NATIONAL UNIVERSITY OF SINGAPORE

SCHOOL OF COMPUTING

FINAL ASSESSMENT FOR
Semester 3 AY2019/20

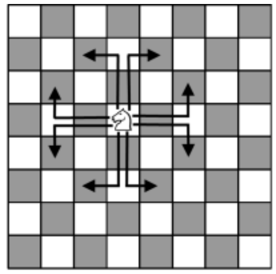
CS3243: INTRODUCTION TO ARTIFICIAL INTELLIGENCE

June 19, 2020 Time Allowed: 2 Hours

INSTRUCTIONS TO CANDIDATES

1. This assessment paper contains **21** questions and comprises **12** printed pages, including this page.
2. Answer **ALL** questions as indicated.
3. This is a **CLOSED BOOK** assessment. Allowed materials: an NUS approved calculator and a single A4 page of your own notes.

1. In International Chess, the Knight piece is able to move as shown in the figure below.



Given a chessboard of arbitrary size, $n \times n$ (e.g., the chessboard in Figure 1 is an 8×8 board), let a Knight's Tour be defined as follows:

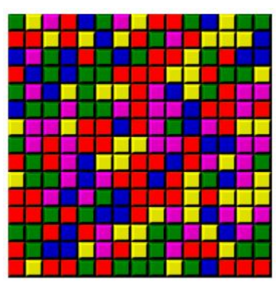
A knight is positioned at some starting position (ROW, COL), where $1 \leq$ ROW, COL $\leq n$ To complete the tour, it must visit every square on the board (i.e., every position (r, c) where $1 \leq r, c \leq n$) **exactly once**.

   (a) (**4 marks**) Model the Knight's Tour as an Uninformed Search Problem. Clearly define the states, actions, transition model, goal test and cost function.

   (b) (**2 marks**) Assuming that you could only choose between Breadth-first Search and Depth-first Search, pick one and explain why it is the better choice.

   (c) (**2 marks**) Would you consider using the Iterative-Deepening Search algorithm? Provide a rationale for your answer.

2. (**10 marks**) In the SameGame puzzle, a player is given a two-dimensional, rectangular, $n \times m$ grid of coloured squares. An example of such a grid is depicted in the figure below.



The grid is initially filled with $n \times m$ blocks with c different colours. The position of a grid/tile location is denoted (ROW, COL), where $1 \leq$ ROW $\leq n$ and $1 \leq$ COL $\leq m$. Further, let the position (1, 1) reference the top left corner of the grid.

Two tiles are directly adjacent if they are horizontal or vertical direct "neighbors". A tile (i, j) not on the edge of the board has neighbors $(i-1, j), (i+1, j), (i, j-1)$ and $(i, j+1)$, while a tile on the edge has only three of these neighbors, and a corner tile only two.

A group is defined as a set of two or more tiles of the same color, where it is possible to go from any of its tiles to any other by repeatedly visiting adjacent tiles; or briefly: a group is connected. A tile at the board that does not belong to any group is called a singleton.

A move consists of deleting a group (not a singleton), after which, vertical gravity and column shifting are applied: i.e., tiles that are above the deleted tiles fall down, and when any column is completely empty, the columns to the right of the empty column(s) shift to the left.

The goal is to empty the board, leaving no tiles. We call a puzzle solvable if the board can be emptied by doing a series of moves.

Let the states in this problem correspond to different tile compositions within the $n \times m$ grid, with the initial state corresponding to some initial placement of nm tiles, with each tile corresponding to one of the possible c colours (an example is given in the figure above).

An action is a legal removal of a group of tiles, with the transition model applying vertical gravity and column shifting. The goal state is an empty grid. The transition cost is 1, except for grids where no groups can be removed, in which case the cost of all actions is $\inf$.

Design an admissible heuristic for this puzzle game. Your heuristic may not be $h(s) = 0$ for all states s, the (abstract) optimal heuristic, or a linear combination/simple function thereof. You may assume that the tile layout in the initial grid is solvable i.e. there is some path to a goal state. **You must prove that your heuristic is admissible.**

3. (**3 marks**) Which of the following statements is true when all the terminal nodes of a game tree is multiplied by a constant k?

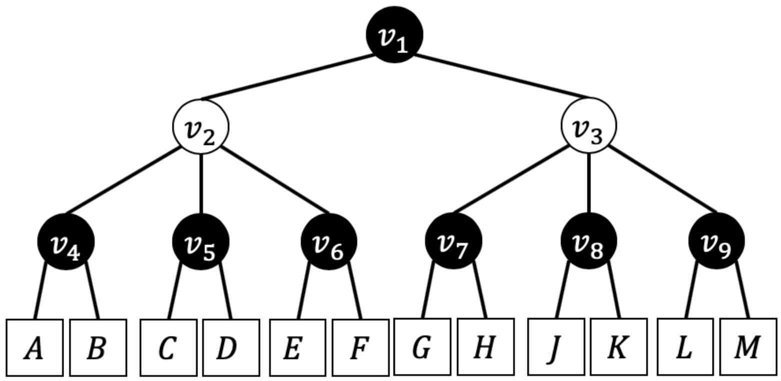
   (a) The minimax value at the root will be multiplied by k.

   (b) The minimax value at the root will be multiplied by $\frac{1}{k}$, only if $k \neq 0$.

   (c) The minimax value at the root will remain unchanged.

   (d) The minimax value at the root will change, but the change cannot be predicted with certainty.

4. (**4 marks**) Black nodes correspond to MAX player, white nodes corresponds to MIN player.



Given we run the alpha-beta pruning algorithm on the above tree from left to right, which of the following is true?

You may assume $A, B, C, D, E, F, G, H, J, K, L, M$ are positive integers.

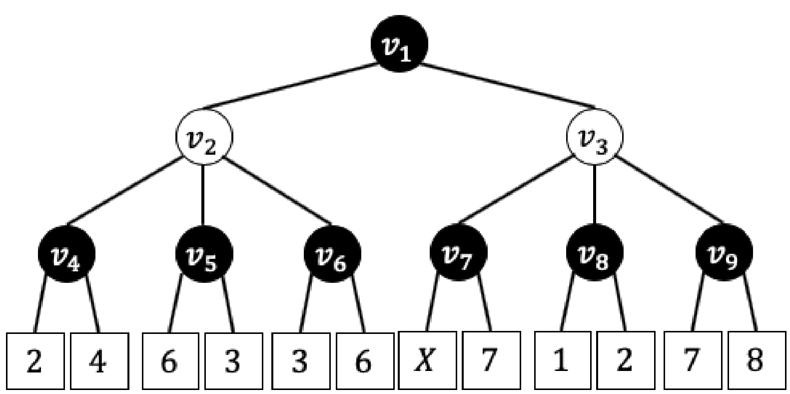
(a) There exist some set of values at the leaf nodes such that node B is not evaluated.

(b) There exist some set of values at the leaf nodes such that node F is not evaluated.

(c) There exist some set of values at the leaf nodes such that both nodes G and H are not evaluated.

(d) All nodes will be evaluated no matter what values are set at the leaf nodes.

5. Black nodes correspond to MAX player, white nodes corresponds to MIN player.



Given we run the alpha-beta pruning algorithm on the above tree from left to right, answer the questions that follow.

(a) (**3 marks**) What is the maximum integer value the leaf node labelled X can take on (assume the range $1 \leq X \leq 100$), such that minimal arcs are pruned?

(b) (**3 marks**) Let the leaf node labelled X take on the value you gave in (a), what is the minimax value at the root?

(c) (**3 marks**) Let the leaf node labelled X take on the value you gave in (a), how many leaf nodes are not evaluated?

6. Hanabi is a cooperative card game in which a set of players are aware of other players' cards but not their own, attempt to play a series of cards in a specific order to set off a simulated fireworks show.

In this question, we will model some elements of agents' initial hands and the playing field as constraints of a constraint satisfaction problem.

The Hanabi deck contains cards $c \in C$ from five possible suits S = {white, yellow, green, blue, and red} and numbers $N = \{1, 2, 3, 4, 5\}$, with quotas: three 1's, two each of 2's, 3's, and 4's, and one 5. The suit (also known as colour), s, of a card c can be evaluated using the function suit(c, s), which returns 1 if the card is of that suit, and 0 otherwise; and the number n of a card c can be evaluated using the function number(c, n), which returns 1 if the card is of that number, and 0 otherwise.

The playing field (to "build fireworks") consist of five (initially empty) piles of cards, each corresponding to a firework of a unique suit (each suit can only have exactly one pile). Denote the jth ($j = 1, 2, 3, 4$ or 5) card of a pile of suit s as `firework`(s, j). If there's no card at index j, then the function returns `NULL`; else, it returns a card. The goal of the players is to build as many firework piles as possible, while maintaining a valid firework display. We assume that when a player plays a card to a deck, it automatically fills the lowest empty index slot on the pile.

- `ValidFireworkDisplay` constraint: a valid firework display is where for every firework pile of suit s, the jth index of the firework pile of suit s contains the card c of suit s and number j, if `firework`(s, j) is non-empty.

To start the game, each player $i \in Q$ is dealt a hand $H_i = \{c_{i1}, c_{i2}, c_{i3}, c_{i4}, c_{i5}\}$ containing five cards, where $\{c_{i1}, c_{i2}, c_{i3}, c_{i4}, c_{i5}\} \in C$.

- `ValidHandSuit` constraint: all players' hands are valid (suit-wise) if for every player i, it respects the initial quantity of cards' suits in the deck (e.g. there should not be eleven red cards in a player's hand at any point in time, because only ten red cards exists in the deck!)
- `ValidHandNumber` constraint: all players' hands are valid (number-wise) if for every player i, it respects the initial quantity of cards' number in the deck (e.g. there should not be five 5's in a player's hand at any point in time, because only four 5 exists in the deck!)

In the questions that follow, you may only use standard mathematical operators $(+, -, \times, \div)$ and standard logical and set operators ($\forall, \exists, \vee, \wedge$ and $x \in X, X \subseteq Y$). You may use English, but it has to be unambiguously directly convertible into logical symbols.

(a) (**6 marks**) Write the `ValidFireworkDisplay` constraint. You may assume you are given the function `empty`(s, j), which returns `true` if there is no card at index j on the fireworks pile belonging to suit s. You may also use any given functions in the question.

(b) (**4 marks**) Write the `ValidHandSuit` constraint. You may assume you are given the function `quantity`(s), which returns the quantity of cards in the initial deck of cards of a particular suit s. You may also use any given functions in the question.

(c) (**4 marks**) Write the `ValidHandNumber` constraint. You may assume you are given the function `quantity`(n), which returns the quantity of cards in the initial deck of cards of a particular number n. You may also use any given functions in the question.

7. (**4 marks**) Which of the following is NOT true about the AC-3 algorithm? You may assume n is the number of variables, and each variable's domain has a maximum of d values.

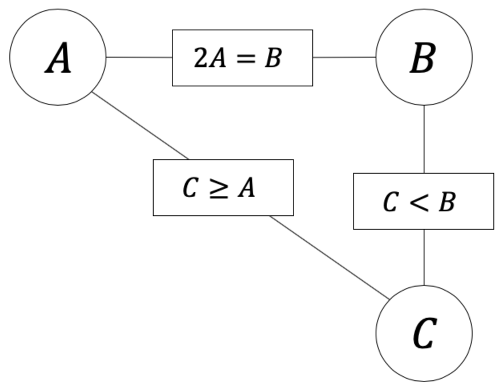
   (a) The AC-3 algorithm has an overall time complexity of $O(n^2d^3)$.

   (b) Checking the consistency of an arc takes $O(d)$ time.

   (c) The AC-3 algorithm can be used as a pre-processing step before running the backtracking algorithm for solving a CSP.

   (d) Whenever the domain of a variable A is reduced to maintain arc-consistency of (A, B), we do not add (B, A) to the queue.

8.



(a) (**8 marks**) Trace the AC-3 algorithm on the above constraint graph.
Initially, the domain of each variable is $D_A = D_B = D_C = \{1, 2, 3, 4\}$
Assume that the initial queue is: $(A, B), (B, A), (B, C), (C, B), (C, A), (A, C)$; where (A, B) is at the head of the queue.
Your answer should be of the form (just an example):
1. Domain of X reduced to $\{5, 6, 7, 8\}$, queue: $(Y, X), (Z, W)$
2. Domain of Y not reduced, queue: (Z, W)
...
where the variable, its domain, and the queue after this processing is clearly shown.
Note: if the arc is already in the queue, do NOT add it to the queue again.

(b) (**2 marks**) With reference to the previous question, provide a valid assignment of values to A, B, and C such that the constraints are satisfied, and $A + B + C$ is minimum.

9. (**2 marks**) Suppose you are given two algorithms for a reinforcement learning problem. Algorithm 1 returns the optimal state value function ($V^*(s)$) for the problem, while Algorithm 2 returns the optimal action value function ($Q^*(s, a)$). Assuming that you do not know the state transition probabilities for this problem, which algorithm would you prefer for designing an agent that can act optimally?

Briefly and clearly explain why you would choose one algorithm over the other.

10. (**4.5 marks**) Consider a 9×9 grid world, where an agent starts each episode in the center square. The goal of the agent is to reach the top-right square in the minimum number of steps (given the usual left/right/up/down moves). You decide to use the following reward formulation in order to find the optimal policy for this problem: the agent receives a reward of +5 on reaching the goal state, and no reward for any other transition.

    Suppose, you try three variants of the above reward formulation with the Q-learning algorithm: A_1 with $\gamma \in (0, 1)$, A_2 with $\gamma = 0$ and A_3 with $\gamma = 1$ (where γ denotes the discount factor). Select all of the following that can be concluded with certainty. If none of the options are correct, leave all options unselected.

    (a) A_1 learns the desired policy.

    (b) A_2 learns the desired policy.

    (c) A_3 learns the desired policy.

    Briefly and clearly explain why each option is correct/incorrect. Note that you need to justify for all cases.

11. (**4.5 marks**) In order to train an RL agent to play the game of golf using a simulator, you are given a reward function such that the agent receives a reward of +10 when the golf ball is hit into the hole, and -1 for all other transitions. An episode terminates when the ball is hit into the hole (goal state). Your want to reach the goal state in the minimum number of hits. In order to help the agent in learning, you decide to provide an additional reward of +5 whenever the ball is within a 0.5 metre radius of the hole. You also choose $\gamma = 1$. Assuming that you have access to an algorithm that can generate the optimal policy given the problem and the reward formulation, which of the following options is/are correct?

    (a) The additional reward helps the agent by nudging it towards a sub-goal, and thus, the agent will learn quicker to play golf.

    (b) The additional reward will slow down the learning process, although the agent will still be able to learn the desired policy for playing golf.

    (c) The additional reward may cause the agent to learn undesired behaviour.

    (d) Your conclusion changes when $\gamma < \frac{1}{2}$

    In the rationale box, briefly and clearly justify the option(s) you select. Note that you do not need to provide a rationale for the option(s) you do not select.

12. (**3 marks**) If $Q^\pi(s,a) > V^\pi(s)$, which of the following can be concluded with certainty?

    (a) a is the best action at state s

    (b) π may be an optimal policy

    (c) π is not an optimal policy

    (d) a is not the best action at state s

    Briefly and clearly justify the option(s) you select. Note that you do not need to provide a rationale for the option(s) you do not select.

13. (**3 marks**) True/False: Suppose, you add a constant $C > 1$ to all rewards in an **infinite horizon** MDP (where there are no terminating states). An optimal policy under the earlier MDP will remain an optimal policy under the transformed MDP.

    Briefly and clearly explain your choice.

14. (**3 marks**) True/False: Suppose, you add a constant $C > 1$ to all rewards in a **finite horizon** MDP (where there are terminating states). An optimal policy under the ealier MDP will remain an optimal policy under the transformed MDP.

    Briefly and clearly explain your choice.

15. (**2 marks**) True/False: The knowledge base of an agent cannot change.

    Justify your answer.

16. (**2 marks**) Consider the following knowledge base:
    "All firetrucks are red"
    "All firetrucks are cars"
    "All cars have four wheels"

An inference algorithm that gets the sentence ”A ferrari is a red car” and infers ”A ferrari is a firetruck” cannot be:

(a) complete

(b) sound

(c) both of the above

Justify your answer.

17. (**2 marks**) Consider the following knowledge base:
“All firetrucks are red”
“All firetrucks are cars”
“All cars have four wheels”

Given the knowledge base, which of the properties would guarantee that an algorithm can infer that ferraris have four wheels from the fact that they are red cars:

(a) completeness

(b) soundness

(c) both of the above need to be combined

Justify your answer.

18. (**2 marks**) Choose which of the following is an example (factually correct) of entailment:

(a) All birds are animals

(b) Most birds can fly

(c) All flying animals are birds

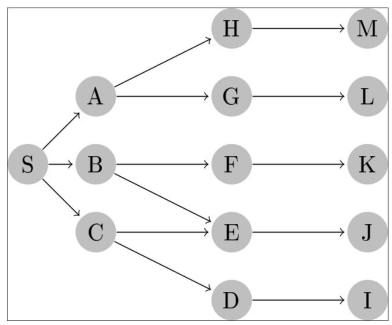
(d) Insects and birds have wings

Justify your answer.

19. (**3 marks**) True/False: "Two agents with the same knowledge base and different inference engines, both of which are complete and sound, always behave in the same way".

    Justify your answer.

20. (**3 marks**) Consider the following AND-OR graph, where S = `True` and J is the query.

    Assuming that ties are broken based on alphabetical ordering (i.e., when considering both A and B simultaneously, A is considered before B), state which is more efficient: Forward Chaining or Backward Chaining. Justify your answer.

21. (**4 marks**) Given the Knowledge Base (KB):

    - $\neg((a \land \neg b) \lor (b \land c))$
    - $\neg e \Rightarrow a$

    And the statement, α

    - $e \lor \neg c$

    Use the Resolution Algorithm to determine if we may infer α from KB. Show your complete working for this resolution. You should make use of any relevant logical symbols $\neg, \land, \lor, \Rightarrow$ in your answer, or directly substitute them with the English words, not, and, or, implies respectively, with brackets where necessary.

END OF EXAM PAPER

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