

# CMSC 671 (Introduction to AI)

Homework 4: **Propositional logic, knowledge-based agents, first-order logic, logical inference**  
Turnin: Blackboard.

Please submit **all parts** together as a **single PDF file** named *lastname\_hw4.pdf*, with parts clearly marked and delineated. This assignment should be worked on individually.

**All** files must start with your last name(s) and have your full name(s) in the file, at/near the top.

**Reminder:** Assignments **must be turned in on time. If Blackboard says it's late, it is late.**

## PART I. KNOWLEDGE-BASED AGENTS (15 PTS.)

(Adapted from R&N 2nd edition, Exercise 7.1.) Consider the game Minesweeper (shown right), in which an agent explores a grid. Each square contains either a mine (if the agent explores this square, it loses the game), nothing, or a number  $\geq 1$  that indicates how many mines are in the 8 adjacent squares. The agent's goal is to explore every unmined (safe) square and no mined squares.<sup>1</sup>



Assignment: Answer the following questions about a Minesweeper agent.

1. Describe the Minesweeper world according to the properties of task environments listed in Chapter 2 (i.e., the seven characteristics described in Section 2.3.2: fully vs. partially observable; single- vs multi-agent; deterministic vs. non-deterministic; episodic vs. sequential; static vs dynamic; discrete vs. continuous; known vs. unknown). Your answer should include a brief (single sentence or phrase) justification for each of the seven answers.
2. How would your answer change in a world in which mines could relocate to a different unexplored square between your moves, according to certain rules known to the agent? Your answer should include a brief (single sentence or phrase) justification for each property *that changes*.
3. Now consider a variation of this world that contains a drone. The squares surrounding the drone are marked with a d as well as a number (see illustration). If the agent explores the square containing a drone, it picks the agent up and drops it on a randomly selected square. Does that change the environment description? Your answer should include a brief (single sentence or phrase) justification for each property *that changes*.

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<sup>1</sup> If you are not familiar with the game, search for online versions and play until you are sure you understand how it works. Instructions: [www.minesweeper.info/wiki/Strategy](http://www.minesweeper.info/wiki/Strategy), online game (one of many): [michaelbutler.github.io/minesweeper](http://michaelbutler.github.io/minesweeper)

## PART II. PROOFS IN PROPOSITIONAL LOGIC (15 PTS.)

Use rules of inference to prove the following statements from the given KB. The most important rules of inference are given in the box below. A simple example proof is performed on slide 61 of lecture 17, and a more complex proof is on slide 69.

4. KB:  $\neg(s \wedge t)$  (premise 1)  
 $\neg w \Rightarrow t$  (premise 2)

Prove:  $s \Rightarrow w$

5. KB:  $\neg(\neg p \vee q)$  (premise 1)  
 $\neg z \Rightarrow \neg s$  (premise 2)  
 $(p \wedge \neg q) \Rightarrow s$  (premise 3)  
 $\neg z \vee r$  (premise 4)

Prove:  $r$

Rules		
Modus Ponens	$A, A \Rightarrow B$	$B$
And Introduction	$A, B$	$A \wedge B$
And Elimination	$A \wedge B$	$A$
Double Negation	$\neg\neg A$	$A$
Unit Resolution	$A \vee B, \neg B$	$A$
Resolution	$A \vee B, \neg B \vee C$	$A \vee C$
de Morgans	$\neg(A \vee B)$	$\neg A \wedge \neg B$
$\vee/\Rightarrow$ Equivalence	$A \Rightarrow B$	$\neg A \vee B$

## PART III. PROPOSITIONAL LOGIC IN WUMPUS WORLD (15 PTS.)

We will use the definition of the Wumpus World given in class: that is, there is a single wumpus somewhere in the maze, along with multiple pits. At each square, a set of five percepts is given (but you only need to consider the ones shown in the sample map below). A wumpus and a pit may occupy the same square. The percept  $S_{ij}$  means there is a stench in cell  $i, j$ ; the percept  $B_{ij}$  means there is a breeze in cell  $i, j$ ; and  $V_{ij}$  means cell  $i, j$  has been visited.

### Rules

- If there is no stench in a cell, then there is no wumpus in any adjacent cell.
- If there is a stench in a cell, then there is a wumpus in some adjacent cell.
- If there is no breeze in a cell, then there is no pit in any adjacent cell.
- If there is a breeze in a cell, then there is a pit in some adjacent cell.
- If a cell has been visited, it has neither a wumpus nor a pit.

V13 S13 B13			
V12 ¬S12 ¬B12	V22 S22 B22		
V11 ¬S11 ¬B11	V21 ¬S21 ¬B21	V31 ¬S31 B31	

Given the observations shown and the rules given, and using the same rules of inference as in Part I:

6. Can you prove there is a pit in square (3,2)? Why or why not? (5 pts)
7. Prove the Wumpus is in square (2,3). (10 pts)

## PART IV. FOL & INFERENCE (35 POINTS)

**Assignment:** Construct the following knowledge base (list the sentences in it). (15 pts)

8. Represent the following knowledge base *in first-order logic*. Use the predicates:

- $\text{is-employee}(x)$       •  $\text{is-boss}(x)$       •  $\text{knows}(x,y)$
- $\text{is-person}(x)$       •  $\text{is-friend-of}(x,y)$       •  $\text{criticizes}(x,y)$

where arguments  $x$  and  $y$  have the domain of all people. Note that friend-of and criticizes are one-way:  $x$  can be a friend of  $y$  without  $y$  being a friend of  $x$ . knows, however, is two-way:  $\text{knows}(x,y) \Rightarrow \text{knows}(y,x)$ .

- a. Dr. Smith is an employee.
- b. All employees are people.
- c. Dr. Lee is the boss.
- d. Bosses are employees.
- e. Everyone is a friend of someone.
- f. All employees either consider the boss a friend or don't know her.
- g. People only criticize people that are not their friends.
- h. Dr. Smith criticized Dr. Lee.

9. Convert the KB to conjunctive normal form (list the new set of sentences in the KB).

**Assignment:** Next, we wish to determine whether Dr. Lee knows Dr. Smith. (15 pts)

10. Write the query in first-order logic.

11. Express the negation of the query in conjunctive normal form.

12. Add the negated goal to the KB, and use forward chaining to prove that it is true. Show your proof as a series of sentences to be added to the KB. (Denote new sentences with letters starting after h.) You must clearly show which sentences are used to produce each new sentence.

**Assignment:** Answer the following questions *in English*. (5 pts)

13. For two of the sentences in the KB, give a 1-2 sentence explanation of how those sentences are a poor representation of the real world.