0900–1200 hrs	7 / June / 2024	Flower Hall	EXAMS OFFICE USE ONLY

University of the Witwatersrand, Johannesburg

Course or topic No(s)	COMS4033A/7044A
Course or topic name(s) Paper Number & title	Artificial Intelligence
Examination to be held during the month(s) of	June, 2024
Year of study	
Degrees/Diplomas for which this course is prescribed	
Faculties presenting candidates	Science
Internal examiner(s)	Dr Steven James x-76157
External examiner(s)	Dr Nakul Gopalan (ASU)
Special materials	None
Time allowance	3 Hours
Instructions to candidates	70 Marks available. 70 marks = 100%. Answer all questions. This is a closed book exam. This exam consists of 14 pages.

Artificial Intelligence
COMS4033A/7044A

Student Number: Memo ____________________ Row: _______ Seat: _______

For marking purposes only

Question 1	
Question 2	
Question 3	
Question 4	
Total	

Instructions

- Please write your student number on each page, including the front cover.
- Answer all questions in pen. **Do not write in pencil.**
- This test consists of 14 pages. Ensure that you are not missing any pages.
- This is a **closed-book** test: you may not consult any written material or notes.
- You are allocated 3 hours to complete this exam.
- There are 4 questions and 70 marks available.
- Ensure your cellphone is switched off.

Question 1 Agents and Search [19 Marks]

1. Define what is meant by a rational agent. [2]

   ACTS in its environment according to what it has PERCEIVED

   in order to MAXIMISE its expected PERFORMANCE measure

   [0.5 for each concept]

2. Define the concept of a Nash equilibrium in a simultaneous-move game. [1]

   An outcome / set of strategies where no player can do better by unilaterally switching

   [1 for switching]

3. Consider the following payoff matrix representing a game between two players A (the "row" player) and B (the "column" player).

	B_1	B_2	B_3	B_4
A_1	$(1,7)$	$(2,5)$	$(7,2)$	$(0,1)$
A_2	$(5,2)$	$(3,3)$	$(5,2)$	$(3,1)$
A_3	$(7,0)$	$(2,5)$	$(0,4)$	$(1,1)$
A_4	$(0,0)$	$(0,2)$	$(0,0)$	$(0,-1)$

   Execute the *Iterated Elimination of Dominated Strategies* algorithm on the payoff matrix to find the outcome, beginning with player B. At each step, list the strategy that is eliminated and why it is eliminated, as well as the final outcome. [3]

   B4 is eliminated (dominated by B2)

   A4 eliminated (dominated by A1/A2/A3)

   B3 eliminated (dominated by B2)

   A1 eliminated (dominated by A2)

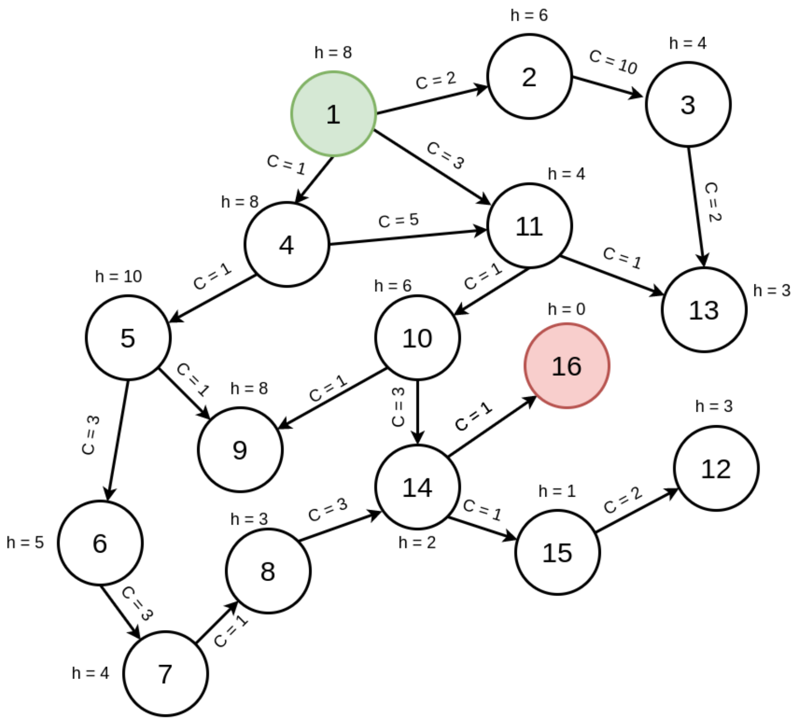
   B1 eliminated (dominated by B2)

   A3 eliminated (dominated by A2)
   Final outcome (A2,B2) = (3,3)

   [0.5 for each correct step]

4. Let C be the cost of traversing an edge between nodes, and let h be the heuristic estimate of a given node to the goal. Consider the graph below, where nodes are labelled with integers and directed edges are indicated by lines with arrows. Each edge is labelled with a cost C, and each node with a heuristic value h.

   Assume that we wish to search for the goal node 16 starting at node 1 using the A* search algorithm. Further, assume that if there are ties in the priority queue, they



are resolved by removing the node with the smallest label first (e.g. if two nodes 2 and 1 both have priority 10, then 1 will be removed before 2).

Given this, detail each step of the A* algorithm. At each iteration, describe what node is popped from the queue and then what nodes are added to the queue subsequently (and their corresponding priority). [4]

Start with 1 (no need to mention priority)

Add 2 (8), 4(9), 11 (7).

Pop 11. Add 10 (10), 13 (7)
Pop 13

Pop 2. Add 3 (16)

Pop 4. Add 5(12)
Pop 10. Add 9(13), 14(9)

Pop 14. Add 16(8), 15(9)
Pop 16.

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5. Define what it means for a heuristic h_1 to *dominate* another heuristic h_2. [1]

h1 dominates h2 if h1(n) >= h2(n) for all nodes n. (or it provides better cost-to-go estimates for all nodes)

6. Assume we have a search problem with zero costs everywhere. In this case, is breadth-first search complete? Why or why not? [2]

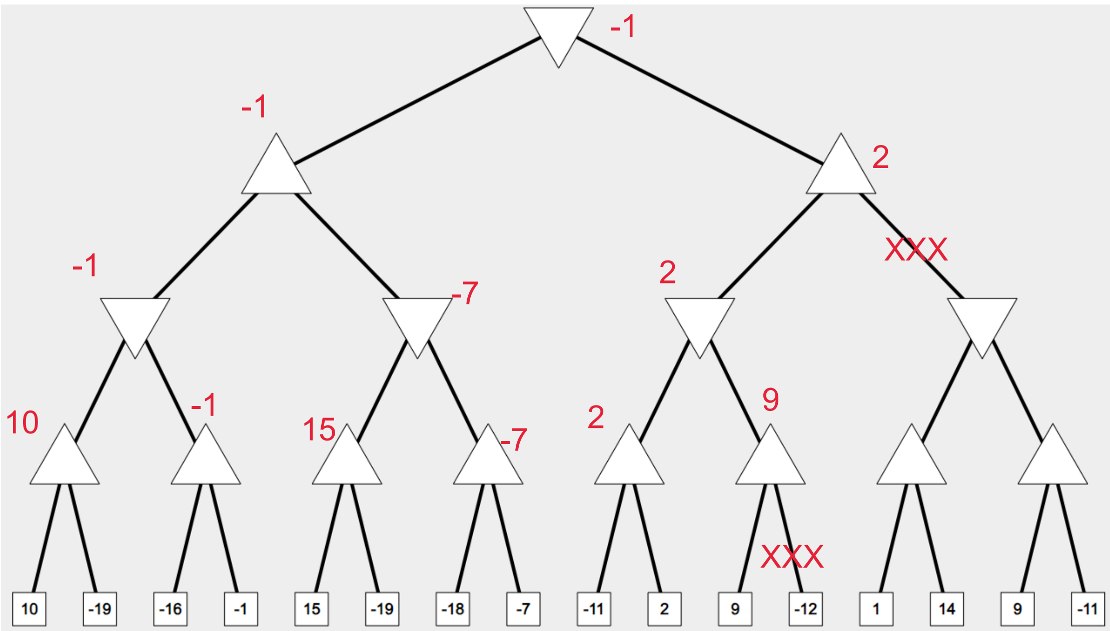
Yes, breadth first search doesn't care about costs, only shortest/shallowest solution

[2 for independent of costs or shortest]

7. Describe under what conditions uniform-cost search is identical to breadth-first search. [1]

When costs are the same everywhere (could also say when they're all zero)

8. Consider the game tree below. Triangles pointing down represent the minimising player, triangles pointing up represent the maximising player and rectangles represent terminal nodes. Execute alpha-beta pruning on the tree. Annotate the tree by writing down the value backed up to each node in the tree (including the root), and indicate where pruning takes place by crossing out the relevant edges. **Note that the root node is a minimising node.** [5]



1 for each correct prune
3 for values
-0.5 for wrong prunes (max -2)

Question 2 Knowledge Representation [11 Marks]

1. Suppose $P(A), P(\neg A), P(B|A)$ and $P(B|\neg A)$ are known. Find an expression for $P(A|B)$ in terms of these four probabilities. [2]

   P(A|B) = numerator/denom

   numerator = P(B|A)P(A) [1]

   denom = P(B|A)P(A) + P(B|not A)P(not A) [1]

2. Consider the rules of soccer in a local league. The rules state that a player who receives a red card during a match may receive a suspension for a number of weeks. Players receive a red card during a match if the referee observes them commit an act of violent conduct. They could also receive a red card if they already have a yellow card and commit another foul. We wish to model this using a Bayesian network with the following random variables: whether the player has a yellow card (`yellow`), whether the player has a red card (`red`), whether the player commits violent conduct (`violence`), and whether they receive a suspension (`suspension`).

   (a) Draw the corresponding Bayesian network for the above four variables. [2]

   violence and yellow are independent [0.5 each]
   both point to red [0.5]
   red points to suspension [0.5]

   (b) Write down the factorisation of joint probability distribution given the Bayesian network's structure in part a). [1]

   P(V)P(Y)P(R|V,Y)P(S|R)

   (or correct wrt (a))

3. Describe what the aim of structure learning is in Bayesian networks. [1]

   Learn the connections/edges/influence/causality between nodes

4. In the context of Hidden Markov Models, what is the difference between determining the most likely path and filtering? Answer this question by writing down the probabilities that each approach attempts to calculate (and define your notation), and then suggest one real-world application for each of them. [3]

Most likely: P(S_0...S_T | O_0...O_T) [1]

e.g. Robot's path through building [0.5]

Filtering: P(S_T | O_0...O_T) [1]

e.g. current patient disease [0.5]

5. Alice wishes to encode the following sentence in first-order logic: "No one who runs walks." She writes this as $\forall x(\neg \text{run}(x) \implies \text{walk}(x))$. Her friend Bob disagrees with her and thinks it should be written as $\neg\exists x(\text{run}(x) \wedge \text{walk}(x))$. Explain who is correct and provide a reason why the other is incorrect. [2]

Bob is right (because it states that no such person who both runs and walks exists) [1]

Alice is wrong because sentence says that for everyone, if they don't run, then they walk

and if they do run, then they walk (or don't walk) [1]

Question 3 Planning [18 Marks]

1. What is the primary difference between the initial state description and the goal description in PDDL? [2]

   Initial state is full description of a single state

   Goal test is partial specification so refers to many states

   [1 each]

2. In STRIPS formulation, preconditions and goals are not allowed to contain negations. Using this fact, explain why removing negative effects from each STRIPS action operator results in a relaxed problem. [2]

   Negative effect can only make it harder to achieve a goal (or a precondition to an action that achieves the goal) by undoing things.
   Therefore, eliminating all negative effects only makes a problem easier.

3. List two reasons why we might need to account for probabilistic action outcomes. [2]

   Anything reasonable. World is stochastic, actions fail, noise, abstraction

   [1 each]

4. Write down the mathematical statement of the Markov property for controlled processes. Your answer should make reference to states and actions. [1]

   P(St | S_t-1, A_t-1 ... S_0, A_0) = P(St | S_t-1, A_t-1)

5. Provide one reason why one would need a policy, rather than a plan, when operating in a domain with stochastic transitions. [1]

   We cannot just follow a sequence of actions, since we may find ourself

   in an unexpected state and need to recover.

6. PDDL separates the domain description from the problem description. In this context, what is the difference between the domain and the problem? Give a real-world example to illustrate this. [2]

Domain: describes the actions and model (how the world works/is modelled)

Problem: a given task in the world (start and goal). e.g. domain is kitchen, problems are make coffee, make tea, etc

[1 for difference, 1 for example]

7. Consider an MDP in which an agent is required to navigate a large grid to reach a goal as quickly as possible. The reward function is 1 when the agent enters the goal state, and 0 for all other transitions. Alice wishes to solve this problem using policy iteration with a discount factor $\gamma = 1$. However, Bob says she should use a discount factor $\gamma = 0$, while Claire says she should use $\gamma = 0.95$. Which person's suggestion should be preferred? For the remaining two people, state what problems would result from their choice of γ. [3]

   Alice wrong. Then all paths regardless of length have same value

   Bob wrong. Will lead to very slow learning since no future accounted for

   Claire right: good balance between prioritising now vs future

   [1 each]

8. Aside from the discount factor, what are the other four components that make up a Markov decision process? Explain what each of them are. [2]

   S - state space, A - action space, R -reward function, T - transitions

   [0.5 each]

9. Consider the Blocksworld environment with ten blocks labelled `A`–`J`. The current state is given by

```
(clear C) (ontable I) (on C E) (on E J)
(on J B) (on B G) (on G H) (on H A) (on A D) (on D I) (holding F)
```

   and there is an operator `stack`, which is defined as follows:

```
(:action stack
  :parameters  (?ob ?underob)
  :precondition (and  (clear ?underob) (holding ?ob))
  :effect (and (arm-empty) (clear ?ob) (on ?ob ?underob)
               (not (clear ?underob)) (not (holding ?ob))))
```

Write down the new state that results from the execution of `stack(F,C)`. [3]

Add: arm-empty, clear(F), on(F, C) [1]

Delete: clear(C), holding(F) [1]

Everything else is the same [1]

Question 4 Learning [22 Marks]

1. What problem does the DQN approach solve when it randomly samples from experience replay, and why does this problem occur in reinforcement learning? [2]

   Ensures data is not correlated (makes it IID)

   Data is correlated because RL data is sequential, so states are related

   [1 each]

2. In general, why can a value function that is only a function of state be used for planning, but not for reinforcement learning? [2]

   We can't act greedily without T and R if we only know V. [1]

   We have that in planning, but not RL [1]

3. Why is it necessary to explore in reinforcement learning? [2]

   We need to discover if there are better actions out there. Without exploration

   we won't know if we're optimal

4. Your friend Bob claims that for any Markov decision process, there always exists exactly one optimal policy. Is he correct? Why or why not? [1]

   No - there is at least one, but could be many more equal.

5. List two reasons why function approximation in reinforcement learning is necessary for real-world environments. [2]

   May never visit a state, may visit state only once, can't fit in memory, etc

   1 each]

6. Write down the mathematical relationship between the value function $V^{\pi}(s)$ and the action value function $Q^{\pi}(s,a)$. [1]

   V = Q(s, pi(s))

7. Describe the difference between a classification and regression problem. [1]

   Classification: predict discrete classes

   Regression: predict continuous values

8. What is the difference between supervised and unsupervised learning? Give a real-world example of each. [2]

   Supervised: have data and labels and must learn map (e.g. image classification)

   Unsupervised: have only data and must find structure (e.g. find similar answers in exam)

9. What is the likeliest outcome of a machine learning model that has been trained on data that has not been partitioned into a train/test split? [1]

   overfit / won't generalise to new data

10. Describe how autoencoders perform dimensionality reduction. [2]

    Learn function that reduces to bottleneck but must be sufficient for reconstruction

    [1 for bottleneck, 1 for recon]

    For each machine learning algorithm below, state whether it is parametric or non-parametric: [2]

    (a) k-nearest neighbours non

    (b) Gaussian mixture model param

    (c) Kernel density estimator non

    (d) k-means clustering non

11. Computing the likelihood of a point using kernel density estimation involves summing over all data points. How does the *bandwidth* parameter influence the contribution of each data point to the sum? [2]

    High bandwith: distant points have higher contribution

    Low: distant points have lower

12. Define what is meant by selection bias. Then, describe how this could result in bias when datasets are labelled by Mechanical Turk workers. [2]

Selection does not reflect truly random sample. [1]

MT workers from specific geog regions, so have that worldview and may

not be familiar with other cultures. [1]

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