Heuristic Analysis Report

Uniformed Search Algorithms – with no heuristics

I chose to analyze breadth first search, depth first search, depth limited search and uniform cost search. Russell and Norvig give the following four ways to evaluate the performance of an algorithm:

- Completeness – Whether or not the algorithm is guaranteed to find a solution;
- Optimality – Whether or not the strategy finds the optimal solution;
- Time complexity – How long it takes to find a solution;
- Space complexity – The amount of memory required to perform a search;

The execution of the four selected unformed search algorithms on each of the different problems produced the results in the table below:

Non-Heuristics Planning Metrics								
Problem	**Search Algorithm**		**Node Expansions**	**Goal Tests**	**New Nodes**	**Time Elapsed (Seconds)**	**Plan Length**	**Optimality**
air_cargo_p1	Breadth First Search		43	56	180	0.030071249	6	Yes
	Depth First Search		12	13	48	0.007765713	12	No
	Depth Limited Search		101	271	414	0.124007656	50	No
	Uniform Cost Search		55	57	224	0.03979607	6	Yes
air_cargo_p2	Breadth First Search		3343	4609	30509	15.48068883	9	Yes
	Depth First Search		582	583	5211	3.465848364	575	No
	Depth Limited Search		222719	2053741	2054119	927.2141033	50	No
	Uniform Cost Search		4853	4855	44041	12.02250109	9	Yes
air_cargo_p3	Breadth First Search		14663	18098	129631	114.5404568	12	Yes
	Depth First Search		627	628	5176	3.612615481	596	No
	Uniform Cost Search		18236	18238	159726	54.44729709	12	Yes

Table 1 - Non-heuristics Metrics

Breadth First Search and Uniform Cost Search are optimal (Russell and Norvig) – they produced the same solutions for the runs per the results table below. We also see from the table below that they found the

optimum solution of plan length 6 for air_cargo_p1, plan length 9 for air_cargo_p2 and plan length 12 for air_caorg_p3. Its not an accident that they found the same solution – its been proven that they are optimal. Depth First Search and Depth Limited Search also found some solutions but these were not the optimal solutions. Depth Limited Search found a plan of length 50 for air_cargo_p1 which intuitively doesn't sound correct for the nature of the problem.

In terms of time complexity Depth First Search outperformed all other algorithms. Suggesting it might be useful if one wanted to only know if a solution exists without worrying about whether or not the solution is optimal. Depth Limited Search performed the worst in terms of time complexity and for air_cargo_p3 I had to stop it without getting a result.

Breadth First Search and Uniform Cost Search expanded nodes and performed goal tests in magnitudes not very far apart which explains the small differences in time complexity although uniform cost search always expanded and performed slightly more than Breadth First Search.

The optimal plans found using the optimal algorithms (Breadth First Search, Uniform Cost Search and all the heuristics for all problems were as follows:

Air_cargo_p1	Air_cargo_p2	Air_Cargo_p3
Load(C2, P2, JFK) Load(C1, P1, SFO) Fly(P2, JFK, SFO) Unload(C2, P2, SFO) Fly(P1, SFO, JFK) Unload(C1, P1, JFK)	Load(C2, P2, JFK) Load(C1, P1, SFO) 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)	Load(C2, P2, JFK) Load(C1, P1, SFO) 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)

Table 2 - Optimal Plans for all problems

Astar Search with Heuristics

For Astar search using heuristics, I obtained the following the results:

Heuristics Planning Metrics

Problem	Search Algorithm		Node Expansions	Goal Tests	New Node	Time Elaped (Seconds)	Plan Length	Optimality
air_cargo_p1	astar_search_h1		55	57	224	0.036702347	6	Yes
	astar_search_ignore_preconditions		41	43	170	0.053852733	6	Yes
	astar_search_h_pg_levelsum		11	13	50	5.405857964	6	Yes
air_cargo_p2	astar_search_h1		4853	4855	44041	12.26337844	9	Yes
	astar_search_ignore_preconditions		1450	1452	13303	4.223984545	9	Yes
	astar_search_h_pg_levelsum		86	88	841	3025.100184	9	Yes

air_cargo_p3	astar_search_h1	18236	18238	159726	55.20007862	12	Yes
	astar_search_ignore_preconditions	4859	4861	43129	17.73678906	12	Yes
	astar_search_h_pg_levelsum	299	301	2760	20887.56664	12	Yes

Table 3 - Heuristics Planning Metrics

The conditions for optimality for Astar search is admissibility and consistency (Russell and Norvig). An admissible heuristic is one that never over estimates the cost to reach the goal. All the heuristics algorithms produced exactly the same result as our optimal algorithms (Breadth First Search and Uniform Cost Search above. So we conclude that they are optimal:

Air_cargo_p1	Air_cargo_p2	Air_Cargo_p3
Load(C2, P2, JFK) Load(C1, P1, SFO) Fly(P2, JFK, SFO) Unload(C2, P2, SFO) Fly(P1, SFO, JFK) Unload(C1, P1, JFK)	Load(C2, P2, JFK) Load(C1, P1, SFO) 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)	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(C4, P2, SFO) Unload(C3, P1, JFK) Unload(C2, P2, SFO) Unload(C1, P1, JFK)

Table 4 - Heuristics Optimal Plans

Next we note that Astar Search produced the same results to Uniform Cost Search when h(n) = 1. The results (nodes expanded, goal tests, new nodes and time complexity) for astar_search_h1 for all problems were exactly the same as those for Uniform Cost Search. We definitely know that astar_search_h1 is optimal, complete and has the same time complexity as Uniform Cost Search.

When we ignore preconditions (a_star_ignore_preconditions) we are actually getting an algorithm which performs better than astar_search_h1 (our proxy for Uniform Cost Search) in terms of nodes expanded, new nodes, goal tests and time complexity.

Astar_search_h_pg_levelsum does even better that a_star_ignore_preconditions in terms of nodes expanded, goal tests and new nodes. However its performance in terms of time complexity is the worst – many folds above uniform cost search or ignore_preconditions on all problems.

In conclusion, a_star_ignore_preconditions was the best performing algorithm in terms of balancing between nodes expanded, goal tests, new nodes, time complexity and optimality. In other words, astar_search_ignore_preconditions expands slightly more nodes and perform slightly more goal tests that astar_search_h_pg_levelsum but it does it this within a much shorter time frame. If we could find a way to reduce to the time complexity of astar_search_h_ph_levelsum then this would be the better choice. All the heuristics algorithms are complete and optimal.