Cognitive Maps-Based Student Model

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Abstract. The main contribution of this PhD thesis is: A proposal for Student Modeling based upon Cognitive Maps. Its purpose is to anticipate the effects that a teaching-learning experience will produce on a student before its delivery. Thus, this dissertation focuses on the Student Modeling from the causal-effect perspective. Also, our approach aims to predict outcomes stemmed from teaching-learning sessions delivered by Web-based Education Systems. So the thesis claims for using Cognitive Maps to state the concepts that identify factors of several domains, as cognitive skills and knowledge about the teaching domain. In addition, the paradigm proposed sets the causal relationships between the factors of several domains. Concepts are valued in a universe of discourse by fuzzy terms. These qualitative values depict the level state or the variation of the state of the concepts after a while. Causal relations are outlined by fuzz-rules bases. Each rule identifies a cause-effect influence that a source concept owns upon a target one. Thus, given a fuzzy term for the antecedent concept, a corresponding linguistic value is assigned to the consequent concept. With this baseline, the approach traces fuzzy-causal inferences for predicting the behavior and outcomes of the student, before he/she faces a given teaching-learning experience. Wherefore in Web-based Education Systems, whose lessons have several sequence strategies and options of content, our Student Model offers a proactive and adaptive support for a student-centered education.

Keywords: Cognitive Maps, Student Model, concepts, relations, causality.

Introduction

Student Modeling is the domain of the PhD dissertation introduced in this paper. In a Web-Based Education System (WBES), the Student Model carries out the generation and maintenance of a mental profile of the individual. Student Modeling is a challenge, and it could be an intractable problem [1], due to it deals with subjective concepts, partial beliefs and complex tasks. Thus, the Student Model field offers a wide spectrum of research and application targets. This study line focuses on a plenty of issues such as: Characterization of the student, representation of the learning process, and design of Student Modeling approaches. In spite of these streams, there is a lack of a fuzzy-causal approach that states the factors that bias the learning of the student and depicts how they are involved to achieve an outcome. As the Cognitive Maps are mental models that depict issues from the causal perspective, this thesis sets the teaching-learning process as a cause-effect phenomenon. Wherefore, our project is a pioneer work that introduces the use of Cognitive Maps for the Student Modeling. Its relevance remains on: A set of theoretical hypothesis and empiric evidence that will be gathered from experimental trials.

Thus the organization of this paper is as follows. In the first section is set up the lay out of the thesis. In the second section is sketched an overall idea of the solution model. In the third section are claimed the main contributions of the dissertation. Finally in the fourth section is pointed out the current state of the PhD project and the further work to be done.
1. Overview of the Dissertation

1.1 Problem Definition

The PhD dissertation focuses on the problems about: How to depict the factors that influence the knowledge acquisition of the student, and how to anticipate their causal effects, before he/she faces a teaching-learning experience? In addition, this PhD thesis pursues to answer the following questions:

1. How to model the cause-effect phenomenon that succeeds during teaching-learning experiences?
2. Which are the relevant domains needed to characterize a student profile?
3. Which are the main domains required to depict a teaching-learning experience?
4. Which are the domains’ concepts to be modeled, and how to evaluate their state?
5. How to outline the cause-effects relationships between pairs of concepts?
6. How to organize the knowledge about the concepts and relationships?
7. How to estimate the fuzzy-causal inferences?, and,
8. How to predict the causal outcomes that it is believed they occur along the session?

1.2 Proposal

As a solution for the problem stated this dissertation proposes: A Cognitive Maps-based Student Model to sketch and predict the causal phenomenon achieved by a teaching-learning experience delivered by a WBES.

The underlying assumption of the thesis is: As a result of identify the factors that bias the teaching-learning, set their cause-effect relationships, and apply a causal-inference mechanism; it is possible to state a Student Model that anticipates the causal impact on the knowledge acquisition that the student faces.

Furthermore, the dissertation tries to answer the prior questions in the order that they were introduced as follows:

1. Based upon the Activity Theory and Cognitive Maps,
2. In regards to the student profile are considered: Cognitive, Personality, Learning Preferences and Independent knowledge domains.
3. Regarding to the teaching-learning experiences are used: Sequence, Content, Assessment and Evaluation domains,
4. A set of concepts is carefully chosen from each domain. Afterwards, they are qualitative evaluated through linguistic values stemmed from their respective universe of discourse,
5. The causal relationships are outlined by fuzzy rule-bases, where the antecedent corresponds to the cause factor and the consequent to the effect concept,
6. The concepts and the relationships are stated as classes and properties that are organized hierarchically in an ontology,
7. Through a Fuzzy Carry Accumulation operation it is estimated the accumulative influence produced by several fuzzy rules that fires simultaneously on the same effect concept, and,
8. By means of a Rule-Base Fuzzy Cognitive Map that simulates the dynamics of a Qualitative System.
2. The Solution Model in a Nutshell

2.1 Conceptual Model

The underlying concepts of the Cognitive Maps-based Student Model rest on: The Activity Theory [2], the Rule-Base Fuzzy Cognitive Maps approach [3], and the Student Model Foundations [4]. So a profile of the baseline elements is outlined next.

The PhD thesis takes into account the five basic principles of the Activity Theory, stated by Leont’ev, for modeling the teaching-learning experience as follows:

1. **Object-orientedness.** Every activity pursues an object. Thus, the activity aims for anticipatory reflection before developing any action. So the activity corresponds to the teaching-learning experience, whilst the object to the knowledge acquisition. Before the WBES delivers any experience, our approach estimates the causal impacts stemmed by every option in order to choose the most suitable one,

2. **Hierarchy structure.** The object is satisfied by an activity that is fulfilled by the achievement of a set of goals. Each goal is accomplished by a set of actions. Each action is carrying out by a set of operations that are constrained by conditions. This principle corresponds to the sequencing strategies and the content taxonomy of the teaching-learning experience,

3. **Tool.** It is the agent that mediates the activity. In the context of the WBES, the system as a whole and more specifically the Student Model play the tool role,

4. **Development.** Human interaction with the reality should be analyzed in the context of the activity. So the results stemmed from the teaching-learning experiences have to be evaluated against the predictions formulated by the Cognitive Maps, and,

5. **Externalization – Internalization.** Externalization turns mental activity into an object. Internalization is the mental activity that is stimulated by the social interaction. Thus, the Externalization corresponds to the teaching action, the cause. Whilst, the Internalization represent the learning, the effect.

In regards to the Cognitive Maps, they are considered as cause-effect prediction models. Cognitive Maps are based on the philosophy principle about causality that states: For every fact there is at least one cause, and given the same conditions, the same causes bias the same effects [5]. The causality is a relationship between events that is able to trigger the occurrence of one of them. The events are associated to physical or abstract entities that are depicted as concepts. So the concepts point out the main attributes of the entities and their internal relationships. A cause-effect relationship is a belief about how a concept promotes or inhibits another concept.

A Cognitive Map is sketched as a digraph, where the nodes correspond to the concepts and the links to the causal relationships between pairs of concepts [5]. Each causal relation is described by a fuzzy rule base. The antecedent of the rule shows the linguistic term of the cause concept. Whilst the consequent part of the rule identifies the fuzzy value assigned to the effect concept. The concepts own a value that points out the *level* of the state in a specific time, or the *variation* that the state suffered after a while.

For instance, in Fig. 1, appear five concepts from content, personality, cognitive, learning preferences and knowledge domains. Those concepts are causal related by arcs, which are labeled by the id of the Rule Base attached. The id owns the acronym RB, plus a consecutive integer and a positive or negative sign. Also, the current concept values appear inside square brackets. In addition, in Table 1, a Rule-Base is stated for defining the causal relationship between two concepts. In its right column appears the linguistic term for the cause concept, whilst in the left column is the fuzzy value for the effect concept.
Figure 1. Cognitive Map composed by text from content, sensitive from personality, visual-spatial from cognitive, divergent from learning preferences, and object from knowledge

Table 1. Rule Base RB 9+ for the relation between the cause concept divergent from learning preferences, and the effect concept object oriented from teaching knowledge

<table>
<thead>
<tr>
<th>Antecedent: Divergent</th>
<th>Consequent: Object Oriented</th>
</tr>
</thead>
<tbody>
<tr>
<td>If divergent’s state increase very high</td>
<td>Then object oriented’s state is stimulated high</td>
</tr>
<tr>
<td>If divergent’s state increase high</td>
<td>Then object oriented’s state is stimulated</td>
</tr>
<tr>
<td>If divergent’s state increase very low</td>
<td>Then object oriented’s state is stimulated low</td>
</tr>
<tr>
<td>If divergent’s state maintains</td>
<td>Then object oriented’s state maintains</td>
</tr>
<tr>
<td>If divergent’s state decrease</td>
<td>Then object oriented’s state is inhibited low</td>
</tr>
</tbody>
</table>

The fuzzy-causal inference is achieved through an iterative process, whereby the concept values are transformed along each step. Prior begin the cycle, the fuzzy values of the concepts are measured and introduced as initial values. Afterwards, the simulation begins through discrete increments of time. Every time new concepts’ values are estimated according to the relations sketched in the Cognitive Map. The causal effects that simultaneously bias a given concept are accumulated by means of a Fuzzy Carry Accumulation. This fuzzy operation is the main contribution of the Carvalho’s PhD thesis [3]. He puts forward a method for computing the accumulative effects over the universe of discourse associated to the consequent concept instead of aggregate the membership degree.

The outcome of the inference does not represent the real state value of the effect concept. However, it expresses a kind of perturbation about the state of the concept. This value means a fuzzy variation, i.e., increases, decrease, maintains, and so on.

The process ends when the concepts’ values reach a state of equilibrium, a limit cycle or a chaotic attractor. The behavior of the concepts and of the whole Cognitive Map is revealed as: The variation of the concepts’ values along the iterations and the final state that they reach. Based on this interpretation, the prediction about the causal outcome is done.

The concepts involved in a Cognitive Map reveal the beliefs (B) that the WBES (s) holds about the student (U). The beliefs are stated as propositions (p). Thus, the mental model (MM) that the system develops is: The set of prepositions that the system believes are believed by the student is: $MM = Bs (U) = \{ p | Bsp (U) \}$ [6].

Based on Koch’s PhD dissertation [4], in this proposal are considered three domains for eliciting the student profile: Cognitive skills, Personality attributes, and Learning preferences. The material regarding to the teaching-learning experiences is authored in several options of: Content type, Sequencing strategy, Assessment method, and Evaluation mechanism. The knowledge domain to be acquired for the student is characterized as concepts, whose initial values correspond to the background of the student about the subject. These concepts values are progressively perturbed as a result of the teaching-learning experiences faced by the student, as it is illustrated in Fig. 2.
2.2 Structure of the Approach

The PhD approach is accomplished along three stages: Development, Initialization and Exploitation. In the development stage are fulfilled five components of the Student Model, as: 1) Module for eliciting the student profile by means of psychological tests. 2) Tool for authoring teaching-learning experiences. 3) Ontology for depicting the concepts stemmed from the domains [7]. 4) Ontology based mechanism for the automatic generation of the Cognitive Maps. 5) Fuzzy causal inference engine.

During the initialization stage is carried out the ontological acquisition task, by means of four processes: 1) Elicitation of the student profile from three domains as cognition skills, personality and learning preferences of the individual. This information is gathered from psychological tests. 2) Description of the teaching-learning experiences. This task depicts the concepts from four domains, as assessment methods, sequencing strategies, type of content and evaluation techniques. 3) Ontology administration. It edits instances of classes and properties, which correspond to concepts and relationships from seven domains.

During the exploitation stage the teaching-learning cycle is achieved in four steps: 1) Selection of the best option for the teaching-learning experience. A Cognitive Map is generated for each option. Next, the Fuzzy causal inference mechanism is triggered over the Cognitive Map. So during the simulation, the behavior of the concepts values is tracked. At the end of the iterative process, the interpretation of the outcomes is done for identifying the degree of convenience of the option. Afterwards, it is chosen the option that predicts the best expectative for teaching the subject. 2) Provision of the selected option of teaching-learning experience through: The sequencing strategy, content delivering, evaluation task, and assessment record. 3) Gathering empirical evidence. Along the sessions are recorded the values of three types of variables that identify the reliability of the approach. 4) Tuning the Student Model. After the experience, the Student Model is updated according to the accuracy of its predictions against the learning achievements.

2.3 Empirical Evaluation

The test of the PhD proposal rests on the analysis of variance and covariance upon the independent, dependent and nuisance variables. Also it is considered the measure of the effect size and the power, which correspond respectively to the treatment magnitude, and the inverse sensitivity [8].

Figure 2. Behavior of the Cognitive Map shows the evolution of concepts during iterations.
3. Contributions

The contribution of the PhD thesis is to propose a new Student Modeling approach causal-centered by means of Cognitive Maps. Its theoretical goals are: A set of hypothesis about the impact on the students that experience the support of the Cognitive Maps-based Student Model; and the empirical results gained from the experiments.

As a deliverables, the PhD dissertation outcomes: A computational prototype of a Cognitive Maps-based Student Models; an ontology of the domain of the application; and a fuzzy-causal inference engine for predicting behavior.

The main contributions of the proposal are: A novel qualitative-causal version of a predictive Student Model; an approach for generating Student Models and Cognitive Maps based on an ontology; a teaching-learning model supported by the Activity Theory; and an extension of the sort of applications of the Student Model and Cognitive Maps.

4. Current and Further Work

As a result of the work already done three technical reports were published, and the research protocol has been approved by Doctoral jury. Twelve work papers have been presented in international conferences whose proceedings have been published by prestigious houses such as Springer Verlag and IEEE (refer for example to [5, 6 and 7]. Nowadays, two more are under revision for conferences supported by Springer. In addition, one full paper will be published by Expert Systems with Applications from Elsevier (a journal classified by ISI), and one more is under the second revision process by the Computation and Systems Iberoamerican International Journal. Besides of this, three chapters of the thesis are already edited, and one more is sketched. The further work to be done is: The development of the prototype, the experimentation of the approach, the edition of four chapters and the publication of the findings in refereed journals classified by ISI.

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References