Heuristic Analysis: Air Cargo Planning

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1 Air Cargo Problem 1

The search results metrics for Air Cargo Problem 1 are shown in table 1. The some of the plans generated are shown in table 2. The outputs of all the search algorithms are in section A.1.

Search Algorithm	Expansions	Goal Tests	New Nodes	Plan length	Time Elapsed
Breadth First	43	56	180	6	0.044s
Breadth First Tree	1458	1459	5960	6	1.399s
Depth First Graph	21	22	84	20	0.021s
Depth Limited Search	101	271	414	50	0.127s
Uniform Cost Search	55	57	224	6	0.054s
Recursive Best First Search with H1	4229	4230	17023	6	3.975s
Greedy Best First Graph Search with H1	7	9	28	6	0.007s
A* with H1	55	57	224	6	0.053s
A* with H ignore preconditions	41	43	170	6	0.055s
A* with H PG levelsum	11	13	50	6	16.195s

Table 1: Air Cargo Problem 1

Search Algorithm	Plan	Optimal?
Breadth First	Load(C1, P1, SFO)	Yes
	Load(C2, P2, JFK)	
	Fly(P2, JFK, SFO)	
	Unload(C2, P2, SFO)	
	Fly(P1, SFO, JFK)	
	Unload(C1, P1, JFK)	
Depth First Graph	Fly(P1, SFO, JFK)	No
	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)	
Greedy Best First Graph Search with H1	Load(C1, P1, SFO)	Yes
	Load(C2, P2, JFK)	
	Fly(P1, SFO, JFK)	
	Fly(P2, JFK, SFO)	
	Unload(C1, P1, JFK)	
	Unload(C2, P2, SFO)	
A* with H1	Load(C1, P1, SFO)	Yes
	Load(C2, P2, JFK)	
	Fly(P1, SFO, JFK)	
	Fly(P2, JFK, SFO)	
	Unload(C1, P1, JFK)	
	Unload(C2, P2, SFO)	

Table 2: Air Cargo Problem 1 Plans

2 Air Cargo Problem 2

The search results metrics for Air Cargo Problem 2 are shown in table 3. The some of the plans generated are shown in table 5. The outputs of all the search algorithms are in section A.2.

Search Algorithm	Expansions	Goal Tests	New Nodes	Plan length	Time Elapsed
Breadth First	3343	4609	30509	9	11.624s
Breadth First Tree					>10m
Depth First Graph	624	625	5602	619	5.296s
Depth Limited Search					>10m
Uniform Cost Search	4853	4855	44041	9	16.794s
Recursive Best First Search with H1					>10m
Greedy Best First Graph Search with H1	998	1000	8982	15	3.393s
A* with H1	4853	4855	44041	9	16.951s
A* with H ignore preconditions	1450	1452	13303	9	6.118s
A* with H PG levelsum					>10m

Table 3: Air Cargo Problem 2

Search Algorithm	Plan	Optimal?
Breadth First	Load(C1, P1, SFO)	Yes
	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)	
Depth First Graph	Plan length is 619 steps.	No
	See A.2 on page 9	
Greedy Best First Graph Search with H1	Load(C1, P1, SFO)	No
	Load(C2, P2, JFK)	
	Load(C3, P3, ATL)	
	Fly(P1, SFO, ATL)	
	Fly(P2, JFK, ATL)	
	Fly(P3, ATL, SFO)	
	Fly(P2, ATL, SFO)	
	Unload(C2, P2, SFO)	
	Load(C2, P3, SFO)	
	Fly(P2, SFO, ATL)	
	Fly(P1, ATL, JFK)	
	Unload(C1, P1, JFK)	
	Fly(P1, JFK, ATL)	
	Unload(C3, P3, SFO)	
	Unload(C2, P3, SFO)	
A* with H1	Load(C1, P1, SFO)	Yes
	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)	

Table 5: Air Cargo Problem 2 Plans

3 Air Cargo Problem 3

The search results metrics for Air Cargo Problem 3 are shown in table 6. The some of the plans generated are shown in table 7. The outputs of all the search algorithms are in section A.3.

Search Algorithm	Expansions	Goal Tests	New Nodes	Plan length	Time Elapsed
Breadth First	14663	18098	129631	12	58.170s
Breadth First Tree					>10m
Depth First Graph	408	409	3364	392	2.630s
Depth Limited Search					>10m
Uniform Cost Search	18223	18225	159618	12	72.813s
Recursive Best First Search with H1					>10m
Greedy Best First Graph Search with H1	5578	5580	49150	22	22.549s
A* with H1	18223	18225	159618	12	72.326s
A* with H ignore preconditions	5040	5042	44944	12	24.146s
A* with H PG levelsum					>10m

Table 6: Air Cargo Problem 3

Search Algorithm	Plan	Optimal?
Breadth First	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)	Yes
Depth First Graph	Plan length is 392 steps. See A.3 on page 15	No
Greedy Best First Graph Search with H1	Load(C1, P1, SFO) Load(C2, P2, JFK) Fly(P1, SFO, ORD) Load(C4, P1, ORD) Fly(P2, JFK, ATL) Load(C3, P2, ATL) Fly(P2, ATL, ORD) Fly(P1, ORD, ATL) Unload(C4, P1, ATL) Fly(P1, ATL, ORD) Fly(P2, ORD, ATL) Load(C4, P2, ATL) Fly(P2, ATL, ORD) Unload(C3, P2, ORD) Load(C3, P1, ORD) Fly(P1, ORD, JFK) Unload(C3, P1, JFK) Unload(C1, P1, JFK) Fly(P1, JFK, ORD) Fly(P2, ORD, SFO) Unload(C4, P2, SFO) Unload(C2, P2, SFO)	No
A* with H1	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)	Yes

Table 7: Air Cargo Problem 3 Plans

4 Analysis

4.1 Non Heuristic

Of the non heuristic algorithms *Breadth First* and *Uniform Cost* were able to always find an optimal plan. Both takes more time than *Depth First* or *Greedy Best First Graph*, but the plans generated are shorter. *Breadth First* and *Uniform Cost* explore shorter plans first, so it helps to keep the generated plans smaller.

Depth First and *Greedy Best First Graph* are among the fastests algorithms evaluated, but generated plans almost one or two orders of magnitude longers than the optimal. *Depth First* and *Greedy Best First Graph* tend to do the least expansions, that explains why are so fast.

Depending on what we are trying to optimize one algorithm could be better than the other one. If we want the best plan then *Breadth First* or *Uniform Cost* are our best option, but if we want to have a plan quickly, any plan, then *Depth First* or *Greedy Best First Graph* could be a better option.

But that depends on the nature of the problem to solve. If the tree of options have a lot of depth branches that are dead ends towards our goal then *Depth First* would require more time than *Breadth First*, for example. In this cases it would be better to benchmark our algorithms against our new data/problem, or maybe consider an informed search algorithm, like A*.

4.2 Heuristic

A* is more complex than non-heuristic algorithms, but have the advantage that explore the steps space smarter, given a "distance" function.

H PG levelsum was too complex for the task, it performed poorly and it didn't even finished in the 10 minutes allocated per run in the last two problems. In the first one it was more than 2 orders of magnitude slower than the other A* algorithms.

A* ignoring preconditions performed in general better than *H1*: it had less expansions, new nodes and goal tests. Also, tend to perform faster than H1.

Given that we actually have a function to measure our distance towards the goal then A* seems a better option than non-heuristic algorithms for search. If we are programming an unknown scenario, when we can't tip A* regarding the distance to goal, then *Breadth First* or *Uniform Cost* could be a better option, at least during the exploratory phase of our problem.

A Run search outputs

A.1 Air Cargo Problem 1 outputs

```
1  $ for s in {1..10}; do python run_search.py -s $s -p 1 ; done
```

Breath First Search

```
1  Solving Air Cargo Problem 1 using breadth_first_search...
2
3  Expansions   Goal Tests   New Nodes
4     43           56          180
5
6  Plan length: 6  Time elapsed in seconds: 0.04448499000136508
7  Load(C1, P1, SFO)
8  Load(C2, P2, JFK)
9  Fly(P2, JFK, SFO)
10 Unload(C2, P2, SFO)
11 Fly(P1, SFO, JFK)
12 Unload(C1, P1, JFK)
```

Breath First Tree Search

```
1  Solving Air Cargo Problem 1 using breadth_first_tree_search...
```

```
2
3  Expansions   Goal Tests   New Nodes
4    1458         1459         5960
5
6  Plan length: 6  Time elapsed in seconds: 1.3990620490003494
7  Load(C1, P1, SFO)
8  Load(C2, P2, JFK)
9  Fly(P2, JFK, SFO)
10 Unload(C2, P2, SFO)
11 Fly(P1, SFO, JFK)
12 Unload(C1, P1, JFK)
```

Depth First Graph Search

```
1  Solving Air Cargo Problem 1 using depth_first_graph_search...
2
3  Expansions   Goal Tests   New Nodes
4     21           22           84
5
6  Plan length: 20  Time elapsed in seconds: 0.02115705000323942
7  Fly(P1, SFO, JFK)
8  Fly(P2, JFK, SFO)
9  Load(C2, P1, JFK)
```

```
10   Fly(P1, JFK, SFO)
11   Fly(P2, SFO, JFK)
12   Unload(C2, P1, SFO)
13   Fly(P1, SFO, JFK)
14   Fly(P2, JFK, SFO)
15   Load(C2, P2, SFO)
16   Fly(P1, JFK, SFO)
17   Load(C1, P2, SFO)
18   Fly(P2, SFO, JFK)
19   Fly(P1, SFO, JFK)
20   Unload(C2, P2, JFK)
21   Unload(C1, P2, JFK)
22   Fly(P2, JFK, SFO)
23   Load(C2, P1, JFK)
24   Fly(P1, JFK, SFO)
25   Fly(P2, SFO, JFK)
26   Unload(C2, P1, SFO)
```

Depth Limited Search

```
1    Solving Air Cargo Problem 1 using depth_limited_search...
2
3    Expansions   Goal Tests   New Nodes
4      101          271          414
5
6    Plan length: 50  Time elapsed in seconds: 0.1274095730004774
7    Load(C1, P1, SFO)
8    Load(C2, P2, JFK)
9    Unload(C1, P1, SFO)
10   Load(C1, P1, SFO)
11   Unload(C1, P1, SFO)
12   Load(C1, P1, SFO)
13   Unload(C1, P1, SFO)
14   Load(C1, P1, SFO)
15   Unload(C1, P1, SFO)
16   Load(C1, P1, SFO)
17   Unload(C1, P1, SFO)
18   Load(C1, P1, SFO)
19   Unload(C1, P1, SFO)
20   Load(C1, P1, SFO)
21   Unload(C1, P1, SFO)
22   Load(C1, P1, SFO)
23   Unload(C1, P1, SFO)
24   Load(C1, P1, SFO)
25   Unload(C1, P1, SFO)
26   Load(C1, P1, SFO)
27   Unload(C1, P1, SFO)
28   Load(C1, P1, SFO)
29   Unload(C1, P1, SFO)
30   Load(C1, P1, SFO)
31   Unload(C1, P1, SFO)
32   Load(C1, P1, SFO)
33   Unload(C1, P1, SFO)
34   Load(C1, P1, SFO)
35   Unload(C1, P1, SFO)
36   Load(C1, P1, SFO)
37   Unload(C1, P1, SFO)
38   Load(C1, P1, SFO)
39   Unload(C1, P1, SFO)
40   Load(C1, P1, SFO)
41   Unload(C1, P1, SFO)
42   Load(C1, P1, SFO)
43   Unload(C1, P1, SFO)
44   Load(C1, P1, SFO)
45   Unload(C1, P1, SFO)
46   Load(C1, P1, SFO)
47   Unload(C1, P1, SFO)
48   Load(C1, P1, SFO)
49   Unload(C1, P1, SFO)
50   Load(C1, P1, SFO)
51   Unload(C1, P1, SFO)
```

```
52   Load(C1, P1, SFO)
53   Fly(P2, JFK, SFO)
54   Unload(C2, P2, SFO)
55   Fly(P1, SFO, JFK)
56   Unload(C1, P1, JFK)
```

Uniform Cost Search

```
1    Solving Air Cargo Problem 1 using uniform_cost_search...
2
3    Expansions   Goal Tests   New Nodes
4      55           57           224
5
6    Plan length: 6  Time elapsed in seconds: 0.05396067100082291
7    Load(C1, P1, SFO)
8    Load(C2, P2, JFK)
9    Fly(P1, SFO, JFK)
10   Fly(P2, JFK, SFO)
11   Unload(C1, P1, JFK)
12   Unload(C2, P2, SFO)
```

Recursive Best First Search with H1

```
1    Solving Air Cargo Problem 1 using recursive_best_first_search with h_1
        ...
2
3    Expansions   Goal Tests   New Nodes
4      4229         4230         17023
5
6    Plan length: 6  Time elapsed in seconds: 3.9745941549990675
7    Load(C2, P2, JFK)
8    Load(C1, P1, SFO)
9    Fly(P2, JFK, SFO)
10   Unload(C2, P2, SFO)
11   Fly(P1, SFO, JFK)
12   Unload(C1, P1, JFK)
```

Greedy Best First Graph Search with H1

```
1    Solving Air Cargo Problem 1 using greedy_best_first_graph_search with
        h_1...
2
3    Expansions   Goal Tests   New Nodes
4      7            9            28
5
6    Plan length: 6  Time elapsed in seconds: 0.007396945002255961
7    Load(C1, P1, SFO)
8    Load(C2, P2, JFK)
9    Fly(P1, SFO, JFK)
10   Fly(P2, JFK, SFO)
11   Unload(C1, P1, JFK)
12   Unload(C2, P2, SFO)
```

A* with H1

```
1    Solving Air Cargo Problem 1 using astar_search with h_1...
2
3    Expansions   Goal Tests   New Nodes
4      55           57           224
5
6    Plan length: 6  Time elapsed in seconds: 0.05333613200127729
7    Load(C1, P1, SFO)
8    Load(C2, P2, JFK)
9    Fly(P1, SFO, JFK)
10   Fly(P2, JFK, SFO)
11   Unload(C1, P1, JFK)
12   Unload(C2, P2, SFO)
```

A* with H ignore preconditions

```
1  Solving Air Cargo Problem 1 using astar_search with
        h_ignore_preconditions...
2
3  Expansions   Goal Tests   New Nodes
4     41          43          170
5
6  Plan length: 6  Time elapsed in seconds: 0.05460188500001095
7  Load(C1, P1, SFO)
8  Fly(P1, SFO, JFK)
9  Unload(C1, P1, JFK)
10 Load(C2, P2, JFK)
11 Fly(P2, JFK, SFO)
12 Unload(C2, P2, SFO)
```

A* with H PG levelsum

```
1  Solving Air Cargo Problem 1 using astar_search with h_pg_levelsum...
2
3  Expansions   Goal Tests   New Nodes
4     11          13          50
5
6  Plan length: 6  Time elapsed in seconds: 16.194907643002807
7  Load(C1, P1, SFO)
8  Fly(P1, SFO, JFK)
9  Load(C2, P2, JFK)
10 Fly(P2, JFK, SFO)
11 Unload(C1, P1, JFK)
12 Unload(C2, P2, SFO)
```

A.2   Air Cargo Problem 2

```
1  $ for s in {1..10}; do time timeout 10m python run_search.py -s $s -p 2
        ; done
```

Breath First Search

```
1  Solving Air Cargo Problem 2 using breadth_first_search...
2
3  Expansions   Goal Tests   New Nodes
4    3343         4609        30509
5
6  Plan length: 9  Time elapsed in seconds: 11.624176827001065
7  Load(C1, P1, SFO)
8  Load(C2, P2, JFK)
9  Load(C3, P3, ATL)
10 Fly(P2, JFK, SFO)
11 Unload(C2, P2, SFO)
12 Fly(P1, SFO, JFK)
13 Unload(C1, P1, JFK)
14 Fly(P3, ATL, SFO)
15 Unload(C3, P3, SFO)
16
17
18 real    0m11,741s
19 user    0m11,697s
20 sys     0m0,021s
```

Breath First Tree Search

```
1  Solving Air Cargo Problem 2 using breadth_first_tree_search...
2
3  real    10m0,034s
4  user    9m57,763s
5  sys     0m1,155s
```

Depth First Graph Search

```
1  Solving Air Cargo Problem 2 using depth_first_graph_search...
2
```

```
3  Expansions   Goal Tests   New Nodes
4     624         625         5602
5
6  Plan length: 619  Time elapsed in seconds: 5.29603099799715
7  Fly(P3, ATL, SFO)
8  Fly(P1, SFO, ATL)
9  Fly(P3, SFO, JFK)
10 Fly(P1, ATL, JFK)
11 Fly(P2, JFK, ATL)
12 Fly(P3, JFK, ATL)
13 Fly(P2, ATL, SFO)
14 Fly(P3, ATL, SFO)
15 Load(C2, P1, JFK)
16 Fly(P2, SFO, ATL)
17 Fly(P1, JFK, ATL)
18 Fly(P2, ATL, JFK)
19 Fly(P1, ATL, SFO)
20 Fly(P3, SFO, ATL)
21 Fly(P1, SFO, JFK)
22 Load(C3, P3, ATL)
23 Fly(P3, ATL, SFO)
24 Fly(P2, JFK, ATL)
25 Fly(P3, SFO, JFK)
26 Fly(P2, ATL, SFO)
27 Fly(P1, JFK, ATL)
28 Fly(P2, SFO, JFK)
29 Fly(P1, ATL, SFO)
30 Unload(C3, P3, JFK)
31 Fly(P1, SFO, JFK)
32 Fly(P3, JFK, ATL)
33 Fly(P2, JFK, ATL)
34 Fly(P3, ATL, SFO)
35 Fly(P2, ATL, SFO)
36 Fly(P1, JFK, ATL)
37 Fly(P3, SFO, ATL)
38 Fly(P1, ATL, SFO)
39 Unload(C2, P1, SFO)
40 Fly(P3, ATL, SFO)
41 Fly(P2, SFO, ATL)
42 Fly(P1, SFO, ATL)
43 Fly(P2, ATL, JFK)
44 Fly(P1, ATL, JFK)
45 Fly(P3, SFO, ATL)
46 Fly(P2, JFK, ATL)
47 Fly(P3, ATL, JFK)
48 Fly(P2, ATL, SFO)
49 Fly(P1, JFK, ATL)
50 Load(C3, P3, JFK)
51 Fly(P1, ATL, SFO)
52 Fly(P2, SFO, ATL)
53 Fly(P3, JFK, ATL)
54 Fly(P2, ATL, JFK)
55 Fly(P3, ATL, SFO)
56 Fly(P1, SFO, ATL)
57 Fly(P2, JFK, ATL)
58 Fly(P1, ATL, JFK)
59 Fly(P2, ATL, SFO)
60 Fly(P3, SFO, ATL)
61 Unload(C3, P3, ATL)
62 Fly(P3, ATL, SFO)
63 Fly(P2, SFO, ATL)
64 Fly(P3, SFO, JFK)
65 Fly(P2, ATL, JFK)
66 Fly(P1, JFK, ATL)
67 Fly(P3, JFK, ATL)
68 Fly(P2, JFK, ATL)
69 Load(C3, P2, ATL)
70 Fly(P3, ATL, SFO)
71 Fly(P2, ATL, SFO)
72 Fly(P1, ATL, SFO)
73 Fly(P3, SFO, ATL)
```

```
 74   Fly(P2, SFO, JFK)                      145   Fly(P2, ATL, JFK)
 75   Fly(P3, ATL, JFK)                      146   Fly(P3, JFK, ATL)
 76   Fly(P1, SFO, JFK)                      147   Fly(P1, JFK, ATL)
 77   Fly(P2, JFK, SFO)                      148   Fly(P3, ATL, SFO)
 78   Unload(C3, P2, SFO)                    149   Fly(P1, ATL, SFO)
 79   Fly(P2, SFO, ATL)                      150   Unload(C3, P2, JFK)
 80   Fly(P3, JFK, ATL)                      151   Fly(P3, SFO, ATL)
 81   Fly(P2, ATL, JFK)                      152   Fly(P2, JFK, ATL)
 82   Fly(P3, ATL, SFO)                      153   Fly(P3, ATL, JFK)
 83   Load(C2, P3, SFO)                      154   Fly(P2, ATL, SFO)
 84   Fly(P3, SFO, ATL)                      155   Fly(P1, SFO, ATL)
 85   Fly(P2, JFK, ATL)                      156   Fly(P2, SFO, JFK)
 86   Fly(P3, ATL, JFK)                      157   Unload(C1, P2, JFK)
 87   Fly(P2, ATL, SFO)                      158   Fly(P1, ATL, SFO)
 88   Fly(P1, JFK, ATL)                      159   Fly(P2, JFK, ATL)
 89   Fly(P2, SFO, JFK)                      160   Fly(P1, SFO, JFK)
 90   Fly(P1, ATL, SFO)                      161   Fly(P2, ATL, SFO)
 91   Unload(C2, P3, JFK)                    162   Fly(P3, JFK, ATL)
 92   Fly(P1, SFO, JFK)                      163   Fly(P2, SFO, JFK)
 93   Fly(P3, JFK, ATL)                      164   Fly(P3, ATL, SFO)
 94   Fly(P2, JFK, ATL)                      165   Load(C3, P2, JFK)
 95   Fly(P3, ATL, SFO)                      166   Fly(P2, JFK, ATL)
 96   Fly(P2, ATL, SFO)                      167   Fly(P3, SFO, ATL)
 97   Fly(P1, JFK, ATL)                      168   Fly(P2, ATL, SFO)
 98   Fly(P3, SFO, ATL)                      169   Fly(P3, ATL, JFK)
 99   Fly(P1, ATL, SFO)                      170   Fly(P1, JFK, ATL)
100   Load(C3, P2, SFO)                      171   Fly(P2, SFO, ATL)
101   Fly(P3, ATL, SFO)                      172   Fly(P1, ATL, SFO)
102   Fly(P2, SFO, ATL)                      173   Unload(C3, P2, ATL)
103   Fly(P1, SFO, ATL)                      174   Fly(P2, ATL, SFO)
104   Fly(P2, ATL, JFK)                      175   Fly(P1, SFO, ATL)
105   Fly(P1, ATL, JFK)                      176   Fly(P2, SFO, ATL)
106   Fly(P3, SFO, ATL)                      177   Fly(P1, ATL, JFK)
107   Load(C2, P2, JFK)                      178   Fly(P3, JFK, ATL)
108   Fly(P3, ATL, JFK)                      179   Fly(P2, JFK, SFO)
109   Fly(P2, JFK, ATL)                      180   Fly(P3, ATL, SFO)
110   Fly(P1, JFK, ATL)                      181   Load(C2, P1, JFK)
111   Fly(P2, ATL, SFO)                      182   Fly(P2, SFO, ATL)
112   Fly(P1, ATL, SFO)                      183   Fly(P3, SFO, ATL)
113   Unload(C3, P2, SFO)                    184   Fly(P1, JFK, ATL)
114   Fly(P2, SFO, ATL)                      185   Fly(P2, ATL, SFO)
115   Fly(P1, SFO, ATL)                      186   Fly(P1, ATL, SFO)
116   Fly(P2, ATL, JFK)                      187   Fly(P3, ATL, JFK)
117   Fly(P3, JFK, ATL)                      188   Fly(P2, SFO, ATL)
118   Fly(P1, ATL, SFO)                      189   Unload(C2, P1, SFO)
119   Fly(P3, ATL, SFO)                      190   Fly(P2, ATL, JFK)
120   Fly(P1, SFO, JFK)                      191   Fly(P1, SFO, ATL)
121   Fly(P2, JFK, ATL)                      192   Fly(P3, JFK, ATL)
122   Fly(P3, SFO, ATL)                      193   Fly(P1, ATL, JFK)
123   Fly(P2, ATL, SFO)                      194   Fly(P3, ATL, SFO)
124   Load(C1, P2, SFO)                      195   Fly(P2, JFK, ATL)
125   Fly(P3, ATL, SFO)                      196   Fly(P1, JFK, ATL)
126   Fly(P2, SFO, ATL)                      197   Fly(P2, ATL, SFO)
127   Fly(P3, SFO, JFK)                      198   Fly(P1, ATL, SFO)
128   Fly(P2, ATL, JFK)                      199   Load(C2, P3, SFO)
129   Fly(P1, JFK, ATL)                      200   Fly(P3, SFO, ATL)
130   Fly(P3, JFK, ATL)                      201   Fly(P2, SFO, ATL)
131   Fly(P1, ATL, SFO)                      202   Fly(P1, SFO, ATL)
132   Fly(P3, ATL, SFO)                      203   Fly(P3, ATL, JFK)
133   Unload(C2, P2, JFK)                    204   Fly(P1, ATL, JFK)
134   Fly(P1, SFO, ATL)                      205   Fly(P2, ATL, SFO)
135   Fly(P2, JFK, ATL)                      206   Load(C1, P3, JFK)
136   Fly(P1, ATL, JFK)                      207   Fly(P2, SFO, JFK)
137   Fly(P3, SFO, ATL)                      208   Fly(P3, JFK, ATL)
138   Fly(P2, ATL, SFO)                      209   Fly(P2, JFK, ATL)
139   Fly(P3, ATL, JFK)                      210   Fly(P3, ATL, SFO)
140   Fly(P1, JFK, ATL)                      211   Fly(P1, JFK, ATL)
141   Load(C3, P2, SFO)                      212   Fly(P2, ATL, SFO)
142   Fly(P1, ATL, SFO)                      213   Fly(P1, ATL, SFO)
143   Fly(P2, SFO, ATL)                      214   Fly(P3, SFO, ATL)
144   Fly(P1, SFO, JFK)                      215   Unload(C2, P3, ATL)
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```
216   Fly(P3, ATL, SFO)
217   Fly(P2, SFO, ATL)
218   Fly(P1, SFO, ATL)
219   Fly(P2, ATL, JFK)
220   Fly(P1, ATL, JFK)
221   Fly(P3, SFO, JFK)
222   Fly(P2, JFK, ATL)
223   Unload(C1, P3, JFK)
224   Fly(P2, ATL, SFO)
225   Fly(P3, JFK, ATL)
226   Fly(P2, SFO, JFK)
227   Fly(P3, ATL, SFO)
228   Fly(P1, JFK, ATL)
229   Fly(P3, SFO, JFK)
230   Fly(P1, ATL, SFO)
231   Load(C1, P2, JFK)
232   Fly(P1, SFO, JFK)
233   Fly(P2, JFK, ATL)
234   Fly(P3, JFK, ATL)
235   Fly(P2, ATL, SFO)
236   Fly(P3, ATL, SFO)
237   Fly(P1, JFK, ATL)
238   Fly(P2, SFO, ATL)
239   Fly(P1, ATL, SFO)
240   Unload(C1, P2, ATL)
241   Fly(P2, ATL, SFO)
242   Fly(P1, SFO, ATL)
243   Fly(P3, SFO, ATL)
244   Fly(P1, ATL, JFK)
245   Fly(P3, ATL, JFK)
246   Fly(P2, SFO, JFK)
247   Fly(P1, JFK, ATL)
248   Fly(P2, JFK, ATL)
249   Load(C3, P2, ATL)
250   Fly(P2, ATL, SFO)
251   Fly(P1, ATL, SFO)
252   Fly(P2, SFO, JFK)
253   Fly(P1, SFO, JFK)
254   Fly(P3, JFK, ATL)
255   Fly(P2, JFK, ATL)
256   Fly(P3, ATL, SFO)
257   Fly(P2, ATL, SFO)
258   Unload(C3, P2, SFO)
259   Fly(P3, SFO, ATL)
260   Fly(P2, SFO, ATL)
261   Fly(P3, ATL, JFK)
262   Fly(P2, ATL, JFK)
263   Fly(P1, JFK, ATL)
264   Fly(P3, JFK, ATL)
265   Fly(P1, ATL, SFO)
266   Fly(P3, ATL, SFO)
267   Fly(P2, JFK, ATL)
268   Fly(P1, SFO, ATL)
269   Load(C3, P3, SFO)
270   Fly(P2, ATL, SFO)
271   Fly(P1, ATL, SFO)
272   Fly(P3, SFO, ATL)
273   Fly(P2, SFO, ATL)
274   Fly(P3, ATL, JFK)
275   Fly(P2, ATL, JFK)
276   Fly(P1, SFO, ATL)
277   Fly(P3, JFK, ATL)
278   Fly(P1, ATL, JFK)
279   Load(C2, P3, ATL)
280   Fly(P3, ATL, SFO)
281   Fly(P2, JFK, ATL)
282   Fly(P3, SFO, JFK)
283   Fly(P2, ATL, SFO)
284   Fly(P1, JFK, ATL)
285   Fly(P2, SFO, JFK)
286   Fly(P1, ATL, SFO)

287   Unload(C3, P3, JFK)
288   Fly(P1, SFO, JFK)
289   Fly(P3, JFK, ATL)
290   Fly(P2, JFK, ATL)
291   Fly(P3, ATL, SFO)
292   Fly(P2, ATL, SFO)
293   Fly(P1, JFK, ATL)
294   Fly(P3, SFO, ATL)
295   Fly(P1, ATL, SFO)
296   Unload(C2, P3, ATL)
297   Fly(P3, ATL, SFO)
298   Fly(P2, SFO, ATL)
299   Fly(P1, SFO, ATL)
300   Fly(P2, ATL, JFK)
301   Fly(P1, ATL, JFK)
302   Load(C3, P1, JFK)
303   Fly(P3, SFO, ATL)
304   Fly(P2, JFK, ATL)
305   Fly(P3, ATL, JFK)
306   Fly(P2, ATL, SFO)
307   Fly(P1, JFK, ATL)
308   Load(C2, P1, ATL)
309   Fly(P1, ATL, SFO)
310   Fly(P2, SFO, ATL)
311   Fly(P1, SFO, JFK)
312   Fly(P2, ATL, JFK)
313   Fly(P3, JFK, ATL)
314   Fly(P1, JFK, ATL)
315   Fly(P3, ATL, SFO)
316   Fly(P1, ATL, SFO)
317   Unload(C3, P1, SFO)
318   Fly(P3, SFO, ATL)
319   Fly(P1, SFO, JFK)
320   Fly(P3, ATL, JFK)
321   Fly(P2, JFK, ATL)
322   Fly(P1, JFK, ATL)
323   Fly(P2, ATL, SFO)
324   Fly(P3, JFK, ATL)
325   Load(C3, P2, SFO)
326   Fly(P3, ATL, SFO)
327   Fly(P1, ATL, SFO)
328   Fly(P2, SFO, ATL)
329   Fly(P3, SFO, ATL)
330   Fly(P2, ATL, JFK)
331   Fly(P3, ATL, JFK)
332   Fly(P1, SFO, ATL)
333   Unload(C3, P2, JFK)
334   Fly(P3, JFK, ATL)
335   Fly(P2, JFK, ATL)
336   Fly(P1, ATL, SFO)
337   Fly(P3, ATL, SFO)
338   Fly(P2, ATL, SFO)
339   Fly(P1, SFO, ATL)
340   Load(C1, P1, ATL)
341   Fly(P1, ATL, SFO)
342   Fly(P2, SFO, ATL)
343   Fly(P3, SFO, ATL)
344   Fly(P2, ATL, JFK)
345   Fly(P1, SFO, JFK)
346   Fly(P3, ATL, SFO)
347   Load(C3, P2, JFK)
348   Fly(P3, SFO, ATL)
349   Fly(P2, JFK, ATL)
350   Fly(P3, JFK, ATL)
351   Fly(P2, ATL, SFO)
352   Fly(P1, JFK, SFO)
353   Fly(P3, ATL, SFO)
354   Fly(P2, SFO, ATL)
355   Fly(P1, SFO, ATL)
356   Unload(C3, P2, ATL)
357   Fly(P2, ATL, SFO)
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358  Fly(P1, ATL, SFO)
359  Fly(P3, SFO, ATL)
360  Fly(P2, SFO, ATL)
361  Fly(P3, ATL, JFK)
362  Fly(P2, ATL, JFK)
363  Fly(P1, SFO, ATL)
364  Fly(P3, JFK, ATL)
365  Fly(P1, ATL, JFK)
366  Fly(P3, ATL, SFO)
367  Unload(C2, P1, JFK)
368  Fly(P2, JFK, ATL)
369  Fly(P3, SFO, ATL)
370  Fly(P1, JFK, ATL)
371  Fly(P2, ATL, SFO)
372  Fly(P3, ATL, SFO)
373  Fly(P1, ATL, SFO)
374  Fly(P3, SFO, JFK)
375  Fly(P2, SFO, ATL)
376  Load(C3, P2, ATL)
377  Fly(P2, ATL, SFO)
378  Fly(P1, SFO, ATL)
379  Fly(P2, SFO, JFK)
380  Fly(P3, JFK, ATL)
381  Fly(P1, ATL, SFO)
382  Fly(P3, ATL, SFO)
383  Unload(C3, P2, JFK)
384  Fly(P1, SFO, ATL)
385  Fly(P2, JFK, ATL)
386  Fly(P1, ATL, JFK)
387  Fly(P2, ATL, SFO)
388  Load(C3, P1, JFK)
389  Fly(P3, SFO, ATL)
390  Fly(P2, SFO, ATL)
391  Fly(P3, ATL, JFK)
392  Fly(P2, ATL, JFK)
393  Fly(P1, JFK, ATL)
394  Fly(P3, JFK, ATL)
395  Fly(P1, ATL, SFO)
396  Fly(P3, ATL, SFO)
397  Fly(P2, JFK, ATL)
398  Fly(P1, SFO, ATL)
399  Unload(C1, P1, ATL)
400  Fly(P2, ATL, SFO)
401  Fly(P1, ATL, SFO)
402  Fly(P3, SFO, ATL)
403  Fly(P2, SFO, ATL)
404  Fly(P3, ATL, JFK)
405  Fly(P2, ATL, JFK)
406  Unload(C3, P1, SFO)
407  Fly(P1, SFO, ATL)
408  Fly(P3, JFK, ATL)
409  Fly(P2, JFK, ATL)
410  Load(C1, P3, ATL)
411  Fly(P3, ATL, SFO)
412  Fly(P1, ATL, SFO)
413  Fly(P2, ATL, SFO)
414  Fly(P3, SFO, ATL)
415  Fly(P2, SFO, JFK)
416  Fly(P3, ATL, JFK)
417  Fly(P1, SFO, ATL)
418  Fly(P2, JFK, SFO)
419  Fly(P1, ATL, JFK)
420  Fly(P2, SFO, ATL)
421  Unload(C1, P3, JFK)
422  Fly(P2, ATL, JFK)
423  Fly(P3, JFK, ATL)
424  Fly(P1, JFK, ATL)
425  Fly(P2, JFK, ATL)
426  Fly(P3, ATL, SFO)
427  Fly(P2, ATL, SFO)
428  Fly(P1, ATL, SFO)

429  Fly(P3, SFO, ATL)
430  Load(C3, P1, SFO)
431  Fly(P3, ATL, JFK)
432  Fly(P2, SFO, ATL)
433  Fly(P1, SFO, ATL)
434  Fly(P3, JFK, ATL)
435  Fly(P2, ATL, JFK)
436  Fly(P3, ATL, SFO)
437  Fly(P1, ATL, SFO)
438  Load(C2, P2, JFK)
439  Fly(P3, SFO, ATL)
440  Fly(P1, SFO, JFK)
441  Fly(P3, ATL, JFK)
442  Fly(P2, JFK, ATL)
443  Fly(P1, JFK, ATL)
444  Fly(P2, ATL, SFO)
445  Fly(P1, ATL, SFO)
446  Unload(C3, P1, SFO)
447  Fly(P2, SFO, ATL)
448  Fly(P1, SFO, ATL)
449  Fly(P3, JFK, ATL)
450  Fly(P2, ATL, SFO)
451  Fly(P3, ATL, SFO)
452  Fly(P1, ATL, JFK)
453  Fly(P2, SFO, ATL)
454  Unload(C2, P2, ATL)
455  Fly(P2, ATL, SFO)
456  Fly(P3, SFO, ATL)
457  Fly(P2, SFO, JFK)
458  Fly(P3, ATL, JFK)
459  Fly(P1, JFK, ATL)
460  Fly(P3, JFK, SFO)
461  Fly(P1, ATL, SFO)
462  Load(C3, P3, SFO)
463  Fly(P3, SFO, ATL)
464  Fly(P1, SFO, ATL)
465  Fly(P3, ATL, JFK)
466  Fly(P1, ATL, JFK)
467  Fly(P2, JFK, ATL)
468  Fly(P3, JFK, ATL)
469  Load(C2, P3, ATL)
470  Fly(P3, ATL, SFO)
471  Fly(P2, ATL, SFO)
472  Fly(P3, SFO, JFK)
473  Fly(P2, SFO, JFK)
474  Fly(P1, JFK, ATL)
475  Fly(P2, JFK, ATL)
476  Fly(P1, ATL, SFO)
477  Load(C1, P3, JFK)
478  Fly(P2, ATL, SFO)
479  Fly(P1, SFO, ATL)
480  Fly(P3, JFK, ATL)
481  Fly(P1, ATL, JFK)
482  Fly(P3, ATL, SFO)
483  Fly(P2, SFO, ATL)
484  Fly(P1, JFK, ATL)
485  Fly(P2, ATL, JFK)
486  Fly(P1, ATL, SFO)
487  Fly(P3, SFO, ATL)
488  Unload(C2, P3, ATL)
489  Fly(P3, ATL, SFO)
490  Fly(P1, SFO, ATL)
491  Fly(P2, JFK, ATL)
492  Fly(P1, ATL, JFK)
493  Fly(P2, ATL, SFO)
494  Fly(P3, SFO, JFK)
495  Fly(P1, JFK, ATL)
496  Unload(C3, P3, JFK)
497  Fly(P1, ATL, SFO)
498  Fly(P2, SFO, ATL)
499  Fly(P1, SFO, JFK)
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```
500  Fly(P2, ATL, JFK)
501  Fly(P3, JFK, ATL)
502  Fly(P1, JFK, ATL)
503  Fly(P3, ATL, SFO)
504  Fly(P1, ATL, SFO)
505  Unload(C1, P3, SFO)
506  Fly(P3, SFO, ATL)
507  Fly(P1, SFO, ATL)
508  Fly(P3, ATL, JFK)
509  Fly(P1, ATL, JFK)
510  Fly(P2, JFK, ATL)
511  Fly(P3, JFK, ATL)
512  Fly(P2, ATL, SFO)
513  Fly(P3, ATL, SFO)
514  Load(C3, P1, JFK)
515  Fly(P2, SFO, ATL)
516  Fly(P1, JFK, ATL)
517  Fly(P2, ATL, JFK)
518  Fly(P1, ATL, SFO)
519  Fly(P3, SFO, ATL)
520  Fly(P1, SFO, JFK)
521  Load(C2, P3, ATL)
522  Fly(P3, ATL, SFO)
523  Fly(P2, JFK, ATL)
524  Fly(P3, SFO, JFK)
525  Fly(P2, ATL, SFO)
526  Fly(P1, JFK, ATL)
527  Fly(P3, JFK, ATL)
528  Fly(P1, ATL, SFO)
529  Fly(P3, ATL, SFO)
530  Unload(C3, P1, SFO)
531  Fly(P2, SFO, ATL)
532  Unload(C2, P3, SFO)
533  Load(C3, P1, SFO)
534  Fly(P2, ATL, JFK)
535  Fly(P3, SFO, ATL)
536  Fly(P2, JFK, SFO)
537  Fly(P3, ATL, JFK)
538  Fly(P1, SFO, ATL)
539  Fly(P3, JFK, SFO)
540  Fly(P1, ATL, JFK)
541  Load(C2, P2, SFO)
542  Fly(P3, SFO, ATL)
543  Fly(P2, SFO, ATL)
544  Fly(P3, ATL, JFK)
545  Fly(P2, ATL, JFK)
546  Fly(P1, JFK, ATL)
547  Fly(P3, JFK, ATL)
548  Unload(C3, P1, ATL)
549  Fly(P1, ATL, JFK)
550  Fly(P3, ATL, SFO)
551  Fly(P2, JFK, ATL)
552  Fly(P1, JFK, ATL)
553  Fly(P2, ATL, SFO)
554  Fly(P1, ATL, SFO)
555  Fly(P3, SFO, ATL)
556  Fly(P2, SFO, ATL)
557  Fly(P3, ATL, JFK)
558  Fly(P2, ATL, JFK)
559  Load(C1, P1, SFO)
560  Fly(P1, SFO, ATL)
561  Fly(P3, JFK, ATL)
562  Fly(P1, ATL, JFK)
563  Fly(P2, JFK, ATL)
564  Fly(P3, ATL, SFO)
565  Fly(P2, ATL, SFO)
566  Fly(P3, SFO, JFK)
567  Unload(C2, P2, SFO)
568  Fly(P2, SFO, ATL)
569  Fly(P3, JFK, ATL)
570  Fly(P1, JFK, ATL)
571  Fly(P3, ATL, SFO)
572  Fly(P2, ATL, SFO)
573  Unload(C1, P1, ATL)
574  Fly(P1, ATL, SFO)
575  Fly(P3, SFO, ATL)
576  Fly(P2, SFO, ATL)
577  Fly(P3, ATL, JFK)
578  Fly(P2, ATL, JFK)
579  Fly(P1, SFO, ATL)
580  Fly(P3, JFK, ATL)
581  Fly(P1, ATL, JFK)
582  Fly(P3, ATL, SFO)
583  Fly(P2, JFK, ATL)
584  Load(C3, P2, ATL)
585  Fly(P2, ATL, SFO)
586  Fly(P3, SFO, ATL)
587  Fly(P2, SFO, JFK)
588  Fly(P3, ATL, JFK)
589  Fly(P1, JFK, ATL)
590  Fly(P2, JFK, ATL)
591  Fly(P3, JFK, ATL)
592  Load(C1, P3, ATL)
593  Fly(P2, ATL, SFO)
594  Fly(P1, ATL, SFO)
595  Fly(P3, ATL, JFK)
596  Fly(P2, SFO, ATL)
597  Fly(P1, SFO, JFK)
598  Fly(P2, ATL, JFK)
599  Fly(P1, JFK, ATL)
600  Fly(P3, JFK, SFO)
601  Fly(P1, ATL, SFO)
602  Unload(C3, P2, JFK)
603  Fly(P3, SFO, ATL)
604  Fly(P1, SFO, ATL)
605  Fly(P2, JFK, ATL)
606  Fly(P3, ATL, JFK)
607  Fly(P2, ATL, SFO)
608  Fly(P1, ATL, SFO)
609  Unload(C1, P3, JFK)
610  Fly(P2, SFO, ATL)
611  Fly(P1, SFO, JFK)
612  Fly(P2, ATL, JFK)
613  Fly(P3, JFK, ATL)
614  Fly(P1, JFK, ATL)
615  Fly(P3, ATL, SFO)
616  Fly(P1, ATL, SFO)
617  Load(C3, P2, JFK)
618  Fly(P3, SFO, ATL)
619  Fly(P2, JFK, ATL)
620  Fly(P1, SFO, ATL)
621  Fly(P2, ATL, SFO)
622  Fly(P3, ATL, SFO)
623  Fly(P1, ATL, JFK)
624  Fly(P3, SFO, JFK)
625  Unload(C3, P2, SFO)
626
627
628  real    0m5,408s
629  user    0m5,388s
630  sys     0m0,012s
```

Depth Limited Search

```
1  Solving Air Cargo Problem 2 using depth_limited_search...
2
3  real    10m0,004s
4  user    9m59,298s
5  sys     0m0,059s
```

Uniform Cost Search

```
1  Solving Air Cargo Problem 2 using uniform_cost_search...
2
3  Expansions    Goal Tests    New Nodes
4    4853          4855         44041
5
6  Plan length: 9  Time elapsed in seconds: 16.79425300299772
7  Load(C1, P1, SFO)
8  Load(C2, P2, JFK)
9  Load(C3, P3, ATL)
10 Fly(P1, SFO, JFK)
11 Fly(P2, JFK, SFO)
12 Fly(P3, ATL, SFO)
13 Unload(C3, P3, SFO)
14 Unload(C2, P2, SFO)
15 Unload(C1, P1, JFK)
16
17
18 real    0m16,902s
19 user    0m16,865s
20 sys     0m0,018s
```

Recursive Best First Search with H1

```
1  Solving Air Cargo Problem 2 using recursive_best_first_search with h_1
     ...
2
3  real    10m0,004s
4  user    9m59,257s
5  sys     0m0,132s
```

Greedy Best First Graph Search with H1

```
1  Solving Air Cargo Problem 2 using greedy_best_first_graph_search with
     h_1...
2
3  Expansions    Goal Tests    New Nodes
4    998          1000          8982
5
6  Plan length: 15  Time elapsed in seconds: 3.3934196189984505
7  Load(C1, P1, SFO)
8  Load(C2, P2, JFK)
9  Load(C3, P3, ATL)
10 Fly(P1, SFO, ATL)
11 Fly(P2, JFK, ATL)
12 Fly(P3, ATL, SFO)
13 Fly(P2, ATL, SFO)
14 Unload(C2, P2, SFO)
15 Load(C2, P3, SFO)
16 Fly(P2, SFO, ATL)
17 Fly(P1, ATL, JFK)
18 Unload(C1, P1, JFK)
19 Fly(P1, JFK, ATL)
20 Unload(C3, P3, SFO)
21 Unload(C2, P3, SFO)
22
23
24 real    0m3,499s
25 user    0m3,487s
26 sys     0m0,008s
```

A* with H1

```
1  Solving Air Cargo Problem 2 using astar_search with h_1...
2
3  Expansions    Goal Tests    New Nodes
4    4853          4855         44041
5
6  Plan length: 9  Time elapsed in seconds: 16.951273193997622
7  Load(C1, P1, SFO)
8  Load(C2, P2, JFK)
```

```
9  Load(C3, P3, ATL)
10 Fly(P1, SFO, JFK)
11 Fly(P2, JFK, SFO)
12 Fly(P3, ATL, SFO)
13 Unload(C3, P3, SFO)
14 Unload(C2, P2, SFO)
15 Unload(C1, P1, JFK)
16
17
18 real    0m17,058s
19 user    0m17,016s
20 sys     0m0,025s
```

A* with H ignore preconditions

```
1  Solving Air Cargo Problem 2 using astar_search with
       h_ignore_preconditions...
2
3  Expansions    Goal Tests    New Nodes
4    1450          1452         13303
5
6  Plan length: 9  Time elapsed in seconds: 6.118248686001607
7  Load(C3, P3, ATL)
8  Fly(P3, ATL, SFO)
9  Unload(C3, P3, SFO)
10 Load(C2, P2, JFK)
11 Fly(P2, JFK, SFO)
12 Unload(C2, P2, SFO)
13 Load(C1, P1, SFO)
14 Fly(P1, SFO, JFK)
15 Unload(C1, P1, JFK)
16
17
18 real    0m6,244s
19 user    0m6,195s
20 sys     0m0,040s
```

A* with H PG levelsum

```
1  Solving Air Cargo Problem 2 using astar_search with h_pg_levelsum...
2
3  real    10m0,007s
4  user    9m59,211s
5  sys     0m0,380s
```

A.3   Air Cargo Problem 3

```
1  $ for s in {1..10}; do time timeout 10m python run_search.py -s $s -p 3
     ; done
```

Breath First Search

```
1  Solving Air Cargo Problem 3 using breadth_first_search...
2
3  Expansions    Goal Tests    New Nodes
4    14663         18098        129631
5
6  Plan length: 12  Time elapsed in seconds: 58.169580712001334
7  Load(C1, P1, SFO)
8  Load(C2, P2, JFK)
9  Fly(P2, JFK, ORD)
10 Load(C4, P2, ORD)
11 Fly(P1, SFO, ATL)
12 Load(C3, P1, ATL)
13 Fly(P1, ATL, JFK)
14 Unload(C1, P1, JFK)
15 Unload(C3, P1, JFK)
16 Fly(P2, ORD, SFO)
17 Unload(C2, P2, SFO)
18 Unload(C4, P2, SFO)
```

```
19
20
21  real    0m58,278s
22  user    0m57,794s
23  sys     0m0,236s
```

Breath First Tree Search

```
1  Solving Air Cargo Problem 3 using breadth_first_tree_search...
2
3  real    10m0,032s
4  user    9m57,923s
5  sys     0m1,244s
```

Depth First Graph Search

```
1   Solving Air Cargo Problem 3 using depth_first_graph_search...
2
3   Expansions   Goal Tests   New Nodes
4      408          409         3364
5
6   Plan length: 392  Time elapsed in seconds: 2.63039746800132
7   Fly(P1, SFO, ORD)
8   Fly(P2, JFK, ORD)
9   Fly(P1, ORD, ATL)
10  Fly(P2, ORD, ATL)
11  Fly(P1, ATL, JFK)
12  Fly(P2, ATL, SFO)
13  Load(C2, P1, JFK)
14  Fly(P2, SFO, ORD)
15  Fly(P1, JFK, ORD)
16  Fly(P2, ORD, ATL)
17  Fly(P1, ORD, ATL)
18  Fly(P2, ATL, JFK)
19  Fly(P1, ATL, SFO)
20  Unload(C2, P1, SFO)
21  Fly(P1, SFO, ORD)
22  Fly(P2, JFK, ORD)
23  Fly(P1, ORD, ATL)
24  Fly(P2, ORD, ATL)
25  Fly(P1, ATL, JFK)
26  Fly(P2, ATL, SFO)
27  Load(C2, P2, SFO)
28  Fly(P2, SFO, ORD)
29  Fly(P1, JFK, ORD)
30  Fly(P2, ORD, ATL)
31  Fly(P1, ORD, ATL)
32  Fly(P2, ATL, JFK)
33  Load(C3, P1, ATL)
34  Fly(P1, ATL, ORD)
35  Fly(P2, JFK, ORD)
36  Fly(P1, ORD, SFO)
37  Fly(P2, ORD, ATL)
38  Fly(P1, SFO, JFK)
39  Fly(P2, ATL, SFO)
40  Unload(C3, P1, JFK)
41  Fly(P2, SFO, ORD)
42  Fly(P1, JFK, ORD)
43  Fly(P2, ORD, ATL)
44  Fly(P1, ORD, ATL)
45  Fly(P2, ATL, JFK)
46  Fly(P1, ATL, SFO)
47  Unload(C2, P2, JFK)
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(C3, P1, JFK)
55  Fly(P2, SFO, ORD)
56  Fly(P1, JFK, ORD)
57  Fly(P2, ORD, ATL)
58  Fly(P1, ORD, SFO)
59  Fly(P2, ATL, JFK)
60  Unload(C3, P1, SFO)
61  Fly(P1, SFO, ORD)
62  Fly(P2, JFK, ORD)
63  Fly(P1, ORD, ATL)
64  Fly(P2, ORD, ATL)
65  Fly(P1, ATL, JFK)
66  Fly(P2, ATL, SFO)
67  Load(C3, P2, SFO)
68  Fly(P2, SFO, ORD)
69  Fly(P1, JFK, ORD)
70  Fly(P2, ORD, ATL)
71  Fly(P1, ORD, SFO)
72  Load(C1, P1, SFO)
73  Fly(P2, ATL, ORD)
74  Fly(P1, SFO, ORD)
75  Fly(P2, ORD, SFO)
76  Fly(P1, ORD, ATL)
77  Fly(P2, SFO, JFK)
78  Fly(P1, ATL, JFK)
79  Unload(C3, P2, JFK)
80  Fly(P2, JFK, ORD)
81  Fly(P1, JFK, ORD)
82  Fly(P2, ORD, ATL)
83  Fly(P1, ORD, ATL)
84  Fly(P2, ATL, SFO)
85  Unload(C1, P1, ATL)
86  Fly(P1, ATL, ORD)
87  Fly(P2, SFO, ORD)
88  Fly(P1, ORD, SFO)
89  Fly(P2, ORD, ATL)
90  Fly(P1, SFO, JFK)
91  Fly(P2, ATL, JFK)
92  Load(C3, P2, JFK)
93  Fly(P2, JFK, ORD)
94  Fly(P1, JFK, ORD)
95  Fly(P2, ORD, ATL)
96  Fly(P1, ORD, ATL)
97  Unload(C3, P2, ATL)
98  Fly(P2, ATL, ORD)
99  Fly(P1, ATL, ORD)
100 Fly(P2, ORD, SFO)
101 Fly(P1, ORD, SFO)
102 Fly(P2, SFO, JFK)
103 Fly(P1, SFO, JFK)
104 Load(C2, P2, JFK)
105 Fly(P2, JFK, ORD)
106 Fly(P1, JFK, ORD)
107 Fly(P2, ORD, ATL)
108 Fly(P1, ORD, ATL)
109 Fly(P2, ATL, SFO)
110 Fly(P1, ATL, SFO)
111 Unload(C2, P2, SFO)
112 Fly(P2, SFO, ORD)
113 Fly(P1, SFO, ORD)
114 Fly(P2, ORD, ATL)
115 Fly(P1, ORD, ATL)
116 Fly(P2, ATL, JFK)
117 Load(C3, P1, ATL)
118 Fly(P1, ATL, ORD)
119 Fly(P2, JFK, ORD)
120 Fly(P1, ORD, SFO)
121 Fly(P2, ORD, ATL)
122 Fly(P1, SFO, JFK)
123 Fly(P2, ATL, SFO)
124 Unload(C3, P1, JFK)
125 Fly(P2, SFO, ORD)
126 Fly(P1, JFK, ORD)
```

```
127   Fly(P2, ORD, ATL)                   198   Fly(P1, SFO, ORD)
128   Fly(P1, ORD, ATL)                   199   Fly(P2, ORD, ATL)
129   Fly(P2, ATL, JFK)                   200   Fly(P1, ORD, ATL)
130   Fly(P1, ATL, SFO)                   201   Fly(P2, ATL, JFK)
131   Load(C3, P2, JFK)                   202   Fly(P1, ATL, JFK)
132   Fly(P1, SFO, ORD)                   203   Unload(C2, P2, JFK)
133   Fly(P2, JFK, ORD)                   204   Fly(P2, JFK, ORD)
134   Fly(P1, ORD, ATL)                   205   Fly(P1, JFK, ORD)
135   Fly(P2, ORD, SFO)                   206   Fly(P2, ORD, ATL)
136   Fly(P1, ATL, JFK)                   207   Fly(P1, ORD, ATL)
137   Fly(P2, SFO, ATL)                   208   Fly(P2, ATL, SFO)
138   Load(C1, P2, ATL)                   209   Fly(P1, ATL, SFO)
139   Fly(P2, ATL, ORD)                   210   Load(C1, P2, SFO)
140   Fly(P1, JFK, ORD)                   211   Fly(P2, SFO, ORD)
141   Fly(P2, ORD, SFO)                   212   Fly(P1, SFO, ORD)
142   Fly(P1, ORD, ATL)                   213   Fly(P2, ORD, ATL)
143   Fly(P2, SFO, JFK)                   214   Fly(P1, ORD, ATL)
144   Fly(P1, ATL, SFO)                   215   Fly(P2, ATL, JFK)
145   Unload(C3, P2, JFK)                 216   Fly(P1, ATL, JFK)
146   Fly(P1, SFO, ORD)                   217   Unload(C1, P2, JFK)
147   Fly(P2, JFK, ORD)                   218   Fly(P2, JFK, ORD)
148   Fly(P1, ORD, ATL)                   219   Load(C4, P1, JFK)
149   Fly(P2, ORD, SFO)                   220   Fly(P2, ORD, ATL)
150   Fly(P1, ATL, JFK)                   221   Fly(P1, JFK, ORD)
151   Load(C3, P1, JFK)                   222   Fly(P2, ATL, SFO)
152   Fly(P2, SFO, ORD)                   223   Fly(P1, ORD, ATL)
153   Fly(P1, JFK, ORD)                   224   Fly(P2, SFO, JFK)
154   Fly(P2, ORD, ATL)                   225   Fly(P1, ATL, SFO)
155   Fly(P1, ORD, ATL)                   226   Unload(C4, P1, SFO)
156   Fly(P2, ATL, JFK)                   227   Fly(P1, SFO, ORD)
157   Fly(P1, ATL, SFO)                   228   Fly(P2, JFK, ORD)
158   Unload(C3, P1, SFO)                 229   Fly(P1, ORD, ATL)
159   Fly(P1, SFO, ORD)                   230   Fly(P2, ORD, ATL)
160   Fly(P2, JFK, ORD)                   231   Fly(P1, ATL, JFK)
161   Fly(P1, ORD, ATL)                   232   Fly(P2, ATL, SFO)
162   Fly(P2, ORD, ATL)                   233   Load(C4, P2, SFO)
163   Fly(P1, ATL, JFK)                   234   Fly(P2, SFO, ORD)
164   Fly(P2, ATL, SFO)                   235   Fly(P1, JFK, ORD)
165   Unload(C1, P2, SFO)                 236   Fly(P2, ORD, ATL)
166   Fly(P2, SFO, ORD)                   237   Fly(P1, ORD, ATL)
167   Fly(P1, JFK, ORD)                   238   Fly(P2, ATL, JFK)
168   Fly(P2, ORD, ATL)                   239   Fly(P1, ATL, SFO)
169   Fly(P1, ORD, ATL)                   240   Load(C3, P2, JFK)
170   Fly(P2, ATL, JFK)                   241   Fly(P1, SFO, ORD)
171   Fly(P1, ATL, SFO)                   242   Fly(P2, JFK, ORD)
172   Load(C3, P1, SFO)                   243   Fly(P1, ORD, ATL)
173   Fly(P1, SFO, ORD)                   244   Fly(P2, ORD, ATL)
174   Fly(P2, JFK, ORD)                   245   Fly(P1, ATL, JFK)
175   Fly(P1, ORD, JFK)                   246   Fly(P2, ATL, SFO)
176   Fly(P2, ORD, ATL)                   247   Unload(C4, P2, SFO)
177   Unload(C3, P1, JFK)                 248   Fly(P2, SFO, ORD)
178   Fly(P2, ATL, JFK)                   249   Fly(P1, JFK, ORD)
179   Fly(P1, JFK, ORD)                   250   Fly(P2, ORD, ATL)
180   Fly(P2, JFK, ORD)                   251   Fly(P1, ORD, ATL)
181   Fly(P1, ORD, ATL)                   252   Fly(P2, ATL, JFK)
182   Load(C4, P2, ORD)                   253   Load(C2, P2, JFK)
183   Fly(P2, ORD, ATL)                   254   Fly(P1, ATL, ORD)
184   Fly(P1, ATL, ORD)                   255   Fly(P2, JFK, ORD)
185   Fly(P2, ATL, SFO)                   256   Fly(P1, ORD, SFO)
186   Fly(P1, ORD, SFO)                   257   Fly(P2, ORD, ATL)
187   Fly(P2, SFO, JFK)                   258   Fly(P1, SFO, JFK)
188   Fly(P1, SFO, JFK)                   259   Fly(P2, ATL, SFO)
189   Unload(C4, P2, JFK)                 260   Unload(C3, P2, SFO)
190   Fly(P2, JFK, ORD)                   261   Fly(P2, SFO, ORD)
191   Fly(P1, JFK, ORD)                   262   Fly(P1, JFK, ORD)
192   Fly(P2, ORD, ATL)                   263   Fly(P2, ORD, ATL)
193   Fly(P1, ORD, ATL)                   264   Fly(P1, ORD, ATL)
194   Fly(P2, ATL, SFO)                   265   Fly(P2, ATL, JFK)
195   Fly(P1, ATL, SFO)                   266   Fly(P1, ATL, SFO)
196   Load(C2, P2, SFO)                   267   Unload(C2, P2, JFK)
197   Fly(P2, SFO, ORD)                   268   Fly(P1, SFO, ORD)
```

```
269  Fly(P2, JFK, ORD)
270  Fly(P1, ORD, ATL)
271  Fly(P2, ORD, ATL)
272  Fly(P1, ATL, JFK)
273  Load(C2, P1, JFK)
274  Fly(P2, ATL, ORD)
275  Fly(P1, JFK, ORD)
276  Fly(P2, ORD, SFO)
277  Fly(P1, ORD, ATL)
278  Fly(P2, SFO, JFK)
279  Fly(P1, ATL, SFO)
280  Unload(C2, P1, SFO)
281  Fly(P1, SFO, ORD)
282  Fly(P2, JFK, ORD)
283  Fly(P1, ORD, ATL)
284  Fly(P2, ORD, ATL)
285  Fly(P1, ATL, JFK)
286  Load(C1, P1, JFK)
287  Fly(P2, ATL, ORD)
288  Fly(P1, JFK, ORD)
289  Fly(P2, ORD, SFO)
290  Fly(P1, ORD, ATL)
291  Fly(P2, SFO, JFK)
292  Fly(P1, ATL, SFO)
293  Unload(C1, P1, SFO)
294  Fly(P1, SFO, ORD)
295  Fly(P2, JFK, ORD)
296  Fly(P1, ORD, ATL)
297  Fly(P2, ORD, ATL)
298  Fly(P1, ATL, JFK)
299  Fly(P2, ATL, SFO)
300  Load(C4, P2, SFO)
301  Fly(P2, SFO, ATL)
302  Fly(P1, JFK, ORD)
303  Fly(P2, ATL, JFK)
304  Fly(P1, ORD, ATL)
305  Fly(P2, JFK, ORD)
306  Fly(P1, ATL, SFO)
307  Load(C3, P1, SFO)
308  Fly(P2, ORD, ATL)
309  Fly(P1, SFO, ORD)
310  Fly(P2, ATL, SFO)
311  Fly(P1, ORD, ATL)
312  Fly(P2, SFO, JFK)
313  Unload(C4, P2, JFK)
314  Fly(P1, ATL, ORD)
315  Fly(P2, JFK, ORD)
316  Fly(P1, ORD, SFO)
317  Fly(P2, ORD, ATL)
318  Fly(P1, SFO, JFK)
319  Fly(P2, ATL, SFO)
320  Load(C4, P1, JFK)
321  Fly(P2, SFO, ORD)
322  Fly(P1, JFK, ATL)
323  Fly(P2, ORD, ATL)
324  Fly(P1, ATL, ORD)
325  Unload(C3, P1, ORD)
326  Fly(P1, ORD, ATL)
327  Fly(P2, ATL, ORD)
328  Fly(P1, ATL, SFO)
329  Fly(P2, ORD, SFO)
330  Fly(P1, SFO, JFK)
331  Fly(P2, SFO, JFK)
332  Unload(C4, P1, JFK)
333  Fly(P2, JFK, ORD)
334  Fly(P1, JFK, ATL)
335  Fly(P2, ORD, ATL)
336  Fly(P1, ATL, ORD)
337  Fly(P2, ATL, SFO)
338  Fly(P1, ORD, SFO)
339  Load(C2, P2, SFO)
340  Fly(P2, SFO, ORD)
341  Fly(P1, SFO, ORD)
342  Fly(P2, ORD, ATL)
343  Fly(P1, ORD, ATL)
344  Fly(P2, ATL, JFK)
345  Fly(P1, ATL, JFK)
346  Unload(C2, P2, JFK)
347  Fly(P2, JFK, ORD)
348  Fly(P1, JFK, ORD)
349  Fly(P2, ORD, ATL)
350  Fly(P1, ORD, ATL)
351  Fly(P2, ATL, SFO)
352  Fly(P1, ATL, SFO)
353  Load(C1, P2, SFO)
354  Fly(P2, SFO, ORD)
355  Fly(P1, SFO, ORD)
356  Fly(P2, ORD, ATL)
357  Fly(P1, ORD, ATL)
358  Fly(P2, ATL, JFK)
359  Fly(P1, ATL, JFK)
360  Unload(C1, P2, JFK)
361  Fly(P2, JFK, ORD)
362  Fly(P1, JFK, ORD)
363  Fly(P2, ORD, ATL)
364  Load(C3, P1, ORD)
365  Fly(P1, ORD, ATL)
366  Fly(P2, ATL, ORD)
367  Fly(P1, ATL, SFO)
368  Fly(P2, ORD, SFO)
369  Fly(P1, SFO, JFK)
370  Load(C4, P1, JFK)
371  Fly(P2, SFO, ORD)
372  Fly(P1, JFK, ORD)
373  Fly(P2, JFK, ORD)
374  Fly(P1, ORD, ATL)
375  Fly(P2, ORD, ATL)
376  Fly(P1, ATL, SFO)
377  Unload(C4, P1, SFO)
378  Fly(P2, ATL, ORD)
379  Fly(P1, SFO, ORD)
380  Fly(P2, ORD, SFO)
381  Fly(P1, ORD, ATL)
382  Fly(P2, SFO, JFK)
383  Fly(P1, ATL, JFK)
384  Load(C2, P2, JFK)
385  Fly(P2, JFK, ORD)
386  Fly(P1, JFK, ORD)
387  Fly(P2, ORD, ATL)
388  Fly(P1, ORD, ATL)
389  Fly(P2, ATL, SFO)
390  Fly(P1, ATL, SFO)
391  Unload(C2, P2, SFO)
392  Fly(P2, SFO, ORD)
393  Fly(P1, SFO, ORD)
394  Fly(P2, ORD, ATL)
395  Fly(P1, ORD, ATL)
396  Fly(P2, ATL, JFK)
397  Fly(P1, ATL, JFK)
398  Unload(C3, P1, JFK)
399
400
401  real    0m2,746s
402  user    0m2,728s
403  sys     0m0,015s
```

Depth Limited Search

```
1  Solving Air Cargo Problem 3 using depth_limited_search...
2
3  real    10m0,003s
4  user    9m59,130s
```

```
5   sys     0m0,250s
```

Uniform Cost Search

```
1   Solving Air Cargo Problem 3 using uniform_cost_search...
2
3   Expansions   Goal Tests   New Nodes
4    18223        18225        159618
5
6   Plan length: 12  Time elapsed in seconds: 72.81308357099988
7   Load(C1, P1, SFO)
8   Load(C2, P2, JFK)
9   Fly(P1, SFO, ATL)
10  Load(C3, P1, ATL)
11  Fly(P2, JFK, ORD)
12  Load(C4, P2, ORD)
13  Fly(P2, ORD, SFO)
14  Fly(P1, ATL, JFK)
15  Unload(C4, P2, SFO)
16  Unload(C3, P1, JFK)
17  Unload(C2, P2, SFO)
18  Unload(C1, P1, JFK)
19
20
21  real    1m12,923s
22  user    1m12,703s
23  sys     0m0,061s
```

Recursive Best First Search with H1

```
1   Solving Air Cargo Problem 3 using recursive_best_first_search with h_1
        ...
2
3   real    10m0,003s
4   user    9m58,234s
5   sys     0m0,671s
```

Greedy Best First Graph Search with H1

```
1   Solving Air Cargo Problem 3 using greedy_best_first_graph_search with
        h_1...
2
3   Expansions   Goal Tests   New Nodes
4     5578         5580        49150
5
6   Plan length: 22  Time elapsed in seconds: 22.548576019999018
7   Load(C1, P1, SFO)
8   Load(C2, P2, JFK)
9   Fly(P1, SFO, ORD)
10  Load(C4, P1, ORD)
11  Fly(P2, JFK, ATL)
12  Load(C3, P2, ATL)
13  Fly(P2, ATL, ORD)
14  Fly(P1, ORD, ATL)
15  Unload(C4, P1, ATL)
16  Fly(P1, ATL, ORD)
17  Fly(P2, ORD, ATL)
18  Load(C4, P2, ATL)
19  Fly(P2, ATL, ORD)
20  Unload(C3, P2, ORD)
21  Load(C3, P1, ORD)
22  Fly(P1, ORD, JFK)
23  Unload(C3, P1, JFK)
24  Unload(C1, P1, JFK)
25  Fly(P1, JFK, ORD)
26  Fly(P2, ORD, SFO)
27  Unload(C4, P2, SFO)
```

```
28  Unload(C2, P2, SFO)
29
30
31  real    0m22,654s
32  user    0m22,617s
33  sys     0m0,016s
```

A* with H1

```
1   Solving Air Cargo Problem 3 using astar_search with h_1...
2
3   Expansions   Goal Tests   New Nodes
4    18223        18225        159618
5
6   Plan length: 12  Time elapsed in seconds: 72.3259903420003
7   Load(C1, P1, SFO)
8   Load(C2, P2, JFK)
9   Fly(P1, SFO, ATL)
10  Load(C3, P1, ATL)
11  Fly(P2, JFK, ORD)
12  Load(C4, P2, ORD)
13  Fly(P2, ORD, SFO)
14  Fly(P1, ATL, JFK)
15  Unload(C4, P2, SFO)
16  Unload(C3, P1, JFK)
17  Unload(C2, P2, SFO)
18  Unload(C1, P1, JFK)
19
20
21  real    1m12,433s
22  user    1m12,268s
23  sys     0m0,092s
```

A* with H ignore preconditions

```
1   Solving Air Cargo Problem 3 using astar_search with
        h_ignore_preconditions...
2
3   Expansions   Goal Tests   New Nodes
4     5040         5042        44944
5
6   Plan length: 12  Time elapsed in seconds: 24.146244273000775
7   Load(C2, P2, JFK)
8   Fly(P2, JFK, ORD)
9   Load(C4, P2, ORD)
10  Fly(P2, ORD, SFO)
11  Unload(C4, P2, SFO)
12  Load(C1, P1, SFO)
13  Fly(P1, SFO, ATL)
14  Load(C3, P1, ATL)
15  Fly(P1, ATL, JFK)
16  Unload(C3, P1, JFK)
17  Unload(C2, P2, SFO)
18  Unload(C1, P1, JFK)
19
20
21  real    0m24,312s
22  user    0m23,949s
23  sys     0m0,233s
```

A* with H PG levelsum

```
1   Solving Air Cargo Problem 3 using astar_search with h_pg_levelsum...
2
3   real    10m0,009s
4   user    9m58,737s
5   sys     0m0,662s
```