Implement a Planning Search

Heuristic Analysis

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**Overview**

The objective of this project is compare different non-heuristic and heuristic search in order to find the optimal plan for an airport cargo system. We are given three problems with different initial states and goals.

The air cargo action schema is described as follows:

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:

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:

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:

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))

**Results**

The Following section contains the results of each of the problems

**Problem 1:**

|  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- |
| **Non Heuristic Search** | | | | | | |
| **Search Method** | **Expansions** | **Goal Tests** | **New Nodes** | **Plan Length** | **Time (s)** | **Optimal** |
| Breadth First Search | 43 | 56 | 180 | 6 | 0.058 | Yes |
| Breadth First Tree Search | 1458 | 1459 | 5960 | 6 | 1.897 | Yes |
| Depth First Graph Search | 21 | 22 | 84 | 20 | 0.026 | No |
| Depth Limited Search | 101 | 271 | 414 | 50 | 0.169 | No |
| Uniform Cost Search | 55 | 57 | 224 | 6 | 0.07 | Yes |
| Recursive Best First Search | 4229 | 4230 | 17023 | 6 | 5.338 | Yes |
| Greedy Best First Search | 7 | 9 | 28 | 6 | 0.0107 | Yes |

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| --- | --- | --- | --- | --- | --- | --- |
| **Heuristic Search** | | | | | | |
| **Search Method** | **Expansions** | **Goal Tests** | **New Nodes** | **Plan Length** | **Time (s)** | **Optimal** |
| A\* search with h1 | 55 | 57 | 224 | 6 | 0.07 | Yes |
| A\* search with h ignore preconditions | 41 | 43 | 170 | 6 | 0.069 | Yes |
| A\* search with h pg levelsum | 11 | 13 | 50 | 6 | 1.55 | Yes |

Five of the non-heuristic searches found the optimal plan, however, Breadth First Search was able to find it in the least amount of time. The optimal suggested by BFS is the following:

Load(C1, P1, SFO)

Load(C2, P2, JFK)

Fly(P2, JFK, SFO)

Unload(C2, P2, SFO)

Fly(P1, SFO, JFK)

Unload(C1, P1, JFK)

All the heuristic searches arrived at the optimal plan, however A\* search with h1 and A\* search with h\_ignore\_preconditions arrived fastest at the solution

**Problem 2:**

|  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- |
| **Non Heuristic Search** | | | | | | |
| **Search Method** | **Expansions** | **Goal Tests** | **New Nodes** | **Plan Length** | **Time (s)** | **Optimal** |
| Breadth First Search | 3343 | 4609 | 30509 | 9 | 10.802 | Yes |
| Breadth First Tree Search | Time Out | | | | | |
| Depth First Graph Search | 624 | 625 | 5602 | 619 | 4.844 | No |
| Depth Limited Search | Time Out | | | | | |
| Uniform Cost Search | 4852 | 4854 | 44030 | 9 | 15.234 | Yes |
| Recursive Best First Search | Time Out | | | | | |
| Greedy Best First Search | 990 | 992 | 8910 | 21 | 3.15 | No |

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| --- | --- | --- | --- | --- | --- | --- |
| **Heuristic Search** | | | | | | |
| **Search Method** | **Expansions** | **Goal Tests** | **New Nodes** | **Plan Length** | **Time (s)** | **Optimal** |
| A\* search with h1 | 4852 | 4854 | 44030 | 9 | 15.487 | Yes |
| A\* search with h ignore preconditions | 1450 | 1452 | 13303 | 9 | 5.48 | Yes |
| A\* search with h pg levelsum | 86 | 88 | 841 | 9 | 218.779 | Yes |

Two of the non-heuristic searches arrived at the optimal plan with Breadth First search being the fastest. The optimal path is as follows:

Load(C1, P1, SFO)

Load(C2, P2, JFK)

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)

All the heuristic searches found the optimal path, however, A\* search with h ignore preconditions was the fastest

**Problem 3:**

|  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- |
| **Non Heuristic Search** | | | | | | |
| **Search Method** | **Expansions** | **Goal Tests** | **New Nodes** | **Plan Length** | **Time (s)** | **Optimal** |
| Breadth First Search | 14663 | 18098 | 129631 | 12 | 94.836 | yes |
| Breadth First Tree Search | Time Out | | | | | |
| Depth First Graph Search | 408 | 409 | 3364 | 392 | 2.257 | No |
| Depth Limited Search | Time Out | | | | | |
| Uniform Cost Search | 18234 | 18236 | 159707 | 12 | 83.396 | yes |
| Recursive Best First Search | Time Out | | | | | |
| Greedy Best First Search | 5605 | 5607 | 49360 | 22 | 24.303 | No |

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| --- | --- | --- | --- | --- | --- | --- |
| **Heuristic Search** | | | | | | |
| **Search Method** | **Expansions** | **Goal Tests** | **New Nodes** | **Plan Length** | **Time (s)** | **Optimal** |
| A\* search with h1 | 18234 | 18236 | 159707 | 12 | 82.299 | yes |
| A\* search with h ignore preconditions | 5040 | 5042 | 44944 | 12 | 29.052 | yes |
| A\* search with h pg levelsum | 325 | 327 | 3002 | 12 | 1384.28 | yes |

Two of the non-heuristic searches found the optimal plan but uniform cost search was faster in this case. The optimal plan for this problem is as follows:

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)

Among the heuristic searches, all of them found the optimal plan and similar to the previous problems, A\* search with h ignore preconditions

**Analysis**

**Non-Heuristic Searches**

Among the non-heuristic searches, Breadth first Search, Depth First Graph Search and Uniform Cost Search were all successful in finding a plan. However, only Breadth First Search and Uniform Cost Search were able to find an optimal solution.

BFS was able to find a solution in the least amount of time in the case of Problem 1 and Problem2. In Problem 3, however, Uniform Cost Search was slightly faster

**Heuristic Searches**

In all the three problems, all the heuristic searches were able to find the optimal plan. A\* search with h ignore preconditions, however did it in the least amount of time. Hence we can conclude that A\* search with h ignore preconditions was the best heuristic used