Name:

Birth Date:

Matriculation Number:

Field of Study:

Exam
Künstliche Intelligenz 1

July 16., 2018

To be used for grading, do not write here											
prob.	1.1	1.2	2.1	2.2	3.1	3.2	4.1	4.2	5.1	5.2	6.1	Sum
total	6	12	5	5	3	12	2	10	10	6	10	81
reached												

Exam Grade: Bonus Points: Final Grade:

Organizational Information

Please read the following directions carefully and acknowledge them with your signature.

1. Please place your student ID card and a photo ID on the table for checking
2. The grading information on the cover sheet holds with the proviso of further checking.
3. no resources or tools except a pen are allowed.
4. You have 90 min(sharp) for the test
5. Write the solutions directly on the sheets.
6. If you have to abort the exam for health reasons, your inability to sit the exam must be certified by an examination at the University Hospital. Please notify the exam proctors and have them give you the respective form.
7. Please make sure that your copy of the exam is complete (10 pages including cover sheet and organizational information pages) and has a clear print. **Do not forget to add your personal information on the cover sheet and to sign this declaration (next page).**

Declaration

With my signature I certify having received the full exam document and having read the organizational information above.

Erlangen, July 16., 2018 ....
(signature)

Organisatorisches

Bitte lesen die folgenden Anweisungen genau und bestätigen Sie diese mit Ihrer Unterschrift.

1. Bitte legen Sie Ihren Studentenausweis und einen Lichtbildausweis zur Personenkontrolle bereit!
2. Die angegebene Punkteverteilung gilt unter Vorbehalt.
3. Es sind keine Hilfsmittel erlaubt.
4. Die Lösung einer Aufgabe muss auf den vorgesehenen freien Raum auf dem Aufgabenblatt geschrieben werden; die Rückseite des Blatts kann mitverwendet werden. Wenn der Platz nicht ausreicht, können bei der Aufsicht zusätzliche Blätter angefordert werden.
5. Wenn Sie die Prüfung aus gesundheitlichen Gründen abbrechen müssen, so muss Ihre Prüfungsunfähigkeit durch eine Untersuchung in der Universitätsklinik nachgewiesen werden. Melden Sie sich in jedem Fall bei der Aufsicht und lassen Sie sich das entsprechende Formular aushändigen.
6. Die Bearbeitungszeit beträgt 90 Minuten.
7. Überprüfen Sie Ihr Exemplar der Klausur auf Vollständigkeit (10 Seiten inklusive Deckblatt und Hinweise) und einwandfreies Druckbild! **Vergessen Sie nicht, auf dem Deckblatt die Angaben zur Person einzutragen und diese Erklärung zu unterschreiben!**

Erklärung

Durch meine Unterschrift bestätige ich den Empfang der vollständigen Klausurunterlagen und die Kenntnisnahme der obigen Informationen.

Erlangen, July 16., 2018 ....
(Unterschrift)

Please consider the following rules; otherwise you may lose points:

- If you continue an answer on another page, please indicate the problem number on the new page and give a page reference on the old page.
- Always justify your statements (we would like to give poins for incorrect answers). Unless you are explicitly allowed to, do not just answer "yes", "no", or "42".
- If you write program code, give comments!

1 Prolog

Problem 1.1 6pt 6min

1. Program a predicate in Prolog for addition and multiplication in unary representation.

Hint: The number 3 in unary representation is the ProLog term s(s(s(o))), i.e. application of the arbitrary function s to an arbitrary value o iterated three times.

Hint: Note that ProLog does not allow you to program (binary) functions, so you must come up with a three-place predicate. You should use add(X,Y,Z) to mean $X + Y = Z$ and program the recursive equations $X + 0 = X$ (base case) and $X + s(Y) = s(X + Y)$.

2. Write a program that computes the n^{th} Fibonacci Number (0, 1, 1, 2, 3, 5, 8, 13,... add the last two to get the next), using the addition predicate above.

Solution:

```
uadd(X,o,X).
uadd(X,s(Y),s(Z)) :- add(X,Y,Z).

umult(_,o,o).
umult(X,s(Y),Z) :- umult(X,Y,W), uadd(X,W,Z).

ufib(o,o).
ufib(s(o),s(o)).
ufib(s(s(X)),Y):-ufib(s(X),Z),ufib(X,W),uadd(Z,W,Y).
```

Problem 1.2 (DFS in Prolog) 12pt 12min

We want to implement DFS in ProLog using the following data structures for search trees:

```
subtrees([]).
subtrees([(Cost,T)|Rest]) :- number(Cost),istree(T), subtrees(Rest).
istree(tree(_,Children)) :- subtrees(Children).
```

Write a method dfs such that dfs(G,T,X,Y) on a tree T returns the path to the goal G in X and the cost of the path in Y

Solution:

```
dfs(GoalValue,tree(GoalValue,_),GoalValue,0).
dfs(GoalValue,tree(Value,[(Cost,T)|Rest]),Path,FinalCost) :- T = tree(IV,_), write(IV ),
dfs(GoalValue, T,P,C),string_concat(Value,P,Path),FinalCost is C+Cost; % go down one depth level
dfs(GoalValue,tree(Value,Rest),Path,FinalCost). % next child
```

2 Search

Problem 2.1 (A^* vs. BFS)

5pt

Does A^* search always expands fewer nodes than BFS? Justify you answer. 5min

Solution: No. With a bad heuristic, A^* can be forced to explore the whole space, just like BFS.

Problem 2.2 (A looping greedy search)

Draw a graph and give a heuristic so that a greedy search for a path from a node A to a node B gets stuck in a loop. Draw the development of the search tree, starting from A, until one node is visited for the second time. 5pt 5min

Indicate, in one or two sentences, how the search algorithm could be modified or changed in order to solve the problem without getting stuck in a loop.

Solution:

1. The example from the lecture, i. e. traveling through Romania.
2. Use A^*, or remember which nodes have been visited before and don't visit them again.

3 Adversarial Search

Problem 3.1 (Minimax Restrictions)

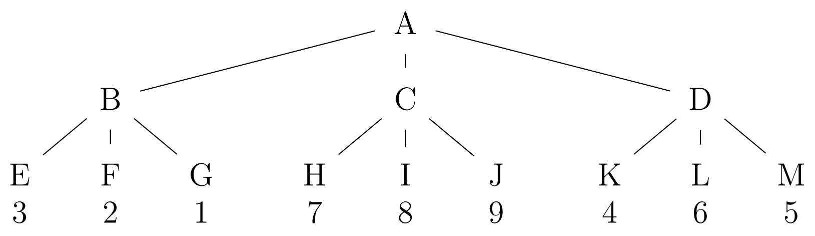
Name at least five criteria that a game has to satisfy in order for the minimax algorithm to be applicable. 3pt 3min

Solution:

- Two-player
- Determininstic
- Fully observable
- Players alternate
- Finitely many / discrete game states
- Zero-sum
- Game ends after finitely many rounds

Problem 3.2 (Game Tree)

Consider the following game tree. Assume it is the maximizing player's turn to move. The values at the leaves are the static evaluation function values of the states at each of those nodes. 12pt 12min



1. Compute the minimax game value of nodes A, B, C, and D
2. Which move would be selected by Max?
3. List the nodes that the alpha-beta algorithm would prune (i.e., not visit). Assume children of a node are visited left-to-right.
4. How would the nodes in the tree need to be ordered to prune as many branches as possible?

Solution:
1. A = 7 ; B = 1 ; C = 7 ; D = 4
2. C
3. L, M
4. Level 2: left to right: C, D, B. Level 3: J,I,H,L,M,K,E,F,G. Prunes M, K, F, G

4 Constraint Satisfaction Problems & Inference

Problem 4.1 (Arc consistency)

Define the concept of *arc consistency* 2pt

Solution: A variable u is arc consistent relative to v, if there is either no constraint between u and v, or for every value $d \in D_u$, there is some $d' \in D_v$ such that $(d, d') \in C_{uv}$. A constraint network is arc consistent if all variables are pairwise arc consistent relative to each other. 2min

Problem 4.2 (Scheduling CS Classes)

You are in charge of scheduling for computer science classes that meet Mondays, Wednesdays and Fridays. There are 5 classes that meet on these days and 3 professors who will be teaching these classes. You are constrained by the fact that each professor can only teach one class at a time. The classes are: 10pt 10min

- Class 1 - Intro to Programming: meets from 8:00-9:00am
- Class 2 - Intro to Artificial Intelligence: meets from 8:30-9:30am
- Class 3 - Natural Language Processing: meets from 9:00-10:00am
- Class 4 - Computer Vision: meets from 9:00-10:00am
- Class 5 - Machine Learning: meets from 9:30-10:30am

The professors are:

- Professor A, who is available to teach Classes 3 and 4.
- Professor B, who is available to teach Classes 2, 3, 4, and 5.
- Professor C, who is available to teach Classes 1, 2, 3, 4, 5.

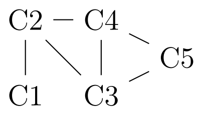
1. Formulate this problem as a CSP problem in which there is one variable per class, stating the domains, and constraints. Constraints should be specified formally and precisely, but may be implicit rather than explicit. 4 pt
2. Give the constraint graph associated with your CSP (e.g. by giving the edges). 2 pt
3. Show the domains of the variables after running arc-consistency on this initial graph (after having already enforced any unary constraints). 4 pt

Solution:

1.

Variables	Domains
C1	C
C2	B,C
C3	A,B,C
C4	A,B,C
C5	B,C

Constraints: C1 $\neq$ C2, C2 $\neq$ C3 , C3 $\neq$ C4, C4 $\neq$ C5, C2 $\neq$ C4, C3 $\neq$ C5

2. 

3.

Variable	Domain
C1	C
C2	B
C3	A,C
C4	A,C
C5	B,C

Note that C5 cannot possibly be C, but arc consistency does not rule it out.

4. C1 = C, C2 = B, C3 = C, C4 = A, C5 = B. One other solution is possible (where C3 and C4 are switched).

5 Logic

Problem 5.1 (First-Order Resolution)

Prove the following formula using resolution. 10pt

$P \in \Sigma_2^p, R \in \Sigma_1^p, a \in \Sigma_0^f$ 10min

$$\forall X \forall Y \forall Z \exists U \exists V \exists W[(P(X,Y) \Rightarrow (P(Z,a) \Rightarrow R(a))) \Rightarrow ((P(U,V) \wedge P(W,a)) \Rightarrow R(a))]$$

Solution: Skolemizing:

$$\exists U \exists V \exists W[(P(c_x,c_y) \Rightarrow (P(c_z,a) \Rightarrow R(a))) \Rightarrow ((P(U,V) \wedge P(W,a)) \Rightarrow R(a))]$$

Negated and in CNF:

$$\forall U \forall V \forall W[(\neg P(c_x,c_y) \vee \neg P(c_z,a) \vee R(a)) \wedge P(U,V) \wedge P(W,a) \wedge \neg R(a)]$$

We have the following clauses:

$$\{\neg P(c_x,c_y), \neg P(c_z,a), R(a)\}, \quad \{P(U,V)\}, \quad \{P(W,a)\}, \quad \{\neg R(a)\}$$

Now for the resolution, where in each step we need to unify the terms:

$$\begin{tikzcd}[column sep=small]
\{\neg P(c_x,c_y),\neg P(c_z,a),R(a)\} \arrow[dr, dash] & & \{P(U,V)\left[\frac{c_x}{U},\frac{c_y}{V}\right]\} \arrow[dl, dash] & & \\
& \{\neg P(c_z,a),R(a)\} \arrow[dr, dash] & & \{P(W,a)\left[\frac{c_z}{W}\right]\} \arrow[dl, dash] & \\
& & \{R(a)\} \arrow[dr, dash] & & \{\neg R(a)\} \arrow[dl, dash] \\
& & & \emptyset &
\end{tikzcd}$$

Problem 5.2 (Natural Deduction)

Prove the following formula using Natural Deduction 6pt

6min

$$((A \vee B) \wedge (A \Rightarrow C) \wedge (B \Rightarrow C)) \Rightarrow C$$

Solution:

(1)	1	$(A \vee B) \wedge ((A \Rightarrow C) \wedge (B \Rightarrow C))$	Assumption
(2)	1	$(A \vee B)$	$\wedge E_\ell$ (on 1)
(3)	1	$(A \Rightarrow C) \wedge (B \Rightarrow C)$	$\wedge E_r$ (on 1)
(4)	1	$(A \Rightarrow C)$	$\wedge E_\ell$ (on 3)
(5)	1	$(B \Rightarrow C)$	$\wedge E_r$ (on 3)
(6)	1,6	A	Assumption
(7)	1,6	C	$\Rightarrow E$ (on 4 and 6)
(8)	1,8	B	Assumption
(9)	1,8	C	$\Rightarrow E$ (on 5 and 8)
(10)	1	C	$\vee E$ (on 2, 7 and 9)
(11)		$((A \vee B) \wedge (A \Rightarrow C) \wedge (B \Rightarrow C)) \Rightarrow C$	$\Rightarrow I$ (on 1 and 10)

6 Planning

Problem 6.1 (STRIPS)

You are given a water spout and two jugs, one holding p and one holding q gallons, where $p < q$ and p and q are relatively prime. Starting with both jugs empty, the goal is to have exactly k gallons in one of the jugs. You can only fill the jugs from the spout fully. 10pt

10min

We use the following predicates:

$$P = \{Jug_p(n) \mid 0 \leq n \leq p,\, n \in \mathbb{N}\} \cup \{Jug_q(n) \mid 0 \leq n \leq q,\, n \in \mathbb{N}\}$$

The intial state is $I = \{Jug_p(0), Jug_q(0)\}$ and the goal state $G = Jug_p(k)$.

Give the pre, add and del lists for the following actions:

- $Empty_p/Empty_q$: Empties jug p/q completely
- $FillUp_p/FillUp_q$: Fill up jug p/q fully

- For all x, y with $0 \leq x \leq p,\ 0 \leq y \leq q$:
  $Fillp_{x,y}/Fillq_{x,y}$: pour the contents of jug q/p into jug p/q until the former is empty or the latter is full.

Solution:

- $Empty_p$: $\mathsf{pre} = \{\}, \mathsf{add} = \{Jug_p(0)\}, \mathsf{del} = \{Jug_p(n) \mid 1 \leq n \leq p\}$
- $Empty_q$: $\mathsf{pre} = \{\}, \mathsf{add} = \{Jug_q(0)\}, \mathsf{del} = \{Jug_q(n) \mid 1 \leq n \leq q\}$
- $FillUp_p$: $\mathsf{pre} = \{\}, \mathsf{add} = \{Jug_p(p)\}, \mathsf{del} = \{Jug_p(n) \mid 0 \leq n < p\}$
- $FillUp_q$: $\mathsf{pre} = \{\}, \mathsf{add} = \{Jug_q(q)\}, \mathsf{del} = \{Jug_q(n) \mid 0 \leq n < q\}$
- For all x, y with $0 \leq x \leq p,\ 0 \leq y \leq q$, and with $m = \mathsf{min}(x + y, p)$:
  $Fillp_{x,y}$:
  $$\mathsf{pre} = \{Jug_p(x), Jug_q(y)\},$$
  $$\mathsf{add} = \{Jug_p(m), Jug_q(m - x)\},$$
  $$\mathsf{del} = \{Jug_p(z) \mid z \neq m\} \cup \{Jug_q(z) \mid z \neq m - x\}$$
  and with $m = \mathsf{min}(x + y, q)$:
  $Fillq_{x,y}$:
  $$\mathsf{pre} = \{Jug_p(x), Jug_q(y)\},$$
  $$\mathsf{add} = \{Jug_p(m - y), Jug_q(m)\},$$
  $$\mathsf{del} = \{Jug_p(z) \mid z \neq m - y\} \cup \{Jug_q(z) \mid z \neq m\}$$
