University of Waterloo
School of Computer Science
CS 486/686, SAMPLE Midterm Examination
Spring 2022

Name:

Waterloo Student ID:

- **Instructor: Jesse Hoey**
- **Date: Any day before June 8th 7pm**
- **Location: Anywhere you want**
- **Time: Anytime before June 8th, 7pm**
- **There are 4 questions on this exam**
- **There are 11 pages in this exam (including cover page and two additional pages at the end for work that does not fit in the spaces provided)**
- **There are a total of 100 marks on the exam**
- **You have 110 minutes to complete the exam**
- **ONLY non-programmable calculators are allowed**

Question	**1**	**2**	**3**	**4**	**TOTAL**
Marks	**20**	**20**	**30**	**30**	**100**
Score					

Question 1: Short Answers (20 marks out of a total of 100 marks)

WRITE ANSWERS IN THE SPACES PROVIDED AFTER EACH QUESTION

(1a) [**4 marks**] Complete the following sentence: A* search uses a priority queue of nodes ranked by ______________, and so is a mixture of ______________ and best-first search.

(1b) [**4 marks**] A heuristic for a search problem is an estimate of the true cost to the goal. Is the following statement true or false: *an admissible heuristic is always greater than the true cost.* Briefly explain

(1c) [**4 marks**] True or False: in a deterministic planner, causal rules specify when a feature keeps its value when not acted upon. Briefly explain why.

(1d) [**4 marks**] Why is variable elimination for constraint satisfaction problems intractable?

(1e) [**4 marks**] Give one reason why Heuristic Depth-First Search is often used in practice.

Question 2: Propositional Logic (20 marks out of a total of 100 marks)

WRITE ANSWERS IN THE SPACES PROVIDED AFTER EACH QUESTION

Consider the following argument

Pablo will go to jail if he breaks the law If Pablo breaks the law, then he'll get rich If Pablo is rich, then he won't go to jail Therefore, Pablo doesn't break the law

(2a) (**3 points**) Assign a set of propositional variables to the statements in this argument.

(2b) (**3 points**) Write the premises as logical statements using your variables from part (a)

(2c) (**1 point**) write the conclusion as a logical statement using your atoms

(2d) (**4 points**) Write a conjunction of the premisses and the refutation of the conclusion in Conjunctive Normal Form (CNF)

(2e) (**4 points**) Prove the validity of the argument using resolution on your CNF

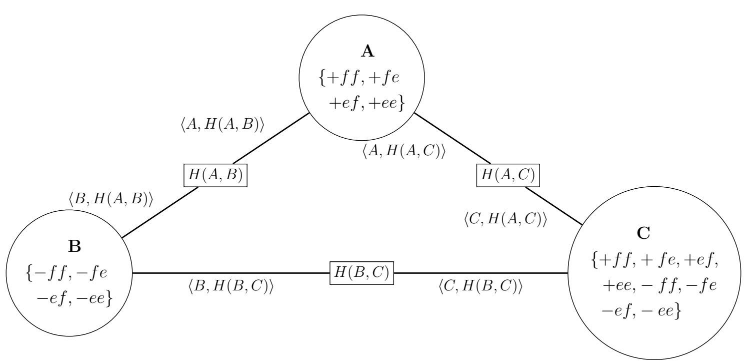
(2f) (**5 points**) Prove the validity of this argument using a truth table

Question 3: Constraint Satisfaction (30 marks marks out of a total of 100 marks)

The KoobeCaf™ social network consists of a number of *members* who can be connected (or not) to each other. Connected members on KoobeCaf™ can be either both *friends* (f) or *enemies* (e) with each other. Members come in two types: positive (+) and negative (−). While connected members of different types *must* be enemies, members of the same type can be friends or enemies. A *stable* social network is one in which all members satisfy these constraints. This can be represented as a constraint satisfaction problem (CSP) as follows:

- **variables and domains**: Each KoobeCaf™ member is represented with a tuple containing: their type (+ or −) and whether they are friends (f) or enemies (e) with each of their (up to $N-1$) connections. Thus, a member b of a network with three fully connected members a, b, c (in that order), would be represented with a variable $B = T_b X_a X_c$ where $T_b \in \{+, -\}$ is b's type and $X_a, X_c \in \{f, e\}$ are b's relationship with a and c, respectively. Thus, B has domain $\{+ff, +fe, +ef, +ee, -ff, -fe, -ef, -ee\}$, where $-fe$ means b is type negative, friends with a, but enemies with c. The order of the friend/enemy relations in each tuple is alphabetic.
- **constraints**: A binary constraint between each pair of connected members that requires the two members to (1) have the same relation (e.g. in the 3-member network A,B,C above, if $A = **f$ then $C = *f*$ where $*$ means either value); and (2) be of the same type OR be enemies. Call this constraint $H(\cdot, \cdot)$. For example, with three fully connected members represented by variables A, B, C: $H(A, C) = True$ for $\{A, C\} \in \{\{+*f, +f*\}, \{+*e, +e*\}, \{-*f, -f*\}, \{-*e, -e*\}, \{+*e, -e*\}, \{-*e, +e*\}\}$.

This graph shows a KoobeCaf™ network with three members: a, b and c, in which a is positive (+), and b is negative (−) and domain values of the wrong type have been removed from the domains of A and B.



(3a) [**25 marks**] Using AC-3, make the CSP shown above arc-consistent by filling in the table on the facing page, in which each iteration is on a single line in the table and a check-mark is under each constraint that is consistent (i.e. the arc is **not** in the

(Question 3 CONTINUES ON NEXT PAGE...)

TDA queue), and the domain values remaining for each variable are shown under each variable name. Always choose the left-most (in the table) inconsistent constraint to make consistent next. You may not need all rows, but you will not need more rows. Don't add redundant arcs back on the TDA (after changing the domain of X for the arc $\langle X, c(X,Y)\rangle$, you only add arcs $\langle Z, c'(Z,X)\rangle$ to TDA where $\mathbf{Z} \neq \mathbf{Y}$).

$\mathbf{A} = T_aX_bX_c$ $T_a = +$ $X_b, X_c \in \{f,e\}$	$\langle A, H(A,B)\rangle$	$\langle B, H(A,B)\rangle$	$\mathbf{B} = T_bX_aX_c$ $T_b = -$ $X_a, X_c \in \{f,e\}$	$\langle B, H(B,C)\rangle$	$\langle C, H(B,C)\rangle$	$\mathbf{C} = T_cX_aX_b$ $T_c \in \{+,-\}$ $X_a, X_b \in \{f,e\}$	$\langle C, H(A,C)\rangle$	$\langle A, H(A,C)\rangle$
$+ff\ +fe\ +ef\ +ee$			$-ff\ -fe\ -ef\ -ee$			$+ff\ +fe\ +ef\ +ee$ $-ff\ -fe\ -ef\ -ee$		
$+ef\ +ee$	✓							

(3b) [**5 marks**] Based only on your arc-consistent network (last line of the table), can you guarantee that there is a solution (a stable network)? Briefly explain why or why not.

Question 4: Search (30 marks marks out of a total of 100 marks)

WRITE ANSWERS IN THE SPACES PROVIDED AFTER EACH QUESTION

An artificial intelligence conference has $N_c + N_s$ attendees, of which N_c do research on connectionist AI ("connectionists") and N_s do research on symbolic AI "symbolicists". On their way to the conference reception, they come across a river with no bridge that they must cross. There is a boat that can carry only 2 people at a time. If more connectionists than symbolicists are left on either side of the river, the connectionists will start a fight with the symbolicists. At least one person must be in the boat on each trip (to paddle the boat). The goal is to move everyone to the other side of the river in the shortest number of trips without a fight starting. Assume $N_c < N_s$ to start with.

The state space can be easily described by the number of connectionists and symbolicists on each side, plus the location of the boat. The cost function, $g(n)$ is simply 1 for each trip across the river. A simple heuristic $h(n)$ for this problem is to relax it by ignoring fights that break out.

(4a) [**10 marks**] Give a formal (mathematical) definition of a state, neighborhood function, cost function and the heuristic function described above.

(4b) [**5 marks**] Is the $h(n)$ defined above admissible? Carefully explain why or why not.

(4c) [**15 marks**] Show part of the search graph that results from applying algorithm A* for the problem with $N_c = N_s = 3$ starting from the configuration where everyone is on one side, with the heuristic $h(n)$ and cost $g(n)$ defined above. Specifically, continue until you have expanded (generated the successors of) four nodes. Break ties arbitrarily. Number the four nodes you expand to indicate the order in which they are expanded ("1","2","3","4"). Then, number (with "5") the next leaf that you would expand if you were to continue with A* search on this graph. Label each node with its $g(n)$ value and its $h(n)$ value. You should label all nodes, not just the ones you expand. Do not add a node to the tree if it is already in the tree somewhere with a lower or equal value of $f(n) = g(n) + h(n)$. Branches of your search graph should terminate (have an infinite heuristic value) if the connectionists outnumber the symbolicists on either side of the river.

ADDITIONAL WORK - Clearly state which question you are working on

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