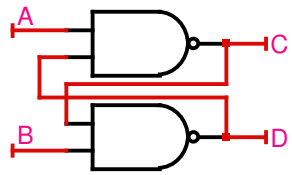
CMPT-150 Assignment 3 SOLUTIONS
NOTE: in this document, / means invert. So /A is not-A

Question 1. Starting with cross-coupled NAND gates, design a positive-edge triggered D-flip-flop, going through the following steps:

a) Clocked RS latch
b) D Latch (positive level triggered)
c) Positive edge triggered D Flip-Flop
Show each step and justify your design decisions. Each device should have identical functionality to the corresponding cross-coupled NOR gate device designed in class.

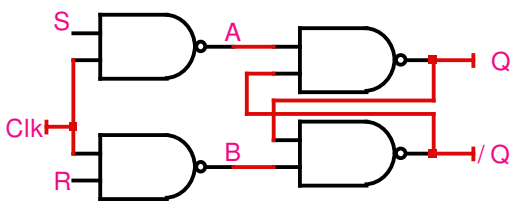
SOLUTION (14 marks)
Cross-coupled NAND gates, and the truth table for NAND:



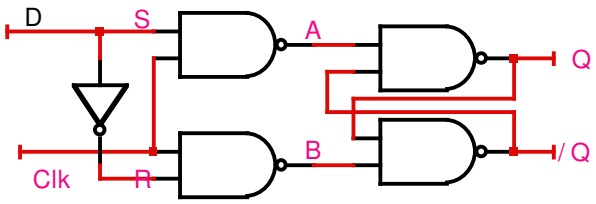
X	Y	/(XY)
0	0	1
0	1	1
1	0	1
1	1	0

We see that X=0 is a forcing value for NAND, forcing a 1 at the output. Because of this, we can see that if we consider C to be our Q, and D be our /Q, then A must be /S and B must be /R. If we assert a "0" on /S, we force Q to be 1, setting the latch. If both inputs are "1" at the same time, the latch holds, and if both are "0" and move to "1" simultaneously, the latch races.

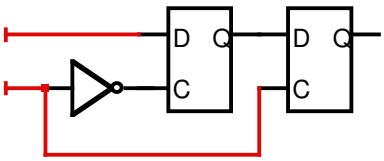
a) Clocked RS latch.
We want to add a clock, and change the functionality so that we have R and S instead of /R and /S. To do this, we add inverters on /R and /S to get R and S, and use AND gates as we did in class. The result is the following circuit:



From here, the functionality is the same as the devices designed in class, so to modify this into a D-latch is the same:



And to make a Flip-flop, we put this into a box and master-slave two of them together:



Note that to make it positive-edge triggered, we use the positive clock level for the slave latch and negative clock level for the master latch.

Question 2. The nifty widget company has a factory that produces widgets. In an effort to cut costs, the manager has decided to replace the quality-control employees with a machine that detects defects. A camera positioned above the conveyer belt can detect 4 types of defects in the widgets: gouges, missing teeth, no paint and incorrect paint colour. Each widget will be assigned to one of three categories (pass, fail, re-cast) based on the following rules:

- a correctly painted widget with no gouges and no missing teeth is passed.
- a painted widget with gouges and/or missing teeth is failed.
- an unpainted widget with gouges and/or missing teeth can be re-cast.
- an unpainted widget is considered to have incorrect paint colour.
- paint will fill gouges but will not repair missing teeth.

Your circuit should have 4 inputs (G, T, P, C) and 3 outputs (R, F, P)

Show your design procedure, justify any design decisions, simulate your circuits in LogicWorks/DesignWorks, test your circuit and justify your choice of test cases. Provide a circuit printout and an annotated timing diagram.

SOLUTION (14 marks)

We begin by making a truth table and filling in what we can, given the design constraints: We must first decide if "0" will mean defect or no defect. I will assume that the camera will produce a 1 when there is a defect, implying "0" is no defect. No defects across the

board can be assumed to be a correct widget and should pass. As for other design constraints, point 2 implies that PG+PT => F
Point 3 suggests that /P(G+T) =>R
Point 4 implies that we can never have a P=1 and C=0, so this is a don't care condition
Point 5 implies that we can never have P=0 and G=1 (there will never be a painted widget with gouges) so this is also a don't care condition
These points create the following table:

G	T	P	C	R	F	P
0	0	0	0	0	0	1
0	0	0	1			
0	0	1	0	x	x	x
0	0	1	1			
0	1	0	0	0	1	0
0	1	0	1	0	1	0
0	1	1	0	x	x	x
0	1	1	1	1	0	0
1	0	0	0	x	x	x
1	0	0	1	x	x	x
1	0	1	0	x	x	x
1	0	1	1	1	0	0
1	1	0	0	x	x	x
1	1	0	1	x	x	x
1	1	1	0	x	x	x
1	1	1	1	1	0	0

There are two conditions not considered: An incorrectly painted widget or an unpainted widget. We must choose what to do in these cases. I will choose to fail the incorrectly painted widget and re-cast the unpainted widget, because both of these are incorrect. One could choose to re-paint these, but that would imply a fourth output for re-painting.

G	T	P	C	R	F	P
0	0	0	0	0	0	1
0	0	0	1	0	1	0
0	0	1	0	x	x	x
0	0	1	1	1	0	0
0	1	0	0	0	1	0
0	1	0	1	0	1	0
0	1	1	0	x	x	x

0	1	1	1	0	1	0
1	0	0	0	x	x	x
1	0	0	1	x	x	x
1	0	1	0	x	x	x
1	0	1	1	1	0	0
1	1	0	0	x	x	x
1	1	0	1	x	x	x
1	1	1	0	x	x	x
1	1	1	1	1	0	0

K-maps:

R

GT \ PC	00	01	11	10
00	0	0	1	X
01	0	0	1	X
11	X	X	1	X
10	X	X	1	X

F

GT \ PC	00	01	11	10
00	0	1	0	X
01	1	1	0	X
11	X	X	0	X
10	X	X	0	x

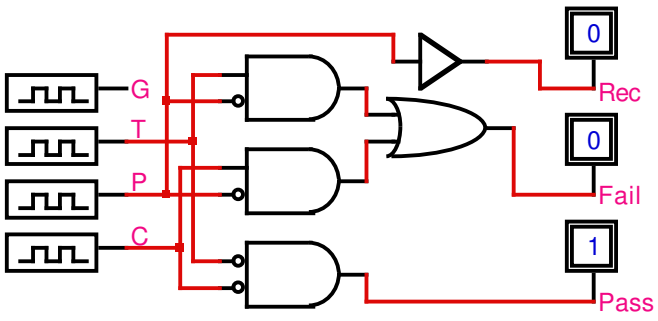
P

GT \ PC	00	01	11	10
00	1	0	0	X
01	0	0	0	X
11	X	X	0	X
10	X	X	0	X

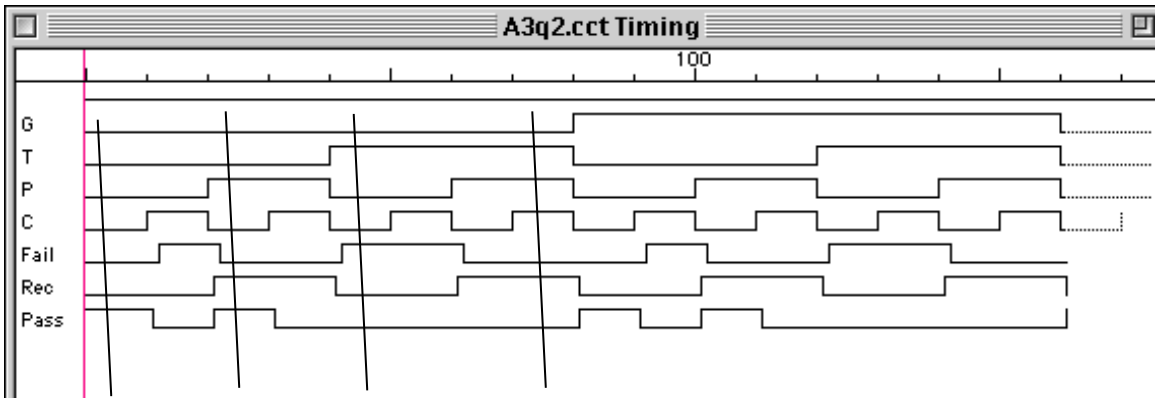
And the equations:

R= P F= /PC + /PT P= /C /T

The circuit looks like this (note that the circuit does not depend on G!):



And the timing to test the circuit looks like this:



Some notes:

A. No errors results in a pass, as expected.

B. Incorrect paint (i.e. no paint) results in a pass when the colour is correct, but remember that it is impossible to have no paint and correct colour.

C. Missing teeth and paint imply the widget should fail

D. No paint implies that the widget can be recycled.

Question 3. Design a sequential circuit using 2 D-flip-flops which will produce the following sequence:

00, 11, 01, 10, 00, ...

Show your design procedure. Provide a circuit printout and timing diagram showing the complete sequence.

SOLUTION (12 marks)

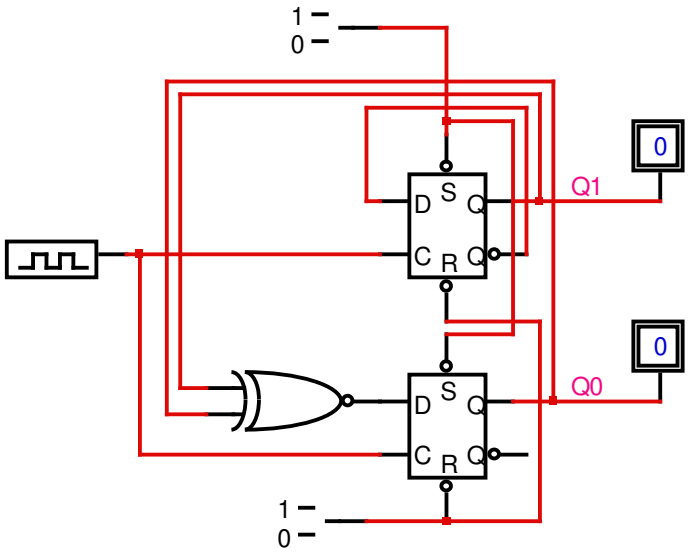
We start with a transition table, and then extend to the truth table :

Q1	Q0	Q1+	Q0+	D1	D0
0	0	1	1	1	1
0	1	1	0	1	0
1	0	0	0	0	0
1	1	0	1	0	1

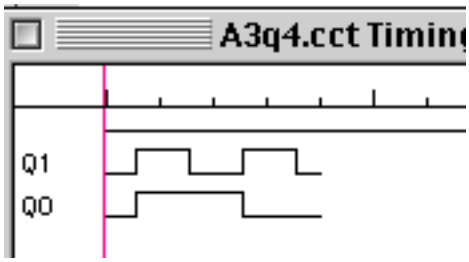
From here, we can make K-maps, or we can recognize the expressions from the tables:

D1=/Q1 D0=Q1 xnor Q0

The circuit:



And the timing diagram



Clearly showing the sequence progressing through 00, 11, 01, 10, 00...