AIND Planning - Heuristic Analysis

The goal of this exercise is to show which of the algorithms and heuristics work best for transporting air cargo. The results show the effectiveness of the heuristics and the ideal results are the ones with the lowest number of processes in the shortest amount of time.

Key:

1. breadth_first_search (BFS)
2. breadth_first_tree_search (BFTS)
3. depth_first_graph_search (DFS)
4. depth_limited_search (DLS)
5. uniform_cost_search (UCS)
6. recursive_best_first_search h_1 (RBFS)
7. greedy_best_first_graph_search h_1 (GBFGS)
8. astar_search h_1 (AS)
9. astar_search h_ignore_preconditions (ASIP)
10. astar_search h_pg_levelsum (ASL)

Air Cargo Problem 1 analysis

As per the guidelines here are the initial states and goals: This involved 2 airports SFO and JFK and 2 planes(P) and 2 sets of cargo (C).

```
Init(At(C1, SFO) ∧ At(C2, JFK)
        ∧ At(P1, SFO) ∧ At(P2, JFK)
        ∧ Cargo(C1) ∧ Cargo(C2)
        ∧ Plane(P1) ∧ Plane(P2)
        ∧ Airport(JFK) ∧ Airport(SFO))
Goal(At(C1, JFK) ∧ At(C2, SFO))
```

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In this case there are 7 algorithms and heuristics that produce the lowest number of processes; breadth_first_search, breadth_first_tree_search, uniform_cost search, recursive_best_first_search with h_1, greedy_best_first_graph_search with h_1, astar_search with h_1and astar_search with h_ignore_preconditions

1 algorithm – ASL took too long to produce a result.

Breadth_first search BFS	breadth_first tree_search BFTS	uniform_cost search UCS	recursive_best first_search with h_1 RBFS	greedy_best first graph search with h_1 GBFGS	astar_search with h_1 AS	astar_search with h_ignore preconditions ASIP	depth_first tree_search DFS
Load(C1, P1, SFO)	Load(C1, P1, SFO)	Load(C1, P1, SFO)	Load(C2, P2, JFK)	Load(C1, P1, SFO)	Load(C1, P1, SFO)	Load(C1, P1, SFO)	Fly(P1, SFO, JFK)
Load(C2, P2, JFK)	Load(C2, P2, JFK)	Load(C2, P2, JFK)	Load(C1, P1, SFO)	Load(C2, P2, JFK)	Load(C2, P2, JFK)	Fly(P1, SFO, JFK)	Fly(P2, JFK, SFO)
Fly(P2, JFK, SFO)	Fly(P2, JFK, SFO)	Fly(P1, SFO, JFK)	Fly(P2, JFK, SFO)	Fly(P1, SFO, JFK)	Fly(P1, SFO, JFK)	Unload(C1, P1, JFK)	Load(C2, P1, JFK)
Unload(C2, P2, SFO)	Unload(C2, P2, SFO)	Fly(P2, JFK, SFO)	Unload(C2, P2, SFO)	Fly(P2, JFK, SFO)	Fly(P2, JFK, SFO)	Load(C2, P2, JFK)	Fly(P1, JFK, SFO)
Fly(P1, SFO, JFK)	Fly(P1, SFO, JFK)	Unload(C1, P1, JFK)	Fly(P1, SFO, JFK)	Unload(C1, P1, JFK)	Unload(C1, P1, JFK)	Fly(P2, JFK, SFO)	Fly(P2, SFO, JFK)
Unload(C1, P1, JFK)	Unload(C1, P1, JFK)	Unload(C2, P2, SFO)	Unload(C1, P1, JFK)	Unload(C2, P2, SFO)	Unload(C2, P2, SFO)	Unload(C2, P2, SFO)	Unload(C2, P1, SFO)
							Fly(P1, SFO, JFK)
							Fly(P2, JFK, SFO)
							Load(C2, P2, SFO)
							Fly(P1, JFK, SFO)
							Load(C1, P2, SFO)….>
	Time						
0.04	1.33	0.05	3.65	0.01	0.05	0.05	0.02
Non-Heuristic	**Non-Heuristic**	**Non-Heuristic**	**Non-Heuristic**	**Non-Heuristic**	**Heuristic**	**Heuristic**	**Non-Heuristic**
				BEST			

The color coding denotes that the same routes were used, in this case breadth_first search and breadth first tree search in yellow have the same routing results whilst greedy best first graph, astar search and astar search with h ignore in blue have the same routing results and recursive best first search in green has a different routing result.

In this case 1 non-heuristic algorithm GBFGS and 2 heuristic algorithms, AS and ASIP produce outcomes that are the nearest to the goal ie load plane 1 at SFO and load plane 2 at JFK fly plane 1 to JFK and fly plane 2 to SFO and finally unload plane 1 at JFK and unload plane 2 at SFO. Out of all the algorithms the non-heuristic algorithm greedy best first graph search with h1 (GBFGS) has the shortest time and is hence the best algorithm for problem 1.

DFS did not produce the the shortest amount of processes (a total of 20 processes compared to 6) but it did produce a quicker time (0.02) compared to the other algorithms.

Air Cargo Problem 2 analysis

The guidelines and goals for this problem are: In this problem there were 3 airports SFO, JFK and ATL and 3 planes (P) with 3 sets of cargo (C).

```
Init(At(C1, SFO) ∧ At(C2, JFK) ∧ At(C3, ATL)
        ∧ At(P1, SFO) ∧ At(P2, JFK) ∧ At(P3, ATL)
        ∧ Cargo(C1) ∧ Cargo(C2) ∧ Cargo(C3)
        ∧ Plane(P1) ∧ Plane(P2) ∧ Plane(P3)
        ∧ Airport(JFK) ∧ Airport(SFO) ∧ Airport(ATL))
Goal(At(C1, JFK) ∧ At(C2, SFO) ∧ At(C3, SFO))
```

In this case 4 algorithms produced the lowest number of processes; breadth_first_search, uniform_cost_search, astar_search with h_1 and astar_search with h_ignore_preconditions

However, 5 algorithms took too long to produce any results; BFTS, DFS, DLS, RBFS and ASIL.

We can also see that for this problem the time that it took to calculate the processes increased when compared to problem 1.

breadth_first search BFS	**uniform_cost search UCS**	**astar_search with h_1 AS**	**astar_search with h_ignore preconditions ASIP**	**depth_first tree_search DFS**
Load(C1, P1, SFO)	Load(C1, P1, SFO)	Load(C1, P1, SFO)	Load(C3, P3, ATL)	Took too long to produce a result
Load(C2, P2, JFK)	Load(C2, P2, JFK)	Load(C2, P2, JFK)	Fly(P3, ATL, SFO)	
Load(C3, P3, ATL)	Load(C3, P3, ATL)	Load(C3, P3, ATL)	Unload(C3, P3, SFO)	
Fly(P2, JFK, SFO)	Fly(P1, SFO, JFK)	Fly(P1, SFO, JFK)	Load(C1, P1, SFO)	
Unload(C2, P2, SFO)	Fly(P2, JFK, SFO)	Fly(P2, JFK, SFO)	Fly(P1, SFO, JFK)	
Fly(P1, SFO, JFK)	Fly(P3, ATL, SFO)	Fly(P3, ATL, SFO)	Unload(C1, P1, JFK)	
Unload(C1, P1, JFK)	Unload(C3, P3, SFO)	Unload(C3, P3, SFO)	Load(C2, P2, JFK)	
Fly(P3, ATL, SFO)	Unload(C1, P1, JFK)	Unload(C1, P1, JFK)	Fly(P2, JFK, SFO)	
Unload(C3, P3, SFO)	Unload(C2, P2, SFO)	Unload(C2, P2, SFO)	Unload(C2, P2, SFO)	
Time				
17.87	24.54	25.67	8.21	-
Non-Heuristic	**Non-Heuristic**	**Heuristic**	**Heuristic**	**Non-Heuristic**
			BEST	

For this problem the heuristic algorithm astar search with h_ignore preconditions (ASIP) found the optimal number of processes in the least amount of time.

Air Cargo Problem 3 analysis

The guidelines and goals for this problem are: In this problem there were 4 airports SFO, JFK, ATL and ORD, 2 planes (P) with 4 sets of cargo (C).

```
Init(At(C1, SFO) ∧ At(C2, JFK) ∧ At(C3, ATL) ∧ At(C4, ORD)
        ∧ At(P1, SFO) ∧ At(P2, JFK)
        ∧ Cargo(C1) ∧ Cargo(C2) ∧ Cargo(C3) ∧ Cargo(C4)
        ∧ Plane(P1) ∧ Plane(P2)
        ∧ Airport(JFK) ∧ Airport(SFO) ∧ Airport(ATL) ∧ Airport(ORD))
Goal(At(C1, JFK) ∧ At(C3, JFK) ∧ At(C2, SFO) ∧ At(C4, SFO))
```

In this case 4 algorithms; BFS, UCS, AS and ASIP produced the optimal outcomes.

4 algorithms did not produce any results as it took too long BFTS, DLS, RBFS and ASL.

breadth_first search BFS	**uniform_cost search UCS**	**astar_search with h_1 AS**	**astar_search with h_ignore preconditions ASIP**	**depth_first tree_search DFS**
Load(C1, P1, SFO)	Load(C1, P1, SFO)	Load(C1, P1, SFO)	Load(C2, P2, JFK)	Fly(P2, SFO, JFK)
Load(C2, P2, JFK)	Load(C2, P2, JFK)	Load(C2, P2, JFK)	Fly(P2, JFK, ORD)	Fly(P1, SFO, JFK)
Fly(P2, JFK, ORD)	Fly(P1, SFO, ATL)	Fly(P1, SFO, ATL)	Load(C4, P2, ORD)	Load(C2, P2, JFK)
Load(C4, P2, ORD)	Load(C3, P1, ATL)	Load(C3, P1, ATL)	Fly(P2, ORD, SFO)	Fly(P2, JFK, ORD)
Fly(P1, SFO, ATL)	Fly(P2, JFK, ORD)	Fly(P2, JFK, ORD)	Unload(C4, P2, SFO)	Fly(P1, JFK, ORD)
Load(C3, P1, ATL)	Load(C4, P2, ORD)	Load(C4, P2, ORD)	Load(C1, P1, SFO)	Fly(P2, ORD, ATL)
Fly(P1, ATL, JFK)	Fly(P2, ORD, SFO)	Fly(P2, ORD, SFO)	Fly(P1, SFO, ATL)	Fly(P1, ORD, ATL)
Unload(C1, P1, JFK)	Fly(P1, ATL, JFK)	Fly(P1, ATL, JFK)	Load(C3, P1, ATL)	Fly(P2, ATL, SFO)
Unload(C3, P1, JFK)	Unload(C4, P2, SFO)	Unload(C4, P2, SFO)	Fly(P1, ATL, JFK)	Fly(P1, ATL, SFO)
Fly(P2, ORD, SFO)	Unload(C3, P1, JFK)	Unload(C3, P1, JFK)	Unload(C3, P1, JFK)	Unload(C2, P2, SFO)
Unload(C2, P2, SFO)	Unload(C1, P1, JFK)	Unload(C1, P1, JFK)	Unload(C1, P1, JFK)	Fly(P2, SFO, ORD)
Unload(C4, P2, SFO)	Unload(C2, P2, SFO)	Unload(C2, P2, SFO)	Unload(C2, P2, SFO)	Fly(P1, SFO, ORD)…….>
Time				
102.98	120.78	122.91	38.21	3.57
Non-Heuristic	**Non-Heuristic**	**Heuristic**	**Heuristic**	**Non_Heuristic**

			BEST	

For this problem the heuristic algorithm ASIP produced the best outcomes in the shortest amount of time.

DFS took the shortest time but it took the most number of processes

Observations

It was interesting to note that the 2 algorithms were more or less similar with their results, one of them is a non-heuristic algorithm, uniform cost search (UCS) and the other is a heuristic algorithm astar search with h1 preconditions AS. These two algorithms produced identical results in expansions, goal tests and new nodes in all three problems. The only difference was the time elapsed.

Search	Expansions	Goal Tests	New Nodes	Time Elapsed
Problem 1				
USC	55	57	224	0.05
AS	55	57	224	0.05
Problem 2				
USC	4852	4854	44030	24.54
AS	4852	4854	44030	25.67
Problem 3				
USC	18235	18237	159716	120.78
AS	18235	18237	159716	122.91

It is interesting to note that DFS was usually involved in the quickest times but returned less than optimal number of processes. In the air_cargo problem 1 it results in more than the optimum 6 number of processes, I did not get any results in the air_cargo 2 problem and in air_cargo 3 problem it returned a lot more than the 12 optimal number of processes. This is because DFS does not search each layer before going deeper, instead it visits the deeper nodes and returns a non-optimal result in a faster time.

Results

1. breadth_first_search (BFS)
2. breadth_first_tree_search (BFTS)
3. depth_first_graph_search (DFS)
4. depth_limited_search (DLS)
5. uniform_cost_search (UCS)
6. recursive_best_first_search h_1 (RBFS)
7. greedy_best_first_graph_search h_1 (GBFGS)

8. astar_search h_1 (AS)

9. astar_search h_ignore_preconditions (ASIP)

10. astar_search h_pg_levelsum (ASL)

Air Cargo Problem 1

Search	Expansions	Goal Tests	New Nodes	Time Elapsed
BFS	43	56	180	0.04
BFTS	1458	1459	5960	1.33
DFS	21	22	84	0.02
DLS	101	217	414	0.11
USC	55	57	224	0.05
RBFS	4229	4230	17023	3.65
GBFGS	7	9	28	0.01
AS	55	57	224	0.05
ASIP	41	43	170	0.05
ASL	*			

*=took too long

Solving Air Cargo Problem 1 using breadth_first search...

Load(C1, P1, SFO)

Load(C2, P2, JFK)

Fly(P2, JFK, SFO)

Unload(C2, P2, SFO)

Fly(P1, SFO, JFK)

Unload(C1, P1, JFK)

Solving Air Cargo Problem 1 using breadth_first_tree_search...

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...

Fly(P1, SFO, JFK)

Fly(P2, JFK, SFO)

Load(C2, P1, JFK)

Fly(P1, JFK, SFO)

Fly(P2, SFO, JFK)

Unload(C2, P1, SFO)

Fly(P1, SFO, JFK)

Fly(P2, JFK, SFO)

Load(C2, P2, SFO)

Fly(P1, JFK, SFO)

Load(C1, P2, SFO)

Fly(P2, SFO, JFK)

Fly(P1, SFO, JFK)

Unload(C2, P2, JFK)

Unload(C1, P2, JFK)

Fly(P2, JFK, SFO)

Load(C2, P1, JFK)

Fly(P1, JFK, SFO)

Fly(P2, SFO, JFK)

Unload(C2, P1, SFO)

Solving Air Cargo Problem 1 using depth_limited_search...

Load(C1, P1, SFO)

Load(C2, P2, JFK)

Unload(C1, P1, SFO)

Load(C1, P1, SFO)

Unload(C1, P1, SFO)

Load(C1, P1, SFO)

Unload(C1, P1, SFO)

Load(C1, P1, SFO)

Unload(C1, P1, SFO)

Load(C1, P1, SFO)

Unload(C1, P1, SFO)

Load(C1, P1, SFO)

Unload(C1, P1, SFO)

Load(C1, P1, SFO)

Unload(C1, P1, SFO)

Load(C1, P1, SFO)

Unload(C1, P1, SFO)

Load(C1, P1, SFO)

Unload(C1, P1, SFO)

Load(C1, P1, SFO)

Unload(C1, P1, SFO)

Load(C1, P1, SFO)

Unload(C1, P1, SFO)

Load(C1, P1, SFO)

Unload(C1, P1, SFO)

Load(C1, P1, SFO)

Unload(C1, P1, SFO)

Load(C1, P1, SFO)

Unload(C1, P1, SFO)

Load(C1, P1, SFO)

Unload(C1, P1, SFO)

Load(C1, P1, SFO)

Unload(C1, P1, SFO)

Load(C1, P1, SFO)

Unload(C1, P1, SFO)

Load(C1, P1, SFO)

Unload(C1, P1, SFO)

Load(C1, P1, SFO)

Unload(C1, P1, SFO)

Load(C1, P1, SFO)

Unload(C1, P1, SFO)

Load(C1, P1, SFO)

Unload(C1, P1, SFO)

Load(C1, P1, SFO)

Unload(C1, P1, SFO)

Load(C1, P1, SFO)

Fly(P2, JFK, SFO)

Unload(C2, P2, SFO)

Fly(P1, SFO, JFK)

Unload(C1, P1, JFK)

Solving Air Cargo Problem 1 using uniform_cost_search...

Load(C1, P1, SFO)

Load(C2, P2, JFK)

Fly(P1, SFO, JFK)

Fly(P2, JFK, SFO)

Unload(C1, P1, JFK)

Unload(C2, P2, SFO)

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

Load(C2, P2, JFK)

Load(C1, P1, SFO)

Fly(P2, JFK, SFO)

Unload(C2, P2, SFO)

Fly(P1, SFO, JFK)

Unload(C1, P1, JFK)

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

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...

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...

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...

Took too long

Air Cargo Problem 2

Search	Expansions	Goal Tests	New Nodes	Time Elapsed
BFS	3343	4609	30509	17.87
BFTS	*			
DFS	*			
DLS	*			
USC	4852	4854	44030	24.54
RBFS	*			
GBFGS	990	992	8910	5.12
AS	4852	4854	44030	25.67
ASIP	1450	1452	13303	8.21
ASL	*			

*=took too long

Solving Air Cargo Problem 2 using breadth_first_search...

Load(C1, P1, SFO)

Load(C2, P2, JFK)

Load(C3, P3, ATL)

Fly(P2, JFK, SFO)

Unload(C2, P2, SFO)

Fly(P1, SFO, JFK)

Unload(C1, P1, JFK)

Fly(P3, ATL, SFO)

Unload(C3, P3, SFO)

Solving Air Cargo Problem 2 using breadth_first_tree_search...

Took too long

Solving Air Cargo Problem 2 using depth_first_graph_search...

Took too long

Solving Air Cargo Problem 2 using depth_limited_search...

Took too long

Solving Air Cargo Problem 2 using uniform_cost_search...

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(C1, P1, JFK)

Unload(C2, P2, SFO)

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

Took too long

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

Load(C1, P1, SFO)

Load(C2, P2, JFK)

Load(C3, P3, ATL)

Fly(P1, SFO, ATL)

Fly(P2, JFK, ATL)

Fly(P3, ATL, JFK)

Fly(P1, ATL, JFK)

Unload(C1, P1, JFK)

Load(C1, P3, JFK)

Fly(P1, JFK, ATL)

Fly(P2, ATL, SFO)

Unload(C2, P2, SFO)

Fly(P2, SFO, ATL)

Fly(P3, JFK, SFO)

Unload(C3, P3, SFO)

Fly(P3, SFO, JFK)

Unload(C1, P3, JFK)

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

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(C1, P1, JFK)

Unload(C2, P2, SFO)

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

Load(C3, P3, ATL)

Fly(P3, ATL, SFO)

Unload(C3, P3, SFO)

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 2 using astar_search with h_pg_levelsum...

Took too long

Air Cargo Problem 3

Search	Expansions	Goal Tests	New Nodes	Time Elapsed
BFS	14663	18098	129631	102.98
BFTS	*			
DFS	408	409	3364	3.57
DLS	*			
USC	18235	18237	159716	120.78
RBFS	*			
GBFGS	5614	5616	49429	38.94
AS	18235	18237	159716	122.91
ASIP	5040	5042	44944	38.21
ASL	*			

*=took too long

Solving Air Cargo Problem 3 using breadth_first_search...

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)

Solving Air Cargo Problem 3 using breadth_first_tree_search...

Took too long

Solving Air Cargo Problem 3 using depth_first_graph_search...

Fly(P2, SFO, JFK)

Fly(P1, SFO, JFK)

Load(C2, P2, JFK)

Fly(P2, JFK, ORD)

Fly(P1, JFK, ORD)

Fly(P2, ORD, ATL)

Fly(P1, ORD, ATL)

Fly(P2, ATL, SFO)

Fly(P1, ATL, SFO)

Unload(C2, P2, SFO)

Fly(P2, SFO, ORD)

Fly(P1, SFO, ORD)

Fly(P2, ORD, ATL)

Fly(P1, ORD, ATL)

Fly(P2, ATL, JFK)

Load(C3, P1, ATL)

Fly(P1, ATL, ORD)

Fly(P2, JFK, ORD)

Fly(P1, ORD, SFO)

Fly(P2, ORD, ATL)

Fly(P1, SFO, JFK)

Fly(P2, ATL, SFO)

Unload(C3, P1, JFK)

Fly(P2, SFO, ORD)

Fly(P1, JFK, ORD)

Fly(P2, ORD, ATL)

Fly(P1, ORD, ATL)

Fly(P2, ATL, JFK)

Fly(P1, ATL, SFO)

Load(C3, P2, JFK)

Fly(P1, SFO, ORD)

Fly(P2, JFK, ORD)

Fly(P1, ORD, ATL)

Fly(P2, ORD, SFO)

Fly(P1, ATL, JFK)

Fly(P2, SFO, ATL)

Load(C1, P2, ATL)

Fly(P2, ATL, ORD)

Fly(P1, JFK, ORD)

Fly(P2, ORD, SFO)

Fly(P1, ORD, ATL)

Fly(P2, SFO, JFK)

Fly(P1, ATL, SFO)

Unload(C3, P2, JFK)

Fly(P1, SFO, ORD)

Fly(P2, JFK, ORD)

Fly(P1, ORD, ATL)

Fly(P2, ORD, SFO)

Fly(P1, ATL, JFK)

Load(C3, P1, JFK)

Fly(P2, SFO, ORD)

Fly(P1, JFK, ORD)

Fly(P2, ORD, ATL)

Fly(P1, ORD, ATL)

Fly(P2, ATL, JFK)

Fly(P1, ATL, SFO)

Unload(C3, P1, SFO)

Fly(P1, SFO, ORD)

Fly(P2, JFK, ORD)

Fly(P1, ORD, ATL)

Fly(P2, ORD, ATL)

Fly(P1, ATL, JFK)

Fly(P2, ATL, SFO)

Unload(C1, P2, SFO)

Fly(P2, SFO, ORD)

Fly(P1, JFK, ORD)

Fly(P2, ORD, ATL)

Fly(P1, ORD, ATL)

Fly(P2, ATL, JFK)

Fly(P1, ATL, SFO)

Load(C3, P1, SFO)

Fly(P1, SFO, ORD)

Fly(P2, JFK, ORD)

Fly(P1, ORD, JFK)

Fly(P2, ORD, ATL)

Unload(C3, P1, JFK)

Fly(P2, ATL, JFK)

Fly(P1, JFK, ORD)

Fly(P2, JFK, ORD)

Fly(P1, ORD, ATL)

Load(C4, P2, ORD)

Fly(P2, ORD, ATL)

Fly(P1, ATL, ORD)

Fly(P2, ATL, SFO)

Fly(P1, ORD, SFO)

Fly(P2, SFO, JFK)

Fly(P1, SFO, JFK)

Unload(C4, P2, JFK)

Fly(P2, JFK, ORD)

Fly(P1, JFK, ORD)

Fly(P2, ORD, ATL)

Fly(P1, ORD, ATL)

Fly(P2, ATL, SFO)

Fly(P1, ATL, SFO)

Load(C2, P2, SFO)

Fly(P2, SFO, ORD)

Fly(P1, SFO, ORD)

Fly(P2, ORD, ATL)

Fly(P1, ORD, ATL)

Fly(P2, ATL, JFK)

Fly(P1, ATL, JFK)

Unload(C2, P2, JFK)

Fly(P2, JFK, ORD)

Fly(P1, JFK, ORD)

Fly(P2, ORD, ATL)

Fly(P1, ORD, ATL)

Fly(P2, ATL, SFO)

Fly(P1, ATL, SFO)

Load(C1, P2, SFO)

Fly(P2, SFO, ORD)

Fly(P1, SFO, ORD)

Fly(P2, ORD, ATL)

Fly(P1, ORD, ATL)

Fly(P2, ATL, JFK)

Fly(P1, ATL, JFK)

Unload(C1, P2, JFK)

Fly(P2, JFK, ORD)

Load(C4, P1, JFK)

Fly(P2, ORD, ATL)

Fly(P1, JFK, ORD)

Fly(P2, ATL, SFO)

Fly(P1, ORD, ATL)

Fly(P2, SFO, JFK)

Fly(P1, ATL, SFO)

Unload(C4, P1, SFO)

Fly(P1, SFO, ORD)

Fly(P2, JFK, ORD)

Fly(P1, ORD, ATL)

Fly(P2, ORD, ATL)

Fly(P1, ATL, JFK)

Fly(P2, ATL, SFO)

Load(C4, P2, SFO)

Fly(P2, SFO, ORD)

Fly(P1, JFK, ORD)

Fly(P2, ORD, ATL)

Fly(P1, ORD, ATL)

Fly(P2, ATL, JFK)

Fly(P1, ATL, SFO)

Load(C3, P2, JFK)

Fly(P1, SFO, ORD)

Fly(P2, JFK, ORD)

Fly(P1, ORD, ATL)

Fly(P2, ORD, ATL)

Fly(P1, ATL, JFK)

Fly(P2, ATL, SFO)

Unload(C4, P2, SFO)

Fly(P2, SFO, ORD)

Fly(P1, JFK, ORD)

Fly(P2, ORD, ATL)

Fly(P1, ORD, ATL)

Fly(P2, ATL, JFK)

Load(C2, P2, JFK)

Fly(P1, ATL, ORD)

Fly(P2, JFK, ORD)

Fly(P1, ORD, SFO)

Fly(P2, ORD, ATL)

Fly(P1, SFO, JFK)

Fly(P2, ATL, SFO)

Unload(C3, P2, SFO)

Fly(P2, SFO, ORD)

Fly(P1, JFK, ORD)

Fly(P2, ORD, ATL)

Fly(P1, ORD, ATL)

Fly(P2, ATL, JFK)

Fly(P1, ATL, SFO)

Unload(C2, P2, JFK)

Fly(P1, SFO, ORD)

Fly(P2, JFK, ORD)

Fly(P1, ORD, ATL)

Fly(P2, ORD, ATL)

Fly(P1, ATL, JFK)

Load(C2, P1, JFK)

Fly(P2, ATL, ORD)

Fly(P1, JFK, ORD)

Fly(P2, ORD, SFO)

Fly(P1, ORD, ATL)

Fly(P2, SFO, JFK)

Fly(P1, ATL, SFO)

Unload(C2, P1, SFO)

Fly(P1, SFO, ORD)

Fly(P2, JFK, ORD)

Fly(P1, ORD, ATL)

Fly(P2, ORD, ATL)

Fly(P1, ATL, JFK)

Load(C1, P1, JFK)

Fly(P2, ATL, ORD)

Fly(P1, JFK, ORD)

Fly(P2, ORD, SFO)

Fly(P1, ORD, ATL)

Fly(P2, SFO, JFK)

Fly(P1, ATL, SFO)

Unload(C1, P1, SFO)

Fly(P1, SFO, ORD)

Fly(P2, JFK, ORD)

Fly(P1, ORD, ATL)

Fly(P2, ORD, ATL)

Fly(P1, ATL, JFK)

Fly(P2, ATL, SFO)

Load(C4, P2, SFO)

Fly(P2, SFO, ATL)

Fly(P1, JFK, ORD)

Fly(P2, ATL, JFK)

Fly(P1, ORD, ATL)

Fly(P2, JFK, ORD)

Fly(P1, ATL, SFO)

Load(C3, P1, SFO)

Fly(P2, ORD, ATL)

Fly(P1, SFO, ORD)

Fly(P2, ATL, SFO)

Fly(P1, ORD, ATL)

Fly(P2, SFO, JFK)

Unload(C4, P2, JFK)

Fly(P1, ATL, ORD)

Fly(P2, JFK, ORD)

Fly(P1, ORD, SFO)

Fly(P2, ORD, ATL)

Fly(P1, SFO, JFK)

Fly(P2, ATL, SFO)

Load(C4, P1, JFK)

Fly(P2, SFO, ORD)

Fly(P1, JFK, ATL)

Fly(P2, ORD, ATL)

Fly(P1, ATL, ORD)

Unload(C3, P1, ORD)

Fly(P1, ORD, ATL)

Fly(P2, ATL, ORD)

Fly(P1, ATL, SFO)

Fly(P2, ORD, SFO)

Fly(P1, SFO, JFK)

Fly(P2, SFO, JFK)

Unload(C4, P1, JFK)

Fly(P2, JFK, ORD)

Fly(P1, JFK, ATL)

Fly(P2, ORD, ATL)

Fly(P1, ATL, ORD)

Fly(P2, ATL, SFO)

Fly(P1, ORD, SFO)

Load(C2, P2, SFO)

Fly(P2, SFO, ORD)

Fly(P1, SFO, ORD)

Fly(P2, ORD, ATL)

Fly(P1, ORD, ATL)

Fly(P2, ATL, JFK)

Fly(P1, ATL, JFK)

Unload(C2, P2, JFK)

Fly(P2, JFK, ORD)

Fly(P1, JFK, ORD)

Fly(P2, ORD, ATL)

Fly(P1, ORD, ATL)

Fly(P2, ATL, SFO)

Fly(P1, ATL, SFO)

Load(C1, P2, SFO)

Fly(P2, SFO, ORD)

Fly(P1, SFO, ORD)

Fly(P2, ORD, ATL)

Fly(P1, ORD, ATL)

Fly(P2, ATL, JFK)

Fly(P1, ATL, JFK)

Unload(C1, P2, JFK)

Fly(P2, JFK, ORD)

Fly(P1, JFK, ORD)

Fly(P2, ORD, ATL)

Load(C3, P1, ORD)

Fly(P1, ORD, ATL)

Fly(P2, ATL, ORD)

Fly(P1, ATL, SFO)

Fly(P2, ORD, SFO)

Fly(P1, SFO, JFK)

Load(C4, P1, JFK)

Fly(P2, SFO, JFK)

Fly(P1, JFK, ORD)

Fly(P2, JFK, ORD)

Fly(P1, ORD, ATL)

Fly(P2, ORD, ATL)

Fly(P1, ATL, SFO)

Unload(C4, P1, SFO)

Fly(P2, ATL, ORD)

Fly(P1, SFO, ORD)

Fly(P2, ORD, SFO)

Fly(P1, ORD, ATL)

Fly(P2, SFO, JFK)

Fly(P1, ATL, JFK)

Load(C2, P2, JFK)

Fly(P2, JFK, ORD)

Fly(P1, JFK, ORD)

Fly(P2, ORD, ATL)

Fly(P1, ORD, ATL)

Fly(P2, ATL, SFO)

Fly(P1, ATL, SFO)

Unload(C2, P2, SFO)

Fly(P2, SFO, ORD)

Fly(P1, SFO, ORD)

Fly(P2, ORD, ATL)

Fly(P1, ORD, ATL)

Fly(P2, ATL, JFK)

Fly(P1, ATL, JFK)

Unload(C3, P1, JFK)

Solving Air Cargo Problem 3 using depth_limited_search...

Took too long

Solving Air Cargo Problem 3 using uniform_cost_search...

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(C1, P1, JFK)

Unload(C2, P2, SFO)

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

Took too long

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

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)

Fly(P2, SFO, ORD)

Fly(P1, SFO, ORD)

Fly(P2, ORD, ATL)

Fly(P1, ORD, ATL)

Fly(P2, ATL, JFK)

Fly(P1, ATL, JFK)

Unload(C1, P2, JFK)

Fly(P2, JFK, ORD)

Fly(P1, JFK, ORD)

Fly(P2, ORD, ATL)

Load(C3, P1, ORD)

Fly(P1, ORD, ATL)

Fly(P2, ATL, ORD)

Fly(P1, ATL, SFO)

Fly(P2, ORD, SFO)

Fly(P1, SFO, JFK)

Load(C4, P1, JFK)

Fly(P2, SFO, JFK)

Fly(P1, JFK, ORD)

Fly(P2, JFK, ORD)

Fly(P1, ORD, ATL)

Fly(P2, ORD, ATL)

Fly(P1, ATL, SFO)

Unload(C4, P1, SFO)

Fly(P2, ATL, ORD)

Fly(P1, SFO, ORD)

Fly(P2, ORD, SFO)

Fly(P1, ORD, ATL)

Fly(P2, SFO, JFK)

Fly(P1, ATL, JFK)

Load(C2, P2, JFK)

Fly(P2, JFK, ORD)

Fly(P1, JFK, ORD)

Fly(P2, ORD, ATL)

Fly(P1, ORD, ATL)

Fly(P2, ATL, SFO)

Fly(P1, ATL, SFO)

Unload(C2, P2, SFO)

Fly(P2, SFO, ORD)

Fly(P1, SFO, ORD)

Fly(P2, ORD, ATL)

Fly(P1, ORD, ATL)

Fly(P2, ATL, JFK)

Fly(P1, ATL, JFK)

Unload(C3, P1, JFK)

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

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(C1, P1, JFK)

Unload(C2, P2, SFO)

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

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(C1, P1, JFK)

Unload(C2, P2, SFO)

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

Took too long