

Heuristic Analysis

1. Analysis

1.1 the optimal plan for problem1,2,3

Problem 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)

Problem 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)

Problem 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)

1.2 non-heuristic planning

For the Compare and contrast non-heuristic search result metrics (optimality, time elapsed, number of node expansions) for Problems 1,2, and 3, let us compare the expansions first.

As we can see the result 1.1, 1.2, 1.3, 2.1, 2.2, 2.3, 3.1, 3.2, 3.3 which represent problem1, 2 and 3 using BFS, DFS and UCS respectively in appendix, it is surprising that the DFS get the least expansions in all the problems. But I think there is some reasons for this phenomenon: 1. it means that the DFS meets the solution in his searching luckily in it's search path. As implied in

the README, there will be probability that It can not find a solution in 10 minutes. 2. for the DFS, it will not expands that much expansions in one search in ome search. In addition, UCS has little more search expansions more than BFS. It indicates that UCS in not better in these problems.

Expansions	BFS	DFS	UCS
Problem 1	43	21	55
Problem 2	3343	624	4852
Problem 3	14663	408	18223

Figure 1 Expansions in non-heuristic

For the time elapsing, it is the same as the expansions. DFS takes the least time as it has the least search expansions. UCS is no better than BFS.

Elapsing	BFS	DFS	UCS
Problem 1	0.036328169	0.01768707	0.043845195
Problem 2	15.9280114	3.775622444	16.55607818
Problem 3	117.7097407	1.99831509	61.07040865

Figure 2 Elapsing in non-heuristic

Comparing with Problem 1, Problem 2 and Problem 3, it can been found that Problem 1 takes least expansions and least times to get the solution and Problem 3 takes most. As the problem become more and more complicated. It takes more times and steps to find solution.

At last, even though DFS has higher score in time and expansions, I think it is not a optimal method to solve such problems because: 1. It is uncertain to find a solution if it get in to a infinite looping. 2.The solution includes a lot of useless steps. So for non-heuristic search the BFS may be the better choice in this kind of problem.

1.3 heuristic planning

For the method using using A* with the "ignore preconditions" and "level-sum" heuristics for Problems 1, 2, and 3, the results are shown as below.

We found that for every problem, method using "ignore preconditions" heuristic has more search expansions than method with "level-sum" heuristic. However, method using "ignore preconditions" heuristic takes less time than another.

Accordingly, I think level-sum is a more efficient heuristic in the measure of expansions. Bu as it has more complex structure and computational process, time for computing each heuristic function will be much longer than ignore preconditions. So as a result. level-sum takes more time and less expansions.

Expansions	ignore preconditions	level-sum
Problem 1	41	11
Problem 2	1450	86
Problem 3	5040	325

Figure 3 Expansions in heuristic

Elapsing	ignore preconditions	level-sum
Problem 1	0.042662473	0.594096801
Problem 2	5.096783525	49.04157916
Problem 3	20.40100506	264.7870964

Figure 4 Elapsing in heuristic

Finally I think method using "ignore preconditions" heuristic may be the best one because it has not that many expansions as method with BFS, takes less time than level-sum and strikes a balance between searching time and search expansions.

But it is not better than non-heuristic in all indexes. As we can find that it is not better in the expansions and elapsing time than DFS. But DFS has a big problem, so we will not consider the DFS. And it is not better than BFS in time, because for simple problem, method with heuristic has no advantages.

2. Appendix

1.1 Solving Air Cargo Problem 1 using breadth_first_search...

Expansions	Goal Tests	New Nodes
43	56	180

Plan length: 6 Time elapsed in seconds: 0.03632816866674119

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

1.2 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: 0.01768707018593312

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)

1.3 Solving Air Cargo Problem 1 using uniform_cost_search...

Expansions	Goal Tests	New Nodes
55	57	224

Plan length: 6 Time elapsed in seconds: 0.04384519482913251

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

1.4 Solving Air Cargo Problem 1 using astar_search with h_ignore_preconditions...

Expansions	Goal Tests	New Nodes
41	43	170

Plan length: 6 Time elapsed in seconds: 0.042662472810620265

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

1.5 Solving Air Cargo Problem 1 using astar_search with h_pg_levelsum...

Expansions	Goal Tests	New Nodes
11	13	50

Plan length: 6 Time elapsed in seconds: 0.594096800591873

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

2.1 Solving Air Cargo Problem 2 using breadth_first_search...

Expansions	Goal Tests	New Nodes
3343	4609	30509

Plan length: 9 Time elapsed in seconds: 15.928011397139452

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)

2.2 Solving Air Cargo Problem 2 using depth_first_graph_search...

Expansions	Goal Tests	New Nodes
624	625	5602

Plan length: 619 Time elapsed in seconds: 3.7756224437289707

Fly(P3, ATL, SFO)
Fly(P1, SFO, ATL)
Fly(P3, SFO, JFK)
Fly(P1, ATL, JFK)
Fly(P2, JFK, ATL)
Fly(P3, JFK, ATL)
Fly(P2, ATL, SFO)
Fly(P3, ATL, SFO)
Load(C2, P1, JFK)
Fly(P2, SFO, ATL)
Fly(P1, JFK, ATL)
Fly(P2, ATL, JFK)
Fly(P1, ATL, SFO)
Fly(P3, SFO, ATL)
Fly(P1, SFO, JFK)
Load(C3, P3, ATL)
Fly(P3, ATL, SFO)
Fly(P2, JFK, ATL)
Fly(P3, SFO, JFK)
Fly(P2, ATL, SFO)
Fly(P1, JFK, ATL)
Fly(P2, SFO, JFK)
Fly(P1, ATL, SFO)
Unload(C3, P3, JFK)
Fly(P1, SFO, JFK)
Fly(P3, JFK, ATL)
Fly(P2, JFK, ATL)

Fly(P3, ATL, SFO)
Fly(P2, ATL, SFO)
Fly(P1, JFK, ATL)
Fly(P3, SFO, ATL)
Fly(P1, ATL, SFO)
Unload(C2, P1, SFO)
Fly(P3, ATL, SFO)
Fly(P2, SFO, ATL)
Fly(P1, SFO, ATL)
Fly(P2, ATL, JFK)
Fly(P1, ATL, JFK)
Fly(P3, SFO, ATL)
Fly(P2, JFK, ATL)
Fly(P3, ATL, JFK)
Fly(P2, ATL, SFO)
Fly(P1, JFK, ATL)
Load(C3, P3, JFK)
Fly(P1, ATL, SFO)
Fly(P2, SFO, ATL)
Fly(P3, JFK, ATL)
Fly(P2, ATL, JFK)
Fly(P3, ATL, SFO)
Fly(P1, SFO, ATL)
Fly(P2, JFK, ATL)
Fly(P1, ATL, JFK)
Fly(P2, ATL, SFO)
Fly(P3, SFO, ATL)
Unload(C3, P3, ATL)
Fly(P3, ATL, SFO)
Fly(P2, SFO, ATL)
Fly(P3, SFO, JFK)
Fly(P2, ATL, JFK)
Fly(P1, JFK, ATL)
Fly(P3, JFK, ATL)
Fly(P2, JFK, ATL)
Load(C3, P2, ATL)
Fly(P3, ATL, SFO)
Fly(P2, ATL, SFO)
Fly(P1, ATL, SFO)
Fly(P3, SFO, ATL)
Fly(P2, SFO, JFK)
Fly(P3, ATL, JFK)
Fly(P1, SFO, JFK)
Fly(P2, JFK, SFO)

Unload(C3, P2, SFO)
Fly(P2, SFO, ATL)
Fly(P3, JFK, ATL)
Fly(P2, ATL, JFK)
Fly(P3, ATL, SFO)
Load(C2, P3, SFO)
Fly(P3, SFO, ATL)
Fly(P2, JFK, ATL)
Fly(P3, ATL, JFK)
Fly(P2, ATL, SFO)
Fly(P1, JFK, ATL)
Fly(P2, SFO, JFK)
Fly(P1, ATL, SFO)
Unload(C2, P3, JFK)
Fly(P1, SFO, JFK)
Fly(P3, JFK, ATL)
Fly(P2, JFK, ATL)
Fly(P3, ATL, SFO)
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Fly(P1, JFK, ATL)
Fly(P3, SFO, ATL)
Fly(P1, ATL, SFO)
Load(C3, P2, SFO)
Fly(P3, ATL, SFO)
Fly(P2, SFO, ATL)
Fly(P1, SFO, ATL)
Fly(P2, ATL, JFK)
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Load(C2, P2, JFK)
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Unload(C3, P2, SFO)
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Fly(P3, ATL, SFO)
Fly(P1, SFO, JFK)
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Unload(C3, P1, SFO)
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Fly(P2, ATL, SFO)
Fly(P3, JFK, ATL)
Load(C3, P2, SFO)
Fly(P3, ATL, SFO)
Fly(P1, ATL, SFO)
Fly(P2, SFO, ATL)
Fly(P3, SFO, ATL)
Fly(P2, ATL, JFK)
Fly(P3, ATL, JFK)
Fly(P1, SFO, ATL)
Unload(C3, P2, JFK)
Fly(P3, JFK, ATL)
Fly(P2, JFK, ATL)
Fly(P1, ATL, SFO)
Fly(P3, ATL, SFO)
Fly(P2, ATL, SFO)
Fly(P1, SFO, ATL)
Load(C1, P1, ATL)
Fly(P1, ATL, SFO)

Fly(P2, SFO, ATL)
Fly(P3, SFO, ATL)
Fly(P2, ATL, JFK)
Fly(P1, SFO, JFK)
Fly(P3, ATL, SFO)
Load(C3, P2, JFK)
Fly(P3, SFO, JFK)
Fly(P2, JFK, ATL)
Fly(P3, JFK, ATL)
Fly(P2, ATL, SFO)
Fly(P1, JFK, SFO)
Fly(P3, ATL, SFO)
Fly(P2, SFO, ATL)
Fly(P1, SFO, ATL)
Unload(C3, P2, ATL)
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Fly(P3, ATL, SFO)
Unload(C2, P1, JFK)
Fly(P2, JFK, ATL)
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Fly(P1, JFK, ATL)
Fly(P2, ATL, SFO)
Fly(P3, ATL, SFO)
Fly(P1, ATL, SFO)
Fly(P3, SFO, JFK)
Fly(P2, SFO, ATL)
Load(C3, P2, ATL)
Fly(P2, ATL, SFO)
Fly(P1, SFO, ATL)
Fly(P2, SFO, JFK)
Fly(P3, JFK, ATL)
Fly(P1, ATL, SFO)
Fly(P3, ATL, SFO)
Unload(C3, P2, JFK)
Fly(P1, SFO, ATL)
Fly(P2, JFK, ATL)

Fly(P1, ATL, JFK)
Fly(P2, ATL, SFO)
Load(C3, P1, JFK)
Fly(P3, SFO, ATL)
Fly(P2, SFO, ATL)
Fly(P3, ATL, JFK)
Fly(P2, ATL, JFK)
Fly(P1, JFK, ATL)
Fly(P3, JFK, ATL)
Fly(P1, ATL, SFO)
Fly(P3, ATL, SFO)
Fly(P2, JFK, ATL)
Fly(P1, SFO, ATL)
Unload(C1, P1, ATL)
Fly(P2, ATL, SFO)
Fly(P1, ATL, SFO)
Fly(P3, SFO, ATL)
Fly(P2, SFO, ATL)
Fly(P3, ATL, JFK)
Fly(P2, ATL, JFK)
Unload(C3, P1, SFO)
Fly(P1, SFO, ATL)
Fly(P3, JFK, ATL)
Fly(P2, JFK, ATL)
Load(C1, P3, ATL)
Fly(P3, ATL, SFO)
Fly(P1, ATL, SFO)
Fly(P2, ATL, SFO)
Fly(P3, SFO, ATL)
Fly(P2, SFO, JFK)
Fly(P3, ATL, JFK)
Fly(P1, SFO, ATL)
Fly(P2, JFK, SFO)
Fly(P1, ATL, JFK)
Fly(P2, SFO, ATL)
Unload(C1, P3, JFK)
Fly(P2, ATL, JFK)
Fly(P3, JFK, ATL)
Fly(P1, JFK, ATL)
Fly(P2, JFK, ATL)
Fly(P3, ATL, SFO)
Fly(P2, ATL, SFO)
Fly(P1, ATL, SFO)
Fly(P3, SFO, ATL)

Load(C3, P1, SFO)
Fly(P3, ATL, JFK)
Fly(P2, SFO, ATL)
Fly(P1, SFO, ATL)
Fly(P3, JFK, ATL)
Fly(P2, ATL, JFK)
Fly(P3, ATL, SFO)
Fly(P1, ATL, SFO)
Load(C2, P2, JFK)
Fly(P3, SFO, ATL)
Fly(P1, SFO, JFK)
Fly(P3, ATL, JFK)
Fly(P2, JFK, ATL)
Fly(P1, JFK, ATL)
Fly(P2, ATL, SFO)
Fly(P1, ATL, SFO)
Unload(C3, P1, SFO)
Fly(P2, SFO, ATL)
Fly(P1, SFO, ATL)
Fly(P3, JFK, ATL)
Fly(P2, ATL, SFO)
Fly(P3, ATL, SFO)
Fly(P1, ATL, JFK)
Fly(P2, SFO, ATL)
Unload(C2, P2, ATL)
Fly(P2, ATL, SFO)
Fly(P3, SFO, ATL)
Fly(P2, SFO, JFK)
Fly(P3, ATL, JFK)
Fly(P1, JFK, ATL)
Fly(P3, JFK, SFO)
Fly(P1, ATL, SFO)
Load(C3, P3, SFO)
Fly(P3, SFO, ATL)
Fly(P1, SFO, ATL)
Fly(P3, ATL, JFK)
Fly(P1, ATL, JFK)
Fly(P2, JFK, ATL)
Fly(P3, JFK, ATL)
Load(C2, P3, ATL)
Fly(P3, ATL, SFO)
Fly(P2, ATL, SFO)
Fly(P3, SFO, JFK)
Fly(P2, SFO, JFK)

Fly(P1, JFK, ATL)
Fly(P2, JFK, ATL)
Fly(P1, ATL, SFO)
Load(C1, P3, JFK)
Fly(P2, ATL, SFO)
Fly(P1, SFO, ATL)
Fly(P3, JFK, ATL)
Fly(P1, ATL, JFK)
Fly(P3, ATL, SFO)
Fly(P2, SFO, ATL)
Fly(P1, JFK, ATL)
Fly(P2, ATL, JFK)
Fly(P1, ATL, SFO)
Fly(P3, SFO, ATL)
Unload(C2, P3, ATL)
Fly(P3, ATL, SFO)
Fly(P1, SFO, ATL)
Fly(P2, JFK, ATL)
Fly(P1, ATL, JFK)
Fly(P2, ATL, SFO)
Fly(P3, SFO, JFK)
Fly(P1, JFK, ATL)
Unload(C3, P3, JFK)
Fly(P1, ATL, SFO)
Fly(P2, SFO, ATL)
Fly(P1, SFO, JFK)
Fly(P2, ATL, JFK)
Fly(P3, JFK, ATL)
Fly(P1, JFK, ATL)
Fly(P3, ATL, SFO)
Fly(P1, ATL, SFO)
Unload(C1, P3, SFO)
Fly(P3, SFO, ATL)
Fly(P1, SFO, ATL)
Fly(P3, ATL, JFK)
Fly(P1, ATL, JFK)
Fly(P2, JFK, ATL)
Fly(P3, JFK, ATL)
Fly(P2, ATL, SFO)
Fly(P3, ATL, SFO)
Load(C3, P1, JFK)
Fly(P2, SFO, ATL)
Fly(P1, JFK, ATL)
Fly(P2, ATL, JFK)

Fly(P1, ATL, SFO)
Fly(P3, SFO, ATL)
Fly(P1, SFO, JFK)
Load(C2, P3, ATL)
Fly(P3, ATL, SFO)
Fly(P2, JFK, ATL)
Fly(P3, SFO, JFK)
Fly(P2, ATL, SFO)
Fly(P1, JFK, ATL)
Fly(P3, JFK, ATL)
Fly(P1, ATL, SFO)
Fly(P3, ATL, SFO)
Unload(C3, P1, SFO)
Fly(P2, SFO, ATL)
Unload(C2, P3, SFO)
Load(C3, P1, SFO)
Fly(P2, ATL, JFK)
Fly(P3, SFO, ATL)
Fly(P2, JFK, SFO)
Fly(P3, ATL, JFK)
Fly(P1, SFO, ATL)
Fly(P3, JFK, SFO)
Fly(P1, ATL, JFK)
Load(C2, P2, SFO)
Fly(P3, SFO, ATL)
Fly(P2, SFO, ATL)
Fly(P3, ATL, JFK)
Fly(P2, ATL, JFK)
Fly(P1, JFK, ATL)
Fly(P3, JFK, ATL)
Unload(C3, P1, ATL)
Fly(P1, ATL, JFK)
Fly(P3, ATL, SFO)
Fly(P2, JFK, ATL)
Fly(P1, JFK, ATL)
Fly(P2, ATL, SFO)
Fly(P1, ATL, SFO)
Fly(P3, SFO, ATL)
Fly(P2, SFO, ATL)
Fly(P3, ATL, JFK)
Fly(P2, ATL, JFK)
Load(C1, P1, SFO)
Fly(P1, SFO, ATL)
Fly(P3, JFK, ATL)

Fly(P1, ATL, JFK)
Fly(P2, JFK, ATL)
Fly(P3, ATL, SFO)
Fly(P2, ATL, SFO)
Fly(P3, SFO, JFK)
Unload(C2, P2, SFO)
Fly(P2, SFO, ATL)
Fly(P3, JFK, ATL)
Fly(P1, JFK, ATL)
Fly(P3, ATL, SFO)
Fly(P2, ATL, SFO)
Unload(C1, P1, ATL)
Fly(P1, ATL, SFO)
Fly(P3, SFO, ATL)
Fly(P2, SFO, ATL)
Fly(P3, ATL, JFK)
Fly(P2, ATL, JFK)
Fly(P1, SFO, ATL)
Fly(P3, JFK, ATL)
Fly(P1, ATL, JFK)
Fly(P3, ATL, SFO)
Fly(P2, JFK, ATL)
Load(C3, P2, ATL)
Fly(P2, ATL, SFO)
Fly(P3, SFO, ATL)
Fly(P2, SFO, JFK)
Fly(P3, ATL, JFK)
Fly(P1, JFK, ATL)
Fly(P2, JFK, ATL)
Fly(P3, JFK, ATL)
Load(C1, P3, ATL)
Fly(P2, ATL, SFO)
Fly(P1, ATL, SFO)
Fly(P3, ATL, JFK)
Fly(P2, SFO, ATL)
Fly(P1, SFO, JFK)
Fly(P2, ATL, JFK)
Fly(P1, JFK, ATL)
Fly(P3, JFK, SFO)
Fly(P1, ATL, SFO)
Unload(C3, P2, JFK)
Fly(P3, SFO, ATL)
Fly(P1, SFO, ATL)
Fly(P2, JFK, ATL)

Fly(P3, ATL, JFK)
 Fly(P2, ATL, SFO)
 Fly(P1, ATL, SFO)
 Unload(C1, P3, JFK)
 Fly(P2, SFO, ATL)
 Fly(P1, SFO, JFK)
 Fly(P2, ATL, JFK)
 Fly(P3, JFK, ATL)
 Fly(P1, JFK, ATL)
 Fly(P3, ATL, SFO)
 Fly(P1, ATL, SFO)
 Load(C3, P2, JFK)
 Fly(P3, SFO, ATL)
 Fly(P2, JFK, ATL)
 Fly(P1, SFO, ATL)
 Fly(P2, ATL, SFO)
 Fly(P3, ATL, SFO)
 Fly(P1, ATL, JFK)
 Fly(P3, SFO, JFK)
 Unload(C3, P2, SFO)

2.3 Solving Air Cargo Problem 2 using uniform_cost_search...

Expansions	Goal Tests	New Nodes
4852	4854	44030

Plan length: 9 Time elapsed in seconds: 16.55607817570675

Load(C1, P1, SFO)
 Load(C2, P2, JFK)
 Load(C3, P3, ATL)
 Fly(P1, SFO, JFK)
 Fly(P2, JFK, SFO)
 Fly(P3, ATL, SFO)
 Unload(C3, P3, SFO)
 Unload(C2, P2, SFO)
 Unload(C1, P1, JFK)

2.4 Solving Air Cargo Problem 2 using astar_search with h_ignore_preconditions...

Expansions	Goal Tests	New Nodes
1450	1452	13303

Plan length: 9 Time elapsed in seconds: 5.096783525177217

Load(C3, P3, ATL)
 Fly(P3, ATL, SFO)

Unload(C3, P3, SFO)
Load(C2, P2, JFK)
Fly(P2, JFK, SFO)
Unload(C2, P2, SFO)
Load(C1, P1, SFO)
Fly(P1, SFO, JFK)
Unload(C1, P1, JFK)

2.5 Solving Air Cargo Problem 2 using astar_search with h_pg_levelsum...

Expansions	Goal Tests	New Nodes
86	88	841

Plan length: 9 Time elapsed in seconds: 49.0415791642951

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)

3.1 Solving Air Cargo Problem 3 using breadth_first_search...

Expansions	Goal Tests	New Nodes
14663	18098	129631

Plan length: 12 Time elapsed in seconds: 117.70974073129085

Load(C1, P1, SFO)
Load(C2, P2, JFK)
Fly(P2, JFK, ORD)
Load(C4, P2, ORD)
Fly(P1, SFO, ATL)
Load(C3, P1, ATL)
Fly(P1, ATL, JFK)
Unload(C1, P1, JFK)
Unload(C3, P1, JFK)
Fly(P2, ORD, SFO)
Unload(C2, P2, SFO)
Unload(C4, P2, SFO)

3.2 Solving Air Cargo Problem 3 using depth_first_graph_search...

Expansions	Goal Tests	New Nodes
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408

409

3364

Plan length: 392 Time elapsed in seconds: 1.9983150904577545

Fly(P1, SFO, ORD)
Fly(P2, JFK, ORD)
Fly(P1, ORD, ATL)
Fly(P2, ORD, ATL)
Fly(P1, ATL, JFK)
Fly(P2, ATL, SFO)
Load(C2, P1, JFK)
Fly(P2, SFO, ORD)
Fly(P1, JFK, ORD)
Fly(P2, ORD, ATL)
Fly(P1, ORD, ATL)
Fly(P2, ATL, JFK)
Fly(P1, ATL, SFO)
Unload(C2, P1, SFO)
Fly(P1, SFO, ORD)
Fly(P2, JFK, ORD)
Fly(P1, ORD, ATL)
Fly(P2, ORD, ATL)
Fly(P1, ATL, JFK)
Fly(P2, ATL, SFO)
Load(C2, P2, SFO)
Fly(P2, SFO, ORD)
Fly(P1, JFK, ORD)
Fly(P2, ORD, ATL)
Fly(P1, ORD, ATL)
Fly(P2, ATL, JFK)
Load(C3, P1, ATL)
Fly(P1, ATL, ORD)
Fly(P2, JFK, ORD)
Fly(P1, ORD, SFO)
Fly(P2, ORD, ATL)
Fly(P1, SFO, JFK)
Fly(P2, ATL, SFO)
Unload(C3, P1, JFK)
Fly(P2, SFO, ORD)
Fly(P1, JFK, ORD)
Fly(P2, ORD, ATL)
Fly(P1, ORD, ATL)
Fly(P2, ATL, JFK)
Fly(P1, ATL, SFO)
Unload(C2, P2, JFK)

Fly(P1, SFO, ORD)
Fly(P2, JFK, ORD)
Fly(P1, ORD, ATL)
Fly(P2, ORD, ATL)
Fly(P1, ATL, JFK)
Fly(P2, ATL, SFO)
Load(C3, P1, JFK)
Fly(P2, SFO, ORD)
Fly(P1, JFK, ORD)
Fly(P2, ORD, ATL)
Fly(P1, ORD, SFO)
Fly(P2, ATL, JFK)
Unload(C3, P1, SFO)
Fly(P1, SFO, ORD)
Fly(P2, JFK, ORD)
Fly(P1, ORD, ATL)
Fly(P2, ORD, ATL)
Fly(P1, ATL, JFK)
Fly(P2, ATL, SFO)
Load(C3, P2, SFO)
Fly(P2, SFO, ORD)
Fly(P1, JFK, ORD)
Fly(P2, ORD, ATL)
Fly(P1, ORD, SFO)
Load(C1, P1, SFO)
Fly(P2, ATL, ORD)
Fly(P1, SFO, ORD)
Fly(P2, ORD, SFO)
Fly(P1, ORD, ATL)
Fly(P2, SFO, JFK)
Fly(P1, ATL, JFK)
Unload(C3, P2, JFK)
Fly(P2, JFK, ORD)
Fly(P1, JFK, ORD)
Fly(P2, ORD, ATL)
Fly(P1, ORD, ATL)
Fly(P2, ATL, SFO)
Unload(C1, P1, ATL)
Fly(P1, ATL, ORD)
Fly(P2, SFO, ORD)
Fly(P1, ORD, SFO)
Fly(P2, ORD, ATL)
Fly(P1, SFO, JFK)
Fly(P2, ATL, JFK)

Load(C3, P2, JFK)
Fly(P2, JFK, ORD)
Fly(P1, JFK, ORD)
Fly(P2, ORD, ATL)
Fly(P1, ORD, ATL)
Unload(C3, P2, ATL)
Fly(P2, ATL, ORD)
Fly(P1, ATL, ORD)
Fly(P2, ORD, SFO)
Fly(P1, ORD, SFO)
Fly(P2, SFO, JFK)
Fly(P1, SFO, JFK)
Load(C2, P2, JFK)
Fly(P2, JFK, ORD)
Fly(P1, JFK, ORD)
Fly(P2, ORD, ATL)
Fly(P1, ORD, ATL)
Fly(P2, ATL, SFO)
Fly(P1, ATL, SFO)
Unload(C2, P2, SFO)
Fly(P2, SFO, ORD)
Fly(P1, SFO, ORD)
Fly(P2, ORD, ATL)
Fly(P1, ORD, ATL)
Fly(P2, ATL, JFK)
Load(C3, P1, ATL)
Fly(P1, ATL, ORD)
Fly(P2, JFK, ORD)
Fly(P1, ORD, SFO)
Fly(P2, ORD, ATL)
Fly(P1, SFO, JFK)
Fly(P2, ATL, SFO)
Unload(C3, P1, JFK)
Fly(P2, SFO, ORD)
Fly(P1, JFK, ORD)
Fly(P2, ORD, ATL)
Fly(P1, ORD, ATL)
Fly(P2, ATL, JFK)
Fly(P1, ATL, SFO)
Load(C3, P2, JFK)
Fly(P1, SFO, ORD)
Fly(P2, JFK, ORD)
Fly(P1, ORD, ATL)
Fly(P2, ORD, SFO)

Fly(P1, ATL, JFK)
Fly(P2, SFO, ATL)
Load(C1, P2, ATL)
Fly(P2, ATL, ORD)
Fly(P1, JFK, ORD)
Fly(P2, ORD, SFO)
Fly(P1, ORD, ATL)
Fly(P2, SFO, JFK)
Fly(P1, ATL, SFO)
Unload(C3, P2, JFK)
Fly(P1, SFO, ORD)
Fly(P2, JFK, ORD)
Fly(P1, ORD, ATL)
Fly(P2, ORD, SFO)
Fly(P1, ATL, JFK)
Load(C3, P1, JFK)
Fly(P2, SFO, ORD)
Fly(P1, JFK, ORD)
Fly(P2, ORD, ATL)
Fly(P1, ORD, ATL)
Fly(P2, ATL, JFK)
Fly(P1, ATL, SFO)
Unload(C3, P1, SFO)
Fly(P1, SFO, ORD)
Fly(P2, JFK, ORD)
Fly(P1, ORD, ATL)
Fly(P2, ORD, ATL)
Fly(P1, ATL, JFK)
Fly(P2, ATL, SFO)
Unload(C1, P2, SFO)
Fly(P2, SFO, ORD)
Fly(P1, JFK, ORD)
Fly(P2, ORD, ATL)
Fly(P1, ORD, ATL)
Fly(P2, ATL, JFK)
Fly(P1, ATL, SFO)
Load(C3, P1, SFO)
Fly(P1, SFO, ORD)
Fly(P2, JFK, ORD)
Fly(P1, ORD, JFK)
Fly(P2, ORD, ATL)
Unload(C3, P1, JFK)
Fly(P2, ATL, JFK)
Fly(P1, JFK, ORD)

Fly(P2, JFK, ORD)
Fly(P1, ORD, ATL)
Load(C4, P2, ORD)
Fly(P2, ORD, ATL)
Fly(P1, ATL, ORD)
Fly(P2, ATL, SFO)
Fly(P1, ORD, SFO)
Fly(P2, SFO, JFK)
Fly(P1, SFO, JFK)
Unload(C4, P2, JFK)
Fly(P2, JFK, ORD)
Fly(P1, JFK, ORD)
Fly(P2, ORD, ATL)
Fly(P1, ORD, ATL)
Fly(P2, ATL, SFO)
Fly(P1, ATL, SFO)
Load(C2, P2, SFO)
Fly(P2, SFO, ORD)
Fly(P1, SFO, ORD)
Fly(P2, ORD, ATL)
Fly(P1, ORD, ATL)
Fly(P2, ATL, JFK)
Fly(P1, ATL, JFK)
Unload(C2, P2, JFK)
Fly(P2, JFK, ORD)
Fly(P1, JFK, ORD)
Fly(P2, ORD, ATL)
Fly(P1, ORD, ATL)
Fly(P2, ATL, SFO)
Fly(P1, ATL, SFO)
Load(C1, P2, SFO)
Fly(P2, SFO, ORD)
Fly(P1, SFO, ORD)
Fly(P2, ORD, ATL)
Fly(P1, ORD, ATL)
Fly(P2, ATL, JFK)
Fly(P1, ATL, JFK)
Unload(C1, P2, JFK)
Fly(P2, JFK, ORD)
Load(C4, P1, JFK)
Fly(P2, ORD, ATL)
Fly(P1, JFK, ORD)
Fly(P2, ATL, SFO)
Fly(P1, ORD, ATL)

Fly(P2, SFO, JFK)
Fly(P1, ATL, SFO)
Unload(C4, P1, SFO)
Fly(P1, SFO, ORD)
Fly(P2, JFK, ORD)
Fly(P1, ORD, ATL)
Fly(P2, ORD, ATL)
Fly(P1, ATL, JFK)
Fly(P2, ATL, SFO)
Load(C4, P2, SFO)
Fly(P2, SFO, ORD)
Fly(P1, JFK, ORD)
Fly(P2, ORD, ATL)
Fly(P1, ORD, ATL)
Fly(P2, ATL, JFK)
Fly(P1, ATL, SFO)
Load(C3, P2, JFK)
Fly(P1, SFO, ORD)
Fly(P2, JFK, ORD)
Fly(P1, ORD, ATL)
Fly(P2, ORD, ATL)
Fly(P1, ATL, JFK)
Fly(P2, ATL, SFO)
Unload(C4, P2, SFO)
Fly(P2, SFO, ORD)
Fly(P1, JFK, ORD)
Fly(P2, ORD, ATL)
Fly(P1, ORD, ATL)
Fly(P2, ATL, JFK)
Load(C2, P2, JFK)
Fly(P1, ATL, ORD)
Fly(P2, JFK, ORD)
Fly(P1, ORD, SFO)
Fly(P2, ORD, ATL)
Fly(P1, SFO, JFK)
Fly(P2, ATL, SFO)
Unload(C3, P2, SFO)
Fly(P2, SFO, ORD)
Fly(P1, JFK, ORD)
Fly(P2, ORD, ATL)
Fly(P1, ORD, ATL)
Fly(P2, ATL, JFK)
Fly(P1, ATL, SFO)
Unload(C2, P2, JFK)

Fly(P1, SFO, ORD)
Fly(P2, JFK, ORD)
Fly(P1, ORD, ATL)
Fly(P2, ORD, ATL)
Fly(P1, ATL, JFK)
Load(C2, P1, JFK)
Fly(P2, ATL, ORD)
Fly(P1, JFK, ORD)
Fly(P2, ORD, SFO)
Fly(P1, ORD, ATL)
Fly(P2, SFO, JFK)
Fly(P1, ATL, SFO)
Unload(C2, P1, SFO)
Fly(P1, SFO, ORD)
Fly(P2, JFK, ORD)
Fly(P1, ORD, ATL)
Fly(P2, ORD, ATL)
Fly(P1, ATL, JFK)
Load(C1, P1, JFK)
Fly(P2, ATL, ORD)
Fly(P1, JFK, ORD)
Fly(P2, ORD, SFO)
Fly(P1, ORD, ATL)
Fly(P2, SFO, JFK)
Fly(P1, ATL, SFO)
Unload(C1, P1, SFO)
Fly(P1, SFO, ORD)
Fly(P2, JFK, ORD)
Fly(P1, ORD, ATL)
Fly(P2, ORD, ATL)
Fly(P1, ATL, JFK)
Fly(P2, ATL, SFO)
Load(C4, P2, SFO)
Fly(P2, SFO, ATL)
Fly(P1, JFK, ORD)
Fly(P2, ATL, JFK)
Fly(P1, ORD, ATL)
Fly(P2, JFK, ORD)
Fly(P1, ATL, SFO)
Load(C3, P1, SFO)
Fly(P2, ORD, ATL)
Fly(P1, SFO, ORD)
Fly(P2, ATL, SFO)
Fly(P1, ORD, ATL)

Fly(P2, SFO, JFK)
Unload(C4, P2, JFK)
Fly(P1, ATL, ORD)
Fly(P2, JFK, ORD)
Fly(P1, ORD, SFO)
Fly(P2, ORD, ATL)
Fly(P1, SFO, JFK)
Fly(P2, ATL, SFO)
Load(C4, P1, JFK)
Fly(P2, SFO, ORD)
Fly(P1, JFK, ATL)
Fly(P2, ORD, ATL)
Fly(P1, ATL, ORD)
Unload(C3, P1, ORD)
Fly(P1, ORD, ATL)
Fly(P2, ATL, ORD)
Fly(P1, ATL, SFO)
Fly(P2, ORD, SFO)
Fly(P1, SFO, JFK)
Fly(P2, SFO, JFK)
Unload(C4, P1, JFK)
Fly(P2, JFK, ORD)
Fly(P1, JFK, ATL)
Fly(P2, ORD, ATL)
Fly(P1, ATL, ORD)
Fly(P2, ATL, SFO)
Fly(P1, ORD, SFO)
Load(C2, P2, SFO)
Fly(P2, SFO, ORD)
Fly(P1, SFO, ORD)
Fly(P2, ORD, ATL)
Fly(P1, ORD, ATL)
Fly(P2, ATL, JFK)
Fly(P1, ATL, JFK)
Unload(C2, P2, JFK)
Fly(P2, JFK, ORD)
Fly(P1, JFK, ORD)
Fly(P2, ORD, ATL)
Fly(P1, ORD, ATL)
Fly(P2, ATL, SFO)
Fly(P1, ATL, SFO)
Load(C1, P2, SFO)
Fly(P2, SFO, ORD)
Fly(P1, SFO, ORD)

Fly(P2, ORD, ATL)
Fly(P1, ORD, ATL)
Fly(P2, ATL, JFK)
Fly(P1, ATL, JFK)
Unload(C1, P2, JFK)
Fly(P2, JFK, ORD)
Fly(P1, JFK, ORD)
Fly(P2, ORD, ATL)
Load(C3, P1, ORD)
Fly(P1, ORD, ATL)
Fly(P2, ATL, ORD)
Fly(P1, ATL, SFO)
Fly(P2, ORD, SFO)
Fly(P1, SFO, JFK)
Load(C4, P1, JFK)
Fly(P2, SFO, JFK)
Fly(P1, JFK, ORD)
Fly(P2, JFK, ORD)
Fly(P1, ORD, ATL)
Fly(P2, ORD, ATL)
Fly(P1, ATL, SFO)
Unload(C4, P1, SFO)
Fly(P2, ATL, ORD)
Fly(P1, SFO, ORD)
Fly(P2, ORD, SFO)
Fly(P1, ORD, ATL)
Fly(P2, SFO, JFK)
Fly(P1, ATL, JFK)
Load(C2, P2, JFK)
Fly(P2, JFK, ORD)
Fly(P1, JFK, ORD)
Fly(P2, ORD, ATL)
Fly(P1, ORD, ATL)
Fly(P2, ATL, SFO)
Fly(P1, ATL, SFO)
Unload(C2, P2, SFO)
Fly(P2, SFO, ORD)
Fly(P1, SFO, ORD)
Fly(P2, ORD, ATL)
Fly(P1, ORD, ATL)
Fly(P2, ATL, JFK)
Fly(P1, ATL, JFK)
Unload(C3, P1, JFK)

3.3 Solving Air Cargo Problem 3 using uniform_cost_search...

Expansions	Goal Tests	New Nodes
18223	18225	159618

Plan length: 12 Time elapsed in seconds: 61.07040865349743

Load(C1, P1, SFO)
Load(C2, P2, JFK)
Fly(P1, SFO, ATL)
Load(C3, P1, ATL)
Fly(P2, JFK, ORD)
Load(C4, P2, ORD)
Fly(P2, ORD, SFO)
Fly(P1, ATL, JFK)
Unload(C4, P2, SFO)
Unload(C3, P1, JFK)
Unload(C2, P2, SFO)
Unload(C1, P1, JFK)

3.4 Solving Air Cargo Problem 3 using astar_search with h_ignore_preconditions...

Expansions	Goal Tests	New Nodes
5040	5042	44944

Plan length: 12 Time elapsed in seconds: 20.4010050577153

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)

3.5 Solving Air Cargo Problem 3 using astar_search with h_pg_levelsum...

Expansions	Goal Tests	New Nodes
325	327	3002

Plan length: 12 Time elapsed in seconds: 264.78709638331117

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)