**NANYANG TECHNOLOGICAL UNIVERSITY**

**SEMESTER 2 EXAMINATION 2020-2021**

**CZ3005 – ARTIFICIAL INTELLIGENCE**

Apr/May 2021 Time Allowed: 2 hours

**INSTRUCTIONS**

1. This paper contains 4 questions and comprises 7 pages.

2. Answer **ALL** questions.

3. This is a closed-book examination.

4. Each question carries equal marks.

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1. (a) Are the following statements True or False?

   (i) No matter how skewed a search tree is, Uniform Cost Search is always optimal.

   (ii) A* search is always faster than any uninformed search.

   (iii) Most constraining heuristics may cause more dead ends than the least constraining heuristic in Constraint Search Problem.

   (iv) Any game must have a Nash equilibrium.

   (v) There is a pure strategy for the game shown in Figure Q1(a).

(5 marks)

Note: Question No. 1 continues on Page 2

| | | Player B: Action 1 | Player B: Action 2 |
|---|---|---|---|
| Player A | Action 1 | 1 -1 | -1 1 |
| | Action 2 | -1 1 | 1 1 |

**Figure Q1(a)**

(b) Figure Q1(b) shows a complete game tree with all the leaf terminal rewards. Suppose you are the "black" player (starting from node A). Please apply the Minimax algorithm to determine your best move. Show all the utility values for the nodes.

(13 marks)

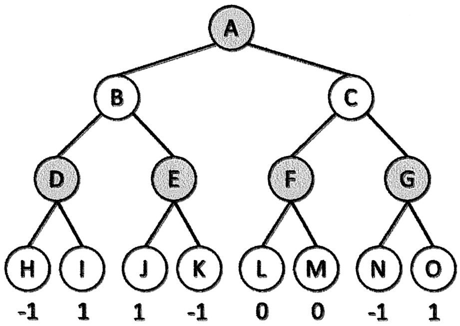


**Figure Q1(b)**

(c) A noob player (who is bad at the game) is always annoying when he/she comments your play in the middle of the game. Please use the tree in Figure Q1(b) to illustrate how the noob player affects your play negatively.

(7 marks)

2. We define a Markov Decision Process (MDP) for the 4-grid world with a transition model as shown in Figure Q2. It has 4 states {**1, 2, 3, 4**} as marked in each grid. State 1 is the start state and state 4 is the goal state. The agent has four actions: Up (**U**), Down (**D**), Left (**L**), and Right (**R**). If the action causes the agent to clash on the wall (solid border), the agent stays in the same grid. For example, $P(s' = 1 | s = 1, a = L) = 0.8 + 0.1 = 0.9$ and $P(s' = 1 | s = 1, a = D) = 0.1 + 0.1 = 0.2$. Any non-goal state receives **0** reward, that is, $r(s, a, s' \neq 4) = 0$, and the goal state receives **1** reward, that is, $r(s, a, s' = 4) = 1$. Being in the goal state means the end of the task, that is, $P(s' | s = 4, a) = 0$.

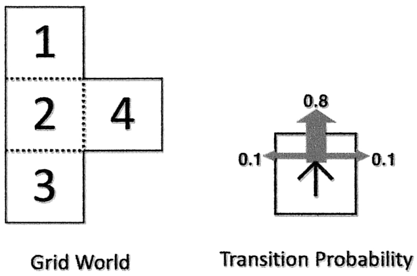


**Figure Q2**

(a) The Q and V tables are initialized in Table 2(a). Update them after ONE round of Value Iteration with reward discount $\gamma = 0.8$. Please consider the asynchronized update of the order: state 1-2-3-4; for example, you may use the updated V(1) just now when you are updating V(2).

(15 marks)

**Table 2(a)**

| | U | D | L | R |
|---|---|---|---|---|
| 1 | 0 | 0 | 0 | 0 |
| 2 | 0 | 0 | 0 | 0 |
| 3 | 0 | 0 | 0 | 0 |
| 4 | 0 | 0 | 0 | 0 |

Q Table

| | |
|---|---|
| 1 | 0 |
| 2 | 0 |
| 3 | 0 |
| 4 | 0 |

V Table

(b) Based on the observation from your updated table, what is the optimal policy for this grid world MDP? You can use N.A. for the policy at the goal state.

(3 marks)

Note: Question No. 2 continues on Page 4

(c) Now consider the case when the transition model is unknown. You may want to use Temporal Difference (TD) learning for the values. Suppose we have an episode sample: $1 \rightarrow 1 \rightarrow 2 \rightarrow 3 \rightarrow 2 \rightarrow 4$. Please show the V table (initialized as 0) after the asynchronized TD update of the order: state 1-2-3-4, with learning rate $\alpha = 0.1$ and reward discount $\gamma = 0.8$. (***Hint***: i) TD V-Learning is similar to TD Q-Learning. ii) $V(s) = \max_a Q(s, a)$).

(4 marks)

(d) Due to the underlying transition model, given a policy, one may easily sample many episodes without the desired $2 \rightarrow 4$. How do you discourage such sampling?

(3 marks)

3. (a) State whether the following statements are True (T) or False (F).

(i) Knowledge representation is a part of the logic used to convert natural sentences into computer-tractable form.

(ii) Sound inference only generates entailed sentences.

(iii) Sound inference does not have to be complete.

(iv) Logical constant is a valid sentence.

(v) $A \lor B$ is a satisfiable sentence where A, B are propositional symbols.

(5 marks)

(b) Given the following logical equivalence relationship:

$$(A \Rightarrow \neg B \lor C) \Leftrightarrow (A \land B \Rightarrow C)$$

where A, B, C are propositional symbols.

(i) Use rewrite rules to determine the validity of the statement.

(5 marks)

Note: Question No. 3 continues on Page 5.

(ii) Use the truth table to determine whether the two propositions are equivalent.

(5 marks)

(c) Provide a correct and concise translation in plain English for each of the sentences below.

(i) $\forall x, \exists y\ Student(x) \wedge Course(y) \Rightarrow Take(x,y)$

(2.5 marks)

(ii) $\neg(\forall x,\ Student(x) \Rightarrow Smart(x))$

(2.5 marks)

(d) Given the following first order logic sentences:

$\forall x,\ Student(x) \wedge Hardworking(x) \wedge Smart(x) \Rightarrow Highmark(x)$
$\forall x,\ Study(x) \Rightarrow Hardworking(x)$
$\forall x,\ Clever(x) \Rightarrow Smart(x)$
$Study(Andy)$
$Clever(Andy)$
$Student(Andy)$

Use Modus Ponens to prove that "Andy scores highmark".

(5 marks)

4. (a) Determine whether the following statements are True (T) or False (F).

(i) A fuzzy set **A** is a subset of the universe of discourse **X**, so that $x \in \mathbf{A}$ if and only if $\mu_A(x)>0$, where $\mu_A$ is the membership function of the form $\mu_A:\mathbf{X} \rightarrow [0,1]$ of the fuzzy set **A**.

(ii) Fuzzy pseudo-partition is akin to soft clustering, even if there are some examples that do not belong to any cluster to any degree.

(iii) Defuzzification is used as the last stage of the Mamdani fuzzy inference to determine the most probable conclusion.

Note: Question No. 4 continues on Page 6

(iv) Let **k** be the number of fuzzy variables in the system and let **n** be the number of linguistic labels (features) that can be applied to each variable. If **k** is bounded and fixed, then the size of the ANFIS network scales polynomially.

(v) The order of Takagi-Sugeno-Kang models refers to the number of variables in the rule conditions (antecedents).

(5 marks)

(b) A Fuzzy Constraint Satisfactions Problem (FCSP) is composed of: a set of variables $\mathbf{V}=\{V_1,\ldots,V_n\}$ over the domain (of discourse) $\mathbf{X}$; a fuzzy pseudo-partition $\{\mu_a\}_{a\in A}$, where $\mathbf{A}$ is a set of linguistic labels (features); and a set of constraints $\mathbf{C}$ where each constraint $c\in\mathbf{C}$ is a Mamdani inference rule of the form

IF $V_{in}$ is **a** THEN $V_{out}$ is **not a**

where $V_{in},V_{out}\in\mathbf{V}$ are two variables and $a\in\mathbf{A}$ is a linguistic label. When the rule is applied to a specific value of $V_{in}$=x, we denote the resultant membership function by $\mu^c[x]$.

We assume that all membership functions $\mu_a$ are fuzzy convex, and define a solution to an FCSP as a substitution $\sigma:\mathbf{V}\rightarrow\mathbf{X}$ so that the following equation holds for all $V_i\in\mathbf{V}$:

$$\sigma(V_i) = \mathbf{D}\Big(\big(\textstyle\sum_{a\in A}\mu_a\big)\prod_{c:V_{in}=V_i}\mu^c[\sigma(V_{in})]\Big)$$

where **D** is a maximum-based defuzzification rule that returns NAN if its argument is a constant zero function.

(i) Consider the ISL logo coloring problem (see Figure Q4), where neighboring elements of the logo need to be colored into distinct colors: red, blue, and green. Assume that the palette of colors is actually continuous and that “red”, “blue” and “green” are not specific colors but linguistic labels. Formulate the ISL logo coloring as an FCSP. Describe how the membership functions of “red”, “blue” and “green” can be obtained.

(8 marks)

Note: Question No. 4 continues on Page 7

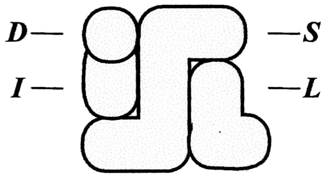


**Figure Q4**

(ii) Given an FCSP $\langle \mathbf{V},\mathbf{X},\mathbf{A},\{\mu_a\}_{a\in \mathbf{A}},\mathbf{C},\mathbf{D}\rangle$, describe how DFS with Forward Checking can be used to solve it. In particular, describe in detail: how the associated search space is defined; how the next state is generated during exploration; and how Forward Checking should be formally performed while running DFS in FCSP.

**Hint:** notice that DFS is designed to work with discrete spaces, while the domain of discourse **X** is not necessarily discrete.

(12 marks)

END OF PAPER

**CZ3005 ARTIFICIAL INTELLIGENCE**

Please read the following instructions carefully:

1. **Please do not turn over the question paper until you are told to do so. Disciplinary action may be taken against you if you do so.**

2. You are not allowed to leave the examination hall unless accompanied by an invigilator. You may raise your hand if you need to communicate with the invigilator.

3. Please write your Matriculation Number on the front of the answer book.

4. Please indicate clearly in the answer book (at the appropriate place) if you are continuing the answer to a question elsewhere in the book.