Lecture – 11

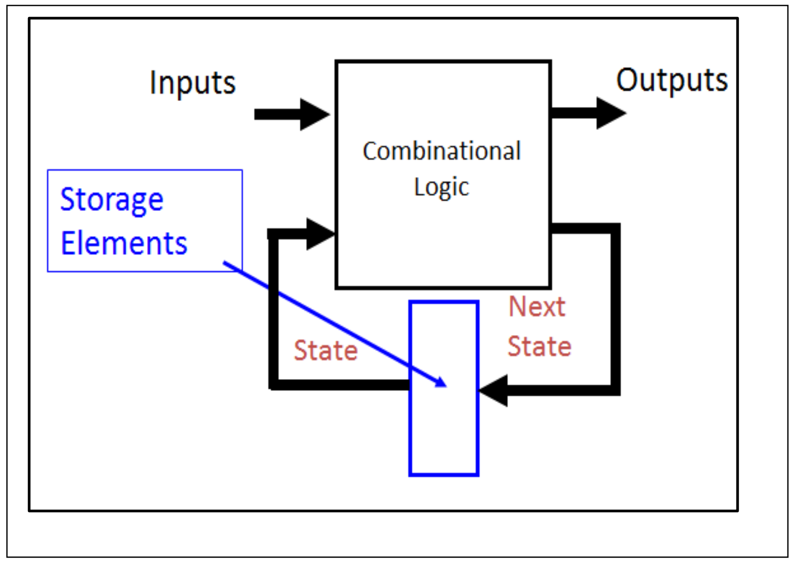
Outline

- sequential circuits
- storage elements: latch and flip-flop

- Sequential circuit analysis
    - ***Moore and Mealy Models***
    - ***State tables***
    - ***State diagrams***

Sequential Circuit Analysis

- General Model
  - Current State at time (t) is stored in flip-flops.



  - Next State at time (t+1) is a Boolean function of State and Inputs.

  - Outputs at time (t) are a Boolean function of State (t) and (sometimes) Inputs (t).

Moore and Mealy Models

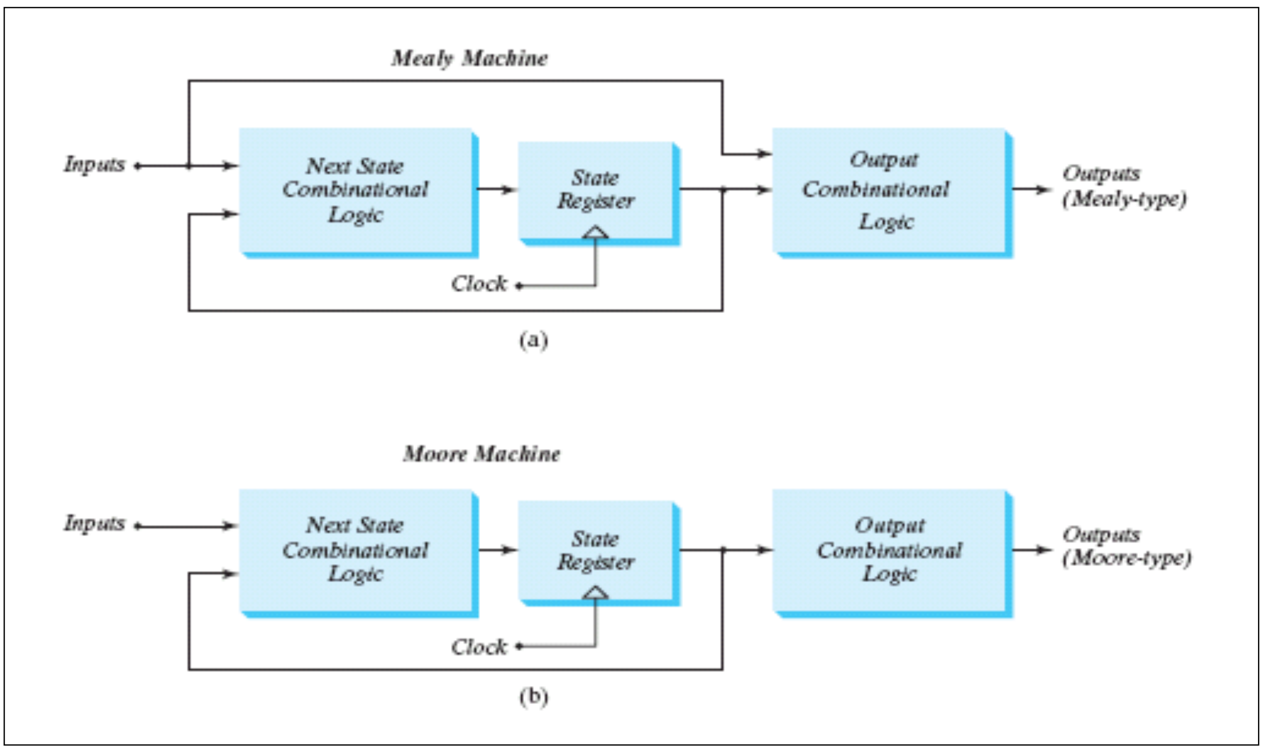
- Sequential Circuits or Sequential Machines are also called *Finite State Machines* (FSMs). Two formal models exist:

Mealy Model

- Named after G. Mealy
- Outputs are a function of inputs AND states

Moore Model

- Named after E.F. Moore
- Outputs are a function ONLY of states

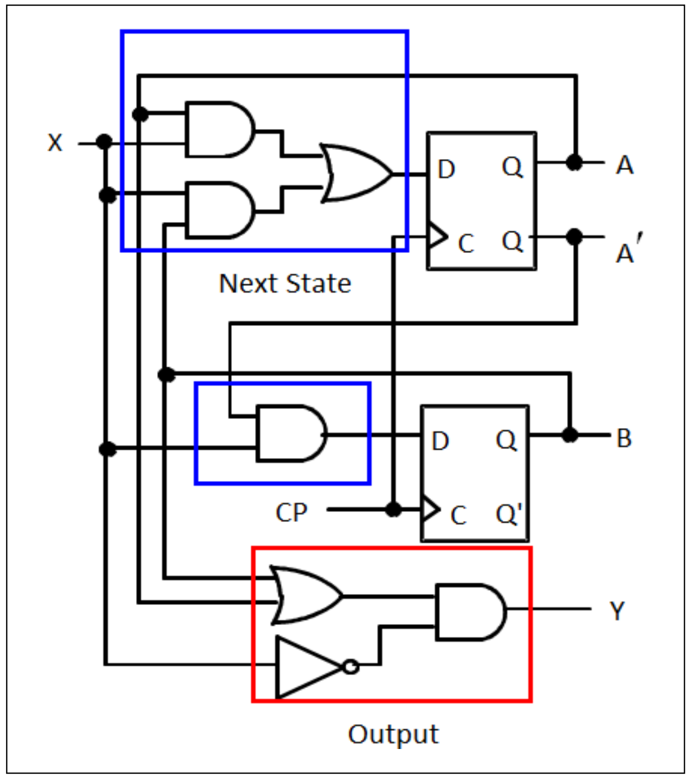


Example 1

Step 1:

- Input flip-flop equations:

  $D_A = Ax + Bx$
  $D_B = A'x$



Step 2:

- State equations:

  $A(t+1) = D_A = Ax + Bx$
  $B(t+1) = D_B = A'\,x$

  Output equations:
  $y = x'\,(B + A)$

Step 3:

- State Table and State Diagram

State Table Characteristics

- *State table* – a multiple variable table with the following four sections:
  - ***Present State*** – the values of the state variables for each allowed state.
  - ***Input*** – the input combinations allowed.
  - ***Next-state*** – the value of the state at time (t+1) based on the present state and the input.
  - ***Output*** – the value of the output as a function of the present state and (sometimes) the input.
- Considered as a truth table:
  - the inputs are Input, Present State
  - and the outputs are Output, Next State

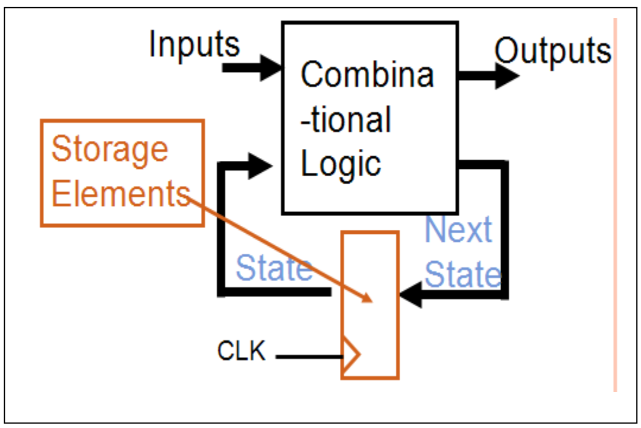
Example1: State Table.

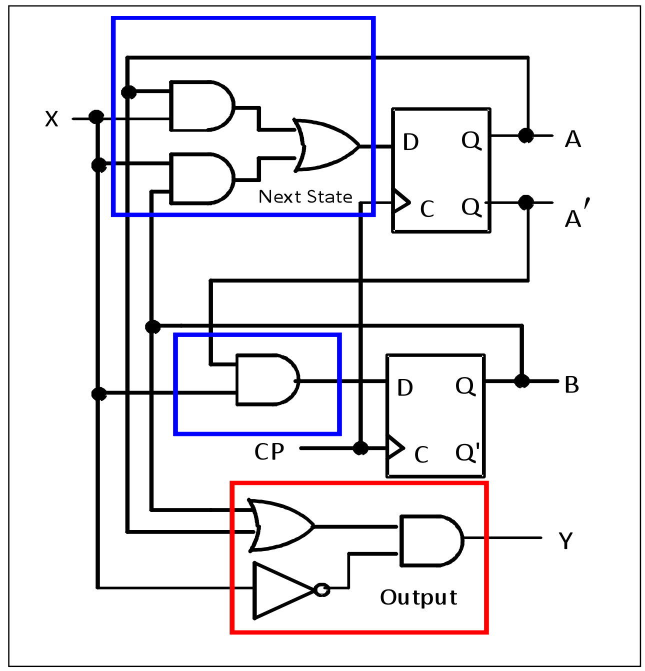
- The state table can be filled in using state equations and output equations:

  $A(t+1) = D_A = A(t)x(t)+B(t)x(t)$

  $B(t+1) = D_B = A(t)'x(t)$

  $y(t) = x(t)'(B(t) + A(t))$

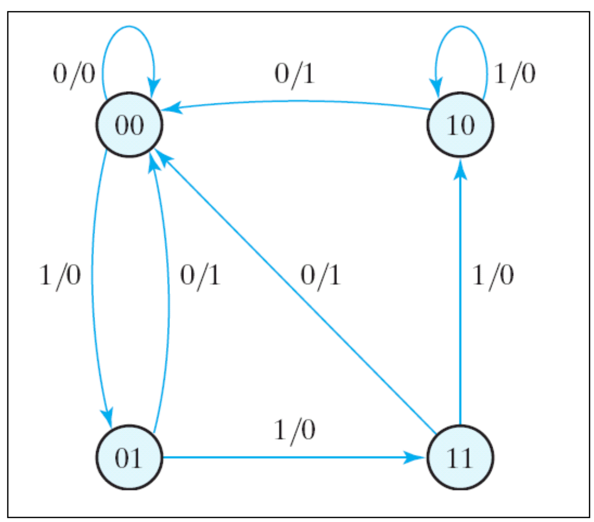




Present State		Input	Next State		Output
A(t)	B(t)	x(t)	A(t+1)	B(t+1)	y(t)
0	0	0	0	0	0
0	0	1	0	1	0
0	1	0	0	0	1
0	1	1	1	1	0
1	0	0	0	0	1
1	0	1	1	0	0
1	1	0	0	0	1
1	1	1	1	0	0

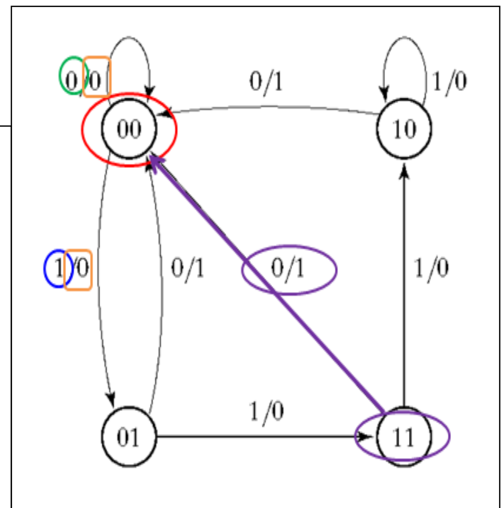
State Diagrams

- The sequential circuit function can be represented in graphical form as a state diagram with the following components:
  - A circle with the state name in it for each state
  - A directed arc from the Present State to the Next State for each state transition
  - A label on each directed arc with the Input values which causes the state transition, and
  - A label:
    - ***On each directed arc with the output value produced (Mealy), or***
    - ***On each circle with the output value produced (Moore)***



Example 1: State Diagram

- On directed arc with the output included:
  - ***input/output***
  - ***Mealy type output depends on state and input***



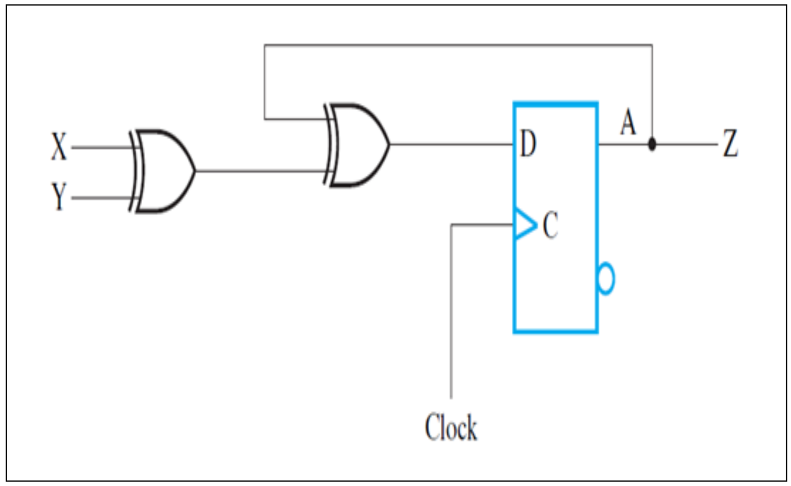
Present State		Input	Next State		Output
A_t	B_t	X_t	A_{t+1}	B_{t+1}	Y_t
0	0	0	0	0	0
0	0	1	0	1	0
0	1	0	0	0	1
0	1	1	1	1	0
1	0	0	0	0	1
1	0	1	1	0	0
1	1	0	0	0	1
1	1	1	1	0	0

$A(t+1) = D_A = A(t)x(t) + B(t)x(t)$

$B(t+1) = D_B = A(t)'x(t)$

$y(t) = x(t)'(B(t) + A(t))$

Example 2



Step 1:

- Input flip-flop equations:
  $D_A = x \oplus y \oplus A$

Step 2:

- State equations:
  $A(t+1) = D_A = x \oplus y \oplus A$
  Output equations:
  $Z(t) = A(t)$

Step 3:

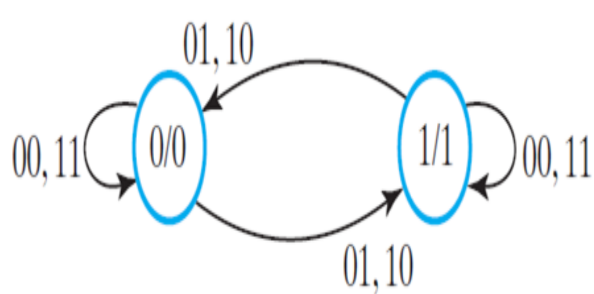
- State Table and State Diagram

Example 3 : State Table

- The state table can be filled in using state equations and output equation:

  $A(t+1) = D_A = x(t) \oplus y(t) \oplus A(t)$
  $Z(t) = A(t)$

Present state	Inputs		Next state	Output
A	X	Y	A	Z
0	0	0	0	0
0	0	1	1	0
0	1	0	1	0
0	1	1	0	0
1	0	0	1	1
1	0	1	0	1
1	1	0	0	1
1	1	1	1	1



SEQUENTIAL CIRCUIT DESIGN

Design steps :

- Given the word description and specifications
- Derive a state diagram for the circuit
- Obtain the binary-coded state table (transition table)
- Derive the simplified flip-flop input equations and output equations.
- Draw the circuit

SEQUENTIAL CIRCUIT DESIGN

Given the word description and specifications
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Mealy Machine Design

- Example 1: design a circuit that detects a sequence of three or more consecutive 1's in a string of bits
- Input: 010011011110
- Output: 000000000110

SEQUENTIAL CIRCUIT DESIGN

- State Diagram

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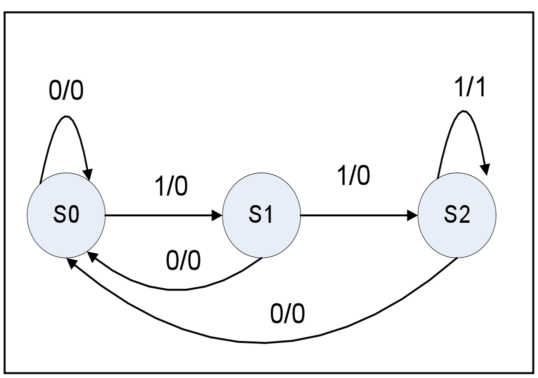

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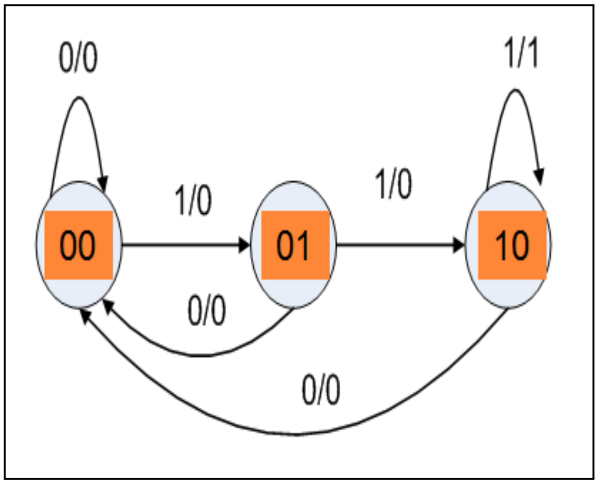
- State Table



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	0	1

SEQUENTIAL CIRCUIT DESIGN

Given the word description and specifications
Derive a state diagram for the circuit
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Derive the simplified flip-flop input equations and output equations.
Draw the circuit

- Use the K-Map to simplify flip-flop input equations and output equations

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	0	1

SEQUENTIAL CIRCUIT DESIGN

Mealy Machine Design

Example 2: design a circuit that detects a transition 0->1

- Input: 010011011110
- Output: 010010010000

Design steps :

- Given the specification
- Derive the state Diagram
- Obtain the binary-coded state table
- Derive the simplified flip-flop input equations and output equations.
- Draw the circuit

SEQUENTIAL CIRCUIT DESIGN

Given the word description and specifications
Derive a state diagram for the circuit
Obtain the binary-coded state table (transition table)
Derive the simplified flip-flop input equations and output equations.
Draw the circuit

Moore Machine Design

Example 1: design a circuit that detects a sequence of three or more consecutive 1's in a string of bits

State Diagram

Given the word description and specifications
Derive a state diagram for the circuit
Obtain the binary-coded state table (transition table)
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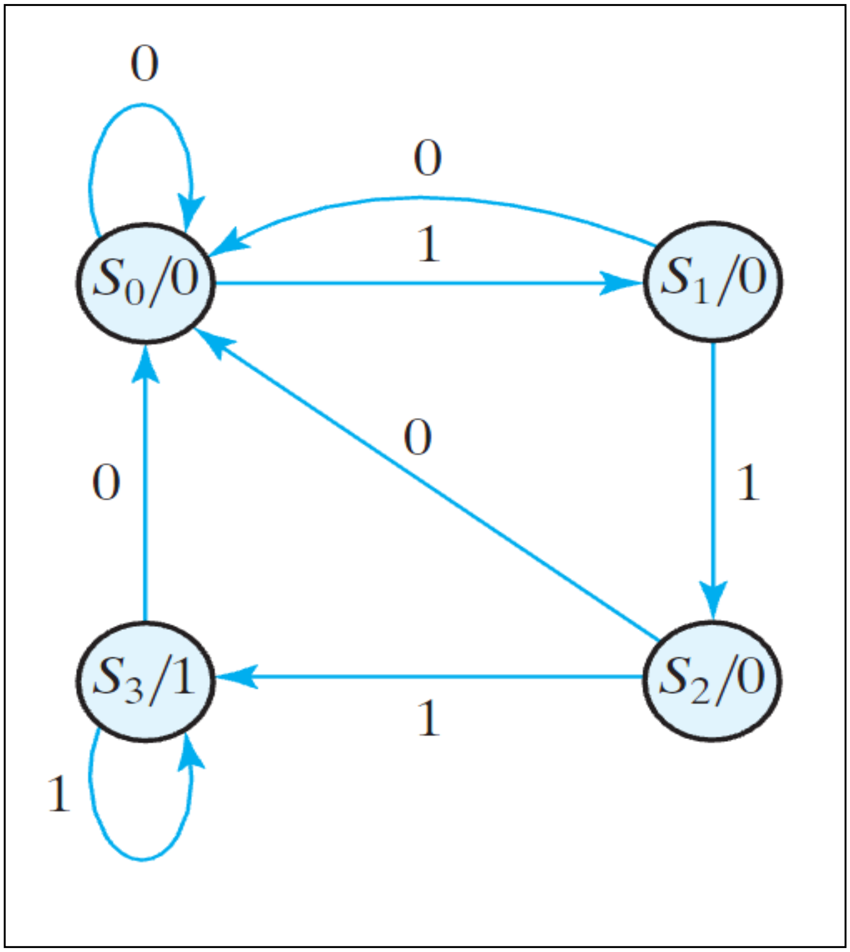
Draw the circuit



State Table

Given the word description and specifications
Derive a state diagram for the circuit
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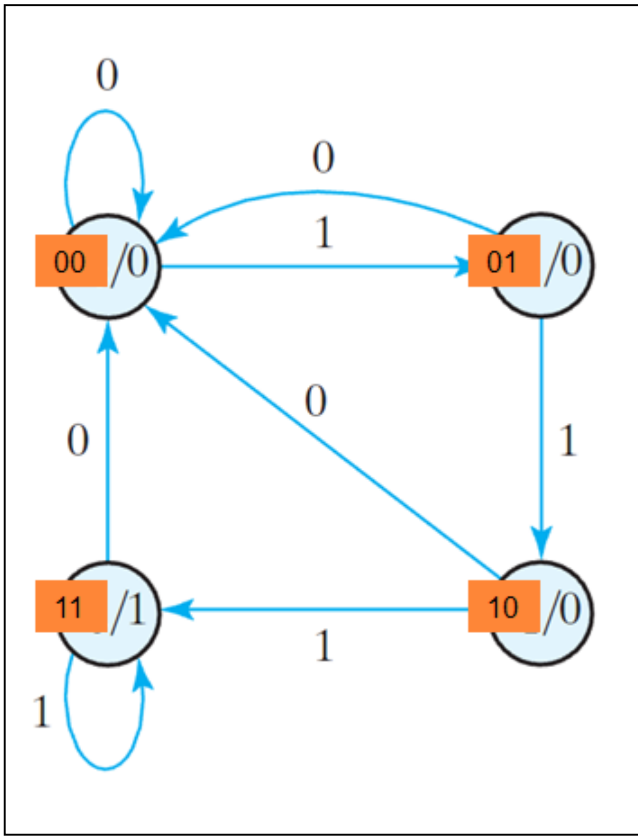

Present State		Input	Next State		Output
A	B	x	A	B	y
0	0	0	0	0	0
0	0	1	0	1	0
0	1	0	0	0	0
0	1	1	1	0	0
1	0	0	0	0	0
1	0	1	1	1	0
1	1	0	0	0	1
1	1	1	1	1	1

Use the K-Map to simplify flip-flop input equations and output equations

Given the word description and specifications
Derive a state diagram for the circuit
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Derive the simplified flip-flop input equations and output equations.
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SEQUENTIAL CIRCUIT DESIGN

Moore Machine Design

- Example 2: design a circuit that detects a

  transition 0->1

Design steps :

- Given the specification
- Derive the state Diagram
- Obtain the binary-coded state table
- Derive the simplified flip-flop input equations and output equations.
- Draw the circuit