

Planning Search Analysis

Bhinesh Patel 20 May 2017

Planning Problems

We were given three classical PDDL problems in the Air Cargo domain. They have the same action schema defined, but different initial states and goals as shown below.

Air Cargo Action Schema
Action(Load(c, p, a),
PRECOND: $\text{At}(c, a) \wedge \text{At}(p, a) \wedge \text{Cargo}(c) \wedge \text{Plane}(p) \wedge \text{Airport}(a)$
EFFECT: $\neg \text{At}(c, a) \wedge \text{In}(c, p)$
Action(Unload(c, p, a),
PRECOND: $\text{In}(c, p) \wedge \text{At}(p, a) \wedge \text{Cargo}(c) \wedge \text{Plane}(p) \wedge \text{Airport}(a)$
EFFECT: $\text{At}(c, a) \wedge \neg \text{In}(c, p)$
Action(Fly(p, from, to),
PRECOND: $\text{At}(p, \text{from}) \wedge \text{Plane}(p) \wedge \text{Airport}(\text{from}) \wedge \text{Airport}(\text{to})$
EFFECT: $\neg \text{At}(p, \text{from}) \wedge \text{At}(p, \text{to})$

Problem 1 Initial State and Goal
Init($\text{At}(C1, \text{SFO}) \wedge \text{At}(C2, \text{JFK})$
$\wedge \text{At}(P1, \text{SFO}) \wedge \text{At}(P2, \text{JFK})$
$\wedge \text{Cargo}(C1) \wedge \text{Cargo}(C2)$
$\wedge \text{Plane}(P1) \wedge \text{Plane}(P2)$
$\wedge \text{Airport}(\text{JFK}) \wedge \text{Airport}(\text{SFO})$
Goal($\text{At}(C1, \text{JFK}) \wedge \text{At}(C2, \text{SFO})$)

Problem 2 Initial State and Goal
Init($\text{At}(C1, \text{SFO}) \wedge \text{At}(C2, \text{JFK}) \wedge \text{At}(C3, \text{ATL})$
$\wedge \text{At}(P1, \text{SFO}) \wedge \text{At}(P2, \text{JFK}) \wedge \text{At}(P3, \text{ATL})$
$\wedge \text{Cargo}(C1) \wedge \text{Cargo}(C2) \wedge \text{Cargo}(C3)$
$\wedge \text{Plane}(P1) \wedge \text{Plane}(P2) \wedge \text{Plane}(P3)$
$\wedge \text{Airport}(\text{JFK}) \wedge \text{Airport}(\text{SFO}) \wedge \text{Airport}(\text{ATL})$
Goal($\text{At}(C1, \text{JFK}) \wedge \text{At}(C2, \text{SFO}) \wedge \text{At}(C3, \text{SFO})$)

Problem 3 Initial State and Goal
Init($\text{At}(C1, \text{SFO}) \wedge \text{At}(C2, \text{JFK}) \wedge \text{At}(C3, \text{ATL}) \wedge \text{At}(C4, \text{ORD})$
$\wedge \text{At}(P1, \text{SFO}) \wedge \text{At}(P2, \text{JFK})$
$\wedge \text{Cargo}(C1) \wedge \text{Cargo}(C2) \wedge \text{Cargo}(C3) \wedge \text{Cargo}(C4)$
$\wedge \text{Plane}(P1) \wedge \text{Plane}(P2)$
$\wedge \text{Airport}(\text{JFK}) \wedge \text{Airport}(\text{SFO}) \wedge \text{Airport}(\text{ATL}) \wedge \text{Airport}(\text{ORD})$
Goal($\text{At}(C1, \text{JFK}) \wedge \text{At}(C3, \text{JFK}) \wedge \text{At}(C2, \text{SFO}) \wedge \text{At}(C4, \text{SFO})$)

Search Strategies

The Planning problems were solved using 10 strategies as shown in the table below. These were separated in two groups; uninformed (blind) search and informed (heuristic) search. Uninformed strategies have no additional information about states beyond that provided in the problem definition. All they can do is generate successors and test them if the goal state has been reached. Informed strategies know whether one state is more promising than another so that the search path can be directed appropriately.

Index	Search Strategy	Search Type
1	breadth first search	Uninformed
2	breadth first tree search	Uninformed
3	depth first graph search	Uninformed
4	depth limited search	Uninformed
5	uniform cost search	Uninformed
6	recursive best first search with h 1	Hueristic
7	greedy best first graph search with h 1	Hueristic
8	astar search with h 1	Hueristic
9	astar search with h ignore preconditions	Hueristic
10	astar search with h pg levelsum	Hueristic

Optimal Plans

The optimal plan for each problem along with the length were obtained as shown below.

Optimal Plans and Length		
Problem 1	Problem 2	Problem 3
Length 6	Length 9	Length 12
Load(C1, P1, SFO)	Load(C1, P1, SFO)	Load(C1, P1, SFO)
Load(C2, P2, JFK)	Load(C2, P2, JFK)	Load(C2, P2, JFK)
Fly(P1, SFO, JFK)	Load(C3, P3, ATL)	Fly(P1, SFO, ATL)
Fly(P2, JFK, SFO)	Fly(P1, SFO, JFK)	Load(C3, P1, ATL)
Unload(C1, P1, JFK)	Fly(P2, JFK, SFO)	Fly(P2, JFK, ORD)
Unload(C2, P2, SFO)	Fly(P3, ATL, SFO)	Load(C4, P2, ORD)
	Unload(C1, P1, JFK)	Fly(P2, ORD, SFO)
	Unload(C2, P2, SFO)	Fly(P1, ATL, JFK)
	Unload(C3, P3, SFO)	Unload(C1, P1, JFK)
		Unload(C2, P2, SFO)
		Unload(C3, P1, JFK)
		Unload(C4, P2, SFO)

Uninformed Search Strategies Comparison

In this section the results of solving each of the three problems by the five **uninformed** search strategies are discussed.

Problem 1

Search Strategy	Plan Length	Expansions	Goal Test	New Nodes	Time (ms)
breadth_first_search	6	43	56	180	39
breadth_first_tree_search	6	1458	1459	5960	1,157
depth_first_graph_search	20	21	22	84	17
depth_limited_search	50	101	271	414	113
uniform_cost_search	6	55	57	224	45

Problem 2

Search Strategy	Plan Length	Expansions	Goal Test	New Nodes	Time (s)
breadth_first_search	9	3343	4609	30509	16
breadth_first_tree_search	-	-	-	-	-
depth_first_graph_search	619	624	625	5602	4
depth_limited_search	50	222719	2053741	2054119	1,791
uniform_cost_search	9	4780	4782	43381	15

Problem 3

Search Strategy	Plan Length	Expansions	Goal Test	New Nodes	Time (s)
breadth_first_search	12	14663	18098	129631	117
breadth_first_tree_search	-	-	-	-	-
depth_first_graph_search	392	408	409	3364	2
depth_limited_search	-	-	-	-	-
uniform_cost_search	12	17882	17884	156769	62

In all three problems, the quickest to produce a solution was **depth_first_graph** search, it also had the least nodes expanded thus consuming the least memory but the plan was far from optimal. **breadth_first** and **uniform_cost** search were close in performance and number of nodes expanded. Both produced optimal length plans. Producing an optimal plan is more important for practical considerations hence **uniform_cost** search is recommended if one needs to use an uninformed search. However if speed and memory usage is a priority then **depth_first_graph** search is recommended at the cost of a sub optimal plan length.

In Problem 2 and Problem 3, some of the search strategies failed to come back with a solution even after running for several hours. These have no data in the table.

Informed Search Strategies Comparison

In this section the results of solving each of the three problems by the five **informed** search strategies are discussed.

Problem 1

Search Strategy	Plan Length	Expansions	Goal Test	New Nodes	Time (ms)
recursive_best_first_search with h_1	6	4229	4230	17023	3,426
greedy_best_first_graph_search with h_1	6	7	9	28	6
astar_search with h_1	6	55	57	224	56
astar_search with h_ignore_preconditions	6	41	43	170	52
astar_search with h_pg_levelsum	6	11	13	50	1,238

Problem 2

Search Strategy	Plan Length	Expansions	Goal Test	New Nodes	Time (s)
recursive_best_first_search with h_1	-	-	-	-	-
greedy_best_first_graph_search with h_1	17	598	600	5382	2
astar_search with h_1	9	4780	4782	43381	15
astar_search with h_ignore_preconditions	9	1450	1452	13303	6
astar_search with h_pg_levelsum	9	86	88	841	247

Problem 3

Search Strategy	Plan Length	Expansions	Goal Test	New Nodes	Time (ms)
recursive_best_first_search with h_1	-	-	-	-	-
greedy_best_first_graph_search with h_1	26	4498	4500	39970	16
astar_search with h_1	12	17882	17884	156769	86
astar_search with h_ignore_preconditions	12	5034	5036	44886	26
astar_search with h_pg_levelsum	12	314	316	2894	1,598

In Problem 1, **greedy_best_first_graph_search_with_h_1** heuristic was quickest and had the least expansions thus using the least memory. It also produced an optimal plan. However in Problems 2 and 3, while still the quickest; it failed to find an optimal solution. **astar_search_with_h_ignore_preconditions** was the second quickest and found the optimal plan in all three problems. It also had a modest number of expansions hence memory consumption. It would be the informed search strategy that is recommended. The least expansions were by **astar_search_with_h_pg_levelsum** but at the cost of a very time consuming search. It also produced an optimal plan in all three problems.

recursive_best_first_search_with_h_1 did not find a solution in Problems 2 and 3 after running for several hours at which point the search was halted.

Uniformed vs Informed Comparison

Problem	Search Strategy	Plan Length	Expansions	Goal Test	New Nodes	Time (s)
1	uniform_cost_search	6	55	57	224	0.045
	astar_search with h_ignore_preconditions	6	41	43	170	0.052
2	uniform cost search	9	4780	4782	43381	15
	astar_search with h_ignore_preconditions	9	1450	1452	13303	6
3	uniform cost search	12	17882	17884	156769	62
	astar_search with h_ignore_preconditions	12	5034	5036	44886	26

uniform_cost search was the recommended uninformed search strategy and **astr_search_with_h_ignore_precondtions** was the recommended informed search strategy. Comparing the two, **astr_search_with_h_ignore_precondtions** was quicker, led to fewer expansions thus memory usage in all three problems, hence it is the recommended search strategy for the problem given.

In Chapter 3.4.2 of AIMA (3rd edition Russell & Norvig) the complexity of **uniform_cost** search is of the order of $O(b^{d+1})$ and we see that the number of **Expansions** increase greatly with the complexity of the problems. In Chapter 10.3 it is shown that Planning Graphs reduce the exponential complexity of the search to polynomial size. This can be seen in the fewer **Expansions** that are carried out in the **astar_search_with_h_ignore_preconditions** search.