

## SIMULATED ANNEALING:

**Q.1 Check whether the heuristics are admissible ?**

**Ans.**  $h_1(n)$  -> Number of displaced tiles  
 $h_2(n)$  -> Manhattan distance

Both the above heuristics are proven to be admissible as each of these never overestimates the cost to reach the goal state.

**Q.2 What happens if we make a new heuristics  $h_3(n) = h_1(n) * h_2(n)$  ?**

**Ans.** It is inferred that the number of states explored and the time taken to reach the goal state is minimum for heuristic  $h_3(n)$ . (Please refer Table 1)

**Q.3 What will happen if we consider the blank tile as another tile?**

**Ans.** If the blank tile is considered as another tile, there is not much difference in the time complexity and the total number of states explored before reaching the goal state. The difference given in Table 1 is subject to the randomness of the algorithm.

**Q.4 What if the search algorithm gets stuck into Local optimum? Will there be any way to get out of this?**

**Ans.** Simulated annealing does not get stuck in local optimum. It has been proved that simulated annealing will converge to its global optimality if enough randomness is used in combination with very slow cooling.

## HILL CLIMBING VS SIMULATED ANNEALING:

- TIME COMPLEXITY

Hill climbing is prone to getting stuck in local maxima. In the worst case it can go upto  $O(n)$ , where 'n' is the total number of states. On the other hand, Simulated annealing has polynomial time complexity.

- NUMBER OF STEPS**

For every node, if we have a child node that has  $h(\text{child node}) > h(\text{parent node})$ , hill climbing algorithm will always have a minimum number of steps. For other cases, simulated annealing will reach the goal state and Hill climbing will get stuck in the local maxima.

## RESULTS:

HILL CLIMBING						SIMULATED ANNEALING		
START STATE	GOAL STATE	HEURISTICS USED	STATUS (SUCCESS/FAILURE)	TOTAL NUMBER OF STATES EXPLORED	TIME TAKEN FOR EXECUTION	STATUS (SUCCESS/FAILURE)	TOTAL NUMBER OF STATES EXPLORED	TIME TAKEN FOR EXECUTION
['T5', 'T4', 'T6'] ['T2', 'T3', 'T1'] ['B', 'T7', 'T8']	['T1', 'T2', 'T3'] ['T4', 'T5', 'T6'] ['T7', 'T8', 'B']	h1 (Number of displaced tiles)	FAILURE	2	0.000568	SUCCESS	89099	15.12099
		h2 (Manhattan distance)	FAILURE	2	0.000664	SUCCESS	1983	0.62928
		h3 ( h1 X h2)	FAILURE	2	0.00084	SUCCESS	549	0.17633

['T6', 'T2', 'B'] ['T4', 'T3', 'T8'] ['T7', 'T1', 'T5']	['T1', 'T2', 'T3'] ['T4', 'T5', 'T6'] ['T7', 'T8', 'B']	h1 (number of displaced tiles)	FAILURE	0	0.000257	SUCCESS	55969	9.52379
		h2 ( Manhattan distance )	FAILURE	0	0.00024	SUCCESS	5747	1.59087
		h3 ( h1 X h2)	FAILURE	0	0.00027	SUCCESS	5287	1.6878
['T1', 'T2', 'B'] ['T7', 'T4', 'T5'] ['T6', 'T8', 'T3']	['T1', 'T2', 'T3'] ['T4', 'T5', 'T6'] ['T7', 'T8', 'B']	h1 (number of displaced tiles)	FAILURE	0	0.0003	SUCCESS	19073	3.26106
		h2 ( Manhattan distance )	FAILURE	0	0.000292	SUCCESS	104101	28.9744
		h3 ( h1 X h2)	FAILURE	0	0.0003	SUCCESS	113823	37.0303
['T4', 'T8', 'T6'] ['T1', 'B', 'T7'] ['T3', 'T5', 'T2']	['T1', 'T2', 'T3'] ['T4', 'T5', 'T6'] ['T7', 'T8', 'B']	h1 (number of displaced tiles)	FAILURE	1	0.00046	SUCCESS	11253	1.9441
		h2 ( Manhattan distance )	FAILURE	1	0.00063	SUCCESS	19799	5.4932
		h3 ( h1 X h2)	FAILURE	2	0.00084	SUCCESS	33121	10.6876
['T4', 'T7', 'T5'] ['T3', 'T8', 'T6'] ['B', 'T1', 'T2']	['T1', 'T2', 'T3'] ['T4', 'T5', 'T6'] ['T7', 'T8', 'B']	h1 (number of displaced tiles)	FAILURE	0	0.0003	SUCCESS	113191	19.5123

		h2 ( Manhattan distance )	FAILURE	4	0.00123	SUCCESS	55317	16.4021
		h3 ( h1 X h2)	FAILURE	4	0.00124	SUCCESS	6433	2.1758
['T6', 'T2', 'T5'] ['T4', 'T7', 'T1'] ['T8', 'B', 'T3']	['T1', 'T2', 'T3'] ['T4', 'T5', 'T6'] ['T7', 'T8', 'B']	h1 (number of displaced tiles)	FAILURE	1	0.00046	SUCCESS	64264	10.9146
		h2 ( Manhattan distance )	FAILURE	3	0.001092	SUCCESS	162790	44.626
		h3 ( h1 X h2)	FAILURE	1	0.00054	SUCCESS	2798	1.04955
['T1', 'T7', 'T2'] ['T5', 'T4', 'T6'] ['T8', 'T3', 'B']	['T1', 'T2', 'T3'] ['T4', 'T5', 'T6'] ['T7', 'T8', 'B']	h1 (number of displaced tiles)	FAILURE	0	0.00027	SUCCESS	10595	1.8078
		h2 ( Manhattan distance )	FAILURE	2	0.00064	SUCCESS	11521	3.1647
		h3 ( h1 X h2)	FAILURE	2	0.00094	SUCCESS	4507	1.4494
['T7', 'T2', 'B'] ['T6', 'T3', 'T8'] ['T4', 'T1', 'T5']	['T1', 'T2', 'T3'] ['T4', 'T5', 'T6'] ['T7', 'T8', 'B']	h1 (number of displaced tiles)	FAILURE	0	0.0003	SUCCESS	22855	3.9369
		h2 ( Manhattan distance )	FAILURE	0	0.000292	SUCCESS	21033	5.7549
		h3 ( h1 X h2)	FAILURE	0	0.0003	SUCCESS	30999	10.2349

['T6', 'T7', 'T3'] ['T8', 'T4', 'T2'] ['T1', 'B', 'T5']	['T1', 'T2', 'T3'] ['T4', 'T5', 'T6'] ['T7', 'T8', 'B']	h1 (number of displaced tiles)	FAILURE	0	0.00027	FAILURE	177528	26.4091
		h2 ( Manhattan distance )	FAILURE	1	0.00052	FAILURE	173926	40.7265
		h3 ( h1 X h2)	FAILURE	1	0.0006	FAILURE	167682	46.1122
['T7', 'T6', 'T2'] ['T4', 'T8', 'B'] ['T3', 'T1', 'T5']	['T1', 'T2', 'T3'] ['T4', 'T5', 'T6'] ['T7', 'T8', 'B']	h1 (number of displaced tiles)	FAILURE	0	0.00027	SUCCESS	113570	19.3688
		h2 ( Manhattan distance )	FAILURE	1	0.00052	SUCCESS	48302	13.3884
		h3 ( h1 X h2)	FAILURE	1	0.0006	SUCCESS	13376	4.2937

**TABLE 1:**

START STATE	GOAL STATE	HEURISTICS USED	BLANK TILE CONSIDERED	BLANK TILE NOT CONSIDERED
['T5', 'T4', 'T6'] ['T2', 'T3', 'T1'] ['B', 'T7', 'T8']	['T1', 'T2', 'T3'] ['T4', 'T5', 'T6'] ['T7', 'T8', 'B']	h1 (number of displaced tiles)	Total number of states explored:143293 Total number of states to optimal path:143293 Time taken for execution:22.771	Total number of states explored:89099 Total number of states to optimal path:89099 Time taken for execution:15.120
		h2 (Manhattan distance )	Total number of states explored:146269 Total number of states to optimal path:146269 Time taken for execution:40.865	Total number of states explored:1983 Total number of states to optimal path:1983 Time taken for execution:0.629

		<b>h3 (h1 X h2)</b>	<b>Total number of states explored:75253 Total number of states to optimal path:75253 Time taken for execution:23.614</b>	<b>Total number of states explored:549 Total number of states to optimal path:549 Time taken for execution:0.176</b>
<b>['T6', 'T2', 'B'] ['T4', 'T3', 'T8'] ['T7', 'T1', 'T5']</b>	<b>['T1', 'T2', 'T3'] ['T4', 'T5', 'T6'] ['T7', 'T8', 'B']</b>	<b>h1 (number of displaced tiles)</b>	<b>Total number of states explored:159103 Total number of states to optimal path:159103 Time taken for execution:25.834</b>	<b>Total number of states explored:55969 Total number of states to optimal path:55969 Time taken for execution:9.523</b>
		<b>h2 (Manhattan distance)</b>	<b>Total number of states explored:27025 Total number of states to optimal path:27025 Time taken for execution:8.073</b>	<b>Total number of states explored:5747 Total number of states to optimal path:5747 Time taken for execution:1.590</b>
		<b>h3 ( h1 X h2)</b>	<b>Total number of states explored:91733 Total number of states to optimal path:91733 Time taken for execution:29.437</b>	<b>Total number of states explored:5287 Total number of states to optimal path:5287 Time taken for execution:1.687</b>
<b>['T4', 'T7', 'T5'] ['T3', 'T8', 'T6'] ['B', 'T1', 'T2']</b>	<b>['T1', 'T2', 'T3'] ['T4', 'T5', 'T6'] ['T7', 'T8', 'B']</b>	<b>h1 (number of displaced tiles)</b>	<b>Total number of states explored:31895 Total number of states to optimal path:31895 Time taken for execution:4.954</b>	<b>Total number of states explored:113191 Total number of states to optimal path:113191 Time taken for execution:19.512</b>

		<b>h2</b> <b>(Manhattan distance )</b>	<b>Total number of states explored:13775</b> <b>Total number of states to optimal path:13775</b> <b>Time taken for execution:3.820</b>	<b>Total number of states explored:55317</b> <b>Total number of states to optimal path:55317</b> <b>Optimal Path Cost:740966</b> <b>Time taken for execution:16.402</b>
		<b>h3 (h1 X h2)</b>	<b>Total number of states explored:12443</b> <b>Total number of states to optimal path:12443</b> <b>Time taken for execution:3.986</b>	<b>Total number of states explored:6433</b> <b>Total number of states to optimal path:6433</b> <b>Optimal Path Cost:541220</b> <b>Time taken for execution:2.175</b>