Name:

Birth Date:

Matriculation Number:

Exam
Artificial Intelligence 1

Feb 15, 2021

	To be used for grading, do not write here													
prob.	1.1	2.1	2.2	2.3	3.1	3.2	4.1	4.2	5.1	5.2	6.1	6.2	Sum	grade
total	10	8	5	8	7	8	7	8	7	8	12	7	95	
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 are allowed except for a pen.
4. You have 90 min(sharp) for the test
5. You can reach 95 points if you fully solve all problems. You will only need 90 points for a perfect score, i.e. 5 points are bonus points.
6. Write the solutions directly on the sheets.
7. 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.
8. Please make sure that your copy of the exam is complete (18 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, Feb 15, 2021 ....

(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 außer eines Stifts.
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 min.
7. Sie können 95 Punkte erreichen, wenn Sie alle Aufgaben vollständig lösen. Allerdings zählen 90 Punkte bereits als volle Punktzahl, d.h. 5 Punkte sind Bonuspunkte.
8. Überprüfen Sie Ihr Exemplar der Klausur auf Vollständigkeit (18 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, Feb 15, 2021 ....

(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 (Reading and Understanding Prolog) 10 pt

Consider the query ?−animal(Y) over the following Prolog program:

```
foo([H|_], X) :− X=H.
foo([_|T], X) :− foo(T,X).

eats(mouse,fruit).
eats(dog,meat).
eats(cat,mouse).
eats(Y,X) :− Y=lion, alive(X).
eats(cat,bird).

animal(X) :− eats(X,Y), alive(X), food(Y).
animal(Y) :− Y=cat.

alive(Y) :− foo([mouse,cat,lion,bird], Y).
alive("dog").

food(X) :− alive(X).
food(fruit).
food(meat).
```

mouse → f
dog → m
cat →
lion →

1. Which answers will the query return for Y? cat, mouse, lion, ~~bird~~ 5 pt
   - Only the **set** of answers matters — order or duplicates do not.
   - Write "none" if the query returns no answers.
2. Which answer is returned (a) first (b) second ("none" if no answer is returned). (a) mouse (b) cat 2 pt
3. Add a rule to the program such that the above query does not return an answer. — 3 pt
   - Indicate exactly where you insert your rule.
   - You may **not** add a rule that is ill-formed (e.g., a syntax error, or calling a predicate that does not exist).
   - You may **not** use functions from standard library.

Prolog uses DFS

send DFS an infinite loop by adding,

animal(x) :− animal(x)

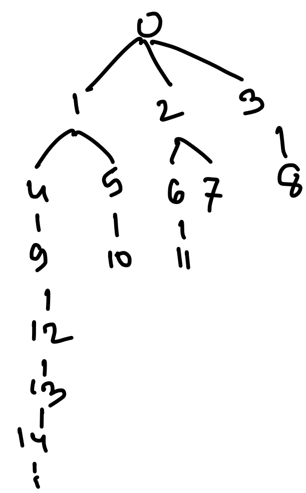
at beginning.

2 Search

Problem 2.1 (DFS and BFS Concretely) 8 pt

Consider the **infinite** tree whose nodes are the natural numbers with root 0. For every node, the children and their order are as follows:

- children of 0: 1, 2, 3
- children of 1: 4, 5
- children of 2: 6, 7
- children of 3: 8
- children of 4: 9
- children of 5: 10
- children of 6: 11
- children of 9: 12
- children of n for $n \geq 12$: n+1
- other nodes have no children



1. List the nodes in the order of expansion during

   (a) depth-first search   0, 1, 4, 9, 12, 13, 14, ...   3 pt

   (b) breadth-first search   0, 1, 2, 3, 4, 5, 6, 7, 8, 9, 10, 11, 12, 13, 14 ---   3 pt

2. Assuming the goal state is 7, why does it matter whether we use depth-first or breadth-first search? 2 pt

   in dfs, it will run forever

   in bfs, we will find 7

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Problem 2.2 (Heuristics) 5 pt

Consider heuristic search with heuristic function h.

1. Briefly explain what is the same and what is different between A^* search and greedy search regarding the decision which node to expand next. 3 pt
2. Is the constant function $h(n) = 0$ an admissible heuristic for A^* search? 2 pt

01. Both choos to minimize a certain f^n

greedy = $h(n)$

A^* = $g(n) + h(n)$ → heuristics

sum of path cost

02. Yes, but it is useless one.

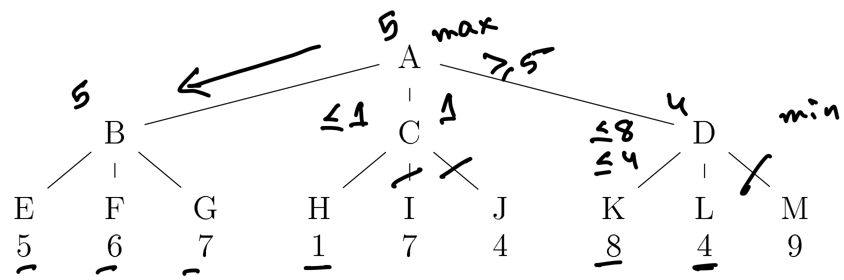
admissible means

$h(n) \le h^*(n)$

for A^* it will be always greater

Problem 2.3 (Adversarial Search) 8 pt

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.



1. Label each non-leaf node with its minimax value. A=5, B=5, C=1, D=4 4 pt

2. Which move would be selected by the player? move B 1 pt

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. 3 pt

I, J, M

3 Constraint Satisfaction/Propagation

Problem 3.1 (3 Rooks on a Small Board) 7 pt

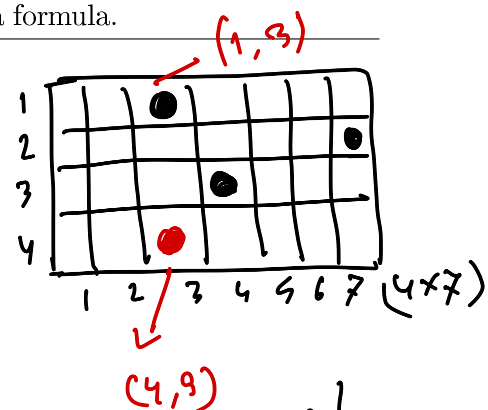
Consider the following problem: We want to place 3 rooks on a 4×7 chess-board such that no two rooks threaten each other. (Rooks move like queens except not diagonally.)
Model the problem as a constraint satisfaction problem (V, D, C).
Explain your model briefly by saying how rook placements correspond to the assignments for the problem.

Note: Make sure you give a formally exact definition, i.e., explicitly define the sets V and all sets D_v. You can describe each constraint as a set of tuples or as a formula.

$V = x_1, y_1, x_2, y_2, x_3, y_3$

$D_{x_1} = D_{x_2} = D_{x_3} = \{1, 2, 3, 4\}$

$D_{y_1} = D_{y_2} = D_{y_3} = \{1, 2, 3, 4, 5, 6, 7\}$



C: $v \neq w$ for all $(v, w) \in \{(x_1, x_2), (x_2, x_3), (x_3, x_1)\}$
$v \neq w$ for all $(v, w) \in \{(y_1, y_2), (y_2, y_3), (y_3, y_1)\}$

$x_1 \neq x_2$

$x_2 \neq x_3$

$x_3 \neq x_1$

Assignment to (x_1, y_1), (x_2, y_2), (x_3, y_3) correspond to the (x, y) coordinates of the (4×7) chessboard where the rooks placed.

Problem 3.2 (CSP Formalization) 8 pt

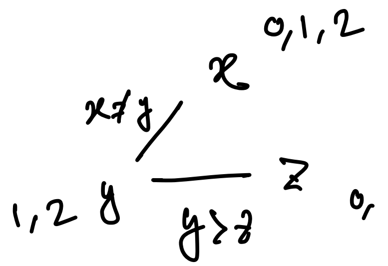
Consider the following binary CSP:

- $V = \{x, y, z\}$
- $D_x = \{0, 1, 2\}$, $D_y = \{1, 2\}$, $D_z = \{0, 1\}$
- Constraints: $x \neq y$, $y > z$

1. Give all pairs (v, w) of variables such that v is arc-consistent relative to w. 3 pt
2. Give all solutions that would remain if we added the constraint $x \neq z$. 3 pt
3. Assume we assign $y = 1$ and apply forward-checking. Give the resulting domains D_x, D_y, D_z. 2 pt

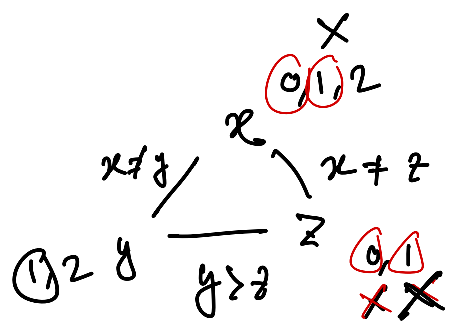
01. (x,y) ✓ (x,z) ✓ (y,z) ✓

(y,x) ✓ (z,x) ✓ (z,y) ✓



02. $(1,2,0)$, $(2,1,0)$

$(0,2,1)$



03. $D_x = \{0, 2\}$

$D_y = \{1\}$

$D_z = \{0\}$

4 Logic

Problem 4.1 (Satisfiability and Validity) 7 pt

Prove or refute each of the following statements about first-order logic:

1. The formula $(\forall x.P(x) \vee Q(x)) \Rightarrow \big((\forall x.P(x)) \vee (\forall x.Q(x))\big)$ is satisfiable. 3 pt

   $\exists x$ T

2. If A is not satisfiable, then $\neg A$ is valid. 4 pt

Q1. True.

satisfying interpretation $\Rightarrow$

P	Q
T	T
T	F
F	T
F	F

— P is T, $\forall x$ T → T   T

— Q is T, $\forall x$ T → T   T

— P, Q are F, $\exists x$ F → F   T

— P is T, Q is F, $\forall x$ T → T   T

— P is F, Q is T, $\forall x$ T → T   T

Q2. True.

A is not satisfiable, means

for all assignment φ, $A = F$

so, for all φ, $\neg A = T$

therefore, $\neg A$ valid

Problem 4.2 (Proving in Natural Deduction) 8 pt

Prove the following formula using natural deduction:

$$(P \Rightarrow Q) \Rightarrow \big(P \Rightarrow (P \wedge Q)\big)$$

01.	$P \Rightarrow Q$	Assump.
02.	P	Assump.
03.	Q	$\Rightarrow E$ (on 1,2)
04.	$P \wedge Q$	$\wedge I$ (on 2,3)
05.	$P \Rightarrow (P \wedge Q)$	$\Rightarrow I$ (on 2,4)
06.	$(P \Rightarrow Q) \Rightarrow (P \Rightarrow (P \wedge Q))$	$\Rightarrow I$ (on 1,5)

$$\dfrac{\dfrac{\dfrac{\dfrac{}{P \Rightarrow Q, P \vdash P}\,\text{Ax} \qquad \dfrac{\dfrac{}{P \Rightarrow Q, P \vdash P \Rightarrow Q}\,\text{Ax} \qquad \dfrac{}{P \Rightarrow Q, P \vdash P}\,\text{Ax}}{P \Rightarrow Q, P \vdash Q}\Rightarrow E}{P \Rightarrow Q, P \vdash (P \wedge Q)}\wedge I}{P \Rightarrow Q \vdash P \Rightarrow (P \wedge Q)}\Rightarrow I}{\vdash (P \Rightarrow Q) \Rightarrow (P \Rightarrow (P \wedge Q))}\Rightarrow I$$

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5 Knowledge Representation

Problem 5.1 (Specifying Properties in ALC) 7 pt

Consider the following ALC setting:

- concepts: `man`, `woman`,
- relations: `parentOf`, `spouseOf`

man ⊆ married

1. Give ALC expressions for
   (a) the concept of all persons in a homosexual marriage 2 pt
   (b) the statement that all men with children are married 2 pt
2. Translate to first-order logic the ALC statement $(\exists p.(m \sqcap w)) \sqsubseteq \forall s.\overline{m \sqcup w}$. 3 pt

PL¹

Note: You may abbreviate every concept/relation by its first letter in your solution.

Q1. (a) $(m \sqcap \exists s.m) \sqcup (w \sqcap \exists s.w)$

(b) $(m \sqcap \exists p.\top) \sqsubseteq \exists s.\top$

parent of someone (children) thus, ⊤ (top concept)

married with someone (man or woman) thus, ⊤ (top concept)

man ⊆ married

Q2. $(\exists p.(m \sqcap w)) \sqsubseteq \forall s.\overline{m \sqcup w}$

$$\forall x.(\exists y.p(x,y) \wedge m(y) \wedge w(y)) \Rightarrow (\forall y.s(x,y) \Rightarrow \neg(m(y) \vee w(y)))$$

??

Problem 5.2 (Induction on ALC) 8 pt

Consider the following fragment of the ALC grammar for concepts C:

$$C ::= a \mid \top \mid C \sqcap C \mid \forall r.C$$

where a and r represent the names of atomic concepts and relations.
We define a substitution s to be a mapping from atomic concepts a to concepts C.

By induction on C, define a function f such that $f(C, s)$ is the concept that arises from C by substituting every a with $s(a)$.

$a \to$ concepts

$r \to$ relations

substitution s : maps

concept $a \to$ concepts C

define $f(C, s) = ?$

$f(a, s) = s(a)$

$f(\top, s) = \top$

$f(C_1 \sqcap C_2, s) = f(C_1, s) \sqcap f(C_2, s)$

$f(\forall r.C, s) = \forall r. f(C, s)$

6 Planning

Problem 6.1 (Planning Deliveries in STRIPS) 12 pt

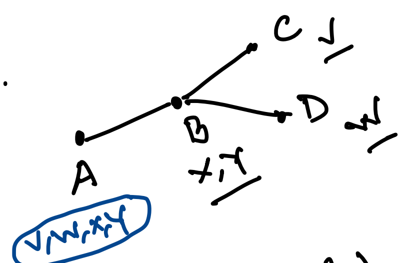
Consider a truck that can carry 2 objects at a time and is supposed to deliver objects $Obj = \{V, W, X, Y\}$ from location A to certain locations $Loc = \{A, B, C, D\}$ along some roads $Roads = \{\{A, B\}, \{B, C\}, \{B, D\}\}$. We use the following STRIPS task:

- facts: $\{\mathtt{at}(l, o) \mid l \in Loc, o \in Obj\} \cup \{\mathtt{truck}(l) \mid l \in Loc\}$
- actions $\mathtt{move}(l, m, O)$ for $\{l, m\} \in Roads$, $O \subseteq Obj$, $|O| \leq 2$ given by
  - precondition: $\mathtt{at}(l, o)$ for all $o \in O$, $\mathtt{truck}(l)$
  - add list: $\mathtt{at}(m, o)$ for all $o \in O$, $\mathtt{truck}(m)$
  - delete list: same as precondition
- initial state: $\mathtt{truck}(A)$, $\mathtt{at}(A, o)$ for $o \in Obj$
- goal state: $\mathtt{at}(C, V)$, $\mathtt{at}(D, W)$, $\mathtt{at}(B, X)$, $\mathtt{at}(B, Y)$

1. Give an action that is applicable in the initial state and the resulting successor state. 4 pt
2. Give an optimal plan for the task above. 4 pt
3. Argue why the following heuristic h is **not** admissible: for any state s, let $h(s)$ be the number of objects that are not at their goal location. 4 pt

01. For, $O \subseteq obj$, $|O| \leq 2$, the action move(A, B, O)
results: truck(B), at(B, o) for $o \in O$
↳ at(A, o) for $o \notin O$

02.



move(A, B, {V, X})
move(B, C, {V})
move(C, B, {})
move(B, A, {})
move(A, B, {W, Y})
move(B, D, {W})

move(A, B, {X, Y})
move(B, A, {})
move(A, B, {V, W})
move(B, C, {V, W})
move(C, B, {W})
move(B, D, {W})

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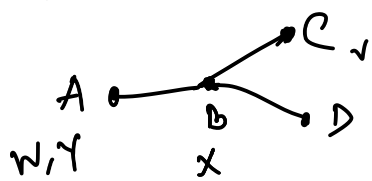
Q3.

Init.

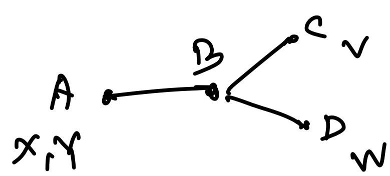
$h^*(s) = 6$

for initial state $h(s) = 4$ $\quad h(s) \leq h^*(s)$ ✓



$h^*(s) = 2$ $\quad h(s) \leq h^*(s)$ ✓

$h(s) = 1+1 = 2$



$h^*(s) = 1$ $\quad h(s) \leq h^*(s)$ ✗

$h(s) = 2$

Problem 6.2 (Partial Order Planning) 7 pt

Consider partial-order planning.

1. Given a STRIPS task $\Pi := \langle P, A, I, G \rangle$, what are the components of a partially ordered plan? 4 pt
2. What are the conditions on a partially ordered plan to be complete and consistent? 2 pt
3. How can we turn such a plan into a solution of the original planning task? 1 pt

01. Component of partial ordered plan:

- start node : it has facts in I as postcondition/effects
- finish node : it has facts in G as precondition
- causal links : $S \xrightarrow{p} T$ where p is effects of S and precondition of T

- temporal ordering constraints $S < T$

02. Complete: partially ordered plan is complete iff all preconditions are achieved by causal link.

Consistent: iff relation induced by causal links and ordering relations is a partial ordering.

?!? 03. any linearization of a complete partially ordered plan is a solution.

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