INDIAN INSTITUTE OF TECHNOLOGY KHARAGPUR

End-Autumn Semester 2022-23

Date of examination: 16.11.2022 **Session (*FN / AN*):** AN **Duration:** *3 hours* **Full marks:** 80

Subject No.: AI61005 **Subject:** Artificial Intelligence: Foundations and Applications

Department/Center/School: Centre of Excellence in Artificial Intelligence (CoEAI)

Instructions: ***Answer all questions. All parts of a question must be answered in the same place.***

PART-A (Four Questions)

A1. Consider the crossword puzzle and the corresponding word list below:

1		2		3
	4		5	
6		7		
8				

Word List		
AFT	HOSES	LINE
ALE	KEEL	SAILS
EEL	KNOT	SHEET
HEEL	LASER	STEER
HIKE	LEE	TIE

The numbers 1,2,3,4,5,6,7,8 in the crossword puzzle correspond to the words that will start at those locations.

a) Let the variables be 1A, 2D, 3D, 4A, 5D, 6D, 7A, 8A where the digits signify the locations marked in the cells; A (ACROSS) and D(DOWN) signify the horizontal and vertical direction respectively. Represent the given crossword problem as a Constraint Satisfaction Problem clearly mentioning the domains of each variable and the constraints.

b) Draw the corresponding constraint graph clearly labeling the nodes and edges.

c) Show the trace of the backtracking search (in tree form) until the first backtracking decision is made. Follow the variable order 1A, 2D, 3D, 4A, 7A, 5D, 8A, 6D.

d) Show one step of AC-3 algorithm in the following format.

$X_i \rightarrow X_j$	Revised domain of D_i of X_i	New edge added in queue

[2+1+2+5 = 10 marks]

A2. Answer the following questions related to Constraint Satisfaction Problems (CSP).

a) Consider two CSP formulations of the N-queen problem. In Formulation 1, each cell is a variable and the domain of each variable is {0,1}. In Formulation 2, we consider each row as a variable and the values are the column indices $\{1,2,\ldots,N\}$. Compare Formulation 1 and 2 in terms of the size and branching factor of their state space and depth of the search tree.

b) Show how any n-ary CSP can be converted into a binary CSP containing only binary constraints. Take a ternary constraint to illustrate.

c) Solve a 5-queen problem using *iterative improvement algorithm*. Show the relevant steps.

[2+3+5 = 10 marks]

A3. Answer the following questions related to propositional satisfiability:

a) Represent a 4-queen problem as a propositional satisfiability problem.

b) Use DPLL algorithm to check the satisfiability of the following CNF knowledge base:

$$\{(p \vee q \vee r \vee s), (\neg p \vee q \vee \neg r), (\neg q \vee \neg r \vee s), (p \vee \neg q \vee r \vee s), (q \vee \neg r \vee \neg s), (\neg p \vee \neg r \vee s), (\neg p \vee \neg s), (p \vee \neg q)\}$$

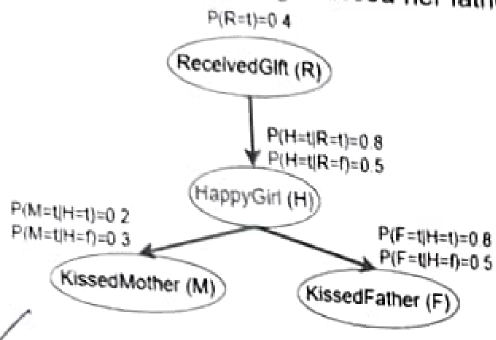
c) Convert the following SAT problem into a CSP clearly mentioning variables, domains and constraints. Als draw the constraint graph.

$$(y \vee z) \wedge (x \vee \neg y \vee z) \wedge (x \vee \neg z) \wedge (x \vee \neg y \vee \neg z)$$

[3+3+(2+2)=10 Marks

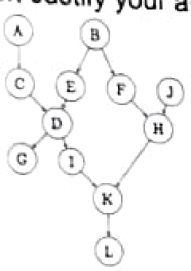
A4. Answer the following questions related Bayesian Belief Network:

a) Consider the following Bayesian Belief Network involving random variables all with binary domains.
ReceivedGift (R): A girl received a gift or not
HappyGirl (H): The girl is happy or not
KissedMother (M): The girl kissed her mother or not
KissedFather (F): The girl kissed her father or not



Calculate the probability that the girl is happy provided she did not kiss her mother (i.e., P(H=t|M=f)). Also calculate the probability that the girl received the gift provided she is happy and did not kiss her mother (i.e., P(R=t|H=t,M=f)).

b) Consider the following Bayesian Belief Network. Infer different d-separation sets for the specifications given below. Justify your answers with explanations.



I. Find set of variables that are d-separated from F given E.

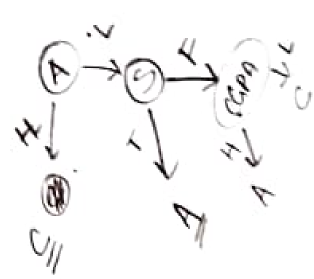
II. Find set of all variables that are d-separated from F given E and K.

[(3+2)+(2+3)=10 Marks]

PART – B (Five Questions)

B1. Use the dataset below to learn a Decision Tree which predicts the grade obtained in the AI course by a student.

Attendance	Studied	CGPA	Grade
L	T	L	A
L	F	H	A
L	T	L	A
H	T	H	C
H	T	L	C
H	F	L	C
H	F	H	C
L	F	L	C



It may be helpful to note that $\log_2 3 \approx 1.6$, $\log_2 5 \approx 2.3$, $\log_2 7 \approx 2.8$

a) What is the entropy of the root state (Grade)?

b) There are 3 possible attributes for the Root node. Find the *information gain* for each attribute and suggest the attribute to be used at the root node.

[6 marks]

B2. Suppose that you want to train a hypothesis of the form

$$h(x) = w_0 + w_1 x + w_2 \cos x$$

a) Find update rules for w_0, w_1 and w_2 assuming you do gradient descent using MSE (Mean square error) as the error function. Assume that there are m training examples.

b) True or False? If true, explain why in at most two sentences. If false, explain why or give a brief counterexample in at most two sentences.

"If you are given m data points, and use half for training and half for testing, the difference between training error and test error decreases as m increases."

[6+2=8 marks]

B3. Answer the following questions in brief.

a) What is syntax? (1 sentence)

b) What is semantics? (1 sentence)

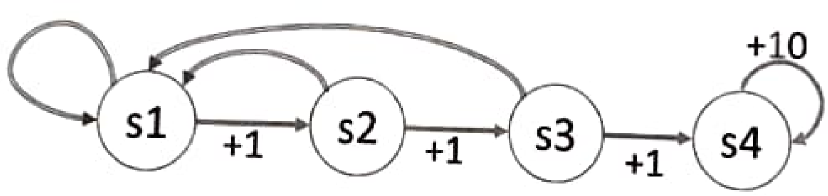
c) Sketch any one word2vec model that can be used to learn word representations. How many parameters are there in your model? State any assumption you make.

[2+2+4=8 marks]

B4. Consider a 4-state MDP as given in the figure below. In state $s4$ there is just one action, **Stay**, that fetches a reward of $+10$. In all the other states there are two actions:

- **Right**, which moves one step to the right with probability 0.9 and stays put with probability 0.1
- **Home**, which deterministically goes back to state $s1$.

There is a reward of $+1$ for Right and 0 for Home. The discount factor is $\gamma = 0.8$



a) What is the optimal policy?

b) What is $V^*(s4)$, that is, the optimal value of state $s4$?

c) What is $V^*(s3)$?

d) Suppose you are doing *value iteration* to figure out these values. You start with all value estimates equal to 0. Show the V values of each state after 1 and 2 iterations respectively by filling up the table below.

	V(S1)	V(S2)	V(S3)	V(S4)
t=0	0	0	0	0
After Iteration 1				
After iteration 2				

[6 marks]

B5. Consider the following domain with two rooms, `R1` and `R2` and a cleaner robot Safa. Safa can be at `R1` or `R2`, which can be represented by the propositions `At(R1)` and `At(R2)` respectively. Each room can be clean or dirty. `Clean(x)` represents that Room x is clean. Safa has three actions: Left and Right for moving between the rooms and `Mop(x)` for cleaning the Room where it is in.

Right:
  Precond: `At(R1)`
  Effect: `At(R2)` $\wedge \neg$`At(R1)`

Left:
  Precond: `At(R2)`
  Effect: `At(R1)` $\wedge \neg$ `At(R2)`

Mop(x)
  Precond: `At(x)`
  Effect: `Clean(x)`

The initial state is `At(R1)`, and goal condition is `Clean(R2)`.

Give a description of this planning problem in terms of propositional formulas, suitable as an input to the SATPLAN algorithm when searching for a plan of length two (consisting of exactly 2 actions).

[12 marks]