Optimal Plans

Problem 1 optimal plan (from levelsum heuristic):

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

Problem 2 optimal plan (from levelsum heuristic):

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

Problem 3 optimal plan (from levelsum heuristic):

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

Unload(C1, P1, JFK)
Unload(C2, P2, SFO)
Unload(C3, P1, JFK)
Unload(C4, P2, SFO)

Non-Heuristic Compare and Contrast

Below is a list of results for uninformed searches and false (h_1) heuristic searches:

	Air Cargo 1	**Air Cargo 2**	**Air Cargo 3**
BFS-node expansions	43	3343	14663
BFS-# goal tests	56	4609	18098
BFS-# new nodes	180	3059	129631
BFS-plan length	6	9	12
BFS-time elapsed	0.03086357901	14.72629713	128.4447374
BFS-optimality of solutions	optimal	optimal	optimal
DFGS-node expansions	12	476	1511
DFGS-# goal tests	13	477	1512
DFGS-# new nodes	48	4253	12611
DFGS-plan length	12	466	1442
DFGS-time elapsed	0.007452471997	2.348740683	13.94696688
DFGS-optimality of solutions	non-optimal	very non-optimal	very non-optimal
UCS-node expansions	55	4780	17532
UCS-# goal tests	57	4782	17534
UCS-# new nodes	224	43381	153777
UCS-plan length	6	9	12
UCS-time elapsed	0.03847271297	11.44945664	53.32030594
UCS-optimality of solutions	optimal	optimal	optimal

GBFGS h_1-node expansions	7	598	3373
GBFGS h_1-# goal tests	9	600	3375
GBFGS h_1-# new nodes	28	5382	30072
GBFGS h_1-plan length	6	21	27
GBFGS h_1-time elapsed	0.004918675986	1.623863283	10.9601263
GBFGS h_1-optimality of solutions	optimal	almost optimal	almost optimal
AS h_1-node expansions	55	4780	17532
AS h_1-# goal tests	57	4782	17534
AS h_1-# new nodes	224	43381	152777
AS h_1-plan length	6	9	12
AS h_1-time elapsed	0.03980848694	12.84616444	51.13964145
AS h_1-optimality of solutions	optimal	optimal	optmial

Summary of Results

The table below lists the performance of each search:

Rank	**Node Expansions**	**Average**	**Goal Tests**	**Average**	**New Nodes**	**Average**	**Plan Length**	**Average**	**Time Elapsed**	**Average**
1	DFGS	666.333	DFGS	667.333	DFGS	5637.33	BFS	9	GBFGS h_1	4.19630
2	GBFGS h_1	1326	GBFGS h_1	1328	GBFGS h_1	11827.3	UCS	9	DFGS	5.43438
3	BFS	6016.33	UCS	7457.66	BFS	44290	AS h_1	9	AS h_1	21.3418
4	UCS	7455.66	AS h_1	7457.66	AS h_1	65460.6	GBFGS h_1	18	UCS	21.6027
5	AS h_1	7455.66	BFS	7587.66	UCS	65794	DFGS	640	BFS	47.7339

In general, DFGS performed the best by far for node expansions, goal tests, and new nodes (and therefore required memory), however it resulted in very non-optimal plan length. This is expected due to the nature of depth first search and the fact that many solutions exist for these

problems. BFS, UCS, and AS h_1 all resulted in optimal planning length, but were also on average the slowest searches and required the most memory. UCS and AS h_1 are essentially the same search due to the simplified h_1 heuristic provided to A*. Both take advantage of more complexity and memory requirements to guide the search to find an optimal solution at a faster rate than BFS. The table below ranks each search based on weighted normalized scores for each category (where W is weight):

Search	Node Expansions	W	Goal Tests	W	New Nodes	W	Plan Length	W	Time Elapsed	W	Weighted Score
GBFGS h_1	0.902	0.2	0.904	0.2	0.8971	0.2	0.98573	1	1	0.75	2.276631392
AS h_1	0	0.2	0.018	0.2	0.0055	0.2	1	1	0.606189	0.75	1.459507736
UCS	0	0.2	0.018	0.2	0	0.2	1	1	0.600198	0.75	1.453905588
DFGS	1	0.2	1	0.2	1	0.2	0	1	0.971562	0.75	1.328672192
BFS	0.211	0.2	0	0.2	0.3574	0.2	1	1	0	0.75	1.113893166

The highest weight was given to the plan length (or optimality) of the plan, followed by the time elapsed, with node expansions, goal tests, and new nodes weighted the lowest. The weights were based on the value and scalability of each metric.

Overall, GBFGS h_1 ranked the highest due to its high performance metrics and semi-optimal plan length. GBFGS h_1 is a balanced method since it approximates the next best node in the path without taking the path cost into consideration. Out of the optimal solutions, AS h_1 and UCS ranked the highest with almost identical scores.

Heuristic Compare and Contrast

Below is a list of results for heuristic searches:

	Air Cargo 1	Air Cargo 2	Air Cargo 3	Average
AS h_IG-node expansions	41	1450	5022	2171
AS h_IG-# goal tests	43	1452	5024	2173
AS h_IG-# new nodes	170	13303	44764	19412.33333
AS h_IG-plan length	6	9	12	9
AS h_IG-time elapsed	0.029407158	3.962436823	16.21032731	6.734057097
AS h_IG-optimality of solutions	optimal	optimal	optimal	
AS h_PGL-node expansions	11	88	318	139
AS h_PGL-# goal tests	13	88	320	140.3333333
AS h_PGL-# new nodes	50	841	2937	1276
AS h_PGL-plan length	6	9	12	9
AS h_PGL-time elapsed	0.865093192	75.79139761	370.0041738	148.8868882
AS h_PGL-optimality of solutions	optimal	optimal	optimal	

Summary of Results

The table below lists the performance of each search :

Rank	**Node Expansions**	**Average**	**Goal Tests**	**Average**	**New Nodes**	**Average**	**Plan Length**	**Average**	**Time Elapsed**	**Average**
1	AS h_PGL	139	AS h_PGL	140.3333333	AS h_PGL	2937	AS h_IG	9	AS h_IG	6.734057097
2	AS h_IG	2171	AS h_IG	2173	AS h_IG	44764	AS h_PGL	9	AS h_PGL	148.8868882

While both searches produce optimal solutions, they are polar opposites in terms of memory and speed. The table below ranks the heuristic searches in comparison with the non-heuristic searches:

Search	Node Expansions	W	Goal Tests	W	New Nodes	W	Plan Length	W	Time Elapsed	W	Weighted Score
GBFGS h_1	0.83776765	0.2	0.840	0.2	0.8585	0.2	0.98573	1	1	0.75	2.243107882
AS h_IG	0.72227790	0.2	0.727	0.2	0.3345	0.2	1	1	0.982460	0.75	2.093627212
AS h_1	0	0.2	0.017	0.2	0.0053	0.2	1	1	0.881501	0.75	1.665678168
UCS	0	0.2	0.017	0.2	0	0.2	1	1	0.879698	0.75	1.663265328
BFS	0.19671981	0.2	0	0.2	0.3421	0.2	1	1	0.699098	0.75	1.632089558
AS h_PGL	1	0.2	1	0.2	1	0.2	1	1	0	0.75	1.6
DFGS	0.92792710	0.2	0.929	0.2	0.9570	0.2	0	1	0.991443	0.75	1.306423139

Using the same weights as before, GBFGS h_1 still scores the highest overall, however AS h_IG takes a close 2nd, and indeed would be the best overall method if optimality is required. Comparing the three AS searches provides a good insight into the power of heuristics. Although the “ignore preconditions” heuristic is quite simple and a rough approximation, it greatly improves the search performance over the constant “h_1” heuristic in both memory and processing requirements. On the other hand, the “levelsum” heuristic provides a much better approximation to the goal, resulting in less exploration and less memory required for a solution, at the cost of extra processing for the planning graph. The time performance for the levelsum heuristic could be improved with a more efficient implementation of the planning graph. If there were a situation where memory was scarce and time/processing power were abundant, then AS h_PGL would by far be the best choice.