CS 188 Introduction to AI
Spring 2004 Stuart Russell
Final

You have 2 hours and 50 minutes. The exam is open-book, open-notes. 100 points total. Panic not.

ALL QUESTIONS IN THIS EXAM ARE TRUE/FALSE, MULTIPLE-CHOICE, OR SHORT-ANSWER.
Mark your answers ON THE EXAM ITSELF. Write your name, SID, and section number at the top of each page.
For true/false questions, CIRCLE *True* OR *False*.
For multiple-choice questions, CIRCLE *ALL* CORRECT CHOICES (in some cases, there may be more than one).

If you are not sure of your answer you may wish to provide a *brief* explanation.

For official use only

Q. 1	Q. 2	Q. 3	Q. 4	Q. 5	Q. 6	Q. 7	Total
/10	/13	/10	/10	/22	/20	/15	/100

1. (10 pts.) Some Easy Questions to Start With

(a) (2) *True/False*: $\exists x \;\; x = Rumpelstiltskin$ is a valid sentence of first-order logic.

(b) (2) *True/False*: Context-free grammars fail to capture English grammar because the meaning of an English sentence may depend on the context of the utterance.

(c) (2) *True/False*: Every Boolean function can be represented by some Bayesian network.

(d) (2) *True/False*: A* search cannot be used in robotics because percepts, states, and actions are continuous.

(e) (2) *True/False*: Probabilistic inference cannot be used in robotics because percepts, states, and actions are continuous.

2. (10 pts.) Propositional Logic

(a) (1) *True/False*: $False \models True$.

(b) (1) *True/False*: $True \models False$.

(c) (2) *True/False*: $(A \wedge B) \models (A \;\Leftrightarrow\; B)$.

(d) (2) *True/False*: $(A \vee B) \wedge \neg(A \;\Rightarrow\; B)$ is satisfiable.

(e) (2) *True/False*: There is an algorithm for determining the logical consistency of any pair of expressions in propositional logic.

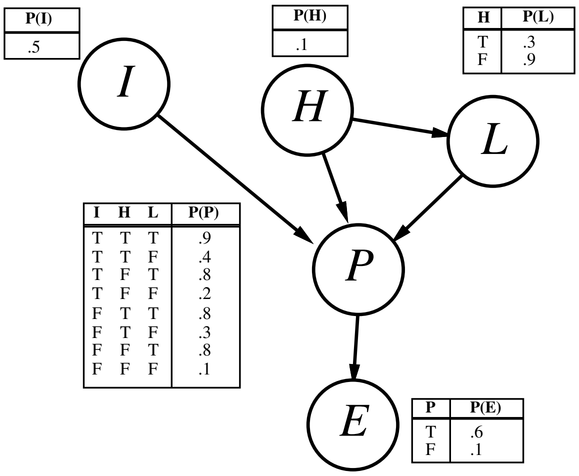
(f) (2) *True/False*: If a propositional clause C can be resolved with a copy of itself, it must be logically equivalent to $True$.

3. (10 pts.) First-Order Logic

(a) (4) Write a successor-state axiom for the *Locked* predicate, which applies to doors, assuming the only actions available are *Lock* and $Unlock$.

(b) (4) Write in first-order logic the assertion that every key will eventually be lost forever, using only the following vocabulary:
$Key(x)$: x is a key; Now: the current time; $Before(t_1, t_2)$: time t_1 comes before time t_2; $Lost(x, t)$: object x is lost at time t.

(c) (2) *True/False*: If a first-order clause C can be resolved with a copy of itself, it must be logically equivalent to $True$.



P(I)
.5

P(H)
.1

H	P(L)
T	.3
F	.9

I	H	L	P(P)
T	T	T	.9
T	T	F	.4
T	F	T	.8
T	F	F	.2
F	T	T	.8
F	T	F	.3
F	F	T	.8
F	F	F	.1

P	P(E)
T	.6
F	.1

Fig. 1: A simple Bayes net with Boolean variables $I = Intelligent$**,** $H = Honest$**,** $P = Popular$**,** $L = LotsOfCampaignFunds$**,** $E = Elected$**.**

4. (22 pts.) Probabilistic inference, decision theory

Consider the Bayes net shown in Fig. 1.

(a) (3) Which, if any, of the following are asserted by the network *structure* (ignoring the CPTs for now)?
(i) $\mathbf{P}(I, L) = \mathbf{P}(I)\mathbf{P}(L)$
(ii) $\mathbf{P}(E|P, L) = \mathbf{P}(E|P, L, H)$
(iii) $\mathbf{P}(P|I, H) \neq \mathbf{P}(P|I, H, L)$

(b) (3) Calculate the value of $P(i, h, \neg l, p, \neg e)$.

(c) (4) Calculate the probability that someone is intelligent given that they are honest, have few campaign funds, and are elected.

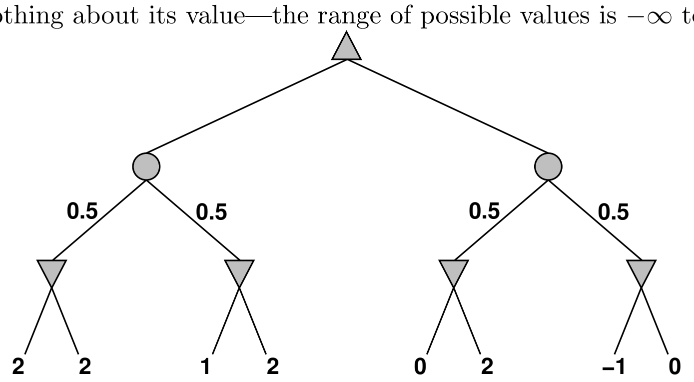
(d) (6) Suppose we want to add the variable $R = RigsElection$ to the network; draw the new network and provide new or modified CPTs as needed.

(e) (2) *True/False*: If there are two candidates in the race, then making two copies of the network will correctly represent the joint distribution over the two sets of variables.

(f) (4) Suppose that you are considering making a large *Donation* to help elect your candidate. Draw the decision network (without CPTs etc) obtained by adding the appropriate nodes to Fig. 1.

5. (13 pts.) Game playing

This question considers pruning in games with chance nodes. Here is the complete game tree for a very simple game. Assume that the leaf nodes are to be evaluated in left-to-right order, and that before a leaf node is evaluated, we know nothing about its value—the range of possible values is $-\infty$ to ∞.



(a) (3) Mark the value of all the internal nodes and indicate the best move at the root with an arrow.

(b) (2) *True/False*: Given the values of the first six leaves, the seventh and eighth leaves are irrelevant and need not be evaluated.

(c) (2) *True/False*: Given the values of the first seven leaves, the eighth leaf is irrelevant and need not be evaluated.

(d) (2) Now suppose all the leaf node values are known to lie between –2 and 2 inclusive. After evaluating the first two leaves, what range of values can be deduced for the left-hand chance node?
(i) –2 to 2 (ii) 0 to 1 (iii) 0 to 2

(e) (4) Circle all the leaves that need not be evaluated under the assumption in (d).

6. (20 pts.) Language and statistical learning

A *probabilistic context-free grammar* (PCFG) is a context-free grammar augmented with a probability value on each rule, so that the PCFG specifies a probability distribution over all allowable strings in the language. Specifically, the rules for each nonterminal are annotated with probabilities that sum to 1; these define how likely it is that each rule is applied to expand that nonterminal; and all such rule choices are made independently. For example, the following is a simple PCFG for noun phrases:

$0.6 : NP \rightarrow Det\ AdjString\ Noun$
$0.4 : NP \rightarrow Det\ NounNounCompound$
$0.5 : AdjString \rightarrow Adj\ AdjString$
$0.5 : AdjString \rightarrow \Lambda$
$1.0 : NounNounCompound \rightarrow Noun\ Noun$
$0.8 : Det \rightarrow$ **the**
$0.2 : Det \rightarrow$ **a**
$0.5 : Adj \rightarrow$ **small**
$0.5 : Adj \rightarrow$ **green**
$0.6 : Noun \rightarrow$ **village**
$0.4 : Noun \rightarrow$ **green**

where Λ denotes the empty string.

(a) (2) What is the longest NP that can be generated by this grammar?
(i) three words (ii) four words (iii) infinitely many words

(b) (3) Which of the following have a nonzero probability of being generated as complete NPs?
(i) a small green village (ii) a green green green (iii) a small village green

(c) (5) What is the probability of generating "the green green"?

(d) (2) What types of ambiguity are exhibited by the phrase in (c)?
(i) lexical (ii) syntactic (iii) referential (iv) none

(e) (2) *True/False*: Given any PCFG and any finite word sequence, it is possible to calculate the probability that the sequence was generated by the PCFG.

(f) (1) Suppose that, out of 1000 observed noun phrases, 700 begin with "**the**" and 300 begin with "**a**", and that as a result we reset the probabilities for the two *Det* rules to 0.7 and 0.3. This is best viewed as an example of
(i) Bayesian learning (ii) MAP learning (iii) maximum likelihood learning.

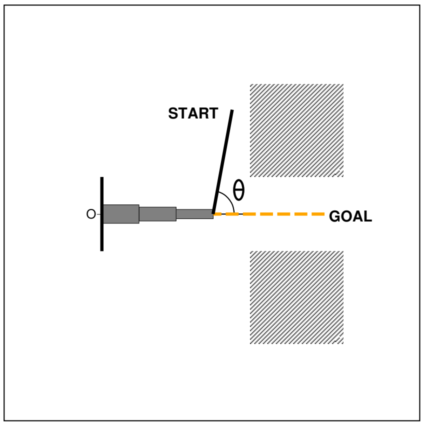
(g) (5) Some linguists have argued as follows:

> Children learning a language hear only *positive examples* of the language and no *negative examples*. Therefore, the hypothesis that "every possible sentence is in the language" is consistent with all the observed examples. Moreover, this is the simplest consistent hypothesis. Furthermore, all grammars for languages that are supersets of the true language are also consistent with the observed data. Yet children do induce (more or less) the right grammar. It follows that they begin with very strong innate grammatical constraints that rule out all of these more general hypotheses *a priori*.

Comment briefly on the weak point(s) in this argument, given what you know about statistical learning.

7. (15 pts.) Robotics

Consider the robotic arm shown in the following figure. The telescoping "upper arm" is fixed at the left-hand end (the origin). Its minimum length is $d = 1$ and its maximum length (shown) is $d = 3$. The "forearm" is a thin wand of length 3 that can rotate at the "elbow" but cannot rotate past vertical in either direction because of self-intersection between forearm and upper arm. There are two obstacles (square boxes) whose left edges are at $x = 4$ and that are separated by a distance of 2. Both a start configuration (solid line) and a goal configuration (dashed line) are shown.

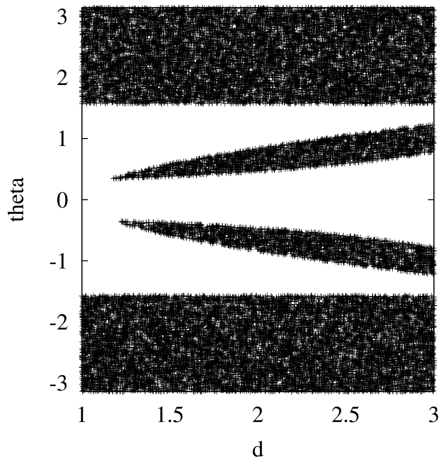


The next page shows four configuration spaces.

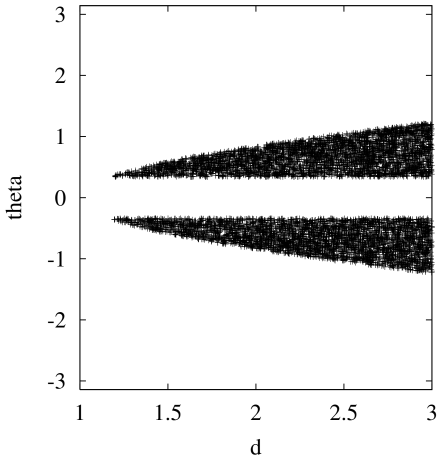
(a) (5) Circle the correct configuration space for this problem.

(b) (5) On that space, mark the start S and goal G, and show an appropriate plan for the robot to move from the start to the goal.

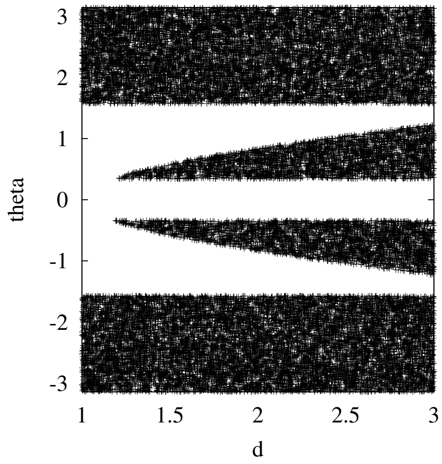
(c) (5) Suppose the robot has *absolutely no position sensing* due to a malfunction, but can sense contact and motion limits; suppose further that the robot's linear and rotary motions are at a constant but unknown speed. Describe a plan that will reach the goal state from the start state, or explain why none exists.


theta
3
2
1
0
-1
-2
-3
1
1.5
2
2.5
3
d

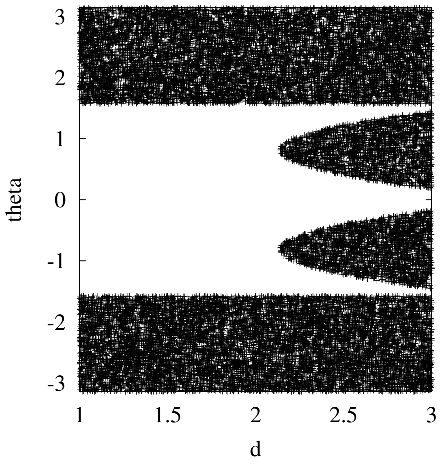
(i)


theta
3
2
1
0
-1
-2
-3
1
1.5
2
2.5
3
d

(ii)


theta
3
2
1
0
-1
-2
-3
1
1.5
2
2.5
3
d

(iii)


theta
3
2
1
0
-1
-2
-3
1
1.5
2
2.5
3
d

(iv)