Intelligent Educational Systems for Individualized Learning

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Abstract

In this paper, we present the basic principles underlying the main types of intelligent educational systems used for individualized learning (i.e. Intelligent Tutoring Systems and Adaptive Educational Hypermedia Systems). Their characteristic is the ability to adapt presentation of the educational content to the needs of specific users. The paper also presents some open issues for future work in both types of systems.

1. Introduction

Numerous computer-based systems have been used in education during the last decades. The first such systems were called Computer Aided Instruction (CAI) systems and were quite effective in helping learners. A major disadvantage, however, was their inability to adapt instruction to the individual's needs. This drawback gave rise to a new generation of education systems encompassing intelligence in order to increase their effectiveness.

Intelligent Tutoring Systems (ITSs) constitute a popular type of intelligent educational systems. ITSs take into account the user's knowledge level and skills and adapt presentation of the teaching content to the needs and abilities of individual users [8, 9, 12, 14]. This is achieved by using Artificial Intelligence techniques to represent pedagogical decisions as well as information regarding each student. ITSs were usually developed as stand-alone systems. However, the emergence of the WWW gave rise to a number of Web-based ITSs.

Another popular type of intelligent educational systems are the Adaptive Educational Hypermedia Systems (AEHSs) [1, 2]. This type of systems is specifically developed for hypertext environments such as the WWW. The main services offered to their users are adaptive presentation of the teaching content and adaptive navigation by adapting the page hyperlinks. Compared to 'classical' ITSs, they offer a greater sense of freedom to the user since they allow a guided navigation to the user-adapted educational pages. Furthermore, they dynamically construct or adapt the educational pages in contrast to 'classical' ITSs in which the contents of the educational pages are static.

In this paper, we describe the main components and functionality of an intelligent educational system such as an ITS or an AEHS (section 2). In addition, the paper presents some open issues for future work in the two types of intelligent educational systems (section 3). Finally, section 4 concludes.

2. Basic Components of an Intelligent Educational System

Figure 1 depicts the basic architecture of an intelligent educational system. It mainly consists of the following components: (a) the domain knowledge containing the teaching content and information about the teaching subject, (b) the user model which records information concerning the user, (c) the pedagogical model which

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encompasses knowledge regarding the various pedagogical decisions, (d) the user interface. The remaining part of this section will elaborate on the first three components.

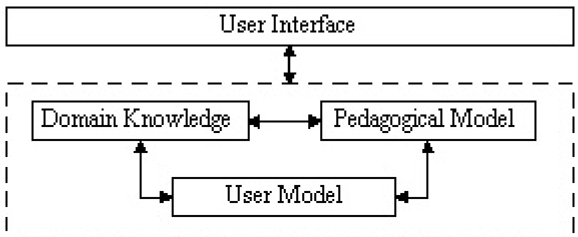

Figure 1 Basic Architecture of an Intelligent Educational System

2.1 Domain Knowledge

Domain knowledge contains knowledge regarding the subject being taught as well as the actual teaching content. It usually consists of two parts: (a) *knowledge concepts* and (b) *course units*.

Knowledge concepts refer to basic pieces of knowledge concerning the domain. Every concept has a number of general attributes such as, its name, its level of difficulty etc. Furthermore, various concepts can be linked to other concepts according to their relation. In this way, one or more *concept networks* are formed representing the pedagogical structure of the domain to be taught. The most usual relations between the concepts are the following:

- *Prerequisite*: Some concepts are prerequisite of others. The user should know some or all the prerequisite concepts of a specific concept before accessing its corresponding educational content. Prerequisite concepts can be disjunctive, conjunctive or combinations of them.
- *Part-of*: Many simpler concepts are part of a more complex concept.
- *Is-a*: This relation connects a concept with others that are its typical instances.

The most usual representation schemes for concept networks are AND-OR graphs, frames and conceptual graphs. AND-OR graphs are the simpler representation schemes containing (AND) links denoting conjunctive prerequisite relations and (OR) links denoting disjunctive prerequisite relations. Frames and conceptual graphs are more complex representation schemes encompassing frequently concepts, course units and sometimes rules for their selection and ordering.

Course units constitute the teaching content presented to system users. A course unit may correspond to theory, examples or exercises. Course units can represent whole educational pages or fragments from which educational pages are generated based on the user model. The second case is most usual in AEHSs. Each course unit is associated with one or more knowledge concepts either prerequisite or outcome. The user is required to know the course unit's prerequisite concepts in order to be able to grasp the corresponding knowledge. By studying course units, the user gains knowledge of its outcome concepts. The distinct representation of the domain's pedagogical structure (concepts) and the actual teaching content (course units) facilitates updates in domain knowledge.

The pedagogical model based on the user model, selects and orders the course units presented to the user. In this way, a user-adapted presentation of the teaching content is achieved. The existence of a variety of relations between concepts enables the system to generate different plans for the teaching of the same educational content. Interconnections between the course units can also facilitate this task [4].

To facilitate selection and ordering of course units, domain knowledge frequently includes a *meta-description* of course units based on their general attributes. There exist standards for the meta-description of course units such as ARIADNE (http://ariadne.unil.ch), IEEE LTSC Learning Object Metadata (http://ltsc.ieee.org/) and Dublin Core (http://purl.org/DC/). Mappings between these standards have also been developed. The primary goal of these standards is to foster the share and reuse of electronic educational material. Key issues that should be dealt with by the standards is the easy creation of metadata by humans and furthermore the efficient exploitation of the metadata by users looking for relevant educational content. The educational metadata is grouped into categories in order to increase their comprehensibility.

2.2 User Model

The user model records information concerning the user and regarding his/her knowledge state and traits. This information is vital for the system's operation according to the user's needs. The process of inferring a user model from observable behavior is called *diagnosis* because it is much like the medical task of inferring a hidden physiological state from observable signs [9]. The term *bandwidth* is used for describing the amount and quality of information available to the diagnosis process. There are many possible user characteristics that can be recorded in the user model and choosing the most appropriate ones can be a problem. If the user model is incomplete, the system's adaptability will be unsuccessful, whereas if it is complex, the system's operation will be encumbered.

Primary user characteristics recorded in the user model are the following:

- *History of the user's interaction with the system*: It contains information such as the course units 'visited' by the user or the answers given to exercises (wrong answers may have preceded the correct one).
- *Mental skills* including characteristics such as learning ability and concentration derived mainly from the user's interaction with the system.
- *Goals*: It is a characteristic that often changes e.g. from session to session or within the same session. The goals can be discerned to high level goals e.g. learning goals or low level goals e.g. problem solving goals [1].
- *Preferences*: They mainly refer to educational content presentation parameters such as multimedia type preferences (e.g. text, images, or animations) regarding the presented course units or their level of detail. Sometimes preference to specific teaching strategies can be denoted. The preferences can be set explicitly by the user or implicitly by recording performance with regard to specific presentation techniques and teaching strategies.
- *Background* and *experience*. The user's background refers to experiences beyond the scope of the teaching subject, which are important enough to be considered. Such information includes experience in other relevant fields, experience in using computers, familiarity with the system, etc.
- *Knowledge regarding the teaching subject*. The user's knowledge regarding the teaching subject constitutes the most important user characteristic as far as an ITS or an AEHS is concerned. The user's knowledge can be represented in a variety of methods. Well known representation methods are the following: (a) the overlay model, (b) the buggy model, (c) stereotypes, (d) uncertainty models, (e) constraints. This characteristic is analyzed in the remaining part of the section.

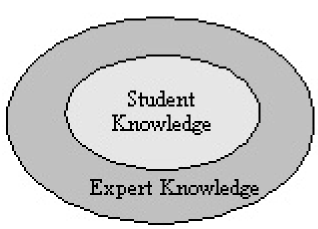

Figure 2 The overlay model

The *overlay model* [9] is the most popular way of representing the user's knowledge. This model is based on the pedagogical structure of the knowledge domain (i.e. knowledge concepts). According to the overlay model, the user's knowledge is considered to be a subset of the expert's knowledge (Figure 2). For each knowledge concept, the model retains a value representing the user's knowledge level. This value can either be boolean (known, not known) or scalar. Based on the overlay model, the system presents educational content until the user's knowledge is identical to the expert's knowledge. The overlay model has been used very often in ITSs and AEHSs since its simplicity is a great advantage.

A disadvantage of the overlay model is its inability to represent possible user misconceptions. For this purpose, the *buggy model* [9] is used which represents the user's knowledge as the union of a subset of the domain knowledge and a set of misconceptions (Figure 3). The buggy model provides great assistance in correcting the user's mistakes because recording his/her erroneous knowledge is pedagogically very useful. There are two variations of the buggy model: the *bug catalogue* and the *bug-parts-library* model.

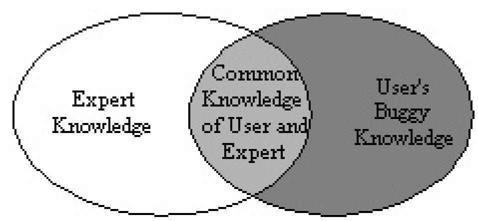

Figure 3 The buggy model

In the bug catalogue model there is a library of predefined misconceptions used to insert the user's corresponding misconceptions in the user model. A disadvantage of this model is the difficulty in constructing this library. In case the library is incomplete, the system may misdiagnose the user's misconceptions. In the second variation, the user's misconceptions are created during the teaching process from a library of bug parts. This library usually contains symbolic rules with conditions and actions executed when the conditions are satisfied. Therefore the bug-parts-library is quite smaller and easier to be constructed.

A simpler way of modeling the user's knowledge is to use stereotypes. Stereotypes denote predefined classes of users. A stereotype model is represented as a set of pairs 'stereotype-value' where 'value' specifies if the user belongs or not to the specific stereotype. A stereotype is activated and deactivated with the use of triggers. Stereotype models are simpler than the other models and can thus be easier initialized and maintained. Some problems of this model are the difficulty in defining the possible stereotype classes for a specific teaching subject, the difficulty in setting boundaries between different stereotypes and the fact that the simplicity of the model restricts the adaptation power of the intelligent educational systems.

Sometimes uncertainty models are employed to model the user's knowledge [7]. Such models use Bayesian networks, fuzzy logic, neurofuzzy representations, etc.

Constraint-based modeling [8] is a representation scheme specially suited for intelligent educational systems. A constraint indirectly represents the solutions violating the knowledge domain. The user's knowledge is represented as a set of constraints that he/she violates or not. Constraints enable the system to focus only on pedagogically significant problem states and provide influential assistance during the solution of problems. A potential disadvantage of this method may be the inability to define constraints for every teaching subject. The number of constraints should be sufficient enough in order to enable detection of user errors. It remains to be seen if this knowledge representation technique is suited for every teaching subject or just for specific subjects.

2.3 Pedagogical Model

The pedagogical model represents the teaching process. It provides the knowledge infrastructure in order to tailor the presentation of teaching content according to the information contained in the user model. The pedagogical model of a 'classical' ITS performs the following tasks: (a) *educational plan construction*, (b) *tutoring strategy selection*, (c) *selection of course units (educational pages)*, (d) *evaluation of user's performance and user-adapted assistance*. The AEHSs support two other tasks: (a) *adaptive presentation* and (b) *adaptive navigation.* Very few stand-alone ITSs use Adaptive Hypermedia technologies but most of the Web-based intelligent educational systems can be classified as both ITSs and AEHSs. In the remaining parts of this section, each one of the pedagogical tasks is further analyzed.

Pedagogical Tasks of a 'Classical' ITS

A primary task of the pedagogical model is to construct a plan of the educational course presented to the user. The plan is based on the concept structure and the user model. Due to the existence of various relations between concepts, alternate plans can be derived in order to teach the same content. These alternate plans will suit the needs of different users. Based on the constructed plan, the course units are selected, ordered and presented to the user. For this purpose, the characteristics of the user model (e.g. presentation preferences) as well as the meta-description of the course units are taken into account. In order to increase the system's teaching effectiveness, construction of the plan as well as selection and ordering of course units should not be static but updated according to the user's performance.

The pedagogical model contains tutoring strategies denoting how the teaching subject should be taught. It is important for an intelligent educational system to offer more than one tutoring strategy because this will entail a richness of tutorial actions. If the system offers limited tutoring strategies, it will be restricted in its pedagogical scope. An important factor is to incorporate an effective mechanism for selecting the appropriate strategy at a given point of the teaching process. Selection is based on various factors [13] such as user's advancement, user's preferences, changes in tutorial material, etc.

Another important aspect of the pedagogical model is to evaluate the user's performance based mainly on the answers to exercises. In this way, the user model is updated and presentation of the educational content is affected accordingly. The system should be able to identify on the one hand what is wrong or incomplete in the user's answers and on the other hand the missing knowledge or misconception causing the error. The system can analyze only the final solutions to the problems, each individual solution step, or several solution steps and accordingly offer user-adapted assistance. Assistance can vary from mere hints to the complete solution to the problem. In case of user errors, remedial tutoring may be necessary causing global or local changes to the lesson plan [14].

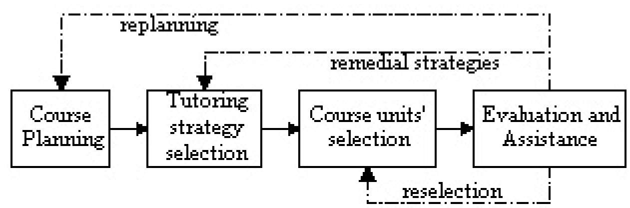

Figure 4 Pedagogical tasks of an ITS

Figure 4 outlines the primary tasks performed by the pedagogical model of a 'classical' ITS. The dashed lines indicate possible affections caused by the user's evaluation.

Pedagogical tasks of an AEHS

Adaptive presentation adapts the contents of an educational page to user model characteristics. A popular method of adaptive presentation is known as *additional explanations* [2]. In this method, the various pieces of information constituting the course units are associated with conditions. When conditions are satisfied, the corresponding information is presented. In this way, some information, which is incompatible with the user's characteristics, is hidden from him/her. This means that some users will obtain additional information compared to others.

Another popular method of adaptive presentation concerns the *explanation variants* [2] that stores variations of the educational content and selects the most suitable one according to the user model. The method can be implemented in two ways. The simplest way of implementing it is to use *page variants*. In this case, the system retains variants of the same page with different presentations for the same subject. A more specialized way of implementing the 'explanation variants' method is to use *fragment variants*. This specialization is useful when an educational page refers to more than one knowledge concepts. These two ways can be combined in order to enable adaptation according to multiple user characteristics. For instance, the appropriate page can be selected from the page variants according to the user's background and the suitable fragments according to the user's knowledge level.

Adaptive navigation assists users in navigating the hyperspace of the educational system by adapting the page hyperlinks to characteristics of the user model. Its goal is to find 'optimal paths' through the learning material [1]. The usual methods of adaptive navigation are the following:

- *Direct guidance*. It is the simplest adaptive navigation method. It shows the next best course unit to access. It is best to use direct guidance in conjunction with other adaptive navigation methods so that the user will have more freedom in his navigation.
- *Link sorting*. The links of a specific page are sorted in decreasing relevance order.
- *Link annotation*. According to the appropriateness of the corresponding pages, links are annotated using link colors, icons, etc.
- *Link hiding, removal, disabling*. Links presumed to be of low interest are hidden and presented as simple text, totally removed or disabled.

3. Open Issues

Some open issues in intelligent educational systems that remain to be dealt with are the following:

- Implementation of intelligent educational systems with various knowledge representation techniques (e.g. neural networks, symbolic rules, frames, hybrid methods, etc.) and comparison of their relative advantages and disadvantages. Knowledge representation techniques specially suited for intelligent educational systems such as constraint-based modeling can also be developed. There is no need to limit knowledge representation of intelligent educational systems to traditional methods [8].
- Checking how effective are the services provided by the intelligent educational systems regarding their response time. This factor is extremely crucial for every system with a high level of human interaction. A system, which is educationally rich but not time-effective, will inevitably deter trainees from using it. The restrictions imposed by the nature of the Web further enhance the importance of time-effectiveness. To increase the speed of the various intelligent educational methods, algorithms such as the one described in [6] may be necessary.
- Finding ways of automatically creating educational content that will decrease the development time of an intelligent educational system. Up to now, creation of educational content (e.g. exercises, examples) was done manually requiring thus a lot of time and increasing development cost. Methods such as the one described in [3] for automatic creation of exercises will be very useful.
- The use of distributed Artificial Intelligence methods to achieve communication of different intelligent educational systems teaching the same or closely related subjects [11]. With such methods, users will effectively exploit the various educational systems existing in the Web.
- The need to formalize the various aspects regarding the intelligent educational systems. There has been work in this field but much remains to be done. For instance in [13] a formalization of tutoring strategy selection in multimedia tutoring systems is described. Moreover, [15] presents a formalization of the curriculum knowledge representation and [10] proposes an evaluation approach to deliver suggestions for the improvement of the architecture and the behavior of an ITS.
- Using intelligent educational systems within the context of collaborative learning environments where users learn as members of groups. In this case, the system should model characteristics of collaborating user groups [5]. The notion of collaborative user modeling has been defined for this purpose.

4. Conclusions

In this paper, we briefly describe the main components and functionality of an intelligent educational system such as an ITS or an AEHS. The basic characteristic of these systems is their ability to tailor presentation of teaching content to the diverse needs of their users. The paper also presents some open issues for future work in such systems.

It is obvious that in a versatile environment such as the WWW where there are users of different backgrounds, skills and preferences an intelligent educational system can play a very important role. Distance learning, a significant aspect of modern education, has become a reality due to the WWW. The role of intelligent educational systems will prove to be very important since they will further enhance the teaching abilities of distance learning systems.

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