FOR INTERNAL SCRUTINY (date of this version: 8/1/2018)

UNIVERSITY OF EDINBURGH

COLLEGE OF SCIENCE AND ENGINEERING

SCHOOL OF INFORMATICS

INFORMATICS 2D: REASONING AND AGENTS

Sunday 1st April 2012

00:00 to 00:00

INSTRUCTIONS TO CANDIDATES

1. **Answer Parts A, B and C.**
2. **The multiple choice questions in Part A are worth 50% in total and are each worth the same amount. Mark one answer only for each question - multiple answers will score 0. Marks will not be deducted for incorrect multiple choice exam answers.**
3. **Parts B and C are each worth 25%. Answer ONE question from Part B and ONE question from Part C.**
4. **Use the special mark sheet for Part A. Answer Parts B and C each in a separate script book.**

CALCULATORS ARE PERMITTED.

THIS EXAMINATION WILL BE MARKED ANONYMOUSLY

Part A
ANSWER ALL QUESTIONS IN PART A. Use the special mark sheet.

1. Which of the following games is **not** fully observable for the players?
   (a) Chess
   (b) Checkers
   (c) Connect Four
   (d) Poker
   (e) Go

2. Which of the following is **not** part of a tree search node?
   (a) Parent node
   (b) Environment state
   (c) Goal specification
   (d) Child nodes
   (e) Path cost

3. Assuming a finite branching factor, which of the following is **not** correct?
   (a) Breath-first search is complete
   (b) Breath-first search is optimal
   (c) Depth-first search is optimal
   (d) Depth-limited search is not complete
   (e) Iterative-deepening search is optimal and complete

4. Which of the following statements about Minimax search is **not** correct?
   (a) It assumes an optimal (worst-case) opponent
   (b) It is optimal against non-optimal opponents
   (c) It requires knowledge of game rules and possible actions
   (d) It is complete if the game tree is finite
   (e) α-β-pruning does not affect final result of search

5. In A^* search, the evaluation function for a node n is $f(n) = g(n) + h(n)$. Which of the following statements is **not** correct?

   (a) $g(n)$ is the cost so far to reach n

   (b) $h(n)$ is the estimated cost from n to goal

   (c) An admissible heuristic never overestimates the cost to reach the goal

   (d) A^* tree search is optimal if the used heuristic is admissible

   (e) The worst-case time complexity of A^* is polynomial in the number of states

6. Consider the propositional logic symbols A, B, C. Which of the following statements is **not** correct?

   (a) $A \wedge (B \vee \neg C)$ is satisfiable

   (b) $(A \Rightarrow B) \wedge (\neg A \vee B)$ is unsatisfiable

   (c) $A \vee (A \Rightarrow C)$ is valid

   (d) $A \wedge (B \vee C)$ is equivalent to $(A \wedge B) \vee (A \wedge C)$

   (e) $\neg(A \Rightarrow B)$ is equivalent to $A \wedge \neg B$

7. Which of the following is **not** part of the DPLL algorithm as given in the lectures?

   (a) The literal in a unit clause must be false

   (b) Sentences are given in conjunctive normal form

   (c) A sentence is false if any of its clauses is false

   (d) A clause is true if one of its literals is true

   (e) Make pure literals true

8. Consider a constraint satisfaction problem with variables $X \in \{1, 2, 3\}, Y \in \{2, 3, 4\}, Z \in \{3, 4, 5\}$ and constraints $X < Y$, $Z < Y$. Which of the following statements is **not** correct?

   (a) The most constraining variable is Y

   (b) The domains of X and Y are arc-consistent

   (c) The least constraining value of Y is 4

   (d) The assignment $X = 1, Y = 4, Z = 3$ is a solution

   (e) The domains of Z and Y are arc-consistent

9. Which of the following is a unifier of $A(x, y) \wedge B(y, x)$ and $a \wedge B(b, a)$? (Note that x, y, a, b are all variables.)
   (a) $\{a/A(x, y), b/x\}$
   (b) $\{a/A(x, y), b/y\}$
   (c) $\{a/A(a, b)\}$
   (d) $\{a/A(a, b), x/a, y/b\}$
   (e) None of the above

10. Which of the following describes the "frame problem" in situation calculus?
    (a) Defining which fluents are unaffected by actions
    (b) Defining the preconditions of actions
    (c) Defining the effects of actions on fluents
    (d) Defining the future ramifications of actions
    (e) Defining the preconditions, effects, and non-effects of actions

11. Assume action D makes postcondition $\neg p$ true and you are given a plan with existing causal links $A \xrightarrow{p} B$ and $B \xrightarrow{p} C$. Which of the following total orderings does *not* resolve all potential conflicts that might arise from the addition of D?
    (a) $D \prec A \prec B \prec C$
    (b) $A \prec B \prec C \prec D$
    (c) $C \prec A \prec B \prec D$
    (d) $C \prec A \prec D \prec B$
    (e) $D \prec C \prec A \prec B$

12. In how many ways is the action schema

    $Action(Fly(p, from, to),$
    $\quad \textsc{Precond}{:}At(p, from) \wedge Plane(p) \wedge Airport(from) \wedge Airport(to)$
    $\quad \textsc{Effect}{:}\neg At(p, from) \wedge At(p, to))$

    applicable in the following state:

    $$\begin{array}{l} At(P_1, SFO) \wedge At(P_2, Heathrow) \wedge At(P_3, CDG) \\ Airport(CDG) \wedge Airport(Heathrow) \wedge Airport(SFO) \wedge \\ Plane(P_1) \wedge Plane(P_2) \end{array}$$

    (a) 3
    (b) 8
    (c) 9
    (d) 11

13. You are given three action descriptions with conditional effects:

    $Action(A, \textsc{Precond}{:}\{X\}, \textsc{Effect}{:}\{(\textbf{when } P : \neg X), Z\})$
    $Action(B, \textsc{Precond}{:}\{Y\}, \textsc{Effect}{:}\{(\textbf{when } Z : \neg P), \neg Y, \neg Z, X\})$
    $Action(C, \textsc{Precond}{:}\{\neg Z\}, \textsc{Effect}{:}\{(\textbf{when } P : \neg X), Y\})$

    What state would result from executing the action sequence $[C, B, A]$ in the state $\{Q, X\}$?

    (a) $\{\neg P, Q, X, \neg Y, Z\}$
    (b) $\{Q, X, Z\}$
    (c) $\{Q, X, \neg Y, Z\}$
    (d) $\{P, Q, X, Z\}$
    (e) The plan isn't executable.

14. An apartment has 2 rooms, and the robot moves from one room to another, cleaning each room. It can sense its location and whether the room it is in is currently clean or dirty. Sometimes when it cleans, its filter deposits dirt onto the floor. Moreover, rooms sometimes get dusty from the airconditioing system that runs throughout the house.

    Which of the following statements is *incorrect*?

    (a) The robot is working in a partially observable environment.
    (b) The robot could use contingent planning to clean the apartment.
    (c) A plan to clean a particular room in the house would include a loop.
    (d) It is impossible for the robot to guarantee that it has achieved the goal of making each room in the apartment clean.
    (e) The robot must monitor and replan if it aims to clean each room in the apartment.

15. Suppose that an agent has a goal $(On(A, B) \vee On(B, C)) \wedge \neg Clear(A)$. Which of the following states satisfies this goal?

    (a) $On(B, C) \wedge On(C, A)$
    (b) $On(A, B) \wedge On(B, C) \wedge Clear(A)$
    (c) $On(B, A)$
    (d) $Clear(C)$
    (e) $On(C, B) \wedge Clear(B)$

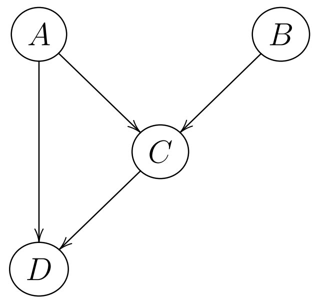
16. Assume the following inhibition probabilities between Boolean cause variables A, B, C and Boolean effect variable X:

$$P(\neg x|a, \neg b, \neg c) = p$$
$$P(\neg x|\neg a, b, \neg c) = q$$
$$P(\neg x|\neg a, \neg b, c) = r$$

    What is the probability $P(x|a, b, \neg c)$ assuming that the conditional probabilities of X are computed using a noisy-OR relation?

    (a) $r \times p \times (1 - q)$
    (b) $(1 - p) \times q \times r$
    (c) $q \times (1 - p)$
    (d) $(1 - r) \times (1 - p) \times q$
    (e) $1 - (p \times q)$

17. Consider the following Bayesian network structure with Boolean variables:



Which of the following statements is correct?

(a) All conditional probability tables in it have the same size.

(b) Given A, C is conditionally independent of B.

(c) Calculating the value of $P(a \wedge \neg b \wedge c \wedge \neg d)$ in this network involves using only multiplication of probabilities.

(d) All variables in the system are conditionally independent.

(e) It takes a total of $2^4 = 16$ probability values to describe the joint probability distribution represented by the network.

18. Assume two random variables X and Y are conditionally independent given a third variable Z. Which of the following statements is incorrect?

(a) This assumption makes a reduced-size representation of the JPD possible

(b) $\mathbf{P}(X, Y|Z) = \mathbf{P}(X|Z)\mathbf{P}(Y|Z)$

(c) $\mathbf{P}(X|Y, Z) = \mathbf{P}(X|Z)$

(d) $\mathbf{P}(Y|X, Z) = \mathbf{P}(Y|Z)$

(e) $\mathbf{P}(X|Y) = \mathbf{P}(X)$

19. The process of computing $\vec{P}(\vec{X}_{t+k}|\vec{e}_{1:t})$ for $k > 0$ in a temporal probabilistic model with state variables $\vec{X}$ and evidence variables $\vec{e}$ is called

(a) smoothing

(b) abstraction

(c) monitoring

(d) prediction

(e) filtering

20. Let strict preference be denoted by the relation symbol $\succ$, indifference by $\sim$, weak preference by $\succsim$, and lotteries be written as $[p_1, O_1; \ldots; p_n, O_n]$, where each p_i is the probability associated with outcome O_i. Which of the following is not an axiom of utility theory that must hold for any outcomes A, B, C?

    (a) $(A \succ B) \wedge (B \succ C) \Rightarrow (A \succ C)$

    (b) $(A \succ B) \vee (B \succ A) \vee (A \sim B)$

    (c) $A \succ B \Rightarrow (p \geq q \Leftrightarrow [p, A; 1-p, B] \succsim [q, A; 1-q, B])$

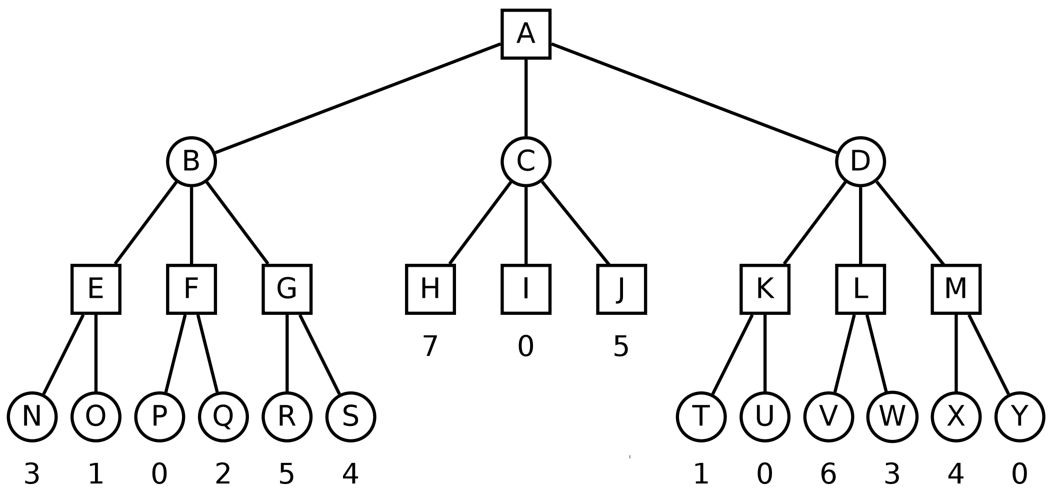
    (d) $A \sim B \Rightarrow [p, A; 1-p, C] \succ [p, B; 1-p, C]$

    (e) $A \succ B \succ C \Rightarrow \exists p \, [p, A; 1-p, C] \sim B$

Part B
ANSWER ONE QUESTION FROM PART B

1. **Adversarial Search**

Consider the following search tree for a 2-player game, which is searched depth-first, left-to-right. Each node is named by a letter. Square nodes are where MAX is due to play and circle nodes are where MIN is due to play. The numbers below the leaves are the results of the evaluation function applied to that leaf.



(a) Define the minimax search algorithm. Using the algorithm, give the scores assigned to the non-leaf nodes in the above search tree, and state which move for MAX is recommended by this process. [*6 marks*]

(b) Give the α/β-search algorithm. [*6 marks*]

(c) Using the α/β-search algorithm on the search tree above (going depth-first, left-to-right), which nodes will be pruned from the tree and why will they be pruned? [*8 marks*]

(d) Answer each of the following questions:

- What is the principal assumption in the minimax algorithm regarding the opponent's strategy?
- Will the minimax algorithm obtain better or worse scores if the above assumption is violated? Explain the reasons.

[*5 marks*]

2. **Propositional Logic**

(a) Give the semantics for each of the propositional operators $\neg, \wedge, \vee, \Rightarrow, \Leftrightarrow$. [*3 marks*]

(b) Explain the conjunctive normal form (CNF). Does every sentence in propositional logic have a CNF equivalent? [*3 marks*]

(c) Give the CNF equivalent of $\neg A \Leftrightarrow (B \wedge C)$. Explain what it means for these two sentences to be equivalent. [*3 marks*]

(d) Give the DPLL algorithm for checking satisfiability. [*5 marks*]

(e) Describe the three basic heuristics used in DPLL (as presented in the lectures and R&N). For each heuristic, explain why it can speed up search. [*5 marks*]

(f) Apply the DPLL algorithm to the CNF sentence from (c). If the sentence is satisfiable, give a model of it. If not, explain why. [*3 marks*]

(g) Define soundness and completeness in satisfiability algorithms. Is DPLL sound and complete? [*3 marks*]

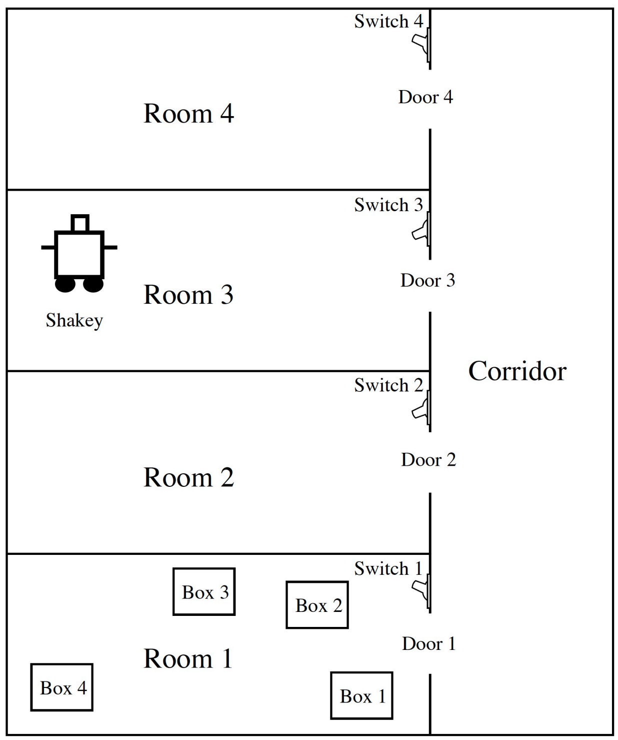


Figure 1: Shakey's World

Part C
ANSWER ONE QUESTION FROM PART C

1. **Planning**

Shakey the robot can perform the following actions:

- $move(r, y)$: Shakey can move to a location y in a room r so long as Shakey is on the floor, and both Shakey and y are in room r.
- $move\text{-}rooms(r1, r2)$: Shakey can move from room $r1$ to room $r2$, so long as Shakey is on the floor, and $r1$ and $r2$ are connected by a door.
- $push(x, r, y)$: Shakey can push a box x to a location y in room r, so long as Shakey is on the floor, Shakey is at the same location as the box x, and they are both in room r, and y is in room r as well.
- $push\text{-}rooms(x, r1, r2)$: Shakey can push a box x from room $r1$ to $r2$, so long as Shakey is on the floor and at the same location as the box x, which is in room $r1$, and $r1$ and $r2$ are connected by a door.
- $ClimbUp(x)$: Shakey can climb onto box x, so long as they are at the same location and Shakey isn't already on a box.
- $ClimbDown(x)$: Shakey can climb down from a box x.

- $Flip(x)$: Shakey can flip a switch, so long as it is in the same location as the switch and on a box.

The initial state is as shown in Figure 1. The goal state is for box 3 to be in room 4 and switch 2 to be up.

(a) Define a PDDL language of constant and predicates, in addition to the above action predicates, that you need to describe Shakey's world. [*4 marks*]

(b) Use your PDDL language to define the initial state and the goal state. [*3 marks*]

(c) Use your PDDL language to define each of the seven actions described above. [*14 marks*]

(d) Define a plan for getting from the initial state to the goal state. [*1 mark*]

(e) Re-define the climbing action so that its effect is one where Shakey may end up on the box, or it may fail to get on the box and stay on the ground. With this new action, define a valid plan for getting from the initial state to the goal state. [*3 marks*]

2. **Bayesian Inference**

Three bus routes, called 1, 2 and 3, regularly come to the stop in front of the Informatics Forum. They all operate 24 hours a day. Route 1 operates more frequently than route 2, which operates more frequently than route 3. In fact, they are in a 6:3:1 ratio, in all hours of operation. Route 1 is a single decker bus in 9 out of 10 cases before 6pm, and it's always single decker after 6pm. Route 2 is always double decker before 6pm, and 1 in 10 of the Route 2 buses is single decker after 6pm. 8 out of 10 of the buses for the route 3 bus is a double decker at all times. You can get to Morningside with route 3, but not with routes 1 or 2.

(a) Model the above description as a Bayes Net, making sure you define the possible values of all the random variables that you use. [*6 marks*]

(b) Write the conditional probability tables for each node in your Bayes Net, capturing the relative frequencies of the events described above. [*6 marks*]

(c) It is after 6pm. A single decker bus is approaching. What is the probability it will *not* go to Morningside? Give your answer to 2 decimal places. [*13 marks*]