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Heuristic Analysis

Abstract

Three air cargo planning problems of increasing complexity have been investigated using six search methods: breadth-first search (BFS), depth-first (DF) graph search, uniform cost search (UCS), A* *h_1*, A* *h_ignore_preconditions*, and A* *h_pg_levelsum*. An optimal plan has been obtained for each problem and the performance of each search method have been analyzed. DF graph search has been identified as the fastest but did not manage to obtain an optimal solution to any of the three problems. A* search with a *h_ignore_preconditions* heuristic was the fastest to discover an optimal plan to all but the first air cargo problem. The performance of the A* with a *h_pg_levelsum* heuristic was nearly identically matched by that of the UCS. The recommendation is to use the DF graph search when solution speed is more important, and A* *h_ignore_preconditions* when it is important to find an optimal plan to the problem.

Results

Table 1. Optimal plans obtained for each air cargo problem.

Air cargo problem number	Optimal plan	Plan length
1	*Load(C1, P1, SFO)* *Load(C2, P2, JFK)* *Fly(P2, JFK, SFO)* *Unload(C2, P2, SFO)* *Fly(P1, SFO, JFK)* *Unload(C1, P1, JFK)*	6
2	*Load(C1, P1, SFO)* *Load(C2, P2, JFK)* *Load(C3, P3, ATL)* *Fly(P1, SFO, JFK)* *Unload(C1, P1, JFK)* *Fly(P2, JFK, SFO)* *Unload(C2, P2, SFO)* *Fly(P3, ATL, SFO)* *Unload(C3, P3, SFO)*	9
3	*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)*	12

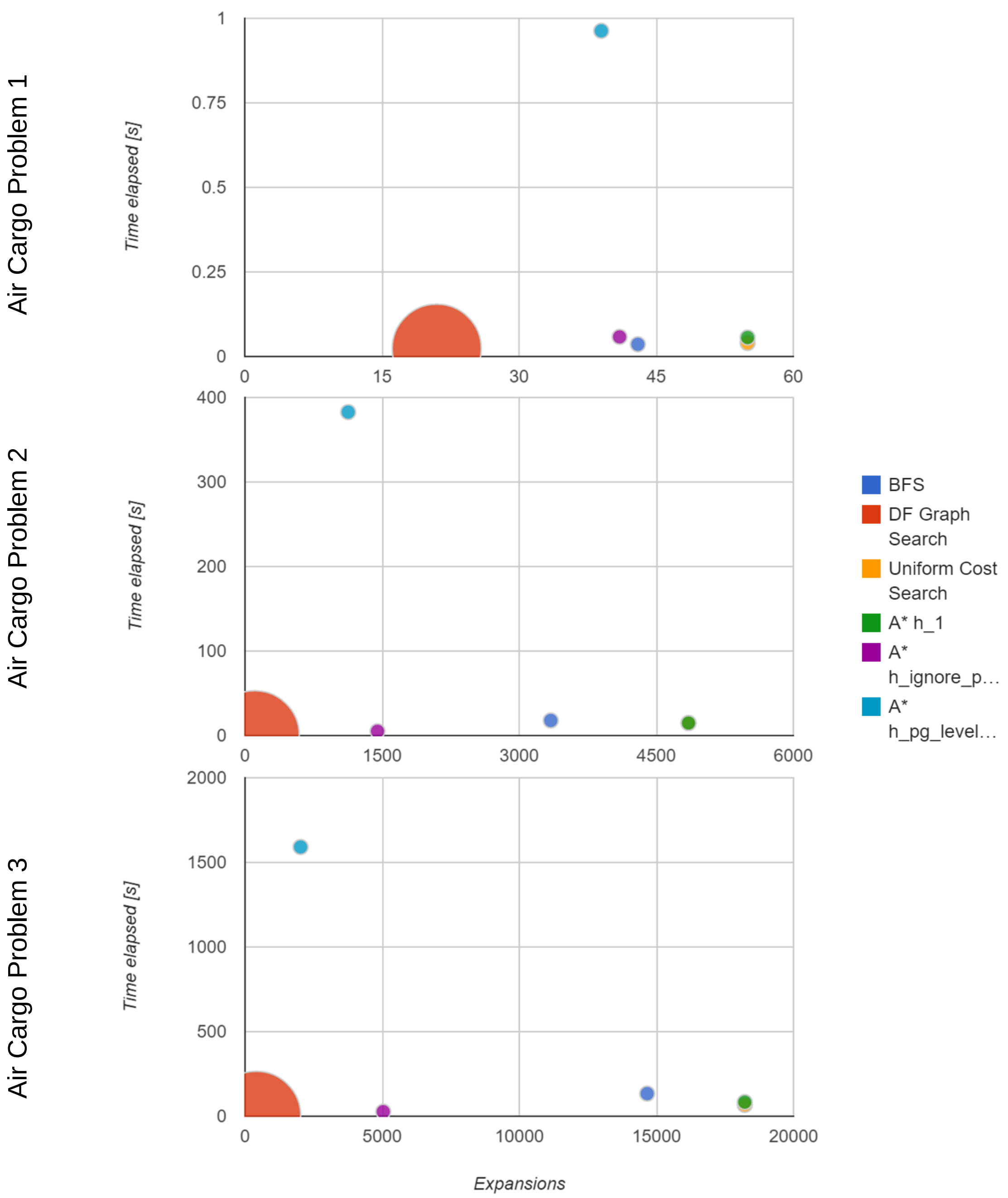

Fig. 1. The performance (i.e. time elapsed, number of node expansions, and plan optimality) of the five different search methods in solving the three air cargo problems (bubble size is directly proportional to the length of the plan found).

Table 2. Complete performance summary report for each of the five search methods.

	BFS	**DF Graph Search**	**Uniform Cost Search**	**A*** ***h_1***	**A*** ***h_ignore_preconditions***	**A*** ***h_pg_levelsum***
			Air cargo problem 1			
Expansions	43	21	55	55	41	39
Plan length	6	20	6	6	6	6
Time elapsed [s]	0.036	0.023	0.04	0.056	0.058	0.963
Goal Tests	56	22	57	57	43	41
New Nodes	180	84	224	224	170	158
			Air cargo problem 1			
Expansions	3346	107	4853	4853	1450	1129
Plan length	9	105	9	9	9	9
Time elapsed [s]	17.843	0.398	14.934	14.81	5.102	382.752
Goal Tests	4612	108	4855	4855	1452	1131
New Nodes	30534	959	44041	44041	13303	10232
			Air cargo problem 1			
Expansions	14663	408	18223	18223	5040	2025
Plan length	12	392	12	12	12	12
Time elapsed [s]	133.74	2.128	67.162	83.45	26.833	1591.058
Goal Tests	18098	409	18225	18225	5042	2027
New Nodes	128554	3364	158186	2E+05	44720	17902

DF graph search was the fastest method with the fewest node expansions (see Fig. 1 and Table 2). However, the length of the solutions obtained using this method was significantly longer compared to the other search methods. In fact, DF graph search was the only method unable to reach an optimal plan for all three air cargo problems. This is not surprising as the depth-first search methods are known to be nonoptimal (Russell and Norvig 2009). The solutions to all three air cargo problems obtained by the other two uninformed search methods, i.e. the BFS and UCS, were both optimal and identical. Even though the BFS had on average fewer node expansions, the UCS was found to be faster (see Fig. 1 and Table 2).

A* search with a constant heuristic *h_1* was nearly identical to the UCS in terms of the number of node expansions, time elapsed, and the solution length. This was expected since the only difference between the two algorithms is that the A* search with *h_1* heuristic adds an additional constant to the path cost. A* search with a *h_pg_levelsum* heuristic was the second method with the fewest node expansions, however it was also the slowest one. The running time of it was significantly slower compared to other search methods, which is mainly because the *h_pg_levelsum* heuristic requires for the graphplan to be generated. A* search with a *h_ignore_preconditions* heuristic was found to be the fastest algorithm on average to deliver an optimal plan for the three air cargo problems.

Based on the results obtained (see Fig. 1 and Table 2), DF graph search is recommended if the optimality of the solution is not a priority and the performance in terms of speed is more important. However, in order to find the optimal plan A* search with *h_ignore_preconditions* should be the strategy of choice especially for more complex problems.

REFERENCES

Russell, S. J. and P. Norvig (2009). Artificial intelligence: a modern approach (3rd edition), Prentice Hall.