AI Education Matters: Teaching Search Algorithms

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DOI: 10.1145/3284751.3284757

Introduction

In this column, we share advice and resources for teaching and learning about heuristic search algorithms. These are algorithms like A* (Hart, Nilsson, & Raphael, 1968), IDA* (Korf, 1985) and others that use admissible heuristics to find optimal and suboptimal solutions to shortest path problems.

While A* and IDA* are well-known and well-covered in many courses, they can still be confusing to students studying them for the first time. But, there is a significant body of work that goes beyond these basic algorithms that can be used as additional projects and to encourage advanced students. These includes topics such as:

- Improving search with better heuristics (Culberson & Schaeffer, 1996; Sturtevant, Felner, Barer, Schaeffer, & Burch, 2009) and constraints (Goldberg, Kaplan, & Werneck, 2006; Rabin & Sturtevant, 2016)
- Exploiting path symmetries on grids (Harabor & Grastien, 2011; Sturtevant & Rabin, 2016)
- Any-angle path planning (Nash & Koenig, 2013)
- 3D Path Planning (Brewer & Sturtevant, 2018)
- Suboptimal path planning (Hatem & Ruml, 2014)
- Bidirectional path planning (Sturtevant & Felner, 2018)
- Multi-agent path planning (Felner et al., 2017)

Textbooks

There are two common textbooks that provide an introduction to heuristic search.

Russell and Norvig's *Artificial Intelligence: A Modern Approach* (Russell & Norvig, 2009) covers the basics of search with heuristics and gives several examples of different heuristics for different domains. This book is relatively high-level with mostly introductory material.

On the opposite spectrum is Stefan Edelkamp's Textbook, *Heuristic Search: Theory and Applications* (Edelkamp & Schrödl, 2012). This excellent book goes into great detail about most aspects of heuristic search, however it may be too advanced for most undergraduates.

Video Introductions

There are many videos available on YouTube which demonstrate the A* algorithm and go through examples of how it works. Our Moving AI web pages[1] feature videos on different aspects of search algorithms that are both available on YouTube or can be download for offline use.

Interactive Web Demos

More useful than static videos are interactive web pages that allow users to interact with the search process by changing problem instances, search algorithms, and other parameters.

Amit Patel has developed a broad range of tutorials for subjects of interest to game developers. Among these, he has many different pages that explore and explain search algorithms, some statically[2] and some interactively.[3]

Two other notable pages have been developed by Xueqiao (Joe) Xu[4] and Dave Churchill[5].

[1] https://www.movingai.com/
[2] http://theory.stanford.edu/~amitp/GameProgramming/
[3] https://www.redblobgames.com/pathfinding/a-star/introduction.html
[4] https://qiao.github.io/PathFinding.js/visual/
[5] http://www.cs.mun.ca/~dchurchill/search/

Each of these pages allow you to interact with a variety of search algorithms and search parameters, visualizing how the algorithms run.

Finally, we have recently released a broad set of demos[6] that we have been using for our cross-listed undergraduate/graduate course on heuristic search. In addition to the regular A*-like algorithms, this page also has demos of IDA*, bidirectional search, heuristics, constraints, and other search techniques. These demos are still under active development, particularly when we teach our heuristic search course. In addition to providing these demos, we give them in class with challenge questions, such as 'Find a problem where A* updates the $g-$cost of a state on the open list'. This gives student more purpose when exploring them.

Model AI Assignments

Model AI Assignments are free, peer-reviewed assignment materials made available in order to advance AI education. There are several model assignments that explore aspects of heuristic search.

Sven Koenig's has two Model AI assignments available. "Any-Angle Path Planning"[7] is for undergraduate or graduate artificial intelligence classes and covers algorithms that use a grid representation of the obstacles in the world when agents are able to move through free space.

"Fast Trajectory Replanning"[8] is also for undergraduate and graduate students and covers algorithms for re-planning when the world representation changes or the agents discover obstacles they were not previously aware of.

"The Pac-Man Projects" by John DeNero and Dan Klein also has a heuristic search project, "Project #1: Search Project"[9] in which "students implement depth-first, breadth-first, uniform cost, and A* search algorithms. These algorithms are used to solve navigation and traveling salesman problems in the Pac-Man world. "

[6] https://movingai.com/SAS/

[7] http://idm-lab.org/project-m/project2.html

[8] http://idm-lab.org/project-m/project1.html

[9] http://modelai.gettysburg.edu/2010/pacman/projects/search/search.html

Conferences for Heuristic Search

For those looking for recent research in the area of heuristic search, there are several venues that regularly publish work in heuristic search. These include the Symposium on Combinatorial Search (SoCS)[10], which specializes particularly in search. The International Conference on Planning and Scheduling (ICAPS)[11] has a broader scope, but regularly contains significant research in heuristic search. Finally, major conferences like the International Joint Conference on Artificial Intelligence (IJCAI)[12] and the AAAI Conference on Artificial Intelligence[13] also publish research in this subfield of Artificial Intelligence.

References

Brewer, D., & Sturtevant, N. R. (2018). Benchmarks for pathfinding in 3d voxel space. *Symposium on Combinatorial Search (SoCS)*, 143 – 147.

Culberson, J. C., & Schaeffer, J. (1996). Searching with pattern databases. *Advances in Artificial Intelligence*, 402-416.

Edelkamp, S., & Schrödl, S. (2012). *Heuristic search - theory and applications*. Academic Press. Retrieved from http://www.elsevierdirect.com/product.jsp?isbn=9780123725127

Felner, A., Stern, R., Shimony, S. E., Boyarski, E., Goldenberg, M., Sharon, G., ... Surynek, P. (2017). Search-based optimal solvers for the multi-agent pathfinding problem: Summary and challenges..

Goldberg, A. V., Kaplan, H., & Werneck, R. F. (2006). Reach for A*: Efficient point-to-point shortest path algorithms. In *ALENEX* (pp. 129–143).

Harabor, D. D., & Grastien, A. (2011). Online graph pruning for pathfinding on grid maps. In *AAAI* (pp. 1114–1119).

[10] http://search-conference.org

[11] http://www.icaps-conference.org

[12] http://www.ijcai.org/

[13] http://www.aaai.org/Conferences/conferences.php

Hart, P., Nilsson, N. J., & Raphael, B. (1968). A formal basis for the heuristic determination of minimum cost paths. *IEEE Transactions on Systems Science and Cybernetics*, *4*, 100–107.

Hatem, M., & Ruml, W. (2014). Simpler bounded suboptimal search. In *AAAI* (pp. 856–862).

Korf, R. E. (1985). Iterative-Deepening-A*: An optimal admissible tree search. In *IJCAI* (p. 1034-1036).

Nash, A., & Koenig, S. (2013). Any-angle path planning. *AI Magazine*, *34*(4), 9.

Rabin, S., & Sturtevant, N. R. (2016). Combining bounding boxes and jps to prune grid pathfinding. In *AAAI.*

Russell, S., & Norvig, P. (2009). *Artificial intelligence: A modern approach* (3rd ed.). Upper Saddle River, NJ, USA: Prentice Hall.

Sturtevant, N. R., & Felner, A. (2018). A brief history and recent achievements in bidirectional search. In *Aaai conference on artificial intelligence.*

Sturtevant, N. R., Felner, A., Barer, M., Schaeffer, J., & Burch, N. (2009). Memory-based heuristics for explicit state spaces. *IJCAI*, 609–614.

Sturtevant, N. R., & Rabin, S. (2016). Canonical orderings on grids. *IJCAI*, 683–689.

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