Heuristic Analysis Report

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Air Cargo Problem	Search	Actions	Nodes Expanded	Search Time	Plan Length
1	breadth_first_search	20	43	0.006293417	6
	depth_first_graph_search	20	21	0.003496752	20
	uniform_cost_search	20	60	0.009874593	6
	greedy_best_first_graph_search (with h_unmet_goals)	20	7	0.001630328	6
	greedy_best_first_graph_search (with h_pg_levelsum)	20	6	0.563421054	6
	greedy_best_first_graph_search (with h_pg_maxlevel)	20	6	0.423652028	6
	greedy_best_first_graph_search (with h_pg_setlevel)	20	6	1.616130634	6
	astar_search (with h_unmet_goals)	20	50	0.010092433	6
	astar_search (with h_pg_levelsum)	20	28	1.441109186	6
	astar_search (with h_pg_maxlevel)	20	43	1.487373637	6
	astar_search (with h_pg_setlevel)	20	33	4.25684926	6
2	breadth_first_search	72	3343	2.083750841	9
	depth_first_graph_search	72	624	3.205605738	619
	uniform_cost_search	72	5154	3.521962068	9
	greedy_best_first_graph_search (with h_unmet_goals)	72	17	0.019826987	9
	greedy_best_first_graph_search (with h_pg_levelsum)	72	9	13.4886938	9
	greedy_best_first_graph_search (with h_pg_maxlevel)	72	27	27.18958961	9
	greedy_best_first_graph_search (with h_pg_setlevel)	72	9	36.47281111	9
	astar_search (with h_unmet_goals)	72	2467	2.383886564	9
	astar_search (with h_pg_levelsum)	72	357	342.794816	9
	astar_search (with h_pg_maxlevel)	72	2887	1982.705623	9
	astar_search (with h_pg_setlevel)	72	1037	2772.184503	9
3	breadth_first_search	88	14663	11.24583944	12
	greedy_best_first_graph_search (with h_unmet_goals)	88	25	0.037850797	15
	greedy_best_first_graph_search (with h_pg_levelsum)	88	14	30.18914174	14
	astar_search (with h_unmet_goals)	88	7388	8.781152834	12
	astar_search (with h_pg_levelsum)	88	369	547.9324188	12
4	breadth_first_search	104	99736	100.7854188	14
	greedy_best_first_graph_search (with h_unmet_goals)	104	29	0.062127575	18
	greedy_best_first_graph_search (with h_pg_levelsum)	104	17	54.55728618	17
	astar_search (with h_unmet_goals)	104	34330	57.65894676	14
	astar_search (with h_pg_levelsum)	104	1208	3095.105708	15

Table 1: Result for Air Cargo Problems

Cargo problems 1 and 2 were solved using all uninformed and informed search algorithms to evaluate their performance in terms of number of expanded nodes and search time. Uniform case search required the most number of nodes expanded for both problems, which might not be admissible for bigger problems. Although depth-first search was able to find solutions with fewer number of nodes expanded than the other two uninformed search algorithms, it resulted in solutions with unacceptably long plan length, which in my opinion, cannot even be considered a suboptimal solution. From greedy best first search result for cargo problem 2, runs with maxlevel and setlevel heuristics resulted in significantly longer search time than the other two. Similarly, maxlevel and setlevel heuristics for a-star search algorithm resulted in significantly longer search time for cargo problem 2. For these reasons, depth-first graph search, uniform cost search, greedy best first search with maxlevel, greedy best first search with setlevel, a-star search with maxlevel, and a-star search with setlevel were excluded from runs for problems 3 and 4, which has even bigger domain than problem 2.

As seen from Table 1, the number of nodes expanded varies widely between different search algorithm and heuristic combinations. For all problems, greedy best first graph search (for all four heuristics) dominated in this regard, and the difference became more apparent for problems with bigger domain (problems 3 and 4). For cargo problem 3, greedy best first graph search with unmet_goals and levelsum heuristic was able to find the solution with 587 times fewer expanded nodes breadth-first search, and about 15 times fewer nodes than best-case a-star search. The difference became even more significant for air cargo problem 4, in which worst-case of greedy best first graph search required about 42 times fewer expanded nodes than best-case a-star search.

For problems with small domain, such as air cargo problems 1 and 2, number of nodes expanded for a-star search did not appear to be significantly better than uninformed searches. However, as the problem domain increased for air cargo problems 3 and 4, a-star search with unmet_goals and levelsum heuristic was able to find optimal solution (with the exception of air cargo problem 4, in which a suboptimal solution with length 15 was found) with significantly fewer number of expanded nodes than breadth-first graph search. Breadth-first graph search, despite being guaranteed to find an optimal solution, performed the worst in this regard as expected.

As far as search time is concerned, a-star search with levelsum heuristic was worse than any other search algorithms. The same algorithm with unmet_goals heuristic found a solution with much shorter search time, despite it required significantly more nodes expanded as discussed earlier. Greedy best first graph search algorithm with unmet_goals dominated in this regard, which is not even comparable to any other algorithms for all problems. In general, difference in terms of search time between each algorithms became much more apparent as the number of actions increased.

As discussed above, depth first graph search was excluded for cargo problems 3 and 4 because it returned solutions with unacceptably long plan length compared to an optimal solution. As expected, breadth first search always returned solutions with the smallest plan length since it's guaranteed to find an optimal solution. For small domain problems (air cargo problems 1 and 2), all informed and uninformed searches except depth first graph search was able to find optimal solutions (with plan lengths 6 and 9 respectively).

A-star search with both unmet_goals and levelsum heuristic was able to find the optimal solution consistently. The only exception was levelsum for air cargo problem 4, but even in this case the plan length differed by only 1. Greedy best first graph search with unmet and levelsum heuristics, despite requiring significantly fewer expanded nodes, returned acceptable suboptimal solutions; plan lengths for problems 3 and 4 was longer by 2~4 compared to an optimal solution.

Based on observations above, it would be wise to choose different search algorithms for different criteria. For planning in a very restricted domain (with small number of actions but requires to operate in real time), greedy best first search with unmet_goals should be used to find a solution with the shortest amount of time. Results for air cargo problems 1 and 2 shows this algorithm was able to quickly find optimal solution for small number of actions.

For planning in very large domains such as planning delivery routes for UPS drivers across the country, it is imperative that the algorithm finds a solution with the fewest number of expanded nodes, even if the solution it found is suboptimal. Based on results obtained from air cargo problems, it would be appropriate to use greedy best first search with levelsum for these kind of problems. It is acceptable for a UPS driver to take a little detour, but it is certainly not acceptable for the planning computer to hang indefinitely because it requires expanding a huge number of nodes which might not even be admissible.

Lastly, if optimality is of top priority, breadth-first search needs to be used since it's the only algorithm (among the five that were chosen for air cargo problems 3 and 4) which guarantees to find an optimal solution. However, if the number of actions in the planning problem is big enough to the point where it wouldn't be admissible to use breadth first search, a-star search with levelsum should be used instead. Results for air cargo problems 3 and 4 shows that this algorithm was able to find solutions that are close enough to the optimal problem consistently while expanding significantly fewer number of nodes.