Introduction to Model Checking (VO) — WS 2007/2008 — LVA 703503

First name: ______________________________

Last name: ______________________________

Matriculation number: ______________________________

- Write your name and matriculation number on every page.
- Please answer all exercises in a readable and precise way. Do *not* write with a pencil or a red pen. Please cross out solution attempts which are replaced by another solution.
- Cheating is not allowed. Everyone who is caught will fail the exam.
- Please do not remove the staples of the exam.

Exercise	**Maximal points**	**Points**
1	**12**	
2	**24**	
3	**15**	
4	**19**	
Σ	**70**	
Grade		

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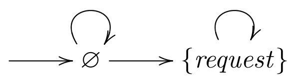
Exercise 1 (12 points)

Each correct answer is worth four points. A wrong answer results in zero points. Giving no answer is worth one point.

	Yes	No
The CTL formula $(\mathsf{A\,G\,A\,F}\,\mathit{request}) \Rightarrow (\mathsf{A\,G\,A\,F}\,\mathit{response})$ is equivalent to the LTL formula $(\mathsf{G\,F}\,\mathit{request}) \Rightarrow (\mathsf{G\,F}\,\mathit{response})$. 		✓
Every language $L \subseteq \Sigma^\omega$ can be recognized by some NBA. (We have the result as for NFAs: regular ω-languages do not cover all ω-languages. A formal prove can be done as follows: For all NBAs $\mathcal{A}$ we know that if $\mathcal{L}(\mathcal{A}) \neq \varnothing$ then by the non-emptyness check we figure out a word $w = vu^\omega \in \mathcal{L}(\mathcal{A})$ for finite words v, u. Hence, the language $L = \{\pi\} \in \{0-9, .\}^\omega$ cannot be accepted by an NBA since π is not a rational number.)		✓
Emptiness of $\mathcal{L}(\mathcal{A})$ for some GNBA $\mathcal{A}$ can directly be decided using an SCC-based analysis, without first translating $\mathcal{A}$ into some NBA. ($\mathcal{L}(\mathcal{A}) \neq \varnothing$ iff there is an SCC of $\mathcal{A}$ that is reachable from the initial state and that contains a state from each set F_i of final states)	✓	

Exercise 2 (21 + 3 points)

Consider the following nanoPromela program which has two clients ($i \in \{1, 2\}$) which send their data via a scheduler to a printer. After a clients data $\mathtt{d}_i$ is delivered at the printer, client i gets an acknowledgement.

```
------- CLIENT i ------------
do :: true => ic ! i; dc ! d_i; ac_i ? ack od

------- SCHEDULER -----------
atomic { x := 0; d := "" };
do :: true => ic ? x; dc ? d; pc ! d; if :: x = 1 => ac_1 ! ack :: x = 2 => ac_2 ! ack fi od

------- PRINTER -------------
do :: true => pc ? d; skip od
```

- Construct the channel-system for the nanoPromela program.

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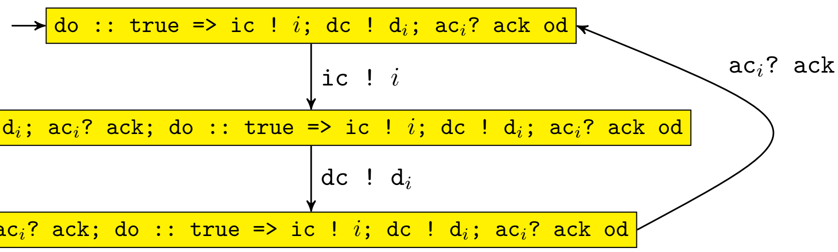

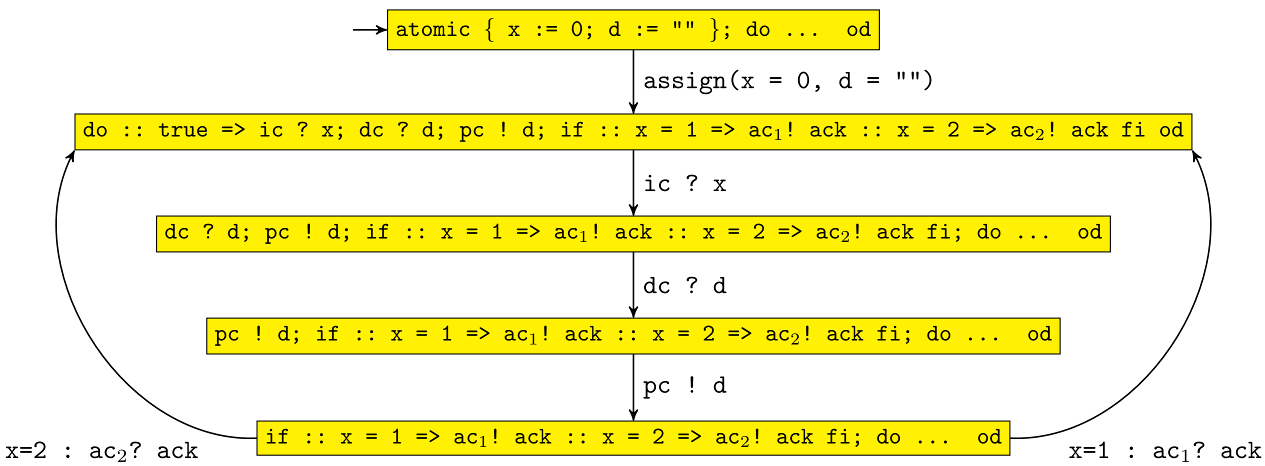

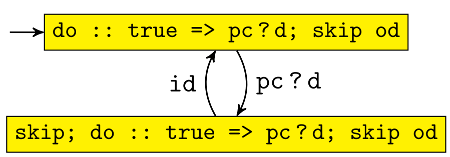

- Does the program contain a serious bug using asynchronous communication? If so, shortly describe it.

  Consider the following situation. Client 1 sends its id which is read by the scheduler. Then client 2 sends both id and data. Then client 1 sends its data, but the scheduler reads the data of client 2, sends it to the printer, but then falsely sends the acknowledgement to client 1.

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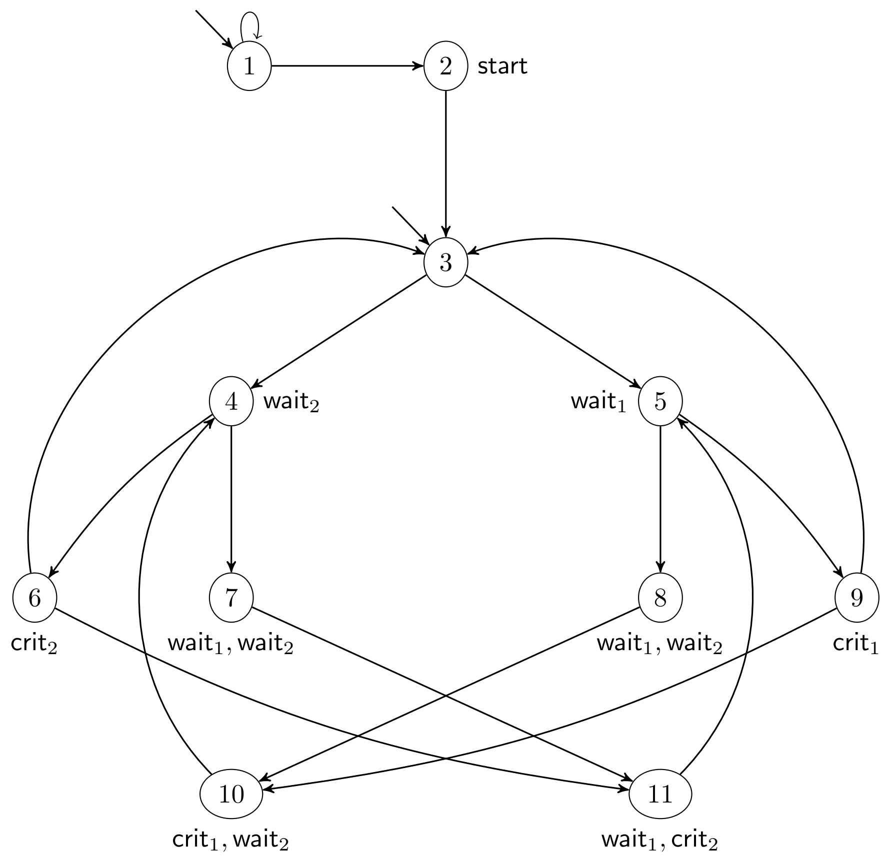
Exercise 3 (15 points)



Consider the above transition system TS of a mutual exclusion protocol and the following CTL*-formula Φ.

$$\Phi = (\mathsf{A}\,((\mathsf{F}\,\mathsf{G}\,\neg\mathsf{start}) \wedge \mathsf{A}\,(\neg\mathsf{wait}_1 \vee \mathsf{F}\,\mathsf{crit}_1))) \wedge \mathsf{A}\,\mathsf{F}\,(\mathsf{crit}_1 \vee \mathsf{crit}_2)$$

Does $TS \models \Phi$ hold? Justify your answer by performing CTL*-model checking, and write down $Sat(\Psi)$ for every state-subformula Ψ of Φ. Whenever one computes a set $Sat(\mathsf{A}\,\varphi)$, additionally write down the corresponding LTL-formula φ' that is checked. However, it is not necessary to perform LTL-model checking explicitly.

- $Sat(\mathsf{start}) = \{2\}$
- $Sat(\mathsf{wait}_1) = \{5, 7, 8, 11\}$
- $Sat(\mathsf{crit}_1) = \{9, 10\}$
- $Sat(\mathsf{crit}_2) = \{6, 11\}$
- $Sat(\mathsf{A}\,\neg\mathsf{wait}_1 \vee \mathsf{F}\,\mathsf{crit}_1) = \{1 - 11\}$. This step involves LTL model checking of the formula $\neg\mathsf{wait}_1 \vee \mathsf{F}\,\mathsf{crit}_1$.

  Alternatively one could have computed $Sat(\neg\mathsf{wait}_1) = \{1-4, 6, 9, 10\}$ and then perform LTL model checking for the formula $a \vee \mathsf{F}\,\mathsf{crit}_1$ where a is a new proposition which is valid in states $Sat(\neg\mathsf{wait}_1)$.
- $Sat(\mathsf{A}\,((\mathsf{F}\,\mathsf{G}\,\neg\mathsf{start}) \wedge \mathsf{A}\,(\neg\mathsf{wait}_1 \vee \mathsf{F}\,\mathsf{crit}_1))) = \{1-11\}$. This step involves LTL model checking of the formula $\mathsf{A}\,((\mathsf{F}\,\mathsf{G}\,\neg\mathsf{start}) \wedge b)$ where b is a new proposition that is valid in states $Sat(\mathsf{A}\,(\neg\mathsf{wait}_1 \vee \mathsf{F}\,\mathsf{crit}_1))$, i.e., which is always valid.

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Alternatively one could have computed $Sat(\neg \mathsf{start}) = \{1, 3 - 11\}$ and then perform LTL model checking for the formula $\mathsf{A}\,((\mathsf{F}\,\mathsf{G}\,c) \wedge b)$ where b is as above and c is another new proposition which is valid in states $Sat(\neg \mathsf{start})$.

- $Sat(\mathsf{A}\,\mathsf{F}\,(\mathsf{crit}_1 \vee \mathsf{crit}_2)) = \{2 - 11\}$. This step involves LTL model checking of the formula $\mathsf{F}\,(\mathsf{crit}_1 \vee \mathsf{crit}_2)$.

  Alternatively one could have computed $Sat(\mathsf{crit}_1 \vee \mathsf{crit}_2) = \{6, 9 - 11\}$ and then perform LTL model checking for the formula $\mathsf{F}\,d$ where d is a new proposition which is valid in states $Sat(\mathsf{crit}_1 \vee \mathsf{crit}_2)$.

- $Sat(\Phi) = \{1 - 11\} \cap \{2 - 11\} = \{2 - 11\}$

Since state 1 is initial and $1 \notin Sat(\Phi)$ we conclude $TS \not\models \Phi$.

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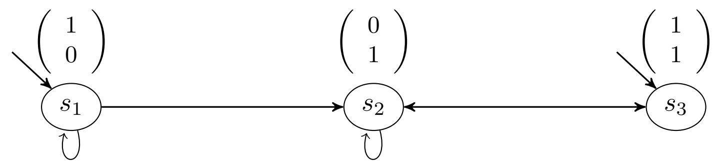
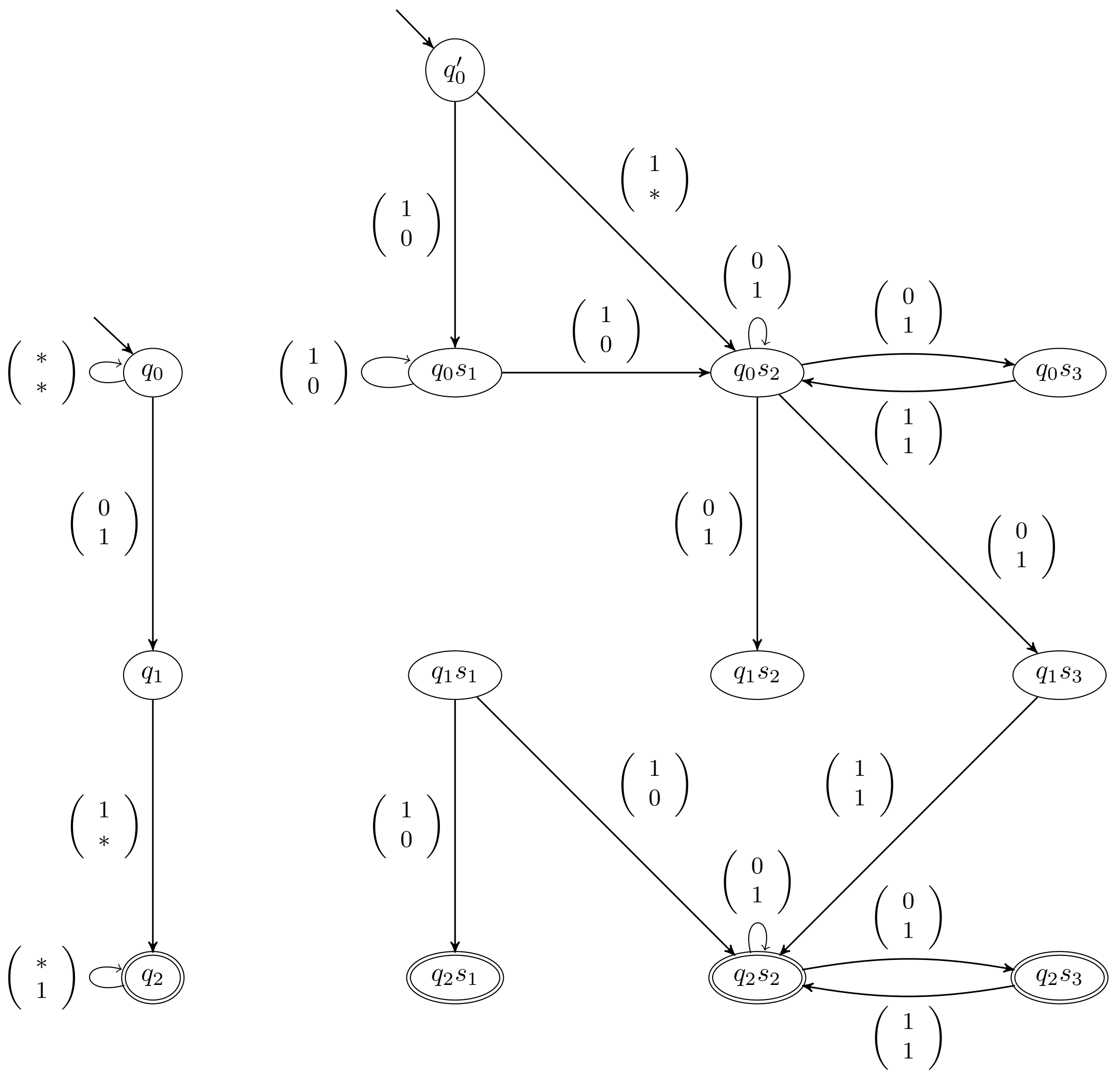
Exercise 4 (18 + 1 points)

Consider the following NBA $\mathcal{A}$ and the following transition system TS.





- Construct the NBA $\mathcal{B} = TS \otimes \mathcal{A}$ which accepts $\mathcal{L}(TS) \cap \mathcal{L}(\mathcal{A})$.
- Is $\mathcal{L}(\mathcal{B}) = \varnothing$? If not, then provide a word which is contained in $\mathcal{L}(\mathcal{B})$.

$\left(\begin{pmatrix} 1 \\ 1 \end{pmatrix} \begin{pmatrix} 0 \\ 1 \end{pmatrix} \right)^{\omega} \in \mathcal{L}(\mathcal{B})$.