Heuristic Analysis

Optimal Plans

I worked out following planning solutions

Problem #	Plan
1	Load(C1, P1, SFO) Fly(P1, SFO, JFK) Load(C2, P2, JFK) Fly(P2, JFK, SFO) Unload(C1, P1, JFK) Unload(C2, P2, SFO)
2	Load(C1, P1, SFO) Fly(P1, SFO, JFK) Load(C2, P2, JFK) Fly(P2, JFK, SFO) Load(C3, P3, ATL) Fly(P3, ATL, SFO) Unload(C3, P3, SFO) Unload(C2, P2, SFO) Unload(C1, P1, JFK)
3	Load(C2, P2, JFK) Fly(P2, JFK, ORD) Load(C4, P2, ORD) Fly(P2, ORD, SFO) Load(C1, P1, SFO) Fly(P1, SFO, ATL) Load(C3, P1, ATL) Fly(P1, ATL, JFK) Unload(C4, P2, SFO) Unload(C3, P1, JFK) Unload(C2, P2, SFO) Unload(C1, P1, JFK)

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Analysis

The performance of the following searches/heuristics were analysed:

Name	Search	Heuristic
breadth_first	Breadth First	None
depth_first_graph	Depth First Graph	None
uniform_cost_search	Uniform Cost Search	None
h_ignore_preconditions	A*-Search	Ignore-Preconditions
h_pg_levelsum	A*-Search	Levelsum

Following tables compare the performance of these searches once by calculating the "optimality" using "Nr Node Expansions" and once by calculating the optimality using "Time Elapsed".

The optimality is calculated by comparing each individual search with the hypothetical "best search". The best search combines the best result of each individual search into once hypothetical best search.

The Optimality is defined by

$$\frac{1}{N \cdot P^2}$$

whereas N is "Nr node expansion" or "Time Elapsed", and P is "Plan Length". P is to the power of 2 to give a small plan length a higher weight.

Search / Problem	Problem 1				Problem 2				Problem 3			
	Nr node expansions	Plan Length	Optimality [Relative]	**Optimality [%]**	Nr node expansions	Plan Length	Optimality [Relative]	**Optimality [%]**	Nr node expansions	Plan Length	Optimality [Relative]	**Optimality [%]**
breadth_first	43	6	0.0006	**25.6%**	3343	9	0.0000	**2.6%**	14663	12	0.0000	**2.2%**
depth_first_graph	21	20	0.0001	**4.7%**	624	619	0.0000	**0.0%**	408	392	0.0000	**0.1%**
uniform_cost_search	55	6	0.0005	**20.0%**	4853	9	0.0000	**1.8%**	18223	12	0.0000	**1.7%**
h_ignore_preconditions	41	6	0.0007	**26.8%**	1450	9	0.0000	**5.9%**	5040	12	0.0000	**6.3%**
h_pg_levelsum	11	6	0.0025	**100.0%**	86	9	0.0001	**100.0%**	316	12	0.0000	**100.0%**
Best Result	11	6	0.0025	100.0%	86	9	0.0001	100.0%	316	12	0.0000	100.0%

Figure 1: Optimality based on "nr nodes expansion" (ideal for memory constraint environments)

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Search / Problem	Problem 1				Problem 2				Problem 3			
	Time elapsed [s]	Plan Length	Optimality [Relative]	**Optimality [%]**	Time elapsed [s]	Plan Length	Optimality [Relative]	**Optimality [%]**	Time elapsed [s]	Plan Length	Optimality [Relative]	**Optimality [%]**
breadth_first	0.014	6	1.9273	**49.5%**	5.067	9	0.0024	**37.8%**	25.887	12	0.0003	**4.0%**
depth_first_graph	0.007	20	0.3503	**9.0%**	1.915	619	0.0000	**0.0%**	1.041	392	0.0000	**0.1%**
uniform_cost_search	0.017	6	1.6155	**41.5%**	7.139	9	0.0017	**26.8%**	32.591	12	0.0002	**3.2%**
h_ignore_preconditions	0.016	6	1.7082	**43.9%**	3.007	9	0.0041	**63.7%**	13.789	12	0.0005	**7.5%**
h_pg_levelsum	0.506	6	0.0549	**1.4%**	45.939	9	0.0003	**4.2%**	234.348	12	0.0000	**0.4%**
Best Result	0.007	6.000	3.892	100.0%	1.915	9	0.0064	100.0%	1.041	12	0.0067	100.0%

Figure 2: Optimality based on "time elapsed" (ideal for CPU constraint environments)

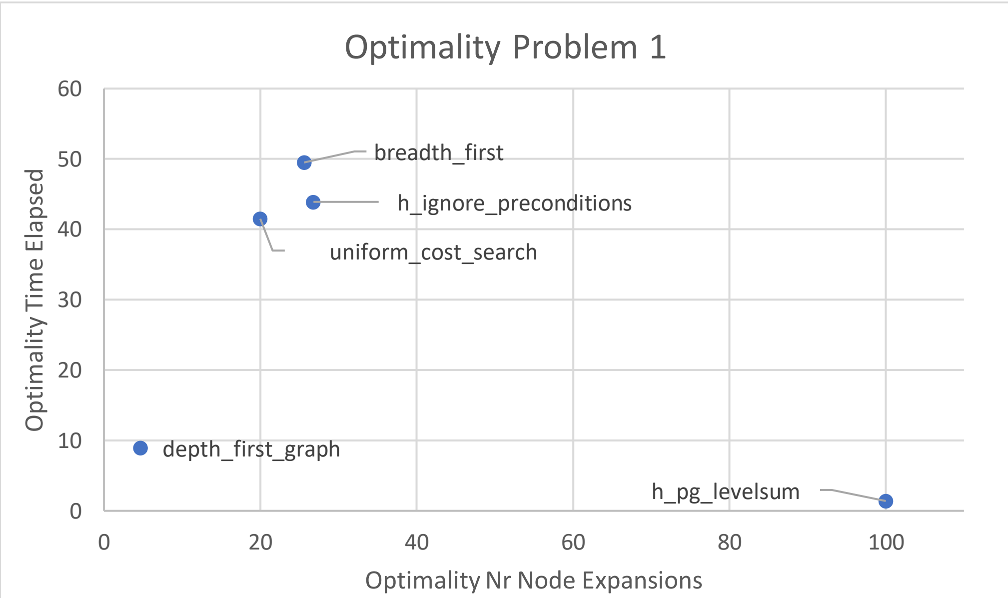

Figure 3: Scatterplot "time elapsed" vs. "nr nodes expanded" for Problem 1

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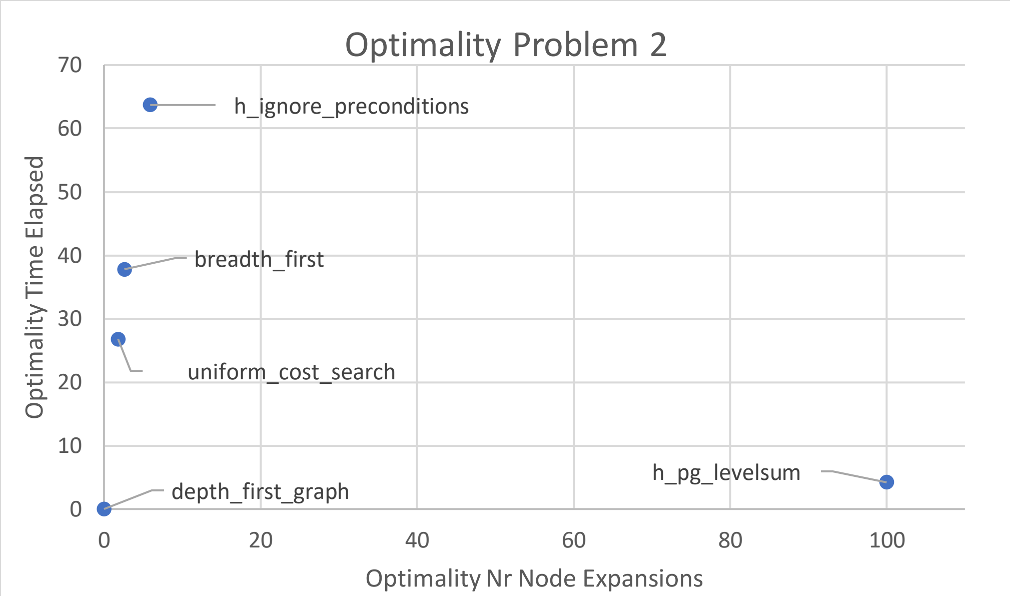

Figure 4: Scatterplot "time elapsed" vs. "nr nodes expanded" for Problem 2

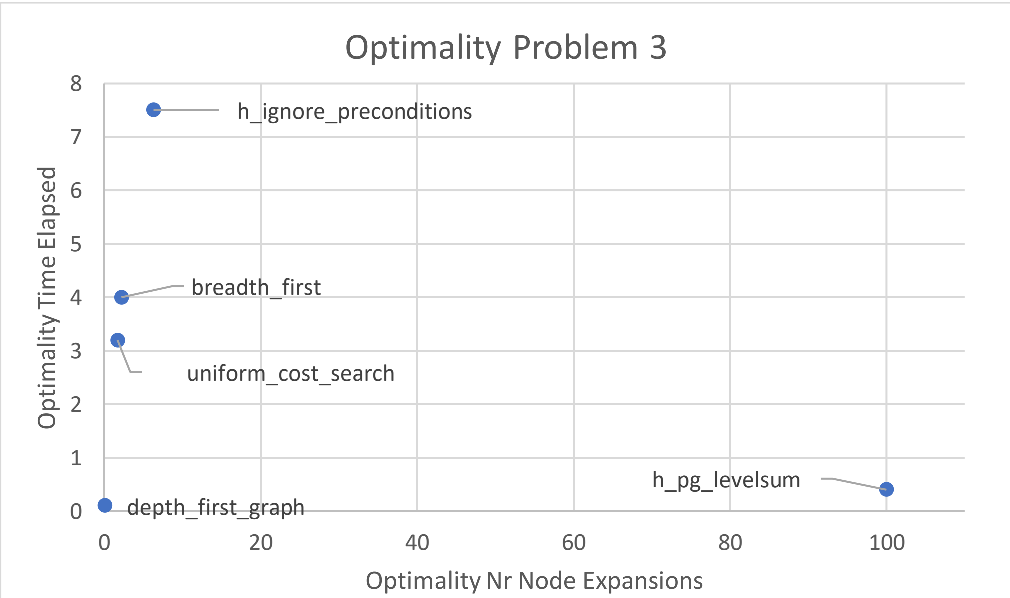

Figure 5: Scatterplot "time elapsed" vs. "nr nodes expanded" for Problem 3

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Discussion

The analysis showed that depending on whether we care about “nr node expansions” or “time elapsed” different searches are optimal. A*-Search with Plangraph Levelsum heuristics is optimal if we want to minimize the number of expanded nodes. A*-Search with Ignore Preconditions heuristics is optimal if we instead optimize time elapsed. Note: Though time elapsed is the wall time I expect the CPU time not to be hugely different. Measuring CPU-cycles instead wall time would further clarify that claim.

I conclude:

1. Depth-First-Graph Search without heuristic doesn’t work at all.
2. Non-heuristic search is fast and yields good results for very easy problems. See Figure 3 where Breadth First and Uniform Cost Search are close to Ignore-Preconditions.
3. To make it more efficient a good heuristic is needed (Russel & Norvig, 2016, p. 376). See Figure 4 and Figure 5 where a heuristic search is better independent of whether time elapsed or nr nodes expanded is important.
4. A*-search with the Plangraph Levelsum heuristic is as expected giving good results even it’s inadmissible. A Plangraph increases the accuracy of the estimates (Russel & Norvig, 2016, p. 379) which can be seen in the minimal number of nodes expanded.
5. A*-search with the Ignore Preconditions heuristic is quicker but less accurate as the Plangraph Levelsum heuristic. More nodes are therefore expanded but overall less CPU cycles are needed. This might be because no Plangraph needs to be constructed.

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