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To answer part C of **assignment 3**
To do the Assignment 3 --- ICS361
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Below, there are four puzzles that we have considered for this assignment. The initial state of the puzzle is given on the left, and the goal state is on the right.

Easy 1:

```
  2 8 3            1 2 3
  1 6 4     -->    8   4
  7   5            7 6 5
```

Easy 2:

```
  1 3 4            1 2 3
  8   5     -->    8   4
  7 2 6            7 6 5
```

Medium:

```
  1 2 3            2 8 1
  8   4     -->      4 3
  7 6 5            7 6 5
```

Hard:

```
  1 2 3            1 2 3
  4 5 6     -->    4 5 6
  6 7              7 8
```

The following table shows the number of moves from the initial to the goal state for each puzzle. Also the size of **open** and **closed** lists are presented to check the performance of the algorithms.

Puzzle	Default Heuristic			Manhattan Distance Heuristic		
	moves	**closed**	**open**	**moves**	**closed**	**open**
Easy 1	5	6	6	5	6	6
Easy 2	6	7	6	6	7	6
Medium	9	**40**	31	9	**23**	19
Hard	12	**112**	78	12	**45**	35

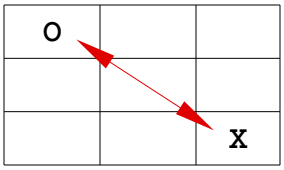
Table 1

- The number of states in the **closed** list shows how many states have been already check to get the results. The performance of an algorithm is better, if fewer number of states would be checked to achieve the goal.
  - As seen, for both **Easy 1** and **Easy 2** puzzles, both algorithms show the same performance.
  - As the problem gets harder, the difference between default and Manhattan-distance heuristics is more pronounced. Manhattan-distance heuristic checks less number of states before achieving to the goal (23 for the **Medium** puzzle and 45 for the **Hard** puzzle), while default heuristic has to check more states.
  - This shows that Manhattan-distance heuristic is more informed helping to reach the goal faster.
  - Both heuristic are admissible:
    - The default heuristic uses the number of tiles that are misplaced, and this number is the lower bound for the number of necessary moves.
    - The Manhattan-distance heuristic uses Manhattan distances of the misplaced tiles from the position they should be when the goal is achieved. This also gives a lower bound on the total number of necessary moves to reach the goal. However this lower bound is much better (much informed) compared to the default heuristic, since it has some information about the 2-dimensional arrangement of tiles.

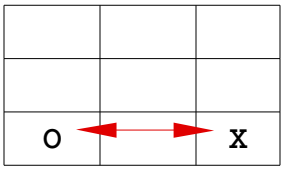
Puzzle	Direct-Distance Heuristic (my heuristic)			Manhattan Distance Heuristic		
	moves	closed	open	moves	closed	open
Easy 1	5	6	6	5	6	6
Easy 2	6	7	6	6	7	6
Medium	9	23	19	9	23	19
Hard	12	65	45	12	45	35

Table 2

- My own heuristic is the sum of the direct distances from the current position of tiles to their goal position. Look at the following boards for see how my heuristic works:



Board-1: *X is the current position of a tile and O is it's desired location. Manhattan-distance between these two positions is 4 while the direct-distance is 2*



Board-2: *X is the current position of a tile and O is it's desired location. Manhattan-distance between these two positions is 2 while the direct-distance is 2*

- Since each tile has to be moves either horizontally or vertically, my heuristic gives also a lower bound on the number of needed moves to reach the goal. However, compared to the Manhattan-distance heuristics, my heuristic seems to be worse. It gives the same results for all considered **Easy** and **Medium** -level puzzles. For the **Hard** puzzle, Manhattan-distance heuristics reaches the goal by checking 45 states, while my own heuristic needs to check 65 states.

- It's trivial that Manhattan-distance is more informed compared to my own heuristic. Manhattan-distances carry more geometrical information about the state of the board

and its difference from the final goal. Looking at **Board-1** and **Board-2** above, my own heuristic turn 2 for both situations, while Manhattan-distance heuristic distinguishes these two boards in a better way by giving 4 to **Board-1** and 2 to **Board-2.**

- Comparing table 1 and 2, one sees that my own heuristic is still more efficient than the default heuristic, but worse than Manhattan heuristics.

- My heuristic is less informed compared to Manhattan heuristic, but more informed than default heuristic, by carrying out some 2-dimensional geometrical information.

- All of these three heuristics are admissible, meaning that they result in the minimal number of moves, to reach the goal state. The reason is that they estimate a lower bound on the number of necessary moves to reach the final state from the current state.