Homework 4 (Lisp Version)

Assigned on: Friday, September 30, 2022
Due: Friday, October 14, 2022

Programming assignment should be submitted with handin.
Do not hesitate to seek help during recitation and office hours.

This homework has two parts:
1. A regular ‘exercise’ on AI games.
2. A programming assignment. The goal of the programming assignment is to implement search, uninformed and heuristic, in Common Lisp.
   (a) Romanian Holidays is mandatory for all students. The implementation is explained in great details.
   (b) Eight-sliding puzzle is a bonus assignment for curious students. Rough explanations about the implementation are provided.

AIMA exercises are available online: "https://aimacode.github.io/aima-exercises"

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1 Adverserial Search (Total 5 points)

Consider the following game tree:
1. Compute the minimax decision. Show your answer by writing the values at the appropriate nodes in the above tree. 4 points

2. What move should Max choose? 1 point
2  Alpha-beta Pruning (Total 5 points)

Using the alpha-beta pruning method, with standard left-to-right evaluation of nodes, show what nodes are not examined by alpha-beta.

![Game Tree Diagram]

3  Chapter 5, Exercise 8, Source: AIMA online site. (Total 10 points)

Consider the two-player game described in Chapter 5, Exercise 7.

1. Draw the complete game tree, using the following conventions:
   - Write each state as \((s_A, s_B)\), where \(s_A\) and \(s_B\) denote the token locations.
   - Put each terminal state in a square box and write its game value in a circle.
   - Put loop states (states that already appear on the path to the root) in double square boxes. Since their value is unclear, annotate each with a “?” in a circle.

2. Now mark each node with its backed-up minimax value (also in a circle). Explain how you handled the “?” values and why.

3. Explain why the standard minimax algorithm would fail on this game tree and briefly sketch how you might fix it, drawing on your answer to part (2). Does your modified algorithm give optimal decisions for all games with loops?

4. This 4-square game can be generalized to \(n\) squares for any \(n > 2\). Prove that \(A\) wins if \(n\) is even and loses if \(n\) is odd.

4  Romanian Holidays (Total 100 points/15 Bonus Points)

This exercise will guide you, step by step, to implement in Lisp the data structures representing Romania’s map and the search algorithms for conducting search. It is mandatory to all students.
4.1 Data structures in Common Lisp (50 points)

Using `defstruct` (see LWH, Chapter 13), create data structures in Common Lisp to represent the map of Romania. Include the information about the distances between two cities linked by a road as well as the distance from any given city to Bucharest as indicated in Figure 1.

![Figure 1: Map of Romania with road distances in kilometers and straight-line distances to Bucharest.](image)

Indications (follow illustration in Figure 2):

- Create a data structure for a city using `defstruct`.
- Include an attribute `name` to store the name of the city.
- Include an attribute `neighbors` to store the neighboring cities.
- Include an attribute `h` that provides the value of the straight-line distance to Bucharest.
• Create a global variable that stores all the cities. Use defvar to declare the global variables. Implement it this in two different ways: a list *all-cities-list* and a hash-table *all-cities-htable*\(^1\). Use the name of a city as key and the structure as value. For sake of clarity, you are not asked to implement a hash-table (which you probably did in CSCE310) but to use a hash-table in Lisp.

• After creating structures for all the cities, loop through them again in order to include, in the relevant attribute of a city, a reference its neighboring cities. Store these neighbors as an association list of the structure of a neighbor and the distance between the two (see LWH, page 31).

4.1.1 Tasks

1. (10 points) Design, implement and test your map.

2. (5 points) Write a function all-cities-from-list that takes a global variable, *all-cities-list*, and returns a list of all names of cities on the map.

3. (5 points) Write a and all-cities-from-htable that takes a global variable, *all-cities-htable* and returns a list of all the structures of cities on the map.

4. (5 point) Write two functions get-city-from-list and get-city-from-htable that take the name of a city as input and return the corresponding structure (by accessing a global variable, *all-cities-list* and *all-cities-htable*, respectively).

5. (5 points) Write two functions neighbors-using-list and neighbors-using-htable that take the name of a city as input and return the list of structures of its direct neighbors. neighbors-using-list and neighbors-using-htable should use get-city-from-list and get-city-from-htable, respectively.

6. (10 points) Using *all-cities-htable*, write a function neighbors-within-d that takes the name of a city my-city and a number distance, then returns, for all direct neighbors within distance from my-city (≤), an association list of the structures of the neighbors of my-city and their distance to my-city.

7. (10 points) Using *all-cities-htable*, write a function neighbors-p that takes the name of two cities city-1 and city-2, and returns the distance between them if they are directly connected or nil if they are not.

Note that the global variables should always be passed as arguments to these functions (becoz it is cleaner).

4.2 Implementing Search in Common Lisp (50 points)

You are asked to implement search the following search strategies, first as a Tree-Search then as a Graph-Search:

- Any uninformed search strategy of your choice, 10 points
- A Greedy search strategy, and 10 points
- An A* search strategy. 10 points

for the ‘Romanian Holiday’ problem. Needless to say, you should first get Section 1 to work. Write Search that take as input the name of any city on the map, the name of a search strategy, and returns:

1. The path to Bucharest,
2. The number of nodes generated/visited by the search process,

3. The cost of the path found (even when the function $g(n)$ is not used to choose the node to expand),
4. The running time spent by Lisp on the search. You can use\textsuperscript{2} the function \texttt{time} and report the value of \texttt{cpu time} \texttt{(non-gc)} as printed on the *standard-output* (i.e., the emacs buffer).

Hints:

- You may want to use the Lisp function \texttt{values} and \texttt{multiple-value-bind}.
- You may choose to write one search function and give it the strategy as an argument.

4.2.1 Results to report

In addition to your code, report the results of your two functions applied to each city in Romania as indicated in the table below. Report two tables:

1. One result table for \texttt{Tree-Search}. 10 points
2. One result table for \texttt{Graph-Search}. 10 points

<table>
<thead>
<tr>
<th>Uninformed search of your choice</th>
<th>City name</th>
<th>#nodes visited</th>
<th>Path to Bucharest</th>
<th>Total cost of path</th>
<th>CPU time</th>
</tr>
</thead>
<tbody>
<tr>
<td>Arad</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Bucharest</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>...</td>
<td></td>
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<td></td>
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<td></td>
</tr>
<tr>
<td>Vaslui</td>
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<td></td>
</tr>
<tr>
<td>Zerind</td>
<td></td>
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</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Greedy Search</th>
<th>City name</th>
<th>#nodes visited</th>
<th>Path to Bucharest</th>
<th>Total cost of path</th>
<th>CPU time</th>
</tr>
</thead>
<tbody>
<tr>
<td>Arad</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Bucharest</td>
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<td>...</td>
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<td></td>
</tr>
<tr>
<td>Vaslui</td>
<td></td>
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<tr>
<td>Zerind</td>
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</tbody>
</table>

<table>
<thead>
<tr>
<th>A* Search</th>
<th>City name</th>
<th>#nodes visited</th>
<th>Path to Bucharest</th>
<th>Total cost of path</th>
<th>CPU time</th>
</tr>
</thead>
<tbody>
<tr>
<td>Arad</td>
<td></td>
<td></td>
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<td></td>
<td></td>
</tr>
<tr>
<td>Bucharest</td>
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<td>...</td>
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<tr>
<td>Vaslui</td>
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</tr>
<tr>
<td>Zerind</td>
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</tbody>
</table>

4.2.2 Some indications

Follow the requirements below:

1. For \texttt{Graph-Search}, modify the data structure of a city that you implemented in Section 4.1 to add one more field \texttt{visited}, initialized to \texttt{Nil}. Use this attribute for loop control during search: when a city is visited, set this field to \texttt{T}.

2. Create a new data structure (e.g., \texttt{defstruct}) to represent a node in the search tree. The structure should have attributes that \texttt{point} to the structures of its parent (when applicable), its children (list), the city it represents. Other attributes may be necessary, such as path value at the node.

\textsuperscript{2}To retrieve the time in Lisp, one can use the function \texttt{get-internal-run-time} and \texttt{get-internal-real-time}. Check them out.
3. Implement a function `expand-node` that takes a node in the search tree and generates its children, which, for `GRAPH-SEARCH`, should correspond to cities not yet visited. It needs to generate one node data-structure per child.

4. Implement a function `evaluate-node` that takes a node and a search strategy and returns the value of the node (e.g., \( g(n), h(n) \) or \( f(n) \)).

5. Implement a function that takes a fringe (i.e., a list of nodes to be expanded) and returns the node to expand. As a refinement, you can provide the name of the search strategy as an optional second argument (check :key in the list of arguments of a function).

6. If you separate the implementation search strategy from the evaluation functions cleverly enough, you may be able to use the same search function for all search strategies you implement.

7. Implement the search strategies iteratively, not recursively.

8. Declare a global variable `*nnv*` for storing the number of nodes visited. The search function should set up its value and the function `expand-node` should increment this value at every expansion (technically, every instantiation of a search-node structure).

9. Load the information about the cities from the file `all-cities.lisp` which is on the course website.

5 Eight-Piece Sliding Puzzle (Bonus 80 points/15 Bonus For Lisp)

The goal is to implement A* search for solving the Eight-Piece Sliding Puzzle Problem with the two admissible heuristics: the displaced tile and the Manhattan distance heuristics.

5.1 Requirements

Below is the list of basic requirements:

1. Implement a generator of random states, to be used to generate an initial and a goal state.

2. Implement A* that

   - takes as arguments an initial state, a goal state, and the name of a heuristic function and
   - returns the list of moves of the empty tile from the initial state to the goal state, the cost of the path found, and the CPU time.

3. Count the movement of each tile as unity cost.

4. Generate 100 combinations of random initial and goal states (more if possible).

5. Run A* with each heuristic on each combination initial and goal states, reporting the following:

<table>
<thead>
<tr>
<th>Combination</th>
<th>Displaced tile</th>
<th>Manhattan Distance</th>
</tr>
</thead>
<tbody>
<tr>
<td>Instance</td>
<td>#NV</td>
<td>Path Cost</td>
</tr>
<tr>
<td>Combination 1</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Combination 2</td>
<td></td>
<td></td>
</tr>
<tr>
<td>...</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Combination 99</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Combination 100</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
5.2 Indications

In contrast to the previous problem, you do not need to generate a state space. Use to the extent possible the explanations provided above for the Romanian Holidays and the mechanisms

1. Implement a state as a 2 dimensional array (Chapter 17 in CITI).
2. Implement a generator of random states, to be used to generate an initial and a goal state.
3. Implement a function that takes as input a state and computes the value of the heuristic function (there are two of them).
4. Implement functions that correspond to the actions of moving the empty tile north, south, east and west (similar to the Farmer’s dilemma).
5. Implement functions that determine whether a move is legal or not (similar to the Farmer’s dilemma). A move north is not legal when the empty tile is in the first row.