Artificial Intelligence for Problem Solving – Transportation Puzzle Using The A* Algorithm

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The heuristic function (h(n)) for the Transport Puzzle problem calculates the total cost for moving each individual cargo from the city it resides in the current state (node) to the city each cargo is meant to be in the goal state. Based on the state of the node that is currently being explored, iterate through all cities and check whether each cargo is already at the desired location. If the cargo is not in the right city, hence would need to be transported, calculate the corresponding variable cost (the cost of moving the cargo based on its weight), and add it to the total. At the end of the function return the total cost which is the sum of the variable cost based on the weight of the cargo that needs to be moved between the current city and the goal city.

Justification of admissibility of the heuristic function used to find the optimal solution for the given problem:

To generate a heuristic function which does not over-estimate the total cost to get from the current node (n) to the goal state some of the restrictions regarding the game rules have been relaxed:

- Eliminate the load limitation on the truck.
- Eliminate the fixed cost of transportation between cities.

The relaxed problem allows all cargo to be moved to the city they must be located at in the goal state using a single action. Assuming that all cargo can be moved regardless of their individual and summed weight the load limit on the truck can be dismissed. This change would make the new problem less difficult than the original problem, eliminating the need to incur fixed cost if the truck moves between cities without carrying cargo.

The cost of the optimal solution (C*) takes into account all existing restrictions, which includes both the cost per ton restriction on individual cargo as well as the fixed cost for moving between cities. Since the heuristic function in the solution assumes that cargo can be 'teleported' from its current location to its destination city without any limitation on maximum weight that can be moved with one action, the 'h1 cost' calculated in the function is guaranteed to be less then the cost of the optimal solution (C*), hence the function will always underestimate.

Examples of running the program on different problem instances:

BASIC PROBLEM:

===Settings===

Truck max: 15.0

Fixed cost: A->B: 80.0 B->C: 20.0 C->A: 50.0

Cost per ton: A->B: 1.0 B->C: 4.0 C->A: 2.0

Solution for the basic problem:

No. of nodes explored: 1000
No. of nodes explored: 2000
No. of nodes explored: 3000
No. of nodes explored: 4000
No. of nodes explored: 5000
No. of nodes explored: 6000
No. of nodes explored: 7000
No. of nodes explored: 8000
No. of nodes explored: 9000
No. of nodes explored: 10000
No. of nodes explored: 11000

A: TRUCK c1 (2.5) c2 (7.5) c3 (3.0)
B: c4 (8.5) c5 (10.0)
C: c6 (12.0)

Move CITY_A -> CITY_C: c3 (3.0) Load: 3.0 Cost: 56.0
A: c1 (2.5) c2 (7.5)
B: c4 (8.5) c5 (10.0)
C: TRUCK c3 (3.0) c6 (12.0)

Move CITY_C -> CITY_B: Load: 0 Cost: 20.0
A: c1 (2.5) c2 (7.5)
B: TRUCK c4 (8.5) c5 (10.0)
C: c3 (3.0) c6 (12.0)

Move CITY_B -> CITY_C: c5 (10.0) Load: 10.0 Cost: 60.0
A: c1 (2.5) c2 (7.5)
B: c4 (8.5)
C: TRUCK c3 (3.0) c5 (10.0) c6 (12.0)

Move CITY_C -> CITY_A: c6 (12.0) Load: 12.0 Cost: 74.0
A: TRUCK c1 (2.5) c2 (7.5) c6 (12.0)
B: c4 (8.5)
C: c3 (3.0) c5 (10.0)
Move CITY_A -> CITY_B: c1 (2.5) c2 (7.5) Load: 10.0 Cost: 90.0
A: c6 (12.0)
B: TRUCK c1 (2.5) c2 (7.5) c4 (8.5)
C: c3 (3.0) c5 (10.0)

Move CITY_B -> CITY_A: c4 (8.5) Load: 8.5 Cost: 88.5
A: TRUCK c4 (8.5) c6 (12.0)
B: c1 (2.5) c2 (7.5)
C: c3 (3.0) c5 (10.0)

Nodes visited: 11851

Cost: 388.5

GENERAL PROBLEM (1):

===Settings===

Truck max: 50.0

Fixed cost: A->B: 1.0 B->C: 2.0 C->A: 3.0

Cost per ton: A->B: 2.0 B->C: 0.8 C->A: 0.3

Solution for the general problem (1):

A: TRUCK c1 (1.5) c2 (3.5)
B: c3 (5.5) c4 (10.0)
C:

Move CITY_A -> CITY_C: c1 (1.5) c2 (3.5) Load: 5.0 Cost: 4.5
A:
B: c3 (5.5) c4 (10.0)
C: TRUCK c1 (1.5) c2 (3.5)

Move CITY_C -> CITY_B: Load: 0 Cost: 2.0
A:
B: TRUCK c3 (5.5) c4 (10.0)
C: c1 (1.5) c2 (3.5)

Move CITY_B -> CITY_C: c3 (5.5) c4 (10.0) Load: 15.5 Cost: 14.4
A:
B:
C: TRUCK c1 (1.5) c2 (3.5) c3 (5.5) c4 (10.0)

Nodes visited: 233
Cost: 20.9

GENERAL PROBLEM (2):

===Settings===

Truck max: 30.0

Fixed cost: A->B: 2.0 B->C: 2.0 C->A: 80.0

Cost per ton: A->B: 1.0 B->C: 4.0 C->A: 2.0

Solution for the general problem (2):

A: TRUCK c1 (1.5) c2 (3.5) c3 (5.5) c4 (10.0)
B:
C:

Move CITY_A -> CITY_B: c1 (1.5) c2 (3.5) c3 (5.5) c4 (10.0) Load: 20.5 Cost: 22.5
A:
B: TRUCK c1 (1.5) c2 (3.5) c3 (5.5) c4 (10.0)
C:

Move CITY_B -> CITY_C: c1 (1.5) c2 (3.5) c3 (5.5) c4 (10.0) Load: 20.5 Cost: 84.0
A:
B:
C: TRUCK c1 (1.5) c2 (3.5) c3 (5.5) c4 (10.0)

Nodes visited: 341
Cost: 106.5

The output of the program shows that it can find an optimal solution for both the basic problem and the general problem (1). In general problem (2) the basic set up is that all cargo could potentially be moved in a single action to the goal city. However, the cost of this action would be higher in total than moving all cargo to the intermediate city (B) then moving from that city to the destination.

A more informed heuristic function:

The heuristic function described above in the report (using the h1 cost in the source code) was used to provide the optimal solution for the basic and general problems. However, the estimation of h2 cost has also been implemented in the solution. Using the h2 cost can improve the informedness of h(n). The calculation of this cost takes into consideration the fixed cost of moving between cities; however, it still ignores the load limitation imposed on the truck. This means that all cargo can be moved in a batch without a total weight limit.

$$h1(n) \le h2(n) \le h^*(n)$$

Using the h2 cost, the heuristic function can provide a more accurate estimate, that is closer to the actual cost from node n to the goal state. If speed is of concern for the given situation using a more informed heuristic could speed up the algorithm since it would explore less nodes. This is represented in the solution generated using a heuristic function with h2 cost:

Solution for general problem(2) using a more informed heuristic:

A: TRUCK c1 (1.5) c2 (3.5) c3 (5.5) c4 (10.0)
B:
C:

Move CITY_A -> CITY_B: c1 (1.5) c2 (3.5) c3 (5.5) c4 (10.0) Load: 20.5 Cost: 22.5
A:
B: TRUCK c1 (1.5) c2 (3.5) c3 (5.5) c4 (10.0)
C:

Move CITY_B -> CITY_C: c1 (1.5) c2 (3.5) c3 (5.5) c4 (10.0) Load: 20.5 Cost: 84.0
A:
B:
C: TRUCK c1 (1.5) c2 (3.5) c3 (5.5) c4 (10.0)

Nodes visited: 197
Cost: 106.5

REFERENCES:

PATEL, A., 2023. Heuristics From Amit's Thoughts on Pathfinding. [Blog] Available from: https://theory.stanford.edu/~amitp/GameProgramming/Heuristics.html [Accessed 14 April 2023].