UDACITY – Artificial Intelligence Nanodegree
Project 3 – Heuristic Analysis

Student: Haraldo Sergio Albergaria Pereira Filho

1 - Project execution

After all the methods and functions were implemented and passed unit and assistant tests, the project was executed in an *Intel Core i5™* machine with 8GB of RAM and using *pypy3* to speed up the execution. The following search functions were executed:

1. breadth_first_search
3. depth_first_graph_search
5. uniform_cost_search
8. astar_search h_1
9. astar_search h_ignore_preconditions
10. astar_search h_pg_levelsum

After the execution, the following results were obtained:

PROBLEM 1		Expansions	Goal Tests	New Nodes	Execution Time (sec)	Plan Length	Optimality
N-HEUR	breadth_first_search	43	56	180	0.08931799	6	OPTIMAL
	depth_first_graph_search	21	22	84	0.043943001	20	NON-OPTIMAL
	uniform_cost_search	55	57	224	0.066716984	6	OPTIMAL
HEUR	astar_search with h_1	55	57	224	0.05807356	6	OPTIMAL
	astar_search with h_ignore_preconditions	41	43	170	0.041950011	6	OPTIMAL
	astar_search with h_pg_levelsum	11	13	50	0.747153769	6	OPTIMAL

PROBLEM 2		Expansions	Goal Tests	New Nodes	Execution Time (sec)	Plan Length	Optimality
N-HEUR	breadth_first_search	3346	4612	30130	5.028010392	9	OPTIMAL
	depth_first_graph_search	107	108	959	0.118126506	105	NON-OPTIMAL
	uniform_cost_search	4853	4855	44041	6.226928126	9	OPTIMAL
HEUR	astar_search with h_1	4853	4855	44041	5.653434349	9	OPTIMAL
	astar_search with h_ignore_preconditions	1450	1452	13303	1.773144239	9	OPTIMAL
	astar_search with h_pg_levelsum	86	88	841	17.013887906	9	OPTIMAL

PROBLEM 3		Expansions	Goal Tests	New Nodes	Execution Time (sec)	Plan Length	Optimality
N-HEUR	breadth_first_search	11229	14955	85772	12.829277586	12	OPTIMAL
	depth_first_graph_search	1578	1579	6702	1.075683241	250	NON-OPTIMAL
	uniform_cost_search	15688	15690	117689	15.63305986	12	OPTIMAL
HEUR	astar_search with h_1	15688	15690	117689	16.022052911	12	OPTIMAL
	astar_search with h_ignore_preconditions	3760	3762	29507	4.268575247	12	OPTIMAL
	astar_search with h_pg_levelsum	891	893	6020	155.72507983	12	OPTIMAL

The complete output of the script can be found on the Appendix at the end of this document.

2 - Analysis of the results

After the analysis of the tables, we can draw the following conclusions:

2.1 - Optimal plans

We can clearly see that the optimal results for all the three problems were the ones obtained using the ***A* Search with the ignore preconditions heuristic*** (astar_search h_ignore_preconditions) as it has the lowest plan length and the second lower execution time. The *Depth First Graph Search* (depth_first_graph_search) has a lower execution time, but it is not optimal. Following, we have the plans for each problem:

Problem 1:

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

Problem 2:

```
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)
```

Problem 3:

```
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)
```

2.2 - Best Non-Heuristic search result analysis

Among the three non-heuristics searches, the *depth_first_graph_search* has the best results regarding *Expansions*, *Goal Tests*, *New Nodes* and *Execution Time*, but its *Plan Lengths* are much worse than the others, so it is not optimal. From the other two, the *breadth_first_search* has the best results on all metrics for problems 2 and 3 but has a slightly higher execution time on problem 1. Considering that this is the simpler problem, with the other two presenting more significant differences, the ***breadth_first_search*** is the best choice among the non-heuristic searches.

2.3 - Best Heuristic search result analysis

All the three heuristics searches are optimal, and among them, the *astar_search with h_pg_levelsum has* the best results for the all three problems regarding *Expansions, Goal Tests* and *New Nodes* but has a much higher *Execution Time.* From the other two, the ***astar_search_with_h_ignore_preconditions*** has the best values for all the metrics and is the best choice among the heuristic searches.

2.4 - Best overall search result analysis

For the best results to *non-heuristic* and *heuristic* searches, from the two, the ***astar_search_with_h_ignore_preconditions*** has much better results for all the metrics, with the difference in execution time increasing together with the complexity of the problem. Comparing it with all the three non-heuristic methods, only *depth_first_graph_search* has better metrics, but as we previously saw, it is not optimal, with plan lengths much worse.

3 - Conclusion

The empirical results are in accordance with the theory. In the book *"Artificial Intelligence: A Modern Approach"*, the authors Stuart Russel and Peter Norvig demonstrated, in section 3.5.2, that *A* Search* is optimal if provided with a heuristic that satisfies two conditions: *admissibility* [1] and *consistency* [2]. In section 10.2.3 they show that *ignore preconditions heuristic* satisfies both conditions. Also, for the non-heuristic searches, the optimality of *breadth-first search* and *uniform-cost search* are demonstrated in sections 3.4.1 and 3.4.2, respectively.

[1] From the book: "An admissible heuristic is one that never overestimates the cost to reach the goal."
[2] From the book: "A heuristic $h(n)$ is consistent if, for every node n and every successor n' of n generated by any action a, the estimated cost of reaching the goal from n is no greater than the step cost of getting to n' plus the estimated cost of reaching the goal from n': $h(n) \leq c(n, a, n') + h(n')$."

Appendix

Following is the output of the script execution. It was used the following command to run it:

```
pypy3 run_search.py -p 1 2 3 -s 1 3 5 8 9 10 > search_results
```

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

Expansions   Goal Tests   New Nodes
    43          56         180

Plan length: 6  Time elapsed in seconds: 0.08931799000004048
Load(C1, P1, SFO)
Load(C2, P2, JFK)
Fly(P2, JFK, SFO)
Unload(C2, P2, SFO)
Fly(P1, SFO, JFK)
Unload(C1, P1, JFK)


Solving Air Cargo Problem 1 using depth_first_graph_search...

Expansions   Goal Tests   New Nodes
    21          22          84

Plan length: 20  Time elapsed in seconds: 0.04394300100000237
Fly(P1, SFO, JFK)
Fly(P2, JFK, SFO)
Load(C2, P1, JFK)
Fly(P1, JFK, SFO)
Fly(P2, SFO, JFK)
Unload(C2, P1, SFO)
Fly(P1, SFO, JFK)
Fly(P2, JFK, SFO)
Load(C2, P2, SFO)
Fly(P1, JFK, SFO)
Load(C1, P2, SFO)
Fly(P2, SFO, JFK)
Fly(P1, SFO, JFK)
Unload(C2, P2, JFK)
Unload(C1, P2, JFK)
Fly(P2, JFK, SFO)
Load(C2, P1, JFK)
Fly(P1, JFK, SFO)
Fly(P2, SFO, JFK)
Unload(C2, P1, SFO)


Solving Air Cargo Problem 1 using uniform_cost_search...

Expansions   Goal Tests   New Nodes
    55          57         224

Plan length: 6  Time elapsed in seconds: 0.0667169839999815
Load(C1, P1, SFO)
Load(C2, P2, JFK)
Fly(P1, SFO, JFK)
Fly(P2, JFK, SFO)
Unload(C1, P1, JFK)
Unload(C2, P2, SFO)


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

Expansions   Goal Tests   New Nodes
    55          57         224

Plan length: 6  Time elapsed in seconds: 0.05807356000002528
Load(C1, P1, SFO)
Load(C2, P2, JFK)
Fly(P1, SFO, JFK)
Fly(P2, JFK, SFO)
Unload(C1, P1, JFK)
Unload(C2, P2, SFO)


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

Expansions   Goal Tests   New Nodes
    41          43         170

Plan length: 6  Time elapsed in seconds: 0.041950010999926235
Load(C1, P1, SFO)
Fly(P1, SFO, JFK)
Unload(C1, P1, JFK)
Load(C2, P2, JFK)
Fly(P2, JFK, SFO)
Unload(C2, P2, SFO)
```

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

Expansions   Goal Tests   New Nodes
    11          13          50

Plan length: 6  Time elapsed in seconds: 0.747153768999965
Load(C1, P1, SFO)
Fly(P1, SFO, JFK)
Load(C2, P2, JFK)
Fly(P2, JFK, SFO)
Unload(C1, P1, JFK)
Unload(C2, P2, SFO)


Solving Air Cargo Problem 2 using breadth_first_search...

Expansions   Goal Tests   New Nodes
   3346        4612       30534

Plan length: 9  Time elapsed in seconds: 5.028010391999942
Load(C1, P1, SFO)
Load(C2, P2, JFK)
Load(C3, P3, ATL)
Fly(P1, SFO, JFK)
Unload(C1, P1, JFK)
Fly(P2, JFK, SFO)
Unload(C2, P2, SFO)
Fly(P3, ATL, SFO)
Unload(C3, P3, SFO)


Solving Air Cargo Problem 2 using depth_first_graph_search...

Expansions   Goal Tests   New Nodes
   107         108         959

Plan length: 105  Time elapsed in seconds: 0.11812650600006691
Fly(P3, ATL, JFK)
Fly(P2, JFK, ATL)
Fly(P3, JFK, SFO)
Fly(P2, ATL, SFO)
Fly(P1, SFO, ATL)
Fly(P3, SFO, ATL)
Fly(P1, ATL, JFK)
Fly(P3, ATL, JFK)
Load(C2, P3, JFK)
Fly(P3, JFK, ATL)
Fly(P1, JFK, ATL)
Fly(P3, ATL, SFO)
Fly(P1, ATL, SFO)
Fly(P2, SFO, ATL)
Fly(P3, SFO, ATL)
Fly(P2, ATL, JFK)
Unload(C2, P3, ATL)
Fly(P3, ATL, JFK)
Fly(P2, JFK, ATL)
Fly(P3, JFK, SFO)
Fly(P2, ATL, SFO)
Fly(P1, SFO, ATL)
Fly(P3, SFO, JFK)
Fly(P1, ATL, JFK)
Load(C1, P2, SFO)
Fly(P3, JFK, ATL)
Fly(P1, JFK, ATL)
Fly(P2, SFO, ATL)
Fly(P3, ATL, JFK)
Fly(P2, ATL, JFK)
Fly(P1, ATL, SFO)
Fly(P3, JFK, ATL)
Unload(C1, P2, JFK)
Fly(P3, ATL, SFO)
Fly(P2, JFK, ATL)
Fly(P1, SFO, ATL)
Fly(P2, ATL, SFO)
Fly(P1, ATL, JFK)
Fly(P3, SFO, ATL)
Fly(P2, SFO, ATL)
Fly(P3, ATL, JFK)
Fly(P2, ATL, JFK)
Load(C1, P3, JFK)
Fly(P3, JFK, ATL)
Fly(P2, JFK, ATL)
Fly(P3, ATL, SFO)
Fly(P1, JFK, ATL)
Fly(P2, ATL, JFK)
Load(C3, P1, ATL)
Fly(P1, ATL, JFK)
Fly(P2, JFK, ATL)
Fly(P1, JFK, SFO)
Fly(P2, ATL, SFO)
Fly(P3, SFO, ATL)
Fly(P1, SFO, ATL)
Fly(P3, ATL, JFK)
Fly(P1, ATL, JFK)
```

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


Solving Air Cargo Problem 2 using uniform_cost_search...

Expansions   Goal Tests   New Nodes
   4853        4855       44041

Plan length: 9  Time elapsed in seconds: 6.226928126000075
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)


Solving Air Cargo Problem 2 using astar_search with h_1...

Expansions   Goal Tests   New Nodes
   4853        4855       44041

Plan length: 9  Time elapsed in seconds: 5.653434349000008
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)


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: 1.7731442389999756
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)


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: 17.013887906000036
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)


Solving Air Cargo Problem 3 using breadth_first_search...

Expansions   Goal Tests   New Nodes
  11229       14955       85772

Plan length: 12  Time elapsed in seconds: 12.82927758599999
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(P1, ATL, JFK)
Unload(C1, P1, JFK)
Unload(C3, P1, JFK)
Fly(P2, ORD, SFO)
Unload(C2, P2, SFO)
Unload(C4, P2, SFO)


Solving Air Cargo Problem 3 using depth_first_graph_search...

Expansions   Goal Tests   New Nodes
   1578        1579        6702

Plan length: 250  Time elapsed in seconds: 1.0756832410000925
Fly(P2, JFK, ORD)
Fly(P1, SFO, ORD)
Fly(P2, ORD, ATL)
Fly(P1, ORD, ATL)
Load(C3, P1, ATL)
Fly(P1, ATL, ORD)
Load(C4, P1, ORD)
Fly(P1, ORD, ATL)
Unload(C4, P1, ATL)
Fly(P1, ATL, JFK)
Unload(C3, P1, JFK)
Fly(P1, JFK, ATL)
Load(C4, P1, ATL)
Fly(P1, ATL, ORD)
Unload(C4, P1, ORD)
Fly(P1, ORD, JFK)
Load(C2, P1, JFK)
Fly(P1, JFK, ORD)
Load(C4, P1, ORD)
Fly(P1, ORD, ATL)
Unload(C4, P1, ATL)
Fly(P1, ATL, SFO)
Unload(C2, P1, SFO)
Fly(P1, SFO, ATL)
Load(C4, P1, ATL)
Fly(P1, ATL, ORD)
Unload(C4, P1, ORD)
Fly(P1, ORD, JFK)
Load(C3, P1, JFK)
Fly(P1, JFK, ORD)
Load(C4, P1, ORD)
Fly(P1, ORD, ATL)
Unload(C4, P1, ATL)
Fly(P1, ATL, SFO)
Unload(C3, P1, SFO)
Fly(P1, SFO, ATL)
Load(C4, P1, ATL)
Fly(P1, ATL, ORD)
Unload(C4, P1, ORD)
Fly(P1, ORD, SFO)
Load(C2, P1, SFO)
Fly(P1, SFO, ORD)
Load(C4, P1, ORD)
Fly(P1, ORD, ATL)
Unload(C4, P1, ATL)
Fly(P1, ATL, JFK)
```

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

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


Solving Air Cargo Problem 3 using uniform_cost_search...

Expansions   Goal Tests   New Nodes
  15688       15690       117689

Plan length: 12  Time elapsed in seconds: 15.633059860000003
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)


Solving Air Cargo Problem 3 using astar_search with h_1...

Expansions   Goal Tests   New Nodes
  15688       15690       117689

Plan length: 12  Time elapsed in seconds: 16.02205291100006
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)


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

Expansions   Goal Tests   New Nodes
   3760        3762       29507

Plan length: 12  Time elapsed in seconds: 4.268575247000058
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)


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

Expansions   Goal Tests   New Nodes
   891         893         6020

Plan length: 12  Time elapsed in seconds: 155.7250798299999
Load(C2, P2, JFK)
Fly(P2, JFK, ORD)
Load(C4, P2, ORD)
Fly(P2, ORD, SFO)
Load(C1, P1, SFO)
Fly(P1, SFO, ATL)
Load(C3, P1, ATL)
Fly(P1, ATL, JFK)
Unload(C4, P2, SFO)
Unload(C3, P1, JFK)
Unload(C2, P2, SFO)
Unload(C1, P1, JFK)
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