

EE2000 Logic Circuit Design

Sequential Logic Circuit Design Part2

Outline

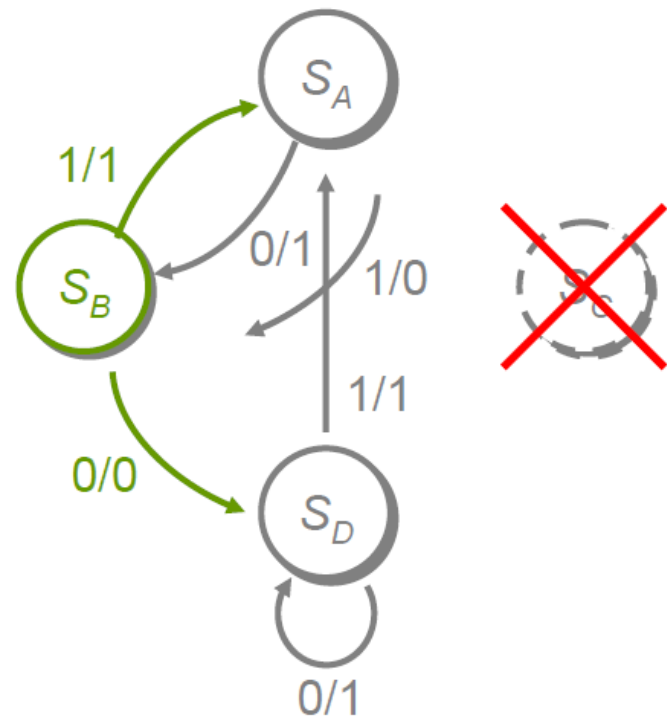
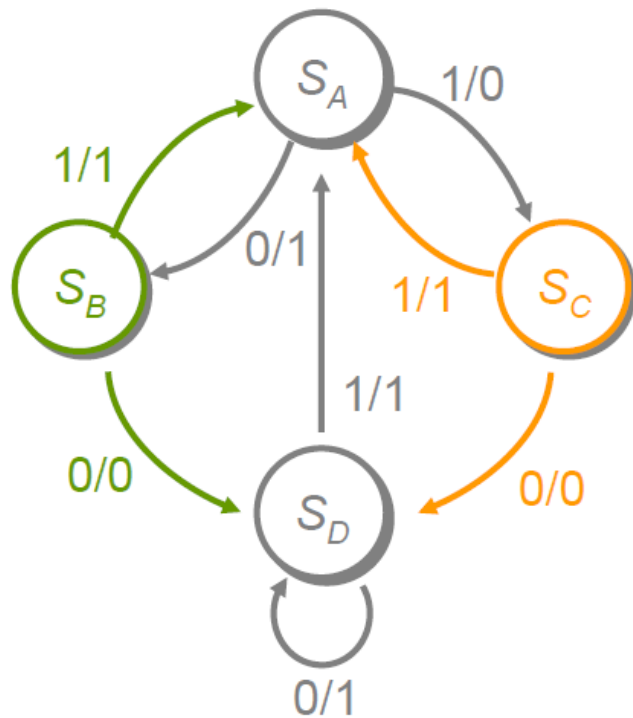
- 8.1 Redundant State Elimination
 - Inspection
 - Partitioning
 - Implication Table
- 8.2 Sequential Circuit Analysis
- 8.3 Design with Programmable Logic Device

State Elimination

- For combination logic circuits, minimizing the output functions means:
 - reducing the number of logic gates
 - reducing the cost and space of the circuit
- For sequential logic circuits, minimizing the state table means
 - reducing the redundant states (e.g number of FlipFlops)
 - Reducing the cost and space

Concept of Equivalent States

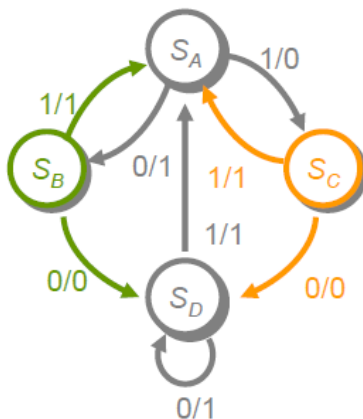
■ Are these two state diagram equivalent?



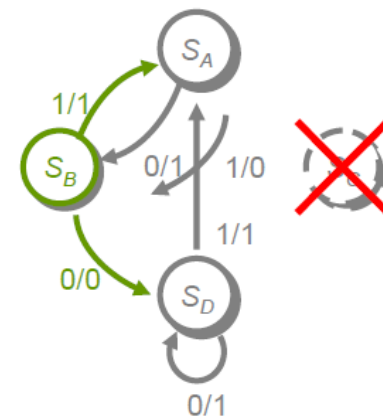
Concept of Equivalent States

■ Compare their state table

Present State (PS)	Input X	
	0	1
S_A	$S_B / 1$	$S_C / 0$
S_B	$S_D / 0$	$S_A / 1$
S_C	$S_D / 0$	$S_A / 1$
S_D	$S_D / 1$	$S_A / 1$



Present State (PS)	Input X	
	0	1
S_A	$S_B / 1$	$S_C / 0$
S_B	$S_D / 0$	$S_A / 1$
~~S_C~~	~~$S_D / 0$~~	~~$S_A / 1$~~
S_D	$S_D / 1$	$S_A / 1$



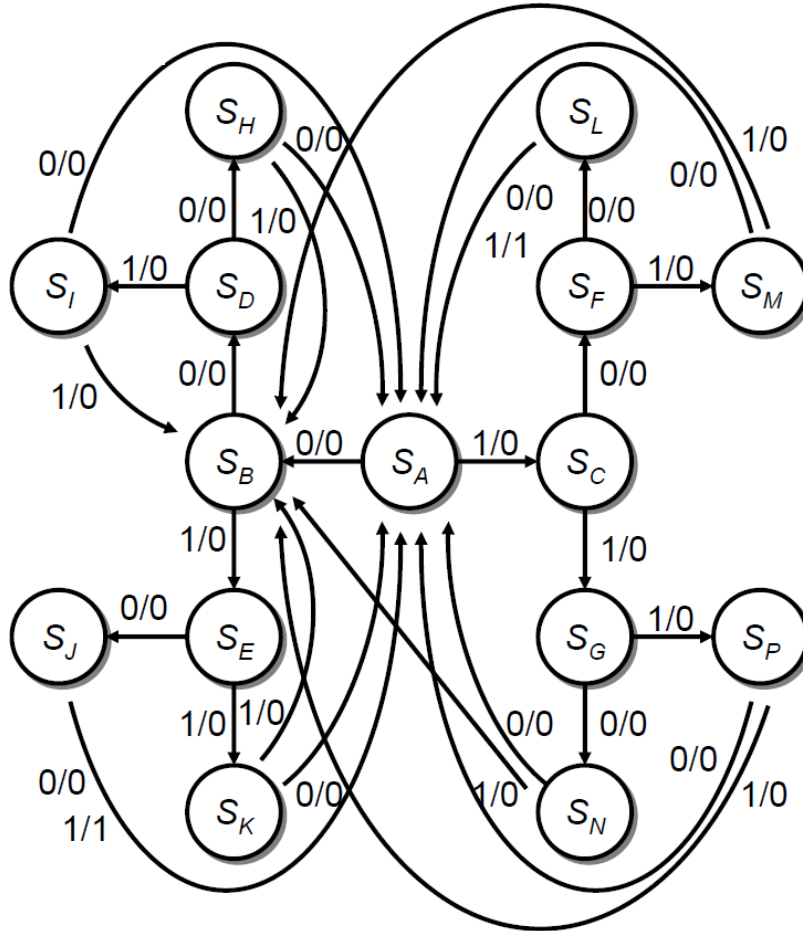
Concept of Equivalent States

- Two states with the same input conditions:
 1. provides same outputs.
 2. provides same corresponding next state.

They are called **equivalent states**.

- If the a redundant state is found, then it can be eliminated.

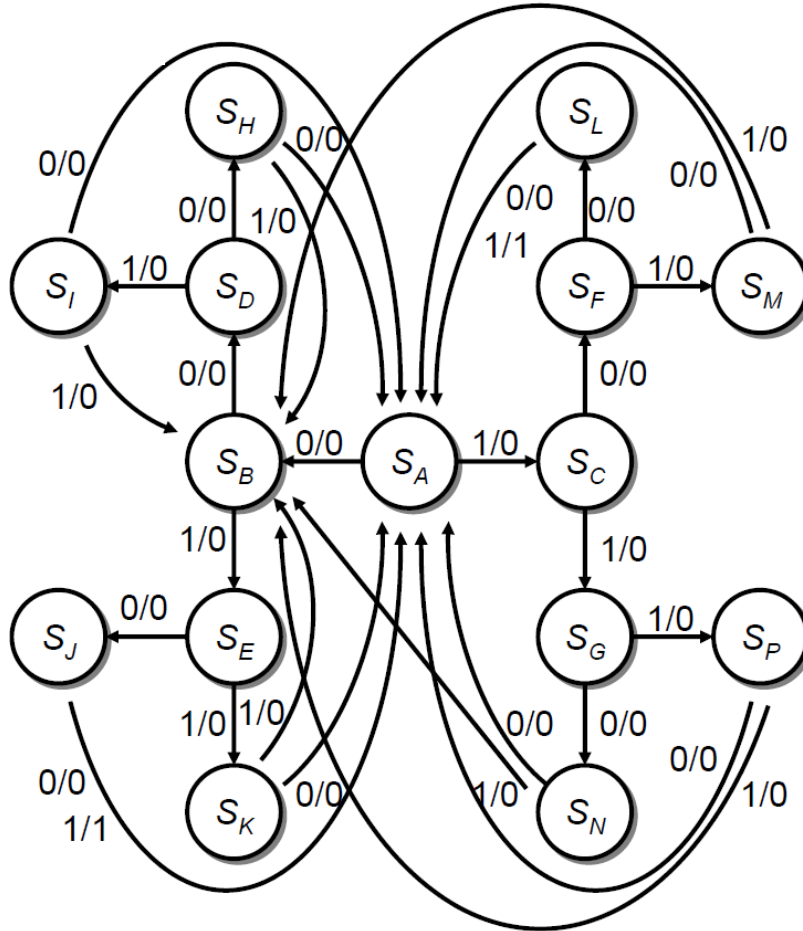
Inspection



Could you find redundant states from the state diagram?

Please derive the state table from the state diagram

Inspection



Present State (PS)	Input X	
	0	1
S_A	$S_B / 0$	$S_C / 0$
S_B	$S_D / 0$	$S_E / 0$
S_C	$S_F / 0$	$S_G / 0$
S_D	$S_H / 0$	$S_I / 0$
S_E	$S_J / 0$	$S_K / 0$
S_F	$S_L / 0$	$S_M / 0$
S_G	$S_N / 0$	$S_P / 0$
S_H	$S_A / 0$	$S_B / 0$
S_I	$S_A / 0$	$S_B / 0$
S_J	$S_A / 0$	$S_A / 1$
S_K	$S_A / 0$	$S_B / 0$
S_L	$S_A / 0$	$S_A / 1$
S_M	$S_A / 0$	$S_B / 0$
S_N	$S_A / 0$	$S_B / 0$
S_P	$S_A / 0$	$S_B / 0$

Inspection

Present State (PS)	Input X	
	0	1
S_A	$S_B / 0$	$S_C / 0$
S_B	$S_D / 0$	$S_E / 0$
S_C	$S_F / 0$	$S_G / 0$
S_D	$S_H / 0$	$S_I / 0$
S_E	$S_J / 0$	$S_K / 0$
S_F	$S_L / 0$	$S_M / 0$
S_G	$S_N / 0$	$S_P / 0$
S_H	$S_A / 0$	$S_B / 0$
S_I	$S_A / 0$	$S_B / 0$
S_J	$S_A / 0$	$S_A / 1$
S_K	$S_A / 0$	$S_B / 0$
S_L	$S_A / 0$	$S_A / 1$
S_M	$S_A / 0$	$S_B / 0$
S_N	$S_A / 0$	$S_B / 0$
S_P	$S_A / 0$	$S_B / 0$

Key: Find states that have same next state and outputs

$S_A / 0 \quad S_B / 0$

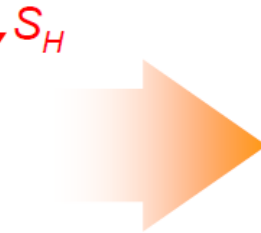
$S_A / 0 \quad S_A / 1$

Result: $S_H = S_I = S_K = S_M = S_N = S_P$

Result: $S_J = S_L$

Eliminate Redundant States

Present State (PS)	Input X	
	0	1
S_A	$S_B / 0$	$S_C / 0$
S_B	$S_D / 0$	$S_E / 0$
S_C	$S_F / 0$	$S_G / 0$
S_D	$S_H / 0$	$S_I / 0$
S_E	$S_J / 0$	$S_K / 0$
S_F	$S_L / 0$	$S_M / 0$
S_G	$S_N / 0$	$S_P / 0$
S_H	$S_A / 0$	$S_B / 0$
~~S_I~~	~~$S_A / 0$~~	~~$S_B / 0$~~
S_J	$S_A / 0$	$S_A / 1$
~~S_K~~	~~$S_A / 0$~~	~~$S_B / 0$~~
~~S_L~~	~~$S_A / 0$~~	~~$S_A / 1$~~
~~S_M~~	~~$S_A / 0$~~	~~$S_B / 0$~~
~~S_N~~	~~$S_A / 0$~~	~~$S_B / 0$~~
~~S_P~~	~~$S_A / 0$~~	~~$S_B / 0$~~



Present State (PS)	Input X	
	0	1
S_A	$S_B / 0$	$S_C / 0$
S_B	$S_D / 0$	$S_E / 0$
S_C	$S_F / 0$	$S_G / 0$
S_D	$S_H / 0$	$S_H / 0$
S_E	$S_J / 0$	$S_H / 0$
S_F	$S_J / 0$	$S_H / 0$
S_G	$S_H / 0$	$S_H / 0$
S_H	$S_A / 0$	$S_B / 0$
S_J	$S_A / 0$	$S_A / 1$

Find and Eliminate Again

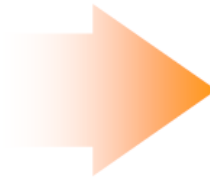
Present State (PS)	Input X	
	0	1
S_A	$S_B / 0$	$S_C / 0$
S_B	$S_D / 0$	$S_E / 0$
S_C	$S_F / 0$	$S_G / 0$
S_D	$S_H / 0$	$S_H / 0$
S_E	$S_J / 0$	$S_H / 0$
S_F	$S_J / 0$	$S_H / 0$
S_G	$S_H / 0$	$S_H / 0$
S_H	$S_A / 0$	$S_B / 0$
S_J	$S_A / 0$	$S_A / 1$

$S_H / 0$ $S_H / 0$

Present State (PS)	Input X	
	0	1
S_A	$S_B / 0$	$S_C / 0$
S_B	$S_D / 0$	$S_E / 0$
S_C	$S_F / 0$	$S_G / 0$
S_D	$S_H / 0$	$S_H / 0$
S_E	$S_J / 0$	$S_H / 0$
S_F	$S_J / 0$	$S_H / 0$
~~S_G~~	~~$S_H / 0$~~	~~$S_H / 0$~~
S_H	$S_A / 0$	$S_B / 0$
S_J	$S_A / 0$	$S_A / 1$

The Final State Table

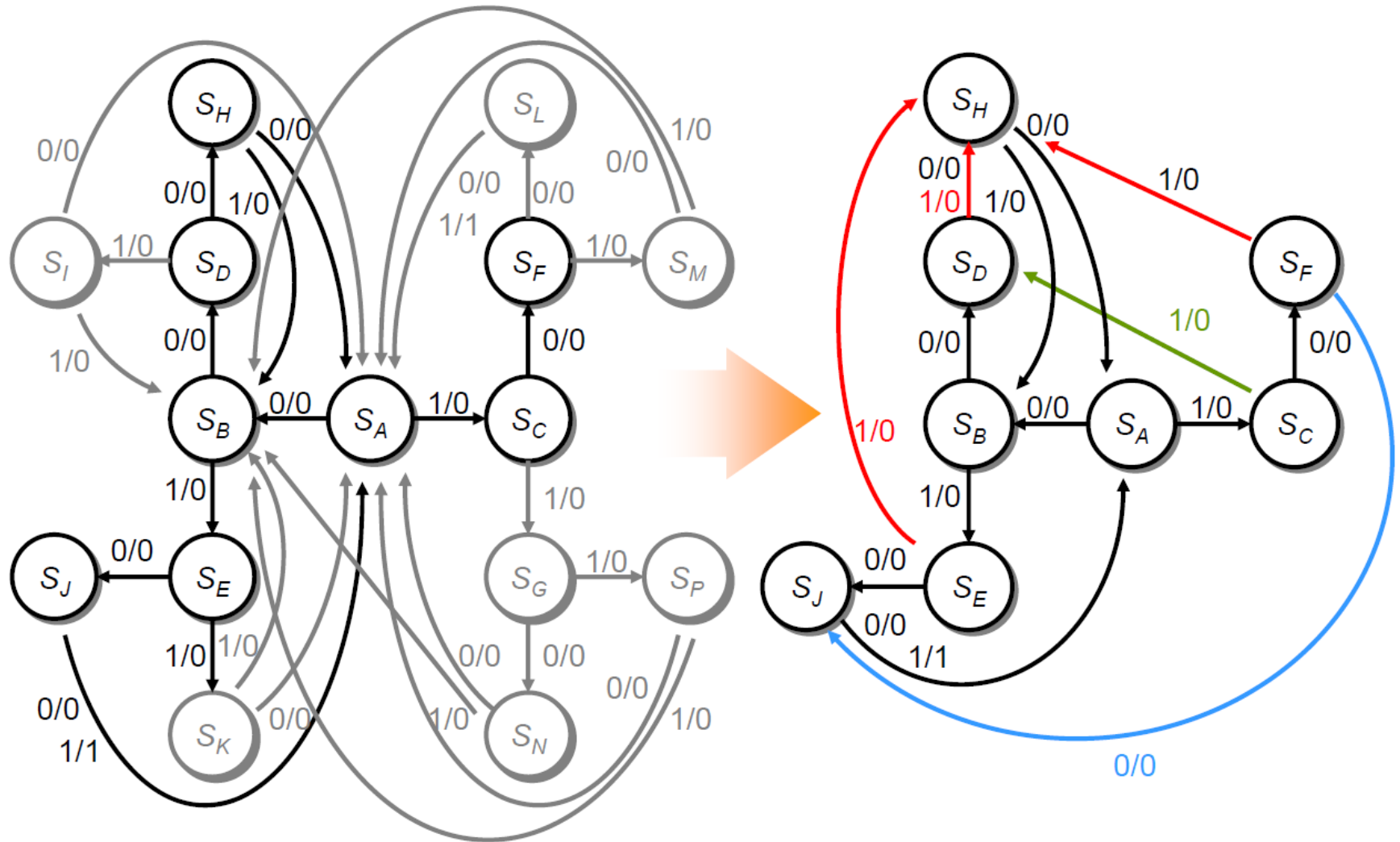
Present State (PS)	Input X	
	0	1
S_A	$S_B / 0$	$S_C / 0$
S_B	$S_D / 0$	$S_E / 0$
S_C	$S_F / 0$	$S_G / 0$
S_D	$S_H / 0$	$S_I / 0$
S_E	$S_J / 0$	$S_K / 0$
S_F	$S_L / 0$	$S_M / 0$
S_G	$S_N / 0$	$S_P / 0$
S_H	$S_A / 0$	$S_B / 0$
S_I	$S_A / 0$	$S_B / 0$
S_J	$S_A / 0$	$S_A / 1$
S_K	$S_A / 0$	$S_B / 0$
S_L	$S_A / 0$	$S_A / 1$
S_M	$S_A / 0$	$S_B / 0$
S_N	$S_A / 0$	$S_B / 0$
S_P	$S_A / 0$	$S_B / 0$



Present State (PS)	Input X	
	0	1
S_A	$S_B / 0$	$S_C / 0$
S_B	$S_D / 0$	$S_E / 0$
S_C	$S_F / 0$	$S_D / 0$
S_D	$S_H / 0$	$S_H / 0$
S_E	$S_J / 0$	$S_H / 0$
S_F	$S_J / 0$	$S_H / 0$
S_H	$S_A / 0$	$S_B / 0$
S_J	$S_A / 0$	$S_A / 1$

Further reduce?

The Final State Diagram



Partitioning

- Step 1
 - Partition the states into different groups such that each group of states have the same outputs for each input
- Step 2
 - Further partition the states into smaller subgroups if their next states are not belongs to the same group
- Step 3
 - Repeat step 2 until no more states can be partitioned
- Finally, the states in the same partition until the end are equivalent

Partitioning

- Group the states that have the same outputs for each input

Present State (PS)	Input X	
	0	1
S_A	$S_B / 0$	$S_E / 0$
S_B	$S_E / 0$	$S_D / 0$
S_C	$S_D / 1$	$S_A / 0$
S_D	$S_C / 1$	$S_E / 0$
S_E	$S_B / 0$	$S_D / 0$

$$P_0 = (S_A S_B S_C S_D S_E)$$



Present State (PS)	Input X	
	0	1
S_A	$S_B / 0$	$S_E / 0$
S_B	$S_E / 0$	$S_D / 0$
S_E	$S_B / 0$	$S_D / 0$
S_C	$S_D / 1$	$S_A / 0$
S_D	$S_C / 1$	$S_E / 0$

$$P_1 = (S_A S_B S_E)(S_C S_D)$$

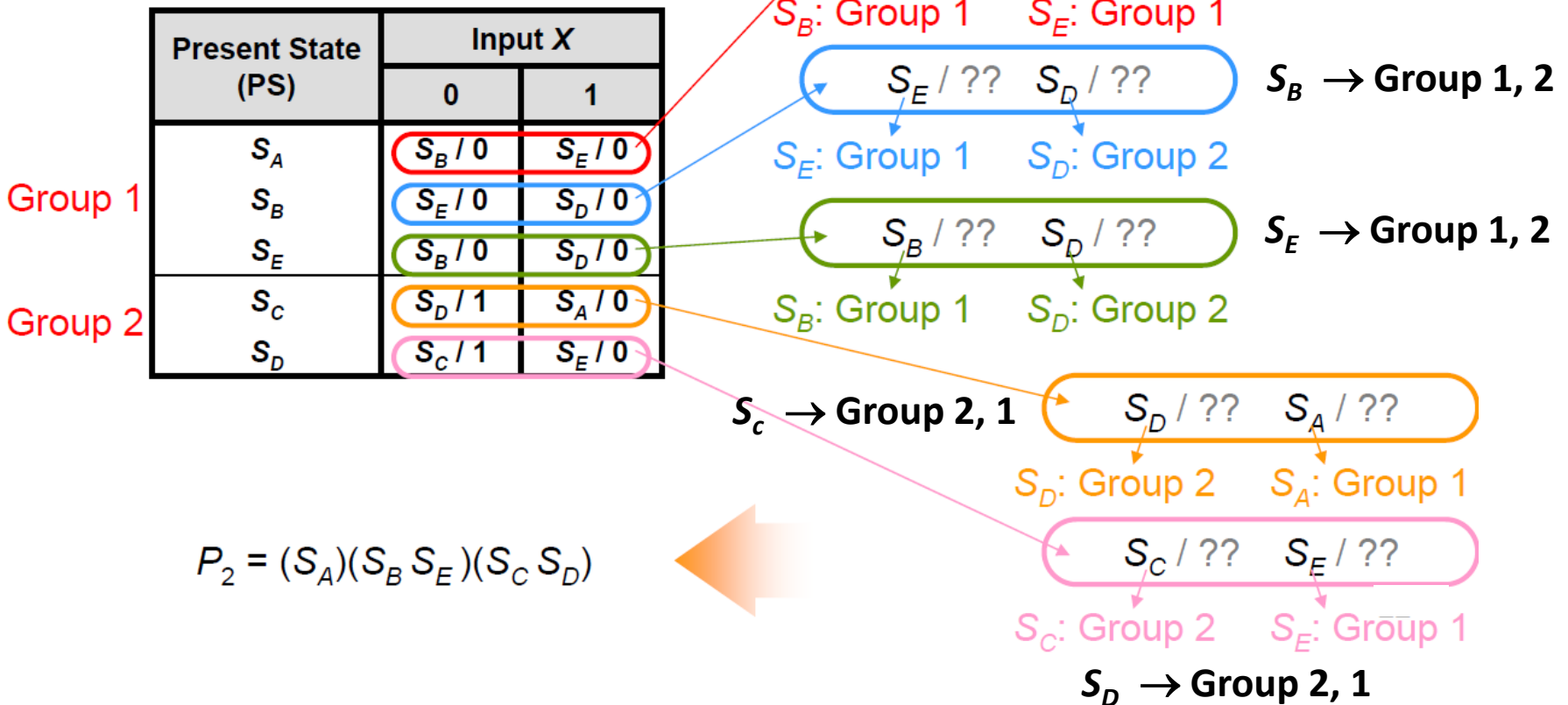
outputs

} 00

} 10

Partitioning

- Group the states that their next states are in the same group



Partitioning

■ Repeat step 2

	Present State (PS)	Input X	
		0	1
Group 1	S_A	$S_B / 0$	$S_E / 0$
Group 2	S_B	$S_E / 0$	$S_D / 0$
	S_E	$S_B / 0$	$S_D / 0$
Group 3	S_C	$S_D / 1$	$S_A / 0$
	S_D	$S_C / 1$	$S_E / 0$

$$P_2 = (S_A) \underset{23}{(S_B \ S_E)} \underset{31 \ 32}{(S_C \ S_D)}$$



	Present State (PS)	Input X	
		0	1
Group 1	S_A	$S_B / 0$	$S_E / 0$
Group 2	S_B	$S_E / 0$	$S_D / 0$
Group 3	S_E	$S_B / 0$	$S_D / 0$
Group 4	S_C	$S_D / 1$	$S_A / 0$
	S_D	$S_C / 1$	$S_E / 0$

$$P_3 = (S_A) \underset{24 \ 24}{(S_B \ S_E)} (S_C) (S_D)$$

Partitioning

- As no more states can be further partitioned, the states in the same partition are equivalent

Present State (PS)	Input X	
	0	1
S_A	$S_B / 0$	$S_E / 0$
S_B	$S_E / 0$	$S_D / 0$
S_E	$S_B / 0$	$S_D / 0$
S_C	$S_D / 1$	$S_A / 0$
S_D	$S_C / 1$	$S_E / 0$

S_B and S_E are equivalent



Final State Table

Eliminated the redundant states, and also replace the next states

Present State (PS)	Input X	
	0	1
S_A	$S_B / 0$	$S_B / 0$
S_B	$S_B / 0$	$S_D / 0$
S_C	$S_D / 1$	$S_A / 0$
S_D	$S_C / 1$	$S_B / 0$

Implication Table

- Step 1: Draw the implication table
- Step 2: Output Partitioning
- Step 3: Find the implied pairs
- Step 4: Cross out the implied pairs if they are not equivalent
- Step 5: Repeat until all non-equivalent implied pairs are crossed out
- Step 6: The remaining squares are equivalent states

Implication Table

- Draw the implication table like the following such that each two pairs of state share a square

State Table

Present State (PS)	Input X	
	0	1
S_A	$S_E / 0$	$S_D / 1$
S_B	$S_F / 0$	$S_D / 0$
S_C	$S_E / 0$	$S_B / 1$
S_D	$S_F / 0$	$S_B / 0$
S_E	$S_C / 0$	$S_F / 1$
S_F	$S_B / 0$	$S_C / 0$

Implication Table

S_B					
S_C					
S_D					
S_E					
S_F					
	S_A	S_B	S_C	S_D	S_E

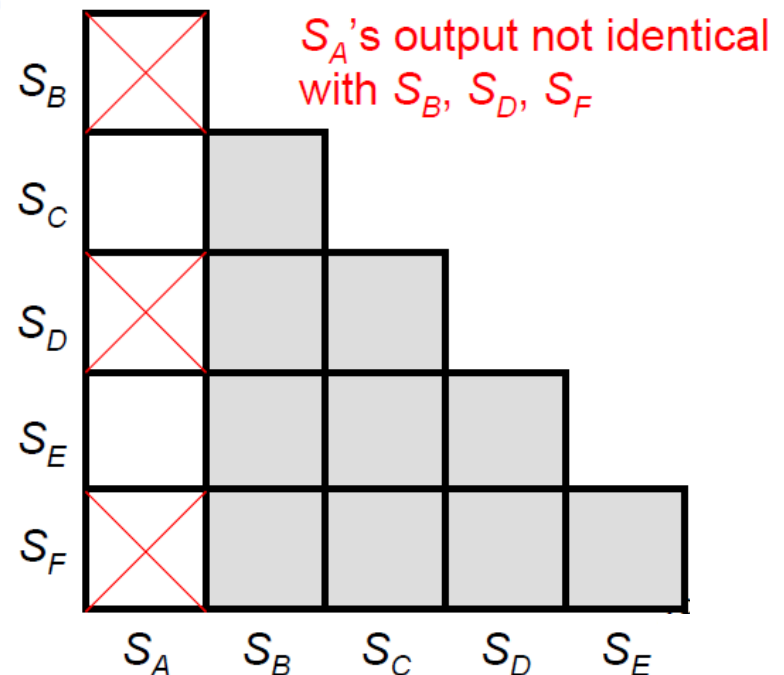
Implication Table

- Output Partitioning: Mark a cross on the squares whose pair of states' output are not identical

State Table

Present State (PS)	Input X	
	0	1
S_A	$S_E / 0$	$S_D / 1$
S_B	$S_F / 0$	$S_D / 0$
S_C	$S_E / 0$	$S_B / 1$
S_D	$S_F / 0$	$S_B / 0$
S_E	$S_C / 0$	$S_F / 1$
S_F	$S_B / 0$	$S_C / 0$

Implication Table



Implication Table

- Now consider column S_B

State Table

Present State (PS)	Input X	
	0	1
S_A	$S_E / 0$	$S_D / 1$
S_B	$S_F / 0$	$S_D / 0$
S_C	$S_E / 0$	$S_B / 1$
S_D	$S_F / 0$	$S_B / 0$
S_E	$S_C / 0$	$S_F / 1$
S_F	$S_B / 0$	$S_C / 0$

?? / 0 ?? / 0

Implication Table

S_B					
S_C					
S_D					
S_E					
S_F					
	S_A	S_B	S_C	S_D	S_E

S_B 's output not identical with S_C , S_E

Implication Table

- Now consider column S_C

State Table

Present State (PS)	Input X	
	0	1
S_A	$S_E / 0$	$S_D / 1$
S_B	$S_F / 0$	$S_D / 0$
S_C	$S_E / 0$	$S_B / 1$
S_D	$S_F / 0$	$S_B / 0$
S_E	$S_C / 0$	$S_F / 1$
S_F	$S_B / 0$	$S_C / 0$

Implication Table

S_B					
S_C					
S_D					
S_E					
S_F					
	S_A	S_B	S_C	S_D	S_E

S_C 's output not identical with S_D , S_F

Implication Table

- Now consider column S_D

State Table

Present State (PS)	Input X	
	0	1
S_A	$S_E / 0$	$S_D / 1$
S_B	$S_F / 0$	$S_D / 0$
S_C	$S_E / 0$	$S_B / 1$
S_D	$S_F / 0$	$S_B / 0$
S_E	$S_C / 0$	$S_F / 1$
S_F	$S_B / 0$	$S_C / 0$

Implication Table

S_D 's output not identical with S_E

S_B				
S_C				
S_D				
S_E				
S_F				
	S_A	S_B	S_C	S_D

Implication Table

■ Now consider column S_E

State Table

Present State (PS)	Input X	
	0	1
S_A	$S_E / 0$	$S_D / 1$
S_B	$S_F / 0$	$S_D / 0$
S_C	$S_E / 0$	$S_B / 1$
S_D	$S_F / 0$	$S_B / 0$
S_E	$S_C / 0$	$S_F / 1$
S_F	$S_B / 0$	$S_C / 0$

Implication Table

S_B					
S_C					
S_D					
S_E					
S_F					
	S_A	S_B	S_C	S_D	S_E

S_E 's output not identical with S_F

Implication Table

- Find the implied pairs by writing the pairs of next states whose equivalence is implied by the two states of blank squares

State Table

Present State (PS)	Input X	
	0	1
S_A	$S_E / 0$	$S_D / 1$
S_B	$S_F / 0$	$S_D / 0$
S_C	$S_E / 0$	$S_B / 1$
S_D	$S_F / 0$	$S_B / 0$
S_E	$S_C / 0$	$S_F / 1$
S_F	$S_B / 0$	$S_C / 0$

$S_E / ??$ $S_D / ??$

Implication Table

S_B					
S_C	$S_E S_E$ $S_D S_B$				
S_D					
S_E					
S_F					
	S_A	S_B	S_C	S_D	S_E

State Table

Present State (PS)	Input X	
	0	1
S_A	$S_E / 0$	$S_D / 1$
S_B	$S_F / 0$	$S_D / 0$
S_C	$S_E / 0$	$S_B / 1$
S_D	$S_F / 0$	$S_B / 0$
S_E	$S_C / 0$	$S_F / 1$
S_F	$S_B / 0$	$S_C / 0$

$S_E / ??$ $S_D / ??$

Implication Table

S_B					
S_C	$S_E S_E$ $S_D S_B$				
S_D					
S_E	$S_E S_C$ $S_D S_F$				
S_F					
	S_A	S_B	S_C	S_D	S_E

S_A equivalent to S_E or not?

State Table

Present State (PS)	Input X	
	0	1
S_A	$S_E / 0$	$S_D / 1$
S_B	$S_F / 0$	$S_D / 0$
S_C	$S_E / 0$	$S_B / 1$
S_D	$S_F / 0$	$S_B / 0$
S_E	$S_C / 0$	$S_F / 1$
S_F	$S_B / 0$	$S_C / 0$

$S_F / ??$ $S_D / ??$

Implication Table

S_B					
S_C	$S_E S_E$ $S_D S_B$				
S_D		$S_F S_F$ $S_D S_B$			
S_E	$S_E S_C$ $S_D S_F$				
S_F					
	S_A	S_B	S_C	S_D	S_E

S_B equivalent to S_D or not?

Implication Table

State Table

Present State (PS)	Input X	
	0	1
S_A	$S_E / 0$	$S_D / 1$
S_B	$S_F / 0$	$S_D / 0$
S_C	$S_E / 0$	$S_B / 1$
S_D	$S_F / 0$	$S_B / 0$
S_E	$S_C / 0$	$S_F / 1$
S_F	$S_B / 0$	$S_C / 0$

$S_F / ??$ $S_B / ??$

Implication Table

S_B					
S_C	$S_E S_E$ $S_D S_B$				
S_D		$S_F S_F$ $S_D S_B$			
S_E	$S_E S_C$ $S_D S_F$		$S_E S_C$ $S_B S_F$		
S_F		$S_F S_B$ $S_D S_C$		$S_F S_B$ $S_B S_C$	
	S_A	S_B	S_C	S_D	S_E

S_D equivalent to S_F or not?

Complete the implied pairs for all blocks without cross $\times$.

Implication Table

- Cross out the implied pairs if their states are not equivalent

S_A and S_C are equivalent only if S_E and S_E are equivalent, AND S_D and S_B are equivalent

Cross out the pair-state if they are identical

Implication Table

The diagram shows an implication table for states $S_A, S_B, S_C, S_D, S_E, S_F$. The table is a lower triangular matrix where each cell contains a pair of states. Red arrows and text highlight the relationship between S_A and S_C .

	S_A	S_B	S_C	S_D	S_E	S_F
S_B	$S_A S_C$					
S_C	$S_E S_E$ $S_D S_B$					
S_D		$S_F S_F$ $S_D S_B$				
S_E	$S_E S_C$ $S_D S_F$		$S_E S_C$ $S_B S_F$			
S_F		$S_F S_B$ $S_D S_C$		$S_F S_B$ $S_B S_C$		

Red arrows point from the text " S_A equivalent to S_C or not?" to the $S_A S_C$ cell and the $S_E S_E$ cell.

Implication Table

■ Now consider another cell

S_B and S_D are equivalent only
if S_F and S_F are equivalent, AND
 S_D and S_B are equivalent

Check the **pair-state** output.
If the output is located at the
correct block, then give a “✓”.

Implication Table

S_B					
S_C	$S_D S_B$				
S_D	~~$S_F S_F$~~ $S_D S_B$ ✓				
S_E	$S_E S_C$ $S_D S_F$		$S_E S_C$ $S_B S_F$		
S_F		$S_F S_B$ $S_D S_C$		$S_F S_B$ $S_B S_C$	
	S_A	S_B	S_C	S_D	S_E

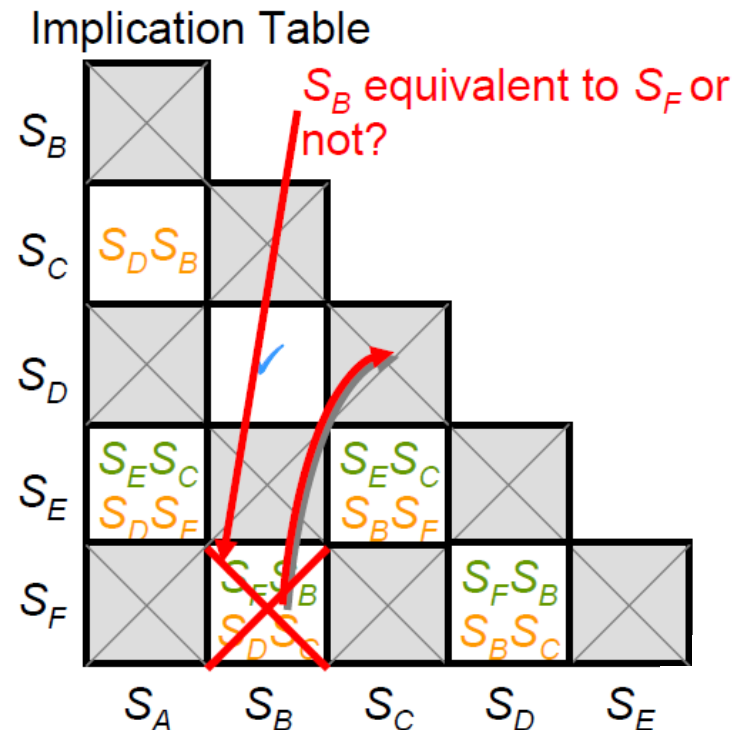
S_B equivalent to S_D or not?

Implication Table

■ Now consider another cell

S_B and S_F are equivalent only
if S_F and S_B are equivalent, AND
 S_D and S_C are equivalent

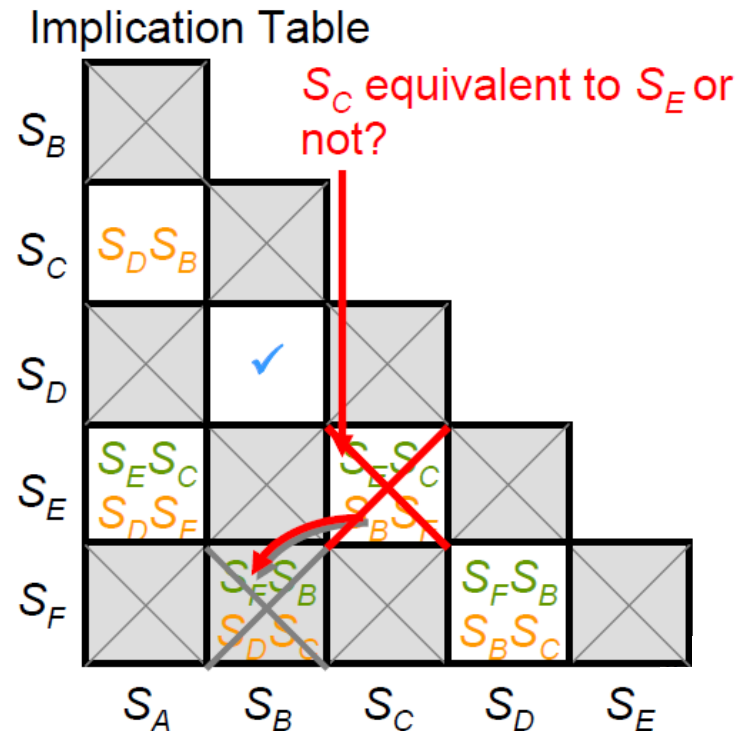
Check the **pair-state** output.
If the output is related to X-
block, then this output should
be crossed out.



Implication Table

Now consider another cell

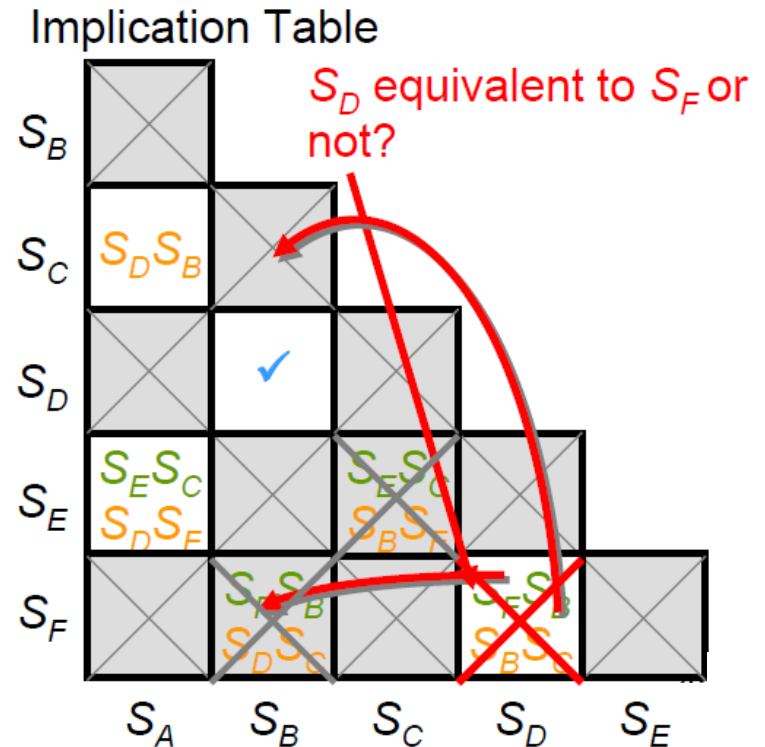
S_C and S_E are equivalent only
if S_E and S_C are equivalent, AND
 S_B and S_F are equivalent



Implication Table

■ Now consider another cell

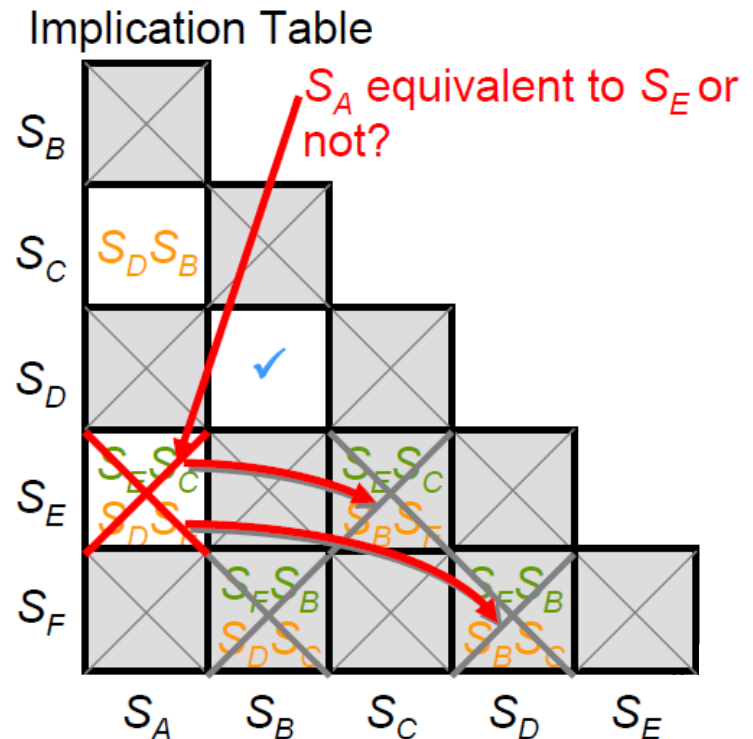
S_C and S_E are equivalent only
if S_E and S_C are equivalent, AND
 S_B and S_F are equivalent



Implication Table

- Now consider another uncrossed cell again

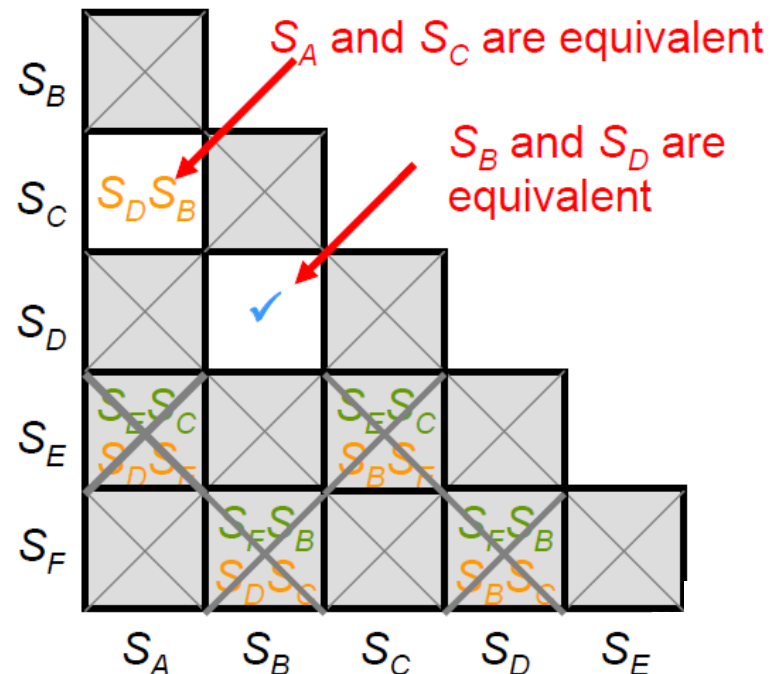
S_A and S_E are equivalent only
if S_E and S_C are equivalent, AND
 S_D and S_F are equivalent



Implication Table

- Repeat until no implied pairs can be further crossed out
- The remaining uncrossed cells are equivalent states

Present State (PS)	Input X	
	0	1
S_A	$S_E / 0$	$S_D / 1$
S_B	$S_F / 0$	$S_D / 0$
~~S_C~~	~~$S_E / 0$~~	~~$S_B / 1$~~
~~S_D~~	~~$S_F / 0$~~	~~$S_B / 0$~~
S_E	$S_C / 0$	$S_F / 1$
S_F	$S_B / 0$	$S_C / 0$

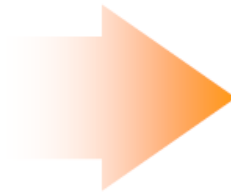


Implication Table

- Eliminate the redundant states
- Also replace the next states

State Table

Present State (PS)	Input X	
	0	1
S_A	$S_E / 0$	$S_D / 1$
S_B	$S_F / 0$	$S_D / 0$
~~S_C~~	~~$S_E / 0$~~	~~$S_B / 1$~~
~~S_D~~	~~$S_F / 0$~~	~~$S_B / 0$~~
S_E	$S_C / 0$	$S_F / 1$
S_F	$S_B / 0$	$S_C / 0$



Reduced State Table

Present State (PS)	Input X	
	0	1
S_A	$S_E / 0$	$S_B / 1$
S_B	$S_F / 0$	$S_B / 0$
S_E	$S_A / 0$	$S_F / 1$
S_F	$S_B / 0$	$S_A / 0$

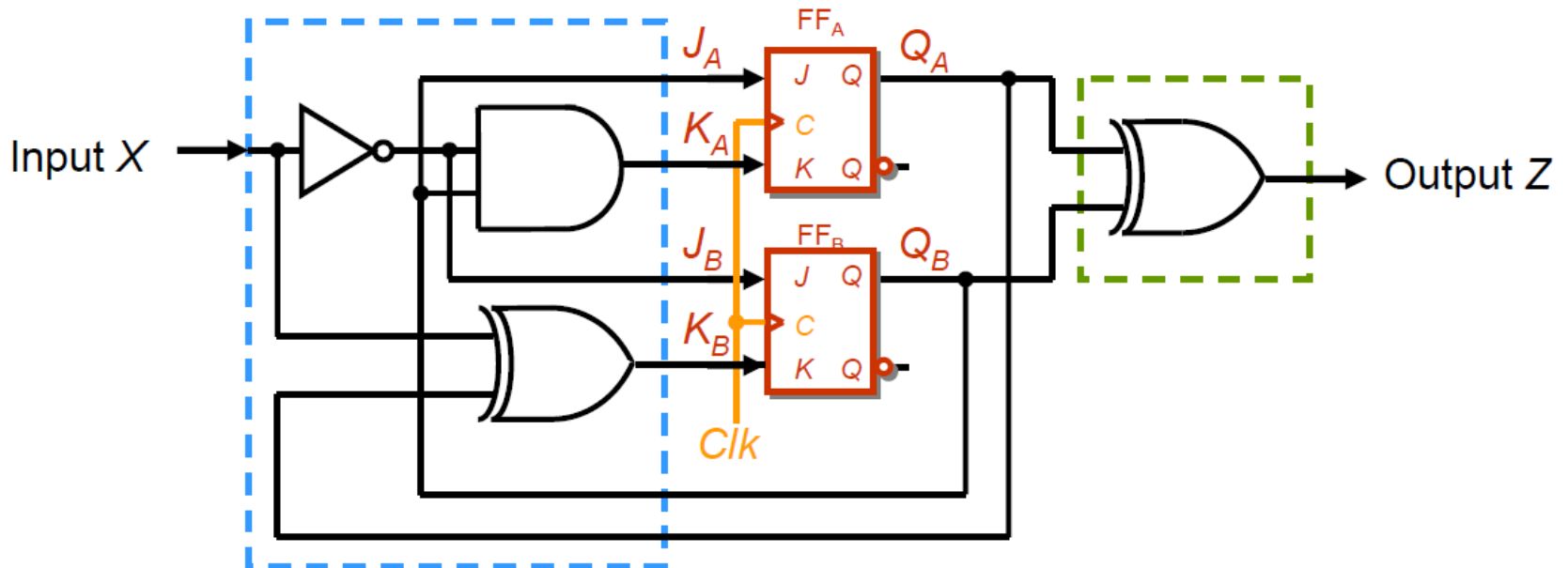
Summary of 8.1

- There are three methods to reduce the state table
 - Inspection
 - Partitioning
 - Implication table
- By eliminating the redundant states
 - Minimize the state table
 - Minimize the number of flip-flops
 - Minimize the implementation cost

8.2 Sequential Circuit Analysis

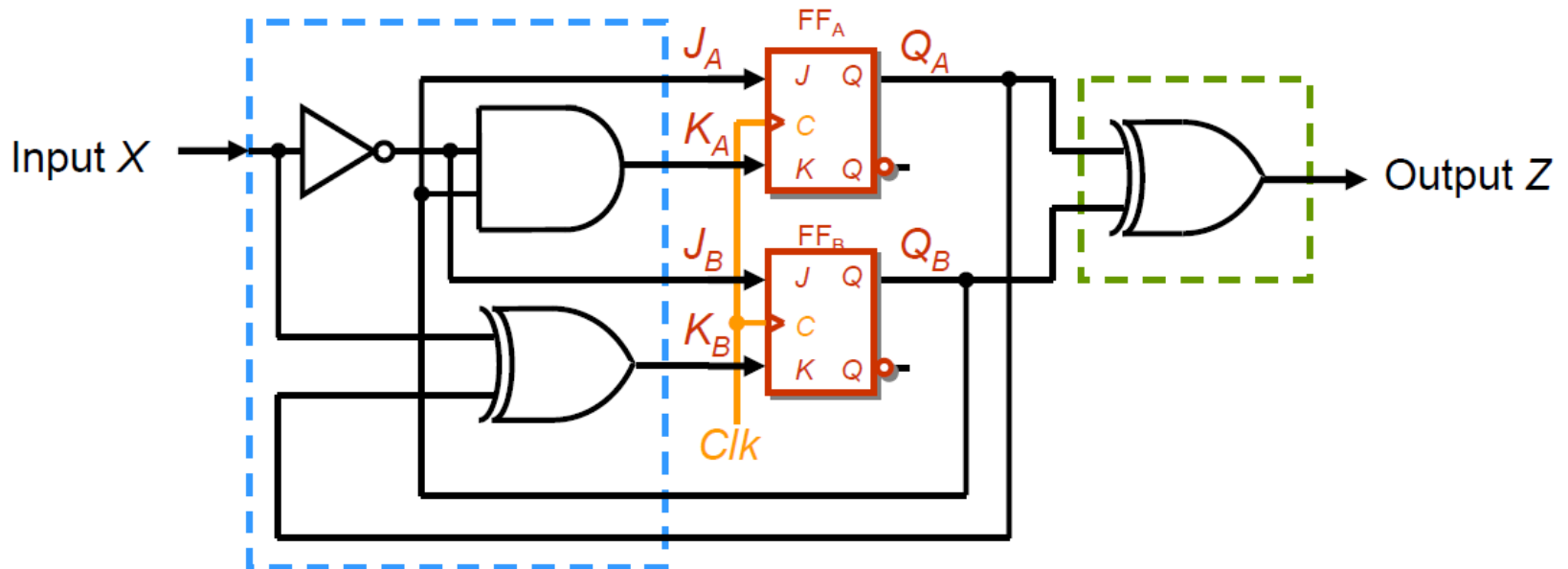
- To analysis a sequential circuit
 - To verify the circuit
 - To determine its state model
 - To obtain its state diagram
 - To obtain its state table
 - To obtain its state equation

Analysis Example



- **First**, determine its state model
 - Mealy, or Moore?

Analysis Example



■ **Next**, determine the flip-flop input functions

■ $J_A = Q_B, K_A = X'Q_B$

■ $J_B = X', K_B = X \oplus Q_A$

Analysis Example

- Start analysis

- Number of flip-flops: 2

- Since there are two flip-flops, this circuit has at most 4 states

- Number of inputs: 1

- Number of outputs: 1

- $Z = Q_A \oplus Q_B$

Write the Analysis Table

- Fill in present state first

Present State (PS)
State ($Q_A Q_B$)
$S_A (00)$
$S_B (01)$
$S_C (10)$
$S_D (11)$

- Then fill in inputs

Present State (PS)	Input
State ($Q_A Q_B$)	X
$S_A (00)$	0
	1
$S_B (01)$	0
	1
$S_C (10)$	0
	1
$S_D (11)$	0
	1

Write the Analysis Table

■ Then fill in inputs to flip-flops

■ $J_A = Q_B, K_A = X'Q_B, J_B = X', K_B = X \oplus Q_A$

Present State (PS)	Input	Flip-Flops' Excitations			
State ($Q_A Q_B$)	X	J_A	K_A	J_B	K_B
$S_A (00)$	0	0	0	1	0
	1	0	0	0	1
$S_B (01)$	0	1	1	1	0
	1	1	0	0	1
$S_C (10)$	0	0	0	1	1
	1	0	0	0	0
$S_D (11)$	0	1	1	1	1
	1	1	0	0	0

Write the Analysis Table

- Then obtain the next state

Present State (PS)	Input	Flip-Flops' Excitations				Next State (NS)
State ($Q_A Q_B$)	X	J_A	K_A	J_B	K_B	$Q_A Q_B$
$S_A(00)$	0	0	0	1	0	0 1
	1	0	0	0	1	0 0
$S_B(01)$	0	1	1	1	0	1 1
	1	1	0	0	1	1 0
$S_C(10)$	0	0	0	1	1	1 1
	1	0	0	0	0	1 0
$S_D(11)$	0	1	1	1	1	0 0
	1	1	0	0	0	1 1

Write the Analysis Table

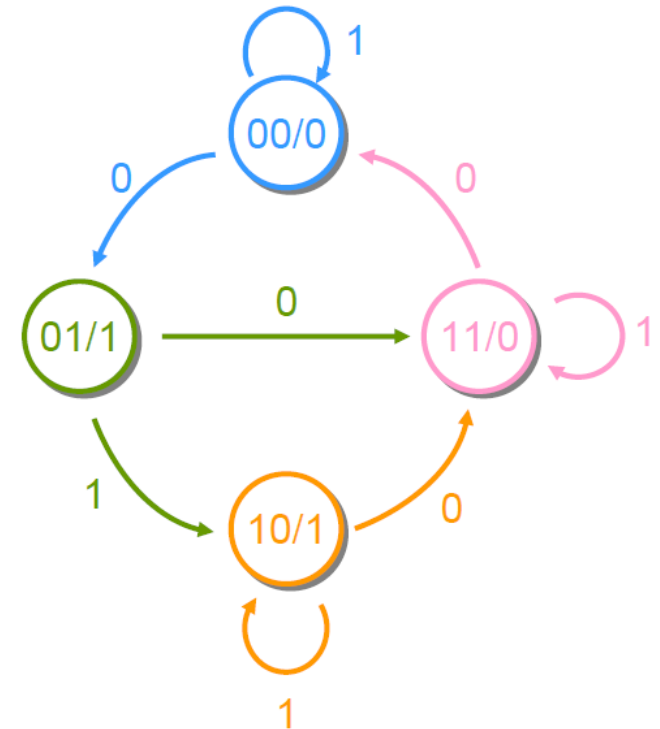
■ Finally obtain the output

■ $Z = Q_A \oplus Q_B$

Present State (PS)	Input	Flip-Flops' Excitations				Next State (NS)	Output
State ($Q_A Q_B$)	X	J_A	K_A	J_B	K_B	$Q_A Q_B$	Z
$S_A(00)$	0	0	0	1	0	0 1	0
	1	0	0	0	1	0 0	0
$S_B(01)$	0	1	1	1	0	1 1	1
	1	1	0	0	1	1 0	1
$S_C(10)$	0	0	0	1	1	1 1	1
	1	0	0	0	0	1 0	1
$S_D(11)$	0	1	1	1	1	0 0	0
	1	1	0	0	0	1 1	0

State Table and State Diagram

Present State (PS)	Input	Next State (NS)	Output
State ($Q_A Q_B$)	X	$Q_A Q_B$	Z
$S_A (00)$	0	0 1	0
	1	0 0	0
$S_B (01)$	0	1 1	1
	1	1 0	1
$S_C (10)$	0	1 1	1
	1	1 0	1
$S_D (11)$	0	0 0	0
	1	1 1	0



State Equation

Present State (PS)	Input	Next State (NS)		Output
State ($Q_A Q_B$)	X	Q_A	Q_B	Z
$S_A (00)$	0	0	1	0
	1	0	0	0
$S_B (01)$	0	1	1	1
	1	1	0	1
$S_C (10)$	0	1	1	1
	1	1	0	1
$S_D (11)$	0	0	0	0
	1	1	1	0

Determine $Q_{A(next)}$ and $Q_{B(next)}$ by means of K-map (or Q-M method)

K-map for $Q_{A(next)}$:

$Q_A \backslash Q_B$	00	01	11	10
0		1		1
1		1	1	1

$$Q_{A(next)} = Q_A'Q_B + Q_AQ_B' + (XQ_A) \text{ or } (XQ_B)$$

K-map for $Q_{B(next)}$:

$Q_A \backslash Q_B$	00	01	11	10
0	1	1		1
1			1	

$$Q_{B(next)} = Q_A'X' + Q_B'X' + Q_AQ_BX$$

Summary of 8.2

Sequential logic
circuit design

State Diagram

State Table
(Minimization)

Output
Equation(s)

Flip-flops Input
Equation(s)

Sequential logic
circuit analysis

8.3 Design with Programmable Logic Device

- Combination logic circuits can be implemented using PLDs
- How about sequential logic circuits?
PLD with flip-flops inside

Example

A “1111” sequential recognizer implemented using PLD with *D* flip-flops inside

Sequential recognizer implemented using PLD

