Written Analysis

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Looking at Report on metrics for planning solution searches, it appears that Breadth First Search and Uniform Cost Search are the only two uninformed search strategies that produce optimal paths for all 3 problems.

The problem statement for problem 1 is

```
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))
```

The optimal path for this problem is

```
Load(C2, P2, JFK)
Load(C1, P1, SFO)
Fly(P2, JFK, SFO)
Unload(C2, P2, SFO)
Fly(P1, SFO, JFK)
Unload(C1, P1, JFK)
```

The problem statement for problem 2 is

```
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))
```

The optimal path for this problem is

```
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)
```

WRITTEN ANALYSIS ON PLANNING SEARCHES

Finally the problem statement for problem 3 is

```
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))
```

The optimal path for this problem is

```
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)
```

First, we will compare and contrast non-heuristic search result metrics for following methods

Breadth First Search, Depth First Search and Uniform Cost Search

Air Cargo Problem 1

Search Method	# of node expansions required	# of goal tests	# of new nodes	Time elapsed in seconds	Total Plan Length
Breadth First Search	43	56	180	0.0268	6
Depth First Graph Search	12	13	48	0.007	12
Uniform Cost Search	55	57	224	0.0344	6

WRITTEN ANALYSIS ON PLANNING SEARCHES

Air Cargo Problem 2

Search Method	# of node expansions required	# of goal tests	# of new nodes	Time elapsed in seconds	Total Plan Length
Breadth First Search	3343	4609	30509	13.56	9
Depth First Graph Search	582	583	5211	2.798	575
Uniform Cost Search	4853	4855	44041	37.36	9

Air Cargo Problem 3

Search Method	# of node expansions required	# of goal tests	# of new nodes	Time elapsed in seconds	Total Plan Length
Breadth First Search	14663	18098	129631	87.64	12
Depth First Graph Search	627	628	5176	2.837	596
Uniform Cost Search	17783	17785	155920	375.56	12

Looking at the above results, it appears that Depth First Graph Search appears to be the fastest. But, if the criteria is to produce optimal path, either Breadth First Search or Uniform Cost Search need to be chosen. Depth First Graph Search, as it expands along the depth first, does not guarantee optimal plan length. If memory needed is a consideration, Depth First Search seems to be the best choice.

WRITTEN ANALYSIS ON PLANNING SEARCHES

Now, we will compare and contrast heuristic search result metrics using Astar Search with h_ignore preconditions, Astar Search with Level Sum heuristics and Astar Search with h1 heuristic.

Air Cargo Problem 1

Search Method	# of node expansions required	# of goal tests	# of new nodes	Time elapsed in seconds	Total Plan Length
Astar Search with h1 heuristic	55	57	224	0.041	6
Astar Search with h_ignore preconditions	41	43	170	0.0407	6
Astar Search with Level Sum heuristics	55	57	224	2.454	6

Air Cargo Problem 2

Search Method	# of node expansions required	# of goal tests	# of new nodes	Time elapsed in seconds	Total Plan Length
Astar Search with h1 heuristic	4853	4855	44041	39.79	9
Astar Search with h_ignore preconditions	1506	1508	13820	12.40	9
Astar Search with Level Sum heuristics	86	88	841	663.10	9

Air Cargo Problem 3

Search Method	# of node expansions required	# of goal tests	# of new nodes	Time elapsed in seconds	Total Plan Length
Astar Search with h1 heuristic	17783	17785	155920	405.92	12

Astar Search with h_ignore precondition	5081	5083	45292	77.21	12
Astar Search with Level Sum heuristics	414	416	3818	4993.29	12

As you can see from the above results, all the Astar Searches result in an optimal plan for each of the problems. But, Astar Search with Ignore Preconditions seem to be fastest. This happens because by ignore preconditions, the planning problem is simplified and Astar Search can solve it quicker. If memory is a consideration, Astar Search with Level Sum heuristics seems to get to the goal with fewest nodes expanded.

Among the best of informed search methods mentioned above and the non-informed methods looked at earlier, If speed is a consideration, the battle is between Depth First Graph Search and Astar Search with Ignore Preconditions heuristics. Let us look at these two methods

Air Cargo Problem 1

Search Method	# of node expansions required	# of goal tests	# of new nodes	Time elapsed in seconds	Total Plan Length
Depth First Graph Search	12	13	48	0.007	12
Astar Search with h_ignore preconditions	41	43	170	0.0407	6

Air Cargo Problem 2

Search Method	# of node expansions required	# of goal tests	# of new nodes	Time elapsed in seconds	Total Plan Length
Depth First Graph Search	582	583	5211	2.798	575
Astar Search with h_ignore preconditions	1506	1508	13820	12.40	9

Air Cargo Problem 3

Search Method	# of node expansions required	# of goal tests	# of new nodes	Time elapsed in seconds	Total Plan Length
Depth First Graph Search	627	628	5176	2.837	596
Astar Search with h_ignore preconditions	5081	5083	45292	77.21	12

Clearly, Depth First Graph Search is the winner. Depth First Graph Search also works better from a memory standpoint. However, as you can see, Depth First Graph Search doesn't return Optimal plan. Thus, the answer to the question, which one is better is it depends on the criteria. One of the other benefits of the informed searches is we could customize the plan using another heuristic of our choice and can obtain a better outcome. It is for this reason that informed heuristics are more widely used.