Assignment-1 Introduction, Graph Search & Simulated Annealing

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Part-I Written Exercises [25 Points]

1. **[5 Points]** MCQs and T/F: Choose the correct answer for each of the following questions.

1.1. Big O specifically describes the limiting behavior of a function (worst-case scenario) when the argument tends towards a particular value or infinity, usually in terms of simpler functions. What is the big-O of this expression: $n^3+n\log(n)+\log(2n)$

a. O(nlogn)

b. $O(n^3)$

c. O(logn)

d. $O(n^2)$

e. None of the above

1.2. Which blind search algorithm implements FIFO operation for searching the states?

a. Breadth-first Search (BFS)

b. Uniform-cost Search (UCS)

c. Bidirectional Search (BS)

d. Depth-first search (DFS)

e. None of the mentioned

1.3. In design problems or strategic functions, optimality is usually traded in for speed gains. a. True

b. False

1.4. A beam search with beam width equals number of nodes in each level is the same: a. Depth-first search

b. Breadth-first search

c. Hill climbing

d. Best-first search

e. Dijkstra's algorithm

1.5. Which of the following statements about the A* algorithm is correct?

a. A* uses only the heuristic function to guide the search.
b. A* algorithm performs an uninformed search like breadth-first search.
c. A* guarantees the shortest path in a weighted graph, provided the heuristic is admissible and consistent.
d. A* is a greedy search algorithm that only focuses on the current state without considering future states.
e. A* cannot be used for pathfinding in dynamic environments.
f. None of the above.

2. **[5 Points]** The knapsack problem is a widely studied problem that appears in real-world decision-making processes in a wide variety of fields, such as finding the least wasteful way to cut raw materials, seating contest of investments and portfolios, seating contest of assets for asset-backed securitization, and knapsack cryptosystems. Consider solving this problem using SA. Assume an instance of the problem where we have Knapsack capacity=50 and a set of 7 objects with weights and utilities shown in the following table:

3.

Item	1	2	3	4	5	6	7
Weight	10	12	15	27	30	20	7
Utility	2	1	3	4	1	2	1

Answer the following questions:

a) Define a suitable representation for the problem solution. **[1 Point]**
b) Suggest a suitable operator that can be used to generate the neighborhood of the current solution. **[1 Point]**

c) Define the objective function for calculating the cost of a solution as well as the underlying constraints. Any overload of the knapsack capacity must be penalized with an amount of 50. **[1 Point]**

d) Apply simulated annealing for ONE iteration using an initial temperature of 500, a final temperature of 50 and a geometric decrement rate of 0.85. **[2 Points]**

Solution:

a) Given, total number of objects $= 7$. $\therefore$ A binary vector of length 7 can be used for suitable representation of the knapsack problem: $x = (x_1, x_2, x_3, x_4, x_5, x_6, x_7)$ and $x_i \in \{0,1\}$, where i is a particular object. If $x_i = 1$, the item i is selected. If $x_i = 0$, the item i is not selected.

b) To generate neighbors in simulated annealing, bit flip operator can be used as an operator to change the current solution. If $x_i = 1$, using bit flip operator makes it 0. If $x_i = 0$, using bit flip operator makes it 1. $\therefore x'_k = 1 - x_k$, where $k \in \{1, \ldots, 7\}$.

c) Let, w_i be the weight of a particular object and u_i be the utility of a particular object. $w = [10, 12, 15, 27, 30, 20, 7]$ and $u = [2, 1, 3, 4, 1, 2, 1]$. $\therefore$ Total weight, $W(x) = \sum_{i=1}^{7} w_i x_i = 10x_1 + 12x_2 + 15x_3 + 27x_4 + 30x_5 + 20x_6 + 7x_7$, and total utility, $U(x) = \sum_{i=1}^{7} u_i x_i = 2x_1 + x_2 + 3x_3 + 4x_4 + x_5 + 2x_6 + x_7$. Given, the knapsack capacity $= 50$. $\therefore W(x) \leq 50$. Maximizing utility is converted into a minimization cost by using negative utility. This is done as simulated annealing often deals with minimization. Also, any overload must be penalized by 50. $\therefore$ f(x) $= -U(x) + 50.I(W(x) > 50)$, where $I(.)$ is an indicator. If overweight, $I(W(x) > 50) = 1$. Otherwise, $I(W(x) > 50) = 0$.

d) Given, initial temperature (T_0) $= 500$, final temperature (T_f) = 50, cooling factor (α) = 0.85. When $T \leq T_f$, stop. Geometric cooling for updating temperature: $T_{new} = \alpha T_0$. Acceptance rule for minimization: for $\Delta f = f(\mathrm{x}') - f(\mathrm{x})$, accept if $\Delta f \leq 0$. Otherwise, accept with probability, $p = e^{-\Delta f / T_0}$. And if random $r \in [0,1]$ satisfies $r < p$, accept. Let the starting point be the empty knapsack. That is, x = (0,0,0,0,0,0,0). $\therefore W(x) = 0$, $U(x) = 0$. It is not overweight. Therefore, no penalty. So, $f(\mathrm{x}) = -0 + 0 = 0$. Temperature at this iteration, $T_0 = 500$. Let, item 4 is flipped. $\therefore$ $\mathrm{x}' = (0,0,0,1,0,0,0)$ and $W(\mathrm{x}') = 27$, $U(\mathrm{x}') = 0$. This is feasible because $27 \leq 50$. So, there is no penalty. So, $f(\mathrm{x}') = -4 + 0 = -4$. Now, $\Delta f = f(\mathrm{x}') - f(\mathrm{x}) = (-4) - 0 = -4$. Since $\Delta f \leq 0$, the neighbor is better. So, it is accepted. Therefore, new solution: $\mathrm{x}' = (0,0,0,1,0,0,0)$ and $T_{new} = 0.85 \times 500 = 425$. Since $425 > 50$, there will be further iterations.

3. **[5 Points]** Consider the following simplified map shown in Figure C.2, where edges are labeled with actual distances between the cities. State the path to go from city A to city M produced by BFS and the path produced by DFS.

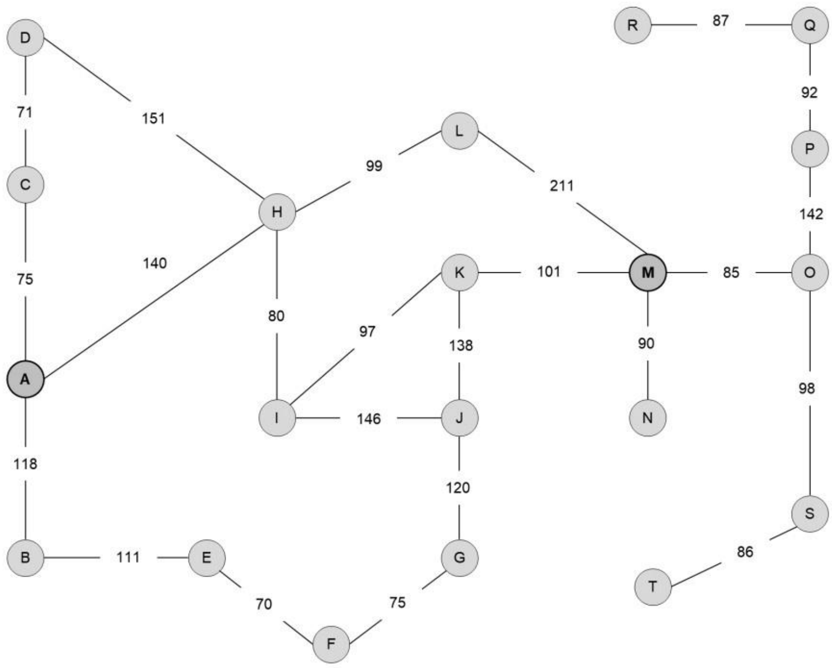


Figure 1 Simplified map.

Answer:

BFS Route:

A→B→H→C→E→I→L→D→F→J→K→M

Final Route:

A→H→L→M

Total distance:

140+99+211=450.

DFS Route:

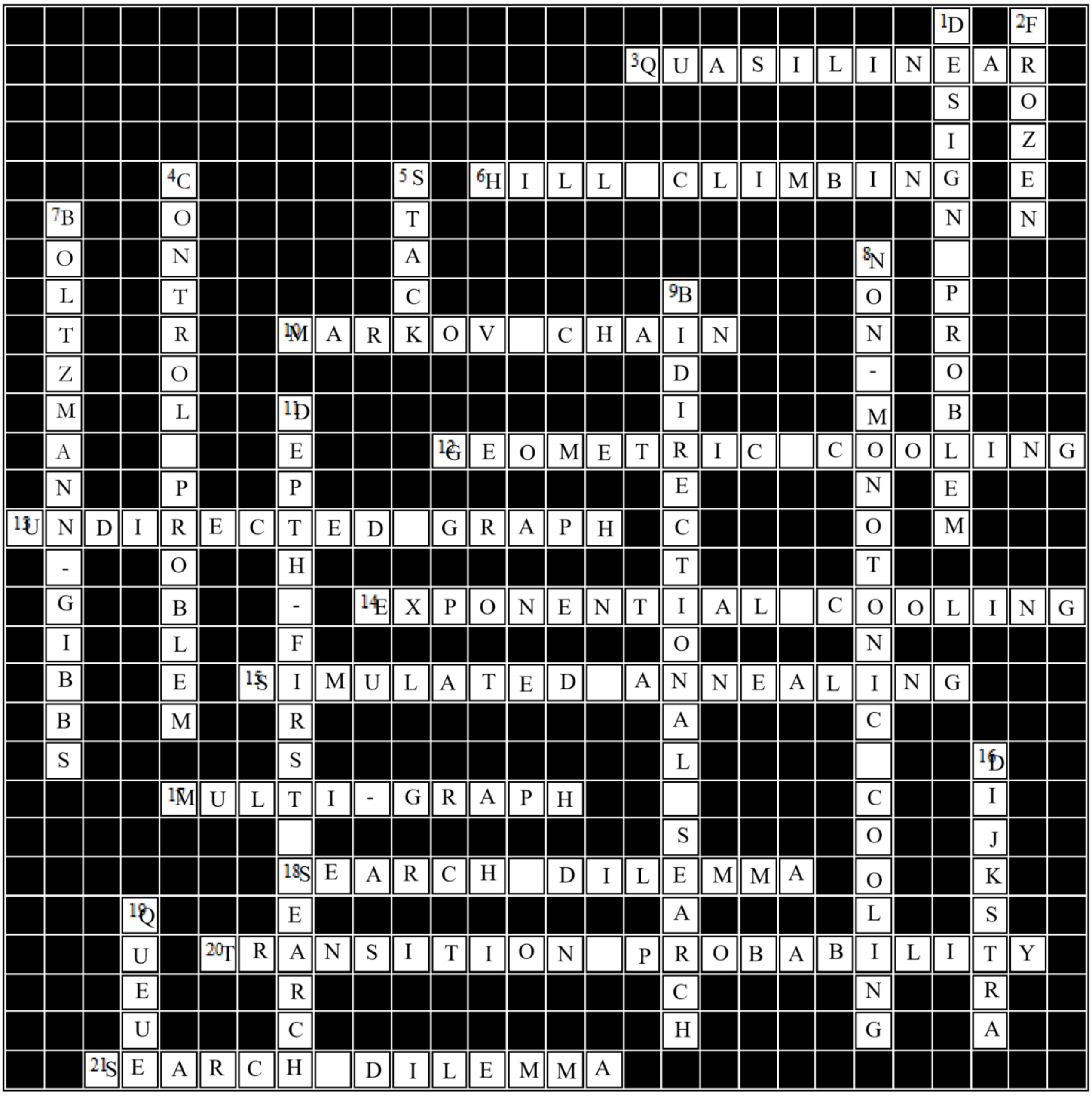
A→B→H→C→E→F→G→J→K→I→M

Final Route:

A→B→E→F→G→J→K→M

Total distance:

118+111+70+75+120+138+101=733.



Part-II Programming Exercises [25 Marks]

Geospatial data is any data related to or containing information about a specific location on the Earth's surface. Answer the following questions:

1. **[5 Marks]** Pick any dataset that contains spatial data and information (preferably related to your course project). Have a look at the list of publicly available spatial datasets here. You can also use Google Dataset Engine or HuggingFace to search for data. If needed, use geocoders to find the geographic coordinates (lat and log) given the location address.

2. **[5 Marks]** Data visualization is a powerful tool to bring data to life, convey information and help in decision making. Spatial data can be visualized in different formats such as chloropleth map, cartogram map, bubble map, hexagonal binning, heat map, cluster map. Write Python script in a Jupyter notebook format to visualize this data in different formats and report the insights that you may observe from these visualizations. Observations can be reported in a markdown cell to be part of the same Jupyter notebook. Here is a sample Jupyter notebook.

3. **[5 Marks]** Pick any two points of interest (preferably in Saudi Arabia) and add markers on the map to highlight these two points.

4. **[10 Marks]** Find and render the routes between the two selected points using BFS, DFS, Dijkstra and simulated annealing. Compare these routing algorithms in terms of time and cost (route length in meters).

Solution: https://github.com/husseinareefurrahman-collab/KFUPM-ISE571