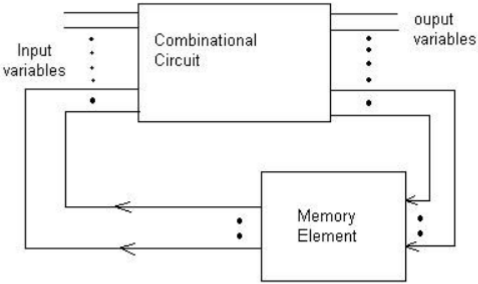
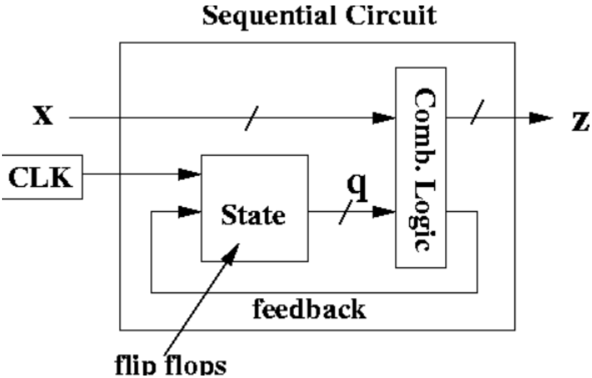
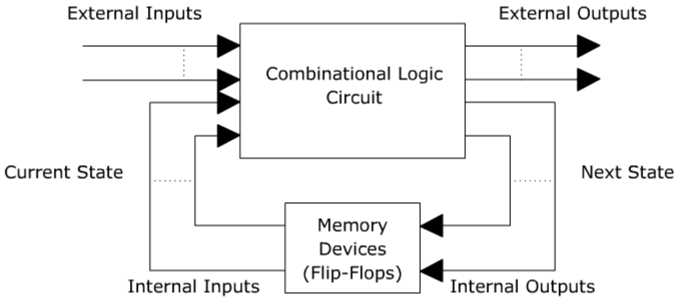
- **Sequential Circuits:**
- **Present I/P + Previous O/P = Present O/p.**
- **Feedback**
- **Memory**
- **Examples:**
- **FF, Registers, Counters etc.**

- **Real life applications:**
- **Traffic light controller:**
- **Color: Green or Red.**
- **Rocket Launcher: Series of actions.**
- **Elevator: Remembering the no. of floor's.**


Combinational
Circuit
Input
variables
ouput
variables
Memory
Element


Sequential Circuit
X
CLK
State
q
Comb. Logic
Z
feedback
flip flops


External Inputs
External Outputs
Combinational Logic Circuit
Current State
Next State
Memory Devices (Flip-Flops)
Internal Inputs
Internal Outputs

- **Figure is theoretical model of sequential circuit with**
- **combinational logic and some storage elements.**
- **There are two types of input to the combinational logic:**
- **External:**
- **Internal:**

Feedback

- Feedback is when either part -or- full output is given back to the input, for further processing.
- Feedback can be positive (e.g., oscillators) or negative (e.g., amplifiers) in terms of values.
- Important:

  The forward path in the circuit should be a function in order to have a meaningful feedback mechanism.

Types of sequential logic circuits

Sequential logic

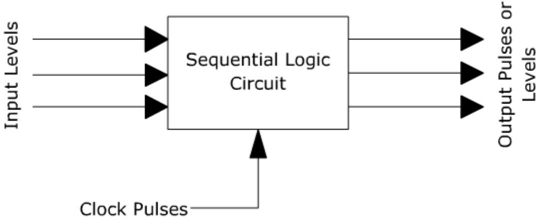
Synchronous

i.e., in general, a master-clock generator controls the time sequence of the entire circuit.

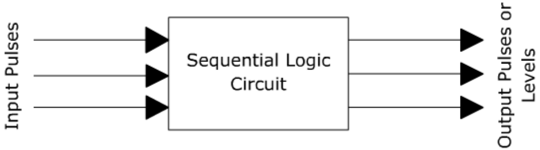
Asynchronous

i.e., different time-delays are incorporated using the memory elements, and hence operations in a circuit may not be synchronized with the master-clock.

- **Synchronous:**



- **Asynchronous:**



Clocked sequential circuits

- Sequential circuits that use clock pulses in the inputs of the memory elements are called clocked sequential circuits.
- Most frequently used types of sequential logic.
- The memory elements used in such circuits are called *flip-flops*.

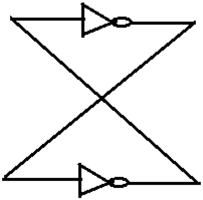
Flip-flop

- Binary cells capable of storing one bit of information, as long as power is deliver to them.

- Two outputs:
  one representing the normal value
  and the second one representing it's complemented value.

- Inputs:
  number of inputs varies and the ways in which binary information can enter a flip-flop also differ and hence generates different types of flip-flops.

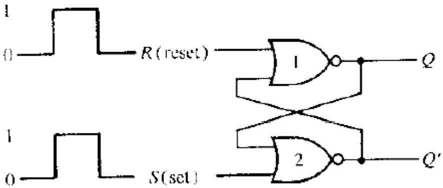
- **SR Latch using NOT Gate: ??**



- **NOT Gate: Only one i/p**
- **We need minimum two i/p one for feedback path and other for external i/p**

A basic Flip-flop using NOR gates

Sometimes called as "**SR Latch**"



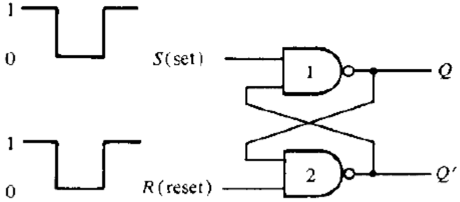
S	R	Q	Q'	
1	0	1	0	
0	0	1	0	(after $S = 1$, $R = 0$)
0	1	0	1	
0	0	0	1	(after $S = 0$, $R = 1$)
1	1	0	0	

- **S = 1, R = 0, Q = 1 and Q' = 0**
- **S = 0, R = 0, Q = 1 and Q' = 0 [Memory State/no change/previous state]**
- **S = 0, R = 1, Q = 0 and Q' = 1**
- **S = 0, R = 0, Q = 0 and Q' = 1 [Memory State]**

- **R=1 and S=0: To store the 0 in the latch.**
- **We can remove the external i/p.**
- **R=0 and S=1: To store the 1 in the latch.**

- **S = 1, R = 1, Q = 0 and Q' = 0 [invalid condition]**
- **S = 0, R = 0, Q = 1 and Q' = 0[MS] [upper Gate o/p first]**
- **S = 0, R = 0, Q = 0 and Q' = 1 [MS][Lower Gate o/p first]**
- **Not reliable circuit.**

A basic Flip-flop using NAND gates



S	R	Q	Q'	
1	0	0	1	
1	1	0	1	(after $S = 1$, $R = 0$)
0	1	1	0	
1	1	1	0	(after $S = 0$, $R = 1$)
0	0	1	1	

- **S = 1, R = 0, Q = 0 and Q' = 1**
- **S = 1, R = 1, Q = 0 and Q' = 1 [Memory State/no change/previous state]**
- **S = 0, R = 1, Q = 1 and Q' = 0**
- **S = 1, R = 1, Q = 1 and Q' = 0 [Memory State]**

- **R=1 and S=0: To store the 1 in the latch.**
- **We can remove the external i/p.**
- **R=0 and S=1: To store the 0 in the latch.**

- **S = 0, R = 0, Q = 1 and Q' = 1 [invalid condition]**
- **S = 1, R = 1, Q = 0 and Q' = 1[MS] [upper Gate o/p first]**
- **S = 1, R = 1, Q = 1 and Q' = 0 [MS][Lower Gate o/p first]**
- **Not reliable circuit.**