Can Empirical Modelling Facilitate Learning?: Modelling Graphs to Assist in the Teaching of AI Search Algorithms

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Abstract

This paper aims to critically assess the claim that Empirical Modelling (EM) tools and techniques can be used to facilitate learning. In Artificial Intelligence, algorithms such as A*, Greedy Best First Search and Dijkstra's algorithm are taught in order to find the most efficient path from one node to another in a graph. When teaching the behaviour of these algorithms, it can often be difficult to ensure that students have the correct understanding. Students may consider the algorithms to be simple, but then find out that they have misinterpreted the taught material when completing practical examples. It is proposed that the use of Empirical Modelling techniques to model graphs and dependencies between nodes and edges could assist traditional methods of teaching the behaviour of graph algorithms. This is illustrated by the creation of a model of a graph, which is fully traversable using the A* algorithm.

1 Introduction

The inspiration for this project arose from previous experience investigating graph search techniques. Whilst studying Artificial Intelligence, the semantics of these search algorithms appeared to be simple. It became apparent that there was scope for misinterpretation however, when attempting to employ the algorithms on example graphs. This can be illustrated with the A* algorithm, where the subsequent node to be expanded is selected by minimum F-cost. The F-cost is calculated such that $F(n) = G(n) + H(n)$, where $G(n)$ is the path cost from the start to that node, and $H(n)$ is the heuristic function; an estimation of the cost to the goal from that node. If the algorithm is only described verbally, or if practical examples are not explored by the student, it can be misconstrued that the G-cost is the path cost to that node from the previous node, rather than from the start.

An interest in the field led the author to investigate other common misconceptions, with the aim of determining whether EM techniques could assist in preventing them, and facilitate the learning process. Technical goals were set to design and develop a model of a graph, providing the ability to traverse it using the A* algorithm. It was deemed important to create a rich model of observation of the data structures and observables involved in the algorithm, and use this as a foundation for the design. The model could then be used as a proof of concept, demonstrating the potential of Empirical Modelling as a teaching aid. In addition to this, some personal goals were to further explore this area of interest, develop knowledge of EM principles through experience, and to consider other aspects of computer models that may influence learning and memory retention.

2 Research

2.1 Algorithm misinterpretations

In addition to the misinterpretation of the A* search algorithm described previously, almost any algorithm can be misconstrued if not taught well. As discussed in (L. Beng, 2006), the instructivist 'spoon-feeding' approach often taken by teachers can have a detrimental effect to the learning process. A constructivist approach is favoured by empiricists, as it is believed that learning can only really occur by constructing one's own knowledge through interaction and exploration.

This can also apply in the case of university lectures, where the onus is on the student to ensure a thorough understanding of the material. Although at this level of education the students must be able to explore concepts themselves, the provision of a model that can be manipulated could prevent any misunderstandings. It is noted by Duffy and Cunningham (1996) that "knowledge is not in the content [of the information being delivered] but in the activity of the person in the content domain".

2.2 Use of colour to aid memory

When analysing other models that are used for educational purposes, it was clear that some communicated the ideas behind them more effectively than others. The use of colour appeared to be a significant factor for the success of a model. In some cases, the absence of colour caused a loss of attention or made it unclear what was happening. Other models used inappropriate colours that could lead to a state of confusion or frustrate the user, which can inhibit the learning process rather than facilitate it. This can also be observed in educational applications developed outside of tkeden. A relevant example of this is the JSearchDemo[1]. This is a piece of software written in Java that enables the user to create graphs and explore them using different algorithms. When utilising the A* algorithm, the shortest path taken so far is coloured yellow, and all other paths taken are orange (see Figure 1). There are several issues with this design:

- The colour of a node can change more than twice as the shortest path in the queue changes, which can lead to confusion.
- The start node is always coloured yellow as it is always part of the shortest path. This may cause difficulty in locating the start node whilst performing a search on a large graph.
- The start and goal node are only identified by the colour of their text label, which is small and difficult to see.
- The colours orange and yellow are too similar and have no significance in their use.

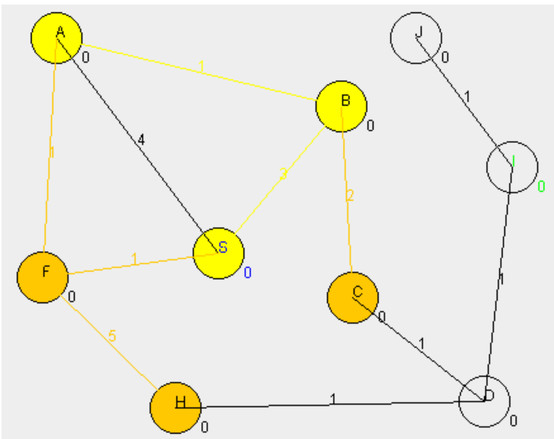

Figure 1: JSearchDemo application. Here, the start node is 'S', (yellow node in the centre), and the goal node is I, (middle clear node)

[1] JSearchDemo: http://el-tramo.be/software/jsearchdemo

In addition to usability issues, it has been demonstrated that the use of colour can influence one's memory capabilities. Myers (2004) discusses a memory experiment which was published in the Journal of Experimental Psychology. Participants looked at a combination of black and white, and colour photographs, and were later shown a super-set of these images. When asked to identify images that had been shown in the previous set, colour images were remembered more than black and white. This may seem unsurprising, but an interesting result was that images which were coloured falsely were remembered no more so than black and white images. The use of appropriate colour is therefore a critical issue when creating a model for educational purposes.

3 Empirical Models for Education

Beynon (1997) describes the empiricist perspective on learning as a process involving personal interaction with artefacts, acquiring skills in their manipulation, and correlation of these experiences. It is also noted that learning is "fundamentally concerned with a process of construing phenomena in terms of agency and dependency". The focus on a requirement for interaction in this definition of learning, corresponds with the potential misconception of seemingly simple techniques in computer science. Without experience of implementing the theory, it is difficult to reveal any misunderstandings.

3.1 Potential Benefits of EM

Shelton (2006) notes three ways in which a model could be used as an educational tool; observation, interaction and redefinition. It is redefinition that is a distinctive quality of empirical models, as regular software does not allow the user to change the underlying structure in a simple manner. This capacity for low level interaction can give the user a richer experience, and allow a deeper insight into the semantics behind it, suggesting that empirical models can facilitate learning.

When manipulating an empirical model, a user does not have to follow any rules. This creates an environment that promotes self exploration, which has been described as "one of the key skills for life-long learning" (Beynon et al., 2006). Although this self exploration can be beneficial as the structure of the model can be examined, there has been little analysis on whether exploration without limits can lead to confusion. It may be the case that by completely opening up the structure of the model to redefinition, the user could change its behaviour without realising. The user could then be utilising an incorrect model, which may lead to further misinterpretations.

3.2 Desirable Attributes for an Educational Model

An empirical model should be accessible, intelligible and correct. Accessibility relates to the Human Computer Interaction (HCI) characteristics of the model, which can enhance or degrade usability depending on the quality of the implementation. As previously mentioned, HCI also has a direct influence over a user's memory retention when using a model for educational purposes. In particular, the use of colour can have a significant impact.

An intelligible model is one that is written in a way which makes it simple to comprehend, and can therefore be extended quickly and easily. This does not only refer to a person wishing to substantially expand the model, but also to the casual user who desires to study various intricacies. A model without this property can limit the value of empirical techniques, as it hinders redefinition of the model.

Correctness is arguably one of the most important features of an educational model. Clearly, if the principles behind the model are incorrect, the user cannot gain accurate knowledge. It could be contended that this property somewhat contradicts the principle of self exploration and redefinition as discussed in Section 3.1.

4 A* Graph Explorer

4.1 Aims and limitations

When developing A* Graph Explorer, the principle aim was to develop a model that could act as a proof of concept for the claim that empirical modelling can be used to facilitate learning. Focus was placed on customisation, interaction and usability. For this application, it is most important that a user can customise the route taken on the graph, the individual path costs and the heuristic values, in order to gain a rich experience. It was decided that given a large enough graph, the ability to add and remove nodes quickly was not a high priority, and should be left for the user to determine from the code if required.

The development of the Heapsort model (Beynon) was considered whilst designing and implementing A* Graph Explorer, as it was hoped that this model could do for searching, what previous models have done for sorting.

4.2 Behavioural to State Based View

One of the key challenges when developing this model was linking a state based view to the essentially behavioural stance associated with the algorithm. In order to depict the A* algorithm, the following observables must be considered:

- List of all known nodes
- List of adjacencies for each node
- Notion of a node being unexpanded
- Notion of a node being expanded
- Notion of a node being a potential next move
- Path costs
- Heuristic value for each node
- The parent of each node

As with the Heapsort model, each of these observables have specific counterparts in the model that can be inspected or modified at any time.

When exploring a graph using the A* algorithm, the state of the search can be defined by the unexpanded nodes, nodes which have been expanded, and nodes that could be reached by the next move (potential nodes). The expanded and potential nodes are displayed in the 'Search Information' area of the model. The relationship between this list representation and the graph must be examined in order to gain a better understanding of the structures involved in the A* algorithm.

When a search commences, the start node is expanded, it's adjacent nodes are added to the potential list, and the parent of these nodes are set as the start node. On each subsequent step of the algorithm, the potential node with the smallest F-Cost is moved to the expanded list, it's adjacent nodes are added to the potential list, and the parent for each of these nodes is set. There are also other considerations, for example if an adjacent node is already on the potential list, the parent will only be updated if the G-Cost of the new path is smaller than that of the original path.

4.3 Agency

The `STEP` button on the UI can be thought of as an 'agent' that takes the search to the next correct state according to the algorithm. It is important to note the difference between an agent performing the algorithm step, and a human agent being able to take the appropriate actions involved in this step. In order for the human agent to 'understand' the domain, a combination of observation, interaction and redefinition must be utilised. This is easily achievable through modifying the route taken, heuristic costs and path costs, and observing the effect that this has on the search. Using the UI to modify the H-Costs and G-Costs, restart the search and reset the graph also demonstrates a form of agency.

4.4 Dependencies

When implementing the model, it was conceived in terms of dependencies. Some of these are detailed below:

- The F-Cost of a node is it's H-Cost + the G-Cost of the path to that node.
- The colour of a node depends on it's state. The start node is green, goal node is red, an unexpanded node is grey, potential nodes are orange and expanded nodes are light green.
- The colour of a path also depends on it's state. Unexplored paths are black, potential paths are orange and explored paths are light green.
- A node is potentially expandable only if it is adjacent to a currently expanded node.

In addition to these dependencies, the modularity of the model was also considered to be important. In order to make it easy to manipulate the aesthetics of the model, all colours, fonts and important variables are stored centrally. For example, to change the background colour of the graph, only the SCOUT variable `graphBGcol` must be altered. The background colour for the H-Cost and G-Cost labels are then taken into account when this variable is modified. Another example is that of transforming the size of the nodes. Rather than modifying each node individually, only the variable `nodeWidth` must be changed. Almost all aspects of the model have central variables that affect more than one feature.

4.5 Design decisions

It was determined in the research stage of the project that the use of appropriate colour could have a positive effect on the acquisition and retention of knowledge. This was kept in mind when designing the interface for the model. Myers (2004) notes that the colour blue gives a calming atmosphere. It was deemed appropriate to use this as the principal background colour, given that people generally learn more efficiently in a relaxing environment. It is widely known that the colour red is associated with adrenaline and excitement, therefore it was chosen to alert the user that the search has been completed, and for the display of the shortest path found, as can be seen in Figure 2.

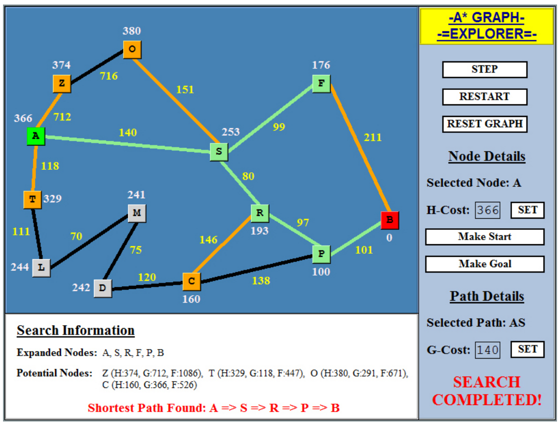

Figure 2: A* Graph Explorer: An example state after a completed search

When selecting node and path colours, the objective was to ensure that they bore significance to the state of the search. This was achieved by setting the start node as green, potential nodes and paths as orange, and the goal node red. It was hoped that people may transfer the association with traffic lights (go, get ready, stop), to that of the model (start, potential, goal), in order to create an intuitive user interface (UI). A lighter shade of green was employed for expanded nodes and paths, so as to separate them from the start node.

A potential argument against using empirical modelling for education was that of the correctness and redefinition contradiction. In order to help guard against erroneous interaction with the model, it was decided that the functionality for manipulating the route taken, path costs and heuristic values should be accessible from the UI.

4.6 Future Extensions

This model was conceived as a proof of concept, thus there are several interesting areas for extension. When adding a new node to this graph, there are a number of functions which need to be modified in order to accommodate it. It may be beneficial to define a new graph notation for use in empirical models, which would enable rapid creation of new graphs.

It may be feasible to consolidate the process of adding or removing nodes and paths into a single function, but in this case it may not necessarily be beneficial. If a user can view the dependencies in the model and determine how to do this themselves, it is likely that a more complete understanding of the model and algorithm will be gained.

It would be possible to implement many other graph search algorithms that can utilise this graph. Uninformed search strategies such as Breadth First Search, Iterative Deepening and Depth First Search could easily be implemented. It would also be motivating to observe and contrast other informed search strategies such as Dijkstra's algorithm and the Bellman-Ford algorithm.

There are currently no textual explanations of the algorithmic process integrated into the model. These could be of significant benefit if other algorithms were to be implemented using this model as a base, as it could reinforce the theory behind them. The EM Presentation Environment[2] could be of particular use in this respect.

5 Conclusions

The design of the physical graph utilised in A* Graph Explorer was based on a graph used in (Russell and Norvig, 2003) . This is a textbook which is commonly employed in university Artificial Intelligence courses. It was decided that this would be beneficial, as it enables a comparison of the textual based description of the algorithm to the empirical model. When the `RESET GRAPH` button is pressed on the model, the start node, goal node, H-Costs and G-Costs are reset to this default graph. When comparing the textual and diagrammatic description of the algorithm to use of the model, it is instantly noticeable that a much richer experience can be gained through the model. The ability to change the route taken on the graph and alter H and G-Costs, permits a deeper exploration of the algorithm. It is also possible to observe the effects of modifying the model in a way which is not generally permitted, such as giving paths negative weights.

It can be concluded that empirical modelling can be used to facilitate learning, but there are some important issues. The usability of a model can directly influence it's effectiveness as a teaching tool. By considering aesthetic properties such as the layout and colour scheme, the memory retention of a user can be maximised. Poor design of a model can make it difficult to maintain attention, or even cause confusion. If this is the case, it may be preferable to use conventional teaching methods. A potential conflict between the correctness requirement for a model and the desire for limitless redefinition of models has also been raised. In order to limit the scope for error, the most frequently used facilities for redefinition should be readily available on the UI. In the example of A* Graph Explorer, the user can modify H-Costs, G-Costs, and the start and goal nodes from the main interface. It may also be useful if tkeden provided the facility to go back to a previous state, without having to manually redefine any modified variables.

The personal aims which were established in the early stages of the project were fully realised. Further knowledge was gained in the field of Artificial Intelligence, and the experience in developing an empirical model provided an opportunity to gain a better understanding of EM principles. In addition to this, it was interesting to research the effect of interface design on the learning process.

[2]EM Presentation Environment: http://empublic.dcs.warwick.ac.uk/projects/empeHarfield2007/

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