

Lecture 7

EE 421 / CS 425

Digital System Design

Fall 2025

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Topics

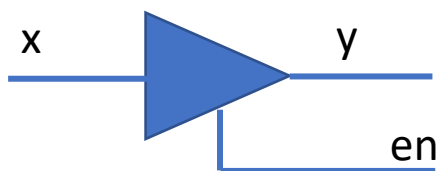
- Three State Drivers (or Buffers)
- D and T Flipflops
- Some Examples of DFF based Circuits:
 - Shift Registers
 - Counters
- Analyzing DFF based Circuits
- Synthesizing DFF Based Counters or Sequencers

Remember:
Quiz 2 Next Week

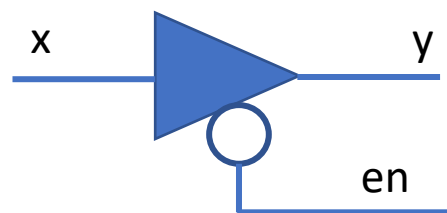
Three State Buffers for Processor Buses

- Buses are multi-wire signal paths that connect multiple functional units in a computer system, e.g., Address bus, peripheral bus, etc.
- Simplifies design and architecture of a computer system
- Tradeoff is that the access to the bus has to be managed to avoid conflicts
- Three state hardware devices provide a dynamic interface between a bus and a circuit, providing signals when enabled else an open circuit
- The input goes to the output of the tri-state buffer when enable signal is asserted

Three State Bus Drivers



x	en	y
0	0	Hi_Z
0	1	0
1	0	Hi_Z
1	1	1

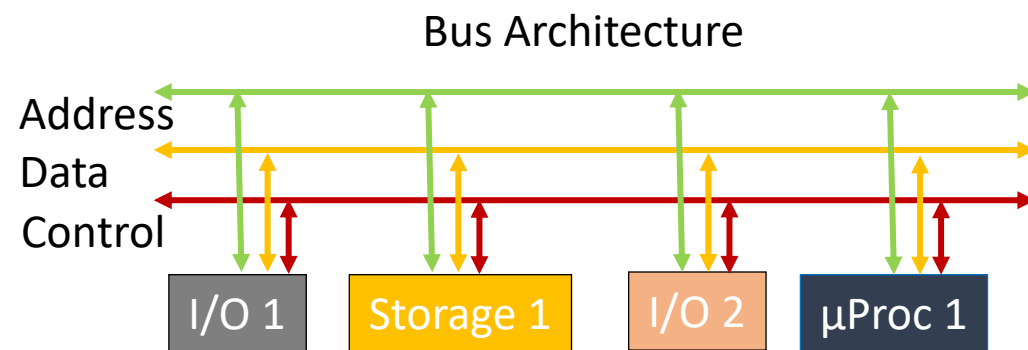


x	en	y
0	0	0
0	1	Hi_Z
1	0	1
1	1	Hi_Z

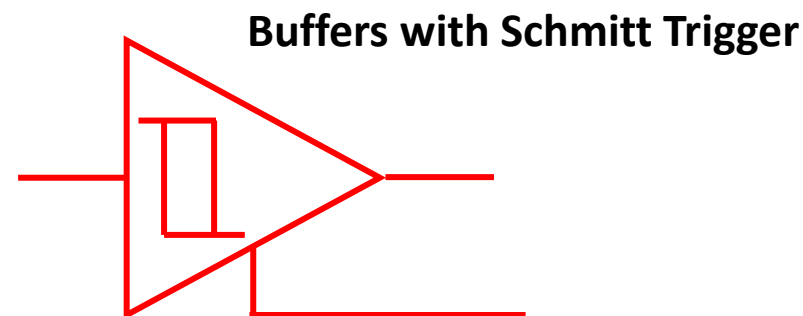
Inverting and Non-Inverting 3-State Buffers / Drivers Exist

The Enable can be active high or active low

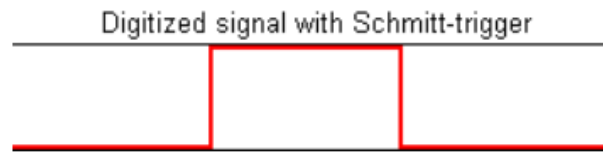
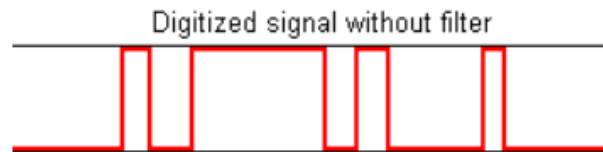
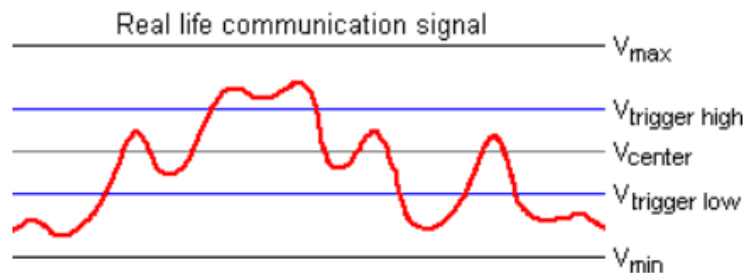
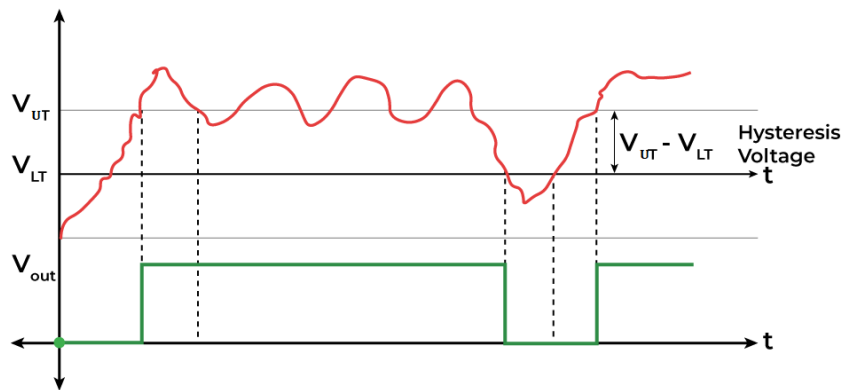
Buffers with Hysteresis Loop are available for better noise immunity



Typical Bus Structure utilizing 3-state buffers



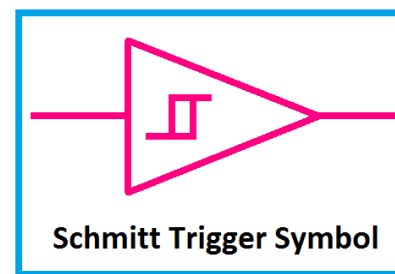
Schmitt Trigger



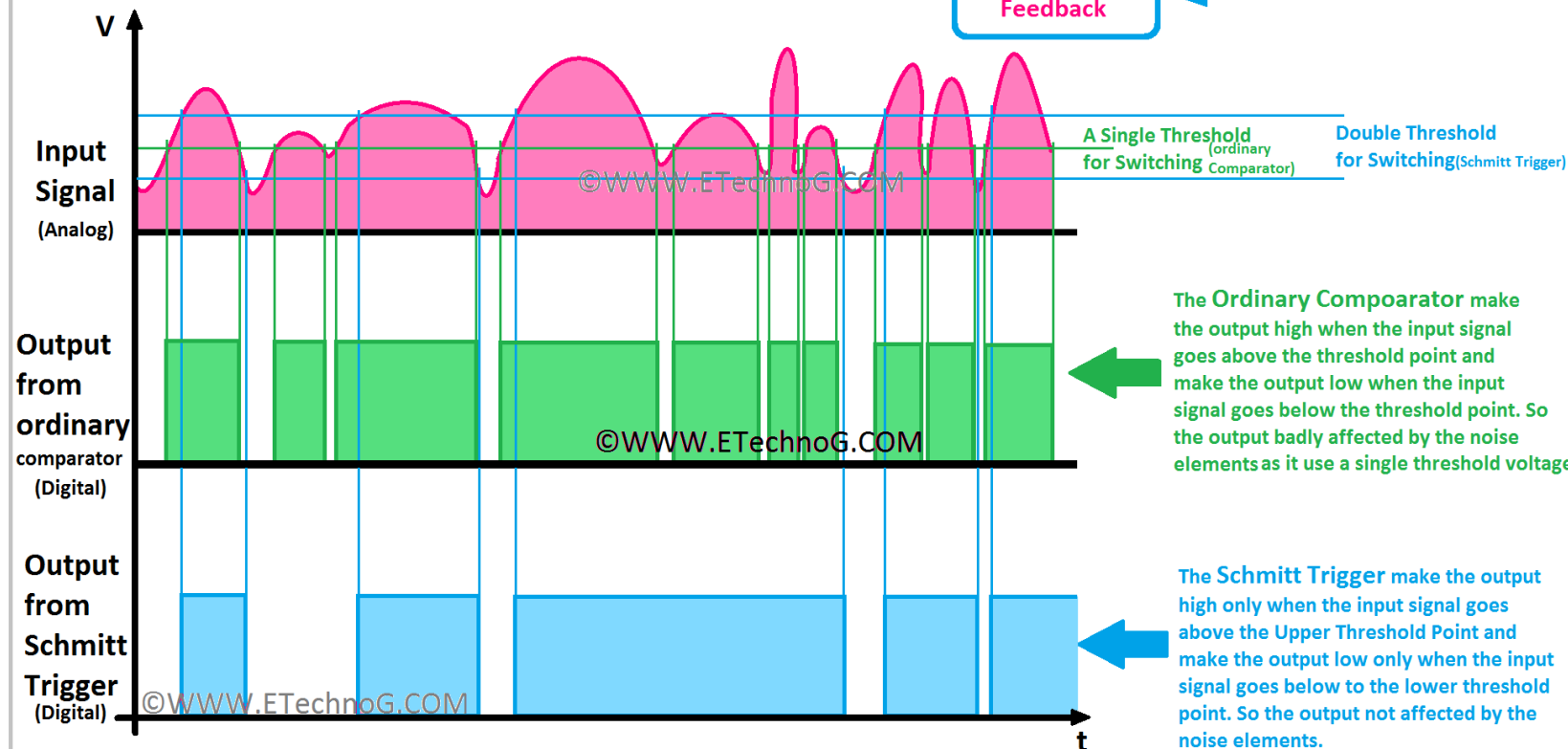
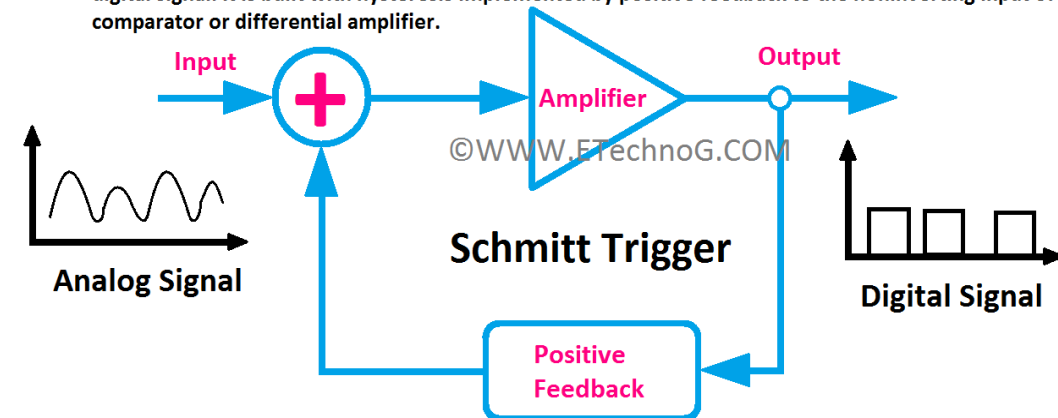
Schmitt trigger voltage levels

Figure. 01

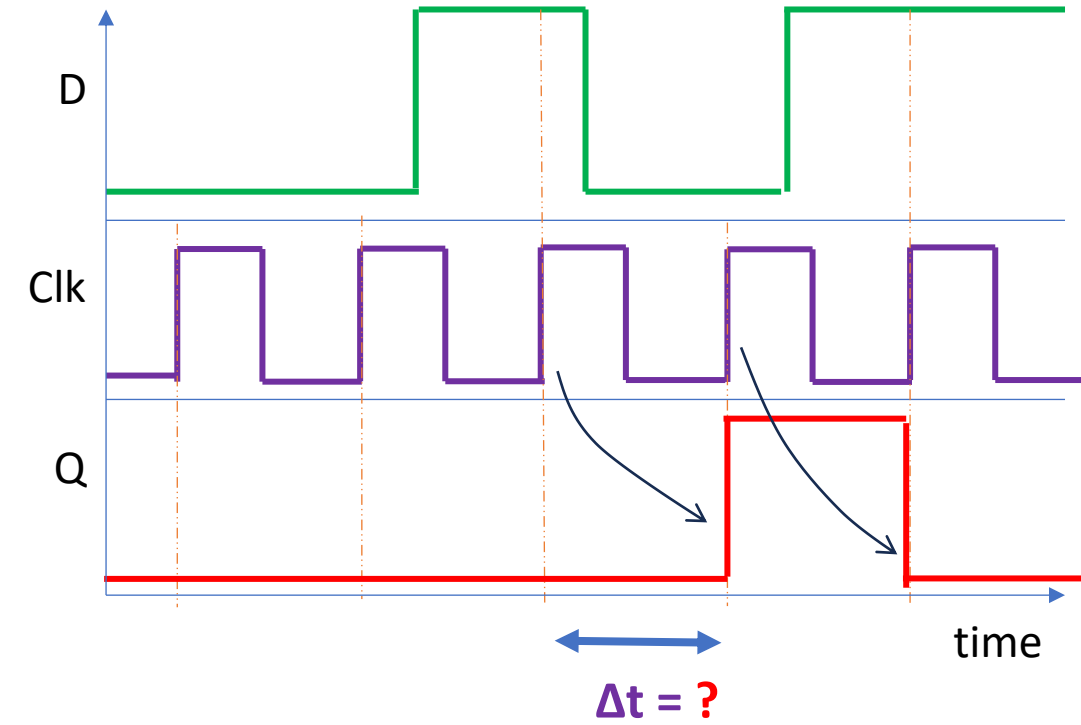
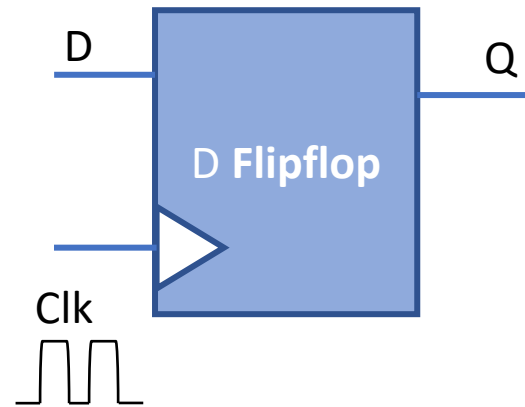
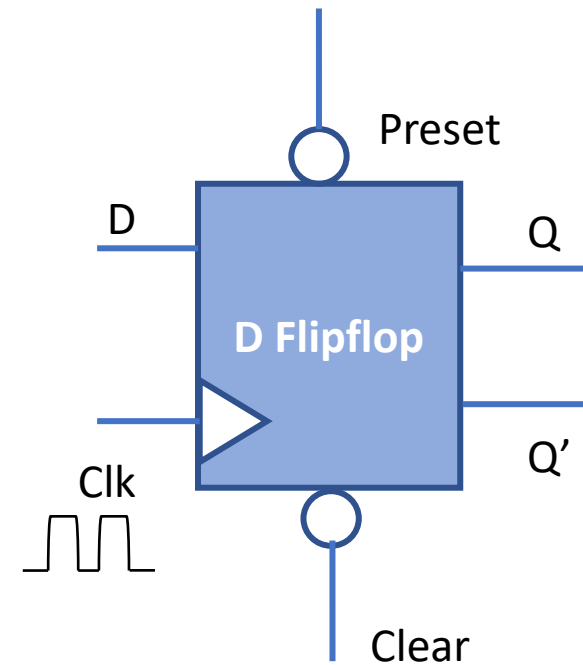
How Schmitt Trigger Works?(Learn with Diagram)



A Schmitt Trigger basically a Active Comparator circuit that is used to convert the analog signal into digital signal. It is built with hysteresis implemented by positive feedback to the noninverting input of a comparator or differential amplifier.



D Flipflops – Behavior and Equation



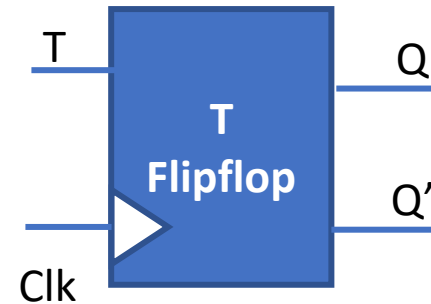
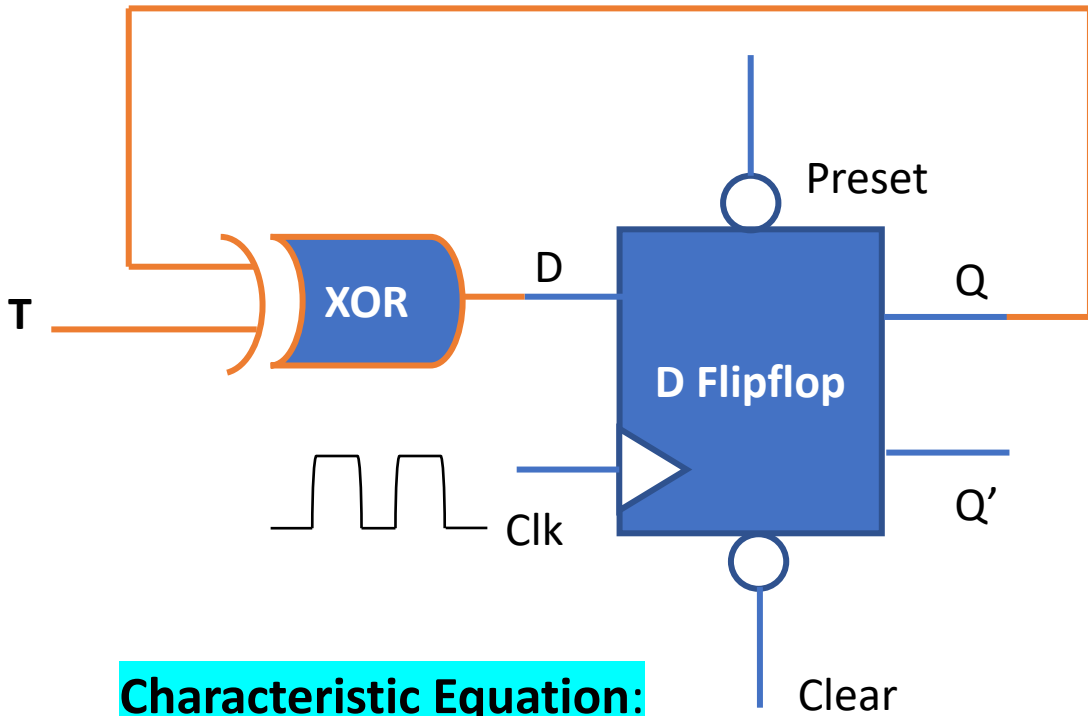
Characteristic Equation:

$$Q(t+1) = D$$

Q after clock pulse gets value of D

D	Q(t+1)
0	0; Reset
1	1; Set

T Flipflop – Behaviour and Equation

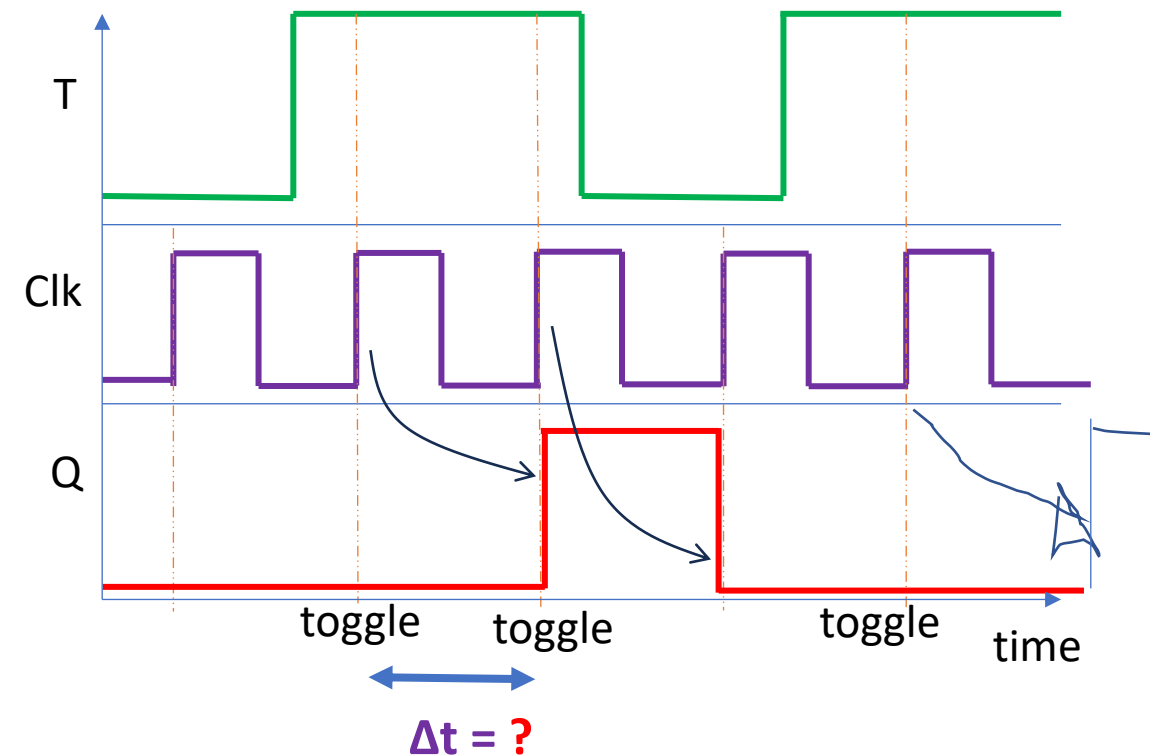


Characteristic Equation:

$$Q(t+1) = T \oplus Q$$

$$= T'Q + TQ'$$

T	Q(t+1)
0	Q(t); No change
1	Q'(t); Toggle or Complement



In this course,

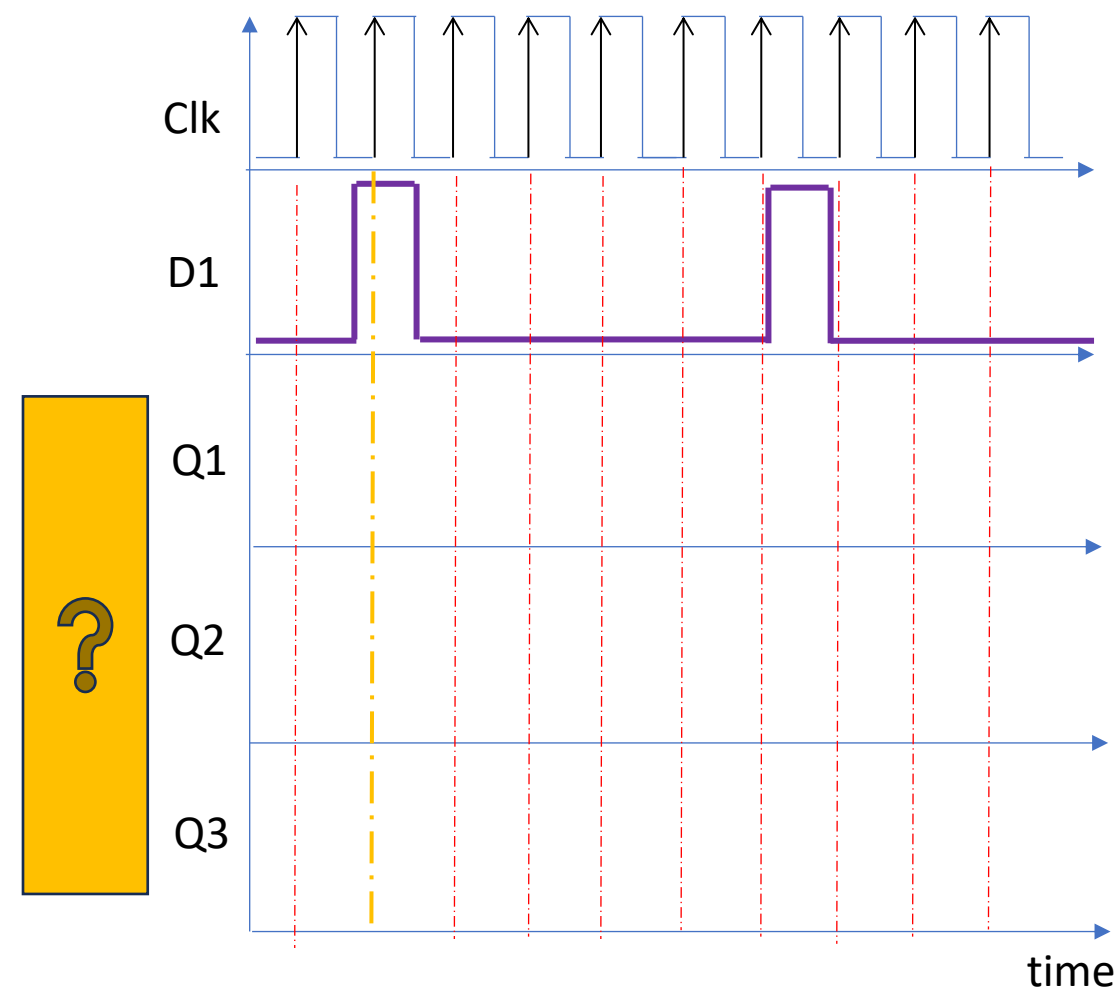
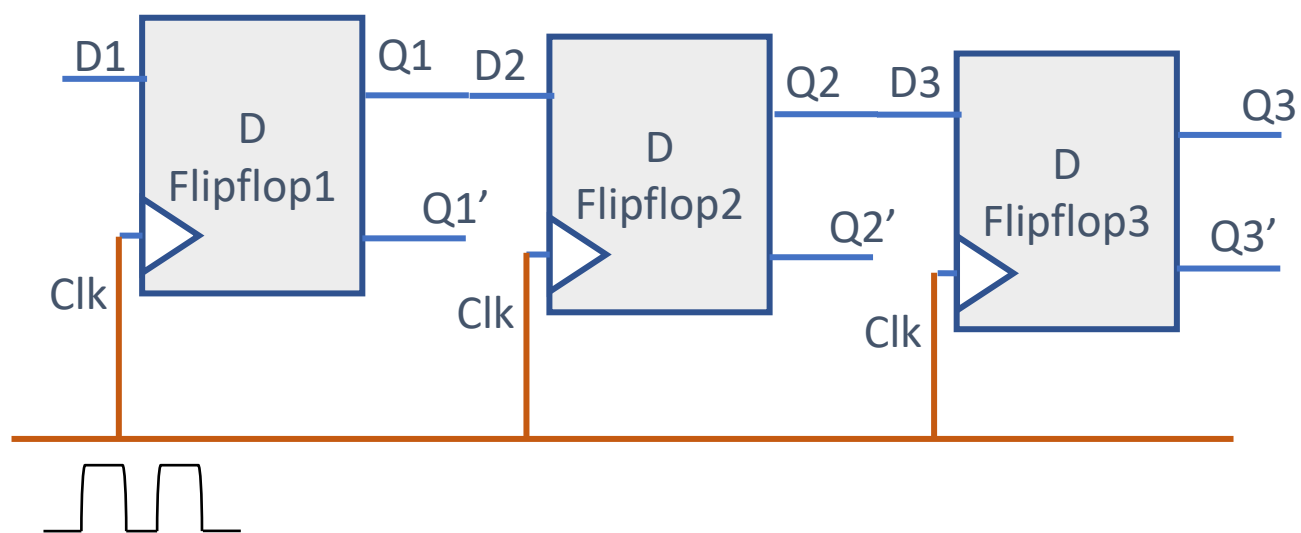
**We will mostly use D Flipflops
and sometimes T Flipflops**

We want to study complex and high-speed designs

Sequential Circuits: Counters, Sequencers, State Machines

- **Counters:** count in a fixed sequence, up or down
- **Sequencers:** sequence through a pre-defined arbitrary sequence
- **State Machines:** Sequential and Combinational Circuits work together to go one of many next states based on current inputs

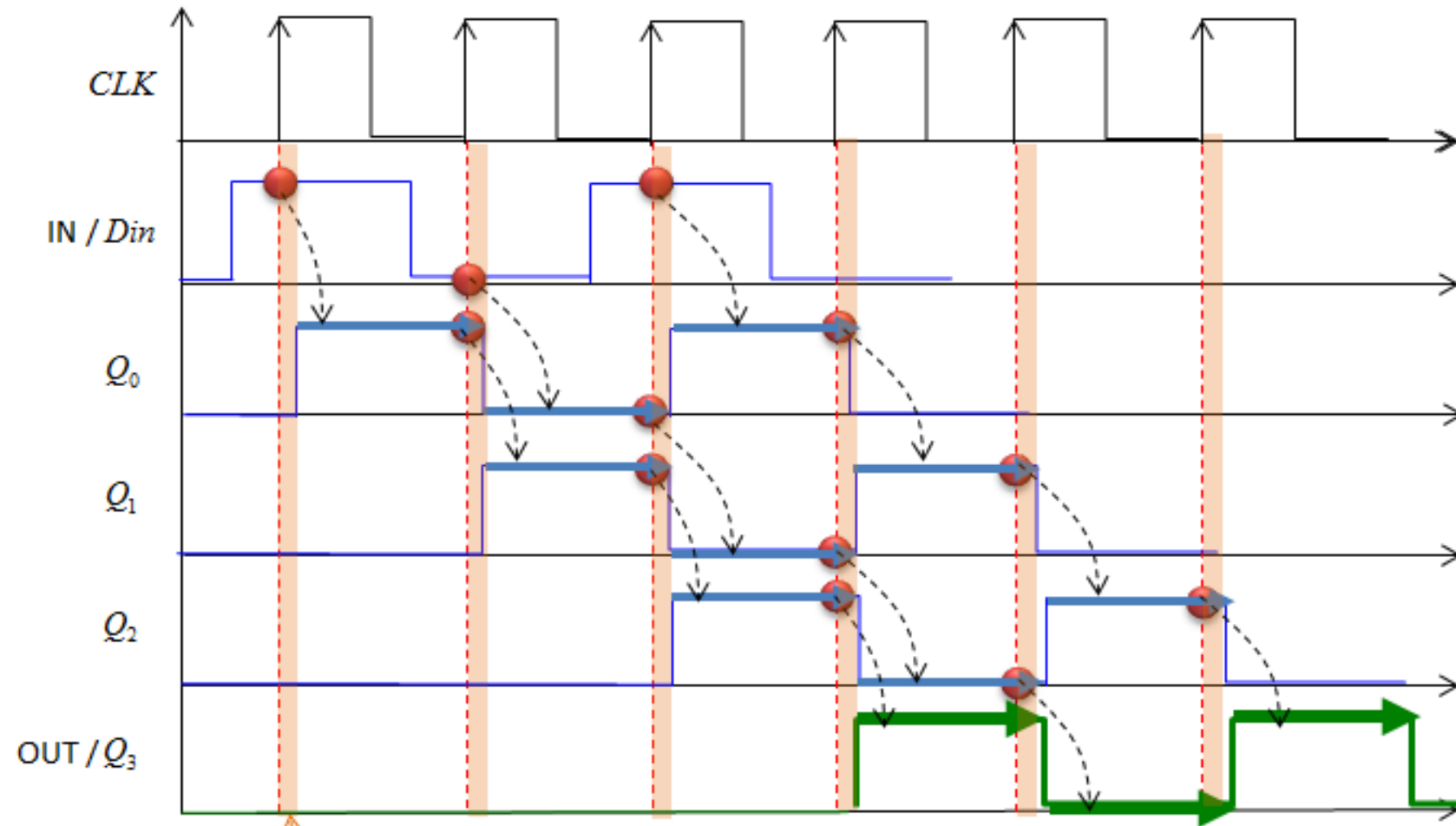
Moving Through Register Chain



Only 'EDGES' of Clocks are important for Flipflops

3 DFF Shift Register Timing Diagram from a website

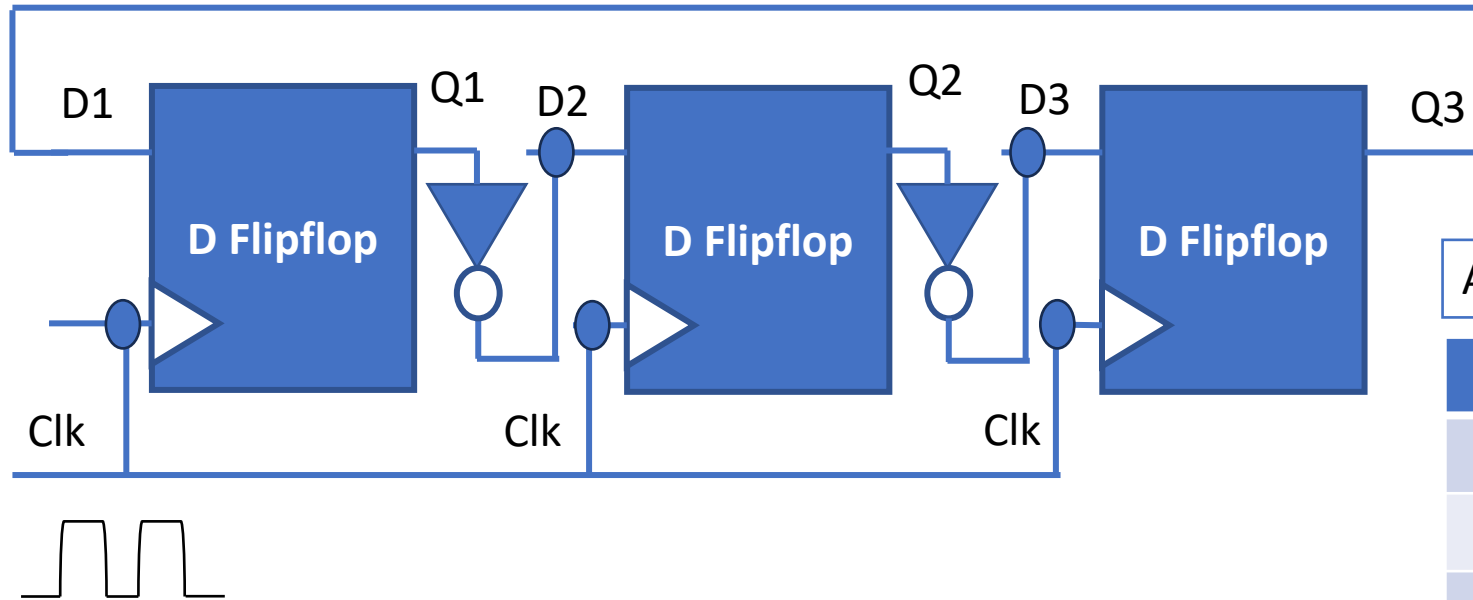
Look closely at the
Area close to
Clock transition,
Shaded pink lines



We assume that there is a small delay at Q state of each flipflop to make the timing diagram easily understandable.

But in reality, the situation would be a little more complicated than this simple time delay.

Cyclic Shift Register using D flipflops



Assume all DFFs are Cleared to **0** at Startup

Clock No.	Q1	Q2	Q3
1	0	0	0
2	0	1	1
3	1	1	0
4	0	0	0
5	0	1	1
6	1	1	0
7	0	0	0
CONTINUE

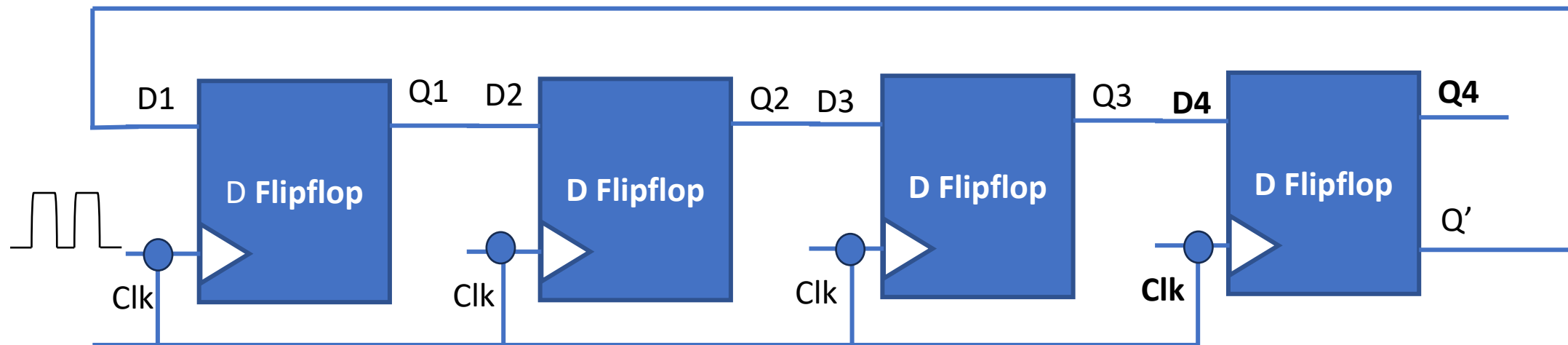
After the clock edge:

$Q1(t+1)$ becomes same as $Q3(t)$

$Q2(t+1)$ becomes inverse of $Q1(t)$

$Q3(t+1)$ becomes inverse of $Q2(t)$

Tail Ring Counter Four Stage



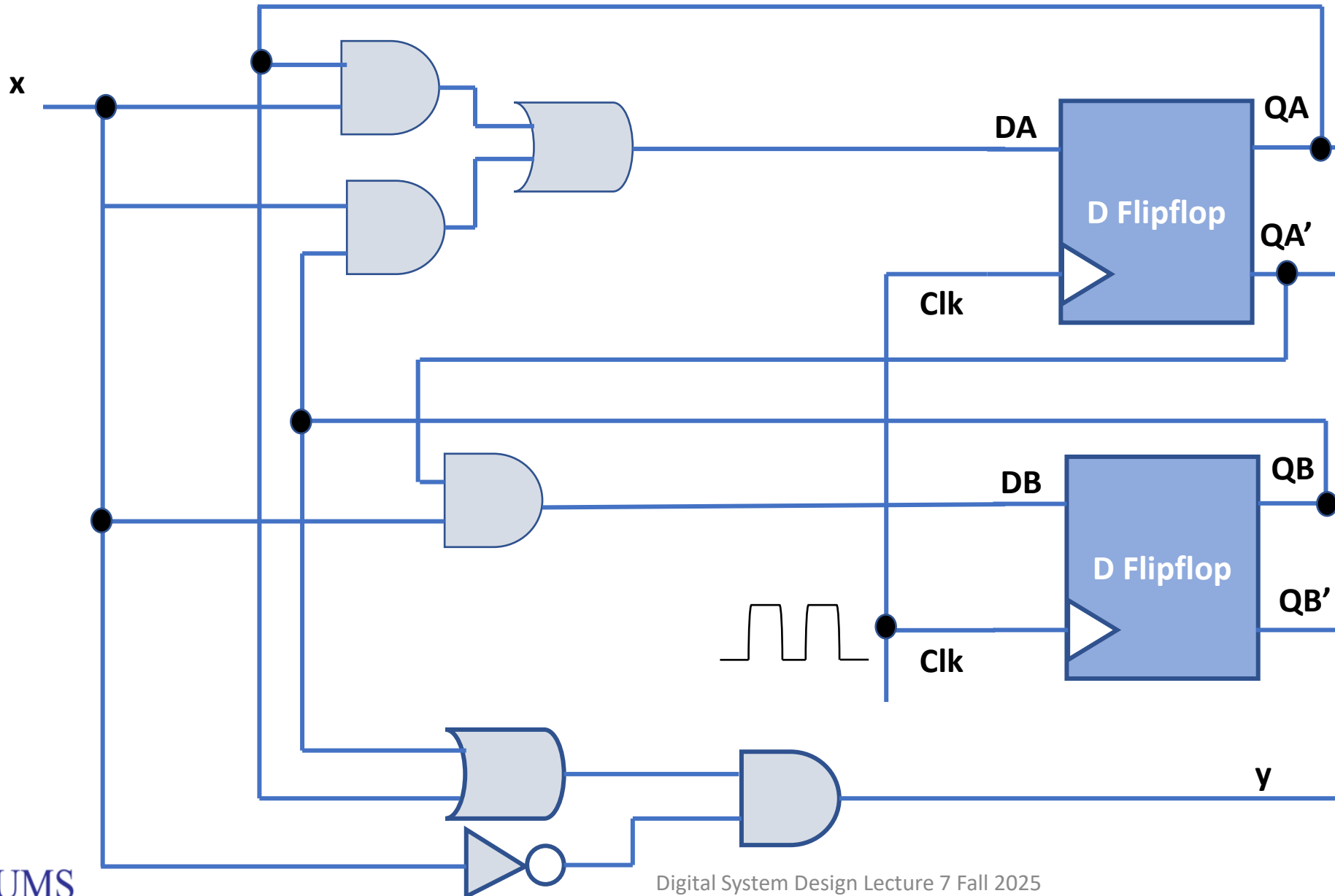
State
Transition
Table

Sequence No.	Q1	Q2	Q3	Q4
1	0	0	0	0
2	1	0	0	0
3	1	1	0	0
4	1	1	1	0
5	1	1	1	1
6	0	1	1	1
7	0	0	1	1
8	0	0	0	1
9	0	0	0	0

Analyze Sequential Circuits

- Concept of State Equations
- Concept of State Tables
- Logic Steering through Combinational Logic
- Arbitrary Counting and Sequencing

Example Sequential Circuit for Analysis



Determine State Equations

$$QA(t+1) = QA(t)x(t) + QB(t) x(t)$$

$$QB(t+1) = QA'(t) x(t)$$

$$y(t) = [QA(t) + QB(t)]x'(t)$$



Can be written in a simplified way:

$$QA(t+1) = QA.(x) + QB.(x)$$

$$QB(t+1) = QA'.(x)$$

$$y = (QA + QB).(x')$$

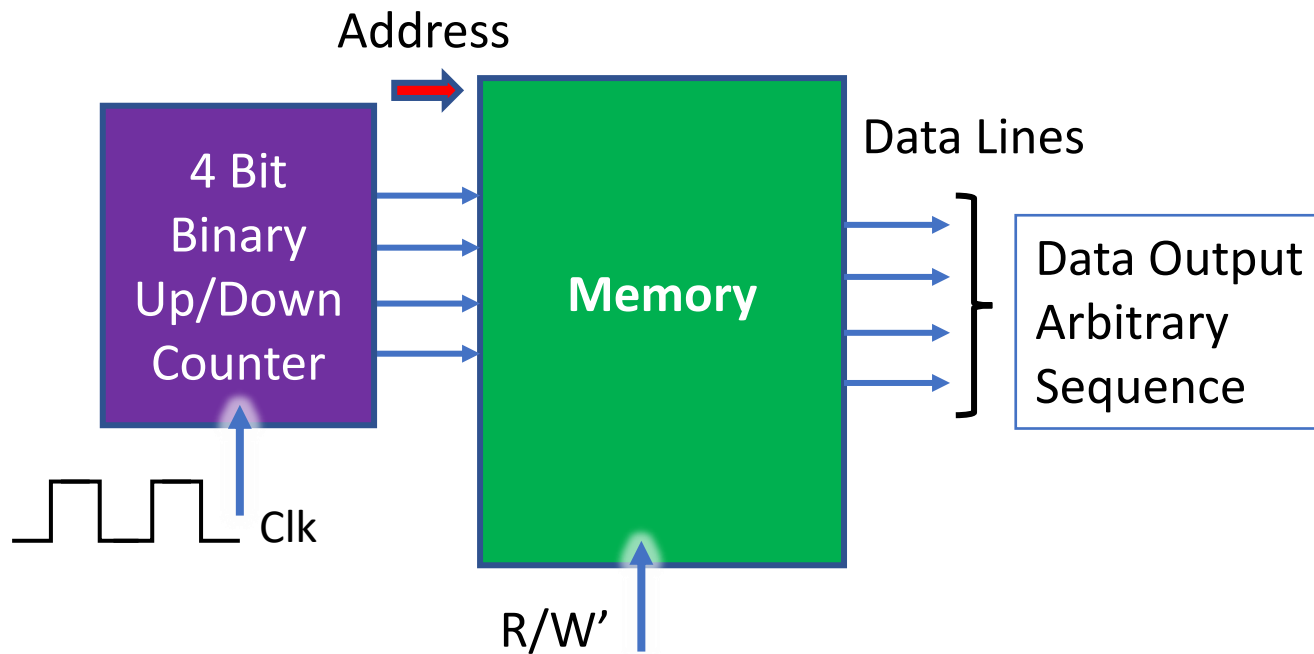
Determine State Table from State Equations

Present State	Present State	Input	Next State	Next State	Output
QA(t)	QB(t)	x	QA(t+1)	QB(t+1)	y
0	0	0	0	0	0
0	0	1	0	1	0
0	1	0	0	0	1
0	1	1	1	1	0
1	0	0	0	0	1
1	0	1	1	0	0
1	1	0	0	0	1
1	1	1	1	0	0

Compact State Table

Present State		Next State				Output	
		When $x = 0$		When $x = 1$		$x = 0$	$x = 1$
$A(t)$	$B(t)$	$A(t+1)$	$B(t+1)$	$A(t+1)$	$B(t+1)$	y	y
0	0	0	0	0	1	0	0
0	1	0	0	1	1	1	0
1	0	0	0	1	0	1	0
1	1	0	0	1	0	1	0

Using Memory to design an arbitrary sequencer



**Desired Sequence is
Stored in Memory Locations**

Design of Synchronous Counter using DFF

- Express each number of sequence in binary code
- Use appropriate number of DFFs to represent entire sequence
- Make a State Table representing Present State and Next State
- Determine Excitation Logic Expression for Next States using K-Maps
- Complete the DFF Based Circuit using Excitation Expressions

Example Design of a Synchronous Counter (Sequencer)

Make a Synchronous Counter for sequence {0 → 3 → 6 → 9 → 12 → 0}

Step 1: Describe Behavior Through Truth Table

Desired Sequence In Binary form:

Clock No.	Sequence	Binary			
		Q3	Q2	Q1	Q0
1	0	0	0	0	0
2	3	0	0	1	1
3	6	0	1	1	0
4	9	1	0	0	1
5	12	1	1	0	0
6	0	0	0	0	0



Present State – Next State Table

Clock No.	Sequence	Present State				Next State			
		Q3(t)	Q2(t)	Q1(t)	Q0(t)	Q3(t+1)	Q2(t+1)	Q1(t+1)	Q0(t+1)
1	0	0	0	0	0	0	0	1	1
2	3	0	0	1	1	0	1	1	0
3	6	0	1	1	0	1	0	0	1
4	9	1	0	0	1	1	1	0	0
5	12	1	1	0	0	0	0	0	0
6	0	0	0	0	0	0	0	1	1

DFF make it convenient as Present State to Next State is only separated by a Clock Pulse

Make K-Maps to determine Next State using Next State Outputs as K-Map Entries

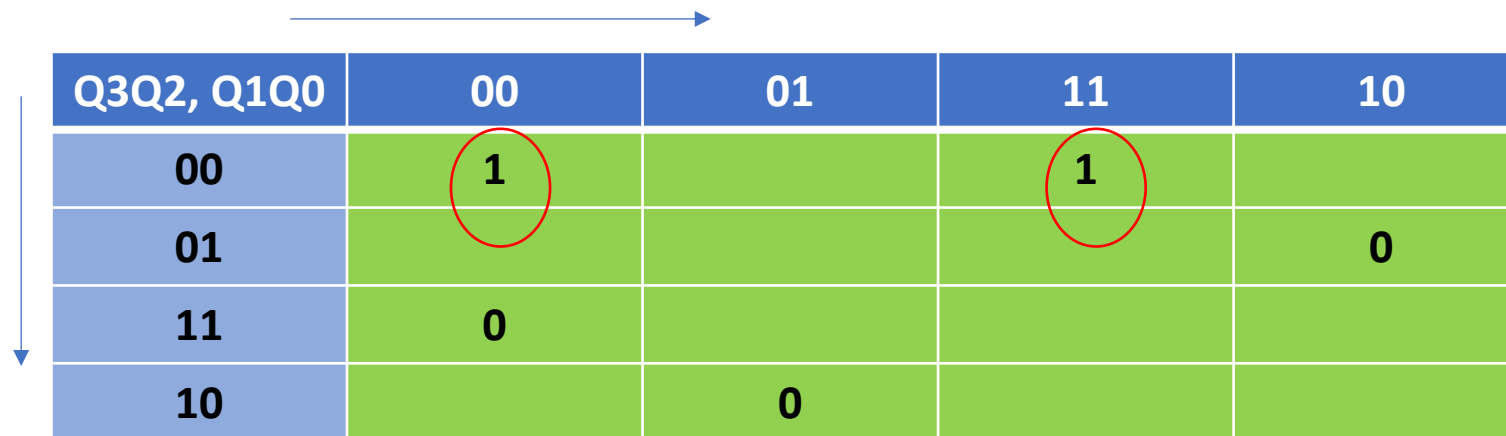
K-Map for D0 (Input that will give correct next state)

Q3Q2, Q1Q0	00	01	11	10
00	1		0	
01				1
11	0			
10		0		

State Equation:

$$D0 = Q3'Q2'Q1'Q0' + Q3'Q2Q1Q0'$$

K-Map for D1



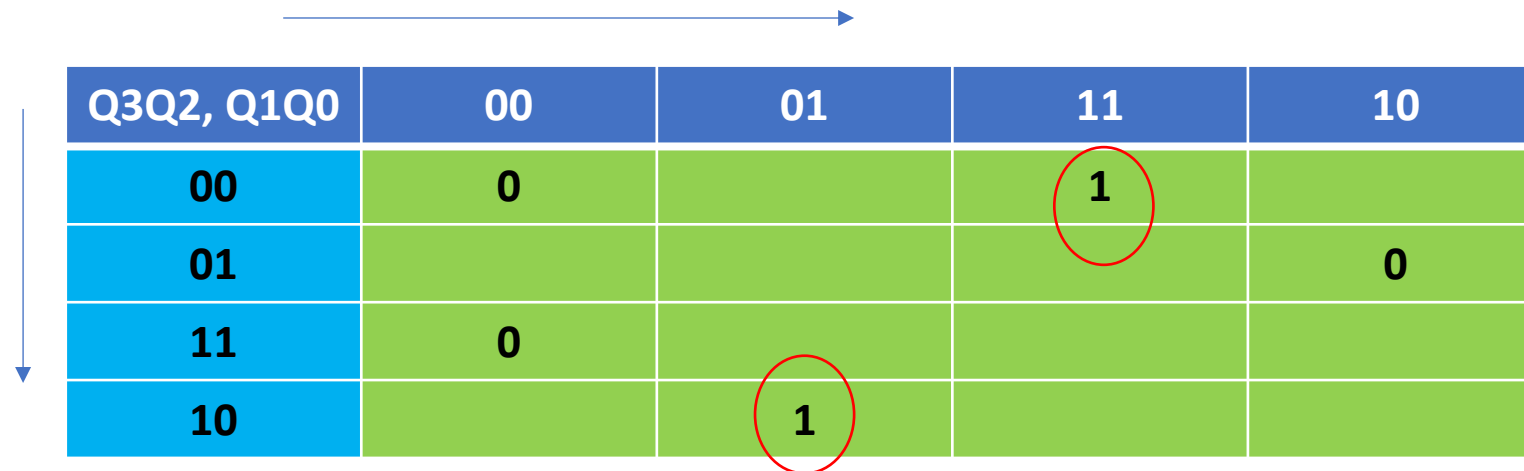
A Karnaugh Map for the output D1. The map is a 4x4 grid. The columns are labeled with Q3Q2, Q1Q0 values: 00, 01, 11, and 10. The rows are labeled with Q3Q2, Q1Q0 values: 00, 01, 11, and 10. The cells contain the values of D1 for each combination of inputs. The cells (00, 00) and (11, 00) contain the value 1 and are circled in red. The cell (01, 01) contains the value 0. The cell (10, 01) contains the value 0. All other cells are empty.

Q3Q2, Q1Q0	00	01	11	10
00	1		1	
01				0
11	0			
10		0		

State Equation:

$$D1 = Q3'Q2'Q1'Q0' + Q3'Q2'Q1Q0$$

K-Map for D2



Q3Q2, Q1Q0	00	01	11	10
00	0		1	
01				0
11	0			
10		1		

State Equation:

$$D2 = Q3Q2'Q1'Q0 + Q3'Q2'Q1Q0$$

K-Map for D3

Q3Q2, Q1Q0	00	01	11	10
00	0		0	
01				1
11	0			
10		1		

State Equation:

$$D3 = Q3'Q2Q1Q0' + Q3Q2'Q1'Q0$$

Final Circuit Design of Sequencer

