Intelligent Collaborating Agents to Support Teaching and Learning

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Abstract

This paper presents the Intelligent Multiagent Infrastructure for Distributed System in Education (I-MINDS), an innovative application using AI and multiagent systems to help teachers teach better and students learn better. The I-MINDS system consists of a group of intelligent agents that work cooperatively in a distributed computing environment. A teacher agent monitors the student activities and helps the teacher manage and better adapt to the class. A student agent interacts with the teacher agent and other student agents to support cooperative learning activities behind-the-scene for a student. This paper describes two innovations in (a) automated ranking of questions and responses, and (b) agent-supported "buddy group" formation. The results of the proof-of-concept tests have demonstrated encouraging effectiveness of I-MINDS in terms of learning gain and deep understanding.

1. Introduction

Computer-aided education environment not only extends the education opportunities beyond the traditional classroom, but also introduces agent-based technologies to support teaching and learning. Advances in information technology, such as Internet and multimedia technology, have dramatically enhanced the way that information and knowledge are represented and delivered to students. The application of agent-based technologies to education can be grouped into two primary categories: (1) Intelligent Tutoring Systems (ITS) and (2) Interactive Learning Environments (ILE) [13] . Current research in this area has approached integrating agent technology into education systems. But most of agent-based education systems use software agents without fully utilizing the power (or intelligence) of agents such as reactivity, pro-activeness, and social ability [18] . Moreover, most agent-based education systems are simply a group of non-collaborative individual agents.

In this paper, we describe a multiagent system (MAS) infrastructure that supports different high-performance distributed applications on heterogeneous systems for a computer-aided, collaborative learning and teaching environment. The infrastructure, called the Intelligent Multiagent Infrastructure for Distributed Systems in Education (I-MINDS), consists of two levels. At the high level, we employ the methodologies in intelligent agents and multiagent systems to develop software decision makers and monitors for educational applications. At the low level, we use distributed computing paradigms to build the infrastructure that supports fast, synchronous, and concurrent information processing.

The goal of I-MINDS is to exploit multiagent system intelligence in computer-aided education system. It consists of two parts:

- Developing a low-level distributed *infrastructure* specifically for education, addressing the interaction issues in real-time classroom scenarios, distance learning, and automated mediation of online discussions, and
- Developing a high-level *intelligent* multiagent system, built atop the infrastructure, that is able to monitor the activities, recognize patterns, and interact with students and instructors alike to improve the quality of teaching and learning.

The current focus of our research centers around two innovations, which are (a) automated ranking of questions and responses, and (b) agent-supported "buddy group" formation. The ranking of questions and responses is based on the profile information queried by the *teacher* agent of the *students* as represented by their respective *student* agents, where the teacher agent serves the instructor and the student agents the students. The "buddy group" is a group of students that are motivated to participate in discussions in the group and considered be potentially helpful to one another. Each student agent forms and refines this group for the student whom it serves.

2. Background

Related to our I-MINDS work is the area of synchronous virtual classrooms. For example, IRI-h [1] offers audio, video and tool sharing services. It also supports class participants with limited multicast capabilities, or limited connection bandwidth by providing a scalable infrastructure. Centra Symposium (http://www.centra.com/) has structured live interaction, asynchronous learning, content support, and enterprise-class management. Interwise E-Learning Solution (http://www.interwise.com) offers 1-on-1 mentoring sessions, collaborative learning sessions, and a knowledge repository with on-demand learning objects. Mimio Classroom (http://www.mimio.com) allows the students to share notes with the instructor in real time, and students can add their own comments and notes that can be saved and reviewed offline. I-MINDS currently has most of the infrastructural features found in the following synchronous virtual classrooms: live video and audio broadcasts, collaborative sessions, online forums, digital archival, text overlay on blackboard and other media.

I-MINDS also has intelligent agents that work individually to serve their users and cooperatively to support teaching and learning. Agents have been used in educational applications in two general roles, as (a) individual tutoring or learning assistant, or (b) information and resource mediator.

Intelligent tutoring systems for algebra, geometry, and computer languages, such as PACT [7] , and physics, such as ANDES [4] , have achieved some level of success in classrooms. Betty's Brain, which is different from other tutoring systems, aims at improving students' deep understanding in science education [8] . It requires students to *teach* the agent, named Betty, before querying Betty with quizzes. Some criticisms of the current state of tutoring systems [5] stem from the lack of sufficient intelligence in the tutoring system necessary to monitor and detect a student's pedagogical behaviors. Students may simply keep guessing until they find an action that gets positive feedback and thus learn to do the right thing for the wrong reasons, and the tutoring system will never detect such shallow leaning [2] . Rosic, Stankov, and Glavinic [14] extended tutoring systems to online, asynchronous distance education. Because these systems work independently of each other and few are capable of machine learning, they fail to fully utilize the potential of multiagent intelligence.

The objective of the applications in the second category is to provide a computing environment where multiple agents can interact to exchange information so that students or teachers may collaborate in the most effective ways to transfer knowledge. Schneider and Jermann [15] discussed three main areas related to such an approach in education: (1) Virtual Campuses, (2) Dynamic Worlds for Learning and Teaching, and (3) Advanced Learning Environment over the Internet. Issues in these areas include multi-user worlds, simulation, and accessibility of Web-based teaching, data analysis, and so on. Some have also used agent-based approaches to create virtual libraries where the students share resources [6] . One key component that is missing in today's multiagent systems in education is to enable the system to utilize and analyze the observed behavior collected from individual agents and accordingly adapt to such behavior. That is, most multi-agent-based education systems do not handle or make use of data or information among the agents.

The design of I-MINDS is aimed at better exploiting these features to help the agents make decisions to support teaching and learning. Our motivations are to make learning more immediate and responsive, to make teaching more immediate and adaptive, and to make knowledge transfer among teachers, among students, and among students and teachers more effective, and collaborative in a real-time classroom environment.

3. I-MINDS Framework

The I-MINDS framework consists of three areas of research: (a) distributed computing as the infrastructure and enabling technology, (b) intelligent agents as the high-level components to enhance the learning experience, and (c) educational research as the domain application that provides evaluation and experiment protocols. Our I-MINDS development also involves hardware-software interface as well as real-time operating and interactive issues. I-MINDS currently supports 2-way live audio, 1-way live video, superimposition of handwriting on lecture screen, automated digital archival of lecture notes, multi-cast/broadcast, multi-character forum and e-whiteboard, annotation and asynchronous review of archived lectures, and rich and flexible control of system features.

3.1. Distributed Computing

Briefly, we describe our distributed computing research here for I-MINDS. The low-level distributed processing system employs a pure Java programming and the Distributed Shared Object (DSO) model [11] to facilitate cooperation among agents, data gathering and information dissemination, making the infrastructure portable, expandable, and secure. The Java object orientation and DSO provide an efficient and seamless interface between the high-level cognitive activities and the low-level enabling technology. In addition, using Java as the programming language makes I-MINDS a platform-independent system that can be used in heterogeneous environments. We have also used a layered architecture and proxy-supported topology to maintain a flexible and scalable design. Readers are referred to [17] for details.

3.1.1. Layered Architecture. We also employ a layered architecture [17] . The first layer (called the network layer) provides the fundamental communication mechanism over Internet, such as sockets. The second layer (i.e., system layer) consists of protocols to provide convenient encapsulations and deployment functions to the upper layers. A java-based data encapsulation mechanism provides an interface for passing objects among agents, while DSO is used for maintaining the consistency and coherence of the shared objects among agents. For example, I-MINDS provides a whiteboard on which students can scratch their ideas and share them with others. Each whiteboard is a shared object among participating student agents and is maintained using DSO. The third layer is the agent-based layer, equipped with decision making, reasoning, and learning capabilities. The fourth layer consists of content-independent modules related to educational heuristics and expertise. The fifth and final layer consists of content-dependent modules related to specific subjects, courses, and curriculum.

This layered logical infrastructure makes I-MINDS highly flexible. When deploying I-MINDS in a new subject or course, the only change that has to be made is the content-dependent module.

3.1.2. Proxy-Supported Topology. We employ a proxy-supported, hierarchical topology to support the agents. At the top is the manager, which gathers and processes the system level information, such as enrollment, all classes offered, currently ongoing classes and their teachers, and other static and dynamic information. Teacher agents sit at the second level. These agents report their locations to and fetch the class information and materials from the manager. Remote proxy servers with a proxy agent each in the third level are key components in improving the scalability of I-MINDS. In the real world, students may access Internet through various network connections, such as dial-up with limited connection bandwidth, high-speed cable modem, or local area networks. As a result, some students and thus their respective student agents may not be able to utilize all functions in I-MINDS due to the limitation of network bandwidth, lack of multicast capability, or other network restrictions. The remote proxy servers are designed to accommodate these differences. The proxy agents adjust the transmission rate or turn off the video transmission according to the students' connection bandwidth. Readers are referred to [10] for a more detailed discussion on the proxy server setup.

3.2. Intelligent Agents

The unique and innovative application to education of I-MINDS is the usage of intelligent and autonomous agents that work behind-the-scenes individually on their own and cooperate and collaborate as a multiagent system. There are three types of agents in I-MINDS: teacher agent, student agent, and remote proxy agent. Here we focus on two types of agents (teacher agent and student agent) and discuss the methodologies and delivery technologies developed.

3.2.1. Teacher Agents. The teacher agent has a content-independent module and a content-dependent module, as shown in Figure 1. In the content-dependent module, there are rules used for inferences, quizzes and exercises and answers from all students, questions asked by the students, and dynamic profiles of the students. Initially all rules, quizzes, and exercises are provided by the teachers or domain knowledge experts, and will be changed in real-time by the learning mechanism in content-independent module.

The teacher agent houses the automated question ranking mechanism. It scores a question based on the profile of the student who asks the question and the quality of the question itself. A student who has been asking good questions will be ranked higher than a student who has been asking poor questions. A good question is based on the number of weighted keywords that it contains and whether it is picked by the teacher to answer in real-time. There are two sets of weighted keywords: topical and intentional. The topical set consists of important acronyms, concept terms, and definitions that are provided by the instructor before the lecture. The intentional set consists of words such as "why," "how," "who", "what," and so on. There are also exceptional heuristics being developed to account for scenarios such as "if a student has never asked a question before, then score his question high" to encourage their participation.

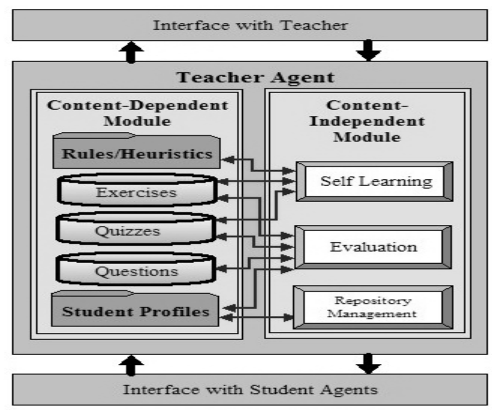

Figure 1: Structure of the I-MINDS teacher agent

When a new question is asked, the teacher agent first evaluates the question and scores it. Then the teacher agent inserts the question into a ranked question list (based on the score of the question and the heuristic rules, which will be introduced later) for the teacher to choose to answer. Whenever the teacher answers a question, he or she *effectively* teaches the teacher agent that the question is indeed valuable. This will lead the teacher agent to refine its own scoring heuristics—reducing keyword and heuristic weights. If the teacher agent ranks the teacher's pick high, for example, then it reinforces positively its heuristics; and vice versa.

We have implemented most components of the content-dependent module such as questions, rules and heuristics, and student profiles of the teacher agent. We have also implemented the Interface modules and the Evaluation module in the content-independent module. A prototype of the Student Profile module and a definition of a student profile are also implemented. The response by each student through his/her respective student agent is evaluated, and the cooperative learning activities among students are captured automatically by student agents and reported to the teacher agent. Figure 2 shows a screen snapshot of our teacher agent interface, where the sub-window at the lower right shows questions in ranked order, the upper left bar contains control bottoms, and background is a PowerPoint lecture slide.

3.2.2. Student Agents. A student agent (shown in Figure 3) supports the student whom it serves, by interacting with the teacher agent and other student agents. A student agent has a content-dependent module and a content-independent module as well.

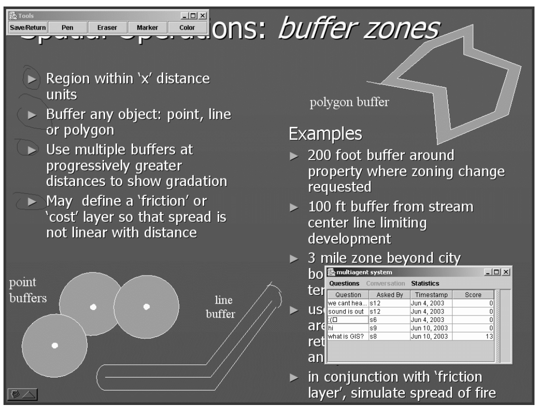

Figure 2: Screen snapshot of the I-MINDS teacher agent

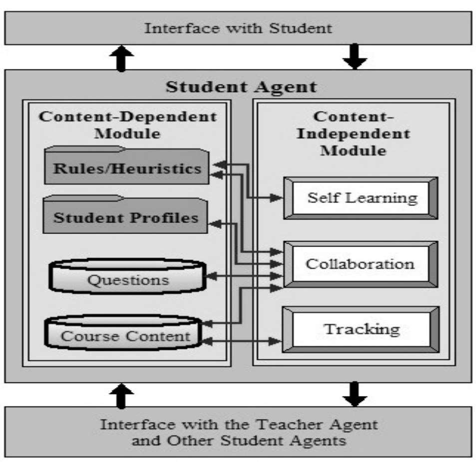

Figure 3: Structure of the I-MINDS student agent

The tracking mechanism tracks the activities and the progress of the student. I-MINDS provides a forum for students to communicate. The posts in the forum, as well as the collaboration activities with other students, of a student will be tracked and analyzed by his/her student agent. The tracking mechanism also tracks the student's attendances. If the student missed part or all of a class session, the tracking mechanism will go to the corresponding teacher agent, find the archived course materials for the missing time period according to the timestamps or the syllabus the teacher provides, and reminds the student about the missed lectures. All the tracking results will be sent to the teacher agent and counted into student's evaluation.

Each student agent supports the "buddy group" formation process, which is a collaboration mechanism that can be turned on/off by the student. A "buddy group" is a group of *students* with complementary characteristics (or profiles) who respond to each other and work together in online discussions. Currently, I-MINDS has two collaborative features: a forum and a whiteboard. The forum allows all buddies to ask and answer questions, and each message is color-coded. The whiteboard allows all buddies to write, draw, and annotate on a community digital whiteboard. The actions are also tracked and recorded.

The following is how a student agent forms and maintains a buddy group for the student whom it serves. The initial formation is based on the profile information queried from the teacher agent and preferences indicated by the student. When a student performs a collaborative activity (initiating a forum discussion or a whiteboard discussion, or asking a question), the student agent informs other student agents identified as buddies in the student's buddy group. Thus, buddies may answer questions that the teacher does not have time to respond to in class. As the semester moves along, the student agent will drop buddies who have not been responsive from the buddy group. The student agent will also rank the buddies based on their responsiveness and helpfulness. The student agent also uses heuristics to determine "when to invite/remove a buddy" and "which buddy to approach for help". The student agent adjusts its heuristic rules according to the current classroom environment. For example, in a class in which students are very active in collaborative learning, a buddy who has not been active for one hour may be dropped.

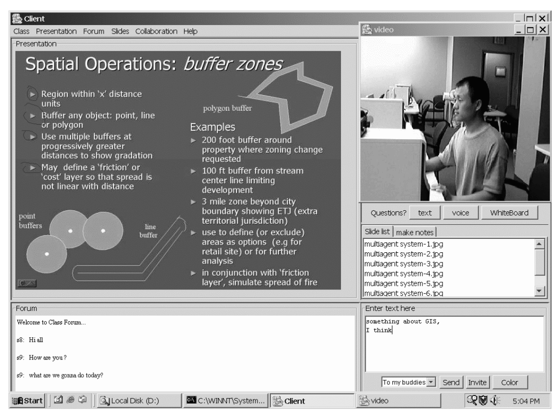

Figure 4: Screen snapshot of the I-MINDS student agent

Currently, we have implemented the prototypes of all the modules in our student agent structure. The I-MINDS student agents are able to form and maintain buddy groups dynamically based on the information shared among the student agents. Figure 4 shows a screen snapshot of the I-MINDS student agent, which is divided into four major regions. The top-left region is the lecture delivered from the teacher to the student. The top-right region consists of a real-time video feed from the teacher agent, and a digital archival repository. The bottom-left region is the forum. The bottom-right region is where some collaboration controls are found.

3.3. Educational Research

In terms of educational research, our objective is to incorporate cooperative learning teams into our buddy group formation process, allowing the teacher agent to grade the collaborative activities and assigning fair scores to the students. We have identified the positive interdependence model [3] to provide joint intentions, self-efficacy evaluation [3] of individual members and team performance, and peer rating [12] of other team members as key components to embed into I-MINDS.

In terms of buddy group formation, each student agent is capable of (a) forming its group based on perceived goodness of other agents, (b) evaluating the observed goodness of a buddy, and (c) revising its buddy group by removing buddies of poor utility to its team and adding other agents perceived to be good. Each student agent thus uses the individual self-efficacy measures to form the buddy group, uses the peer rating mechanism to evaluate its members, and uses the team-based efficacy to measure the performance of its team.

The teacher agent shoulders the responsibility of giving out rewards (or penalties) to each agent, based on the self-reported team performance and peer rating. With this, each agent will be kept in check—students that do not do well as a buddy will be scored low and vice versa. Thus, the teacher agent impacts the team formation process by giving out penalties and rewards. It is also capable of comparing and ranking the performances among teams.

Finally, to encourage the agents to form teams, we use a set of positive interdependence. These relationships supply the joint intentions for the agents to work together in a team.

4. Experiments & Evaluation

To determine the potential impact of I-MINDS on student learning, a pilot study was conducted in May 2003 where I-MINDS was used by subjects in a controlled experiment to assess what impact it had on student learning of Global Information Systems (GIS) content. Here we briefly report on the experiments. For details, please refer to [16] and [9] .

There were two groups: I-MINDS group and control group. Each group took two days of lectures, separately. On Day 1, subjects in both groups completed a 109-item pretest of the content that was to be taught during the two sessions. At the conclusion of the class on Day 1 for both groups, a subset (60 items) related to the content of that class was included on the posttest. After the Day 2 instruction, another subset (49 items) related to the content of that class constituted the posttest. Subjects in both the control and I-MINDS groups learned the identical content during each of the two sessions. The control group's sessions were taught in a traditional manner without I-MINDS support, with the professor using PowerPoint slides identical to those used for the I-MINDS group to teach the content.

Table 1 shows the statistics of the pretests and posttests from the educator's point of view. Separate 2x2 (groups by pretest-posttest) mixed-model analysis of variance was used. The numbers in the tables are proportional to students' scores. Results from the two testing sessions are encouraging. In the first session (Test 1), the I-MINDS group and the instructor acquired some degree of familiarity with the distance education setup and the software interfaces, but it was hardly sufficient to master the numerous I-MINDS tools. So, as expected, the control group would either score better than the I-MINDS group. In the second session, the I-MINDS group performed better.

Table 1: Experiment results.

Test 1			
Group	**Pretest**	**Posttest**	**Marg.Means**
I-MINDS	13.1	33.4	23.25
Control	17.4	41.3	29.35
Marg.Means	15.25	37.5	

Test 2			
Group	**Pretest**	**Posttest**	**Marg.Means**
I-MINDS	12.0	22.2	17.1
Control	15.78	20.67	18.2
Marg.Means	13.79	21.47	

Though the test scope was limited (only 19 students and 2 sessions), the experiment we had is promising: *the amount that the I-MINDS group improved from the pretest to the posttest was nearly twice that of the control group*.

Comments from the instructor who used I-MINDS in teaching both of the lectures were also encouraging. He indicated that the teaching tool was very easy to learn and use. He also said that the tool could enhance distance learning, especially by making it possible for building an archive of information that could be accessed "on-demand" by students. The instructor also noted that questions asked of him via I-MINDS tended to be of a higher quality, reflect a deeper understanding, and demand a richer response than those questions posed during the control sessions [16] .

Table 2 shows the average number of messages posted on the forum per student. Each message was also evaluated manually to see whether it was "on task"—pertinent to the subject topics. There were some promising indicators (see [10] for details):

- Students in the second lecture were able to be more *selective* as they sent more messages to their buddies than to all other students, indicating that the students were able to collaborate better in the second lecture.
- Fewer incoming messages in general were ontask, compared to messages received from buddies. That means questions from buddies were generally more ontask than messages from non-buddies.

Table 2: Average number of messages posted per student agent (Tot: Total, OnT: Ontask) for the two I-MINDS lectures.

		From Buddies		From Others		Outgoing	
	Tot	OnT	Tot	OnT	Tot	OnT	ToI
T1	15.55	7.55	36.91	1.82	16.55	2.18	2.45
T2	29.40	8.50	24.40	1.80	12.30	2.00	1.70

5. Conclusions

We have built a multiagent infrastructure, I-MINDS, aimed at helping teachers teach better and students learn better. The I-MINDS framework has many applications in education, due to its real-time capabilities and agent-based approach, such as real-time in-class instructions with instant data gathering and information dissemination, unified agent and distributed computing architecture, group learning, and real-time student response monitoring. Our pilot study demonstrated the effectiveness and feasibility of I-MINDS.

Based on our current implementation status, we are ready to bring I-MINDS into deployment and services in the near future. For example, we aim to incorporate I-MINDS into our on-going, department-wide Reinventing CS Curriculum Project. Specifically, we plan to use I-MINDS to support our laboratory-supported introductory CS courses in CS1 and CS2. In addition we plan to deploy I-MINDS, as a Web-based tool, to support a synchronized incorporation of distance education into an on-site teaching classroom, in which remote students will be able to use I-MINDS to experience similar student-student and student-instructor learning environments.

We will also continue to improve I-MINDS along two fronts. First, we will address the operational issue in scalability, consistency and security. We plan to extend I-MINDS to accommodate different bandwidths, information needs, and computing constraints. Second we want to enhance the intelligence of the agents to learn to adapt to different instructors, students, and lectures.

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