**Project 3 - Implement a Planning Search**

**I. Optimal plan for Air Cargo Problems 1, 2, and 3.**

**a. Air Cargo 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))

Optimal plan length for problem 1 is = **6**

Here are the 6 actions:

|  |
| --- |
| 1. Load(C1, P1, SFO) |
| 1. Load(C2, P2, JFK) 2. Fly(P1, SFO, JFK) |
| 1. Fly(P2, JFK, SFO) 2. Unload(C1, P1, JFK) |
| 1. Unload(C2, P2, SFO) |
|  |
| **b. Air Cargo 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)) |

Optimal plan length for problem 2 is = **9**

Here are the 9 actions:

|  |
| --- |
| 1. Load(C1, P1, SFO) |
| 1. Load(C2, P2, JFK) |
| 1. Load(C3, P3, ATL) 2. Fly(P1, SFO, JFK) |
| 1. Fly(P2, JFK, SFO) 2. Fly(P3, ATL, SFO) |
| 1. Unload(C2, P2, SFO) |
| 1. Unload(C1, P1, JFK) |
| 1. Unload(C3, P3, SFO) |

**c. Air Cargo 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))

Optimal plan length for problem 3 is= **12**

Here are the 12 actions:

|  |
| --- |
| 1. Load(C1, P1, SFO) |
| 1. Load(C2, P2, JFK) 2. Load(C3, P1, ATL) 3. Load(C4, P2, ORD) |
| 1. Fly(P1, SFO, ATL) |
| 1. Fly(P2, JFK, ORD) |
| 1. Fly(P2, ORD, SFO) |
| 1. Fly(P1, ATL, JFK) |
| 1. Unload(C4, P2, SFO) |
| 1. Unload(C3, P1, JFK) |
| 1. Unload(C2, P2, SFO) |
| 1. Unload(C1, P1, JFK) |

**II Uninformed Non-heuristic search result metrics**

|  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- |
| **Air Cargo Problem 1** | | | | | | |
| Search algo | Node Expansions | Goal Tests | New nodes | Time elapsed(seconds) | Plan length | Optimal Plan Len? Y/N |
|  |  |  |  |  |  |  |
| Breadth First Search | 43 | 56 | 180 | 0.033 | 6 | Y |
| Depth First Graph Search | 21 | 22 | 84 | 0.015 | 20 | N |
| **greedy\_best\_first\_graph\_search h\_1** | **7** | **9** | **28** | **0.006** | **6** | **Y** |
| uniform\_cost\_search | 55 | 57 | 224 | 0.036 | 6 | Y |

|  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- |
| **Air Cargo Problem 2** | | | | | | |
| Search algo | Node Expansions | Goal Tests | New nodes | Time elapsed(seconds) | Plan length | Optimal Plan Len? Y/N |
|  |  |  |  |  |  |  |
| **Breadth First Search** | 3343 | 4609 | 30509 | 14.18 | **9** | Y |
| **Depth First Graph Search** | **624** | 625 | 5602 | **3.18** | 619 | N |
| greedy\_best\_first\_graph\_search h\_1 | 998 | 1000 | 8982 | 6.59 | 13 | N |
| uniform\_cost\_search | 4853 | 4855 | 44041 | 49.024 | 9 | Y |

|  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- |
| **Air Cargo Problem 3** | | | | | | |
| Search algo | Node Expansions | Goal Tests | New nodes | Time elapsed(seconds) | Plan length | Optimal Plan Len? Y/N |
|  |  |  |  |  |  |  |
| **Breadth First Search** | **14663** | **18098** | **129631** | **100.793** | **12** | **Y** |
| **Depth First Graph Search** | **408** | 409 | 3364 | **1.63** | 392 | N |
| greedy\_best\_first\_graph\_search h\_1 | **5578** | 5580 | 49150 | 116.48 | 22 | N |
| uniform\_cost\_search | 18223 | 18225 | 159618 | 417.16 | 12 | Y |

Breadth First search always results in an optimal plan length for all three problems. However it is not computationally efficient because it expands more nodes and takes a lot longer to complete. Depth First search in all three problems expands fewer nodes, uses less memory and is significantly faster as seen in problem #3. Greedy best first graph search is a good option as well. While it is not as fast as Depth FirstGraph Search it still has fewer node expansions than Breadth First Search.

**III Informed heuristic search result metrics**

|  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- |
| **Air Cargo Problem 1** | | | | | | |
| Search algo | Node Expansions | Goal Tests | New nodes | Time elapsed(seconds) | Plan length | Optimal Plan Len? Y/N |
|  |  |  |  |  |  |  |
| Breadth First Search | 43 | 56 | 180 | 0.033 | 6 | Y |
| Depth First Graph Search | 21 | 22 | 84 | 0.015 | 20 | N |
| **greedy\_best\_first\_graph\_search h\_1** | **7** | **9** | **28** | **0.006** | **6** | **Y** |
| uniform\_cost\_search | 55 | 57 | 224 | 0.036 | 6 | Y |
| astar\_search h\_1 | 55 | 57 | 224 | 0.039 | 6 | Y |
| **astar\_search h\_ignore\_preconditions** | **41** | **43** | **170** | **0.034** | **6** | **Y** |
| astar\_search h\_pg\_levelsum | 11 | 13 | 50 | 1.44 | 6 | Y |
|  |  |  |  |  |  |  |
|  |  |  |  |  |  |  |
| **Air Cargo Problem 2** | | | | | | |
| Search algo | Node Expansions | Goal Tests | New nodes | Time elapsed(seconds) | Plan length | Optimal Plan Len? Y/N |
|  |  |  |  |  |  |  |
| Breadth First Search | 3343 | 4609 | 30509 | 14.18 | 9 | Y |
| Depth First Graph Search | 624 | 625 | 5602 | 3.18 | 619 | N |
| greedy\_best\_first\_graph\_search h\_1 | 998 | 1000 | 8982 | 6.59 | 13 | N |
| uniform\_cost\_search | 4853 | 4855 | 44041 | 49.024 | 9 | Y |
| astar\_search h\_1 | 4853 | 4855 | 44041 | 45.946 | 9 | Y |
| **astar\_search h\_ignore\_preconditions** | **1506** | **1508** | **13820** | **13.3897** | **9** | **Y** |
| astar\_search h\_pg\_levelsum | 86 | 88 | 839 | 155.179 | 9 | Y |
|  |  |  |  |  |  |  |
|  |  |  |  |  |  |  |
| **Air Cargo Problem 3** | | | | | | |
| Search algo | Node Expansions | Goal Tests | New nodes | Time elapsed(seconds) | Plan length | Optimal Plan Len? Y/N |
|  |  |  |  |  |  |  |
| Breadth First Search | 14663 | 18098 | 129631 | 100.793 | 12 | Y |
| Depth First Graph Search | 408 | 409 | 3364 | 1.71 | 392 | N |
| greedy\_best\_first\_graph\_search h\_1 | 5578 | 5580 | 49150 | 116.48 | 22 | N |
| uniform\_cost\_search | 18223 | 18225 | 159618 | 417.16 | 12 | Y |
| astar\_search h\_1 | 18223 | 18225 | 159618 | 385.649 | 12 | Y |
| **astar\_search h\_ignore\_preconditions** | **5118** | **5120** | **45650** | **87.03** | **12** | **Y** |
| astar\_search h\_pg\_levelsum | 404 | 406 | 3718 | 1068.75 | 12 | Y |

All three A\* searches reach the optimal plan length 6, 9, and 12 for problems 1, 2 and 3 respectively.

A\* search that ignores preconditions does best for all three air cargo problems. It is the fastest but it also expands more nodes.

A\* search with level sum heuristic uses the least memory expanding fewer nodes, but performs poorly compared to search that ignores preconditions.

**A\* search that ignores preconditons** performs better than Breadth First Search in that it reaches optimal plan length faster and expands fewer nodes.