Heuristic analysis

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The target of heuristic analysis is to find the best algorithms for each problem, with the smallest path and lowest time. There are exhibits in the end show the performance of different algorithm on different problems.

We can easily find the **Breath First Search** worked best on Problem 1 and Problem 2, and **A* search h ignore preconditions** worked best on Problem 3, here is the summary from the exhibits:

P	Best Search Type	Expansions	Goal Tests	New Nodes	Length	Time	Optimal Sequence of Actions
1	Breadth first search	43	56	180	6	0.0304	**Load(C1, P1, SFO)** **Load(C2, P2, JFK)** **Fly(P2, JFK, SFO)** **Unload(C2, P2, SFO)** **Fly(P1, SFO, JFK)** **Unload(C1, P1, JFK)**
2	Breadth first search	3343	4609	30509	9	12.8157	**Load(C1, P1, SFO)** **Load(C2, P2, JFK)** **Load(C3, P3, ATL)** **Fly(P2, JFK, SFO)** **Unload(C2, P2, SFO)** **Fly(P1, SFO, JFK)** **Unload(C1, P1, JFK)** **Fly(P3, ATL, SFO)** **Unload(C3, P3, SFO)**
3	A* search h ignore preconditions	5040	5042	44944	12	33.9542	**Load(C2, P2, JFK)** **Fly(P2, JFK, ORD)** **Load(C4, P2, ORD)** **Fly(P2, ORD, SFO)** **Unload(C4, P2, SFO)** **Load(C1, P1, SFO)** **Fly(P1, SFO, ATL)** **Load(C3, P1, ATL)** **Fly(P1, ATL, JFK)** **Unload(C3, P1, JFK)** **Unload(C2, P2, SFO)** **Unload(C1, P1, JFK)**

We can easily find the "**Optimal sequence of actions**" for each problem in **rightmost** column of the above table.

There are two categories of Search Strategy: One is Strategy with no heuristic, such as breadth first search, uniform cost search, and depth first search; Another is Strategy with heuristic, such as A* Search with h-ignore-preconditions or h-pg-levelsum. Non-heuristic strategy works well in simple problem, and heuristic strategy works well in complex problem.

Breath First Search[1]:

It always tried to find shortest path first, thus provides optimal plan. However, as problem got complex, the time for search would also increase.

Depth First Search:

It always tried to minimize the search time, but not consider the shortest path.

Uniform Cost Search and A* Search with h1:

The goal is to find the cheap path, even when they find the goal. Both guarantee the optimal paths, but consume more time then Breath First Search.

A* search with h-ignore-preconditions or h-pg-level-sum:

These are search strategy with heuristics. The heuristic of h-ignore-preconditions estimate the min number of actions need from current state to satisfy all the goal conditions, ignore the preconditions need for action executed. The heuristic of h-pg-level-sum sum the level costs of individual goal. Heuristic Search strategy works worse in simple problem such as 1 and 2, but works better in complex situation such as 3. However, the h-ignore-preconditions works better then h-pg-level-sum, since the latter is far more complex in heuristic and take too much time for calculations.

Exhibits1-Problem1

Solving Air Cargo Problem 1 using breadth_first_search...

Expansions	Goal Tests	New Nodes
43	56	180

Plan length: 6 Time elapsed in seconds: 0.030409315779454785

Load(C1, P1, SFO)
Load(C2, P2, JFK)
Fly(P2, JFK, SFO)
Unload(C2, P2, SFO)
Fly(P1, SFO, JFK)
Unload(C1, P1, JFK)

Solving Air Cargo Problem 1 using breadth_first_tree_search...

Expansions	Goal Tests	New Nodes
1458	1459	5960

Plan length: 6 Time elapsed in seconds: 0.9285095905237646

Load(C1, P1, SFO)
Load(C2, P2, JFK)
Fly(P2, JFK, SFO)
Unload(C2, P2, SFO)
Fly(P1, SFO, JFK)
Unload(C1, P1, JFK)

Solving Air Cargo Problem 1 using depth_first_graph_search...

Expansions	Goal Tests	New Nodes
21	22	84

Plan length: 20 Time elapsed in seconds: 0.019362654466181357

Fly(P1, SFO, JFK)
Fly(P2, JFK, SFO)
Load(C2, P1, JFK)
Fly(P1, JFK, SFO)
Fly(P2, SFO, JFK)
Unload(C2, P1, SFO)
Fly(P1, SFO, JFK)
Fly(P2, JFK, SFO)
Load(C2, P2, SFO)
Fly(P1, JFK, SFO)
Load(C1, P2, SFO)
Fly(P2, SFO, JFK)
Fly(P1, SFO, JFK)
Unload(C2, P2, JFK)
Unload(C1, P2, JFK)
Fly(P2, JFK, SFO)
Load(C2, P1, JFK)
Fly(P1, JFK, SFO)
Fly(P2, SFO, JFK)
Unload(C2, P1, SFO)

Solving Air Cargo Problem 1 using depth_limited_search...

Expansions	Goal Tests	New Nodes
101	271	414

Plan length: 50 Time elapsed in seconds: 0.08012366775995503

Load(C1, P1, SFO)
Load(C2, P2, JFK)
Unload(C1, P1, SFO)
Load(C1, P1, SFO)
Unload(C1, P1, SFO)
Load(C1, P1, SFO)
Unload(C1, P1, SFO)
Load(C1, P1, SFO)
Unload(C1, P1, SFO)
Load(C1, P1, SFO)

Solving Air Cargo Problem 1 using uniform_cost_search...

Expansions	Goal Tests	New Nodes
55	57	224

Plan length: 6 Time elapsed in seconds: 0.03162768681628453

Load(C1, P1, SFO)
Load(C2, P2, JFK)
Fly(P1, SFO, JFK)
Fly(P2, JFK, SFO)
Unload(C1, P1, JFK)
Unload(C2, P2, SFO)

Solving Air Cargo Problem 1 using recursive_best_first_search with

Expansions	Goal Tests	New Nodes
4229	4230	17023

Plan length: 6 Time elapsed in seconds: 2.2778786705205265

Load(C2, P2, JFK)
Load(C1, P1, SFO)
Fly(P2, JFK, SFO)
Unload(C2, P2, SFO)
Fly(P1, SFO, JFK)
Unload(C1, P1, JFK)

Solving Air Cargo Problem 1 using greedy_best_first_graph_search

Expansions	Goal Tests	New Nodes
7	9	28

Plan length: 6 Time elapsed in seconds: 0.009111344015322083

Load(C1, P1, SFO)
Load(C2, P2, JFK)
Fly(P1, SFO, JFK)
Fly(P2, JFK, SFO)
Unload(C1, P1, JFK)
Unload(C2, P2, SFO)

Solving Air Cargo Problem 1 using astar_search with h_1...

Expansions	Goal Tests	New Nodes
55	57	224

Plan length: 6 Time elapsed in seconds: 0.04910133740016177

Load(C1, P1, SFO)
Load(C2, P2, JFK)
Fly(P1, SFO, JFK)
Fly(P2, JFK, SFO)
Unload(C1, P1, JFK)
Unload(C2, P2, SFO)

Solving Air Cargo Problem 1 using astar_search with h_ignore_pre

Expansions	Goal Tests	New Nodes
41	43	170

Plan length: 6 Time elapsed in seconds: 0.04503779101782301

Load(C1, P1, SFO)
Fly(P1, SFO, JFK)
Unload(C1, P1, JFK)
Load(C2, P2, JFK)
Fly(P2, JFK, SFO)
Unload(C2, P2, SFO)

Solving Air Cargo Problem 1 using astar_search with h_pg_levelsur

Expansions	Goal Tests	New Nodes
11	13	50

Plan length: 6 Time elapsed in seconds: 1.2422807934983258

Load(C1, P1, SFO)
Fly(P1, SFO, JFK)
Load(C2, P2, JFK)
Fly(P2, JFK, SFO)
Unload(C1, P1, JFK)
Unload(C2, P2, SFO)

Exhibits2-Problem2

Solving Air Cargo Problem 2 using breadth_first_search...			Solving Air Cargo Problem 2 using uniform_cost_search...		
Expansions	Goal Tests	New Nodes	Expansions	Goal Tests	New Nodes
3343	4609	30509	4853	4855	44041
Plan length: 9 Time elapsed in seconds: 12.815755751068673			Plan length: 9 Time elapsed in seconds: 27.320608813552397		
Load(C1, P1, SFO)			Load(C1, P1, SFO)		
Load(C2, P2, JFK)			Load(C2, P2, JFK)		
Load(C3, P3, ATL)			Load(C3, P3, ATL)		
Fly(P2, JFK, SFO)			Fly(P1, SFO, JFK)		
Unload(C2, P2, SFO)			Fly(P2, JFK, SFO)		
Fly(P1, SFO, JFK)			Fly(P3, ATL, SFO)		
Unload(C1, P1, JFK)			Unload(C3, P3, SFO)		
Fly(P3, ATL, SFO)			Unload(C2, P2, SFO)		
Unload(C3, P3, SFO)			Unload(C1, P1, JFK)		
Solving Air Cargo Problem 2 using greedy_best_first_graph_search			Solving Air Cargo Problem 2 using astar_search with h_pg_levelsur		
Expansions	Goal Tests	New Nodes	Expansions	Goal Tests	New Nodes
998	1000	8982	86	88	841
Plan length: 15 Time elapsed in seconds: 4.955958129754874			Plan length: 9 Time elapsed in seconds: 305.42684303690555		
Load(C1, P1, SFO)			Load(C1, P1, SFO)		
Load(C2, P2, JFK)			Fly(P1, SFO, JFK)		
Load(C3, P3, ATL)			Load(C2, P2, JFK)		
Fly(P1, SFO, ATL)			Fly(P2, JFK, SFO)		
Fly(P2, JFK, ATL)			Load(C3, P3, ATL)		
Fly(P3, ATL, SFO)			Fly(P3, ATL, SFO)		
Fly(P2, ATL, SFO)			Unload(C3, P3, SFO)		
Unload(C2, P2, SFO)			Unload(C2, P2, SFO)		
Load(C2, P3, SFO)			Unload(C1, P1, JFK)		
Fly(P2, SFO, ATL)					
Fly(P1, ATL, JFK)					
Unload(C1, P1, JFK)					
Fly(P1, JFK, ATL)					
Unload(C3, P3, SFO)					
Unload(C2, P3, SFO)					
Solving Air Cargo Problem 2 using astar_search with h_1...			Solving Air Cargo Problem 2 using astar_search with h_ignore_pre		
Expansions	Goal Tests	New Nodes	Expansions	Goal Tests	New Nodes
4853	4855	44041	1450	1452	13303
Plan length: 9 Time elapsed in seconds: 28.958147988502603			Plan length: 9 Time elapsed in seconds: 11.937256991320064		
Load(C1, P1, SFO)			Load(C3, P3, ATL)		
Load(C2, P2, JFK)			Fly(P3, ATL, SFO)		
Load(C3, P3, ATL)			Unload(C3, P3, SFO)		
Fly(P1, SFO, JFK)			Load(C2, P2, JFK)		
Fly(P2, JFK, SFO)			Fly(P2, JFK, SFO)		
Fly(P3, ATL, SFO)			Unload(C2, P2, SFO)		
Unload(C3, P3, SFO)			Load(C1, P1, SFO)		
Unload(C2, P2, SFO)			Fly(P1, SFO, JFK)		
Unload(C1, P1, JFK)			Unload(C1, P1, JFK)		
Solving Air Cargo Problem 2 using depth_limited_search...			Solving Air Cargo Problem 2 using depth_first_graph_search...		
Expansions	Goal Tests	New Nodes	Expansions	Goal Tests	New Nodes
222719	2053741	2054119	624	625	5602
Plan length: 50 Time elapsed in seconds: 1933.8933325456405			Plan length: 619 Time elapsed in seconds: 5.7627024570908025		
Load(C1, P1, SFO)			Fly(P3, ATL, SFO)		
Load(C2, P2, JFK)			Fly(P1, SFO, ATL)		

Exhibits3-Problem3

Solving Air Cargo Problem 3 using breadth_first_search...	Solving Air Cargo Problem 3 using astar_search with h_1...
Expansions Goal Tests New Nodes	Expansions Goal Tests New Nodes
14663 18098 129631	18223 18225 159618
Plan length: 12 Time elapsed in seconds: 99.50863107024833	Plan length: 12 Time elapsed in seconds: 86.2406229920217
Load(C1, P1, SFO)	Load(C1, P1, SFO)
Load(C2, P2, JFK)	Load(C2, P2, JFK)
Fly(P2, JFK, ORD)	Fly(P1, SFO, ATL)
Load(C4, P2, ORD)	Load(C3, P1, ATL)
Fly(P1, SFO, ATL)	Fly(P2, JFK, ORD)
Load(C3, P1, ATL)	Load(C4, P2, ORD)
Fly(P1, ATL, JFK)	Fly(P2, ORD, SFO)
Unload(C1, P1, JFK)	Fly(P1, ATL, JFK)
Unload(C3, P1, JFK)	Unload(C4, P2, SFO)
Fly(P2, ORD, SFO)	Unload(C3, P1, JFK)
Unload(C2, P2, SFO)	Unload(C2, P2, SFO)
Unload(C4, P2, SFO)	Unload(C1, P1, JFK)

Solving Air Cargo Problem 3 using uniform_cost_search...	Solving Air Cargo Problem 3 using astar_search with h_ignore_pre
Expansions Goal Tests New Nodes	Expansions Goal Tests New Nodes
18223 18225 159618	5040 5042 44944
Plan length: 12 Time elapsed in seconds: 63.67955273639352	Plan length: 12 Time elapsed in seconds: 33.95428683539337
Load(C1, P1, SFO)	Load(C2, P2, JFK)
Load(C2, P2, JFK)	Fly(P2, JFK, ORD)
Fly(P1, SFO, ATL)	Load(C4, P2, ORD)
Load(C3, P1, ATL)	Fly(P2, ORD, SFO)
Fly(P2, JFK, ORD)	Unload(C4, P2, SFO)
Load(C4, P2, ORD)	Load(C1, P1, SFO)
Fly(P2, ORD, SFO)	Fly(P1, SFO, ATL)
Fly(P1, ATL, JFK)	Load(C3, P1, ATL)
Unload(C4, P2, SFO)	Fly(P1, ATL, JFK)
Unload(C3, P1, JFK)	Unload(C3, P1, JFK)
Unload(C2, P2, SFO)	Unload(C2, P2, SFO)
Unload(C1, P1, JFK)	Unload(C1, P1, JFK)

Solving Air Cargo Problem 3 using greedy_best_first_graph_search	Solving Air Cargo Problem 3 using depth_first_graph_search...
Expansions Goal Tests New Nodes	Expansions Goal Tests New Nodes
5578 5580 49150	408 409 3364
Plan length: 22 Time elapsed in seconds: 26.146428433373956	Plan length: 392 Time elapsed in seconds: 4.230691499409595
Load(C1, P1, SFO)	Fly(P1, SFO, ORD)
Load(C2, P2, JFK)	Fly(P2, JFK, ORD)
Fly(P1, SFO, ORD)	Fly(P1, ORD, ATL)
Load(C4, P1, ORD)	Fly(P2, ORD, ATL)
Fly(P2, JFK, ATL)	Fly(P1, ATL, JFK)
Load(C3, P2, ATL)	Fly(P2, ATL, SFO)
Fly(P2, ATL, ORD)	Load(C2, P1, JFK)
Fly(P1, ORD, ATL)	Fly(P2, SFO, ORD)
Unload(C4, P1, ATL)	Fly(P1, JFK, ORD)
Fly(P1, ATL, ORD)	Fly(P2, ORD, ATL)
Fly(P2, ORD, ATL)	Fly(P1, ORD, ATL)
Load(C4, P2, ATL)	Fly(P2, ATL, JFK)
Fly(P2, ATL, ORD)	Fly(P1, ATL, SFO)
Unload(C3, P2, ORD)	Unload(C2, P1, SFO)
Load(C3, P1, ORD)	Fly(P1, SFO, ORD)
Fly(P1, ORD, JFK)	Fly(P2, JFK, ORD)

Reference

[1] Stuart J. Russell, Peter Norvig (2010), Artificial Intelligence: A Modern Approach (3rd Edition).