

# CS-171, Intro to A.I. — Mid-term Exam — Summer Quarter, 2016

YOUR NAME: \_\_\_\_\_

YOUR ID: \_\_\_\_\_ ID TO RIGHT: \_\_\_\_\_ ROW: \_\_\_\_\_ SEAT: \_\_\_\_\_

The exam will begin on the next page. Please, do not turn the page until told.

When you are told to begin the exam, please check first to make sure that you have all eleven pages, as numbered 1-11 in the bottom-right corner of each page. We wish to avoid copy problems. We will supply a new exam for any copy problems.

The exam is closed-notes, closed-book. No calculators, cell phones, electronics.

Please turn off all cell phones now.

Please clear your desk entirely, except for pen, pencil, eraser, a blank piece of paper (for scratch pad use), and an optional water bottle. Please write your name and ID# on the blank piece of paper and turn it in with your exam. Please show your UCI ID when you turn it in.

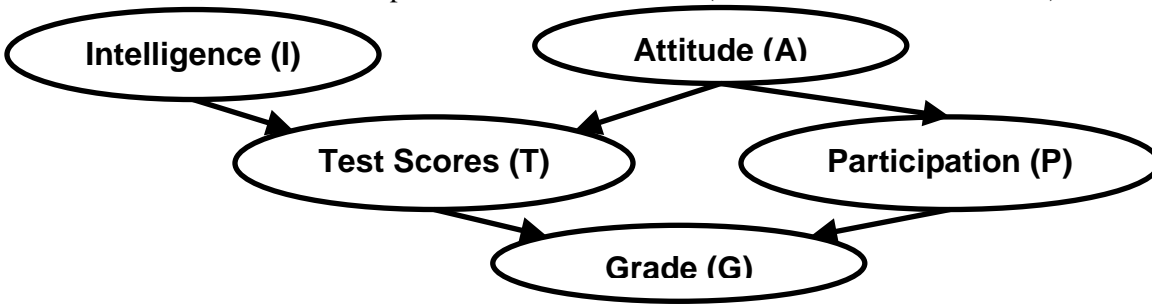
This page summarizes the points for each question, so you can plan your time.

1. (9 pts total) Bayesian networks.
2. (12 pts total, 3 pts each) STATE-SPACE SEARCH STRATEGIES
3. (10 pts total, 2 pts each) WUMPUS WORLD MODELS.
4. (12 pts total, 4 pts each) Fun in the kinship domain: English and FOL.
5. (10 pts total, -5 for each error, but not negative) RESOLUTION THEOREM PROVING.
6. (10 pts total, 1 pt each) Probability Rules and Independence.
7. (5 pts total) Hierarchical Agglomerative Clustering.
8. (5 pts total) k-Means Clustering.
9. Logic Concepts (6 pts total, 1 pt each).
10. Probability concepts and formulae (9 pts total, 1 pt each).
11. (8 pts total, -1 pt each wrong answer, but not negative) SEARCH PROPERTIES.
12. (4 pts total, 1 pt each) TASK ENVIRONMENT.

The Exam is printed on both sides to save trees! Work both sides of each page!



1. (9 pts total) **Bayesian networks.** Consider the Bayesian network shown below. Recall that each node represents a random variable, and each arc represents a direct influence (either causal or correlational) from head to tail.



1.a. (3 pts) Write the factored conditional probability expression that corresponds to this graphical Bayesian Network. Use the variable ordering indicated below, (G, T, P, I, A).

$P(G, T, P, I, A) =$  \_\_\_\_\_

1.b. (4 pts, 1 pt each) Label each statement below as T (= True) or F (= False) based on the network above.

(A) \_\_\_\_\_  $P(A | I) = P(A)$ .

(B) \_\_\_\_\_ Attitude (A) and Grade (G) are independent of each other.

~~(C)~~ \_\_\_\_\_ Intelligence (I) and Grade (G) are conditionally independent given Test Scores (T).

(D) \_\_\_\_\_  $P(I \wedge A \wedge T) = P(A) P(I) P(T)$

**Problem 1.b.(C) was cancelled.** Everyone gets 1.b.(C) right, regardless of your actual answer.

1.c. (2 pts, 1 pts each) For each of the marginal probabilities shown below, write the letter of the following sum rule formula that calculates it correctly. Here, Domain(Attitude) = {good, bad} and Domain(Participation) = {pass, fail}. The first one is done for you as an example.

(example)  $P(A = \text{good}) = \sum_{g, t, p, i} P(G = g \wedge T = t \wedge P = p \wedge I = i \wedge A = \text{good})$

(A)  $P(A = \text{good} \wedge P = \text{pass}) =$  \_\_\_\_\_

(A)  $\sum_{g, t, p, i} P(G = g \wedge T = t \wedge I = i \wedge A = \text{good} | P = \text{pass})$

(B)  $\sum_{g, t, i} P(G = g \wedge T = t \wedge I = i | P = \text{pass} \wedge A = \text{good})$

(C)  $\sum_{p, a} P(G = g \wedge T = t \wedge P = \text{pass} \wedge I = i \wedge A = \text{good})$

(D)  $\sum_{g, t, i} P(G = g \wedge T = t \wedge P = \text{pass} \wedge I = i \wedge A = \text{good})$

(B)  $P(P = \text{fail}) =$  \_\_\_\_\_

(A)  $\sum_{p} P(G = g \wedge T = t \wedge P = \text{fail} \wedge I = i \wedge A = a)$

(B)  $\sum_{g, t, i, a} P(G = g \wedge T = t \wedge I = i \wedge A = a | P = \text{fail})$

(C)  $\sum_{g, t, i, a} P(G = g \wedge T = t \wedge P = \text{fail} \wedge I = i \wedge A = a)$

(D)  $\sum_{g, t, p, i, a} P(P = \text{fail} | G = g \wedge T = t \wedge I = i \wedge A = a)$

Problem 1.b.(C) should have read: "Intelligence (I) and Grade (G) are conditionally independent given Test Scores (T) and Attitude (A)."

In that case, it would have been True. As stated, it is False. Please see the discussion about Markov blanket in Fig. 14.4(b), p. 518.

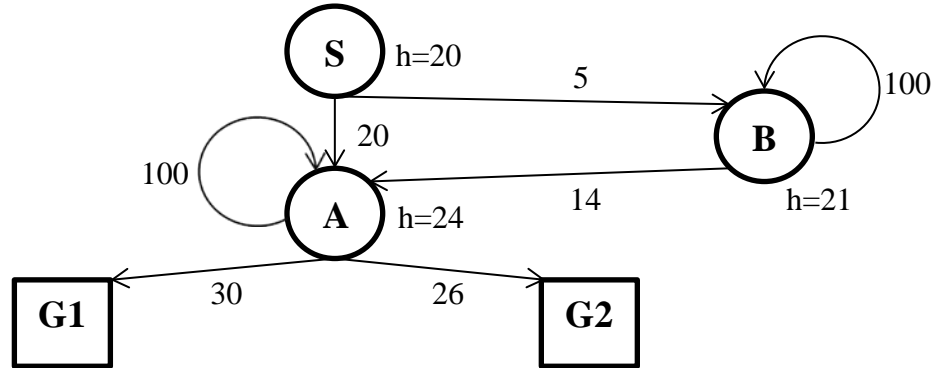
We decided that this distinction was too subtle and complicated to be a fair question on a timed closed-book Exam, so 1.b.(C) is cancelled.

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**2. (12 pts total, 3 pts each) STATE-SPACE SEARCH STRATEGIES.** Execute Tree Search through this graph (i.e., do not remember visited nodes). Step costs are given next to each arc. Heuristic values are given next to each node (as  $h=x$ ). The successors of each node are indicated by the arrows out of that node. Child nodes are returned in left-to-right order, i.e., children of S are (A, B), children of A are (A, G1, G2), and children of B are (A,B), in that order.

For each search strategy below, show the order in which nodes are expanded (i.e., to expand a node means that its children are generated), ending with the goal node that is found, or indicate the repeating cycle if the search gets stuck in a loop. Show the path from start to goal, or write "None". Give the cost of the path that is found, or write "None"

**The first one is done for you as an example. (Note that here, G1 and G2 are different nodes, unlike Quiz 1.)**



**2.example. DEPTH FIRST SEARCH.**

Order of node expansion: S A G1

Path found: None Cost of path found: None

**2.a. (3 pts) UNIFORM COST SEARCH.**

(1 pt) Order of node expansion: \_\_\_\_\_

(1 pt) Path found: \_\_\_\_\_ (1 pt) Cost of path found: \_\_\_\_\_

**2.b. (3 pts) GREEDY (BEST-FIRST) SEARCH.**

(1 pt) Order of node expansion: \_\_\_\_\_

(1 pt) Path found: \_\_\_\_\_ (1 pt) Cost of path found: \_\_\_\_\_

**2.c. (3 pts) ITERATED DEEPENING SEARCH.**

(1 pt) Order of node expansion: \_\_\_\_\_

(1 pt) Path found: \_\_\_\_\_ (1 pt) Cost of path found: \_\_\_\_\_

**2.d. (3 pts) A\* SEARCH.**

(1 pt) Order of node expansion: \_\_\_\_\_

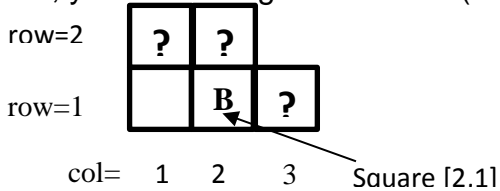
(1 pt) Path found: \_\_\_\_\_ (1 pt) Cost of path found: \_\_\_\_\_

**3. (10 pts total, 2 pts each) WUMPUS WORLD MODELS.**

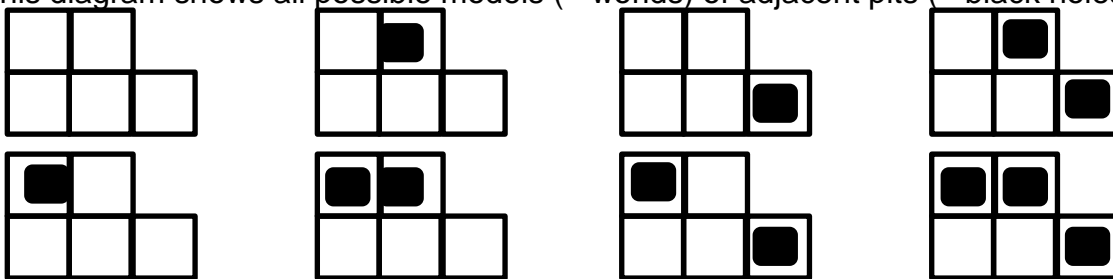
Recall that a knowledge base KB entails a sentence S (written  $KB \models S$ ) just in case the set of models that make the knowledge base true is a subset of the models that make S true (a model is a possible world). If this condition holds, it is impossible for KB to be true and S to be false. In such a case, S must be true in all worlds in which KB is true.

This question will concern only breezes and pits. Squares next to pits are breezy, and breezy squares are next to squares with pits. Pits are represented as black boxes in the world drawings below, and breezes are represented by the letter B. We ignore the wumpus, gold, etc.

Your agent did not detect a breeze at square [1,1] (**column, row**). Square [2,1] has a breeze. Thus, your knowledge base  $KB = (\neg B_{1,1}) \wedge (B_{2,1})$ , where B = Breeze.



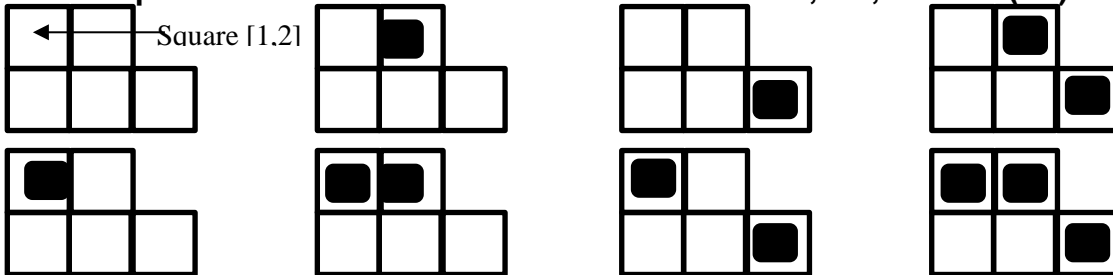
This diagram shows all possible models (= worlds) of adjacent pits (= black holes):



3.a. Circle the possible worlds above that are models of KB, i.e., circle  $M(KB)$ .

3.b. Consider ONLY the sentence  $S1 = \text{"Square [1,2] does not have a pit."}$

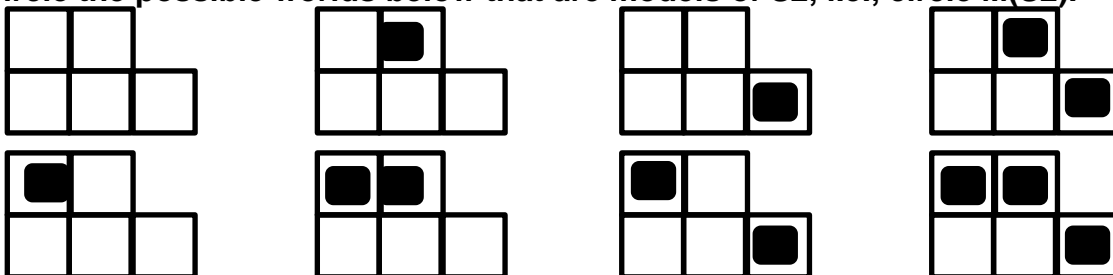
Circle the possible worlds below that are models of  $S1$ , i.e., circle  $M(S1)$ .



3.c. Does  $KB \models S1$ ? (Y = yes, N = no) \_\_\_\_\_

3.d. Consider ONLY the sentence  $S2 = \text{"Square [2,2] does not have a pit."}$

Circle the possible worlds below that are models of  $S2$ , i.e., circle  $M(S2)$ .



3.e. Does  $KB \models S2$ ? (Y = yes, N = no) \_\_\_\_\_

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**4. (12 pts total, 4 pts each) Fun in the kinship domain: English and FOL.** For each English sentence, write the letter of the best or closest FOL sentence (wff, or well-formed formula).

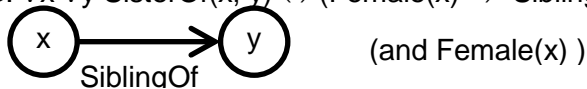
**ParentOf(x, y)** means x is a parent of y. **MarriedTo(x, y)** means x is married to y. **SiblingOf(x, y)** means x is a sibling of y. **Female(x)** means x is female. Once a predicate has been defined in a problem, it may be used in subsequent problems. All objects are persons, i.e., no need for Person(x) guard predicates.

English definitions are “Your ... is/has ... of/with you.” FOL definitions are  $\forall x \forall y (P(x,y) \leftrightarrow \dots)$ ; y = you. To help you, the intended variable bindings are identified. The first one is done for you, as an example.

For the benefit of non-native English speakers, the diagrams below each problem illustrate the intended relationships described by the English statements above. The arc tail is the predicate first argument, the arc head is the second argument, and additional predicates are given as text.

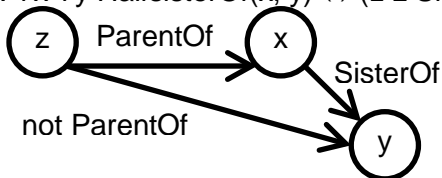
**4.example A** “Your sister(x) is a female who is a sibling of you (y).”

- A.  $\forall x \forall y \text{ SisterOf}(x, y) \leftrightarrow (\text{Female}(x) \wedge \text{SiblingOf}(x, y))$   
 B.  $\forall x \forall y \text{ SisterOf}(x, y) \leftrightarrow (\text{Female}(x) \Rightarrow \text{SiblingOf}(x, y))$



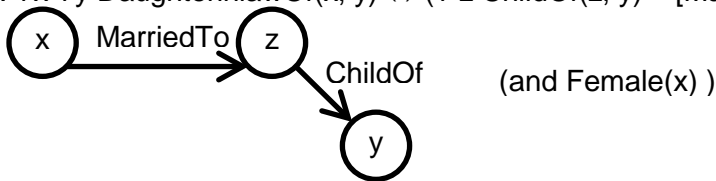
**4.a (4 pts)** \_\_\_\_\_ “Your Half-sister (x) is a sister who has a parent (z) that is not a parent of you (y).”

- A.  $\forall x \forall y \text{ HalfsisterOf}(x, y) \leftrightarrow (\exists z [\text{SisterOf}(x, y) \Rightarrow \text{ParentOf}(z, x)] \wedge \neg \text{ParentOf}(z, y))$   
 B.  $\forall x \forall y \text{ HalfsisterOf}(x, y) \leftrightarrow (\forall z \text{ SisterOf}(x, y) \wedge [\text{ParentOf}(z, x) \Rightarrow \neg \text{ParentOf}(z, y)])$   
 C.  $\forall x \forall y \text{ HalfsisterOf}(x, y) \leftrightarrow (\forall z \text{ SisterOf}(x, y) \wedge \text{ParentOf}(z, x) \wedge \neg \text{ParentOf}(z, y))$   
 D.  $\forall x \forall y \text{ HalfsisterOf}(x, y) \leftrightarrow (\exists z \text{ SisterOf}(x, y) \wedge \text{ParentOf}(z, x) \wedge \neg \text{ParentOf}(z, y))$



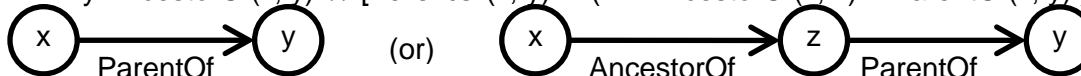
**4.b (4 pts)** \_\_\_\_\_ “Your daughter-in-law (x) is a female who is married to a child (z) of you (y).”

- A.  $\forall x \forall y \text{ DaughterinlawOf}(x, y) \leftrightarrow (\exists z [\text{ChildOf}(z, y) \wedge \text{MarriedTo}(x, z)] \Rightarrow \text{Female}(x))$   
 B.  $\forall x \forall y \text{ DaughterinlawOf}(x, y) \leftrightarrow (\forall z \text{ ChildOf}(z, y) \wedge \text{MarriedTo}(x, z) \wedge \text{Female}(x))$   
 C.  $\forall x \forall y \text{ DaughterinlawOf}(x, y) \leftrightarrow (\exists z \text{ ChildOf}(z, y) \wedge \text{MarriedTo}(x, z) \wedge \text{Female}(x))$   
 D.  $\forall x \forall y \text{ DaughterinlawOf}(x, y) \leftrightarrow (\forall z \text{ ChildOf}(z, y) \vee [\text{MarriedTo}(x, z) \wedge \text{Female}(x)])$



~~**4.c (4 pts)**~~ \_\_\_\_\_ “Your ancestor (x) is a parent of you (y) or an ancestor of a parent (z) of you (y).”

- A.  $\forall x \forall y \text{ AncestorOf}(x, y) \leftrightarrow [\text{ParentOf}(x, y) \vee (\exists z \text{ AncestorOf}(x, z) \wedge \text{ParentOf}(z, y))]$   
 B.  $\forall x \forall y \text{ AncestorOf}(x, y) \leftrightarrow [\text{ParentOf}(x, y) \vee (\forall z \text{ AncestorOf}(x, z) \wedge \text{ParentOf}(z, y))]$   
 C.  $\forall x \forall y \text{ AncestorOf}(x, y) \leftrightarrow [\text{ParentOf}(x, y) \vee (\exists z \text{ AncestorOf}(x, z) \vee \text{ParentOf}(z, y))]$   
 D.  $\forall x \forall y \text{ AncestorOf}(x, y) \leftrightarrow [\text{ParentOf}(x, y) \vee (\forall z \text{ AncestorOf}(x, z) \wedge \text{ParentOf}(z, y))]$



**4.c IS CANCELLED.**

Everyone gets 4.c right, regardless of your answer.

The reason was a copy-and-edit bug on the original Exam, which has been fixed in this revised version.

So, for future study, you may use this revised version as a reliable guide.

**5. (10 pts total, -5 for each error, but not negative) RESOLUTION THEOREM PROVING.** You are engaged in Knowledge Engineering for the Wumpus Cave. You have interviewed an expert on the Wumpus Cave who told you, among other things, "A breeze in square (1,1) is equivalent to a pit in square (1,2) or a pit in square (2,1)." You translated this into propositional logic as, " $(B11 \Leftrightarrow P12 \vee P21)$ ," and then into Conjunctive Normal Form as " $(\neg B11 \vee P12 \vee P21) \wedge (\neg P12 \vee B11) \wedge (\neg P21 \vee B11)$ ."

Now it is time for the first "live" test of your system. An agent has been lowered down into the Wumpus cave, and reports back by radio, "Square (1,1) has a breeze. Also, I went into square (1,2) and I did not die, so it does not have a pit." You translate this knowledge into propositional logic as " $(B11) \wedge (\neg P12)$ " and add it to your knowledge base.

Next your system is asked to perform inference. The agent asks by radio, "Is it true that square (2,1) has a pit?" You translate this query into propositional logic as the goal sentence " $(P21)$ ." You form the negated goal as " $(\neg P21)$ ." Your knowledge base plus negated goal is:

- $(\neg B11 \vee P12 \vee P21)$
- $(\neg P12 \vee B11)$
- $(\neg P21 \vee B11)$
- $(B11)$
- $(\neg P12)$
- $(\neg P21)$

Run resolution on this knowledge base until you produce the null clause, " $( )$ ", thereby proving that the goal sentence is true. The shortest proof I know of is only three lines long. (Bonus points for a shorter proof.) It is OK to use more than lines, if your proof is correct.

Repeatedly choose two clauses, write one clause in the first blank space on a line, and the other clause in the second. Apply resolution to them. Write the resulting clause in the third blank space, and insert it into the knowledge base.

Resolve \_\_\_\_\_ and \_\_\_\_\_ to give \_\_\_\_\_

Resolve \_\_\_\_\_ and \_\_\_\_\_ to give \_\_\_\_\_

Resolve \_\_\_\_\_ and \_\_\_\_\_ to give \_\_\_\_\_

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Resolve \_\_\_\_\_ and \_\_\_\_\_ to give \_\_\_\_\_

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**6. (10 pts total, 1 pt each) Probability Rules and Independence.**

Consider the following full joint distribution for Boolean variables A, B, and C:

A	B	C	$P(a,b,c)$
t	t	t	0.03
t	t	f	0.12
t	f	t	0.17
t	f	f	0.18
f	t	t	0.03
f	t	f	0.12
f	f	t	0.24
f	f	f	0.11

Write an arithmetical expression that will evaluate to the following probabilities. You do not need to add up the numbers to produce a single numerical result. It is sufficient for you to write an arithmetical expression that will evaluate to the correct numerical result. The first one is done for you, as an example.

6.example  $P(A = f, B = f, C = f \mid A = f, B = f) = \underline{0.11 / (0.24 + 0.11) [\approx 0.3143]}$

6.a. (1 pt)  $P(A = f) = \underline{\hspace{10cm}}$

6.b. (1 pt)  $P(B = t) = \underline{\hspace{10cm}}$

6.c. (1 pt)  $P(B = t, C = t) = \underline{\hspace{10cm}}$

6.d. (1 pt)  $P(A = f, C = t) = \underline{\hspace{10cm}}$

6.e. (1 pt)  $P(A = t \mid B = t) = \underline{\hspace{10cm}}$

6.f. (1 pt)  $P(C = f \mid B = t) = \underline{\hspace{10cm}}$

6.g. (1 pt) Are A and B independent of each other? (Y=Yes, N=No):                     

6.h. (1 pt) Are B and C independent of each other? (Y=Yes, N=No):                     

~~6.i.~~ (1 pt) Are B and C conditionally independent given A? (Y=Yes, N=No):                     

~~6.j.~~ (1 pt) Are A and C conditionally independent given B? (Y=Yes, N=No):                     

**Problem 6.i and 6.j are cancelled.**  
Everyone gets 6.i and 6.j right, regardless of your actual answer.

Problem 6.i and 6.j may require calculating up to eight numeric conditional probabilities before the correct answer is apparent. Yet, we prohibit electronic calculators, so all calculations must be done by hand.

**We decided that this laborious manual process was too tedious, time-consuming, and complicated to be a fair question on a timed closed-book no-calculator Exam, so 6.i and 6.j are cancelled.**

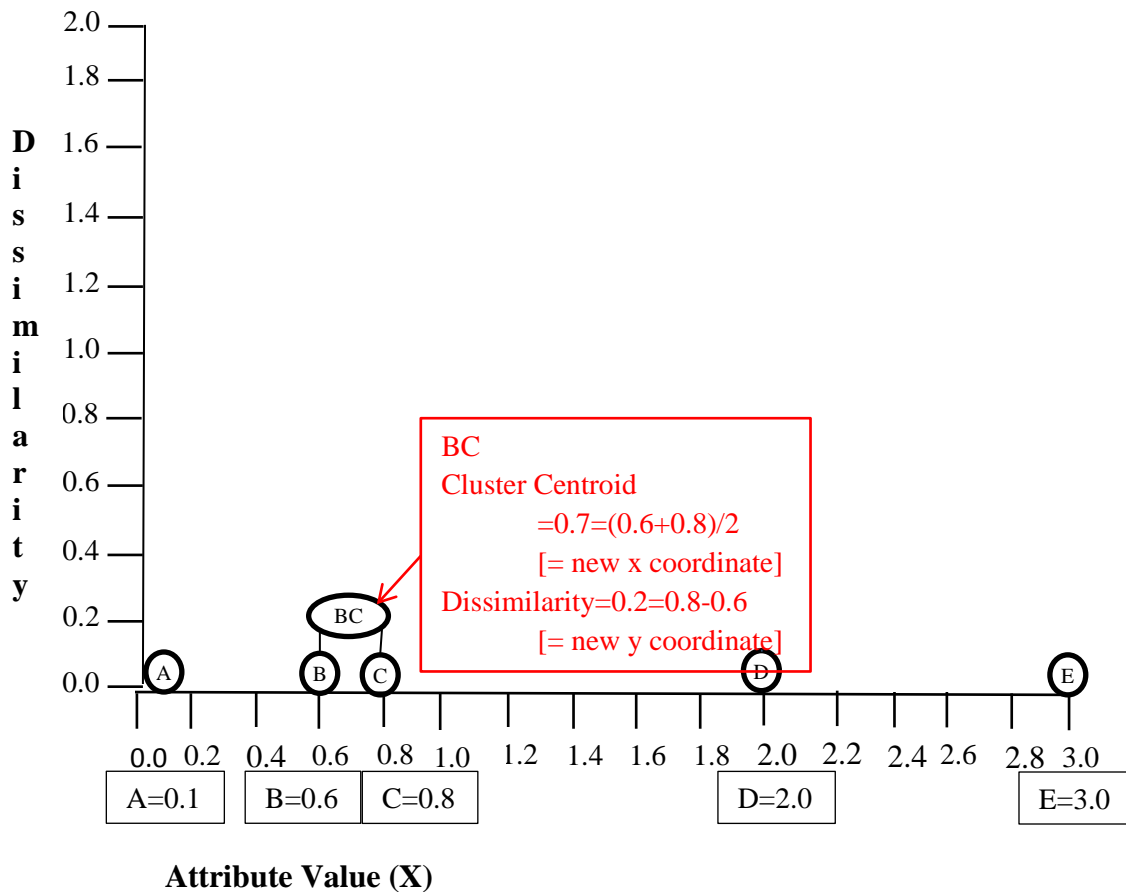


7. (5 pts total) **Hierarchical Agglomerative Clustering.** Consider this training data set (it is the same as in problem 1). Examples are A-E, and the single attribute is X.

Example	A	B	C	D	E
Attribute Value (X)	0.1	0.6	0.8	2.0	3.0

**Draw the dendrogram (clustering tree) that results from applying hierarchical agglomerative clustering to this data.** When two clusters are merged, replace them with their cluster centroid, i.e., the statistical mean of all cluster members. This rule means, (1) each cluster is represented by its cluster centroid which is the numerical mean (average) of all of its cluster members; and (2) dissimilarity between clusters is computed as the distance between their cluster centroids using Euclidean distance. **(Note: A better measure of dissimilarity is the root-mean-squared-deviation [RMSD] of each cluster member from its cluster centroid; but that is infeasible in an exam like this.)** Label the cluster centroids by drawing an oval around the data points that are included in that cluster centroid. The first one is done for you as an example.

You are only obliged draw the clustering tree (dendrogram) that results. You do not need to write in the Cluster Centroid and Dissimilarity information shown in the square box below, which is provided only for your information about how to work the problem.



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**9. Logic Concepts (6 pts total, 1 pt each).**

A .	Logic	A	Formal symbol system for representation and inference
	Valid	B	The idea that a sentence follows logically from other sentences
	Complete	C	True in every possible world
	Conjunctive Normal Form	D	True in at least one possible world
	Sound	E	A sentence expressed as a conjunction of clauses (disjuncts)
	Satisfiable	F	Inference system derives only entailed sentences
	Entailment	G	Inference system can derive any sentence that is entailed

**10. Probability concepts and formulae (9 pts total, 1 pt each).**

A .	Probability Theory	A	Assigns each sentence a degree of belief ranging from 0 to 1
	Conditional independence	B	Degree of belief accorded without any other information
	Independence	C	Degree of belief accorded after some evidence is obtained
	Product rule (chain rule)	D	Gives probability of all combinations of values of all variables
	Conditional probability	E	Takes values from its domain with specified probabilities
	Unconditional probability	F	A possible world is represented by variable/value pairs
	Factored representation	G	$P(a \wedge b) = P(a) P(b)$
	Random variable	H	$P(a \wedge b   c) = P(a   c) P(b   c)$
	Bayes' rule	I	$P(a   b) = P(b   a) P(a) / P(b)$
	Joint probability distribution	J	$P(a \wedge b \wedge c) = P(a   b \wedge c) P(b   c) P(c)$

**11. (8 pts total, -1 pt each wrong answer, but not negative) SEARCH PROPERTIES.**

Fill in the values of the four evaluation criteria for each search strategy shown. Assume a tree search where  $b$  is the finite branching factor;  $d$  is the depth to the shallowest goal node;  $m$  is the maximum depth of the search tree;  $C^*$  is the cost of the optimal solution; step costs are identical and equal to some positive  $\epsilon$ ; and in Bidirectional search both directions use breadth-first search.

Note that these conditions satisfy all of the footnotes of Fig. 3.21 in your book.

Criterion	Complete?	Time complexity	Space complexity	Optimal?
Breadth-First				
Uniform-Cost				
Depth-First				
Iterative Deepening				
Bidirectional (if applicable)				

**12. (4 pts total, 1 pt each) TASK ENVIRONMENT.** Your book defines a task environment as a set of four things, with the acronym PEAS. Fill in the blanks with the names of the PEAS components.

P \_\_\_\_\_ E \_\_\_\_\_ A \_\_\_\_\_ S \_\_\_\_\_

\*\*\*\* THIS IS THE END OF THE MID-TERM EXAM \*\*\*\*