Synchronous Sequential Logic
Part I

BME208 – Logic Circuits

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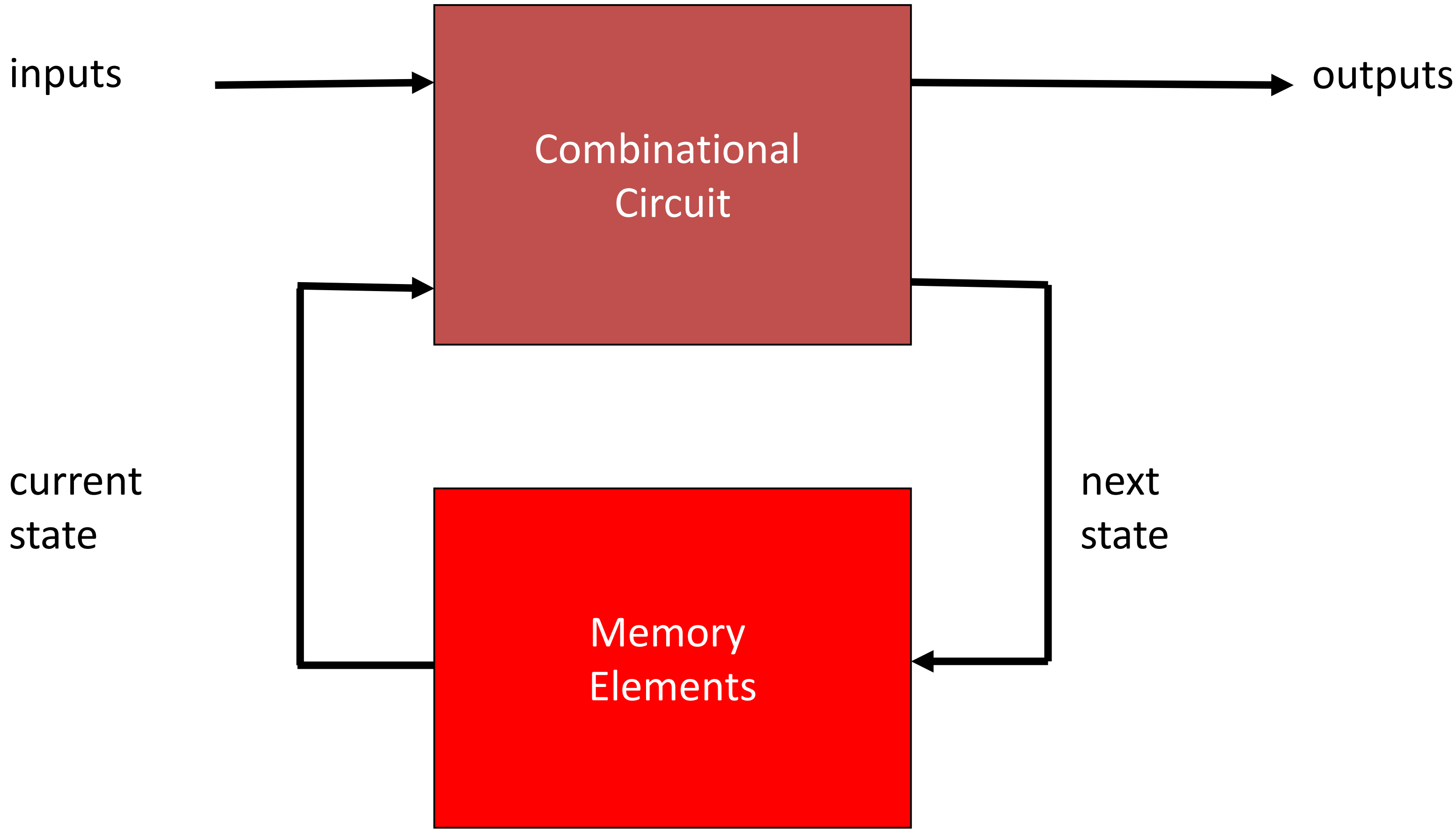
Sequential Logic

- Digital circuits we have learned, so far, have been combinational
  - no memory,
  - outputs are entirely defined by the "current" inputs
- However, many digital systems encountered everyday life are sequential (i.e. they have memory)
  - the memory elements remember past inputs
  - outputs of sequential circuits are not only dependent on the current input but also the state of the memory elements.

Sequential Circuits Model



current state is a function of past inputs and initial state

Classification 1/2

- Two types of sequential circuits

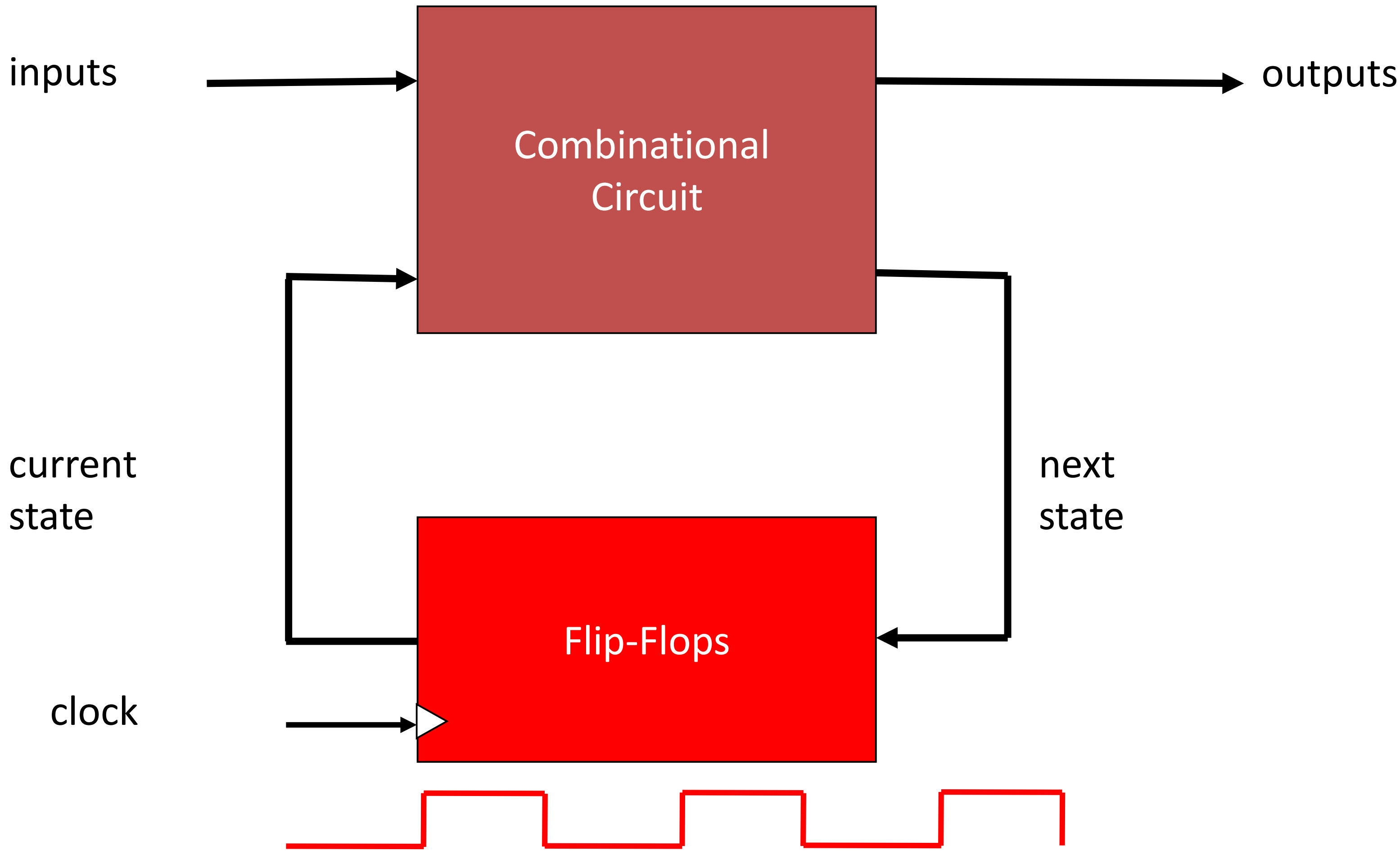
1. Synchronous
   - Signals affect the memory elements at discrete instants of time.
   - Discrete instants of time requires synchronization.
   - Synchronization is usually achieved through the use of a common clock.
   - A "clock generator" is a device that generates a periodic train of pulses.

Classification 2/2

1. Synchronous
   - The state of the memory elements are updated with the arrival of each pulse
   - This type of logical circuit is also known as <u>clocked sequential</u> circuits.
2. Asynchronous
   - No clock
   - behavior of an asynchronous sequential circuits depends upon the input signals at any instant of time and the order in which the inputs change.
   - Memory elements in asynchronous circuits are regarded as time-delay elements

Clocked Sequential Circuits

- Memory elements are flip-flops which are logic devices, each of which is capable of storing one bit of information.



Clocked Sequential Circuits

- The outputs of a clocked sequential circuit can come from the combinational circuit, from the outputs of the flip-flops or both.
- The state of the flip-flops can change only during a clock pulse transition
  - i.e. low-to-high and high-to-low
  - clock edge
- When the clock maintains its value, the flip-flop output does not change
- The transition from one state to the next occurs at the clock edge.

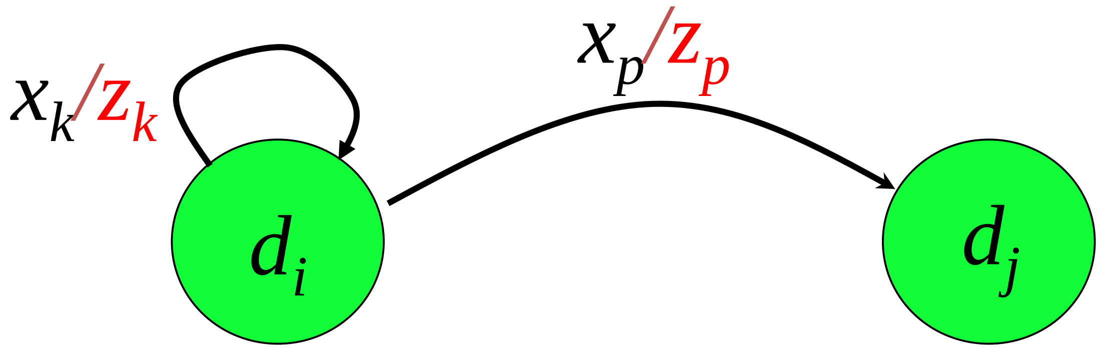
Machine

- Machine(
  Inputs {X},
  States {D},
  Outputs {Z},
  Output Function {F : $X \times D \rightarrow Z$},
  Next State Function {G : $X \times D \rightarrow D$})

Representation with State Diagram

	x_1	x_2	…	x_i	…	x_l
d_1						
d_2						
⋮						
d_i				d_j, z		
⋮						
d_{r-1}						
d_r						

Assign a Node to Each State



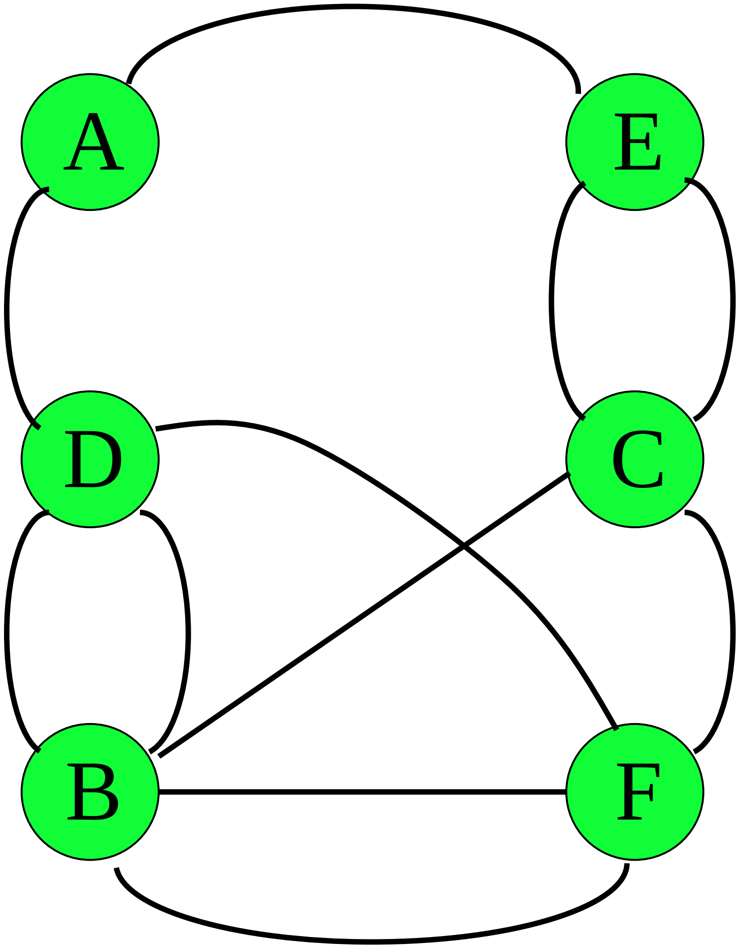
- Machine is at state d_i, input x_k comes, the next state will be di and the output is z_k
- Machine is at state di, input x_p comes, the next state will be d_j and the output is z_p

Notation

- Let I_k be an input sequence with length equals to k, i.e. $I_k = x_1x_2...x_k$
- $f(I_k,d_i) = z_1z_2...z_k$ is an output sequence
- $g(I_k,d_i) = d_{i1}d_{i2}...d_{ik}$ is a state sequence
- $d_i \xrightarrow{I_k} d_{ik}$ Follower of d_i after the input sequence I_k

Example - Fill out the rest

	0	1
A	E, 0	D, 1
B	F, 0	D, 0
C	E, 0	B, 1
D	F, 0	B, 0
E	C, 0	F, 1
F	B, 0	C, 0



Example

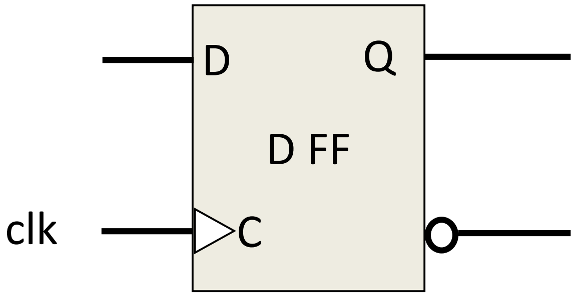
	0	1
A	E, 0	D, 1
B	F, 0	D, 0
C	E, 0	B, 1
D	F, 0	B, 0
E	C, 0	F, 1
F	B, 0	C, 0

- Let I_5=10110, find $g(I_5,C)$ and $f(I_5,C)$

I_5	1	0	1	1	0	
$g(I_5,C)$	C	B	F	C	B	F
$f(I_5,C)$	1	0	0	1	0	

- I_5 follower of C is F

D Flip-Flop



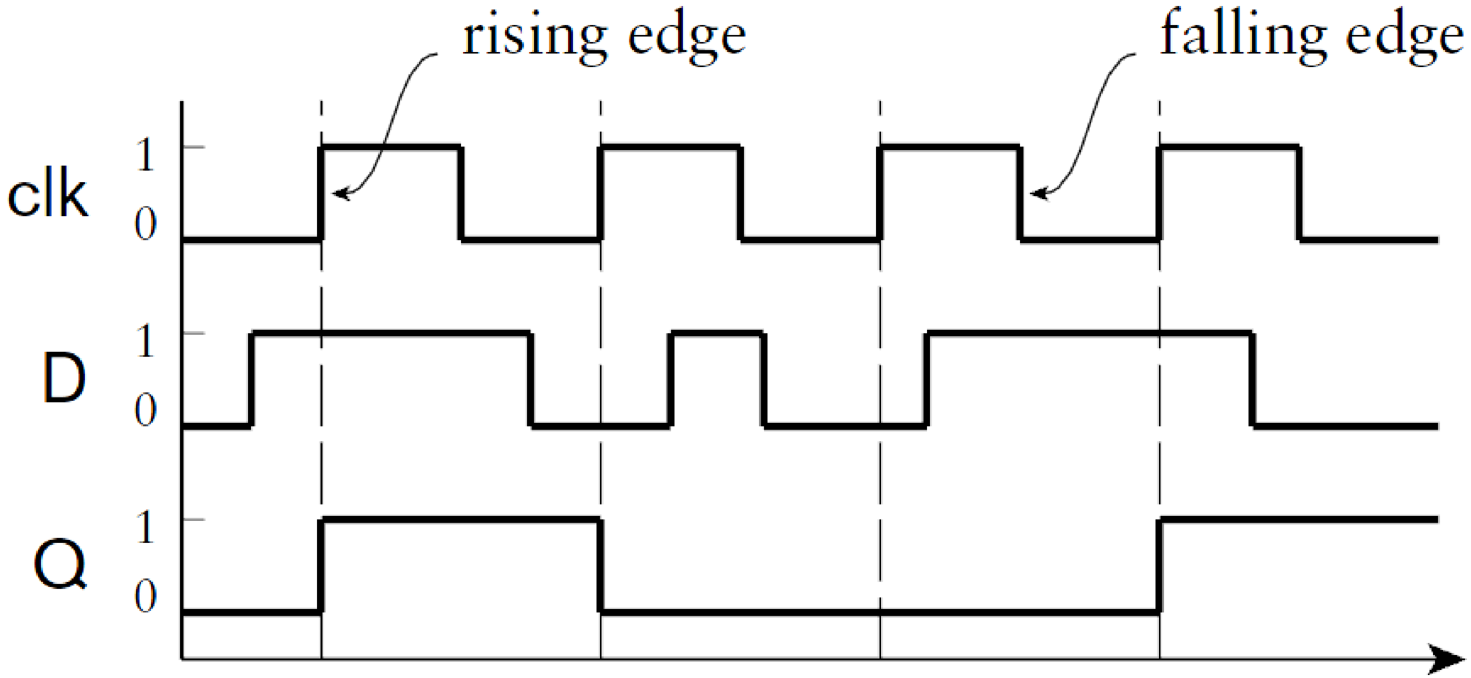
Positive edge-triggered
D Flip-Flop

- Characteristic equation
  - Q(t+1) = D

D	Q(t+1)
0	0
1	1

Characteristic Table

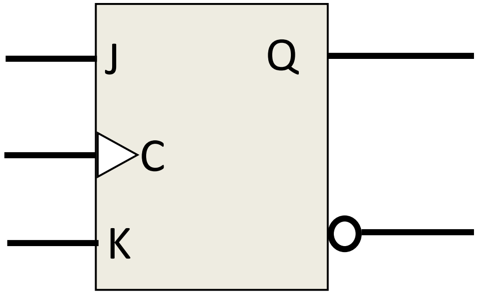
Timing Diagram of D Flip-Flop



Other Flip-Flops

- D flip-flop is the most common
  - since it requires the fewest number of gates to construct.
- Two other widely used flip-flops
  - JK flip-flops
  - T flip-flops
- JK flip-flops
  - Three FF operations
    1. Set
    2. Reset
    3. Complement

JK Flip-Flops



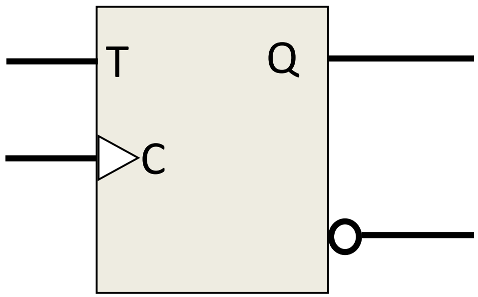
J	K	Q(t+1)	next state
0	0	Q(t)	no change
0	1	0	Reset
1	0	1	Set
1	1	Q'(t)	Complement

Characteristic Table

- Characteristic equation
  - Q(t+1) = JQ'(t) + K'Q(t)

T (Toggle) Flip-Flop

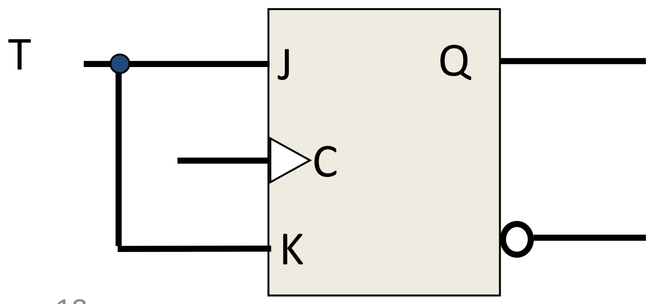
- Complementing flip-flop

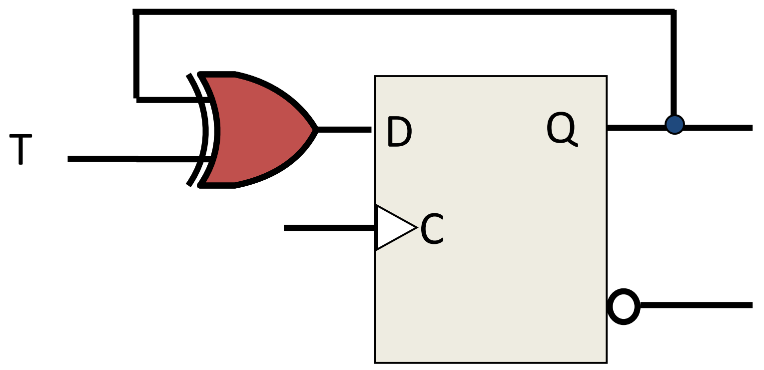


T	Q(t+1)	next state
0	Q(t)	no change
1	Q′(t)	Complement

Characteristic Table

- Characteristic equation
  - Q(t+1) =





Characteristic Equations

- The logical properties of a flip-flop can be expressed algebraically using characteristic equations
- D flip-flop
  - $Q(t+1) = D$
- JK flip-flop
  - $Q(t+1) = JQ'(t) + K'Q(t)$
- T flip-flop
  - $Q(t+1) = Q(t) \oplus T$

What if we have Q(t+1) and Q(t), and looking for J and K values?

Q(t)Q(t+1)

00	01	11	10
0,X	1,X	X,0	X,1

J,K

$$J = \begin{cases} Q(t+1) & Q(t)=0 \\ X & Q(t)=1 \end{cases}$$

$$K = \begin{cases} Q(t+1)' & Q(t)=1 \\ X & Q(t)=0 \end{cases}$$

What if we have Q(t+1) and Q(t), and looking for D value?

Q(t)Q(t+1)

00	01	11	10
0	1	1	0

D= Q(t+1)

What if we have Q(t+1) and Q(t), and looking for T value?

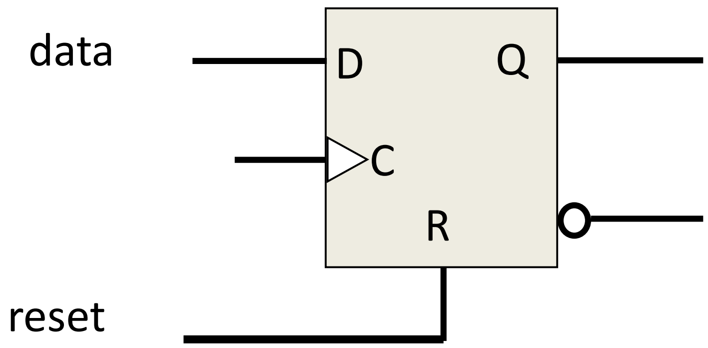
Q(t)Q(t+1) 00	01	11	10
0	1	0	1

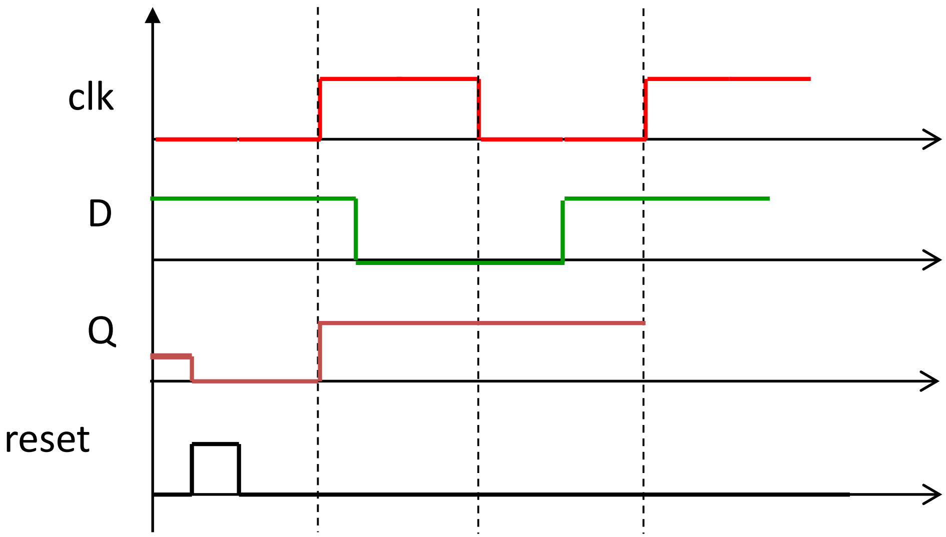
$T = Q(t+1) \oplus Q(t)$

Asynchronous Inputs of Flip-Flops

- They are used to force the flip-flop to a particular state independent of clock
  - "Preset" (direct set) set FF state to 1
  - "Clear" (direct reset) set FF state to 0
- They are especially useful at startup.
  - In digital circuits when the power is turned on, the state of flip-flops are unknown.
  - Asynchronous inputs are used to bring all flip-flops to a known "starting" state prior to clock operation.

Asynchronous Inputs



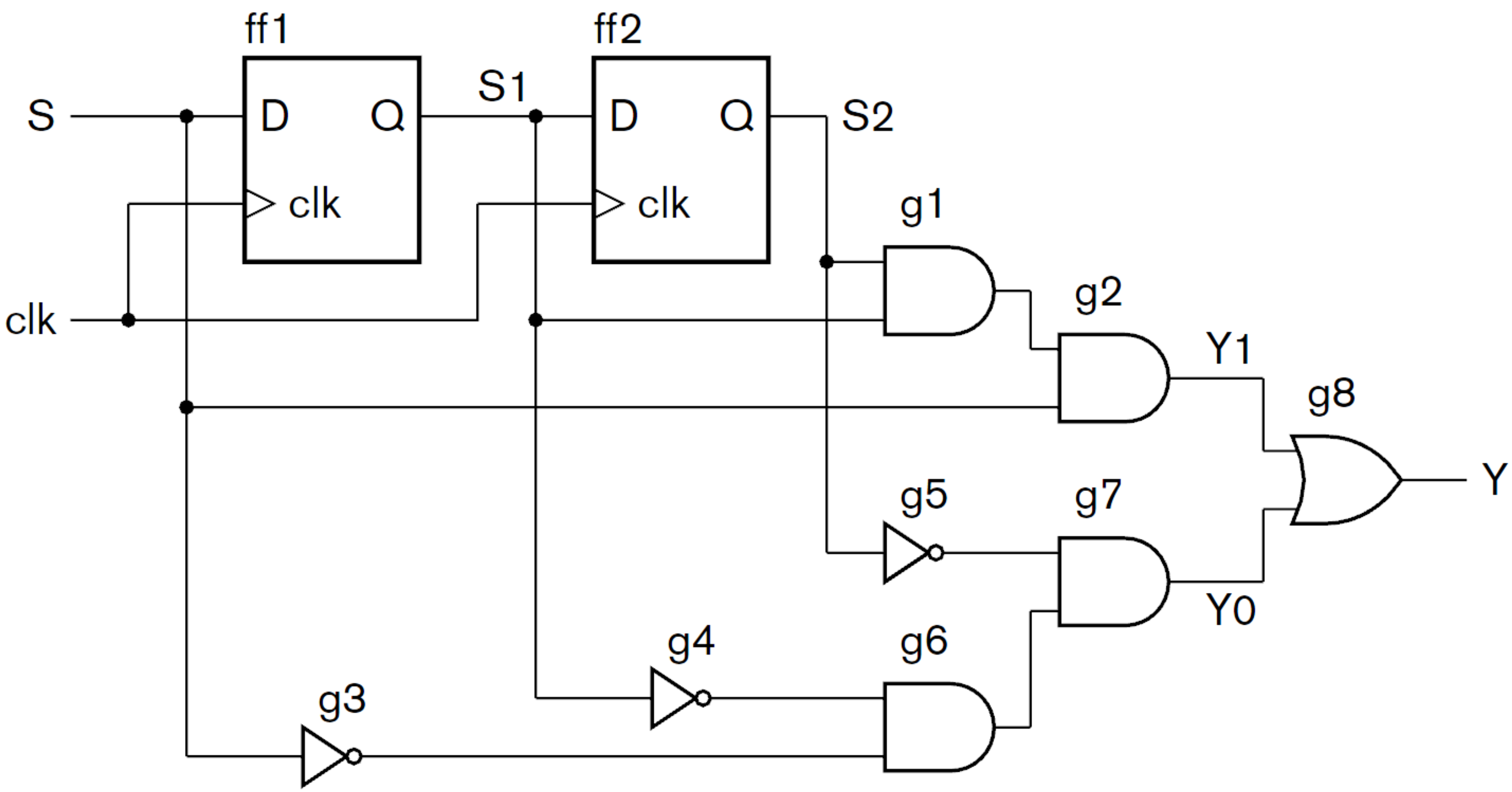


reset	C	D	Q	Q'	
1	X	X	0	1	Starting State
0	↑	0	0	1	
0	↑	1	1	0	

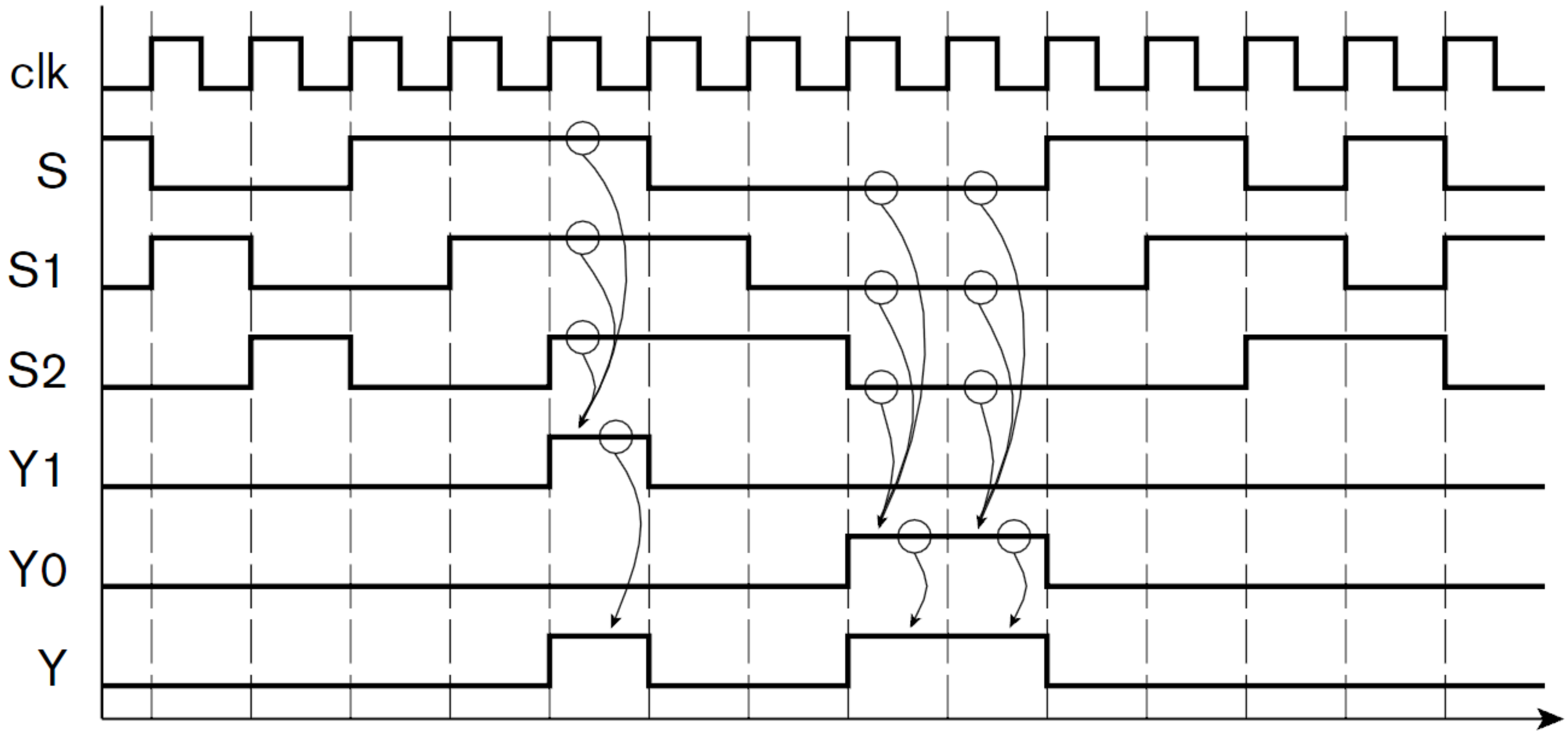
Analysis of Clocked Sequential Circuits

- Goal:
  - to determine the behavior of clocked sequential circuits
  - "Behavior" is determined from
    - Inputs
    - Outputs
    - State of the flip-flops
  - We have to obtain
    - Boolean expressions for output and next state
      - output & state equations
    - (state) table
    - (state) diagram

Analyze the circuit

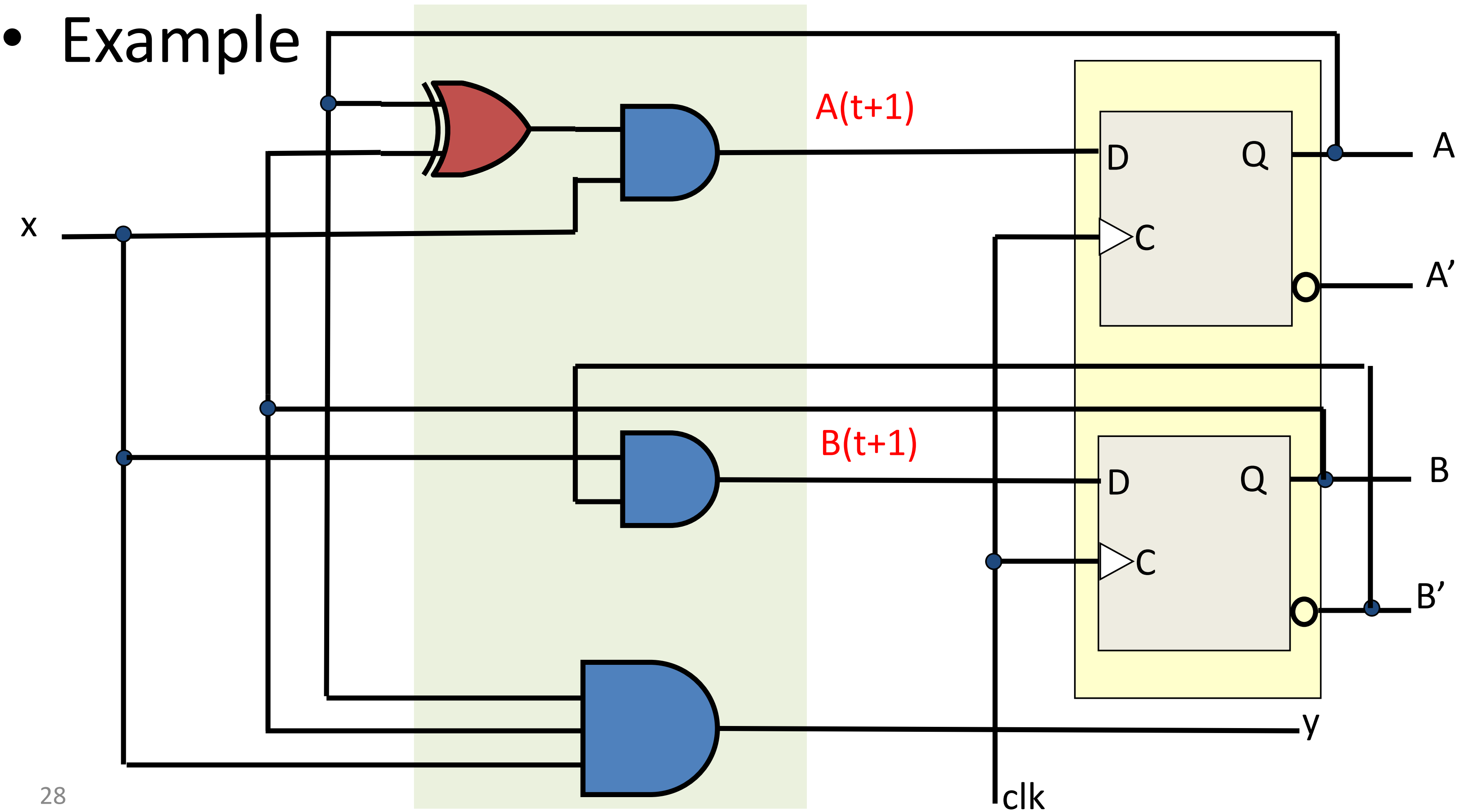


Run it and check the timing diagram



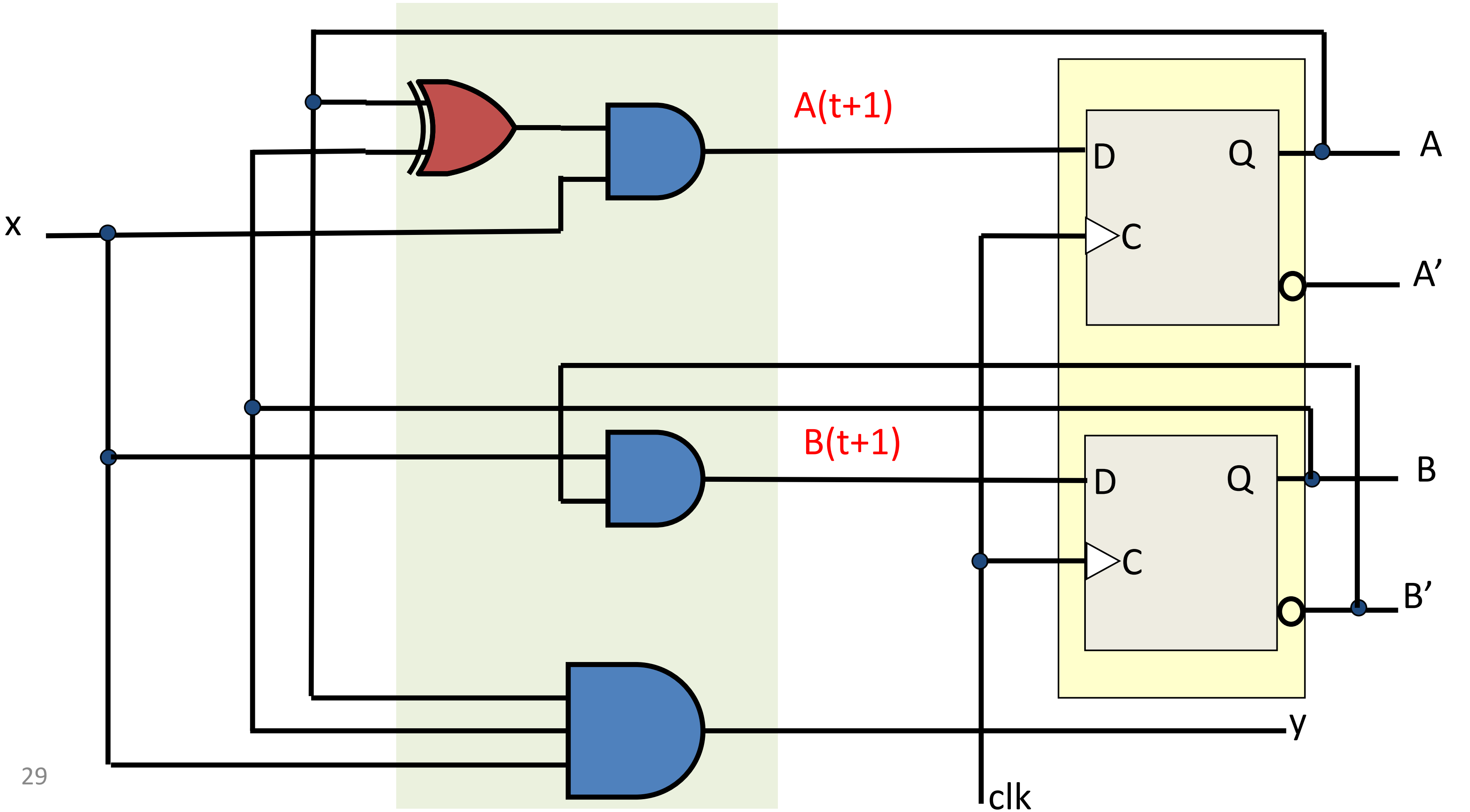
State Equations

- Also known as “transition equations”
  - specify the next state as a function of the present state and inputs
- Example



Output and State Equations

- A(t+1) =
- B(t+1) =
- y =



Flip Flop Input Equations

- Flip-Flop input (excitation) equations
- Same as the state equations in D flip-flops

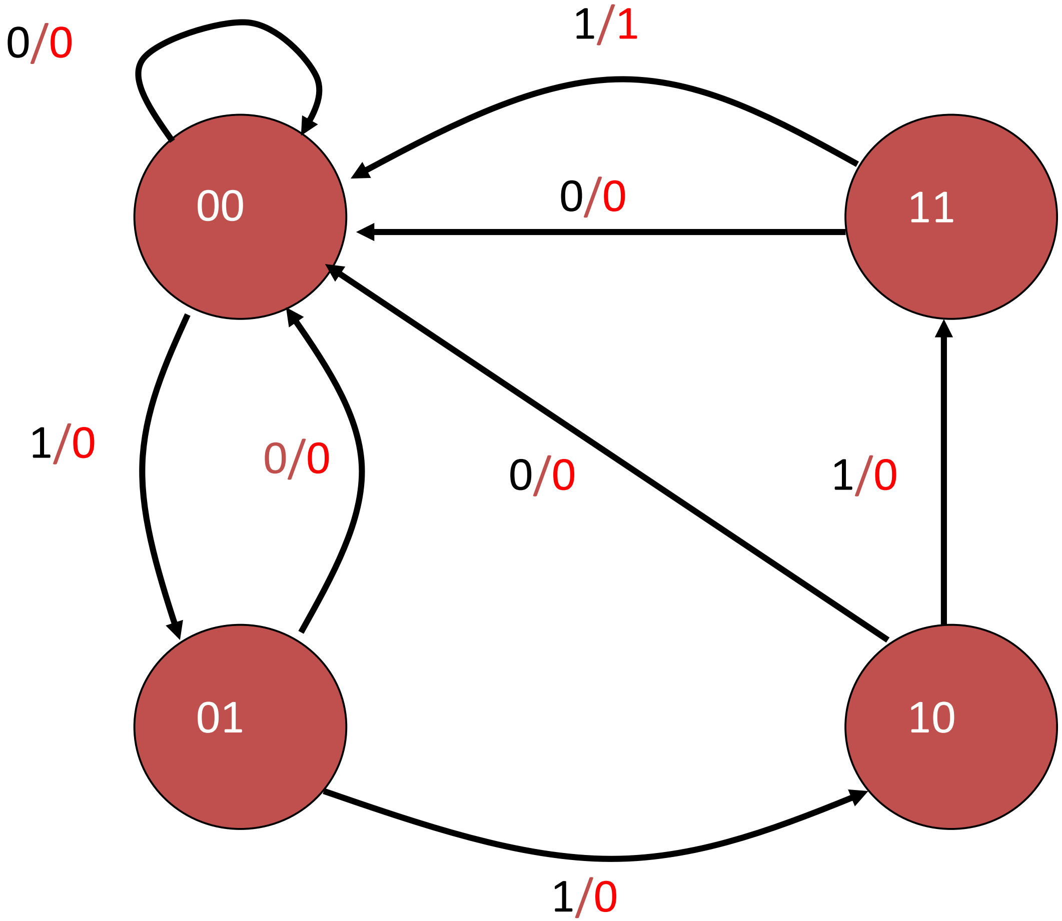
Example: State (Transition) Table

A(t+1) = B(t+1) = y =

Present state		input	Next state		output
A	B	x	A	B	y
0	0	0	0	0	0
0	0	1	0	1	0
0	1	0	0	0	0
0	1	1	1	0	0
1	0	0	0	0	0
1	0	1	1	1	0
1	1	0	0	0	0
1	1	1	0	0	1

A sequential circuit with m FFs and n inputs needs 2^{m+n} rows in the transition table

Example: State Diagram



Present state		input	Next state		output
A	B	x	A	B	y
0	0	0	0	0	0
0	0	1	0	1	0
0	1	0	0	0	0
0	1	1	1	0	0
1	0	0	0	0	0
1	0	1	1	1	0
1	1	0	0	0	0
1	1	1	0	0	1

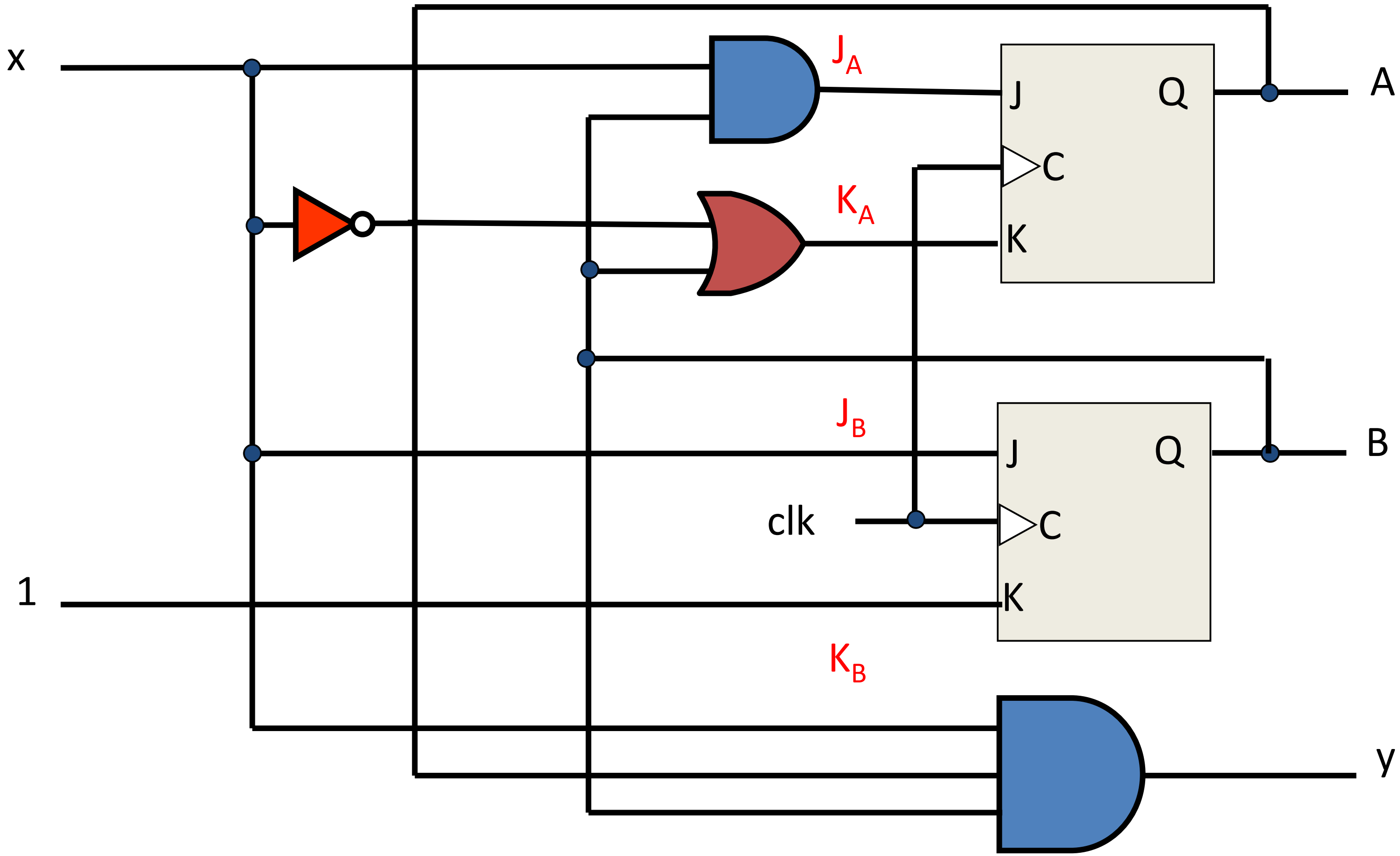
What is this circuit doing?

State diagram provides the same information as state table

Analysis with JK Flip-Flops

- For a D flip-flop, the state equation is the same as the flip-flop input equation
  - $Q(t+1) = D$
- For JK flip-flops, situation is different
  - Goal is to find state equations
  - Method
    1. determine flip-flop input equations
    2. List the binary values of each input equation
    3. Use the corresponding flip-flop characteristic table to determine the next state values in the state table

Example: Analysis with JK FFs



- Flip-flop input equations
  - $J_A =$ and $K_A =$
  - $J_B =$ and $K_B =$

Example: Analysis with JK FFs

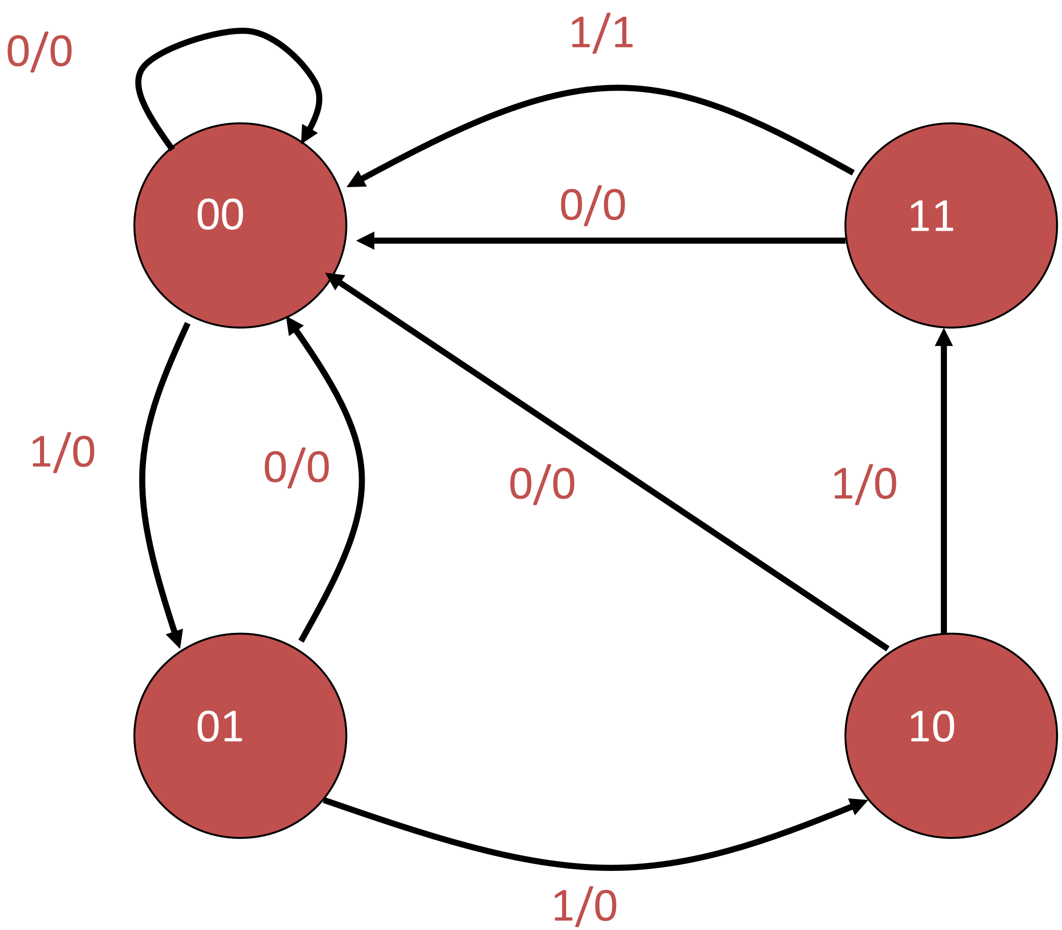
- J_A = Bx and K_A = x'+B
- J_B = x and K_B = 1

present State		input	next state		FF inputs			
A	B	x	A	B	J_A	K_A	J_B	K_B
0	0	0	0	0	0	1	0	1
0	0	1	0	1	0	0	1	1
0	1	0	0	0	0	1	0	1
0	1	1	1	0	1	1	1	1
1	0	0	0	0	0	1	0	1
1	0	1	1	1	0	0	1	1
1	1	0	0	0	0	1	0	1
1	1	1	0	0	1	1	1	1

Example: Analysis with JK FFs

- Characteristic equations
  - $A(t+1) = J_A A' + K'_A A$
  - $B(t+1) = J_B B' + K'_B B$
- Input equations
  - $J_A = Bx$ and $K_A = x'+B$
  - $J_B = x$ and $K_B = 1$
- State equations
  - $A(t+1) =$
    $=$
  - $B(t+1) =$

State Diagram



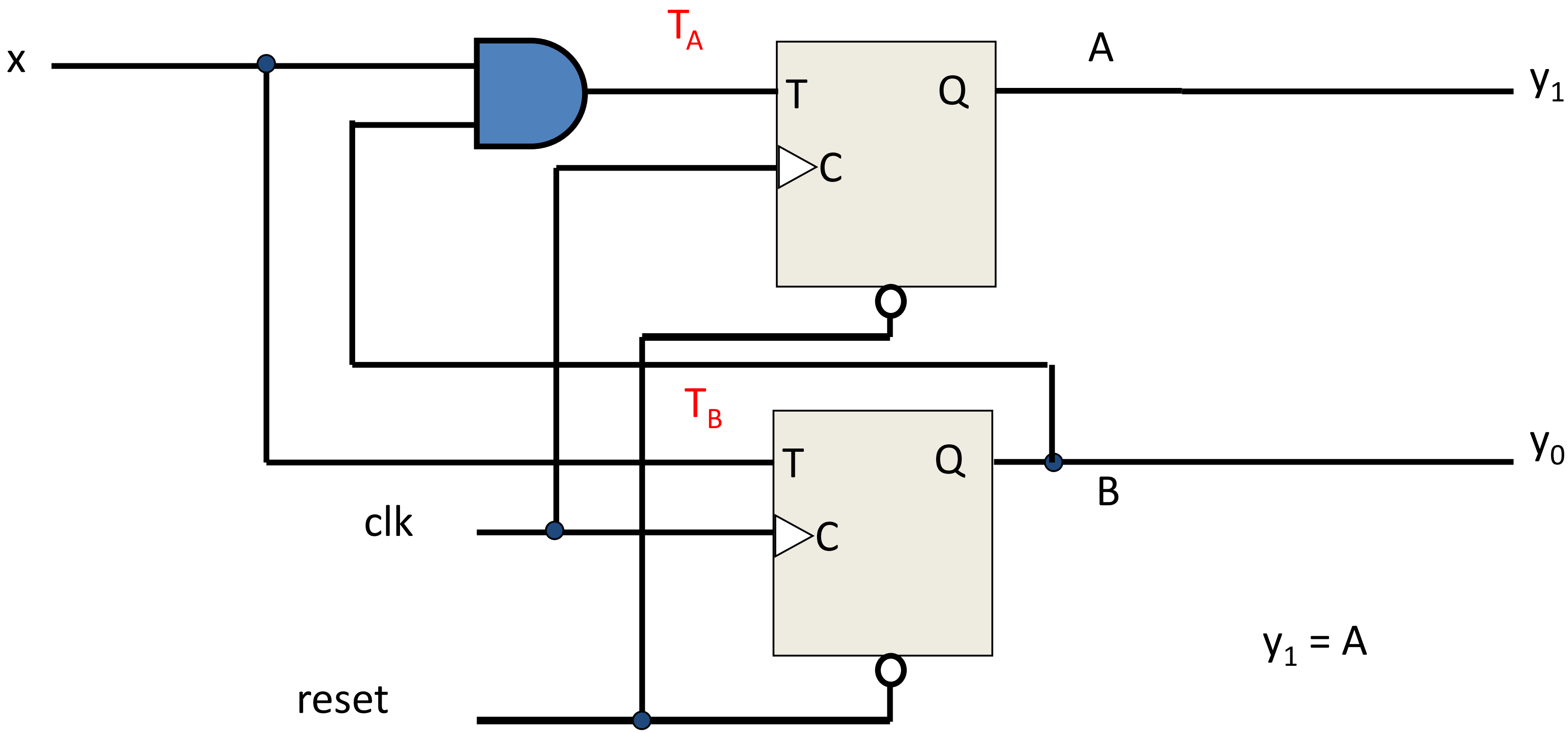
Present state		input	Next state		output
A	B	x	A	B	y
0	0	0	0	0	0
0	0	1	0	1	0
0	1	0	0	0	0
0	1	1	1	0	0
1	0	0	0	0	0
1	0	1	1	1	0
1	1	0	0	0	0
1	1	1	0	0	1

What is the circuit doing?

Analysis with T Flip-Flops

- Method is the same
- Example

$T_A =$
$T_B =$



$y_1 = A$

$y_0 = B$

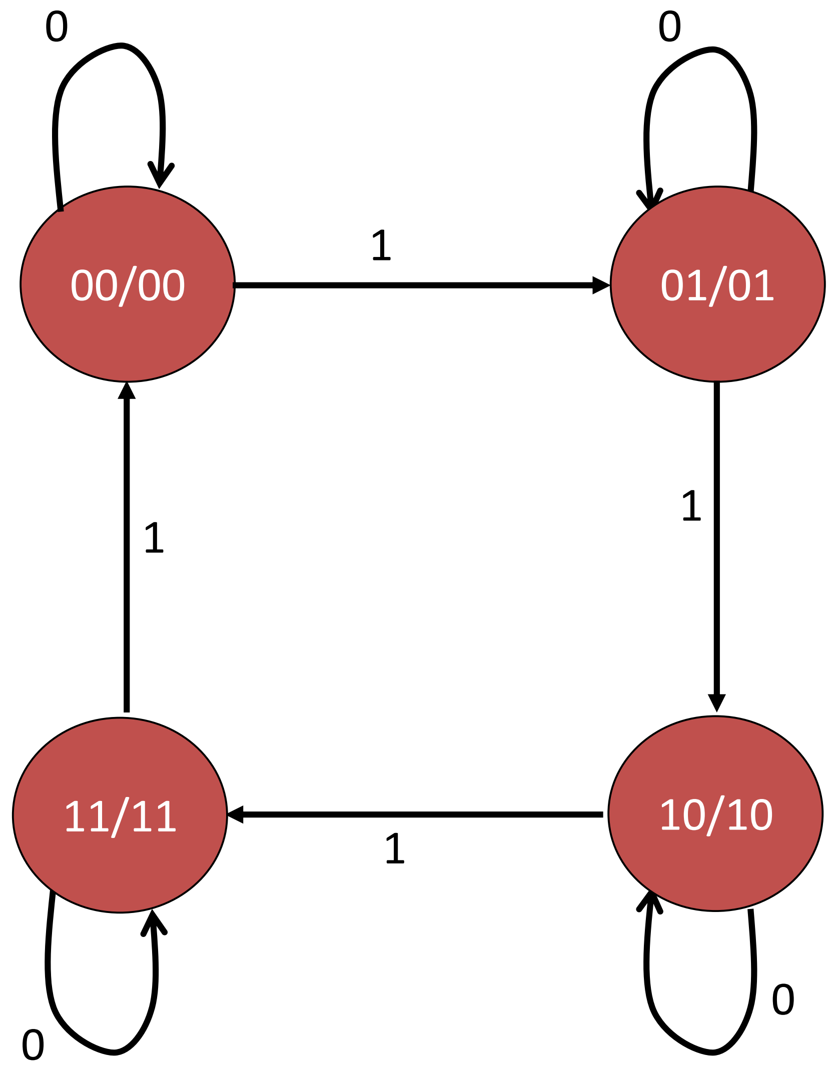
Example: Analysis with T Flip-Flops

- Characteristic equation
  - $A(t+1) = T_A \oplus A$
  - $B(t+1) = T_B \oplus B$
- Input equations
  - $T_A = xB$
  - $T_B = x$
- Output equations
  - $y_1 = A$
  - $y_0 = B$
- State equations
  - $A(t+1) =$
  - $B(t+1) =$

State Table & Diagram

- $A(t+1) = xB \oplus A$
- $B(t+1) = x \oplus B$
- $y_1 = A$; $y_0 = B$

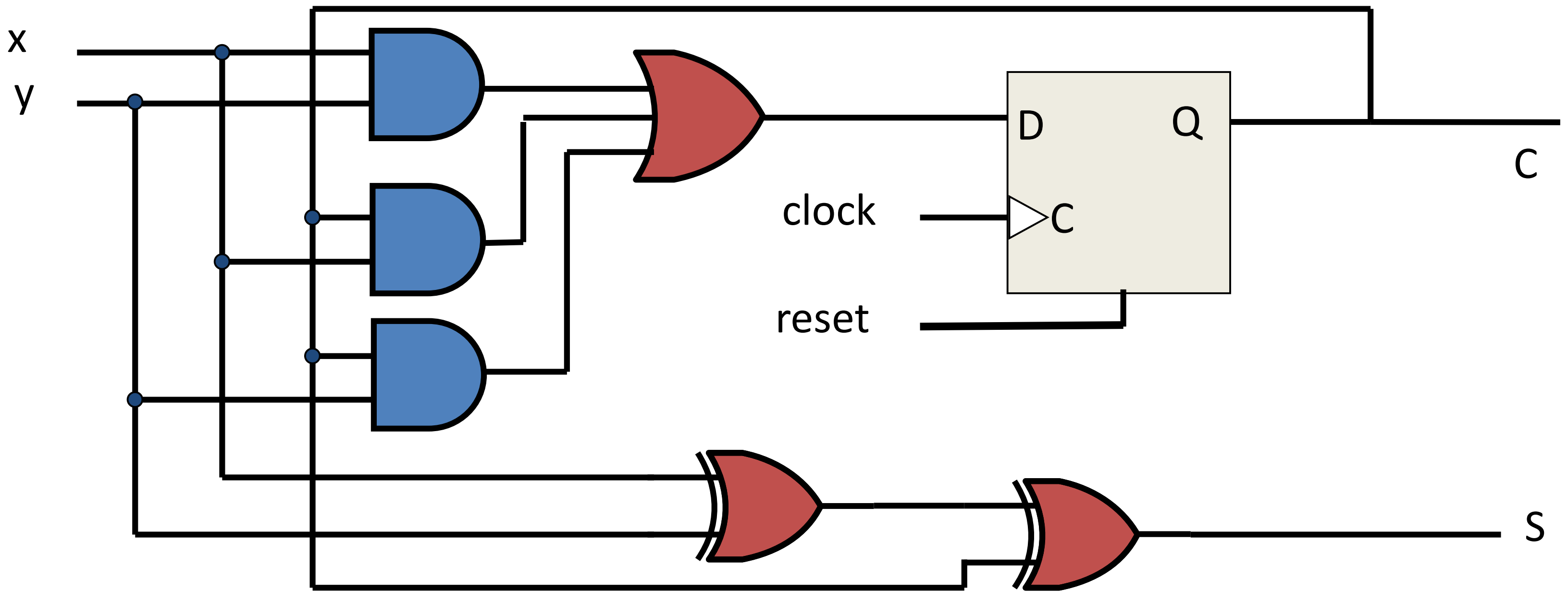
Present state A	Present state B	input x	Next state A	Next state B	output y_1	output y_0
0	0	0	0	0	0	0
0	0	1	0	1	0	0
0	1	0	0	1	0	1
0	1	1	1	0	0	1
1	0	0	1	0	1	0
1	0	1	1	1	1	0
1	1	0	1	1	1	1
1	1	1	0	0	1	1



Mealy and Moore Models

- There are two models for sequential circuits
  - Mealy
  - Moore
- They differ in the way the outputs are generated
  - Mealy:
    - output is a function of both present states and inputs
  - Moore
    - output is a function of present state only

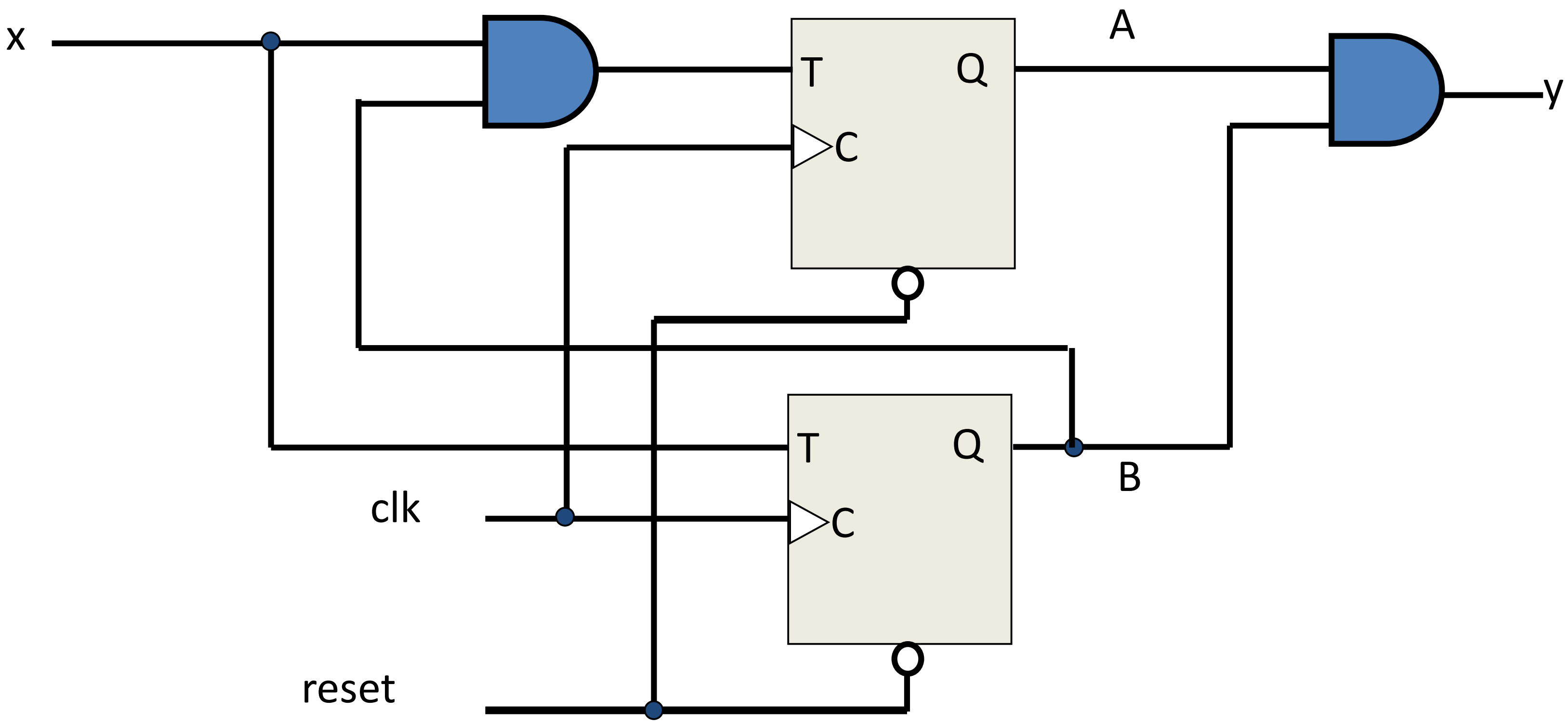
Example: Mealy and Moore Machines



Mealy machine

- External inputs, x and y, are asynchronous
- Thus, outputs may have momentary (incorrect) values
- Inputs must be synchronized with clocks
- Outputs must be sampled only during clock edges

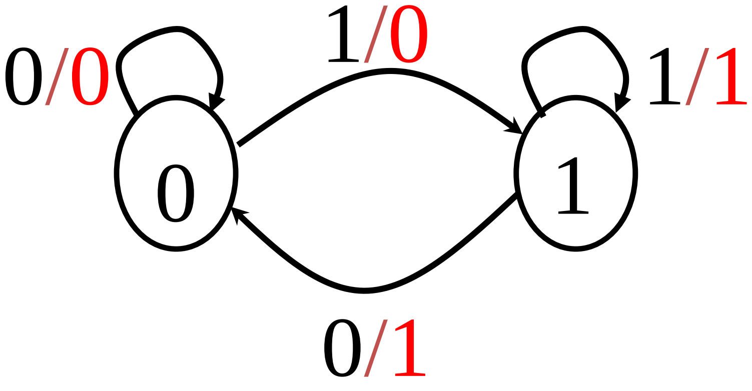
Example: Moore Machines



- Outputs are already synchronized with clock.
- They change synchronously with the clock edge.

Design Example - 1

- Implement the following state diagram with D FFs.



Design Example - 1

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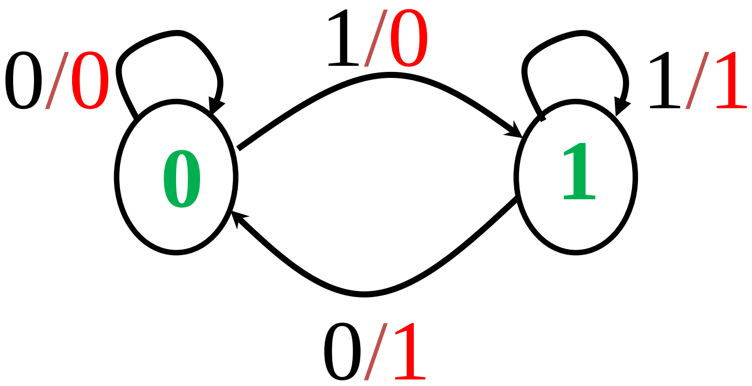
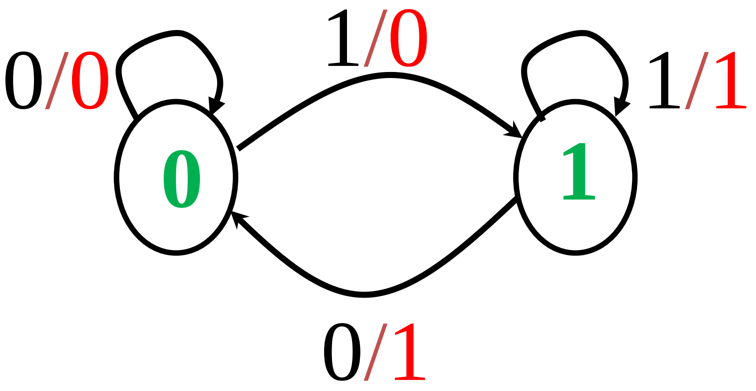


x	Q(t)	Q(t+1)	D	Z
0	**0**			
0	**1**			
1	**0**			
1	**1**			

Design Example - 1

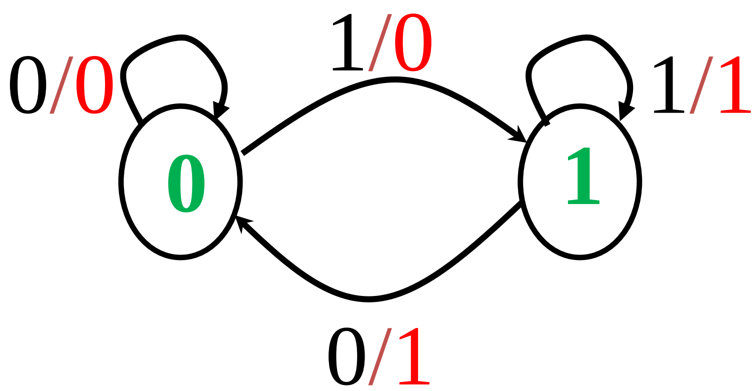
- Implement the following state diagram with D FFs.



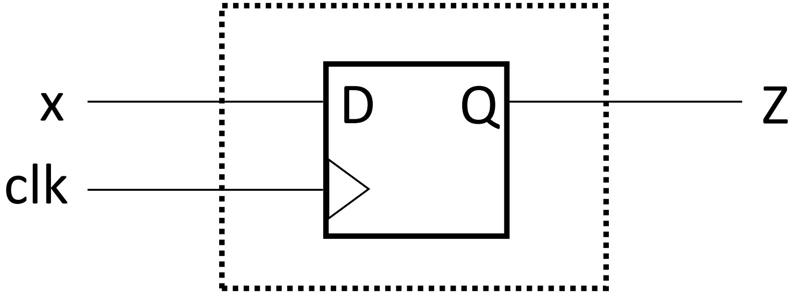
x	Q(t)	Q(t+1)	D	Z
0	0	0		0
0	1	0		1
1	0	1		0
1	1	1		1

Design Example - 1

- Implement the following state diagram with D FFs.



x	Q(t)	Q(t+1)	D	Z
0	0	0	0	0
0	1	0	0	1
1	0	1	1	0
1	1	1	1	1

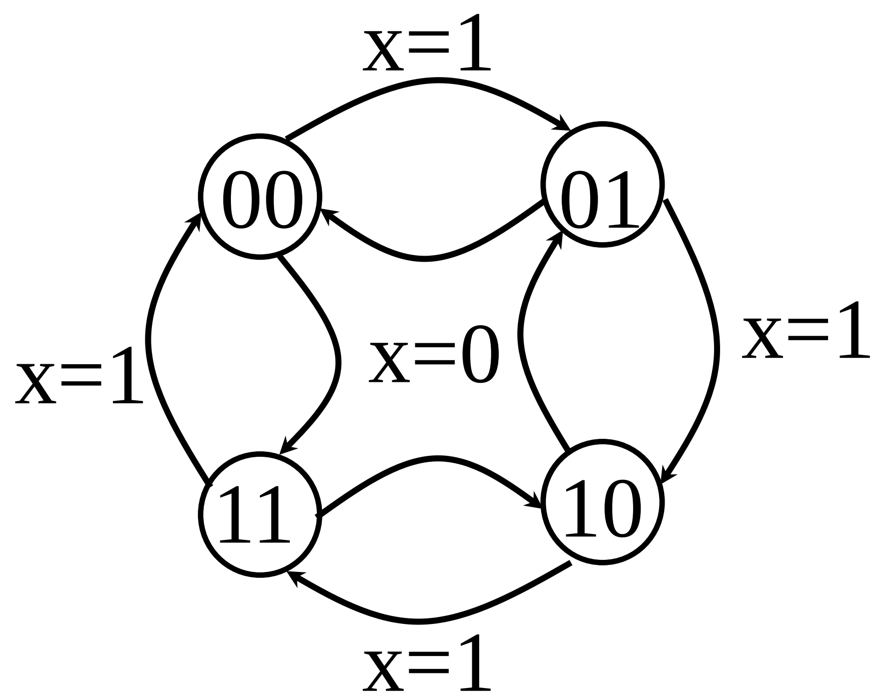


Design Example - 2

- Design a sequential circuit that counts up (00, 01, 10, 11,00,…) when x=1, and counts down (00,11,10,01,00,…) when x=0. Use JK FFs.

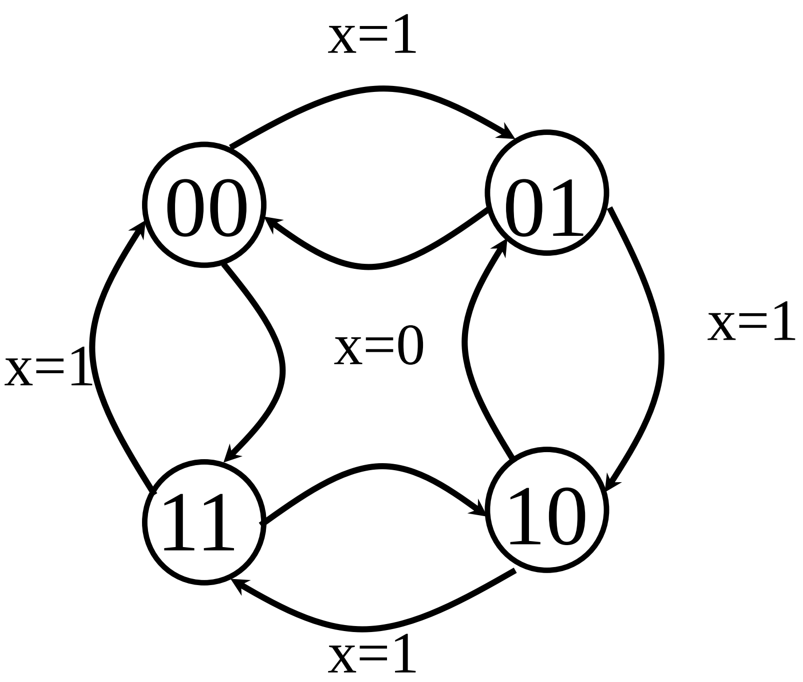
Design Example - 2

- Design a sequential circuit that counts up (00, 01, 10, 11,00,…) when x=1, and counts down (00,11,10,01,00 ,…) when x=0. Use JK FFs.



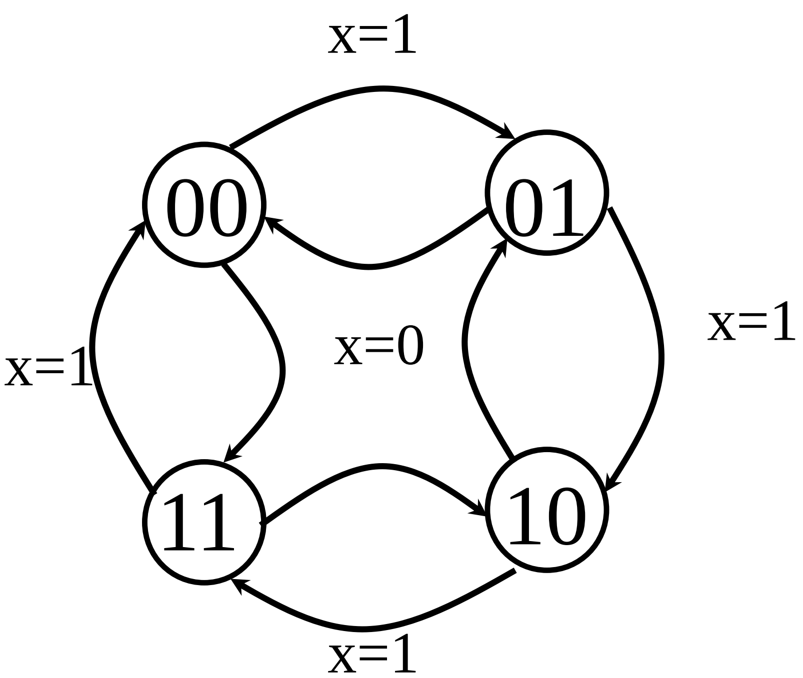
Design Example - 2

x	A	B	A(t+1)	B(t+1)	J_A	K_A	J_B	K_B
0	0	0	1	1				
0	0	1	0	0				
0	1	0	0	1				
0	1	1	1	0				
1	0	0	0	1				
1	0	1	1	0				
1	1	0	1	1				
1	1	1	0	0				



Design Example - 2

x	A	B	A(t+1)	B(t+1)	J_A	K_A	J_B	K_B
0	0	0	1	1	1			
0	0	1	0	0	0			
0	1	0	0	1	X			
0	1	1	1	0	X			
1	0	0	0	1	0			
1	0	1	1	0	1			
1	1	0	1	1	X			
1	1	1	0	0	X			

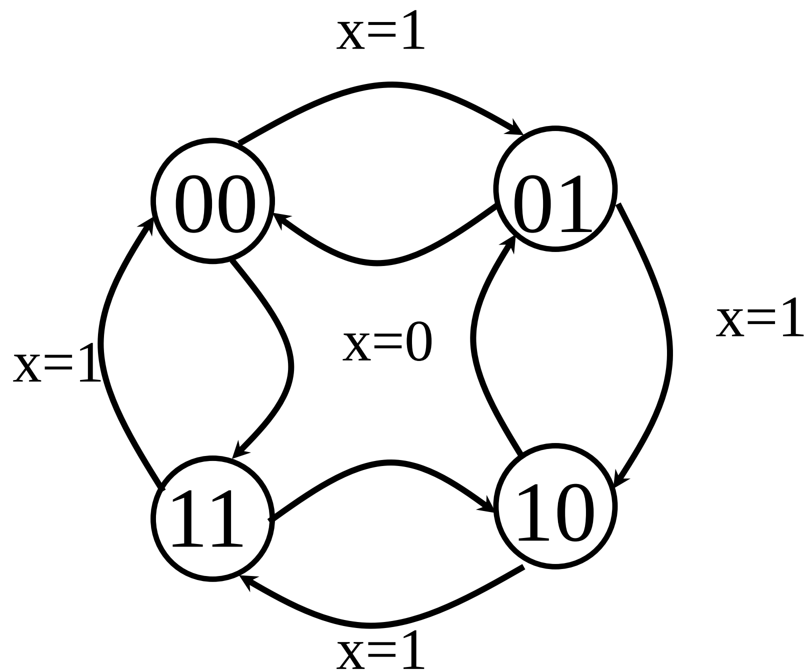


$$J = \begin{cases} Q(t+1) & Q(t)=0 \\ X & Q(t)=1 \end{cases}$$

$$K = \begin{cases} Q(t+1)' & Q(t)=1 \\ X & Q(t)=0 \end{cases}$$

Design Example - 2

x	A	B	A(t+1)	B(t+1)	J_A	K_A	J_B	K_B
0	0	0	1	1	1	X		
0	0	1	0	0	0	X		
0	1	0	0	1	X	1		
0	1	1	1	0	X	0		
1	0	0	0	1	0	X		
1	0	1	1	0	1	X		
1	1	0	1	1	X	0		
1	1	1	0	0	X	1		

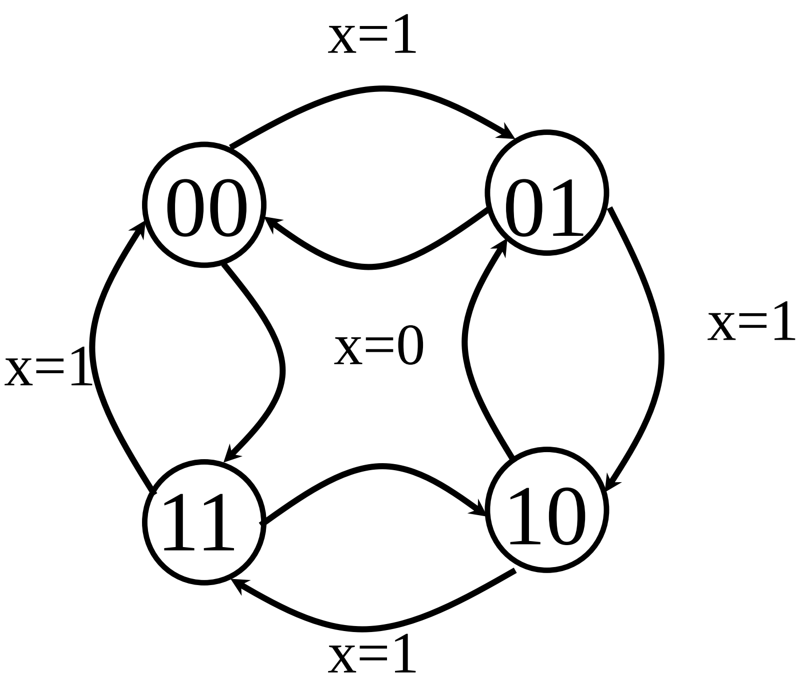


$$J = \begin{cases} Q(t+1) & Q(t)=0 \\ X & Q(t)=1 \end{cases}$$

$$K = \begin{cases} Q(t+1)' & Q(t)=1 \\ X & Q(t)=0 \end{cases}$$

Design Example - 2

x	A	B	A(t+1)	B(t+1)	J_A	K_A	J_B	K_B
0	0	0	1	1	1	X	1	
0	0	1	0	0	0	X	X	
0	1	0	0	1	X	1	1	
0	1	1	1	0	X	0	X	
1	0	0	0	1	0	X	1	
1	0	1	1	0	1	X	X	
1	1	0	1	1	X	0	1	
1	1	1	0	0	X	1	X	

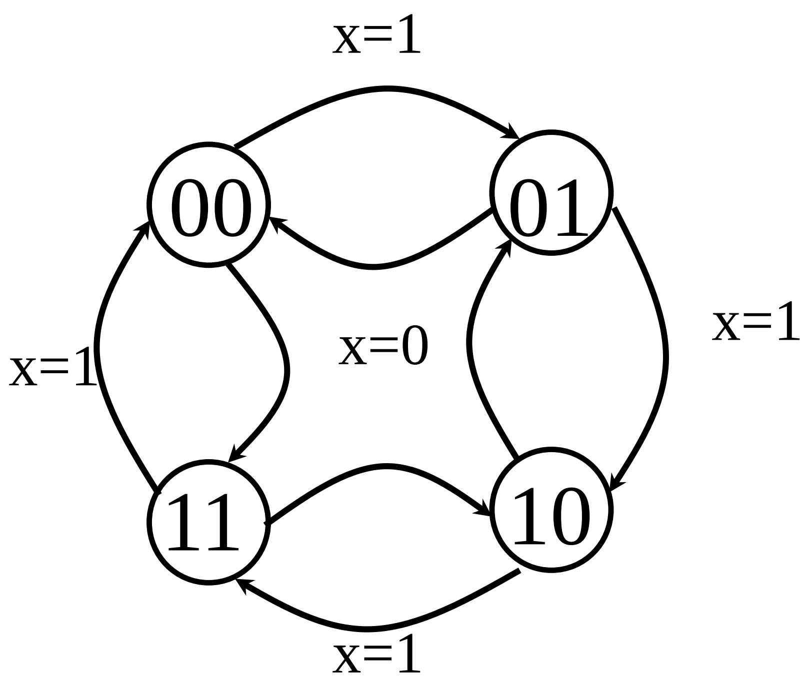


$$J = \begin{cases} Q(t+1) & Q(t)=0 \\ X & Q(t)=1 \end{cases}$$

$$K = \begin{cases} Q(t+1)' & Q(t)=1 \\ X & Q(t)=0 \end{cases}$$

Design Example - 2

x	A	B	A(t+1)	B(t+1)	J_A	K_A	J_B	K_B
0	0	0	1	1	1	X	1	X
0	0	1	0	0	0	X	X	1
0	1	0	0	1	X	1	1	X
0	1	1	1	0	X	0	X	1
1	0	0	0	1	0	X	1	X
1	0	1	1	0	1	X	X	1
1	1	0	1	1	X	0	1	X
1	1	1	0	0	X	1	X	1

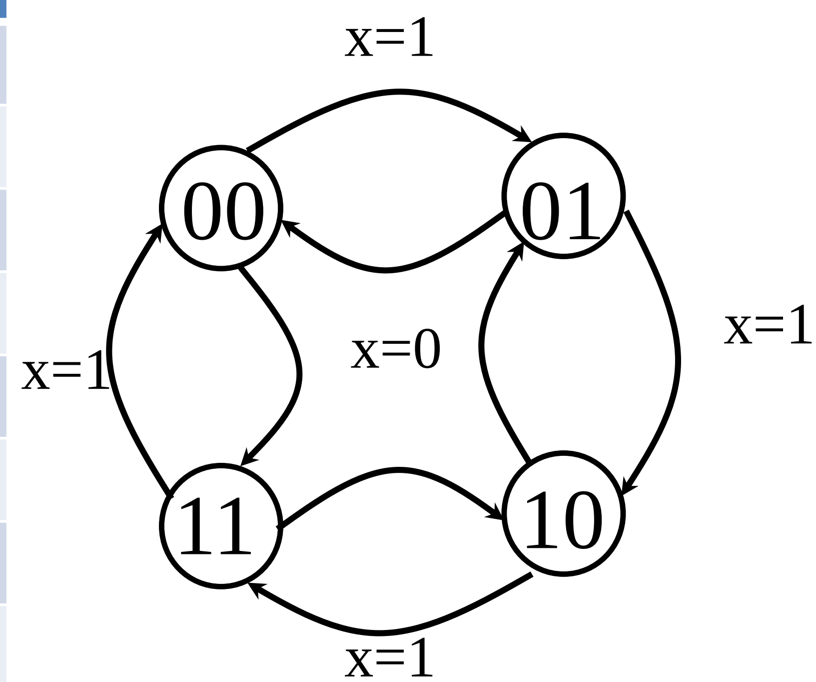


$$J = \begin{cases} Q(t+1) & Q(t)=0 \\ X & Q(t)=1 \end{cases}$$

$$K = \begin{cases} Q(t+1)' & Q(t)=1 \\ X & Q(t)=0 \end{cases}$$

Design Example - 2

x	A	B	A(t+1)	B(t+1)	J_A	K_A	J_B	K_B
0	0	0	1	1	1	X	1	X
0	0	1	0	0	0	X	X	1
0	1	0	0	1	X	1	1	X
0	1	1	1	0	X	0	X	1
1	0	0	0	1	0	X	1	X
1	0	1	1	0	1	X	X	1
1	1	0	1	1	X	0	1	X
1	1	1	0	0	X	1	X	1



x \ AB	00	01	11	10
0	1	0	X	X
1	0	1	X	X

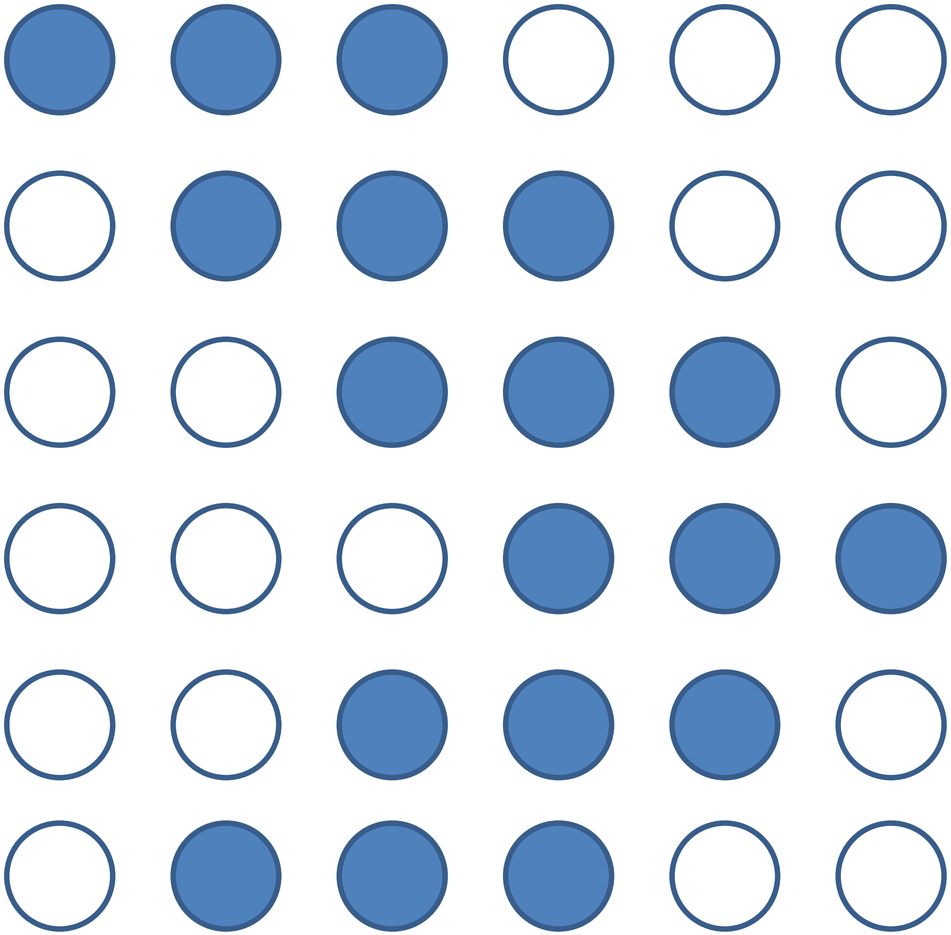
x \ AB	00	01	11	10
0	X	X	0	1
1	X	X	1	0

Design Example - 2

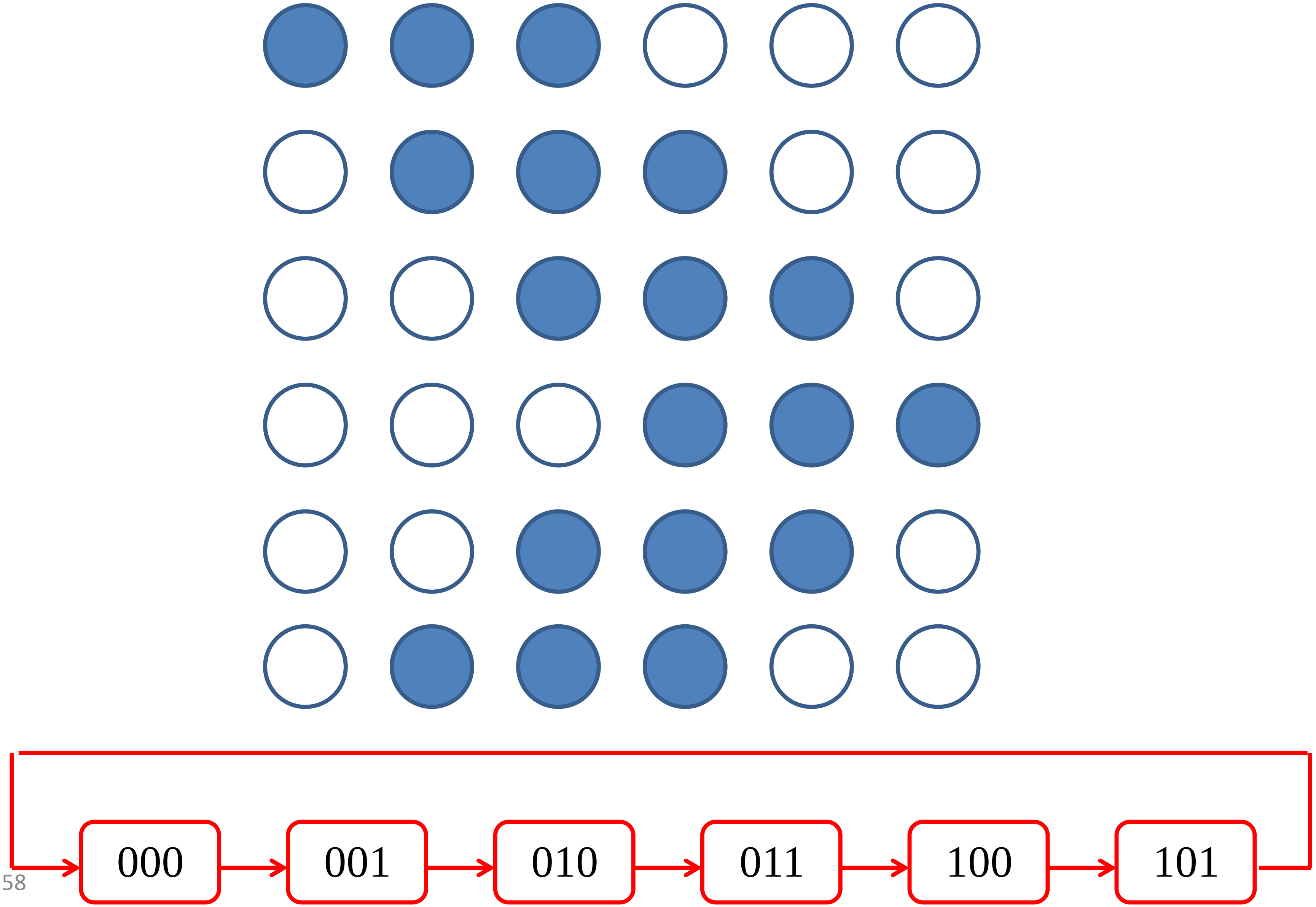
- J_A=xB+x'B'
- K_A=xB+x'B'
- J_B=1
- K_B=1
- Draw the circuit

Left to students

Design Example - 3



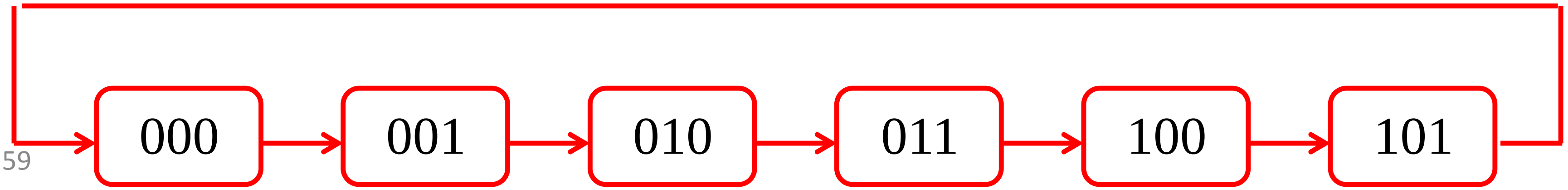
Design Example - 3



Design Example - 3

A(t)	B(t)	C(t)	A (t+1)	B (t+1)	C (t+1)	z1	z2	z3	z4	z5	z6	JA	KA	JB	KB	JC	KC
0	0	0	0	0	1	1	1	1	0	0	0						
0	0	1	0	1	0	0	1	1	1	0	0						
0	1	0	0	1	1	0	0	1	1	1	0						
0	1	1	1	0	0	0	0	0	1	1	1						
1	0	0	1	0	1	0	0	1	1	1	0						
1	0	1	0	0	0	0	1	1	1	0	0						

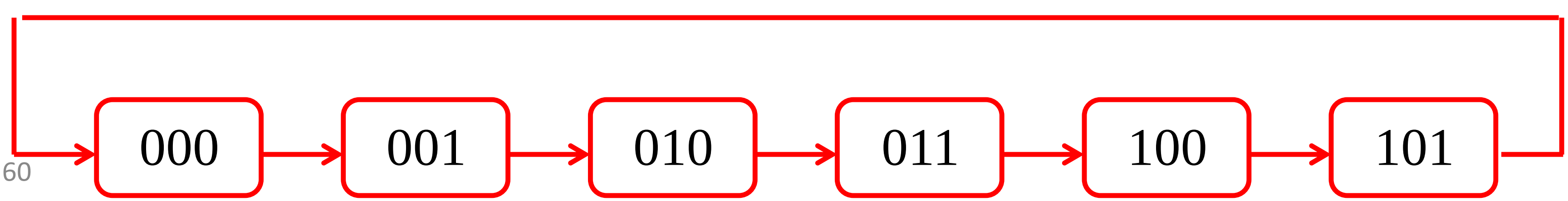
$$J = \begin{cases} Q(t+1) & Q(t)=0 \\ X & Q(t)=1 \end{cases} \qquad K = \begin{cases} Q(t+1)' & Q(t)=1 \\ X & Q(t)=0 \end{cases}$$



Design Example - 3

A(t)	B(t)	C(t)	A (t+1)	B (t+1)	C (t+1)	z1	z2	z3	z4	z5	z6	JA	KA	JB	KB	JC	KC
0	0	0	0	0	1	1	1	1	0	0	0	0		0		1	
0	0	1	0	1	0	0	1	1	1	0	0	0		1			
0	1	0	0	1	1	0	0	1	1	1	0	0				1	
0	1	1	1	0	0	0	0	0	1	1	1	1					
1	0	0	1	0	1	0	0	1	1	1	0			0		1	
1	0	1	0	0	0	0	1	1	1	0	0			0			

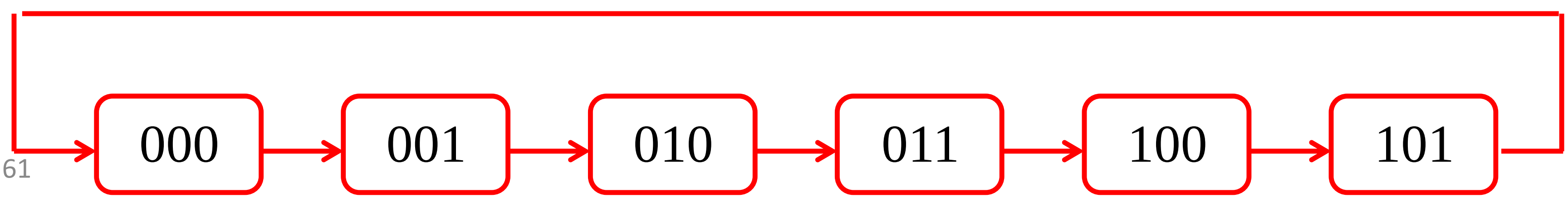
$$J = \begin{cases} Q(t+1) & Q(t)=0 \\ X & Q(t)=1 \end{cases} \qquad K = \begin{cases} Q(t+1)' & Q(t)=1 \\ X & Q(t)=0 \end{cases}$$



Design Example - 3

A(t)	B(t)	C(t)	A (t+1)	B (t+1)	C (t+1)	z1	z2	z3	z4	z5	z6	JA	KA	JB	KB	JC	KC
0	0	0	0	0	1	1	1	1	0	0	0	0		0		1	
0	0	1	0	1	0	0	1	1	1	0	0	0		1		X	
0	1	0	0	1	1	0	0	1	1	1	0	0		X		1	
0	1	1	1	0	0	0	0	0	1	1	1	1		X		X	
1	0	0	1	0	1	0	0	1	1	1	0	X		0		1	
1	0	1	0	0	0	0	1	1	1	0	0	X		0		X	

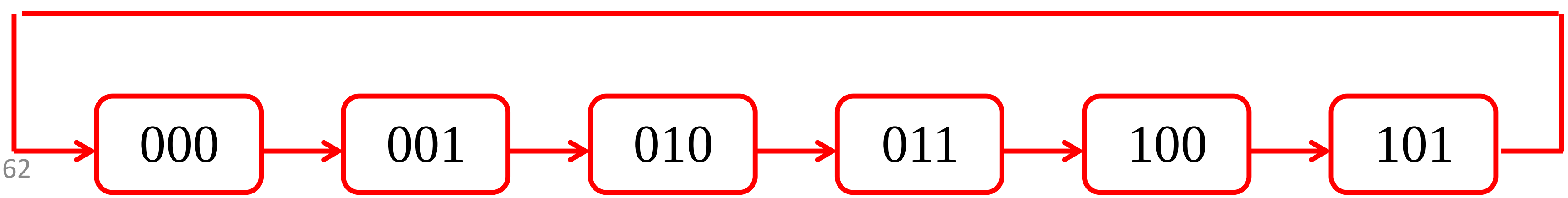
$$J = \begin{cases} Q(t+1) & Q(t)=0 \\ X & Q(t)=1 \end{cases} \qquad K = \begin{cases} Q(t+1)' & Q(t)=1 \\ X & Q(t)=0 \end{cases}$$



Design Example - 3

A(t)	B(t)	C(t)	A (t+1)	B (t+1)	C (t+1)	z1	z2	z3	z4	z5	z6	JA	KA	JB	KB	JC	KC
0	0	0	0	0	1	1	1	1	0	0	0	0		0		1	
0	0	1	0	1	0	0	1	1	1	0	0	0		1		X	1
0	1	0	0	1	1	0	0	1	1	1	0	0		X	0	1	
0	1	1	1	0	0	0	0	0	1	1	1	1		X	1	X	1
1	0	0	1	0	1	0	0	1	1	1	0	X	0	0		1	
1	0	1	0	0	0	0	1	1	1	0	0	X	1	0		X	1

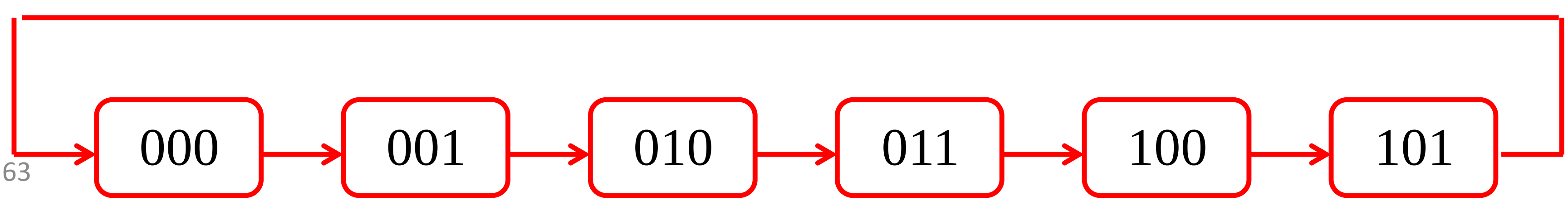
$$J = \begin{cases} Q(t+1) & Q(t)=0 \\ X & Q(t)=1 \end{cases} \qquad K = \begin{cases} Q(t+1)' & Q(t)=1 \\ X & Q(t)=0 \end{cases}$$



Design Example - 3

A(t)	B(t)	C(t)	A (t+1)	B (t+1)	C (t+1)	z1	z2	z3	z4	z5	z6	J_A	K_A	J_B	K_B	J_C	K_C
0	0	0	0	0	1	1	1	1	0	0	0	0	X	0	X	1	X
0	0	1	0	1	0	0	1	1	1	0	0	0	X	1	X	X	1
0	1	0	0	1	1	0	0	1	1	1	0	0	X	X	0	1	X
0	1	1	1	0	0	0	0	0	1	1	1	1	X	X	1	X	1
1	0	0	1	0	1	0	0	1	1	1	0	X	0	0	X	1	X
1	0	1	0	0	0	0	1	1	1	0	0	X	1	0	X	X	1

$$J = \begin{cases} Q(t+1) & Q(t)=0 \\ X & Q(t)=1 \end{cases} \qquad K = \begin{cases} Q(t+1)' & Q(t)=1 \\ X & Q(t)=0 \end{cases}$$



Design Example - 3

A(t)	B(t)	C(t)	A (t+1)	B (t+1)	C (t+1)	z1	z2	z3	z4	z5	z6	J_A	K_A	J_B	K_B	J_C	K_C
0	0	0	0	0	1	1	1	1	0	0	0	0	X	0	X	1	X
0	0	1	0	1	0	0	1	1	1	0	0	0	X	1	X	X	1
0	1	0	0	1	1	0	0	1	1	1	0	0	X	X	0	1	X
0	1	1	1	0	0	0	0	0	1	1	1	1	X	X	1	X	1
1	0	0	1	0	1	0	0	1	1	1	0	X	0	0	X	1	X
1	0	1	0	0	0	0	1	1	1	0	0	X	1	0	X	X	1
1	1	0										X	X	X	X	X	X
1	1	1										X	X	X	X	X	X

A \ BC	00	01	11	10
0	0	0	1	0
1	X	X	X	X

$J_A = BC$

A \ BC	00	01	11	10
0	X	X	X	X
1	0	1	X	X

$K_A = C$

Design Example - 3

A(t)	B(t)	C(t)	A (t+1)	B (t+1)	C (t+1)	z1	z2	z3	z4	z5	z6	J_A	K_A	J_B	K_B	J_C	K_C
0	0	0	0	0	1	1	1	1	0	0	0	0	X	0	X	1	X
0	0	1	0	1	0	0	1	1	1	0	0	0	X	1	X	X	1
0	1	0	0	1	1	0	0	1	1	1	0	0	X	X	0	1	X
0	1	1	1	0	0	0	0	0	1	1	1	1	X	X	1	X	1
1	0	0	1	0	1	0	0	1	1	1	0	X	0	0	X	1	X
1	0	1	0	0	0	0	1	1	1	0	0	X	1	0	X	X	1
1	1	0										X	X	X	X	X	X
1	1	1										X	X	X	X	X	X

A \ BC	00	01	11	10
0	0	1	X	X
1	0	0	X	X

$J_B = A'C$

A \ BC	00	01	11	10
0	X	X	1	0
1	X	X	X	X

$K_B = C$

Design Example - 3

A(t)	B(t)	C(t)	A (t+1)	B (t+1)	C (t+1)	z1	z2	z3	z4	z5	z6	J_A	K_A	J_B	K_B	J_C	K_C
0	0	0	0	0	1	1	1	1	0	0	0	0	X	0	X	1	X
0	0	1	0	1	0	0	1	1	1	0	0	0	X	1	X	X	1
0	1	0	0	1	1	0	0	1	1	1	0	0	X	X	0	1	X
0	1	1	1	0	0	0	0	0	1	1	1	1	X	X	1	X	1
1	0	0	1	0	1	0	0	1	1	1	0	X	0	0	X	1	X
1	0	1	0	0	0	0	1	1	1	0	0	X	1	0	X	X	1
1	1	0										X	X	X	X	X	X
1	1	1										X	X	X	X	X	X

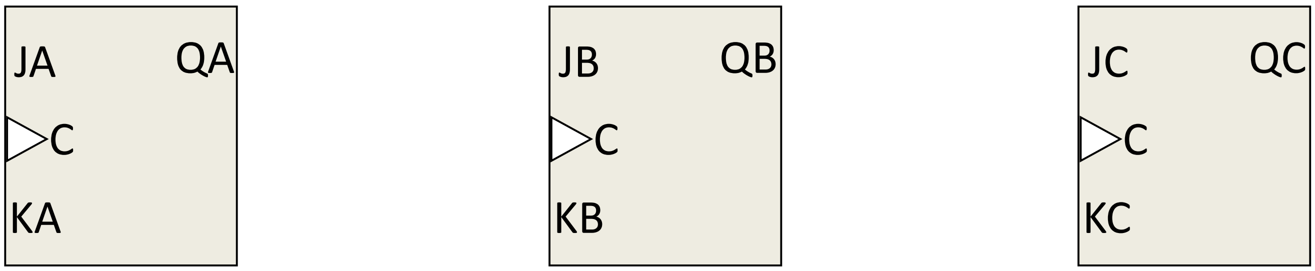
A \ BC	00	01	11	10
0	1	X	1	X
1	1	X	X	X

$J_C=1$

A \ BC	00	01	11	10
0	X	1	1	X
1	X	1	X	X

$K_C=1$

Design Example - 3



Left to students

Design Example - 3

A(t)	B(t)	C(t)	A (t+1)	B (t+1)	C (t+1)	z1	z2	z3	z4	z5	z6	J_A	K_A	J_B	K_B	J_C	K_C
0	0	0	0	0	1	1	1	1	0	0	0	0	0	0	0	1	1
0	0	1	0	1	0	0	1	1	1	0	0	0	1	1	1	1	1
0	1	0	0	1	1	0	0	1	1	1	0	0	0	0	0	1	1
0	1	1	1	0	0	0	0	0	1	1	1	1	1	1	1	1	1
1	0	0	1	0	1	0	0	1	1	1	0	0	0	0	0	1	1
1	0	1	0	0	0	0	1	1	1	0	0	0	1	0	1	1	1
1	1	0										0	0	0	0	1	1
1	1	1										1	1	0	1	1	1

$J_A = BC$ $\qquad$ $K_A = C$

$J_B = A'C$ $\qquad$ $K_B = C$

$J_C = 1$ $\qquad$ $K_C = 1$

Design Example - 3

A(t)	B(t)	C(t)	A (t+1)	B (t+1)	C (t+1)	z1	z2	z3	z4	z5	z6	J_A	K_A	J_B	K_B	J_C	K_C
0	0	0	0	0	1	1	1	1	0	0	0	0	0	0	0	1	1
0	0	1	0	1	0	0	1	1	1	0	0	0	1	1	1	1	1
0	1	0	0	1	1	0	0	1	1	1	0	0	0	0	0	1	1
0	1	1	1	0	0	0	0	0	1	1	1	1	1	1	1	1	1
1	0	0	1	0	1	0	0	1	1	1	0	0	0	0	0	1	1
1	0	1	0	0	0	0	1	1	1	0	0	0	1	0	1	1	1
1	1	0	1	1	1							0	0	0	0	1	1
1	1	1	0	0	0							1	1	0	1	1	1

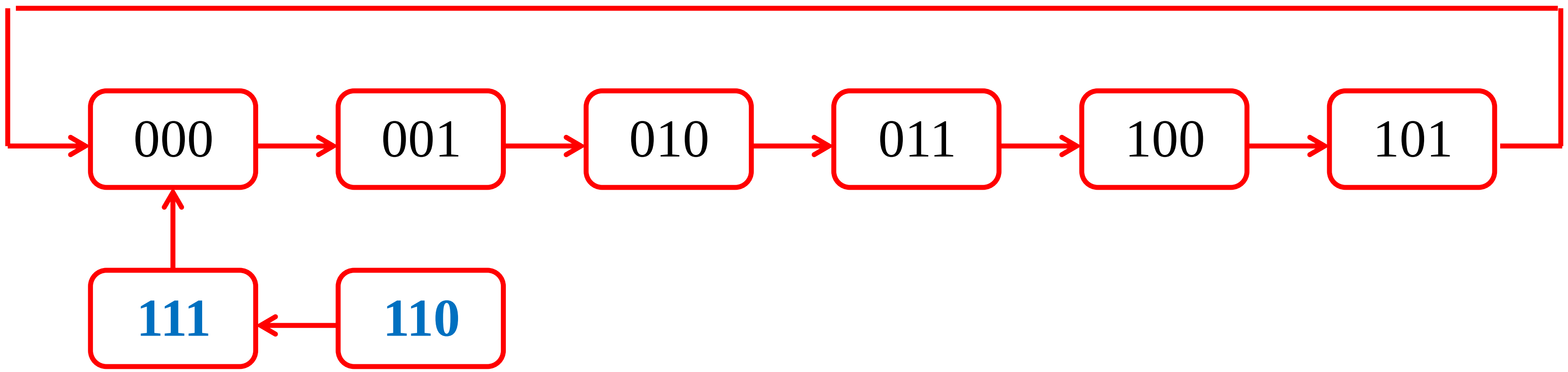
$J_A = BC$ $\quad A(t+1) = BCA' + C'A$ $\quad K_A = C$

$J_B = A'C$ $\quad B(t+1) = A'CB' + C'B$ $\quad K_B = C$

$J_C = 1$ $\quad C(t+1) = C'$ $\quad K_C = 1$

Design Example - 3

A(t)	B(t)	C(t)	A (t+1)	B (t+1)	C (t+1)	z1	z2	z3	z4	z5	z6	JA	KA	JB	KB	JC	KC
0	0	0	0	0	1	1	1	1	0	0	0	0	0	0	0	1	1
0	0	1	0	1	0	0	1	1	1	0	0	0	1	1	1	1	1
0	1	0	0	1	1	0	0	1	1	1	0	0	0	0	0	1	1
0	1	1	1	0	0	0	0	0	1	1	1	1	1	1	1	1	1
1	0	0	1	0	1	0	0	1	1	1	0	0	0	0	0	1	1
1	0	1	0	0	0	0	1	1	1	0	0	0	1	0	1	1	1
1	1	0	1	1	1							0	0	0	0	1	1
1	1	1	0	0	0							1	1	0	1	1	1



Design Example - 3

- Repeat your design with D FFs

Left to students

Design Example - 3

A(t)	B(t)	C(t)	A (t+1)	B (t+1)	C (t+1)	z1	z2	z3	z4	z5	z6	DA	DB	DC
0	0	0	0	0	1	1	1	1	0	0	0			1
0	0	1	0	1	0	0	1	1	1	0	0		1	
0	1	0	0	1	1	0	0	1	1	1	0		1	1
0	1	1	1	0	0	0	0	0	1	1	1	1		
1	0	0	1	0	1	0	0	1	1	1	0	1		1
1	0	1	0	0	0	0	1	1	1	0	0			
1	1	0	1	1	1							1	1	1
1	1	1	0	0	0									

$A(t+1) = BCA' + C'A = D_A$

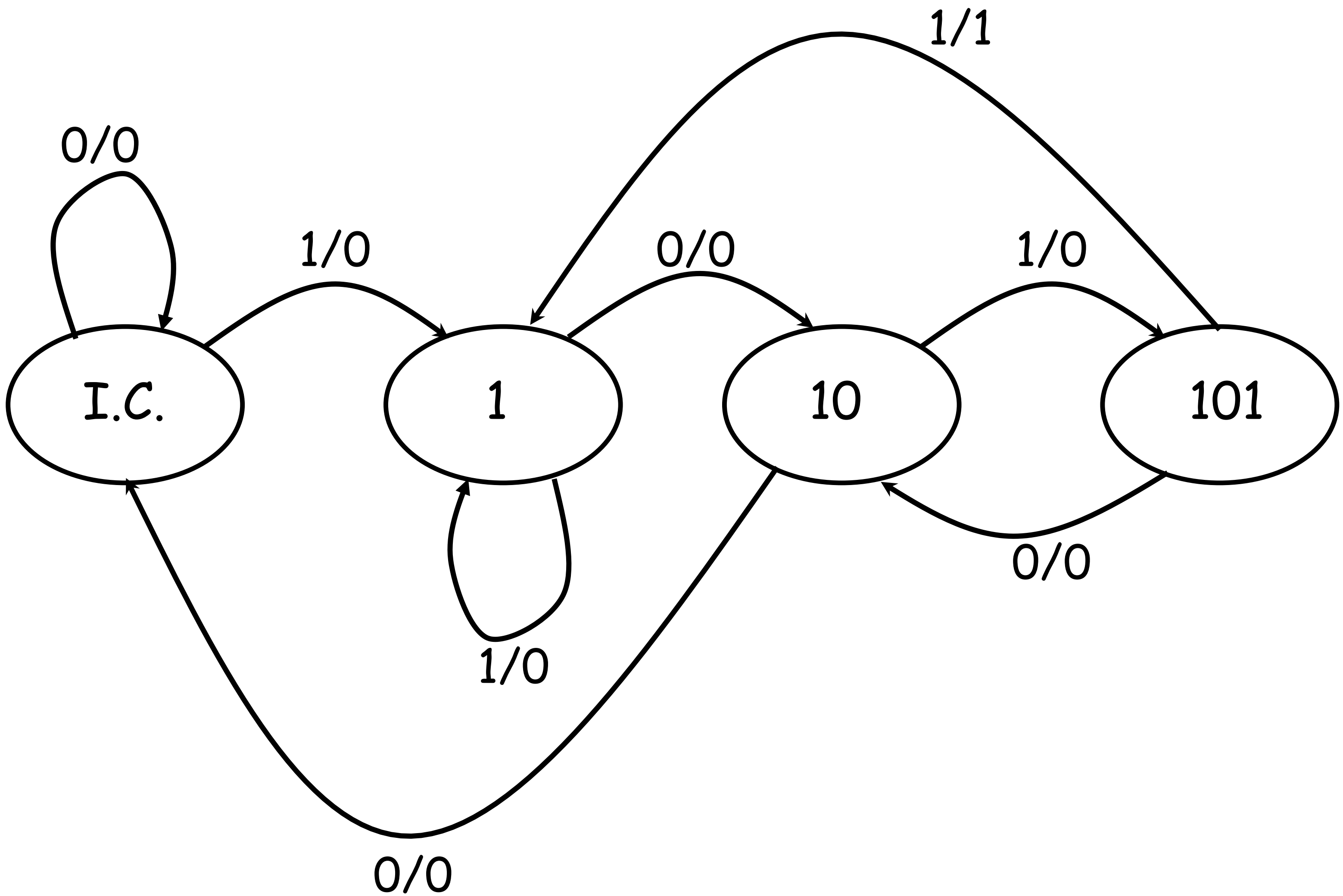
$B(t+1) = A'CB' + C'B = D_B$

$C(t+1) = C' = D_C$

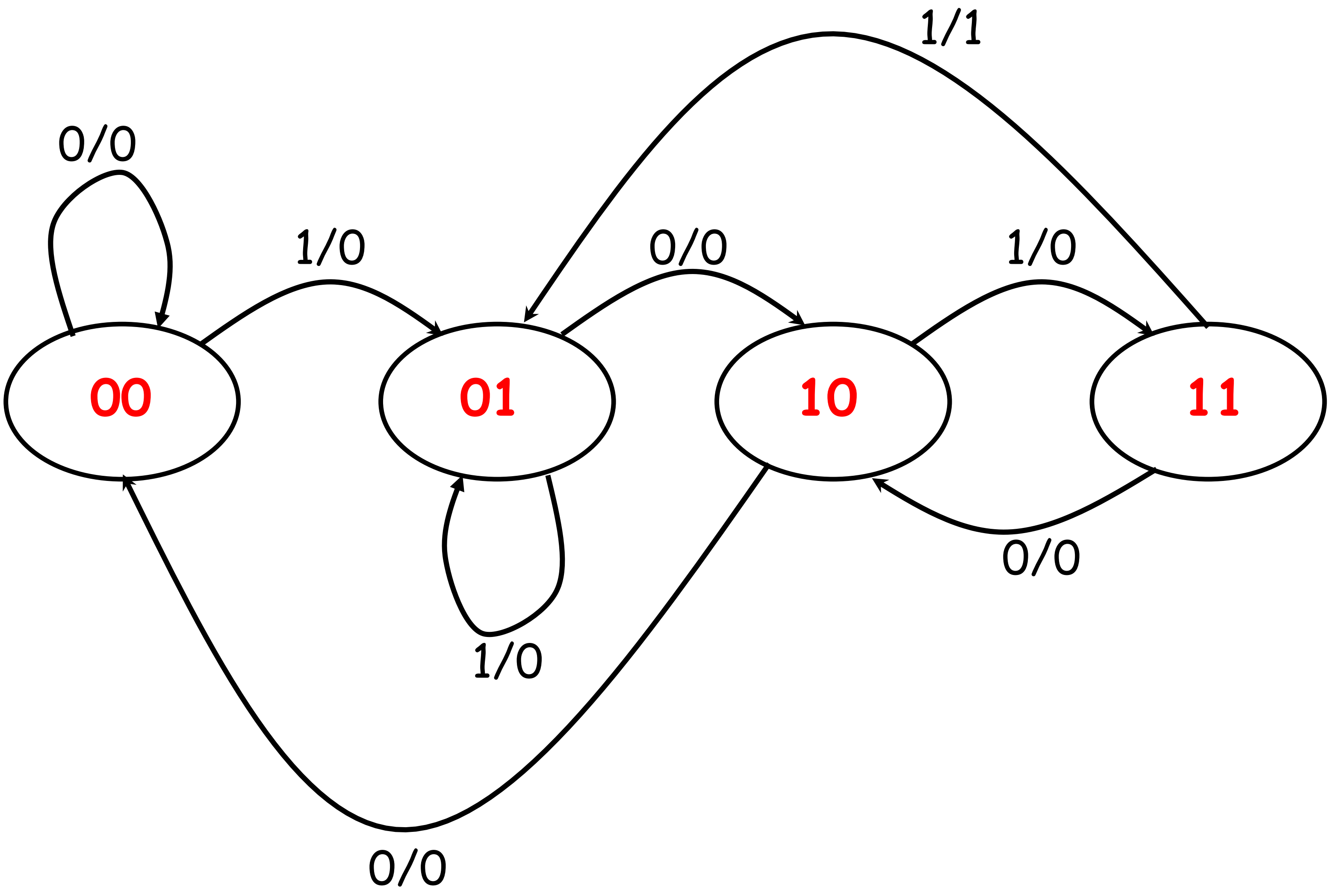
Design Example - 4

- Design a logic circuit that detects the sequence 1011 and outputs 1 in that case, 0 otherwise.

Design Example - 4



Design Example - 4



Design Example - 4

x(t)	A(t)	B(t)	A (t+1)	B (t+1)	Z	J_A	K_A	J_B	K_B
0	0	0	0	0	0				
0	0	1	1	0	0				
0	1	0	0	0	0				
0	1	1	1	0	0				
1	0	0	0	1	0				
1	0	1	0	1	0				
1	1	0	1	1	0				
1	1	1	0	1	1				

Design Example - 4

x(t)	A(t)	B(t)	A (t+1)	B (t+1)	Z	J_A	K_A	J_B	K_B
0	0	0	0	0	0	0	X	0	X
0	0	1	1	0	0	1	X	X	1
0	1	0	0	0	0	X	1	0	X
0	1	1	1	0	0	X	0	X	1
1	0	0	0	1	0	0	X	1	X
1	0	1	0	1	0	0	X	X	0
1	1	0	1	1	0	X	0	1	X
1	1	1	0	1	1	X	1	X	0

Design Example - 4

x \ AB	00	01	11	10
0	0	1	X	X
1	0	0	X	X

$J_A = x'B$

x \ AB	00	01	11	10
0	X	X	0	1
1	X	X	1	0

$K_A = xB + x'B'$

x \ AB	00	01	11	10
0	0	X	X	0
1	1	X	X	1

$J_B = x$

x \ AB	00	01	11	10
0	X	1	1	X
1	X	0	0	X

$K_B = x'$

Design Example - 4

Left to students

Design Example - 4

Left to students