HEURISTIC ANALYSIS

In the following sections, I will compare the performance of heuristic and non-heuristic search algorithms for the Air Cargo search problem. The algorithsm compared are:

- Non-heuristic: Breadth First Search (BFS), Depth First Graph Search (DFGS), Uniform Cost Search (UCS)
- Heuristic: A* with constant heuristic, A*with ignore preconditions, A* with level sum heuristic.

PROBLEM 1

The table below illustrate the performance of non-heuristic (blue shaded) and heuristic (yellow shaded) search algorithms on Problem 1. Among the non-heuristic methods, BFS and UCS perform similarly since BFS and UCS are equivalent in the setting of uniform, fixed cost for all edges. DFGS expands the fewest nodes, but obtains a plan that is unreasonably long. This is consistent with the depth-first search strategy which returns the first solution found but not necessarily the shallowest solution.

The heuristic methods A* with non-trivial heuristics (i.e $h \neq 1$) perform similarly in terms of node expansion and goal tests (note that A star with h=1 is UCS). A* with "ignore preconditions" arrives at a solution faster than A* with "level-sum" because it is simpler to compute. However, both do a similar amount of work since the search space is small.

This is the smallest of the three search problems when considering the size of the state space to be search (number of fluents is 12). Consequently, one expects heuristic and non-heuristic methods to perform comparably. Note how the BFS algorithm and A* algorithm with "ignore preconditions" heuristic perform similarly in terms of number of nodes expanded, plan length, and elapsed time.

	Expansions	Goal Tests	New Nodes	Plan Length	Time Elapsed
BFS	43	56	180	6	0.023 sec
DFGS	21	22	84	20	0.011 sec
UCS	55	57	224	6	0.030 sec
$A^*_{h\_1}$	55	57	224	6	0.029 sec
$A^*_{h\_ignore\_preconditions}$	41	43	170	6	0.034 sec
$A^*_{h\_pg\_level\_sum}$	41	43	170	6	1.659 sec

The optimal plan is of length 6 and corresponds to
Load(C1, P1, SFO)
Load(C2, P2, JFK)
Fly(P2, JFK, SFO)
Unload(C2, P2, SFO)
Fly(P1, SFO, JFK)
Unload(C1, P1, JFK)

PROBLEM 2

The table below illustrate the performance of non-heuristic (blue shaded) and heuristic (yellow shaded) search algorithms on Problem 2. Once again, DFGS expands the fewest nodes, but obtains a plan that is unreasonably long (619 actions) due to favoring the first solution found but not necessarily the shallowest solution. BFS is the best performing non-heuristic method in terms of arriving at an optimal plan of length 9.

Among the heuristic methods, A* with "ignore preconditions" arrives the quickest at an optimal plan of length 9 but expands more nodes than the the "level-sum" heuristic. The level-sum heuristic would have been the best in terms of minimizing work and arriving at the shortest plan length, but it required ~13 minutes to return an answer. So, while the complexity of evaluating the "level-sum" heuristic relative to the "ignore preconditions" heuristic in my code is greater, the "level-sum" heuristic does a better job at guiding the search since it is a more accurate heuristic.

Problem 2 is considerably larger than Problem (number of fluents 27 as opposed 12). Consequently, one expects heuristic and non-heuristic method performance to diverge at least in the amount of work done (number of nodes expanded). Note how the BFS algorithm expands nearly twice as many nodes as A* algorithm with "ignore preconditions" heuristic.

	Expansions	Goal Tests	New Nodes	Plan Length	Time Elapsed
BFS	3343	4609	30509	9	10.01 sec
DFGS	624	625	5602	619	2.5 sec
UCS	4852	4854	44030	9	32.68 sec
$A^*_{h\_1}$	4852	4854	44030	9	32.11 sec
$A^*_{h\_ignore\_preconditions}$	1506	1508	13280	9	10.35 sec
$A^*_{h\_pg\_level\_sum}$	1245	1247	11307	9	789.32 sec

The optimal plan is of length 9 and corresponds to
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)

PROBLEM 3

The table below illustrate the performance of non-heuristic (blue shaded) and heuristic (yellow shaded) search algorithms on Problem 3. As usual, DFGS expands the fewest nodes, but obtains a plan that is unreasonably long (392 actions). BFS is again the best performing non-heuristic method in terms of arriving at an optimal plan of length 12.

Among the heuristic methods, A* with "ignore preconditions" arrives the quickest at an optimal plan of length 12, but expands nearly twice as many nodes as the "level-sum" heuristic. However, the level-sum heuristic required ~50 minutes to return an answer. So as in problem 2, the "level-sum" heuristic does a better job of guiding the search (leads to fewer expanded nodes and an optimal plan) since it is a more accurate heuristic, but is expensive to compute in my implementation.

Problem 3 is the largest of all the problems (32 fluents). Once again, one expects a big divergence in the performance of heuristic and non-heuristic method. Note how the BFS algorithm expands nearly three times as many nodes as A* algorithm with "ignore preconditions" heuristic and also requires a longer amount of time to return an answer.

	Expansions	Goal Tests	New Nodes	Plan Length	Time Elapsed
BFS	14663	18098	129631	12	75.22 sec
DFGS	408	409	3364	392	1.31 sec
UCS	18235	18237	159716	12	278.23 sec
$A^*_{h\_1}$	18235	18237	159716	12	278.5 sec
$A^*_{h\_ignore\_preconditions}$	5118	5120	45650	12	62.85 sec
$A^*_{h\_pg\_level\_sum}$	2934	2936	26122	12	3071.4 sec

The optimal plan is of length 12 and corresponds to
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(C1, P1, JFK)
Unload(C2, P2, SFO)