Implementing Search

Assigned on: Friday, Oct 27, 2023

Due: Friday, Nov 10, 2023

Value: Bonus homework, 80 points / 15 Bonus For Lisp.

The goal of the programming assignment is to give a chance to implement search, run experiments, and report your results. There are two options:

1. Romanian Holidays

2. The 3×3 sliding-tile puzzle

We provide detailed guidance on how to implement the first option. We provide significantly less guidance for the second option.

1. You can do either option. You will receive a grade for *only one* of the options, not both. If you do both, you must specify the one for which you want to be graded.

2. Programming assignment should be submitted with `handin`.

3. Do not hesitate to seek help during recitation and office hours.

Contents

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1 Romanian Holidays (Total 80 points / 15 Bonus For Lisp)

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.

1.1 Data structures in Common Lisp (38 points / 5 Bonus For Lisp)

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.

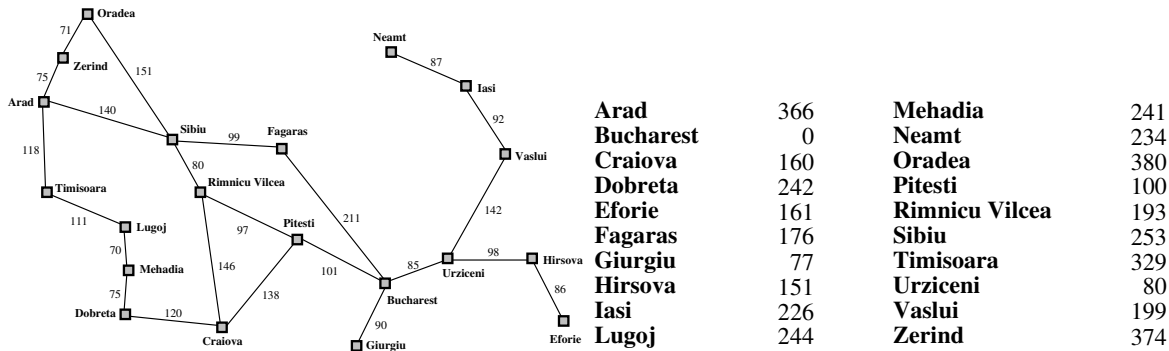| Arad | 366 | Mehadia | 241 |
Bucharest	0	Neamt	234
Craiova	160	Oradea	380
Dobreta	242	Pitesti	100
Eforie	161	Rimnicu Vilcea	193
Fagaras	176	Sibiu	253
Giurgiu	77	Timisoara	329
Hirsova	151	Urziceni	80
Iasi	226	Vaslui	199
Lugoj	244	Zerind	374

Figure 1: Map of Romania with road distances in kilometers and straight-line distances to Bucharest.

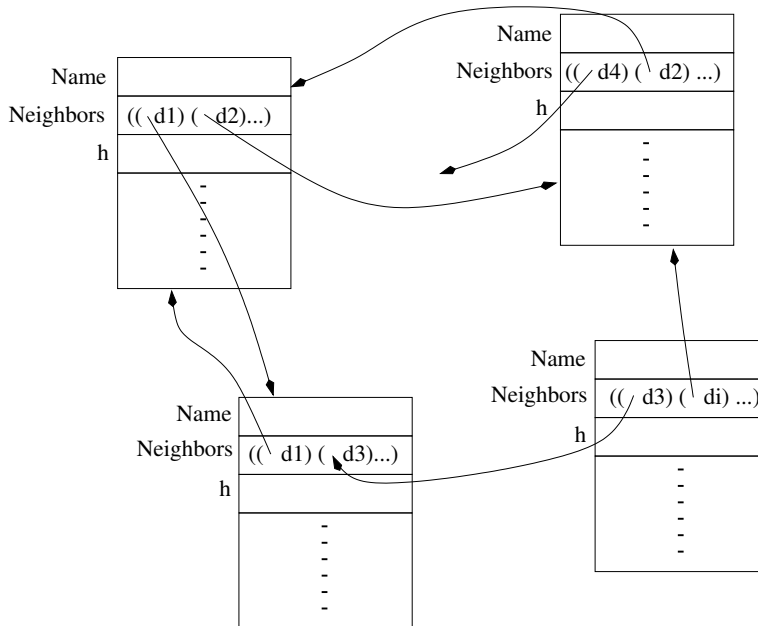Indications (follow illustration in Figure 2):

Figure 2: Data structures.

- 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).

1.1.1 Tasks

1. (8 points) Design, implement and test your map.

2. (4 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. (4 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. (4 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. (4 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. (7 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` ($\leq$), an association list of the structures of the neighbors of `my-city` and their distance to `my-city`.

7. (7 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.

8. (5 points) All functions and data structures above are written in Lisp.

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

1.2 Implementing Search in Common Lisp (42 points / 10 Bonus For Lisp)

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

- (7 points) Any uninformed search strategy of your choice,

- (7 points) A Greedy search strategy, and

- (7 points) An A* search strategy.

- (10 points) All functions and data structures are written in Lisp.

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[1] Check documentation on hash-tables in http://www.cs.cmu.edu/afs/cs.cmu.edu/project/ai-repository/ai/html/cltl/cltl2.html and http://www.lisp.org/HyperSpec/Body/fun_make-hash-table.html.

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 <u>any city</u> 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[2] the function `time` and report the value of `cpu time (non-gc)` as printed on the *standard-output* (i.e., the emacs buffer).

Hints:

- You may want to use the Lisp function `values` and `multiple-value-bind`.

- You may choose to write one search function and give it the strategy as an argument.

1.2.1   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 six total tables:

1. (7×3 points) Three (one for each search strategy) result table for TREE-SEARCH.

2. (7×3 points) Three (one for each search strategy) result table for GRAPH-SEARCH.

Uninformed search of your choice				
City name	**#nodes visited**	**Path to Bucharest**	**Total cost of path**	**CPU time**
Arad				
Bucharest				
⋮				
Vaslui				
Zerind				

Greedy Search				
City name	**#nodes visited**	**Path to Bucharest**	**Total cost of path**	**CPU time**
Arad				
Bucharest				
⋮				
Vaslui				
Zerind				

A^* Search				
City name	**#nodes visited**	**Path to Bucharest**	**Total cost of path**	**CPU time**
Arad				
Bucharest				
⋮				
Vaslui				
Zerind				

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[2]To retrieve the time in Lisp, one can use the function `get-internal-run-time` and `get-internal-real-time`. Check them out.

1.2.2 Some indications

Follow the requirements below:

1. For GRAPH-SEARCH, modify the data structure of a city that you implemented in Section 1.1 to add one more field `visited`, initialized to `Nil`. Use this attribute for loop control during search: when a city is visited, set this field to `T`.

2. Create a new data structure (e.g., `defstruct`) to represent a node in the search tree. The structure should have attributes that *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.

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.

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

The goal is to implement A* search for solving the 3×3 sliding-tile puzzle with the two admissible heuristics, namely,

1. the displaced tile heuristics and

2. the Manhattan distance heuristics.

2.1 Requirements

1. (15 points) Implement a generator of random states, to be used to generate an initial and a goal state.

2. (2×8 points) Implement the two heuristics as functions that take a current state and a goal state and compute the value of the heuristic as the estimate of the distance between the two states.

3. (20 points) 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 (i.e., actions) of the empty tile from the initial state to the goal state, the cost of the path found, and the CPU time.

4. Count the movement of each tile as utility cost.

5. (9 points) Generate 100 combinations of random initial and goal states (more if possible).

6. (2 × 10 points) Run A* with each heuristic on each combination initial and goal states, reporting the following:

	Displaced tile			Manhattan Distance		
Instance	#NV	Path Cost	CPU time	#NV	Path Cost	CPU time
Combination 1						
Combination 2						
⋮						
Combination 99						
Combination 100						

7. (15 points) All functions and data structures are written in Lisp.

2.2 Indications

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

1. Implement a state as a 2 dimensional array (Chapter 17 in ClTl).

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.

Alert: The state space of this puzzle has two connected components. If the initial state and the goal state are chosen from a different component, the puzzle instance is not solvable. To test whether or not an instance is solvable, a simple test exists, see `https://www.geeksforgeeks.org/check-instance-8-puzzle-solvable/`.