Bonus

Reimplement your design using T flip-flops instead of JK flip-flops:

- Determine the inputs, outputs, number of flip-flops needed and their type:

  Input

  - **Direction** (we can call it **x**)

  Output

  4 LED lights, we can call them:

  - LED **A**
  - LED **B**
  - LED **C**
  - LED **D**

  The number of flip-flops

  - 4 T flip-flops, we call them T_A, T_B, T_C, T_D respectively.

- Base on the naming convention mentioned in the previous step, we derive the excitation table for the state machine as below:

$A(t)$	$B(t)$	$C(t)$	$D(t)$	x	$A(t+1)$	$B(t+1)$	$C(t+1)$	$D(t+1)$	T_A	T_B	T_C	T_D
0	0	0	0	0	0	0	0	1	0	0	0	1
0	0	0	0	1	1	0	0	0	1	0	0	0
0	0	0	1	0	0	0	1	1	0	0	1	0
0	0	0	1	1	0	0	0	0	0	0	0	1
0	0	1	1	0	0	0	1	0	0	0	0	1
0	0	1	1	1	0	0	0	1	0	0	1	0

0	0	1	0	0	0	1	1	0	0	1	0	0
0	0	1	0	1	0	0	1	1	0	0	0	1
0	1	1	0	0	0	1	1	1	0	0	0	1
0	1	1	0	1	0	0	1	0	0	1	0	0
0	1	1	1	0	0	1	0	1	0	0	1	0
0	1	1	1	1	0	1	1	0	0	0	0	1
0	1	0	1	0	0	1	0	0	0	0	0	1
0	1	0	1	1	0	1	1	1	0	0	1	0
0	1	0	0	0	1	1	0	0	1	0	0	0
0	1	0	0	1	0	1	0	1	0	0	0	1
1	1	0	0	0	1	1	0	1	0	0	0	1
1	1	0	0	1	0	1	0	0	1	0	0	0
1	1	0	1	0	1	1	1	1	0	0	1	0
1	1	0	1	1	1	1	0	0	0	0	0	1
1	1	1	1	0	1	1	1	0	0	0	0	1
1	1	1	1	1	1	1	0	1	0	0	1	0
1	1	1	0	0	1	0	1	0	0	1	0	0
1	1	1	0	1	1	1	1	1	0	0	0	1

1	0	1	0	0	1	0	1	1	0	0	0	1
1	0	1	0	1	1	1	1	0	0	1	0	0
1	0	1	1	0	1	0	0	1	0	0	1	0
1	0	1	1	1	1	0	1	0	0	0	0	1
1	0	0	1	0	1	0	0	0	0	0	0	1
1	0	0	1	1	1	0	1	1	0	0	1	0
1	0	0	0	0	0	0	0	0	1	0	0	0
1	0	0	0	1	1	0	0	1	0	0	0	1

- Since the circuit output function of A, B, C, D are obtained from **Page 3** to **Page 6**, we have:

$$A(t+1) = AD + AC + B'C'D'x + BC'D'x'$$

$$B(t+1) = BC' + BD + A'CD'x' + ACD'x$$

$$C(t+1) = CD' + A'B'Dx' + A'BDx + AB'Dx + ABDx'$$

$$D(t+1) = A'B'C'x' + A'B'Cx + A'BC'x + A'BCx' + AB'C'x + AB'Cx' + ABC'x' + ABCx$$

  such that $A = A(t)$, $B = B(t)$, $C = C(t)$, $D = D(t)$.

- Now we derive all 4 T flip-flop input functions using the map method:
  - For K-Map of T_A, we have
    - When $A = 0$

$ABC\backslash Dx$	00	01	11	10
000	0	1	0	0
001	0	0	0	0
011	0	0	0	0
010	1	0	0	0

- When $A = 1$

$ABC\backslash Dx$	00	01	11	10
100	1	0	0	0
101	0	0	0	0
111	0	0	0	0
110	0	1	0	0

Thus, we have

$$T_A = A'B'C'D'x + A'BC'D'x' + AB'C'D'x' + ABC'D'x$$

- For K-Map of T_B, we have
  - When $A = 0$

$ABC\backslash Dx$	00	01	11	10
000	0	0	0	0
001	1	0	0	0
011	0	1	0	0
010	0	0	0	0

- When $A = 1$

$ABC\backslash Dx$	00	01	11	10
100	0	0	0	0
101	0	1	0	0
111	1	0	0	0
110	0	0	0	0

Thus, we have

$$T_B = A'B'CD'x' + A'BCD'x + AB'CD'x + ABCD'x'$$

- For K-Map of T_C, we have
  - When $A = 0$

$ABC\backslash Dx$	00	01	11	10
000	0	0	0	1
001	0	0	1	0
011	0	0	0	1
010	0	0	1	0

- When $A = 1$

$ABC\backslash Dx$	00	01	11	10
100	0	0	1	0
101	0	0	0	1
111	0	0	1	0
110	0	1	0	1

Thus we have

$$T_C = A'B'C'Dx' + A'B'CDx + A'BC'Dx + A'BCDx'$$
$$+AB'C'Dx + AB'CDx' + ABC'Dx' + ABCDx$$

- For K-Map of T_D, we have
  - When $A = 0$

$ABC\backslash Dx$	00	01	11	10
000	1	0	1	0
001	0	1	0	1
011	1	0	1	0
010	0	1	0	1

- When $A = 1$

$ABC\backslash Dx$	00	01	11	10
100	0	1	0	1
101	1	0	1	0
111	0	1	0	1
110	1	0	1	0

Thus we have

$$\begin{aligned} T_D = &A'B'C'D'x' + A'B'C'Dx + A'B'CD'x + A'B'CDx' \\ &+A'BC'D'x + A'BC'Dx' + A'BCD'x' + A'BCDx \\ &+AB'C'D'x + AB'C'Dx' + AB'CD'x' + AB'CDx \\ &+ABC'D'x' + ABC'Dx + ABCD'x + ABCDx' \end{aligned}$$

- Draw the logic diagram for the circuit

NOTE The file *assign2.circ* has been uploaded to D2L dropbox. And diagrams for T_A, T_B, T_C, T_D and the diagram for the whole circuit are shown below by hand-written: