For each question on the Mid-term Exam, “Zero” below gives the fraction of students who scored zero, “Partial” gives the fraction who got partial credit, and “Perfect” gives the fraction who scored 100%.

Problem 1
Zero: 11% (~20 students), Partial: 66% (~120 students) , Perfect: 23% (~43 students)

Problem 2
Zero: 6% (~11 students), Partial: 68% (~124 students), Perfect: 26% (~47 students)

Problem 3
Zero: 19% (~34 students), Partial: 43% (~78 students), Perfect: 38% (~70 students)

Problem 4
Zero: 5% (~10 students), Partial: 75% (~136 students), Perfect: 20% (~36 students)

Problem 5
Zero: 4% (~8 students), Partial: 90% (~163 students), Perfect: 6% (~11 students)

Problem 6
Zero: 2% (~3 students), Partial: 1% (~2 students), Perfect: 97% (~177 students)

Problem 7
Zero: 5% (~9 students), Partial: 32% (~59 students), Perfect: 63% (~114 students)

Problem 8
Zero: 0% (~0 students), Partial: 45% (~82 students), Perfect: 55% (~100 students)

Problem 9
Zero: 13% (~25 students), Partial: 63% (~114 students), Perfect: 24% (~43 students)

Problem 10
Zero: 1% (~2 students), Partial: 76% (~138 students), Perfect: 23% (~41 students)

The Mid-term exam is now a pedagogical device.

You can recover 50% of your missed points by showing that you have debugged and repaired your knowledge base.

For each question on your exam where points were deducted:

Write about 4 sentences, and perhaps an equation or two.

Describe:

* What was the bug in your knowledge base that led to the error?

* How have you repaired your knowledge base so that the error will not happen again?

Please, do not write on your exam.

Please prepare a written document that describes the points above, print it out, and staple it to the first page of your exam. Please place the staple so that we can still read the header information on your exam.

Turn it in at the beginning of class on Tuesday, 2 December.

CS-171, Intro to A.I. — Mid-term Exam — Fall Quarter, 2014

YOUR NAME: ______________________________________

YOUR ID: __________ ID TO RIGHT: __________ ROW: ________ SEAT: ________

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

When you are told to begin the exam, please check first to make sure that you have all ten pages, as numbered 1-10 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 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.

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

1. (10 pts total, -1 pt each wrong answer, but not negative) MINIMAX WITH ALPHA-BETA PRUNING.

2. (10 pts total, 2 pts each) CSP WITH BACKTRACKING SEARCH.

3. (6 pts total, 2 pts each) CONVERSION TO CNF.

4. (6 pts total, 2 pts each) RESOLUTION OF CLAUSES.

5. (10 pts total, 1 pt each) LOGIC.

6. (8 pts total, 2 pts each) TASK ENVIRONMENT.

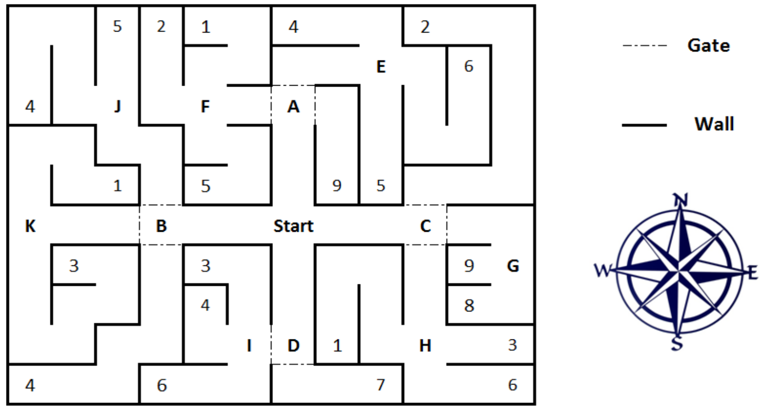
7. (10 pts total, 1/2 pt each) SEARCH PROPERTIES.

8. (15 points total, 3 pts each) CONSTRAINT SATISFACTION PROBLEMS.

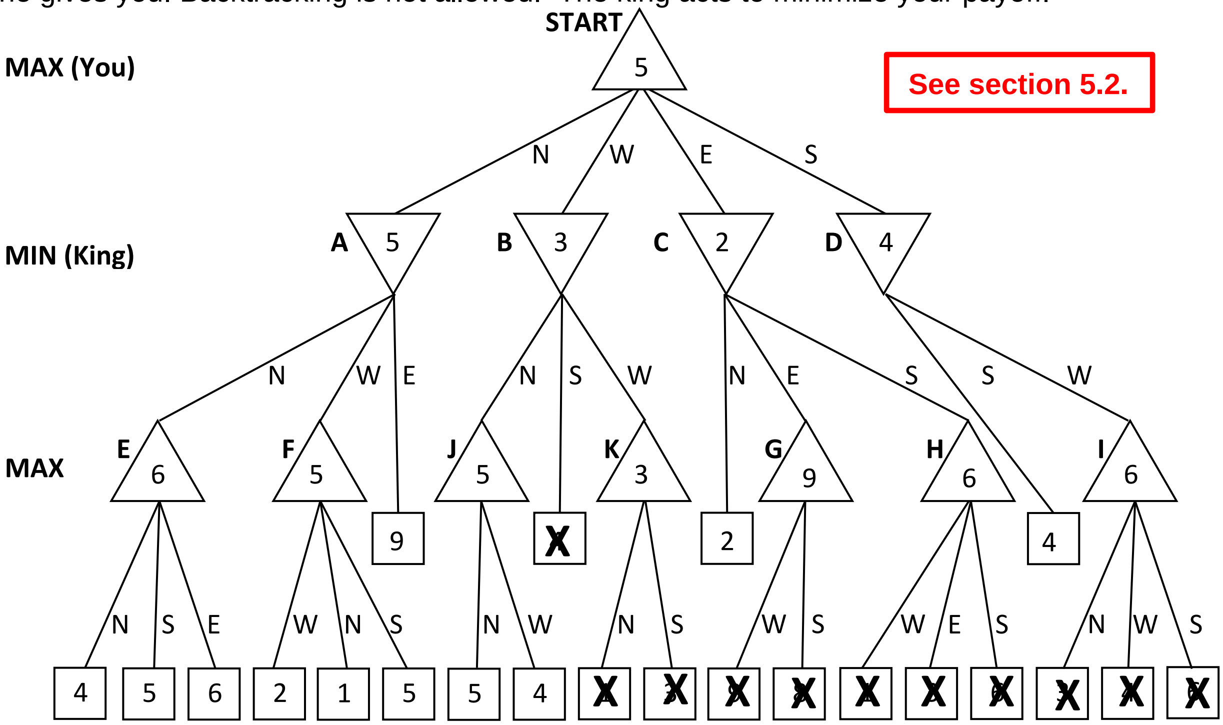
9. (10 pts total) RESOLUTION THEOREM PROVING.

10. (15 pts total, 3 pts each) STATE-SPACE SEARCH.

1. **(10 pts total, -1 pt each wrong answer, but not negative) MINIMAX WITH ALPHA-BETA PRUNING.** While visiting Crete, you are challenged by a passing king to what he calls the "Labyrinth Challenge". The rules are simple: you must make your way through a maze to find the largest prize for yourself. You are given the following map to plan your route:



You will start in the maze at the location labeled START and may travel North (N), South (S), East (E), or West (W). Your goal is to secure the largest, single prize for yourself, represented by the numbers spread across the maze. At four specific intersections (A, B, C, D), the king will be able to close off all but one pathway by closing gates around you, forcing you to take the path he gives you. Backtracking is not allowed. The king acts to minimize your payoff.



1.a. Fill in each blank triangle with its Mini-Max value. Process the game tree left-to-right.

1.b. Cross out each leaf node that will be pruned by Alpha-Beta pruning. Go left-to-right.

See section 5.3.

1.c. What is the best move for MAX? (write N, W, E, or S) ____N______

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2. (10 pts total, 2 pts each) CSP WITH BACKTRACKING SEARCH. This question will use CSP algorithms on a 6-queens problem. Variable Vi represents the row of the queen placed in column i. Each variable Vi has domain Di = {1,2,3,4,5,6}. The 6-queens problem requires that we place all 6 queens on the board such that none of them can attack each other; so we cannot have 2 queens in the same row, column, or diagonal. At this point we are part-way through the search, so one of the variables already has been assigned as V1 = 3 (see figure below).

Show the search state after going all the way down the first branch in the search tree. Stop when you have either (1) found a solution, or (2) fail and need to backtrack.

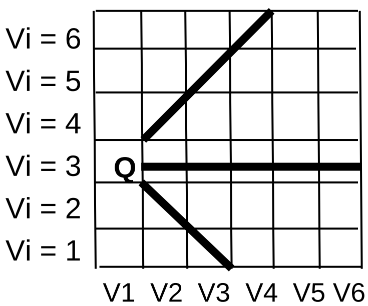
Use (1) Forward Checking, (2) variable ordering by the Minimum Remaining Values (MRV) heuristic, (3) value ordering by the Least Constraining Value (LCV) heuristic. When there are ties on variable ordering from the MRV heuristic, break the tie by preferring the left-most tied variable. When there are ties on value ordering from the LCV heuristic, break ties by preferring the smallest value. At this point, you are part-way through the search, and you have just failed at V1 = 1 and V1 = 2, so V1 = 3 is the only assignment now. The first one (V1 = 3) is done for you as an example of what the problem asks for and how to fill it in ("Q" means queen).

2.a. Write the next selected variable, or "Fail" if you need to backtrack now: ____V1____

Write the value assigned to the selected variable: ______3______

See section 6.3.

Write Q where you put your queen. Draw a line through values removed by Forward Checking. You will find it helpful to propagate your previous Qs and lines, but that is not required.

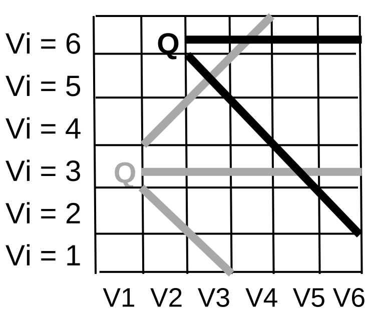


Before the first assignment, all variables have MRV=6, and so you choose the left-most, V1, as the instructions state. All choices of values for V1 remove 10 values from other domains, so you order them smallest-to-largest as the instructions state. You have just failed on V1=1 and V1=2. Now you have made the assignment V1=3, as shown.

2.b. (2 pts) Write the next selected variable, or "Fail" if you need to backtrack now: ____V2____

Write the value assigned to the selected variable: ______6______

Write Q where you put your queen. Draw a line through values removed by Forward Checking. You will find it helpful to propagate your previous Qs and lines, but that is not required.

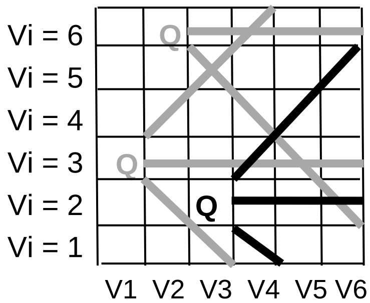


Both V2&V3 have the same MRV=3, while V4 has MRV=4 and V5&V6 have MRV=5. We break the tie between V2&V3 by preferring the left-most, which is V2. At this point, D2={1,5,6}. Assigning V2=1 removes 6 values, and V2=5 removes 7 values, from unassigned variable domains. Assigning V2=6 removes only 5, and so V2=6 is preferred by the LCV heuristic. Remember that the LCV heuristic counts <u>ONLY values that have not previously been removed.</u>

2.c. (2 pts) Write the next selected variable, or “Fail” if you need to backtrack now: ______V3____

Write the value assigned to the selected variable: ________2______

Write Q where you put your queen. Draw a line through values removed by Forward Checking. You will find it helpful to propagate your previous Qs and lines, but that is not required.

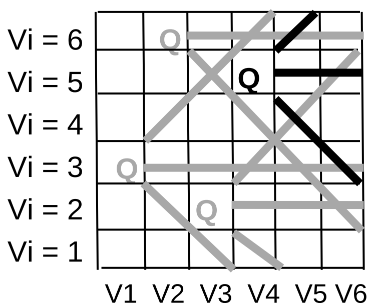


V3 has MRV=2, while V4&V6 have MRV=3 and V5 has MRV=4. So MRV prefers V3. At this point, D3={2,4}. Assigning V3=2 or V3=4 both remove 5 values from unassigned variables domains, so neither is preferred by the LCV heuristic. We break the tie by assigning the least value, V3=2, as stated in the instructions.

2.d. (2 pts) Write the next selected variable, or “Fail” if you need to backtrack now: ______V4____

Write the value assigned to the selected variable: ________5______

Write Q where you put your queen. Draw a line through values removed by Forward Checking. You will find it helpful to propagate your previous Qs and lines, but that is not required.

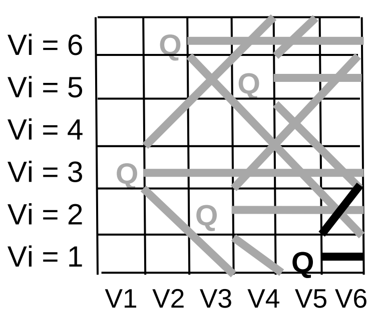


V4 has MRV=1 while V5&V6 have MRV=2. So MRV prefers V4. At this point, D4={5}, so there is only one assignment available and it is made.

2.e. (2 pts) Write the next selected variable, or “Fail” if you need to backtrack now: ______V5____

Write the value assigned to the selected variable: ________1______

Write Q where you put your queen. Draw a line through values removed by Forward Checking. You will find it helpful to propagate your previous Qs and lines, but that is not required.



V5 has MRV=1 while V6 has MRV=2. So MRV prefers V5. At this point, D5={1}, so there is only one assignment available and it is made.

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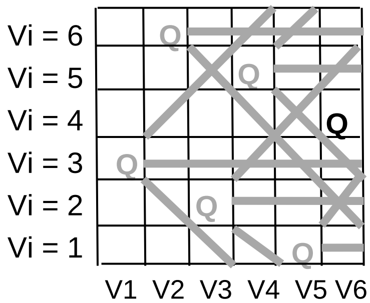
2.f. (2 pts) Write the next selected variable, or “Fail” if you need to backtrack now: ______V6____

Write the value assigned to the selected variable: _________4______

Write Q where you put your queen. Draw a line through values removed by Forward Checking. You will find it helpful to propagate your previous Qs and lines, but that is not required.



V6 has MRV=1 while no other variables are available. So MRV prefers V6. At this point, D6={4}, so there is only one assignment available and it is made.

Success!!

In a “real” search, we actually would have succeeded at V1 = 2, as you can see easily by rotating this solution 90 degrees in either direction. But to do so requires backtracking, and that would have made the problem too long and complicated to work in an exam. So, you were asked to start at V1 = 3 instead.

3. (6 pts total, 2 pts each) CONVERSION TO CNF. Convert these expressions to CNF.

See section 7.5.

3.a. (2 pts) (A ⇔ (B ∨ C)) ______((A ¬B) (A ¬C) (¬A B C))________

3.b. (2 pts) ((C ∧ D) ⇒ ¬E) ______(¬C ¬D ¬E)______

3.c. (2 pts) ((A ⇒ B) ⇒ C) ______((A C) (¬B C))______

3.a is sentence S1, and 3.b is sentence S3, of problem 7.20, p. 283, in your textbook, after variable relabeling.

It is OK if you put in “∨” and “∧” above. For example, it is OK if you answered 3.a. as ((A ∨ ¬B) ∧ (A ∨ ¬C) ∧ (¬A ∨ B ∨ C)), and so on.

4. (6 pts total, 2 pts each) RESOLUTION OF CLAUSES. Use resolution to resolve the following pairs of clauses, simplify, and write the resulting clause. If no resolution is possible write “None”. If the resolvent simplifies to True write “True.” If more than one resolution is possible, pick any one that you like, and write its simplified result.

See section 7.5.

4.a. (2 pts) Resolve (A B C) with (B ¬C ¬D) to yield ____(A B ¬D)________________

4.b. (2 pts) Resolve (A B C) with (¬B ¬C ¬D) to yield ____True________________

4.c. (2 pts) Resolve (A B C) with (B C ¬D) to yield _____None________________

Problem 5 here is a subset of problem 7.4, p. 280, in your textbook.

The deduction theorem, section 7.5, p. 249, turns "A |= B" into "A ⇒ B is valid."

5. (10 pts total, 1 pt each) LOGIC. Which of the following are correct? **(T = True, F**
Recall that the symbol "|=" means "entails."

5.a. (1 pt) ___T___ *False* |= *True*. **(*False* ⇒ *True*) is valid.**

5.b. (1 pt) ___F___ *True* |= *False*. **(*True* ⇒ *False*) is unsatisfiable.**

5.c. (1 pt) ___T___ $(A \land B) \models (A \Leftrightarrow B)$. **(A ∧ B) entails (A = *True*) and (B = *True*).**

5.d. (1 pt) ___F___ $(A \Leftrightarrow B) \models (A \lor B)$. **Suppose (A = *False*) and (B = *False*).**

5.e. (1 pt) ___T___ $(A \Leftrightarrow B) \models (\neg A \lor B)$. **A & B are both true or both false, so (¬ A ∨ B) is true.**

5.f. (1 pt) ___T___ $((A \land B) \Rightarrow C) \models (A \Rightarrow C) \lor (B \Rightarrow C)$. **Work it out; when must KB be true?**

5.g. (1 pt) ___T___ $(A \lor B) \land (\neg C \lor \neg D \lor E) \models (A \lor B)$. **A conjunction entails every conjunct.**

5.h. (1 pt) ___F___ $(A \lor B) \land (\neg C \lor \neg D \lor E) \models (A \lor B) \land (\neg D \lor E)$. **(C = E = *False*), (A = B = D = *True*).**

5.i. (1 pt) ___T___ $(A \lor B) \land \neg (A \Rightarrow B)$ is satisfiable. **Suppose (A = *True*) and (B = *False*).**

5.j. (1 pt) ___T___ $(A \Leftrightarrow B) \land (\neg A \lor B)$ is satisfiable. **Suppose (A = *True*) and (B = *True*).**

6. (8 pts total, 2 pts 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.

See Section 2.3.1.

Performance (measure)   Environment   Actuators   Sensors

7. (10 pts total, 1/2 pt each) 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 ε; and in Bidirectional search both directions using breadth-first search.

See Figure 3.21.

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	Yes	O(b^d)	O(b^d)	Yes
Uniform-Cost	Yes	O(b^(1+floor(C*/ε))) O(b^(d+1)) also OK	O(b^(1+floor(C*/ε))) O(b^(d+1)) also OK	Yes
Depth-First	No	O(b^m)	O(bm)	No
Iterative Deepening	Yes	O(b^d)	O(bd)	Yes
Bidirectional (if applicable)	Yes	O(b^(d/2))	O(b^(d/2))	Yes

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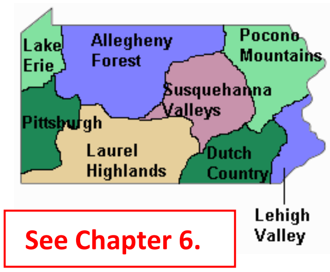
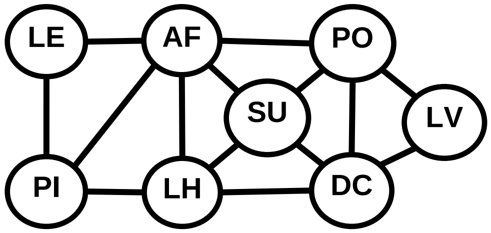
8. (15 points total, 3 pts each) CONSTRAINT SATISFACTION PROBLEMS.



See Chapter 6.



AF = Allegheny Forest
DC = Dutch Country
LE = Lake Erie
LH = Laurel Highlands
LV = Lehigh Valley
PI = Pittsburgh
PO = Pocono Mountains
SU = Susquehanna Valleys

You are a map-coloring robot assigned to color this Pennsylvania region map. Adjacent regions must be colored a different color (R=Red, B=Blue, G=Green). The constraint graph is shown.

8.a. (3 pts total) FORWARD CHECKING. Cross out all values that wo See section 6.3.2. by Forward Checking, after variable LH has just been assigned value G, as shown:

AF	DC	LE	LH	LV	PI	PO	SU
R ~~G~~ B	R ~~G~~ B	R G B	G	R G B	R ~~G~~ B	R G B	R ~~G~~ B

8.b. (3 pts total) ARC CONSISTENCY.
AF and LE have been assigned values, but no constraint propagation h See section 6.2.2.
Cross out all values that would be eliminated by Arc Consistency (AC-3 in your book).

AF	DC	LE	LH	LV	PI	PO	SU
B	~~R~~ ~~G~~ B	R	R ~~G~~ ~~B~~	~~R~~ G ~~B~~	~~R~~ G ~~B~~	R ~~G~~ ~~B~~	~~R~~ G ~~B~~

8.c. (3 pts total) MINIMUM-REMAINING-VALUES HEURISTIC. Consider the assignment below. PO is assigned and constraint propagation has been done. List all unassigned variables that might be selected by the Minimum-Remainin See section 6.3.1. Heuristic:_______**AF, DC, LV, SU**____________.

AF	DC	LE	LH	LV	PI	PO	SU
G B	G B	R G B	R G B	G B	R G B	R	G B

8.d. (3 pts total) DEGREE HEURISTIC. Consider the assignment below. (It is the same assignment as in problem 8.c. above.) PO is assigned and constraint propagation has been done. List all unassigned variables that might be selected by See section 6.3.1. Heuristic:_______**LH, AF**____________.

AF	DC	LE	LH	LV	PI	PO	SU
G B	G B	R G B	R G B	G B	R G B	R	G B

8.e. (3 pts total) MIN-CONFLICTS HEURISTIC. Consider the complete but inconsistent assignment below. AF has just been selected to be assigned a new valu See section 6.4. search for a complete and consistent assignment. What new value would below for AF by the Min-Conflicts Heuristic?.__________**R**__________.

AF	DC	LE	LH	LV	PI	PO	SU
?	G	G	R	G	B	B	G

9. (10 pts total) RESOLUTION THEOREM PROVING. Solve this puzzle as a logic agent.

"Three girls took part in a race. Alison (A) finished before Betty (B) but behind Clare (C). What was the finishing order?"

Obviously, the finishing order was C, A, B. You will use resolution to prove this fact.

You create 9 propositional variables, A/B/C1/2/3, to indicate that A, B, or C finished in place 1, 2, or 3. Your Knowledge Base is:

See section 7.5.

A bright and clever student has constructed a shorter proof than I was able to find:

1. **Resolve (A1 A2) and (¬A1 ¬A3) to give (A2 ¬A3)**
2. **Resolve (A2 ¬A3) and (A2 A3) to give (A2)**
3. **Resolve (A2) and (¬C1 ¬A2 ¬B3) to give (¬C1 ¬B3)**
4. **Resolve (A2) and (¬A1 ¬A2) to give (¬A1)**
5. **Resolve (¬A1) and (A1 B3) to give (B3)**
6. **Resolve (A3 C1) and (¬C1 ¬B3) to give (A3 ¬B3)**
7. **Resolve (A3 ¬B3) and (¬A3 ¬B3) to give (¬B3)**
8. **Resolve (¬B3) and (B3) to give ()**

(A1 ∧ B3) ∨ (A2 ∧ B3))

∨ (C1 ∧ A3) ∨ (C2 ∧ A3))

ond, or third:

((… => ¬(A1 ∨ A2))

((… => ¬(B1 ∨ B2))

((… => ¬(C1 ∨ C2))

… ve among contestants:

((… => ¬(A1 ∨ B1))

((… => ¬(A2 ∨ B2))

((… => ¬(A3 ∨ B3))

… to CNF is:

In a "real" situation, you would create one such sentence for each such possible finishing order, and submit them all at the same time in parallel. The correct finishing order would produce its own proof of its own correctness.

(¬A3 ¬B3) (¬ A3 ¬C3) (¬ B3 ¬C3)

Your goal sentence is (C1 ∧ A2 ∧ B3) so your negated goal sentence is:

(¬C1 ¬A2 ¬B3)

Other proofs are OK as long as they are correct.

Produce a resolution proof that the finishing order was (C1 ∧ A2 ∧ B3). 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. Continue until ( ). Use more lines if needed.

Resolve (A1 A2) and (¬ A1 ¬A3) to give (A2 ¬A3).

Resolve (A2 ¬A3) and (A2 A3) to give (A2).

Resolve (A2) and (¬C1 ¬A2 ¬B3) to give (¬C1 ¬B3)

Resolve (A2) and (¬A1 ¬A2) to give (¬A1).

Resolve (¬A1) and (A1 B3) to give (B3).

Resolve (B3) and (¬C1 ¬B3) to give (¬C1).

Resolve (¬C1) and (A3 C1) to give (A3).

Resolve (A3) and (¬ A2 ¬A3) to give (¬ A2).

Resolve (¬ A2) and (A2) to give ( ).

Keep reducing the number of literals per clause, until you reach zero. Most resolvents (3rd column) have only one literal; two have two, and one (the last) has zero (goal).

Extra lines or steps are OK as long as your proof is correct.

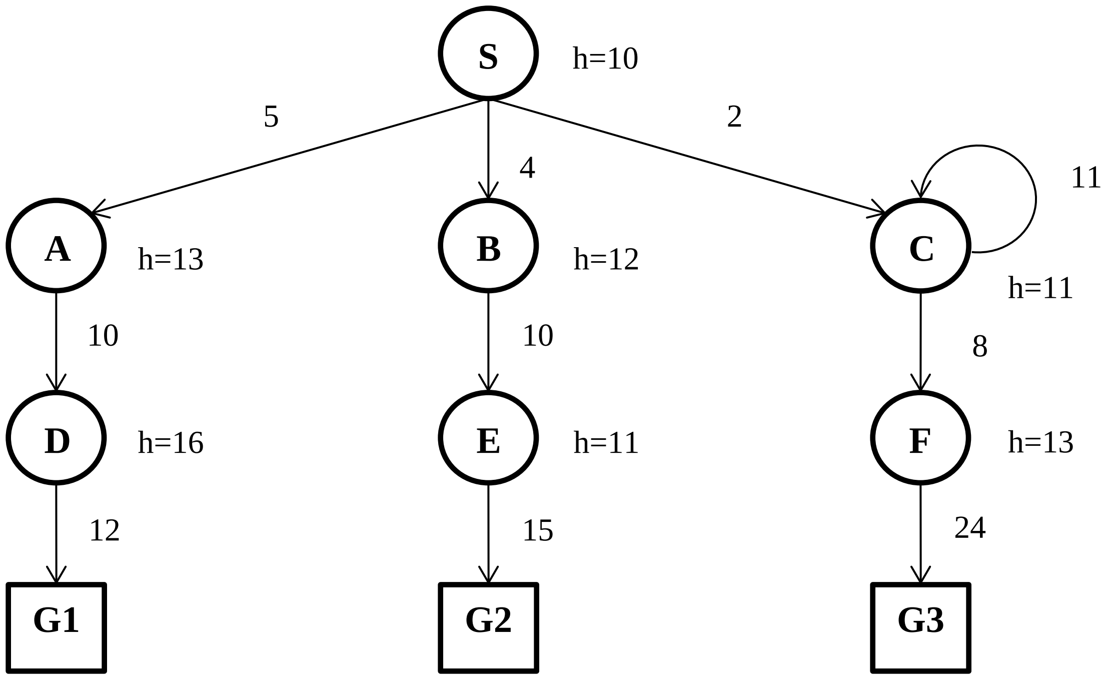
It is expected you will simplify expressions. E.g., if you resolved (¬ B ∨ ¬ D) and (B ∨ ¬ D) to give (¬ D ∨ ¬ D), of course you would simplify it to (¬ D). You will simplify the expressions as you go, you don't need a separate step.

10. (15 pts total, 3 pts each) STATE-SPACE SEARCH. Execute Tree Search through this graph (i.e., d… d nodes, so repeated nodes are possible). It is not a tree, but pretend you don't k… e given next to ea… The successors of each node are indicated… to-right order. The successors of S are A/…

See Chapter 3.

Please see the lecture slides for Uninformed Search, topic "When to do Goal-Test? When generated? When popped?" for clarification about exactly what to do in practical cases.

For each search strategy below, in… are generated), ending with the goal node that is found. The first one is done for you as an example.



10.a. DEPTH FIRST SEARCH.

See section 3.4.3.

S A D G1

10.b. (3 pts, -1 for each wrong answer, but not negative) UNIFORM COST SEARCH.

See section 3.4.2. **UCS does goaltest when node is popped off queue.**

S C B A F C E D F C G1

10.c. (3 pts, -1 for each wrong answer, but not negative) GREEDY (BEST-FIRST) SEARCH.

See section 3.5.1. **C always has lower h(=11) than any other node on queue.**

S C C C C C C C C C C etc.

10.d. (3 pts, -1 for each wrong answer, but not negative)

IDS does goaltest when node is generated. Goal G1 is found when D is expanded.

See section 3.4.5

S S A B C S A D G1

10.e. (3 pts, -1 for each wrong answer, but not negative) A* SEARCH.

See section 3.5.2. **A* does goaltest when node is popped off queue.**

S C B A F C E G2

10.f. (3 pts, -1 for each wrong answer, but not negati…

See section 3.3.2.

Question 10.f will be graded based on your answers to11.b (for UCS) and 11.e (for A*).

… find the optimal goal? Yes Why or why not? Step costs are ≥ ε > 0

…timal goal? No Why or why not? heuristic is not admissible (at D)

THIS IS THE END OF THE M…

OK to say "Heuristic overestimated" or "Heuristic is too high."