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**Planning Heuristic Analysis**

For this heuristic analysis, we implemented planning search to solve the airport cargo transport problem. We compared the performance of various search algorithms. (Best performer has been highlighted in green)

**Problem 1:**

Search Algorithm:	Expansions:	Goal Tests:	New Nodes:	Elapsed Time:	Solution Length	Optimal?
breadth_first_search	43	56	180	0.03915682301	6	Y
breadth_first_tree_search	1458	1459	5960	0.97320180	6	Y
depth_first_graph_search	21	22	84	0.014537023	20	N
depth_limited_search	101	271	414	0.0978282139	50	N
uniform_cost_search	55	57	224	0.0448007939	6	Y
recursive_best_first_search with h_1	4229	4230	17023	3.17068510397	6	Y
greedy_best_first_graph_search with h_1	7	9	28	0.00472294099	6	Y
astar_search with h_1	55	57	224	0.03686098201	6	Y
astar_search with h_ignore_preconditions	41	43	170	0.04346117901	6	Y
astar_search with h_pg_levelsum	11	13	50	1.6562842809	6	Y

**Problem 2:**

Search Algorithm:	Expansions:	Goal Tests:	New Nodes:	Elapsed Time:	Solution Length	Optimal?
breadth_first_search	3343	4609	30509	14.186	9	Y
breadth_first_tree_search	NA	NA	NA	NA	NA	NA
depth_first_graph_search	624	625	5602	3.12879	619	N
depth_limited_search	222719	2053741	2054119	951.555	50	N
uniform_cost_search	4853	4855	44041	43.736	9	Y
recursive_best_first_search with h_1	NA	NA	NA	NA	NA	NA
greedy_best_first_graph_search with h_1	NA	NA	NA	NA	NA	NA
astar_search with h_1	4853	4855	44041	43.433	9	Y
astar_search with h_ignore_preconditions	1506	1508	13820	14.683	9	Y
astar_search with h_pg_levelsum	86	88	841	1001.124	9	Y

NA = did not finish running

**Problem 3:**

Search Algorithm:	Expansions:	Goal Tests:	New Nodes:	Elapsed Time:	Solution Length	Optimal?
breadth_first_search	14663	18098	129631	125.880	12	Y
breadth_first_tree_search	NA	NA	NA	NA	NA	NA
depth_first_graph_search	408	409	3364	1.968	392	N
depth_limited_search					NA	NA
uniform_cost_search	18223	18225	159618	580.428	12	Y
recursive_best_first_search with h_1	NA	NA	NA	NA	NA	NA
greedy_best_first_graph_search with h_1	NA	NA	NA	NA	NA	NA
astar_search with h_1	18223	18225	159618	623.935	12	Y
astar_search with h_ignore_preconditions	5118	5120	45650	107.493	12	Y
astar_search with h_pg_levelsum	NA	NA	NA	NA	NA	NA

NA = did not finish running

## **Compare and contrast heuristic search result metrics using A\* with the "ignore preconditions" and "level-sum" heuristics for Problems 1, 2, and 3.**

In problem 1, A star search with ignore preconditions performed better than A star search with level-sum.

In problem 2, A star search with ignore preconditions performed better than A star search with level-sum.

In problem 3, A star search with ignore preconditions performed better than A star search with level-sum (which did not run within 10 minutes).

## **What was the best heuristic used in these problems? Was it better than non-heuristic search planning methods for all problems? Why or why not?**

In problem 1 and 2, breadth first search and greedy best first search with h1 were the best search strategies. In problem 3, A star search with ignore preconditions was the best search strategy. Out of all the heuristics, the A star search with ignore preconditions performed the best. It seems like as a problem complexity increased, the heuristics started to perform better than the non heuristic strategies.

## **Optimal Solution Examples:**

### **Problem 1 (length 6):**

Load(C1, P1, SFO)  
Load(C2, P2, JFK)  
Fly(P2, JFK, SFO)  
Unload(C2, P2, SFO)  
Fly(P1, SFO, JFK)  
Unload(C1, P1, JFK)

### **Problem 2 (length 9):**

Load(C1, P1, SFO)  
Load(C2, P2, JFK)  
Load(C3, P3, ATL)  
Fly(P2, JFK, SFO)  
Unload(C2, P2, SFO)  
Fly(P1, SFO, JFK)  
Unload(C1, P1, JFK)  
Fly(P3, ATL, SFO)  
Unload(C3, P3, SFO)

### **Problem 3 (length 12):**

Load(C1, P1, SFO)

Load(C2, P2, JFK)  
Fly(P2, JFK, ORD)  
Load(C4, P2, ORD)  
Fly(P1, SFO, ATL)  
Load(C3, P1, ATL)  
Fly(P1, ATL, JFK)  
Unload(C1, P1, JFK)  
Unload(C3, P1, JFK)  
Fly(P2, ORD, SFO)  
Unload(C2, P2, SFO)  
Unload(C4, P2, SFO)

## Appendix:

### Problem 1:

Solving Air Cargo Problem 1 using breadth\_first\_search...

Expansions	Goal Tests	New Nodes
43	56	180

Plan length: 6 Time elapsed in seconds: 0.039156823011580855

Load(C1, P1, SFO)  
Load(C2, P2, JFK)  
Fly(P2, JFK, SFO)  
Unload(C2, P2, SFO)  
Fly(P1, SFO, JFK)  
Unload(C1, P1, JFK)

Solving Air Cargo Problem 1 using breadth\_first\_tree\_search...

Expansions	Goal Tests	New Nodes
1458	1459	5960

Plan length: 6 Time elapsed in seconds: 0.9732018020004034

Load(C1, P1, SFO)  
Load(C2, P2, JFK)  
Fly(P2, JFK, SFO)  
Unload(C2, P2, SFO)  
Fly(P1, SFO, JFK)  
Unload(C1, P1, JFK)

Solving Air Cargo Problem 1 using depth\_first\_graph\_search...

Expansions	Goal Tests	New Nodes
21	22	84

Plan length: 20 Time elapsed in seconds: 0.01453702399157919

Fly(P1, SFO, JFK)  
Fly(P2, JFK, SFO)  
Load(C2, P1, JFK)  
Fly(P1, JFK, SFO)  
Fly(P2, SFO, JFK)  
Unload(C2, P1, SFO)  
Fly(P1, SFO, JFK)  
Fly(P2, JFK, SFO)  
Load(C2, P2, SFO)  
Fly(P1, JFK, SFO)  
Load(C1, P2, SFO)  
Fly(P2, SFO, JFK)  
Fly(P1, SFO, JFK)  
Unload(C2, P2, JFK)  
Unload(C1, P2, JFK)  
Fly(P2, JFK, SFO)  
Load(C2, P1, JFK)  
Fly(P1, JFK, SFO)  
Fly(P2, SFO, JFK)  
Unload(C2, P1, SFO)

Solving Air Cargo Problem 1 using depth\_limited\_search...

Expansions	Goal Tests	New Nodes
101	271	414

Plan length: 50 Time elapsed in seconds: 0.09782821399858221

Load(C1, P1, SFO)  
Load(C2, P2, JFK)  
Unload(C1, P1, SFO)  
Load(C1, P1, SFO)  
Unload(C1, P1, SFO)  
Load(C1, P1, SFO)  
Unload(C1, P1, SFO)  
Load(C1, P1, SFO)

Unload(C1, P1, SFO)  
Load(C1, P1, SFO)  
Unload(C1, P1, SFO)  
Load(C1, P1, SFO)  
Unload(C1, P1, SFO)  
Load(C1, P1, SFO)  
Unload(C1, P1, SFO)  
Load(C1, P1, SFO)  
Unload(C1, P1, SFO)  
Load(C1, P1, SFO)  
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Load(C1, P1, SFO)  
Unload(C1, P1, SFO)  
Load(C1, P1, SFO)  
Unload(C1, P1, SFO)  
Load(C1, P1, SFO)  
Fly(P2, JFK, SFO)  
Unload(C2, P2, SFO)  
Fly(P1, SFO, JFK)  
Unload(C1, P1, JFK)

Solving Air Cargo Problem 1 using uniform\_cost\_search...

Expansions	Goal Tests	New Nodes
55	57	224

Plan length: 6 Time elapsed in seconds: 0.044800793984904885

Load(C1, P1, SFO)

Load(C2, P2, JFK)

Fly(P1, SFO, JFK)

Fly(P2, JFK, SFO)

Unload(C1, P1, JFK)

Unload(C2, P2, SFO)

Solving Air Cargo Problem 1 using recursive\_best\_first\_search with h\_1...

Expansions	Goal Tests	New Nodes
4229	4230	17023

Plan length: 6 Time elapsed in seconds: 3.1706851039780304

Load(C2, P2, JFK)

Load(C1, P1, SFO)

Fly(P2, JFK, SFO)

Unload(C2, P2, SFO)

Fly(P1, SFO, JFK)

Unload(C1, P1, JFK)

Solving Air Cargo Problem 1 using greedy\_best\_first\_graph\_search with h\_1...

Expansions	Goal Tests	New Nodes
7	9	28

Plan length: 6 Time elapsed in seconds: 0.0047229409974534065

Load(C1, P1, SFO)

Load(C2, P2, JFK)

Fly(P1, SFO, JFK)

Fly(P2, JFK, SFO)

Unload(C1, P1, JFK)

Unload(C2, P2, SFO)



Solving Air Cargo Problem 1 using astar\_search with h\_1...

Expansions	Goal Tests	New Nodes
55	57	224

Plan length: 6 Time elapsed in seconds: 0.03686098201433197

Load(C1, P1, SFO)

Load(C2, P2, JFK)

Fly(P1, SFO, JFK)

Fly(P2, JFK, SFO)

Unload(C1, P1, JFK)

Unload(C2, P2, SFO)

Solving Air Cargo Problem 1 using astar\_search with h\_ignore\_preconditions...

Expansions	Goal Tests	New Nodes
41	43	170

Plan length: 6 Time elapsed in seconds: 0.04346117901150137

Load(C1, P1, SFO)

Fly(P1, SFO, JFK)

Unload(C1, P1, JFK)

Load(C2, P2, JFK)

Fly(P2, JFK, SFO)

Unload(C2, P2, SFO)

Solving Air Cargo Problem 1 using astar\_search with h\_pg\_levelsum...

Expansions	Goal Tests	New Nodes
11	13	50

Plan length: 6 Time elapsed in seconds: 1.6562842809944414

Load(C1, P1, SFO)

Fly(P1, SFO, JFK)

Load(C2, P2, JFK)

Fly(P2, JFK, SFO)

Unload(C1, P1, JFK)

Unload(C2, P2, SFO)

**References**

Stuart J. Russell, Peter Norvig (2010), Artificial Intelligence: A Modern Approach (3rd Edition).