Lesson 17: State-Based Design Example

ET 438B Sequential Control and Data Acquisition

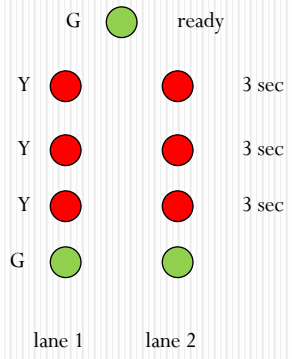
Department of Technology

Learning Objectives

After this presentation you will be able to:

- Determine the inputs, outputs and states of a sequential process from the problem statement
- Write state equations based on defined inputs, outputs and previous states
- Convert state equations into ladder rungs.

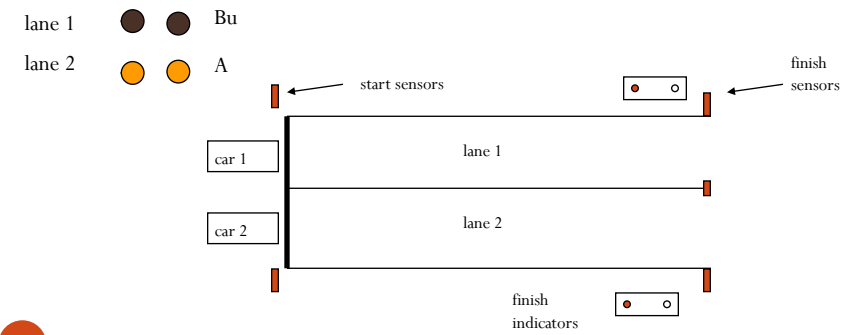
DESIGN EXAMPLE - DRAG STRIP "CHRISTMAS TREE"



A simplified starting timer is to be constructed for a drag strip. To enable the start timing for a race both cars must actuate sensor switches at the start line that indicate they are in position. When the cars are in position, the race judge receives a green light on his control panel and a green light comes on of the "Christmas Tree". He then presses a race initial button on his control panel. The Christmas tree times through the sequence shown at left.

DESIGN EXAMPLE - DRAG STRIP "CHRISTMAS TREE"

When the lower pair of green lamps come on the racers begin. A pair of photo eyes located at the finish line indicate the winner by lighting a blue light for a winner and a amber light for a loser. after the race results are indicated, the judge can press a reset button to prepare the system for the next race



DESIGN EXAMPLE - DRAG STRIP "CHRISTMAS TREE"

Design Problem

1.) Identify the states, conditions and actions for this system
2.) Construct a flow chart of the logic for this system
3.) Construct a state transition diagram for this system
4.) Design a ladder logic system to implement these functions

Part 1: States, Conditions, Actions

States

S0 : reset
S1: cars at start line
S2: 1st set red lamps on
S3: 2nd set red lamps on
S4: 3rd set red lamps on
S5: Green lamps on (race start)
S6: Lane 1 Wins
S7: Lane 2 Wins

DESIGN EXAMPLE - DRAG STRIP "CHRISTMAS TREE"

Define conditions (Inputs)

Conditions

I0: reset pressed
I1: racer 1 positioned
I2: racer 2 positioned
I3: race timing initiated
I4: 1st set red lamps timed out
I5: 2nd set red lamps timed out
I6: 3rd set red lamps timed out
I7: lane 1 finish photo eye tripped
I8: lane 2 finish photo eye tripped
I9: start pressed

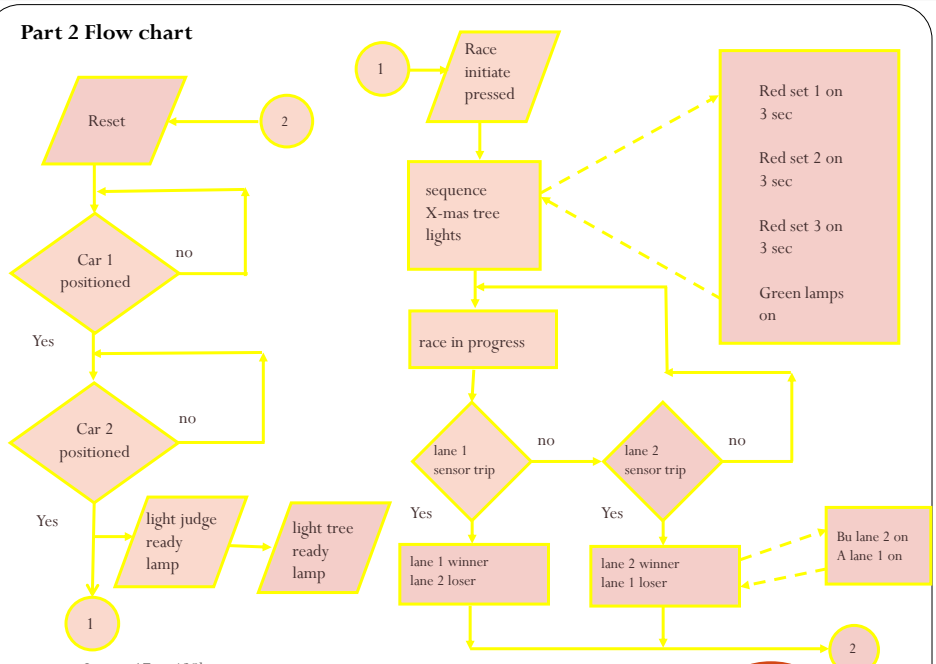
DESIGN EXAMPLE - DRAG STRIP "CHRISTMAS TREE"

Define actions (Outputs)

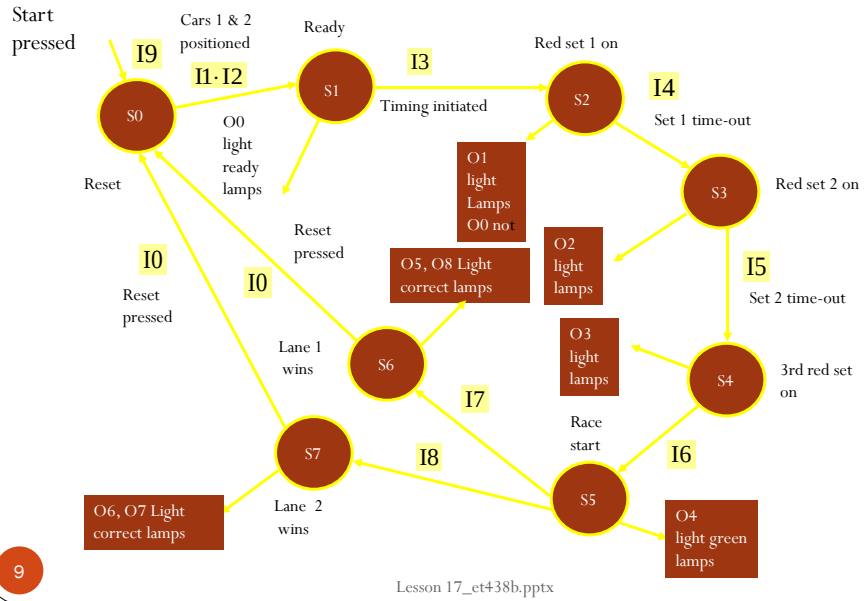
Actions

O0: light green ready lamp
O1: light red lamps set 1
O2: light red lamp set 2
O3: light red lamp set 3
O4: light green lamp set
O5: light blue lamp 1 if lane 1 wins
O6: light blue lamp 2 if lane 2 wins
O7: light amber lamp 1 if lane 1 loses
O8: light amber lamp 2 if lane 2 loses

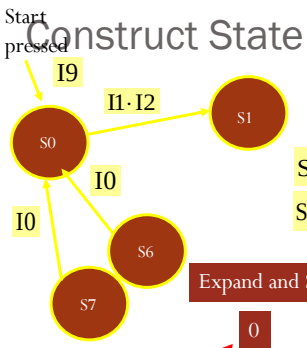
Part 2 Flow chart



Example State Transition Diagram



Construct State Equations



State 0

$$S0^{+1} = (S0 + I0 \cdot (S6 + S7) + I9) \cdot (\overline{I1 \cdot I2 \cdot S0})$$

$$S0^{+1} = (S0 + I0 \cdot (S6 + S7) + I9) \cdot (\overline{I1} + \overline{I2} + \overline{S0})$$

DeMorgans

Expand and Simplify

0

$$S0^{+1} = S0 \cdot \overline{I1} + S0 \cdot \overline{I2} + S0 \cdot \overline{S0} + (I0 \cdot (S6 + S7) + I9) \cdot \overline{I1} + (I0 \cdot (S6 + S7) + I9) \cdot \overline{I2} + (I0 \cdot (S6 + S7) + I9) \cdot \overline{S0}$$

Factor

$$S0^{+1} = S0 \cdot (\overline{I1} + \overline{I2}) + I9 \cdot (\overline{I1} + \overline{I2}) + I0 \cdot (S6 + S7) \cdot (\overline{I1} + \overline{I2}) + I0 \cdot (S6 + S7) \cdot \overline{S0} + I9 \cdot \overline{S0}$$

Regroup

$$S0^{+1} = S0 \cdot (\overline{I1} + \overline{I2}) + [I0 \cdot (S6 + S7) + I9] \cdot (\overline{I1} + \overline{I2}) + [I0 \cdot (S6 + S7) + I9] \cdot \overline{S0}$$

Construct State Equations

State 0 continued

Factor

$$S0^{+1} = [S0 \cdot (\overline{I1} + \overline{I2}) + (I0 \cdot (S6 + S7) + I9)](\overline{I1} + \overline{I2})[(\overline{I1} + \overline{I2}) + \overline{S0}]$$

Simplify & Regroup

1

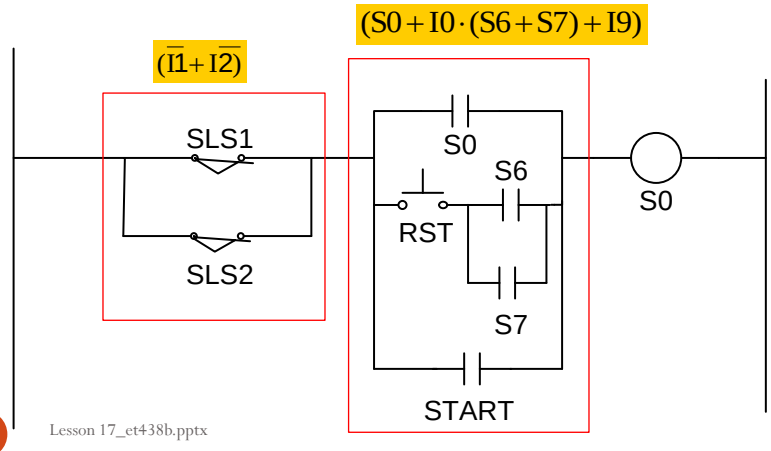
$$S0^{+1} = (\overline{I1} + \overline{I2}) \cdot [S0 + (I0 \cdot (S6 + S7) + I9)] \cdot [1 + \overline{S0}]$$

$$S0^{+1} = (\overline{I1} + \overline{I2}) \cdot [S0 + (I0 \cdot (S6 + S7) + I9)]$$

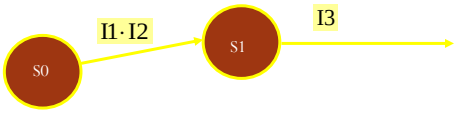
$$S0^{+1} = (S0 + I0 \cdot (S6 + S7) + I9)(\overline{I1} + \overline{I2})$$ Reduced Equation

Construct Ladder Logic

$$S0^{+1} = (S0 + I0 \cdot (S6 + S7) + I9) \cdot (\overline{I1} + \overline{I2})$$



Construct State Equations



State 1

$$S1^{+1} = (S1 + I1 \cdot I2 \cdot S0) \cdot (\overline{\overline{I3} \cdot \overline{S1}})$$

$$S1^{+1} = (S1 + I1 \cdot I2 \cdot S0) \cdot (\overline{I3} + \overline{S1})$$

$$S1^{+1} = S1 \cdot \overline{I3} + S1 \cdot \overline{S1} + I1 \cdot I2 \cdot S0 \cdot \overline{I3} + I1 \cdot I2 \cdot S0 \cdot \overline{S1}$$

$$S1^{+1} = S1 \cdot (\overline{I3}) + I1 \cdot I2 \cdot S0 \cdot (\overline{I3} + \overline{S1})$$

$$S1^{+1} = S1 \cdot (\overline{I3}) + I1 \cdot I2 \cdot S0 \cdot (\overline{I3}) \cdot I0 \cdot I1 \cdot I2 \cdot S0 + I1 \cdot I2 \cdot S0 \cdot \overline{S1}$$

$$S1^{+1} = S1 \cdot (\overline{I3}) + (\overline{I3})(1 + \overline{S1}) \cdot I1 \cdot I2 \cdot S0$$

$$S1^{+1} = S1 \cdot (\overline{I3}) + (\overline{I3}) \cdot I1 \cdot I2 \cdot S0$$

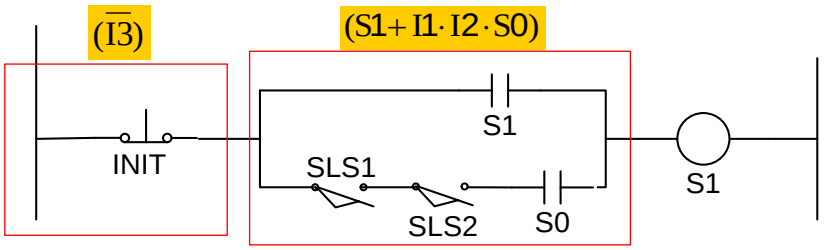
$$S1^{+1} = (S1 + I1 \cdot I2 \cdot S0)(\overline{I3})$$

Construct Ladder Logic

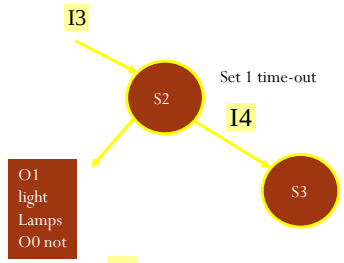
$$S1^{+1} = (S1 + I1 \cdot I2 \cdot S0)(\overline{I3})$$

State 1 Output Equation

$$O0 = S1$$



Construct State Equations



State 2

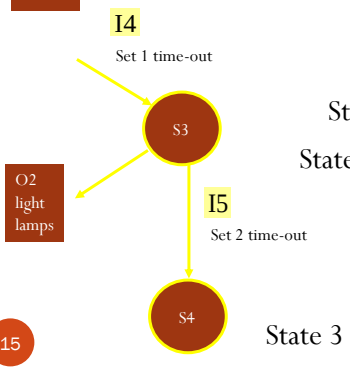
$$S2^{+1} = (S2 + I3) \cdot (\overline{I4})$$

TON#(c,t)=On-delay timer #
c = input condition
t = time delay

so

$$I4 = TON1(S2,3) = \text{timer done}$$

$$S2^{+1} = (S2 + I3) \cdot (\overline{TON1(S2,3)})$$



$$S2^{+1} = (S2 + I3) \cdot (\overline{TON1(S2,3)})$$

State 2 Output Equation $O1 = S2$

State 3

$$S3^{+1} = (S3 + I4 \cdot S2) \cdot (\overline{I5})$$

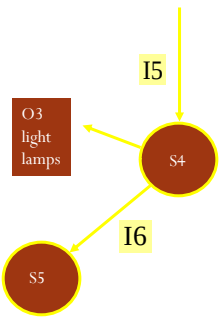
$$I5 = TON2(S3,3) = \text{timer done}$$

$$S3^{+1} = (S3 + TON1(S2,3) \cdot S2) \cdot (\overline{TON2(S3,3)})$$

State 3 Output Equation $O2 = S3$

Construct State Equations

State 4



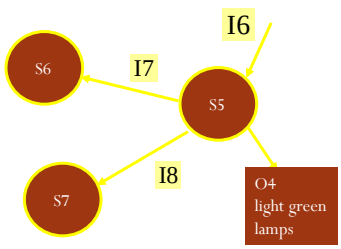
$$S4^{+1} = (S4 + I5 \cdot S3) \cdot (\overline{I6})$$

$$I5 = TON3(S4,3) = \text{timer done}$$

$$S4^{+1} = (S4 + TON2(S3,3) \cdot S3) \cdot (\overline{TON3(S4,3)})$$

State 4 Output Equation $O3 = S4$

State 5



$$S5^{+1} = (S5 + I6 \cdot S4) \cdot (\overline{(I7 + I8)})$$

$$I6 = TON3(S4,3) = \text{timer done}$$

$$S5^{+1} = (S5 + TON3(S4,3) \cdot S4) \cdot (\overline{(I7 + I8)})$$

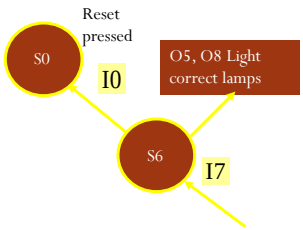
Construct State Equations

State 5 simplification

$$S5^{+1} = (S5 + TON3(S4,3) \cdot S4) \cdot (\overline{(I7 + I8)})$$

$$S5^{+1} = (S5 + TON3(S4,3) \cdot S4) \cdot (\overline{I7} \cdot \overline{I8})$$

State 5 Output Equation $O4 = S5$



State 6

Block Lane 2

$$S6^{+1} = (S6 + I7 \cdot \overline{I8} \cdot S5) \cdot (\overline{I0})$$

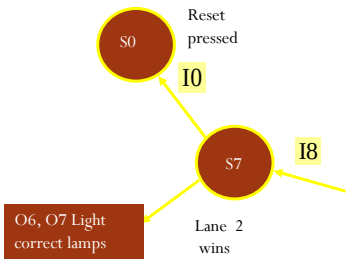
State 6 Output Equations

$O5 = S6$

$O8 = S6$

Construct State Equations

State 7



$$S7^{+1} = (S7 + \overline{I7} \cdot I8 \cdot S5) \cdot (\overline{I0})$$

Block Lane 1

State 7 Output Equations

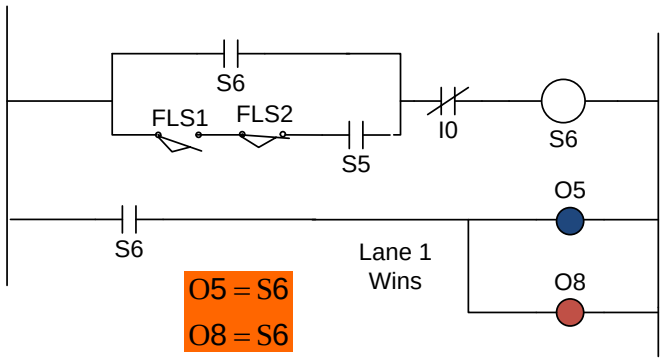
$O6 = S7$

$O7 = S7$

Construct Ladder Logic

State 6

$$S6^{+1} = (S6 + I7 \cdot \overline{I8} \cdot S5) \cdot (\overline{I0})$$



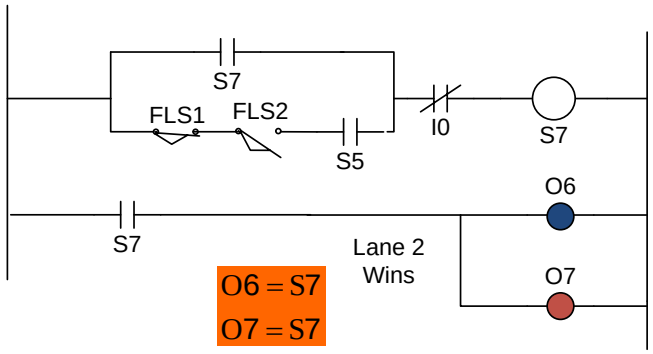
$O5 = S6$

$O8 = S6$

Construct Ladder Logic

State 7

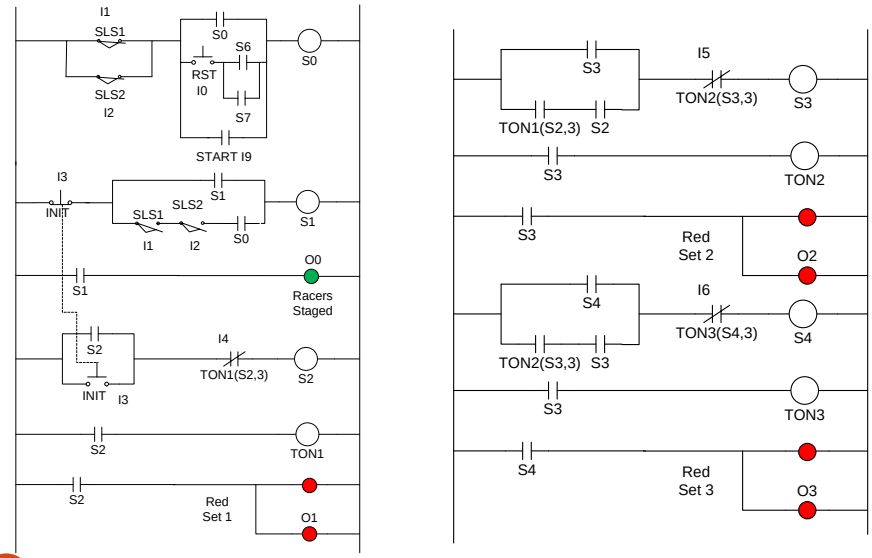
$$S7^{+1} = (S7 + \overline{I7} \cdot I8 \cdot S5) \cdot (\overline{I0})$$



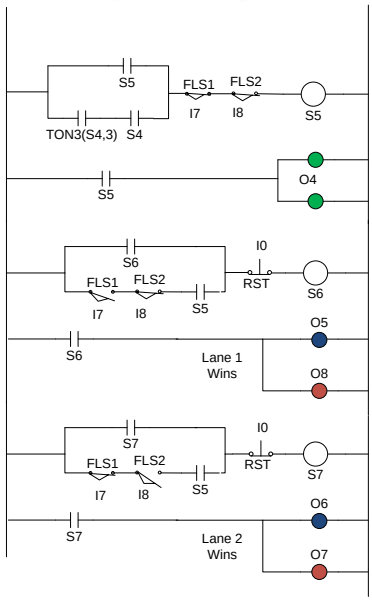
$O6 = S7$

$O7 = S7$

Complete System



Complete System



Design Considerations

Personnel and Equipment Safety

Fail-safe operation - component fail results in little or no damage or inconvenience

Common Practice
1.) start sequence by closing NO contacts
2.) stop a sequence by opening NC contact

Practice Results: if device fails to start process stops, If started would stop **Example:** Motor starter

Troubleshooting Tips

Common causes of Failure
1.) Dirty or oxidized contacts
2.) Broken wire or loose connection
3.) Up stream power source interrupted causing input device to de-activate

Other Issues

Contact operation sequence
break-before-make standard
See previous example limit switches

End Lesson 17: State-Based Design Example

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