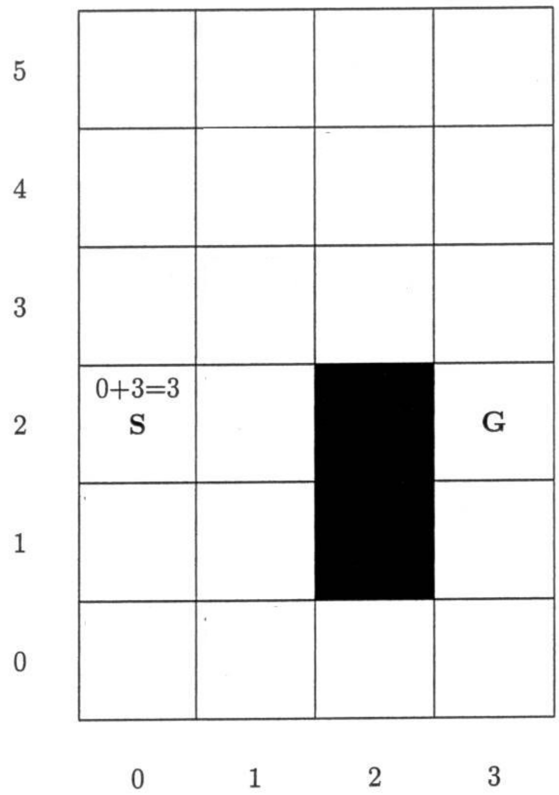
Name:

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.

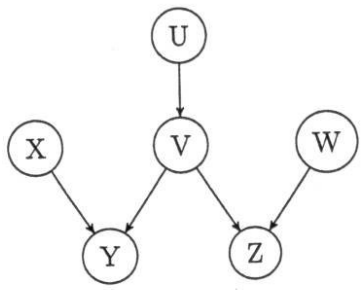
Name:

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) FIRST-ORDER LOGIC

(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