Last Name: First Name:

Matriculation Number:

Exam
Artificial Intelligence 1

October, 2024

	To be used for grading, do not write here														
prob.	1.1	2.1	2.2	3.1	3.2	4.1	4.2	5.1	5.2	5.3	6.1	7.1	7.2	Sum	grade
total	10	12	8	5	3	9	7	6	6	8	6	6	5	91	
reached															

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. You can reach 91 points if you fully solve all problems. You will only need 85 points for a perfect score, i.e. 6 points are bonus points.
3. No resources or tools are allowed except for a pen.
4. You have 90 min (sharp) for the exam.
5. Write the solutions directly on the sheets, no other paper will be graded.
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 (4 pages excluding 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.**

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

Erlangen, October, 2024 ....
(signature)

Please consider the following guidelines to avoid losing points:

- If you continue an answer on another page, clearly give the problem number on the new page and a page reference on the old page.
- If you do not want something to be graded, clearly cross it out. Adding a wrong statement to a correct solution may lead to deductions.
- The instructions “Give X”, “List X” or similar mean that only X is needed. If you additionally justify your answer, we will try to give you partial credit for a wrong answer (but there is no guarantee that we will).
- The instruction “Assume X” means that X is information that you may use in your answer.
- The instruction “Model X as a Y” means that you have to describe X formally and exactly as an instance of Y using the definition of Y from the lecture.
- If you are uncertain how long or complex an answer should be, use the number of points as an indication: 1 point roughly corresponds to 1 minute.
- In all calculation questions, you have to simplify as much as reasonably possible without a calculator. For example, $\log 2$ or 3^7 should not be calculated, but $0.4 \cdot 0.3 \cdot 0.5 = 0.06$ should be.

1 Prolog

Problem 1.1 (Analyzing a Prolog Program)
Consider the following Prolog program:

```
1 rch(X,[],X).
2 rch(X,[A|As],Z) :- trns(X,A,Y), rch(Y,As,Z).
3
4 slt(As) :- i(X), g(Z), rch(X,As,Z).
```

1. Extend this program with clauses so that the query `slt([a,b])` succeeds. 3 Points
2. Which definition from the course does the program `slt(As)` implement? 3 Points

For the remaining questions, assume that the predicates `i`, `g`, and `trns` are defined by a finite set of facts. We now reverse the order of the subgoals in line 2, i.e., change line 2 to

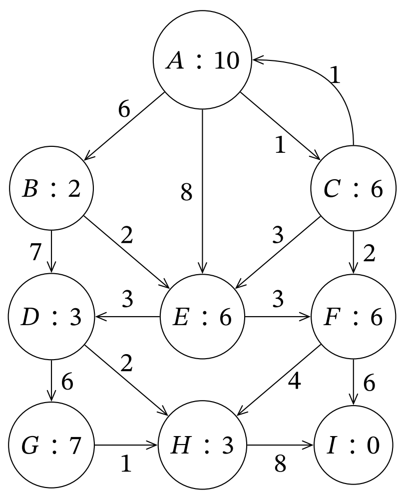
```
rch(X,[A|As],Z) :- rch(Y,As,Z), trns(X,A,Y).
```

Explain (in about 2 sentences each) if/how this change affects the query `slt(As)` regarding

3. …correctness? 2 Points
4. …time efficiency? 2 Points

2 Search

Problem 2.1 (Search Algorithms)
Consider the following directed graph:



Every node is labeled with $n : h(n)$ where n is the identifier of the node and $h(n)$ is the heuristic for estimating the cost from n to a goal node.
Each node's children are ordered **alphabetically**.
Every edge is labeled with its actual cost.

1. Show or refute that the heuristic is admissible. 2 Points
2. Give one example of a transition in that graph that makes the heuristic inconsistent. 2 Points

Assume you have already expanded the node A. List the **next** 4 **nodes (i.e., excluding** A**)** that will be expanded using the respective algorithm.
If there is a tie, break it using **alphabetical order**.

3. Depth-first search 1 Points
4. Breadth-first search 1 Points
5. uniform-cost search 2 Points
6. greedy search 2 Points
7. A^*-search 2 Points

Problem 2.2 (Search Problems)
Consider the family of search problems P_n given for $n = 1, 2, \ldots$ by $\langle S_n, A_n, T_n, I_n, G_n \rangle$ where

- $S_n = \{0, 1\}^n$, i.e., states $x \in S_n$ are n-tuples $(x_1, \ldots, x_n)$
- $A_n = \{l, r, i\}$
- T_n is given by
  - $T_n(l, x) = \{(x_2, \ldots, x_n, 0)\}$
  - $T_n(r, x) = \{(0, x_1, \ldots, x_{n-1})\}$
  - $T_n(i, x) = \{u\}$ where
    - if $x_n = 0$: $u = (x_1, \ldots, x_{n-1}, 1)$
    - if $x_n = 1$: $u_n = 0$ and (if $n > 1$) $(u_1, \ldots, u_{n-1}) \in T_{n-1}(i, (x_1, \ldots, x_{n-1}))$
- $I = \{(0, \ldots, 0)\}$
- $G = \{(1, \ldots, 1)\}$

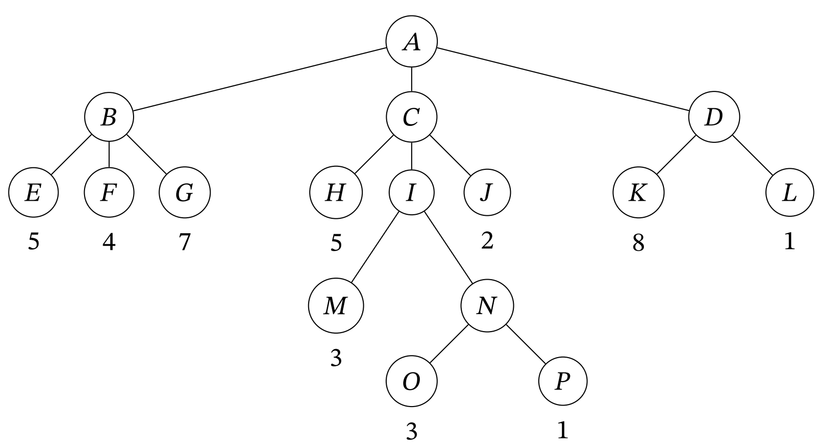
1. For $n = 5$, give the result of applying the action sequence i, l, i, i in the initial state. 2 Points
2. What is the shortest solution to P_n? 2 Points

Now we try to solve P_n using depth-first search. We avoid cycles by only applying an action if it leads to a previously unexpanded state.
Discuss this strategy for the particular case of P_n (in about 1-2 sentences each) regarding

3. …completeness. 2 Points
4. optimality. 2 Points

3 Adversarial Search

Problem 3.1 (Minimax)
Consider the following minimax game tree for the **maximizing** player's turn. The values at the leaves are the static evaluation function values of those states; some of those values are currently missing.



1. Label the node A with its minimax value. 2 Points
2. Which move would be chosen by the player? 1 Points
3. Which nodes does $\alpha\beta$-pruning prune? We expand child nodes in alphabetical order. 2 Points

Problem 3.2 (Minimax Applicability)
Consider the following game:

- Initially, 2 players have 10 tokens each, and there is an empty bag of tokens in the center.
- The players take turns either putting an odd number of tokens into the bag or taking a non-zero even number of tokens from the bag.
- A player loses if they have no more tokens.

1. Explain why minimax can/cannot be used to find a perfect strategy for this game. 3 Points

4 Constraint Satisfaction

Problem 4.1 (Solving and Propagation)
Consider the following binary CSP:

- $V = \{a, b, c, d, e\}$
- $D_a = D_b = D_c = \{0, 1, 2, 3\}$, $D_d = D_e = \{0, 1, 2, 3, 4, 5\}$
- Constraints:
  - $a > 1$ or $d > 2$
  - $b \cdot e > 8$
  - $d = 2c$
  - $a > b$
  - $b > c$

1. Give an **inconsistent** total assignment to the variables. 1 Points
2. Give **the two** solutions. 3 Points
3. Check the boxes for (v, w) where v is arc-consistent relative to w. 2 Points

   ☐ (a, d) ☐ (d, a) ☐ (c, d) ☐ (d, c)

4. Now assume you have assigned $b = 2$. Give the domains after forward-checking. 2 Points
5. What additional step can be taken if forward-checking results in a variable domain of size 1? 1 Points

Problem 4.2 (Relating CSP and SAT)
We want to reduce SAT to CSP.

1. Explain (in 2 sentences) why it is easier and sufficient to reduce SAT to higher-order CSPs (as opposed to reducing SAT to binary CSPs). 2 Points
2. Show that SAT can be reduced to CSP by defining 5 Points
   - for every SAT-instance P a CSP-instance $Q = (V, D, C)$ and
   - a bijection between Q-solutions and satisfying P-instances

5 Logic

Problem 5.1 (Propositional Logic)
Consider the formula $A = (p \wedge q \wedge \neg r) \vee (\neg p \Rightarrow r) \vee (p \wedge q \wedge r)$ using propositional variables p, q, r.

1. Give all falsifying assignments for A. 2 Points
2. Give a formula in CNF that is equivalent to A. 2 Points
3. Give a formula B such that $A \vee (B \Rightarrow A)$ is valid. 2 Points

Problem 5.2 (Modeling in First-Order Logic)
Consider the following situation:

- Some individuals are persons, some are animals.
- Individuals may own other individuals.

1. Model this situation in first-order logic by giving a signature, i.e., a list of function/predicate symbols with arity. 2 Points
2. State formulas over your signature that capture the following properties: 2 Points
   1. There is a person that owns an animal.
   2. Persons cannot be owned.
3. Give a model of your signature in which the universe is as small as possible and the above two formulas are true. 2 Points

Problem 5.3 (Resolution)
Consider the signature of first-order logic with unary predicate symbol P, binary predicate symbol R, and nullary function symbols a, b.

1. Prove the following formula using the first-order resolution calculus. 8 Points

$$\exists X.\forall Y.\exists Z.\exists W.(\neg P(Z) \land \neg R(b,a)) \lor \neg R(a,b) \lor R(W,a) \lor (P(Y) \land R(X,b))$$

6 Knowledge Representation

Problem 6.1 (ALC)
Consider the following ALC signature

- concept symbols: p (for person), a (for animal)
- role symbols: o (for owns)

1. Give a concept that represents the set of people that own animals. 1 Points
2. Give an axiom that states that people cannot be owned. 2 Points
3. Give an ABox that represents a person Alice owning an animal Bubbles. 1 Points
4. Calculate the translation to first-order logic of the concept $\forall o.\exists o.a$. 2 Points

7 Planning

Problem 7.1 (STRIPS and Relaxation)
Consider the STRIPS task given by

- facts: $\{a, b, c, d\}$
- actions: $\{p, q, r\}$ with $p = \langle\{a\},\{b\},\{a\}\rangle$, $q = \langle\{c\},\{d\},\{c\}\rangle$, and $r = \langle\{b\},\{c\},\{b\}\rangle$, where each action is given as a triple of preconditions, add list, and delete list
- initial state: $\{a\}$
- goal state: $\{d\}$

1. Give the optimal plan for this problem. 2 Points
2. Give the optimal delete-relaxed plan for this problem. 2 Points
3. Give the optimal only-adds-relaxed plan for this problem. 2 Points

Problem 7.2 (Kinds of Planning)

1. Explain (in about 3-5 sentences) the differences between satisficing, optimal, and relaxed planning. 5 Points