# Heuristic Analysis

In the project we defined three different problems in classisical PDDM for the air cargo domain as discussed by Peter Norvig in his book on Artificial Intelligence. We apply several searh strategies, both uninformed and informed to find an optimal solution. The difference between the two approaches is that uninformed algorithms doesn’t use any specific knowledge of the domain.

Next in the document we will discuss the performance of the search strategies applied, comparing them in terms of speed, optimality and memory usage.

# Problem 1

## Definition:

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))

## Optimal path:

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

| Search Strategy | Search Type | Plan Length | Time Elapsed | # Node Expanded | Goal Tests | Optimality |
|---|---|---|---|---|---|---|
| Uninformed | Breadth first search | 6 | 0.0362 | 43 | 56 | Yes |
| | Breadth first tree search | 6 | 1.0640 | 1468 | 1459 | Yes |
| | Depth first graph search | 20 | 0.0195 | 21 | 22 | No |
| | Depth limited search | 50 | 0.1453 | 101 | 271 | No |
| | Uniform cost search | 6 | 0.0589 | 55 | 57 | Yes |
| | Recursive best first search with h_1 | 6 | 3.2698 | 4229 | 4230 | Yes |
| | Greedy best first graph search with h_1 | 6 | 0.0059 | 7 | 9 | Yes |
| Informed | A*search with h_1 | 6 | 0.04253 | 55 | 57 | Yes |
| | A*search with h_ignore_preconditions | 6 | 0.05649 | 41 | 43 | Yes |
| | A*search with h_pg_levelsum | 6 | 0.6424 | 11 | 13 | Yes |

As depicted in the table above, in case of uninformed search algorithms, **BFS**, **GBFGS**, **RBFS** and **UCS** yield to optimal results. In terms of execution time GBFGS results to be the fastest, as well as the one with the least number of nodes expanded. Also BFS performs quire well. RBFS find the optimal path buti it has the highest number of nodes expanded. DFS find a solution very quickly, but the resulting plan is longer than necessary.

The heuristic planning was performed with: **h_1**, **h_ignore_preconditions** and **h_pg_levelsum**.
All the heuristics find optimal plan for the first problem, h_1 was the quickest while h_pg_levelsum was the one with least number of nodes expanded.

# Problem 2

## Definition:

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))

## Optimal path:

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

| Search Strategy | Search Type | Plan Length | Time Elapsed | # Node Expanded | Goal Tests | Optimality |
|---|---|---|---|---|---|---|
| Uninformed | Breadth first search | 9 | 14.9574 | 3343 | 4609 | Yes |
| | Breadth first tree search | ??? | ??? | ??? | ??? | No |
| | Depth first graph search | 619 | 4.0132 | 624 | 625 | No |
| | Depth limited search | ??? | ??? | ??? | ??? | No |
| | Uniform cost search | 9 | 13.1602 | 4849 | 4851 | Yes |
| | Recursive best first search with h_1 | ??? | ??? | ??? | ??? | No |
| | Greedy best first graph search with h_1 | 12 | 2.5814 | 966 | 968 | No |

| | | | | | | |
|---|---|---|---|---|---|---|
| **Informed** | A*search with h_1 | 9 | 13.0823 | 4849 | 4851 | Yes |
| | A*search with h_ignore_preconditions | 9 | 4.7573 | 1443 | 1445 | Yes |
| | A*search with h_pg_levelsum | 9 | 51.8104 | 85 | 87 | Yes |

BFS and UCS  yield optimal results. DFS is quicker, but the resulting plani s the longest among the uninfirmed search strategies. BFTS and DLS took more than 10 minutes and so they were stopped. Regarding informed search all of them yield optimal results: h_pg_levelsum is the one with least nodes expanded but h_1 and h_ignore_preconditions are better in terms of execution time.

# Problem 3

## Definition:

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))

## Optimal path:

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)

| Search Strategy | Search Type | Plan Length | Time Elapsed | # Node Expanded | Goal Tests | Optimality |
|---|---|---|---|---|---|---|
| Uninformed | Breadth first search | 12 | 14.9574 | 14463 | 18098 | Yes |
| | Breadth first tree search | ??? | ??? | ??? | ??? | No |
| | Depth first graph search | 392 | 2.0198 | 408 | 409 | No |
| | Depth limited search | ??? | ??? | ??? | ??? | No |
| | Uniform cost search | 12 | 55.6888 | 18235 | 18237 | Yes |
| | Recursive best first search with h_1 | ??? | ??? | ??? | ??? | No |
| | Greedy best first graph search with h_1 | 21 | 17.2825 | 5462 | 5464 | No |
| Informed | A*search with h_1 | 12 | 56.3599 | 18235 | 18237 | Yes |
| | A*search with h_ignore_preconditions | 12 | 18.3654 | 4945 | 4947 | Yes |
| | A*search with h_pg_levelsum | ??? | ??? | ??? | ??? | Yes |

Even in this case BFS and UCS yield the best results among uninformed search strategies. Like for the problem N.2 BFTS and DLS took more than ten minutes. DFS is the best search strategy in of execution time but not in terms of plan length.

Among informed strategies h_ignore_preconditions performs the best in terms of time execution and number of nodes expanded. In this case h_pg_levelsum took more than ten minutes adnd were skipped.