Inspecting and Visualizing Distributed Bayesian Student Models

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Abstract. Bayesian Belief Networks provide a principled, mathematically sound, and logically rational mechanism to represent student models. The belief net backbone structure proposed by Reye [14,15] offers a practical way to represent and update Bayesian student models describing both cognitive and social aspects of the learner. Considering students as active participants in the modelling process, this paper explores visualization and inspectability issues of Bayesian student modelling. This paper also presents ViSMod (Visualization of Bayesian Student Models) an integrated tool to visualize and inspect distributed Bayesian student models.

1 Introduction

Ideas such as open student models and the active role of students in the modelling process have led several authors in the student modelling field to consider visualization and inspection of student models as two significant research areas [18]. When student models are presented to students and teachers various questions arise, such as:

- Are students able to understand their student model?
- What kind of representation is more appropriate –textual, graphical, etc. – and in which conditions?
- How does the student model information support students' reflection? Is it possible to use student feedback to build more accurate models?
- What kind of information is it possible to acquire by interacting with the model? Which components of the model should be available to students to visualize and manipulate?
- To what extent can information given by students, teachers and the system be combined to improve the modelling process?

Several authors have been working on some of these questions and interesting results have been found. In a preliminary study, Bull and Pain [2] found that students seem to understand textually presented models. Bull and Shurville [3] show how students and the system can co-operate for the construction of writer models improving the model and accuracy of their predictions. Morales et al. [11] show a graphical representation of the model for a sensori-motor task where modularity and interaction with the model are presented in a complementary way. Dimitrova et al. [6] explore a collaborative construction of student models promoting student's reflection and knowledge awareness. Mühlenbrock et al. [12] propose a teacher assistant which allows teachers to inspect student models in order to assess student's current state of knowledge, arrange students in groups, and suggest appropriate peer helpers. Paiva et al. [13] externalise the student model to the teacher, in order to test the modelling process, support self-assessment, and promote reflection and interactive diagnosis.

Most of the student models in the systems mentioned above are easily inspectable because the modelling approaches are relatively simple to understand. The models are slots and values, feature vectors, simple overlays or rules. More complicated representational formalisms, such as Bayesian belief networks can be effectively used to construct student models, but these representations are harder to inspect.

Several authors in different areas have explored the use of Bayesian belief networks to represent student models [4, 5, 8, 10, 14, 15, and 17]. Martin & VanLehn [10] propose a special interface (assessor's interface) that allows a human (The assessor) to create a Bayesian network of rules and factors. Using this interface the assessor can get an overview of the student's competence and manually increase the probability of a rule when new information is available. Although Bayesian belief networks provide a solid framework for student models in a computationally tractable fashion, understanding the status of a Bayesian network can be difficult. In previous work, we developed VisNet [7, 19] to experiment with how to visualize Bayesian networks.

In this paper, we extend our previous work to permit learners and teachers to inspect student models represented as Bayesian networks. We present a multiple-view application, ViSMod, that has been designed and built to allow students and teachers to experiment with creation of Bayesian what-if scenarios; providing not only a visualization tool, but also an interactive tool for inspection of and reflection on Bayesian student models. In addition, ViSMod has been adapted to visualize and inspect distributed Bayesian student models, allowing the use of student model information from different sources.

2 Visualizing Bayesian Student Models

One of the main advantages of Bayesian belief networks is that they provide an inspectable cause and effect structure among their nodes and direct specification of probabilities in the model [17]. BBNs offer a mathematically sound mechanism to represent uncertainty. Using such a technique (BBNs), assessment of students' knowledge can be carried out effectively. Visualizing and inspecting Bayesian student models becomes an interesting and challenging task that opens not only the internal representation of the student's knowledge, but also the mechanisms to update it to the human interested in knowing more about their representation on the system.

Previous work on how to visualize Bayesian students models showed how a graphical representation of the model in conjunction with different visualization techniques facilitates understanding of cause-effect relationships among nodes, marginal probabilities, changes in probability, and propagation of beliefs throughout the model. Figure 1 shows a screen shot from VisNet, an environment for experimenting with different visualization techniques for Bayes Nets.

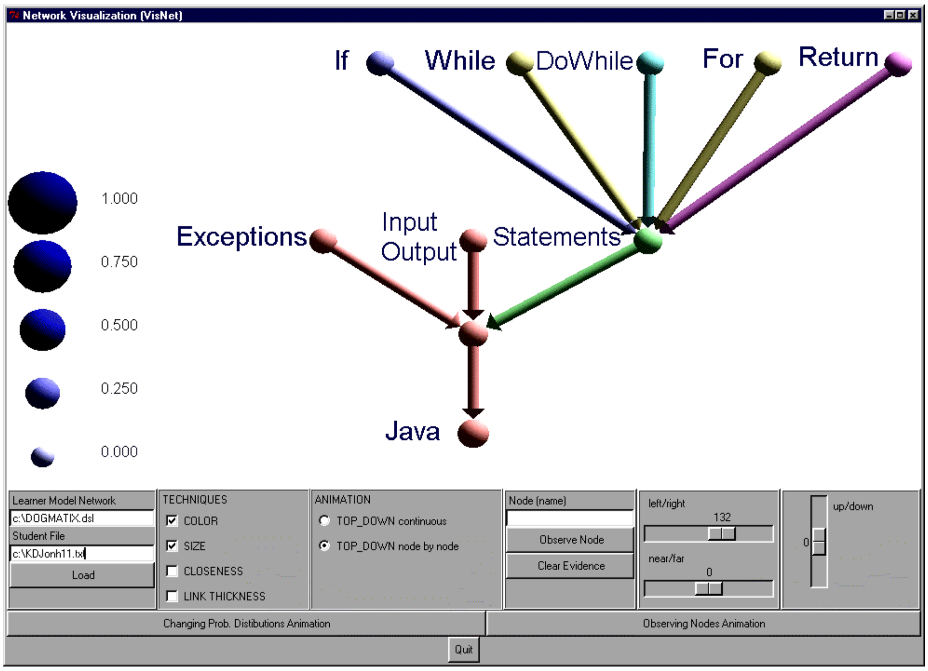

Fig. 1. VisNet– Using various visualization techniques

ViSMod, an extended version of VisNet, provides a flexible architecture where students and teachers can create their own views of a student model by choosing nodes they want to inspect from the Bayesian network representing the student model. Our system assumes the belief net backbone structure for student models proposed by Reye [14, 15], which covers content and social attributes in a three-level structure. The first level covers a prerequisite structure of nodes (e.g. student-knows(topic)), the second level consists of a set of topic clusters directly related to each of the nodes from the first level (e.g. student-claims-to-know(topic)), and the third level holds global nodes that represent general characteristics of the student that affect his/her learning process (e.g. eagerness).

ViSMod offers several widgets to visualize and inspect the model. For example, using the widgets "scrolling up-down", "left-right", and "near-far", it is possible to navigate throughout the model and focus on specific regions. The widgets "observe node" and "clear evidence" allow students to suppose that a specific node has been observed (believed to be true) and visualize how this change on belief is propagated throughout the model. Figures 2, 3, and 4 show a sample of the general three-level backbone structure and two different possible views of the model. A multiple-view platform is particularly useful to determine what components of the model are interesting for students and teachers and which components should be available to students for further visualization or inspection.

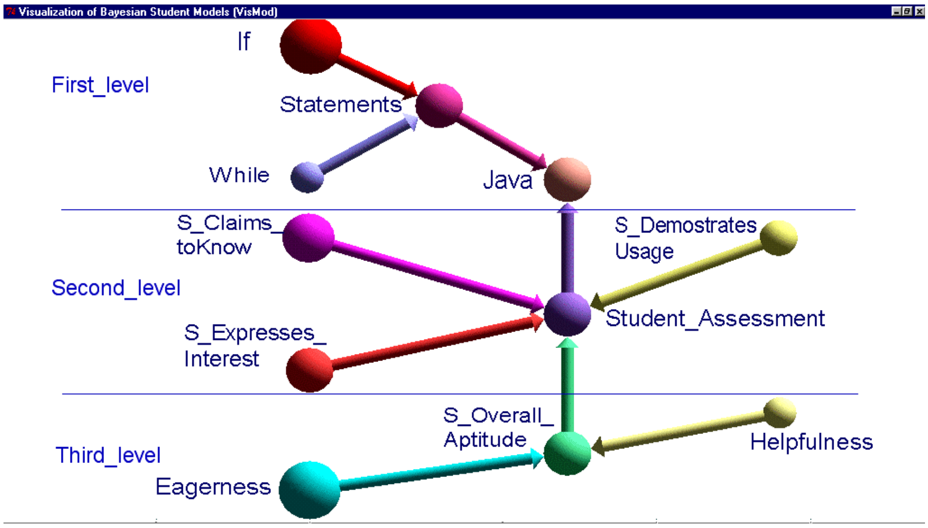

Fig. 2. ViSMod. A sample three-level backbone structure

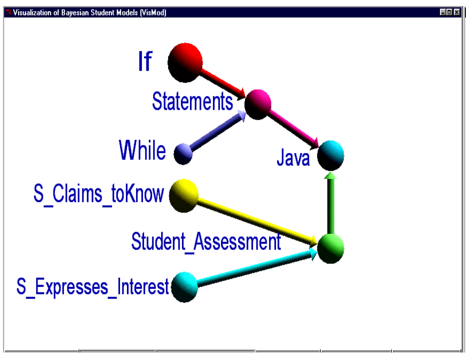

Fig. 3. Sample student view

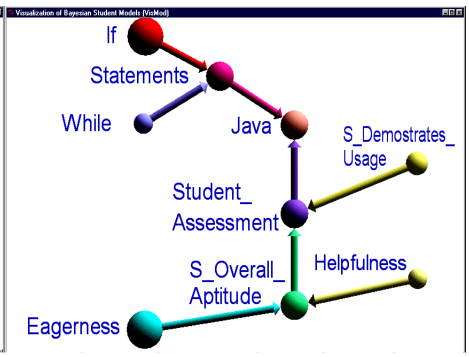

Fig. 4. Sample teacher view

3 Using ViSMod

An initial Bayesian student model organized according to Reye's belief backbone structure [14,15] must be provided to ViSMod. Such a model consists of nodes representing concepts of interest in the domain and directed links indicating influence of one node on another. Probabilities are associated with nodes and strengths of relationships are associated with links. Propagation of probabilities among the nodes, based on observed evidence, is computed according to Bayes rule. For a particular domain, the initial Bayes belief network can be created by the teacher as an overlay on a prerequisite relationship structure or concept map. New nodes and links can be added on any level according to students' or teachers' interests. This model (structure information and evidence) can be derived from the student model of a single ITS or from distributed models of a students from various ITSs.

Students and teachers can visualize the student model using visualization techniques where influence of one node on another or likelihood of a node being known are represented by such things as: colour, size, proximity (closeness), link thickness, and animation. Using ViSMod, it is possible to inspect the model of a single student, compare several students by comparing their models, navigate throughout the model changing focus according to students' and teachers' interests, and use several sources of evidence to animate the evolution of a new model.

Students and teachers can create their own views in order to visualize and inspect the model without changing the internal representation. Using their own views, it is possible to change probability values and add or remove nodes graphically. These views can be used as an important element to promote reflection and engage students and teachers in interesting discussions about their models and to use the results to refine their models.

Besides the obvious goal of continuous student assessment, teachers can also be interested in knowing what kind of evidence is being collected in order to detect possible inconsistencies, misconceptions, or gaps in student knowledge. By using ViSMod, it is possible to visualize and distil distributed student models into a single model, to find causes for inconsistencies and refine the model by changing the structure or adjusting probabilities values of the student model.

In a typical ITS, students are modelled according to their interactions with the system. Using this information, several decisions are taken inside the system in order to adapt the curriculum to the student. Although this approach has been used in many real applications, traditional student models do not differentiate students' and teachers' points of view about the model. Visualization and inspection of student models provide a means of capturing this information and allows for the creation of collaborative student models. By opening the student model, students, teachers, and the system collaborate to improve the accuracy of the model and the quality of help provided by the system.

Some of the benefits that ViSMod provides to students and teachers are:

- A graphical representation of the student model makes it easier for students to understand Bayesian student models.
- A tool that supports multiple views of the student model makes it possible to inspect, modify and create interesting representations of the learning process.
- By allowing inspection of student models and the creation of what-if scenarios, ViSMod supports students' reflection, knowledge awareness, and refining of student models.
- Finally, ViSMod allows visualization of distributed Bayesian student models with different levels of granularity using several sources of evidence.

4 Inspecting Bayesian Student Models

When the model maintained by the system differs in some way to the model that the student or the teacher expects, the capabilities of ViSMod to support the creation of what-if scenarios allow students and teachers to interact with the model and refining it.

One of the main problems found when using Bayesian networks is the intense knowledge engineering effort of specifying prior and conditional probabilities [17]. In order to facilitate inspection and understanding of Bayesian belief student models by students and teachers, custom interfaces have been implemented. Using such interfaces, it is possible to avoid direct manipulation of prior, conditional probabilities and integration of new evidence.

Using their own views, students and teachers can create what-if scenarios by choosing nodes, changing probabilities, and adding new evidence without changing the internal state of beliefs. Students and teachers can adjust and experiment with their views in order to create a model that reflects their perception of the learning process with high fidelity. Those scenarios are an important element to find conflicts between what the student and the system may believe about the student's knowledge state.

Working with ViSMod, students and teachers can discuss the student's knowledge state and thus actively engage in knowledge reflection. These discussions can result on changes to the underlying structure of the system's representation of beliefs and a more accurate version of the student model

5 Distributed Bayesian Student Models

Data for student models can be obtained and processed using software tools from widely diverse sources distributed across the Internet. In fact, a student model can itself be distributed. This requires a modelling technique that can store student model data in a distributed fashion and at the same time provide a common inference mechanism.

ViSMod provides a flexible architecture for visualizing distributed Bayesian student models. Figure 5 shows how ViSMod is organized to use student’s information from three software applications derived from the matchmaker component of I-Help [16], an online testing system named Dogmatix [9], and a web-based discussion forum named CPR [1]. ViSMod allows visualization of student models using different levels of granularity, and integrating several sources of evidence.

A Bayesian student model can integrate information from any telelearning system that has a model of the learner. It is especially useful in systems like I-Help, which integrate student model information form several sources. With ViSMod, students and teachers can visualize and inspect aggregate models maintained by the system.

VisMod can be used to create and maintain different kinds of student model views, to determine the effectiveness of a particular application in maintaining an accurate representation of the student, and to integrate evidence from various sources to be used for various purposes.

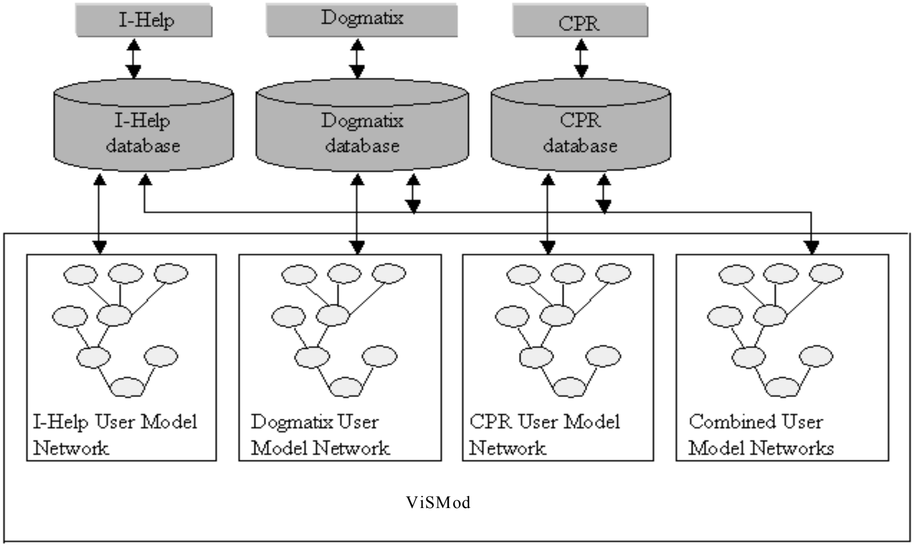

Fig. 5. ViSMod – Visualizing student models from several information sources

Figures 6, 7, and 8 show a fragment of a student model from three different applications –CPR, IHelp, and Dogmatix. Figure 9 shows how ViSMod combines student model information –structure and evidence- from all three applications in a single structure for further visualization and inspection.

Using ViSMod it is possible to integrate evidence from several sources into a single model. The combination of student models relies on the assumption that there is a common ontology among the various student model fragments (segments of a general model with some degree of overlapping) and that all of the distributed models were represented as Bayesian belief nets. This process is done by connecting the segments of the network based on the common nodes. That is, per each common node a new link is added and the conditional probabilities of the common node are changed to reflect the new evidence that comes from the new segment.

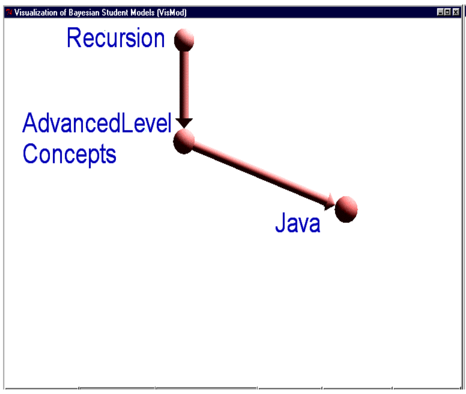

Fig. 6. CPR student model

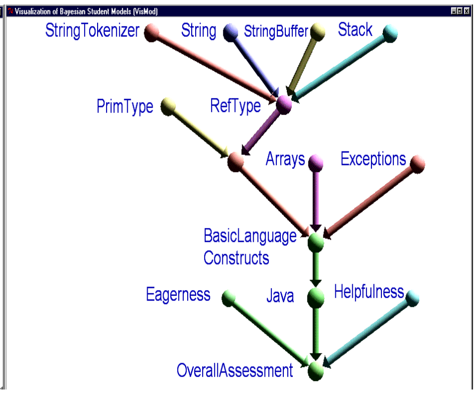

Fig. 7. Ihelp student model

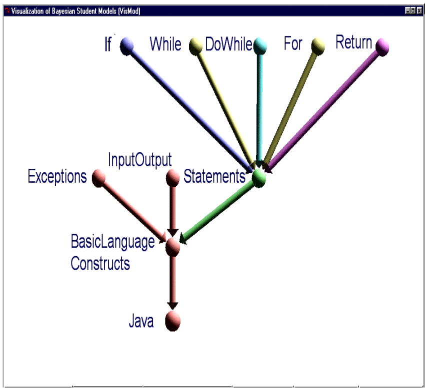

Fig. 8. DogMatix student model

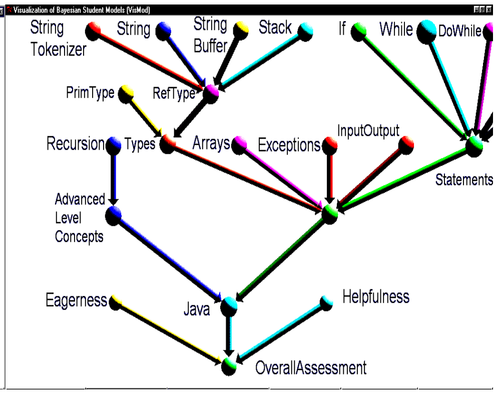

Fig. 9. Combined student model

6 Evaluation

A usability study was conducted with the visualization features of ViSMod. Spatial order, colour, size, proximity (closeness), link thickness, and animation were the visualization techniques evaluated by the participants. After a short explanation about cause-effect relationships and directed acyclic graphs (DAG), ten graduate students were asked to perform a sequence of tasks to determine the efficacy of each of the visualization techniques.

Some of the results found in this study are:

- Spatial order was chosen as an appropriate way to show cause-effect relationships; participants preferred size over colour to represent marginal probability.
- Combinations of techniques appear to be clearer than a single technique; participants chose size and colour as a good combination to represent marginal probability (size) and strength of a relationship (colour).
- For large networks, which are very sensitive to changes in size and position of the nodes, colour is a better alternative.
- Closeness of nodes proved to be an interesting and powerful way to show probability propagation and changes in probability.
- Finally, animation was useful for representing probability propagation; especially node by node animation, which was preferred because it shows both the sequence of Bayesian belief updating and probability propagation.

Future evaluation efforts will be designed to examine scaling up issues, such as:

- expanding and collapsing nodes when using bigger graphs (containing over 50 nodes)
- changing focus to specific regions of the model,
- using different visualization techniques on specific areas of the model, and
- comparing models by showing each model on a transparent layer.

7 Conclusions

ViSMod provides a flexible architecture where students and teachers can create their own views by choosing nodes from a Bayesian student model with a general backbone structure. Using ViSMod, students can understand, explore, inspect, and modify Bayesian student models.

The creation of what-if scenarios in ViSMod promotes students' reflection and knowledge awareness. ViSMod offers a practical tool to determine which components of the model are interesting to students and teachers. Students and teachers create, share and discuss interesting representations of learning process. ViSMod facilitates the evolution of student models by capturing and reflecting the information given by students and teachers during their explorations. Finally, ViSMod allows visualization of distributed Bayesian student models using different levels of granularity, and several sources of evidence.

One future goal will involve refining ViSMod into an authoring tool for creating, tuning and maintaining distributed Bayesian student models. Our aim is to employ this tool to visualize and inspect Bayesian student models in conjunction with different software applications that make use of student model information.

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