Contents

Mealy and Moore m/cs



Section outline

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- Mealy→Moore ex 1
- Mealy→Moore ex 2
- Moore→Mealy ex 1





Mealy m/c

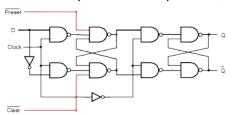
- Mealy machines are finite state machines whose outputs depends on the present state and on the inputs
- It can be defined as $\langle Q, q_0, \Sigma, \Delta, \delta, \lambda \rangle$ where:
- is a finite set of states.
 - q_0 is the initial state
 - \sum is the input alphabet
 - is the output alphabet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

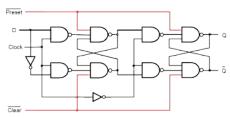




D flip flop

- 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)

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

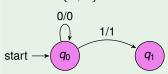
start $\rightarrow q_0$



5/17

•
$$\Sigma = \{0, 1\}$$

•
$$\Delta = \{0, 1\}$$

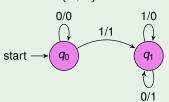






•
$$\Sigma = \{0, 1\}$$

•
$$\Delta = \{0, 1\}$$

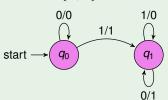






•
$$\Sigma = \{0, 1\}$$

•
$$\Delta = \{0, 1\}$$

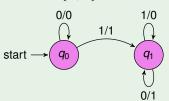


	0		1	
PS	NS	0	NS	0



•
$$\Sigma = \{0, 1\}$$

•
$$\Delta = \{0, 1\}$$



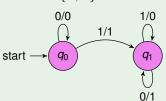
I 0		0		
PS	NS	0	NS	0
q_0	q ₀	0	<i>q</i> ₁	1





•
$$\Sigma = \{0, 1\}$$

•
$$\Delta = \{0, 1\}$$



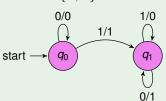
I	0		1	
PS	NS	0	NS	0
q_0	q_0	0	q_1	1
q_1	q_1	1	q_1	0





•
$$\Sigma = \{0, 1\}$$

•
$$\Delta = \{0, 1\}$$



F	nco	dings	Other	en-	
		$\frac{q_1}{q_1}$	<u> </u>	codings	also
q_0	'	41	U	possible	,

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

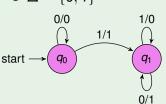




Example (2's complement of input, starting from LSB)

•
$$\Sigma = \{0, 1\}$$

•
$$\Delta = \{0, 1\}$$



_	noo	dina	Other	en-	
Encodings q_0 1 q_1 0			codings also		
q_0	'	9 1	U	possible	9

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

I	0		I 0 1		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)

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



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

 $\left(q_2\right)$

 q_3

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

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

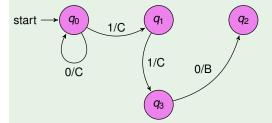




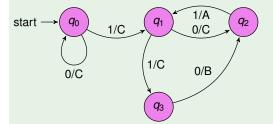


 $\left(q_3\right)$

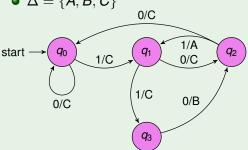
- $\Sigma = \{0, 1\}$
- $\bullet \ \Delta = \{A, B, C\}$



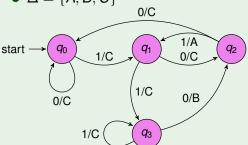
- $\Sigma = \{0, 1\}$
- $\bullet \ \Delta = \{A, B, C\}$



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



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



•
$$\Sigma = \{0, 1\}$$

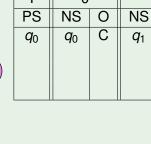


I	0		1	
PS	NS	0	NS	0

start $\rightarrow q_0$ 1/C	q_1	1/A 0/C	q_2
0/C	1/C	0/B	/
1/C	q_3		

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

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



$\bullet \ \Delta = \{A, B, C\}$			
	0/C	_	
start $\rightarrow q_0$ 1/C	q_1	1/A 0/C	q_2
0/C	1/C	0/B	
1/C	q_3		

0

С

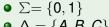
•
$$\Sigma = \{0, 1\}$$

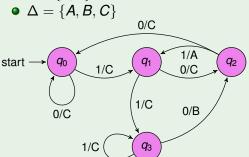
• $\Lambda = \{A, B, C\}$



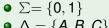
ı	0		1	
PS	NS	0	NS	0
9 ₀ 9 ₁	9 ₀ 9 ₂	C	9 ₁ 9 ₃	CC

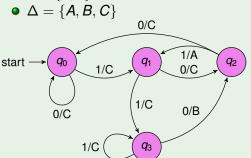
	0/C	_
start $\rightarrow q_0$ 1/C	q_1	1/A 0/C q ₂
0/C	1/C	0/B
1/C	q_3	





1			•		
	I	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



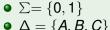


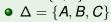
1	•					
	I	0		1		
	PS	NS	0	NS	0	
	q_0	q_0	С	q_1	C	
	q_1	q_2	C	q_3	С	
	q_2	q_1	C	q_1	Α	
	q_3	q_2	В	q ₃	С	

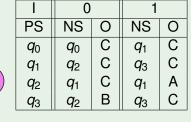
0/C

Mealy m/c ex 2

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







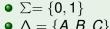
start $\rightarrow q_0$ 1/C	q_1	1/A 0/C	9
0/C	1/C	0/B	<i>†</i>
1/C	q_3		
Encodingo			

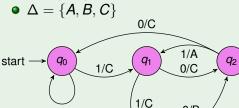
Encodings

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

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

0/B





 q_3

Encodings

0/C

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

1/C

	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

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

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



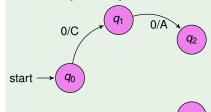


start
$$\rightarrow q_0$$



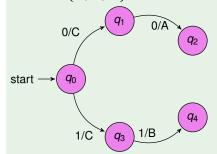


- $\Sigma = \{0, 1\}$
- $\bullet \ \Delta = \{A, B, C\}$





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



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

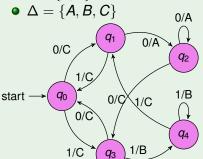
Example (Output on ending with 00:A, 11:B, C, otherwise)

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

 q_3

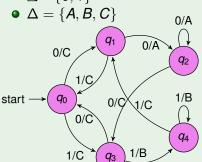
1/B

•
$$\Sigma = \{0, 1\}$$



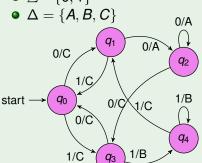
4, 11.D, 0, otherwise)						
ı	0		1			
PS	NS	0	NS	0		

•
$$\Sigma = \{0, 1\}$$



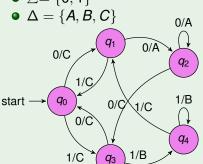
•	r, IIID, O, Other Mide)					
	I	0	0			
	PS	NS	0	NS	0	
	q 0	<i>q</i> ₁	С	<i>q</i> ₃	С	

•
$$\Sigma = \{0, 1\}$$



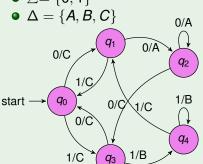
A, TTIB, O, Other Misc)					
I	0 1				
PS	NS	0	NS	0	
9 ₀ 9 ₁	q ₁ q ₂	С	9 ₃ 9 ₀	С	
q_1	q_2	Α	q_0	С	

•
$$\Sigma = \{0, 1\}$$



,	, -,			,	
I	0		1		
PS	NS	0	NS	0	
q_0	q_1	С	q ₃	С	
9 ₀ 9 ₁ 9 ₂	q ₂ q ₂	Α	9 ₃ 9 ₀ 9 ₃	С	
q 2	q_2	Α	q ₃	С	

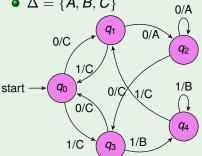
•
$$\Sigma = \{0, 1\}$$



,	, -,			,	
ı	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	

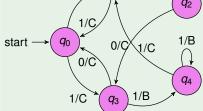
•
$$\Sigma = \{0, 1\}$$

• $\Delta = \{A, B, C\}$



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

•
$$\Sigma = \{0, 1\}$$



E	Enco	dings	
		~ ~ ~	

q_0	000	q_3	011	Α	01
q_1	000 001	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	Α	q_0	C
q 2	q_2	A	q ₃	C
q ₃	q_0	C	q_4	B
q_4	q_1	C	q_4	В

 q_4

1/B

Mealy m/c ex 3

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



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

$$0/C$$

$$0/A$$

$$q_1$$

$$0/A$$

$$q_2$$

$$1/C$$

$$0/C$$

$$1/B$$

Encodings

 q_3

0/C

1/C

	Litoutings										
q_0	000	q ₃	011	Α	01						
q_1	000 001	q_4	100	В	10						
q_2	010			С	00						

ı		0			- 1			
ĺ	PS	NS	0	I	NS	С		
	q_0	q_1	С		q 3	С		
	q_1	q_2	Α		q_{0}	C		
	q_2	q_2	Α		q 3	С		
	q_3	q_0	С		9 ₄ 9 ₄	В		
	q_4	q_1	O		q_4	В	}	
			0			1		
	PS	NS	С)	NS			0
ĺ	000	001	00)	01	011		00
	001	010	0.	1	00	0	(00
ĺ	010	010	0.	1	01	1	(00

Complete the realisation using DFF

00

00

000

001

010

100

100

100

01

01

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

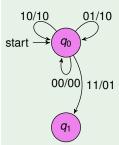
Example (Serial adder, starting from LSB)

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

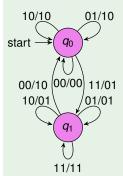
start $\rightarrow q_0$

 q_1

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



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



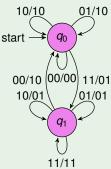
- $\Sigma = \{00, 01, 10, 11\} \triangleq \{\langle a_i, b_i \rangle\}, i \geq 0$ • $\Delta = \{00, 01, 10, 11\} \triangleq \{\langle s_i, c_i^o \rangle\}, i \geq 0$
- 10/10 01/10

 start q_0 00/10 00/00 11/01

 11/11

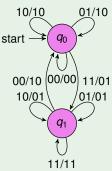
I	00	00		00 01		10		11	
PS	NS	0	NS	0	NS	0	NS	0	

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



	0	0	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

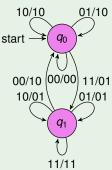
- $\Sigma = \{00, 01, 10, 11\} \triangleq \{\langle a_i, b_i \rangle\}, i \geq 0$
- $\bullet \ \Delta = \left\{00, 01, 10, 11\right\} \triangleq \left\{\left\langle s_i, c_i^{\text{o}}\right\rangle\right\}, i \geq 0$



I	00				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)

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



I	00				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

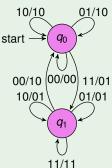
Encodings

 q_0 0 q_1

Example (Serial adder, starting from LSB)

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

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



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

I	0	0	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
 - \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 $Q \to \Delta$





Moore m/c

- Moore machines are finite state machines whose outputs depends only on the present state
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- 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 $Q \to \Delta$

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

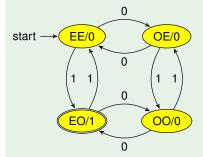
- The Mealy m/c has the same set of states and transitions as the Moore m/c
- $\forall a \in \Sigma, q \in Q : \lambda_{\mathsf{Mealy}}(q, a) = \lambda_{\mathsf{Moore}}(\delta_{\mathsf{Moore}}(q, a))$





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

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



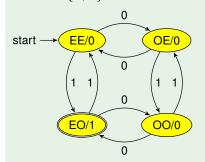
Encodings

EE 00 OE 01 EO 01 OO 11

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

•
$$\Sigma = \{0, 1\}$$

• $\Delta = \{0, 1\}$



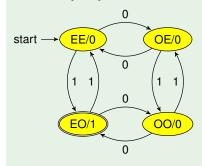
PS	N	0	
	I=0		
EE	OE	EO	0
OE	EE	00	0
EO	00	EE	1
00	EO	OE	0

Encodings

EE	00	OE	01
FΩ	01	$\cap \cap$	11

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

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

EE	00	OE	01
EO	01	00	11

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

PS	N	0	
	I=0		
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

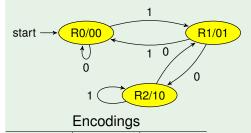
- Initial remainder is taken as zero
- On every new bit existing remainder is doubled
- Also, add 1 to new remainder on getting 1, nothing for 0





Example (Remainder on division by 3, from MSB)

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



01

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



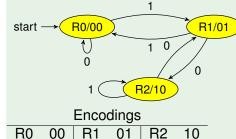


R1

R0

Example (Remainder on division by 3, from MSB)

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



- 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





Example (Remainder on division by 3, from LSB)

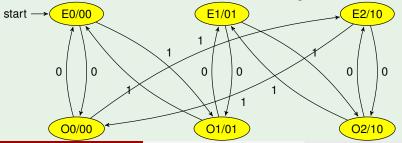
- $\Sigma = \{0, 1\}$
- $\Delta = \{00, 01, 10\}$

- 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)

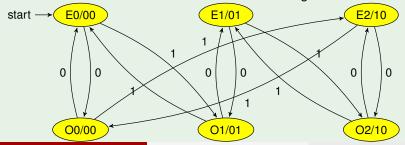
- $\Sigma = \{0, 1\}$
- $\Delta = \{00, 01, 10\}$

Encodings

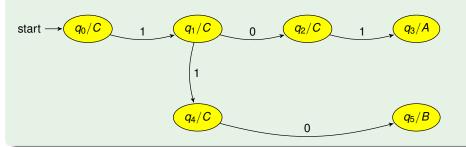
E0	000	E1	001	E2	010
O0	100	01	001 101	O2	110

Complete the realisation using DFF

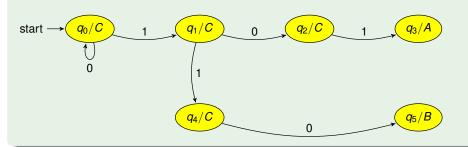
- Initial remainder is taken as zero
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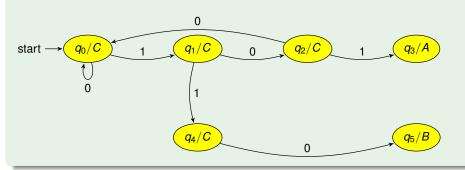
- $\Sigma = \{0, 1\}$
- $\Delta = \{00, 01, 10\} \triangleq \{C, A, B\}$



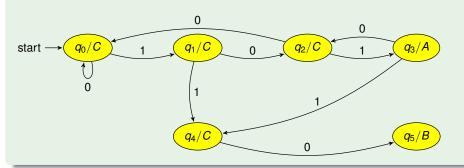
- $\Sigma = \{0, 1\}$
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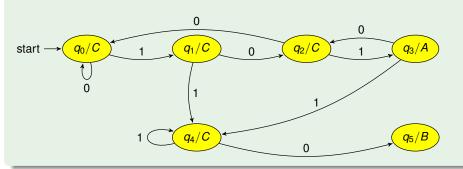
- $\Sigma = \{0, 1\}$
- $\Delta = \{00, 01, 10\} \triangleq \{C, A, B\}$



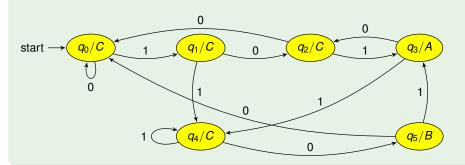
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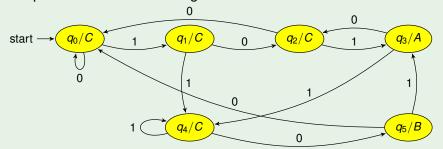
Example (Output A on 101, B on 110, C otherwise)

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

Encodings

3-1-9-										
q_0	000	q_1	001	q_2	011	Α	01	C	00	
q_3	010	q_4	110	q ₅	011 111	В	10			

Complete the realisation using DFF



• In the Mealy m/c let s_j have input transitions with outputs $o_{k_1}, o_{k_2}, \dots, o_{k_j}$





- In the Mealy m/c let s_j have input transitions with outputs $o_{k_1}, o_{k_2}, \dots, o_{k_s}$
- ullet In the Moore m/c create states $s_{\jmath,k_1}/o_{k_1},s_{\jmath,k_2}/o_{k_2},\ldots,s_{\jmath,k_j}/o_{k_j}$





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- $s_{j,k_{\ell}}/o_{k_{\ell}}$ means copy of Mealy m/c state s_{j} as $s_{j,k_{\ell}}$ to output $o_{k_{\ell}}$ 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 $s_{j,k}$





- In the Mealy m/c let s_j have input transitions with outputs $o_{k_1}, o_{k_2}, \dots, o_{k_n}$
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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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- 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 $s_{j,k}$
- 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 $\Delta_{\mathsf{Moore}} = \Delta_{\mathsf{Mealv}} \cup \{o_{\epsilon}\}$
- 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

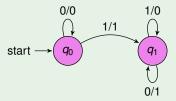




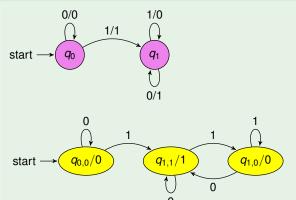
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- $s_{j,k_\ell}/o_{k_\ell}$ means copy of Mealy m/c state s_j as s_{j,k_ℓ} to output o_{k_ℓ} in the Moore m/c
- If there is a transition from s_i to s_j on input a with output o_k in the Mealy m/c, create a transition on a from each copy of s_i to $s_{j,k}$
- 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 $\Delta_{\text{Moore}} = \Delta_{\text{Mealy}} \cup \{o_{\epsilon}\}$
- 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



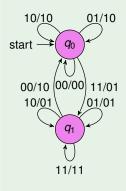
Example (2's complement of input, starting from LSB)

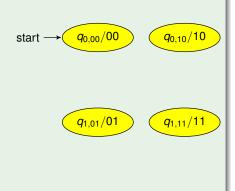


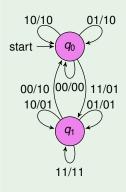
Example (2's complement of input, starting from LSB)

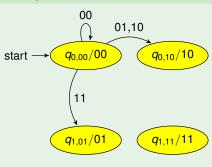


Here the output initial state state has been set to 0 as all incoming transitions to q_0 in the Mealy m/c had output a 0



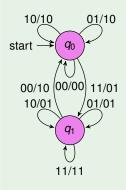


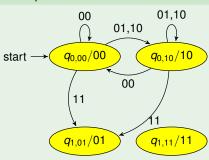






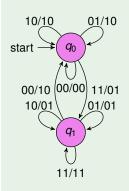


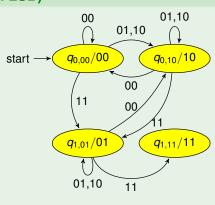




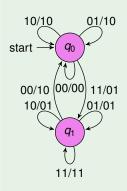


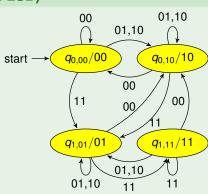








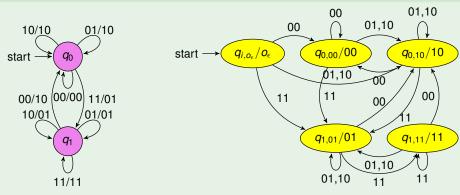








Example (Serial adder, starting from LSB)



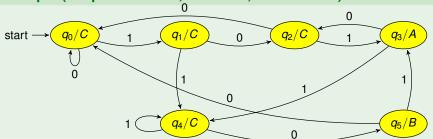
For the adder $q_{i,o_{\epsilon}}/o_{\epsilon}$ is semantically not needed, $q_{0,00}/00$ may be retained as the initial state



CM & PM (IIT Kharagpur)

Moore→Mealy ex 1

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



Moore→Mealy ex 1

