NATIONAL UNIVERSITY OF SINGAPORE

SCHOOL OF COMPUTING

FINAL ASSESSMENT FOR
Semester 1 AY2022/2023

CS3243: INTRODUCTION TO ARTIFICIAL INTELLIGENCE

November 28, 2022 Time Allowed: 120 Minutes

INSTRUCTIONS TO CANDIDATES

1. This assessment contains FOUR (4) questions. All the questions are worth a total of 60 MARKS. It is set for a total duration of 120 MINUTES. You are to complete all 4 questions.
2. This is a CLOSED BOOK assessment. However, you may reference a SINGLE DOUBLE-SIDED A4 CHEAT SHEET.
3. You are allowed to use NUS APPROVED CALCULATORS.
4. If something is unclear, solve the question under a reasonable assumption. State your assumption clearly in the answer. If you must seek a clarification, the invigilators will only answers questions with Yes/No/No Comment answers.
5. You may not communicate with anyone other than invigilators in any way.

STUDENT NUMBER: _____

EXAMINER'S USE ONLY		
Question	Mark	Score
1	21	
2	11	
3	13	
4	15	
TOTAL	60	

1a. [1 mark] Let G denote a search problem, which is to be solved using the Uniform Cost Search (UCS) algorithm. Let G' denote a variant of G, where each step cost (i.e., in G') has a constant value, $c \in \mathbb{Z}^+$, added to the original step cost (i.e., added to the corresponding step cost in G). Consider the following statements.

- S_a: The UCS algorithm is guaranteed to return the same optimal path for G and G'.
- S_b: The UCS algorithm always returns different paths for G and G'.
- S_c: Any path the UCS algorithm returns for G' is an optimal path on G.

Specify which among the statements, S_a, S_b, and S_c, is/are true. If none are true, simply specify "none".

Solution:

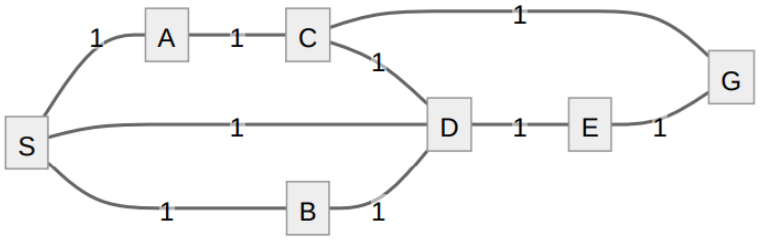
1b. [1 mark] Given a collection of admissible heuristics (for the A* search algorithm), $H = \{h_1, h_2, \ldots, h_m\}$, and a corresponding collection of weights, $W = \{w_1, w_2, \ldots, w_m\}$, such that $\forall w_i \in W$, $w_i \in \mathbb{R}$, consider the following new heuristics.

- $h_a(n) = \sum_{h_i \in H} h_i(n)$
- $h_b(n) = \frac{1}{10} \sum_{h_i \in H} h_i(n)$
- $h_c(n) = \sum_{i=1}^{m} w_i . h_i(n)$

Specify which among the new heuristics, h_a, h_b, and h_c, are admissible heuristics (again, for the A* search algorithm). If none are admissible, simply specify "none".

Solution:

1c. Consider the following undirected graph and the accompanying heuristic h.



n	$h(n)$
S	3
A	2
B	3
C	1
D	2
E	1
G	0

Assuming that all algorithms use the same tiebreaking strategy, apply the graph and heuristic above to the **following three questions** (i.e., to **Part (i)**, **Part (ii)**, and **Part (iii)** below).

(i) [1 mark] Assume the use of the A* search algorithm using a graph-search implementation with late-goal testing. Which one statement among the following is true?

- S_a: Graph search version 3 returns the same path as version 1.
- S_b: Graph search version 3 returns the optimal path, but version 1 does not.
- S_c: Graph search version 1 returns the optimal path, but version 3 does not.
- S_d: There is not enough information; none of the above are true.

Solution:

(ii) [1 mark] Which one among the following statements about the heuristic, h, is true?

- S_a: h is consistent and is admissible.
- S_b: h is consistent but is not admissible.
- S_c: h is not consistent but is admissible.
- S_d: h is not consistent and is not admissible.

Solution:

(iii) [1 mark] Consider the Uniform Cost Search (UCS) algorithm implemented using graph search with late-goal testing. Running UCS, which of the following statements is/are true?

- S_a: UCS returns the optimal path *S-D-C-G*.
- S_b: UCS returns the optimal path *S-D-E-G*.
- S_c: UCS returns the same path as A* search using graph search version 3.
- S_d: There is not enough information; none of the above are true.

Solution:

1d. [4 marks] Prove or disprove the following statement. Given a consistent heuristic, h_1, and an admissible but inconsistent heuristic, h_2, A* search using h_1 will expand no more nodes than A* search using h_2.

Solution:

1e. [6 marks] Mike is a founder of a web development start-up. He is looking to recruit three new staff – i.e., such that there will be a total of four in his start-up, including himself. The staff must fulfil the following roles: two JavaScript Programmers, two UX/UI Designers, one Marketing Guru, one Database Administrator, and one Systems Engineer. Assume that if a person possesses two skills, he/she can take on two roles in the company.

Mike has narrowed his recruitment options down to the following people.

Name	***Skills***
Mike (founder)	JavaScript
Samuel	JavaScript and UX/UI
Jonathan	Marketing and UX/UI
Tom	UX/UI and Systems
Susan	JavaScript and Database
Linda	Marketing and UX/UI
Wayne	Systems and JavaScript
Jimmy	Marketing and UX/UI

Model this scenario as a Constraint Satisfaction Problem (CSP). Specifically, state the variables, domains, and constraints.

Solution:

1f. [4 marks] Continuing from **Part (f)** above, suppose that Mike decides to make Tom a co-founder. Mike and Tom discover that all the prospective staff absolutely refuse to abandon their favourite platforms. Further, given that the start-up can only afford two single-boot workstations, it may thus only operate with two distinct Operating Systems (OS). The table below shows the relevant skills (unchanged from **Part (f)**) and the OS preferences.

Name	***Skills***	***OS***
Mike (founder)	JavaScript	Windows
Samuel	JavaScript and UX/UI	Windows
Jonathan	Marketing and UX/UI	Windows
Tom (co-founder)	UX/UI and Systems	FreeBSD
Susan	JavaScript and Database	FreeBSD
Linda	Marketing and UX/UI	Linux
Wayne	Systems and JavaScript	Linux
Jimmy	Marketing and UX/UI	Windows

Given this newly added requirement, enforce node consistency and determine the domain values once node consistency has been achieved – i.e., specify the domains after all unary constraints are satisfied. Next, perform forward-checking and list the resultant domains. You are to assume that the above are done as pre-processing steps.

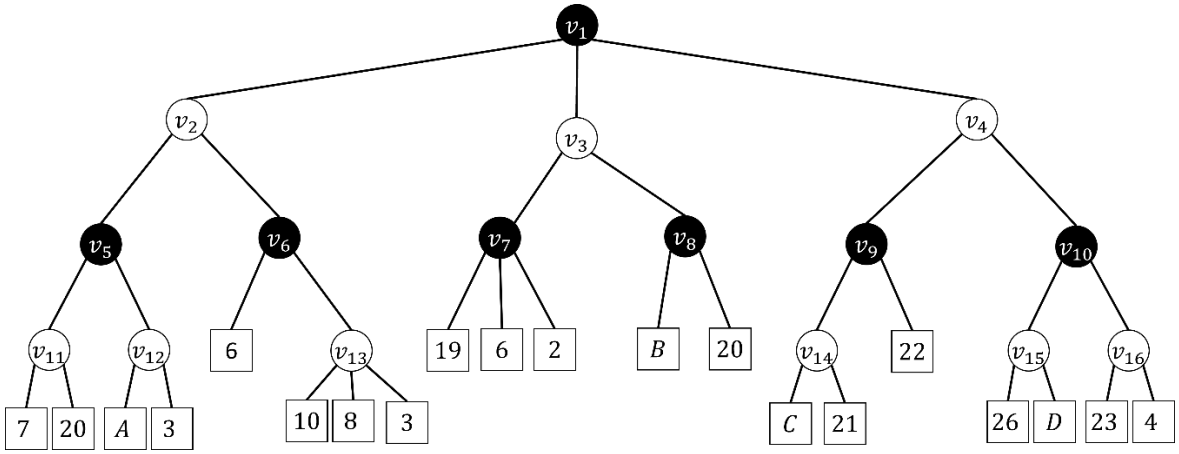
Note that there will be **NO Error Carried Forward** considered.

Solution:

1g. [2 marks] Determine if the following statement is true or false and provide a clear and concise rationale. Once arc consistency is enforced as a pre-processing step, forward checking can be used during backtracking search to maintain arc consistency for all variables.

Solution:

2a. Consider the following game tree in an adversarial search problem.



Circular black nodes correspond to the MAX player while circular white nodes correspond to the MIN player. The utility values at the terminal states are specified in the square leaf nodes. Assume that all utility values are stated in terms of the MAX player's utility and that the utility values are in the interval [-100, 100].

(i) [6 marks] Given that the Alpha-Beta Pruning algorithm is executed on the above tree from **left to right**, determine the largest range of values for the variables *A*, *B*, *C*, and *D* such that no arcs are pruned.

Solution:

_____ $\leq A \leq$ _____ _____ $\leq C \leq$ _____

_____ $\leq B \leq$ _____ _____ $\leq D \leq$ _____

(ii) [1 mark] Assuming that no nodes are pruned from the given game tree, determine the utility value at the root based on the execution of the Alpha-Beta Pruning algorithm.

Solution:

2b. [4 marks] Consider the following function.

$$F(x) = ax + b, \text{ where } a > 0, x \in \mathbb{R}$$

Prove that when F is applied to each utility value, x, in any Minimax search tree, the nodes pruned by the Alpha-Beta Pruning algorithm will remain unchanged (relative to the original utility values).

Solution:

3. Alice, Beth, Cathy, and Diana have just had lunch at a restaurant. Each of the four ladies ordered one of two possible lunch sets: *Lunch Set X* or *Lunch Set Y*.

The waiter who served the four ladies reports the following.

- Alice and Beth had different lunch sets.
- Beth and Cathy had different lunch sets.
- Cathy and Diana had different lunch sets.
- Alice, Cathy, and Diana had exactly two of *Lunch Set X*.

Apart from the above statements, the waiter does not recall who exactly had which lunch set.

We denote the following.

- *A*: Alice had *Lunch Set X*
- *B*: Beth had *Lunch Set X*
- *C*: Cathy had *Lunch Set X*
- *D*: Diana had *Lunch Set X*

Consequently, note that negation of any of the above literals refers to that person having *Lunch Set Y* instead – e.g., ¬A refers to Alice having *Lunch Set Y*.

Answer the **following three questions** (i.e., **Part (i)**, **Part (ii)**, and **Part (iii)**) based on the above context. Note that there will be **NO Error Carried Forward** considered.

(i) [4 marks] Define the knowledge base (KB) using the four statements given by the waiter. Specify the KB using propositional logic and the literals *A*, *B*, *C*, and *D*. **Do not convert the KB into Conjunctive Normal Form (CNF) for this part**.

Solution:

(ii) [6 marks] Suppose that we are given the query, α: "Did Beth have Lunch Set Y?" Assuming that we wish to prove that KB ⊨ α via resolution, update the KB accordingly, and then convert the KB such that it is fully represented in CNF.

Solution:

(iii) [3 marks] Apply the resolution algorithm to prove or disprove the query specified in **Part (ii)**.

Solution:

4. You work in an oil refinery, where the temperature of the oil is codified into either 'Normal' or 'Abnormal'.

An alarm is activated when the thermal sensor, which measures the temperature of the oil in the refinery, detects an 'Abnormal' temperature. This thermal sensor will only display 'Normal' or 'Abnormal'. Further, the thermal sensor's manufacturer informs you that the temperature of the oil may cause it to fail.

The alarm is located far away from any elements that can cause its failure.

For this question, consider only the following Boolean variables:

- F_A : Alarm is faulty
- F_G : Thermal sensor is faulty
- A : Alarm activates
- G : 'Abnormal' thermal sensor reading
- T : 'Abnormal' temperature of the oil in the refinery

Your boss asks you to model the system as a Bayesian Network.

Answer the **following seven questions** (i.e., **Part (a)**; **Parts (b)(i)**, **(b)(ii)**, and **(b)(iii)**; **Part (c)**; and **Parts (d)(i)** and **(d)(ii)**) based on the above context. Some additional information may also be provided before some questions. Note that there will be **NO Error Carried Forward** considered.

(a) [3 marks] Draw a Bayesian Network for this problem.

Solution:

4b. Due to a lack of information, you must model the probability that the thermal sensor gives the correct temperature using the following variables (instead of specific probabilities).

- x: when the thermal sensor is working correctly
- y: when the thermal sensor is faulty

The alarm is guaranteed to activate correctly unless it is faulty, in which case it will never activate.

(i) [2 marks] Present the conditional probability table for G = True.

Solution:

(ii) [2 marks] Present the conditional probability table for A = True.

Solution:

(iii) [1 mark] Present the conditional probability table for F_G = True. Define new variables within your table where necessary, similar to the setup in **Part (b)(i)** and **Part (b)(ii)** above, where the variables x and y were utilised.

Solution:

4c. [4 marks] Studying the literature, you discover that 'Abnormal' oil temperatures occur with probability z.

Suppose the alarm and thermal sensor are working and the alarm activates, what is the probability that the temperature of the oil is 'Abnormal'?

You must express this probability only in terms of the variables x, y, and z, and any variables you defined in **Part (b)(iii)**.

Solution:

4d. To improve operations, the probability determined in **Part (c)** should be as high as possible. Your boss suggests purchasing a new alarm (represented by B when it activates) of the same specifications, so that it can be connected to the existing thermal sensor.

(i) [1 mark] Draw an updated Bayesian Network given the addition of this new alarm.

Solution:

(ii) [2 marks] Suppose that both alarms and the thermal sensor are working, and that both alarms activate. Considering the probability calculated in **Part (c)**, and the Bayesian Network that includes the new alarm, should your boss purchase the new alarm? Why?

Solution:

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