UNIVERSITY OF ILLINOIS AT URBANA-CHAMPAIGN
Department of Electrical and Computer Engineering

CS 440/ECE 448 Artificial Intelligence
Spring 2020

EXAM 1

Monday, February 24, 2020

- This is a CLOSED BOOK exam. Book and notes are not allowed.
- No calculators are permitted. You need not simplify explicit numerical expressions.
- There are 40 points in the exam. Plan your work accordingly.
- You must SHOW YOUR WORK to get full credit.

Name: ____

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Problem 1 (5 points)

What is *acting rationally*? What is *thinking rationally*? How can an agent act rationally without thinking rationally?

Solution: To think rationally is to use logic in order to infer the sequence of actions that maximizes your own benefit. To act rationally is to act in a manner that maximizes your own benefit. It is possible to for an agent to act rationally without thinking rationally if it follows the instructions given by somebody else, e.g., by its programmer, without explicitly reasoning about the consequences of its actions.

Problem 2 (5 points)

An agent might be placed into an environment that is fully observable or partially observable, deterministic or stochastic, single-player or multi-player, known or unknown. The adjectives "partially observable," "stochastic," "multi-player," and "unknown" are used to describe different types of gaps in the agent's knowledge. Define each of these four adjectives: specifically, what type of knowledge about the environment is lacking, in each of these four cases?

Solution:

- **Partially observable** means that the agent does not know the current state.
- **Stochastic** means that, given the current state and the agent's action, the next state is determined by a random process.
- **Multi-player** means that other players are able to act, and the agent does not know, in advance, what their actions will be.
- **Unknown** means that, given the current state and the agent's action, the agent does not know what the next state will be.

Problem 3 (10 points)

Consider the following maze. There are 11 possible positions, numbered 1 through 11. The agent starts in the position marked S (position number 3). From any position, there are from one to four possible moves, depending on position: Left, Right, Up, and/or Down. The agent's goal is to find the shortest path that will touch both of the goals (G_1 and G_2).

1	2 G_1	3 S	4
5		6 G_2	7
8	9	10	11

(a) Define a notation for the state of this agent. How many distinct non-terminal states are there?

Solution: The state can be defined by a pair of variables: (P, G) where $P \in \{1, \ldots, 11\}$ specifies the current position, $G \in \{\varnothing, G_1, G_2\}$ specifies which of the goals have been reached. There are nine values of P that can be reached without touching either goal, ten that can be reached without touching G_1, and ten that can be reached without touching G_2, so the total number of non-terminal states is $9 + 10 + 10 = 29$.

(b) Draw a search tree out to a depth of 2 moves, including repeated states. Circle repeated states.

Solution: After the first move, possible states are $(2, G_1)$,$(6, G_2)$, and $(4, \varnothing)$. After the second move, possible states are $(1, G_1)$, $(3, G_1)$, $(3, G_2)$, $(10, G_2)$, $(7, G_2)$, $(3, \varnothing)$ (a repeated state), and $(7, \varnothing)$.

(c) For A* search, one possible heuristic, h_1, is the number of goals not yet reached. Prove that h_1 is consistent.

Solution: The heuristic difference between two neighboring states is either $h_1[n_1] - h_1[n_2] = 1$ (if they differ in the number of goals remaining) or $h_1[n_2] - h_1[n_1] = 0$ (if they have the same number of goals remaining. The distance is always $d[n_1, n_2] = 1$. So $h_1[n_1] - h_1[n_2] \leq d[n_1, n_2]$.

(d) Another possible heuristic is based on the Manhattan distance $M[n, g]$ between two positions, and is given by

$$h_2[n] = M[n, G_1] + M[G_1, G_2]$$

that is, h_2 is the sum of the Manhattan distance from the current position to G_1, plus the Manhattan distance from G_1 to G_2. Prove that h_2 is not admissible.

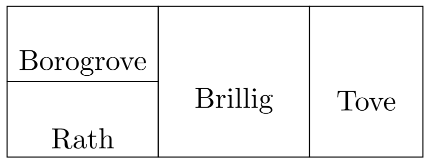
Solution: Proof by counter-example: for example, consider the state $n = (7, \varnothing)$. From this state, the shortest solution goes left, then up, then left: $d[n] = 3$ steps. The heuristic, however, is $h_2[n] = M[n, G_1] + M[G_1, G_2] = 3 + 2 = 5$, so $h[n] > d[n]$.

(e) Prove that $h_2[n]$ is dominant to $h_1[n]$.

Solution: $h_1[n] \in \{0, 1, 2\}$. The Manhattan distance $M[G_1, G_2] = 2$, therefore $h_2[n] \geq 2 \geq h_1[n]$.

Problem 4 (5 points)

The figure below shows the map of a fictional country, with four provinces: Borogrove, Rath, Brillig, and Tove. The "map coloring problem" requires you to color each province red, blue, or green, without using the same color for any two neighboring provinces.



Remember that, in choosing an evaluation sequence for the depth-first search in a constraint satisfaction problem, three heuristics are often useful: LRV (least remaining values), MCV (most constraining variable), and LCV (least constraining value).

(a) According to the LRV, MCV, and LCV heuristics, which region should be colored first, and why?

Solution: Brillig. MCV (3 constraints, versus 2 for Borogrove and Rath, 1 for Tove).

(b) Suppose Borogrove has already been colored red, all others are not colored yet. Would it make more sense to color Rath next, or Tove? Why?

Solution: Rath. LRV (2 remaining values, versus 3 for Tove).

(c) Suppose Borogrove has already been colored red, all others are not colored yet. Now Tove is to be colored. What color should it be, and why?

Solution: Red. LCV (coloring Tove red does not impose any further constraints on any other region. Coloring it blue would would impose the constraint that Brillig not be blue; likewise green).

Problem 5 (5 points)

A robot fire truck is able to manipulate its own horizontal location (D), the angle of its ladder (θ), and the length of its ladder (L). The ladder has a length of L, and an angle (relative to the x axis) of θ ($0 \leq \theta \leq \frac{\pi}{2}$ radians), so that the position of the tip of the ladder is

$$(x, z) = (D + L\cos\theta, L\sin\theta)$$

(a) What is the dimension of the configuration space of this robot?

Solution: There are three dimensions: D, L, and θ.

(b) The robot must operate between two buildings, positioned at $x = 0$ and at $x = 10$ meters. No part of the robot (neither its base, nor the tip of the ladder) may ever come closer than 1 meter to either building. What portion of configuration space is permitted? Express your answer as a set of inequalities involving only the variables D, L, and θ; the variables x and z should not appear in your answer.

Solution:

$$1 \leq D + L\cos\theta \leq 9, \quad 1 \leq D \leq 9$$

(c) The robot's objective is to save a cat from a tree. The cat is at position $(x, z) = (5, 5)$. The robot begins at position $(D = 5, L = 3, \theta = 0)$. The final position of the robot depends on how much it costs to raise the ladder by one radian, as compared to the relative cost of extending the ladder by one meter, and the relative cost of moving the truck by one meter. Why?

Solution: Minimum-cost search for the solution will explore steps, in configuration space, that are of equal cost in each direction. The resulting shortest path will depend on the number of steps required to raise the ladder by $\pi/4$ radians, versus shifting the truck by 4m and extending the ladder. Equivalently: if raising the ladder is more expensive, then the truck will move 4m away, and raise the ladder only a little, but if raising the ladder is cheap, then the truck will raise the ladder up to vertical.

Problem 6 (5 points)

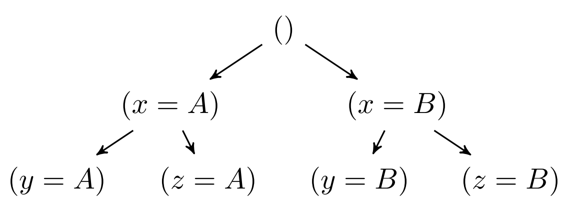
A particular planning problem is defined by a set of three variables (x, y and z) and a set of two possible values (A and B). At any given state of the planning process, each of the three variables may be set to either value, or to the value null ($\varnothing$). There are only two possible actions, called SETX and MOVE:

Action	Preconditions	Results
SETX(val)	$x = \varnothing$	$x =$ val
for val $\in \{A, B\}$		
MOVE(var1,var2)	var1 = val, var2 = $\varnothing$	var1 = $\varnothing$, var2 = val
for val $\in \{A, B\}$, var1,var2 $\in \{x, y, z\}$, var1 $\neq$ var2		

In the starting condition, all variables are set to null. In the desired ending condition, $y = B$ and $z = B$.

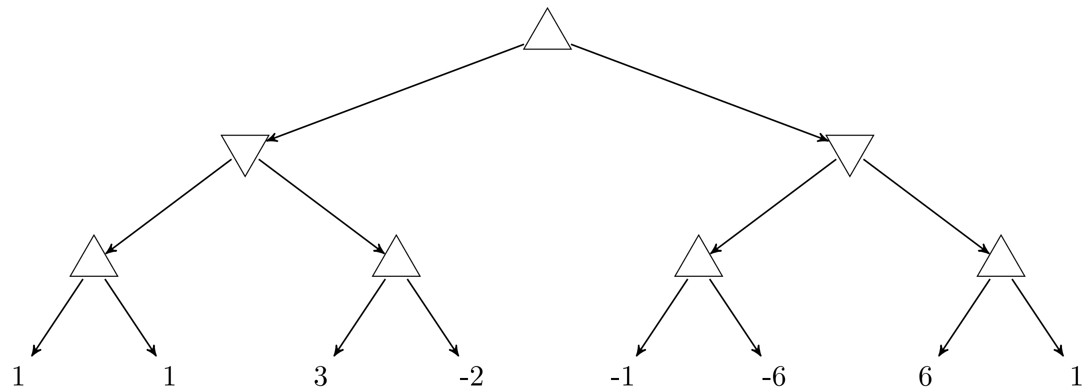
Draw a breadth-first 2-level **forward-chaining** tree, showing all of the possible n-step successors of the starting condition for $n \leq 2$.

Solution:



Problem 7 (5 points)

Two players, MAX and MIN, are playing a game. The game tree is shown below. Upward-pointing triangles denote decisions by MAX; downward-pointing triangles denote decisions by MIN. Numbers on the terminal nodes show the final score: MAX seeks to maximize the final score, MIN seeks to minimize the final score.



(a) Write the minimax value of each nonterminal node (each upward-pointing or downward-pointing triangle) next to it.

Solution: From top to bottom, left to right, the values are 1, 1, -1, 1, 3, -1, 6.

(b) Suppose that the minimax values of the nodes at each level are computed in order, from left to right. Draw an X through any edge that would be pruned (eliminated from consideration) using alpha-beta pruning.

Solution: The 4th edge at the bottom level, and the 4th edge at the middle level, would both be pruned.

(c) In this game, alpha-beta pruning did not change the minimax value of the start node. Is there any deterministic two-player game tree in which alpha-beta pruning changes the minimax value of the start node? Why or why not?

Solution: No. Alpha-beta pruning only prunes branches that have no effect on the start node.

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