

## Plane Cargo Planning Search Heuristic Analysis

Below are the results of different searches and heuristics on air cargo problems:

### Air Cargo 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: 0.02797540999017656

Load(C1, P1, SF0)  
 Load(C2, P2, JFK)  
 Fly(P2, JFK, SF0)  
 Unload(C2, P2, SF0)  
 Fly(P1, SF0, 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: 0.015653430018574

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

Solving Air Cargo Problem 1 using **uniform\_cost\_search...**

Expansions	Goal Tests	New Nodes
55	57	224

Plan length: 6 Time elapsed in seconds: 0.04098645504564047

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

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: 0.039149136980995536

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

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: 1.111613300978206

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

## Air Cargo 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: 13.063607363030314

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

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: 3.30969224893488  
The plan length is too long to be included in this document, and it is not optimal.

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

Expansions	Goal Tests	New Nodes
4853	4855	44041

Plan length: 9 Time elapsed in seconds: 10.724383275955915

```
Load(C1, P1, SF0)
Load(C2, P2, JFK)
Load(C3, P3, ATL)
Fly(P1, SF0, JFK)
Fly(P2, JFK, SF0)
Fly(P3, ATL, SF0)
Unload(C3, P3, SF0)
Unload(C2, P2, SF0)
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: 3.880263695027679

```
Load(C3, P3, ATL)
Fly(P3, ATL, SF0)
Unload(C3, P3, SF0)
Load(C2, P2, JFK)
Fly(P2, JFK, SF0)
Unload(C2, P2, SF0)
Load(C1, P1, SF0)
Fly(P1, SF0, 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: 180.10296602000017

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

### Air Cargo 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: 95.10760533099528

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

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: 1.6633030170341954

The plan length is too long to be included in this document, and it is not optimal.

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

Expansions    Goal Tests    New Nodes

18223        18225        159618

Plan length: 12 Time elapsed in seconds: 46.874651882913895

Load(C1, P1, SF0)  
 Load(C2, P2, JFK)  
 Fly(P1, SF0, ATL)  
 Load(C3, P1, ATL)  
 Fly(P2, JFK, ORD)  
 Load(C4, P2, ORD)  
 Fly(P2, ORD, SF0)  
 Fly(P1, ATL, JFK)  
 Unload(C4, P2, SF0)  
 Unload(C3, P1, JFK)  
 Unload(C2, P2, SF0)  
 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: 15.685840989113785

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

Solving Air Cargo Problem 3 using **astar\_search with h\_pg\_levelsum...**

Expansions    Goal Tests    New Nodes

325        327        3002

Plan length: 12 Time elapsed in seconds: 907.4600900450023

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

## Performance Comparison

From the videos in Lesson 10 about searches, we learn that Breadth-first search (BFS) is optimal and Depth-first search (DFS) is not. This can be seen in the resulting Plan length of the two searches. BFS always find the shortest path to the goal, while DFS often end up with a goal that takes hundreds of actions more than BFS. The reason for BFS optimality is in the way it expands the shortest node first. We see the number of expansions, goal tests, and new nodes of BFS far exceed that of DFS with this particular search space. DFS will search down a path until it reaches its leaf node and back propagate, which is why the first goal state that DFS might run into is quite long in terms of planning steps. Uniform-cost search is similar to BFS, so we see similar performance. In summary, of the non-heuristic searches BFS is optimal but DFS is faster and expands less nodes.

A\* search is said to be optimal only if the heuristic is admissible, that is it never overestimates the true cost of reaching the goal. Both our heuristic in this case, pg-levelsum and ignore-preconditions, are admissible thus the searches are optimal. In terms of expansions and goal tests, heuristic searches perform better than uniform searches because they use heuristics as sort of mental shortcut to traverse the search space smartly. However, this does not mean the search time is better. Some of these heuristics take drastic amount of time to compute, which is why we see A\* search with pg-levelsum taking 907 seconds to complete problem 3. Between the two heuristics, pg-levelsum expand far less nodes and goal tests than ignore-preconditions making it the winner in space complexity. Whereas ignore-preconditions takes far less time making it the winner in time complexity.

## The Optimal Plan for each Problem

The optimal plan for each problem can be found with either BFS, uniform-cost, or our A\* heuristic searches because all of these were optimal. The only non-optimal search is DFS. Note that there can be multiple optimal solutions for one problem.

### Problem 1

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

### Problem 2

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

### Problem 3

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