**Heuristic Analysis**

This project to solve deterministic logistics planning problems for an Air Cargo transport system using a planning search agent (AI: A Modern Approach by Norvig And Russel) given classical PDDL. The goal of this project run both uninformed non heuristic and domain independent heuristic with A\* search and obtain an optimal and fastest solution for this problem.

All problems are in the Air Cargo domain. They have the same action schema.

* Air Cargo Action Schema:

Action(Load(c, p, a), PRECOND: At(c, a) ∧ At(p, a) ∧ Cargo(c) ∧ Plane(p) ∧ Airport(a) EFFECT: ¬ At(c, a) ∧ In(c, p)) Action(Unload(c, p, a), PRECOND: In(c, p) ∧ At(p, a) ∧ Cargo(c) ∧ Plane(p) ∧ Airport(a) EFFECT: At(c, a) ∧ ¬ In(c, p)) Action(Fly(p, from, to), PRECOND: At(p, from) ∧ Plane(p) ∧ Airport(from) ∧ Airport(to) EFFECT: ¬ At(p, from) ∧ At(p, to))

* Problem 1 initial state and goal:

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))

* Problem 2 initial state and goal:

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))

* Problem 3 initial state and goal:

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))

**An optimal sequence of actions:**

|  |  |  |
| --- | --- | --- |
| **Problem1:** | **Problem2:** | **Problem3:** |
| Load(C1, P1, SFO)  Load(C2, P2, JFK) Fly(P1, SFO, JFK)  Fly(P2, JFK, SFO) Unload(C1, P1, JFK) Unload(C2, P2, SFO) | 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(C1, P1, JFK) Unload(C2, P2, SFO)  Unload(C3, P3, SFO) | Load(C1, P1, SFO)  Load(C2, P2, JFK)  Fly(P1, SFO, ATL)  Fly(P2, JFK, ORD)  Load(C3, P1, ATL)  Load(C4, P2, ORD) Fly(P1, ATL, JFK)  Fly(P2, ORD, SFO) Unload(C1, P1, JFK) Unload(C2, P2, SFO)  Unload(C3, P1, JFK)  Unload(C4, P2, SFO) |
|  |  |  |
| **Optimal plan Length:6** | **Optimal plan Length:9** | **Optimal plan Length:12** |

**Uninformed Non-heuristic Search Analysis:**

The Uninformed non-heuristic search agent ran with Breadth first search (BFS), and Depth first search (DFS) and Uniform cost search (UCS) . Here results table.

|  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- |
| Problem | Search Type | Expansions | Goal Tests | New Nodes | Path Length | Execution Time (s) | Optimal |
| P1 | BFS | 43 | 56 | 180 | 6 | 0.029 | YES |
| P1 | DFS | 101 | 271 | 414 | 50 | 0.074 | NO |
| P1 | UCS | 55 | 57 | 224 | 6 | 0.030 | YES |
| P2 | BFS | 3343 | 4609 | 30509 | 9 | 2.369 | YES |
| P2 | DFS | 624 | 625 | 5602 | 619 | 0.033 | NO |
| P2 | UCS | 4843 | 4855 | 44041 | 9 | 0.038 | YES |
| P3 | BFS | 14663 | 18098 | 129631 | 12 | 90.39 | YES |
| P3 | DFS | 408 | 409 | 3364 | 392 | 1.53 | NO |
| P3 | UCS | 18223 | 18225 | 159618 | 12 | 44.59 | YES |

Comparison between search agents for Uninformed Non-heuristic

* Node Expansion: Depth First Search (DFS) taking less memory compare to BFS and UCS, because expanding less nodes. UCS > BFS > DFS
* Execution Time: Depth First Search (DFS) is faster than BFS and UCS. UCS > BFS > DFS
* Optimal: Based on Path length (P1->6, P2->9, P3->12) Breadth First Search (BFS) And Uniform cost search (UCS) is provide optimal action plan. DFS not provide optimal action plan based on path lengths 50,619,392 instead of 6,9,12, because it does not consider better node due to once reach the goal, then not look other nodes even though better nodes available.

Based on factor (memory, Time, Optimal) **Breadth First Search (BFS)** is recommended uninformed non-heuristic search agent,

**Domain independent heuristic with A\* Search Analysis:**

The domain independent heuristic with A\* search agent ran with

* Greedy\_best\_first\_graph\_search with h\_1
* A \* Search h\_1
* A\* Search h\_ignore\_preconditions
* A\* Search h\_pg\_levelsum

Here results table.

|  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- |
| Problem | Search Type | Expansions | Goal Tests | New Nodes | Path Length | Execution Time (s) | Optimal |
| P1 | Greedy\_best\_first\_graph\_search with h\_1 | 7 | 9 | 28 | 6 | 0.004 | YES |
| P1 | A \* Search h\_1 | 55 | 57 | 224 | 6 | 0.033 | YES |
| P1 | A\* Search h\_ignore\_preconditions | 41 | 43 | 170 | 6 | 0.032 | YES |
| P1 | A\* Search h\_pg\_levelsum | 11 | 13 | 50 | 6 | 0.038 | YES |
|  |  |  |  |  |  |  |  |
| P2 | Greedy\_best\_first\_graph\_search with h\_1 | 998 | 1000 | 8982 | 9 | 2.07 | YES |
| P2 | A \* Search h\_1 | 4853 | 4855 | 44041 | 9 | 10.07 | YES |
| P2 | A\* Search h\_ignore\_preconditions | 1450 | 1452 | 13303 | 9 | 3.63 | YES |
| P2 | A\* Search h\_pg\_levelsum | 86 | 88 | 841 | 9 | 29.32 | YES |
|  |  |  |  |  |  |  |  |
| P3 | Greedy\_best\_first\_graph\_search with h\_1 | 5577 | 5579 | 49141 | 21 | 13.80 | NO |
| P3 | A \* Search h\_1 | 18223 | 18225 | 159618 | 12 | 44.70 | YES |
| P3 | A\* Search h\_ignore\_preconditions | 5040 | 5042 | 44994 | 12 | 14.39 | YES |
| P3 | A\* Search h\_pg\_levelsum | 328 | 330 | 3032 | 12 | 145.62 | YES |

Comparison between search agents for domain independent heuristic with A\* search

* Node Expansion: A\* Search h\_pg\_levelsum taking less memory compare to Greedy\_best\_first\_graph\_search with h\_1, A \* Search h\_1 and A\* Search h\_ignore\_preconditions, because expanding less nodes.

**A \* Search h\_1 > A\* Search h\_ignore\_preconditions > Greedy\_best\_first\_graph\_search > A\* Search h\_pg\_levelsum**

* Execution Time: A\* Search h\_pg\_levelsum faster compare to Greedy\_best\_first\_graph\_search with h\_1, A \* Search h\_1 and A\* Search h\_ignore\_preconditions, because expanding less nodes.

**A \* Search h\_1 > A\* Search h\_ignore\_preconditions > Greedy\_best\_first\_graph\_search > A\* Search h\_pg\_levelsum**

* Optimal: Based on Path length (P1->6, P2->9, P3->12) A \* Search h\_1 and A\* Search h\_ignore\_preconditions and A\* Search h\_pg\_levelsum is provide optimal action plan. Greedy\_best\_first\_graph\_search with h\_1 not provide optimal action plan based on path lengths 6,9,21 instead of 6,9,12.

Based on factor (memory, Time, Optimal) **A\* Search h\_pg\_levelsum** is recommended domain independent heuristic with A\* search agent. This heuristic Search Agents perform better as the problem complexity increased.

**Search Agents Comparison Between Individual Problems.**

**Problem1:**

|  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- |
| Problem | Search Type | Expansions | Goal Tests | New Nodes | Path Length | Execution Time (s) | Optimal |
| P1 | BFS | 43 | 56 | 180 | 6 | 0.029 | YES |
| P1 | DFS | 101 | 271 | 414 | 50 | 0.074 | NO |
| P1 | UCS | 55 | 57 | 224 | 6 | 0.030 | YES |
| P1 | Greedy\_best\_first\_graph\_search with h\_1 | 7 | 9 | 28 | 6 | 0.004 | YES |
| P1 | A \* Search h\_1 | 55 | 57 | 224 | 6 | 0.033 | YES |
| P1 | A\* Search h\_ignore\_preconditions | 41 | 43 | 170 | 6 | 0.032 | YES |
| P1 | A\* Search h\_pg\_levelsum | 11 | 13 | 50 | 6 | 0.038 | YES |

Greedy\_best\_first\_graph\_search with h\_1 using less memory, execution time and optimal solution compare to across all search agents in problem use case. Less complexity problems recommended Greedy\_best\_first\_graph\_search with h\_1 for Problem1.

**Problem2:**

|  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- |
| Problem | Search Type | Expansions | Goal Tests | New Nodes | Path Length | Execution Time (s) | Optimal |
| P2 | BFS | 3343 | 4609 | 30509 | 9 | 2.369 | YES |
| P2 | DFS | 624 | 625 | 5602 | 619 | 0.033 | NO |
| P2 | UCS | 4843 | 4855 | 44041 | 9 | 0.038 | YES |
| P2 | Greedy\_best\_first\_graph\_search with h\_1 | 998 | 1000 | 8982 | 9 | 2.07 | YES |
| P2 | A \* Search h\_1 | 4853 | 4855 | 44041 | 9 | 10.07 | YES |
| P2 | A\* Search h\_ignore\_preconditions | 1450 | 1452 | 13303 | 9 | 3.63 | YES |
| P2 | A\* Search h\_pg\_levelsum | 86 | 88 | 841 | 9 | 29.32 | YES |

A\* Search h\_ignore\_preconditions using execution time and optimal solution compare to across all search agents in problem use case. Medium complexity problems recommended A\* Search h\_ignore\_preconditions for Problem2, (Note:if memory is constrain A\* Search h\_pg\_levelsum using less memory)

**Problem3:**

|  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- |
| Problem | Search Type | Expansions | Goal Tests | New Nodes | Path Length | Execution Time (s) | Optimal |
| P3 | BFS | 14663 | 18098 | 129631 | 12 | 90.39 | YES |
| P3 | DFS | 408 | 409 | 3364 | 392 | 1.53 | NO |
| P3 | UCS | 18223 | 18225 | 159618 | 12 | 44.59 | YES |
| P3 | Greedy\_best\_first\_graph\_search with h\_1 | 5577 | 5579 | 49141 | 21 | 13.80 | NO |
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| P3 | A\* Search h\_pg\_levelsum | 328 | 330 | 3032 | 12 | 145.62 | YES |

A\* Search h\_pg\_levelsum using less memory, execution time and optimal solution compare to across all search agents in problem use case. More complexity problems recommended A\* Search h\_pg\_levelsum for Problem3.

**Conclusion**:

Based on results domain independent heuristic with A\* search agent good for complexity problems, and less complexity problems good for uninformed search agent. **A\* Search h\_pg\_levelsum** using less memory, execution time and optimal solution compare to across all search agents.

Reference:

Stuart J. Russel, Peter Norvig, Artificial Intelligence A Modern Approach (3rd Edition)