Lecture 01

Basic Concepts of Sequential Circuits

Section 5.1-5.3

Definitions of Sequential Circuit
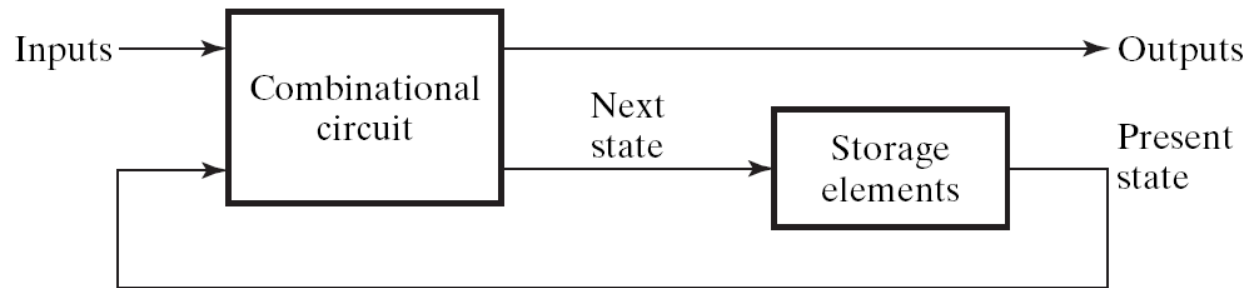
(Section 5-1)

What is a sequential circuit

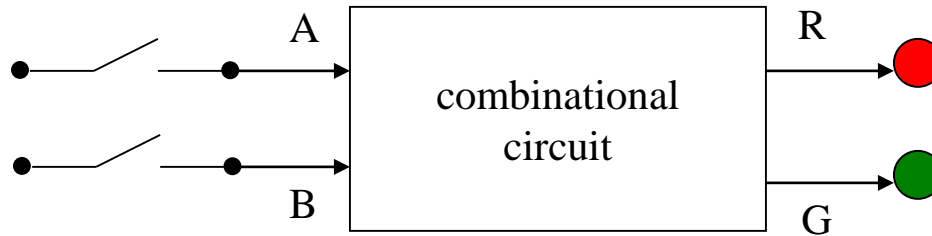- Sequential Circuit:
    - a digital circuit with storage element to memorize current state
    - Figure 5-1:

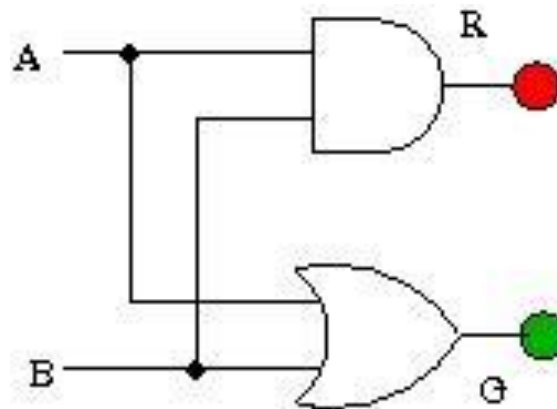

- the counter part -- Combinational Circuit
    - a digital circuit without storage element

Example 1: combinational circuit

- turn-on the RED LED when both of the two buttons pressed
- turn-on the Green LED when only one the two buttons pressed
- turn-off the two LEDs when no buttons pressed
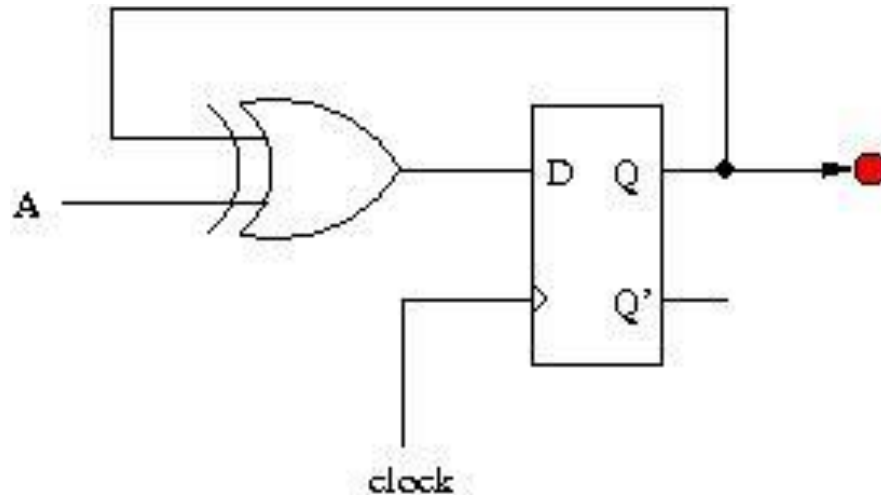
Example 1: combinational circuit

- turn-on the RED light when one of the two buttons pressed
- turn-on the Green light when both the two buttons pressed
- none of the LED ON when you release the buttons
- there is no memory in this circuit
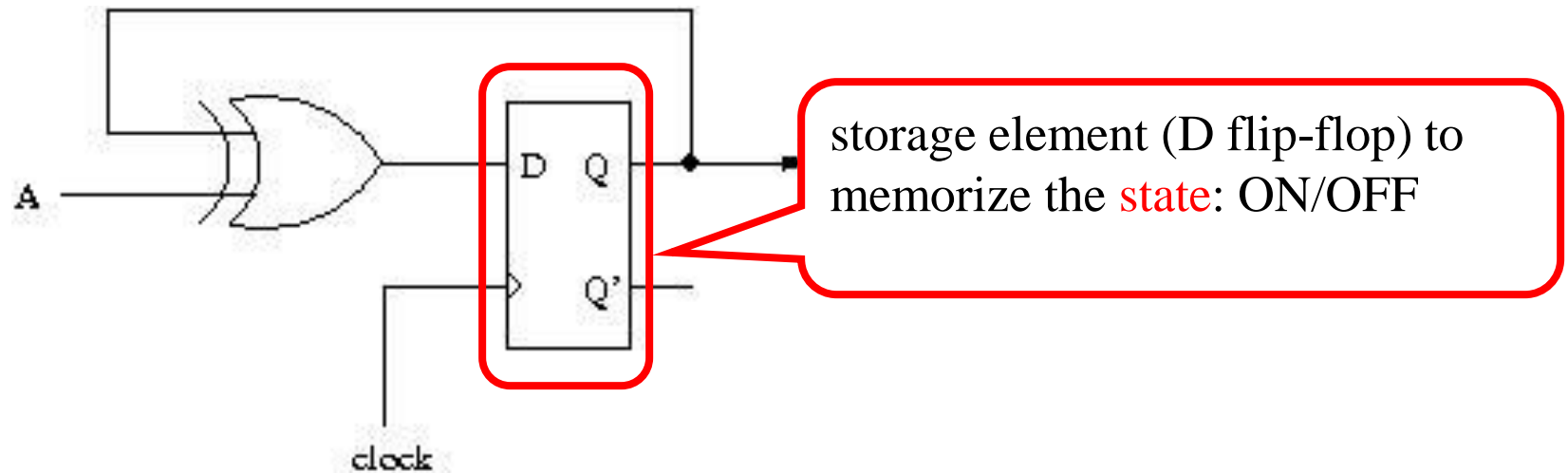
Example 2: sequential circuit
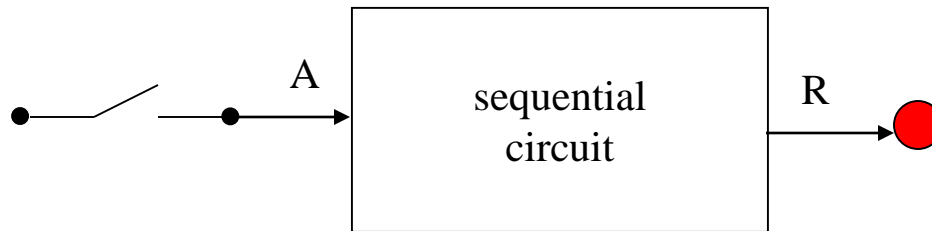
- turn ON/OFF the LED by press button A
  - 1st hit: ON
  - 2nd hit: OFF
  - 3rd hit: ON
  - 4th hit: OFF
  - ...

Example 2: sequential circuit
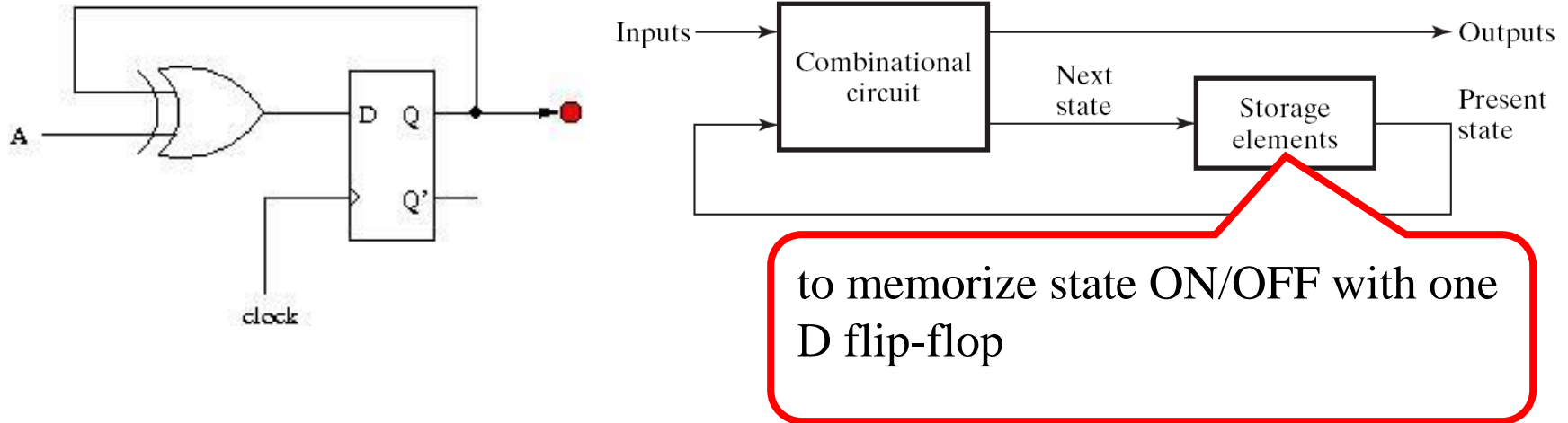

- the LED may keep ON after you release the button

Example 2: sequential circuit

storage element (D flip-flop) to memorize the state: ON/OFF

- the LED may keep ON after you release the button

Example 2: sequential circuit

Inputs → Combinational circuit → Outputs

Next state

Storage elements

Present state

A

D Q

Q'

clock

to memorize state ON/OFF with one D flip-flop

- hit the button A to control which LED on
  - 1st hit: turn on R
  - 2nd hit: turn off R
  - 3rd hit: turn on R again
  - ...

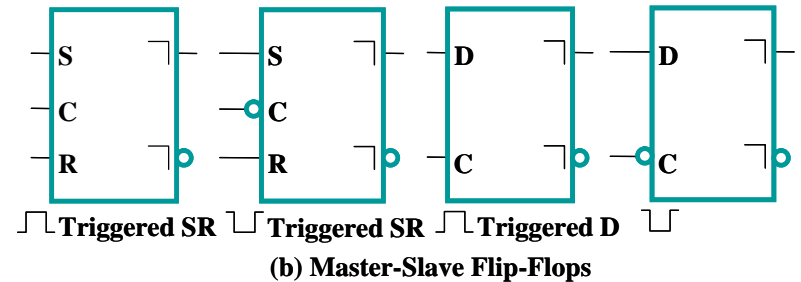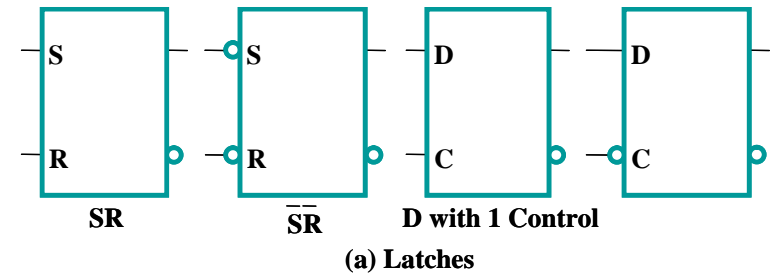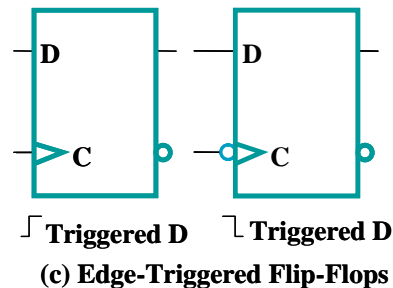# How to distinguish combinational and sequential circuit?

Storage elements

(1) SR latches and D-latches

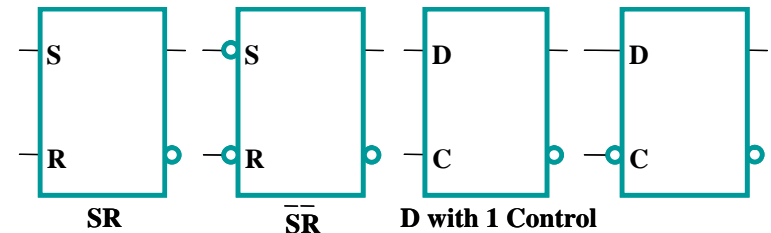(2) edge-triggered D flip-flops

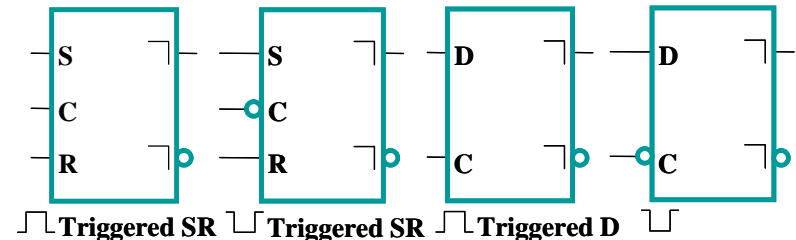(a) Latches

(b) Master-Slave Flip-Flops

(c) Edge-Triggered Flip-Flops

Storage elements

- a circuit contains one of these symbols is a sequential circuit

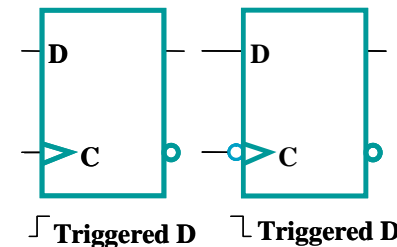- otherwise it is a combinational circuit

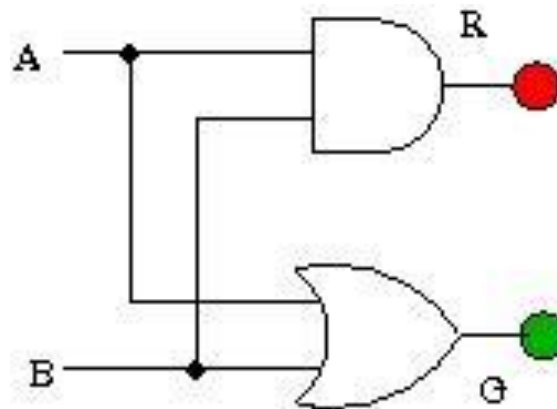SR $\overline{SR}$ D with 1 Control

(a) Latches

Triggered SR Triggered SR Triggered D

(b) Master-Slave Flip-Flops
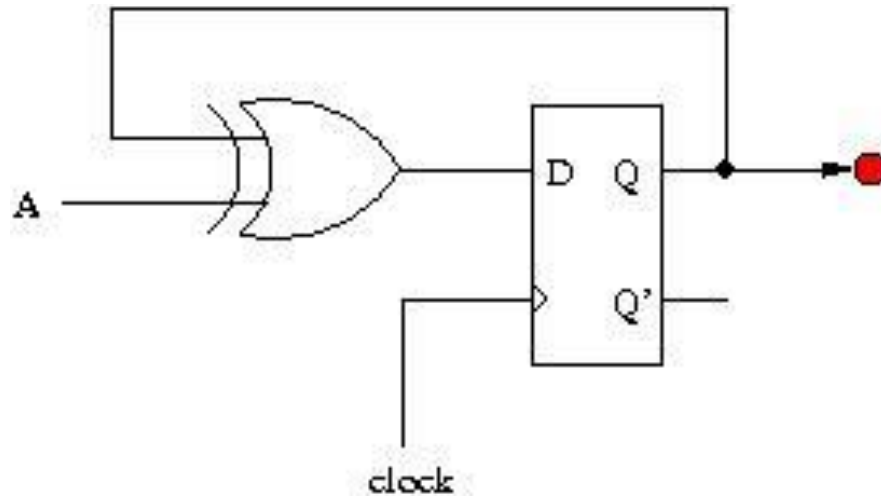
Triggered D Triggered D

(c) Edge-Triggered Flip-Flops

Example 1: combinational circuit

- turn-on the RED light when one of the two buttons pressed
- turn-on the Green light when both the two buttons pressed
- none of the LED ON when you release the buttons
- there is no memory in this circuit

Example 2: sequential circuit

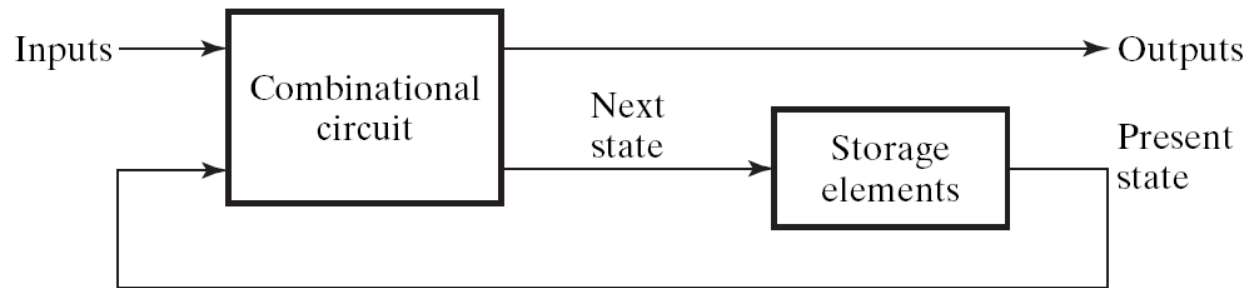- the LED may keep ON after you release the button

Storage Element

the D flip-flop

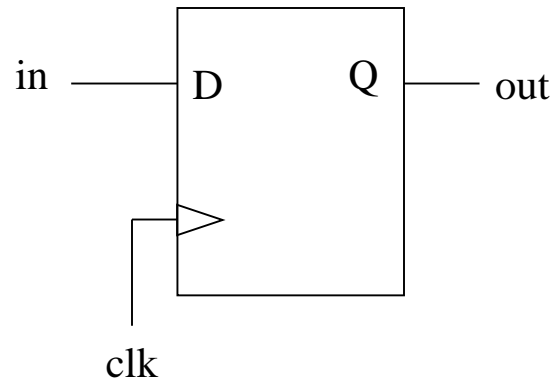# Recall: What is a sequential circuit

- Sequential Circuit:
  - a digital circuit with storage element to memorize current state
  - Figure 5-1:

- Q1: When the storage element will memorize the input?
- Q2: How long the storage element will keep its memory?

The D Flip-Flop

in ——— D   Q ——— out

clk

- Imagine that a D flip-flop is a box of 1-bit memory

- When the D flip-flop memorize the input?
  - at (positive) edge trigger of the clock (clk) signal
  - like a snapshot of a camera!

Timing Waveform of the D Flip-Flop

in —— D   Q —— out

clk   time →

clk

in   0   1

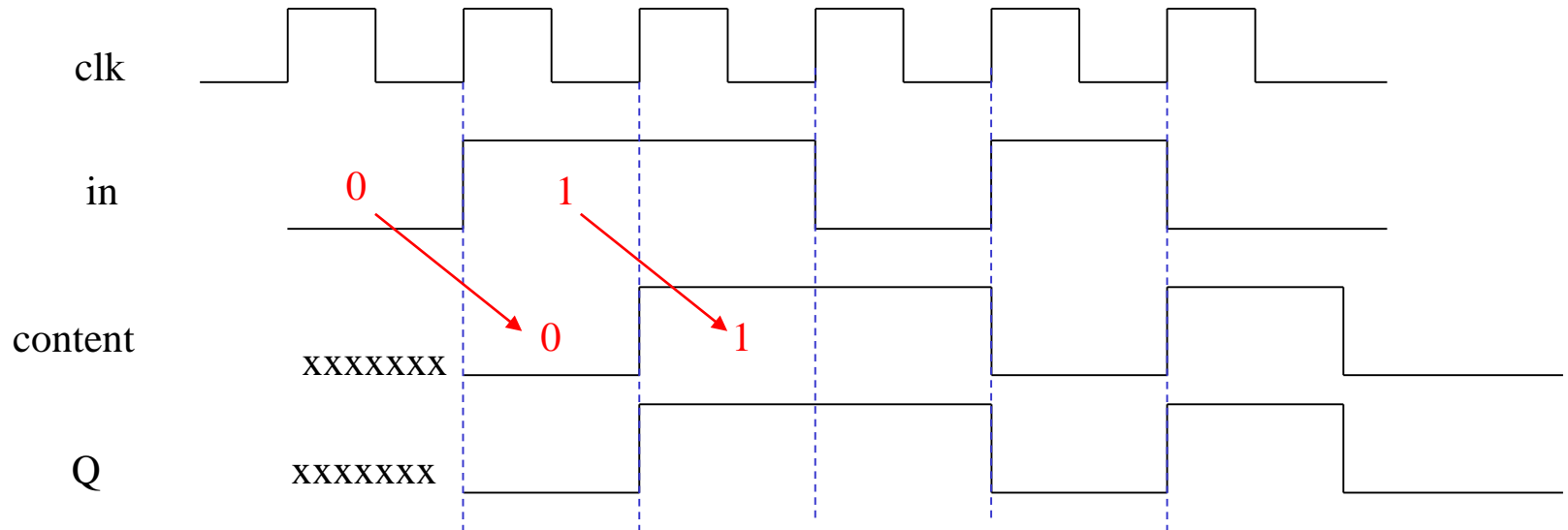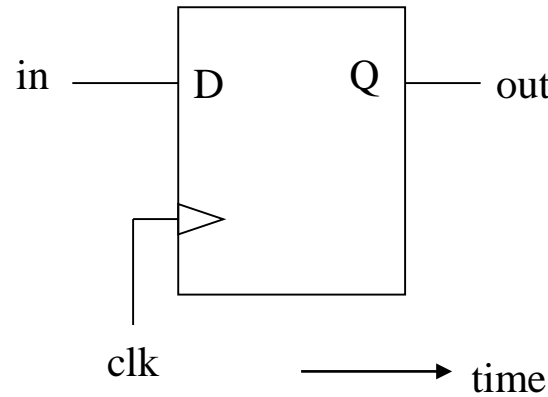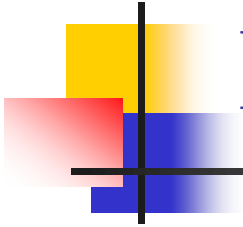content   XXXXXXX   0   1
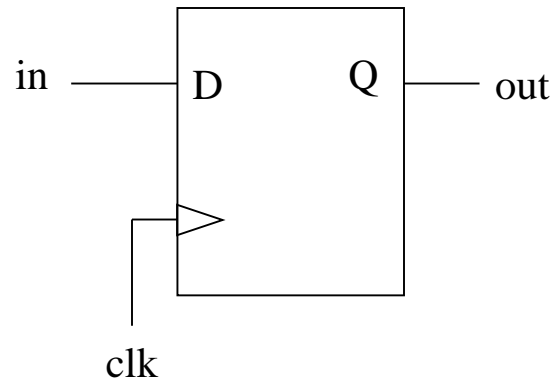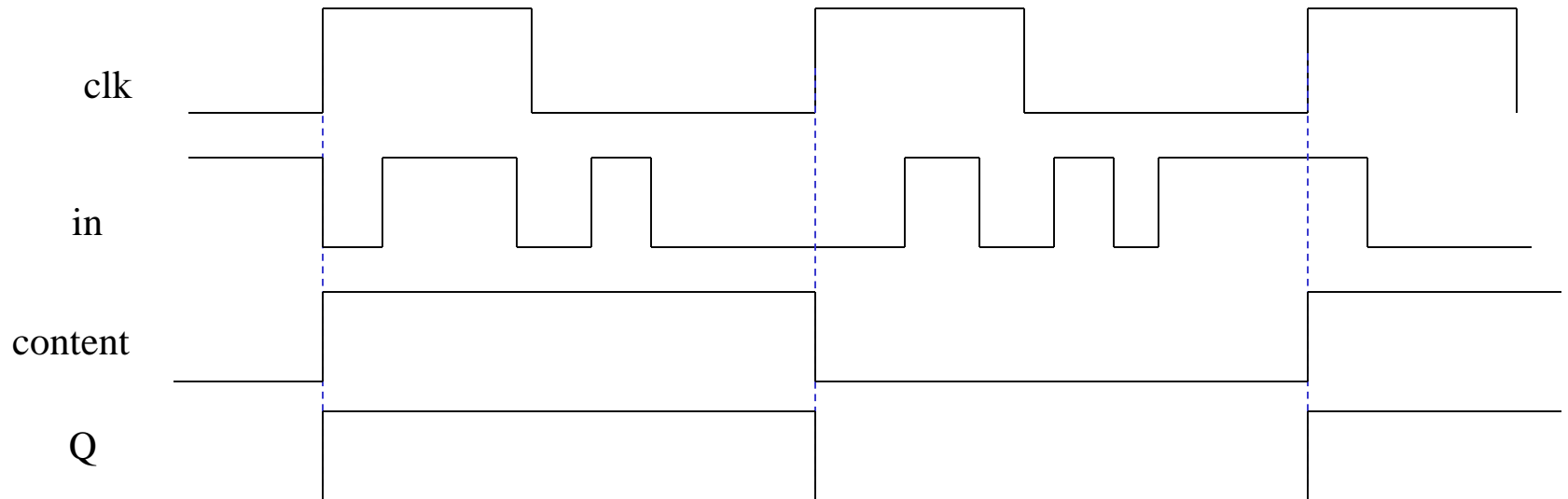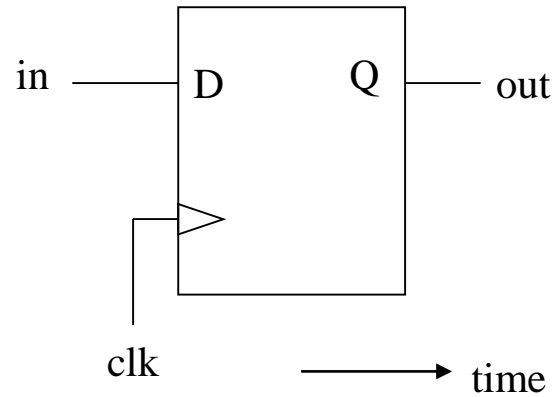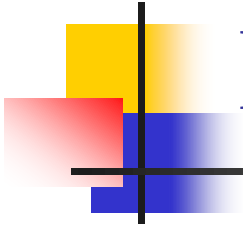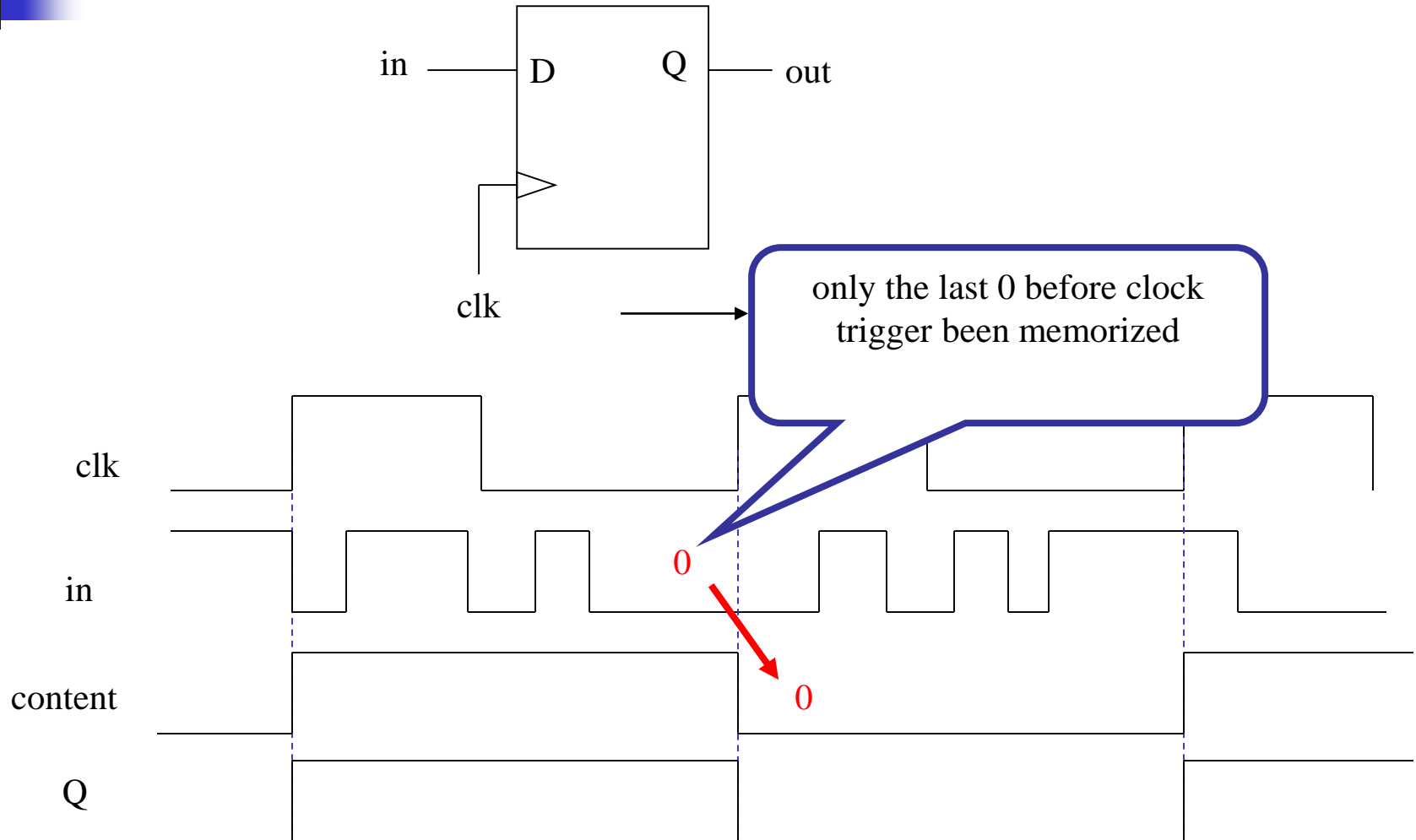
Q   XXXXXXX
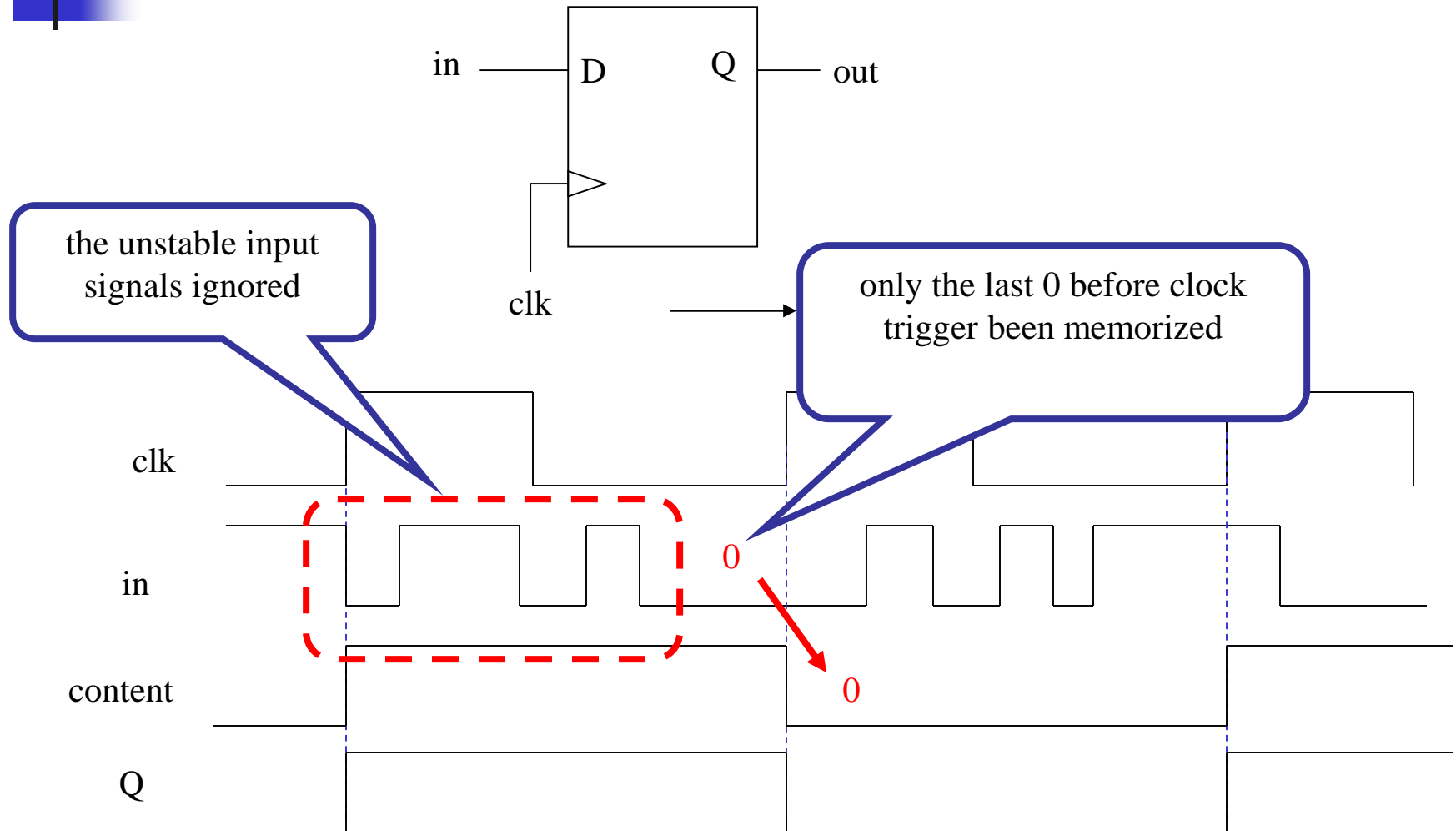
The D Flip-Flop

- Imagine that a D flip-flop is a box of 1-bit memory
- When the D flip-flop memorize the input?
  - at (positive) edge trigger of the clock (clk) signal
  - like a snapshot of a camera!
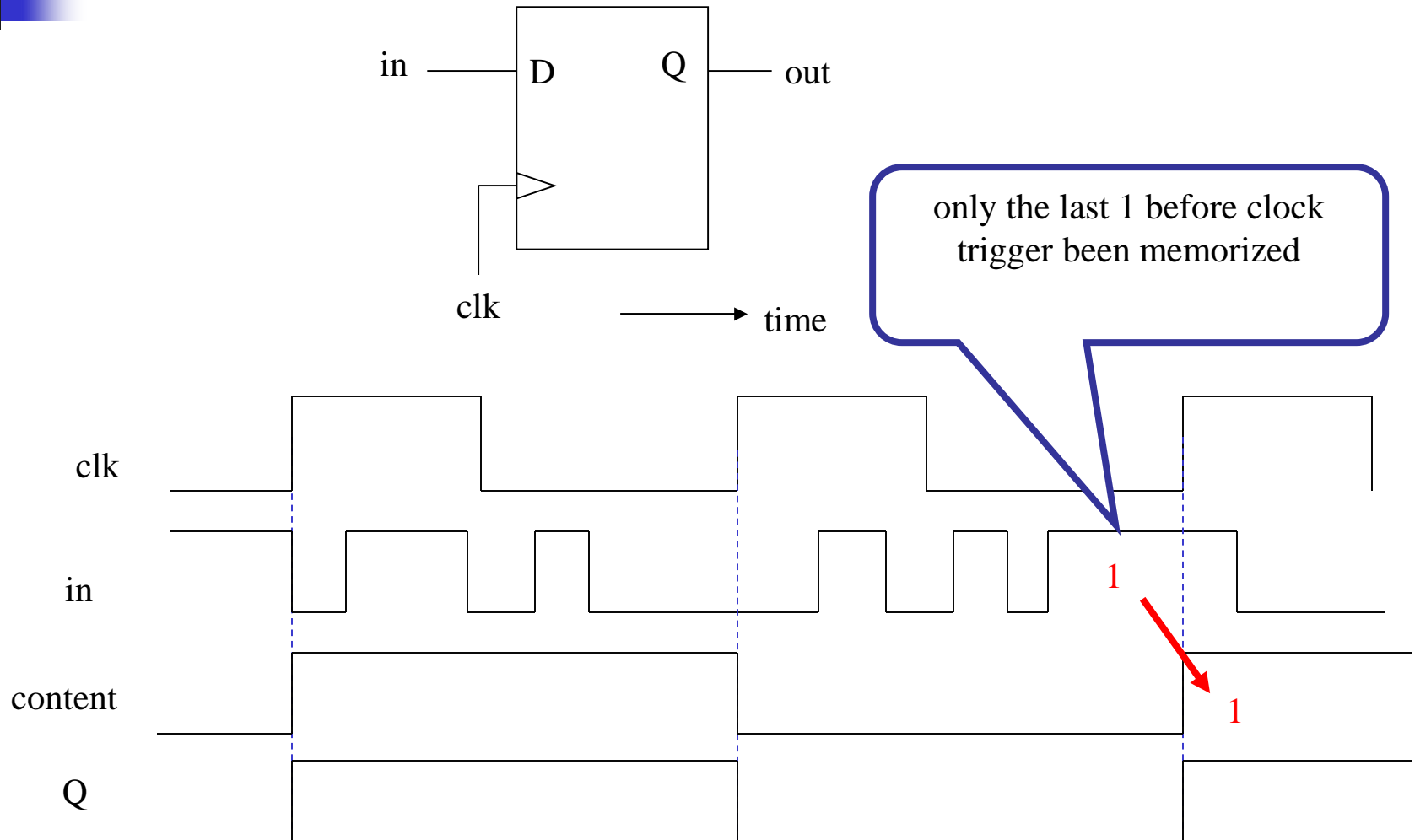 - unstable input signal between two clock triggers will be ignored!

Timing Waveform of the D Flip-Flop

Timing Waveform of the D Flip-Flop

Timing Waveform of the D Flip-Flop

Timing Waveform of the D Flip-Flop

in —— D   Q —— out

clk   time

only the last 1 before clock trigger been memorized

clk

in

content

Q

1

1

Timing Waveform of the D Flip-Flop

in ——— D   Q ——— out

clk   time ———→

clk

in | v0 | v1 | v2 | v3 |

content | v0 | v1 | v2 | v3 |

Q | v0 | v1 | v2 | v3 |
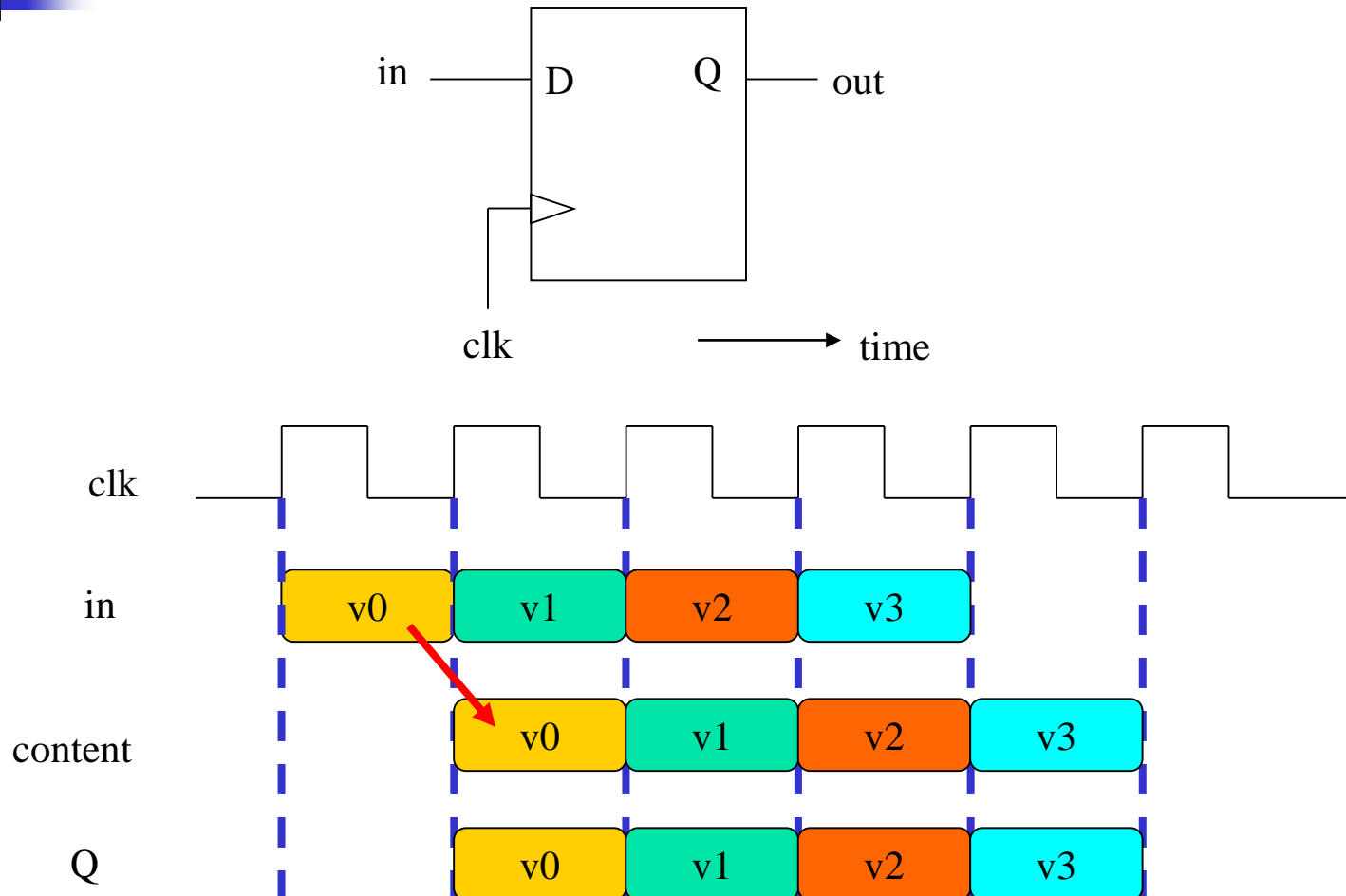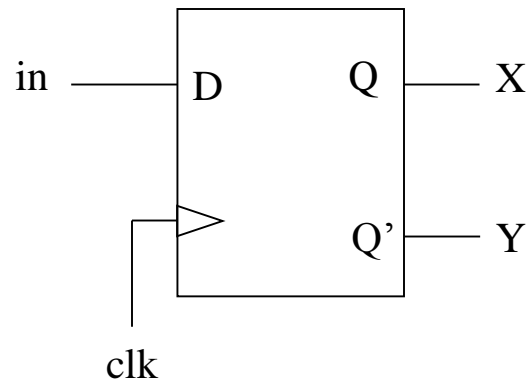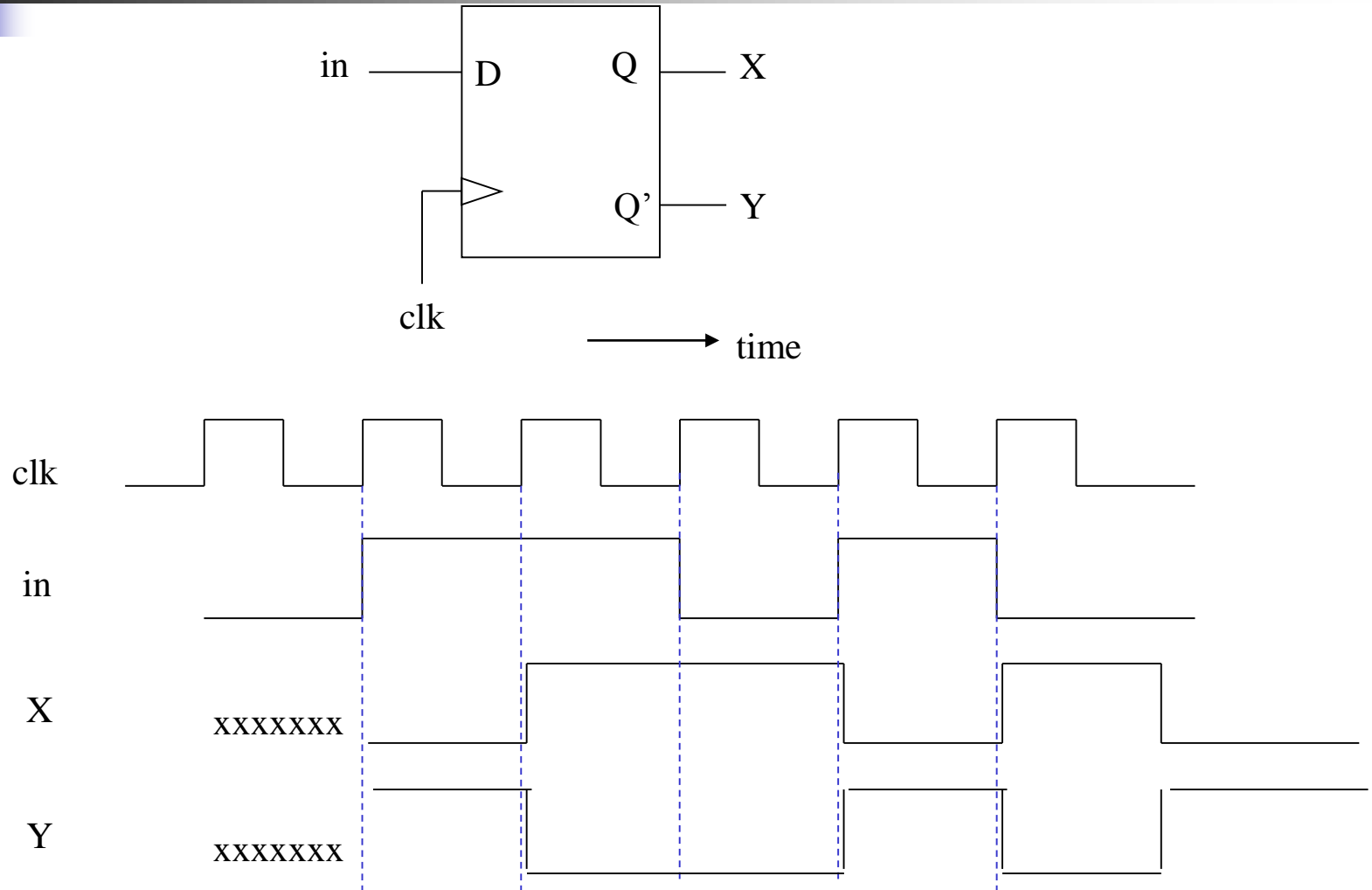
The D Flip-Flop

- the inverse of the memory content can also be retrieved

Timing Waveform of the D Flip-Flop

in ── D   Q ── X

        ▷

        Q' ── Y

clk

time

clk

in

X   xxxxxxx

Y   xxxxxxx

Timing Waveform of the D Flip-Flop

in —— D   Q —— X

           Q' —— Y

clk   ——→ time

clk

in

X   xxxxxxx   0   1   1   0   1   0

Y   xxxxxxx   1   0   0   1   0   1
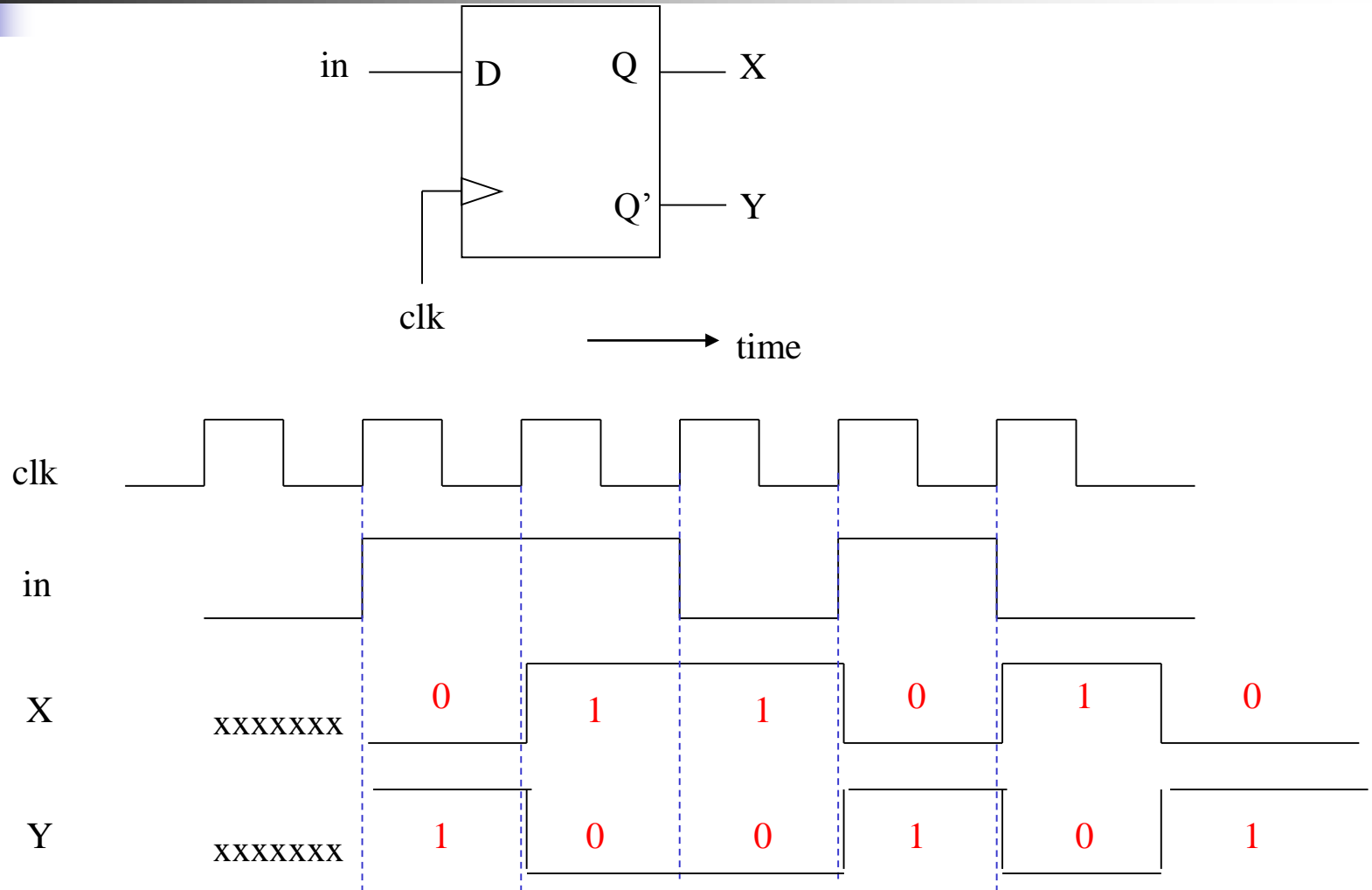
Timing Waveform of the D Flip-Flop
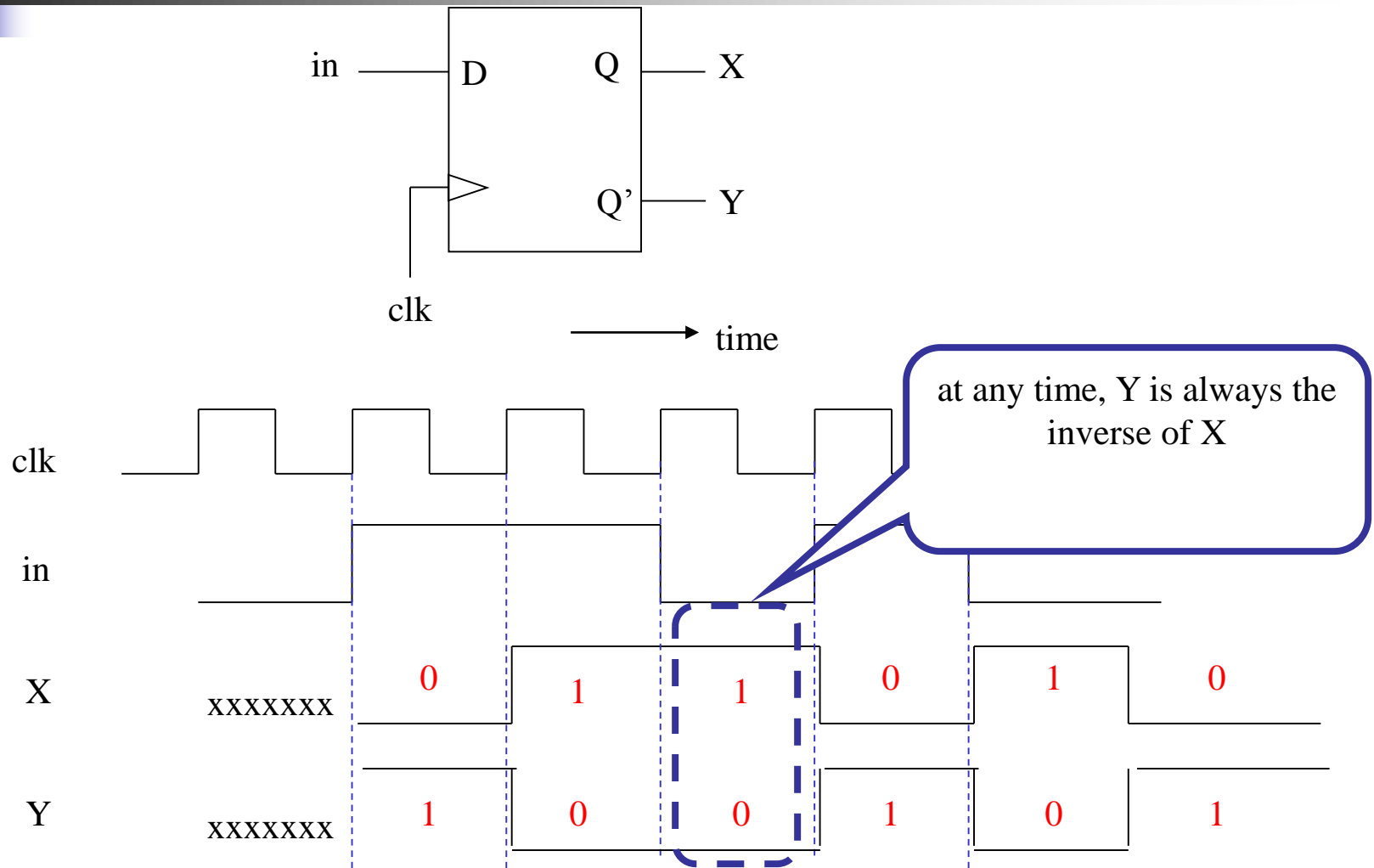
Summary

Answer these questions briefly

- Q1: What is a sequential circuit?

- Q2: What's the clock signal for?

- Q3: When a D flip flop will memorize it's input?

- Q4: How long a D flip flop will keep it's memory?

Skipped Part

- latches

- J-K flip flop

- T flip-flop

- Remark: only D flip-flop is available in modern IC design!

Next Lecture

- sequential circuit analysis
  - to draw the timing waveform from a circuit diagram

- Please study Section 5.4 before the class!