

# Planning Heuristics Analysis

## Comparison of Breadth First Search, Depth First Search and Uniform Cost Search

Generally speaking, when comparing the breadth-first, depth-first and uniform-cost search heuristics - uniform-cost search seems to provide the best overall metrics when node expansions, plan length and time elapsed are taken into consideration.

### Node Expansions

	Breadth First	Depth First	Uniform Cost
Problem 1	43	21	55
Problem 2	3346	107	4853
Problem 3	14663	408	18223

### Plan Length

	Breadth First	Depth First	Uniform Cost
Problem 1	6	20	6
Problem 2	9	105	9
Problem 3	12	392	12

### Time Elapsed

	Breadth First	Depth First	Uniform Cost
Problem 1	0.049 s	0.028 s	0.056 s
Problem 2	23.083 s	0.619 s	26.297 s
Problem 3	182.905 s	3.244 s	116.567 s

Depth-first search has a smaller memory-footprint and is orders of magnitude faster at finding a solution than breadth-first and uniform-cost search. However it produces action plans that are terribly non-optimal and impractical. This is because Depth-first search continues to follow nodes by expanding into an endless depth without considering nodes on shallower levels.

Uniform cost search seems to produce action plans that are equivalent to breadth-first however it is ~ 36% faster. It should be noted that uniform cost search performs ~24% more node expansions than breadth-first search which means that the probability of it finding the most efficient path is higher since it searches through a broader set of all possibilities. The conclusion is that, out of the 3 heuristics, uniform-cost search performs the best.

## A\* Search Comparisons

### Node Expansions

	A* h_1	A* h_ignore_preconditions	A* h_pg_levelsum
Problem 1	55	41	11
Problem 2	4853	1450	86
Problem 3	18223	5040	325

### Goal Tests

	A* h_1	A* h_ignore_preconditions	A* h_pg_levelsum
Problem 1	57	43	13
Problem 2	4855	1452	88
Problem 3	18225	5042	327

### Plan Length

	A* h_1	A* h_ignore_preconditions	A* h_pg_levelsum
Problem 1	6	6	6
Problem 2	9	9	9
Problem 3	12	12	12

### Time Elapsed

	A* h_1	A* h_ignore_preconditions	A* h_pg_levelsum
Problem 1	0.053 s	0.057 s	0.606 s
Problem 2	25.998 s	9.470 s	61.277 s
Problem 3	129.774 s	39.575 s	270.798 s

The A\* Search with h\_ignore\_preconditions seems to be the superior heuristic over the h\_pg\_levelsum heuristic. Though h\_pg\_levelsum seems to be more efficient in that it performs about 93% less node expansions and goal tests, it took more than 6x longer to search. The intuition here is that though the h\_pg\_levelsum performs less goal tests, each goal test is very expensive since the algorithm is much more complex, thus providing less overall benefit.

### Final Conclusion

The final conclusion is that of all the heuristics that were tested, Uniform Cost Search is the superior choice with the best balance, finding the most optimal path in the shortest amount of time.

### Problem 1 Solutions

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

Expansions	Goal Tests	New Nodes
43	56	180

Plan length: 6 Time elapsed in seconds: 0.04959469700406771

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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: 0.02897417900385335

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

Expansions	Goal Tests	New Nodes
55	57	224

Plan length: 6 Time elapsed in seconds: 0.05672826599038672

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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: 0.05373104699538089

Load(C1, P1, SFO)

Load(C2, P2, JFK)

Fly(P1, SFO, JFK)

Fly(P2, JFK, SFO)

Unload(C1, P1, JFK)

Unload(C2, P2, SFO)

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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: 0.057158559997333214

Load(C1, P1, SFO)

Fly(P1, SFO, JFK)

Unload(C1, P1, JFK)

Load(C2, P2, JFK)

Fly(P2, JFK, SFO)

Unload(C2, P2, SFO)

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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: 0.6067427699745167

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 Solutions

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

Expansions	Goal Tests	New Nodes
3346	4612	30534

Plan length: 9 Time elapsed in seconds: 23.083968239996466

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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: 0.6198255799972685

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

Expansions	Goal Tests	New Nodes
4853	4855	44041

Plan length: 9 Time elapsed in seconds: 26.297774580001715

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Solving Air Cargo Problem 2 using astar\_search with h\_1...

Expansions	Goal Tests	New Nodes
4853	4855	44041

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Plan length: 9 Time elapsed in seconds: 25.99857044601231

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)

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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: 9.470294747006847

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)

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Solving Air Cargo Problem 2 using astar\_search with h\_pg\_levelsum...

Expansions	Goal Tests	New Nodes
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86

88

841

Plan length: 9 Time elapsed in seconds: 61.277761244011344

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)

## Problem 3 Solutions

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

Expansions	Goal Tests	New Nodes
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14663	18098	129631
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Plan length: 12 Time elapsed in seconds: 182.90545364900026

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Solving Air Cargo Problem 3 using depth\_first\_graph\_search...

Expansions	Goal Tests	New Nodes
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408	409	3364
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Plan length: 392 Time elapsed in seconds: 3.2446576380025363

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

Expansions	Goal Tests	New Nodes
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18223	18225	159618
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Plan length: 12 Time elapsed in seconds: 116.56708693499968

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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: 129.77453505501035

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)

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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: 39.575983192014974

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)

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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: 286.7985359909944

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)