Contents

Mealy and Moore m/cs



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- Mealy to Moore conversion
- Mealy→Moore ex 1
- Mealy→Moore ex 2
- Moore→Mealy ex 1





Mealy m/c

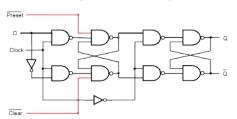
- Mealy machines are finite state machines whose outputs depends on the present state and on the inputs
- It can be defined as $\langle Q, q_0, \Sigma, \Delta, \delta, \lambda \rangle$ where:
- Q is a finite set of states
 - q_0 is the initial state
 - \sum is the input alphabet
 - △ is the output alphabet
 - δ is transition function which maps $Q \times \Sigma \rightarrow Q$
 - λ is the output function which maps $Q \times \Sigma \rightarrow \Delta$

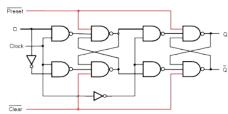




D flip flop

- At the appropriate edge of clock data is transferred from D to Q
- Two SR latches in series clocked with complementary clocks to prevent racing through the FF and the combinational circuits
- Synchronous or asynchronous preset/clear possible
- Some problems still possible, better circuit to be discussed later





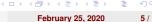
DFF (-ve edge) with synchronous present/clear

DFF (-ve edge) with asynchronous present/clear



- $\Sigma = \{0, 1\}$
- $\Delta = \{0, 1\}$





Example (2's complement of input, starting from LSB)

- $\Sigma = \{0, 1\}$
- $\Delta = \{0, 1\}$

start $\rightarrow q_0$

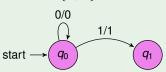
 $\left(q_{1}\right)$



Example (2's complement of input, starting from LSB)

•
$$\Sigma = \{0, 1\}$$

•
$$\Delta = \{0, 1\}$$



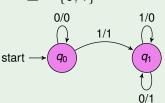




February 25, 2020

•
$$\Sigma = \{0, 1\}$$

•
$$\Delta = \{0, 1\}$$

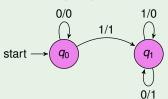






•
$$\Sigma = \{0, 1\}$$

•
$$\Delta = \{0, 1\}$$



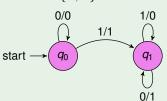
I	0		I 0 1		
PS	NS	0	NS	0	





•
$$\Sigma = \{0, 1\}$$

•
$$\Delta = \{0, 1\}$$



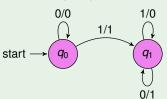
I	0		1	
PS	NS	0	NS	0
q_0	90	0	<i>q</i> ₁	1





•
$$\Sigma = \{0, 1\}$$

•
$$\Delta = \{0, 1\}$$



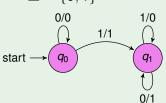
I	0		1	
PS	NS	0	NS	0
q 0	q 0	0	q_1	1
q_1	q_1	1	q_1	0





•
$$\Sigma = \{0, 1\}$$

• $\Delta = \{0, 1\}$



_	nco	dings	Other	en-	
			codings	also	
q_0	1	q_1	0	nossible	

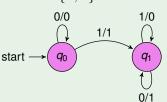
I	0		1	
PS	NS	0	NS	0
q 0	q_0	0	q_1	1
q_1	q_1	1	q_1	0



Example (2's complement of input, starting from LSB)

•
$$\Sigma = \{0, 1\}$$

•
$$\Delta = \{0, 1\}$$



_	noo	dings	Other	en-	
	-		codings also		
q_0	1	q_1	U	possible	Э

I	0		1	
PS	NS	0	NS	0
q 0	q_0	0	<i>q</i> ₁	1
q_1	q_1	1	q_1	0

I	0		1	
PS	NS	0	NS	0
0	0	1	0	0
1	1	0	0	1

Complete the realisation using DFF





- $\Sigma = \{0, 1\}$
- $\bullet \ \Delta = \{A, B, C\}$

Example (Output A on 101, B on 110, C otherwise)

- $\Sigma = \{0, 1\}$
- $\bullet \ \Delta = \{A, B, C\}$

start $\rightarrow q_0$

 $\left(q_1\right)$

 $\left(q_2\right)$

 q_3

Example (Output A on 101, B on 110, C otherwise)

- $\Sigma = \{0, 1\}$
- $\bullet \ \Delta = \{A, B, C\}$

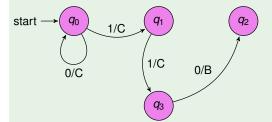




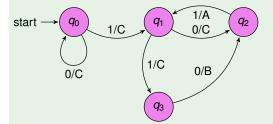


 $\left(q_3\right)$

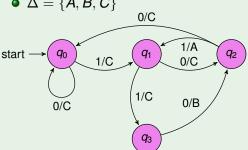
- $\Sigma = \{0, 1\}$
- $\bullet \ \Delta = \{A, B, C\}$



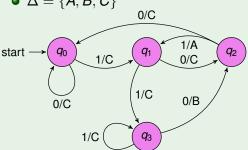
- $\Sigma = \{0, 1\}$
- $\bullet \ \Delta = \{A, B, C\}$



- $\Sigma = \{0, 1\}$
- \bullet $\Delta = \{A, B, C\}$

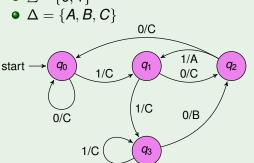


- $\Sigma = \{0, 1\}$
- $\bullet \ \Delta = \{A, B, C\}$

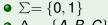


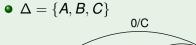
Example (Output A on 101, B on 110, C otherwise)

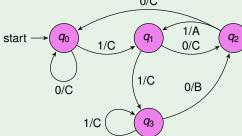
• $\Sigma = \{0, 1\}$



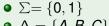
•					
I	0		1		
PS	NS	0	NS	0	

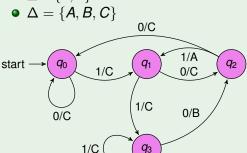




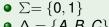


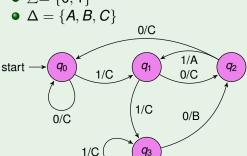
•	,					
	I	0	0			
	PS	NS	0	NS	0	
	9 0	90	O	91	C	





1	•					
	ı	0		1		
	PS	NS	0	NS	0	
	q_0	q_0	С	q_1	C	
	9 ₀ 9 ₁	9 ₀ 9 ₂	С	9 ₁ 9 ₃	С	



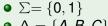


	0		1			
PS	NS	0	NS	0		
q_0	q_0	С	q_1	C		
<i>q</i> ₁	q ₂	C	q ₃	С		
q_2	q_1	C	q_1	Α		

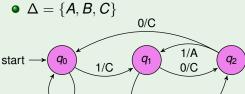
0/B

Mealy m/c ex 2

Example (Output A on 101, B on 110, C otherwise)



0/C

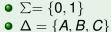


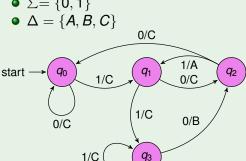
1/C

 q_3

	0	0		1		
PS	NS	0	NS	0		
q_0	q_0	С	q_1	С		
q_1	q ₂	C	q ₃	С		
q_2	q_1	C	q_1	Α		
<i>q</i> ₃	q_2	В	q_3	С		

Example (Output A on 101, B on 110, C otherwise)



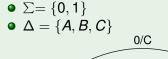


I	0		1	
PS	NS	0	NS	0
q_0	q_0	С	q_1	C
q_1	q_2	C	q 3	С
q_2	q_1	C	q_1	Α
q ₃	q_2	B	q_3	С

Encodings

		_			
q_0	00	Α	01	Other codings	en-
q_1	01	В	10	codings	also
q_2	10	С	00	codings	е
q_3	11				

Example (Output A on 101, B on 110, C otherwise)



$\bullet \Delta = \{A, B, C\}$		
(0/C	
		1/1
start $\rightarrow (q_0)$ 1/C	(q_1)	1/A 0/C
170		0/0
	1/C	
0/C	\170	0/B
	4	
1/C ((q_3)	
Encodinas		

	=nco				
q_0	00	Α	01	Other	

4 0	UU	A	UΙ	Other	en-
				codings	
q_2	10		00	possible	Э
q_3	11				

	0		1	
PS	NS	0	NS	0
q_0	q_0	С	q_1	C
q_1	q ₂	C	q ₃	С
q_2	q_1	C	q_1	Α
q ₃	q_2	В	q_3	С

I	0		1	
PS	NS	0	NS	0
00	00	00	01	00
01	10	00	11	00
10	01	00	01	01
11	10	10	11	00

Complete the realisation using **DFF**

- $\Sigma = \{0, 1\}$
- $\bullet \ \Delta = \{A, B, C\}$

Example (Output on ending with 00:A, 11:B, C, otherwise)

- $\Sigma = \{0, 1\}$



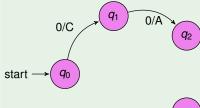
 q_2

start $\rightarrow (q_0)$



 $\left(q_4\right)$

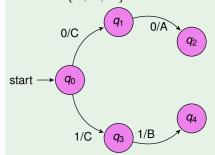
- $\Sigma = \{0, 1\}$







- $\Sigma = \{0, 1\}$

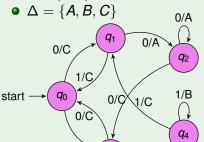


- $\Sigma = \{0, 1\}$
- $\Delta = \{A, B, C\}$ 0/C 0/C 0/A 0/A

- $\Sigma = \{0, 1\}$
- \bullet $\Delta = \{A, B, C\}$ 0/A q_1 0/A 0/C q_2 1/C 1/B start q_0 0/C 1/C 0/C q_4 1/B q_3

Example (Output on ending with 00:A, 11:B, C, otherwise)

•
$$\Sigma = \{0, 1\}$$



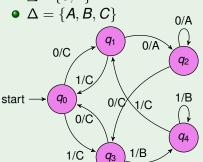
 q_3

1/B

1	.,, ., .,,						
		0	0		1		
	PS	NS	0	NS	0		

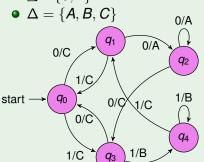
1/C

•
$$\Sigma = \{0, 1\}$$



.,, ., .,						
- 1	0	0				
PS	NS	0	NS	0		
q_0	q_1	С	q ₃	С		

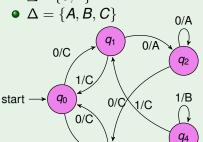
•
$$\Sigma = \{0, 1\}$$



1	, , , , , , , , , , , , , , , , , , ,						
	I	0		1			
	PS	NS	0	NS	0		
	9 ₀ 9 ₁	q ₁ q ₂	С	93 90	С		
	q_1	q_2	A	q_0	С		

Example (Output on ending with 00:A, 11:B, C, otherwise)

•
$$\Sigma = \{0, 1\}$$



 q_3

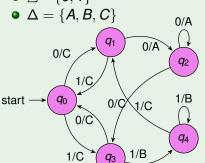
1/B

.,	-, · · , ·	• • • • • • • • • • • • • • • • • • • •		,
I	0		1	
PS	NS	0	NS	0
q ₀	q_1	С	q ₃	С
9 ₀ 9 ₁ 9 ₂	9 ₁ 9 ₂ 9 ₂	Α	9 ₃ 9 ₀ 9 ₃	С
q 2	q_2	Α	q ₃	С

1/C

Example (Output on ending with 00:A, 11:B, C, otherwise)

•
$$\Sigma = \{0, 1\}$$



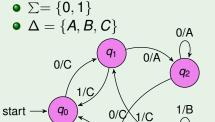
•				•	
I	0		1		
PS	NS	0	NS	0	
q_0	q_1	С	q ₃	С	
q_1	q_2	Α	q_0	С	
q ₂ q ₃	q_2	Α	q ₃	С	
q ₃	q_0	С	q_4	В	

 q_4

1/B

Mealy m/c ex 3

Example (Output on ending with 00:A, 11:B, C, otherwise)



 q_3

0/C

1/C

,	, ,			,
I	0		1	
PS	NS	0	NS	0
q_0	q_1	С	q ₃	С
$ q_1 $	q_2	Α	q_0	С
q ₂	q_2	Α	q ₃	С
q ₃	q_0	C	q_4	В
q_4	q_1	C	q_4	В

Example (Output on ending with 00:A, 11:B, C, otherwise)

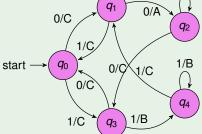
$$\Sigma = \{0, 1\}$$

$$\Delta = \{A, B, C\}$$

$$0/C$$

$$q_1$$

$$0/A$$



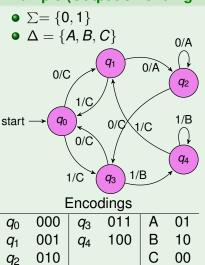
ŀ	Encodings								
)	(Ja	011	Α	0					

9 0	000	43	011	_ ^	Οī
q_1	000 001 010	q_4	100	В	10
q_2	010			С	00

,	, ,			,	
I	0		1		
PS	NS	0	NS	0	
q_0	q_1	С	q ₃	С	
$ q_1 $	q_2	A	q_0	С	
q_2	q_2	A	q ₃	С	
q ₃	q_0	C	q_4	В	
$ q_4 $	q_1	C	q_4	В	

 $\overline{\Omega}$

Example (Output on ending with 00:A, 11:B, C, otherwise)



,	, ,				,		
	0			1			
PS	NS	0	I	NS	0		
q_0	q_1	С		q 3	С		
q_1	q_2	Α		q_0	С		
$ q_2 $	q_2	Α		q 3	С	,	
q_3	q_0	С		q_4	В		
q_4	q_1	С		q_4		}	
		0			1		
PS	NS	С)	NS			0
000	001	00)	01	1	(00
001	010	0.	1	00	0	(00
010	010	0.	1	01	1	(00
010	000	00)	10	0	(01
100	001	00)	10	0	(01

Complete the realisation using DFF

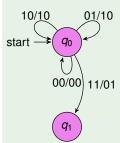
- $\Sigma = \{00, 01, 10, 11\} \triangleq \{\langle a_i, b_i \rangle\}, i \geq 0$

- $\bullet \ \Sigma = \{00, 01, 10, 11\} \triangleq \{\langle \textbf{\textit{a}}_i, \textbf{\textit{b}}_i \rangle\} \,, \ i \geq 0$

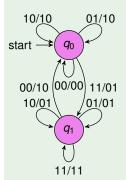
start
$$\rightarrow q_0$$



- $\bullet \ \Sigma = \{00, 01, 10, 11\} \triangleq \{\langle \textbf{\textit{a}}_i, \textbf{\textit{b}}_i \rangle\} \,, \ i \geq 0$



- $\Sigma = \{00, 01, 10, 11\} \triangleq \{\langle a_i, b_i \rangle\}, i \geq 0$
- $\Delta = \{00, 01, 10, 11\} \triangleq \left\{\left\langle s_i, c_i^0 \right\rangle \right\}, i \geq 0$

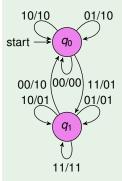


- $\Sigma = \{00, 01, 10, 11\} \triangleq \{\langle a_i, b_i \rangle\}, i \geq 0$ • $\Delta = \{00, 01, 10, 11\} \triangleq \{\langle s_i, c_i^o \rangle\}, i \geq 0$

I	00		01		10		11	
PS	NS	0	NS	0	NS	0	NS	0

Example (Serial adder, starting from LSB)

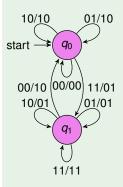
• $\Sigma = \{00, 01, 10, 11\} \triangleq \{\langle a_i, b_i \rangle\}, i \geq 0$ • $\Delta = \{00, 01, 10, 11\} \triangleq \{\langle s_i, c_i^o \rangle\}, i \geq 0$



ı	00		01		10		11	
PS	NS	0	NS	0	NS	0	NS	0
q_0	q_0	00	q_0	10	q_0	10	q_1	01

•
$$\Sigma = \{00, 01, 10, 11\} \triangleq \{\langle a_i, b_i \rangle\}, i \geq 0$$

• $\Delta = \{00, 01, 10, 11\} \triangleq \{\langle s_i, c_i^o \rangle\}, i \geq 0$



I	00		00 01		10		11	
PS	NS	0	NS	0	NS	0	NS	0
q_0	q_0	00	q_0	10	q_0	10	q_1	01
q_1	q_0	10	q_1	01	q_1	01	q_1	11

Example (Serial adder, starting from LSB)

- $\Sigma = \{00, 01, 10, 11\} \triangleq \{\langle a_i, b_i \rangle\}, i \geq 0$ • $\Delta = \{00, 01, 10, 11\} \triangleq \{\langle s_i, c_i^o \rangle\}, i \geq 0$
- 10/10 01/10
 start q_0 00/10 00/00 11/01
 10/01 01/01
 11/11

	00		01		10		11	
PS	NS	0	NS	0	NS	0	NS	0
q_0	q_0	00	q_0	10	q_0	10	q_1	01
q_1	q_0	10	q_1	01	q_1	01	q_1	11

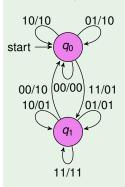
Encodings

 $q_0 \ 0 \ q_1 \ 1$

Example (Serial adder, starting from LSB)

•
$$\Sigma = \{00, 01, 10, 11\} \triangleq \{\langle a_i, b_i \rangle\}, i \geq 0$$

• $\Delta = \{00, 01, 10, 11\} \triangleq \{\langle s_i, c_i^o \rangle\}, i \geq 0$



ı	00		01		10		11	
PS	NS	0	NS	0	NS	0	NS	0
q_0	q_0	00	q_0	10	q_0	10	q_1	01
q_1	q_0	10	q_1	01	q_1	01	q_1	11

	00		00 01		10		11	
PS	NS	0	NS	0	NS	0	NS	0
0	0	00	0	10	0	10	1	01
1	0	10	1	01	1	01	1	11

Encodings

 $q_0 \ 0 \ q_1 \ 1$

Complete the realisation using DFF

Moore m/c

- Moore machines are finite state machines whose outputs depends only on the present state
- It can be defined as $\langle Q, q_0, \Sigma, \Delta, \delta, \lambda \rangle$ where:
- Q is a finite set of states
 - q_0 is the initial state
 - ∑ is the input alphabet
 - △ is the output alphabet
 - δ is transition function which maps $Q \times \Sigma \rightarrow Q$
 - λ is the output function which maps $Q \to \Delta$





Moore m/c

- Moore machines are finite state machines whose outputs depends only on the present state
- It can be defined as $\langle Q, q_0, \Sigma, \Delta, \delta, \lambda \rangle$ where:
- is a finite set of states
 - q_0 is the initial state
 - is the input alphabet
 - is the output alphabet
 - δ is transition function which maps $Q \times \Sigma \rightarrow Q$
 - λ is the output function which maps $Q \to \Delta$

Conversion of Moore m/c to a Mealy m/c

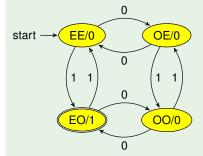
- The Mealy m/c has the same set of states and transitions as the Moore m/c
- $\forall a \in \Sigma, q \in Q : \lambda_{\mathsf{Mealv}}(q, a) = \lambda_{\mathsf{Moore}}(\delta_{\mathsf{Moore}}(q, a))$





Example (Acceptor for even 0s, odd 1s)

- $\Sigma = \{0, 1\}$
- $\Delta = \{0, 1\}$



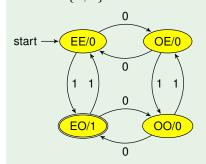
Encodings

EE 00 OE 01

Example (Acceptor for even 0s, odd 1s)

•
$$\Sigma = \{0, 1\}$$

• $\Delta = \{0, 1\}$



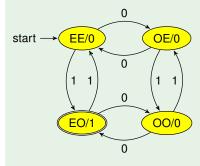
PS	N	0	
	I=0 I=1		
EE	OE	EO	0
OE	EE OO		0
EO	00	EE	1
00	EO OE		0

Encodings

EE	00	OE	01
EO	01	00	11

Example (Acceptor for even 0s, odd 1s)

- $\Sigma = \{0, 1\}$
- $\Delta = \{0, 1\}$



Encodings

EE	00	OE	01
EO	01	00	11

PS	N	0	
	I=0 I=1		
EE	OE	EO	0
OE	EE OO		0
EO	00	EE	1
00	EO OE		0

PS	N	0	
	I=0 I=1		
00	10	10	0
10	00 11		0
10	11	00	1
11	10 10		0

Complete the realisation using DFF

Example (Remainder on division by 3, from MSB)

- $\Sigma = \{0, 1\}$
- $\Delta = \{00, 01, 10\}$

Encodings

- Initial remainder is taken as zero
- On every new bit existing remainder is doubled
- Also, add 1 to new remainder on getting 1, nothing for 0

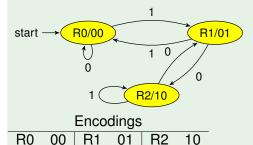




February 25, 2020

Example (Remainder on division by 3, from MSB)

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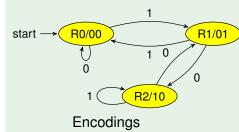




February 25, 2020

Example (Remainder on division by 3, from MSB)

- $\Sigma = \{0, 1\}$
- $\Delta = \{00, 01, 10\}$



R2

10

- Initial remainder is taken as zero
- On every new bit existing remainder is doubled
- Also, add 1 to new remainder on getting 1, nothing for 0

PS	N	0	
	I=0	l=1	
R0 (00)	R0 (00)	R1 (01)	00
R1 (01)	R2 (10)	R0 (00)	01
R2 (10)	R1 (01)	R2 (10)	10

Complete the realisation using DFF





R0

Example (Remainder on division by 3, from LSB)

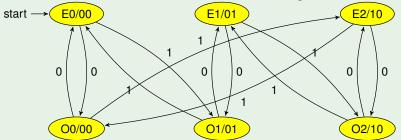
- $\Sigma = \{0, 1\}$
- $\Delta = \{00, 01, 10\}$

- Initial remainder is taken as zero
- 1 on an even index bit adds 1 to the accumulated remainder
- 1 on an odd index bit adds 2 to the accumulated remainder
- Need to keep track of parity of bit index being handled

Example (Remainder on division by 3, from LSB)

- $\Sigma = \{0, 1\}$
- $\Delta = \{00, 01, 10\}$

- Initial remainder is taken as zero
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- 1 on an odd index bit adds 2 to the accumulated remainder
- Need to keep track of parity of bit index being handled



Example (Remainder on division by 3, from LSB)

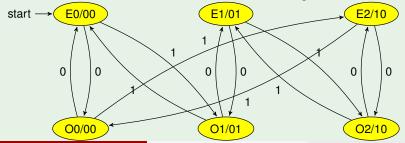
- $\Sigma = \{0, 1\}$
- $\Delta = \{00, 01, 10\}$

Encodings

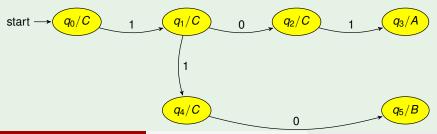
			001		
O0	100	01	101	O2	110

Complete the realisation using DFF

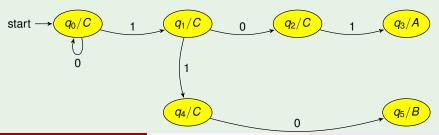
- Initial remainder is taken as zero
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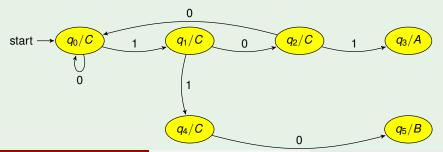
- $\Sigma = \{0, 1\}$
- $\Delta = \{00, 01, 10\} \triangleq \{C, A, B\}$



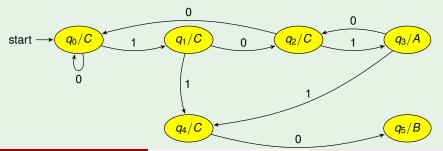
- $\Sigma = \{0, 1\}$
- $\Delta = \{00, 01, 10\} \triangleq \{C, A, B\}$



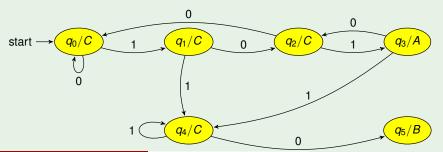
- $\Sigma = \{0, 1\}$
- $\Delta = \{00, 01, 10\} \triangleq \{C, A, B\}$



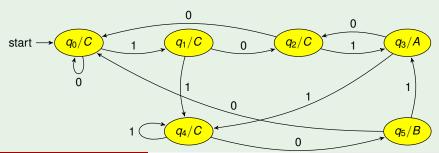
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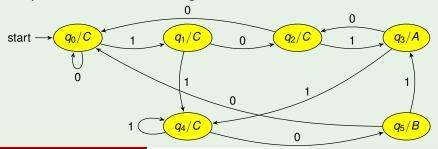


Example (Output A on 101, B on 110, C otherwise)

- $\Sigma = \{0, 1\}$
- $\Delta = \{00, 01, 10\} \triangleq \{C, A, B\}$

Encodings $q_0 \ 000 \ q_1 \ 001 \ q_2 \ 011 \ A \ 01 \ C \ 00 \ q_3 \ 010 \ q_4 \ 110 \ q_5 \ 111 \ B \ 10$

Complete the realisation using DFF



ullet In the Mealy m/c let s_i have input transitions with outputs

$$\textit{o}_{\textit{j}_1},\textit{o}_{\textit{j}_2},\ldots,\textit{o}_{\textit{j}_i}$$





- In the Mealy m/c let s_i have input transitions with outputs $o_{i_1}, o_{i_2}, \ldots, o_{i_i}$
- In the Moore m/c create states $s_{i,j_1}/o_{j_1}$, $s_{i,j_2}/o_{j_2}$, ..., $s_{i,j_i}/o_{j_i}$





- In the Mealy m/c let s_i have input transitions with outputs $o_{i_1}, o_{i_2}, \ldots, o_{i_i}$
- In the Moore m/c create states $s_{i,j_1}/o_{j_1}, s_{i,j_2}/o_{j_2}, \ldots, s_{i,j_i}/o_{j_i}$
- $s_{i,j_k}/o_{j_k}$ means copy of Mealy m/c state s_i as s_{i,j_k} to output o_{j_k} in the Moore m/c





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- If there is a transition from s_i to s_j on input a with output o_k in the Mealy m/c, create a transition on a from each copy of s_i to $s_{j,k}$





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- For the Moore m/c, let o_{ϵ} be a special symbol which is output at the beginning when no inputs have been received, then $\Delta_{\mathsf{Moore}} = \Delta_{\mathsf{Mealv}} \cup \{o_{\epsilon}\}$





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- A new state q_0'/o_{ϵ} is created as the initial state of the Moore m/c





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- A new state q_0'/o_ϵ is created as the initial state of the Moore m/c
- Sucessors of q_0'/o_ϵ are same as those of any copy of q_0 in the created Moore m/c

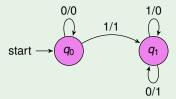




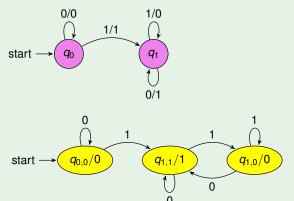
- In the Mealy m/c let s_i have input transitions with outputs $o_{i_1}, o_{i_2}, \ldots, o_{i_i}$
- In the Moore m/c create states $s_{i,j_1}/o_{j_1}, s_{i,j_2}/o_{j_2}, \ldots, s_{i,j_i}/o_{j_i}$
- $s_{i,j_k}/o_{j_k}$ means copy of Mealy m/c state s_i as s_{i,j_k} to output o_{j_k} in the Moore m/c
- If there is a transition from s_i to s_j on input a with output o_k in the Mealy m/c, create a transition on a from each copy of s_i to $s_{i,k}$
- For the Moore m/c, let o_{ϵ} be a special symbol which is output at the beginning when no inputs have been received, then $\Delta_{\mathsf{Moore}} = \Delta_{\mathsf{Mealy}} \cup \{o_{\epsilon}\}$
- A new state q_0'/o_ϵ is created as the initial state of the Moore m/c
- Sucessors of q_0'/o_ϵ are same as those of any copy of q_0 in the created Moore m/c
- However, if the start state in Mealy m/c has not been split to multiple states, that may be retained as the start state of the Moore m/c; here o_{ϵ} is arbitrarily taken as the unique output of q_0



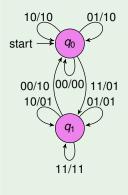
Example (2's complement of input, starting from LSB)

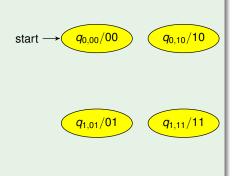


Example (2's complement of input, starting from LSB)

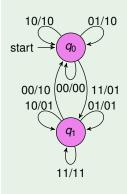


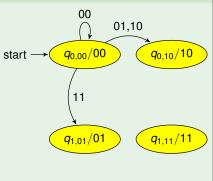
Here the output initial state state has been set to 0 as all incoming transitions to q_0 in the Mealy m/c had output a 0



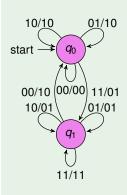


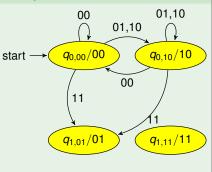




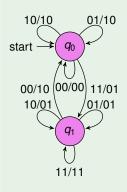


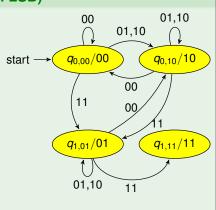




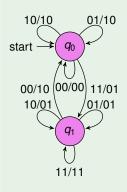


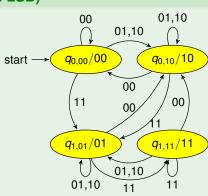


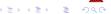




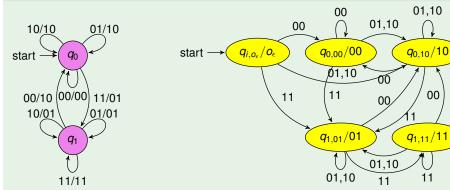








Example (Serial adder, starting from LSB)



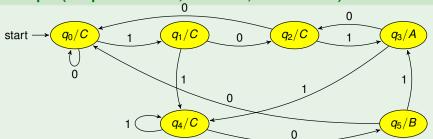
For the adder $q_{i,o_{\epsilon}}/o_{\epsilon}$ is semantically not needed, $q_{0,00}/00$ may be retained as the initial state



00

Moore→Mealy ex 1

Example (Output A on 101, B on 110, C otherwise)



Moore→Mealy ex 1

