



Implement a Planning Search

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1. Results

The results of running air_cargo_p1, air_cargo_p2 and air_cargo_p3 using different search algorithms and heuristics are included in this section.

1.1. Uniformed planning searches

Running air_cargo_p1, air_cargo_p2 and air_cargo_p3 in at least three searches got the results:

Problem 1						
Non-heuristic search	Expansions	Goal Tests	New Nodes	Time elapsed	Plan Length	Optimality
breadth first search	43	56	180	0.034020	6	Yes
depth first graph search	12	13	48	0.015669	12	No
uniform cost search	55	57	224	0.042764	6	Yes
breadth first tree search	1458	1459	5960	1.041977	6	Yes
depth limited search	101	271	414	0.098663	50	No

Problem 2						
Non-heuristic search	Expansions	Goal Tests	New Nodes	Time elapsed	Plan Length	Optimality
breadth first search	3343	4609	30509	15.074803	9	Yes
depth first graph search	582	583	5211	3.408410	575	No
uniform cost search	4852	4854	44030	48.573169	9	Yes

Problem 3						
Non-heuristic search	Expansions	Goal Tests	New Nodes	Time elapsed	Plan Length	Optimality
breadth first search	14663	18098	129631	109.917191	12	Yes
depth first graph search	627	628	5176	3.479658	596	No
uniform cost search	18235	18237	159716	393.794051	12	Yes

Note: The optimality factor is determined using the plan length.

Note2: Time is expressed in milliseconds (ms).

1.2. Planning searches using heuristics

The results of running A* search with the three heuristics: h1, h_ignore_preconditions and h_level_sum are included next:

Problem 1						
Heuristic search	Expansions	Goal Tests	New Nodes	Time elapsed	Plan Length	Optimality
A* h 1	55	57	224	0.043659	6	Yes
A* h ignore_preconditions	41	43	170	0.050567	6	Yes
A* h pg_levelsum	11	13	50	2.400568	6	Yes

Problem 2						
Heuristic search	Expansions	Goal Tests	New Nodes	Time elapsed	Plan Length	Optimality
A* h 1	4852	4854	44030	48.006498	9	Yes
A* h ignore_preconditions	1506	1508	13820	15.426104	9	Yes
A* h pg_levelsum	86	88	841	289.391001	9	Yes

Problem 3						
Heuristic search	Expansions	Goal Tests	New Nodes	Time elapsed	Plan Length	Optimality
A* h 1	18235	18237	159716	452.494614	12	Yes
A* h ignore_preconditions	5118	5120	45650	99.098676	12	Yes
A* h pg_levelsum	408	410	3758	2017.625442	12	Yes

Note: The optimality factor is determined using the plan length.

Note2: Time is expressed in milliseconds (ms).

2. Analysis

2.1. Optimal plan

2.1.1. Problem 1

Three of the non-heuristic searches have found a minimum length plan. Those searches are `uniform_cost_search`, `breadth_first_search` and `breadth_first_tree_search`.

Any of these six length plans are optimal.

For example, `breadth_first_search` suggests:

```
Load(C2, P2, JFK)
Load(C1, P1, SF0)
Fly(P2, JFK, SF0)
Unload(C2, P2, SF0)
Fly(P1, SF0, JFK)
Unload(C1, P1, JFK)
```

In the case of heuristic search, all of them have found a six length optimal plan.

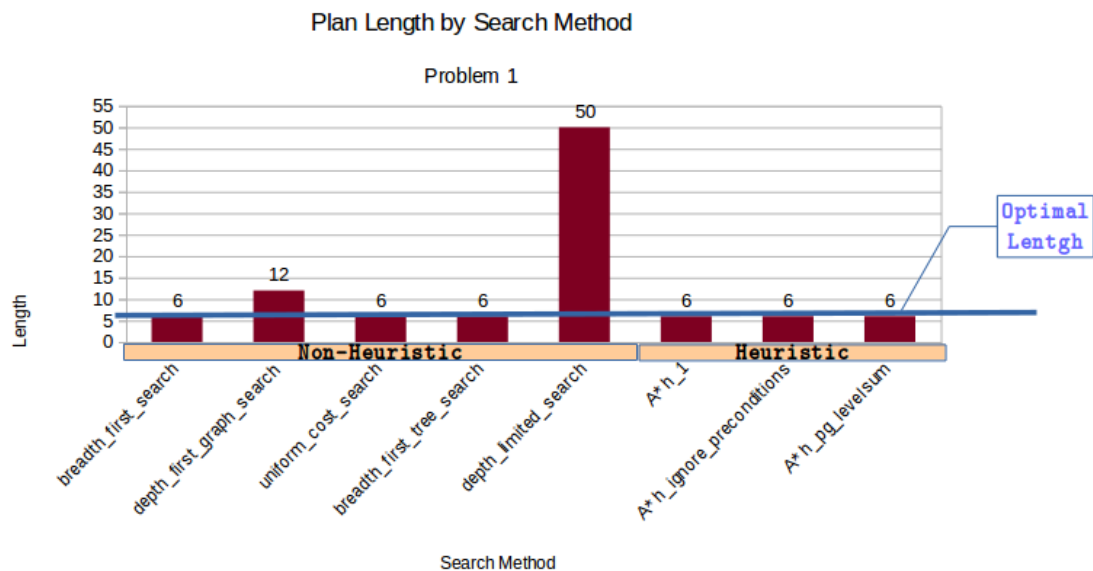


Figura 1: Problem 1 - Search Methods Optimal Plan

The difference between these non-heuristic and heuristic searches, that have found an optimal plan, is going to be discussed in following sections of this report.

2.1.2. Problem 2

As problem 1, all the heuristic searches have found optimal length plan. In the case of non-heuristic search just `uniform_cost_search` and `breadth_first_search` have found an optimal plan.

Only `depth_first_graph_search` has failed in the task of finding an optimal plan. The length of the plan found was larger with 575 actions.

For example, an optimal plan found using `uniform_cost_search`:

```

Load(C1, P1, SF0)
Load(C2, P2, JFK)
Load(C3, P3, ATL)
Fly(P1, SF0, JFK)
Fly(P2, JFK, SF0)
Fly(P3, ATL, SF0)
Unload(C3, P3, SF0)
Unload(C1, P1, JFK)
Unload(C2, P2, SF0)

```

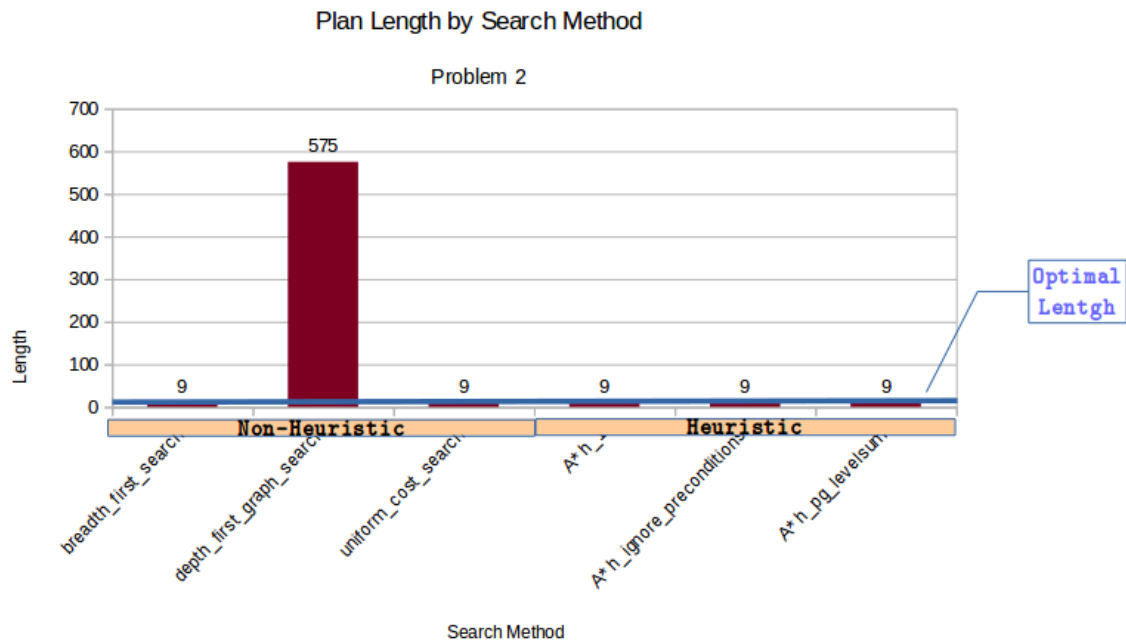


Figura 2: Problem 2 - Search Methods Optimal Plan

2.1.3. Problem 3

For problem 3, depth_first_graph_search hasn't reached an optimal plan.

Uniform_cost_search and breadth_first_tree_search have arrived to an optimal plan of length 12, in the case of non-heuristic searches.

As happen before, all the heuristics have arrived to an optimal plan.

For example, breadth_first_tree_search has found this plan:

```

Load(C2, P2, JFK)
Load(C1, P1, SF0)
Fly(P2, JFK, ORD)
Load(C4, P2, ORD)
Fly(P1, SF0, ATL)
Load(C3, P1, ATL)
Fly(P1, ATL, JFK)
Unload(C1, P1, JFK)
Unload(C3, P1, JFK)
Fly(P2, ORD, SF0)

```

```

Unload(C2, P2, SF0)
Unload(C4, P2, SF0)

```

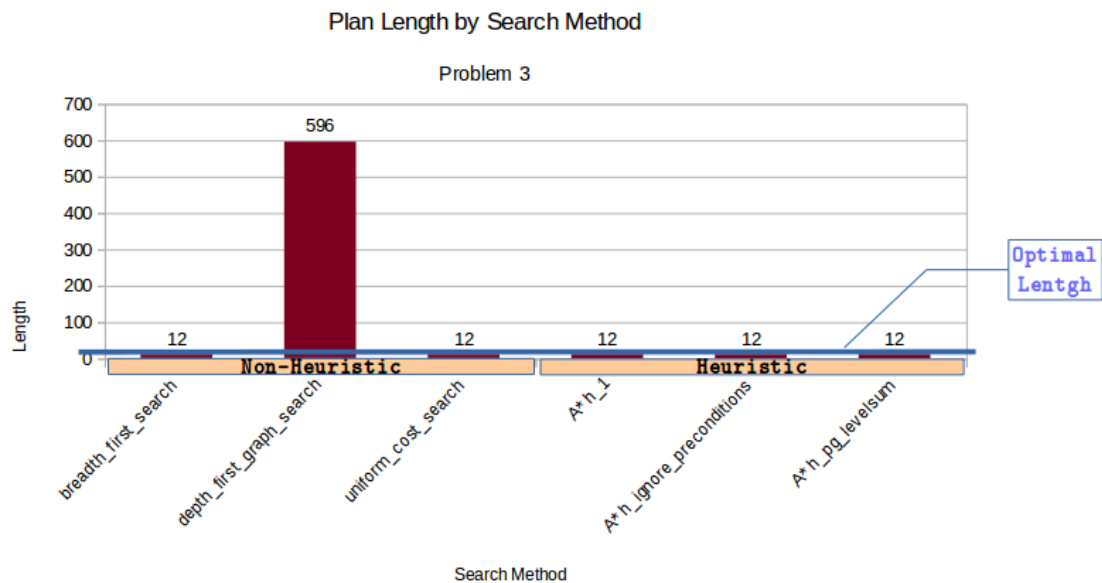


Figura 3: Problem 3 - Search Methods Optimal Plan

2.2. Best non-heuristic search

The evaluation regarding the best non-heuristic used is done in general, without taking a particular problem.

The results that are taking into account to make the selection are: plan length and time. The best non-heuristic search is going to be that one that finds the optimal plan in the less time as possible.

In the case of non-heuristic search, only uniform_cost_search and breadth_first_tree_search have arrived to an optimal plan.

In the three problems, BFS has done it in less time.

BFS has found the optimal plan, in less time for the three problems so we can conclude that is the best non-heuristic search.

2.3. Best heuristic used

In this case, the three heuristics tested have arrived to an optimal plan but with different elapsed time.

H_ignore_preconditions has done it faster than the rest in almost all problems. For problem 1, h_1 was a little bit faster but in the rest of the problem it doesn't happen this way.

So, we can conclude that in overall, h_ignore_preconditions was the best heuristic used.

3. Conclusions

In the experimentation above, there are three problems where a series of search methods were applied to find an optimal plan.

In the case of non-heuristic search, `uniform_cost_search` and `breadth_first_tree_search` have arrived an optimal plan in all the problems. Both search graph breadth/least cost wise and return the optimal (first goal-state encounter) value for even an infinite graph. (Lesson 7 - 22. Quiz: Search Comparison)

But `depth_first_search` fails in the task. It returns a plan but it could be not the optimal. This is related with the way that `depth_first_search` walk-through the graph/tree nodes. It explores the nodes depth wise and goes to deeper nodes first and returns the first goal-state encounter value for even an infinite graph which may not be optimal. (Lesson 7 - 22. Quiz: Search Comparison)

As it is explained in video lessons, we can summarize the optimality of each search in this image:

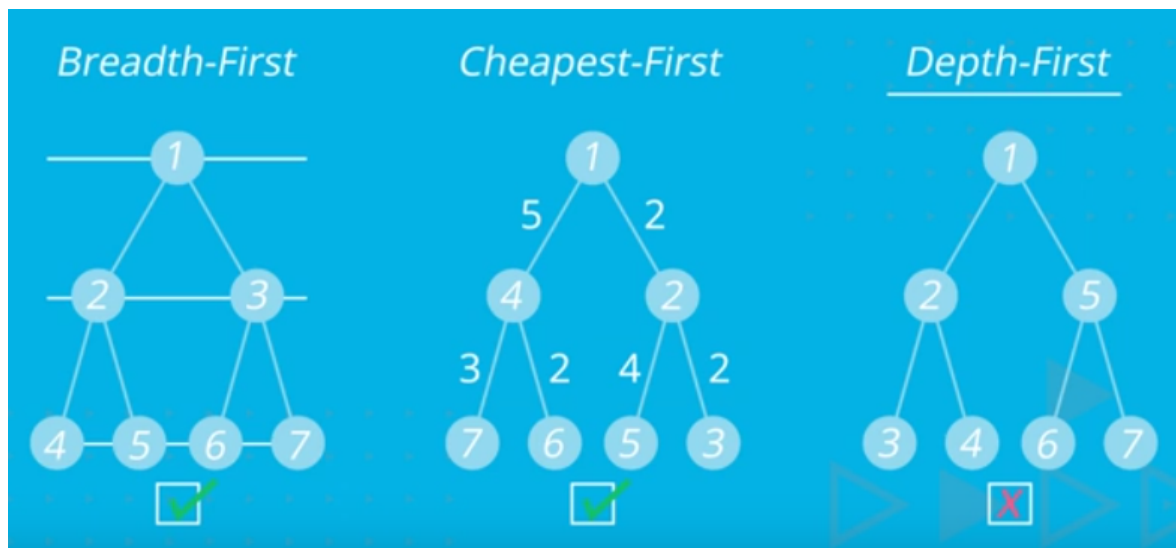


Figura 4: Lesson 7 - 22. Quiz: Search Comparison

About the heuristic search, all the tested heuristics have found an optimal plan for the three problems. That happens because they are admissible, each h function doesn't overestimate the distance to goal (Lesson 7 - 32. A* Search 5).

h_1 returns a constant value 1. So, the estimation to the goal for each node is going to be the same. In the algorithm A*, to select which node expand is going to depend on g , path cost, and h , the heuristic. In this case, it's going to have more weight the function g because h is the same for every node.

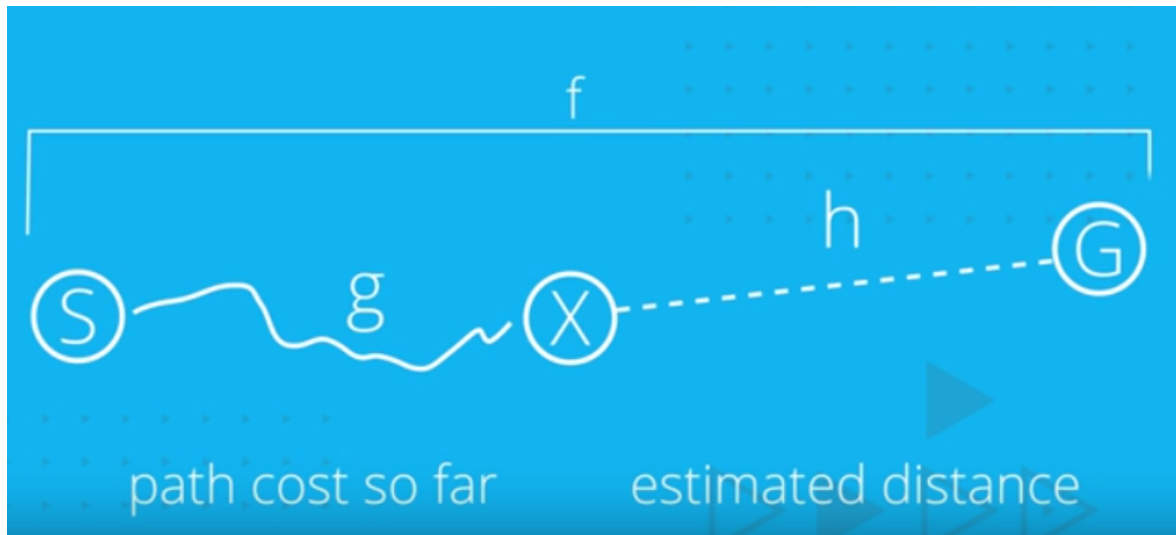


Figura 5: Lesson 7 - 27. Quiz: A* Search

In `h_ignore_preconditions`, every action is applicable in every step so that makes that a single goal fluent could be reachable in one step (AIMA - 10.2.3 - Heuristics for planning). In metrics, we can see that in the number of expansions that are less than `h` heuristic.

`H.levelsum` works well in practice for problems that are largely decomposable (AIMA Book - Chapter 10 - 10.3.1. Planning graphs for heuristic estimation). It does less expansions than `h_ignore_preconditions`, besides that the elapsed time is higher.

4. Appendix

The complete results of the testing is included for reference.

4.1. Problem 1

```

1
2 Solving Air Cargo Problem 1 using breadth_first_search...
3
4 Expansions Goal Tests New Nodes
5      43      56      180
6
7 Plan length: 6 Time elapsed in seconds: 0.0340201889994205
8 Load(C2, P2, JFK)
9 Load(C1, P1, SFO)
10 Fly(P2, JFK, SFO)
11 Unload(C2, P2, SFO)
12 Fly(P1, SFO, JFK)
13 Unload(C1, P1, JFK)
14
15
16 Solving Air Cargo Problem 1 using depth_first_graph_search...
17
18 Expansions Goal Tests New Nodes
19      12      13      48
20
21 Plan length: 12 Time elapsed in seconds: 0.015669232998334337
22 Fly(P1, SFO, JFK)
23 Fly(P2, JFK, SFO)
24 Load(C1, P2, SFO)
25 Fly(P2, SFO, JFK)
26 Fly(P1, JFK, SFO)
27 Unload(C1, P2, JFK)
28 Fly(P2, JFK, SFO)
29 Fly(P1, SFO, JFK)
30 Load(C2, P1, JFK)
31 Fly(P2, SFO, JFK)

```

```
32 Fly(P1, JFK, SFO)
33 Unload(C2, P1, SFO)
34
35
36 Solving Air Cargo Problem 1 using uniform_cost_search...
37
38 Expansions Goal Tests New Nodes
39      55      57      224
40
41 Plan length: 6 Time elapsed in seconds: 0.0427645300005679
42 Load(C1, P1, SFO)
43 Load(C2, P2, JFK)
44 Fly(P1, SFO, JFK)
45 Fly(P2, JFK, SFO)
46 Unload(C1, P1, JFK)
47 Unload(C2, P2, SFO)
48
49
50 Solving Air Cargo Problem 1 using breadth_first_search...
51
52 Expansions Goal Tests New Nodes
53      43      56      180
54
55 Plan length: 6 Time elapsed in seconds: 0.03434167399973376
56 Load(C2, P2, JFK)
57 Load(C1, P1, SFO)
58 Fly(P2, JFK, SFO)
59 Unload(C2, P2, SFO)
60 Fly(P1, SFO, JFK)
61 Unload(C1, P1, JFK)
62
63
64 Solving Air Cargo Problem 1 using depth_limited_search...
65
66 Expansions Goal Tests New Nodes
67      101      271      414
68
69 Plan length: 50 Time elapsed in seconds: 0.09866303400121978
70 Load(C2, P2, JFK)
71 Load(C1, P1, SFO)
72 Unload(C2, P2, JFK)
73 Load(C2, P2, JFK)
74 Unload(C2, P2, JFK)
75 Load(C2, P2, JFK)
76 Unload(C2, P2, JFK)
77 Load(C2, P2, JFK)
78 Unload(C2, P2, JFK)
79 Load(C2, P2, JFK)
80 Unload(C2, P2, JFK)
81 Load(C2, P2, JFK)
82 Unload(C2, P2, JFK)
83 Load(C2, P2, JFK)
84 Unload(C2, P2, JFK)
85 Load(C2, P2, JFK)
86 Unload(C2, P2, JFK)
87 Load(C2, P2, JFK)
88 Unload(C2, P2, JFK)
89 Load(C2, P2, JFK)
90 Unload(C2, P2, JFK)
91 Load(C2, P2, JFK)
92 Unload(C2, P2, JFK)
93 Load(C2, P2, JFK)
94 Unload(C2, P2, JFK)
95 Load(C2, P2, JFK)
96 Unload(C2, P2, JFK)
97 Load(C2, P2, JFK)
98 Unload(C2, P2, JFK)
99 Load(C2, P2, JFK)
100 Unload(C2, P2, JFK)
101 Load(C2, P2, JFK)
102 Unload(C2, P2, JFK)
103 Load(C2, P2, JFK)
104 Unload(C2, P2, JFK)
105 Load(C2, P2, JFK)
106 Unload(C2, P2, JFK)
107 Load(C2, P2, JFK)
108 Unload(C2, P2, JFK)
109 Load(C2, P2, JFK)
110 Unload(C2, P2, JFK)
111 Load(C2, P2, JFK)
112 Unload(C2, P2, JFK)
113 Load(C2, P2, JFK)
114 Unload(C2, P2, JFK)
115 Load(C2, P2, JFK)
116 Fly(P2, JFK, SFO)
117 Unload(C2, P2, SFO)
```

```

118 Fly(P1, SFO, JFK)
119 Unload(C1, P1, JFK)
120
121
122 Solving Air Cargo Problem 1 using astar_search with h_1...
123
124 Expansions Goal Tests New Nodes
125      55      57      224
126
127 Plan length: 6 Time elapsed in seconds: 0.04365915800008224
128 Load(C1, P1, SFO)
129 Load(C2, P2, JFK)
130 Fly(P1, SFO, JFK)
131 Fly(P2, JFK, SFO)
132 Unload(C1, P1, JFK)
133 Unload(C2, P2, SFO)
134
135
136 Solving Air Cargo Problem 1 using astar_search with h_ignore_preconditions...
137
138 Expansions Goal Tests New Nodes
139      41      43      170
140
141 Plan length: 6 Time elapsed in seconds: 0.050567197999043856
142 Load(C1, P1, SFO)
143 Fly(P1, SFO, JFK)
144 Unload(C1, P1, JFK)
145 Load(C2, P2, JFK)
146 Fly(P2, JFK, SFO)
147 Unload(C2, P2, SFO)
148
149
150 Solving Air Cargo Problem 1 using astar_search with h_pg_levelsum...
151
152 Expansions Goal Tests New Nodes
153      11      13      50
154
155 Plan length: 6 Time elapsed in seconds: 2.4005685669999366
156 Load(C1, P1, SFO)
157 Fly(P1, SFO, JFK)
158 Load(C2, P2, JFK)
159 Fly(P2, JFK, SFO)
160 Unload(C1, P1, JFK)
161 Unload(C2, P2, SFO)

```

4.2. Problem 2

```

1
2
3 Solving Air Cargo Problem 2 using breadth_first_search...
4
5 Expansions Goal Tests New Nodes
6      3343      4609      30509
7
8 Plan length: 9 Time elapsed in seconds: 15.07480358900284
9 Load(C2, P2, JFK)
10 Load(C1, P1, SFO)
11 Load(C3, P3, ATL)
12 Fly(P2, JFK, SFO)
13 Unload(C2, P2, SFO)
14 Fly(P1, SFO, JFK)
15 Unload(C1, P1, JFK)
16 Fly(P3, ATL, SFO)
17 Unload(C3, P3, SFO)
18
19
20 Solving Air Cargo Problem 2 using depth_first_graph_search...
21
22 Expansions Goal Tests New Nodes
23      582      583      5211
24
25 Plan length: 575 Time elapsed in seconds: 3.4084108200004266
26 Fly(P3, ATL, SFO)
27 Fly(P1, SFO, ATL)
28 Fly(P3, SFO, JFK)
29 Fly(P1, ATL, JFK)
30 Fly(P2, JFK, ATL)
31 Fly(P3, JFK, ATL)
32 Fly(P2, ATL, SFO)
33 Fly(P3, ATL, SFO)
34 Load(C1, P3, SFO)
35 Fly(P3, SFO, ATL)

```

```
36 Fly(P2, SFO, ATL)
37 Fly(P3, ATL, JFK)
38 Fly(P2, ATL, JFK)
39 Fly(P1, JFK, ATL)
40 Fly(P3, JFK, ATL)
41 Fly(P1, ATL, SFO)
42 Unload(C1, P3, ATL)
43 Fly(P3, ATL, SFO)
44 Fly(P1, SFO, ATL)
45 Fly(P3, SFO, JFK)
46 Fly(P1, ATL, JFK)
47 Fly(P2, JFK, ATL)
48 Fly(P3, JFK, SFO)
49 Fly(P2, ATL, SFO)
50 Load(C2, P1, JFK)
51 Fly(P3, SFO, ATL)
52 Fly(P2, SFO, ATL)
53 Fly(P1, JFK, ATL)
54 Fly(P3, ATL, SFO)
55 Fly(P1, ATL, SFO)
56 Fly(P2, ATL, JFK)
57 Fly(P3, SFO, ATL)
58 Unload(C2, P1, SFO)
59 Fly(P3, ATL, JFK)
60 Fly(P1, SFO, ATL)
61 Fly(P2, JFK, ATL)
62 Fly(P1, ATL, JFK)
63 Fly(P2, ATL, SFO)
64 Fly(P3, JFK, ATL)
65 Fly(P1, JFK, ATL)
66 Fly(P3, ATL, SFO)
67 Fly(P1, ATL, SFO)
68 Load(C2, P3, SFO)
69 Fly(P3, SFO, ATL)
70 Fly(P2, SFO, ATL)
71 Fly(P3, ATL, JFK)
72 Fly(P1, SFO, ATL)
73 Fly(P2, ATL, SFO)
74 Load(C3, P1, ATL)
75 Fly(P1, ATL, SFO)
76 Fly(P2, SFO, ATL)
77 Fly(P1, SFO, JFK)
78 Fly(P2, ATL, JFK)
79 Fly(P3, JFK, ATL)
80 Fly(P1, JFK, ATL)
81 Fly(P3, ATL, SFO)
82 Fly(P1, ATL, SFO)
83 Unload(C2, P3, SFO)
84 Fly(P3, SFO, ATL)
85 Fly(P1, SFO, ATL)
86 Fly(P2, JFK, ATL)
87 Fly(P3, ATL, SFO)
88 Fly(P1, ATL, JFK)
89 Fly(P2, ATL, SFO)
90 Fly(P3, SFO, ATL)
91 Unload(C3, P1, JFK)
92 Fly(P3, ATL, JFK)
93 Fly(P2, SFO, ATL)
94 Fly(P1, JFK, ATL)
95 Fly(P2, ATL, JFK)
96 Fly(P1, ATL, SFO)
97 Fly(P3, JFK, ATL)
98 Fly(P2, JFK, ATL)
99 Fly(P3, ATL, SFO)
100 Fly(P2, ATL, SFO)
101 Fly(P1, SFO, ATL)
102 Load(C1, P1, ATL)
103 Fly(P1, ATL, SFO)
104 Fly(P3, SFO, ATL)
105 Fly(P2, SFO, ATL)
106 Fly(P3, ATL, JFK)
107 Fly(P2, ATL, JFK)
108 Fly(P1, SFO, JFK)
109 Fly(P3, JFK, ATL)
110 Fly(P1, JFK, ATL)
111 Load(C3, P2, JFK)
112 Fly(P3, ATL, SFO)
113 Fly(P1, ATL, SFO)
114 Fly(P2, JFK, ATL)
115 Fly(P3, SFO, ATL)
116 Fly(P2, ATL, SFO)
117 Fly(P3, ATL, JFK)
118 Fly(P1, SFO, ATL)
119 Fly(P2, SFO, ATL)
120 Fly(P1, ATL, JFK)
121 Unload(C3, P2, ATL)
```

```
122 Fly(P2, ATL, SF0)
123 Fly(P3, JFK, ATL)
124 Fly(P2, SF0, JFK)
125 Fly(P3, ATL, SF0)
126 Fly(P1, JFK, ATL)
127 Fly(P2, JFK, ATL)
128 Fly(P3, SF0, ATL)
129 Load(C3, P3, ATL)
130 Fly(P3, ATL, SF0)
131 Fly(P2, ATL, SF0)
132 Fly(P1, ATL, SF0)
133 Fly(P3, SF0, ATL)
134 Fly(P2, SF0, JFK)
135 Unload(C1, P1, SF0)
136 Fly(P3, ATL, SF0)
137 Fly(P1, SF0, ATL)
138 Fly(P3, SF0, JFK)
139 Fly(P1, ATL, JFK)
140 Fly(P2, JFK, ATL)
141 Fly(P3, JFK, ATL)
142 Fly(P2, ATL, SF0)
143 Fly(P3, ATL, SF0)
144 Unload(C3, P3, SF0)
145 Fly(P3, SF0, ATL)
146 Fly(P2, SF0, ATL)
147 Fly(P3, ATL, JFK)
148 Fly(P2, ATL, JFK)
149 Fly(P1, JFK, ATL)
150 Fly(P3, JFK, ATL)
151 Fly(P1, ATL, SF0)
152 Load(C3, P1, SF0)
153 Fly(P3, ATL, SF0)
154 Fly(P1, SF0, ATL)
155 Fly(P3, SF0, JFK)
156 Fly(P1, ATL, JFK)
157 Fly(P2, JFK, ATL)
158 Fly(P3, JFK, ATL)
159 Fly(P2, ATL, SF0)
160 Fly(P3, ATL, SF0)
161 Unload(C3, P1, JFK)
162 Fly(P2, SF0, ATL)
163 Fly(P1, JFK, ATL)
164 Fly(P2, ATL, JFK)
165 Fly(P1, ATL, SF0)
166 Fly(P3, SF0, ATL)
167 Fly(P1, SF0, JFK)
168 Load(C3, P2, JFK)
169 Fly(P3, ATL, SF0)
170 Fly(P2, JFK, ATL)
171 Fly(P3, SF0, JFK)
172 Fly(P2, ATL, SF0)
173 Fly(P1, JFK, ATL)
174 Fly(P2, SF0, JFK)
175 Fly(P1, ATL, SF0)
176 Load(C2, P1, SF0)
177 Fly(P1, SF0, ATL)
178 Fly(P3, JFK, ATL)
179 Fly(P1, ATL, JFK)
180 Fly(P3, ATL, SF0)
181 Fly(P2, JFK, ATL)
182 Fly(P3, SF0, JFK)
183 Fly(P2, ATL, SF0)
184 Unload(C3, P2, SF0)
185 Fly(P2, SF0, ATL)
186 Fly(P3, JFK, ATL)
187 Fly(P2, ATL, JFK)
188 Fly(P3, ATL, SF0)
189 Fly(P1, JFK, ATL)
190 Fly(P3, SF0, JFK)
191 Fly(P1, ATL, SF0)
192 Load(C3, P1, SF0)
193 Fly(P1, SF0, ATL)
194 Fly(P3, JFK, ATL)
195 Fly(P1, ATL, JFK)
196 Fly(P3, ATL, SF0)
197 Fly(P2, JFK, ATL)
198 Fly(P3, SF0, JFK)
199 Fly(P2, ATL, SF0)
200 Unload(C3, P1, JFK)
201 Fly(P2, SF0, JFK)
202 Unload(C2, P1, JFK)
203 Fly(P3, JFK, ATL)
204 Fly(P2, JFK, ATL)
205 Fly(P3, ATL, SF0)
206 Fly(P2, ATL, SF0)
207 Fly(P1, JFK, ATL)
```

```
208 Fly(P3, SFO, ATL)
209 Fly(P1, ATL, SFO)
210 Fly(P3, ATL, JFK)
211 Fly(P2, SFO, ATL)
212 Fly(P1, SFO, ATL)
213 Load(C3, P3, JFK)
214 Fly(P2, ATL, SFO)
215 Fly(P1, ATL, JFK)
216 Fly(P3, JFK, SFO)
217 Fly(P2, SFO, ATL)
218 Fly(P1, JFK, SFO)
219 Fly(P2, ATL, JFK)
220 Fly(P1, SFO, ATL)
221 Fly(P3, SFO, ATL)
222 Fly(P1, ATL, JFK)
223 Load(C2, P2, JFK)
224 Fly(P3, ATL, SFO)
225 Fly(P2, JFK, ATL)
226 Fly(P3, SFO, JFK)
227 Fly(P2, ATL, SFO)
228 Fly(P1, JFK, ATL)
229 Fly(P2, SFO, JFK)
230 Fly(P1, ATL, SFO)
231 Unload(C3, P3, JFK)
232 Fly(P3, JFK, ATL)
233 Fly(P1, SFO, ATL)
234 Fly(P3, ATL, SFO)
235 Fly(P1, ATL, JFK)
236 Fly(P2, JFK, ATL)
237 Fly(P3, SFO, ATL)
238 Fly(P2, ATL, SFO)
239 Load(C1, P2, SFO)
240 Fly(P3, ATL, SFO)
241 Fly(P2, SFO, ATL)
242 Fly(P3, SFO, JFK)
243 Fly(P2, ATL, JFK)
244 Fly(P1, JFK, ATL)
245 Fly(P3, JFK, ATL)
246 Fly(P1, ATL, SFO)
247 Fly(P3, ATL, SFO)
248 Unload(C2, P2, JFK)
249 Fly(P1, SFO, ATL)
250 Fly(P2, JFK, ATL)
251 Fly(P1, ATL, JFK)
252 Fly(P3, SFO, ATL)
253 Fly(P2, ATL, SFO)
254 Fly(P3, ATL, JFK)
255 Fly(P1, JFK, ATL)
256 Load(C2, P3, JFK)
257 Fly(P1, ATL, SFO)
258 Fly(P2, SFO, ATL)
259 Fly(P1, SFO, JFK)
260 Fly(P2, ATL, JFK)
261 Fly(P3, JFK, ATL)
262 Fly(P1, JFK, ATL)
263 Fly(P3, ATL, SFO)
264 Fly(P1, ATL, SFO)
265 Unload(C2, P3, SFO)
266 Fly(P3, SFO, ATL)
267 Fly(P1, SFO, ATL)
268 Fly(P3, ATL, JFK)
269 Fly(P1, ATL, JFK)
270 Fly(P2, JFK, SFO)
271 Fly(P1, JFK, SFO)
272 Fly(P2, SFO, ATL)
273 Load(C2, P1, SFO)
274 Fly(P2, ATL, JFK)
275 Fly(P1, SFO, ATL)
276 Fly(P3, JFK, ATL)
277 Fly(P1, ATL, JFK)
278 Fly(P3, ATL, SFO)
279 Fly(P2, JFK, SFO)
280 Fly(P1, JFK, ATL)
281 Fly(P2, SFO, ATL)
282 Unload(C1, P2, ATL)
283 Fly(P2, ATL, SFO)
284 Fly(P1, ATL, JFK)
285 Fly(P3, SFO, ATL)
286 Fly(P2, SFO, ATL)
287 Fly(P3, ATL, JFK)
288 Fly(P2, ATL, JFK)
289 Fly(P1, JFK, ATL)
290 Fly(P3, JFK, ATL)
291 Unload(C2, P1, ATL)
292 Fly(P3, ATL, SFO)
293 Fly(P1, ATL, SFO)
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294 Fly(P3, SFO, JFK)
295 Fly(P1, SFO, JFK)
296 Fly(P2, JFK, ATL)
297 Fly(P3, JFK, ATL)
298 Fly(P2, ATL, SFO)
299 Fly(P3, ATL, SFO)
300 Load(C3, P1, JFK)
301 Fly(P2, SFO, ATL)
302 Fly(P1, JFK, ATL)
303 Fly(P2, ATL, JFK)
304 Fly(P1, ATL, SFO)
305 Fly(P3, SFO, ATL)
306 Fly(P2, JFK, ATL)
307 Fly(P3, ATL, JFK)
308 Fly(P2, ATL, SFO)
309 Fly(P1, SFO, ATL)
310 Fly(P3, JFK, ATL)
311 Unload(C3, P1, ATL)
312 Fly(P3, ATL, SFO)
313 Fly(P1, ATL, SFO)
314 Fly(P2, SFO, ATL)
315 Fly(P3, SFO, JFK)
316 Fly(P2, ATL, JFK)
317 Fly(P1, SFO, ATL)
318 Load(C2, P1, ATL)
319 Fly(P2, JFK, SFO)
320 Load(C1, P1, ATL)
321 Fly(P1, ATL, SFO)
322 Fly(P2, SFO, ATL)
323 Fly(P1, SFO, JFK)
324 Fly(P2, ATL, JFK)
325 Fly(P3, JFK, ATL)
326 Fly(P1, JFK, ATL)
327 Fly(P3, ATL, SFO)
328 Fly(P1, ATL, SFO)
329 Unload(C1, P1, SFO)
330 Fly(P3, SFO, ATL)
331 Fly(P2, JFK, ATL)
332 Fly(P1, SFO, ATL)
333 Fly(P3, ATL, SFO)
334 Fly(P2, ATL, SFO)
335 Fly(P3, SFO, JFK)
336 Fly(P1, ATL, JFK)
337 Load(C1, P2, SFO)
338 Fly(P2, SFO, ATL)
339 Fly(P1, JFK, ATL)
340 Fly(P2, ATL, JFK)
341 Fly(P1, ATL, SFO)
342 Fly(P3, JFK, ATL)
343 Fly(P1, SFO, JFK)
344 Fly(P3, ATL, SFO)
345 Unload(C1, P2, JFK)
346 Fly(P2, JFK, ATL)
347 Fly(P3, SFO, ATL)
348 Fly(P2, ATL, SFO)
349 Fly(P3, ATL, JFK)
350 Fly(P1, JFK, ATL)
351 Fly(P2, SFO, ATL)
352 Fly(P1, ATL, SFO)
353 Unload(C2, P1, SFO)
354 Fly(P2, ATL, SFO)
355 Fly(P1, SFO, ATL)
356 Fly(P2, SFO, JFK)
357 Fly(P1, ATL, JFK)
358 Load(C1, P3, JFK)
359 Fly(P3, JFK, ATL)
360 Fly(P2, JFK, ATL)
361 Fly(P3, ATL, SFO)
362 Fly(P2, ATL, SFO)
363 Fly(P1, JFK, ATL)
364 Fly(P2, SFO, JFK)
365 Fly(P1, ATL, SFO)
366 Load(C2, P3, SFO)
367 Fly(P3, SFO, ATL)
368 Fly(P1, SFO, ATL)
369 Fly(P2, JFK, ATL)
370 Fly(P3, ATL, SFO)
371 Unload(C1, P3, SFO)
372 Fly(P2, ATL, SFO)
373 Fly(P1, ATL, SFO)
374 Fly(P3, SFO, ATL)
375 Fly(P2, SFO, ATL)
376 Fly(P3, ATL, JFK)
377 Fly(P2, ATL, JFK)
378 Load(C1, P1, SFO)
379 Fly(P1, SFO, ATL)
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380 Fly(P3, JFK, ATL)
381 Fly(P1, ATL, JFK)
382 Fly(P2, JFK, ATL)
383 Fly(P3, ATL, SFO)
384 Fly(P2, ATL, SFO)
385 Fly(P3, SFO, JFK)
386 Unload(C2, P3, JFK)
387 Fly(P3, JFK, ATL)
388 Fly(P2, SFO, ATL)
389 Fly(P3, ATL, SFO)
390 Fly(P2, ATL, JFK)
391 Load(C2, P2, JFK)
392 Fly(P3, SFO, ATL)
393 Fly(P2, JFK, ATL)
394 Fly(P3, ATL, JFK)
395 Fly(P1, JFK, ATL)
396 Fly(P2, ATL, SFO)
397 Fly(P1, ATL, SFO)
398 Fly(P2, SFO, JFK)
399 Unload(C1, P1, SFO)
400 Fly(P2, JFK, ATL)
401 Fly(P1, SFO, ATL)
402 Fly(P2, ATL, SFO)
403 Fly(P1, ATL, JFK)
404 Fly(P3, JFK, ATL)
405 Fly(P2, SFO, ATL)
406 Fly(P3, ATL, SFO)
407 Fly(P2, ATL, JFK)
408 Load(C1, P3, SFO)
409 Fly(P3, SFO, ATL)
410 Fly(P2, JFK, ATL)
411 Fly(P3, ATL, JFK)
412 Fly(P2, ATL, SFO)
413 Fly(P1, JFK, ATL)
414 Fly(P3, JFK, ATL)
415 Fly(P1, ATL, SFO)
416 Fly(P3, ATL, SFO)
417 Fly(P2, SFO, ATL)
418 Fly(P1, SFO, ATL)
419 Unload(C2, P2, ATL)
420 Fly(P2, ATL, SFO)
421 Fly(P1, ATL, SFO)
422 Fly(P3, SFO, ATL)
423 Fly(P2, SFO, ATL)
424 Fly(P3, ATL, JFK)
425 Fly(P2, ATL, JFK)
426 Fly(P1, SFO, ATL)
427 Unload(C1, P3, JFK)
428 Fly(P1, ATL, JFK)
429 Fly(P3, JFK, ATL)
430 Fly(P2, JFK, ATL)
431 Fly(P3, ATL, SFO)
432 Fly(P2, ATL, SFO)
433 Fly(P1, JFK, ATL)
434 Fly(P3, SFO, ATL)
435 Fly(P1, ATL, SFO)
436 Load(C3, P3, ATL)
437 Fly(P3, ATL, SFO)
438 Fly(P2, SFO, ATL)
439 Fly(P1, SFO, ATL)
440 Fly(P2, ATL, JFK)
441 Fly(P1, ATL, JFK)
442 Fly(P3, SFO, JFK)
443 Fly(P2, JFK, ATL)
444 Unload(C3, P3, JFK)
445 Fly(P2, ATL, SFO)
446 Fly(P3, JFK, ATL)
447 Fly(P2, SFO, JFK)
448 Fly(P3, ATL, SFO)
449 Fly(P1, JFK, ATL)
450 Fly(P3, SFO, JFK)
451 Fly(P1, ATL, SFO)
452 Load(C1, P3, JFK)
453 Fly(P1, SFO, JFK)
454 Fly(P3, JFK, ATL)
455 Load(C2, P3, ATL)
456 Fly(P3, ATL, SFO)
457 Fly(P2, JFK, ATL)
458 Fly(P3, SFO, JFK)
459 Fly(P2, ATL, SFO)
460 Fly(P1, JFK, ATL)
461 Fly(P2, SFO, JFK)
462 Fly(P1, ATL, SFO)
463 Unload(C2, P3, JFK)
464 Fly(P1, SFO, JFK)
465 Fly(P3, JFK, ATL)
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466 Fly(P2, JFK, ATL)
467 Fly(P1, JFK, ATL)
468 Fly(P3, ATL, SFO)
469 Fly(P1, ATL, SFO)
470 Fly(P2, ATL, SFO)
471 Fly(P3, SFO, ATL)
472 Unload(C1, P3, ATL)
473 Fly(P3, ATL, SFO)
474 Fly(P2, SFO, ATL)
475 Fly(P3, SFO, JFK)
476 Fly(P2, ATL, JFK)
477 Fly(P1, SFO, ATL)
478 Fly(P3, JFK, ATL)
479 Load(C1, P1, ATL)
480 Fly(P3, ATL, SFO)
481 Fly(P1, ATL, SFO)
482 Fly(P3, SFO, JFK)
483 Fly(P1, SFO, JFK)
484 Fly(P2, JFK, ATL)
485 Fly(P3, JFK, ATL)
486 Fly(P2, ATL, SFO)
487 Fly(P3, ATL, SFO)
488 Unload(C1, P1, JFK)
489 Fly(P2, SFO, ATL)
490 Fly(P1, JFK, ATL)
491 Fly(P3, SFO, ATL)
492 Fly(P2, ATL, SFO)
493 Fly(P1, ATL, SFO)
494 Fly(P3, ATL, JFK)
495 Fly(P2, SFO, ATL)
496 Load(C3, P3, JFK)
497 Fly(P2, ATL, JFK)
498 Fly(P1, SFO, ATL)
499 Fly(P3, JFK, ATL)
500 Fly(P1, ATL, JFK)
501 Fly(P3, ATL, SFO)
502 Fly(P2, JFK, ATL)
503 Fly(P1, JFK, ATL)
504 Fly(P2, ATL, SFO)
505 Fly(P1, ATL, SFO)
506 Fly(P3, SFO, ATL)
507 Unload(C3, P3, ATL)
508 Fly(P3, ATL, SFO)
509 Fly(P2, SFO, ATL)
510 Fly(P1, SFO, ATL)
511 Fly(P2, ATL, JFK)
512 Load(C3, P1, ATL)
513 Fly(P1, ATL, SFO)
514 Fly(P3, SFO, ATL)
515 Fly(P1, SFO, JFK)
516 Fly(P3, ATL, JFK)
517 Fly(P2, JFK, ATL)
518 Fly(P1, JFK, ATL)
519 Fly(P2, ATL, SFO)
520 Fly(P1, ATL, SFO)
521 Unload(C3, P1, SFO)
522 Fly(P2, SFO, ATL)
523 Fly(P1, SFO, ATL)
524 Fly(P2, ATL, JFK)
525 Fly(P1, ATL, JFK)
526 Fly(P3, JFK, ATL)
527 Fly(P2, JFK, ATL)
528 Load(C2, P1, JFK)
529 Fly(P3, ATL, SFO)
530 Fly(P2, ATL, SFO)
531 Fly(P3, SFO, JFK)
532 Fly(P1, JFK, ATL)
533 Fly(P2, SFO, ATL)
534 Fly(P1, ATL, SFO)
535 Fly(P2, ATL, JFK)
536 Fly(P3, JFK, ATL)
537 Fly(P1, SFO, ATL)
538 Fly(P3, ATL, SFO)
539 Load(C1, P2, JFK)
540 Fly(P1, ATL, SFO)
541 Fly(P2, JFK, ATL)
542 Fly(P3, SFO, ATL)
543 Fly(P2, ATL, SFO)
544 Fly(P3, ATL, JFK)
545 Fly(P1, SFO, ATL)
546 Fly(P2, SFO, ATL)
547 Fly(P1, ATL, JFK)
548 Unload(C1, P2, ATL)
549 Fly(P2, ATL, SFO)
550 Fly(P3, JFK, ATL)
551 Fly(P2, SFO, JFK)
```

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552 Fly(P3, ATL, SFO)
553 Fly(P1, JFK, ATL)
554 Fly(P3, SFO, JFK)
555 Fly(P1, ATL, SFO)
556 Unload(C2, P1, SFO)
557 Fly(P1, SFO, ATL)
558 Fly(P3, JFK, ATL)
559 Fly(P1, ATL, JFK)
560 Fly(P3, ATL, SFO)
561 Fly(P2, JFK, ATL)
562 Fly(P3, SFO, JFK)
563 Fly(P2, ATL, SFO)
564 Load(C3, P2, SFO)
565 Fly(P2, SFO, JFK)
566 Fly(P3, JFK, ATL)
567 Fly(P2, JFK, ATL)
568 Fly(P3, ATL, SFO)
569 Fly(P1, JFK, ATL)
570 Fly(P2, ATL, SFO)
571 Fly(P1, ATL, SFO)
572 Fly(P3, SFO, ATL)
573 Unload(C3, P2, SFO)
574 Fly(P2, SFO, ATL)
575 Load(C1, P3, ATL)
576 Fly(P3, ATL, SFO)
577 Fly(P2, ATL, SFO)
578 Fly(P1, SFO, ATL)
579 Fly(P3, SFO, ATL)
580 Fly(P1, ATL, JFK)
581 Fly(P3, ATL, JFK)
582 Fly(P2, SFO, ATL)
583 Fly(P1, JFK, ATL)
584 Fly(P2, ATL, JFK)
585 Fly(P1, ATL, SFO)
586 Load(C3, P1, SFO)
587 Fly(P1, SFO, ATL)
588 Fly(P2, JFK, ATL)
589 Fly(P1, ATL, JFK)
590 Fly(P2, ATL, SFO)
591 Unload(C1, P3, JFK)
592 Fly(P2, SFO, JFK)
593 Fly(P3, JFK, ATL)
594 Fly(P2, JFK, ATL)
595 Fly(P3, ATL, SFO)
596 Fly(P1, JFK, ATL)
597 Fly(P2, ATL, SFO)
598 Fly(P1, ATL, SFO)
599 Fly(P3, SFO, ATL)
600 Unload(C3, P1, SFO)
601
602
603 Solving Air Cargo Problem 2 using uniform_cost_search...
604
605 Expansions   Goal Tests   New Nodes
606     4852       4854       44030
607
608 Plan length: 9 Time elapsed in seconds: 48.57316937900032
609 Load(C1, P1, SFO)
610 Load(C2, P2, JFK)
611 Load(C3, P3, ATL)
612 Fly(P1, SFO, JFK)
613 Fly(P2, JFK, SFO)
614 Fly(P3, ATL, SFO)
615 Unload(C3, P3, SFO)
616 Unload(C1, P1, JFK)
617 Unload(C2, P2, SFO)
618
619
620
621 Solving Air Cargo Problem 2 using astar_search with h_1...
622
623 Expansions   Goal Tests   New Nodes
624     4852       4854       44030
625
626 Plan length: 9 Time elapsed in seconds: 48.00649836100092
627 Load(C1, P1, SFO)
628 Load(C2, P2, JFK)
629 Load(C3, P3, ATL)
630 Fly(P1, SFO, JFK)
631 Fly(P2, JFK, SFO)
632 Fly(P3, ATL, SFO)
633 Unload(C3, P3, SFO)
634 Unload(C1, P1, JFK)
635 Unload(C2, P2, SFO)
636
637

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

639
640 Expansions Goal Tests New Nodes
641 1506 1508 13820

642
643 Plan length: 9 Time elapsed in seconds: 15.4261049859997
644 Load(C3, P3, ATL)
645 Fly(P3, ATL, SFO)
646 Unload(C3, P3, SFO)
647 Load(C1, P1, SFO)
648 Fly(P1, SFO, JFK)
649 Unload(C1, P1, JFK)
650 Load(C2, P2, JFK)
651 Fly(P2, JFK, SFO)
652 Unload(C2, P2, SFO)
653

654
655 Solving Air Cargo Problem 2 using astar_search with h_pg_levelsum...

656
657 Expansions Goal Tests New Nodes
658 86 88 841

659
660 Plan length: 9 Time elapsed in seconds: 289.3910018229999
661 Load(C1, P1, SFO)
662 Fly(P1, SFO, JFK)
663 Load(C2, P2, JFK)
664 Fly(P2, JFK, SFO)
665 Load(C3, P3, ATL)
666 Fly(P3, ATL, SFO)
667 Unload(C3, P3, SFO)
668 Unload(C1, P1, JFK)
669 Unload(C2, P2, SFO)

4.3. Problem 3

1
2 Solving Air Cargo Problem 3 using breadth_first_search...

3
4 Expansions Goal Tests New Nodes
5 14663 18098 129631

6
7 Plan length: 12 Time elapsed in seconds: 109.91719108899997
8 Load(C2, P2, JFK)
9 Load(C1, P1, SFO)
10 Fly(P2, JFK, ORD)
11 Load(C4, P2, ORD)
12 Fly(P1, SFO, ATL)
13 Load(C3, P1, ATL)
14 Fly(P1, ATL, JFK)
15 Unload(C1, P1, JFK)
16 Unload(C3, P1, JFK)
17 Fly(P2, ORD, SFO)
18 Unload(C2, P2, SFO)
19 Unload(C4, P2, SFO)
20

21
22 Solving Air Cargo Problem 3 using uniform_cost_search...

23
24 Expansions Goal Tests New Nodes
25 18235 18237 159716

26
27 Plan length: 12 Time elapsed in seconds: 393.7940513680005
28 Load(C1, P1, SFO)
29 Load(C2, P2, JFK)
30 Fly(P1, SFO, ATL)
31 Load(C3, P1, ATL)
32 Fly(P2, JFK, ORD)
33 Load(C4, P2, ORD)
34 Fly(P2, ORD, SFO)
35 Fly(P1, ATL, JFK)
36 Unload(C4, P2, SFO)
37 Unload(C3, P1, JFK)
38 Unload(C1, P1, JFK)
39 Unload(C2, P2, SFO)
40

41
42 Solving Air Cargo Problem 3 using depth_first_graph_search...

43
44 Expansions Goal Tests New Nodes
45 627 628 5176

46
47 Plan length: 596 Time elapsed in seconds: 3.479658971002209


```
48 Fly(P1, SFO, ORD)
49 Fly(P2, JFK, ORD)
50 Fly(P1, ORD, ATL)
51 Fly(P2, ORD, ATL)
52 Fly(P1, ATL, JFK)
53 Fly(P2, ATL, SFO)
54 Load(C1, P2, SFO)
55 Fly(P2, SFO, ORD)
56 Fly(P1, JFK, ORD)
57 Fly(P2, ORD, ATL)
58 Fly(P1, ORD, ATL)
59 Fly(P2, ATL, JFK)
60 Fly(P1, ATL, SFO)
61 Unload(C1, P2, JFK)
62 Fly(P1, SFO, ORD)
63 Fly(P2, JFK, ORD)
64 Fly(P1, ORD, ATL)
65 Fly(P2, ORD, ATL)
66 Fly(P1, ATL, JFK)
67 Fly(P2, ATL, SFO)
68 Load(C2, P1, JFK)
69 Fly(P2, SFO, ORD)
70 Fly(P1, JFK, ORD)
71 Fly(P2, ORD, ATL)
72 Fly(P1, ORD, ATL)
73 Fly(P2, ATL, JFK)
74 Fly(P1, ATL, SFO)
75 Unload(C2, P1, SFO)
76 Fly(P1, SFO, ORD)
77 Fly(P2, JFK, ORD)
78 Fly(P1, ORD, ATL)
79 Fly(P2, ORD, ATL)
80 Fly(P1, ATL, JFK)
81 Fly(P2, ATL, SFO)
82 Load(C2, P2, SFO)
83 Fly(P2, SFO, ORD)
84 Fly(P1, JFK, ORD)
85 Fly(P2, ORD, ATL)
86 Fly(P1, ORD, ATL)
87 Fly(P2, ATL, JFK)
88 Load(C3, P1, ATL)
89 Fly(P1, ATL, ORD)
90 Fly(P2, JFK, ORD)
91 Fly(P1, ORD, SFO)
92 Fly(P2, ORD, ATL)
93 Fly(P1, SFO, JFK)
94 Fly(P2, ATL, SFO)
95 Unload(C2, P2, SFO)
96 Fly(P2, SFO, ORD)
97 Fly(P1, JFK, ORD)
98 Fly(P2, ORD, ATL)
99 Fly(P1, ORD, SFO)
100 Fly(P2, ATL, JFK)
101 Fly(P1, SFO, ATL)
102 Load(C1, P2, JFK)
103 Fly(P1, ATL, ORD)
104 Fly(P2, JFK, ORD)
105 Fly(P1, ORD, SFO)
106 Fly(P2, ORD, ATL)
107 Fly(P1, SFO, JFK)
108 Fly(P2, ATL, SFO)
109 Unload(C1, P2, SFO)
110 Fly(P2, SFO, ORD)
111 Fly(P1, JFK, ORD)
112 Fly(P2, ORD, ATL)
113 Fly(P1, ORD, ATL)
114 Fly(P2, ATL, JFK)
115 Fly(P1, ATL, SFO)
116 Unload(C3, P1, SFO)
117 Fly(P1, SFO, ORD)
118 Fly(P2, JFK, ORD)
119 Fly(P1, ORD, ATL)
120 Fly(P2, ORD, ATL)
121 Fly(P1, ATL, JFK)
122 Fly(P2, ATL, SFO)
123 Load(C3, P2, SFO)
124 Fly(P2, SFO, ORD)
125 Fly(P1, JFK, ORD)
126 Fly(P2, ORD, ATL)
127 Fly(P1, ORD, ATL)
128 Fly(P2, ATL, JFK)
129 Fly(P1, ATL, SFO)
130 Unload(C3, P2, JFK)
131 Fly(P1, SFO, ORD)
132 Fly(P2, JFK, ORD)
133 Fly(P1, ORD, ATL)
```

```
134 Fly(P2, ORD, SFO)
135 Load(C2, P2, SFO)
136 Fly(P1, ATL, ORD)
137 Fly(P2, SFO, ORD)
138 Fly(P1, ORD, SFO)
139 Fly(P2, ORD, ATL)
140 Fly(P1, SFO, JFK)
141 Fly(P2, ATL, JFK)
142 Unload(C2, P2, JFK)
143 Fly(P2, JFK, ORD)
144 Fly(P1, JFK, ORD)
145 Fly(P2, ORD, ATL)
146 Fly(P1, ORD, ATL)
147 Fly(P2, ATL, SFO)
148 Fly(P1, ATL, SFO)
149 Load(C1, P2, SFO)
150 Fly(P2, SFO, ORD)
151 Fly(P1, SFO, ORD)
152 Fly(P2, ORD, ATL)
153 Fly(P1, ORD, ATL)
154 Fly(P2, ATL, JFK)
155 Fly(P1, ATL, JFK)
156 Unload(C1, P2, JFK)
157 Fly(P2, JFK, ORD)
158 Fly(P1, JFK, ORD)
159 Fly(P2, ORD, ATL)
160 Load(C4, P1, ORD)
161 Fly(P1, ORD, ATL)
162 Fly(P2, ATL, ORD)
163 Fly(P1, ATL, SFO)
164 Fly(P2, ORD, SFO)
165 Fly(P1, SFO, JFK)
166 Fly(P2, SFO, JFK)
167 Unload(C4, P1, JFK)
168 Fly(P2, JFK, ORD)
169 Load(C3, P1, JFK)
170 Fly(P2, ORD, ATL)
171 Fly(P1, JFK, ORD)
172 Fly(P2, ATL, SFO)
173 Fly(P1, ORD, ATL)
174 Fly(P2, SFO, JFK)
175 Fly(P1, ATL, SFO)
176 Unload(C3, P1, SFO)
177 Fly(P1, SFO, ORD)
178 Fly(P2, JFK, ORD)
179 Fly(P1, ORD, ATL)
180 Fly(P2, ORD, ATL)
181 Fly(P1, ATL, JFK)
182 Fly(P2, ATL, SFO)
183 Load(C3, P2, SFO)
184 Fly(P2, SFO, ORD)
185 Fly(P1, JFK, ORD)
186 Fly(P2, ORD, ATL)
187 Fly(P1, ORD, ATL)
188 Fly(P2, ATL, JFK)
189 Fly(P1, ATL, SFO)
190 Load(C4, P2, JFK)
191 Fly(P1, SFO, ORD)
192 Fly(P2, JFK, ORD)
193 Fly(P1, ORD, ATL)
194 Fly(P2, ORD, ATL)
195 Fly(P1, ATL, JFK)
196 Fly(P2, ATL, SFO)
197 Unload(C4, P2, SFO)
198 Fly(P2, SFO, ORD)
199 Fly(P1, JFK, ORD)
200 Fly(P2, ORD, ATL)
201 Fly(P1, ORD, ATL)
202 Fly(P2, ATL, JFK)
203 Fly(P1, ATL, SFO)
204 Unload(C3, P2, JFK)
205 Fly(P1, SFO, ORD)
206 Fly(P2, JFK, ORD)
207 Fly(P1, ORD, ATL)
208 Fly(P2, ORD, ATL)
209 Fly(P1, ATL, JFK)
210 Fly(P2, ATL, SFO)
211 Load(C4, P2, SFO)
212 Fly(P2, SFO, ATL)
213 Fly(P1, JFK, ORD)
214 Unload(C4, P2, ATL)
215 Fly(P1, ORD, SFO)
216 Fly(P2, ATL, ORD)
217 Fly(P1, SFO, JFK)
218 Fly(P2, ORD, SFO)
219 Fly(P1, JFK, ATL)
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220 Fly(P2, SFO, JFK)
221 Load(C3, P2, JFK)
222 Fly(P1, ATL, ORD)
223 Fly(P2, JFK, ORD)
224 Fly(P1, ORD, SFO)
225 Fly(P2, ORD, ATL)
226 Unload(C3, P2, ATL)
227 Fly(P2, ATL, ORD)
228 Fly(P1, SFO, ORD)
229 Fly(P2, ORD, SFO)
230 Fly(P1, ORD, ATL)
231 Fly(P2, SFO, JFK)
232 Fly(P1, ATL, JFK)
233 Load(C2, P2, JFK)
234 Fly(P2, JFK, ORD)
235 Fly(P1, JFK, ORD)
236 Fly(P2, ORD, ATL)
237 Fly(P1, ORD, ATL)
238 Fly(P2, ATL, SFO)
239 Fly(P1, ATL, SFO)
240 Unload(C2, P2, SFO)
241 Fly(P2, SFO, ORD)
242 Fly(P1, SFO, ORD)
243 Fly(P2, ORD, ATL)
244 Fly(P1, ORD, ATL)
245 Fly(P2, ATL, JFK)
246 Fly(P1, ATL, JFK)
247 Load(C1, P2, JFK)
248 Fly(P2, JFK, ORD)
249 Fly(P1, JFK, ORD)
250 Fly(P2, ORD, ATL)
251 Fly(P1, ORD, ATL)
252 Fly(P2, ATL, SFO)
253 Fly(P1, ATL, SFO)
254 Unload(C1, P2, SFO)
255 Fly(P2, SFO, ORD)
256 Fly(P1, SFO, ORD)
257 Fly(P2, ORD, ATL)
258 Fly(P1, ORD, ATL)
259 Fly(P2, ATL, JFK)
260 Load(C4, P1, ATL)
261 Fly(P1, ATL, ORD)
262 Fly(P2, JFK, ORD)
263 Fly(P1, ORD, SFO)
264 Fly(P2, ORD, ATL)
265 Fly(P1, SFO, JFK)
266 Fly(P2, ATL, SFO)
267 Unload(C4, P1, JFK)
268 Fly(P2, SFO, ORD)
269 Fly(P1, JFK, ORD)
270 Fly(P2, ORD, ATL)
271 Fly(P1, ORD, ATL)
272 Fly(P2, ATL, JFK)
273 Fly(P1, ATL, SFO)
274 Load(C2, P1, SFO)
275 Fly(P1, SFO, ORD)
276 Fly(P2, JFK, ORD)
277 Fly(P1, ORD, ATL)
278 Fly(P2, ORD, ATL)
279 Fly(P1, ATL, JFK)
280 Fly(P2, ATL, SFO)
281 Unload(C2, P1, JFK)
282 Fly(P2, SFO, ORD)
283 Fly(P1, JFK, ORD)
284 Fly(P2, ORD, ATL)
285 Fly(P1, ORD, ATL)
286 Fly(P2, ATL, JFK)
287 Fly(P1, ATL, SFO)
288 Load(C1, P1, SFO)
289 Fly(P1, SFO, ORD)
290 Fly(P2, JFK, ORD)
291 Fly(P1, ORD, ATL)
292 Fly(P2, ORD, ATL)
293 Fly(P1, ATL, JFK)
294 Fly(P2, ATL, SFO)
295 Unload(C1, P1, JFK)
296 Fly(P2, SFO, ORD)
297 Fly(P1, JFK, ORD)
298 Fly(P2, ORD, JFK)
299 Fly(P1, ORD, SFO)
300 Load(C4, P2, JFK)
301 Fly(P1, SFO, ATL)
302 Fly(P2, JFK, SFO)
303 Fly(P1, ATL, ORD)
304 Unload(C4, P2, SFO)
305 Fly(P1, ORD, SFO)
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306 Fly(P2, SFO, ORD)
307 Fly(P1, SFO, ATL)
308 Fly(P2, ORD, JFK)
309 Fly(P1, ATL, JFK)
310 Fly(P2, JFK, ATL)
311 Load(C2, P1, JFK)
312 Fly(P2, ATL, ORD)
313 Fly(P1, JFK, ORD)
314 Fly(P2, ORD, SFO)
315 Fly(P1, ORD, ATL)
316 Fly(P2, SFO, JFK)
317 Fly(P1, ATL, SFO)
318 Unload(C2, P1, SFO)
319 Fly(P1, SFO, ORD)
320 Fly(P2, JFK, ORD)
321 Fly(P1, ORD, ATL)
322 Fly(P2, ORD, ATL)
323 Fly(P1, ATL, JFK)
324 Fly(P2, ATL, SFO)
325 Load(C4, P2, SFO)
326 Fly(P2, SFO, ORD)
327 Fly(P1, JFK, SFO)
328 Fly(P2, ORD, ATL)
329 Load(C3, P2, ATL)
330 Fly(P2, ATL, ORD)
331 Fly(P1, SFO, ORD)
332 Fly(P2, ORD, SFO)
333 Fly(P1, ORD, ATL)
334 Fly(P2, SFO, JFK)
335 Fly(P1, ATL, JFK)
336 Unload(C4, P2, JFK)
337 Fly(P2, JFK, ORD)
338 Fly(P1, JFK, ORD)
339 Fly(P2, ORD, ATL)
340 Fly(P1, ORD, ATL)
341 Fly(P2, ATL, SFO)
342 Fly(P1, ATL, SFO)
343 Unload(C3, P2, SFO)
344 Fly(P2, SFO, ORD)
345 Fly(P1, SFO, ORD)
346 Fly(P2, ORD, ATL)
347 Fly(P1, ORD, ATL)
348 Fly(P2, ATL, JFK)
349 Fly(P1, ATL, JFK)
350 Load(C4, P2, JFK)
351 Fly(P2, JFK, ORD)
352 Fly(P1, JFK, ORD)
353 Fly(P2, ORD, ATL)
354 Fly(P1, ORD, ATL)
355 Unload(C4, P2, ATL)
356 Fly(P2, ATL, ORD)
357 Fly(P1, ATL, ORD)
358 Fly(P2, ORD, SFO)
359 Fly(P1, ORD, SFO)
360 Fly(P2, SFO, JFK)
361 Fly(P1, SFO, JFK)
362 Load(C1, P2, JFK)
363 Fly(P2, JFK, ORD)
364 Fly(P1, JFK, ORD)
365 Fly(P2, ORD, ATL)
366 Fly(P1, ORD, ATL)
367 Fly(P2, ATL, SFO)
368 Fly(P1, ATL, SFO)
369 Unload(C1, P2, SFO)
370 Fly(P2, SFO, ORD)
371 Fly(P1, SFO, ORD)
372 Fly(P2, ORD, ATL)
373 Fly(P1, ORD, ATL)
374 Fly(P2, ATL, JFK)
375 Load(C4, P1, ATL)
376 Fly(P1, ATL, SFO)
377 Fly(P2, JFK, ORD)
378 Fly(P1, SFO, JFK)
379 Fly(P2, ORD, ATL)
380 Fly(P1, JFK, ORD)
381 Fly(P2, ATL, SFO)
382 Load(C3, P2, SFO)
383 Fly(P1, ORD, ATL)
384 Fly(P2, SFO, ORD)
385 Fly(P1, ATL, SFO)
386 Fly(P2, ORD, JFK)
387 Fly(P1, SFO, JFK)
388 Unload(C3, P2, JFK)
389 Fly(P2, JFK, ORD)
390 Fly(P1, JFK, ATL)
391 Fly(P2, ORD, ATL)
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392 Fly(P1, ATL, ORD)
393 Fly(P2, ATL, SFO)
394 Fly(P1, ORD, SFO)
395 Unload(C4, P1, SFO)
396 Fly(P2, SFO, ORD)
397 Fly(P1, SFO, ORD)
398 Fly(P2, ORD, ATL)
399 Fly(P1, ORD, ATL)
400 Fly(P2, ATL, JFK)
401 Fly(P1, ATL, JFK)
402 Load(C3, P2, JFK)
403 Fly(P2, JFK, ORD)
404 Fly(P1, JFK, ORD)
405 Fly(P2, ORD, ATL)
406 Fly(P1, ORD, ATL)
407 Fly(P2, ATL, SFO)
408 Fly(P1, ATL, SFO)
409 Unload(C3, P2, SFO)
410 Fly(P1, SFO, ORD)
411 Load(C4, P2, SFO)
412 Fly(P1, ORD, ATL)
413 Fly(P2, SFO, JFK)
414 Fly(P1, ATL, SFO)
415 Fly(P2, JFK, ORD)
416 Load(C3, P1, SFO)
417 Fly(P2, ORD, ATL)
418 Fly(P1, SFO, ORD)
419 Fly(P2, ATL, SFO)
420 Fly(P1, ORD, ATL)
421 Fly(P2, SFO, JFK)
422 Fly(P1, ATL, JFK)
423 Unload(C4, P2, JFK)
424 Fly(P2, JFK, ORD)
425 Fly(P1, JFK, ORD)
426 Fly(P2, ORD, ATL)
427 Fly(P1, ORD, SFO)
428 Fly(P2, ATL, SFO)
429 Fly(P1, SFO, ATL)
430 Load(C2, P2, SFO)
431 Fly(P1, ATL, ORD)
432 Fly(P2, SFO, ORD)
433 Fly(P1, ORD, SFO)
434 Fly(P2, ORD, ATL)
435 Fly(P1, SFO, JFK)
436 Fly(P2, ATL, JFK)
437 Unload(C2, P2, JFK)
438 Fly(P2, JFK, ORD)
439 Fly(P1, JFK, ORD)
440 Fly(P2, ORD, ATL)
441 Fly(P1, ORD, SFO)
442 Fly(P2, ATL, SFO)
443 Fly(P1, SFO, ATL)
444 Load(C1, P2, SFO)
445 Fly(P1, ATL, ORD)
446 Fly(P2, SFO, ORD)
447 Fly(P1, ORD, SFO)
448 Fly(P2, ORD, ATL)
449 Fly(P1, SFO, JFK)
450 Fly(P2, ATL, JFK)
451 Load(C4, P2, JFK)
452 Fly(P2, JFK, ORD)
453 Fly(P1, JFK, ORD)
454 Fly(P2, ORD, ATL)
455 Fly(P1, ORD, ATL)
456 Fly(P2, ATL, SFO)
457 Fly(P1, ATL, SFO)
458 Unload(C4, P2, SFO)
459 Fly(P2, SFO, ORD)
460 Fly(P1, SFO, ORD)
461 Fly(P2, ORD, ATL)
462 Fly(P1, ORD, ATL)
463 Fly(P2, ATL, JFK)
464 Fly(P1, ATL, JFK)
465 Unload(C1, P2, JFK)
466 Fly(P2, JFK, ORD)
467 Fly(P1, JFK, ORD)
468 Fly(P2, ORD, ATL)
469 Fly(P1, ORD, ATL)
470 Fly(P2, ATL, SFO)
471 Fly(P1, ATL, SFO)
472 Unload(C3, P1, SFO)
473 Fly(P2, SFO, ORD)
474 Fly(P1, SFO, ORD)
475 Fly(P2, ORD, ATL)
476 Fly(P1, ORD, ATL)
477 Fly(P2, ATL, JFK)
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478 Fly(P1, ATL, JFK)
479 Load(C2, P2, JFK)
480 Fly(P2, JFK, ORD)
481 Fly(P1, JFK, ORD)
482 Fly(P2, ORD, ATL)
483 Fly(P1, ORD, ATL)
484 Fly(P2, ATL, SFO)
485 Fly(P1, ATL, SFO)
486 Unload(C2, P2, SFO)
487 Fly(P2, SFO, ORD)
488 Fly(P1, SFO, ORD)
489 Fly(P2, ORD, ATL)
490 Fly(P1, ORD, ATL)
491 Fly(P2, ATL, JFK)
492 Fly(P1, ATL, JFK)
493 Load(C1, P2, JFK)
494 Fly(P2, JFK, ORD)
495 Fly(P1, JFK, ORD)
496 Fly(P2, ORD, ATL)
497 Fly(P1, ORD, ATL)
498 Fly(P2, ATL, SFO)
499 Load(C2, P2, SFO)
500 Fly(P1, ATL, ORD)
501 Fly(P2, SFO, ORD)
502 Fly(P1, ORD, SFO)
503 Fly(P2, ORD, ATL)
504 Fly(P1, SFO, JFK)
505 Unload(C2, P2, ATL)
506 Fly(P2, ATL, ORD)
507 Fly(P1, JFK, ORD)
508 Fly(P2, ORD, SFO)
509 Fly(P1, ORD, ATL)
510 Fly(P2, SFO, JFK)
511 Fly(P1, ATL, SFO)
512 Unload(C1, P2, JFK)
513 Fly(P1, SFO, ORD)
514 Fly(P2, JFK, ORD)
515 Fly(P1, ORD, ATL)
516 Fly(P2, ORD, SFO)
517 Fly(P1, ATL, JFK)
518 Fly(P2, SFO, ATL)
519 Load(C1, P1, JFK)
520 Fly(P2, ATL, ORD)
521 Fly(P1, JFK, ORD)
522 Fly(P2, ORD, SFO)
523 Fly(P1, ORD, ATL)
524 Fly(P2, SFO, JFK)
525 Fly(P1, ATL, SFO)
526 Unload(C1, P1, SFO)
527 Fly(P1, SFO, ORD)
528 Fly(P2, JFK, ORD)
529 Fly(P1, ORD, ATL)
530 Fly(P2, ORD, ATL)
531 Fly(P1, ATL, JFK)
532 Fly(P2, ATL, SFO)
533 Load(C4, P2, SFO)
534 Fly(P2, SFO, ORD)
535 Fly(P1, JFK, ORD)
536 Fly(P2, ORD, ATL)
537 Fly(P1, ORD, ATL)
538 Fly(P2, ATL, JFK)
539 Fly(P1, ATL, SFO)
540 Unload(C4, P2, JFK)
541 Fly(P1, SFO, ORD)
542 Fly(P2, JFK, ORD)
543 Fly(P1, ORD, ATL)
544 Fly(P2, ORD, ATL)
545 Fly(P1, ATL, JFK)
546 Fly(P2, ATL, SFO)
547 Load(C3, P2, SFO)
548 Fly(P2, SFO, ORD)
549 Fly(P1, JFK, ORD)
550 Fly(P2, ORD, ATL)
551 Fly(P1, ORD, ATL)
552 Fly(P2, ATL, JFK)
553 Fly(P1, ATL, SFO)
554 Unload(C3, P2, JFK)
555 Fly(P1, SFO, ORD)
556 Fly(P2, JFK, ORD)
557 Fly(P1, ORD, ATL)
558 Fly(P2, ORD, ATL)
559 Fly(P1, ATL, JFK)
560 Fly(P2, ATL, SFO)
561 Load(C1, P2, SFO)
562 Fly(P2, SFO, ORD)
563 Fly(P1, JFK, ORD)
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564 Fly(P2, ORD, ATL)
565 Fly(P1, ORD, ATL)
566 Fly(P2, ATL, JFK)
567 Fly(P1, ATL, SFO)
568 Unload(C1, P2, JFK)
569 Fly(P1, SFO, ORD)
570 Fly(P2, JFK, ORD)
571 Fly(P1, ORD, ATL)
572 Fly(P2, ORD, ATL)
573 Fly(P1, ATL, JFK)
574 Fly(P2, ATL, SFO)
575 Load(C4, P1, JFK)
576 Fly(P2, SFO, ORD)
577 Fly(P1, JFK, ORD)
578 Fly(P2, ORD, ATL)
579 Fly(P1, ORD, ATL)
580 Fly(P2, ATL, JFK)
581 Fly(P1, ATL, SFO)
582 Unload(C4, P1, SFO)
583 Fly(P1, SFO, ORD)
584 Fly(P2, JFK, ORD)
585 Fly(P1, ORD, ATL)
586 Fly(P2, ORD, ATL)
587 Fly(P1, ATL, JFK)
588 Fly(P2, ATL, SFO)
589 Load(C4, P2, SFO)
590 Fly(P2, SFO, ORD)
591 Fly(P1, JFK, ORD)
592 Fly(P2, ORD, ATL)
593 Fly(P1, ORD, ATL)
594 Fly(P2, ATL, JFK)
595 Load(C2, P1, ATL)
596 Fly(P1, ATL, ORD)
597 Fly(P2, JFK, ORD)
598 Fly(P1, ORD, SFO)
599 Fly(P2, ORD, ATL)
600 Unload(C4, P2, ATL)
601 Fly(P2, ATL, ORD)
602 Fly(P1, SFO, ORD)
603 Fly(P2, ORD, SFO)
604 Fly(P1, ORD, ATL)
605 Fly(P2, SFO, JFK)
606 Fly(P1, ATL, JFK)
607 Load(C3, P2, JFK)
608 Fly(P2, JFK, ORD)
609 Fly(P1, JFK, ORD)
610 Fly(P2, ORD, ATL)
611 Fly(P1, ORD, ATL)
612 Fly(P2, ATL, SFO)
613 Unload(C2, P1, ATL)
614 Fly(P1, ATL, ORD)
615 Fly(P2, SFO, ORD)
616 Fly(P1, ORD, SFO)
617 Fly(P2, ORD, ATL)
618 Fly(P1, SFO, JFK)
619 Fly(P2, ATL, JFK)
620 Unload(C3, P2, JFK)
621 Fly(P2, JFK, ORD)
622 Fly(P1, JFK, ORD)
623 Fly(P2, ORD, SFO)
624 Fly(P1, ORD, SFO)
625 Fly(P2, SFO, ATL)
626 Load(C2, P2, ATL)
627 Fly(P2, ATL, ORD)
628 Fly(P1, SFO, ORD)
629 Fly(P2, ORD, SFO)
630 Fly(P1, ORD, ATL)
631 Unload(C2, P2, SFO)
632 Fly(P1, ATL, SFO)
633 Fly(P2, SFO, JFK)
634 Fly(P1, SFO, ORD)
635 Fly(P2, JFK, ORD)
636 Fly(P1, ORD, JFK)
637 Fly(P2, ORD, ATL)
638 Load(C4, P2, ATL)
639 Fly(P2, ATL, ORD)
640 Fly(P1, JFK, ORD)
641 Fly(P2, ORD, SFO)
642 Fly(P1, ORD, ATL)
643 Unload(C4, P2, SFO)
644
645
646 Solving Air Cargo Problem 3 using astar_search with h_1...
647
648 Expansions Goal Tests New Nodes
649 18235 18237 159716

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650
651 Plan length: 12 Time elapsed in seconds: 452.49461412800156
652 Load(C1, P1, SFO)
653 Load(C2, P2, JFK)
654 Fly(P1, SFO, ATL)
655 Load(C3, P1, ATL)
656 Fly(P2, JFK, ORD)
657 Load(C4, P2, ORD)
658 Fly(P2, ORD, SFO)
659 Fly(P1, ATL, JFK)
660 Unload(C4, P2, SFO)
661 Unload(C3, P1, JFK)
662 Unload(C1, P1, JFK)
663 Unload(C2, P2, SFO)
664
665
666 Solving Air Cargo Problem 3 using astar_search with h_ignore_preconditions...
667
668 Expansions  Goal Tests  New Nodes
669      5118      5120      45650
670
671 Plan length: 12 Time elapsed in seconds: 99.0986766499991
672 Load(C2, P2, JFK)
673 Fly(P2, JFK, ORD)
674 Load(C4, P2, ORD)
675 Fly(P2, ORD, SFO)
676 Unload(C4, P2, SFO)
677 Load(C1, P1, SFO)
678 Fly(P1, SFO, ATL)
679 Load(C3, P1, ATL)
680 Fly(P1, ATL, JFK)
681 Unload(C3, P1, JFK)
682 Unload(C1, P1, JFK)
683 Unload(C2, P2, SFO)
684
685
686 Solving Air Cargo Problem 3 using astar_search with h_pg_levelsum...
687
688 Expansions  Goal Tests  New Nodes
689      408      410      3758
690
691 Plan length: 12 Time elapsed in seconds: 2017.6254424609997
692 Load(C2, P2, JFK)
693 Fly(P2, JFK, ORD)
694 Load(C4, P2, ORD)
695 Fly(P2, ORD, SFO)
696 Load(C1, P1, SFO)
697 Fly(P1, SFO, ATL)
698 Load(C3, P1, ATL)
699 Fly(P1, ATL, JFK)
700 Unload(C4, P2, SFO)
701 Unload(C3, P1, JFK)
702 Unload(C1, P1, JFK)
703 Unload(C2, P2, SFO)
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