Chapter 10
Finite State Machine Synthesis
SKEE2263 Digital Systems

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FSM Design Process

Step	Description
Conceptualize	Understand the statement of the specification.
Capture the FSM	Translate the problem into state diagram. Determine the number of **states** required, **inputs**, **outputs** and state **transitions**.
Encode the states	Assign a unique binary number to each state.
Create the state table	Create a truth table for the combinational logic for **next state** generation and **output** decoding.
Extract the equations	Express the logic circuits as Boolean equations.
Implement the FSM	Enter and verify the design.

Counters

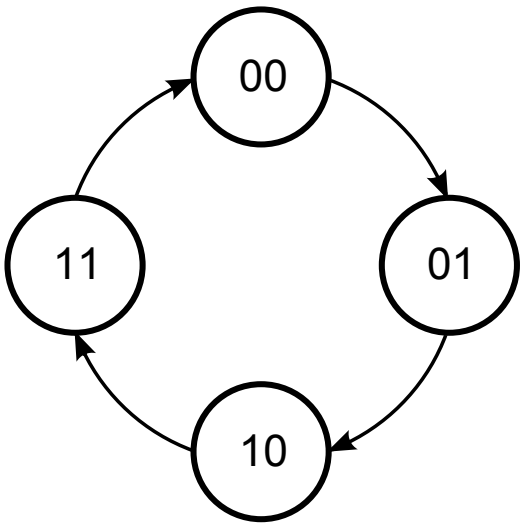
- Definition of counters:
  - Starts from a particular state
  - Goes thru fixed sequence of states
  - Returns to initial state
  - Repeats indefinitely
- Most counters (but not all) are Medvedev state machines
  - Medvedev machine have not output logic.
  - Register outputs = system outputs.
- Single-mode counters:
  - The only input is the clock signal
- Multi-mode counters:
  - Has input to select mode of operation

2-bit Binary Counter

Binary Counters

n state variables $\Rightarrow 2^n$ sequential states

Binary 2-bit counter : straight binary sequence 0→1→2→3→0

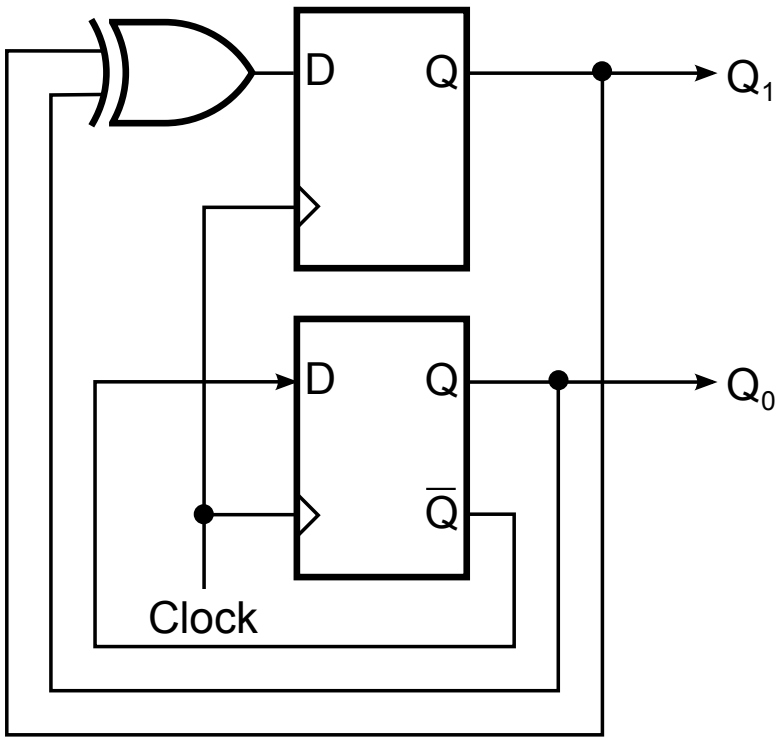


Present State		**Next State**	
Q_1	Q_0	Q_1^+	Q_0^+
0	0	0	1
0	1	1	0
1	0	1	1
1	1	0	0

2-bit Binary Counter

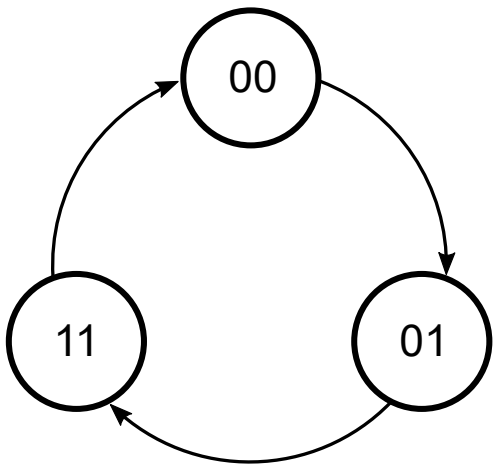
Present State		Next State	
Q_1	Q_0	Q_1^+	Q_0^+
0	0	0	1
0	1	1	0
1	0	1	1
1	1	0	0

$$Q_1^+ = Q_1 \oplus Q_0$$
$$Q_0^+ = Q_0'$$



Counter with Arbitrary Sequence

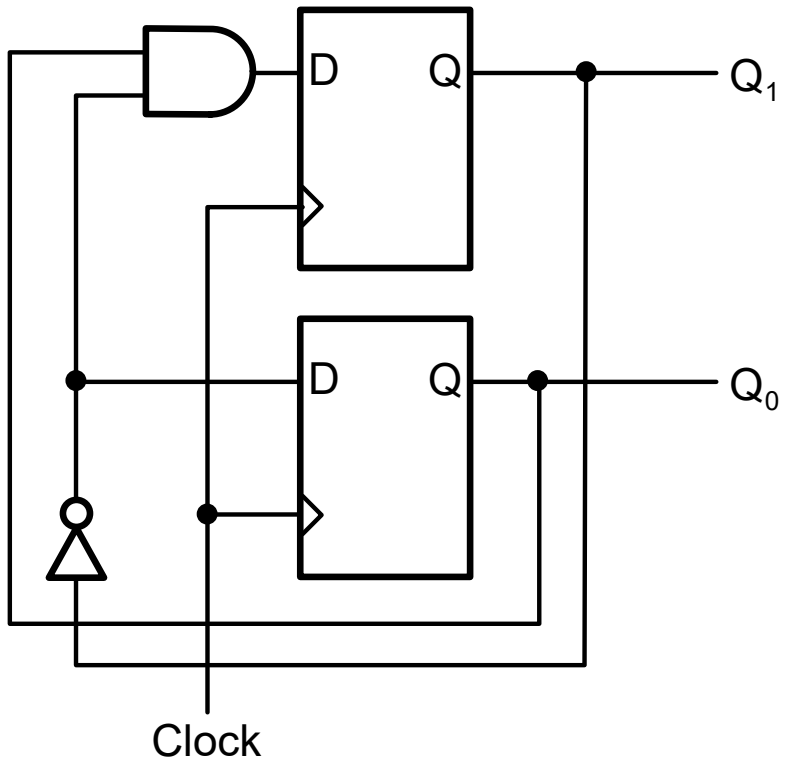
- Counter next states can be non-sequential
- Number of states can be < 2^n
- All valid:
  - 0→3→1→2→0,
  - 0→1→3→2→0,
  - 0→1→3→0



Counter with Arbitrary Sequence

Present State		Next State	
Q_1	Q_0	Q_1^+	Q_0^+
0	0	0	1
0	1	1	1
1	0	×	×
1	1	0	0

$$Q_1^+ = Q_1' Q_0$$
$$Q_0^+ = Q_1'$$



Definition

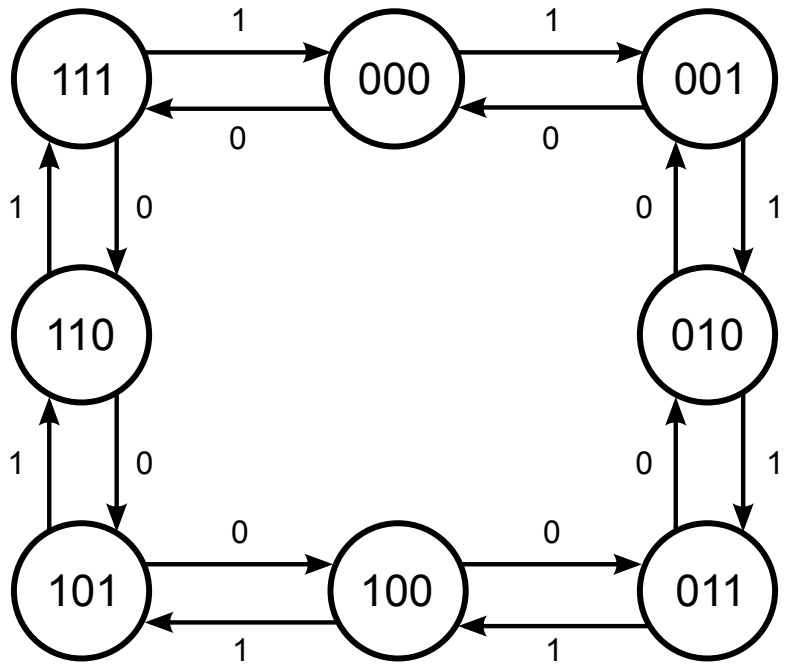
Multi-Mode Counter

A counter whose counting sequence depends not only on the clock but also on some other control signal(s).

Examples:

- Counts up or down
- Counts in binary or Gray sequence
- Increments either +1 or -2
- Counts up or holds count value

3-bit Up/Down Counter



3-bit Up/Down Counter

Present State			Input	Next State		
Q_2	Q_1	Q_0	U	Q_2^+	Q_1^+	Q_0^+
0	0	0	0	1	1	1
0	0	0	1	0	0	1
0	0	1	0	0	0	0
0	0	1	1	0	1	0
0	1	0	0	0	0	1
0	1	0	1	0	1	1
0	1	1	0	0	1	0
0	1	1	1	1	0	0
1	0	0	0	0	1	1
1	0	0	1	1	0	1
1	0	1	0	1	0	0
1	0	1	1	1	1	0
1	1	0	0	1	0	1
1	1	0	1	1	1	1
1	1	1	0	1	1	0
1	1	1	1	0	0	0

3-bit Up/Down Counter

$$Q_2^+ = Q_2'Q_1'Q_0'U' + Q_2'Q_1Q_0U + Q_2Q_1Q_0' + Q_2Q_0U' + Q_2Q_1'U$$
$$Q_1^+ = Q_1'Q_0'U' + Q_1'Q_0U + Q_1Q_0'U + Q_1Q_0U'$$
$$Q_0^+ = Q_0'$$

Several ways to realize the design:

- Logic gates: complex wiring
- Mux
- Decoder
- ROM
- Behavioral Verilog: easiest

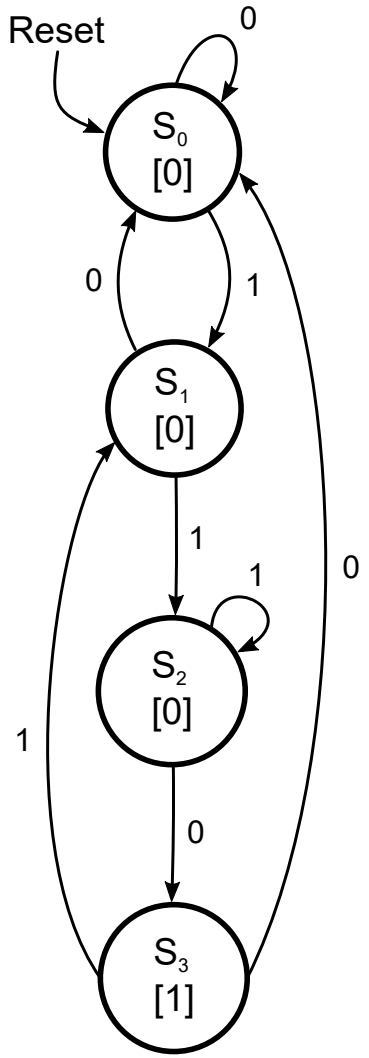
How to Design a Sequence Detector

- Start with the expected sequence first.
- Assert the output at the last state.
- Add exit arrows to cover all possible transitions.
  - Each state must have two exit arrows.

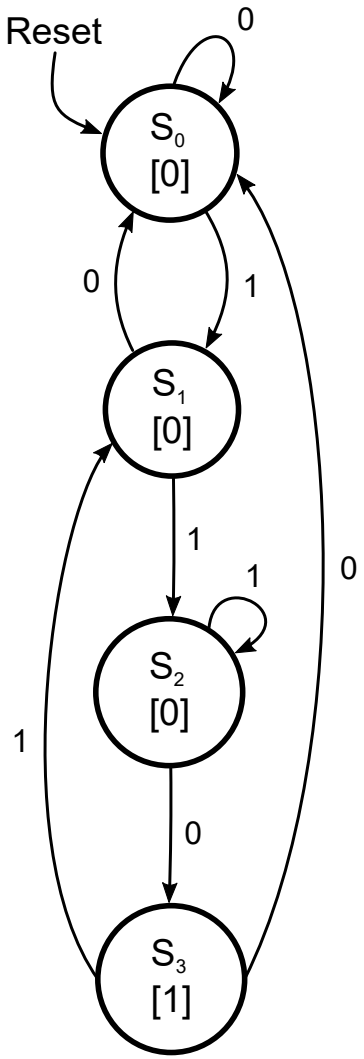
110 Sequence Detector: Moore

```
IN  :  1 1 0 0 0 1 1 0 1 1 1 1 0
OUT :  0 0 1 0 0 0 0 1 0 0 0 0 1
```

State	Meaning
S_0	No matching bits yet
S_1	1 (first bit) found
S_2	1 (second bit) found
S_3	0 (third bit) found, assert output



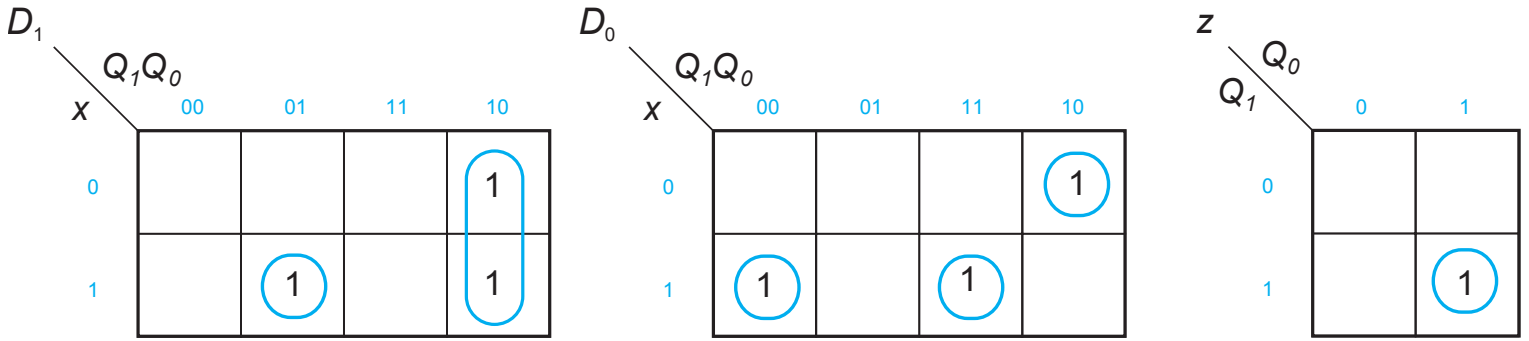
110 Sequence Detector: Moore



State Encoding	
Symbolic	Encoded
S0	00
S1	01
S2	10
S3	11

Present State		Input	Next State		Output
Q_1	Q_0	x	Q_1^+	Q_0^+	z
0	0	0	0	0	0
0	0	1	0	1	
0	1	0	0	0	0
0	1	1	1	0	
1	0	0	1	1	0
1	0	1	1	0	
1	1	0	0	0	1
1	1	1	0	1	

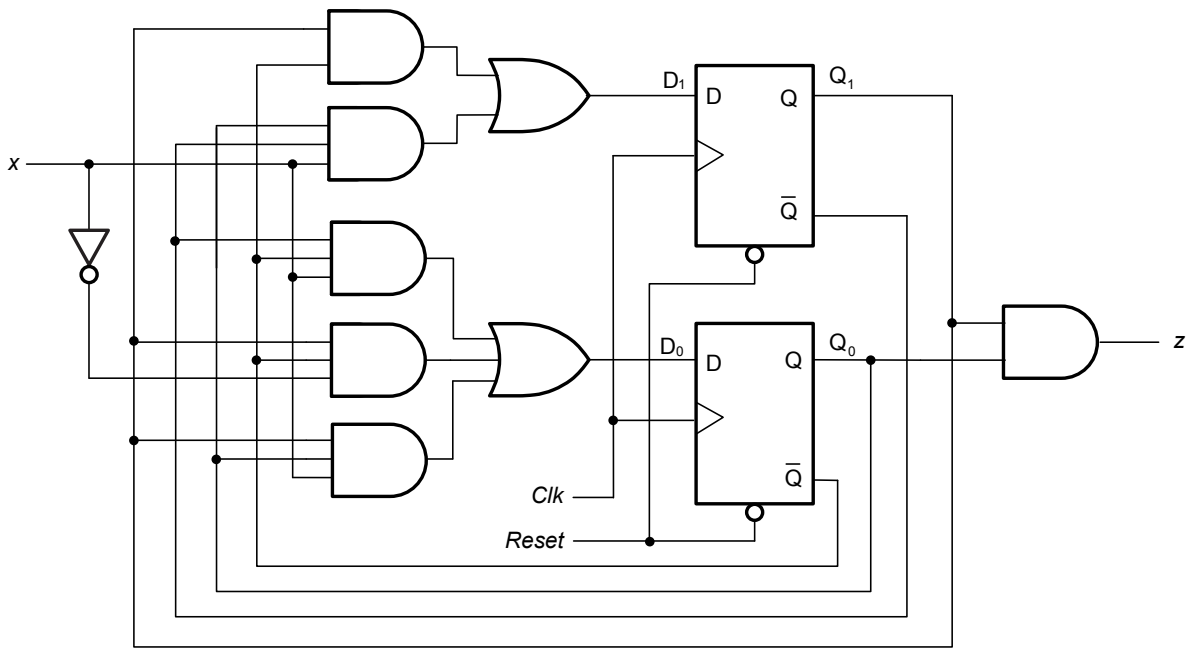
110 Sequence Detector: Moore



$$D_1 = Q_1 Q_0' + Q_1' Q_0 x$$
$$D_0 = Q_1' Q_0' x + Q_1 Q_0' x' + Q_1 Q_0 x$$
$$z = Q_1 Q_0$$

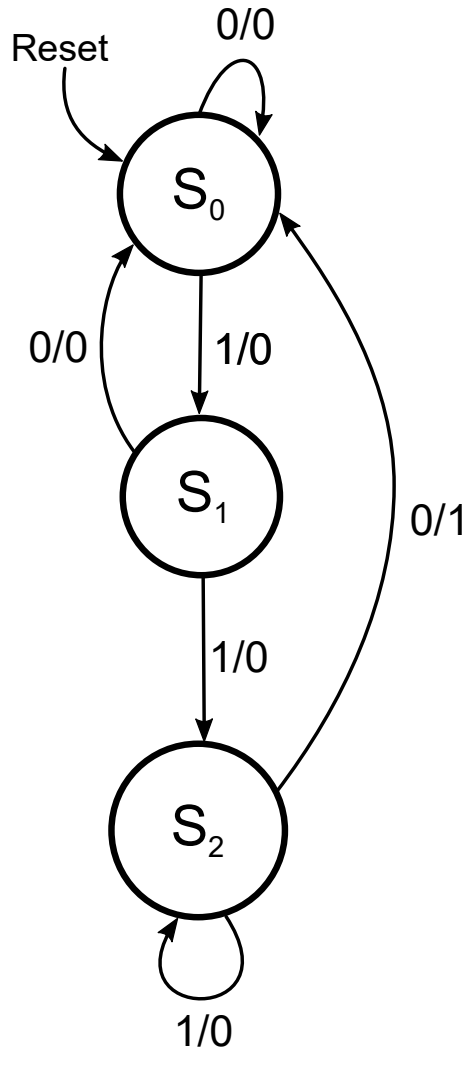
110 Sequence Detector: Moore

$$D_1 = Q_1 Q_0' + Q_1' Q_0 x$$
$$D_0 = Q_1' Q_0' x + Q_1 Q_0' x' + Q_1 Q_0 x$$
$$z = Q_1 Q_0$$

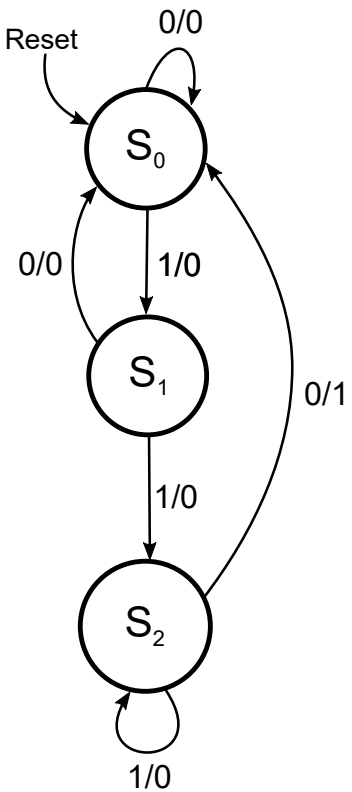


110 Sequence Detector: Mealy

```
IN   :  1 1 0 0 0 1 1 0 1 1 1 1 0
OUT  :  0 0 1 0 0 0 0 1 0 0 0 0 1
```



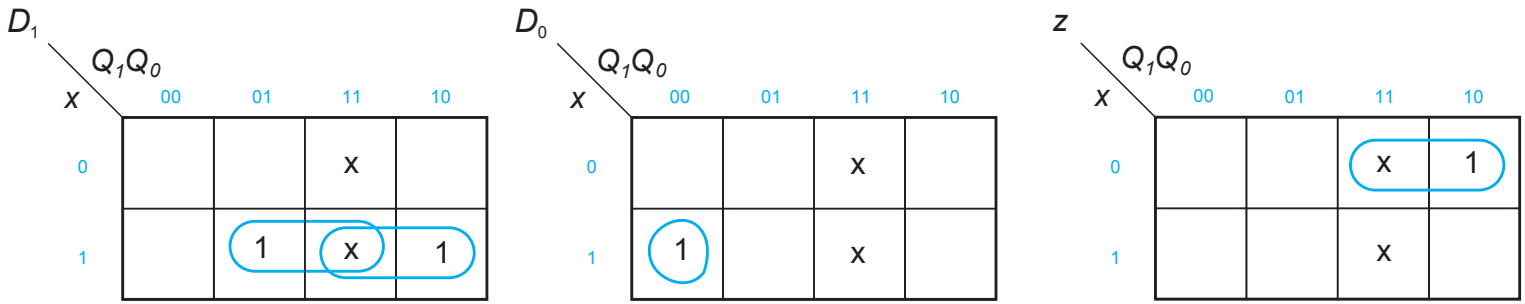
110 Sequence Detector: Mealy



State Encoding	
Symbolic	Encoded
S0	00
S1	01
S2	10
S3	11

Present State		Input	Next State		Output
Q_1	Q_0	x	Q_1^+	Q_0^+	z
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	1
1	0	1	1	0	0
1	1	0	X	X	X
1	1	1	X	X	X

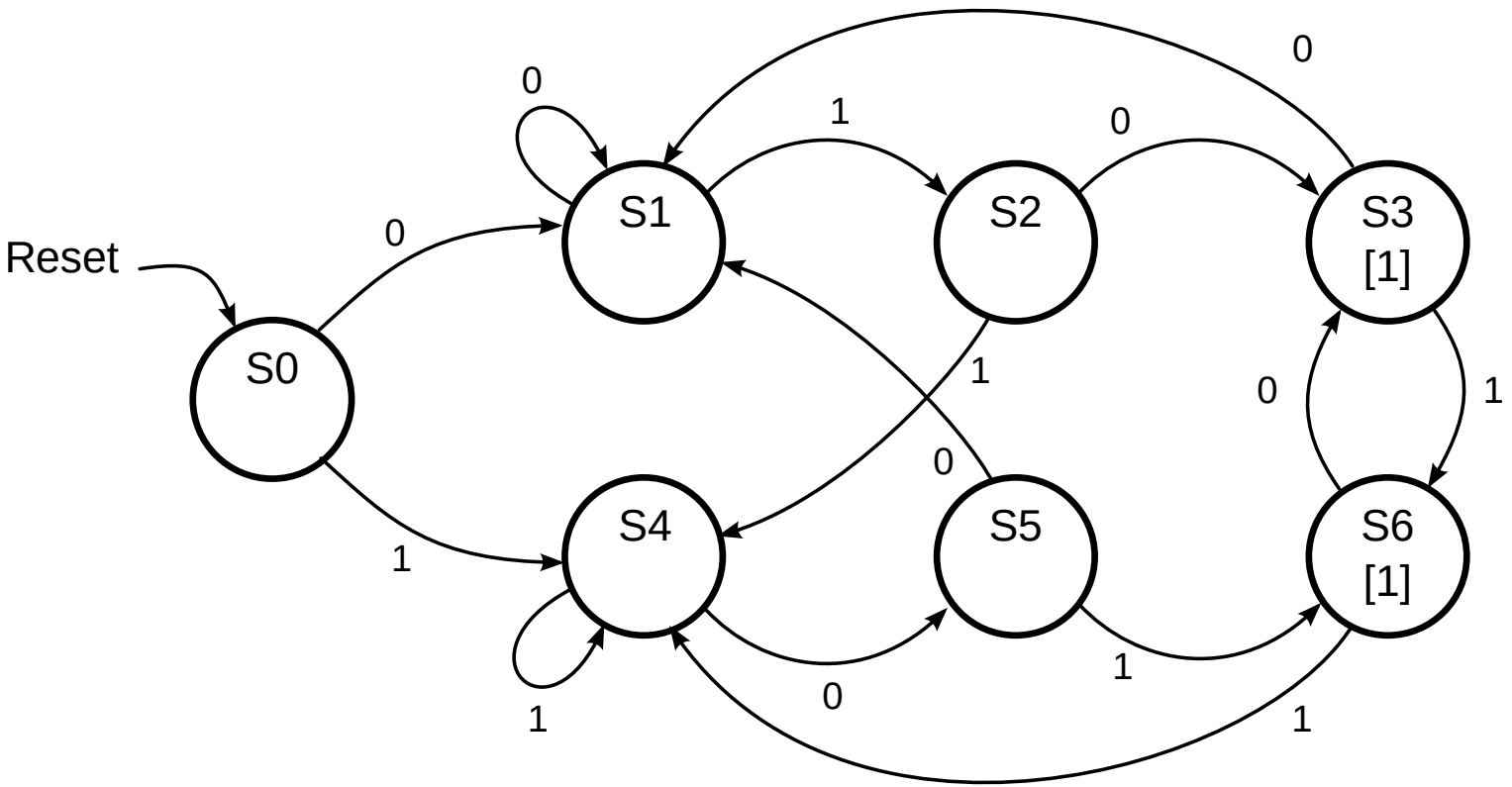
110 Sequence Detector: Mealy



$$D_1 = Q_1 x + Q_0 x$$
$$D_0 = Q_1' Q_0' x$$
$$z = Q_1 x'$$

010 or 101 Detector

x	:	0	1	0	0	0	1	0	1	0	1	0	1	0	1	1	1	0	0	1	1	0
z	:	0	0	1	0	0	0	0	1	0	0	0	1	1	0	0	0	0	0	0	0	0



Alternating Input Detector

010 or 101 detector

Present State			Input	Next State			Output
Q_2	Q_1	Q_0	x	Q_2^+	Q_1^+	Q_0^+	z
0	0	0	0 1	0 1	0 0	1 0	0
0	0	1	0 1	0 0	0 1	1 0	0
0	1	0	0 1	0 1	1 0	1 0	0
0	1	1	0 1	0 1	0 1	1 0	1
1	0	0	0 1	1 1	0 0	1 0	0
1	0	1	0 1	0 1	0 1	1 0	0
1	1	0	0 1	0 1	1 0	1 0	1
1	1	1	X	X	X	X	X