Heuristic Analysis

Planning Search for Air Cargo Transport System

Optimal Sequence of Actions

Optimal sequence of actions for the three problems are as follows:

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

Performance Summary

Three **uninformed search** algorithms are evaluated and their respective KPIs are as follows.

Problem	Name	Is Optimal	Time Elapsed	Node Expansions	Goal Tests	New Nodes
1	Breadth First Search	True	0.0284	43	56	180
2	Breadth First Search	True	3.8321	1855	2582	14801
3	Breadth First Search	True	37.3692	14120	17673	124926
1	Depth First Graph Search	False	0.0124	21	22	84
2	Depth First Graph Search	False	0.3721	184	185	1143
3	Depth First Graph Search	False	1.081	292	293	2388
1	Uniform Cost Search	True	0.03170	55	57	224
2	Uniform Cost Search	True	5.4067	2724	2726	21377
3	Uniform Cost Search	True	45.4621	18223	18225	159618

Three **automatic heuristics with A* search** algorithms are evaluated and their respective KPIs are as follows.

Problem	Name	Is Optimal	Time Elapsed	Node Expansions	Goal Tests	New Nodes
1	A* with h_1	True	0.0330	55	57	224
2	A* with h_1	True	5.9361	2724	2726	21377
3	A* with h_1	True	49.8126	18223	18225	159618
1	A* with h_ignore_preconditions	True	0.0325	41	43	170
2	A* with h_ignore_preconditions	True	2.2290	876	878	7199
3	A* with h_ignore_preconditions	True	15.6028	5040	5042	44944
1	A* with h_pg_levelsum	True	0.5447	11	13	50
2	A* with h_pg_levelsum	True	57.2826	238	240	1911
3	A* with h_pg_levelsum	True	241.8140	325	327	3002

Performance Analysis for Uninformed Search

According to the above results, among the three uninformed search algorithms, **Breadth First Search** and **Uniform Cost Search** are the only algorithms attain optimality. **Depth First Search** is the fastest one and has the least space complexity although it is not complete. This agrees very well with the justification from **section 3.4.7 of *Artificial Intelligence: A Modern Approach* by Norvig and Russell.**

Criterion	Breadth-First	Uniform-Cost	Depth-First	Depth-Limited	Iterative Deepening	Bidirectional (if applicable)
Complete?	Yes[a]	Yes[a,b]	No	No	Yes[a]	Yes[a,d]
Time	$O(b^d)$	$O(b^{1+\lfloor C^*/\epsilon \rfloor})$	$O(b^m)$	$O(b^\ell)$	$O(b^d)$	$O(b^{d/2})$
Space	$O(b^d)$	$O(b^{1+\lfloor C^*/\epsilon \rfloor})$	$O(bm)$	$O(b\ell)$	$O(bd)$	$O(b^{d/2})$
Optimal?	Yes[c]	Yes	No	No	Yes[c]	Yes[c,d]

Figure 3.21 Evaluation of tree-search strategies. b is the branching factor; d is the depth of the shallowest solution; m is the maximum depth of the search tree; l is the depth limit. Superscript caveats are as follows: [a] complete if b is finite; [b] complete if step costs $\geq \epsilon$ for positive ϵ; [c] optimal if step costs are all identical; [d] if both directions use breadth-first search.

Performance Analysis for Heuristic Search

According to the above results, the two A* search algorithms with non-trivial heuristic, namely **A* with h_ignore_preconditions** and **A* with h_pg_levelsum**, have better performance than uninformed ones. The two algorithms both attain optimality. **A* with h_ignore_preconditions** has both better time and space complexity than BFS and UCS. **A* with h_pg_levelsum** has the least space complexity among all candidates(its extra high time complexity is caused by overhead incurred by dynamic planning graph construction). This agrees very well with the the justification from **section 3.5 of *Artificial Intelligence: A Modern Approach* by Norvig and Russell: I**nformed search strategy — one that uses problem-specific knowledge beyond the definition of the problem itself — can find solutions more efficiently than can an uninformed strategy.

Optimal Search Strategy

From the above performance summary, **the A* search with h_ignore_preconditions heuristic appears to be the best planning algorithm for air cargo planning**. The reasons are as follows.

1. The algorithm is optimal.

2. Among all optimal algorithms, it has the second least node expansions, that is, the second least resource constraints on target system.

3. Among all optimal algorithms, it has the fastest running time and scales well as the problem complexity goes up.

Compared with uninformed algorithms, namely BFS, UCS and A* with trivial heuristic, the best one has far less node expansions due to the knowledge induced by informative heuristic. Since less node expansions means less resource constraints on target system, the best algorithm is on the one hand resource friendly.

On the other hand, although the A* with h_pg_levelsum has the least number of node expansions, it suffers from significant runtime overhead incurred by the dynamic construction of planning graph. It makes the algorithm not scalable as the problem complexity goes up.

To sum up, the A* search with h_ignore_preconditions heuristic is the best planning algorithm for air cargo planning.