

**COS 402 – Program 1 Report**

The advanced heuristic is similar to the BlockingHeuristic in that it counts the number of cars that block the goal car, but extends this by also checking the number of cars that block blocking-cars. This is because in order to remove blocking-cars, cars that are in the blocking-cars' way must also by necessity be removed. It does this by checking which directions a blocking-car can move (e.g. if a blocking-car moves all the way in one direction will it still be in the way of the goal car?) this is to determine the feasibility of the exit strategy of a blocking-car. If the blocking-car can move in a particular direction, count the number of cars needed to be moved to move the blocking car and take the minimum of either direction.

To prove consistency of the BlockingHeuristic let's imagine a puzzle that has one car blocking the goal car and an additional car arbitrarily placed, but is not a blocking-car. A heuristic is consistent if the estimated cost to reach the goal from a node is at most equal to the cost of reaching every successor plus the estimated cost to reach the goal from the successor. So let's say a move is made on the puzzle, the blocking car has either been removed from the goal car's path or it has not. If it has then it took one move to get there and the heuristic has decreased by one and hence the estimated cost from the initial node was two which is equal to the cost to reach this next node (one) plus the estimated cost (two - one). Let's say that the move did not remove the blocking car (the goal car or the arbitrary car was moved), then the heuristic of both states remain the same, but the cost has increased by one and thus the estimated cost of the initial node (one) is less than the cost to reach the subsequent node (one) plus the estimated cost of this subsequent node (two). In more advanced puzzles a move can be made that moves a car to a position that blocks the goal car, in which case the cost and the estimated cost of the subsequent state has increased and remains consistent. This extends to all generated puzzles, and therefore the BlockingHeuristic is consistent. The same argument can be made for the AdvancedHeuristic; instead of only considering blocking-cars we must also consider cars that block the blocking-cars. A move will either remove the car from a blocking state or it won't (in the case that it does the right hand side of the inequality is always greater than the left). If it removes it the cost increases by one and the heuristic decreases by one and thus the left and right side are equal. In the case that a move doesn't remove a car from a blocking state the cost has increased, but the estimated cost remains the same and the left side is less than the right side. Therefore, the AdvancedHeuristic is also consistent.

1. For the "easier" puzzles, namely the ones that were tested first, both heuristics did significantly better than the ZeroHeuristic. In most cases the BlockingHeuristic examined less than 50% of the nodes that the ZeroHeuristic, sometimes as low as 25% of the nodes when compared to the ZeroHeuristic. Similarly, the AdvancedHeuristic did significantly better than the BlockingHeuristic, examining less than 50% of the nodes that the BlockingHeuristic examined in the first few puzzles. In all the 40 puzzles, the AdvancedHeuristic did strictly better than the BlockingHeuristic, which performed strictly better than the ZeroHeuristic. In the early puzzles the branching factors of the BlockingHeuristic were approximately 0.25 less than that of the ZeroHeuristic while the AdvancedHeuristic was about 0.5 less than the ZeroHeuristic.
2. In the context of the A\* algorithm, less searching is possible due to heuristics. This gives weights towards certain moves that we believe are closer to the solution. This essentially is a directed-BFS in the sense that the search takes the lowest weight, but the weights are in part determined

by the heuristic. The reason we can search less and arrive at the solution is because we are naturally less inclined to make moves that complicate the puzzle (e.g. move a car to a position that blocks the goal car) and are more inclined to make moves that are beneficial to the goal (e.g. move a blocking car out of the way) as determined by the heuristic.

3. It is generally possible to discern what makes a problem hard or easy for humans relatively. This is based on what the heuristic generates on the frontier. For example, for the more difficult problems there are more cars in configurations such that each car can move only one square at a time, as such immediate moves don't decrease a heuristic by much, if any. These more difficult puzzles typically involve multiple steps or strategies to reach the solution; a hard puzzle in terms of the Rush Hour game could be multiple cars that can only be moved one square at a time and a solution would be one such that a car behind the goal car would need to be moved in order to move a car that blocks a blocking-car, in order to move the blocking car. Or a solution might involve moving the goal car back. Both of these would be counter-intuitive to a heuristic because the heuristic does not decrease on the frontier as the solution requires thinking multiple steps ahead in a directed manner. So in terms of how a heuristic reacts to expansion, it is possible to see what makes a problem hard or easy for humans in terms of the search characteristics.
4. The search approach in this puzzle is similar to how a human might solve these problems, albeit much simpler. A human looking at the Rush Hour puzzle might try to remove the blocking cars as it's a necessity for the goal. However, rather than looking to purely remove cars that block the goal car, a human might start with the left-most blocking car and attempt to move the goal car forward. Additionally a human might change strategies; for example, if the first goal is to remove the left-most blocking car, a human would begin looking many moves ahead to remove that blocking car. In general a human attempting to solve the Rush Hour puzzle could have more sophisticated and multiple strategies for solving the puzzle, whereas the search looks purely to one strategy which is the heuristic (as well as the cost).