Digital Logic Design
ENEE 244-010x

Lecture 20

Announcements

- HW8 due today
- Please read Section 6.8.3 in Textbook
  - Additional types of counters
- Next class: State diagrams, State reduction
  - Notes and class exercise (as always) will be posted online

Agenda

- New topic: Synchronous Sequential Networks
  - Structure and Operation of Clocked Synchronous Sequential Networks (7.1)
  - Analysis of Clocked Synchronous Sequential Networks (7.2)
  - Modeling Clocked Synchronous Sequential Network Behavior (7.3)

Clocked Synchronous Sequential Networks

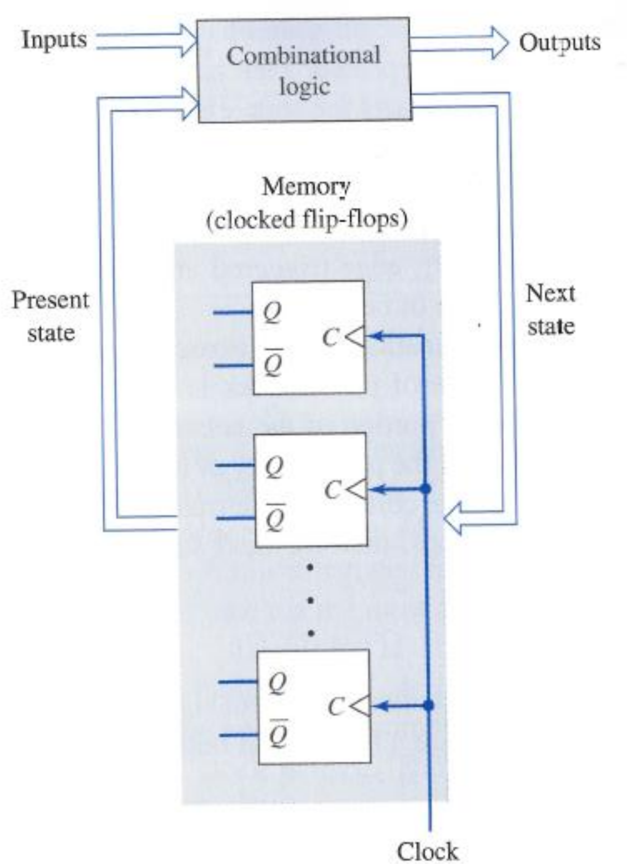


Figure 7.2 Structure of a clocked synchronous sequential network.

- Network behavior is defined at specific instants of time associated with a clock signal.
- Usually a master clock that appears at the control inputs of all the flip-flops.
- Combinational logic is used to generate the next-state and output signals.

Clocked Synchronous Sequential Networks

- Input and new present state signals are applied to the combinational logic.
- Effects of the signals must propagate through the network.
  - Final values at the flip-flop inputs occur at different times depending upon the number of gates involved in the signal paths.
- Only after final values are reached, active time of the clock signal is allowed to occur and cause any state changes.
- All state changes of the flip-flops occur at the same time.

Clocked Synchronous Sequential Networks

- Next state of the network: $Q^{+} = f(X, Q)$
  - X denotes the collective external input signals
  - Q denotes the collective present states of the flip-flops.
- Z denotes the collective output signals of the network: $Z = g(X, Q)$.

Mealy model

- The general structure of a clocked synchronous sequential network.

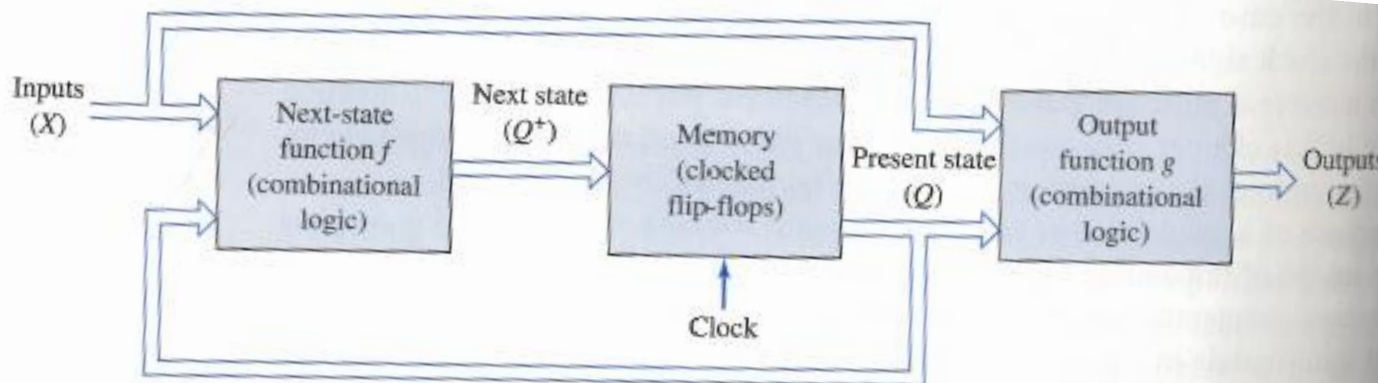


Figure 7.3 Mealy model of a clocked synchronous sequential network.

Moore Model

- Variation of Mealy model when the outputs are only a function of the present state and not of the external inputs: $Z = g(Q)$.

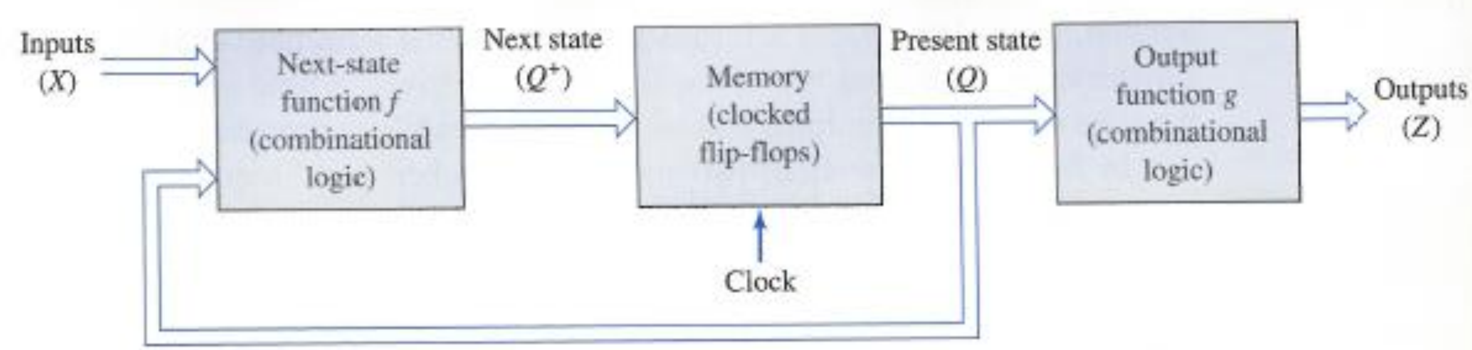
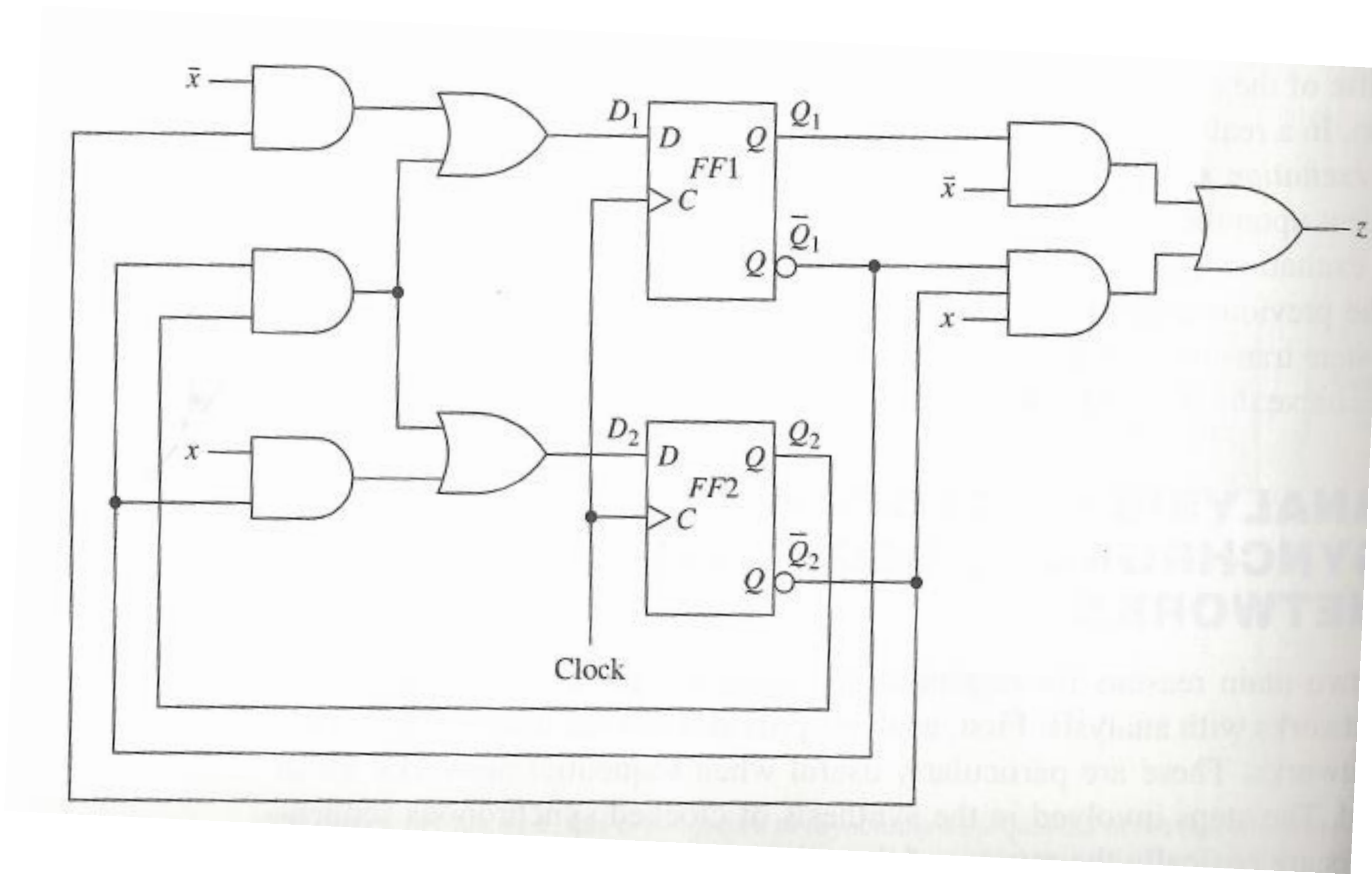


Figure 7.4 Moore model of a clocked synchronous sequential network.

Analysis of clocked Synchronous Sequential Network

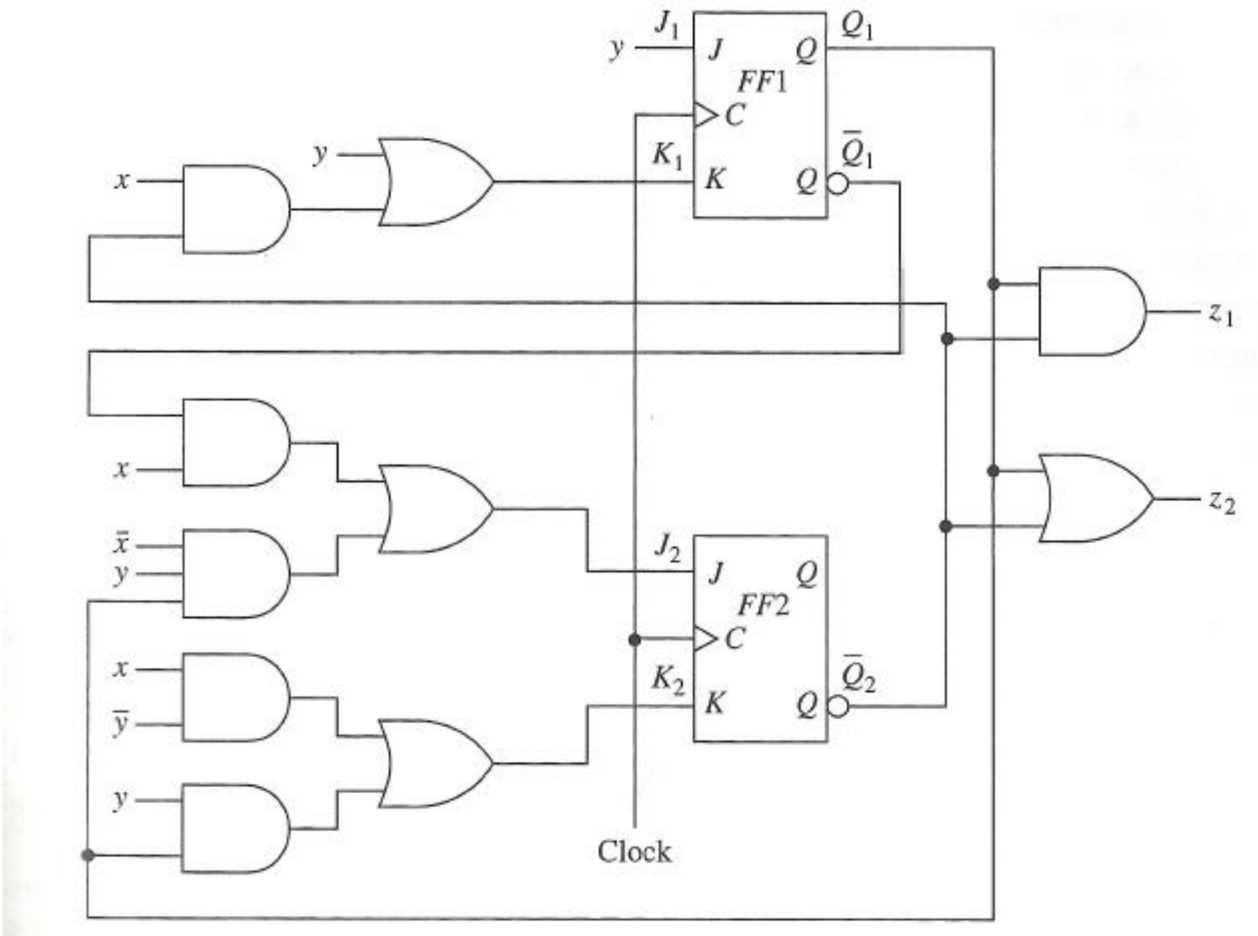
Two Examples

Figure 1: Mealy network



Two Examples

Figure 2: Moore network



Excitation and Output Expressions

- Assign variables to flip flop-states $Q_1, \overline{Q}_1, Q_2, \overline{Q}_2$
- Assign excitation variables to flip-flop inputs $D_1, D_2, J_1, K_1, J_2, K_2$

Excitation and output expressions for Fig. 1:

- $D_1 = \overline{x}\overline{Q}_2 + \overline{Q}_1 Q_2$
- $D_2 = x\overline{Q}_1 + \overline{Q}_1 Q_2$
- $z = \overline{x}Q_1 + x\overline{Q}_1\overline{Q}_2$

Excitation and output expressions for Fig 2:

- $J_1 = y$
- $K_1 = y + x\overline{Q}_2$
- $J_2 = x\overline{Q}_1 + \overline{x}yQ_1$
- $K_2 = x\overline{y} + yQ_1$
- $z_1 = Q_1\overline{Q}_2$
- $z_2 = Q_1 + \overline{Q}_2$

Transition Equations

Transition Equations for Figure 1:

- $Q^+{}_1 = D_1$
- $Q^+{}_2 = D_2$
- $Q^+{}_1 = \overline{x}\overline{Q}_2 + \overline{Q}_1 Q_2$
- $Q^+{}_2 = x\overline{Q}_1 + \overline{Q}_1 Q_2$

Transition Equations for Figure 2:

- $Q^+{}_1 = J_1\overline{Q}_1 + \overline{K}_1 Q_1$
- $Q^+{}_2 = \mathrm{J}_2\overline{Q}_2 + \overline{K}_2 Q_2$
- $Q^+{}_1 = \mathrm{y}\overline{Q}_1 + \overline{(y + x\overline{Q}_2)}Q_1 = \mathrm{y}\overline{Q}_1 + \overline{x}\,\overline{y}Q_1 + \overline{y}Q_1 Q_2$
- $Q^+{}_2 = (x\overline{Q}_1 + \overline{x}yQ_1)\overline{Q}_2 + \overline{(x\overline{y} + yQ_1)}Q_2 = \mathrm{x}\overline{Q}_1\overline{Q}_2 + \overline{x}yQ_1\overline{Q}_2 + \overline{x}\,\overline{y}Q_2 + \overline{x}\overline{Q}_1 Q_2 + y\overline{Q}_1 Q_2$

Excitation Table

- Excitation table consists of three parts:
  - Present-state section
  - Excitation section
  - Output section

Excitation Tables

Table 7.3 Excitation table for Example 7.1

Present state (Q_1Q_2)	Excitation (D_1D_2)		Output (z)	
	Input (x)		Input (x)	
	0	1	0	1
00	10	01	0	1
01	11	11	0	0
10	10	00	1	0
11	00	00	1	0

Table 7.4 Excitation table for Example 7.2

Present state (Q_1Q_2)	Excitation (J_1K_1,J_2K_2)				Output (z_1,z_2)
	Inputs (xy)				
	00	01	10	11	
00	00,00	11,00	01,11	11,10	01
01	00,00	11,00	00,11	11,10	00
10	00,00	11,11	01,01	11,01	11
11	00,00	11,11	00,01	11,01	01

Transition Tables

Rather than using algebraic descriptions can express the information in tabular form.

- Table consists of three sections
  - Present state variables
  - Next-state variables
  - Output variables
- Present state variables:
  - Lists all the possible combinations of values for the state variables.
  - If there are p state variables, then 2^p rows.
- Next-state section
  - One column for each combination of values of the external input variables.
  - If there are n external input variables, then 2^n columns.
  - Each entry is a p-tuple corresponding to the next state for each combination of present state and external input.
- Mealy network outputs:
  - One column for each combination of values of the external input variables.
  - Entries within the section indicate the outputs for each present-state/input combination.
- Moore network outputs:
  - Output section has only a single column.

Transition Tables

Table 7.3 Excitation table for Example 7.1

Present state (Q_1Q_2)	Excitation (D_1D_2) Input (x) 0	1	Output (z) Input (x) 0	1
00	10	01	0	1
01	11	11	0	0
10	10	00	1	0
11	00	00	1	0

Table 7.1 Transition table for Example 7.1

Present state (Q_1Q_2)	Next state ($Q_1^+Q_2^+$) Input (x) 0	1	Output (z) Input (x) 0	1
00	10	01	0	1
01	11	11	0	0
10	10	00	1	0
11	00	00	1	0

Transition Tables

Table 7.4 Excitation table for Example 7.2

Present state (Q_1Q_2)	Excitation (J_1K_1,J_2K_2) Inputs (xy) 00	01	10	11	Output (z_1,z_2)
00	00,00	11,00	01,11	11,10	01
01	00,00	11,00	00,11	11,10	00
10	00,00	11,11	01,01	11,01	11
11	00,00	11,11	00,01	11,01	01

Table 7.2 Transition table for Example 7.2

Present state (Q_1Q_2)	Next state ($Q_1^+Q_2^+$) Inputs (xy) 00	01	10	11	Output (z_1z_2)
00	00	10	01	11	01
01	01	11	00	11	00
10	10	01	00	00	11
11	11	00	10	00	01

Constructing Transition Tables from Excitation Tables

- The transition table is constructed as the result of substituting excitation expressions into the flip-flop characteristic equations.
- An alternative approach:
  - First construct the excitation table directly from the excitation and output expressions.

Constructing Transition Tables from Excitation Tables

- Consider entry in fourth column, first row of 7.2 excitation table:
  - $J_1K_1, J_2K_2 = 11{,}10$
  - Present state: $Q_1Q_2 = 00$
  - So due to behavior of JK-flip-flop next state is: ${Q^+}_1 = 1, {Q^+}_2 = 1.$

State Tables

- State table consists of three sections:
  - Present state
  - Next state
  - Output
- Actual binary codes used to represent the states are not important.
- Alphanumeric symbols can be assigned to represent these states.
- State table is essentially a relabeling of the transition table.

State Tables

Table 7.1 Transition table for Example 7.1

Present state (Q_1Q_2)	Next state ($Q_1^+Q_2^+$)		Output (z)	
	Input (x)		Input (x)	
	0	**1**	**0**	**1**
00	10	01	0	1
01	11	11	0	0
10	10	00	1	0
11	00	00	1	0

Table 7.5 State table for Example 7.1

Present state	Next state		Output (z)	
	Input (x)		Input (x)	
	0	**1**	**0**	**1**
$00 \rightarrow A$	C	B	0	1
$01 \rightarrow B$	D	D	0	0
$10 \rightarrow C$	C	A	1	0
$11 \rightarrow D$	A	A	1	0

State Tables

Table 7.2 Transition table for Example 7.2

Present state (Q_1Q_2)	Next state ($Q_1^+Q_2^+$) Inputs (xy) 00	01	10	11	Output (z_1z_2)
00	00	10	01	11	01
01	01	11	00	11	00
10	10	01	00	00	11
11	11	00	10	00	01

Table 7.6 State table for Example 7.2

Present state	Next state Inputs (xy) 00	01	10	11	Output (z_1z_2)
$00 \rightarrow A$	A	C	B	D	01
$01 \rightarrow B$	B	D	A	D	00
$10 \rightarrow C$	C	B	A	A	11
$11 \rightarrow D$	D	A	C	A	01

State Diagrams

- Graphical representation of the state table.
  - Each state is represented by a labeled node.
  - Directed branches connect the nodes to indicate transitions between states.
  - Directed branches are labeled according to the values of the external input variables.
  - Outputs of the sequential network are also entered on a state diagram.
- Mealy network:
  - Outputs appear on the directed branches along with the external inputs.
- Moore network:
  - Outputs are included within the nodes along with their associated states.

State Diagrams

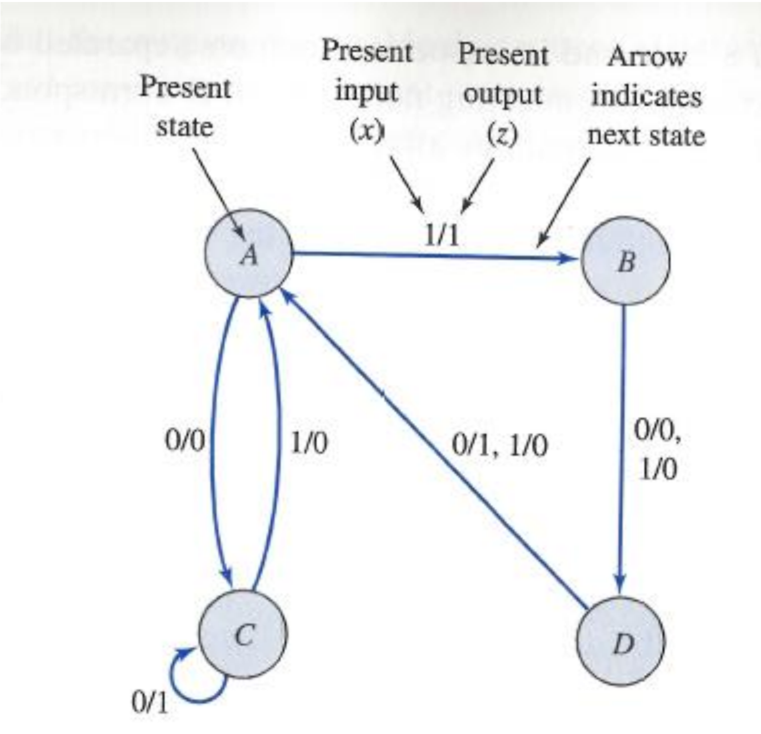


Figure 7.7 State diagram for Example 7.1.

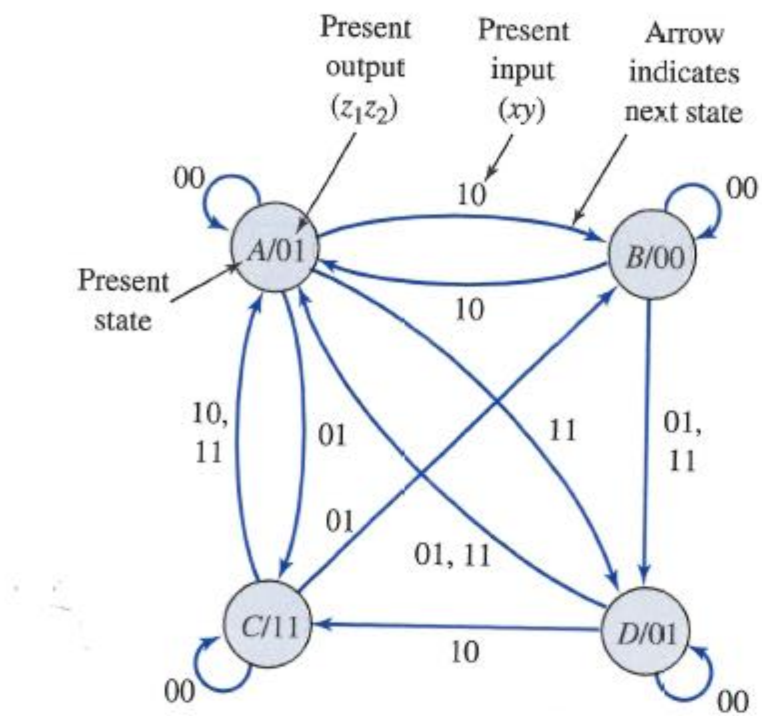


Figure 7.8 State diagram for Example 7.2.