HEURISTIC ANALYSIS

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PART-1

Table 1 Results for BFS, DFS and UCS for Air Cargo Problems 1,2,3

	Breadth_first_search (BFS)					Depth_first_graph_search (DFS)					Uniform_cost_search (UCS)				
	Expansion	Goal Tests	Time Elapsed	Optimality	Plan Length	Expansion	Goal Tests	Time Elapsed	Optimality	Plan Length	Expansion	Goal Tests	Time Elapsed	Optimality	Plan Length
P1	43	56	0.0601	Yes	6	12	13	0.0191	No	12	55	57	0,0724	Yes	6
P2	3343	4609	27.496	Yes	9	582	583	6.142	No	575	4852	4854	21.808	Yes	9
P3	14663	18098	210.06	Yes	12	627	628	6.183	No	596	18235	18237	101.14	Yes	12

For the uninformed search method, I have chosen Breadth First Search, Depth FIrst Search and Uniform Cost Search methods for comparison. As specified in the project requirement, I have collected data regarding the node expansion, number of Goal Tests, Time elapsed, Optimality and also the Plan length for all the methods.

BFS proceeds to find the solution to a search problem but starting at the initial stage and perform goal test. If goal is not achieved then expand to the next level. All the states in that level are goal-tested and proceeds to the next level only if goal was not achieved.in the current level. Thus BFS is guaranteed to find a solution (complete) if a solution if a solution exists and is optimal. It is optimal only if the path cost is non-decreasing [1]. In this project, the path cost satisfies this criterion and hence gives us optimal result.

UCS is also a complete and optimal search algorithm. Here, the distance to all neighbours of a state are considered before choosing the node with the shortest distance. The distance in the next level is considered cumulatively from all its previous nodes. Again, like in BFS, many nodes are explored before reaching the goal. The advantage of this method is that a solution, if it exists, will be found (provided every step has at least a small positive cost [2]) and also it will be the shortest path. This is probably the best uninformed search method.

As can be seen in Table 1, the number of node expansion is quite big for both BFS and UCS. This is because both these methods search for solutions in all directions without any sense of the goal position. The plan length for both methods are the same the path cost for all path are equal. Hence P1, P2 and P3 have the same plan length of 6,9 and 12.

With more number of node expansion for UCS compared to BFS, I expected the time elapsed to be greater for UCS. However, in my results, the time elapsed in less for UCS (in Problem 2 and 3) compared to the time elapsed in BFS. As explained in [2], when all the

step costs are the same the complexity of UCS and BFS are approximately the same except that UCS does not terminate as soon as it reaches the goal. This implies that UCS takes more time to solve than BFS. A satisfactory explanation could not be found. BFS takes almost double the time taken by UCS for solving Problem 3.

DFS explores the solution depth-wise and hence has the possibility of getting stuck in an infinite deepening case without ever reaching a solution . Hence this method is not complete. We can see from the plan lengths for DFS (12, 575, 596) that it is significantly greater than the plan lengths of BFS and UCS and hence not optimal as well.

PART-2

Table 2 Results for A* search with heuristics h_ignore_preconditions and h_level_sum for Air Cargo Problems 1,2,3

	A* with h_ignore_preconditions					A* with h_pg_levelsum				
	Expansion	Goal Tests	Time Elapsed	Optimality	Plan Length	Expansion	Goal Tests	Time Elapsed	Optimality	Plan Length
P1	41	43	0.073	Yes	6	11	13	0.835	Yes	6
P2	1450	1452	7.851	Yes	9	86	88	70.987	Yes	9
P3	5040	5042	31.29	Yes	12	325	327	332.82	Yes	12

The search method A* with h_ignore_preconditions or h_level_sum heuristics is an informed search method where unlike BFS, DFS and UCS, the search method has information regarding the 'distance' to goal while making decisions at all steps.
The h_ignore_preconditions heuristics gives an estimate of the distance to the goal from a given node as the least number of actions required to achieve the goal state. Here the assumption is that the one action can only achieve one state in the goal. This heuristic, therefore, never overestimates the cost in goal attainment and hence is admissible.
The number of node expansion and the time elapsed is significantly less for A* search with ignore_preconditions heuristics compared to BFS and UCS uninformed search. The plan length of these methods are the same for all three problems (which indirectly points to the optimality of the solution obtained by BFS and UCS).
The heuristic h_pg_levelsum is based on the assumption of subgoal independence [1]. This heuristic is computed by taking the sum of level cost (the level at which a goal is first attained) of each subgoal. The result with this search method is optimal. The plan length is same as that of BFS, UCS and A* with h_ignore_preconditions. But, from the table, we can see that the node expansions and goal tests are very small when compared to the other methods. This heuristic gives a much better estimate of the distance to goal than the h_ignore_preconditions and hence as result the search towards the goal is more focused [1]. But the time elapsed is much longer than the other methods. This could be because of the computation time for the heuristic.

REFERENCES

[1] P Norvig, S. Russel, Artificial Intelligence- A Modern Approach Ed 3, Section 3.4.1
[2] P Norvig, S. Russel, Artificial Intelligence- A Modern Approach Ed 3, Section 3.4.2
[3] P Norvig, S. Russel, Artificial Intelligence- A Modern Approach Ed 3, Section 10.3.1

APPENDIX

BFS 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: 0.060120592566296024
Load(C2, P2, JFK)
Load(C1, P1, SFO)
Fly(P2, JFK, SFO)
Unload(C2, P2, SFO)
Fly(P1, SFO, JFK)
Unload(C1, P1, JFK)
```

BFS 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: 27.49612484536512
Load(C2, P2, JFK)
Load(C1, P1, SFO)
Load(C3, P3, ATL)
Fly(P2, JFK, SFO)
Unload(C2, P2, SFO)
Fly(P1, SFO, JFK)
Unload(C1, P1, JFK)
Fly(P3, ATL, SFO)
Unload(C3, P3, SFO)
```

BFS 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: 210.05678005652285
Load(C2, P2, JFK)
Load(C1, P1, SFO)
Fly(P2, JFK, ORD)
Load(C4, P2, ORD)
Fly(P1, SFO, ATL)
Load(C3, P1, ATL)
Fly(P1, ATL, JFK)
Unload(C1, P1, JFK)
Unload(C3, P1, JFK)
Fly(P2, ORD, SFO)
Unload(C2, P2, SFO)
Unload(C4, P2, SFO)
```

DFS Problem1

```
Solving Air Cargo Problem 1 using depth_first_graph_search...

Expansions    Goal Tests    New Nodes
   12            13            48

Plan length: 12   Time elapsed in seconds: 0.019095332366122951
Fly(P1, SFO, JFK)
Fly(P2, JFK, SFO)
Load(C1, P2, SFO)
Fly(P2, SFO, JFK)
Fly(P1, JFK, SFO)
Unload(C1, P2, JFK)
Fly(P2, JFK, SFO)
Fly(P1, SFO, JFK)
Load(C2, P1, JFK)
Fly(P2, SFO, JFK)
Fly(P1, JFK, SFO)
Unload(C2, P1, SFO)
```

DFS Problem2 (Partial list)

```
Solving Air Cargo Problem 2 using depth_first_graph_search...

Expansions    Goal Tests    New Nodes
  582            583           5211

Plan length: 575  Time elapsed in seconds: 6.141901841490871
Fly(P3, ATL, SFO)
Fly(P1, SFO, ATL)
Fly(P3, SFO, JFK)
Fly(P1, ATL, JFK)
Fly(P2, JFK, ATL)
Fly(P3, JFK, ATL)
Fly(P2, ATL, SFO)
Fly(P3, ATL, SFO)
Load(C1, P3, SFO)
Fly(P3, SFO, ATL)
Fly(P2, SFO, ATL)
Fly(P3, ATL, JFK)
Fly(P2, ATL, JFK)
Fly(P1, JFK, ATL)
Fly(P3, JFK, ATL)
Fly(P1, ATL, SFO)
Unload(C1, P3, ATL)
Fly(P3, ATL, SFO)
Fly(P1, SFO, ATL)
Fly(P3, SFO, JFK)
Fly(P1, ATL, JFK)
Fly(P2, JFK, ATL)
Fly(P3, JFK, SFO)
Fly(P2, ATL, SFO)
Load(C2, P1, JFK)
Fly(P3, SFO, ATL)
Fly(P2, SFO, ATL)
Fly(P1, JFK, ATL)
Fly(P3, ATL, SFO)
Fly(P1, ATL, SFO)
Fly(P2, ATL, JFK)
Fly(P3, SFO, ATL)
Unload(C2, P1, SFO)
Fly(P3, ATL, JFK)
Fly(P1, SFO, ATL)
Fly(P2, JFK, ATL)
```

DFS Problem3 (Partial List)

```
Solving Air Cargo Problem 3 using depth_first_graph_search...

Expansions   Goal Tests   New Nodes
   627          628          5176

Plan length: 596  Time elapsed in seconds: 6.183067171158248
Fly(P1, SFO, ORD)
Fly(P2, JFK, ORD)
Fly(P1, ORD, ATL)
Fly(P2, ORD, ATL)
Fly(P1, ATL, JFK)
Fly(P2, ATL, SFO)
Load(C1, P2, SFO)
Fly(P2, SFO, ORD)
Fly(P1, JFK, ORD)
Fly(P2, ORD, ATL)
Fly(P1, ORD, ATL)
Fly(P2, ATL, JFK)
Fly(P1, ATL, SFO)
Unload(C1, P2, JFK)
Fly(P1, SFO, ORD)
Fly(P2, JFK, ORD)
Fly(P1, ORD, ATL)
Fly(P2, ORD, ATL)
Fly(P1, ATL, JFK)
Fly(P2, ATL, SFO)
Load(C2, P1, JFK)
Fly(P2, SFO, ORD)
Fly(P1, JFK, ORD)
Fly(P2, ORD, ATL)
Fly(P1, ORD, ATL)
Fly(P2, ATL, JFK)
Fly(P1, ATL, SFO)
Unload(C2, P1, SFO)
Fly(P1, SFO, ORD)
Fly(P2, JFK, ORD)
Fly(P1, ORD, ATL)
Fly(P2, ORD, ATL)
Fly(P1, ATL, JFK)
Fly(P2, ATL, SFO)
Load(C2, P2, SFO)
Fly(P2, SFO, ORD)
Fly(P1, JFK, ORD)
Fly(P2, ORD, ATL)
Fly(P1, ORD, ATL)
Fly(P2, ATL, JFK)
Load(C3, P1, ATL)
```

UCS Problem 1

```
Solving Air Cargo Problem 1 using uniform_cost_search...

Expansions   Goal Tests   New Nodes
    55           57          224

Plan length: 6  Time elapsed in seconds: 0.072444429069002928
Load(C1, P1, SFO)
Load(C2, P2, JFK)
Fly(P1, SFO, JFK)
Fly(P2, JFK, SFO)
Unload(C1, P1, JFK)
Unload(C2, P2, SFO)
```

UCS Problem 2

```
Solving Air Cargo Problem 2 using uniform_cost_search...

Expansions    Goal Tests    New Nodes
   4852          4854          44030

Plan length: 9  Time elapsed in seconds: 21.807822275996017
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)
```

UCS Problem 3

```
Solving Air Cargo Problem 3 using uniform_cost_search...

Expansions    Goal Tests    New Nodes
  18235         18237         159716

Plan length: 12  Time elapsed in seconds: 101.13609076984473
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)
```

A* ignore-preconditions Problem 1

```
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: 0.07340183454777184
Load(C1, P1, SFO)
Fly(P1, SFO, JFK)
Unload(C1, P1, JFK)
Load(C2, P2, JFK)
Fly(P2, JFK, SFO)
Unload(C2, P2, SFO)
```

A* ignore-preconditions Problem 2

```
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: 7.851010160470102
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)
```

A* ignore-preconditions Problem 3

```
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: 31.286475266569706
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)
```

A* level-sum Problem 1

```
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: 0.834585807944233
Load(C1, P1, SFO)
Fly(P1, SFO, JFK)
Load(C2, P2, JFK)
Fly(P2, JFK, SFO)
Unload(C1, P1, JFK)
Unload(C2, P2, SFO)
```

A* level-sum Problem 2

```
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: 70.98694516340733
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)
```

A* Level-sum Problem 3

```
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: 332.8224704027782
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)
```