

# **Classical Planning Project Report**

Analysis of different search algorithms

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# Introduction

Air cargo problems were solved using uninformed and heuristic based search algorithms that are used in artificial intelligence, this report presents gathered data about the used algorithms and analyze the results to evaluate used algorithms. This report is a part of Udacity artificial intelligence nano-degree course.

## Gathered Data

This section presents data gathered in the process and highlights the optimal solution for each problem.

Air Cargo Problem 1

Search Type	# Actions	Expansions	Goal Tests	New Nodes	Plan Length	Time
Breadth First Search	20	43	56	178	6	0.0193399409981794
Depth First Graph Search	20	21	22	84	20	0.00494992500171065
Uniform Cost Search	20	60	62	240	6	0.0259665499979747
Greedy Best First Graph Search: unmet_goals	20	7	9	29	6	0.00214204499934567
Greedy Best First Graph Search: levelsum	20	6	8	28	6	0.461486643998796
Greedy Best First Graph Search: maxlevel	20	6	8	24	6	0.128882494998834
Greedy Best First Graph Search: setlevel	20	6	8	28	6	1.00500732699948
A* Search: unmet_goals	20	50	52	206	6	0.0260773540030641
A* Search: levelsum	20	28	30	122	6	0.71113001899721
A* Search: maxlevel	20	43	45	180	6	0.25313364700196
A* Search: setlevel	20	33	35	138	6	1.42548410499876

### Air Cargo Problem 2

Search Type	# Actions	Expansions	Goal Tests	New Nodes	Plan Length	Time
Breadth First Search	72	3343	4609	30503	9	0.303926701999444
Depth First Graph Search	72	624	625	5602	619	0.455988511002943
Uniform Cost Search	72	5154	5156	46618	9	0.576046678001148
Greedy Best First Graph Search: unmet_goals	72	17	19	170	9	0.00954214499870432
Greedy Best First Graph Search: levelsum	72	9	11	86	9	0.936994275998586
Greedy Best First Graph Search: maxlevel	72	27	29	249	9	1.64088618999813
Greedy Best First Graph Search: setlevel	72	9	11	84	9	2.39540349099843
A* Search: unmet_goals	72	2467	2469	22522	9	0.654041262001556
A* Search: levelsum	72	357	359	3426	9	19.6712099059987
A* Search: maxlevel	72	2887	2889	26594	9	113.869673854999
A* Search: setlevel	72	1037	1039	9605	9	160.419788576

### Air Cargo Problem 3

Search Type	# Actions	Expansions	Goal Tests	New Nodes	Plan Length	Time
Breadth First Search	88	14663	18098	129625	12	0.844827367000107
Depth First Graph Search	88	408	409	3364	392	0.196061834001739
Uniform Cost Search	88	18510	18512	161936	12	1.32558855699972
Greedy Best First Graph Search: unmet_goals	88	25	27	230	15	0.0151579129997117
Greedy Best First Graph Search: levelsum	88	14	16	126	14	2.51630606199979
Greedy Best First Graph Search: maxlevel	88	21	23	195	13	2.07617405700148
Greedy Best First Graph Search: setlevel	88	35	37	345	17	10.263465107997
A* Search: unmet_goals	88	7388	7390	65711	12	1.0603646999989
A* Search: levelsum	88	369	371	3403	12	32.6002606549992
A* Search: maxlevel	88	9580	9582	86312	12	582.903048366999
A* Search: setlevel	88	3423	2425	31596	12	853.564276072

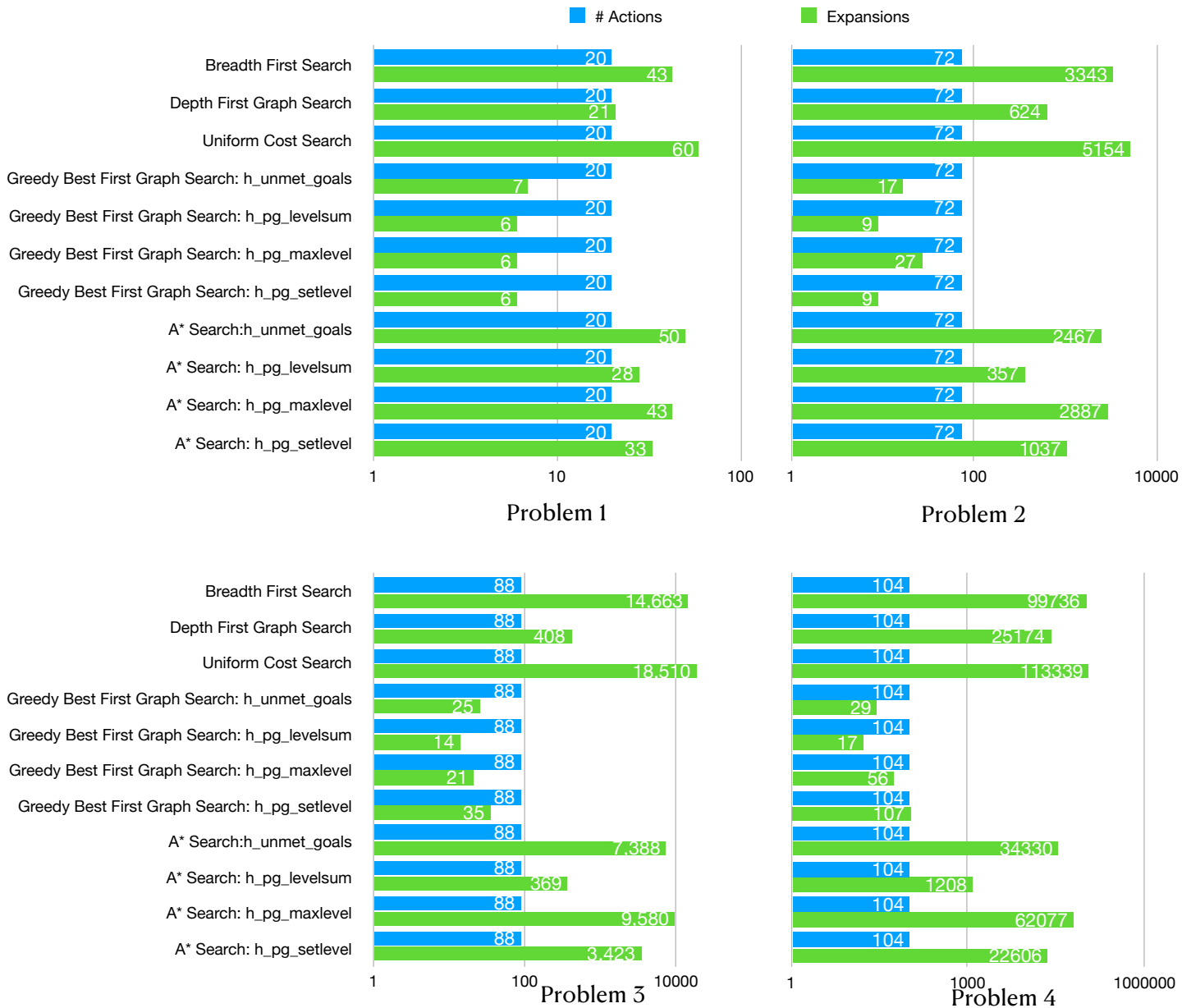
#### Air Cargo Problem 4

Search Type	# Actions	Expansions	Goal Tests	New Nodes	Plan Length	Time
Breadth First Search	104	99736	114953	944130	14	5.03151987200181
Depth First Graph Search	104	25174	25175	228849	24132	986.212432060001
Uniform Cost Search	104	113339	113341	1066413	14	7.7409355689997
Greedy Best First Graph Search: unmet_goals	104	29	31	280	18	0.0413694630005921
Greedy Best First Graph Search: levelsum	104	17	19	165	17	4.573165309000062
Greedy Best First Graph Search: maxlevel	104	56	58	580	17	8.56812989000173
Greedy Best First Graph Search: setlevel	104	107	109	1164	23	49.5047112199973
A* Search: unmet_goals	104	34330	34332	328509	14	3.90934586000003
A* Search: levelsum	104	1208	1210	12210	15	176.508068353
A* Search: maxlevel	104	62077	62079	599376	14	5857.624045844
A* Search: setlevel	104	22606	22608	224229	14	8989.634067552

As shown in the tables above, for problem 1 and 2 all search methods achieve optimal solutions except for depth first search. As for problem 3 only some of the methods turned optimal solutions: BFS, UCS and A\* with every heuristic. For problem 4, both BFS and UCS find optimal solutions, but A\* with level sum heuristic fails to achieve an optimal goal, but unmet goals, max level and set level heuristics achieved optimal solutions.

# Analysis

Number of nodes expanded against number of actions in the domain.



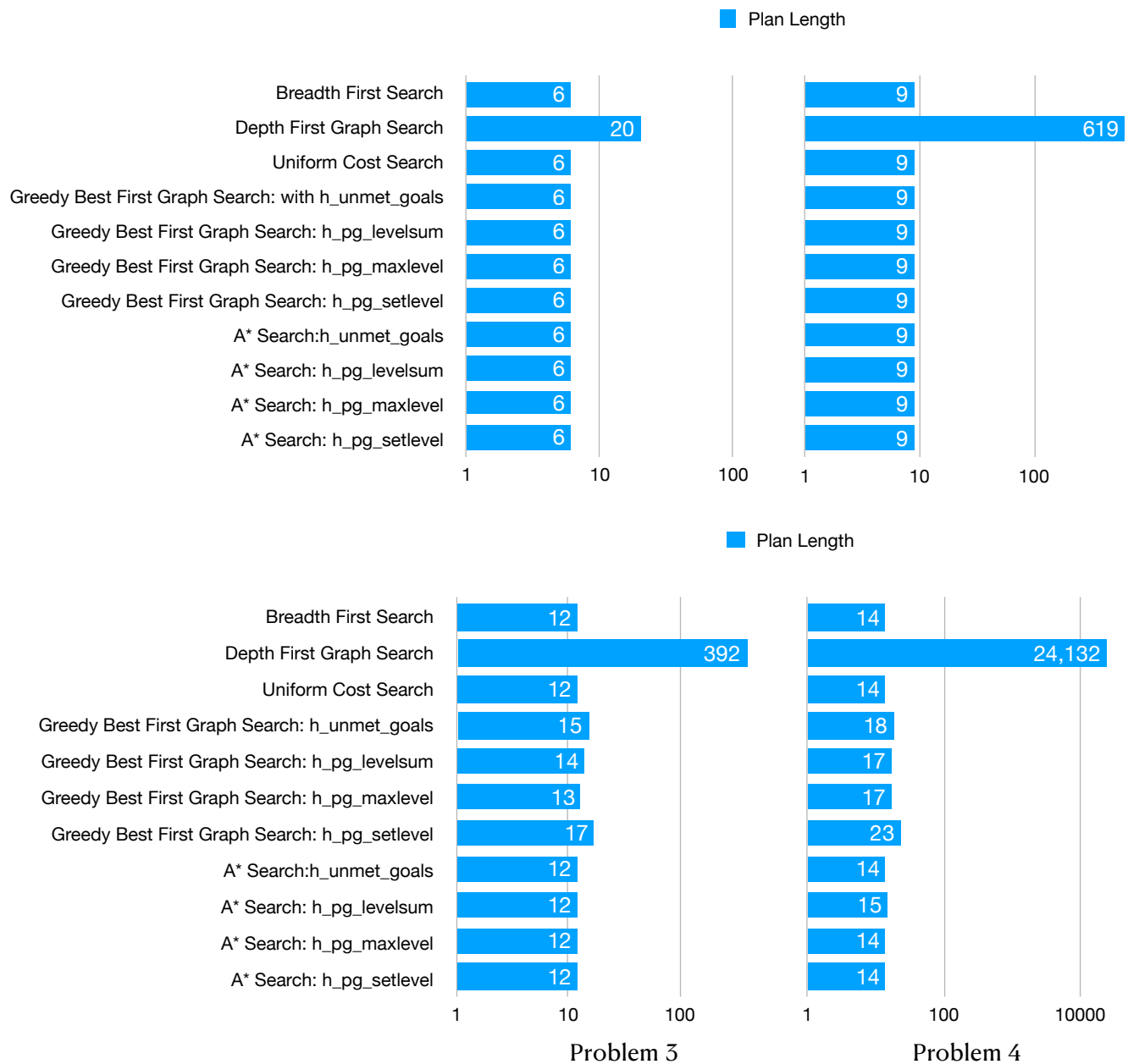
These graphs highlights that for all problems, greedy best first graph search turned the least number of expanded nodes, but the plan length returned are distant from optimum. Among the approaches that achieved optimality, it's worth noting that A\* search with level sum heuristic returned the least number of expanded nodes for problems 1, 2 and 3. With the increasing size of problem 4, it failed to achieve optimality with a very small margin but also returned the least number of expanded nodes.

Search time against the number of actions in the domain.

	Problem 1		Problem 2		Problem 3		Problem 4	
Search Type	#	Time	#	Time	#	Time	#	Time
Breadth First Search	20	0.0193399	72	0.3039267	88	0.8448274	104	5.0315199
Depth First Graph Search	20	0.0049499	72	0.4559885	88	0.1960618	104	986.2124321
Uniform Cost Search	20	0.0259665	72	0.5760467	88	1.3255886	104	7.7409356
Greedy Best First Graph Search: unmet_goals	20	0.0021420	72	0.0095421	88	0.0151579	104	0.0413695
Greedy Best First Graph Search: levelsum	20	0.4614866	72	0.9369943	88	2.5163061	104	4.5731653
Greedy Best First Graph Search: maxlevel	20	0.1288825	72	1.6408862	88	2.0761741	104	8.5681299
Greedy Best First Graph Search: setlevel	20	1.0050073	72	2.3954035	88	10.2634651	104	49.5047112
A* Search: unmet_goals	20	0.0260774	72	0.6540413	88	1.0603647	104	3.9093459
A* Search: levelsum	20	0.7111300	72	19.6712099	88	32.6002607	104	176.5080684
A* Search: maxlevel	20	0.2531336	72	113.8696739	88	582.9030484	104	5857.6240458
A* Search: setlevel	20	1.4254841	72	160.4197886	88	853.5642761	104	8989.6340676

This table highlights that greedy best first graph search with unmet goals heuristic is the fastest of all tested algorithms. It achieved optimal solutions for problem 1 & 2 but failed to achieve optimality for problem 3 & 4. Also, with respect to time, A\* search with set level heuristic performs the slowest among tested approaches.

Length of the plans returned by each algorithm.



This set of results shows the disadvantage of depth first search with respect to optimality, as the resulting plan is much longer than optimal and the deviation is proportional with problem size.



## Conclusion

As shown in the results, greedy best first search with unmet goals heuristic proves the best option overall, and the best informed search strategy for planning in a very restricted domain, as it achieved optimal solution in the least time for problem 1 which has 20 actions and problem 2 which has 72 actions.

Looking at the performance of breadth first search and A\* search with unmet goals heuristic while solving the large domain of problem 4, both achieved optimal solutions very fast compared to other algorithms that reached optimal solutions, no other search strategy could achieve both goals. With such results it's reasonable to conclude that they are the most appropriate algorithms for planning in very large domains.

When the main goal is to find the optimal plan, then breadth first search, uniform cost search and A\* search with unmet goals or max level or set level heuristics are the way to go, as they achieved optimal solutions for all problems.