Heuristic Analysis

August 5, 2017

Overview

We used PDDL and search for solving the real-life inspired air cargo shipping. In this paper, there is analysis of both heuristic search and non-heuristic search and comparison between these methods for solving the problems presented. Additionally, it includes the specifcs of using depth first search , breadth first search, uniformcost search and A* search. From this comparison we will determine which search is optimal, the effect of heuristic-driven search on the computational expenditure, and whether A* with the levelsum heuristic search consistently outperforms all other methods. All of our analysis will be based on data, which can be found in the "Data" section.

Optimal Plan

Heuristic-search vs. Non-heuristic search Performance

Non-Heuristic Search Comparison

1. P1
   (a) breadth first search-It came up with the optimal plan length in the least amount of computation time. Thats is beacuse the amount of ne nodes, goal tests and expansions were lower than that of uniform cost search.
   (b) depth first search-It took the shortest amount of time to run yet the plan length was longest. It just goes through the entire search space indiscriminately and ends up picking actions that are recursive. Such as flying the airplanes back anf forth between airports without no purpose. It has no memory storage of frontier and explored so it runs fast.
   (c) unifrom cost search-It came up with the optimal plan length albeit more expensive than breadth first search. Intuitively, it searches for paths with least cost rather than least number of steps, therefore it results in more redundant paths being explored before reaching the goal.
2. P2
   (a) breadth first search-
   (b) depth first search-
   (c) unifrom cost search-
3. P3
   (a) breadth first search-

(b) depth first search-

(c) unifrom cost search-

Heuristic Search Comparison

1. Ignore Preconditions-
2. Levelsum-

A* search with level-sum Heuristic as Optimal Planning Search

Results from analysis above. Background on heuristic and intuition why it is better than non-heuristic search planning methods for all problems

Data

ACP1 using breadth first search

```
Expansions   Goal Tests   New Nodes
    43          56         180

Plan length: 6  Time elapsed in seconds: 0.026820736686953884
Load(C1, P1, SFO)
Load(C2, P2, JFK)
Fly(P2, JFK, SFO)
Unload(C2, P2, SFO)
Fly(P1, SFO, JFK)
Unload(C1, P1, JFK)
```

ACP1 using depth first search

```
Expansions   Goal Tests   New Nodes
    21          22          84

Plan length: 20  Time elapsed in seconds: 0.012762258721975783
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)
```

Air Cargo Problem 1 using uniform cost search

```
Expansions   Goal Tests   New Nodes
    55          57         224

Plan length: 6  Time elapsed in seconds: 0.030471730713625814
Load(C1, P1, SFO)
Load(C2, P2, JFK)
Fly(P1, SFO, JFK)
Fly(P2, JFK, SFO)
Unload(C1, P1, JFK)
Unload(C2, P2, SFO)
```

ACP1 using A* with Ignore Preconditions

```
Expansions   Goal Tests   New Nodes
    41          43         170

Plan length: 6  Time elapsed in seconds: 0.023959604222938413
Load(C1, P1, SFO)
Fly(P1, SFO, JFK)
Unload(C1, P1, JFK)
Load(C2, P2, JFK)
Fly(P2, JFK, SFO)
Unload(C2, P2, SFO)
```

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: 0.4048636430954109
Load(C1, P1, SFO)
Fly(P1, SFO, JFK)
Load(C2, P2, JFK)
Fly(P2, JFK, SFO)
Unload(C1, P1, JFK)
Unload(C2, P2, SFO)
```

Air Cargo Problem 2 using breadth first search

```
Expansions   Goal Tests   New Nodes
   3346        4612       30534

Plan length: 9  Time elapsed in seconds: 10.861962171273017
Load(C1, P1, SFO)
Load(C2, P2, JFK)
Load(C3, P3, ATL)
Fly(P1, SFO, JFK)
Unload(C1, P1, JFK)
Fly(P2, JFK, SFO)
Unload(C2, P2, SFO)
Fly(P3, ATL, SFO)
Unload(C3, P3, SFO)
```

Air Cargo Problem 2 using depth first graph search

```
Expansions   Goal Tests   New Nodes
   107         108         959

Plan length: 105  Time elapsed in seconds: 0.258578813374049
Fly(P3, ATL, JFK)
Fly(P2, JFK, ATL)
Fly(P3, JFK, SFO)
Fly(P2, ATL, SFO)
Fly(P1, SFO, ATL)
Fly(P3, SFO, ATL)
Fly(P1, ATL, JFK)
Fly(P3, ATL, JFK)
Load(C2, P3, JFK)
Fly(P3, JFK, ATL)
Fly(P1, JFK, ATL)
Fly(P3, ATL, SFO)
```

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

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

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

Solving Air Cargo Problem 2 using uniform cost search

```
Expansions   Goal Tests   New Nodes
   4853        4855       44041

Plan length: 9  Time elapsed in seconds: 9.275755481427675
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)
```

Air Cargo Problem 2 using astarsearch with ignore pre-conditions

```
Expansions   Goal Tests   New Nodes
   1450        1452       13303

Plan length: 9  Time elapsed in seconds: 3.310493169813185
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)
```

Air Cargo Problem 2 using A* search with levelsum

```
Expansions   Goal Tests   New Nodes
    86          88         841

Plan length: 9  Time elapsed in seconds: 42.71138670070594
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)
```

Air Cargo Problem 3 using breadth first search

```
Expansions   Goal Tests   New Nodes
  14120       17673       124926

Plan length: 12  Time elapsed in seconds: 94.91550561718513
Load(C1, P1, SFO)
Load(C2, P2, JFK)
Fly(P1, SFO, ATL)
Load(C3, P1, ATL)
Fly(P2, JFK, ORD)
Load(C4, P2, ORD)
Fly(P1, ATL, JFK)
Unload(C1, P1, JFK)
Unload(C3, P1, JFK)
Fly(P2, ORD, SFO)
Unload(C2, P2, SFO)
Unload(C4, P2, SFO)
```

Air Cargo Problem 3 using depth first graph search

```
Expansions   Goal Tests   New Nodes
   292         293         2388

Plan length: 288  Time elapsed in seconds: 1.1553460228354595
Fly(P2, JFK, ORD)
Fly(P1, SFO, ORD)
Fly(P2, ORD, ATL)
Fly(P1, ORD, ATL)
Fly(P2, ATL, SFO)
Fly(P1, ATL, JFK)
Load(C2, P1, JFK)
Fly(P1, JFK, ORD)
Fly(P2, SFO, ORD)
```

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

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

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

```
Load(C4, P2, ORD)
Fly(P2, ORD, ATL)
Fly(P1, ORD, ATL)
Fly(P2, ATL, JFK)
Fly(P1, ATL, JFK)
Fly(P2, JFK, SFO)
Fly(P1, JFK, SFO)
Unload(C4, 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(C4, P2, SFO)
Fly(P2, SFO, ORD)
Fly(P1, SFO, JFK)
Fly(P2, ORD, ATL)
Fly(P1, JFK, ORD)
Fly(P2, ATL, JFK)
Unload(C4, P2, JFK)
Fly(P1, ORD, ATL)
Fly(P2, JFK, ORD)
Fly(P1, ATL, JFK)
Fly(P2, ORD, ATL)
Fly(P1, JFK, SFO)
Load(C3, P2, ATL)
Fly(P2, ATL, ORD)
Fly(P1, SFO, ORD)
Fly(P2, ORD, JFK)
Fly(P1, ORD, ATL)
Fly(P2, JFK, SFO)
Fly(P1, ATL, JFK)
Unload(C3, P2, SFO)
Fly(P1, JFK, ORD)
Fly(P2, SFO, ORD)
Fly(P1, ORD, ATL)
```

```
Fly(P2, ORD, ATL)
Fly(P1, ATL, SFO)
Fly(P2, ATL, JFK)
Load(C4, P2, JFK)
Fly(P2, JFK, ORD)
Fly(P1, SFO, ORD)
Fly(P2, ORD, ATL)
Fly(P1, ORD, ATL)
Fly(P2, ATL, SFO)
Fly(P1, ATL, JFK)
Unload(C4, P2, SFO)
Fly(P1, JFK, ORD)
Fly(P2, SFO, ORD)
Fly(P1, ORD, ATL)
Fly(P2, ORD, ATL)
Fly(P1, ATL, SFO)
Fly(P2, ATL, JFK)
Load(C4, P1, SFO)
Fly(P2, JFK, ORD)
Fly(P1, SFO, ORD)
Fly(P2, ORD, ATL)
Fly(P1, ORD, ATL)
Fly(P2, ATL, SFO)
Unload(C4, P1, ATL)
Fly(P1, ATL, ORD)
Fly(P2, SFO, ORD)
Fly(P1, ORD, JFK)
Fly(P2, ORD, ATL)
Fly(P1, JFK, SFO)
Fly(P2, ATL, JFK)
Load(C3, P1, SFO)
Fly(P2, JFK, ORD)
Fly(P1, SFO, ORD)
Fly(P2, ORD, ATL)
Fly(P1, ORD, ATL)
Fly(P2, ATL, SFO)
Fly(P1, ATL, JFK)
Unload(C3, P1, JFK)
Fly(P1, JFK, ORD)
Fly(P2, SFO, ORD)
Fly(P1, ORD, ATL)
Fly(P2, ORD, ATL)
Fly(P1, ATL, SFO)
Fly(P2, ATL, JFK)
```

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

```
Unload(C2, P2, SFO)
Fly(P1, JFK, ORD)
Fly(P2, SFO, ORD)
Fly(P1, ORD, ATL)
Fly(P2, ORD, ATL)
Fly(P1, ATL, SFO)
Fly(P2, ATL, JFK)
Load(C4, P2, JFK)
Fly(P2, JFK, ORD)
Fly(P1, SFO, JFK)
Fly(P2, ORD, ATL)
Fly(P1, JFK, ORD)
Fly(P2, ATL, SFO)
Fly(P1, ORD, ATL)
Unload(C4, P2, SFO)
```

Air Cargo Problem 3 using uniform cost search

```
Expansions   Goal Tests   New Nodes
  18234       18236       159707

Plan length: 12  Time elapsed in seconds: 52.293134551506725
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)
```

Air Cargo Problem 3 using A* search with ignore preconditions

```
Expansions   Goal Tests   New Nodes
   5040        5042       44944

Plan length: 12  Time elapsed in seconds: 16.202921077314755
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)
```

Air Cargo Problem 3 using A* search with levelsum

```
Expansions   Goal Tests   New Nodes
   313         315         2881

Plan length: 12  Time elapsed in seconds: 207.9568407653194
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)
```