CSE 140: Components and Design Techniques for Digital Systems

Lecture 9:
Sequential Networks: Implementation

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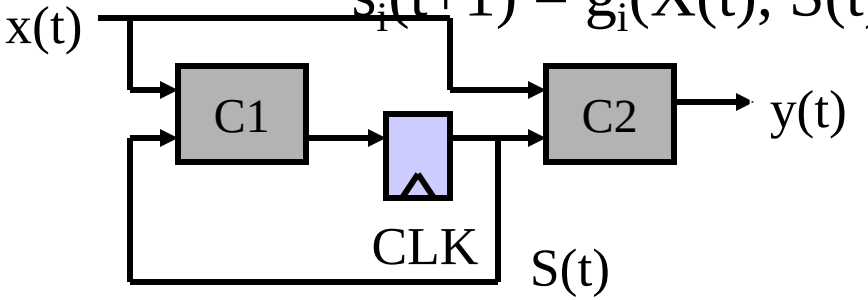
Implementation

- Format and Tool
- Procedure
- Excitation Tables
- Example

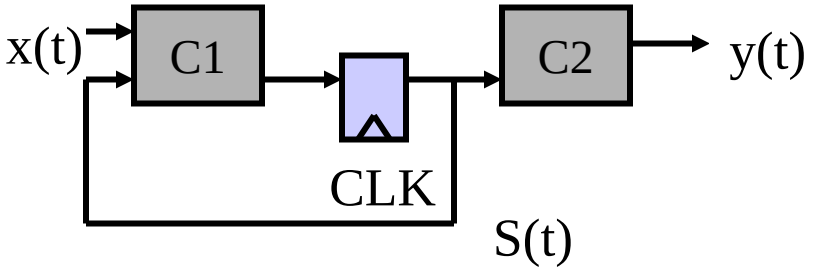
Canonical Form: Mealy and Moore Machines

Mealy Machine: $y_i(t) = f_i(X(t), S(t))$
Moore Machine: $y_i(t) = f_i(S(t))$

$s_i(t+1) = g_i(X(t), S(t))$



Mealy Machine



Moore Machine

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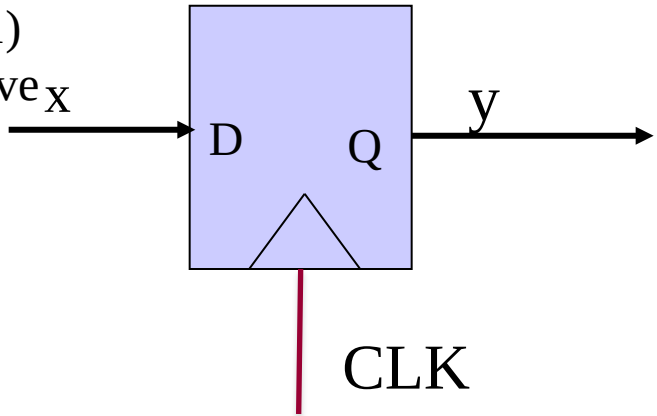
In the logic diagram below, a D flip-flop has input x and output y.

A: x= Q(t), y=Q(t)

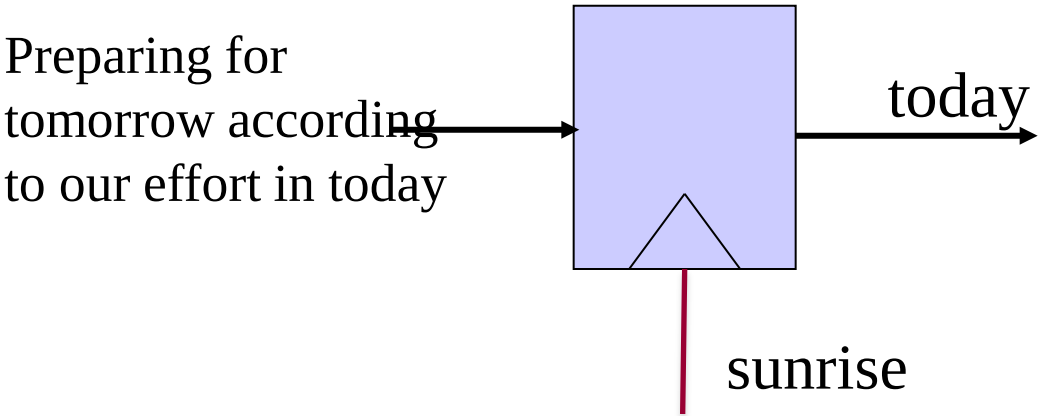
B: x=Q(t+1), y=Q(t)

C: x=Q(t), y=Q(t+1)

D: None of the above



Understanding Current State and Next State in a sequential circuit

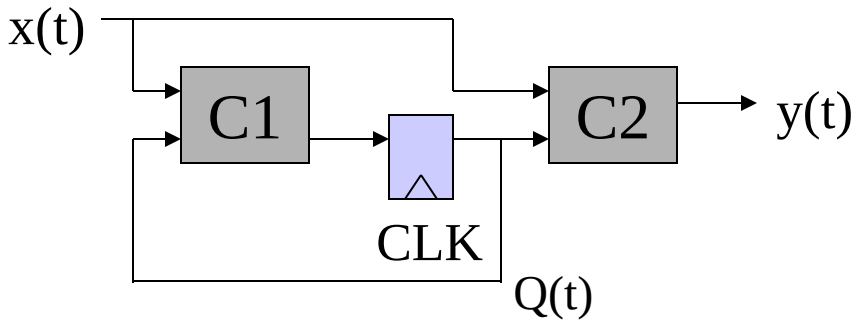


Implementation Format

Canonical Form: Mealy & Moore machines

State Table → Netlist

Tool: Excitation Table



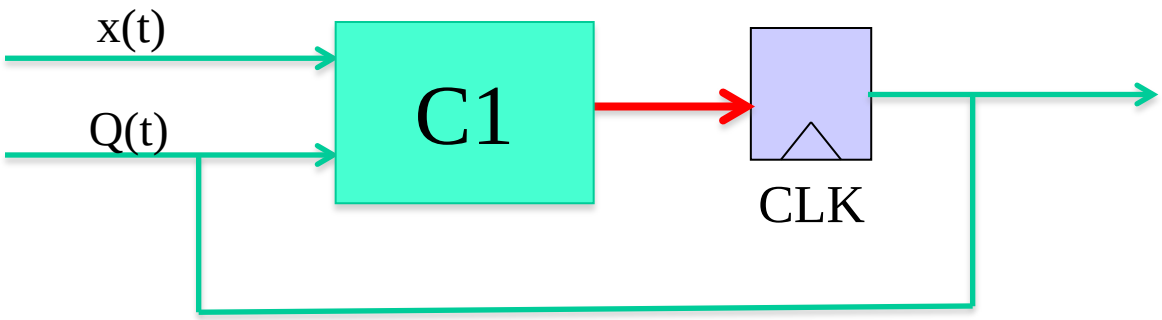
$Q(t+1) = h(x(t), Q(t))$ Circuit C1

$y(t) = f(x(t), Q(t))$ Circuit C2

Implementation Tool: Excitation Table

State Table

id	x(t)	Q(t)	Q(t+1)
0	0	0	1
1	1	1	0
2	0	0	1
3	1	1	0

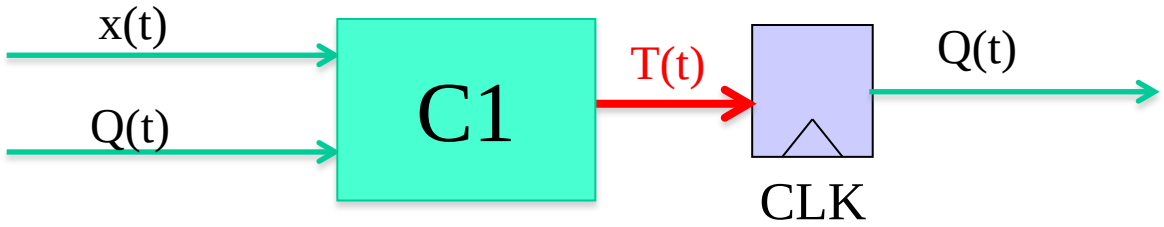


Find D, T, (S R), (J K) to drive F-Fs

Implementation Tool: Excitation Table

State Table

id	x(t)	Q(t)	Q(t+1)
0	0	0	1
1	1	1	0
2	0	1	1
3	1	1	0



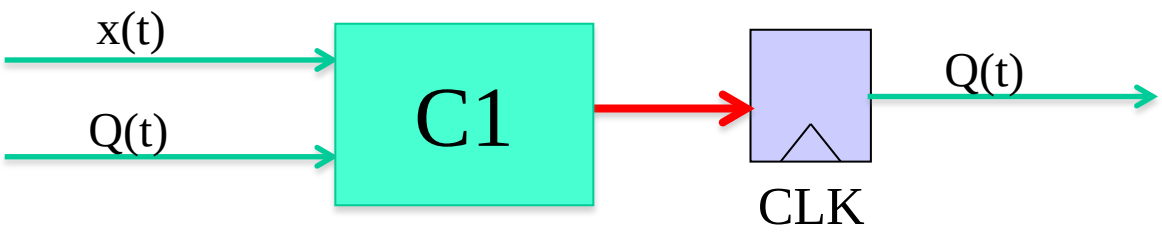
Excitation Table

id	x(t)	Q(t)	T(t)	Q(t+1)
0	0	0	1	1
1	1	1	1	0
2	0	1	0	1
3	1	1	1	0

Example with T flip flop

Implementation Tool: Excitation Table

Implement combinational logic C1
D(t), T(t), (S(t) R(t)), (J(t) K(t)) are functions of (x,Q(t))



Excitation Table

id	x(t)	Q(t)	T(t)	Q(t+1)
0	0	0	1	1
1	1	1	1	0
2	0	1	0	1
3	1	1	1	0

Implementation: Procedure

State Table => Excitation Table

Problem: Given a state table, we have

NS: $Q(t+1) = h(x(t),Q(t))$

We find D, T, (S R), (J K) to drive F-Fs from

$Q(t)$ to $Q(t+1)$.

Excitation Table: The setting of

D(t), T(t), (S(t) R(t)), (J(t) K(t)) to drive

$Q(t)$ to $Q(t+1)$.

We implement combinational logic C1

D(t), T(t), (S(t) R(t)), (J(t) K(t)) are functions of

(x,Q(t)).

Implementation: Procedure

State Table => Excitation Table

Problem: Given a state table, we have

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Excitation Table: The setting of

D(t), T(t), (S(t) R(t)), (J(t) K(t)) to drive

$Q(t)$ to $Q(t+1)$.

We implement combinational logic C1

D(t), T(t), (S(t) R(t)), (J(t) K(t)) are functions of

$(x,Q(t))$.

Implementation: Procedure

F-F State Table <=> F-F Excitation Table

PS Q(t)	NS Q(t+1)
	DTSRJK

PS Q(t)	NS Q(t+1)
	DTSRJK

- D F-F
  - D(t)= $e_D(Q(t+1), Q(t))$
- T F-F
  - T(t)= $e_T(Q(t+1), Q(t))$
- SR F-F
  - S(t)= $e_S(Q(t+1), Q(t))$
  - R(t)= $e_R(Q(t+1), Q(t))$
- JK F-F
  - J(t)= $e_J(Q(t+1), Q(t))$
  - K(t)= $e_K(Q(t+1), Q(t))$

Excitation Table

State table of JK F-F:

		JK				
		00	01	10	11	
Q(t)	0	0	0	1	1	Q(t+1)
	1	1	0	1	0	

Excitation table of JK F-F:

	NS	Q(t+1)	
PS		0	1
Q(t)	0	0-	1-
	1	-1	-0
		JK	

If Q(t) is 1, and Q(t+1) is 0, then JK needs to be -1.

Excitation Tables and State Tables

Excitation Tables:

SR

PS \ NS	0	1
0	0-	10
1	01	-0

Q(t) Q(t+1)

T

PS \ NS	0	1
0	0	1
1	1	0

Q(t) Q(t+1)

State Tables:

SR

PS \ SR	00	01	10	11
0	0	0	1	-
1	1	0	1	-

Q(t) Q(t+1)

T

PS \ T	0	1
0	0	1
1	1	0

Q(t) Q(t+1)

Excitation Tables and State Tables

Excitation Tables:

JK

PS \ NS	0	1
0	0-	1-
1	-1	-0

Q(t) — Q(t+1)

D

PS \ NS	0	1
0	0	1
1	0	1

Q(t) — Q(t+1)

State Tables:

JK

PS \ JK	00	01	10	11
0	0	0	1	1
1	1	0	1	0

Q(t) — Q(t+1)

D

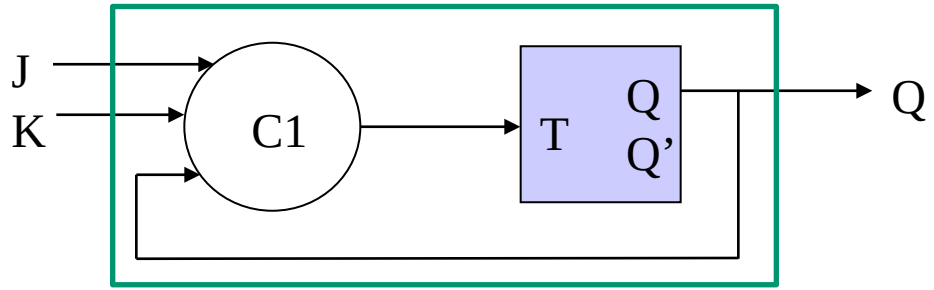
PS \ D	0	1
0	0	1
1	0	1

Q(t) — Q(t+1)

Implementation: Procedure

1. State table: $y(t)= f(Q(t), x(t)), \quad Q(t+1)= h(x(t),Q(t))$
2. Excitation table of F-Fs:
   - $D(t)= e_D(Q(t+1), Q(t));$
   - $T(t)= e_T(Q(t+1), Q(t));$
   - (S, R), or (J, K)
3. From 1 & 2, we derive excitation table of the system
   - $D(t)= g_D(x(t),Q(t))= e_D(h(x(t),Q(t)),Q(t));$
   - $T(t)= g_T(x(t),Q(t))= e_T(h(x(t),Q(t)),Q(t));$
   - (S, R) or (J, K).
4. Use K-map to derive optional combinational logic implementation.
   - $D(t)= g_D(x(t),Q(t))$
   - $T(t)= g_T(x(t),Q(t))$
   - $y(t)= f(x(t),Q(t))$

Implementation: Example
Implement a JK F-F with a T F-F



Implement a JK F-F: $Q(t+1) = h(J(t),K(t),Q(t)) = J(t)Q'(t)+K'(t)Q(t)$

JK

PS \ JK	00	01	10	11
Q(t) 0	0	0	1	1
Q(t) 1	1	0	1	0

Example: Implement a JK flip-flop using a T flip-flop

Excitation Table of T Flip-Flop $T(t) = Q(t) \oplus Q(t+1)$

Q(t) \ Q(t+1)	0	1
0	0	1
1	1	0

T

Excitation Table of the Design

id	J(t)	K(t)	Q(t)	Q(t+1)	T(t)
0	0	0	0	0	0
1	0	0	1	1	0
2	0	1	0	0	0
3	0	1	1	0	1
4	1	0	0	1	1
5	1	0	1	1	0
6	1	1	0	1	1
7	1	1	1	0	1

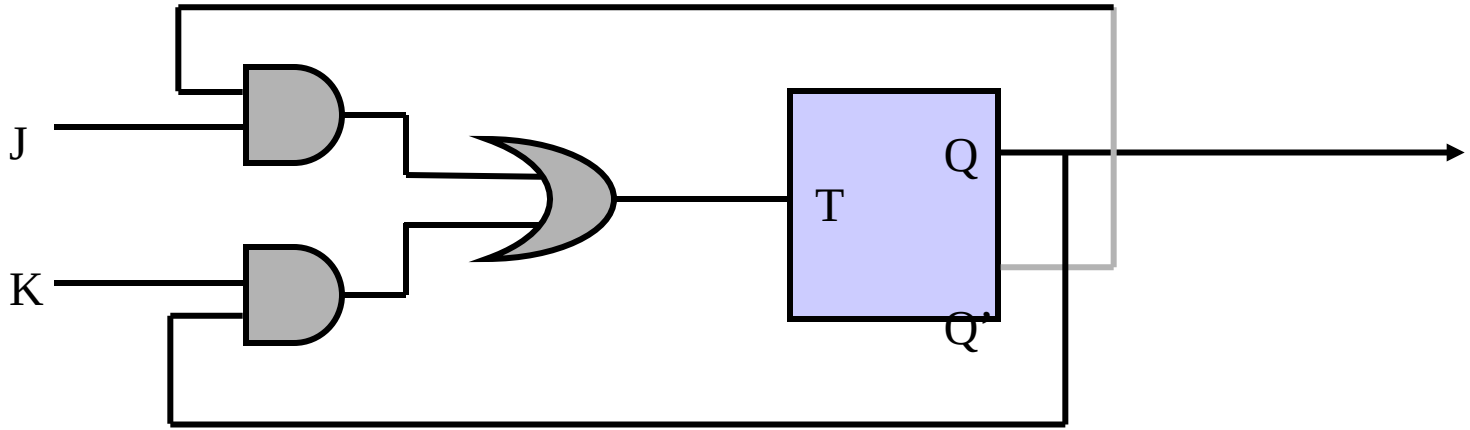
$T(t) = Q(t)$ XOR $(J(t)Q'(t) + K'(t)Q(t))$

Example: Implement a JK flip-flop using a T flip-flop

T(J,K,Q):

Q(t) \ K		J	
	0	2	6	4
0	0	0	1	1
1	1	3	7	5
	0	1	1	0

$$T = K(t)Q(t) + J(t)Q'(t)$$



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Given a flip-flop, the relation of its state table and excitation table is

A.One to one

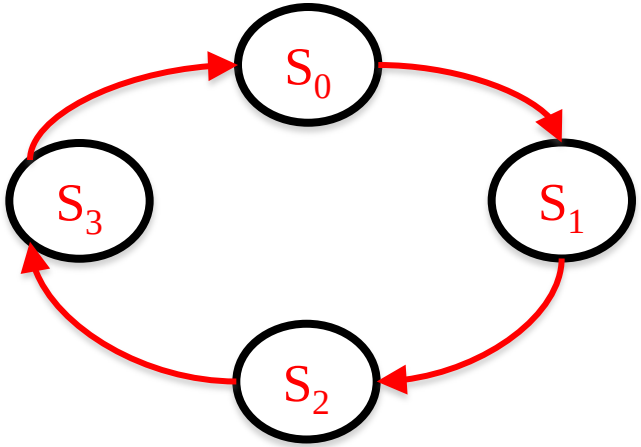
B.One to many

C.Many to one

D.Many to many

E.None of the above

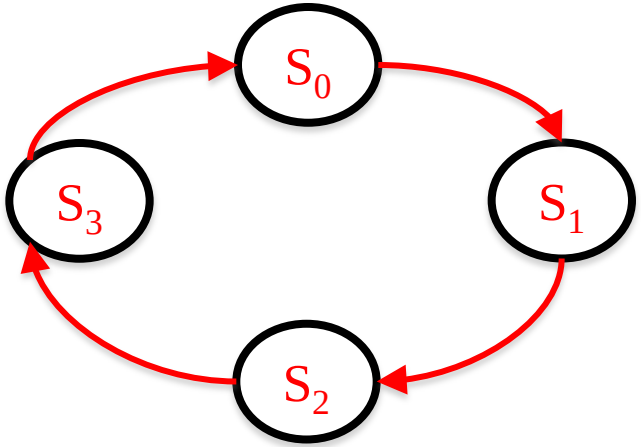
Let’s implement our free running 2-bit counter using T-flip flops



State Table

PS	Next state
S_0	S_1
S_1	S_2
S_2	S_3
S_3	S_0

Let’s implement our free running 2-bit counter using T-flip flops



State Table

S_0	S_1
S_1	S_2
S_2	S_3
S_3	S_0

State Table with Assigned Encoding

Current	Next
0 0	01
0 1	10
1 0	11
1 1	00

Let’s implement our free running 2-bit counter using T-flip flops

Excitation table

id	$Q_1(t)$	$Q_0(t)$	$T_1(t)$	$T_0(t)$	$Q_1(t+1)$	$Q_0(t+1)$
0	0	0			0	1
1	0	1			1	0
2	1	0			1	1
3	1	1			0	0

Let’s implement our free running 2-bit counter using T-flip flops

Excitation table

id	$Q_1(t)$	$Q_0(t)$	$T_1(t)$	$T_0(t)$	$Q_1(t+1)$	$Q_0(t+1)$
0	0	0	0	1	0	1
1	0	1	1	1	1	0
2	1	0	0	1	1	1
3	1	1	1	1	0	0

Let’s implement our free running 2-bit counter using T-flip flops

Excitation table

id	$Q_1(t)$	$Q_0(t)$	$T_1(t)$	$T_0(t)$	$Q_1(t+1)$	$Q_0(t+1)$
0	0	0	0	1	0	1
1	0	1	1	1	1	0
2	1	0	0	1	1	1
3	1	1	1	1	0	0

$T_0(t) =$

$T_1(t) =$

$Q_0(t+1) = T_0(t)\, Q'_0(t) + T'_0(t) Q_0(t)$

$Q_1(t+1) = T_1(t)\, Q'_1(t) + T'_1(t) Q_1(t)$

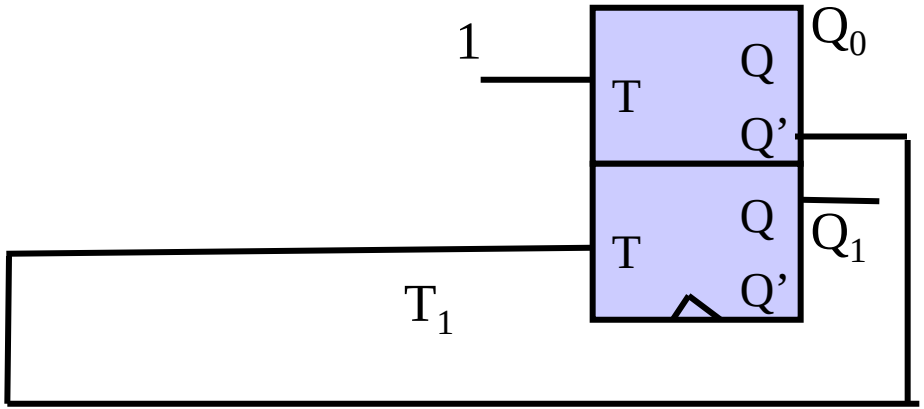
Let’s implement our free running 2-bit counter using T-flip flops

Excitation table

id	$Q_1(t)$	$Q_0(t)$	$T_1(t)$	$T_0(t)$	$Q_1(t+1)$	$Q_0(t+1)$
0	0	0	0	1	0	1
1	0	1	1	1	1	0
2	1	0	0	1	1	1
3	1	1	1	1	0	0

$$T_0(t) = 1$$
$$T_1(t) = Q_0(t)$$

Free running counter with T flip flops



$T_0(t) = 1$

$T_1(t) = Q_0(t)$

Summary: Implementation

- Set up canonical form
  - Mealy or Moore machine
- Identify the next states
  - state diagram ⇨ state table
  - state assignment
- Derive excitation table
  - Inputs of flip flops
- Design the combinational logic
  - don’t care set utilization