INFORMATION REUSE AND INTEGRATION WITH FUZZY COGNITIVE STRUCTURES

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Abstract

Fuzzy cognitive structures may be used to facilitate information reuse and integration in the realm of cognitive diagnosis. In particular, the use of *fuzzy chain-of-thought structures* [5], and their corresponding homomorphisms, for cognitive diagnosis in a tutoring environment is proposed for systems that are distributed, heterogeneous, and possibly autonomous. Such systems are based on mediator and multiagent architectures where multiple heterogeneous information sources are used to accomplish a global task. A design framework is proposed for use with intelligent tutoring systems that may be embedded into existing web-based learning and collaboration systems.

Keywords: Cognitive diagnosis, fuzzy chain-of-thought structures, web-based learning and collaboration systems.

1 Introduction

Cognitive diagnosis was defined in [4] as "the task of inferring the differences between a person's perceived cognitive state and some desired or expected target cognitive state". We perform this task whenever we interact with one another. When monitoring the problem solving performance of an individual in a tutoring environment, for example, an approximation of this individual's mental cognitive processes is required to correctly identify misconceptions or bugs in the problem solving approach [5].

Systems for cognitive diagnosis typically have several modules that need to contribute and share information in order to accomplish common, global tasks. Diagnostic systems may also be concerned with information integration or, more generally, information fusion. Such fusion may stem from the diagnostic system's use of various tools to arrive at a unified diagnostic estimate about the state of the system being diagnosed.

The author has proposed the use of fuzzy cognitive structures to model *chains of thought*. In [5], chains of thought are defined as "a string of cognitive states representing some aspect of an individual's thought processes." These thought processes pertain to a (cognitive) task under consideration.

2 Motivation and Related Work

Next to expert systems design and implementation, intelligent tutoring systems [10], or ITSs, were once one of the largest areas of research in artificial intelligence. Perhaps the biggest bottleneck in ITS research was the development of a viable solution to maintaining an accurate and reliable student model. Not too far off was the development of a plausible diagnostic method. Numerous solutions were forwarded, but after a slow start, interest in ITS research soon waned.

Today, the Web is used as a distance education medium to provide web-based learning and collaboration systems [1], such as *VU* (see http://virtual-u.cs.sfu.ca) and *WebCT* (see http://www.webct.com). Such systems provide research and assessment tools that track online course activities from various perspectives. Although some of these tools facilitate the study of user behavior and teaching/learning processes, these are not at the level that cognitive diagnosis demands. Perhaps ITS research can be revived by a need to provide these web-based learning and collaboration systems with built-in intelligent tutors?

Table1. Various combinations of teacher and tutor interactions available to students.

Teacher \ Tutor	*Local*	*Remote*
Local	*(L,L)*	*(L,R)*
Remote	*(R,L)*	*(R,R)*

As shown in Table 1, the *(L,L)* teacher-tutor interaction is the traditional instructional experience by a student. Web-based learning and collaboration systems currently provide students with *(R,L)* teacher-tutor interaction, since these systems are primarily used as distance education tools. In these situations, remote students use the Web to asynchronously access live lectures and course materials. Gearing ITS research for implementations that may be embedded into web-based learning and collaboration systems is a much more challenging undertaking than whatever obstacles were prevalent up to the late 1980s. The Web has changed the features of most software systems, most of which are becoming more and more distributed, heterogeneous (varying data models, hardware platforms, operating systems, etc.), and in some cases autonomous [11]. ITS research should now focus on the premise of providing the student with either (L,R) or (R,R) teacher-tutor interaction, where the tutor may actually be an inanimate intelligent agent. In such an arena, facilitating information reuse and integration becomes more crucial.

The use of *fuzzy chain-of-thought structures* to model cognitive diagnosis in a tutoring environment was first proposed in [5]. These structures are derived from a variant of *fuzzy cognitive maps*, whose formulations also appear in [4]. Since the approximation of chain of thought structures is inherently fuzzy, its connection and relevance to current work in *computing with words* [13] and *fuzzy information granulation* [12] have also been investigated [3]. Furthermore, in [2], details of inference and decision making mechanisms using fuzzy chain-of-thought structures were presented and discussed.

More closely related to issues of information integration or information fusion are morphisms. Preliminary work on homomorphisms between fuzzy cognitive maps and fuzzy chain-of-thought structures were presented in [8] and generalized for hasse diagrams in [6]. The dynamics and semiotic implications of these formalisms are presented in [4,9].

In the next section, the author will bring together the previous work on fuzzy chain-of-thought structures just mentioned to illustrate how these structures facilitate information reuse and integration in the realm of cognitive diagnosis. The underlying motivation is to ease the design and implementation of a distributed, web-based intelligent tutoring system that conducts cognitive diagnosis by relying on various diagnostic tools.

3 Detail of Proposed Framework

3.1 User Interface Considerations

In designing a distributed, web-based intelligent tutoring system, the design of an appropriate interface is one of the most important tasks. One way to look at this is to note that in addition to the interface's implied primary task of facilitating the user's experience and interaction with the underlying system, it should also contribute to a global effort to construct an approximation of a novice user's chain-of-thought. Such an intelligent interface may allow user interaction through various methods, including linguistic-like input (typed or vocal), form-based input (checkboxes, radio buttons, etc.), and the use of other domain-specific tools. The intention in the last method listed is to provide tools that the user can exploit in attempting to solve a problem, at the same time providing the system with a way to reverse-exploit the use of these tools to determine some way of building a student model. Some examples of such domain-specific tools are clickable periodic table and/or virtual laboratory for a chemistry tutor, an allele-based generational drawing tool for a genetics tutor, an icon-based data structures design tool for an object-oriented programming tutor, and many others. After all, there is a growing desire for web-based learning and collaboration systems that provide course templates [1] to some degree, perhaps even at the user interface level.

To facilitate the rest of the discussion, the author will focus on a proposed implementation of an intelligent tutoring system called *Diagnosis in Problem Solving* (or *DIPS*) [4,5]. In particular, the discussion will revolve around the *Diagnosis Module* of the *Cube Processor* of DIPS (see Figure 1). The DIPS Diagnosis Module consists of a Chain-of-thought Analyzer and a Cube Processor. (The concept of the "Cube" is discussed in [5] and is not pertinent to this discussion.) The Chain-of-Thought Analyzer embodies all FCM and chain-of-thought structure operations, including all homomorphims [5].

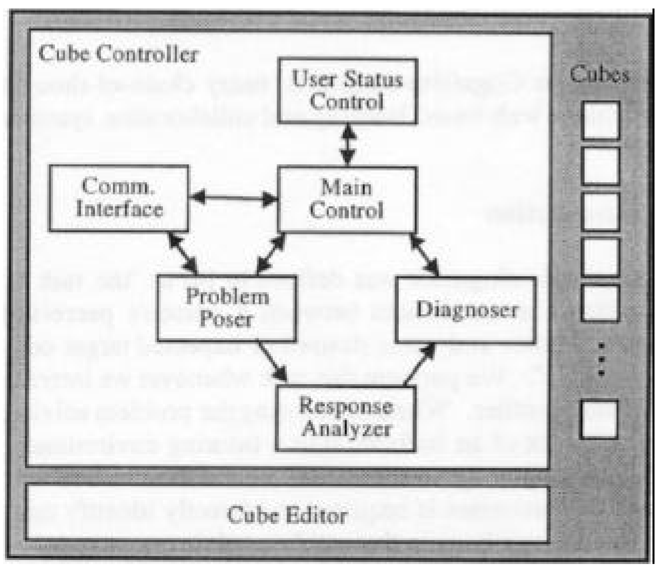

Figure 1. Submodules of the DIPS *Cube Processor* [5].

3.2 Representation and Operations

Each of the DIPS Cube Processor's submodules share information through the use of fuzzy chain-of-thought structures and their corresponding homomorphims. For example, the response analyzer module (see Figure 1) takes "linguistic" input from the user and converts it to a fuzzy cognitive map (or FCM), $M = (C_M, R_M)$ where:

$C_M \in [0,1]^X$ is a *fuzzy concept space* of the finite universe X; and

R_M is a *fuzzy multirelation* on $C_M \in [0,1]^X$.

Structure preserving FCM homomorphisms, defined in [5] as consisting of both node and path mappings, derive a degree of similarity between FCMs.

Fuzzy chain-of-thought structures are defined in terms of FCMs [5]. Denote by $F(A)$ the fuzzy power set of a fuzzy set $A \in [0,1]^X$. Then, a fuzzy chain of thought structure is a 5-tuple $S = \langle C, R, \Psi, \Phi, \delta \rangle$ where:

> C and R denote a fuzzy concept space and a fuzzy multirelational space for an FCM denoted by $\langle C,R \rangle$;
>
> Ψ and Φ are sets of sub-FCMs of $\langle C,R \rangle$ such that for $\langle C_\Psi,R_\Psi \rangle \sqsubseteq \Psi$ and $\langle C_\Phi,R_\Phi \rangle \sqsubseteq \Phi$ then $C_\Psi, C_\Phi \sqsubseteq F(C)$ and $R_\Psi, R_\Phi \sqsubseteq F(R)$; Ψ and Φ denote the *knowledge state space* and *input space*, respectively; and
>
> δ: $\Psi \times \Phi \rightarrow \Psi$ a transition function for the chain of thought structure.

Structure preserving, transition preserving, and consistency preserving chain-of-thought homomorphisms, defined in [5], are used to derive a degree of similarity between chain-of-thought structures.

Measures of similarity between FCMs and/or fuzzy chain-of-thought structures are used to calculate how far or near a user's partial and/or complete solutions are from an "ideal" solution recognized by the system. A fuzzy rule base may then be used to formulate appropriate responses to the user.

3.3 Facilitating Information Reuse and Integration

The role of fuzzy rule bases in the DIPS framework was investigated in [2] where the author presented the design of an intelligent controller for cognitive diagnosis based on the DIPS Cube Processor. The intelligent controller replaces the main control submodule (see Figure 1) of the original design. This modification is based on the proposed use of fuzzy inferencing techniques in conjunction with fuzzy decision making techniques to coordinate the tasks of the relevant submodules [2]. The components of the proposed intelligent controller are shown in Figure 2.

Recall the four possible combinations of teacher-tutor interactions (see Table 1) that a student can experience. In the (L,L) teacher-tutor case, since both teacher and tutor are available at the local site, they can coordinate their activities so as to maximize the benefit for the students. Current web-based learning and collaboration systems provide the (R,L) teacher-tutor case, where either the teacher or the student may be remotely located (depending on the perspective) and the student may have access to a tutor locally at the student's site. Hence, with the (L,R) and (R,R) teacher-tutor case where the author proposes that ITSs take the role of the tutors, these tutors have to be designed as mediators in a collaborative learning environment. This mediator view of ITSs is based on the motivation of making the (L,R) and (R,R) teacher-tutor case closer to the traditional (L,L) teacher-tutor case where information is shared between teacher and tutor as both coordinate their activities. As an example, note that most web-based learning and collaboration systems provide assessment tools that are based on log data (logins, page hits, messages sent, chat sessions, etc.) and student records (scores/grades, distribution of scores, etc.) [1]. Similarly, in a tutoring situation within the (L,L) teacher-tutor student experience, such data would be pertinent in enriching the tutoring experience. Hence, log data and student records should be exploited by ITSs integrated into web-based learning and collaboration systems.

Figure 2. Components of an intelligent controller for cognitive diagnosis[2].

Based on the DIPS Cube Processor design depicted in Figure 1, ITSs integrated into web-based learning and collaboration systems may need to be designed as multiagent systems. Likewise, incorporating fuzzy inferencing techniques and fuzzy decision making techniques into ITSs (as exemplified in [2]) based on mediator and multi agent architectures facilitates the integration of heterogeneous information sources, where the compatibility of the information to be integrated or fused needs to be addressed. Information compatibility, in this situation, can be plagued with questions of vagueness, ambiguity, and similarity – all of which are typically fuzzy in nature.

As an example, a web-based ITS for a programming class may be faced with the situation where:

(a) a student seems to exhibit good participation in class (this information may derived from login logs and chat or bulletin board message logs);

(b) the same student seems to be doing very good with the laboratory exercises, but only fairly with the quizzes and the exams (this information may derived from student records, which may also provide student performance in comparison with the rest of the class); and

(c) the same student is having difficulty solving a relatively simple problem that he/she should manage easily at this point in the semester (this information may be derived from the current tutoring session with the student, a record of past tutoring sessions with the student, and the set course schedule/curriculum).

There are numerous ways to handle this situation, all of which are based on the integration of the available information from various sources. Again, fuzzy inferencing techniques (where a fuzzy rule base may be used to represent subjective tutoring and/or pedagogical information) and fuzzy decision making techniques (along with subjective preference and objectives) may be used in managing this feature of an ITS.

In [2], the author also emphasizes the use of fuzzy inferencing techniques and fuzzy decision making techniques in the user status control module and the diagnoser module (see Figure 1), for updating and maintaining a student model.

4 Summary and Conclusions

Artificial intelligence techniques are finding their niche in information system integration. Typically, mediator and multiagent architectures are used to integrate heterogeneous information sources by means of distributed AI techniques [11]. In this paper, the author proposed the use of *fuzzy chain-of-thought structures* [5] for cognitive diagnosis in a tutoring environment, and the use of the corresponding homomorphismsto facilitate information reuse and integration when systems are distributed, heterogeneous, and possibly autonomous. The proposed framework relies on fuzzy inferencing and fuzzy decision making techniques [2], and is designed for use with intelligent tutoring systems (ITSs) that may be embedded into existing web-based learning and collaboration systems.

The author also proposes that ITS research focus on ITS integration into web-based systems. This seems to be a promising area for further information reuse and integration research.

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