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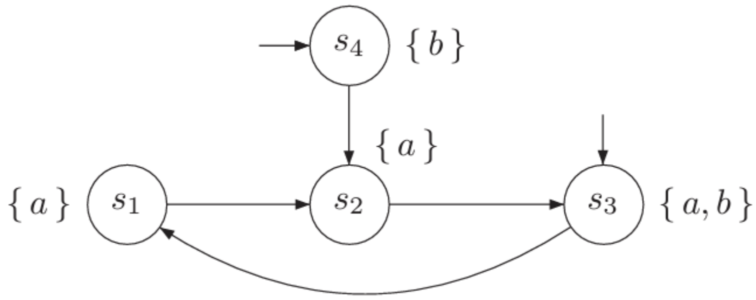
Indian Institute of Technology Kanpur
CS637 Embedded and Cyber-Physical Systems
Homework Assignment 3
Deadline: November 8, 2024

Total: **40 marks**

Problem 1. (10 points)
Consider the following state machine over the set of atomic propositions $\{a, b\}$:



Decide for each of the following LTL specifications whether the model satisfies it. For the positive outcome, provide a proof. For the negative outcome, provide a counterexample trace.
Note that the symbols $\bigcirc$, $\Box$, $\Diamond$, and $\mathtt{U}$ represent the "next", "always", "eventually", and "until" temporal operators respectively.

(a) $\bigcirc \bigcirc \bigcirc\, a$
(b) $\Box\, b$
(c) $\Box \Diamond\, a$
(d) $\Box(b \,\mathtt{U}\, a)$
(e) $\Diamond(a \,\mathtt{U}\, b)$

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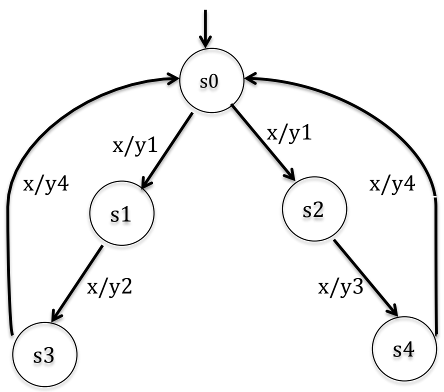
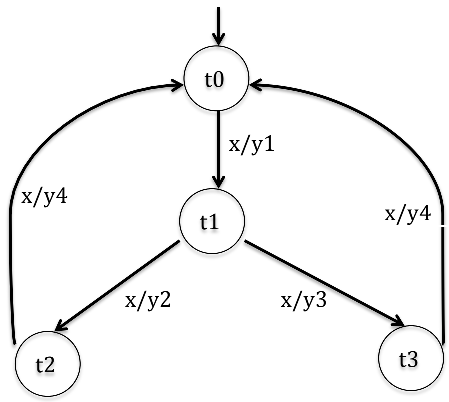
Problem 2. (10 points)
Consider the two state machines in Figure 1 and answer the following questions:



(a) M_1



(b) M_2

Figure 1

(a) Does the state machine M_1 simulate the state machine M_2? If yes, provide the simulation relation. If no, provide a transition of M_2 that M_1 cannot match.

(b) Does the state machine M_2 simulate the state machine M_1? If yes, provide the simulation relation. If no, provide a transition of M_1 that M_2 cannot match.

(c) Are the two state machines bisimilar? If yes, provide the bisimulation relation. If no, provide one reason.

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Problem 3. (10 points)
Consider the processes P_1 and P_2 with the shared variables b_1, b_2, and x. Variables b_1 and b_2 are Boolean variables, while variable x can take either the value 1 or 2. Initially, each process P_i is in the non-critical section (i.e., P_i is in location $noncrit_i$). The scheduling strategy for giving the processes access to the critical section is realized using x as follows. If both processes want to enter the critical section (i.e., P_i is in location $wait_i$), the value of variable x decides which of the two processes may enter its critical section: if $x = i$, then P_i may enter its critical section $crit_i$ (for $i = 1, 2$). On entering location $wait_1$, process P_1 performs $x := 2$, thus giving privilege to process P_2 to enter the critical section. The value of x thus indicates which process has its turn to enter the critical section. Symmetrically, P_2 sets x to 1 when starting to wait. The variables b_i provide information about the current location of P_i. More precisely, b_i is set when P_i starts to wait, and is reset when the process exits the critical section. In pseudocode, P_1 performs as follows (the code for process P_2 is similar):

P_1 **loop** forever

$\vdots$ (∗noncritical actions∗)

$b_1 := true; x := 2$

wait until $(x = 1 \lor \neg b_2)$ (∗request∗)

do critical section **od**

$b_1 := false$ (∗release∗)

$\vdots$ (∗noncritical actions∗)

end loop

(a) Draw the state machines for P_1 and P_2.
(b) Show the state machine that is obtained by asynchronous composition of P_1 and P_2.
(c) How many total states are there in the composed state machine? How many of them are reachable?
(d) Provide an LTL formula that captures the requirement that the process P_1 and P_2 will not enter the critical section simultaneously. Using the composed state machine, determine whether the two systems satisfy the formula (property).

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Problem 4. (10 points)
Consider the following program:

```
int count (int a, int b)
{
    int count;
    for (count = 0; count < 2; count++)
    {
        if (a > b)
            b = a + 1;
        else
            b = a - 1;
    }
    return b;
}
```

(a) Draw a control flow graph for the program.
(b) How many paths are there in the program? How many paths are feasible?
(c) Assume the following:

- An assignment statement (for example, $\texttt{count} = \texttt{0}$) requires 2 unit time for execution.
- A statement involving an arithmetic operation followed by an assignment (for example, $\texttt{count}++$, $\texttt{b} = \texttt{a} + \texttt{1}$) requires 6 unit time for execution.
- A comparison statement (for example, $\texttt{count} < \texttt{2}$) requires 4 unit time for execution.

Compute a tight bound on the worst-case execution time for the program.

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