Heuristic Analysis

The heuristic analysis for various search algorithms in the planning domain for Air Cargo transport System was investigated in this report. Three planning problems were explored in this analysis.

1. **Problem1**

**Initial and Goal state:**

Init(At(C1, SFO) ∧ At(C2, JFK)

∧ At(P1, SFO) ∧ At(P2, JFK)

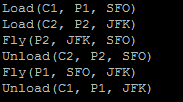
∧ Cargo(C1) ∧ Cargo(C2)

∧ Plane(P1) ∧ Plane(P2)

∧ Airport(JFK) ∧ Airport(SFO))

Goal(At(C1, JFK) ∧ At(C2, SFO))

**Optimal solution:**



|  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- |
| **Search Method** | **Expansions** | **Goal Tests** | **New nodes** | **Plan Length** | **Time elapsed** |
| Breadth first search | 43 | 56 | 180 | 6 | 0.05131842568516731 |
| Breadth first tree search | 1458 | 1459 | 5960 | 6 | 1.2910030148923397 |
| Depth first graph search | 21 | 22 | 84 | 20 | 0.019316416233778 |
| Depth limited search | 101 | 217 | 414 | 50 | 0.11441627144813538 |
| Uniform cost search | 55 | 57 | 224 | 6 | 0.05175059661269188 |
| Recursive best first search H1 | 4229 | 4230 | 17023 | 6 | 3.7619022615253925 |
| Greedy best first graph search H1 | 7 | 9 | 28 | 6 | 0.006927903741598129 |
| A\* search H1 | 55 | 57 | 224 | 6 | 0.0543329231441021 |
| A\* search H ignore preconditions | 41 | 43 | 170 | 6 | 0.058746494352817535 |
| A\* search H PG level sum | 11 | 13 | 50 | 6 | 1.8830320574343204 |
|  |  |  |  |  |  |

**Analysis:**

* In total, there are total 12 clauses in this problem. Therefore, the search space consists of 212 states.
* From various search algorithms, the optimal plan has length of 6. The *“Greedy best first graph search H1”* generated this plan in less time compared with other searches and, therefore it is the clear winner among all of them. Breadth first search, Uniform Cost Search, A\* search H1 and A\* search H ignore preconditions are other searches that gave comparable performances.
* Greedy best first graph search H1 Search also generated the least number of new nodes and performs minimum expansions and goal tests. Therefore, the amount of memory required to perform this problem was also less for this search method compared with other searches.

1. **Problem 2**

**Initial and goal state:**

Init(At(C1, SFO) ∧ At(C2, JFK) ∧ At(C3, ATL)

∧ At(P1, SFO) ∧ At(P2, JFK) ∧ At(P3, ATL)

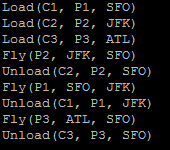
∧ Cargo(C1) ∧ Cargo(C2) ∧ Cargo(C3)

∧ Plane(P1) ∧ Plane(P2) ∧ Plane(P3)

∧ Airport(JFK) ∧ Airport(SFO) ∧ Airport(ATL))

Goal(At(C1, JFK) ∧ At(C2, SFO) ∧ At(C3, SFO))

**Optimal solution:**



|  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- |
| **Search Method** | **Expansions** | **Goal Tests** | **New nodes** | **Plan Length** | **Time elapsed** |
| Breadth first search | 3343 | 4609 | 30509 | 9 | 22.549732822924852 |
| Breadth first tree search | **Aborted** | | | | |
| Depth first graph search | 624 | 625 | 5602 | 619 | 5.075781349092722 |
| Depth limited search | **Aborted** | | | | |
| Uniform cost search | 4853 | 4855 | 44041 | 9 | 55.8272700458765 |
| Recursive best first search H1 | **Aborted** | | | | |
| Greedy best first graph search H1 | 998 | 1000 | 8982 | 17 | 9.590353012084961 |
| A\* search H1 | 4853 | 4855 | 44041 | 9 | 54.92506242915988 |
| A\* search H ignore preconditions | 1506 | 1508 | 13820 | 9 | 18.358902972191572 |
| A\* search H PG level sum | 86 | 88 | 841 | 9 | 195.83575819432735 |

**Solution:**

* There are total 27 clauses in this problem. Thus, the search space consists of 227 states
* From above table, we can find that the optimal plan has length of 9 for many of searches. Overall, A\* with ignore preconditions heuristic search performed better compared with all searches in terms of all parameters and Breadth first search was the best search among non-heuristic search algorithms.
* Recursive best first search H1, Breadth First Tree Search and Depth Limited Search also fail to report a plan in expected time, then, they were aborted.
* However, A\* search H PG level sum heuristic generated less expansions , Goal Tests, New Nodes compared with A\* search H ignore preconditions search but it was computationally expensive search

1. **Problem 3**

**Initial and goal state**

Init(At(C1, SFO) ∧ At(C2, JFK) ∧ At(C3, ATL) ∧ At(C4, ORD)

∧ At(P1, SFO) ∧ At(P2, JFK)

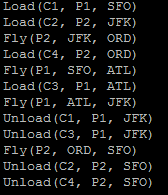
∧ Cargo(C1) ∧ Cargo(C2) ∧ Cargo(C3) ∧ Cargo(C4)

∧ 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 solution:**



|  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- |
| **Search Method** | **Expansions** | **Goal Tests** | **New nodes** | **Plan Length** | **Time elapsed** |
| Breadth first search | 14663 | 18098 | 129631 | 12 | 155.92375200241804 |
| Breadth first tree search | **Aborted** | | | | |
| Depth first graph search | 408 | 409 | 3364 | 392 | 3.241663482040167 |
| Depth limited search | **Aborted** | | | | |
| Uniform cost search | 18236 | 18238 | 159726 | 12 | 444.99206521734595 |
| Recursive best first search H1 | **Aborted** | | | | |
| Greedy best first graph search H1 | 5623 | 5625 | 49495 | 33 | 116.27293657884002 |
| A\* search H1 | 18236 | 18238 | 159726 | 12 | 445.79096511378884 |
| A\* search H ignore preconditions | 5118 | 5120 | 45650 | 12 | 108.85167675465345 |
| A\* search H PG level sum | 404 | 406 | 3718 | 12 | 1356.3477477617562 |
|  |  |  |  |  |  |

**Solution:**

* In this problem, there are total 32 clauses. Therefore, the search space consists of 232 states
* There are a few search produced the optimal plan with length of 12. Similar to problem2, A\* search H ignore preconditions search performed best among all searches and, among non-heuristic searches, BFS Breadth first search performed best with the least amount of time.
* In summary, with size of a problem increases, heuristic search algorithms like A\* is performing better than non-heuristic searches as A\* search is produces optimal plans.
* Another observation is that A\* Search with level sum heuristic takes much more time than ignore preconditions heuristic. However, PG level sum heuristic generates fewer new nodes and performs lesser goal tests. This is because level sum heuristics is computationally more expensive [1].
* Finally, we can conclude that for large size of Air Cargo Transportation System, A\* Search with ignore preconditions heuristic outperforms all other search methods.

References

[1]Russell, Stuart and Norvig, Peter. Artificial Intelligence: A Modern Approach 3nd Edition, P.394.