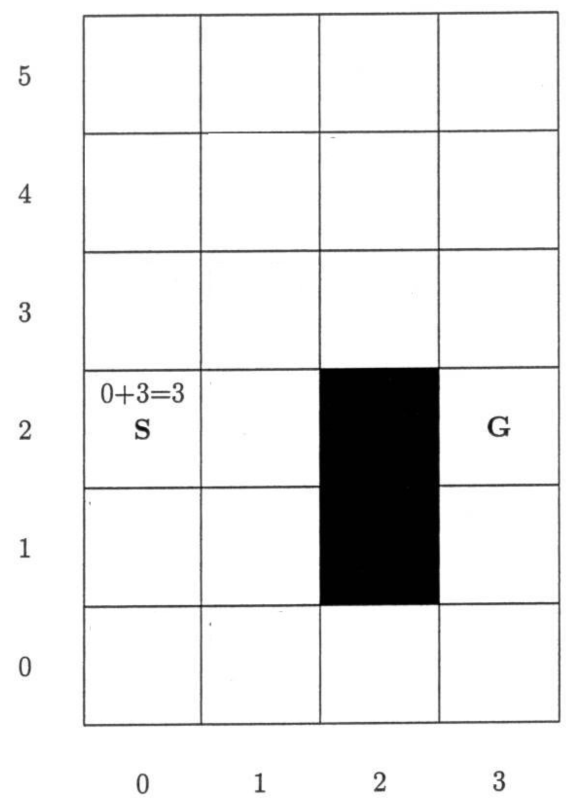
Name:

Question 1 (8+4 **marks**) HEURISTIC SEARCH / HEURISTISCHE SUCHE

A robot has to move from position S = (0, 2) to position G = (3, 2). Only horizontal and vertical movements (no diagonal ones) by one position per step are allowed. Positions marked black are inaccessible. A^* is employed to construct a search tree. Assuming unit cost, the heuristic is the Manhattan distance from the current position to G (ignoring the obstacles).



(a) Compute the f values of each node in the search tree, and mark the corresponding values in form of "$g + h = f$" in the grids (exemplary done for cell (0,2)). The cells which are not visited (A^* would not calculate the f value) in the search should be left empty.

(b) Correct or wrong? For each of the following statements, decide whether or not it is correct. For every correct answer you get 1 point, for every wrong answer you get -1 point. Thus, if unsure, don't give an answer. In total, the lowest possible score is 0.

1) In the above search problem, the Manhatten distance is an admissible heuristic.
2) Uniform cost search and A^* (assuming an admissible heuristic) both are complete and optimal.
3) The space complexity of breadth-first search is lower than that of deepth-first search.
4) A search problem consists of five parts: The state space, initial situation, actions, goal test and path costs.

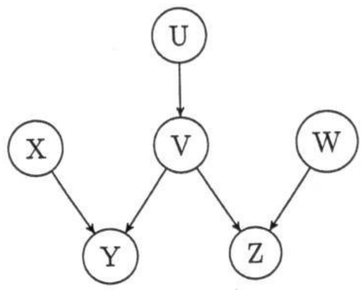
Name:

Question 2 (3+2+2+5 marks) CONDITIONAL INDEPENDENCE

(a) Given the unconditional probabilities $P(A \wedge B) = 0.3$, $P(\neg A) = 0.6$, and $P(B) = 0.5$, are A and B independent? Justify your answer.

(b) Given the joint probability $P(C \wedge D) = 0.21$ and the unconditional probability $P(D) = 0.5$ calculate the conditional probability $P(C \mid D)$.

(c) Rewrite the joint probability distribution $P(U, V, W, X, Y, Z)$ using the conditional independencies expressed by the following network:



(d) Determine, which of the following conditional independence statements follow from the structure of the Bayesian network ($Ind(A, B \mid C)$ denotes that A is conditionally independent of B given C).

statement	correct	not correct
$Ind(V, X \mid U)$		
$Ind(V, Z \mid U)$		
$Ind(U, Z \mid V)$		
$Ind(Y, Z \mid X, V)$		
$Ind(U, V \mid Y, Z)$		

Name: ______________________________

Question 3 (5+5 marks)

(a) Consider the following set of formulas:

$$\Theta = \left\{ \begin{array}{l} \forall x \forall y (f(x) = f(y) \Rightarrow x = y) \\ \forall x \forall y (P(x, y) \Rightarrow \neg(x = y)) \\ \forall x P(f(x), x) \end{array} \right\}$$

Specify an satisfying interpretation $\mathcal{I} = \langle \mathcal{D}, \cdot^{\mathcal{I}} \rangle$ with domain $\mathcal{D} = \{d_1, d_2, d_3, d_4\}$.

(b) Transform the following formula to Skolem normal form:

$$\forall x \forall y (P(x, y) \Rightarrow \exists z (P(x, z) \land P(z, y)))$$

Name: ____

Question 4 (4+6+4 marks) MDP

s_0			G

Consider the markov decision process (MDP) with the four states $s \in S$ that correspond to the cells of the grid world depicted above. In each of the cells the agent can select one of the actions West or East. The action West moves the agent one cell to the left with a probability of 0.8. With a probability of 0.2 the action West fails, leaving the agent in the same cell. The action East has a probability of 0.8 for moving the agent one cell to the right, and 0.2 for failing. If the action West is used in the leftmost cell (state s_0), the agent stays in place with probability 1. Furthermore, once it's reached, the goal state G cannot be left by the agent. The immediate reward is $R(s) = -1$ for state $s \in S \setminus \{G\}$ other than the terminal state G, and $R(G) = 0$ for a step within the terminal state G. Hint: By definition, the utility U of the terminal state G always is $U(G) = 0$. Furthermore, the rewards in this problem are **additive**!

(a) *Value Iteration Algorithm.* How could a non-optimal utility function $U^t : S \mapsto \mathbb{R}$ be improved using the **value iteration** algorithm? Either write down the exact formal definition for calculating the updated utility $U^{t+1}(s)$ of a state s or explain (exactly!) the iterative update rule using natural language.

(b) *Applying Value Iteration.* Consider the following sub-optimal utility function U^t. Do one iteration of the Value Iteration algorithm updating all states $s \in S$ and filling the improved utilities $U^{t+1}(s)$ into the right figure. Write down the necessary calculations for each of the three states to update.

−5	−2	−10	0

U^{t+1}

			0

(c) *Policy Improvement.* Consider the utilities $U^{\pi^t}(s)$ under a policy π^t as depicted in the upper-left grid of the figure below. Do a *Policy Improvement* step based on this utility function and fill in the resulting policy π^{t+1} in the right grid of the upper row. Finally fill in the optimal policy into the remaining grid in the lower row (on the next page).

U^{π^t}

$-\infty$	+2	−10	0

π^{t+1}

			0

π^*

			0

Foundations of Artificial Intelligence
Reconstruction of 2014's exam (16.09.2014)

Lecturers:	Prof. Dr. Wolfram Burgard
	Prof. Dr. Bernhard Nebel
	Prof. Dr. Martin Riedmiller
Assistants:	Johannes Aldinger
	Dr. Joschka Boedecker
	Philipp Ruchti

Permitted exam aids:	none
Duration:	90 Minutes

Task 1 – MinMax Algorithm

Sadly, we weren't able to reconstruct this task.

The only thing we remember is that the tree had a probabilistic step.

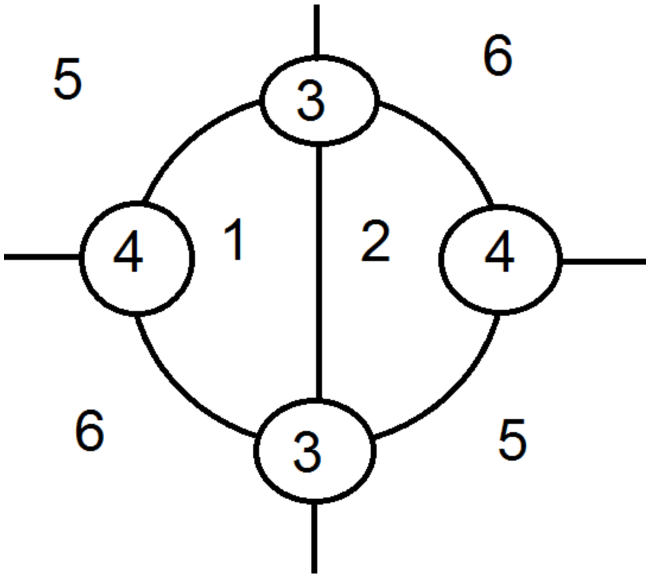
Task 2 – Decision Trees

Sadly, we weren't able to reconstruct this task.

The only thing we remember is that a table was given, one was supposed to calculate the gain values and then build a decision tree and convert it to DNF. The task did have some similarities with Task 6.5 on `http://gki.informatik.uni-freiburg.de/teaching/ss14/gki/exercises/sheet06-english.pdf`.

Task 3 – Forward Checking

You are a gardener assigned to the following garden:



You can choose one flower-type for each patch (1-6). Available flower-types are A, B, C, D and E. You may not assign the same flower-type to two adjacent patches. Execute the forward checking algorithm using the following tie-breakers:

- most constrained first
- if equally many constraints apply, choose the flower-type earlier in the alphabet for the patch with the smaller number

---

The result should get inserted into a table, one calculation step per line (one column for each patch). The first line contained the first step as an example.

Task 4 – Allen's Interval Calculus

a) Given the following statements

$$\text{popcorn } overlaps^{-1} \text{ movie} \qquad \text{credits } finishes \text{ movie}$$

Which statements can get deduced between popcorn and credits?

b) Is $starts^{-1}$ equal to $finishes$? Explain your solution.

Task 5 – STRIPS

Consider $< \mathcal{S}, \mathcal{O}, \mathcal{I}, \mathcal{G} >$ with

$$\begin{aligned} \mathcal{S} &= \{X, Y, Z, G\} \\ \mathcal{O} &= \{A, B, C, D\} \\ \mathcal{I} &= \{X\} \\ \mathcal{G} &= \{G\} \end{aligned}$$

where the actions A, B, C, D are given as

$$\begin{array}{lll} A & \text{pre} : \neg Y & \text{post} : \neg X \\ B & \text{pre} : \neg X & \text{post} : X, Y \\ C & \text{pre} : X, Y & \text{post} : \neg Y, Z \\ D & \text{pre} : X, Y, Z & \text{post} : G \end{array}$$

and the plan π, given as

$$\pi = < A, B, C, B, D >$$

a) Execute π as far as possible, and give the set of predicates active after each step of your execution. If π cannot get executed completely, state the reason why the execution failed.

b) Derive a plan π' from π, which solves the planning task. You may only add one single action.

Task 6 – A*-Algorithm

Sadly, we weren't able to reconstruct the actual graph, its costs, and the actual heuristic function. You were given a graph with labeled nodes, and costs assigned to each edge. A text described one note as starting point, and another node as target node. Additionally, a heuristic function h was given as a table (one value for each node in the graph, excluding the target node).

a) Execute the A*-Algorithm. While executing, annotate the graph with all f and g values. Mark each node with the number of the iteration in which it was expanded.

   Draw the resulting tree.

b) What property of the heuristic function is required for A^* to yield a optimal result? What happens if this property is violated?

Although we weren't able to completely reproduce this task, we'd like to note an (in our opinion) important fact about the actual graph that was used in the exam:

One node's g value was updated while applying the algorithm. When drawing the tree while applying the algorithm, this lead to the tree no longer be a tree (as there are two edges towards the updated edge). To preserve the tree, the old edge has to be removed, or the solution wouldn't get accepted.

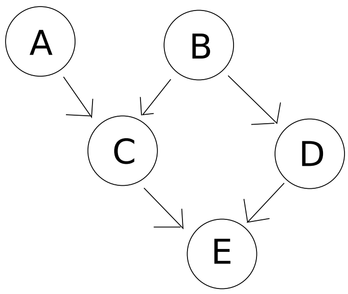
Task 7 – Bayesian Networks

Tables with conditional probabilities were given. **(Which sadly couldn't be reconstructed)**

a) Draw the corresponding Bayesian-Network.

b) Calculate P(D).

c) Give a definition of the Markov Blanked and indicate the Markov Blanket of D in the following network.



Task 8 – Satisfiability

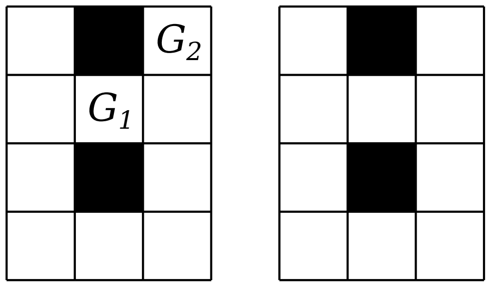
a) Apply the Resolution method to something given (**which is obviously missing in this reconstruction**).

b) Apply the DPLL algorithm on a given Formula (**which is obviously missing in this reconstruction**). **Note: There was one backtrack in the solution.**

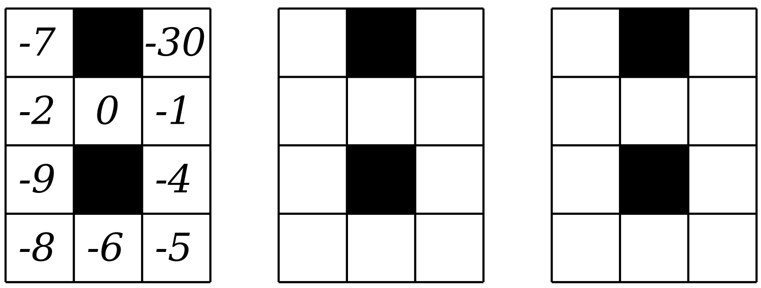
Task 9 – Grid World

Consider the grid world, where only horizontal and vertical movements by one position per step are allowed. Positions marked black are inaccessible.

a) Unfortunately, we couldn't remember this task exactly. The rewards of the end positions G_1 and G_2 were given. One $G_?$ had a bad reward and should have been avoided. There must have been further information about the rewarding system (e.g. discount) and probabilities to success or fail, when making a move.
One task was to calculate the *utilites or rewards* of the empty cells on the left. The other task was to fill in the *optimal policy* (obtained by human intuition) on the right.



b) Apply two steps of *value iteration* on the following grid with given (sub-optimal) utilities. Fill in the improved utilities after each step.



Gedankenaufschrieb der KI Nachklausur SoSe 2014

1. α-β Pruning

In nicht beschrifteten Tabellen α und β eintragen. In das jeweilige Δ den v-Wert

2. Entscheidungsbaum

Nr	Actor	Genre	Sell-out
1	Mell Gibson	Thriller	yes
2	Tom Cruise	Action	yes
3	Mell Gibson	Thriller	yes
4	Angelina Jolie	Romance	no
5	Mell Gibson	Action	yes
6	Tom Cruise	Romance	no
7	Mell Gibson	Action	ys
8	Angelina Jolie	Thriller	no
9	Angelina Jolie	Romance	no
10	Mell Gibson	Action	yes

(a) Berechne für *Genre* den R-Wert um zu bestimmen, wie viel es den Gain für Sell-out reduziert.

(b) Gebe einen Entscheidungsbaum an. Bei Actor bin ich mir mit der Verteilung nicht mehr 100% sicher. Jedoch hat sie für das Genre Thriller die Mengen geteilt.

3. Suchalgorithmen

(a) Ein Graph gegeben, an den Kanten die g-Werte. In einer Tabelle die h-Werte. Man sollte A* durchführen. F, h und g-Werte an die Knoten. Und die Reihenfolge der Expandierung an Knoten durchnummerieren. Knoten sollten nicht nochmals rückwärts expandiert werden. (Wenn von A -> B und nun B expandiert, dann ist A nicht nochmals Kindsknoten)

(b) Unter welchen Bedingungen ist Breitensuche vollständig? Unter welchen Bedingungen ist Breitensuche optimal?

4. CSP

Gegeben war die Belegung α wie sie in der unten stehenden Tabelle zu sehen ist.

	1	2	3	4	5
v1		X			
v2					
v3					
v4					
v5					

(a) Führe Forwardchecking für Belegung α aus

	v1	v2	v3	v4	v5
	{2}	{1, 2, 3, 4, 5}	{1, 2, 3, 4, 5}	{1, 2, 3, 4, 5}	{1, 2, 3, 4, 5}
Fwc					

(b) Führe ARC-Consistency für Belegung α aus

	v1	v2	v3	v4	v5
ACv1	{2}	{1, 2, 3, 4, 5}	{1, 2, 3, 4, 5}	{1, 2, 3, 4, 5}	{1, 2, 3, 4, 5}
ACv2	{2}		{1, 2, 3, 4, 5}	{1, 2, 3, 4, 5}	{1, 2, 3, 4, 5}
ACv3	{2}			{1, 2, 3, 4, 5}	{1, 2, 3, 4, 5}
ACv4	{2}				{1, 2, 3, 4, 5}
ACv5	{2}				
	{2}				
	{2}				
	{2}				
	{2}				

5. Kann ich mich leider nicht mehr erinnern.

6. Byes' Netzwerk

Man hatte A, B, C, D, E als Knoten und ihre bedingte Abhängigkeiten in Wahrheitstabellen. An die Werte kann ich mich nicht mehr erinnern kann.

D	C	P(E| C, B)
t	t	
t	f	
f	t	
f	f	

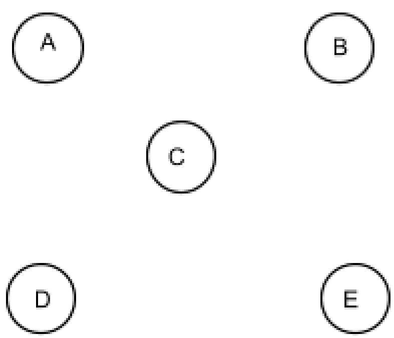
D	P(A| D)
t	
f	

C	P(C)
t	0.2

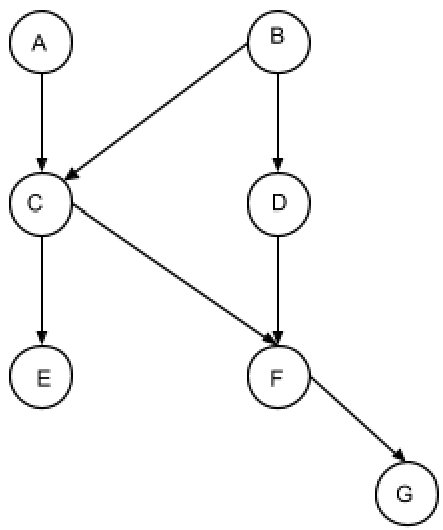
D	C	P(B| D, C)
t	t	
t	f	
f	t	
f	f	

C	P(D| C)
t	
f	

(a) Zeichne das Baysche Netz anhand der gegebenen Tabellen ein.



(b) Berechne Joint Probability von P(A, ¬B, C, D, E).



(c) Bedingt Unabhängigkeit ja, nein. Bin mir nicht 100% sicher, jedoch sah Graph so ähnlich aus.
Ind(F, B | D)
Ind(E, F | C)
Ind(F, A | C, B, G)
Ind(C, D | F, B)

7. Kann ich mich leider nicht mehr erinnern.

8. Unifizierung
Tabelle war gegeben, die man ausfüllen sollte. Ich erinnere mich nicht mehr 100% an T. Es musste mind. 4 mal substituiert werden.

	T{ }	S { }	D { }	v	t
0	{R(x, y, f(A, y)), R(A, g(x), f(x, g(x)))}	{ }			

9. Logik 2. Stufe

(a) DPLL. Achtung hier war angegeben, dass wenn Splitting-Rule, dann der Buchstabe, der im Alphabet zu erst kommt, gewählt und zu erst auf TRUE gesetzt werden soll.

(b) Formel in Skolem Normalform überführen

Department of Computer Science

Exam:	**Foundations of Artificial Intelligence - Mock-Exam**
Duration:	90 minutes
Permitted exam aids:	Indelible pen (e. g. ball pen, *no* pencil!), nothing else.

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.

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.

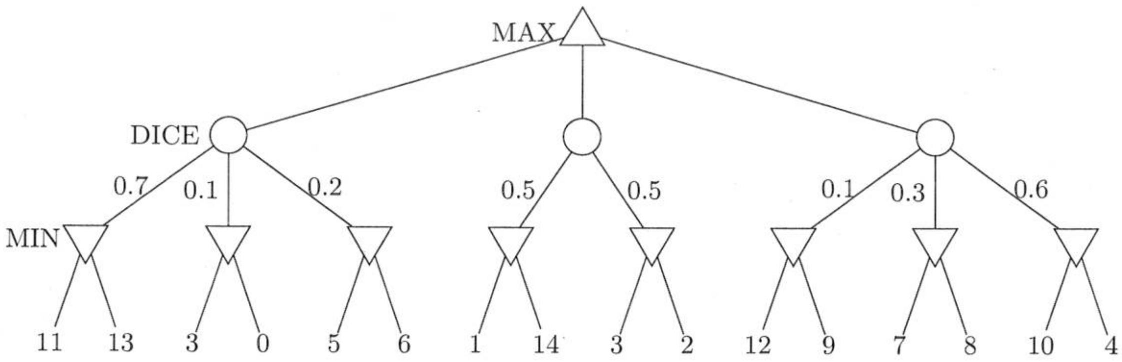
Question	Score	Reached score	Comments	Initials
1	6			
2	15			
3	15			
4	6			
5	13			
6	15			
7	20			
Sum	90			

Name and matriculation number:

Question 1 (6 points) BOARD GAMES / BRETTSPIELE

Consider the following game tree for a two-person game with chance nodes:

Betrachten Sie den folgenden Spielbaum für ein 2-Personen-Spiel mit Zufallsknoten:



Determine the utility of all nodes in the game tree.

Bestimmen Sie die Bewertungen der Knoten des Spielbaumes.

Name and matriculation number:

Question 2 (8+7 points) DECISION TREES / ENTSCHEIDUNGSBÄUME

No *Nr.*	LeadingActor *Hauptdarsteller*	Genre *Genre*	SoldOut? *ausverkauft?*
1	Matt Damon	Thriller / *Krimi*	yes / *ja*
2	Tom Cruise	Action / *Action*	yes / *ja*
3	Matt Damon	Action / *Action*	yes / *ja*
4	Angelina Jolie	Romance / *Liebesfilm*	no / *nein*
5	Matt Damon	Romance / *Liebesfilm*	no / *nein*
6	Angelina Jolie	Thriller / *Krimi*	no / *nein*
7	Angelina Jolie	Action / *Action*	yes / *yes*
8	Tom Cruise	Thriller / *Krimi*	no / *nein*
9	Tom Cruise	Romance / *Liebesfilm*	no / *nein*
10	Matt Damon	Action / *Action*	yes / *yes*

Consider the above record of movie screenings a cinema owner has produced.

Betrachten Sie die von einem Kinobetreiber gesammelten Daten bisheriger Vorführungen.

(a) We consider the attribute **Genre** as candidate for the first node in a decision tree used to classify whether a movie screening was sold out or not. How much would this attribute reduce the uncertainty about the classification? Justify your answer with detailed calculations. You can make use of the following values:

Wir betrachten das Attribut ***Genre*** *als Kandidaten für den ersten Knoten eines Entscheidungsbaums der klassifizieren soll, ob eine Vorstellung ausverkauft war oder nicht. Um wieviel würde das Attribut die Unsicherheit der Klassifikation reduzieren? Rechtfertigen Sie Ihre Antwort mit detaillierten Berechnungen. Sie können folgende Werte benutzen:*

$\log_2(\frac{1}{3}) \approx -\frac{3}{2}$, $\log_2(\frac{2}{3}) \approx -\frac{1}{2}$, $\log_2(\frac{1}{2}) = -1$, $\log_2(1) = 0$, $0 \cdot log_2(0) = 0$.

Name and matriculation number:

(b) Produce a decision tree, which, by means of the given attributes, correctly classifies whether the given examples have been sold out or not.

Geben Sie einen Entscheidungsbaum an, der für die gegebenen Beispiele anhand der Attribute korrekt klassifiziert, ob die jeweilige Vorstellung ausverkauft war oder nicht.

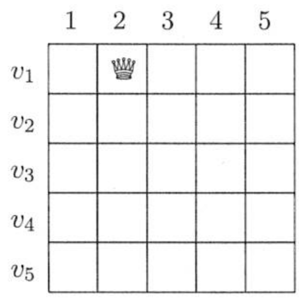
(additional room for answer to Question 2)

Name and matriculation number:

Question 3 (4+11 points) CONSTRAINT SATISFACTION PROBLEMS / CSPs

Consider the 5-queens problem, where 5 pieces have to be placed on a size 5×5 board in such a way that no two queens are on the same horizontal, vertical, or diagonal line. The Variables $v_i \in V = \{v_1 \dots v_5\}$ indicate the position of the i-th queen with domain $dom(v_i) = 1, \dots, 5$ for all variables $v_i \in V$. Consider now state $\alpha = \{v_1 \mapsto 2\}$.

Betrachten Sie das 5-Damen Problem, bei dem 5 Spielfiguren auf einem 5×5 Felder großen Brett so platziert werden sollen, dass sich keine zwei Damen auf der selben horizontalen, vertikalen oder diagonalen Line befinden. Die Variablen $v_i \in V = \{v_1 \dots v_5\}$ geben die Position der i-ten Dame an und haben einen Wertebereich $dom(v_i) = 1, \dots, 5$ für alle Variablen $v_i \in V$. Betrachten Sie nun den Zustand $\alpha = \{v_1 \mapsto 2\}$.



(a) Apply forward-checking in α. Fill the table below with the domains of the missing variables.

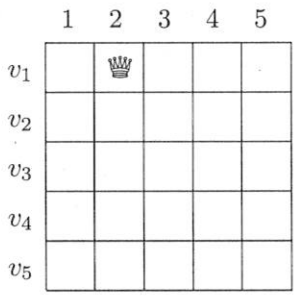
Führen Sie Forward-Checking in α aus. Tragen Sie die Domänen der fehlenden Variablen in die Tabelle ein.

	v_1	v_2	v_3	v_4	v_5
init	$\{2\}$	$\{1,2,3,4,5\}$	$\{1,2,3,4,5\}$	$\{1,2,3,4,5\}$	$\{1,2,3,4,5\}$
FC	$\{2\}$				

Name and matriculation number:

(b) Enforce arc consistency in α. Specify the domains of the variables after applying arc consistency to all constraints belonging to one variable. (E.g. in the first row you should depict the domain of v_2 after enforcing arc consistency for all constraints containing v_2.)

Erzeugen Sie Kantenkonsistenz in α. Geben Sie hierzu die Wertebereiche der Variablen nach dem Erzeugen der Kantenkonsistenz für alle Constraints an, in welchen die aktuell betrachtete Variable beteiligt ist. (Z.B. in der ersten Reihe ist die neue Domäne von v_2 anzugeben, nachdem Kantenkonsistenz für alle Constraints an denen v_2 beteiligt ist, erzeugt wurde.)



Additional sketch of the state α so you don't have to flip pages.

Weitere Skizze des Zustands α damit Sie nicht umblättern müssen.

	v_1	v_2	v_3	v_4	v_5
init	$\{2\}$	$\{1,2,3,4,5\}$	$\{1,2,3,4,5\}$	$\{1,2,3,4,5\}$	$\{1,2,3,4,5\}$
AC - v_2	$\{2\}$		$\{1,2,3,4,5\}$	$\{1,2,3,4,5\}$	$\{1,2,3,4,5\}$
AC - v_3	$\{2\}$			$\{1,2,3,4,5\}$	$\{1,2,3,4,5\}$
AC - v_4	$\{2\}$				$\{1,2,3,4,5\}$
AC - v_5	$\{2\}$				
	$\{2\}$				
	$\{2\}$				
	$\{2\}$				
	$\{2\}$				

Question 4 (4 + 2 **points**) PLANNING / HANDLUNGSPLANUNG

Consider the following STRIPS-Task $\Pi = \langle \mathcal{S}, O, I, G \rangle$:

Betrachten Sie folgenden STRIPS-Task $\Pi = \langle \mathcal{S}, O, I, G \rangle$*:*

- $\mathcal{S}$: {X, Y, Z, G}
- O: {A, B, C, D} where

$$\begin{aligned} A:&\ pre(A) = \{\neg Y\}, & eff(A) = \{\neg X\}\\ B:&\ pre(B) = \{\neg X\}, & eff(B) = \{X, Y\}\\ C:&\ pre(C) = \{Y\}, & eff(C) = \{\neg Y, Z\}\\ D:&\ pre(D) = \{X, Y, Z\}, & eff(D) = \{G\} \end{aligned}$$

- I: {X}
- G: {G}

(a) Derive the states from executing the plan $\pi = \langle A, B, C, B, D \rangle$ in $I := s_0$, as long as actions can be legally applied.

Leiten Sie die Zustände her, welche bei Ausführung des Plans $\pi = \langle A, B, C, B, D \rangle$ *entstehen, solange die Aktionen legal angewendet werden.*

$s_0 = \{X\}$

$s_1 = App(s_0, A) =$

$s_2 = App(s_1, B) =$

$s_3 = App(s_2, C) =$

$s_4 = App(s_3, B) =$

$s_5 = App(s_4, D) =$

Name and matriculation number: ______________________________

(b) Is the Plan in (a) applicable? If not, can it be fixed by adding an action to the plan? State a plan which solves the problem.

Ist der Plan in (a) anwendbar? Falls nicht, kann er durch Hinzufügen einer Aktion repariert werden? Geben Sie einen Plan an, der das Problem löst.

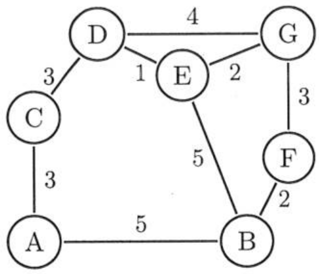
(additional room for answer to Question 4)

Name and matriculation number: ______________________________

Question 5 (10 + 3 points) A* SEARCH / A*SUCHE

(a) Draw the search tree generated by the A* algorithm when searching for a shortest path from Node **A** to Node **G**, using the heuristic distance to node **G** given in the table. Indicate in which order the nodes are expanded and annotate each node with its f, g, and h value. Edges back to parent nodes do not have to be generated. Mark the goal node.

Zeichnen Sie den Suchbaum, der vom A-Algorithmus für die Suche eines kürzesten Weges von Knoten **A** zu Knoten **G** erzeugt wird. Verwenden Sie hierzu den heuristischen Abstand zu Knoten **G** welcher in der Tabelle angegeben ist. Geben Sie an, in welcher Reihenfolge die Knoten expandiert werden, und annotieren Sie jeden Knoten mit seinen f-, g-, und h-Werten. Kanten noten zurück zu Elternknoten müssen nicht generiert werden. Markieren sie den Zielknoten.*



	$h(x)$
A	7
B	3
C	6
D	3
E	2
F	3
G	0

(b) Is breadth-first search complete? Under which condition does it find the optimal solution?

Ist Breitensuche vollständig? Unter welchen Bedingungen findet die Breitensuche die optimale Lösung?

(additional room for answer to Question 5)

Name and matriculation number:

Question 6 (3.5 + 7.5 + 4 points) BAYES / BAYES

Consider the following probability tables (all variables are binary, thus they can be either true or false)

Betrachen Sie die folgenden Wahrscheinlichkeitstafeln (alle Variablen sind binär und können somit entweder wahr oder falsch sein)

B	D	$\mathbf{P}(A \mid B, D)$
T	T	0.6
T	F	0.3
F	T	0.2
F	F	0.7

C	$\mathbf{P}(B \mid C)$
T	0.7
F	0.2

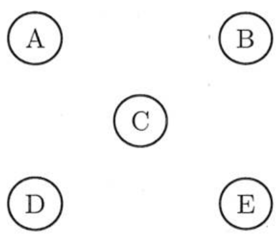
$\mathbf{P}(C)$
0.2

B	C	$\mathbf{P}(D \mid B, C)$
T	T	0.2
T	F	0.7
F	T	0.5
F	F	0.4

B	C	$\mathbf{P}(E \mid B, C)$
T	T	0.3
T	F	0.4
F	T	0.1
F	F	0.7

(a) Draw the corresponding Bayesian network. Use the already drawn nodes and add the corresponding edges:

Zeichnen Sie das zugehörige Bayes'sche Netz. Verwenden Sie hierzu die vorgegebenen Knoten und ergänzen die fehlenden Kanten:



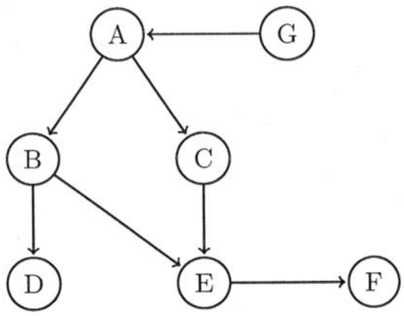
(b) Compute the probability $P(A, \neg B, C, E)$.

Berechnen Sie die Wahrscheinlichkeit $P(A, \neg B, C, E)$.

Name and matriculation number:

(c) Determine, which of the following independence statements follow from the structure of the Bayesian network given below. $\mathrm{Ind}(U, V \mid W)$ denotes that U is independent of V given W:

Bestimmen Sie, welche der folgenden Unabhängigkeiten aus der Struktur des untenstehenden Bayes'schen Netzes folgen. Hierbei steht $\mathrm{Ind}(U, V \mid W)$ *dafür, dass* U *unabhängig von* V *gegeben* W *ist:*



- $\mathrm{Ind}(B, C \mid A)$
- $\mathrm{Ind}(C, G \mid A)$
- $\mathrm{Ind}(E, A \mid C)$
- $\mathrm{Ind}(E, A \mid B, C, F)$

Name and matriculation number:

Question 7 (6 + 8 + 6 **points**) LOGIC / LOGIK

(a) Apply the unification algorithme to the following set of literals: (As usual, we use $\{P\}$ for predicate symbols, $\{f, g\}$ for function symbols, $\{x, y, z\}$ for variables and $\{A\}$ for constants.)

Wenden Sie den Unifikationsalgorithmus auf die folgende Literalmenge an: (Wie üblich verwenden wir $\{P\}$ für Prädikatensymbole, $\{f, g\}$ für Funktionssymbole, $\{x, y, z\}$ für Variablen und $\{A\}$ für Konstanten.)

$$\{P(x, y, g(A, f(z))), P(g(z, y), y, g(z, y))\}$$

In each step k, give the the values of the set of Terms T_k, the substitiution s_k, the disagreement set D_k replaced variable v_k and the replacement term t_k.

Geben Sie für jeden Schritt k die Werte für die Menge von Termen T_k, die Substitiution s_k, die "Disagreement" Menge D_k die ersetze Variable v_k und der Ersetzungsterm t_k an.

k	T_k	s_k	D_k	v_k	t_k
0	$\{P(x, y, g(A, f(z))), P(g(z, y), y, g(z, y))\}$	$\emptyset$			
1					
2					
3					

Name and matriculation number:

(b) Use the Davis-Putnam-Logemann-Loveland (DPLL) Procedure to find a satisfying assignment for the formula ϕ. Write out all steps of the algorithm. If you have to apply a splitting rule, split on variables in alphabetical order, trying *true* first, then *false*. Indicate the satisfying assignment.

Verwenden Sie die Davis-Putnam-Logemann-Loveland(DPLL)-Prozedur, um eine erfüllende Belegung der Formel ϕ zu finden. Schreiben Sie alle Schritte des Algorithmus auf. Wenn Sie eine Verzweiguns-Regel anwenden müssen, wählen Sie die Verzweigungs-Variablen in alphabetischer Reihenfolge aus, und wählen Sie zuerst wahr, *dann* falsch. *Geben Sie die erfüllende Belegung an.*

$$\phi = (\neg A \vee \neg C \vee D) \wedge (A \vee \neg C) \wedge (B \vee C \vee D) \wedge (A \vee D) \wedge (\neg A \vee \neg B) \wedge (B \vee \neg D)$$

(c) Convert the following formula to Skolem normal form.

Wandeln Sie die folgende Formel in Skolem-Normalform um.

$$\neg \forall x \exists y P(x, f(y)) \wedge \forall z \exists x \big(Q(z) \vee R(z, g(x))\big)$$

(additional room for answer to Question 7)

Name and matriculation number: *FIRSTNAME LASTNAME, MATRICULATIONNUMBER*

Additional room for notes. If you write any solutions here, please point it out at the question.
Zusätzlicher Platz für Notizen. Falls Sie Lösungen hier aufschreiben, weisen Sie bitte bei der Aufgabe darauf hin.