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# HEURISTIC ANALYSIS

*Heuristic analysis* covers the comparison and contrast heuristic search result metrics using A\* with the "ignore preconditions" and "level-sum" heuristics for Problems 1, 2, and 3.

This project was defined in PDDL as:

*Action(Load(c, p, a),*

*PRECOND: At(c, a) ∧ At(p, a) ∧ Cargo(c) ∧ Plane(p) ∧ Airport(a)*

*EFFECT: ¬ At(c, a) ∧ In(c, p))*

*Action(Unload(c, p, a),*

*PRECOND: In(c, p) ∧ At(p, a) ∧ Cargo(c) ∧ Plane(p) ∧ Airport(a)*

*EFFECT: At(c, a) ∧ ¬ In(c, p))*

*Action(Fly(p, from, to),*

*PRECOND: At(p, from) ∧ Plane(p) ∧ Airport(from) ∧ Airport(to)*

*EFFECT: ¬ At(p, from) ∧ At(p, to))*

## Measuring problem-solving performance:

We can evaluate an algorithm’s performance in four ways:[[1]](#footnote-1)

* **Completeness**: Is the algorithm guaranteed to find a solution when there is one?
* **Optimality**: Does the strategy find the optimal solution (goal state reached with the lowest path cost among all solutions)
* **Time complexity:** How long does it take to find a solution?
* **Space Complexity**: How much memory is needed to perform the search?

Complexity is expressed in terms of branching factor, the depth of the shallowest goal node (number of steps along the path from the root); and the maximum length of any path in the state space.

### PROBLEM 1

##### Problem definition

Problem 1 initial state and goal:

*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))*

That is:

* Two cargos [C1, C2]
* Two planes [P1, P2]
* Two airports [JFK, CFO]

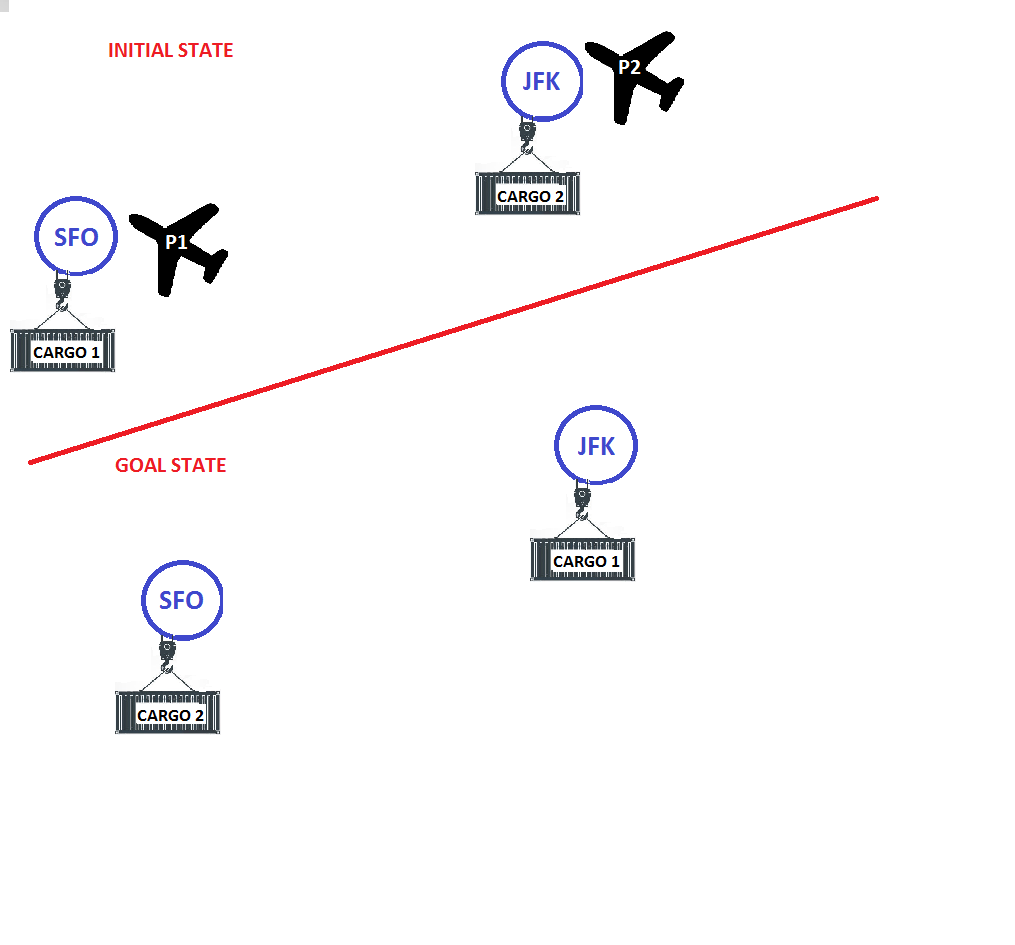


Figure 1 Problem 1: Initial State and Goal State graphic representation.

The metrics gathered for Problem 1 are summarised in the following table:

|  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- |
|  |  | Expansions | Goal Tests | New Nodes | Plan length | Time (seconds) |
| 1 | breadth\_first\_search | 43 | 56 | 180 | 6 | 0.06817695 |
| 2 | breadth\_first\_tree\_search | 1458 | 1459 | 5960 | 6 | 1.932569177 |
| 3 | depth\_first\_graph\_search | 21 | 22 | 84 | 20 | 0.029160107 |
| 4 | depth\_limited\_search | 101 | 271 | 414 | 50 | 0.148578431 |
| 5 | uniform\_cost\_search | 55 | 57 | 224 | 6 | 0.087215695 |
| 6 | recursive\_best\_first\_search | 4229 | 4230 | 17023 | 6 | 5.777305052 |
| 7 | greedy\_best\_first\_graph\_search | 7 | 9 | 28 | 6 | 0.012970658 |
| 8 | astar\_search h\_1 | 55 | 57 | 224 | 6 | 0.081050772 |
| 9 | astar\_search h\_ignore\_preconditions | 41 | 43 | 170 | 6 | 0.065016618 |
| 10 | astar\_search h\_pg\_levelsum | 45 | 47 | 188 | 6 | 2.891080564 |

##### Optimal Plan

The **greedy\_best\_first\_graph\_search** is the optimum. It optimum and the fastest heuristic. The reason remains in the definition of the algorithm itself: It expands the node closest to the goal, leading quickly to a solution. Therefore, expands fewer nodes, take less time and finds quicker a solution.

The steps for the sequence are:

Load(C1, P1, SFO)

Load(C2, P2, JFK)

Fly(P1, SFO, JFK)

Fly(P2, JFK, SFO)

Unload(C1, P1, JFK)

Unload(C2, P2, SFO)

##### Comparison of non-heuristic search

Regarding the comparison of non-heuristic search result metrics:

|  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- |
|  |  | Expansions | Goal Tests | New Nodes | Plan length | Time |
| 1 | breadth\_first\_search | 43 | 56 | 180 | 6 | 0.06817695 |
| 3 | depth\_first\_graph\_search | 21 | 22 | 84 | 20 | 0.029160107 |
| 5 | uniform\_cost\_search | 55 | 57 | 224 | 6 | 0.087215695 |

In this problem, depth\_first\_graph\_search results in less time complexity, less space complexity but needs more steps (not optimum) that **breadth-first search** and **uniform cost search**. The last two are optimum while are a bit more complex. Although **breadth-first** search is faster than **uniform\_cost\_search** there is not a big gap between the two of them considering time and goal test needed.

##### Are heuristic search planning methods better?

|  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- |
|  |  | Expansions | Goal Tests | New Nodes | Plan length | Time |
| 8 | astar\_search h\_1 | 55 | 57 | 224 | 6 | 0.081050772 |
| 9 | astar\_search h\_ignore\_preconditions | 41 | 43 | 170 | 6 | 0.065016618 |
| 10 | astar\_search h\_pg\_levelsum | 45 | 47 | 188 | 6 | 2.891080564 |

For Heuristic search, the **astar\_search h\_ignore\_preconditions** performs much better while keeping optimum. Comparing it with the fastest non-heuristic & optimum method, **astar\_search h\_ignore\_preconditions**, beats on metrics.

### PROBLEM 2

##### Problem definition

- Problem 2 initial state and goal:

*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))*

That is:

* Three cargos [C1, C2, C3]
* Three planes [P1, P2, P3]
* Three airports [JFK, CFO, ATL]

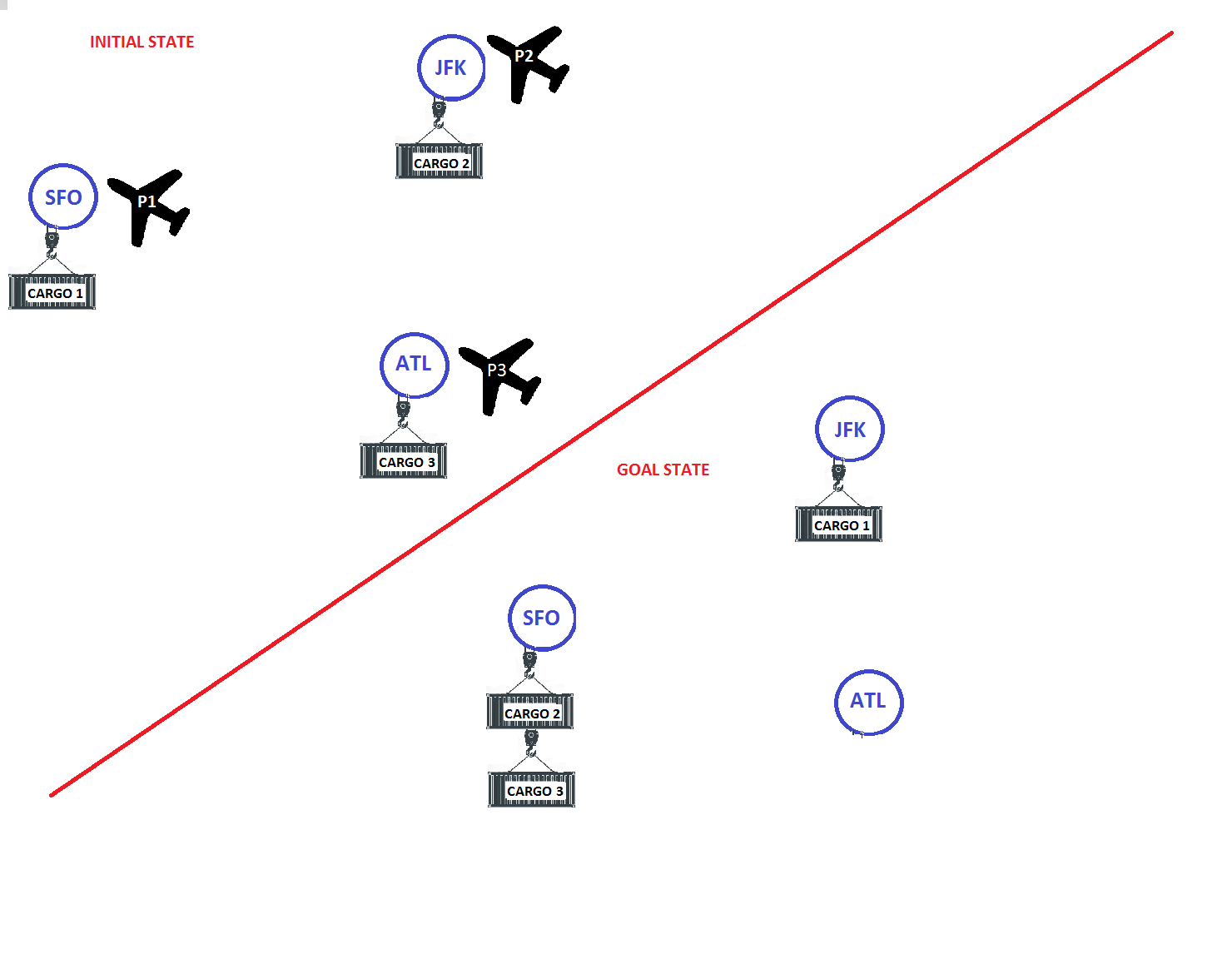


Figure 2 Problem 2: Initial State and Goal State graphic representation.

|  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- |
|  |  | Expansions | Goal Tests | New Nodes | Plan length | Time (seconds) |
| 1 | breadth\_first\_search | 3343 | 4609 | 30509 | 9 | 33.79900031 |
| 2 | breadth\_first\_tree\_search | TO | TO | TO | TO | TO |
| 3 | depth\_first\_graph\_search | 624 | 625 | 5602 | 619 | 6.695474237 |
| 4 | depth\_limited\_search | TO | TO | TO | TO | TO |
| 5 | uniform\_cost\_search | 4853 | 4855 | 44041 | 9 | 48.80281886 |
| 6 | recursive\_best\_first\_search | TO | TO | TO | TO | TO |
| 7 | greedy\_best\_first\_graph\_search | 998 | 1000 | 8982 | 21 | 7.331830368 |
| 8 | astar\_search h\_1 | 4853 | 4855 | 44041 | 9 | 34.45352545 |
| 9 | astar\_search h\_ignore\_preconditions | 1450 | 1452 | 13303 | 9 | 17.43890903 |
| 10 | astar\_search h\_pg\_levelsum | TO | TO | TO | TO | TO |

The metrics gathered for Problem 2 are summarised in the following table (where TO = Timed Out):

##### Optimal Plan

For this second problem, we find that depth\_first\_graph\_search is te less complex in time heuristic. However, it does not find the optimum plan length. This is reached with breath\_first\_search, uniform\_cost\_search, astar\_search h\_1 and astar\_search h\_ignore\_preconditions. From all of these **astar\_search h\_ignore\_preconditions** takes the less time, needs fewer expansions and fewer goal tests to reach the solution. Therefore it is optimum.

The steps for the sequence are:

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)

##### Comparison of non-heuristic search

Regarding the comparison of non-heuristic search result metrics:

|  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- |
|  |  | Expansions | Goal Tests | New Nodes | Plan length | Time |
| 1 | breadth\_first\_search | 3343 | 4609 | 30509 | 9 | 33.79900031 |
| 3 | depth\_first\_graph\_search | 624 | 625 | 5602 | 619 | 6.695474237 |
| 5 | uniform\_cost\_search | 4853 | 4855 | 44041 | 9 | 48.80281886 |

The comparison reaches the same conclusion as in problem 1, Depth-first search results in less time complexity, less space complexity but needs more steps (less optimality) that breadth-first search and uniform cost search. The last two are optimum while are a bit much more complex. This time the gap between these two methods clearly makes **breadth\_first\_search** the best non-heuristic method.

##### Are heuristic search planning methods better?

|  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- |
|  |  | Expansions | Goal Tests | New Nodes | Plan length | Time |
| 8 | astar\_search h\_1 | 4853 | 4855 | 44041 | 9 | 34.45352545 |
| 9 | astar\_search h\_ignore\_preconditions | 1450 | 1452 | 13303 | 9 | 17.43890903 |
| 10 | astar\_search h\_pg\_levelsum | TO | TO | TO | TO | TO |

Considering Problem 2, we find astar\_search\_pg\_levelsum and uniform\_cost\_search\_ having the same complexity and cost metrics. In this specific case, astar\_search\_pg\_levelsum beats in time complexity its non-heuristic metric-twin method. In both cases, there are two methods that are optimum.

As heuristic method we can see **astar\_search h\_ignore\_preconditions** is both the most optimum method between heuristic ones, as well as less complex in space and time. If we compare this one with the optimum in non-heuristic, the best performance is reached in astar\_search h\_ignore\_preconditions as has fewer expansions and need less goal test with a better time metric.

|  |
| --- |
|  |

### PROBLEM 3

##### Problem definition

- Problem 3 initial state and goal:

*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))*

That is:

* Four cargos [C1, C2, C3, C4]
* Two planes [P1, P2]
* Four airports [JFK, CFO, ATL, ORD]

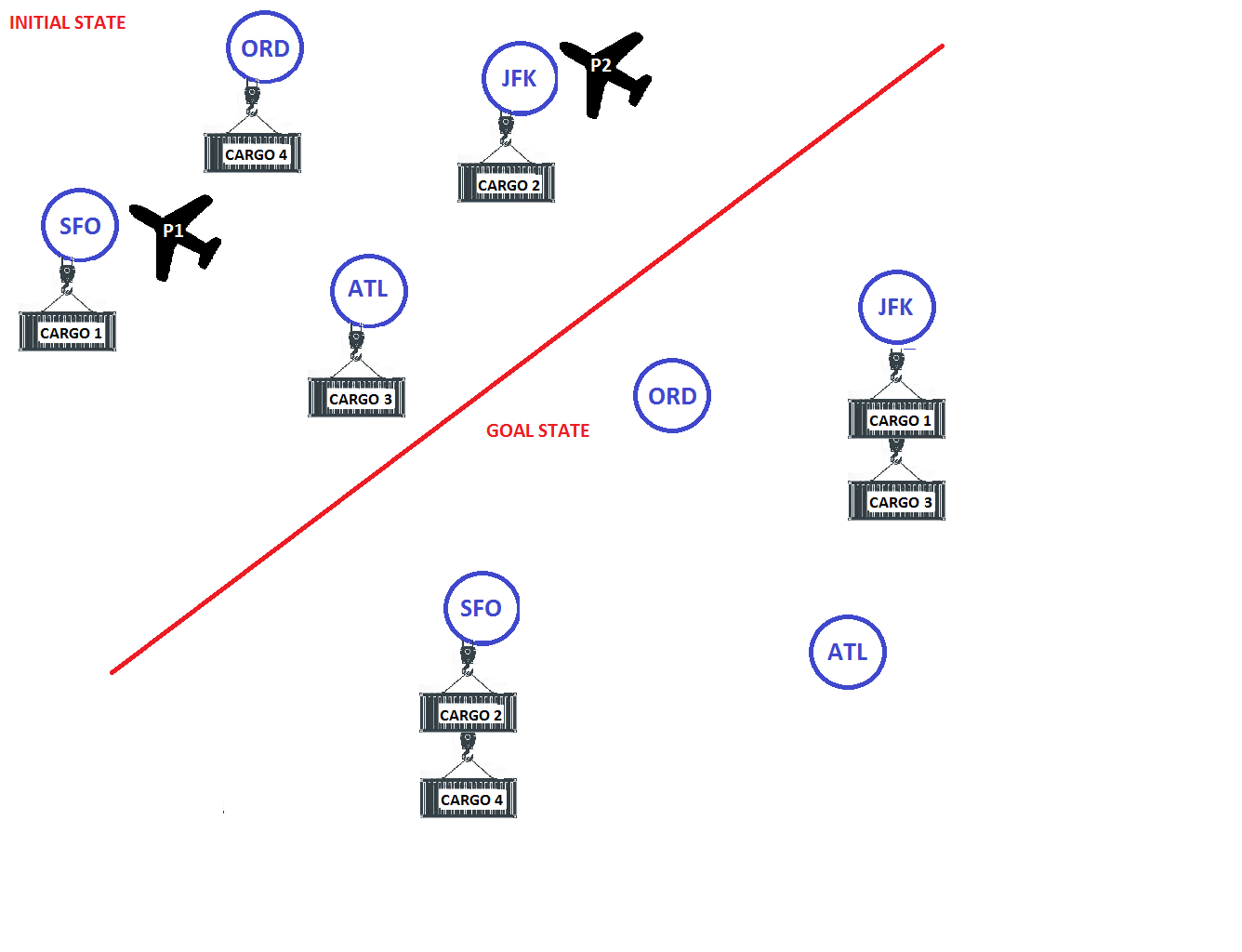


Figure 3 Problem 3: Initial State and Goal State graphic representation.

The metrics gathered for Problem 3 are summarised in the following table (where TO = Timed Out):

|  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- |
|  |  | Expansions | Goal Tests | New Nodes | Plan length | Time (seconds) |
| 1 | breadth\_first\_search | 3343 | 4609 | 30509 | 12 | 336.2690923 |
| 2 | breadth\_first\_tree\_search | TO | TO | TO | TO | TO |
| 3 | depth\_first\_graph\_search | 624 | 625 | 5602 | 392 | 3.190495443 |
| 4 | depth\_limited\_search | TO | TO | TO | TO | TO |
| 5 | uniform\_cost\_search | 4853 | 4855 | 44041 | 12 | 180.3116849 |
| 6 | recursive\_best\_first\_search | TO | TO | TO | TO | TO |
| 7 | greedy\_best\_first\_graph\_search | 998 | 1000 | 8982 | 22 | 54.17322964 |
| 8 | astar\_search h\_1 | 4853 | 4855 | 44041 | 12 | 164.9216165 |
| 9 | astar\_search h\_ignore\_preconditions | 1450 | 1452 | 13303 | 12 | 57.23769514 |
| 10 | astar\_search h\_pg\_levelsum | TO | TO | TO | TO | TO |

##### Optimal Plan

The optimum is reached in **astar\_search h\_ignore\_preconditions**

The steps for the sequence are:

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)

The fastest algorithm is reached in depth\_first\_graph, but it is not optimum. From the optimum methods, breadth\_first\_search, uniform\_cost\_search, astar\_search h\_1, astar\_search h\_ignore\_preconditions; **astar\_search h\_ignore\_preconditions** is the fastest as it needs to expand fewer nodes and needs fewer goal tests.

##### Comparison of non-heuristic search

Regarding the comparison of non-heuristic search result metrics:

|  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- |
|  |  | Expansions | Goal Tests | New Nodes | Plan length | Time |
| 1 | breadth\_first\_search | 3343 | 4609 | 30509 | 12 | 336.2690923 |
| 3 | depth\_first\_graph\_search | 624 | 625 | 5602 | 392 | 3.190495443 |
| 5 | uniform\_cost\_search | 4853 | 4855 | 44041 | 12 | 180.3116849 |

Considering the non-heuristic search methods, we found two excellent methods: breadth\_first\_search and uniform\_cost\_search.

Comparing them, breadth\_first\_search results on less space complexity (fewer expansions and fewer goal tests) while uniform\_cost\_search results on less time complexity.

##### Are heuristic search planning methods better?

|  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- |
|  |  | Expansions | Goal Tests | New Nodes | Plan length | Time |
| 8 | astar\_search h\_1 | 4853 | 4855 | 44041 | 12 | 164.9216165 |
| 9 | astar\_search h\_ignore\_preconditions | 1450 | 1452 | 13303 | 12 | 57.23769514 |
| 10 | astar\_search h\_pg\_levelsum | TO | TO | TO | TO | TO |

In problem 3, we find that **astar\_search h\_ignore\_preconditions** are optimism and the fastest of heuristic methods. If we compare it with an-heuristic optimum solution astar\_search h\_ignore\_preconditions beat the metrics.

## CONCLUSION

Considering the comparison of 3 non-heuristic and three heuristic methods in all three problems the conclusion is that **astar\_search h\_ignore\_preconditions** were optimum while had better metrics.

As stated on Artificial Intelligence a Modern Approach [[2]](#footnote-2) “an admissible heuristic can be derived by defining a relaxed problem easier to solve” like the mentioned **ignore\_preconditions** heuristic.

By removing the precondition, we make much more efficient forward and backward search, and therefore we can use A\* search to find optimal solutions.

# APPENDIX

These are the complete results appears on the screen after

*python run\_search.py -p x -s y,*

where -*x-* is the number of Problem in [1,2,3]

and -*y-* the heuristic in [1,2,3,4,5,6,7,8,9,10]

## PROBLEM 1

#### Solving Air Cargo Problem 1 using breadth\_first\_search...

Expansions Goal Tests New Nodes

43 56 180

Plan length: 6 Time elapsed in seconds: 0.06817695001660044

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.

Expansions Goal Tests New Nodes

1458 1459 5960

Plan length: 6 Time elapsed in seconds: 1.932569177439105

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: 0.0291601068140359

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...

Expansions Goal Tests New Nodes

101 271 414

Plan length: 50 Time elapsed in seconds: 0.1485784308475506

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...

Expansions Goal Tests New Nodes

55 57 224

Plan length: 6 Time elapsed in seconds: 0.0872156950944798

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

Expansions Goal Tests New Nodes

4229 4230 17023

Plan length: 6 Time elapsed in seconds: 5.777305051889773

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

Expansions Goal Tests New Nodes

7 9 28

Plan length: 6 Time elapsed in seconds: 0.01297065827005461

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: 0.08105077236686498

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

Expansions Goal Tests New Nodes

41 43 170

Plan length: 6 Time elapsed in seconds: 0.06501661829333116

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\_lev

Expansions Goal Tests New Nodes

45 47 188

Plan length: 6 Time elapsed in seconds: 2.8910805639152777

Load(C1, P1, SFO)

Fly(P1, SFO, JFK)

Load(C2, P2, JFK)

Fly(P2, JFK, SFO)

Unload(C1, P1, JFK)

Unload(C2, P2, SFO)

## PROBLEM 2

#### Solving Air Cargo Problem 2 using breadth\_first\_search...

Expansions Goal Tests New Nodes

3343 4609 30509

Plan length: 9 Time elapsed in seconds: 33.79900031415893

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 depth\_first\_graph\_search...

Expansions Goal Tests New Nodes

624 625 5602

Plan length: 619 Time elapsed in seconds: 6.695474237182851

Fly(P3, ATL, SFO)

Fly(P1, SFO, ATL)

Fly(P3, SFO, JFK)

Fly(P1, ATL, JFK)

Fly(P2, JFK, ATL)

Fly(P3, JFK, ATL)

Fly(P2, ATL, SFO)

Fly(P3, ATL, SFO)

Load(C2, P1, JFK)

Fly(P2, SFO, ATL)

Fly(P1, JFK, ATL)

Fly(P2, ATL, JFK)

Fly(P1, ATL, SFO)

Fly(P3, SFO, ATL)

Fly(P1, SFO, JFK)

Load(C3, P3, ATL)

Fly(P3, ATL, SFO)

Fly(P2, JFK, ATL)

Fly(P3, SFO, JFK)

Fly(P2, ATL, SFO)

Fly(P1, JFK, ATL)

Fly(P2, SFO, JFK)

Fly(P1, ATL, SFO)

Unload(C3, P3, JFK)

Fly(P1, SFO, JFK)

Fly(P3, JFK, ATL)

Fly(P2, JFK, ATL)

Fly(P3, ATL, SFO)

Fly(P2, ATL, SFO)

Fly(P1, JFK, ATL)

Fly(P3, SFO, ATL)

Fly(P1, ATL, SFO)

Unload(C2, P1, SFO)

Fly(P3, ATL, SFO)

Fly(P2, SFO, ATL)

Fly(P1, SFO, ATL)

Fly(P2, ATL, JFK)

Fly(P1, ATL, JFK)

Fly(P3, SFO, ATL)

Fly(P2, JFK, ATL)

Fly(P3, ATL, JFK)

Fly(P2, ATL, SFO)

Fly(P1, JFK, ATL)

Load(C3, P3, JFK)

Fly(P1, ATL, SFO)

Fly(P2, SFO, ATL)

Fly(P3, JFK, ATL)

Fly(P2, ATL, JFK)

Fly(P3, ATL, SFO)

Fly(P1, SFO, ATL)

Fly(P2, JFK, ATL)

Fly(P1, ATL, JFK)

Fly(P2, ATL, SFO)

Fly(P3, SFO, ATL)

Unload(C3, P3, ATL)

Fly(P3, ATL, SFO)

Fly(P2, SFO, ATL)

Fly(P3, SFO, JFK)

Fly(P2, ATL, JFK)

Fly(P1, JFK, ATL)

Fly(P3, JFK, ATL)

Fly(P2, JFK, ATL)

Load(C3, P2, ATL)

Fly(P3, ATL, SFO)

Fly(P2, ATL, SFO)

Fly(P1, ATL, SFO)

Fly(P3, SFO, ATL)

Fly(P2, SFO, JFK)

Fly(P3, ATL, JFK)

Fly(P1, SFO, JFK)

Fly(P2, JFK, SFO)

Unload(C3, P2, SFO)

Fly(P2, SFO, ATL)

Fly(P3, JFK, ATL)

Fly(P2, ATL, JFK)

Fly(P3, ATL, SFO)

Load(C2, P3, SFO)

Fly(P3, SFO, ATL)

Fly(P2, JFK, ATL)

Fly(P3, ATL, JFK)

Fly(P2, ATL, SFO)

Fly(P1, JFK, ATL)

Fly(P2, SFO, JFK)

Fly(P1, ATL, SFO)

Unload(C2, P3, JFK)

Fly(P1, SFO, JFK)

Fly(P3, JFK, ATL)

Fly(P2, JFK, ATL)

Fly(P3, ATL, SFO)

Fly(P2, ATL, SFO)

Fly(P1, JFK, ATL)

Fly(P3, SFO, ATL)

Fly(P1, ATL, SFO)

Load(C3, P2, SFO)

Fly(P3, ATL, SFO)

Fly(P2, SFO, ATL)

Fly(P1, SFO, ATL)

Fly(P2, ATL, JFK)

Fly(P1, ATL, JFK)

Fly(P3, SFO, ATL)

Load(C2, P2, JFK)

Fly(P3, ATL, JFK)

Fly(P2, JFK, ATL)

Fly(P1, JFK, ATL)

Fly(P2, ATL, SFO)

Fly(P1, ATL, SFO)

Unload(C3, P2, SFO)

Fly(P2, SFO, ATL)

Fly(P1, SFO, ATL)

Fly(P2, ATL, JFK)

Fly(P3, JFK, ATL)

Fly(P1, ATL, SFO)

Fly(P3, ATL, SFO)

Fly(P1, SFO, JFK)

Fly(P2, JFK, ATL)

Fly(P3, SFO, ATL)

Fly(P2, ATL, SFO)

Load(C1, P2, SFO)

Fly(P3, ATL, SFO)

Fly(P2, SFO, ATL)

Fly(P3, SFO, JFK)

Fly(P2, ATL, JFK)

Fly(P1, JFK, ATL)

Fly(P3, JFK, ATL)

Fly(P1, ATL, SFO)

Fly(P3, ATL, SFO)

Unload(C2, P2, JFK)

Fly(P1, SFO, ATL)

Fly(P2, JFK, ATL)

Fly(P1, ATL, JFK)

Fly(P3, SFO, ATL)

Fly(P2, ATL, SFO)

Fly(P3, ATL, JFK)

Fly(P1, JFK, ATL)

Load(C3, P2, SFO)

Fly(P1, ATL, SFO)

Fly(P2, SFO, ATL)

Fly(P1, SFO, JFK)

Fly(P2, ATL, JFK)

Fly(P3, JFK, ATL)

Fly(P1, JFK, ATL)

Fly(P3, ATL, SFO)

Fly(P1, ATL, SFO)

Unload(C3, P2, JFK)

Fly(P3, SFO, ATL)

Fly(P2, JFK, ATL)

Fly(P3, ATL, JFK)

Fly(P2, ATL, SFO)

Fly(P1, SFO, ATL)

Fly(P2, SFO, JFK)

Unload(C1, P2, JFK)

Fly(P1, ATL, SFO)

Fly(P2, JFK, ATL)

Fly(P1, SFO, JFK)

Fly(P2, ATL, SFO)

Fly(P3, JFK, ATL)

Fly(P2, SFO, JFK)

Fly(P3, ATL, SFO)

Load(C3, P2, JFK)

Fly(P2, JFK, ATL)

Fly(P3, SFO, ATL)

Fly(P2, ATL, SFO)

Fly(P3, ATL, JFK)

Fly(P1, JFK, ATL)

Fly(P2, SFO, ATL)

Fly(P1, ATL, SFO)

Unload(C3, P2, ATL)

Fly(P2, ATL, SFO)

Fly(P1, SFO, ATL)

Fly(P2, SFO, JFK)

Fly(P1, ATL, JFK)

Fly(P3, JFK, ATL)

Fly(P2, JFK, SFO)

Fly(P3, ATL, SFO)

Load(C2, P1, JFK)

Fly(P2, SFO, ATL)

Fly(P3, SFO, ATL)

Fly(P1, JFK, ATL)

Fly(P2, ATL, SFO)

Fly(P1, ATL, SFO)

Fly(P3, ATL, JFK)

Fly(P2, SFO, ATL)

Unload(C2, P1, SFO)

Fly(P2, ATL, JFK)

Fly(P1, SFO, ATL)

Fly(P3, JFK, ATL)

Fly(P1, ATL, JFK)

Fly(P3, ATL, SFO)

Fly(P2, JFK, ATL)

Fly(P1, JFK, ATL)

Fly(P2, ATL, SFO)

Fly(P1, ATL, SFO)

Load(C2, P3, SFO)

Fly(P3, SFO, ATL)

Fly(P2, SFO, ATL)

Fly(P1, SFO, ATL)

Fly(P3, ATL, JFK)

Fly(P1, ATL, JFK)

Fly(P2, ATL, SFO)

Load(C1, P3, JFK)

Fly(P2, SFO, JFK)

Fly(P3, JFK, ATL)

Fly(P2, JFK, ATL)

Fly(P3, ATL, SFO)

Fly(P1, JFK, ATL)

Fly(P2, ATL, SFO)

Fly(P1, ATL, SFO)

Fly(P3, SFO, ATL)

Unload(C2, P3, ATL)

Fly(P3, ATL, SFO)

Fly(P2, SFO, ATL)

Fly(P1, SFO, ATL)

Fly(P2, ATL, JFK)

Fly(P1, ATL, JFK)

Fly(P3, SFO, JFK)

Fly(P2, JFK, ATL)

Unload(C1, P3, JFK)

Fly(P2, ATL, SFO)

Fly(P3, JFK, ATL)

Fly(P2, SFO, JFK)

Fly(P3, ATL, SFO)

Fly(P1, JFK, ATL)

Fly(P3, SFO, JFK)

Fly(P1, ATL, SFO)

Load(C1, P2, JFK)

Fly(P1, SFO, JFK)

Fly(P2, JFK, ATL)

Fly(P3, JFK, ATL)

Fly(P2, ATL, SFO)

Fly(P3, ATL, SFO)

Fly(P1, JFK, ATL)

Fly(P2, SFO, ATL)

Fly(P1, ATL, SFO)

Unload(C1, P2, ATL)

Fly(P2, ATL, SFO)

Fly(P1, SFO, ATL)

Fly(P3, SFO, ATL)

Fly(P1, ATL, JFK)

Fly(P3, ATL, JFK)

Fly(P2, SFO, JFK)

Fly(P1, JFK, ATL)

Fly(P2, JFK, ATL)

Load(C3, P2, ATL)

Fly(P2, ATL, SFO)

Fly(P1, ATL, SFO)

Fly(P2, SFO, JFK)

Fly(P1, SFO, JFK)

Fly(P3, JFK, ATL)

Fly(P2, JFK, ATL)

Fly(P3, ATL, SFO)

Fly(P2, ATL, SFO)

Unload(C3, P2, SFO)

Fly(P3, SFO, ATL)

Fly(P2, SFO, ATL)

Fly(P3, ATL, JFK)

Fly(P2, ATL, JFK)

Fly(P1, JFK, ATL)

Fly(P3, JFK, ATL)

Fly(P1, ATL, SFO)

Fly(P3, ATL, SFO)

Fly(P2, JFK, ATL)

Fly(P1, SFO, ATL)

Load(C3, P3, SFO)

Fly(P2, ATL, SFO)

Fly(P1, ATL, SFO)

Fly(P3, SFO, ATL)

Fly(P2, SFO, ATL)

Fly(P3, ATL, JFK)

Fly(P2, ATL, JFK)

Fly(P1, SFO, ATL)

Fly(P3, JFK, ATL)

Fly(P1, ATL, JFK)

Load(C2, P3, ATL)

Fly(P3, ATL, SFO)

Fly(P2, JFK, ATL)

Fly(P3, SFO, JFK)

Fly(P2, ATL, SFO)

Fly(P1, JFK, ATL)

Fly(P2, SFO, JFK)

Fly(P1, ATL, SFO)

Unload(C3, P3, JFK)

Fly(P1, SFO, JFK)

Fly(P3, JFK, ATL)

Fly(P2, JFK, ATL)

Fly(P3, ATL, SFO)

Fly(P2, ATL, SFO)

Fly(P1, JFK, ATL)

Fly(P3, SFO, ATL)

Fly(P1, ATL, SFO)

Unload(C2, P3, ATL)

Fly(P3, ATL, SFO)

Fly(P2, SFO, ATL)

Fly(P1, SFO, ATL)

Fly(P2, ATL, JFK)

Fly(P1, ATL, JFK)

Load(C3, P1, JFK)

Fly(P3, SFO, ATL)

Fly(P2, JFK, ATL)

Fly(P3, ATL, JFK)

Fly(P2, ATL, SFO)

Fly(P1, JFK, ATL)

Load(C2, P1, ATL)

Fly(P1, ATL, SFO)

Fly(P2, SFO, ATL)

Fly(P1, SFO, JFK)

Fly(P2, ATL, JFK)

Fly(P3, JFK, ATL)

Fly(P1, JFK, ATL)

Fly(P3, ATL, SFO)

Fly(P1, ATL, SFO)

Unload(C3, P1, SFO)

Fly(P3, SFO, ATL)

Fly(P1, SFO, JFK)

Fly(P3, ATL, JFK)

Fly(P2, JFK, ATL)

Fly(P1, JFK, ATL)

Fly(P2, ATL, SFO)

Fly(P3, JFK, ATL)

Load(C3, P2, SFO)

Fly(P3, ATL, SFO)

Fly(P1, ATL, SFO)

Fly(P2, SFO, ATL)

Fly(P3, SFO, ATL)

Fly(P2, ATL, JFK)

Fly(P3, ATL, JFK)

Fly(P1, SFO, ATL)

Unload(C3, P2, JFK)

Fly(P3, JFK, ATL)

Fly(P2, JFK, ATL)

Fly(P1, ATL, SFO)

Fly(P3, ATL, SFO)

Fly(P2, ATL, SFO)

Fly(P1, SFO, ATL)

Load(C1, P1, ATL)

Fly(P1, ATL, SFO)

Fly(P2, SFO, ATL)

Fly(P3, SFO, ATL)

Fly(P2, ATL, JFK)

Fly(P1, SFO, JFK)

Fly(P3, ATL, SFO)

Load(C3, P2, JFK)

Fly(P3, SFO, JFK)

Fly(P2, JFK, ATL)

Fly(P3, JFK, ATL)

Fly(P2, ATL, SFO)

Fly(P1, JFK, SFO)

Fly(P3, ATL, SFO)

Fly(P2, SFO, ATL)

Fly(P1, SFO, ATL)

Unload(C3, P2, ATL)

Fly(P2, ATL, SFO)

Fly(P1, ATL, SFO)

Fly(P3, SFO, ATL)

Fly(P2, SFO, ATL)

Fly(P3, ATL, JFK)

Fly(P2, ATL, JFK)

Fly(P1, SFO, ATL)

Fly(P3, JFK, ATL)

Fly(P1, ATL, JFK)

Fly(P3, ATL, SFO)

Unload(C2, P1, JFK)

Fly(P2, JFK, ATL)

Fly(P3, SFO, ATL)

Fly(P1, JFK, ATL)

Fly(P2, ATL, SFO)

Fly(P3, ATL, SFO)

Fly(P1, ATL, SFO)

Fly(P3, SFO, JFK)

Fly(P2, SFO, ATL)

Load(C3, P2, ATL)

Fly(P2, ATL, SFO)

Fly(P1, SFO, ATL)

Fly(P2, SFO, JFK)

Fly(P3, JFK, ATL)

Fly(P1, ATL, SFO)

Fly(P3, ATL, SFO)

Unload(C3, P2, JFK)

Fly(P1, SFO, ATL)

Fly(P2, JFK, ATL)

Fly(P1, ATL, JFK)

Fly(P2, ATL, SFO)

Load(C3, P1, JFK)

Fly(P3, SFO, ATL)

Fly(P2, SFO, ATL)

Fly(P3, ATL, JFK)

Fly(P2, ATL, JFK)

Fly(P1, JFK, ATL)

Fly(P3, JFK, ATL)

Fly(P1, ATL, SFO)

Fly(P3, ATL, SFO)

Fly(P2, JFK, ATL)

Fly(P1, SFO, ATL)

Unload(C1, P1, ATL)

Fly(P2, ATL, SFO)

Fly(P1, ATL, SFO)

Fly(P3, SFO, ATL)

Fly(P2, SFO, ATL)

Fly(P3, ATL, JFK)

Fly(P2, ATL, JFK)

Unload(C3, P1, SFO)

Fly(P1, SFO, ATL)

Fly(P3, JFK, ATL)

Fly(P2, JFK, ATL)

Load(C1, P3, ATL)

Fly(P3, ATL, SFO)

Fly(P1, ATL, SFO)

Fly(P2, ATL, SFO)

Fly(P3, SFO, ATL)

Fly(P2, SFO, JFK)

Fly(P3, ATL, JFK)

Fly(P1, SFO, ATL)

Fly(P2, JFK, SFO)

Fly(P1, ATL, JFK)

Fly(P2, SFO, ATL)

Unload(C1, P3, JFK)

Fly(P2, ATL, JFK)

Fly(P3, JFK, ATL)

Fly(P1, JFK, ATL)

Fly(P2, JFK, ATL)

Fly(P3, ATL, SFO)

Fly(P2, ATL, SFO)

Fly(P1, ATL, SFO)

Fly(P3, SFO, ATL)

Load(C3, P1, SFO)

Fly(P3, ATL, JFK)

Fly(P2, SFO, ATL)

Fly(P1, SFO, ATL)

Fly(P3, JFK, ATL)

Fly(P2, ATL, JFK)

Fly(P3, ATL, SFO)

Fly(P1, ATL, SFO)

Load(C2, P2, JFK)

Fly(P3, SFO, ATL)

Fly(P1, SFO, JFK)

Fly(P3, ATL, JFK)

Fly(P2, JFK, ATL)

Fly(P1, JFK, ATL)

Fly(P2, ATL, SFO)

Fly(P1, ATL, SFO)

Unload(C3, P1, SFO)

Fly(P2, SFO, ATL)

Fly(P1, SFO, ATL)

Fly(P3, JFK, ATL)

Fly(P2, ATL, SFO)

Fly(P3, ATL, SFO)

Fly(P1, ATL, JFK)

Fly(P2, SFO, ATL)

Unload(C2, P2, ATL)

Fly(P2, ATL, SFO)

Fly(P3, SFO, ATL)

Fly(P2, SFO, JFK)

Fly(P3, ATL, JFK)

Fly(P1, JFK, ATL)

Fly(P3, JFK, SFO)

Fly(P1, ATL, SFO)

Load(C3, P3, SFO)

Fly(P3, SFO, ATL)

Fly(P1, SFO, ATL)

Fly(P3, ATL, JFK)

Fly(P1, ATL, JFK)

Fly(P2, JFK, ATL)

Fly(P3, JFK, ATL)

Load(C2, P3, ATL)

Fly(P3, ATL, SFO)

Fly(P2, ATL, SFO)

Fly(P3, SFO, JFK)

Fly(P2, SFO, JFK)

Fly(P1, JFK, ATL)

Fly(P2, JFK, ATL)

Fly(P1, ATL, SFO)

Load(C1, P3, JFK)

Fly(P2, ATL, SFO)

Fly(P1, SFO, ATL)

Fly(P3, JFK, ATL)

Fly(P1, ATL, JFK)

Fly(P3, ATL, SFO)

Fly(P2, SFO, ATL)

Fly(P1, JFK, ATL)

Fly(P2, ATL, JFK)

Fly(P1, ATL, SFO)

Fly(P3, SFO, ATL)

Unload(C2, P3, ATL)

Fly(P3, ATL, SFO)

Fly(P1, SFO, ATL)

Fly(P2, JFK, ATL)

Fly(P1, ATL, JFK)

Fly(P2, ATL, SFO)

Fly(P3, SFO, JFK)

Fly(P1, JFK, ATL)

Unload(C3, P3, JFK)

Fly(P1, ATL, SFO)

Fly(P2, SFO, ATL)

Fly(P1, SFO, JFK)

Fly(P2, ATL, JFK)

Fly(P3, JFK, ATL)

Fly(P1, JFK, ATL)

Fly(P3, ATL, SFO)

Fly(P1, ATL, SFO)

Unload(C1, P3, SFO)

Fly(P3, SFO, ATL)

Fly(P1, SFO, ATL)

Fly(P3, ATL, JFK)

Fly(P1, ATL, JFK)

Fly(P2, JFK, ATL)

Fly(P3, JFK, ATL)

Fly(P2, ATL, SFO)

Fly(P3, ATL, SFO)

Load(C3, P1, JFK)

Fly(P2, SFO, ATL)

Fly(P1, JFK, ATL)

Fly(P2, ATL, JFK)

Fly(P1, ATL, SFO)

Fly(P3, SFO, ATL)

Fly(P1, SFO, JFK)

Load(C2, P3, ATL)

Fly(P3, ATL, SFO)

Fly(P2, JFK, ATL)

Fly(P3, SFO, JFK)

Fly(P2, ATL, SFO)

Fly(P1, JFK, ATL)

Fly(P3, JFK, ATL)

Fly(P1, ATL, SFO)

Fly(P3, ATL, SFO)

Unload(C3, P1, SFO)

Fly(P2, SFO, ATL)

Unload(C2, P3, SFO)

Load(C3, P1, SFO)

Fly(P2, ATL, JFK)

Fly(P3, SFO, ATL)

Fly(P2, JFK, SFO)

Fly(P3, ATL, JFK)

Fly(P1, SFO, ATL)

Fly(P3, JFK, SFO)

Fly(P1, ATL, JFK)

Load(C2, P2, SFO)

Fly(P3, SFO, ATL)

Fly(P2, SFO, ATL)

Fly(P3, ATL, JFK)

Fly(P2, ATL, JFK)

Fly(P1, JFK, ATL)

Fly(P3, JFK, ATL)

Unload(C3, P1, ATL)

Fly(P1, ATL, JFK)

Fly(P3, ATL, SFO)

Fly(P2, JFK, ATL)

Fly(P1, JFK, ATL)

Fly(P2, ATL, SFO)

Fly(P1, ATL, SFO)

Fly(P3, SFO, ATL)

Fly(P2, SFO, ATL)

Fly(P3, ATL, JFK)

Fly(P2, ATL, JFK)

Load(C1, P1, SFO)

Fly(P1, SFO, ATL)

Fly(P3, JFK, ATL)

Fly(P1, ATL, JFK)

Fly(P2, JFK, ATL)

Fly(P3, ATL, SFO)

Fly(P2, ATL, SFO)

Fly(P3, SFO, JFK)

Unload(C2, P2, SFO)

Fly(P2, SFO, ATL)

Fly(P3, JFK, ATL)

Fly(P1, JFK, ATL)

Fly(P3, ATL, SFO)

Fly(P2, ATL, SFO)

Unload(C1, P1, ATL)

Fly(P1, ATL, SFO)

Fly(P3, SFO, ATL)

Fly(P2, SFO, ATL)

Fly(P3, ATL, JFK)

Fly(P2, ATL, JFK)

Fly(P1, SFO, ATL)

Fly(P3, JFK, ATL)

Fly(P1, ATL, JFK)

Fly(P3, ATL, SFO)

Fly(P2, JFK, ATL)

Load(C3, P2, ATL)

Fly(P2, ATL, SFO)

Fly(P3, SFO, ATL)

Fly(P2, SFO, JFK)

Fly(P3, ATL, JFK)

Fly(P1, JFK, ATL)

Fly(P2, JFK, ATL)

Fly(P3, JFK, ATL)

Load(C1, P3, ATL)

Fly(P2, ATL, SFO)

Fly(P1, ATL, SFO)

Fly(P3, ATL, JFK)

Fly(P2, SFO, ATL)

Fly(P1, SFO, JFK)

Fly(P2, ATL, JFK)

Fly(P1, JFK, ATL)

Fly(P3, JFK, SFO)

Fly(P1, ATL, SFO)

Unload(C3, P2, JFK)

Fly(P3, SFO, ATL)

Fly(P1, SFO, ATL)

Fly(P2, JFK, ATL)

Fly(P3, ATL, JFK)

Fly(P2, ATL, SFO)

Fly(P1, ATL, SFO)

Unload(C1, P3, JFK)

Fly(P2, SFO, ATL)

Fly(P1, SFO, JFK)

Fly(P2, ATL, JFK)

Fly(P3, JFK, ATL)

Fly(P1, JFK, ATL)

Fly(P3, ATL, SFO)

Fly(P1, ATL, SFO)

Load(C3, P2, JFK)

Fly(P3, SFO, ATL)

Fly(P2, JFK, ATL)

Fly(P1, SFO, ATL)

Fly(P2, ATL, SFO)

Fly(P3, ATL, SFO)

Fly(P1, ATL, JFK)

Fly(P3, SFO, JFK)

Unload(C3, P2, SFO)

#### Solving Air Cargo Problem 2 using depth\_first\_graph\_search...

Expansions Goal Tests New Nodes

624 625 5602

Plan length: 619 Time elapsed in seconds: 6.466916030316336

Fly(P3, ATL, SFO)

Fly(P1, SFO, ATL)

Fly(P3, SFO, JFK)

Fly(P1, ATL, JFK)

Fly(P2, JFK, ATL)

Fly(P3, JFK, ATL)

Fly(P2, ATL, SFO)

Fly(P3, ATL, SFO)

Load(C2, P1, JFK)

Fly(P2, SFO, ATL)

Fly(P1, JFK, ATL)

Fly(P2, ATL, JFK)

Fly(P1, ATL, SFO)

Fly(P3, SFO, ATL)

Fly(P1, SFO, JFK)

Load(C3, P3, ATL)

Fly(P3, ATL, SFO)

Fly(P2, JFK, ATL)

Fly(P3, SFO, JFK)

Fly(P2, ATL, SFO)

Fly(P1, JFK, ATL)

Fly(P2, SFO, JFK)

Fly(P1, ATL, SFO)

Unload(C3, P3, JFK)

Fly(P1, SFO, JFK)

Fly(P3, JFK, ATL)

Fly(P2, JFK, ATL)

Fly(P3, ATL, SFO)

Fly(P2, ATL, SFO)

Fly(P1, JFK, ATL)

Fly(P3, SFO, ATL)

Fly(P1, ATL, SFO)

Unload(C2, P1, SFO)

Fly(P3, ATL, SFO)

Fly(P2, SFO, ATL)

Fly(P1, SFO, ATL)

Fly(P2, ATL, JFK)

Fly(P1, ATL, JFK)

Fly(P3, SFO, ATL)

Fly(P2, JFK, ATL)

Fly(P3, ATL, JFK)

Fly(P2, ATL, SFO)

Fly(P1, JFK, ATL)

Load(C3, P3, JFK)

Fly(P1, ATL, SFO)

Fly(P2, SFO, ATL)

Fly(P3, JFK, ATL)

Fly(P2, ATL, JFK)

Fly(P3, ATL, SFO)

Fly(P1, SFO, ATL)

Fly(P2, JFK, ATL)

Fly(P1, ATL, JFK)

Fly(P2, ATL, SFO)

Fly(P3, SFO, ATL)

Unload(C3, P3, ATL)

Fly(P3, ATL, SFO)

Fly(P2, SFO, ATL)

Fly(P3, SFO, JFK)

Fly(P2, ATL, JFK)

Fly(P1, JFK, ATL)

Fly(P3, JFK, ATL)

Fly(P2, JFK, ATL)

Load(C3, P2, ATL)

Fly(P3, ATL, SFO)

Fly(P2, ATL, SFO)

Fly(P1, ATL, SFO)

Fly(P3, SFO, ATL)

Fly(P2, SFO, JFK)

Fly(P3, ATL, JFK)

Fly(P1, SFO, JFK)

Fly(P2, JFK, SFO)

Unload(C3, P2, SFO)

Fly(P2, SFO, ATL)

Fly(P3, JFK, ATL)

Fly(P2, ATL, JFK)

Fly(P3, ATL, SFO)

Load(C2, P3, SFO)

Fly(P3, SFO, ATL)

Fly(P2, JFK, ATL)

Fly(P3, ATL, JFK)

Fly(P2, ATL, SFO)

Fly(P1, JFK, ATL)

Fly(P2, SFO, JFK)

Fly(P1, ATL, SFO)

Unload(C2, P3, JFK)

Fly(P1, SFO, JFK)

Fly(P3, JFK, ATL)

Fly(P2, JFK, ATL)

Fly(P3, ATL, SFO)

Fly(P2, ATL, SFO)

Fly(P1, JFK, ATL)

Fly(P3, SFO, ATL)

Fly(P1, ATL, SFO)

Load(C3, P2, SFO)

Fly(P3, ATL, SFO)

Fly(P2, SFO, ATL)

Fly(P1, SFO, ATL)

Fly(P2, ATL, JFK)

Fly(P1, ATL, JFK)

Fly(P3, SFO, ATL)

Load(C2, P2, JFK)

Fly(P3, ATL, JFK)

Fly(P2, JFK, ATL)

Fly(P1, JFK, ATL)

Fly(P2, ATL, SFO)

Fly(P1, ATL, SFO)

Unload(C3, P2, SFO)

Fly(P2, SFO, ATL)

Fly(P1, SFO, ATL)

Fly(P2, ATL, JFK)

Fly(P3, JFK, ATL)

Fly(P1, ATL, SFO)

Fly(P3, ATL, SFO)

Fly(P1, SFO, JFK)

Fly(P2, JFK, ATL)

Fly(P3, SFO, ATL)

Fly(P2, ATL, SFO)

Load(C1, P2, SFO)

Fly(P3, ATL, SFO)

Fly(P2, SFO, ATL)

Fly(P3, SFO, JFK)

Fly(P2, ATL, JFK)

Fly(P1, JFK, ATL)

Fly(P3, JFK, ATL)

Fly(P1, ATL, SFO)

Fly(P3, ATL, SFO)

Unload(C2, P2, JFK)

Fly(P1, SFO, ATL)

Fly(P2, JFK, ATL)

Fly(P1, ATL, JFK)

Fly(P3, SFO, ATL)

Fly(P2, ATL, SFO)

Fly(P3, ATL, JFK)

Fly(P1, JFK, ATL)

Load(C3, P2, SFO)

Fly(P1, ATL, SFO)

Fly(P2, SFO, ATL)

Fly(P1, SFO, JFK)

Fly(P2, ATL, JFK)

Fly(P3, JFK, ATL)

Fly(P1, JFK, ATL)

Fly(P3, ATL, SFO)

Fly(P1, ATL, SFO)

Unload(C3, P2, JFK)

Fly(P3, SFO, ATL)

Fly(P2, JFK, ATL)

Fly(P3, ATL, JFK)

Fly(P2, ATL, SFO)

Fly(P1, SFO, ATL)

Fly(P2, SFO, JFK)

Unload(C1, P2, JFK)

Fly(P1, ATL, SFO)

Fly(P2, JFK, ATL)

Fly(P1, SFO, JFK)

Fly(P2, ATL, SFO)

Fly(P3, JFK, ATL)

Fly(P2, SFO, JFK)

Fly(P3, ATL, SFO)

Load(C3, P2, JFK)

Fly(P2, JFK, ATL)

Fly(P3, SFO, ATL)

Fly(P2, ATL, SFO)

Fly(P3, ATL, JFK)

Fly(P1, JFK, ATL)

Fly(P2, SFO, ATL)

Fly(P1, ATL, SFO)

Unload(C3, P2, ATL)

Fly(P2, ATL, SFO)

Fly(P1, SFO, ATL)

Fly(P2, SFO, JFK)

Fly(P1, ATL, JFK)

Fly(P3, JFK, ATL)

Fly(P2, JFK, SFO)

Fly(P3, ATL, SFO)

Load(C2, P1, JFK)

Fly(P2, SFO, ATL)

Fly(P3, SFO, ATL)

Fly(P1, JFK, ATL)

Fly(P2, ATL, SFO)

Fly(P1, ATL, SFO)

Fly(P3, ATL, JFK)

Fly(P2, SFO, ATL)

Unload(C2, P1, SFO)

Fly(P2, ATL, JFK)

Fly(P1, SFO, ATL)

Fly(P3, JFK, ATL)

Fly(P1, ATL, JFK)

Fly(P3, ATL, SFO)

Fly(P2, JFK, ATL)

Fly(P1, JFK, ATL)

Fly(P2, ATL, SFO)

Fly(P1, ATL, SFO)

Load(C2, P3, SFO)

Fly(P3, SFO, ATL)

Fly(P2, SFO, ATL)

Fly(P1, SFO, ATL)

Fly(P3, ATL, JFK)

Fly(P1, ATL, JFK)

Fly(P2, ATL, SFO)

Load(C1, P3, JFK)

Fly(P2, SFO, JFK)

Fly(P3, JFK, ATL)

Fly(P2, JFK, ATL)

Fly(P3, ATL, SFO)

Fly(P1, JFK, ATL)

Fly(P2, ATL, SFO)

Fly(P1, ATL, SFO)

Fly(P3, SFO, ATL)

Unload(C2, P3, ATL)

Fly(P3, ATL, SFO)

Fly(P2, SFO, ATL)

Fly(P1, SFO, ATL)

Fly(P2, ATL, JFK)

Fly(P1, ATL, JFK)

Fly(P3, SFO, JFK)

Fly(P2, JFK, ATL)

Unload(C1, P3, JFK)

Fly(P2, ATL, SFO)

Fly(P3, JFK, ATL)

Fly(P2, SFO, JFK)

Fly(P3, ATL, SFO)

Fly(P1, JFK, ATL)

Fly(P3, SFO, JFK)

Fly(P1, ATL, SFO)

Load(C1, P2, JFK)

Fly(P1, SFO, JFK)

Fly(P2, JFK, ATL)

Fly(P3, JFK, ATL)

Fly(P2, ATL, SFO)

Fly(P3, ATL, SFO)

Fly(P1, JFK, ATL)

Fly(P2, SFO, ATL)

Fly(P1, ATL, SFO)

Unload(C1, P2, ATL)

Fly(P2, ATL, SFO)

Fly(P1, SFO, ATL)

Fly(P3, SFO, ATL)

Fly(P1, ATL, JFK)

Fly(P3, ATL, JFK)

Fly(P2, SFO, JFK)

Fly(P1, JFK, ATL)

Fly(P2, JFK, ATL)

Load(C3, P2, ATL)

Fly(P2, ATL, SFO)

Fly(P1, ATL, SFO)

Fly(P2, SFO, JFK)

Fly(P1, SFO, JFK)

Fly(P3, JFK, ATL)

Fly(P2, JFK, ATL)

Fly(P3, ATL, SFO)

Fly(P2, ATL, SFO)

Unload(C3, P2, SFO)

Fly(P3, SFO, ATL)

Fly(P2, SFO, ATL)

Fly(P3, ATL, JFK)

Fly(P2, ATL, JFK)

Fly(P1, JFK, ATL)

Fly(P3, JFK, ATL)

Fly(P1, ATL, SFO)

Fly(P3, ATL, SFO)

Fly(P2, JFK, ATL)

Fly(P1, SFO, ATL)

Load(C3, P3, SFO)

Fly(P2, ATL, SFO)

Fly(P1, ATL, SFO)

Fly(P3, SFO, ATL)

Fly(P2, SFO, ATL)

Fly(P3, ATL, JFK)

Fly(P2, ATL, JFK)

Fly(P1, SFO, ATL)

Fly(P3, JFK, ATL)

Fly(P1, ATL, JFK)

Load(C2, P3, ATL)

Fly(P3, ATL, SFO)

Fly(P2, JFK, ATL)

Fly(P3, SFO, JFK)

Fly(P2, ATL, SFO)

Fly(P1, JFK, ATL)

Fly(P2, SFO, JFK)

Fly(P1, ATL, SFO)

Unload(C3, P3, JFK)

Fly(P1, SFO, JFK)

Fly(P3, JFK, ATL)

Fly(P2, JFK, ATL)

Fly(P3, ATL, SFO)

Fly(P2, ATL, SFO)

Fly(P1, JFK, ATL)

Fly(P3, SFO, ATL)

Fly(P1, ATL, SFO)

Unload(C2, P3, ATL)

Fly(P3, ATL, SFO)

Fly(P2, SFO, ATL)

Fly(P1, SFO, ATL)

Fly(P2, ATL, JFK)

Fly(P1, ATL, JFK)

Load(C3, P1, JFK)

Fly(P3, SFO, ATL)

Fly(P2, JFK, ATL)

Fly(P3, ATL, JFK)

Fly(P2, ATL, SFO)

Fly(P1, JFK, ATL)

Load(C2, P1, ATL)

Fly(P1, ATL, SFO)

Fly(P2, SFO, ATL)

Fly(P1, SFO, JFK)

Fly(P2, ATL, JFK)

Fly(P3, JFK, ATL)

Fly(P1, JFK, ATL)

Fly(P3, ATL, SFO)

Fly(P1, ATL, SFO)

Unload(C3, P1, SFO)

Fly(P3, SFO, ATL)

Fly(P1, SFO, JFK)

Fly(P3, ATL, JFK)

Fly(P2, JFK, ATL)

Fly(P1, JFK, ATL)

Fly(P2, ATL, SFO)

Fly(P3, JFK, ATL)

Load(C3, P2, SFO)

Fly(P3, ATL, SFO)

Fly(P1, ATL, SFO)

Fly(P2, SFO, ATL)

Fly(P3, SFO, ATL)

Fly(P2, ATL, JFK)

Fly(P3, ATL, JFK)

Fly(P1, SFO, ATL)

Unload(C3, P2, JFK)

Fly(P3, JFK, ATL)

Fly(P2, JFK, ATL)

Fly(P1, ATL, SFO)

Fly(P3, ATL, SFO)

Fly(P2, ATL, SFO)

Fly(P1, SFO, ATL)

Load(C1, P1, ATL)

Fly(P1, ATL, SFO)

Fly(P2, SFO, ATL)

Fly(P3, SFO, ATL)

Fly(P2, ATL, JFK)

Fly(P1, SFO, JFK)

Fly(P3, ATL, SFO)

Load(C3, P2, JFK)

Fly(P3, SFO, JFK)

Fly(P2, JFK, ATL)

Fly(P3, JFK, ATL)

Fly(P2, ATL, SFO)

Fly(P1, JFK, SFO)

Fly(P3, ATL, SFO)

Fly(P2, SFO, ATL)

Fly(P1, SFO, ATL)

Unload(C3, P2, ATL)

Fly(P2, ATL, SFO)

Fly(P1, ATL, SFO)

Fly(P3, SFO, ATL)

Fly(P2, SFO, ATL)

Fly(P3, ATL, JFK)

Fly(P2, ATL, JFK)

Fly(P1, SFO, ATL)

Fly(P3, JFK, ATL)

Fly(P1, ATL, JFK)

Fly(P3, ATL, SFO)

Unload(C2, P1, JFK)

Fly(P2, JFK, ATL)

Fly(P3, SFO, ATL)

Fly(P1, JFK, ATL)

Fly(P2, ATL, SFO)

Fly(P3, ATL, SFO)

Fly(P1, ATL, SFO)

Fly(P3, SFO, JFK)

Fly(P2, SFO, ATL)

Load(C3, P2, ATL)

Fly(P2, ATL, SFO)

Fly(P1, SFO, ATL)

Fly(P2, SFO, JFK)

Fly(P3, JFK, ATL)

Fly(P1, ATL, SFO)

Fly(P3, ATL, SFO)

Unload(C3, P2, JFK)

Fly(P1, SFO, ATL)

Fly(P2, JFK, ATL)

Fly(P1, ATL, JFK)

Fly(P2, ATL, SFO)

Load(C3, P1, JFK)

Fly(P3, SFO, ATL)

Fly(P2, SFO, ATL)

Fly(P3, ATL, JFK)

Fly(P2, ATL, JFK)

Fly(P1, JFK, ATL)

Fly(P3, JFK, ATL)

Fly(P1, ATL, SFO)

Fly(P3, ATL, SFO)

Fly(P2, JFK, ATL)

Fly(P1, SFO, ATL)

Unload(C1, P1, ATL)

Fly(P2, ATL, SFO)

Fly(P1, ATL, SFO)

Fly(P3, SFO, ATL)

Fly(P2, SFO, ATL)

Fly(P3, ATL, JFK)

Fly(P2, ATL, JFK)

Unload(C3, P1, SFO)

Fly(P1, SFO, ATL)

Fly(P3, JFK, ATL)

Fly(P2, JFK, ATL)

Load(C1, P3, ATL)

Fly(P3, ATL, SFO)

Fly(P1, ATL, SFO)

Fly(P2, ATL, SFO)

Fly(P3, SFO, ATL)

Fly(P2, SFO, JFK)

Fly(P3, ATL, JFK)

Fly(P1, SFO, ATL)

Fly(P2, JFK, SFO)

Fly(P1, ATL, JFK)

Fly(P2, SFO, ATL)

Unload(C1, P3, JFK)

Fly(P2, ATL, JFK)

Fly(P3, JFK, ATL)

Fly(P1, JFK, ATL)

Fly(P2, JFK, ATL)

Fly(P3, ATL, SFO)

Fly(P2, ATL, SFO)

Fly(P1, ATL, SFO)

Fly(P3, SFO, ATL)

Load(C3, P1, SFO)

Fly(P3, ATL, JFK)

Fly(P2, SFO, ATL)

Fly(P1, SFO, ATL)

Fly(P3, JFK, ATL)

Fly(P2, ATL, JFK)

Fly(P3, ATL, SFO)

Fly(P1, ATL, SFO)

Load(C2, P2, JFK)

Fly(P3, SFO, ATL)

Fly(P1, SFO, JFK)

Fly(P3, ATL, JFK)

Fly(P2, JFK, ATL)

Fly(P1, JFK, ATL)

Fly(P2, ATL, SFO)

Fly(P1, ATL, SFO)

Unload(C3, P1, SFO)

Fly(P2, SFO, ATL)

Fly(P1, SFO, ATL)

Fly(P3, JFK, ATL)

Fly(P2, ATL, SFO)

Fly(P3, ATL, SFO)

Fly(P1, ATL, JFK)

Fly(P2, SFO, ATL)

Unload(C2, P2, ATL)

Fly(P2, ATL, SFO)

Fly(P3, SFO, ATL)

Fly(P2, SFO, JFK)

Fly(P3, ATL, JFK)

Fly(P1, JFK, ATL)

Fly(P3, JFK, SFO)

Fly(P1, ATL, SFO)

Load(C3, P3, SFO)

Fly(P3, SFO, ATL)

Fly(P1, SFO, ATL)

Fly(P3, ATL, JFK)

Fly(P1, ATL, JFK)

Fly(P2, JFK, ATL)

Fly(P3, JFK, ATL)

Load(C2, P3, ATL)

Fly(P3, ATL, SFO)

Fly(P2, ATL, SFO)

Fly(P3, SFO, JFK)

Fly(P2, SFO, JFK)

Fly(P1, JFK, ATL)

Fly(P2, JFK, ATL)

Fly(P1, ATL, SFO)

Load(C1, P3, JFK)

Fly(P2, ATL, SFO)

Fly(P1, SFO, ATL)

Fly(P3, JFK, ATL)

Fly(P1, ATL, JFK)

Fly(P3, ATL, SFO)

Fly(P2, SFO, ATL)

Fly(P1, JFK, ATL)

Fly(P2, ATL, JFK)

Fly(P1, ATL, SFO)

Fly(P3, SFO, ATL)

Unload(C2, P3, ATL)

Fly(P3, ATL, SFO)

Fly(P1, SFO, ATL)

Fly(P2, JFK, ATL)

Fly(P1, ATL, JFK)

Fly(P2, ATL, SFO)

Fly(P3, SFO, JFK)

Fly(P1, JFK, ATL)

Unload(C3, P3, JFK)

Fly(P1, ATL, SFO)

Fly(P2, SFO, ATL)

Fly(P1, SFO, JFK)

Fly(P2, ATL, JFK)

Fly(P3, JFK, ATL)

Fly(P1, JFK, ATL)

Fly(P3, ATL, SFO)

Fly(P1, ATL, SFO)

Unload(C1, P3, SFO)

Fly(P3, SFO, ATL)

Fly(P1, SFO, ATL)

Fly(P3, ATL, JFK)

Fly(P1, ATL, JFK)

Fly(P2, JFK, ATL)

Fly(P3, JFK, ATL)

Fly(P2, ATL, SFO)

Fly(P3, ATL, SFO)

Load(C3, P1, JFK)

Fly(P2, SFO, ATL)

Fly(P1, JFK, ATL)

Fly(P2, ATL, JFK)

Fly(P1, ATL, SFO)

Fly(P3, SFO, ATL)

Fly(P1, SFO, JFK)

Load(C2, P3, ATL)

Fly(P3, ATL, SFO)

Fly(P2, JFK, ATL)

Fly(P3, SFO, JFK)

Fly(P2, ATL, SFO)

Fly(P1, JFK, ATL)

Fly(P3, JFK, ATL)

Fly(P1, ATL, SFO)

Fly(P3, ATL, SFO)

Unload(C3, P1, SFO)

Fly(P2, SFO, ATL)

Unload(C2, P3, SFO)

Load(C3, P1, SFO)

Fly(P2, ATL, JFK)

Fly(P3, SFO, ATL)

Fly(P2, JFK, SFO)

Fly(P3, ATL, JFK)

Fly(P1, SFO, ATL)

Fly(P3, JFK, SFO)

Fly(P1, ATL, JFK)

Load(C2, P2, SFO)

Fly(P3, SFO, ATL)

Fly(P2, SFO, ATL)

Fly(P3, ATL, JFK)

Fly(P2, ATL, JFK)

Fly(P1, JFK, ATL)

Fly(P3, JFK, ATL)

Unload(C3, P1, ATL)

Fly(P1, ATL, JFK)

Fly(P3, ATL, SFO)

Fly(P2, JFK, ATL)

Fly(P1, JFK, ATL)

Fly(P2, ATL, SFO)

Fly(P1, ATL, SFO)

Fly(P3, SFO, ATL)

Fly(P2, SFO, ATL)

Fly(P3, ATL, JFK)

Fly(P2, ATL, JFK)

Load(C1, P1, SFO)

Fly(P1, SFO, ATL)

Fly(P3, JFK, ATL)

Fly(P1, ATL, JFK)

Fly(P2, JFK, ATL)

Fly(P3, ATL, SFO)

Fly(P2, ATL, SFO)

Fly(P3, SFO, JFK)

Unload(C2, P2, SFO)

Fly(P2, SFO, ATL)

Fly(P3, JFK, ATL)

Fly(P1, JFK, ATL)

Fly(P3, ATL, SFO)

Fly(P2, ATL, SFO)

Unload(C1, P1, ATL)

Fly(P1, ATL, SFO)

Fly(P3, SFO, ATL)

Fly(P2, SFO, ATL)

Fly(P3, ATL, JFK)

Fly(P2, ATL, JFK)

Fly(P1, SFO, ATL)

Fly(P3, JFK, ATL)

Fly(P1, ATL, JFK)

Fly(P3, ATL, SFO)

Fly(P2, JFK, ATL)

Load(C3, P2, ATL)

Fly(P2, ATL, SFO)

Fly(P3, SFO, ATL)

Fly(P2, SFO, JFK)

Fly(P3, ATL, JFK)

Fly(P1, JFK, ATL)

Fly(P2, JFK, ATL)

Fly(P3, JFK, ATL)

Load(C1, P3, ATL)

Fly(P2, ATL, SFO)

Fly(P1, ATL, SFO)

Fly(P3, ATL, JFK)

Fly(P2, SFO, ATL)

Fly(P1, SFO, JFK)

Fly(P2, ATL, JFK)

Fly(P1, JFK, ATL)

Fly(P3, JFK, SFO)

Fly(P1, ATL, SFO)

Unload(C3, P2, JFK)

Fly(P3, SFO, ATL)

Fly(P1, SFO, ATL)

Fly(P2, JFK, ATL)

Fly(P3, ATL, JFK)

Fly(P2, ATL, SFO)

Fly(P1, ATL, SFO)

Unload(C1, P3, JFK)

Fly(P2, SFO, ATL)

Fly(P1, SFO, JFK)

Fly(P2, ATL, JFK)

Fly(P3, JFK, ATL)

Fly(P1, JFK, ATL)

Fly(P3, ATL, SFO)

Fly(P1, ATL, SFO)

Load(C3, P2, JFK)

Fly(P3, SFO, ATL)

Fly(P2, JFK, ATL)

Fly(P1, SFO, ATL)

Fly(P2, ATL, SFO)

Fly(P3, ATL, SFO)

Fly(P1, ATL, JFK)

Fly(P3, SFO, JFK)

Unload(C3, P2, SFO)

#### Solving Air Cargo Problem 2 using uniform\_cost\_search...

Expansions Goal Tests New Nodes

4853 4855 44041

Plan length: 9 Time elapsed in seconds: 48.802818862387674

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 greedy\_best\_first\_graph\_search with h\_1...

Expansions Goal Tests New Nodes

998 1000 8982

Plan length: 21 Time elapsed in seconds: 7.331830368458441

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(P2, ATL, SFO)

Unload(C2, P2, SFO)

Fly(P2, SFO, ATL)

Fly(P3, JFK, SFO)

Load(C2, P3, SFO)

Fly(P3, SFO, JFK)

Fly(P1, ATL, JFK)

Unload(C1, P1, JFK)

Load(C1, P3, JFK)

Fly(P1, JFK, ATL)

Fly(P3, JFK, SFO)

Unload(C3, P3, SFO)

Unload(C2, P3, SFO)

Fly(P3, SFO, JFK)

Unload(C1, P3, 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: 34.453525452228206

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: 17.438909029570198

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

#### Solving Air Cargo Problem 3 using breadth\_first\_search...

Expansions Goal Tests New Nodes

14663 18098 129631

Plan length: 12 Time elapsed in seconds: 336.2690922948953

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 depth\_first\_graph\_search...

Expansions Goal Tests New Nodes

408 409 3364

Plan length: 392 Time elapsed in seconds: 3.1904954429105397

Fly(P1, SFO, ORD)

Fly(P2, JFK, ORD)

Fly(P1, ORD, ATL)

Fly(P2, ORD, ATL)

Fly(P1, ATL, JFK)

Fly(P2, ATL, SFO)

Load(C2, P1, JFK)

Fly(P2, SFO, ORD)

Fly(P1, JFK, ORD)

Fly(P2, ORD, ATL)

Fly(P1, ORD, ATL)

Fly(P2, ATL, JFK)

Fly(P1, ATL, SFO)

Unload(C2, P1, SFO)

Fly(P1, SFO, ORD)

Fly(P2, JFK, ORD)

Fly(P1, ORD, ATL)

Fly(P2, ORD, ATL)

Fly(P1, ATL, JFK)

Fly(P2, ATL, SFO)

Load(C2, P2, SFO)

Fly(P2, SFO, ORD)

Fly(P1, JFK, ORD)

Fly(P2, ORD, ATL)

Fly(P1, ORD, ATL)

Fly(P2, ATL, JFK)

Load(C3, P1, ATL)

Fly(P1, ATL, ORD)

Fly(P2, JFK, ORD)

Fly(P1, ORD, SFO)

Fly(P2, ORD, ATL)

Fly(P1, SFO, JFK)

Fly(P2, ATL, SFO)

Unload(C3, P1, JFK)

Fly(P2, SFO, ORD)

Fly(P1, JFK, ORD)

Fly(P2, ORD, ATL)

Fly(P1, ORD, ATL)

Fly(P2, ATL, JFK)

Fly(P1, ATL, SFO)

Unload(C2, P2, JFK)

Fly(P1, SFO, ORD)

Fly(P2, JFK, ORD)

Fly(P1, ORD, ATL)

Fly(P2, ORD, ATL)

Fly(P1, ATL, JFK)

Fly(P2, ATL, SFO)

Load(C3, P1, JFK)

Fly(P2, SFO, ORD)

Fly(P1, JFK, ORD)

Fly(P2, ORD, ATL)

Fly(P1, ORD, SFO)

Fly(P2, ATL, JFK)

Unload(C3, P1, SFO)

Fly(P1, SFO, ORD)

Fly(P2, JFK, ORD)

Fly(P1, ORD, ATL)

Fly(P2, ORD, ATL)

Fly(P1, ATL, JFK)

Fly(P2, ATL, SFO)

Load(C3, P2, SFO)

Fly(P2, SFO, ORD)

Fly(P1, JFK, ORD)

Fly(P2, ORD, ATL)

Fly(P1, ORD, SFO)

Load(C1, P1, SFO)

Fly(P2, ATL, ORD)

Fly(P1, SFO, ORD)

Fly(P2, ORD, SFO)

Fly(P1, ORD, ATL)

Fly(P2, SFO, JFK)

Fly(P1, ATL, JFK)

Unload(C3, P2, JFK)

Fly(P2, JFK, ORD)

Fly(P1, JFK, ORD)

Fly(P2, ORD, ATL)

Fly(P1, ORD, ATL)

Fly(P2, ATL, SFO)

Unload(C1, P1, ATL)

Fly(P1, ATL, ORD)

Fly(P2, SFO, ORD)

Fly(P1, ORD, SFO)

Fly(P2, ORD, ATL)

Fly(P1, SFO, JFK)

Fly(P2, ATL, JFK)

Load(C3, P2, JFK)

Fly(P2, JFK, ORD)

Fly(P1, JFK, ORD)

Fly(P2, ORD, ATL)

Fly(P1, ORD, ATL)

Unload(C3, P2, ATL)

Fly(P2, ATL, ORD)

Fly(P1, ATL, ORD)

Fly(P2, ORD, SFO)

Fly(P1, ORD, SFO)

Fly(P2, SFO, JFK)

Fly(P1, SFO, JFK)

Load(C2, P2, JFK)

Fly(P2, JFK, ORD)

Fly(P1, JFK, ORD)

Fly(P2, ORD, ATL)

Fly(P1, ORD, ATL)

Fly(P2, ATL, SFO)

Fly(P1, ATL, SFO)

Unload(C2, P2, SFO)

Fly(P2, SFO, ORD)

Fly(P1, SFO, ORD)

Fly(P2, ORD, ATL)

Fly(P1, ORD, ATL)

Fly(P2, ATL, JFK)

Load(C3, P1, ATL)

Fly(P1, ATL, ORD)

Fly(P2, JFK, ORD)

Fly(P1, ORD, SFO)

Fly(P2, ORD, ATL)

Fly(P1, SFO, JFK)

Fly(P2, ATL, SFO)

Unload(C3, P1, JFK)

Fly(P2, SFO, ORD)

Fly(P1, JFK, ORD)

Fly(P2, ORD, ATL)

Fly(P1, ORD, ATL)

Fly(P2, ATL, JFK)

Fly(P1, ATL, SFO)

Load(C3, P2, JFK)

Fly(P1, SFO, ORD)

Fly(P2, JFK, ORD)

Fly(P1, ORD, ATL)

Fly(P2, ORD, SFO)

Fly(P1, ATL, JFK)

Fly(P2, SFO, ATL)

Load(C1, P2, ATL)

Fly(P2, ATL, ORD)

Fly(P1, JFK, ORD)

Fly(P2, ORD, SFO)

Fly(P1, ORD, ATL)

Fly(P2, SFO, JFK)

Fly(P1, ATL, SFO)

Unload(C3, P2, JFK)

Fly(P1, SFO, ORD)

Fly(P2, JFK, ORD)

Fly(P1, ORD, ATL)

Fly(P2, ORD, SFO)

Fly(P1, ATL, JFK)

Load(C3, P1, JFK)

Fly(P2, SFO, ORD)

Fly(P1, JFK, ORD)

Fly(P2, ORD, ATL)

Fly(P1, ORD, ATL)

Fly(P2, ATL, JFK)

Fly(P1, ATL, SFO)

Unload(C3, P1, SFO)

Fly(P1, SFO, ORD)

Fly(P2, JFK, ORD)

Fly(P1, ORD, ATL)

Fly(P2, ORD, ATL)

Fly(P1, ATL, JFK)

Fly(P2, ATL, SFO)

Unload(C1, P2, SFO)

Fly(P2, SFO, ORD)

Fly(P1, JFK, ORD)

Fly(P2, ORD, ATL)

Fly(P1, ORD, ATL)

Fly(P2, ATL, JFK)

Fly(P1, ATL, SFO)

Load(C3, P1, SFO)

Fly(P1, SFO, ORD)

Fly(P2, JFK, ORD)

Fly(P1, ORD, JFK)

Fly(P2, ORD, ATL)

Unload(C3, P1, JFK)

Fly(P2, ATL, JFK)

Fly(P1, JFK, ORD)

Fly(P2, JFK, ORD)

Fly(P1, ORD, ATL)

Load(C4, P2, ORD)

Fly(P2, ORD, ATL)

Fly(P1, ATL, ORD)

Fly(P2, ATL, SFO)

Fly(P1, ORD, SFO)

Fly(P2, SFO, JFK)

Fly(P1, SFO, JFK)

Unload(C4, P2, JFK)

Fly(P2, JFK, ORD)

Fly(P1, JFK, ORD)

Fly(P2, ORD, ATL)

Fly(P1, ORD, ATL)

Fly(P2, ATL, SFO)

Fly(P1, ATL, SFO)

Load(C2, P2, SFO)

Fly(P2, SFO, ORD)

Fly(P1, SFO, ORD)

Fly(P2, ORD, ATL)

Fly(P1, ORD, ATL)

Fly(P2, ATL, JFK)

Fly(P1, ATL, JFK)

Unload(C2, P2, JFK)

Fly(P2, JFK, ORD)

Fly(P1, JFK, ORD)

Fly(P2, ORD, ATL)

Fly(P1, ORD, ATL)

Fly(P2, ATL, SFO)

Fly(P1, ATL, SFO)

Load(C1, P2, SFO)

Fly(P2, SFO, ORD)

Fly(P1, SFO, ORD)

Fly(P2, ORD, ATL)

Fly(P1, ORD, ATL)

Fly(P2, ATL, JFK)

Fly(P1, ATL, JFK)

Unload(C1, P2, JFK)

Fly(P2, JFK, ORD)

Load(C4, P1, JFK)

Fly(P2, ORD, ATL)

Fly(P1, JFK, ORD)

Fly(P2, ATL, SFO)

Fly(P1, ORD, ATL)

Fly(P2, SFO, JFK)

Fly(P1, ATL, SFO)

Unload(C4, P1, SFO)

Fly(P1, SFO, ORD)

Fly(P2, JFK, ORD)

Fly(P1, ORD, ATL)

Fly(P2, ORD, ATL)

Fly(P1, ATL, JFK)

Fly(P2, ATL, SFO)

Load(C4, P2, SFO)

Fly(P2, SFO, ORD)

Fly(P1, JFK, ORD)

Fly(P2, ORD, ATL)

Fly(P1, ORD, ATL)

Fly(P2, ATL, JFK)

Fly(P1, ATL, SFO)

Load(C3, P2, JFK)

Fly(P1, SFO, ORD)

Fly(P2, JFK, ORD)

Fly(P1, ORD, ATL)

Fly(P2, ORD, ATL)

Fly(P1, ATL, JFK)

Fly(P2, ATL, SFO)

Unload(C4, P2, SFO)

Fly(P2, SFO, ORD)

Fly(P1, JFK, ORD)

Fly(P2, ORD, ATL)

Fly(P1, ORD, ATL)

Fly(P2, ATL, JFK)

Load(C2, P2, JFK)

Fly(P1, ATL, ORD)

Fly(P2, JFK, ORD)

Fly(P1, ORD, SFO)

Fly(P2, ORD, ATL)

Fly(P1, SFO, JFK)

Fly(P2, ATL, SFO)

Unload(C3, P2, SFO)

Fly(P2, SFO, ORD)

Fly(P1, JFK, ORD)

Fly(P2, ORD, ATL)

Fly(P1, ORD, ATL)

Fly(P2, ATL, JFK)

Fly(P1, ATL, SFO)

Unload(C2, P2, JFK)

Fly(P1, SFO, ORD)

Fly(P2, JFK, ORD)

Fly(P1, ORD, ATL)

Fly(P2, ORD, ATL)

Fly(P1, ATL, JFK)

Load(C2, P1, JFK)

Fly(P2, ATL, ORD)

Fly(P1, JFK, ORD)

Fly(P2, ORD, SFO)

Fly(P1, ORD, ATL)

Fly(P2, SFO, JFK)

Fly(P1, ATL, SFO)

Unload(C2, P1, SFO)

Fly(P1, SFO, ORD)

Fly(P2, JFK, ORD)

Fly(P1, ORD, ATL)

Fly(P2, ORD, ATL)

Fly(P1, ATL, JFK)

Load(C1, P1, JFK)

Fly(P2, ATL, ORD)

Fly(P1, JFK, ORD)

Fly(P2, ORD, SFO)

Fly(P1, ORD, ATL)

Fly(P2, SFO, JFK)

Fly(P1, ATL, SFO)

Unload(C1, P1, SFO)

Fly(P1, SFO, ORD)

Fly(P2, JFK, ORD)

Fly(P1, ORD, ATL)

Fly(P2, ORD, ATL)

Fly(P1, ATL, JFK)

Fly(P2, ATL, SFO)

Load(C4, P2, SFO)

Fly(P2, SFO, ATL)

Fly(P1, JFK, ORD)

Fly(P2, ATL, JFK)

Fly(P1, ORD, ATL)

Fly(P2, JFK, ORD)

Fly(P1, ATL, SFO)

Load(C3, P1, SFO)

Fly(P2, ORD, ATL)

Fly(P1, SFO, ORD)

Fly(P2, ATL, SFO)

Fly(P1, ORD, ATL)

Fly(P2, SFO, JFK)

Unload(C4, P2, JFK)

Fly(P1, ATL, ORD)

Fly(P2, JFK, ORD)

Fly(P1, ORD, SFO)

Fly(P2, ORD, ATL)

Fly(P1, SFO, JFK)

Fly(P2, ATL, SFO)

Load(C4, P1, JFK)

Fly(P2, SFO, ORD)

Fly(P1, JFK, ATL)

Fly(P2, ORD, ATL)

Fly(P1, ATL, ORD)

Unload(C3, P1, ORD)

Fly(P1, ORD, ATL)

Fly(P2, ATL, ORD)

Fly(P1, ATL, SFO)

Fly(P2, ORD, SFO)

Fly(P1, SFO, JFK)

Fly(P2, SFO, JFK)

Unload(C4, P1, JFK)

Fly(P2, JFK, ORD)

Fly(P1, JFK, ATL)

Fly(P2, ORD, ATL)

Fly(P1, ATL, ORD)

Fly(P2, ATL, SFO)

Fly(P1, ORD, SFO)

Load(C2, P2, SFO)

Fly(P2, SFO, ORD)

Fly(P1, SFO, ORD)

Fly(P2, ORD, ATL)

Fly(P1, ORD, ATL)

Fly(P2, ATL, JFK)

Fly(P1, ATL, JFK)

Unload(C2, P2, JFK)

Fly(P2, JFK, ORD)

Fly(P1, JFK, ORD)

Fly(P2, ORD, ATL)

Fly(P1, ORD, ATL)

Fly(P2, ATL, SFO)

Fly(P1, ATL, SFO)

Load(C1, P2, SFO)

Fly(P2, SFO, ORD)

Fly(P1, SFO, ORD)

Fly(P2, ORD, ATL)

Fly(P1, ORD, ATL)

Fly(P2, ATL, JFK)

Fly(P1, ATL, JFK)

Unload(C1, P2, JFK)

Fly(P2, JFK, ORD)

Fly(P1, JFK, ORD)

Fly(P2, ORD, ATL)

Load(C3, P1, ORD)

Fly(P1, ORD, ATL)

Fly(P2, ATL, ORD)

Fly(P1, ATL, SFO)

Fly(P2, ORD, SFO)

Fly(P1, SFO, JFK)

Load(C4, P1, JFK)

Fly(P2, SFO, JFK)

Fly(P1, JFK, ORD)

Fly(P2, JFK, ORD)

Fly(P1, ORD, ATL)

Fly(P2, ORD, ATL)

Fly(P1, ATL, SFO)

Unload(C4, P1, SFO)

Fly(P2, ATL, ORD)

Fly(P1, SFO, ORD)

Fly(P2, ORD, SFO)

Fly(P1, ORD, ATL)

Fly(P2, SFO, JFK)

Fly(P1, ATL, JFK)

Load(C2, P2, JFK)

Fly(P2, JFK, ORD)

Fly(P1, JFK, ORD)

Fly(P2, ORD, ATL)

Fly(P1, ORD, ATL)

Fly(P2, ATL, SFO)

Fly(P1, ATL, SFO)

Unload(C2, P2, SFO)

Fly(P2, SFO, ORD)

Fly(P1, SFO, ORD)

Fly(P2, ORD, ATL)

Fly(P1, ORD, ATL)

Fly(P2, ATL, JFK)

Fly(P1, ATL, JFK)

Unload(C3, P1, JFK)

#### Solving Air Cargo Problem 3 using uniform\_cost\_search...

Expansions Goal Tests New Nodes

18223 18225 159618

Plan length: 12 Time elapsed in seconds: 180.31168492715437

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 greedy\_best\_first\_graph\_search with h\_1...

Expansions Goal Tests New Nodes

5578 5580 49150

Plan length: 22 Time elapsed in seconds: 54.17322964303692

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)

#### Solving Air Cargo Problem 3 using astar\_search with h\_1...

Expansions Goal Tests New Nodes

18223 18225 159618

Plan length: 12 Time elapsed in seconds: 164.92161645478788

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

5040 5042 44944

Plan length: 12 Time elapsed in seconds: 57.23769514445956

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)

1. *Artificial Intelligence: A modern Approach.* Stuart Russell & Peter Norvig. 3rd edition C hapter 3 [↑](#footnote-ref-1)
2. Stuart Russell & Peter Norvig. 3r Edition(Chapter 10. Classical Planning. Section 10.2.3 Heuristics for planning). Page 376 [↑](#footnote-ref-2)