

Heuristics and A* implementations

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Abstract

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Domains

Six domains were tested in the implementations. In this section, I explain this domains.

Blocksworld

Dinner

Dompteur

DWR - Dock Worker Robots

Logistics

TSP - Travel Sales Person

Heuristics

In this section, I discuss the different heuristics implemented in the Jupyter notebook. The implementation uses the *pddl* package to parse the tested PDDL domains and problems.

h_{max} heuristic

In a nutshell, this heuristic returns the maximum cost to achieve a goal. From an initial state, the heuristic returns the longest path to reach all goals.

```
1 from pddl.heuristic import Heuristic
2
3 class MaxHeuristic(Heuristic):
4     def h(self, actions, state, goals):
5         reachable = state
6         goals_missing = goals[0]
7         max_cost = 0
8         while not goals_missing.issubset(
9             reachable):
10            last_state = frozenset(
11                [a for a in actions if a.
12                 positive_preconditions.issubset(
13                     reachable)]
```

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```
11         )
12         new_reachable = reachable.union([pre
13             for a in last_state for pre in a.
14             add_effects])
15         if new_reachable == reachable:
16             return float("inf")
17         reachable = new_reachable
18         max_cost += 1
19         return max_cost
```

Listing 1: h_{max} implementation

In the Listing 1, the function h returns the maximum cost to reach the *goals* from an initial *state*, considering a set of possible *actions*.

The first reachable states are the initial states, as shown in line 5. The next two lines define the goals¹ and the maximum cost to achieve the goals from the reachable state. Therefore, if all goals are in the initial state, the maximum cost is 0 and the return in line 8 is *False*.

When the goals are not in the reachable state, the algorithm takes two step:

- line 9: get all actions in which the preconditions are applicable to the current set of reachable actions.
- line 12: get the effects from the actions applicable to the current reachable state. Each time the algorithm performs this step, the reachable state becomes larger, that is, it is more likely that the goals are in the reachable state.

At least, in line 13, it is tested whether the new reachable states are the same as the current reachable state. If true, there are no more states to reach and the heuristic has not achieved the goals. Therefore, *inf* is returned. When there are more states to test, the maximum cost is increased until all goals are reached.

h_{add} heuristic

In a nutshell, this heuristic returns the sum of all the costs to reach the goals. The Listing 2 shows the algorithm that performs this heuristic.

¹The goals received as a parameter are divided into positive and negative. Negative goals are those with the negative sign (*not*) in the PDDL. To perform the heuristic I only consider the positive goal.

```

1 from pddl.heuristic import Heuristic
2
3 class AdditiveHeuristic(Heuristic):
4     def h(self, actions, state, goals):
5         reachable = state
6         goals_missing = goals[0]
7         goals_reached = None
8         last_state = None
9         add = 0
10        costs = {p: 0 for p in state}
11        while last_state != reachable:
12            goals_reached = goals_missing.intersection(reachable)
13            if goals_reached:
14                add += sum(costs[g] for g in goals_reached)
15            goals_missing = goals_missing.difference(goals_reached)
16            if not goals_missing:
17                return add
18            last_state = reachable
19            for action in actions:
20                if action.positive_preconditions.issubset(last_state):
21                    new_reachable = action.add_effects.difference(reachable)
22                    for effect in new_reachable:
23                        costs[effect] = sum(costs[pre] for pre in action.positive_preconditions) + 1
24            reachable = reachable.union(new_reachable)
25        return float("inf")

```

Listing 2: h_{add} implementation

Similar to the h_{max} heuristic, the first reachable state will be the initial state and the cost of reaching goals that are in the initial state, is 0 (line 10). As we need to add the cost of reaching all goals, it is necessary to maintain a set of all goals that have not yet been achieved.

When a goal is reached in the current reachable state (line 12), the cost of all goals reached is added to the variable *add*, as shown in line 14.

After reaching all the goals, the variable *add* is returned (line 17). If some goal cannot be reached, at some point in the execution, the previous state will be equal to the reachable state, and then return *inf* (line 25).

The first step to get the next reachable state is to filter only the actions applicable to the current state and obtain the effects of those actions (line 21). After that, the cost of each effect is calculated and added to the variable *costs* (line 23). The cost of the effect will be the sum of the costs of the preconditions plus 1, because it is the next step in the search tree.

Plan Validation

In some scenarios, it is necessary to validate whether a given plan is valid or not. Listing 3 shows a Python code for performing plan validation.

```

1 def validate(self, actions, initial_state, goals, plan):

```

```

2     state = initial_state
3     for line in plan:
4         for action in actions:
5             if line.parameters == action.parameters:
6                 if applicable(state, (action.positive_preconditions, action.negative_preconditions)):
7                     state = apply(state, (action.add_effects, action.del_effects))
8                     break
9             goals_reached = goals[0].intersection(state)
10            return goals_reached == goals[0]

```

Listing 3: Plan validation implementation

The function *validate* takes as parameters the actions that can be applied to the state, the initial state, the goals and the plan to be validated. An example of a plan to be validated is shown in Listing 4.

```

( take k1 cc cb p1 l1 )
( load k1 r1 cc l1 )
( move r1 l1 l2 )
...

```

Listing 4: Example of a plan

The main idea of validation is to apply each line of the plan to the state and test whether the goals have been reached or not. In lines 3 and 4 of Listing 3, I search for the action that is applicable to the current line of the plan. When the plan line and an action have the same parameters (line 5), I apply the action on the state, interrupt the search for another action and move to the next plan line.

After all the effects of the plan line are applied to the state, I search in the state for the goals. If all goals can be found in the state, the plan is valid.

Solver using A* and h_{max}

A solver is responsible for finding the best path to achieve the goal. In STRIPS planning, the best path is the path that performs the least actions to achieve all goals. In this section, I will show how the A* differs from the Dijkstra algorithm and also an algorithm to search for the shortest path using A* search, guided by the h_{max} heuristic.

Dijkstra and A*

A* is based on the Dijkstra algorithm. In a nutshell, Dijkstra's algorithm searches for the node in the tree that has the lowest cost. The Figure 1 helps to understand the Dijkstra's algorithm. Our goal is to be in city E, starting from city A.

The distance between cities A and B is 40 kilometers. Therefore, Dijkstra's algorithm will choose the path from city A to C, since the distance is shorter. In the next step, the algorithm have two possible nodes to expand: B and D. As the distance from city C to D is less than city A to B, the algorithm will choose the path from city C to D. Following

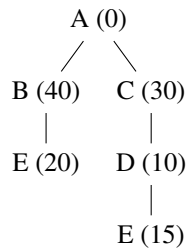


Figure 1: Dijkstra search tree

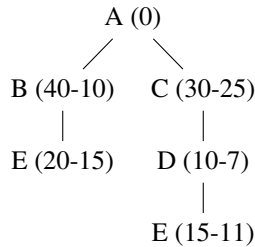


Figure 2: A* search tree

the same logic, in the end, the algorithm will choose the path from city D to E, reaching the goal.

From the Dijkstra's algorithm, the A* algorithm adds a heuristic value to the cost of moving from a city to another, for example. In Figure 2, I show an example of heuristic: the straight line distance between two cities. The straight line between cities C and E, for example, I considered inf, because I cannot travel between these two cities without going through city D.

Now, the distance between cities A and B is 50 kilometers and between cities A and C is 55 kilometers. Therefore, the A* algorithm will choose the path between cities A and B. In the next step, the algorithm chooses the path between B and E, because the distance, considering the heuristic, is shortest. A bad heuristic will guide the A* algorithm to the wrong direction. However, with good heuristics, A* algorithm needs to expand fewer nodes to reach the goal.

Solver Explanation

The solver uses the A* algorithm, guided by the h_{max} heuristic. To implement the search, I used the *heapq* and the *pddl* packages. The first was used for the priority queue and the second for parsing the PDDL domain file and problem file.

explain priority queue

get some lines of the implementation and explain

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\And ... \And Author n \ \
Address line \ \ ... \ \ Address line}
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\AND
Author 2 \ \ Address line \ \ ... \ \ Address line \ \
\And
Author 3 \ \ Address line \ \ ... \ \ Address line \ \
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The illustration number and caption should appear under the illustration. Labels, and other text in illustrations must be at least nine-point type.

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L^AT_EX Overflow. L^AT_EX users please beware: L^AT_EX will sometimes put portions of the figure or table or an equation in the margin. If this happens, you need to scale the figure or table down, or reformat the equation. Check your log file! You must fix any overflow into the margin (that means no overfull boxes in L^AT_EX). If you don't, the overflow text will simply be eliminated. **Nothing is permitted to intrude into the margins.**

Using Color. Your paper will be printed in black and white and grayscale. Consequently, because conversion to grayscale can cause undesirable effects (red changes to black, yellow can disappear, and so forth), we strongly suggest you avoid placing color figures in your document. Of course, any reference to color will be indecipherable to your reader.

Drawings. We suggest you use computer drawing software (such as Adobe Illustrator or, (if unavoidable), the drawing tools in Microsoft Word) to create your illustrations. Do not use Microsoft Publisher. These illustrations will look best if all line widths are uniform (half- to two-point in size), and you do not create labels over shaded areas. Shading should be 133 lines per inch if possible. Use Times Roman or Helvetica for all figure call-outs. **Do not use hairline width lines** — be sure that the stroke width of all lines is at least .5 pt. Zero point lines will print on a laser printer, but will completely disappear on the high-resolution devices used by our printers.

Photographs and Images. Photographs and other images should be in grayscale (color photographs will not reproduce well; for example, red tones will reproduce as black, yellow may turn to white, and so forth) and set to a minimum of 266 dpi. Do not prescreen images.

Resizing Graphics. Resize your graphics **before** you include them with L^AT_EX. You may **not** use trim or clip options as part of your \includgraphics command. Resize the media box of your PDF using a graphics program instead.

Fonts in Your Illustrations You must embed all fonts in your graphics before including them in your L^AT_EX document.

References

The aaai.sty file includes a set of definitions for use in formatting references with BibTeX. These definitions make the bibliography style fairly close to the one specified below.

To use these definitions, you also need the BibTeX style file “aaai.bst,” available in the author kit on the AAAI web site. Then, at the end of your paper but before \enddocument, you need to put the following lines:

```
\bibliographystyle{aaai} \bibliography{bibfile1,bibfile2,...}
```

The list of files in the \bibliography command should be the names of your BibTeX source files (that is, the .bib files referenced in your paper).

The following commands are available for your use in citing references:

\cite: Cites the given reference(s) with a full citation. This appears as “(Author Year)” for one reference, or “(Author Year; Author Year)” for multiple references.

\shortcite: Cites the given reference(s) with just the year. This appears as “(Year)” for one reference, or “(Year; Year)” for multiple references.

\citeauthor: Cites the given reference(s) with just the author name(s) and no parentheses.

\citeyear: Cites the given reference(s) with just the date(s) and no parentheses.

Warning: The aaai.sty file is incompatible with the hyperref and natbib packages. If you use either, your references will be garbled.

Formatted bibliographies should look like the following examples.

Book with Multiple Authors

Engelmore, R., and Morgan, A. eds. 1986. *Blackboard Systems*. Reading, Mass.: Addison-Wesley.

Journal Article

Robinson, A. L. 1980a. New Ways to Make Microcircuits Smaller. *Science* 208: 1019–1026.

Magazine Article

Hasling, D. W.; Clancey, W. J.; and Rennels, G. R. 1983. Strategic Explanations in Consultation. *The International Journal of Man-Machine Studies* 20(1): 3–19.

Proceedings Paper Published by a Society

Clancey, W. J. 1983b. Communication, Simulation, and Intelligent Agents: Implications of Personal Intelligent Machines for Medical Education. In *Proceedings of the Eighth International Joint Conference on Artificial Intelligence*, 556–560. Menlo Park, Calif.: International Joint Conferences on Artificial Intelligence, Inc.

Proceedings Paper Published by a Press or Publisher

Clancey, W. J. 1984. Classification Problem Solving. In *Proceedings of the Fourth National Conference on Artificial Intelligence*, 49–54. Menlo Park, Calif.: AAAI Press.

University Technical Report

Rice, J. 1986. Poligon: A System for Parallel Problem Solving, Technical Report, KSL-86-19, Dept. of Computer Science, Stanford Univ.

Dissertation or Thesis

Clancey, W. J. 1979b. Transfer of Rule-Based Expertise through a Tutorial Dialogue. Ph.D. diss., Dept. of Computer Science, Stanford Univ., Stanford, Calif.

Producing Reliable PDF Documents with L^AT_EX

Generally speaking, PDF files are platform independent and accessible to everyone. When creating a paper for a proceedings or publication in which many PDF documents must be merged and then printed on high-resolution PostScript RIPs, several requirements must be met that are not normally of concern. Thus to ensure that your paper will look like it does when printed on your own machine, you must take several precautions:

- Use type 1 fonts (not type 3 fonts)
- Use only standard Times, Nimbus, and CMR font packages (not fonts like F3 or fonts with tildes in the names or fonts—other than Computer Modern—that are created for specific point sizes, like Times~19) or fonts with strange combinations of numbers and letters
- Embed all fonts when producing the PDF
- Do not use the [T1]fontenc package (install the CM super fonts package instead)

Creating Output Using PDFL^AT_EX Is Required

By using the PDFL^AT_EX program instead of straight L^AT_EX or T_EX, you will probably avoid the type 3 font problem altogether (unless you use a package that calls for metafont). PDFL^AT_EX enables you to create a PDF document directly from L^AT_EX source. The one requirement of this software is that all your graphics and images must be available in a format that PDFL^AT_EX understands (normally PDF).

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dvipdf Script Scripts such as dvipdf which ostensibly bypass the Postscript intermediary should not be used since they generally do not instruct dvips to use the config.pdf file.

dvipdfm Do not use this dvi-PDF conversion package if your document contains graphics (and we recommend you avoid it even if your document does not contain graphics).

Ghostscript

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If you are still finding type 3 fonts in your PDF file, look at your graphics! L^AT_EX users should check all their imported graphics files as well for font problems.

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Additional Resources

L^AT_EX is a difficult program to master. If you've used that software, and this document didn't help or some items were not explained clearly, we recommend you read Michael Shell's excellent document (testflow doc.txt V1.0a 2002/08/13) about obtaining correct PS/PDF output on L^AT_EX systems. (It was written for another purpose, but it has general application as well). It is available at www.ctan.org in the tex-archive.

Acknowledgments

AAAI is especially grateful to Peter Patel Schneider for his work in implementing the aaai.sty file, liberally using the ideas of other style hackers, including Barbara Beeton. We also acknowledge with thanks the work of George Ferguson for his guide to using the style and BibT_EX files — which has been incorporated into this document — and Hans Guesgen, who provided several timely modifications, as well as the many others who have, from time to time, sent in suggestions on improvements to the AAAI style.

The preparation of the L^AT_EX and BibT_EX files that implement these instructions was supported by Schlumberger Palo Alto Research, AT&T Bell Laboratories, Morgan Kaufmann Publishers, The Live Oak Press, LLC, and AAAI Press. Bibliography style changes were added by Sunil Issar. \pubnote was added by J. Scott Penberthy. George Ferguson added support for printing the AAAI copyright slug. Additional changes to aaai.sty and aaai.bst have been made by the AAAI staff.

Thank you for reading these instructions carefully. We look forward to receiving your electronic files!