**Heuristic Analysis by Ng Fang Kiang**

**Udacity – Artificial Intelligence Nanodegree (Class of 2017)**

**Air Cargo Problem 1**

*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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| Air Cargo Problem 1 |  |  |  |  |  |
| Search | Expansions | Goal\_Tests | New Nodes | Plan Length | Time |
| breadth\_first\_search | 43 | 56 | 180 | 6 | 0.084193586 |
| breadth\_first\_tree\_search | 1456 | 1459 | 5960 | 6 | 2.817626083 |
| depth\_first\_graph\_search | 12 | 13 | 48 | 12 | 0.022848891 |
| depth\_limited\_search | 101 | 271 | 414 | 50 | 0.207606009 |
| uniform\_cost\_search | 55 | 57 | 224 | 6 | 0.108275467 |
| recursive\_best\_first\_search h\_1 | 4229 | 4230 | 17029 | 4230 | 8.009237971 |
| greedy\_best\_first\_graph\_search h\_1 | 7 | 9 | 28 | 6 | 0.013341891 |
| astar\_search h\_1 | 55 | 57 | 224 | 6 | 0.1030313 |
| astar\_search h\_ignore\_preconditions | 41 | 43 | 170 | 6 | 0.087809522 |
| astar\_search h\_pg\_levelsum | 11 | 13 | 50 | 6 | 0.545721415 |

Best plan consist of 6 actions:

1. Load(C1, P1, SFO)
2. Load(C2, P2, JFK)
3. Fly(P1, SFO, JFK)
4. Fly(P2, JFK, SFO)
5. Unload(C1, P1, JFK)
6. Unload(C2, P2, SFO)

The best performance is greedy\_best\_first\_graph\_search h\_1.

**Air Cargo Problem 2**

*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))*

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| Air Cargo Problem 2 |  |  |  |  |  |
| Search | Expansions | Goal\_Tests | New Nodes | Plan Length | Time |
| breadth\_first\_search | 3401 | 4672 | 31049 | 9 | 36.24551419 |
| breadth\_first\_tree\_search | inf | inf | inf | inf | inf |
| depth\_first\_graph\_search | 350 | 351 | 3142 | 346 | 3.543807292 |
| depth\_limited\_search | 254020 | 2344879 | 2345254 | 50 | 2604.373427 |
| uniform\_cost\_search | 4761 | 4762 | 43206 | 9 | 43.96447017 |
| recursive\_best\_first\_search h\_1 | inf | inf | inf | inf | inf |
| greedy\_best\_first\_graph\_search h\_1 | 550 | 552 | 4950 | 9 | 4.998992351 |
| astar\_search h\_1 | 4761 | 4763 | 43206 | 9 | 46.4472368 |
| astar\_search h\_ignore\_preconditions | 1450 | 1452 | 13303 | 9 | 13.64528777 |
| astar\_search h\_pg\_levelsum | 86 | 88 | 841 | 9 | 51.4787299 |

Best plan consist of 9 actions:

1. Load(C1, P1, SFO)
2. Load(C2, P2, JFK)
3. Load(C3, P3, ATL)
4. Fly(P1, SFO, JFK)
5. Fly(P2, JFK, SFO)
6. Fly(P3, ATL, SFO)
7. Unload(C3, P3, SFO)
8. Unload(C2, P2, SFO)
9. Unload(C1, P1, JFK)

The best performance is depth\_first\_graph\_search in Air Cargo Problem 2, but the plan length with 346 is not optimal. The greedy\_best\_first\_graph\_search h\_1 has best optimal plan together with the performance.

**Air Cargo Problem 3**

*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))*

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| Air Cargo Problem 3 |  |  |  |  |  |
| Search | Expansions | Goal\_Tests | New Nodes | Plan Length | Time |
| breadth\_first\_search | 14663 | 18098 | 129631 | 12 | 350.2327689 |
| breadth\_first\_tree\_search | inf | inf | inf | inf | inf |
| depth\_first\_graph\_search | 627 | 628 | 5176 | 596 | 11.2504045 |
| depth\_limited\_search | inf | inf | inf | inf | inf |
| uniform\_cost\_search | 18235 | 18237 | 159716 | 12 | 333.1951215 |
| recursive\_best\_first\_search h\_1 | inf | inf | inf | inf | inf |
| greedy\_best\_first\_graph\_search h\_1 | 5614 | 5616 | 49429 | 22 | 98.42954981 |
| astar\_search h\_1 | 18235 | 18237 | 159716 | 12 | 313.1379738 |
| astar\_search h\_ignore\_preconditions | 5040 | 5042 | 44944 | 12 | 96.92856017 |
| astar\_search h\_pg\_levelsum | 318 | 320 | 2934 | 12 | 398.0241286 |

Best plan consist of 12 actions:

1. Load(C2, P2, JFK)
2. Fly(P2, JFK, ORD)
3. Load(C4, P2, ORD)
4. Fly(P2, ORD, SFO)
5. Unload(C4, P2, SFO)
6. Load(C1, P1, SFO)
7. Fly(P1, SFO, ATL)
8. Load(C3, P1, ATL)
9. Fly(P1, ATL, JFK)
10. Unload(C3, P1, JFK)
11. Unload(C1, P1, JFK)
12. Unload(C2, P2, SFO)

The best performance is depth\_first\_graph\_search in Air Cargo Problem 3, but the plan length with 596 is not optimal. The astar\_search h\_ignore\_preconditions has best optimal plan together with the performance.