

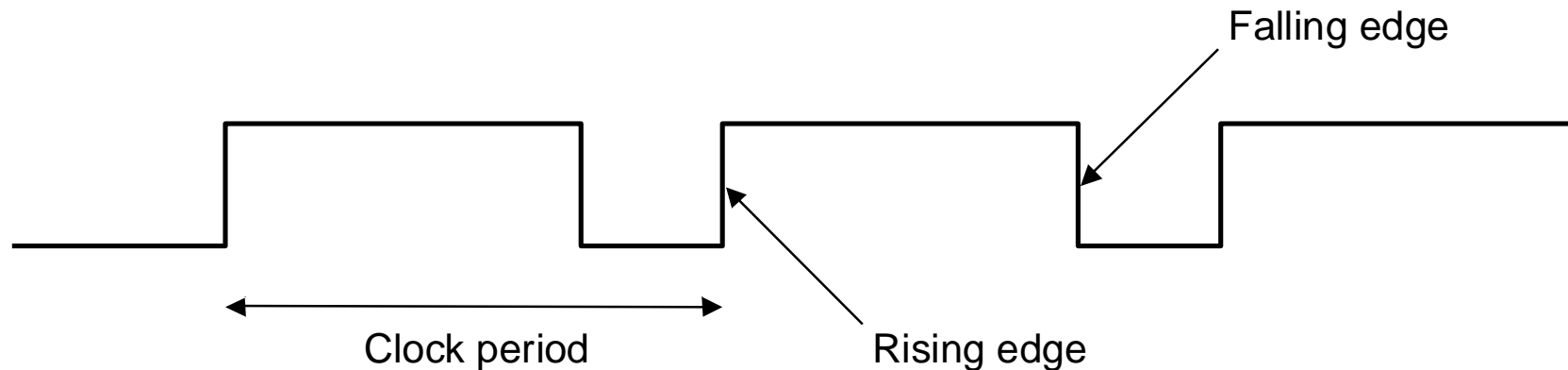
TUTORIAL 2 SEQUENTIAL LOGIC CIRCUIT

Overview

- We will review the following concept in this tutorial:
- Sequential logic circuits
 - Have memory
 - Output depends on the current input(s) and value stored in the memory (called *state*)
- Clock
- Timing diagram
 - To describe the behavior of the circuit along time
- Work with a few practical examples
 - S-R latch and D latch with NAND gates
 - Edge-triggered D flip-flop
 - Register
 - Binary counter

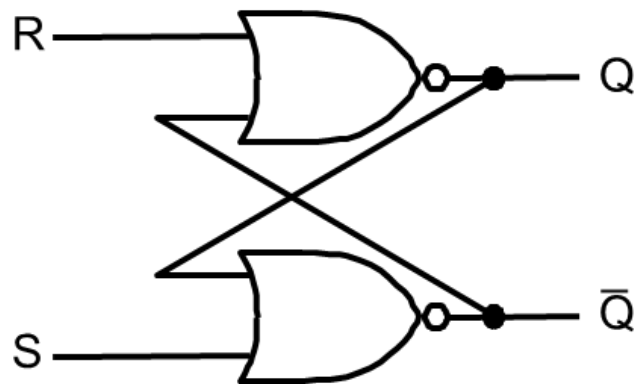
Clock

- A **clock** acts as a global signal that gives all the components in the system an indication of time.
- Clock is used in sequential logic to decide and co-ordinate state updates.
- A clock signal has three important key words that you need to know:



S-R Latch: the Simplest Memory Element

- A **S-R latch** (Set-Reset latch) using **NOR** gates shown below is the simplest memory element.
- Un-clocked memory element (Asynchronous device)



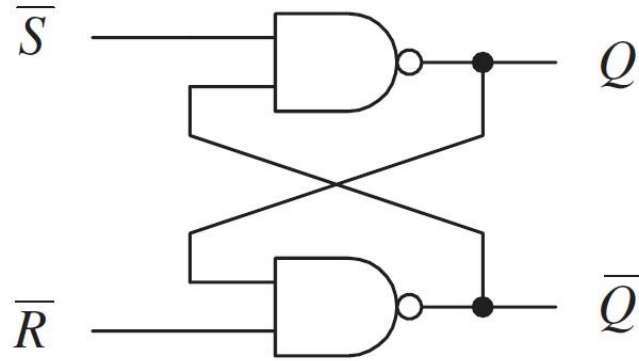
S	R	Action on Q
0	0	latched
0	1	Q = 0
1	0	Q = 1
1	1	forbidden

- **Question:** How does this circuit “stores” information? What is the size of the information being stored?



S-R Latch with NAND Gates

- **S-R latch** (Set-Reset latch) can also be implemented by **NAND** gates
- **Un-clocked** memory element (**Asynchronous** device)

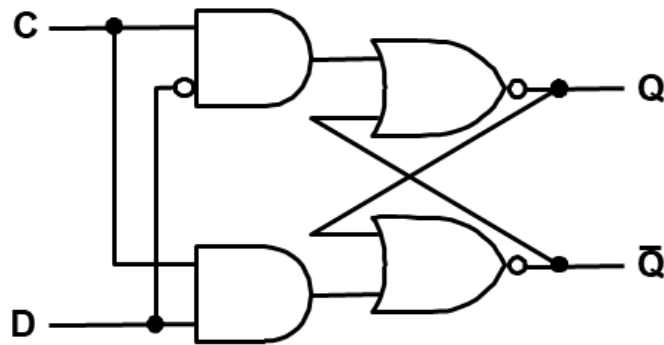


\bar{S}	\bar{R}	Action on Q
0	0	forbidden
0	1	$Q = 1$
1	0	$Q = 0$
1	1	latched

- **Note**
 - S-R NAND latch is an inverted version of S-R NOR latch. Thus, the truth table is also inverted.
 - The input signal is effective when it is de-asserted.

A Clocked Memory Element: D-latch

- The value stored in a D-latch can be updated iff the clock is asserted (i.e. $C=1$).
- An implementation using NOR gates is shown below. S-R latch (Set-Reset latch) can also be implemented NAND gates



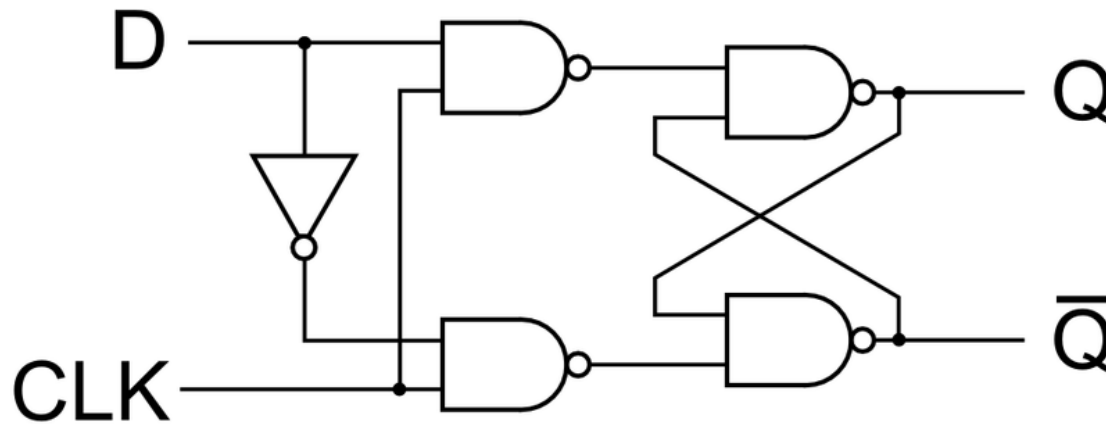
C (Clock)	D	Action on Q
0	0	Nothing changed
0	1	Nothing changed
1	0	$Q = 0$
1	1	$Q = 1$

■ Note

- the S-R latch on the right part of the D-latch circuit.
- From the circuit, argue whether it is possible to do update when the clock is not asserted?

D-latch with NAND Gates

- D latch can also be implemented with NAND gates as shown in below figure.
- Clocked memory element (Synchronous device)

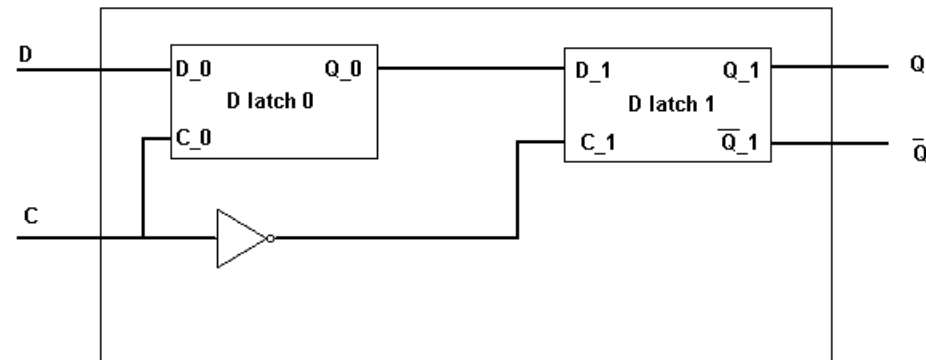


C (Clock)	D	Action on Q
0	0	Nothing changed
0	1	Nothing changed
1	0	$Q = 0$
1	1	$Q = 1$

$$Q = (D \text{ nand } C) \text{ nand } \bar{Q}, \quad \bar{Q} = (\bar{D} \text{ nand } C) \text{ nand } Q.$$

D Flip-flop

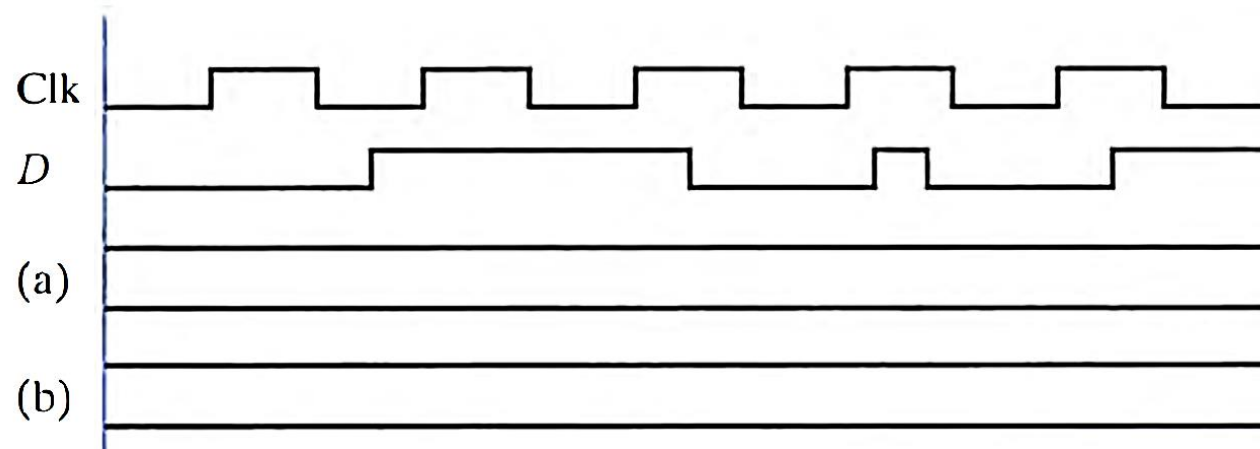
- A **D Flip-flop** can be updated only on a rising/falling clock edge.
 - There are many ways to create a D flip flop, the figure below (from the lecture notes) shows a D flip flop created from two D latches.



- Question: Can this flip-flop be updated on a rising or falling clock edge?
- Question: Without adding new hardware (wires are OK), how to modify the device so that it can be updated on the other clock edge?

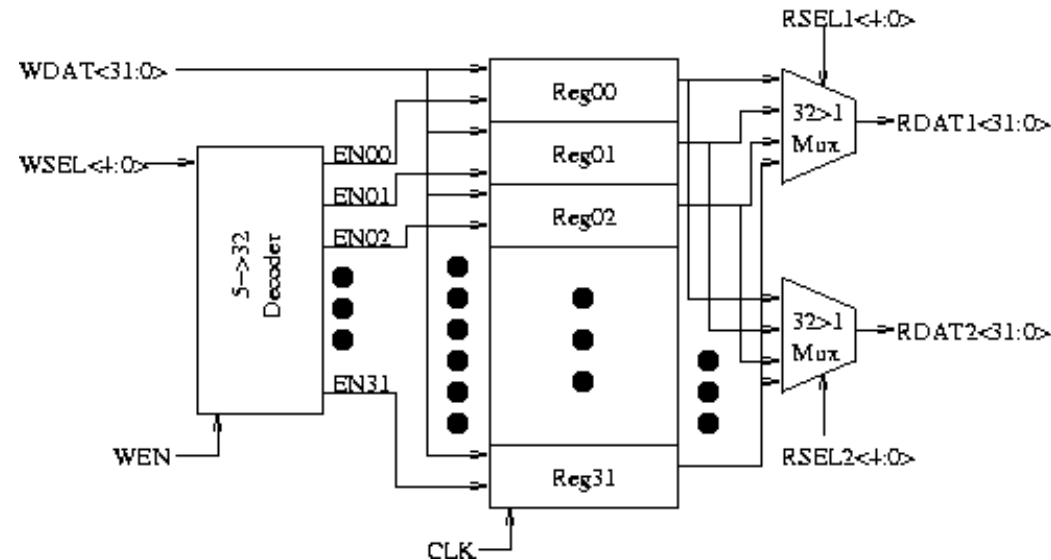
Exercise

- Given the input (D) and clock transitions (Clk) of the Figure below, determine the output of the device if it is a:
 - (a) Falling-edge triggered D flip flop.
 - (b) Rising-edge-triggered D flip-flop.



Register File

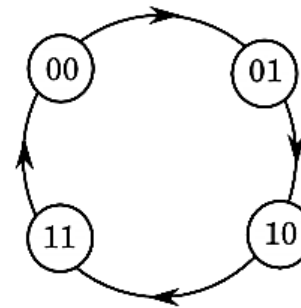
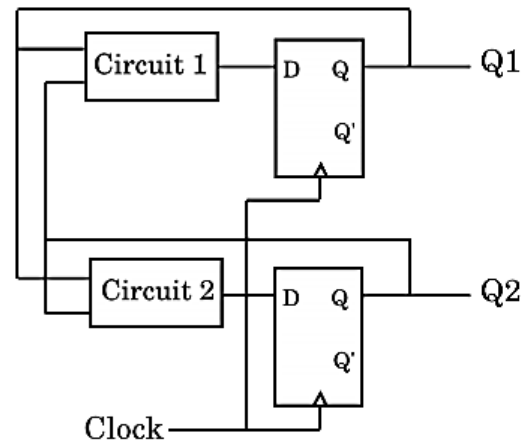
- A **register file** is a piece of hardware that allows reading from and writing to the desired registers.
- It is usually implemented by way of fast static RAMs with multiple ports.



- How do you read from a register (what are the inputs)?
- How do you write to a register (what are the inputs)?

Synchronous Binary Counters

- **Synchronous digital circuit – Binary counter with 2-bit memory**
 - Only has clock signal as input
 - At each clock pulse, the counter takes up a new state and thus goes through a specific count sequence.
 - The block diagram, structure and state transition diagram of a two-bit binary counter is of the following form.
 - Design the state sequencing logic which consists of the two combinational circuits labelled Circuit 1 and Circuit 2.



Synchronous Binary Counters - Solution

