Heuristic Analysis – Planning Search

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## Udacity Artificial Intelligence Nanodegree

## Term 1, Project 3 (November 2017)

For project 3, I implemented a search planning agent to solve deterministic air cargo transport logistics problems. The tables below compare multiple uninformed and informed search algorithms. The best solution for the problem (the one which found the optimal solution in the fastest time) is highlighted in bold.

**Uninformed search (without heuristics)**

Problem 1:

|  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- |
| Search algorithm | Best solution? | Optimal | Expansions | Goal Tests | Plan length | Time |
| Breadth first search | No | Yes | 43 | 56 | **6** | 0.031 |
| Breadth first tree search | Yes | 1458 | 1459 | **6** | 0.825 |
| Depth first graph search | No | 12 | 13 | 12 | 0.009 |
| Depth limited search | No | 101 | 271 | 50 | 0.085 |
| Uniform cost search | Yes | 55 | 57 | **6** | 0.040 |
| Recursive best first search | Yes | 4229 | 4230 | **6** | 2.870 |
| **Greedy best first graph search** | **Yes** | **Yes (but not always)** | **7** | **9** | **6** | **0.004** |

Due to the higher search time required for problems 2 and 3, I chose to test only 4 of the search algorithms those two problems.

Problem 2:

|  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- |
| Search algorithm | Best solution? | Optimal | Expansions | Goal Tests | Plan length | Time |
| **Breadth** **first search** | **Yes** | **Yes** | **3343** | **4609** | **9** | **7.141** |
| Depth first graph search | No | No | 582 | 583 | 575 | 2.887 |
| Uniform cost search | Yes | 4853 | 4855 | **9** | 11.222 |
| Greedy best first graph search | No | 998 | 1000 | 21 | 2.125 |

Problem 3:

|  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- |
| Search algorithm | Best solution? | Optimal | Expansions | Goal Tests | Plan length | Time |
| **Breadth** **first search** | **Yes** | **Yes** | **12358** | **15077** | **12** | **32.629** |
| Depth first graph search | No | No | 4315 | 4316 | 815 | 18.898 |
| Uniform cost search | Yes | 15601 | 15603 | **12** | 41.816 |
| Greedy best first graph search | No | 5297 | 5299 | 24 | 13.334 |

**Informed search (using heuristics)**

Problem 1:

|  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- |
| Search algorithm | Best solution? | Optimal | Expansions | Goal Tests | Plan length | Time |
| A\* with h1 | No | Yes | 55 | 57 | **6** | 0.033 |
| **A\* with ignore preconditions** | **Yes** | **Yes** | **41** | **43** | **6** | **0.031** |
| A\* with level sum | No | Yes | 11 | 13 | **6** | 0.932 |

Problem 2:

|  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- |
| Search algorithm | Best solution? | Optimal | Expansions | Goal Tests | Plan length | Time |
| A\* with h1 | No | Yes | 4853 | 4855 | **9** | 11.680 |
| **A\* with ignore preconditions** | **Yes** | **Yes** | **1450** | **1452** | **9** | **4.481** |
| A\* with level sum | No | Yes | 86 | 88 | **9** | 158.721 |

Problem 3:

|  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- |
| Search algorithm | Best solution? | Optimal | Expansions | Goal Tests | Plan length | Time |
| A\* with h1 | No | Yes | 18223 | 18225 | **12** | 50.298 |
| **A\* with ignore preconditions** | **Yes** | **Yes** | **5040** | **5042** | **12** | **18.665** |
| A\* with level sum | No | Yes | 315 | 317 | **12** | 898.438 |

**Optimal Actions**

Here is the optimal sequence of actions for each problem, as found by *greedy best first graph search* (problem 1) and *A\* with ignore preconditions* (problems 2 and 3):

**Problem 1:**

Load(C1, P1, SFO)

Fly(P1, SFO, JFK)

Unload(C1, P1, JFK)

Load(C2, P2, JFK)

Fly(P2, JFK, SFO)

Unload(C2, P2, SFO)

**Problem 2:**

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)

**Problem 3:**

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)

**Results summary and analysis**

The best heuristics for each problem were: *greedy best first graph search* for problem 1; *A\* with ignore preconditions heuristic* for problems 2 and 3. *Breadth first*, *breadth first tree search*, *uniform cost search*, *recursive best first search*, and all three *A\** searches found the optimal solution, but *greedy best first graph search* found it in the shortest time.

For problems 2 and 3, *breadth first search*, *uniform cost search*, *A\**, and *A\* with ignore preconditions* each found the shortest solutions. *A\* with ignore preconditions* was the fastest in both problems, typically taking around half the time of the next-best search algorithm (*breadth first search*).

Interestingly enough, *depth first* and *greedy best first* both completed problems 2 and 3 in similar times to *A\* with ignore preconditions*, but neither of them found the shortest solution because they are not optimal[1]. Although *greedy best first* performed more expansions than *depth first*, it always found a significantly shorter solution in a similar time.

These results indicate that for simple problems, heuristics may make little difference, and so uninformed search can be faster. For more complex problems, however, informed search appears to be always better: typically finding an optimal solution in far less time than optimal uninformed search. However, if an optimal solution is not needed and the search must be uninformed, then *greedy best first graph search* is a good option.

**References**

Source 1: figure 3.21 from chapter 3.4.7 of AI: A Modern Approach