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A fuzzy linguistic algorithm for adaptive test in Intelligent Tutoring System based on competences

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ABSTRACT

The Computerized Adaptive Tests (CAT) are common tools for the diagnosis process in Intelligent Tutor System based on Competency education (ITS-C). The item selection process to form a CAT plays a key role because it must ensure the selection of the item that best contributes to student assessment at any time. The item selection mechanisms proposed in the literature present some limitations that decrease the efficiency of CAT and its adaptation to the student profile. This paper introduces a new item selection algorithm, based on a multi-criteria decision model that integrates experts' knowledge modeled by fuzzy linguistic information that overcomes previous limitations and enhances the accuracy of diagnosis and the adaptation of CAT to student's competence level. Finally, such an algorithm is deployed in a mobile tool for an ITS-C.

1. Introduction

An ITS provides direct customized instruction or feedback to students in their learning processes by means of Artificial Intelligence (AI) techniques, being mainly applied to knowledge representation, managing an instruction strategy as an expert both in the teaching and pedagogical issues in order to diagnose properly the student learning status at any time. To fulfill its objective, an ITS is organized by an architecture (see Fig. 1) composed by a domain model (what is taught?), student model (who is taught?), diagnosis of the student (Wenger, 1987), instructional model (how is it taught?) (Bourdeau & Grandbastien, 2010) and the interface (man–machine interaction) (Nkambou, 2010; Wenger, 1987). It is worthy to highlight that the pedagogical model of reference guides the design of each component of the architecture of an ITS, so the knowledge representation in the domain model, student model and the diagnosis process will depend on the adopted model.

In Badaracco and Martínez (2011) has been designed a novel architecture for an Intelligent Tutoring System based on competency education (ITS-C) in which the diagnosis process estimates, updates and stores, in the student's model, the knowledge achieved by the student during the learning process. The quality of instruction provided by an ITS depends on the amount and accuracy of the information stored and updated in the student model.

Tests are tools widely accepted for evaluation by its generality, ease of deployment and automatic correction. During the 80s emerged the *Computer-Administered Tests* (Weiss, 1982) that have evolved to the current sophisticated *Computerized Adaptive Tests* (CAT), which are used for evaluation in most of ITS (Guzmán, Conejo, & Pérez de la Cruz, 2007; Jeremić, Jovanović, & Gašević, 2012). A CAT evaluates and updates the student model by displaying an item/question to the student at each time, that is selected according to his/her level of knowledge and other criteria such as minimum entropy, maximum information, difficulty, etc. (Guzmán et al., 2007; Neira, 2002; Rudner, 2009).

The item selection process in a CAT plays a key role for the usefulness and adaptation of the diagnosis process. In ITS-C is defined a domain model of competency, a curriculum domain model, a student model based on competences and a diagnosis process based on CAT whose performance improved classical ITS (Badaracco & Martínez, 2011). However the current performance of CAT avoids a better efficiency and adaptation to the student's profile because it still needs the calibration of characteristic curves that is intractable in small institutions and whose parameters are uncertain and hard to understand. The item selection algorithm uses one single criterion, is time consuming and does not take into account dynamics of the process.

To overcome previous drawbacks this paper proposes a new fuzzy linguistic item selection algorithm implemented for the diagnosis process in ITS-C. Such an algorithm models the item selection process as an Multi-Criteria Decision Making (MCDM) problem by

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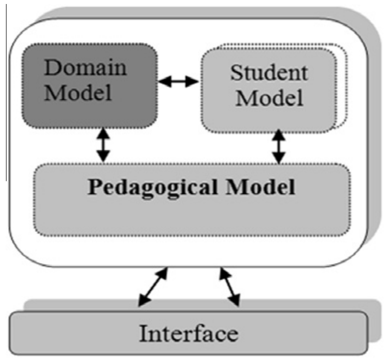

Fig. 1. Generic architecture of ITS.

using experts' knowledge linguistically modeled (Herrera & Martínez, 2000; Zadeh, 1975a, 1975b, 1975c) to avoid calibration, and it includes a dynamic component in the selection process. Finally the algorithm is implemented in a ITS-C with a mobile client.

The paper is organized as follows, Section 2 reviews the ITS-C architecture and the diagnosis by means CAT. Section 3 presents the fuzzy linguistic dynamic algorithm for CAT in ITS-C. Section 4 shows an ITS-C with a mobile client that runs the previous algorithm. Finally some concluding remarks are pointed out.

2. Intelligent tutoring systems based on competency-based education. Architecture and diagnosis process

An ITS-C extends an ITS by linking the latter and the pedagogical model based on Competency-based Education (CBE) using the architecture showed in Fig. 2 (Badaracco & Martínez, 2011). The domain model, student model are briefly reviewed and then a further detailed revision of the diagnosis of an ITS-C (Badaracco & Martínez, 2012) is presented to facilitate the understanding of the proposal introduced in section 3.

2.1. Domain model of ITS-C

The representation of the *domain model* in an ITS-C is based on the descriptors utilized in CBE (Badaracco & Martínez, 2011) that reflect good professional practices to guide the development of the competency associated with an occupational role or profile (Catalano et al., 2004; Europe Tuning, 2000; Zalba, 2006). Such a set of descriptors are:

- *Competency unit* (*cu*): It is a main function that describes and groups the different activities concerning the role or profile chosen.
- *Competency element* (*ce*): It is the disaggregation of a main function (*cu*) that aims to specify some critical activities. A function (*cu*) can be specified by one or more competency elements (*ce*), according to its complexity or variety.
- *Evidence of performance* (*evd*): It checks if a process is performed according to best practices.
- *Evidence of product* (*evp*): It is a descriptor of tangible evidence in the results level, when the best practices have been used.
- *Evidence of knowledge* (*evk*): It is a descriptor about scientific-technologic knowledge that allows the user understands, reflects and justifies competent performance.

Therefore the *domain model* contains the expert's competences profile about a knowledge domain, hence for an ITS-C it will consist of four components briefly detailed below, further description see (Badaracco & Martínez, 2011):

(i) *A domain model of competency (DMCo)*: It is represented by a semantic network whose nodes are competence units (*cu*), competence elements (*ce*), descriptors (*evd, evp, evk*) and their relations.
(ii) *A curriculum domain model (CuDM):* It deploys the DMCo according to a teaching strategy that defines the competences associated to a professional profile to perform a training proposal in different situations. The CuDM based on the CBE takes a modular structure, in which each module (M_i) contains competency elements *(ce)* belonging to the DMCo.
(iii) *A set of descriptors*: The descriptors associated with the *ce* of the didactic modules are *evd, evp*, and *evk*, that belong to a bank of items.
(iv) *Test specifications:* They are provided by the teachers and associated with the diagnosis process considering the scope of application and the rules that the system should follow to propose adaptive tests according to the student's necessities of learning.

2.2. Student model of ITS-C

In an ITS-C the *student model of competence (SMC)* stores student's information, whose data are updated through a diagnosis process. For the representation of the student's knowledge and learning process, the SMC uses an overlay model in the semantic network of the CuDM (Badaracco & Martínez, 2012).

In such a semantic network the nodes *evp, evd* and *evk* store a probability distribution $P(\theta_{evp} = k|\vec{u}_i), P(\theta_{evd} = k|\vec{u}_i)$, and $P(\theta_{evk} = k|\vec{u}_i)$ regarding the student's level of competency k in the corresponding node, k can take values from 1 to the maximum number of level of competency on which the student is evaluated. Being θ the student's level of technical-scientific knowledge about a descriptor for a response pattern $\vec{u}_i$ obtained from the responses provided by the student in the test T (see Fig. 3) during the diagnosis process.

2.3. Diagnosis for ITS-C based on CAT

Our interest in the diagnosis for ITS-C is because its key role in ITS due to the fact that the quality of instruction offered by an ITS depends on it. In ITS-Competency based Education (ITS-C) (Badaracco & Martínez, 2011), the diagnosis process follows the pedagogical model of reference for achieving a greater efficiency. The diagnosis process estimates and updates the level of competency achieved by the student in the nodes of the SMC. To carry out the diagnosis of an ITS-C, it was adapted and extended the Computerized Adaptive Test (CAT) based on the Item Response Theory (IRT) (Badaracco & Martínez, 2012; Guzmán et al., 2007). In CAT systems the relationship between student outcomes in the test and its response to a certain item can be described by a monotone increasing function called the Item Characteristic Curve (ICC). The ICC of an ITS-C coincides with the correct response option of the characteristic curve of option (CCO). Its main components are:

- *A response model associated to the items*: It describes the student's expected performance according to his/her estimated knowledge. An ITS-C uses a *discrete* and *non parametric* response model based on the Item Response Theory (IRT) (van der Linden & Hambleton, 1997) able to evaluate multiple choice answers (Guzmán et al., 2007).
- *Bank of Items*: Each item I_i is associated to its descriptors (evd, evp or evk) and each option of I_i corresponds to a characteristic curve of option (CCO) obtained by a calibration process based on the Ramsay algorithm (Ramsay, 1991). Each CCO is