

University of Victoria
Department of Computer Science
CSC 355 Digital Logic and Computer Design
Lab 7: Finite State Machine Design

Introduction

This lab provides practice designing and (possibly) implementing a Finite State Machine (FSM) starting either from some initial specifications of the problem to be solved or from a given State Diagram.

Pre-Lab Exercises

1. Pre-Lab #1 : FSM #1

You are part of a design team that has been asked to design a controller for a home heating system to be marketed across the cold Canadian prairies.¹ Heat is provided from two sources, a natural gas fired furnace and a passive solar window system that includes insulated shutters. If the sun is shining² and the outdoor temperature is more than -25°C the windows provide enough heat to warm the building. When there are clouds in the sky, when it is very cold ($\leq -25^{\circ}\text{C}$) and during the night the windows shed heat and the shutters must be closed.

The specification of the controller is as follows:

There are three external inputs (simulated using data switches):

- **D**, which is to be attached to a solar detector. However, in the laboratory testing environment, a simple data switch is used to simulate the input from this device. Hence D set to 1 indicates that the sun is shining and a 0 indicates that it is not.
- **T**, which is to be attached to a thermostat placed inside the house. It returns a 1 when the building needs more heat and a 0 when it does not.
- **G**, which is attached to an outdoor temperature sensor. It returns a 1 when the outdoor temperature is $> -25^{\circ}\text{C}$, and a 0 otherwise.

The controller can be in four different states:

- **S0**: In this state the furnace (F) is off and the shutters (S) are closed. Thus state **S0** is labeled with two bit state variables, $F = 0$ and $S = 0$.
- **S1**: In this state the furnace is on and the shutters are open. Thus state **S1** is labeled with two bit state variables, $F = 1$ and $S = 1$.
- **S2**: In this state the furnace is on and the shutters are closed. Thus state **S2** is labeled with two bit state variables, $F = 1$ and $S = 0$.
- **S3**: In this state the furnace is off and the shutters are open. Thus state **S3** is labeled with two bit state variables, $F = 0$ and $S = 1$.

¹ In this climate it is very cold for half the year and every home must be heated.

² Fortunately the sun shines frequently.

The table below indicates the results of the analysis phase of this project.

From state	Input sensors: DTG=	Go to state:
S0	000, 001, 100 or 101	S0
	110	S1
	010 or 011	S2
	111	S3
S1	000, 001, 100 or 101	S0
	110	S1
	010, 011 or 111	S2
S2	000, 001, 100 or 101	S0
	110	S1
	010 or 011	S2
	111	S3
S3	000, 001, 100 or 101	S0
	110	S1
	010 or 011	S2
	111	S3

All other input combinations cause the system to go to state S3. The sequential machine for the controller has four states and uses two state variables for this purpose, F and S. F and S can be monitored using two output LEDs

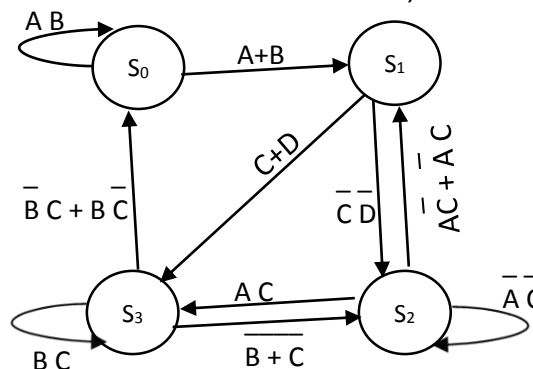
- Draw the state diagram for a FSM to represent the given specifications above.
- Write an encoded state table (transition table) corresponding to the state diagram of the previous step.
- Fill in the Karnaugh maps for the next states F^+ , S^+ , and write minimal sum-of-products equations for F^+ , S^+ (show your work).
- For the circuit, it has been decided to use D flip-flops, so the equations created in c) above can be used directly for the flip-flop inputs. (i.e., $D=Q^+$). **On a separate piece of paper** that you bring with you to your lab, draw the complete circuit diagram (properly labeled), including pin numbers, for your design.

Note: A maximum of one 7474, three 7400, one 7404 and one 7410 chips can be used!

2. Pre-Lab #2: FSM #2

Design a circuit with the specifications described below.

- **External inputs:** A, B, C and D, controlled from the data switches.
- **Number of states:** 4 (The state assignment to be used is defined below.)
- **Outputs:** Two LEDs to monitor the values of the state variables, called X and Y.
- **State diagram:** shown here:



- a) Complete a state table corresponding to the state diagram. Use *don't cares* for input combinations, where appropriate, so that your table can be abbreviated. In the example on the pre-lab worksheet, the first four rows are shown as a guide. Make sure that the total number of rows (i.e., combinations for A, B, C and D) covers all the 16 possibilities for each of the states. (You may not need all of the rows shown in the table.)
- b) Complete the encoded state table (transition table) corresponding to the state table of the previous step. Use the following state assignment (it will be just the first and last columns that change – the number of rows you use will be the same as in the previous part):

State	X	Y
S0	0	0
S1	0	1
S2	1	0
S3	1	1

- c) Fill in the Karnaugh maps for the next states X^+ , Y^+ . Remember that X^+ and Y^+ are functions of X, Y, A, B, C and D. Please use this ordering of inputs.
- d) From these maps, fill in the maps for the inputs for J-K flip flops representing X and Y. You need 4 Karnaugh maps of 6 inputs each.
- e) Determine the minimal sum-of-products equations for each of J_X , K_X , J_Y and K_Y .
- f) **On a separate piece of paper** that you bring with you to your lab, draw the complete circuit diagram (properly labeled), including pin numbers, for your complete circuit design.

Note: A maximum of three 7400 chips, one 7404 chip, one 7410 chip and one 7476 chip can be used for this experiment.

Part 2: Procedures for the In-Lab Exercises

1. Greet your lab instructor and obtain your graded Pre-Lab 7.
2. Build circuit 1 and demo its functions to the lab instructor.
3. Build circuit 2 and demo its functions to the lab instructor.

Pre-Lab Worksheet #7 NAME: _____ LAB Section: B0__

1 a) Draw the state diagram for a FSM to represent the given specifications.

1 b) Write an encoded state table (transition table) corresponding to the state diagram above.

Present State		Next State		F ⁺ S ⁺					
F	S	DTG = 000	DTG = 001	DTG = 010	DTG = 011	DTG = 100	DTG = 101	DTG = 110	DTG = 111
0	0								
0	1								
1	0								
1	1								

1 c) Fill in the Karnaugh maps and write minimal sum-of-products equations

FS\TG 00 01 11 10

00				
01				
11				
10				

D=0

FS\TG 00 01 11 10

00				
01				
11				
10				

D=1

F⁺ =

FS\TG 00 01 11 10

00				
01				
11				
10				

D=0

FS\TG 00 01 11 10

00				
01				
11				
10				

D=1

S⁺ =

2 a) Complete a state table corresponding to the state diagram.

present state	condition				next state
	A	B	C	D	
S ₀	0	0	x	x	S ₀
S ₀	1	x	x	x	S ₁
S ₀	x	1	x	x	S ₁
S ₁	x	x	0	0	S ₂

2 b) Complete the encoded state table (transition table).

present state	condition				next state
XY	A	B	C	D	X ⁺ Y ⁺
00	0	0	x	x	00
00	1	x	x	x	01
00	x	1	x	x	01
01	x	x	0	0	10

2 c) Fill in the Karnaugh maps for the next states X^+ , Y^+ .

AB\CD	00	01	11	10
00				
01				
11				
10				

XY=00

AB\CD	00	01	11	10
00				
01				
11				
10				

XY=01

Maps for X^+

AB\CD	00	01	11	10
00				
01				
11				
10				

XY=10

AB\CD	00	01	11	10
00				
01				
11				
10				

XY=11

AB\CD	00	01	11	10
00				
01				
11				
10				

XY=00

AB\CD	00	01	11	10
00				
01				
11				
10				

XY=01

Maps for Y^+

AB\CD	00	01	11	10
00				
01				
11				
10				

XY=10

AB\CD	00	01	11	10
00				
01				
11				
10				

XY=11

2 d) Fill in the maps for each of J_x , K_x , J_y and K_y .

AB\CD	00	01	11	10
00				
01				
11				
10				

XY=00

AB\CD	00	01	11	10
00				
01				
11				
10				

XY=01

Map for J_x

AB\CD	00	01	11	10
00				
01				
11				
10				

XY=10

AB\CD	00	01	11	10
00				
01				
11				
10				

XY=11

AB\CD	00	01	11	10
00				
01				
11				
10				

XY=00

AB\CD	00	01	11	10
00				
01				
11				
10				

XY=01

Map for K_x

AB\CD	00	01	11	10
00				
01				
11				
10				

XY=10

AB\CD	00	01	11	10
00				
01				
11				
10				

XY=11

AB\CD	00	01	11	10
00				
01				
11				
10				

XY=00

AB\CD	00	01	11	10
00				
01				
11				
10				

XY=01

Map for J_Y

AB\CD	00	01	11	10
00				
01				
11				
10				

XY=10

AB\CD	00	01	11	10
00				
01				
11				
10				

XY=11

AB\CD	00	01	11	10
00				
01				
11				
10				

XY=00

AB\CD	00	01	11	10
00				
01				
11				
10				

XY=01

Map for K_Y

AB\CD	00	01	11	10
00				
01				
11				
10				

XY=10

AB\CD	00	01	11	10
00				
01				
11				
10				

XY=11

2 e) Determine the minimal sum-of-products equations for each of J_X , K_X , J_Y and K_Y .

$J_X =$

$K_X =$

$J_Y =$

$K_Y =$