Heuristic Analysis

Uninformed (Non Heuristic) Searches

Problem 1:

For problem Air Cargo 1 the following are the metrics for three uninformed searches namely **Breadth First Search**, **Depth First Graph Search**, **Uniform Cost Search**.

```
Solving Air Cargo Problem 1 using breadth_first_search...

Expansions   Goal Tests   New Nodes
    43           56          180

Plan length: 6  Time elapsed in seconds: 0.04327233500225702
Load(C2, P2, JFK)
Load(C1, P1, SFO)
Fly(P2, JFK, SFO)
Unload(C2, P2, SFO)
Fly(P1, SFO, JFK)
Unload(C1, P1, JFK)


Solving Air Cargo Problem 1 using depth_first_graph_search...

Expansions   Goal Tests   New Nodes
    12           13           48

Plan length: 12  Time elapsed in seconds: 0.015903925006568898
Fly(P1, SFO, JFK)
Fly(P2, JFK, SFO)
Load(C1, P2, SFO)
Fly(P2, SFO, JFK)
Fly(P1, JFK, SFO)
Unload(C1, P2, JFK)
Fly(P2, JFK, SFO)
Fly(P1, SFO, JFK)
Load(C2, P1, JFK)
Fly(P2, SFO, JFK)
Fly(P1, JFK, SFO)
Unload(C2, P1, SFO)
```

```
Solving Air Cargo Problem 1 using uniform_cost_search...

Expansions   Goal Tests   New Nodes
    55          57          224

Plan length: 6  Time elapsed in seconds: 0.054749476999859326
Load(C1, P1, SFO)
Load(C2, P2, JFK)
Fly(P1, SFO, JFK)
Fly(P2, JFK, SFO)
Unload(C1, P1, JFK)
Unload(C2, P2, SFO)
```

These metrics are compared and out of these the best performing one is **Breadth First Search** (~0.04s) for this problem as it gives a plan of **Plan Length 6** (which is the least in this case) within a lesser amount of time.

Problem 2:

For problem Air Cargo 2 the following are the metrics for three uninformed searches namely **Breadth First Search**, **Depth First Graph Search**, **Uniform Cost Search**.

```
Solving Air Cargo Problem 2 using breadth_first_search...

Expansions   Goal Tests   New Nodes
   3343         4609        30509

Plan length: 9  Time elapsed in seconds: 17.59424814600061
Load(C2, P2, JFK)
Load(C1, P1, SFO)
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)


Solving Air Cargo Problem 2 using depth_first_graph_search...

Expansions   Goal Tests   New Nodes
   582          583          5211

Plan length: 575  Time elapsed in seconds: 4.651938140996208
Fly(P3, ATL, SFO)
Fly(P1, SFO, ATL)
Fly(P3, SFO, JFK)
Fly(P1, ATL, JFK)
Fly(P2, JFK, ATL)
Fly(P3, JFK, ATL)
Fly(P2, ATL, SFO)
Fly(P3, ATL, SFO)
Load(C1, P3, SFO)
Fly(P3, SFO, ATL)
Fly(P2, SFO, ATL)
Fly(P3, ATL, JFK)
```

```
Solving Air Cargo Problem 2 using uniform_cost_search...

Expansions   Goal Tests   New Nodes
   4853         4855        44041

Plan length: 9  Time elapsed in seconds: 17.24846267099288
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)
```

These metrics are compared and out of these the best performing one is <u>**Uniform Cost Search**</u> (~17.24s) for this problem as it gives a plan of **Plan Length 12** (which is the least in this case) within a lesser amount of time.

Problem 3:

```
Solving Air Cargo Problem 3 using breadth_first_search...

Expansions   Goal Tests   New Nodes
  14663        18098       129631

Plan length: 12  Time elapsed in seconds: 155.258390666997
Load(C2, P2, JFK)
Load(C1, P1, SFO)
Fly(P2, JFK, ORD)
Load(C4, P2, ORD)
Fly(P1, SFO, ATL)
Load(C3, P1, ATL)
Fly(P1, ATL, JFK)
Unload(C1, P1, JFK)
Unload(C3, P1, JFK)
Fly(P2, ORD, SFO)
Unload(C2, P2, SFO)
Unload(C4, P2, SFO)


Solving Air Cargo Problem 3 using depth_first_graph_search...

Expansions   Goal Tests   New Nodes
   627          628         5176

Plan length: 596  Time elapsed in seconds: 4.475295659998665
Fly(P1, SFO, ORD)
Fly(P2, JFK, ORD)
Fly(P1, ORD, ATL)
Fly(P2, ORD, ATL)
Fly(P1, ATL, JFK)
Fly(P2, ATL, SFO)
Load(C1, P2, SFO)
Fly(P2, SFO, ORD)
Fly(P1, JFK, ORD)
Fly(P2, ORD, ATL)
Fly(P1, ORD, ATL)
Fly(P2, ATL, JFK)
Fly(P1, ATL, SFO)
Unload(C1, P2, JFK)
Fly(P1, SFO, ORD)
```

For problem Air Cargo 3 the following are the metrics for three uninformed searches namely **Breadth First Search**, **Depth First Graph Search**, **Uniform Cost** Search.

```
Solving Air Cargo Problem 3 using uniform_cost_search...

Expansions   Goal Tests   New Nodes
  17426        17428       152869

Plan length: 12  Time elapsed in seconds: 73.4023101290004
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(C1, P1, JFK)
Unload(C2, P2, SFO)
Unload(C3, P1, JFK)
Unload(C4, P2, SFO)
```

These metrics are compared and out of these the best performing one is **Uniform Cost Search** (~73.40s) for this problem as it gives a plan of **Plan Length 12** (which is the least in this case) within a lesser amount of time.

Informed (Heuristic) Searches

Problem 1:

```
Solving Air Cargo Problem 1 using astar_search with h_ignore_preconditions...

Expansions   Goal Tests   New Nodes
    41          43          170

Plan length: 6  Time elapsed in seconds: 0.04887804199825041
Load(C1, P1, SFO)
Fly(P1, SFO, JFK)
Unload(C1, P1, JFK)
Load(C2, P2, JFK)
Fly(P2, JFK, SFO)
Unload(C2, P2, SFO)


Solving Air Cargo Problem 1 using astar_search with h_pg_levelsum...

Expansions   Goal Tests   New Nodes
    11          13          50

Plan length: 6  Time elapsed in seconds: 0.7086610390033456
Load(C1, P1, SFO)
Fly(P1, SFO, JFK)
Load(C2, P2, JFK)
Fly(P2, JFK, SFO)
Unload(C1, P1, JFK)
Unload(C2, P2, SFO)
```

For Air Cargo 1 problem the following are the A* Search metrics for **Ignore Precondition Heuristic** and **Level Sum Heuristic**.

These metrics are compared and out of these, clearly the best performing one is **Ignore Precondition Heuristic** since it took ~0.05 seconds which is far less than the **Level Sum Heuristic** (~0.7s) to find a plan of **Plan Length 6** for this problem.

Problem 2:

```
Solving Air Cargo Problem 2 using astar_search with h_ignore_preconditions...

Expansions   Goal Tests   New Nodes
   1450         1452       13303

Plan length: 9  Time elapsed in seconds: 5.66287944400392
Load(C1, P1, SFO)
Fly(P1, SFO, JFK)
Unload(C1, P1, JFK)
Load(C2, P2, JFK)
Fly(P2, JFK, SFO)
Unload(C2, P2, SFO)
Load(C3, P3, ATL)
Fly(P3, ATL, SFO)
Unload(C3, P3, SFO)
```

For Air Cargo 2 problem the following are the A* Search metrics for **Ignore Precondition Heuristic** and **Level Sum Heuristic**.

```
Solving Air Cargo Problem 2 using astar_search with h_pg_levelsum...

Expansions   Goal Tests   New Nodes
    86          88           841

Plan length: 9  Time elapsed in seconds: 57.53924099099822
Load(C1, P1, SFO)
Fly(P1, SFO, JFK)
Load(C2, P2, JFK)
Fly(P2, JFK, SFO)
Load(C3, P3, ATL)
Fly(P3, ATL, SFO)
Unload(C1, P1, JFK)
Unload(C2, P2, SFO)
Unload(C3, P3, SFO)
```

These metrics are compared and out of these, clearly the best performing one is **<u>Ignore Precondition Heuristic</u>** since it took ~5 seconds which is far less than the **Level Sum Heuristic** (~57s) to find a plan of **Plan Length 9** for this problem.

Problem 3:

```
Solving Air Cargo Problem 3 using astar_search with h_pg_levelsum...

Expansions   Goal Tests   New Nodes
   314          316          2894

Plan length: 12  Time elapsed in seconds: 283.85366487000283
Load(C2, P2, JFK)
Fly(P2, JFK, ORD)
Load(C4, P2, ORD)
Fly(P2, ORD, SFO)
Load(C1, P1, SFO)
Fly(P1, SFO, ATL)
Load(C3, P1, ATL)
Fly(P1, ATL, JFK)
Unload(C1, P1, JFK)
Unload(C2, P2, SFO)
Unload(C3, P1, JFK)
Unload(C4, P2, SFO)
```

For Air Cargo 3 problem the following are the A* Search metrics for **Ignore Precondition Heuristic** and **Level Sum Heuristic**.

```
Solving Air Cargo Problem 3 using astar_search with h_ignore_preconditions...

Expansions   Goal Tests   New Nodes
   5022         5024        44764

Plan length: 12  Time elapsed in seconds: 23.75540649699542
Load(C1, P1, SFO)
Fly(P1, SFO, ATL)
Load(C3, P1, ATL)
Fly(P1, ATL, JFK)
Unload(C1, P1, JFK)
Load(C2, P2, JFK)
Fly(P2, JFK, ORD)
Load(C4, P2, ORD)
Fly(P2, ORD, SFO)
Unload(C2, P2, SFO)
Unload(C3, P1, JFK)
Unload(C4, P2, SFO)
```

These metrics are compared and out of these, clearly the best performing one is **Ignore Precondition Heuristic** since it took ~23 seconds which is far less than the **Level Sum Heuristic** (~284s) to find a plan of **Plan Length 12** for this problem.

Analysis

From the above results it can be concluded that when the states of a problem are greater in number then a tradeoff between **Time** and **Plan Length** becomes necessary as seen in the case of **Problem 1** where a **BFS** performs just marginally **faster** than **Ignore Precondition Heuristic A* Search** with similar **Plan Length** but fails to scale when nodes are increased in the problem.

Thus it can be concluded even by looking at the tables below that **Ignore Precondition Heuristic A* Search** performs better than other uninformed or **Level Sum Heuristic A* Search** by providing a minimum of **Plan Length** in a lesser amount of time. A **DFS** was faster in all the cases but its **Plan Length** was **significantly** higher than that provided by other searches.

A more detailed performance comparison is provided in the tables below :-

Air Cargo Problem 1 :

Searches	Node Expansions	Goal Tests	New Nodes	Time Taken	Plan Length
->Breadth First Search	43	56	180	0.043	6
Depth First Search	12	13	48	0.01	12
Uniform Cost Search	55	57	224	0.05	6
A* Ignore Precondition Search	41	43	170	0.048	6
A* Level Sum Search	11	13	50	0.7	6

Air Cargo Problem 2 :

Searches	Node Expansions	Goal Tests	New Nodes	Time Taken	Plan Length
Breadth First Search	3343	4609	30509	17.59	9
Depth First Search	582	583	5211	4.65	575
Uniform Cost Search	4853	4855	44041	17.24	9
->A* Ignore Precondition Search	1450	1452	13303	5.66	9
A* Level Sum Search	86	88	841	57.53	9

Air Cargo Problem 3 :

Searches	Node Expansions	Goal Tests	New Nodes	Time Taken	Plan Length
Breadth First Search	14663	18098	129631	155.25	12
Depth First Search	627	628	5176	4.47	596
Uniform Cost Search	17426	17428	152869	73.40	12
->A* Ignore Precondition Search	5022	5024	44764	23.75	12
A* Level Sum Search	314	316	2894	283.85	12

Optimal sequence of actions that reaches the goal in least number of node expansions, goal tests and new nodes for each problem :

Problem 1:

Found using BFS - Plan Length = 6

Load(C2, P2, JFK)

Load(C1, P1, SFO)

Fly(P2, JFK, SFO)

Unload(C2, P2, SFO)

Fly(P1, SFO, JFK)

Unload(C1, P1, JFK)

Problem 2:

Found using A* Ignore Precondition Search - Plan Length = 9

Load(C1, P1, SFO)

Fly(P1, SFO, JFK)

Unload(C1, P1, JFK)

Load(C2, P2, JFK)

Fly(P2, JFK, SFO)

Unload(C2, P2, SFO)

Load(C3, P3, ATL)

Fly(P3, ATL, SFO)

Unload(C3, P3, SFO)

Problem 3:

Found using A* Ignore Precondition Search - Plan Length = 12

Load(C1, P1, SFO)

Fly(P1, SFO, ATL)

Load(C3, P1, ATL)

Fly(P1, ATL, JFK)

Unload(C1, P1, JFK)

Load(C2, P2, JFK)

Fly(P2, JFK, ORD)

Load(C4, P2, ORD)

Fly(P2, ORD, SFO)

Unload(C2, P2, SFO)

Unload(C3, P1, JFK)

Unload(C4, P2, SFO)

The explanation of the above results can be given as provided in AIMA book as clearly mentioned that there are two ways to make a search problem easier by relaxing the problem. One of them is by adding more edges to the search problem's graph, making it strictly easier to find a path from the initial state to the goal state. Thus by doing this it becomes easier to search.

Here we use **Ignore Precondition Heuristic** that drops all preconditions from actions, thereby increasing the number of edges. By doing this every action becomes applicable in every state, and any single goal fluent can be achieved in one step. This implies no. of steps required to solve the problem is the no. of unsatisfied goals (excluding cases when some action may achieve multiple goals and some might undo the action of others).