Department of Computer Science
Research Group Foundations of Artificial Intelligence
Prof. Dr. B. Nebel

Exam:	**Knowledge Representation and Reasoning**
Date and time:	MOCK EXAM
Duration:	90 minutes
Room:	
Permitted exam aids:	Indelible pen (e. g. ball pen, *no* pencil!), nothing else.
Examiner:	

Last name:	
First name:	
Matriculation number:	
Field of study:	
Degree program:	
Signature:	....

Notes:

- Please fill out this form.
- Please write only on one side of your paper sheets.
- Please write your name and your matriculation number on each paper sheet.
- Please use a new paper sheet for each question.
- Please turn off your mobile phone.
- Regarding multiple-choice questions: within a block of items, you earn plus points per correct answer, you earn minus points per wrong answer, and you earn no less than 0 points in total.

Withdrawing from an examination:
In case of illness, you must supply proof of your illness by submitting a medical report to the Examinations Office. Please note that the medical examination must be done at the latest on the same day of the missed exam. More information: `http://www.tf.uni-freiburg.de/studies/exams/withdrawing_exam.html`

Cheating/disturbing in examinations:
A student who disrupts the orderly proceedings of an examination will be excluded from the remainder of the exam by the respective examiners or invigilators. In such a case, the written exam of the student in question will be graded as “nicht bestanden” (5.0, fail) on the grounds of cheating. In severe cases, the Board of Examiners will exclude the student from further examinations.

Question	Score	Reached score	Comments	Initials
1	16			
2	22			
3	18			
4	17			
5	17			
Sum	90			

Grade: ....

Date of the review of the exam: ....

Signature of the examiner: ....

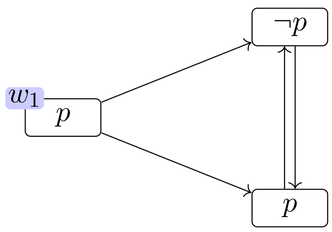
Question 1 (6+5+5 points) MODAL LOGIC

(a) Let p be a propositional atom. Decide for each of the following statements whether it is *true* or *false* (no proof required). Note that you receive one point for each correct answer but you lose one point for each wrong answer. If you don't give an answer you will neither receive nor lose a point. You cannot get less than zero points in total.

- $\Box p \to \Diamond p$ is valid in every *reflexive* Kripke frame. ○ True ○ False
- $\Box p \to \Diamond p$ is valid in every *serial* Kripke frame. ○ True ○ False
- $\Box p \to p$ is valid in every *reflexive* Kripke frame. ○ True ○ False
- $\Box p \to p$ is valid in every *serial* Kripke frame. ○ True ○ False
- $p \to \Box\Diamond p$ is valid in every *symmetric* Kripke frame. ○ True ○ False
- Every Kripke *model* in which $p \to \Box\Diamond p$ is true is *symmetric*. ○ True ○ False

(b) Consider the following Kripke model (note that all edges are given explicitly, i. e., there are no implied reflexive or transitive edges):

M_1:



Decide for each of the following statements whether it is *true* or *false* (no proof required). Note that you receive one point for each correct answer but you lose one point for each wrong answer. If you don't give an answer you will neither receive nor lose a point. You cannot get less than zero points in total.

- $M_1, w_1 \models \Diamond p \wedge \Diamond\neg p$ ○ True ○ False
- $M_1, w_1 \models \Diamond\Box p \wedge \Diamond\Box\neg p$ ○ True ○ False
- $M_1, w_1 \models \Box\Diamond p \vee \Box\Diamond\neg p$ ○ True ○ False
- $M_1, w_1 \models \Box(\Diamond p \vee \Diamond\neg p)$ ○ True ○ False
- $M_1 \models p \vee \Box p$ ○ True ○ False

(c) Construct an epistemic Kripke model M_2 that contains a world w_1 such that

$$M_2, w_1 \models p \wedge K_1 p \wedge \neg K_2 p \wedge \neg K_1 \neg K_2 p.$$

Remember that in multi-agent epistemic logic, K_1 and K_2 are different box operators which refer to their individual respective accessibility relations R_1 and R_2. For example, $K_1\phi$ is the same as $\Box_1\phi$ and can be read as "Agent 1 knows that ϕ". Both R_1 and R_2 must be reflexive, symmetric and transitive. For readability, you may omit reflexive edges.

Question 2 (6+6+2+8 points) DESCRIPITON LOGIC

(a) Decide for each of the following statements whether it is *true* or *false* (no proof required). Note that you receive one point for each correct answer but you lose one point for each wrong answer. If you don't give an answer you will neither receive nor lose a point. You cannot get less than zero points in total.

- In the context of inheritance networks, the formula C_1 **isa** C_2 has the logical semantics $\forall x(C_2(x) \rightarrow C_1(x))$.
  ◯ True ◯ False
- The concept description $\exists r.A \sqcap \exists r.\neg A \sqcap (\leq 1 r)$ is unsatisfiable.
  ◯ True ◯ False
- A TBox together with an ABox always has a model.
  ◯ True ◯ False
- If an individual a is an instance of C and the TBox contains $C \sqsubseteq D$, then a is also an instance of D.
  ◯ True ◯ False
- All concept descriptions in $\mathcal{FL}^-$ are satisfiable.
  ◯ True ◯ False
- In $\mathcal{FL}^-$, concept subsumption in the empty TBox has the same complexity as concept subsumption in a non-empty TBox.
  ◯ True ◯ False

(b) Consider the following TBox and ABox, describing a small Greek mythology ontology:

$$\begin{aligned} \texttt{Mortal} &\doteq \neg\texttt{Immortal} \\ \texttt{God} &\sqsubseteq \texttt{Immortal} \\ \texttt{Demigod} &\doteq \exists\texttt{has-parent.God} \sqcap \\ &\quad\ \exists\texttt{has-parent.Mortal} \end{aligned}$$

KRONOS:	God	
ZEUS:	God	
DANAE:	Mortal	
(ZEUS,	KRONOS):	has-parent
(THESEUS,	ZEUS):	has-parent
(THESEUS,	DANAE):	has-parent

Normalize the TBox (you may omit concepts that are already normalized) and provide an initial interpretation for the primitive components of this normalized TBox, based on the given ABox. Subsequently, unfold the concept `Demigod` and extend your initial interpretation to it.

(c) Give a concept description for the new concept `DeifiedMortal`, i.e., a god who has only mortal parents. This description should only use concepts and roles already present in the TBox from (b), along with any concept and role operators introduced in the lecture.

(d) Consider the $\mathcal{ALC}$ concept $C \doteq \forall r.A \sqcap (\exists r.\neg A \sqcup \exists r.\forall r \neg A)$. Use the tableau algorithm to show that C is satisfiable and extract a model for C from your tableau.

Question 3 (6+6+6 points) DEFAULT LOGIC

(a) Decide for each of the following statements whether it is *true* or *false* (no proof required). Note that you receive one point for each correct answer but you lose one point for each wrong answer. If you don't give an answer you will neither receive nor lose a point. You cannot get less than zero points in total.

- Every default theory has at least one extension. ◯ True ◯ False
- Every normal default theory has exactly one extension. ◯ True ◯ False
- The default theory $\left\langle\{\frac{a:b}{b}, \frac{b:a}{a}\}, \emptyset\right\rangle$ has exactly one exension. ◯ True ◯ False
- $\mathrm{Th}(\{a, b\})$ is an extension to the def. theory $\left\langle\{\frac{\top:a}{a}, \frac{\top:b}{b}\}, \emptyset\right\rangle$. ◯ True ◯ False
- $a \wedge b$ follows creduously from the def. theory $\left\langle\{\frac{\top:\neg b}{a}, \frac{\top:\neg a}{b}\}, \emptyset\right\rangle$. ◯ True ◯ False
- $a \vee b$ follows skeptically from the def. theory $\left\langle\{\frac{\top:\neg b}{a}, \frac{\top:\neg a}{b}\}, \emptyset\right\rangle$. ◯ True ◯ False

(b) Model the following as a first-order normal default theory $\langle D, W\rangle$ using the predicates *Clown*, *Funny*, *Criminal*, and *Scary*:

> By default, clowns are funny. But clowns who are criminal are typically scary and someone who is scary is usually not funny. *Krusty* is a clown and *Joker* is a clown who is also criminal.

(c) Use the definition of 'extension of a default theory' from the lecture to prove that $E = \mathrm{Th}(\{\mathit{Clown}(\mathit{Krusty}), \mathit{Funny}(\mathit{Krusty}), \mathit{Clown}(\mathit{Joker}), \mathit{Criminal}(\mathit{Joker}), \mathit{Scary}(\mathit{Joker}), \neg\mathit{Funny}(\mathit{Joker})\})$ is an extension to $\langle D, W\rangle$.

$$E_0 =$$
$$E_1 = \mathrm{Th}(E_0) \cup$$
$$E_2 = \mathrm{Th}(E_1) \cup$$
$$E_3 = \mathrm{Th}(E_2) \cup \qquad\qquad = E$$

Question 4 (5+5+7 points) ANSWER SET PROGRAMMING

(a) Decide for each of the following statements whether it is *true* or *false* (no proof required). Note that you receive one point for each correct answer but you lose one point for each wrong answer. If you don't give an answer you will neither receive nor lose a point. You cannot get less than zero points in total.

- The answer set of a normal logic program which does *not* contain **not** is unique.
  ◯ True ◯ False
- A stratified normal logic program has exactly one answer set.
  ◯ True ◯ False
- $\{a, b\}$ is an answer set for the normal logic program $\{a \leftarrow b; b \leftarrow a\}$.
  ◯ True ◯ False
- The normal logic program $\{a \leftarrow \text{not } b; b \leftarrow \text{not } a\}$ has exactly two answer sets.
  ◯ True ◯ False
- The AnsProlog program `{a(1..2)}. a(1):-a(2).` generates 3 different answer sets.
  ◯ True ◯ False

(b) Use the fixpoint algorithm from the lecture to find an answer set for the following propositional normal logic program.

$$
\begin{array}{ll}
a \leftarrow d & b \leftarrow d, e \\
b \leftarrow c & e \leftarrow d \\
d \leftarrow &
\end{array}
$$

$$\Gamma^0 = \emptyset$$

$$\Gamma^1 =$$

$$\Gamma^2 =$$

$$\Gamma^3 =$$

$$\Gamma^4 =$$

(c) First ground the following normal logic program (where x is the only variable) to obtain a grounded normal logic program P and then compute the reduct P^X for the set of atoms $X = \{foo(spam), bar(spam), bar(eggs), bla(eggs)\}$.

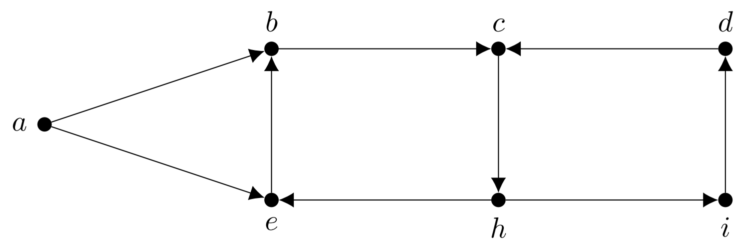
$$
\begin{aligned}
foo(x) &\leftarrow bar(x),\ \text{not } bla(x) \\
bar(x) &\leftarrow bla(x) \\
bar(spam) &\leftarrow \\
bla(eggs) &\leftarrow
\end{aligned}
$$

Question 5 (5 + 4 + 8 points) Linear Temporal Logic

(a) Decide for each of the following statements whether it is *true* or *false* (no proof required). Note that you receive one point for each correct answer but you lose one point for each wrong answer. If you don't give an answer you will neither receive nor lose a point. You cannot get less than zero points in total.

- LTL assumes that time is linear and continuous.
  ◯ True ◯ False
- If a transition system does not induce any paths, it satisfies every possible LTL formula.
  ◯ True ◯ False
- Given a transition system $\mathcal{T}$, an LTL formula φ and a fairness condition ψ: If φ is valid for $\mathcal{T}$ then φ is also ψ-valid for $\mathcal{T}$. Formally, $\mathcal{T} \models \varphi$ implies $\mathcal{T} \models_{\psi} \varphi$.
  ◯ True ◯ False
- Every Büchi automaton has at least one accepting run.
  ◯ True ◯ False
- Reactive Synthesis for an LTL formula φ asks to find a strategy σ s.t. all executions of σ satisfy φ.
  ◯ True ◯ False

(b) Consider the following transition system $\mathcal{T}$ with $q_i = a$ and $\forall q : \tau(q) = \{q\}$:



Decide for each for the following LTL formulae, whether it is valid for $\mathcal{T}$, satisfied but not valid for $\mathcal{T}$, or not satisfied by $\mathcal{T}$.
As for *true or false* questions, you receive one point for each correct answer and lose one point for every wrong answer. If you don't give an answer you will neither receive or lose a point. You cannot get less than zero points in total.

- $GFe \wedge FG\neg b$ ◯ Valid ◯ Satisfied but not valid ◯ Not Satisfied
- $G(d \rightarrow X\neg c)$ ◯ Valid ◯ Satisfied but not valid ◯ Not Satisfied
- $G((X\neg h)Uc)$ ◯ Valid ◯ Satisfied but not valid ◯ Not Satisfied
- $aU(eUb)$ ◯ Valid ◯ Satisfied but not valid ◯ Not Satisfied

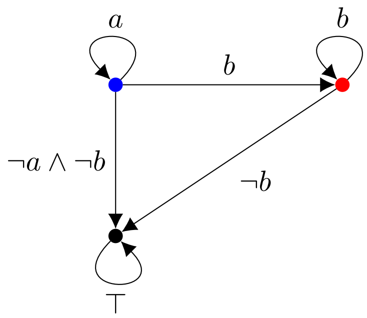
(c) Decide for each of the following LTL formulae by which of the given Büchi Automata it is represented. The initial state is marked in blue while the goal states are red.
For this question, you will **not** lose points for wrong answers.

(i) $G(a \rightarrow Xb)$

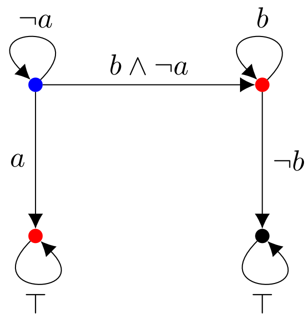
(ii) $aUGb$

(iii) $a \wedge Xb$

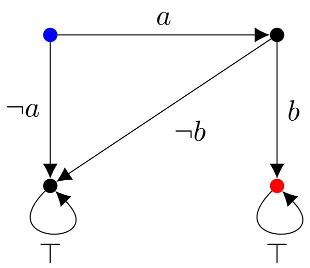
(iv) $F(a \vee Gb)$



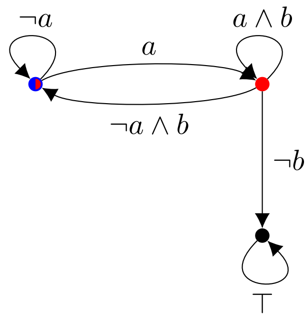
(A)



(B)



(C)



(D)