

Udacity AI Nanodegree
Project 2 – Forward Planning Agent

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- 1) Analyze the search complexity as a function of domain size, search algorithm, and heuristic.

Search	20	72	88	104
Breadth First Search	43	3343	14663	99736
Depth First Graph Search	21	624	408	25174
Uniform Cost Search	60	5154	18510	113339
Greedy Best First Search with h_unmet_goals	7	17	25	29
Greedy Best First Search with h_pg_levelsum	6	9	14	17
Greedy Best First Search with h_pg_maxlevel	6	27	21	56
Greedy Best First Search with h_pg_setlevel	6	9	35	107
A* Search with h_unmet_goals	50	2467	7388	34330
A* Search with h_pg_levelsum	28	357	369	1208
A* Search with h_pg_maxlevel	43	2887	9580	62077
A* Search with h_pg_setlevel	33	1037	3423	22606

Figure 1 - Actions vs Expanded Nodes

Figure 1 shows the number of expanded nodes for each number of actions for each search algorithm. I have colored the cells green for the lowest number of nodes expanded for each number of actions and red for the highest number expanded. It is easy to see that the Greedy Best First Search algorithms all expand the fewest nodes for the four heuristics tested. Breadth First Search and Uniform Cost Search expand the most nodes. This table makes it easy to see which algorithms and heuristics will expand the fewest and the most nodes as the number of actions in the domain continues to increase.

- 2) Analyze search time as a function of domain size, search algorithm, and heuristic.

Search	20	72	88	104
Breadth First Search	0.003566	1.106208	5.990785	55.22623
Depth First Graph Search	0.001954	1.625992	0.642064	2276.519
Uniform Cost Search	0.005625	1.871376	8.000985	67.02948
Greedy Best First Search with h_unmet_goals	0.000962	0.010953	0.020434	0.034245
Greedy Best First Search with h_pg_levelsum	0.3115	7.040004	15.8088	30.30131
Greedy Best First Search with h_pg_maxlevel	0.228897	14.14175	19.08094	73.67826
Greedy Best First Search with h_pg_setlevel	0.793634	17.62334	85.83039	413.2171
A* Search with h_unmet_goals	0.005005	1.227088	4.636046	31.90939
A* Search with h_pg_levelsum	0.780065	178.374	287.3965	1723.163
A* Search with h_pg_maxlevel	0.787484	1025.968	5142.155	51875.21
A* Search with h_pg_setlevel	2.075342	1346.402	6513.484	62613.47

Figure 2 - Actions vs Elapsed Time

Figure 2 shows the time elapsed for each number of actions for each search algorithm. The cells in green are the shortest elapsed time for each number of actions and the cells in red are the longest elapsed time

for each number of actions. Greedy Best First Search with unmet goals heuristic is consistently the fastest algorithm and heuristic. The unmet goals heuristic estimates the minimum number of actions that must be carried out from the current state to satisfy all goal conditions by ignoring the preconditions for an action to be executed. Ignoring the preconditions allows for quicker runtime. Using this heuristic with Greedy Best First Search and with A* results in the top runtimes for the number of actions defined above.

- 3) Analyze the optimality of solution as a function of domain size, search algorithm, and heuristic.

Search	20	72	88	104
Breadth First Search	6	9	12	14
Depth First Graph Search	20	619	392	24132
Uniform Cost Search	6	9	12	14
Greedy Best First Search with h_unmet_goals	6	9	15	18
Greedy Best First Search with h_pg_levelsum	6	9	14	17
Greedy Best First Search with h_pg_maxlevel	6	9	13	17
Greedy Best First Search with h_pg_setlevel	6	9	17	23
A* Search with h_unmet_goals	6	9	12	14
A* Search with h_pg_levelsum	6	9	12	15
A* Search with h_pg_maxlevel	6	9	12	14
A* Search with h_pg_setlevel	6	9	12	14

Figure 3 - Actions vs Plan Length

Figure 3 shows the plan length for each number of actions for each search algorithm. The cells in green are the shortest plans for each number of actions and the cells in red are the longest plans. Depth First Graph Search consistently produces the longest plans, producing a plan that is more than 24,000 steps longer than the optimal plan for 104 domain actions. This table makes it easy to see that Breadth First Search, Uniform Cost Search, A* Search with unmet goals heuristic, A* Search with max level heuristic, and A* search with set level heuristic consistently produce optimal plans. The Greedy Best First Search algorithm is faster but does not always produce optimal plans.

- 4) Which algorithm or algorithms would be most appropriate for planning in a very restricted domain (i.e., one that has only a few actions) and needs to operate in real time?

Greedy Best First Search with unmet goals heuristic is the most appropriate for real-time scenarios. It consistently had the fastest time elapsed across all 4 problems. For Problem 4, Greedy Best First Search with unmet goals heuristic completed in 0.034 seconds and performed 884 times faster than the second fastest algorithm (which took over 30 seconds).

- 5) Which algorithm or algorithms would be most appropriate for planning in very large domains (e.g., planning delivery routes for all UPS drivers in the U.S. on a given day)?

For large domains, speed is essential. Greedy Best First Search with unmet goals heuristic would be the most appropriate because it could arrive at a solution in the least amount of time. The plan may not be optimal, but it will find a plan for large domains in a reasonable amount of time.

- 6) Which algorithm or algorithms would be most appropriate for planning problems where it is important to find only optimal plans?

A* Search with unmet goals, Breadth First Search, and Uniform Cost Search will find the optimal plan and are also relatively fast. A* search with `pg_maxlevel`, and A* search with `pg_setlevel` also find the optimal plan but are extremely slow in large domains.

Appendix – Full Data Tables

Air Cargo Problem 1

Search	Actions	Expansions	Goal Tests	New Nodes	Plan Length	Time Elapsed
Breadth First Search	20	43	56	178	6	0.003566
Depth First Graph Search	20	21	22	84	20	0.001954
Uniform Cost Search	20	60	62	240	6	0.005625
Greedy Best First Search with h_unmet_goals	20	7	9	29	6	0.000962
Greedy Best First Search with h_pg_levelsum	20	6	8	28	6	0.3115
Greedy Best First Search with h_pg_maxlevel	20	6	8	24	6	0.228897
Greedy Best First Search with h_pg_setlevel	20	6	8	28	6	0.793634
A* Search with h_unmet_goals	20	50	52	206	6	0.005005
A* Search with h_pg_levelsum	20	28	30	122	6	0.780065
A* Search with h_pg_maxlevel	20	43	45	180	6	0.787484
A* Search with h_pg_setlevel	20	33	35	138	6	2.075342

Air Cargo Problem 2

Search	Actions	Expansions	Goal Tests	New Nodes	Plan Length	Time Elapsed
Breadth First Search	72	3343	4609	30503	9	1.106208
Depth First Graph Search	72	624	625	5602	619	1.625992
Uniform Cost Search	72	5154	5156	46618	9	1.871376
Greedy Best First Search with h_unmet_goals	72	17	19	170	9	0.010953
Greedy Best First Search with h_pg_levelsum	72	9	11	86	9	7.040004
Greedy Best First Search with h_pg_maxlevel	72	27	29	249	9	14.14175
Greedy Best First Search with h_pg_setlevel	72	9	11	84	9	17.62334
A* Search with h_unmet_goals	72	2467	2469	22522	9	1.227088
A* Search with h_pg_levelsum	72	357	359	3426	9	178.374
A* Search with h_pg_maxlevel	72	2887	2889	26594	9	1025.968
A* Search with h_pg_setlevel	72	1037	1039	9605	9	1346.402

Air Cargo Problem 3

Search	Actions	Expansions	Goal Tests	New Nodes	Plan Length	Time Elapsed
Breadth First Search	88	14663	18098	129625	12	5.990785
Depth First Graph Search	88	408	409	3364	392	0.642064
Uniform Cost Search	88	18510	18512	161936	12	8.000985
Greedy Best First Search with h_unmet_goals	88	25	27	230	15	0.020434
Greedy Best First Search with h_pg_levelsum	88	14	16	126	14	15.8088
Greedy Best First Search with h_pg_maxlevel	88	21	23	195	13	19.08094
Greedy Best First Search with h_pg_setlevel	88	35	37	345	17	85.83039
A* Search with h_unmet_goals	88	7388	7390	65711	12	4.636046
A* Search with h_pg_levelsum	88	369	371	3403	12	287.3965
A* Search with h_pg_maxlevel	88	9580	9582	86312	12	5142.155
A* Search with h_pg_setlevel	88	3423	3425	31596	12	6513.484

Air Cargo Problem 4

Search	Actions	Expansions	Goal Tests	New Nodes	Plan Length	Time Elapsed
Breadth First Search	104	99736	114953	944130	14	55.22623
Depth First Graph Search	104	25174	25175	228849	24132	2276.519
Uniform Cost Search	104	113339	113341	1066413	14	67.02948
Greedy Best First Search with h_unmet_goals	104	29	31	280	18	0.034245
Greedy Best First Search with h_pg_levelsum	104	17	19	165	17	30.30131
Greedy Best First Search with h_pg_maxlevel	104	56	58	580	17	73.67826
Greedy Best First Search with h_pg_setlevel	104	107	109	1164	23	413.2171
A* Search with h_unmet_goals	104	34330	34332	328509	14	31.90939
A* Search with h_pg_levelsum	104	1208	1210	12210	15	1723.163
A* Search with h_pg_maxlevel	104	62077	62079	599376	14	51875.21
A* Search with h_pg_setlevel	104	22606	22608	224229	14	62613.47