For the Final Exam, “Perfect” gives the percentage of students who received full credit, “Partial” gives the percentage who received partial credit, and “Zero” gives the percentage who received zero credit.

(Due to rounding, etc., values below may be only approximate estimates.)

CS-171, Intro to A.I. — Final Exam — Winter Quarter, 2016

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 14 pages, as numbered 1-14 in the bottom-right corner of each page (including scratch paper at the end). 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.

<u>Please turn off all cell phones now. No electronics are allowed at any point of the exam.</u>

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 <u>turn it in with your exam</u>.

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

1. (10 pts total, -1 for each error, but not negative) Mini-Max, Alpha-Beta Pruning.

2. (10 pts total, -1 pt each wrong answer, but not negative) Search Properties.

3. (4 pts total, 1 pt each) TASK ENVIRONMENT.

4. (15 pts total) Bayesian Networks.

5. (15 pts total) Decision Tree Learning.

6. (15 pts total; full credit for a correct proof, else 2 pts each useful resolution up to 10 pts) Easter Bunny Resolution Theorem Proving in Propositional Logic.

7. (15 points total, 3 pts each) Constraint Satisfaction Problems.

8. (16 pts total, 2 pts each) English and FOL correspondence.

<u>The Exam is printed on both sides to save trees! Work both sides of each page!</u>

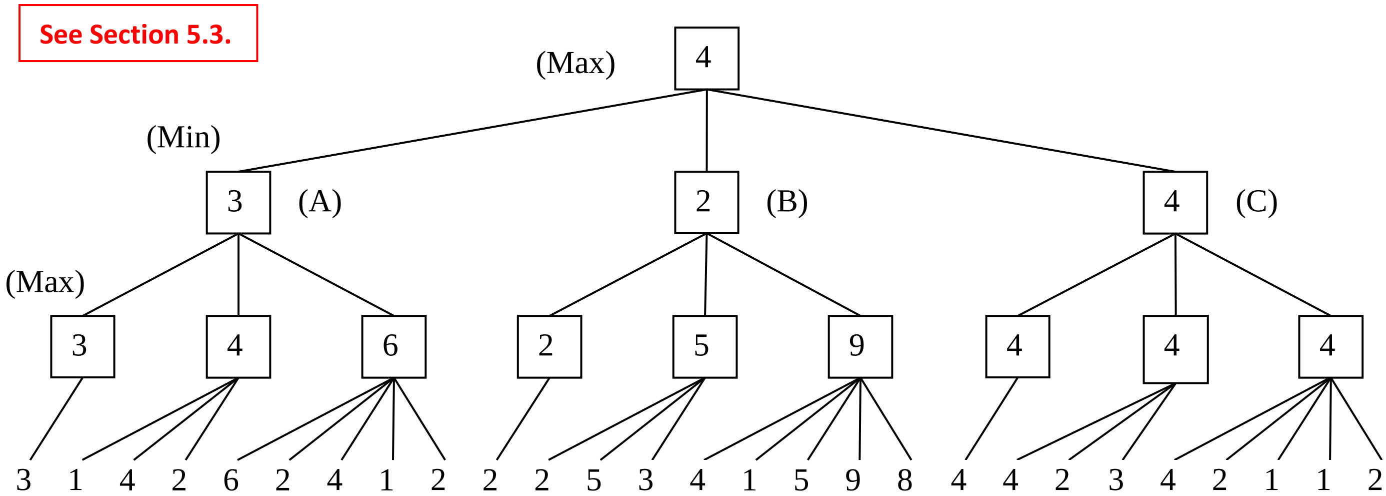
1. (10 pts total, -1 for each error, but not negative) Mini-Max, Alpha-Beta Pruning. In the game tree below it is **Max**'s turn to move. At each leaf node is the estimated score of that resulting position as returned by the heuristic static evaluator.

(1) Perform Mini-Max search and label each branch node with its value.

(2) Put X in the box beneath each leaf node that would be pruned by alpha-beta pruning. The first one has been done for you, as an example.

(3) What is Max's best move (A, B, or C)? C

See Section 5.3.



			X		X	X	X	X		X	X	X	X	X	X	X	X			X	X		X	X	X	X

Put X in the box beneath each leaf node that would be pruned by alpha-beta pruning.
The first one has been done for you, as an example.

2. (10 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 ε; and in Bidirectional search both directions use breadth-first search.

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

See Figure 3.21.

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

3. (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.

Performance (measure)   Environment   Actuators   Sensors

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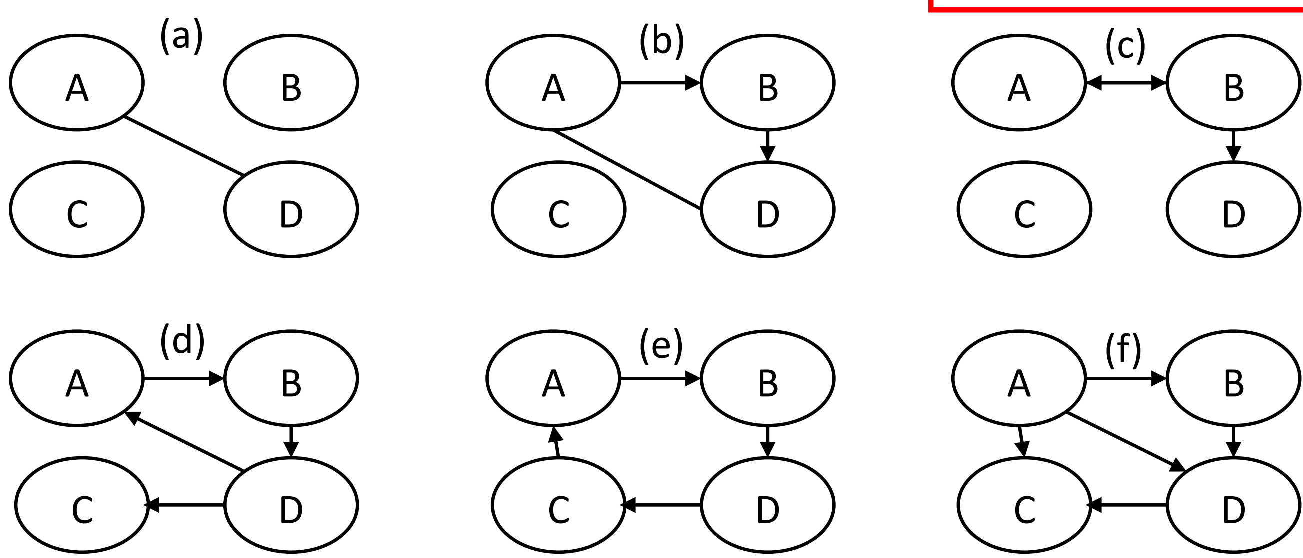
4. (15 pts total) Bayesian Networks.

4.a. (2 pts total, -1 for each error, but not negative) Circle the letters that correspond to all valid Bayesian Networks in the following figure. (If there is not any valid Bayesian Network, circle None.)

Bayesian Networks: None (a) (b) (c) (d) (e) (f)

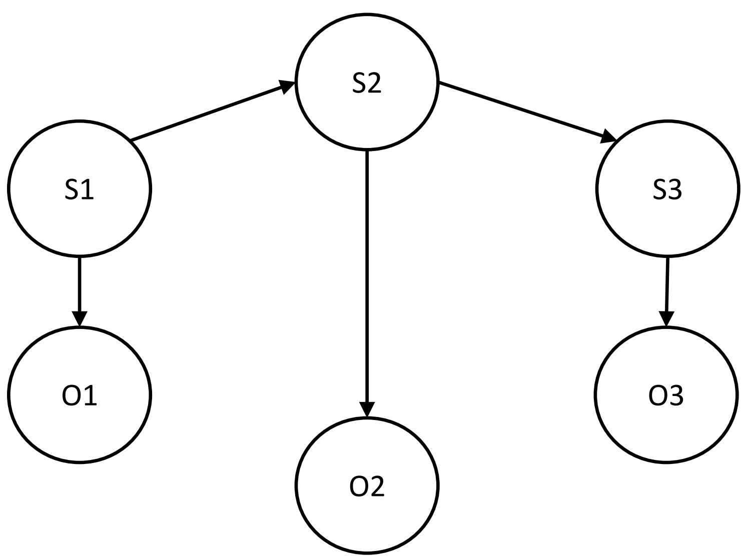
(a), (b) has undirected edge

(c), (d), (e) has a cycle



4.b. (3 pts, -1 for each error, but not negative) Draw the Bayesian Network that corresponds to the following probability distribution. (It is a Hidden Markov Model, popular in speech recognition, etc. By convention, Si = state_i, Oi = observation_i.)

$$P(S1, S2, S3, O1, O2, O3) = P(S1)\, P(S2|S1)\, P(S3|S2)\, P(O1|S1)\, P(O2|S2)\, P(O3|S3)$$



****** PROBLEM CONTINUES ON THE NEXT PAGE ******

4.c. (10 pts total, 2 pts each) Compute the symbolic posterior probability of P(S2 | O1, O2, O3).
Use the probability distribution given in problem 4.b:

$$P(S1, S2, S3, O1, O2, O3) = P(S1)\, P(S2|S1)\, P(S3|S2)\, P(O1|S1)\, P(O2|S2)\, P(O3|S3)$$

All the necessary steps are given below, except for six empty places, circled and labeled (a) to (f).
Fill in the six empty places (a) to (f) below. The first one is done for you as an example.
(Aside: The procedure below follows the forward-backward algorithm.)

$$P(S2 \mid O1,\ O2,\ O3)$$
$$= \frac{P(S2, O1, O2, O3)}{P(O1, O2, O3)} \quad \rightarrow \text{By Definition of Conditional Probability}$$
$$= \frac{P(S2, O1, O2)\, P(O3 \mid S2, O1, O2)}{P(O1, O2, O3)} \rightarrow \text{Apply Product Rule}$$
$$= \frac{P(S2, O1, O2)\, P(O3 \mid \ (\boldsymbol{a})\ )}{P(O1, O2, O3)} \rightarrow \text{Apply Conditional Independence}$$

(example) (a) = S2

$$P(S2,\ O1,\ O2)$$
$$= \sum_{(\boldsymbol{b})} P(S1,\ S2,\ O1, O2) \quad \rightarrow \text{Apply Summation Rule}$$
$$= \sum_{(\boldsymbol{b})} P(S1,\ O1)\, P(S2,\ O2 \mid S1,\ O1) \quad \rightarrow \text{Apply Product Rule}$$
$$= \sum_{(\boldsymbol{b})} P(S1,\ O1)\, P(S2 \mid S1,\ O1)\, P(O2 \mid S1,\ O1,\ S2) \rightarrow \text{Apply Product Rule}$$
$$= \sum_{(\boldsymbol{b})} P(S1,\ O1)\, P(S2 \mid \ (\boldsymbol{c})\ )\, P(O2 \mid \ (\boldsymbol{d})\ ) \rightarrow \text{Apply Conditional Independence}$$

(2 pts) (b) = S1 [s1 ∈ S1 is also OK]

(2 pts) (c) = S1 [s1 is OK if you wrote s1 ∈ S1 in (b) above]

(2 pts) (d) = S2

$$P(O3 \mid S2)$$
$$= \sum_{(\boldsymbol{e})} P(S3,\ O3 \mid (\boldsymbol{a})) \quad \rightarrow \text{Apply Summation Rule}$$
$$= \sum_{(\boldsymbol{e})} P(S3 \mid (\boldsymbol{a})\,)\, P(O3 \mid (\boldsymbol{a}),\ S3) \rightarrow \text{Apply Product Rule}$$
$$= \sum_{(\boldsymbol{e})} P(S3 \mid (\boldsymbol{a})\,)\, P(O3 \mid \ (\boldsymbol{f})\ ) \quad \rightarrow \text{Apply Conditional Independence}$$

(2 pt) (e) = S3 [s3 ∈ S3 is also OK]

(2 pts) (f) = S3 [s3 is OK if you wrote s3 ∈ S3 in (e) above]

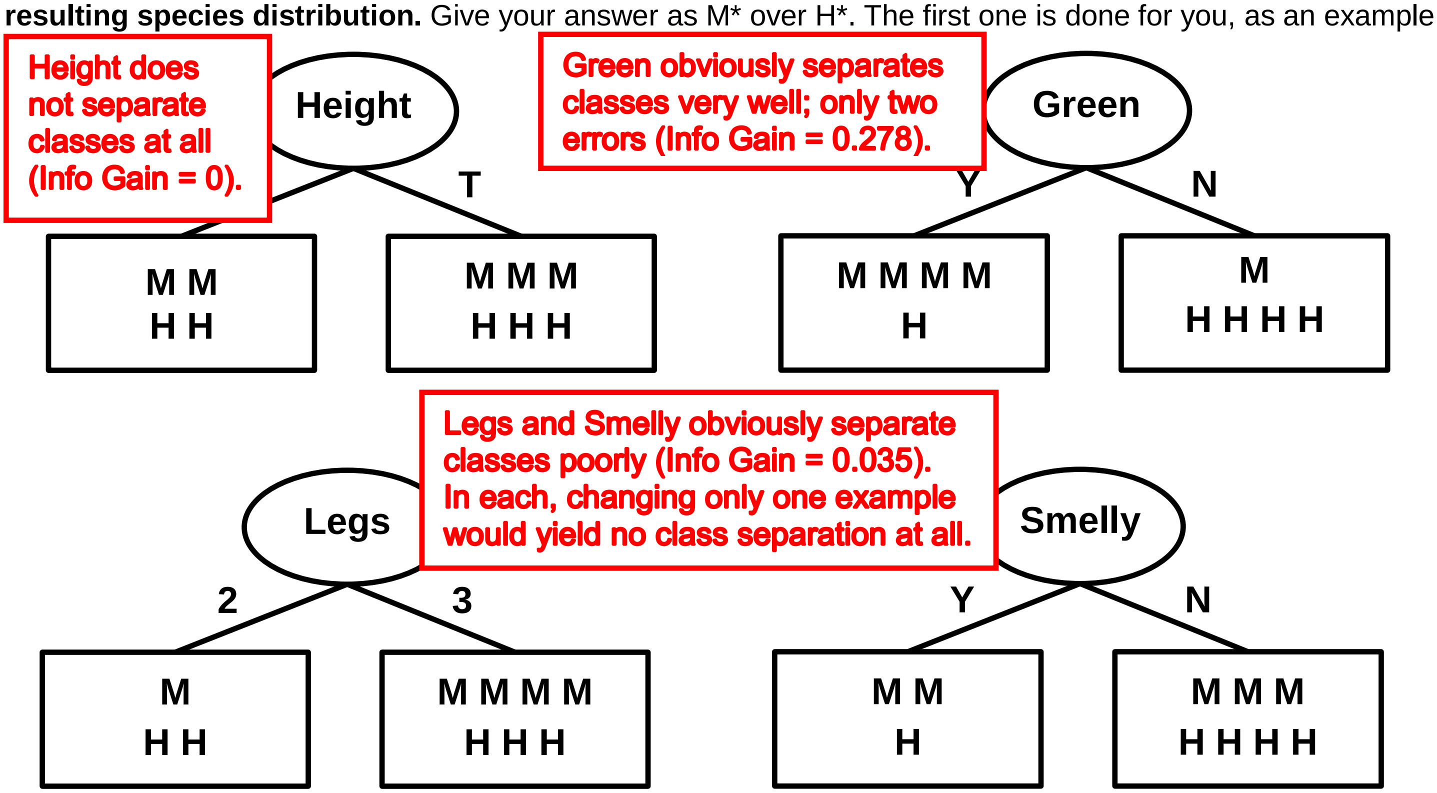
****** TURN PAGE OVER AND CONTINUE ON THE OTHER SIDE ******

5. (15 pts total) Decision Tree Learning. (Adapted from Prof. Ziv-Bar Joseph, Carnegie Mellon University, Course 10-701 Machine Learning materials.) NASA wants to discriminate Martians (M) from Humans (H) based on these features (attributes): Green $\in \{N, Y\}$, Legs $\in \{2, 3\}$, Height $\in \{S, T\}$, Smelly $\in \{N, Y\}$. Your available training data is as follows (N = No, Y = Yes, S = Small, T = Tall):

Example Number		Height	Green	Legs	Smelly		Target: Species
1		S	Y	3	Y		M
2		T	Y	3	N		M
3		S	Y	3	N		M
4		T	Y	3	N		M
5		T	N	2	Y		M
6		T	Y	2	Y		H
7		S	N	2	N		H
8		T	N	3	N		H
9		S	N	3	N		H
10		T	N	3	N		H

Please note:
A human might be green or have three legs for many possible reasons, e.g., if they were an actor playing a Martian as a role in a film or play. Anyway, it's a made-up problem for the test.

5.a. (6 pts total, 3 pts each) For each possible choice of root feature (attribute) below, show the resulting species distribution. Give your answer as M* over H*. The first one is done for you, as an example.

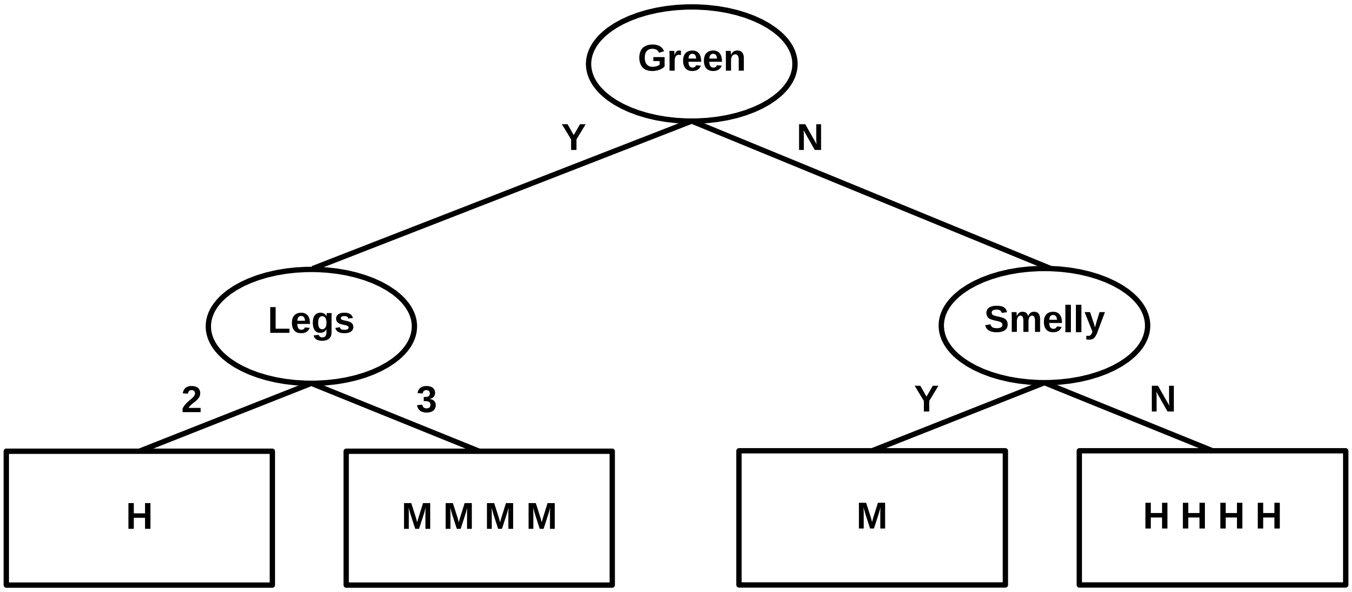


5.b. (4 pts) Which root feature (attribute) would information gain select as the "best" root feature (i.e., the highest information gain)? (No calculator is needed; the numbers have been chosen to be obvious.)

Circle one of: Height Green Legs Smelly

****** PROBLEM CONTINUES ON THE NEXT PAGE ******

5.c. (5 pts) Draw the decision tree that results from your choice of root feature (attribute) in 5.b above. (No calculator is needed; the numbers have been chosen to be obvious.) Your tree will be considered correct if it is correct for the root feature you chose in 5.b above, even if that answer was wrong.



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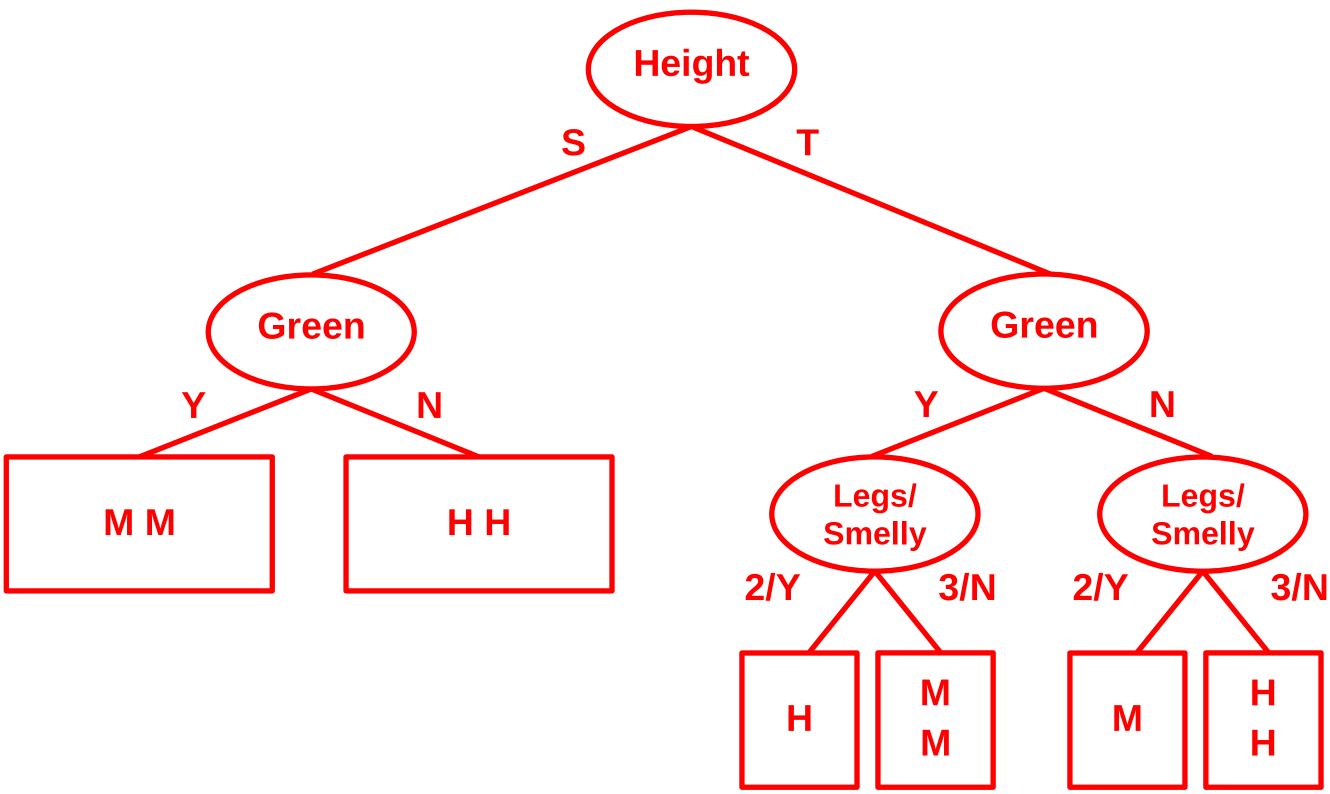
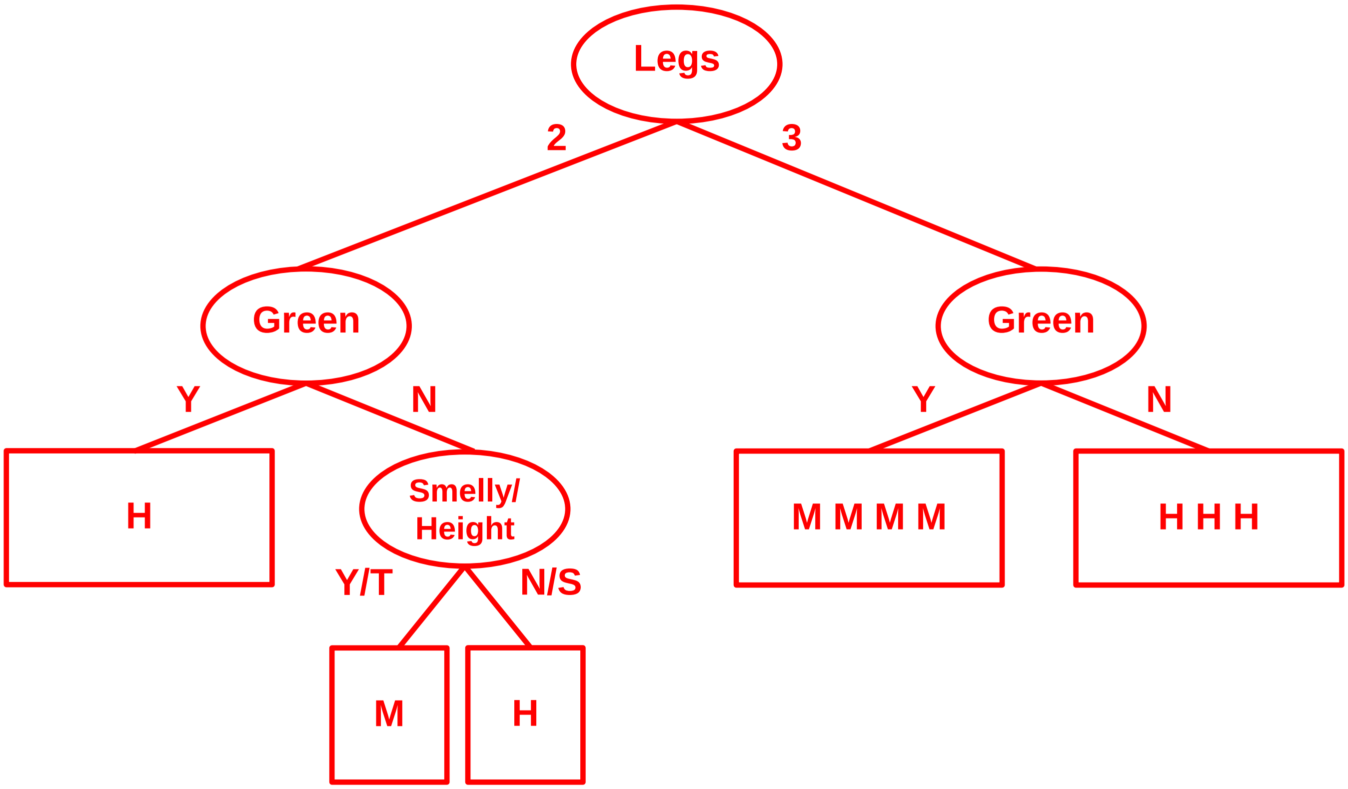
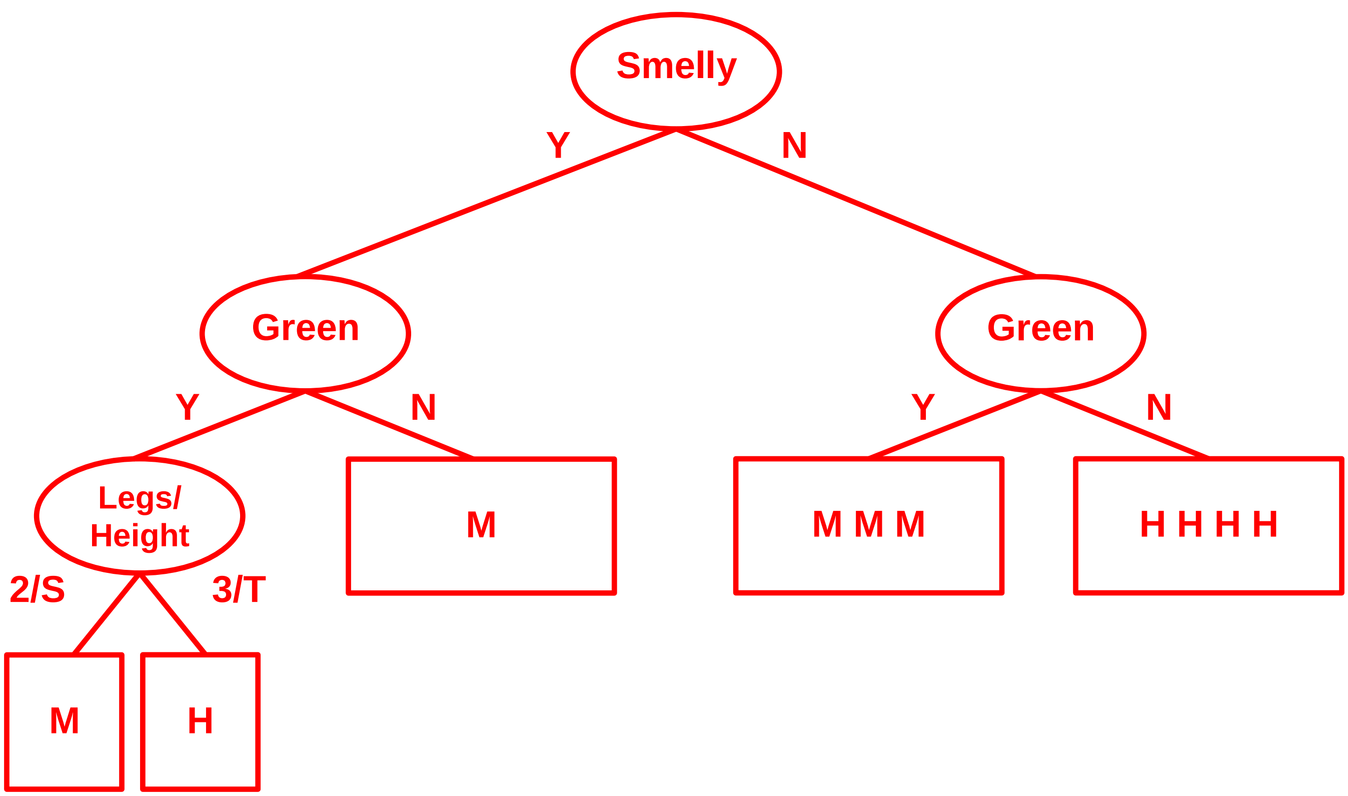
If you chose Height as the root attribute in 5.b above, then your correct tree is:



If you chose Legs as the root attribute in 5.b above, then your correct tree is:



If you chose Smelly as the root attribute in 5.b above, then your correct tree is:



6. (15 pts total; full credit for a correct proof, else 2 pts each useful resolution up to 10 pts) Easter Bunny Resolution Theorem Proving in Propositional Logic. (Adapted from http://brainden.com/logic-puzzles.htm.)

Four bunny rabbits played together in the bushes. Two were brown bunny rabbits and two were white bunny rabbits. You translate this fact into Propositional Logic (in prefix form) as:

/* Bi means bunny i is brown. */

(or (and B1 B2 (¬ B3) (¬ B4)) (and B1 (¬ B2) B3 (¬ B4))
(and B1 (¬ B2) (¬ B3) B4) (and (¬ B1) B2 B3 (¬ B4))
(and (¬ B1) B2 (¬ B3) B4) (and (¬ B1) (¬ B2) B3 B4)))

See Section 7.5.2.

However, none of them could see each other very clearly, and their views were obscured by branches
. Bunny 1 reported, "One of bunnies 2 & 3 is brown and one is white, but I can't tell which."
Bunny 2 reported, "One of bunnies 3 & 4 is brown and one is white, but I can't tell which."
Bunny 3 reported, "Bunny 4 is brown."

You translate these facts into Propositional Logic (in prefix form) as:

(or (and B2 (¬ B3)) (and (¬ B2) B3)) (or (and B3 (¬ B4)) (and (¬ B3) B4)) B4

Bunny 1 asks, "Is it true that I am a white bunny rabbit?"

You translate this query into Propositional Logic as "(¬ B1)" and form the negated goal as "B1." Your knowledge base (KB) in CNF plus negated goal (in clausal form) is:

(B1 B2 B3)	((¬ B1) (¬ B2) (¬ B3))
(B1 B2 B4)	((¬ B1) (¬ B2) (¬ B4))
(B1 B3 B4)	((¬ B1) (¬ B3) (¬ B4))
(B2 B3 B4)	((¬ B2) (¬ B3) (¬ B4))
(B2 B3)	((¬ B2) (¬ B3))
(B3 B4)	((¬ B3) (¬ B4))
B4	B1

Write a resolution proof that Bunny 1 is a white bunny rabbit.

For each step of the proof, fill in the first two blanks with CNF sentences from KB that will resolve to produce the CNF result that you write in the third (resolvent) blank. The resolvent is the result of resolving the first two sentences. Add the resolvent to KB, and repeat. Use as many steps as necessary, ending with the empty clause.

The shortest proof I know of is only four lines long. (A Bonus Point for a shorter proof.)

Resolve B4 with ((¬ B3) (¬ B4)) to produce: (¬ B3)

Resolve (¬ B3) with (B2 B3) to produce: B2

Resolve B4 with ((¬ B1) (¬ B2) (¬ B4)) to produce: ((¬ B1) (¬ B2))

Resolve B2 with ((¬ B1) (¬ B2)) to produce: (¬ B1)

Resolve (¬ B1) with B1 to produce: ( )

You received full credit if your proof was correct, regardless of length.

Resolve ______ with ______

Resolve ______ with ______

Resolve ______ with ______

Resolve ______ with ______

Two examples of 4-line proofs are:

1. Resolve (B2 B3) and (¬B3 ¬B4) to give (B2 ¬B4)
2. Resolve (¬B1 ¬B2 ¬B4) and (B2 ¬B4) to give (¬B1 ¬B4)
3. Resolve (¬B1 ¬B4) and (B1) to give (¬B4)
4. Resolve (¬B4) and (B4) to give ( )

1. Resolve (B1) and (¬B1 ¬B2 ¬B4) to give (¬B2 ¬B4)
2. Resolve (¬B2 ¬B4) and (B2 B3) to give (B3 ¬B4)
3. Resolve (B3 ¬B4) and (¬B3 ¬B4) to give (¬B4)
4. Resolve (¬B4) and (B4) to give ( )

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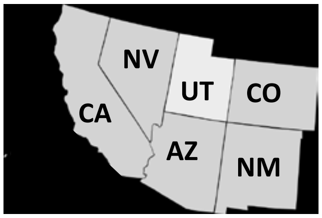
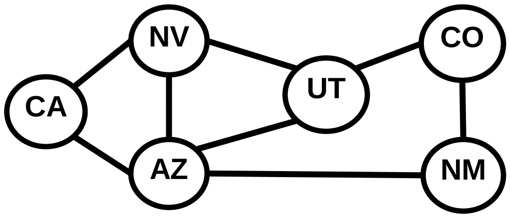
7. (15 points total, 3 pts each) Constraint Satisfaction Proble See Chapter 6.





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

7.a. (3 pts total, -1 each wrong answer, but not negative) FORWARD CHECKING. Cross out all values that would be eliminated by Forward Checking, after variable AZ has just been assigned value R as shown:

CA	NV	AZ	UT	CO	NM
~~R~~ G B	~~R~~ G B	R	~~R~~ G B	R G B	~~R~~ G B

7.b. (3 pts total, -1 each wrong answer, but not negative) ARC CONSISTENCY.
CA and AZ have been assigned values, but no constraint propagation has been done. Cross out all values that would be eliminated by Arc Consistency (AC-3 in your book).

CA	NV	AZ	UT	CO	NM
B	~~R~~ G ~~B~~	R	~~R~~ ~~G~~ B	R G ~~B~~	~~R~~ G B

7.c. (3 pts total, -1 each wrong answer, but not negative) MINIMUM-REMAINING-VALUES HEURISTIC. Consider the assignment below. NV is assigned and constraint propagation has been done. List all unassigned variables that might be selected by the Minimum-Remaining-Values (MRV) Heuristic:______**CA, AZ, UT**____________________.

CA	NV	AZ	UT	CO	NM
R B	G	R B	R B	R G B	R G B

7.d. (3 pts total, -1 each wrong answer, but not negative) DEGREE HEURISTIC. Consider the assignment below. (It is the same assignment as in problem 7.c above.) NV is assigned and constraint propagation has been done. List all unassigned variables that might be selected by the Degree Heuristic:.______**AZ**__________________.

CA	NV	AZ	UT	CO	NM
R B	G	R B	R B	R G B	R G B

7.e. (3 pts total) MIN-CONFLICTS HEURISTIC. Consider the complete but inconsistent assignment below. AZ has just been selected to be assigned a new value during local search for a complete and consistent assignment. What new value would be chosen below for AZ by the Min-Conflicts Heuristic?.______________**R**__________________.

CA	NV	AZ	UT	CO	NM
B	G	**?**	G	G	B

8. (16 pts total, 2 pts each) English and FOL correspondence. For each English sentence below, write the letter corresponding to its best or closest FOPC (FOL) sentence (wff, or well-formed formula).

8.a (2 pts) __D__ "Every person plays some game."

A. $\forall x\ \forall y\ Person(x) \wedge Game(y) \wedge Plays(x, y)$

B. $\forall x\ \exists y\ Person(x) \wedge Game(y) \wedge Plays(x, y)$

C. $\forall x\ \forall y\ Person(x) \Rightarrow (Game(y) \wedge Plays(x, y))$

D. $\forall x\ \exists y\ Person(x) \Rightarrow (Game(y) \wedge Plays(x, y))$

8.b (2 pts) __B__ "All games are fun."

A. $\forall x\ Game(x) \wedge Fun(x)$

B. $\forall x\ Game(x) \Rightarrow Fun(x)$

C. $\exists x\ Game(x) \wedge Fun(x)$

D. $\exists x\ Game(x) \Rightarrow Fun(x)$

8.c (2 pts) __C__ "For every game, there is a person th

A. $\forall x\ \exists y\ Game(x) \wedge Person(y) \wedge Plays(y, x)$

B. $\forall x\ \exists y\ [Game(x) \wedge Person(y)] \Rightarrow Plays(y, x)$

C. $\forall x\ \exists y\ Game(x) \Rightarrow [Person(y) \wedge Plays(y, x)]$

D. $\forall x\ \forall y\ Game(x) \wedge Person(y) \wedge Plays(y, x)$

8.d (2 pts) __A__ "Every person plays every game."

A. $\forall x\ \forall y\ [Person(x) \wedge Game(y)] \Rightarrow Plays(x, y)$

B. $\forall x\ \forall y\ Person(x) \Rightarrow [Game(y) \wedge Plays(x, y)]$

C. $\forall x\ \forall y\ Person(x) \wedge Game(y) \wedge Plays(x, y)$

D. $\forall x\ \exists y\ [Person(x) \wedge Game(y)] \Rightarrow Plays(x, y)$

8.e (2 pts) __B__ "There is some person in Irvine who

A. $\forall x\ Person(x) \wedge In(x, Irvine) \wedge Smart(x)$

B. $\exists x\ Person(x) \wedge In(x, Irvine) \wedge Smart(x)$

C. $\forall x\ [Person(x) \wedge In(x, Irvine)] \Rightarrow Smart(x)$

D. $\exists x\ Person(x) \Rightarrow [In(x, Irvine) \wedge Smart(x)]$

8.f (2 pts) __C__ "Every person in Irvine is smart."

A. $\forall x\ Person(x) \wedge In(x, Irvine) \wedge Smart(x)$

B. $\exists x\ Person(x) \wedge In(x, Irvine) \wedge Smart(x)$

C. $\forall x\ [Person(x) \wedge In(x, Irvine)] \Rightarrow Smart(x)$

D. $\exists x\ Person(x) \Rightarrow [In(x, Irvine)] \wedge Smart(x)$

8.g (2 pts) __D__ "Some person plays every game."

A. $\exists x\ \forall y\ [Person(x) \wedge Game(y)] \Rightarrow Plays(x, y)$

B. $\exists x\ \forall y\ Person(x) \wedge Game(y) \wedge Plays(x, y)$

C. $\forall x\ \forall y\ Person(x) \wedge Game(y) \wedge Plays(x, y)$

D. $\exists x\ \forall y\ Person(x) \wedge [Game(y) \Rightarrow Plays(x, y)]$

8.h (2 pts) __A__ "Some person plays some game."

A. $\exists x\ \exists y\ Person(x) \wedge Game(y) \wedge Plays(x, y)$

B. $\exists x\ \exists y\ [Person(x) \wedge Game(y)] \Rightarrow Plays(x, y)$

C. $\exists x\ \exists y\ Person(x) \Rightarrow [Game(y) \wedge Plays(x, y)]$

D. $\forall x\ \forall y\ Person(x) \wedge Game(y) \wedge Plays(x, y)$

8.a **"Every person plays some game."**
A. Everything(x,y) is a person(x) and is a game(y) and x plays y.
B, Everything(x) is a person(x) and there is some game(y) and x plays y.
C. If something(x) is a person(x) then everything(y) is a game(y) and x plays y.
D. Correct.

8.b **"All games are fun."**
A. Everything(x) is a game(x) and is fun(x).
B. Correct.
C. There is something(x) that is a game(x) and is fun(x).
D. Vacuously true if there is anything(x) that is not a game(x).

8.c **"For every game, there is a person that plays that game."**
A. Everything(x) is a game and there is some person(y) and y plays x.
B. Vacuously true if there is anything(y) that is not a person(y).
C. Correct.
D. Everything(x,y) is a game(x) and is a person(y) and y plays x.

8.d **"Every person plays every game."**
A. Correct.
B. If anything(x) is a person(x) then everything(y) is a game(y) and x plays y.
C. Everything(x,y) is a person(x) and is a game(y) and x plays y.
D. Vacuously true if anything(y) is not a game.

8.e. **"There is some person in Irvine who is smart."**
A. Everything(x) is a person and is in Irvine(x) and is smart(x).
B. Correct.
C. If something(x) is a person(x) and is in Irvine(x) then that thing is smart(x).
D. Vacuously true if anything(x) is not a person(x).

8.f **"Every person in Irvine is smart."**
A. Everything(x) is a person(x) and is in Irvine(x) and is smart(x).
B. There is something(x) that is a person(x) and is in Irvine(x) and is smart(x).
C. Correct.
D. Vacuously true if anything(x) is not a person(x).

8.g **"Some person plays every game."**
A. Vacuously true if there is anything(x) that is not a person(x)).
B. There is some person(x) and everything(x) is a game(y) and x plays y.
C. Everything(x,y) is a person(x) and is a game(y) and x plays y.
D. Correct.

8.h **"Some person plays some game."**
A. Correct.
B. Vacuously true if there is anything(x,y) that is not a person(x) or is not a game(y).
C. Vacuously true if there is anything(x) that is not a person(x).
D. Everything(x,y) is a person and is a game(y) and x plays y.

****** THIS IS THE END OF THE FINAL EXAM. HAPPY SPRING BREAK!! ******