

EE 421 / CS 425

Digital System Design

Fall 2024 Lecture 8

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State Machines

Vending Machine Example

Topics

- State Diagrams
- Introduction to State Machines
- Moore State Machine and Mealy State Machine
- State Tables Description of State Machines
- Design Example of a State Machine (Vending Machine)
- Sequential State Machine Circuit Design
- One Hot Encoding and ASMD

ANNOUNCEMENT

QUIZ 2

Monday, 30 Sep, 2024

Practice Questions from Past Papers

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Mission

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The library aims to encourage and support the academic and research activities of LUMS faculty, staff and students. It provides a full range of reference services, inter-library loan, document delivery, photocopying, viewing audiovisual and microfilm materials, and access to virtual etc.

Renowned Calligrapher and Artist of Pakistan, Mr. Saeed Ahmad Bodla has donated his prestigious Islamic Calligraphy Art to library.

Events

There are currently no upcoming events.

Opening Hours

Monday to Sunday
8:30 am - 2:00 am

- Library remain opened around-the-clock during exams (mid-terms & finals)
- Library Help Desk at both floors provides services from 8:30 am to 8:00 pm.
- Library remain closed (not more than two days) on public holidays.

Check folders:

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and

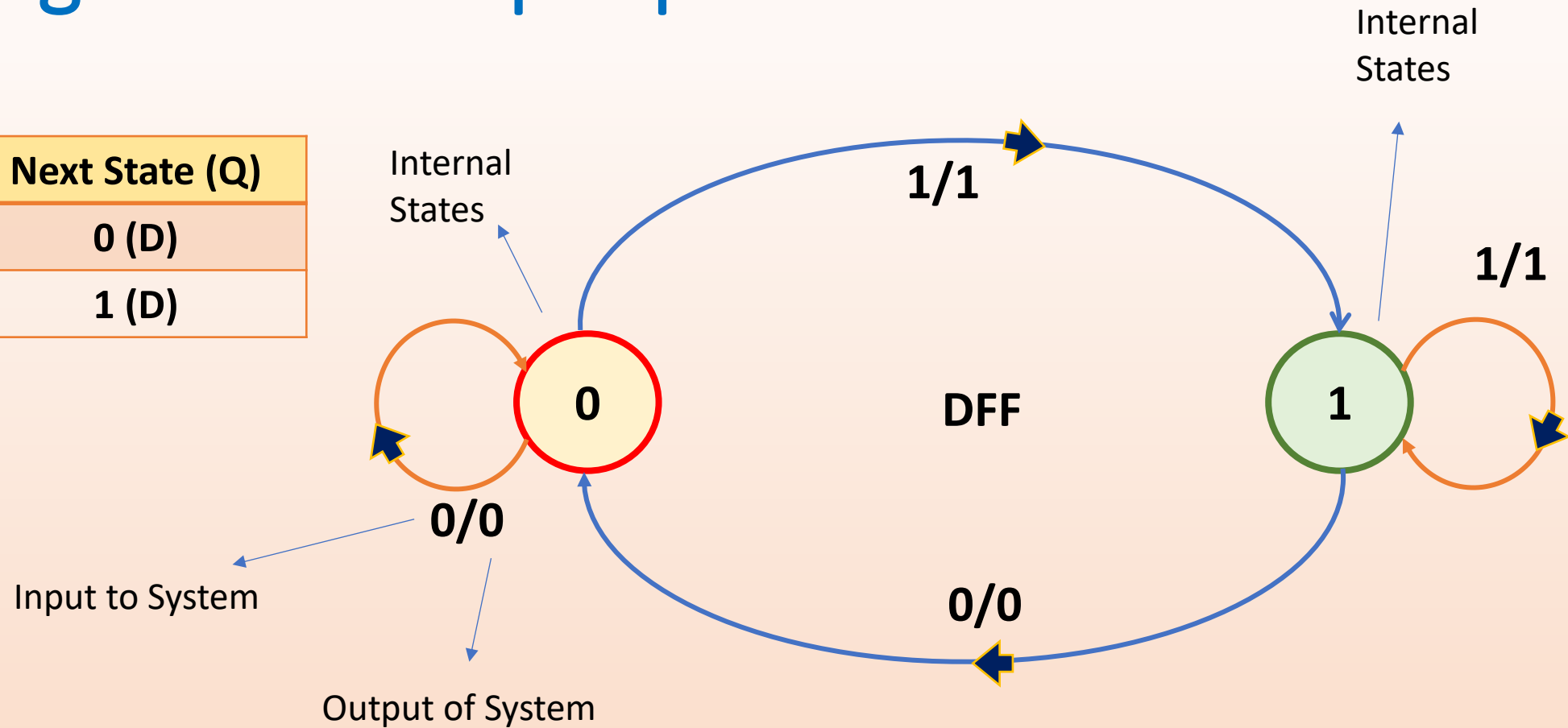
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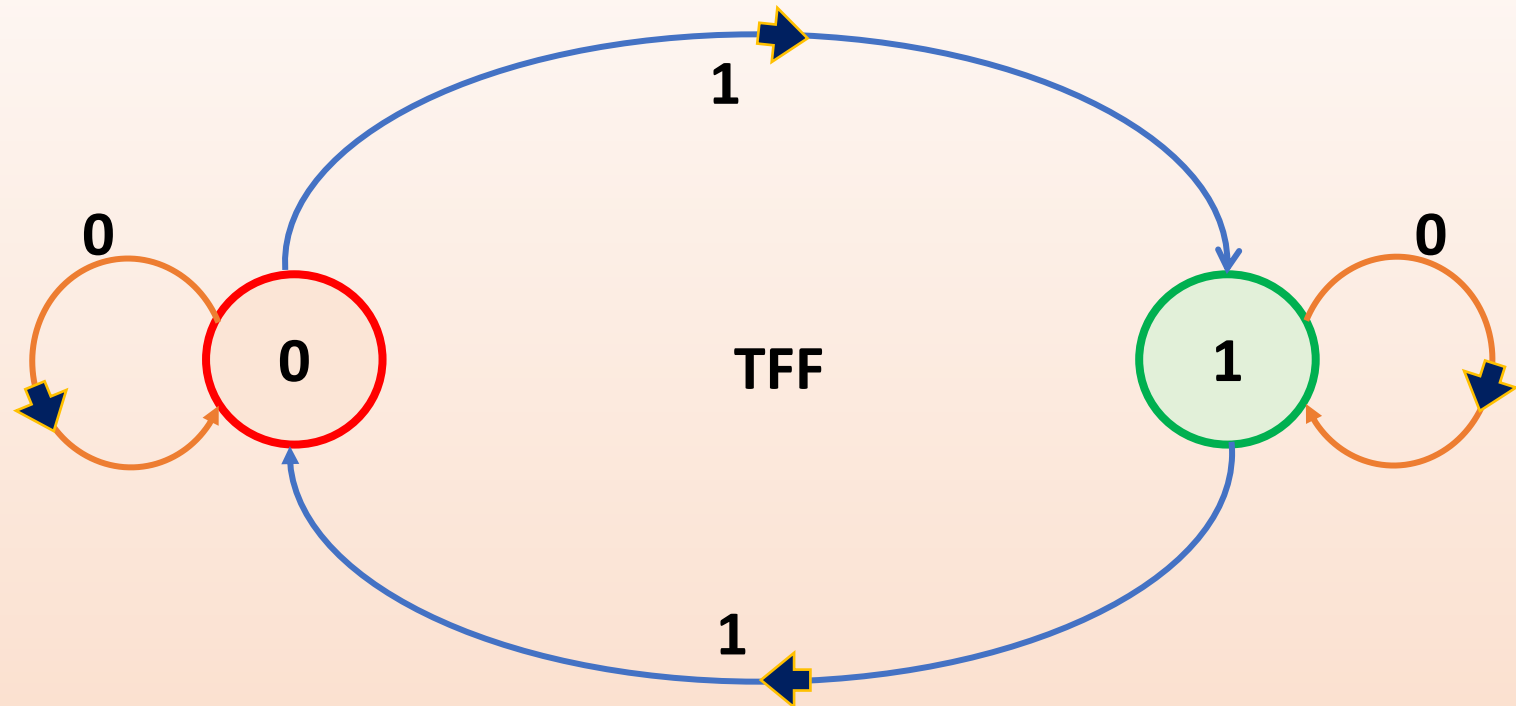
State Diagram of D Flipflop

Input (D)	Next State (Q)
0	0 (D)
1	1 (D)



State Diagram of T Flipflop

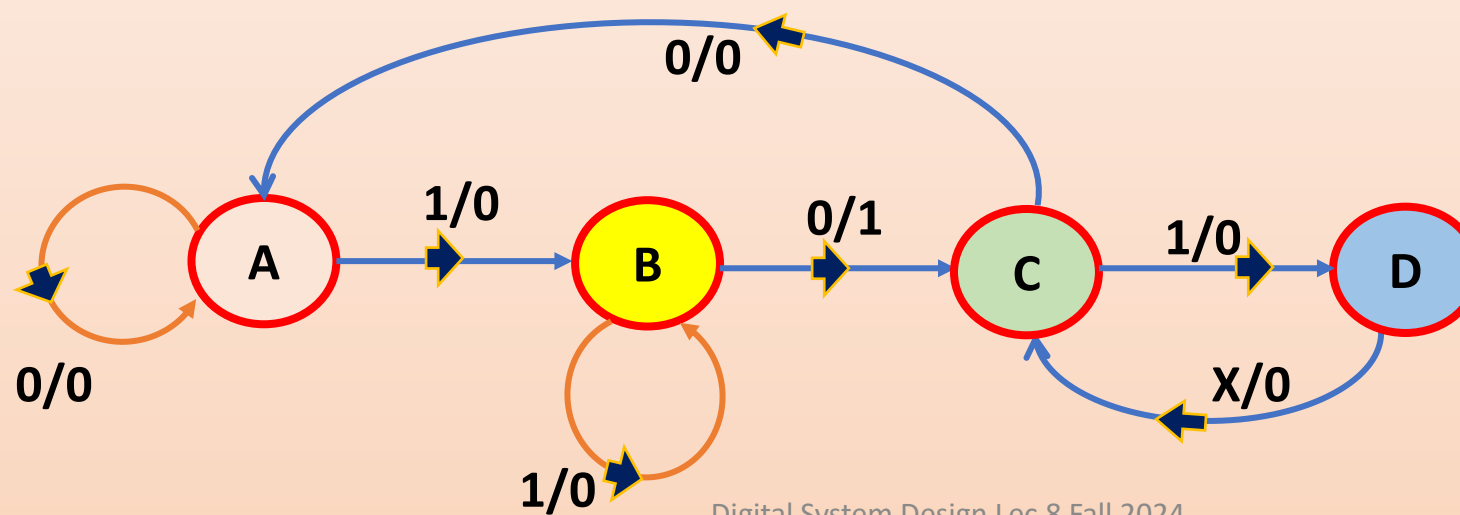
Input (T)	Next State (Q)
0	Q
1	Q'



Linking State Table with State Diagram

Complete State Description Including Inputs, Present State, Outputs and Next State

Q (t)	Q (t+1)		Z (Output)	
	Input X=0	Input X=1	Input X=0	Input X=1
A	A	B	0	0
B	C	B	1	0
C	A	D	0	0
D	C	C	0	0



Types of State Machines

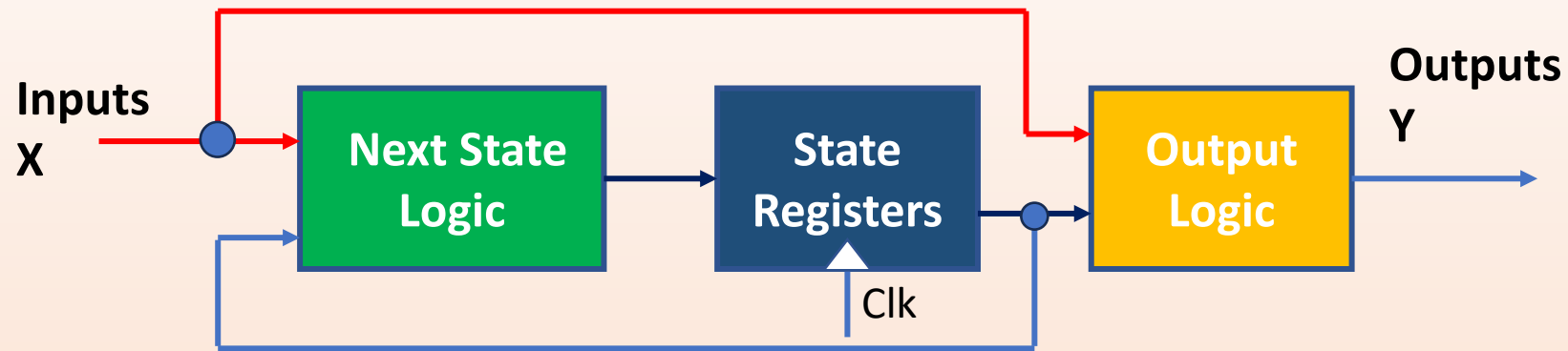
- **Mealy Machine**

- Output depends upon Internal State plus External Inputs
- Output can change at any time and not necessarily after a Clocked event

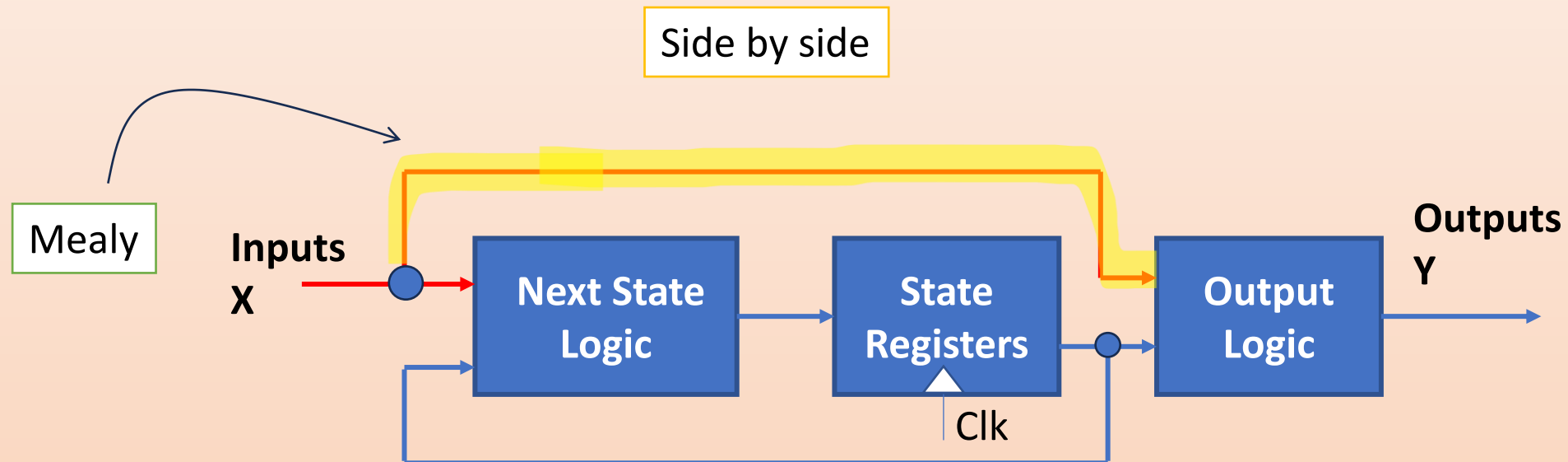
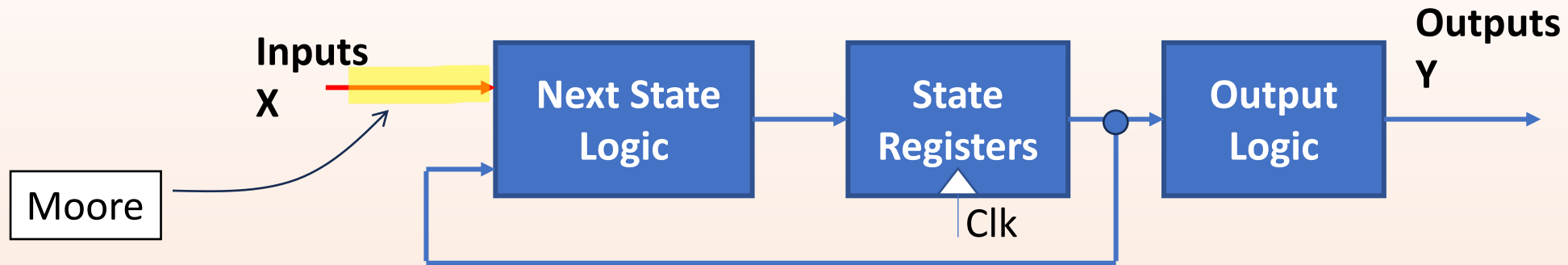
- **Moore Machine**

- Output depends upon External Inputs and Current Internal State
- Output is Synchronized with the Change in Internal States

Mealy State Machine Block Diagram



State Machine Block Diagrams - Comparison



State Machine Based Synchronous Design

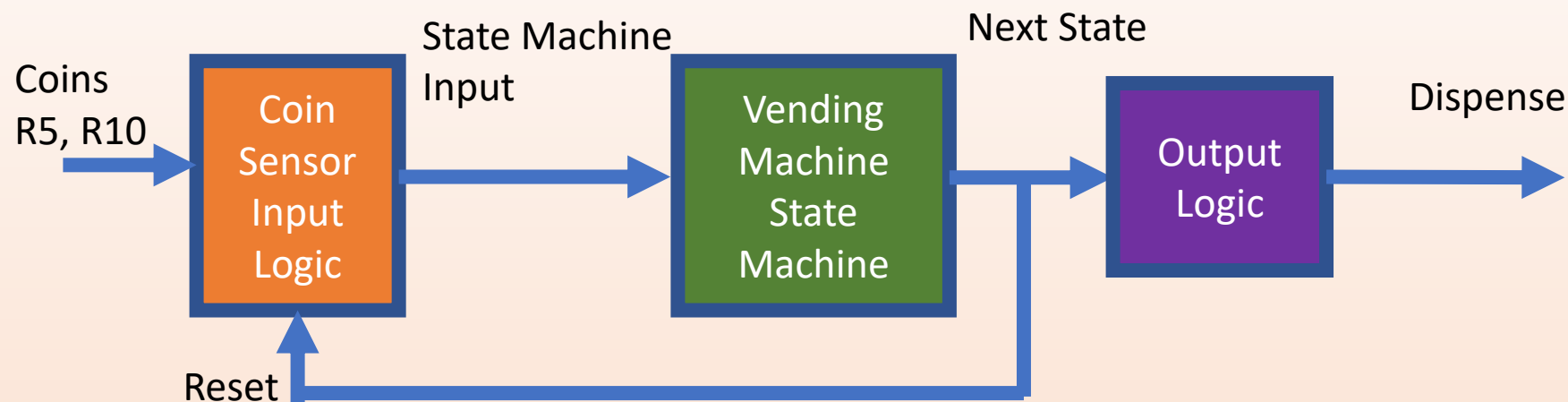
- Understand the Problem – desired sequence based on inputs and present state
- Develop abstract representation of FSM – A state diagram or a state table that shows all possible states and transitions
- Perform state minimization – to achieve efficient implementation
- Perform state assignment
- Choose appropriate flipflop for storage elements (eg. D flipflops)
- Use K-maps to determine characteristic equations for Next State
- After K-maps based minimization; draw complete logic circuit using combinational and sequential elements

Example of a State Machine Based Design – Coke (Next Cola 🍷) Vending Machine

- Machine dispenses a can of coke for Rs. 15/-
- You can provide coins of either Rs. 5/- or Rs. 10/-
- The Machine does not provide any change back
- The Machine is 'Reset' after the can has been dispensed



Block Diagram of Vending Machine Example



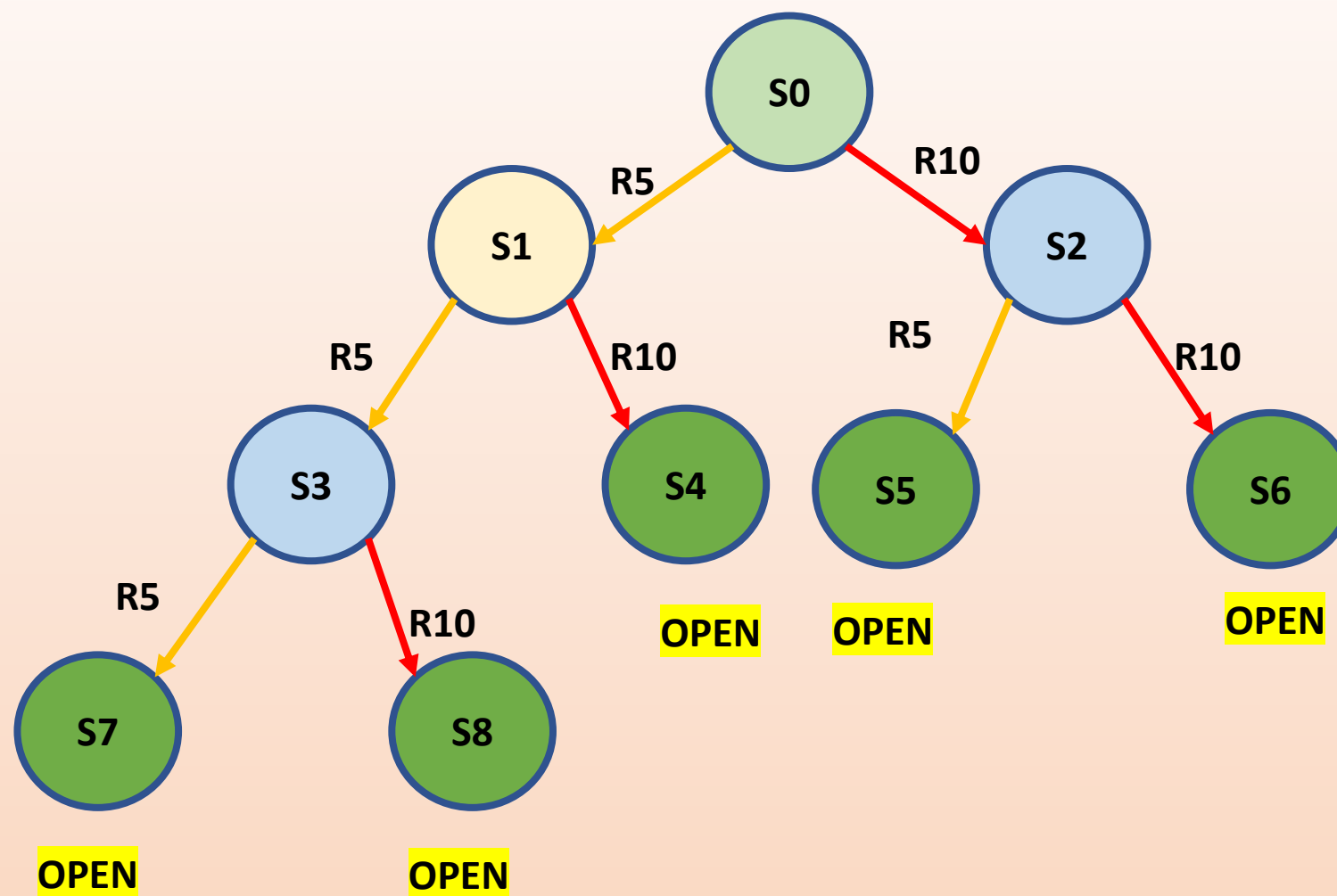
Is Input Directly Connected to Output Logic?

Question: Which type is this? **Moore or Mealy??**

Elaborate State Machine in text description

- Enumerate all possible inputs and outputs
- Objective: Insert sufficient coins to release a can of Coke
- Either Insert $R5 + R5 + R5$ in sequence
- OR Insert $R5 + R10$ in sequence
- OR Insert $R10 + R5$ in sequence
- OR Insert $R10 + R10$ in sequence
- OR Insert $R5 + R5 + R10$ in sequence

Make a State Diagram Representation of State Machine (Moore Machine)

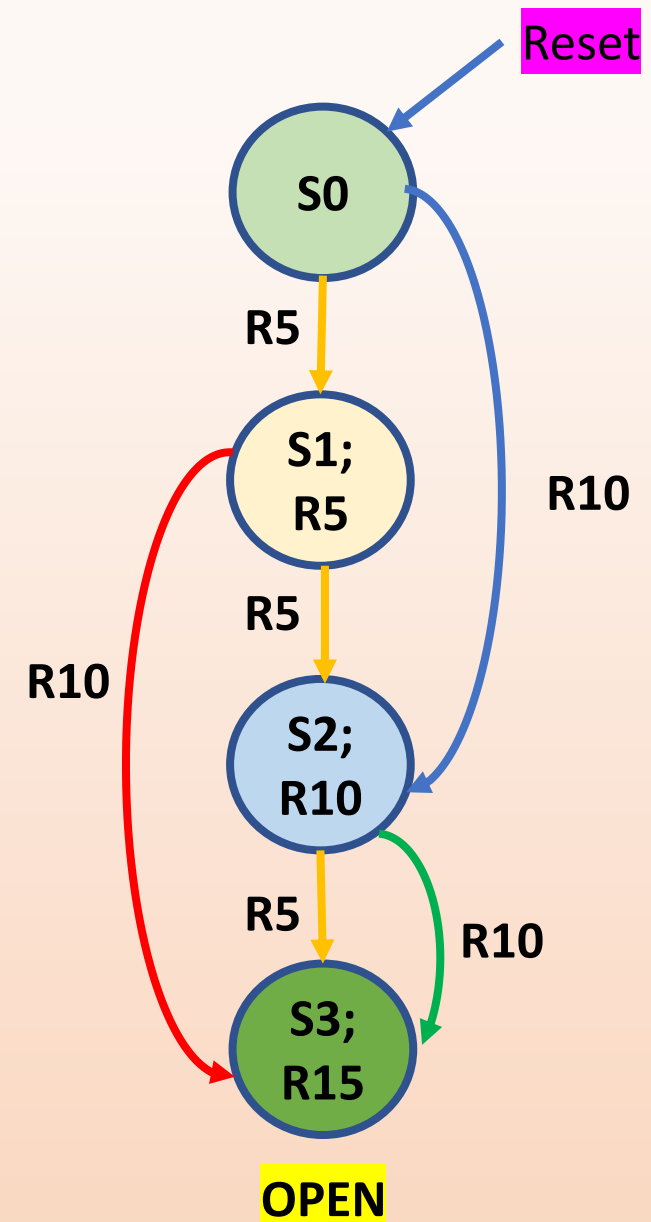


Simplifying the State Machine

Identify Similar States (same present state and next state)

State Minimization by Observation

- Reset brings to State S0
- State S1 represents R5 received so far, one possible path
- State S2 represents R10 received so far, two possible paths;
- State S3 represents R15 received so far, three possible paths
- S4, S5, S6, S7 have identical behaviour so they can be Combined into one state



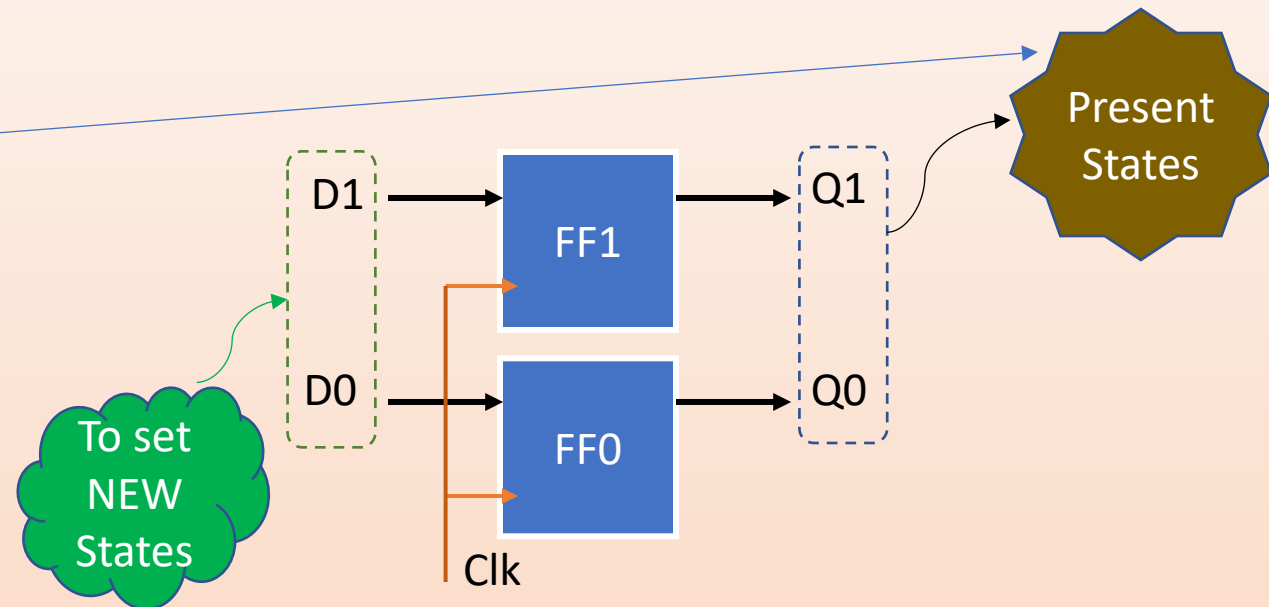
State Transition Table Describing Vending Machine

Q1	Q0	Present State	Inputs		Next State	Output OPEN
			R10	R5		
0	0	S0; R0	0	0	S0; R0	0
			0	1	S1; R5	0
			1	0	S2; R10	0
			1	1	Not Allowed	X
0	1	S1; R5	0	0	S1; R5	0
			0	1	S2; R10	0
			1	0	S3; R15	0
			1	1	Not Allowed	X
1	0	S2; R10	0	0	S2; R10	0
			0	1	S3; R15	0
			1	0	S3; R20	0
			1	1	Not Allowed	X
1	1	S3; R15	0	0	S3; R15	1
			0	1	S3; R15	1
			1	0	S3; R15	1
			1	1	Not Allowed	X

State Mapping to Flipflops

- In the reduced State Diagram, there are 4 states
- We can distinctly represent these states using two Flipflops
- Assign states as follows:

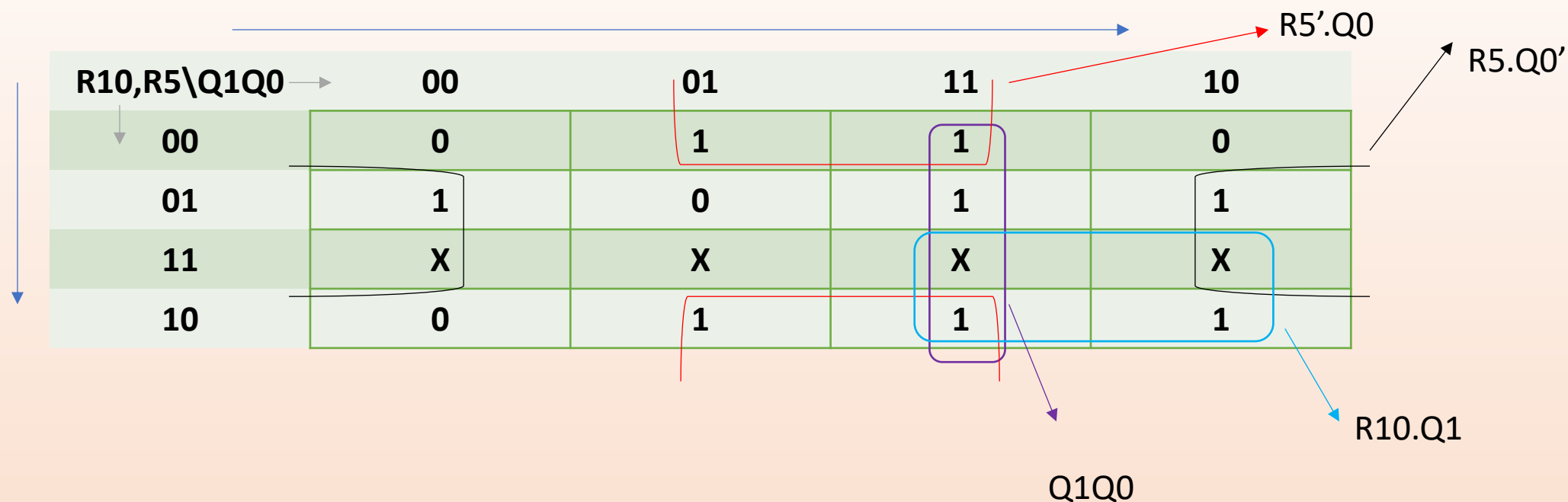
States	Code	Q1	Q0
S0	00	0	0
S1	01	0	1
S2	10	1	0
S3	11	1	1



Present State to Next State Table using DFF

Present State		Inputs		Next State		Output OPEN
Q1	Q0	R10	R5	D1	D0	
0	0 (S0)	0	0	0	0 (S0)	0
		0	1	0	1 (S1)	0
		1	0	1	0 (S2)	0
		1	1	X	X	X
0	1 (S1)	0	0	0	1 (S1)	0
		0	1	1	0 (S2)	0
		1	0	1	1 (S3)	0
		1	1	X	X	X
1	0 (S2)	0	0	1	0 (S2)	0
		0	1	1	1 (S3)	0
		1	0	1	1 (S3)	0
		1	1	X	X	X
1	1 (S3)	0	0	1	1 (S3)	1
		0	1	1	1 (S3)	1
		1	0	1	1 (S3)	1
		1			X	X

Characteristic Equation for D0 using K-Map



$$D0 = (R5'.Q0) + (R5.Q0') + (R10.Q1) + (Q1.Q0)$$

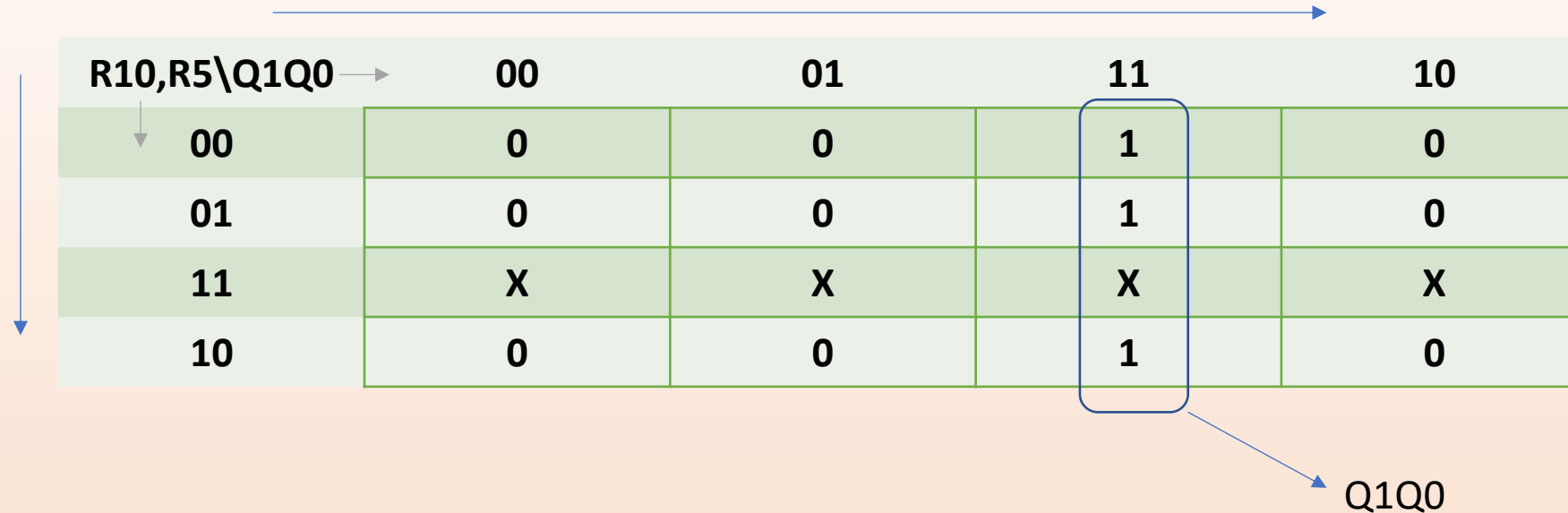
Characteristic Equation for D1 using K-Map

A Karnaugh Map for the characteristic equation of D1. The map is a 4x4 grid with columns labeled 00, 01, 11, 10 and rows labeled 00, 01, 11, 10. The header is R10,R5\Q1Q0. The cells contain values: (00,00)=0, (01,00)=0, (11,00)=1, (10,00)=1; (00,01)=0, (01,01)=1, (11,01)=1, (10,01)=1; (00,11)=X, (01,11)=X, (11,11)=X, (10,11)=X; (00,10)=1, (01,10)=1, (11,10)=1, (10,10)=1. Three groupings are shown: a red circle grouping the four 1s in the top row (labeled Q1), a blue circle grouping the four 1s in the bottom row (labeled R10), and a green circle grouping the four 1s in the middle two columns (labeled R5.Q0).

R10,R5\Q1Q0 →	00	01	11	10
00	0	0	1	1
01	0	1	1	1
11	X	X	X	X
10	1	1	1	1

$$D1 = Q1 + R10 + (R5.Q0)$$

Characteristic Equation for OPEN using K-Map

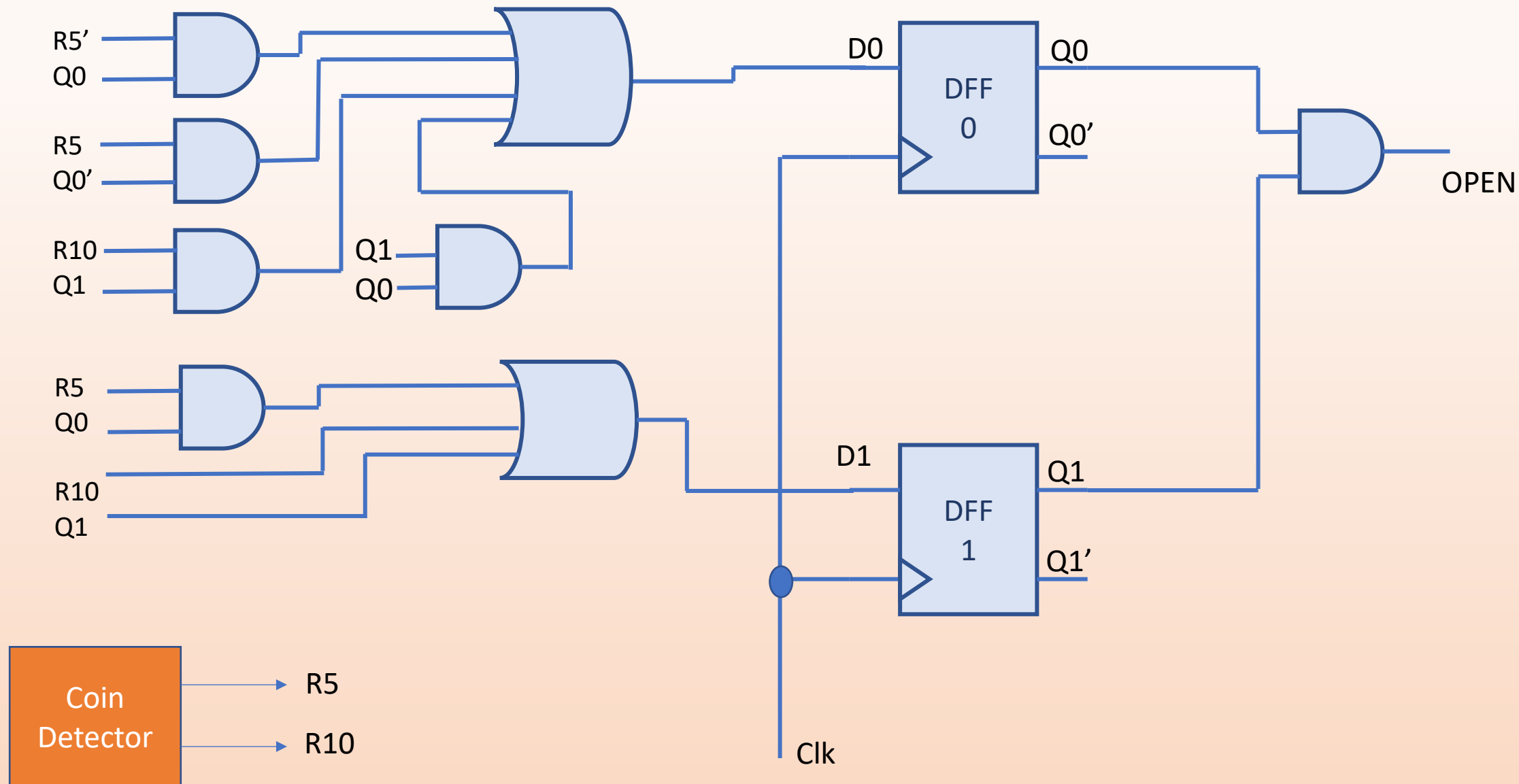


R10,R5\Q1Q0 →	00	01	11	10
00	0	0	1	0
01	0	0	1	0
11	X	X	X	X
10	0	0	1	0

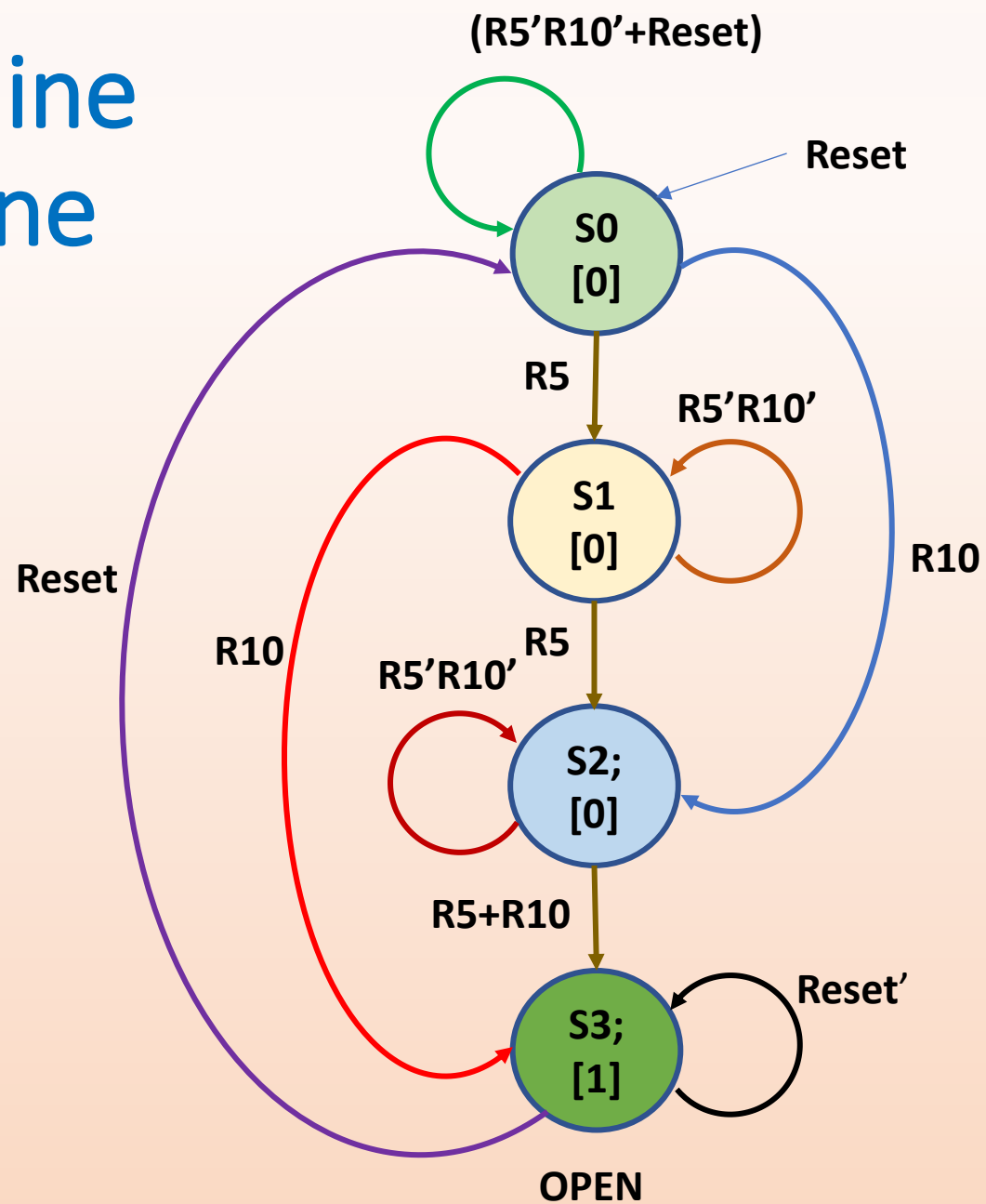
Q1Q0

$$\text{OPEN} = Q1Q0$$

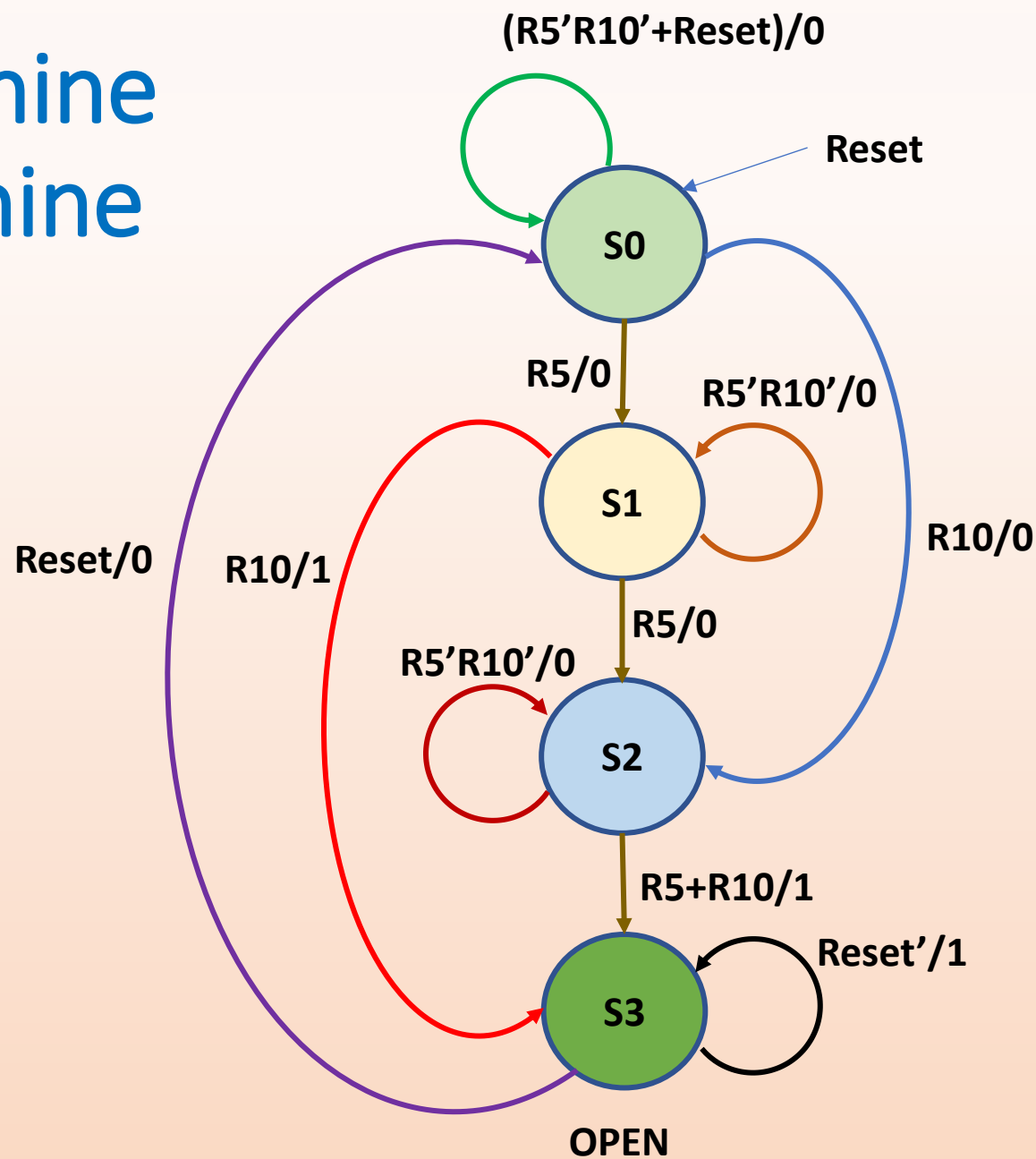
Vending Machine Circuit using DFF



Moore State Machine for Vending Machine



Mealy State Machine for Vending Machine



Some Comparison Moore vs Mealy

- Mealy machine **requires fewer states** to reach output in comparison with Moore machine
- Mealy machine is **more susceptible to glitches**
- Explicit **output values** are shown in Mealy machine associated with each transition
- Output **changes after state** is changed in Moore machine
- Output in Moore machine **depends upon state only**; inputs can steer the output towards a particular state that affects output
- Output **depends upon present state and the present value** at the input; thus, output **can change immediately** with the change in input, independent of synchronous clock.

One Hot Encoding – one FF for each state

Present State				Inputs		Next State				Output OPEN
Q3	Q2	Q1	Q0	R10	R5	D3	D2	D1	D0	Y
0	0	0	1	0	0	0	0	0	1	
				0	1	0	0	1	0	
				1	0	0	1	0	0	
				1	1	X	X	X	X	
0	0	1	0	0	0	0	0	1	0	
				0	1	0	1	0	0	
				1	0	1	0	0	0	1
				1	1	X	X	X	X	
0	1	0	0	0	0	0	1	0	0	
				0	1	1	0	0	0	1
				1	0	1	0	0	0	1
				1	1	X	X	X	X	
1	0	0	0	X	X	1	0	0	0	1

D3 is directly
the Output and
Its State

The Design Becomes Simpler
Less Combinational Logic – At the Expense of Extra DFF

Algorithmic State Machine Description - ASMD

