# Department of Computer Science

# CS-354 Artificial Intelligence

# Class: BSCS

# Lab05: Knowledge II

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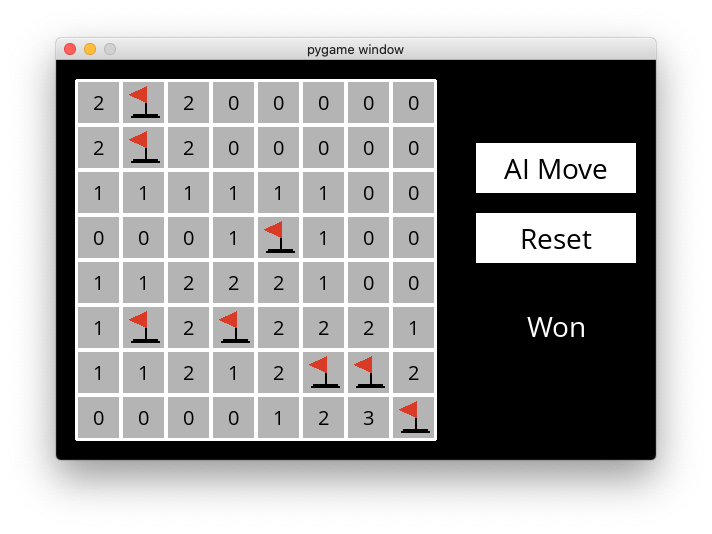
# Dr. Muhammad Tahir

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# Mr. Rozi Khan

**Minesweeper**

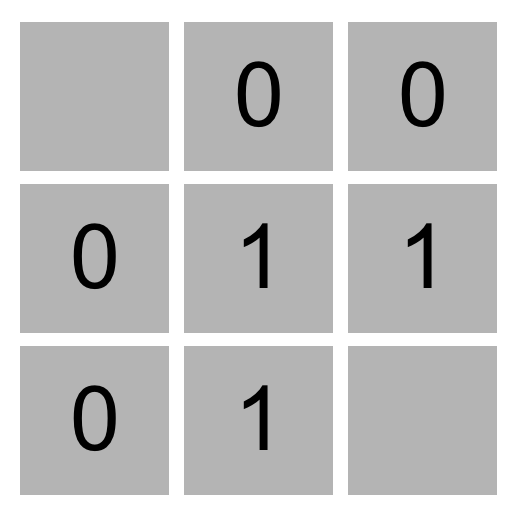
Write an AI to play Minesweeper.



**Background**

Minesweeper is a puzzle game that consists of a grid of cells, where some of the cells contain hidden “mines.” Clicking on a cell that contains a mine detonates the mine and causes the user to lose the game. Clicking on a “safe” cell (i.e., a cell that does not contain a mine) reveals a number that indicates how many neighboring cells – where a neighbor is a cell that is one square to the left, right, up, down, or diagonal from the given cell – contain a mine.

In this 3x3 Minesweeper game, for example, the three 1 values indicate that each of those cells has one neighboring cell that is a mine. The four 0 values indicate that each of those cells has no neighboring mine.



Given this information, a logical player could conclude that there must be a mine in the lower-right cell and that there is no mine in the upper-left cell, for only in that case would the numerical labels on each of the other cells be accurate.

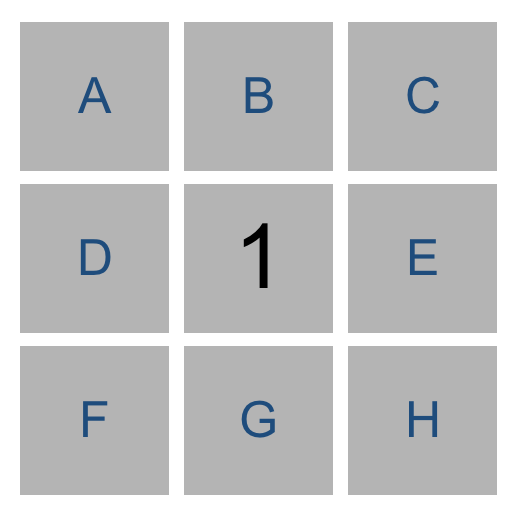
The goal of the game is to flag (i.e., identify) each of the mines. In many implementations of the game, including the one in this project, the player can flag a mine by right-clicking on a cell (or two-finger clicking, depending on the computer).

### Propositional Logic

Your goal in this project will be to build an AI that can play Minesweeper. Recall that knowledge-based agents make decisions by considering their knowledge base, and making inferences based on that knowledge.

One way we could represent an AI’s knowledge about a Minesweeper game is by making each cell a propositional variable that is true if the cell contains a mine, and false otherwise.

What information does the AI have access to? Well, the AI would know every time a safe cell is clicked on and would get to see the number for that cell. Consider the following Minesweeper board, where the middle cell has been revealed, and the other cells have been labeled with an identifying letter for the sake of discussion.



What information do we have now? It appears we now know that one of the eight neighboring cells is a mine. Therefore, we could write a logical expression like the one below to indicate that one of the neighboring cells is a mine.

Or(A, B, C, D, E, F, G, H)

But we actually know more than what this expression says. The above logical sentence expresses the idea that at least one of those eight variables is true. But we can make a stronger statement than that: we know that exactly one of the eight variables is true. This gives us a propositional logic sentence like the below.

Or(

And(A, Not(B), Not(C), Not(D), Not(E), Not(F), Not(G), Not(H)),

And(Not(A), B, Not(C), Not(D), Not(E), Not(F), Not(G), Not(H)),

And(Not(A), Not(B), C, Not(D), Not(E), Not(F), Not(G), Not(H)),

And(Not(A), Not(B), Not(C), D, Not(E), Not(F), Not(G), Not(H)),

And(Not(A), Not(B), Not(C), Not(D), E, Not(F), Not(G), Not(H)),

And(Not(A), Not(B), Not(C), Not(D), Not(E), F, Not(G), Not(H)),

And(Not(A), Not(B), Not(C), Not(D), Not(E), Not(F), G, Not(H)),

And(Not(A), Not(B), Not(C), Not(D), Not(E), Not(F), Not(G), H)

)

That’s quite a complicated expression! And that’s just to express what it means for a cell to have a 1 in it. If a cell has a 2 or 3 or some other value, the expression could be even longer.

Trying to perform model checking on this type of problem, too, would quickly become intractable: on an 8x8 grid, the size Microsoft uses for its Beginner level, we’d have 64 variables, and therefore 2^64 possible models to check – far too many for a computer to compute in any reasonable amount of time. We need a better representation of knowledge for this problem.

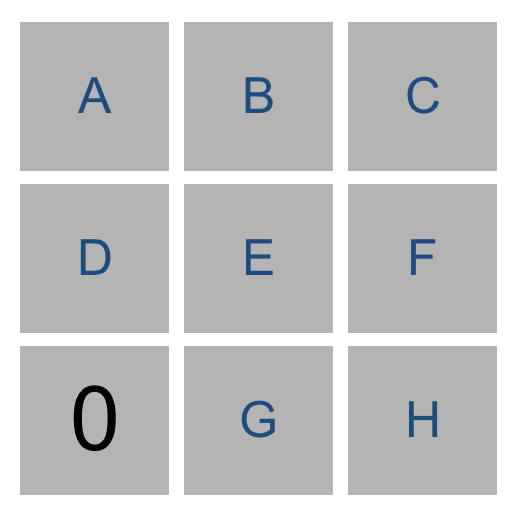
### Knowledge Representation

Instead, we’ll represent each sentence of our AI’s knowledge like the one below.

{A, B, C, D, E, F, G, H} = 1

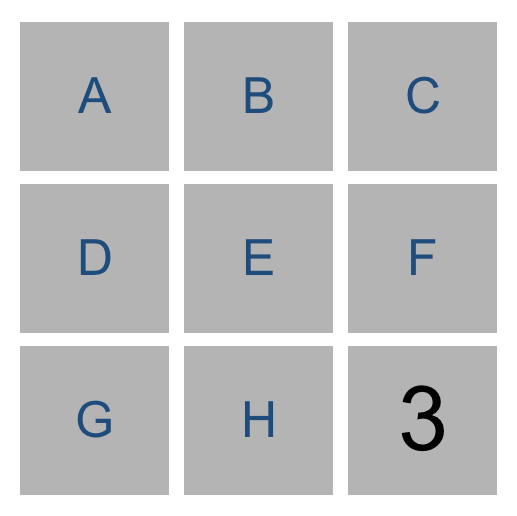
Every logical sentence in this representation has two parts: a set of cells on the board that are involved in the sentence, and a number count, representing the count of how many of those cells are mines. The above logical sentence says that out of cells A, B, C, D, E, F, G, and H, exactly 1 of them is a mine.

Why is this a useful representation? In part, it lends itself well to certain types of inference. Consider the game below.



Using the knowledge from the lower-left number, we could construct the sentence {D, E, G} = 0 to mean that out of cells D, E, and G, exactly 0 of them are mines. Intuitively, we can infer from that sentence that all of the cells must be safe. By extension, any time we have a sentence whose count is 0, we know that all of that sentence’s cells must be safe.

Similarly, consider the game below.



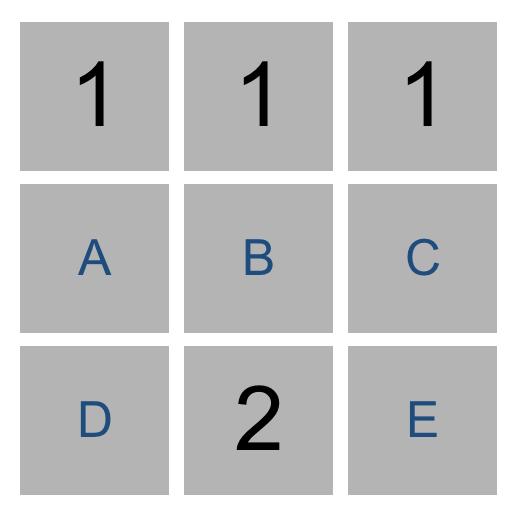
Our AI would construct the sentence {E, F, H} = 3. Intuitively, we can infer that all of E, F, and H are mines. More generally, any time the number of cells is equal to the count, we know that all of that sentence’s cells must be mines.

In general, we’ll only want our sentences to be about cells that are not yet known to be either safe or mines. This means that, once we know whether a cell is a mine or not, we can update our sentences to simplify them and potentially draw new conclusions.

For example, if our AI knew the sentence {A, B, C} = 2, we don’t yet have enough information to conclude anything. But if we were told that C were safe, we could remove C from the sentence altogether, leaving us with the sentence {A, B} = 2 (which, incidentally, does let us draw some new conclusions.)

Likewise, if our AI knew the sentence {A, B, C} = 2, and we were told that C is a mine, we could remove C from the sentence and decrease the value of count (since C was a mine that contributed to that count), giving us the sentence {A, B} = 1. This is logical: if two out of A, B, and C are mines, and we know that C is a mine, then it must be the case that out of A and B, exactly one of them is a mine.

If we’re being even more clever, there’s one final type of inference we can do.



Consider just the two sentences our AI would know based on the top middle cell and the bottom middle cell. From the top middle cell, we have {A, B, C} = 1. From the bottom middle cell, we have {A, B, C, D, E} = 2. Logically, we could then infer a new piece of knowledge, that {D, E} = 1. After all, if two of A, B, C, D, and E are mines, and only one of A, B, and C are mines, then it stands to reason that exactly one of D and E must be the other mine.

More generally, any time we have two sentences set1 = count1 and set2 = count2 where set1 is a subset of set2, then we can construct the new sentence set2 - set1 = count2 - count1. Consider the example above to ensure you understand why that’s true.

So using this method of representing knowledge, we can write an AI agent that can gather knowledge about the Minesweeper board, and hopefully select cells it knows to be safe!

**Getting Started:**

* Download the distribution code from <https://cdn.cs50.net/ai/2020/x/projects/1/minesweeper.zip> and unzip it.
* Once in the directory for the project, run pip3 install -r requirements.txt to install the required Python package (pygame) for this project if you don’t already have it installed.

**Understanding:**

There are two main files in this project: runner.py and minesweeper.py. minesweeper.py contains all of the logic the game itself and for the AI to play the game. runner.py has been implemented for you, and contains all of the code to run the graphical interface for the game. Once you’ve completed all the required functions in minesweeper.py, you should be able to run python runner.py to play Minesweeper (or let your AI play for you)!

Let’s open up minesweeper.py to understand what’s provided. There are three classes defined in this file, Minesweeper, which handles the gameplay; Sentence, which represents a logical sentence that contains both a set of cells and a count; and MinesweeperAI, which handles inferring which moves to make based on knowledge.

The Minesweeper class has been entirely implemented for you. Notice that each cell is a pair (i, j) where i is the row number (ranging from 0 to height - 1) and j is the column number (ranging from 0 to width - 1).

The Sentence class will be used to represent logical sentences of the form described in the Background. Each sentence has a set of cells within it and a count of how many of those cells are mines. The class also contains functions known\_mines and known\_safes for determining if any of the cells in the sentence are known to be mines or known to be safe. It also contains functions mark\_mine and mark\_safe to update a sentence in response to new information about a cell.

Finally, the MinesweeperAI class will implement an AI that can play Minesweeper. The AI class keeps track of a number of values. self.moves\_made contains a set of all cells already clicked on, so the AI knows not to pick those again. self.mines contains a set of all cells known to be mines. self.safes contains a set of all cells known to be safe. And self.knowledge contains a list of all of the Sentences that the AI knows to be true.

The mark\_mine function adds a cell to self.mines, so the AI knows that it is a mine. It also loops over all sentences in the AI’s knowledge and informs each sentence that the cell is a mine, so that the sentence can update itself accordingly if it contains information about that mine. The mark\_safe function does the same thing, but for safe cells instead.

The remaining functions, add\_knowledge, make\_safe\_move, and make\_random\_move, are left up to you!

**Specification:**

Complete the implementations of the Sentence class and the MinesweeperAI class in minesweeper.py.

In the Sentence class, complete the implementations of known\_mines, known\_safes, mark\_mine, and mark\_safe.

* The known\_mines function should return a set of all of the cells in self.cells that are known to be mines.
* The known\_safes function should return a set of all the cells in self.cells that are known to be safe.
* The mark\_mine function should first check to see if cell is one of the cells included in the sentence.
  + If cell is in the sentence, the function should update the sentence so that cell is no longer in the sentence, but still represents a logically correct sentence given that cell is known to be a mine.
  + If cell is not in the sentence, then no action is necessary.
* The mark\_safe function should first check to see if cell is one of the cells included in the sentence.
  + If cell is in the sentence, the function should update the sentence so that cell is no longer in the sentence, but still represents a logically correct sentence given that cell is known to be safe.
  + If cell is not in the sentence, then no action is necessary.

In the MinesweeperAI class, complete the implementations of add\_knowledge, make\_safe\_move, and make\_random\_move.

* add\_knowledge should accept a cell (represented as a tuple (i, j)) and its corresponding count, and update self.mines, self.safes, self.moves\_made, and self.knowledge with any new information that the AI can infer, given that cell is known to be a safe cell with count mines neighboring it.
  + The function should mark the cell as one of the moves made in the game.
  + The function should mark the cell as a safe cell, updating any sentences that contain the cell as well.
  + The function should add a new sentence to the AI’s knowledge base, based on the value of cell and count, to indicate that count of the cell’s neighbors are mines. Be sure to only include cells whose state is still undetermined in the sentence.
  + If, based on any of the sentences in self.knowledge, new cells can be marked as safe or as mines, then the function should do so.
  + If, based on any of the sentences in self.knowledge, new sentences can be inferred (using the subset method described in the Background), then those sentences should be added to the knowledge base as well.
  + Note that any time that you make any change to your AI’s knowledge, it may be possible to draw new inferences that weren’t possible before. Be sure that those new inferences are added to the knowledge base if it is possible to do so.
* make\_safe\_move should return a move (i, j) that is known to be safe.
  + The move returned must be known to be safe, and not a move already made.
  + If no safe move can be guaranteed, the function should return None.
  + The function should not modify self.moves\_made, self.mines, self.safes, or self.knowledge.
* make\_random\_move should return a random move (i, j).
  + This function will be called if a safe move is not possible: if the AI doesn’t know where to move, it will choose to move randomly instead.
  + The move must not be a move that has already been made.
  + The move must not be a move that is known to be a mine.
  + If no such moves are possible, the function should return None.

**Hints:**

* Be sure you’ve thoroughly read the Background section to understand how knowledge is represented in this AI and how the AI can make inferences.
* If feeling less comfortable with object-oriented programming, you may find [Python’s documentation on classes](https://docs.python.org/3/tutorial/classes.html) helpful.
* You can find some common set operations in [Python’s documentation on sets](https://docs.python.org/3/library/stdtypes.html#set).
* When implementing known\_mines and known\_safes in the Sentence class, consider: under what circumstances do you know for sure that a sentence’s cells are safe? Under what circumstances do you know for sure that a sentence’s cells are mines?
* add\_knowledge does quite a lot of work, and will likely be the longest function you write for this project by far. It will likely be helpful to implement this function’s behavior one step at a time.
* You’re welcome to add new methods to any of the classes if you would like, but you should not modify any of the existing functions’ definitions or arguments.
* When you run your AI (as by clicking “AI Move”), note that it will not always win! There will be some cases where the AI must guess, because it lacks sufficient information to make a safe move. This is to be expected. runner.py will print whether the AI is making a move it believes to be safe or whether it is making a random move.
* Be careful not to modify a set while iterating over it. Doing so may result in errors!

| import random  class Minesweeper():  """  Minesweeper game representation  """  def \_\_init\_\_(self, height=8, width=8, mines=8):  *# Set initial width, height, and number of mines*  *self*.height = height  *self*.width = width  *self*.mines = set()  *# Initialize an empty field with no mines*  *self*.board = []  for i in range(*self*.height):  row = []  for j in range(*self*.width):  row.append(False)  *self*.board.append(row)  *# Add mines randomly*  while len(*self*.mines) != mines:  i = random.randrange(height)  j = random.randrange(width)  if not *self*.board[i][j]:  *self*.mines.add((i, j))  *self*.board[i][j] = True  *# At first, player has found no mines*  *self*.mines\_found = set()  def print(self):  """  Prints a text-based representation  of where mines are located.  """  for i in range(*self*.height):  print("--" \* *self*.width + "-")  for j in range(*self*.width):  if *self*.board[i][j]:  print("|X", end="")  else:  print("| ", end="")  print("|")  print("--" \* *self*.width + "-")  def is\_mine(self, cell):  i, j = cell  return *self*.board[i][j]  def nearby\_mines(self, cell):  """  Returns the number of mines that are  within one row and column of a given cell,  not including the cell itself.  """  *# Keep count of nearby mines*  count = 0  *# Loop over all cells within one row and column*  for i in range(cell[0] - 1, cell[0] + 2):  for j in range(cell[1] - 1, cell[1] + 2):  *# Ignore the cell itself*  if (i, j) == cell:  continue  *# Update count if cell in bounds and is mine*  if 0 <= i < *self*.height and 0 <= j < *self*.width:  if *self*.board[i][j]:  count += 1  return count  def won(self):  """  Checks if all mines have been flagged.  """  return *self*.mines\_found == *self*.mines  class Sentence():  """  Logical statement about a Minesweeper game  A sentence consists of a set of board cells,  and a count of the number of those cells which are mines.  """  def \_\_init\_\_(self, cells, count):  *self*.cells = set(cells)  *self*.count = count  def \_\_eq\_\_(self, other):  return *self*.cells == other.cells and *self*.count == other.count  def \_\_str\_\_(self):  return f"{*self*.cells} = {*self*.count}"  def known\_mines(self):  """  Returns the set of all cells in self.cells known to be mines.  """  *# If count of mines is equal to number of cells (and > 0), all cells are mines:*  if len(*self*.cells) == *self*.count and *self*.count != 0:  print('Mine Identified! - ', *self*.cells)  return *self*.cells  else:  return set()  def known\_safes(self):  """  Returns the set of all cells in self.cells known to be safe.  """  *# If count of mines is zero then all cells in the sentence are safe:*  if *self*.count == 0:  return *self*.cells  else:  return set()  def mark\_mine(self, cell):  """  Updates internal knowledge representation given the fact that  a cell is known to be a mine.  """  *# If cell is in the sentence, remove it and decrement count by one*  if cell in *self*.cells:  *self*.cells.remove(cell)  *self*.count -= 1  def mark\_safe(self, cell):  """  Updates internal knowledge representation given the fact that  a cell is known to be safe.  """  *# If cell is in the sentence, remove it, but do not decrement count*  if cell in *self*.cells:  *self*.cells.remove(cell)  class MinesweeperAI():  """  Minesweeper game player  """  def \_\_init\_\_(self, height=8, width=8):  *# Set initial height and width*  *self*.height = height  *self*.width = width  *# Keep track of which cells have been clicked on*  *self*.moves\_made = set()  *# Keep track of cells known to be safe or mines*  *self*.mines = set()  *self*.safes = set()  *# List of sentences about the game known to be true*  *self*.knowledge = []  def mark\_mine(self, cell):  """  Marks a cell as a mine, and updates all knowledge  to mark that cell as a mine as well.  """  *self*.mines.add(cell)  for sentence in *self*.knowledge:  sentence.mark\_mine(cell)  def mark\_safe(self, cell):  """  Marks a cell as safe, and updates all knowledge  to mark that cell as safe as well.  """  *self*.safes.add(cell)  for sentence in *self*.knowledge:  sentence.mark\_safe(cell)  def add\_knowledge(self, cell, count):  """  Called when the Minesweeper board tells us, for a given  safe cell, how many neighboring cells have mines in them.  This function should:  1) mark the cell as a move that has been made  2) mark the cell as safe  3) add a new sentence to the AI's knowledge base  based on the value of `cell` and `count`  4) mark any additional cells as safe or as mines  if it can be concluded based on the AI's knowledge base  5) add any new sentences to the AI's knowledge base  if they can be inferred from existing knowledge  """  *# Mark the cell as a move that has been made, and mark as safe:*  *self*.moves\_made.add(cell)  *self*.mark\_safe(cell)  *# Create set to store undecided cells for KB:*  new\_sentence\_cells = set()  *# Loop over all cells within one row and column*  for i in range(cell[0] - 1, cell[0] + 2):  for j in range(cell[1] - 1, cell[1] + 2):  *# Ignore the cell itself*  if (i, j) == cell:  continue  *# If cells are already safe, ignore them:*  if (i, j) in *self*.safes:  continue  *# If cells are known to be mines, reduce count by 1 and ignore them:*  if (i, j) in *self*.mines:  count = count - 1  continue  *# Otherwise add them to sentence if they are in the game board:*  if 0 <= i < *self*.height and 0 <= j < *self*.width:  new\_sentence\_cells.add((i, j))  *# Add the new sentence to the AI's Knowledge Base:*  print(f'Move on cell: {cell} has added sentence to knowledge {new\_sentence\_cells} = {count}' )  *self*.knowledge.append(Sentence(new\_sentence\_cells, count))  *# Iteratively mark guaranteed mines and safes, and infer new knowledge:*  knowledge\_changed = True  while knowledge\_changed:  knowledge\_changed = False  safes = set()  mines = set()  *# Get set of safe spaces and mines from KB*  for sentence in *self*.knowledge:  safes = safes.union(sentence.known\_safes())  mines = mines.union(sentence.known\_mines())  *# Mark any safe spaces or mines:*  if safes:  knowledge\_changed = True  for safe in safes:  *self*.mark\_safe(safe)  if mines:  knowledge\_changed = True  for mine in mines:  *self*.mark\_mine(mine)  *# Remove any empty sentences from knowledge base:*  empty = Sentence(set(), 0)  *self*.knowledge[:] = [x for x in *self*.knowledge if x != empty]  *# Try to infer new sentences from the current ones:*  for sentence\_1 in *self*.knowledge:  for sentence\_2 in *self*.knowledge:  *# Ignore when sentences are identical*  if sentence\_1.cells == sentence\_2.cells:  continue  if sentence\_1.cells == set() and sentence\_1.count > 0:  print('Error - sentence with no cells and count created')  raise ValueError  *# Create a new sentence if 1 is subset of 2, and not in KB:*  if sentence\_1.cells.issubset(sentence\_2.cells):  new\_sentence\_cells = sentence\_2.cells - sentence\_1.cells  new\_sentence\_count = sentence\_2.count - sentence\_1.count  new\_sentence = Sentence(new\_sentence\_cells, new\_sentence\_count)  *# Add to knowledge if not already in KB:*  if new\_sentence not in *self*.knowledge:  knowledge\_changed = True  print('New Inferred Knowledge: ', new\_sentence, 'from', sentence\_1, ' and ', sentence\_2)  *self*.knowledge.append(new\_sentence)  *# Print out AI current knowledge to terminal:*  print('Current AI KB length: ', len(*self*.knowledge))  print('Known Mines: ', *self*.mines)  print('Safe Moves Remaining: ', *self*.safes - *self*.moves\_made)  print('====================================================')  def make\_safe\_move(self):  """  Returns a safe cell to choose on the Minesweeper board.  The move must be known to be safe, and not already a move  that has been made.  This function may use the knowledge in self.mines, self.safes  and self.moves\_made, but should not modify any of those values.  """  *# Get set of safe cells that are not moves already done:*  safe\_moves = *self*.safes - *self*.moves\_made  if safe\_moves:  print('Making a Safe Move! Safe moves available: ', len(safe\_moves))  return random.choice(list(safe\_moves))  *# Otherwise no guaranteed safe moves can be made*  return None  def make\_random\_move(self):  """  Returns a move to make on the Minesweeper board.  Should choose randomly among cells that:  1) have not already been chosen, and  2) are not known to be mines  """  *# dictionary to hold possible moves and their mine probability:*  moves = {}  MINES = 8  *# Calculate basic probability of any cell being a mine with no KB:*  num\_mines\_left = MINES - len(*self*.mines)  spaces\_left = (*self*.height \* *self*.width) - (len(*self*.moves\_made) + len(*self*.mines))  *# If no spaces are left that are acceptable moves, return no move possible*  if spaces\_left == 0:  return None  basic\_prob = num\_mines\_left / spaces\_left  *# Get list of all possible moves that are not mines*  for i in range(0, *self*.height):  for j in range(0, *self*.width):  if (i, j) not in *self*.moves\_made and (i, j) not in *self*.mines:  moves[(i, j)] = basic\_prob  *# If no moves have been made (nothing in KB) then any is a good option:*  if moves and not *self*.knowledge:  move = random.choice(list(moves.keys()))  print('AI Selecting Random Move With Basic Probability: ', move)  return move  *# Otherwise can potentially improve random choice using KB:*  elif moves:  for sentence in *self*.knowledge:  num\_cells = len(sentence.cells)  count = sentence.count  mine\_prob = count / num\_cells  *# If mine probabilty of each cell is worse than listed, update it:*  for cell in sentence.cells:  if moves[cell] < mine\_prob:  moves[cell] = mine\_prob  *# Get and return random move with lowest mine probability:*  move\_list = [[x, moves[x]] for x in moves]  move\_list.sort(key=lambda x: x[1])  best\_prob = move\_list[0][1]  best\_moves = [x for x in move\_list if x[1] == best\_prob]  move = random.choice(best\_moves)[0]  print('AI Selecting Random Move with lowest mine probability using KB: ', move)  *# Return a random choice from the best moves list*  return move  <https://github.com/muhammadharoon26/minesweeper.git> |
| --- |