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Department of Information and Computer Science

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CS-E4560 Parallel and Distributed Systems

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Write down on every answer sheet: the name of the course, the course code, the date, your name, your student id, and your signature. You are not allowed to use any material or equipment for this exam.

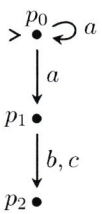
In general when you need to construct the parallel composition or some automaton, give their graphical representation.

Assignment 1 Consider the Kripke structure $M = (S, s^0, R, L)$ with $S = \{s_0, s_1, s_2, s_3, s_4\}$, $s^0 = s_0$, $R = \{(s_0, s_1), (s_1, s_2), (s_2, s_3), (s_3, s_4), (s_4, s_0), (s_0, s_4), (s_1, s_3), (s_2, s_0), (s_2, s_2), (s_3, s_3)\}$, and the function L is defined by $L(s_0) = \emptyset$, $L(s_1) = \{start\}$, $L(s_2) = \{heat\}$, $L(s_3) = \{heat, error\}$, and $L(s_4) = \{open\}$. For each of the formulas below, check whether it holds in M. If the formula holds, give a brief explanation (max 5 lines of text) why it is true. If the formula does not hold, give a counterexample execution of M and explain why it violates the formula.

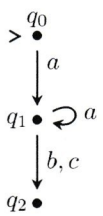
1. $\mathbf{G}\,(heat \Rightarrow \neg open)$ (2p)
2. $\mathbf{G}\,(open \Rightarrow \mathbf{Y}\,\mathbf{H}\,\neg open)$ (2p)
3. $\mathbf{G}\,(error \Rightarrow ((\neg open)\,\mathbf{S}\,start))$ (2p)
4. $\mathbf{G}\,(start \Rightarrow \mathbf{X}\,(heat\,\mathbf{U}\,open))$ (2p)
5. $(\mathbf{G}\,\mathbf{F}\,start) \Rightarrow (\mathbf{G}\,\mathbf{F}\,heat)$ (2p)
6. $\mathbf{F}\,\mathbf{G}\,(heat \vee open \vee start)$ (2p)

Assignment 2 Consider the following LTSs over $\Sigma = \{a, b, c\}$.

L_1:



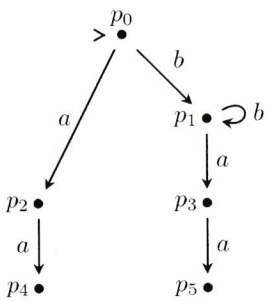
L_2:



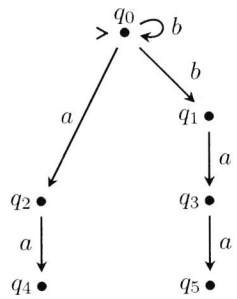
1. Construct a deterministic finite state automaton A' that recognizes the language $\Sigma^* \setminus traces(L_1)$.(2p)
2. See A' as an LTS L' and compute the asynchronous product LTS $P = L_2 \,||\, L'$. Explain how P can be used to argue that $L_2 \leq_{tr} L_1$. (2p)
3. Does $L_1 \leq_{sim} L_2$ hold? Justify your answer. (2p)
4. Does $L_2 \leq_{sim} L_1$ hold? Justify your answer. (2p)
5. From the theory of LTSs, define "bisimulation relation". (2p)
6. Does $L_1 \sim L_2$ hold? Justify your answer. (2p)

Assignment 3 Consider the following LTSs over $\Sigma = \{a, b\}$.

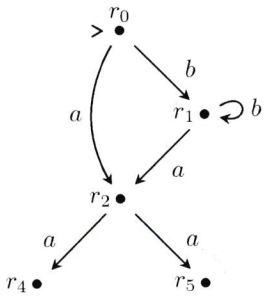
L_A:



L_B:



L_C:



1. Are L_A and L_C bisimilar? Justify your answer. (2p)
2. Are L_B and L_C bisimilar? Justify your answer. (2p)
3. Are L_A and L_C trace equivalent? Justify your answer. (2p)
4. Are L_B and L_C trace equivalent? Justify your answer. (2p)
5. Construct a deterministic FSA A that recognizes the language $\Sigma^* \setminus \mathit{traces}(L_B)$. (2p)

Assignment 4 Consider the following Promela model.

```
int a=2;
active proctype A() {
    int b = 0;
    do :: a < 3 -> b = a; a = b + 2; od
}
active proctype B() {
    do :: a = a / 2 + 2; od // Rounding towards zero
}
```

1. What pieces of data are needed to identify a single state of this model? Design a way to represent an arbitrary state. (2p)
2. Construct the reachability graph of the model. (4p)
3. Interpret the reachability graph as a Kripke structure M over the atomic propositions (`a==5`) and (`a>3`). Does the LTL formula $\mathbf{G}\neg$(`a==5`) hold in M? Does $\mathbf{F}$(`a > 3`) hold in M? Justify your answers. (4p)
4. Using the definition of safety property, explain why $\mathbf{F}$(`a>3`) is not a safety property. (2p)