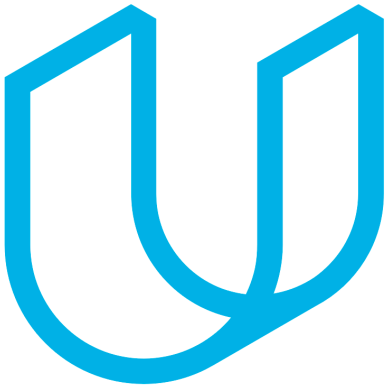
Artificial Intelligence Nanodegree



UDACITY

Build A Forward Planning Agent

Report

Prepared by: Apoorv Malik

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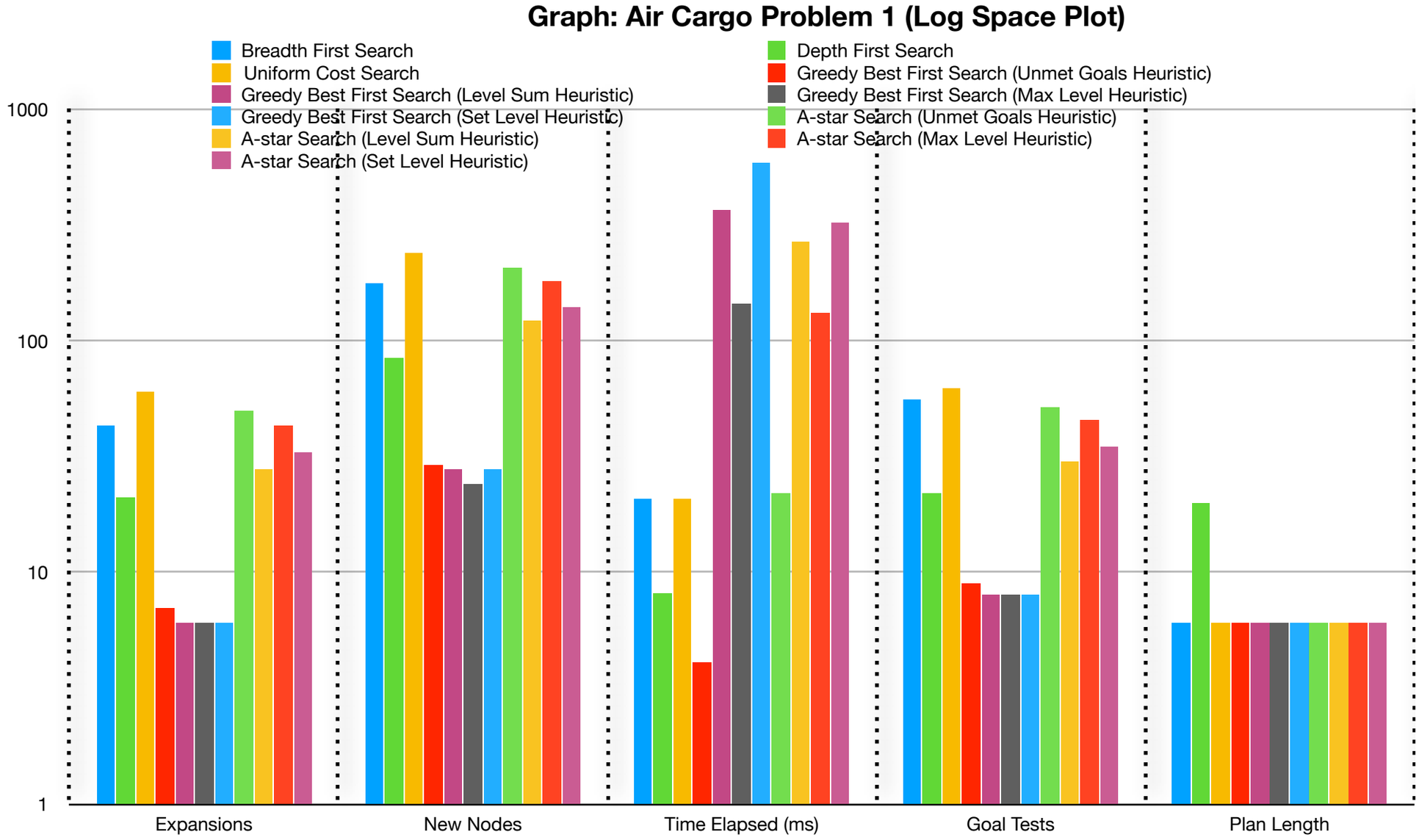
Table: Air Cargo Problem 1

Algorithm	Actions	Expansions	Goal Tests	New Nodes	Plan Length	Time Elapsed (ms)
Breadth First Search	20	43	56	178	6	20.8280109945918
Depth First Search	20	21	22	84	20	8.06107500102371
Uniform Cost Search	20	60	62	240	6	20.601483003702
Greedy Best First Search (Unmet Goals Heuristic)	20	7	9	29	6	4.07382499543019
Greedy Best First Search (Level Sum Heuristic)	20	6	8	28	6	364.27379300585
Greedy Best First Search (Max Level Heuristic)	20	6	8	24	6	143.078630004311
Greedy Best First Search (Set Level Heuristic)	20	6	8	28	6	585.332607995952
A-star Search (Unmet Goals Heuristic)	20	50	52	206	6	21.8071630079066
A-star Search (Level Sum Heuristic)	20	28	30	122	6	266.455688004498
A-star Search (Max Level Heuristic)	20	43	45	180	6	131.36858100188
A-star Search (Set Level Heuristic)	20	33	35	138	6	324.577932988177

Graph: Air Cargo Problem 1 (Log Space Plot)



Air Cargo Problem 1 is the simplest (smallest domain size) of all the four problems.

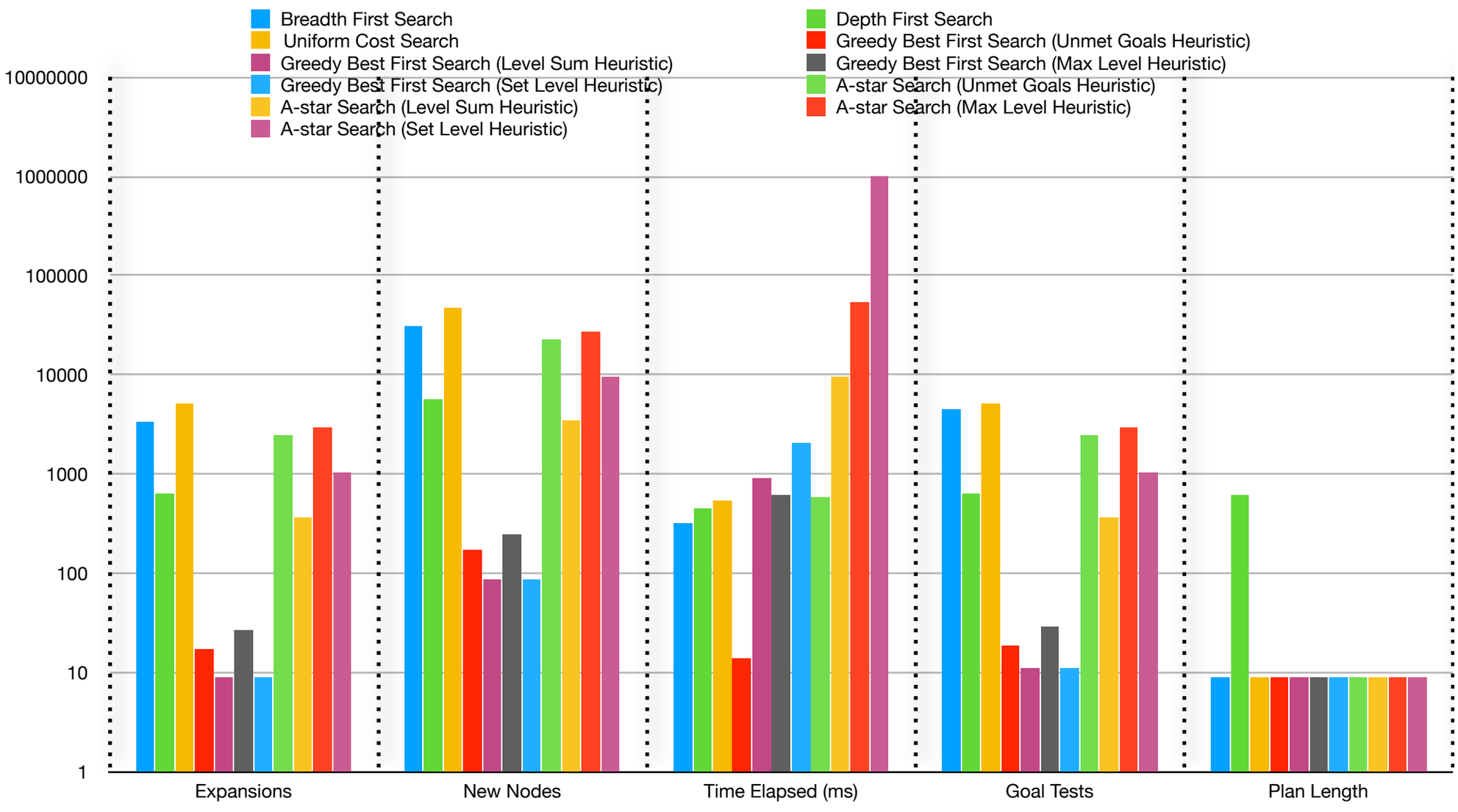
Summary of the results:

- Greedy Best First Algorithm with Unmet goals heuristic is the most efficient (has the lowest completion time), and it is one of the most optimal and effective algorithm (produces smallest plan length).
- Greedy Best First Algorithm with Set Level heuristic performs the worst in terms of completion time.
- From the data, we can infer that the Informed Search algorithms with Set Level heuristic are inefficient (highest completion time). But they are optimal and effective (smaller plan length).
- From the data, we can infer that the Informed Search algorithms with Unmet Goals heuristic are efficient (lowest completion time) and are optimal and effective (smaller plan length).
- Depth First Search is the least effective & optimal algorithm here, it has the largest plan length, therefore a large number of steps to reach the solution or goal.
- Greedy Best First algorithms (all heuristic combinations) have fewer expansions, do fewer goal tests, and have fewer new nodes as compared to Uninformed Search algorithms and A* algorithms (all heuristic combinations). Therefore these are memory-efficient algorithms.

Table: Air Cargo Problem 2

Algorithm	Actions	Expansions	Goal Tests	New Nodes	Plan Length	Time Elapsed (ms)
Breadth First Search	72	3343	4609	30503	9	311.922941007651
Depth First Search	72	624	625	5602	619	448.767492998741
Uniform Cost Search	72	5154	5156	46618	9	528.993615997024
Greedy Best First Search (Unmet Goals Heuristic)	72	17	19	170	9	13.6766619980335
Greedy Best First Search (Level Sum Heuristic)	72	9	11	86	9	903.40858300624
Greedy Best First Search (Max Level Heuristic)	72	27	29	249	9	600.366139988182
Greedy Best First Search (Set Level Heuristic)	72	9	11	84	9	2028.80329999607
A-star Search (Unmet Goals Heuristic)	72	2467	2469	22522	9	582.823040997027
A-star Search (Level Sum Heuristic)	72	357	359	3426	9	9612.89845399733
A-star Search (Max Level Heuristic)	72	2887	2889	26594	9	53587.4400920002
A-star Search (Set Level Heuristic)	72	1037	1039	9605	9	1014777.6320944

Graph: Air Cargo Problem 2 (Log Space Plot)



We see similar results (as in Air Cargo Problem 1) here in Air Cargo Problem 2.

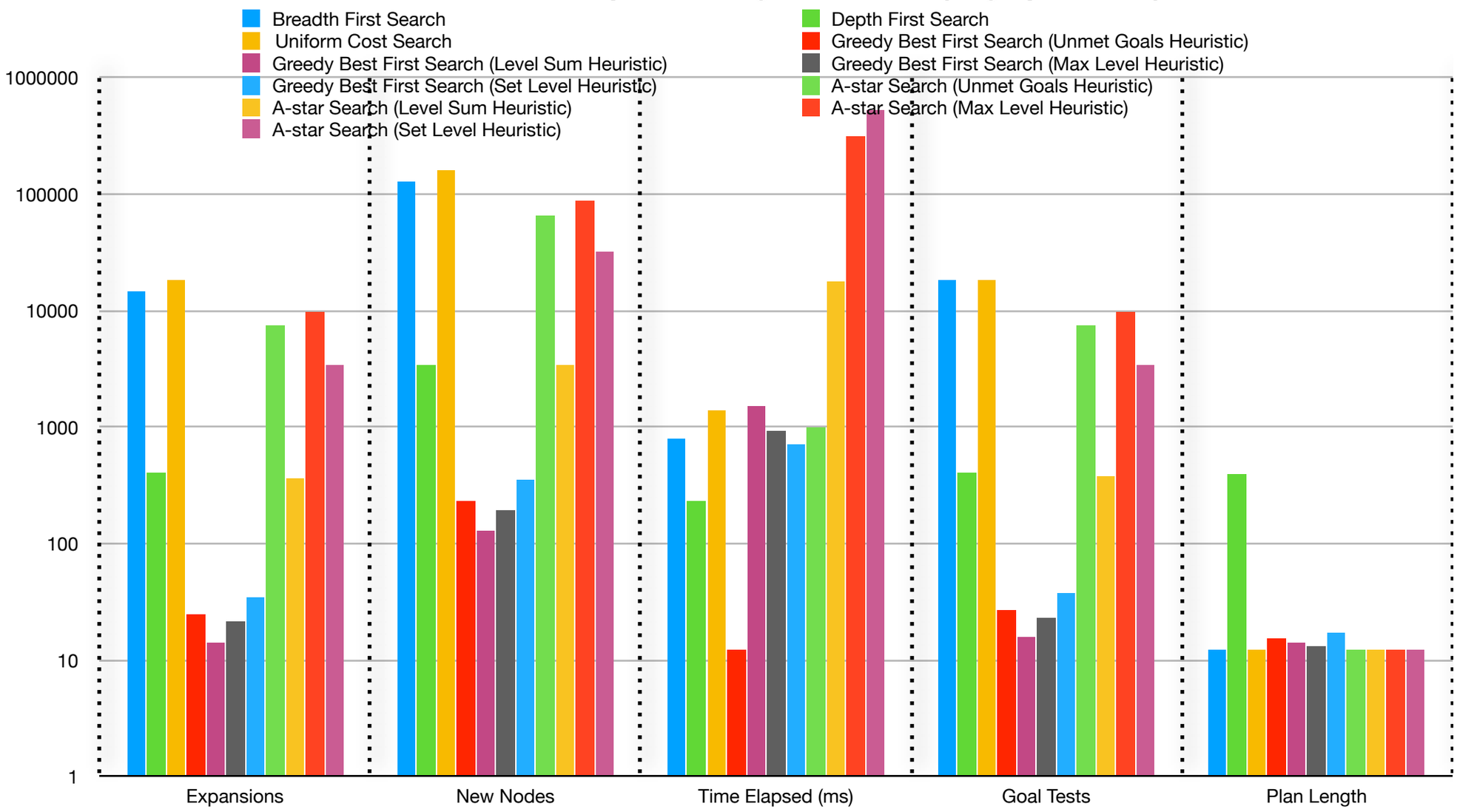
Summary of the results:

- Greedy Best First Algorithm with Unmet goals heuristic is the most efficient (has the lowest completion time), and it is one of the most optimal and effective algorithm (produces smallest plan length).
- A* Search algorithm with Set Level heuristic performs the worst in terms of completion time.
- From the data, we can infer that the Informed Search algorithms with Set Level heuristic are inefficient (highest completion time). But they are optimal and effective (smaller plan length).
- From the data, we can infer that the Informed Search algorithms with Unmet Goals heuristic are efficient (lowest completion time) and are optimal and effective (smaller plan length).
- Depth First Search is the least effective & optimal algorithm here, it has the largest plan length, therefore a large number of steps to reach the solution or goal.
- Greedy Best First algorithms (all heuristic combinations) have fewer expansions, do fewer goal tests, and have fewer new nodes as compared to Uninformed Search algorithms and A* algorithms (all heuristic combinations). Therefore these are memory-efficient algorithms.

Table: Air Cargo Problem 3

Algorithm	Actions	Expansions	Goal Tests	New Nodes	Plan Length	Time Elapsed (ms)
Breadth First Search	88	14663	18098	129625	12	806.847704996471
Depth First Search	88	408	409	3364	392	228.635648003547
Uniform Cost Search	88	18510	18512	161936	12	1369.36441098806
Greedy Best First Search (Unmet Goals Heuristic)	88	25	27	230	15	11.9352779875044
Greedy Best First Search (Level Sum Heuristic)	88	14	16	126	14	1494.36301700189
Greedy Best First Search (Max Level Heuristic)	88	21	23	195	13	931.372235994786
Greedy Best First Search (Set Level Heuristic)	88	35	37	345	17	717.60834900488
A-star Search (Unmet Goals Heuristic)	88	7388	7390	65711	12	1003.47361199965
A-star Search (Level Sum Heuristic)	88	369	371	3403	12	17587.8604809986
A-star Search (Max Level Heuristic)	88	9580	9582	86312	12	316208.757440996
A-star Search (Set Level Heuristic)	88	3423	3425	31596	12	532234.690079

Graph: Air Cargo Problem 3 (Log Space Plot)



Air Cargo Problem 3 comes with larger domain size, some new results come in light (contrasting few of the previous ones) as the domain size increases.

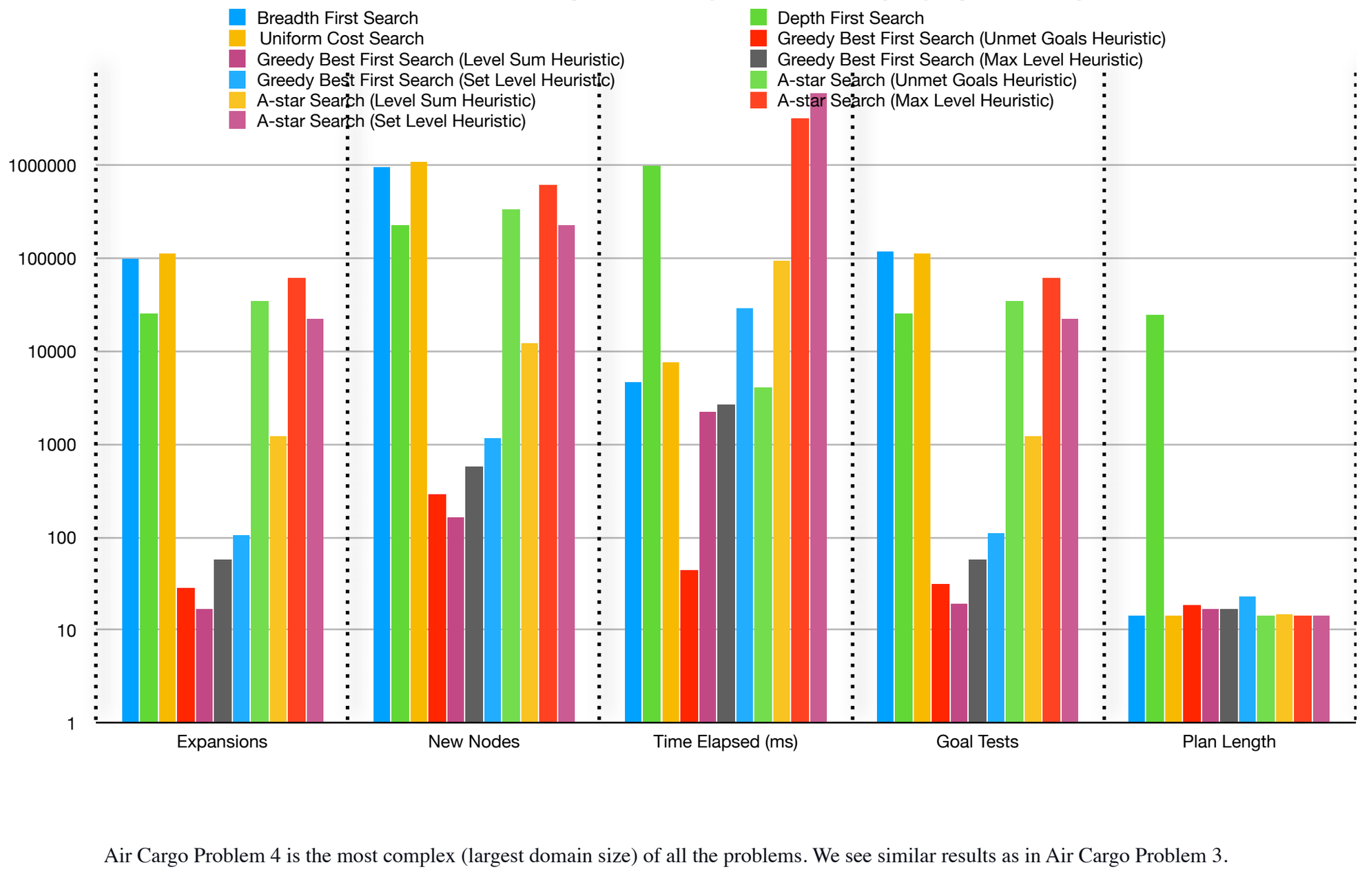
Summary of the results:

- Greedy Best First Algorithms with Unmet goals heuristic is the most efficient (lowest completion time). But it is not the most effective and optimal one, there are other algorithms with more effective and optimal plans (smaller plan length; a lesser number of steps to reach the solution/goal).
- A* Search algorithms (all heuristic combinations except Unmet Goals Heuristic) performs the worst in terms of completion time. A-star Search algorithm with Set Level Heuristic is the least efficient (highest completion time) one. But it is one of the algorithms that yield the most effective and optimal plans (smaller plan length).
- Depth First Search is the least effective & optimal algorithm here, it has the largest plan length, therefore a large number of steps to reach the solution or goal.
- Greedy Best First algorithms (all heuristic combinations) have fewer expansions, do fewer goal tests, and have fewer new nodes as compared to Uninformed Search algorithms and A* algorithms (all heuristic combinations). Therefore these are memory-efficient algorithms.

Table: Air Cargo Problem 4

Algorithm	Actions	Expansions	Goal Tests	New Nodes	Plan Length	Time Elapsed (ms)
Breadth First Search	104	99736	114953	944130	14	4732.26119400351
Depth First Search	104	25174	25175	228849	24132	975184.910922995
Uniform Cost Search	104	113339	113341	1066413	14	7402.5641370099
Greedy Best First Search (Unmet Goals Heuristic)	104	29	31	280	18	43.1991810037289
Greedy Best First Search (Level Sum Heuristic)	104	17	19	165	17	2173.96889999509
Greedy Best First Search (Max Level Heuristic)	104	56	58	580	17	2608.5232530022
Greedy Best First Search (Set Level Heuristic)	104	107	109	1164	23	29269.7781919997
A-star Search (Unmet Goals Heuristic)	104	34330	34332	328509	14	4090.60831199167
A-star Search (Level Sum Heuristic)	104	1208	1210	12210	15	93413.2841680112
A-star Search (Max Level Heuristic)	104	62077	62079	599376	14	3220582.893058
A-star Search (Set Level Heuristic)	104	22606	22608	224229	14	5852113.215609

Graph: Air Cargo Problem 4 (Log Space Plot)



Air Cargo Problem 4 is the most complex (largest domain size) of all the problems. We see similar results as in Air Cargo Problem 3.

Summary of the results:

- Greedy Best First Algorithms with Unmet goals heuristic is the most efficient (lowest completion time). But it is not the most effective and optimal one, there are other algorithms with more effective and optimal plans (smaller plan length; a lesser number of steps to reach the solution/goal).
- A* Search algorithms (all heuristic combinations except Unmet Goals Heuristic) performs the worst in terms of completion time. A-star Search algorithm with Set Level Heuristic is the least efficient (highest completion time) one. But it is one of the algorithms that yield the most effective and optimal plans (smaller plan length).
- Depth First Search is the least effective & optimal algorithm here, it has the largest plan length, therefore a large number of steps to reach the solution or goal.
- Greedy Best First algorithms (all heuristic combinations) have fewer expansions, do fewer goal tests, and have fewer new nodes as compared to Uninformed Search algorithms and A* algorithms (all heuristic combinations). Therefore these are memory-efficient algorithms.

Summary:

To summarise all the results, it can be seen that:

- Greedy Best First Search algorithms are the most memory-efficient algorithms, these have fewer expansions, do fewer goal tests, and has fewer new nodes as compared to Uninformed Search algorithms and A* algorithms (all heuristic combinations).Â
- For problems with small domains, Informed Search algorithms with Unmet Goals heuristic are very fast and effective (produces plans with small lengths). But as the domain size increases, Greedy Best First Search with Unmet Goals Heuristic fails to produce the most effective plans (small lengths plans). Also, as the domain size increase, A* Search with Unmet Goals heuristic produces very effective and efficient results (but it is not optimal if limited memory is a constraint).Â
- Depth First Search is the least effective & least optimal algorithm; it produces plans that are very large and has a large completion time.
- Both Breadth First Search and Uniform Cost Search produces effective results, but they are not efficient in terms of memory and completion time for problems with large domains.

Q&A:

Q1. 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?

Ans: The most efficient (low completion time) and the most effective (small plan lengths), therefore the most appropriate algorithm for planning in a very restricted domain which needs to operate in real-time, would be **Greedy Best First Search with Unmet Goals Heuristic**. It is very quick and produces plans with small lengths. Other algorithms that can produce quick and effective plans are **Breadth First Search, Uniform Cost Search** and **A* Search with Unmet Goals heuristic**.

Q2. 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)

Ans: The most efficient (low completion time) and the most effective (small plan lengths), therefore the most appropriate algorithm for planning in very large domains would be **A* Search with Unmet Goals heuristic**. If limited memory is also a constraint, then **A* Search with Level Sum** heuristic can be used.

Q3. Which algorithm or algorithms would be most appropriate for planning problems where it is important to find only optimal plans.

Ans: To find only optimal plans, the following algorithms can be used:

- Breadth First Search.
- Uniform Cost Search.
- A* Search with Unmet Goals heuristic.
- A* Search with Max Level heuristic
- A* Search with Set Level heuristic.

(Note: All the code execution is done with pypy3 interpreter for python, and all the charts are in Log-space.