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AN AUTONOMOUS MULTI-AGENT SOLUTION FOR ADAPTIVE EDUCATION

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Abstract
Adaptive learning and teaching strategies are increasingly demanded in order to improve the efficiency and effectiveness of the education process, but few adaptive tutoring systems exist which satisfy individual students' requirements. We have developed a novel use of agent technology using autonomous agents to address the key functions of intelligent tutoring systems, which uses learning style schemes to adapt to students individual needs, and which supports the use of learning objects. The incorporation of agents and learning objects is based on learning style – a pedagogic foundation for adaptivity, and this is one of the contributions of the research. Several case studies have been applied to the system, and a prototype of the agent is implemented.

Keywords
Autonomous Agents, Adaptive Education, Intelligent Tutoring System, Learning Objects

1. Issues of Adaptivity in Education

Advanced information technologies are increasingly used in higher education to facilitate learning and teaching, but inadequacies exist in current systems, materials, and pedagogy. For example, the application of similar learning strategies to all students in a class can be ineffective, and the failure to include design skills in introductory modules becomes apparent later on in the students' course. Students often tend to treat a course as a series of mechanical exercises rather than systemic concepts [1], and a specific framework to support the change process is often lacking [2]. Currently, much courseware and software used in higher education are unstructured and isolated from each other.

People learn in different ways. It is important to be aware of the differences between learners, and this is especially relevant during the current expansion of tertiary education to a greater proportion of the population. New delivery mechanisms are required, including online, open and distance learning [3].

These issues can be partially resolved by providing student-centred, self-paced, highly interactive teaching materials and introducing automatic and asynchronous teaching methods. Although there are many educational technology projects, both stand-alone learning systems and Web-based tools, using techniques such as multimedia interaction, learning models and asynchronous learning, there is as yet no integrated approach to the design of pedagogic information architectures [1].

Such intelligent collaborative systems must still be adaptive, learnable and dynamic [4], and agent technology can provide a dynamic adaptation not only of domain knowledge, but also of the behaviour of individual learners. Agent technology is influenced by advanced information and Internet technologies, and it appears to be a very promising approach which addresses the challenges of modern day education [5].

2. Introduction of Related Technologies

To enhance adaptivity in intelligent tutoring systems, we have incorporated compatible technologies and concepts.

2.1 Agent Technology

Agent technology is a new paradigm for developing software systems [6]. A wide variety of definitions for agents have been proposed, but until now there is no universally accepted definition. However, we can consider an agent as being a software entity that is capable of carrying out flexible autonomous activities in an intelligent manner in order to accomplish tasks to meet its design objectives, without direct and constant intervention and guidance of humans.

Depending on the roles of agents in the different environments in which they may be deployed, their abilities vary significantly, and this has motivated the adoption of different definitions of an agent. However, we still can identify essential and commonly agreed properties of agents, which include: a*utonomy*, *proactivity*, *responsivity*, and *adaptivity.* Agents should know users' preferences and tailor interactions to reflect these [6].

Multi-agent systems contain many agents that communicate with each other. Each agent has control over certain parts of the environment, so they are designed and implemented as a collection of individual interacting agents. Luck et al. remark "Multi-agent systems provide a natural basis for training decision makers in complex decision-making domains [in education and training]" [7]. Multi-agent systems can also substantially contain the "spread of uncertainty", since agents typically process information locally [8].

2.2 Learning Objects

Many learning materials are distributed using Web technology. Most of them are currently developed for a specific purpose, for example, courseware is usually for a specific module, and the content probably will not be reused or will only be reused for a few times. Both for educators and learners, the concept of *learning object* has been proposed to address these issues.

A learning object is a "self-standing, reusable, discrete piece of content that meets an instructional objective" [9]. Learning objects may be tagged with meta-data so that their identity and content are available to software systems, which use them. The decomposition of educational content into learning objects is analogous to the decomposition of an object-oriented program into objects and classes, and permits an individual learning object to be used in a variety of educational contexts.

2.3 Learning Style Theories

People never learn in a same way. The concept of *learning style* has been introduced by educationalists, and is the subject of increasing academic interest. The term is used as a "description of the attitudes and behaviours that determine our preferred way of learning" [11].

Learning styles depend on a variety of factors, and are individual to different people. Even for the same person, it can change over time. Learning styles may also differ between men and women, and between children and adults [12]. In this paper, we restrict our view of learning styles to those applicable for students in higher education.

Models used to classify students' learning styles include Kolb's Learning Style Inventory [13], Gardner's Multiple Intelligences [14], and Felder-Silverman Learning Style Model [15].

3. Pedagogical Agent Systems – A Solution

Agent technology is a promising new information technology that has already been applied in several areas, such as manufacturing, air traffic control, electronic commerce, and business process management [6].

In the context of adaptive education, agent technology can provide a dynamic adaptation not only of domain knowledge but also of the behaviour of individual learners, and has already been used in a number of educational tools. However, most systems incorporating agent technology, such as [4, 16, 17, 18], have decoupled the agent technology from the pedagogic foundations of the system, and each emphasises a particular aspect, such as training, group work, and human resources requirement. Each has its individual ways of organizing the learning materials, and few have considered the effect of different learning styles. The use of learning objects in such systems is rare, although the technology has begun to be used in non-adaptive training software [19].

The functionality of current intelligent tutoring systems can be classified according to the following three aspects:

- The students' aspect, which includes communication and information storage.
- The teaching and learning aspect, which includes the modelling of students and their learning requirements, and methods of organizing learning materials.
- The system aspect, which includes the system communication and quality control of the output.

We have developed a novel approach to the problem of supporting adaptive learning. Our autonomous multi-agent system architecture maintains the distinction between these three types of functionality. In contrast to other agent-based pedagogic architectures, learning style schemes form the pedagogic foundation for adaptivity and learning objects which are used as an appropriate technology for incorporating reusable learning material.

4. An Autonomous Multi-Agent System

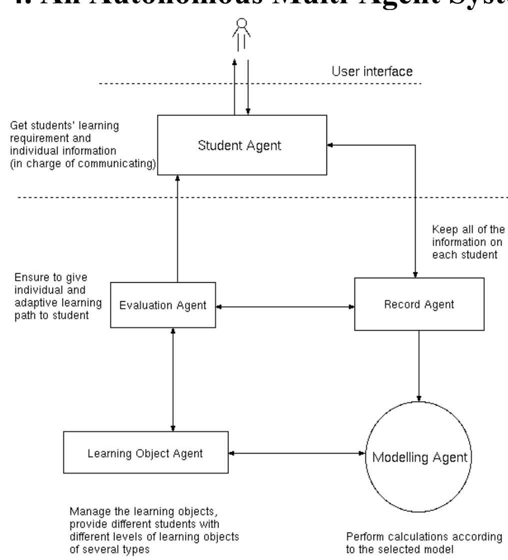

Figure 1: System Architecture

The multi-agent system (figure 1) is composed of five agents: the *Student Agent*, the *Record Agent*, the

Modelling Agent, the *Learning Object Agent*, and the *Evaluation Agent*. The Student Agent is in charge of communicating with students, and the Record Agent keeps all of the information about each student. These two agents are designed to satisfy the communication and the information storage requirements of the students' aspect. The Modelling Agent creates models of students' skills and learning objectives, and the Learning Object Agent manages all of the learning objects. These agents are designed to model students' learning and to organise the learning materials. The Evaluation Agent ensures learning objects are given in individual and adaptive learning paths to each individual student, and is in charge of quality control of the learning objects output.

4.1 Student Agent

The Student Agent (figure 2) takes charge of communicating with student when the student first logs into the system. It initially engages in a dialogue with the student in order to ascertain the knowledge level of the student, and to get information about the student's learning requirements, such as which module the student wishes to participate in, or what knowledge the student wants to gain. During the time the student is in the system, it records all of their actions, such as the time they spend engaging in each activity presented to them by the system, clicking times, active or not, etc.

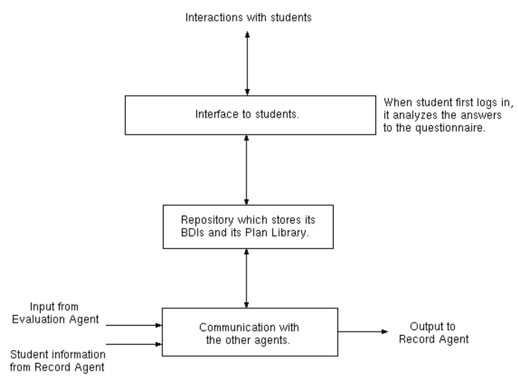

Figure 2: Student Agent

The Student Agent is a BDI-based agent [8], which makes decisions according to its knowledge, and its reasoning is directed towards action. It has explicit knowledge of its beliefs (about the student's knowledge), desires (as to how the student's aspirations may be fulfilled), and intentions (concrete actions it may take to achieve those desires which can be satisfied). It is comprised of three main components: a communication *interface* to students; a *repository* of its beliefs, desires and intentions, and its plan library; and *communication* with the other agents. This agent uses means-ends reasoning (or planning), the process using the available means to decide how to achieve an end [20].

4.2 Record Agent

The Record Agent (figure 3) keeps all of the information about each student. Since the type of data received from or sent to the other agents may be unpredictable, the Record Agent is a BDI agent supporting beliefs about its ability to provide those data, and desires to support those agents appropriately.

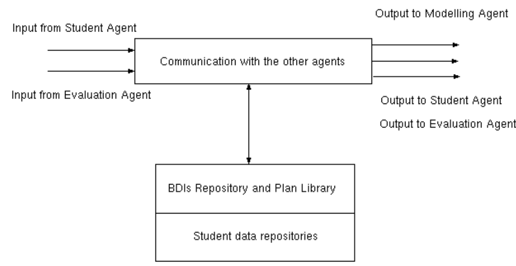

Figure 3: Record Agent

4.3 Modelling Agent

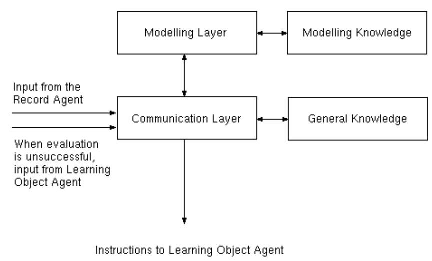

Figure 4: Modelling Agent

This agent generates a representation of each student based on their academic progress and learning desires, returning its results to the Learning Object Agent. This agent requires a large volume of data, supported by its own regularly updated knowledge base.

The Modelling Agent (figure 4) has a hybrid architecture. Student data is regularly received from the Record Agent by its *communication layer*, which maps the data to the *knowledge component* and the goals within this layer, to establish what information should be sent to the *modelling layer*. When the *modelling layer* receives the data, it maps the data to its *modelling knowledge* component and the goals in the *modelling layer*, using Bayesian networks [21] to perform its calculations. Results, such as the index of each student's related knowledge level, and instructions suggesting which level of learning materials should be sent to the student, are sent to the Learning Object Agent.

4.4 Learning Object Agent

The Learning Object Agent (figure 5) manages the learning objects, which are organized in different levels of difficulty. According to instructions from the Modelling Agent, it provides different students with appropriate learning objects. This agent is a hybrid agent in which its subsystems are arranged into a hierarchy of layers. Communication with the Modelling and Evaluation Agents is handled by a *communication layer*, which supports a *learning path layer* (which handles individual students' learning paths). The learning objects management layer then handles a repository of learning objects.

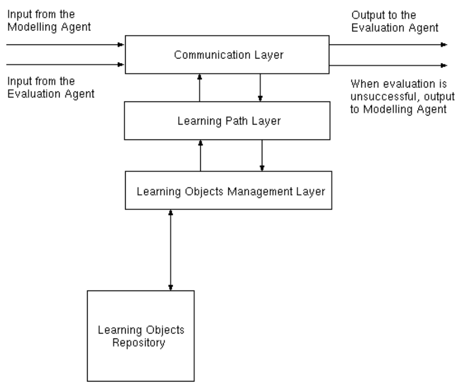

Figure 5: Learning Object Agent

The *learning path layer* adopts Felder-Silverman Learning Style Model [15] to organize learning objects to fulfil different students' requirements. The learning objects in the *repository* are categorized by items of the learning style model. To organize the learning materials as learning objects, which based on a pedagogic learning style scheme, in an agent environment, is a distinct character from this architecture to the existed pedagogical agent work.

4.5 Evaluation Agent

The Evaluation Agent (figure 6) ensures learning objects are presented in an individual and adaptive learning path to each student, using *all* the student data from the system to evaluate which learning objects are sent to students. The Modelling Agent may not use all of the available information on a given student, and can only advise the Learning Object Agent. If the selected learning objects are evaluated as appropriate for the student, the series of learning objects are sent to the Student Agent directly, otherwise the Evaluation Agent requests the Learning Object Agent to resend learning materials. Then the Learning Object Agent transfers these and asks the Modelling Agent to model again by using the data and suggestions from the Evaluation Agent.

The Evaluation Agent is a hybrid agent capable of reactive and proactive behaviours. It has a vertical layered architecture similar to InteRRaP [22], consisting of an *information interface* supporting two layers, each with its own knowledge base containing information repositories. The Agent has an open architecture and the Evaluation Layer has plug-in functionality, allowing different evaluation schemes to be incorporated in addition to the current fuzzy logic based scheme, thus offering the possibility of supporting other technologies in the future.

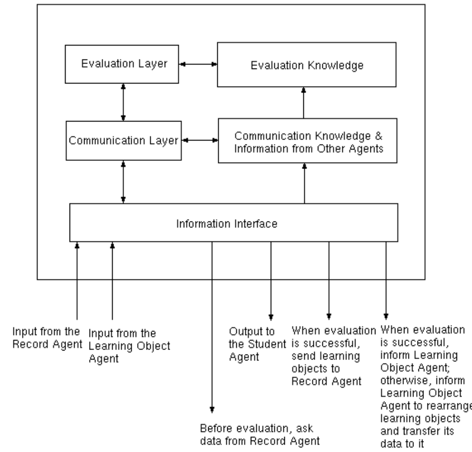

Figure 6: Evaluation Agent

4.6 Using the system

When the student first logs into the system, the Student Agent enters into a dialogue with the student to ascertain the student's learning requirements. After analyzing the answers, the Record Agent is sent the student's learning requirements together with a suggested knowledge level for the student. These items of information are recorded and then passed to the Modelling Agent, which then sends results and instructions to the Learning Object Agent, which arranges the first batch of learning objects to be sent to the Student Agent according to the difficulty level of the learning objects. These learning objects are first sent to the Evaluation Agent, which checks the student's data from the Record Agent to evaluate whether the learning objects are suitable for this student. If the evaluation is successful, the series of learning objects is sent to the Student Agent (and then to the student) and recorded by the Record Agent. Otherwise, the Evaluation Agent asks the Learning Object Agent to provide alternative learning objects. After the student has used the learning objects, response data is returned to the Student Agent, which transmits them to the Record Agent.

5. Discussion and Implementation

The adaptivity requirement suggests that the set of interactions and communications within the system should be dynamic. The use of autonomous agents is appropriate since it allows us to abstract the data at a higher level than that which would be appropriate for conventional software technologies, and enables us to conceptualize the system in a natural fashion. The modelling and the evaluation components of the system need to be able to give *suggestions* to the other agents, and to exhibit both reactive and proactive capabilities; these components may naturally be viewed as agents which can direct their behaviours in order to satisfy their design objectives.

The material in the system is not constructed for a specific course or module, but to meet individual needs, so learning objects are incorporated within the architecture to address this requirement.

The Student Agent and the Record Agent is each supposed to make decisions according to its knowledge, in other word, its reasoning is directed towards the action, so is naturally a BDI-based agent [8]. A deductive reasoning agent, was considered, however it is doubtful whether such a logic-based agent can react effectively in a time-constrained environment. The Learning Object Agent, the Modelling Agent and the Evaluation Agent need to perform relatively complex functions, so only a hybrid architecture, in which the subsystems are arranged into a hierarchy of layers, can satisfy these requirements.

Several case studies have been used to verify the consistency of the proposed architecture, including first year undergraduate programming topics, covering introductory Java programming and UNIX shell programming. The Learning Object Agent is currently developed using JADE (Java Agent DEvelopment Framework), and we are working towards the implementation of the prototype system architecture. The learning style scheme has been designed, and related experiments are in progress. Available learning objects have been categorized according to the scheme, and appropriate samples have been incorporated into the system.

6. Conclusions and Future Work

We have presented a novel approach, an autonomous multi-agent system that uses learning style schemes to adapt to students, and supports the use of learning objects to enable incorporation of reusable learning material. We have developed a prototype of the system, and evaluation of the effectiveness of the Learning Object and Evaluation agents is in progress prior to implementation of the complete system.

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