Planning Search Heuristic Analysis

Introduction

This project involved defining a group of problems in classical PDDL (Planning Domain Definition Language) for the Air Cargo domain. The goal is to develop a planning search agent that solves a deterministic logic problem for an Air Cargo transport system. The agent uses both uninformed non-heuristic searches (breadth-first, depth-first) and domain-independent heuristic based search strategies (A* search).

The following metrics will be used to compare each strategy:

- Optimal path length
- Search time
- Memory usage

Action Schema

All problems are in the Air Cargo domain. They have the same action schema defined, but different initial states and goals.

```
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))
```

Optimal plan:

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

Metric comparison by strategy:

Strategy	**Type**	**Optimal**	**Expansions**	**Goal Tests**	**New Nodes**	**Plan Length**	**Search Time(s)**
Breadth First Search	Uninformed	Yes	43	56	180	6	0.028
Breadth First Tree Search	Uninformed	Yes	1458	1459	5960	6	0.901
Depth First Graph Search	Uninformed	No	21	22	84	20	0.018
Depth Limited Search	Uninformed	No	101	271	414	50	0.086
Uniform Cost Search	Uninformed	Yes	55	57	224	6	0.034
Recursive Best First Search	Uninformed	Yes	4229	4230	17023	6	2.586
Greedy Best First Graph Search	**Uninformed**	**Yes**	**7**	**9**	**28**	**6**	**0.004**
A* Search	Heuristic	Yes	55	57	224	6	0.035
A* Search (Ignore Preconditions)	Heuristic	Yes	41	43	170	6	0.067
A* Search (PlanningGraph Levelsum)	Heuristic	Yes	11	13	50	6	1.123

Note: The dashed lines (**-**) mean that the strategy exceeded 10 minutes and were unable to find a solution. The bolded strategy is the one that found an optimal solution the fastest.

Five out of seven uninformed strategies (Breadth First, Breadth First Tree, Uniform Cost, Recursive Best, Greedy Best First) and all the heuristic strategies found the optimal solution of a plan length of 6. Greedy Best First Graph found the optimal solution the fastest and with the lowest memory consumption.

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))
```

Optimal plan:

```
Load(C3, P3, ATL)
Fly(P3, ATL, SFO)
Unload(C3, P3, SFO)
Load(C2, P2, JFK)
Fly(P2, JFK, SFO)
Unload(C2, P2, SFO)
Load(C1, P1, SFO)
Fly(P1, SFO, JFK)
Unload(C1, P1, JFK)
```

Metric comparison by strategy:

Strategy	**Type**	**Optimal**	**Expansions**	**Goal Tests**	**New Nodes**	**Plan Length**	**Search Time(s)**
Breadth First Search	Uninformed	Yes	3343	4609	30509	9	13.320
Breadth First Tree Search	Uninformed	-	-	-	-	-	-
Depth First Graph Search	Uninformed	No	624	625	5602	619	3.391
Depth Limited Search	Uninformed	-	-	-	-	-	-
Uniform Cost Search	Uninformed	Yes	4853	4855	44041	9	11.299
Recursive Best First Search	Uninformed	-	-	-	-	-	-
Greedy Best First Graph Search	Uninformed	No	998	1000	8962	21	2.344
A* Search	Heuristic	Yes	4853	4855	44041	9	12.841
A* Search (Ignore Preconditions)	**Heuristic**	**Yes**	**1450**	**1452**	**13303**	**9**	**4.102**
A* Search (PlanningGraph Levelsum)	Heuristic	Yes	86	88	841	9	186.723

Note: The dashed lines (**-**) mean that the strategy exceeded 10 minutes and were unable to find a solution. The bolded strategy is the one that found an optimal solution the fastest.

Two out of seven uninformed strategies (Breadth First, Uniform Cost) and all heuristic strategies found the optimal solution of length 9. Breadth First Tree, Depth Limited, Recursive Best First were unable to find a solution within 10 minutes. The A* Search with Ignore Precondtions found the optimal solution almost the fastest but with the lowest memory computation.

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))
```

Optimal plan:

```
Load(C2, P2, JFK)
Fly(P2, JFK, ORD)
Load(C4, P2, ORD)
Fly(P2, ORD, SFO)
Unload(C4, P2, SFO)
Load(C1, P1, SFO)
Fly(P1, SFO, ATL)
Load(C3, P1, ATL)
Fly(P1, ATL, JFK)
Unload(C3, P1, JFK)
Unload(C2, P2, SFO)
Unload(C1, P1, JFK)
```

Metric comparison by strategy:

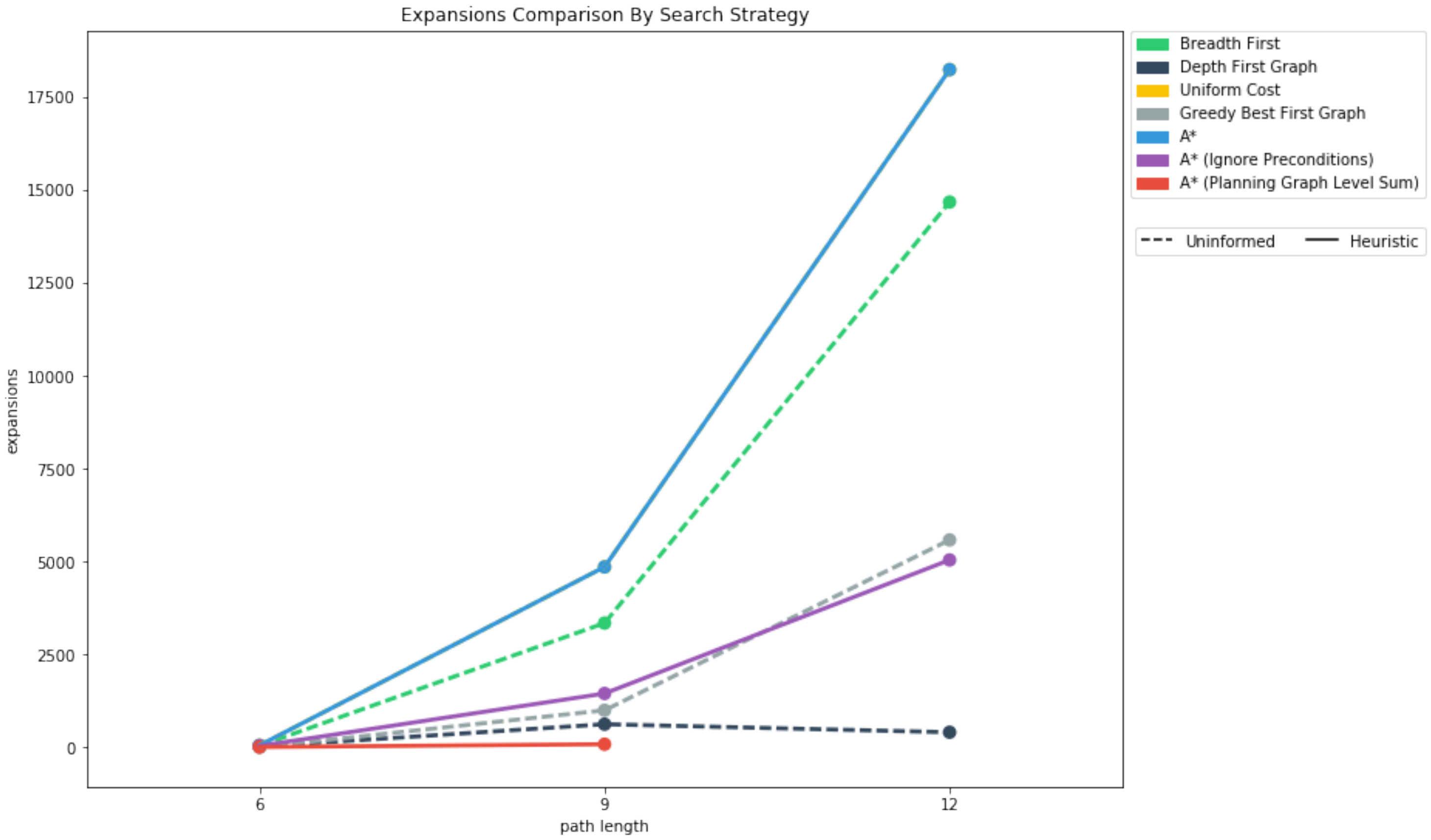
Strategy	Type	Optimal	Expansions	Goal Tests	New Nodes	Plan Length	Search Time(s)
Breadth First Search	Uninformed	Yes	14663	18098	129631	12	96.356
Breadth First Tree Search	Uninformed	-	-	-	-	-	-
Depth First Graph Search	Uninformed	No	408	409	3364	392	1.950
Depth Limited Search	Uninformed	-	-	-	-	-	-
Uniform Cost Search	Uninformed	Yes	18223	18225	159618	12	47.596
Recursive Best First Search	Uninformed	-	-	-	-	-	-
Greedy Best First Graph Search	Uninformed	No	5578	5580	49150	22	15.126
A* Search	Heuristic	Yes	18223	18225	159618	12	52.729
A* Search (Ignore Preconditions)	**Heuristic**	**Yes**	**5040**	**5042**	**44944**	**12**	**15.788**
A* Search (PlanningGraph Levelsum)	Heuristic	-	-	-	-	-	-

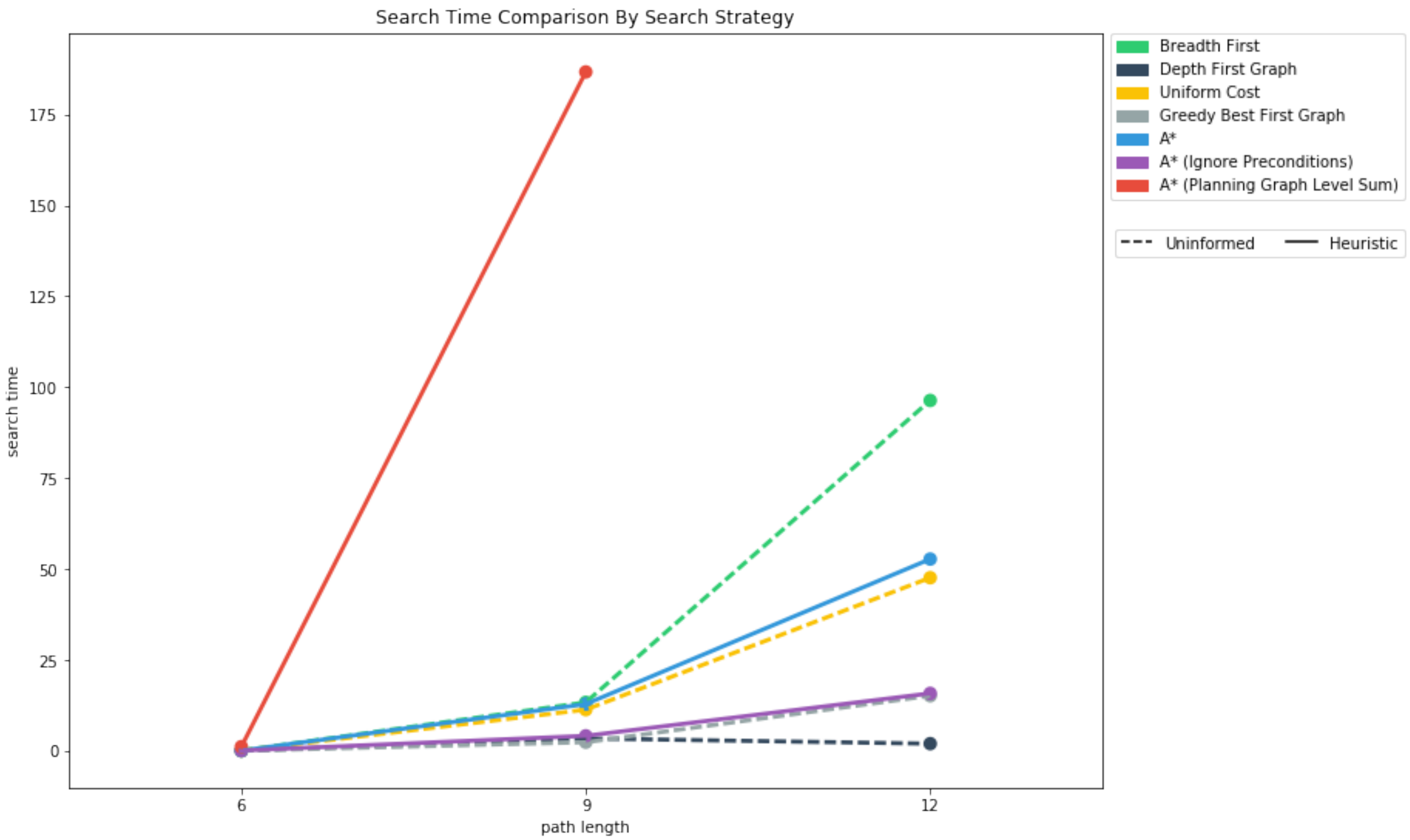
Note: The dashed lines (**-**) mean that the strategy exceeded 10 minutes and were unable to find a solution. The bolded strategy is the one that found an optimal solution the fastest.

Two out of seven uninformed strategies (Breadth First, Uniform Cost) and two out of three heuristic strategies found optimal solutions with length 12. Breadth First, Depth Limited, and Recursive Best First were unable to find a solution within 10 minutes. The A* Search with Ignore Preconditions found an optimal plan with one of the fastest times and lowest memory computations.

Discussion

You can see from the plots below as problem complexity and path length increase, the time and memory space required to find the optimal solution also increases (regardless of the strategy).





A quick glance across the tables and plots show that heuristic strategies almost always outperform uninformed strategies as complexity increases. If the solution requires a quick search and memory space is not a concern then an A* Search (especially the **A* Search Ignoring Preconditions**) appears to be the best strategy based on the three problems. Although it appears Depth First Graph performs well in regards to memory and time, it did not find the optimal solution in any of the problems.

Overall, if the problem is less complex it might be easier to start with an uninformed search like Greedy Best First Graph Search or Breadth First Search because they will be relatively fast and find the optimal solution. As the complexity increases, you should consider switching to a heuristic based search like an A* Search.