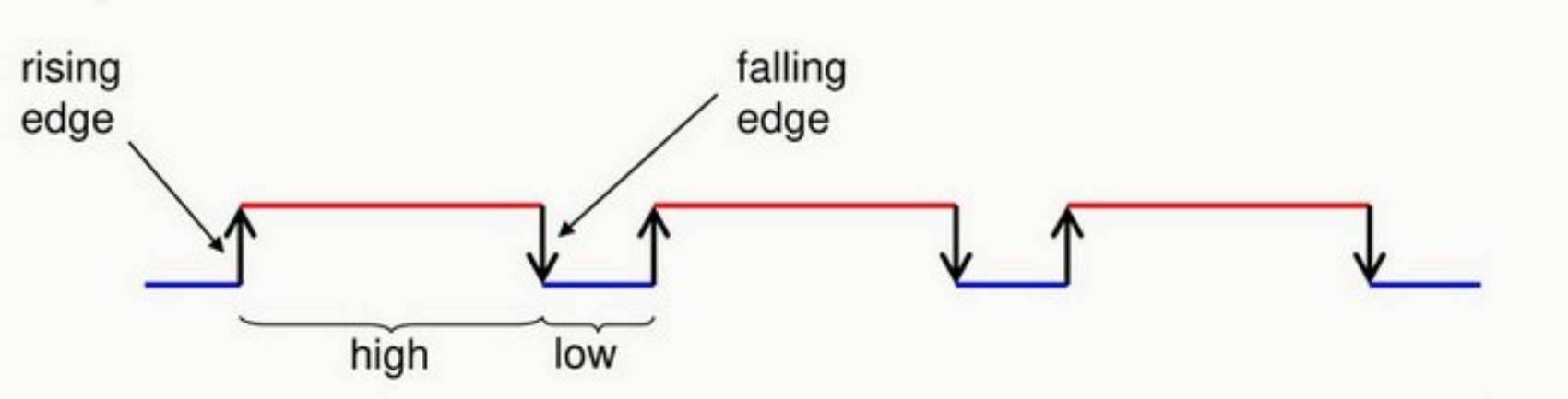
- A duty cycle is a percentage of time at a high level



# 2. Sequential circuits

## Definitions: clock signal

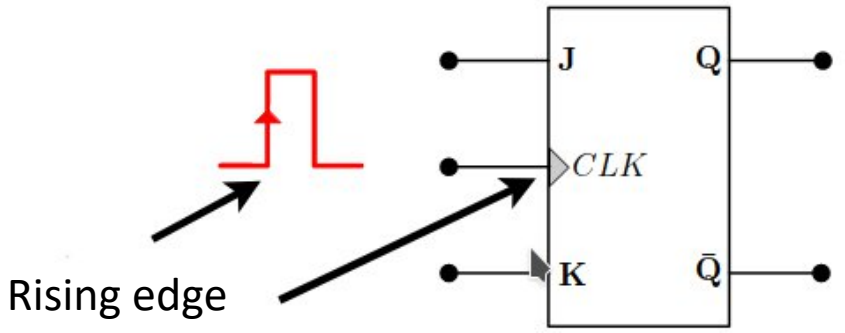
- A rising edge is the clock edge that comes from 0 and ends at 1 level
- A falling edge is the clock ede that comes from 1 and ends at 0 level



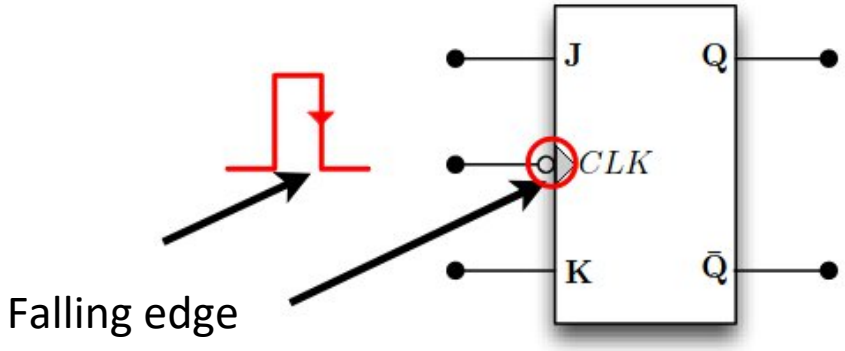
# 2. Sequential circuits

## Definitions: clock signal

- On graphical representation of gates, the edge detection type is indicated by a triangle
- And a circle before for the falling edge




Rising edge detection

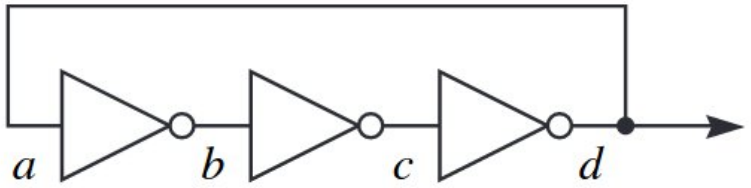



Falling edge detection

# 2. Sequential circuits

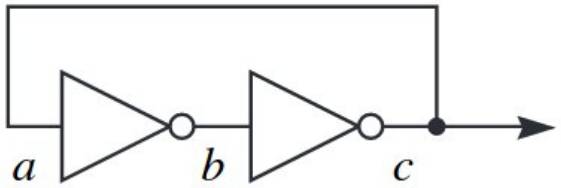
## Sequential circuit basics

- We are going to use basic gates but with a feedback connection from an output to an input




(a) An unstable circuit.

*NOT gate with feedback*

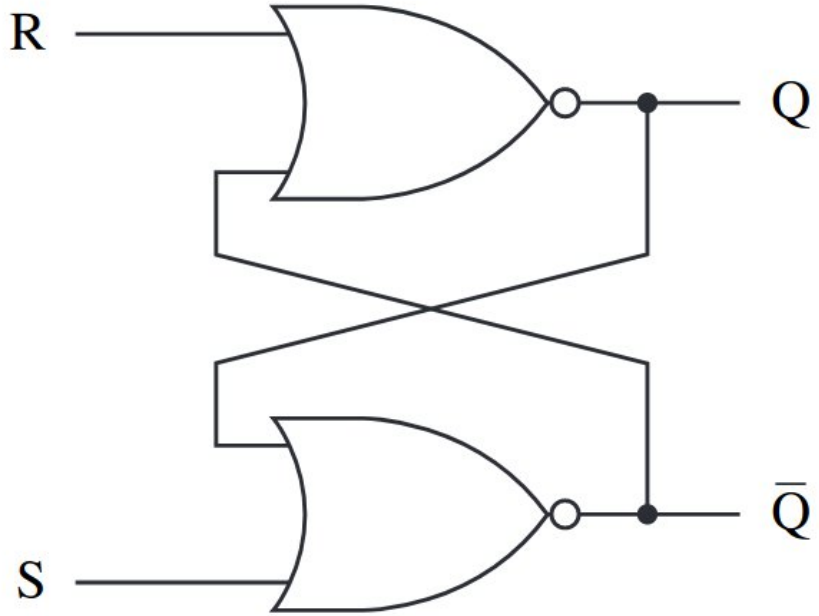



(b) A stable circuit.

# 2. Sequential circuits

## Definitions: latch circuits "SR" type

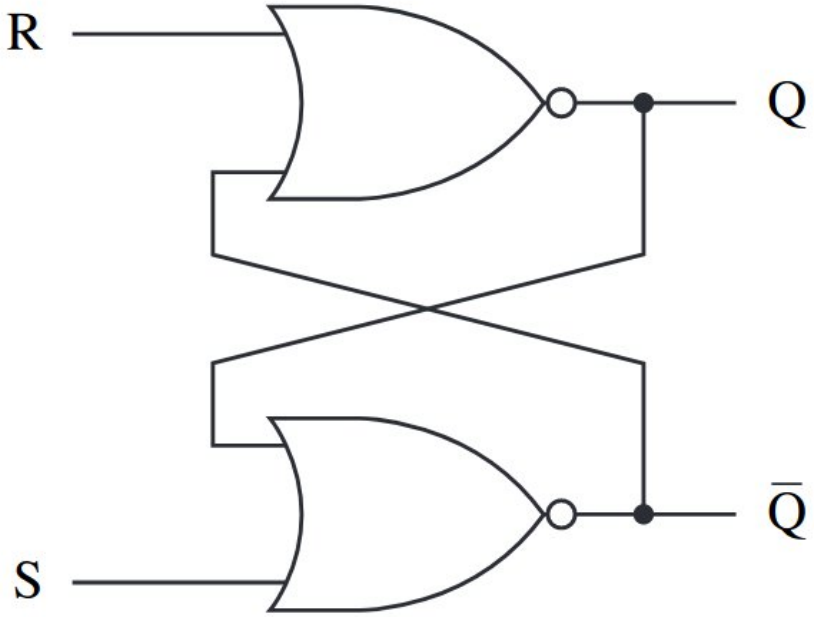
- Latch circuits are used to memorize a stable binary state
- Typical application is memory, data storage elements




Here a latch circuit is built using two NOR gates
S stands for Set
R stands for Reset

# 2. Sequential circuits

## Definitions: latch circuits "SR type"




With an initial state, we want to "set" the output Q to 1. Here are the intermediate states:

| Time | S | R | Q | Q' | Stability |
|---|---|---|---|---|---|
| Initial | 0 | 0 | 0 | 1 | Stable |
| 0 | 1 | 0 | 0 | 1 | Unstable |
| T | 1 | 0 | 0 | 0 | Unstable |
| 2T | 1 | 0 | 1 | 0 | Stable |

T is the propagation delay of a single gate

This latch circuit is the simplier version of all latches but it misses any synchronization, it is asynchronous. In a complex system, we may want to synchronize multiple latches.

# 2. Sequential circuits

## Definitions: flip-flop circuits

Flip-flop circuits are latches with a synchronization mechanism, typically a clock.

There are multiple sorts of flip-flops:

- D (data)
- JK (Universal:set/reset/toogle)
- T (toogle)

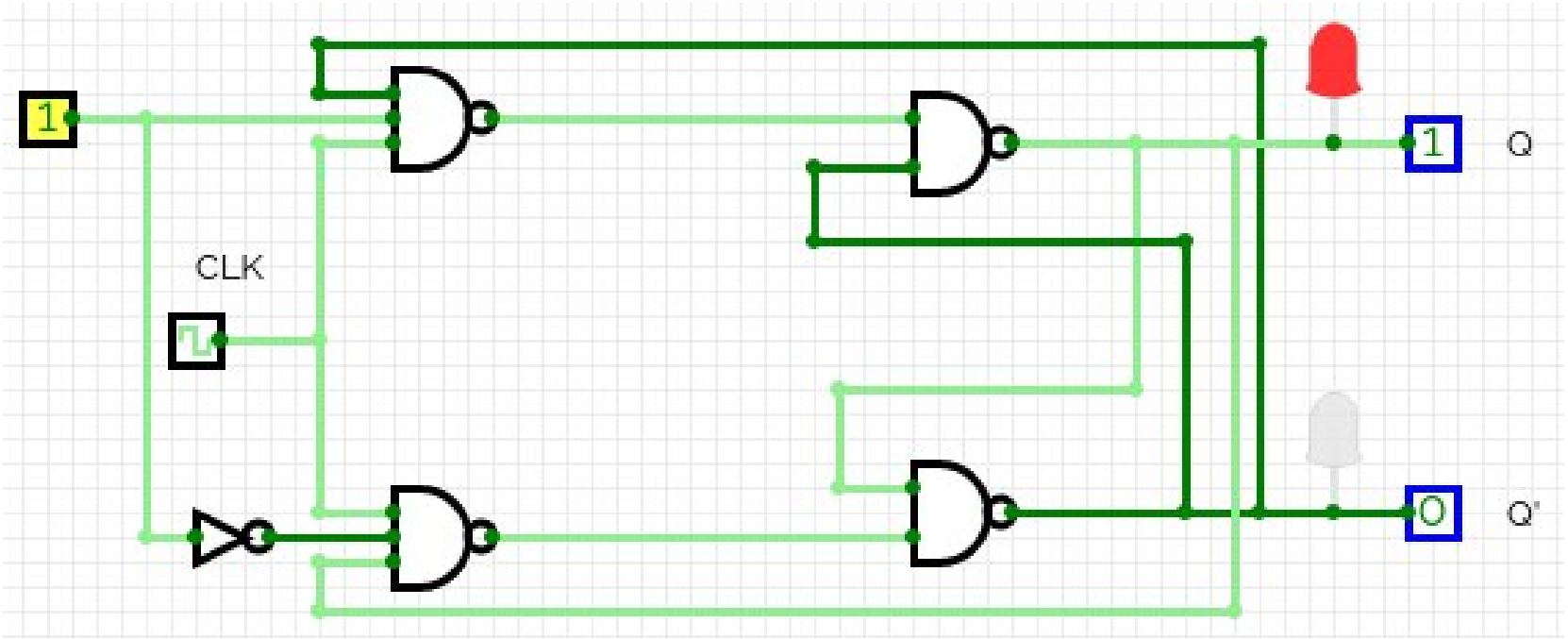

*Static RAM from the Nintendo NES clone (2K × 8 bits) uses flip-flop*

Other usages : frequency dividers. Counters. Storage registers. Shift registers.

# 2. Sequential circuits

## Definitions: D flip-flop

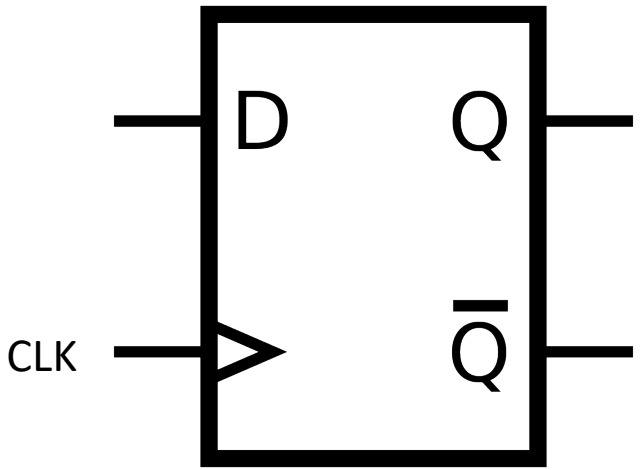
With a D flip-flop, the output D will be copied from the input on a clock edge.



# 2. Sequential circuits

## Definitions: D flip-flop

Symbol and truth table

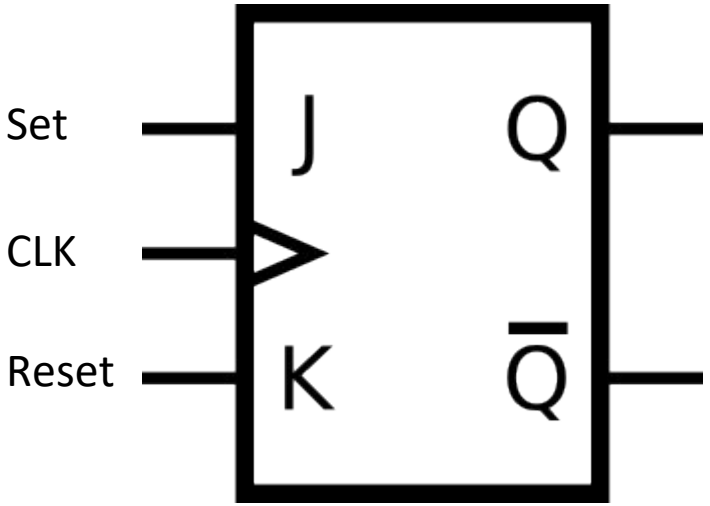



| D | CLK | Q | Q' |
|---|---|---|---|
| 0 | 0 | 0 | 1 |
| 0 | 1 | 0 | 1 |
| 1 | 0 | 0 | 1 |
| 1 | 1 | 1 | 0 |

# 2. Sequential circuits

## Definitions: JK flip-flop (named after its invento Jack Kilby)

Symbol and truth table

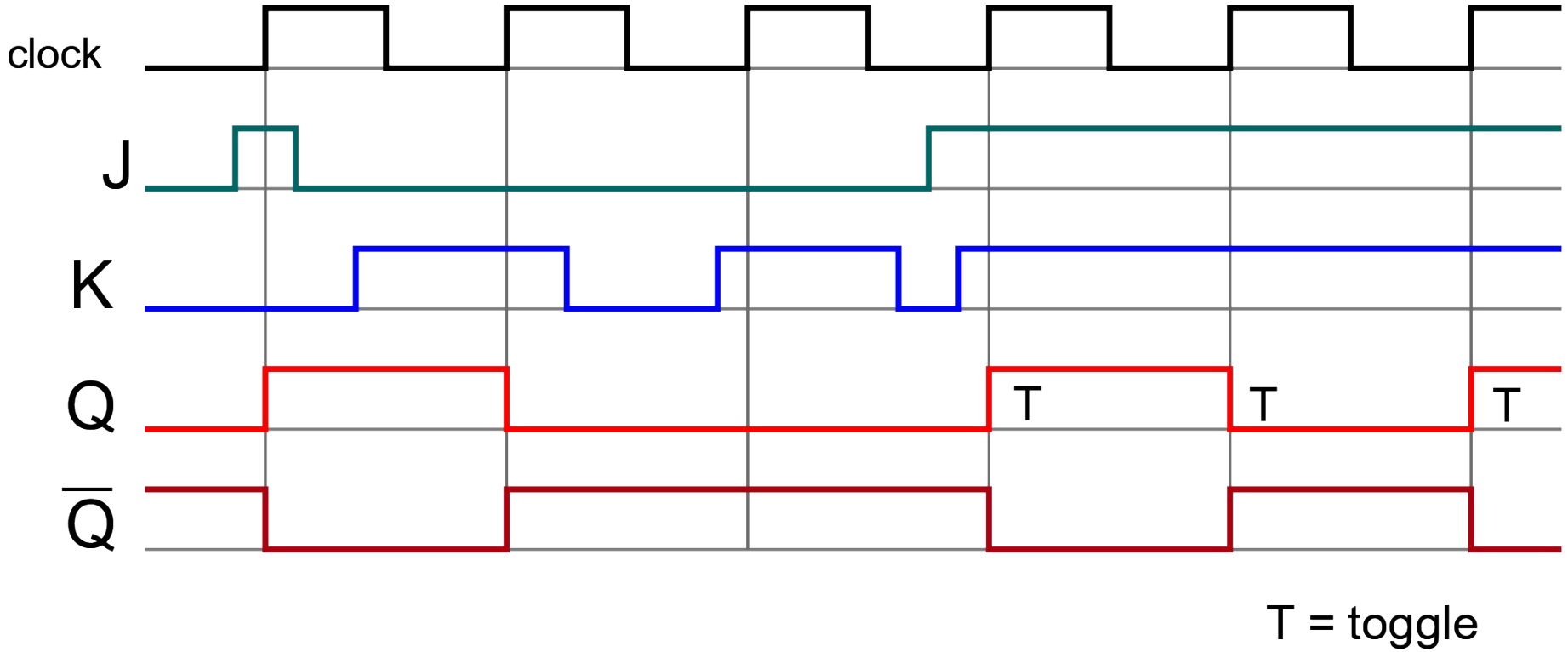



| CLK | J | K | Q | Q' |
|---|---|---|---|---|
| 0 | 0 | 0 | Latch | Latch |
| 0 | 0 | 1 | Latch | Latch |
| 0 | 1 | 0 | Latch | Latch |
| 0 | 1 | 1 | Latch | Latch |
| 1 | 0 | 0 | Latch | Latch |
| 1 | 0 | 1 | 0 | 1 |
| 1 | 1 | 0 | 1 | 0 |
| 1 | 1 | 1 | **Toggle** | **Toggle** |

JK flip-flop are mainly used to build counters

# 2. Sequential circuits

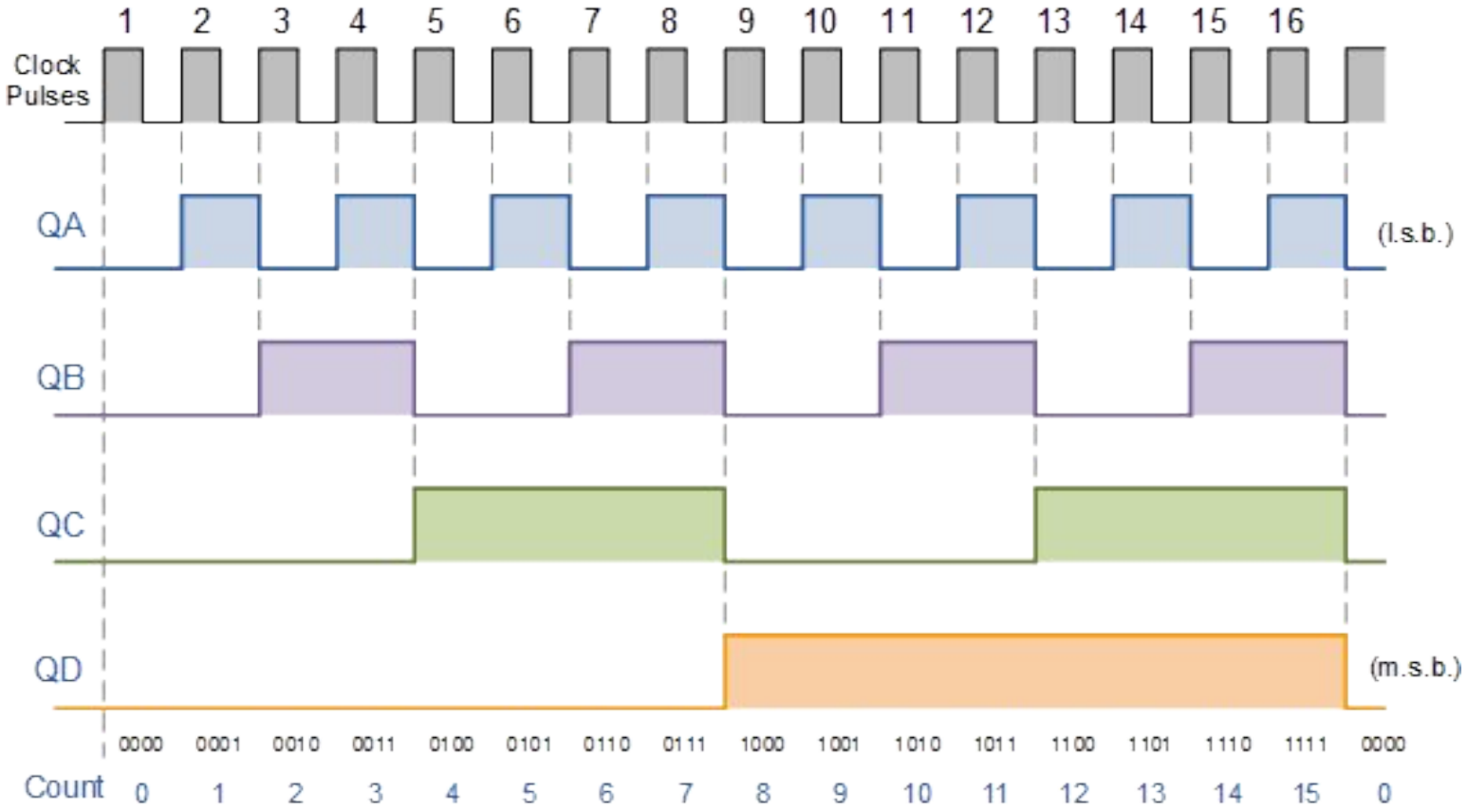
## Definitions: JK flip-flop timing diagram




In a toggle mode, the period of Q is half the period of the clock.
It can be used as a frequency divider

# 2. Sequential circuits

## Definitions: JK flip-flop timing diagram



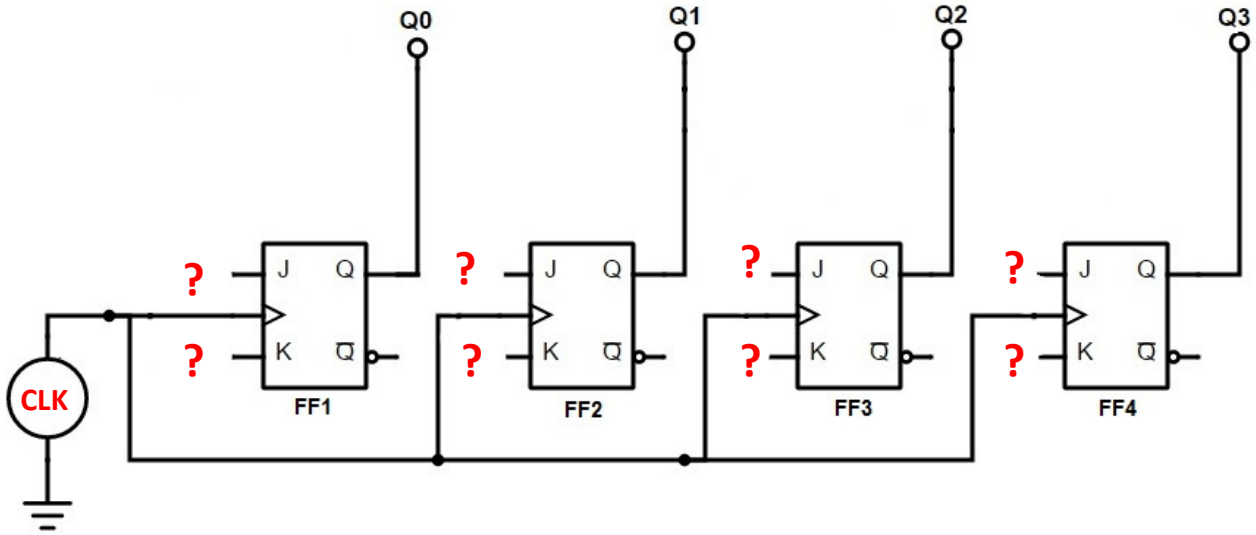

If we chain multiple JK flip flops together, the output of each JK is a counter digit.
Then, we can use every Qn as the inputs of a truth table and build some logic to reset it at a predetermined value.

# 2. Sequential circuits

## Definitions: JK flip-flop, synchronous counter

It is possible to design two types of counters:

1. Asynchronous counters: the output Q if a JK will feed theclock of the next gate
2. Synchronous counters: the clock of all the gates will be connected to the same clock signal




Synchronous counters are more stables and efficient.
Generally, the work to do is to find the number of JK to use and then, the suitable logic for the J and K inputs. This is what we are going to do now.

# 2. Sequential circuits

## The end

Now you can start the lab exercises
to discover sequential circuits!

# 1. Combinational circuits

**Exercises:**

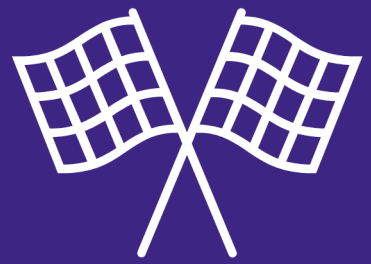
- **Modulo-10 counter**
- **Digital 24-hours clock**

# 2. Sequential circuits

**Questions**

# Logic for IT

**History, definitions and numbers representation**



Thank you for your attention

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