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(reachable):
9        last_state = frozenset(
10         [a for a in actions if a.positive_preconditions.issubset(reachable)]
11       )
12       new_reachable = reachable.union([pre for a in last_state for pre in a.add_effects])
13       if new_reachable == reachable:
14         return float("inf")
15       reachable = new_reachable
16       max_cost += 1
17     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 goals[1] 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.

Finally, 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.

```
from pddl.heuristic import Heuristic
```

[1] The goals received as a parameter are divided into positive and negative. Negative goals are those with the negative sign (*not*) in the PDDL. In all heuristics, I consider only the positive goals.

```
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 sum 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).

To get the next reachable state I need 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 validade 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(
7           state, (action.positive_preconditions, action.negative_preconditions)
8         ):
9           state = apply(state, (action.add_effects, action.del_effects))
10          break
11
12  goals_reached = goals[0].intersection(state)
13  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 a plan 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 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. We can consider the best path as the path that performs the least actions to achieve all goals. However, the path found can be a local minimum result, that is, there is a better path but the solver cannot see it. The solver would need to keep searching to find that path. This algorithm just searches for a path that reaches all goals, not necessarily the global minimum path.

Hence, 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

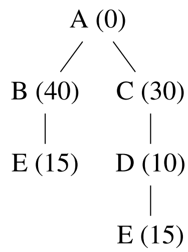

Figure 1: Dijkstra search tree

algorithm have two possible nodes to expand: A or D. The cost to travel to each of these cities will be the current cost, 30 kilometers, plus the cost to reach A or D. Therefore, the cost to reach cities A or D is 60 and 40, respectively. Now the algorithm has three options: 1) go back and, instead of city C, choose city B, which costs 40; 2) go to city A, which costs 60; 3) go to city D, which costs 40. The algorithm will choose the cheapest path. In this case, let's assume that it arbitrarily chooses B. Following the same logic, the algorithm will have to expand all the nodes until reaching the goal.

To solve this problem, the A* algorithm adds a heuristic value to the cost of moving from a city to another, for example. The heuristic may be the straight line distance between two cities. Now the algorithm can know, for example, that the path from city A to C is longer to reach the goal than from city A to B. 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 implentation and explain

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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 LaTeX. 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 LaTeX 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.

Forthcoming Publication
Clancey, W. J. 1986a. The Engineering of Qualitative Models. Forthcoming.

Producing Reliable PDF Documents with LaTeX

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:

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- 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 PDFLaTeX Is Required

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

PDFLaTeX's default is to create documents with type 1 fonts. If you find that it is not doing so in your case, it is likely that one or more fonts are missing from your system or are not in a path that is known to PDFLaTeX.

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).

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Additional Resources

LaTeX 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 LaTeX 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 BibTeX 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 LaTeX and BibTeX 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!