UDC 004.2

InCA: a Cognitive Multi-Agents Architecture for Designing Intelligent & Adaptive Learning Systems

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Abstract. This paper presents a cognitive multi-agents architecture called Intelligent Cognitive Agents (InCA) that was elaborated for the design of Intelligent Adaptive Learning Systems. The InCA architecture relies on a personal agent that is aware of the user's characteristics, and that coordinates the intervention of a set of expert cognitive agents (such as story telling agents, assessment agents, stimulation agents or help agents). This InCA architecture has been applied for the design of K-InCA, an e-learning system aimed at helping people to learn and adopt knowledge-sharing management practices.

1. Introduction

The advent of the Information Society, in which knowledge has progressively become one of the most decisive elements in people's and organizations' success, has considerably increased the need for improving education and the effective application of knowledge. Thus, in recent years there has been a focus on increasing the deployment and take-up of technology-enabled learning through multiple delivery channels (education and training, through Internet and Intranet), and we have assisted to the creation and the development of e-Learning. This trend has furthermore been facilitated by the emergence of new technologies and standards (SCORM, semantic web, grid computing, etc) that have opened new perspectives for more advanced learning services and promised to "industrialize" the world of education.

1.1. The limited success of traditional e-learning

However, the success of e-learning in the real world has been at best disappointing, and is certainly very far from fulfilling the high expectations that the more forward-looking students, educators and institutions had of it. The reason for this limited success originates, in our belief, from a too narrow and conservative vision of the learning processes to be supported. In most cases, e-learning systems still rely upon the same good old educational classroom-based instructor-led teaching method that has existed for years in the off-line world. This method is characterized by: considering students as relatively passive recipient of teacher-delivered material, and by a body of knowledge to be offered that is dominantly of generic theoretical/conceptual nature. As a result, the functions of traditional e-learning systems' (the Learning Management Systems) concentrate on supporting the distribution of generic and often passive learning materials to a group of students, sometimes also aiming at assessing how material is absorbed by students. Whilst this method, that has been successfully applied for mass education, can be considered as adequate to complement the training of inexperienced learners co-located in a same campus or school for acquiring the basic body of theoretical knowledge, it falls short of accommodating the needs of more demanding and experienced distributed knowledge workers, for whom the relevant knowledge is very specific and has to be quickly and directly applicable to their particular problems and situations.

1.2. The new e-learning vision: rich and highly engaging learning systems

In this article, we start from the premise that e-learning has to rely on a new vision that requires a fundamental shift from current content-oriented e-learning solutions towards a more user-centred, interactive and collaborative model of learning. In the new model, the learner is no longer considered as a simple passive recorder of data and information, but is seen as a participant that is actively engaged through a rich set of interactions (e.g. learning by doing, educational games, simulation environments, problem-based learning, learning by discussing, knowledge discovery, etc). This set of processes plays an important role not only for the delivery of the knowledge, but also in the knowledge selection process, the stimulation of the learner, the construction and the internalization of this knowledge, the validation of this knowledge, its situating in a social context, and its application in real world situations.

The implementation of this more ambitious e-learning vision has been the object of much research in the field of the advanced educational applications, such as Intelligent Tutoring Systems (ITS), Intelligent

Learning Environments (ILE) and other AI-based software [1]. Researchers of intelligent learning systems have designed, mainly from scratch, their own system architectures, have defined knowledge representation of the relevant domain knowledge, have acquired and encoded this knowledge, and finally have implemented some reasoning mechanisms aimed at delivering a more intelligent and interactive experience to the learners. Although significant research has been undertaken in the field of agent-based learning systems [2-8], because of the high cost and high complexity involved, the realization of this later vision has yet to be delivered, and often it has not yet passed the door of the research laboratories. In other words, additional work has to be done before the design of such systems can be achieved in a way that is technically and economically feasible.

1.3. InCA: An agent-based architecture for designing rich and engaging learning systems

InCA (Intelligent Cognitive Agents) represents the architecture that we have elaborated in response to the need to design rich and highly engaging Intelligent Learning systems without initially mobilizing too high a level of effort and expertise and that could later be expanded with richer functionalities. InCA's main goal is to provide the means to facilitate the integration of a variety of active learning components that are used for the interaction with the learner.

Practically, the InCA infrastructure is an open, modular, agent-enhanced, ontology-driven platform designed to support a user-centred, interactive and collaborative model of learning. The core component of this platform consists in a personal agent that is associated to each user, that is aware of the user's characteristics, and that coordinates the intervention of a set of expert cognitive agents. The role of these expert agents is to carry out the rich and diverse set of interactions that are activated to make people learn. Examples of these expert agents include story telling agents, which are able to deliver knowledge in the form of narratives, assessment agents which are able to help the users to evaluate themselves, stimulation agents whose role is to motivate the users or help agents which can provide assistance on some specific points. Of course, other categories of agents can be implemented as new categories of intervention that are not already covered by existing agents emerge (for instance we could imagine a devil advocate agent, a role-playing negotiation agent, etc.). In this sense, our architecture is modular: agents implementing new intervention strategies can be added to the system as long as they implement the appropriate interface with the Personal Agent which coordinates their activity and interfaces with the user.

In this paper, the use of the InCA framework is illustrated with a concrete scenario within the Knowledge Intelligent Conversational Agent (K-InCA) system. K-InCA is a learning system aimed at helping people to learn about, and to adopt knowledge sharing management practices. Built on the InCA principles, K-InCA consists in a set of conversational agents that are employed to assess and suggest the use of knowledge sharing management practices, as well as to tell stories on this subject.
The paper is structured as follows: the second section presents the framework design principles. The third section describes the InCA's architecture and its basic modules. The fourth section describes the implementation of InCA and it gives a concrete example of conversational agents supporting learning processes. The fifth section comprises some conclusions and pinpoints future work and future research directions.

2. The Principles of InCA

2.1. The learning processes in InCA

Learning is a complex process that consists in all the operations and elements that intervene from the moment when the knowledge to be transmitted is selected (determining the knowledge that is the most relevant to a particular student in a particular situation), until the time when this knowledge is put into application by the learner into a real situation (which is the only guarantee that learning has been effective). Supporting the learning process involves addressing a set of important issues. First, it is important to achieve and maintain the student's involvement and motivation (e.g. stimulation, emotional support, support for attention). Second, it is necessary to facilitate the effective delivery of knowledge (for instance by selecting the best delivery channel, location and time). Third, the way in which knowledge is acquired and retained by the learner may be targeted, for instance via the selection of a delivery mode that is the most adapted to the student's cognitive style. Fourth it is possible to improve assimilation and internalization of knowledge (e.g. helping the student to make sense of knowledge and situating it in the perspective of his/her previous experiences and needs). Fifth, the use of knowledge must be validated by the students, who should have the opportunity to experiment in safe settings. Sixth, learners must be helped in situating the knowledge in a social context by providing them with the possibility to exchange experiences with other learners.

To implement this view in a more straightforward manner, we have approached learning in InCA from a change management perspective, by assimilating the acquisition of a new piece of knowledge to the adoption of a new practice (if we follow the change management terminology, people learn when they adopt new practices). According to change management theories [9], learning (or the adoption process) happens when the learner goes through a series of stages in order to adopt a new practice. In the first stage learners are totally unaware of what they have to learn; in the second stage learners become aware of the knowledge to be acquired; in the third stage learners becomes interested by the acquisition of this knowledge and start to dedicate some attention to the subject; in the fourth stage learners experiment with the new knowledge in order to understand it in a more practical manner; finally, in the last stage learners may adopt this knowledge in their practice (see Figure 2).

In this perspective, InCA consists in a series of targeted interventions aimed at making the learner progressively pass from one stage to another, until reaching the ultimate stage, in which the learner is considered to have acquired the new knowledge and integrated it in his practice. More concretely, the whole process consists in the following series of steps:

(1) InCA determines the stage of adoption in which the user is situated by tracking the activity of this user (for example by monitoring the interaction of the user with the system);

(2) This adoption information, as well as the other characteristics of the user that are also managed in the user model (such as his/her cognitive style, preference, and context) are then used to determine the interventions that are the most likely to be effective in making the user move to the next step;

(3) One of the interventions is selected and activated.

These different steps are then repeated until the learner has reached the final stage (adoption) for all of the desired practices, and therefore he has achieved the learning objective.

As indicated in the introduction, these principles have been applied for the design of an e-learning system K-InCA (Knowledge Intelligent Conversational Agent) aimed at helping people to acquire knowledge sharing management practices [10, 11]. In the K-InCA application, the knowledge sharing management practices to be "transmitted" consist in the set of different behaviours (about 30 of them were defined in the first version of the system) that have been identified as reflecting people's ability and desire to share effectively knowledge with others such as: "valuing other people's ideas", "making my knowledge easy to access and understand" or "asking for ideas and advice outside my team". The formal description of these practices, and the associated documents (publications, company procedures description, etc.) are collected in a structure called the *domain model*.

The determination of the user's characteristics related to his/her level of adoption of a set of behaviours is accomplished by observing the interactions of the user with the system (observing for instance the level of activity, types of activities in which the user has been engaged, etc.). In the current version of InCA, these interactions mainly consist in the series of "conversations" that are conducted between the users and the different agents. However, in a later version, it is envisaged that the system will be able to directly capture the user behavioural activities such as for instance the user's knowledge sharing actions (e.g. sending emails, contributing to information repositories). The assessment of the user's state of adoption is performed in the InCA system by a *diagnostic agent*.

Different categories of *interventions* strategies can be activated to stimulate and coach the user towards the adoption of a set of desired behaviours. These categories include:

(1) The diagnostic of current level of adoption of the knowledge sharing management practices. This diagnostic is useful to help users to situate themselves in their learning path, as well as to stimulate user's desire to learn about new practices (these interventions consist in visualising the assessments performed by the *diagnostic agent*).

(2) Informing the user about a practice he/she may not be aware of (e.g. by providing a short description of the practice).

(3) Stimulating the user's curiosity and interest in a practice of which he is already aware of (e.g. supplying introductory readings, information on how other people have applied that practice, providing information about acquaintances of the user who already have adopted the practice, etc.)

(4) Encouraging the user to try a practice for which he has already demonstrated some interest by situating it in the environment of the user (e,g, by providing explicit examples of how the knowledge and skills may be implemented by the user in his environment).

(5) Convincing a user, who has already tried a practice, to definitively adopt it (e.g. by reminding the user of some positive effects of his previous trials) .

Interventions 2, 3 and 5 can be efficiently implemented with the use of narratives. Narratives represent indeed a very effective way to persuade people to change [12] and in the case of K-InCA to adopt a new practice.

More details will be provided in section 3 on user modelling, on behavioural profiling, and on how cognitive agents are used in K-InCA to implement these interventions.

2.2. InCA as a cognitive multi-agents system

Artificial agents [13-16] can be defined as software entities that possess the properties of identity, autonomy, sensing, and that interact with the environment. Multi-agent systems are systems which are enhanced with a number of artificial agents that fulfil a certain number of tasks in a more or less coordinated way. Cognitive agents represent the category of the agents that have cognitive capabilities, i.e. are entities that maintain an explicit and high-level representation of their environment, have well-expressed goals and motivation, and that have some reasoning capabilities.

Multi-agent systems are ideally suited to representing problems that have multiple problem solving methods, multiple perspectives and/or multiple problem solving entities. Such systems have the traditional advantages of distributed and concurrent problem solving and have the additional advantage of sophisticated patterns of interactions. The flexibility and high-level nature of these interactions distinguish multi-agent systems from other forms of software and provide the underlying power of the paradigm [17].

The main advantage of cognitive agents over simpler agents is the deep understanding that they have of the environment in which they operate (they build a semantic representation of the world in which they operate) and of the different processes that take place in this environment. Another important advantage is that cognitive agents have higher level reasoning capabilities. Consequently, cognitive agents are able to intervene much more effectively to support the different processes taking place in these environments. For instance, they are able, by building a sophisticated model of the user (based on a rich set of characteristics that are stated by the users, or extracted / inferred from the observation of their activities), to offer a high level of interaction and personalization, which is more likely to deliver value to the user. In particular, they may play the role of an "augmenter" of human capability by entering in symbiosis with the user, rather than just fulfilling a simpler role of automating some tasks [18].

InCA has been implemented as a cognitive multi agents system in order to build on the combined benefits of the two approaches. Theexpert InCA system includes a set of *expert* cognitive *agents* each implementing a category of the interventions (give an advice, tell a story, etc.) described in the previous section. These *expert agents* are coordinated by a *personal agent*, which is assigned to each user, and that coordinates the activity of the *expert agents* and guaranties a consistent machine – user interaction. This enables the support of a variety of methods and perspective in the interventions, whilst maintaining a high abstraction level for the interaction with the user in order to maximise the impact and the effectiveness of the interventions.

Each *expert agent* has a specific goal and has a limited set of instructional strategy for involving the learner in an interactive learning process. Using its reasoning capabilities and the information about the user's characteristics, a expert agent can propose an intervention to the *personal agent*. The *personal agent* decides whether to accept the intervention for an immediate execution, postpone it for a later execution, or decline it (if another *expert agent* has already submitted a better quality proposals for intervention). Of course, this selection is the subject of a continuous revision that follows the evolution of the user's behaviours in the learning environment.

To conclude this section, we have to add that we have tried in the design of K-InCA to follow the two design principles emphasized by Malone [19], namely the principle of semiformal system and the principle of radical tailorability. The principle of semiformal system states: "don't build computational agents that try to solve complex problems all by themselves. Instead build systems where the boundary between what the agents do and what the humans do is a flexible one" [19, p. 110]. In the design of InCA we argue for computational agents that gradually support more and more the knowledge and processing based on an increasing "knowledge" of the user and the learning processes. The second principle, the principle of radical tailorability recommends: "Don't build agents that try to figure out for themselves things that humans could easily tell them. Instead try to build systems that make it as easy as possible for humans to see and modify the same information and reasoning processes their agents are using" [19, p.110]. In the InCA framework, the user is in fact able to access and control his/her user model and the associated learning processes and; in particular the user is able to access and modify the curriculum sequencing [20] and the agent's interventions.

3. The General Architecture of InCA

The framework of InCA is articulated according to three interrelated components:

(1) *The domain model* - A set of structured knowledge elements (a domain ontology containing learning objects, principle knowledge, and how-to knowledge) to be delivered to the user accessible by the agents,

(2) *The user model* – based on a user ontology that covers elements such as level of knowledge sharing, learning goals, domains of interests, etc.,

(3) *A set of agents - expert agents* coordinated by a *personal agent* which accesses the user model in order to select the appropriate instructional strategy, by adapting the curriculum to the user's level of expertise, his goals, etc.

3.1. InCA's Domain Model

One of the main goals of the learning process is to understand and to acquire a body of knowledge for a given domain. Educational researchers agree on the fact that providing domain knowledge for learning environments is difficult and time consuming [21]. Often the domain model can be structured as a taxonomy of concepts, with attributes and relations connecting them with other concepts, which naturally leads to the idea of using ontologies to represent this knowledge. Mizoguchi [22] argues that "making systems intelligent requires a declarative representation of what they know. Conceptualization should be explicit to make authoring systems literate and intelligent, standardization or shared vocabulary will facilitate the reusability components and enable sharable specification of them and theory-awareness makes authoring systems knowledgeable." [p. 110]

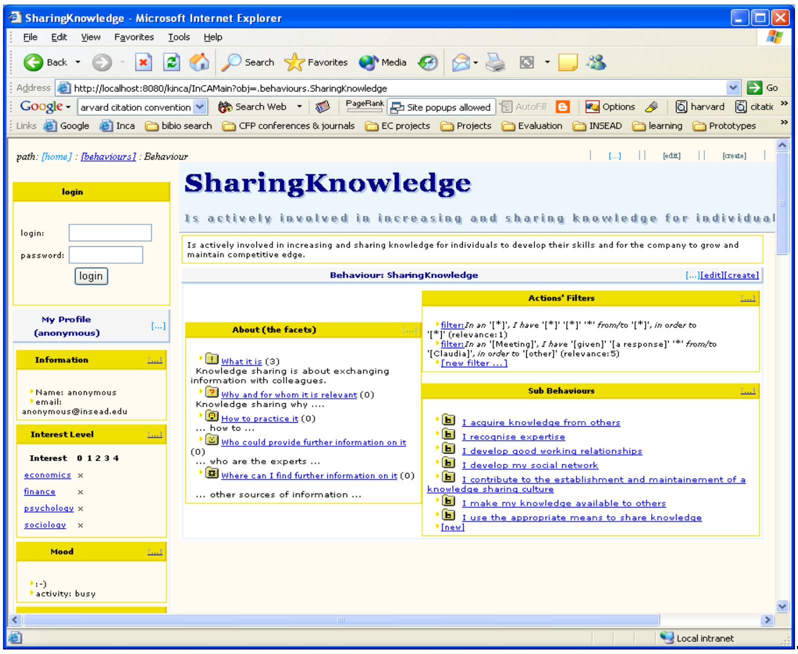

Fig. 1. InCA's domain knowledge

InCA organises the domain knowledge around a set of data structures stored in the *domain model*. These structures correspond to concepts, relationships between concepts, and answers to the questions: What is this practice? Why and for whom is the practice relevant? How it is the practice implemented? Who can provide further information about the practice? These knowledge units may be displayed by the system (see, for example, the "About" section in the central part of Figure 1).
The above basic structures may be integrated with different types of learning objects (e.g. hypertext, images, videos, stories, role-playing games) managed by one or more of the *expert agents*

3.2. User modelling and behavioural modelling process in Inca

One of the main objectives related to user modelling processes in K-InCA was to model the knowledge sharing behaviour of the users. Through the knowledge sharing behaviour we are trying to capture the level of adoption of knowledge sharing practices. We consider organizational and behavioural change management to be a critical success factor in the implementation of knowledge management strategies. "We describe users as undergoing a change process that brings them from their old practices to the conscious adoption of knowledge management practices (e.g. transition from low or non-existing levels of knowledge sharing practices to the widespread adoption of best behaviours in knowledge sharing)." [11, p.61]
We define a change process as a sequence of change operations upon user states, leading to the acquisition of the desired behaviours. Using Near's [23] terminology and mapping it into Rogers' theory [9] we identify (see Figure 2) a set of user states representing the level of adoption of a the desired practices: unaware, aware, interested, trial and adopter.

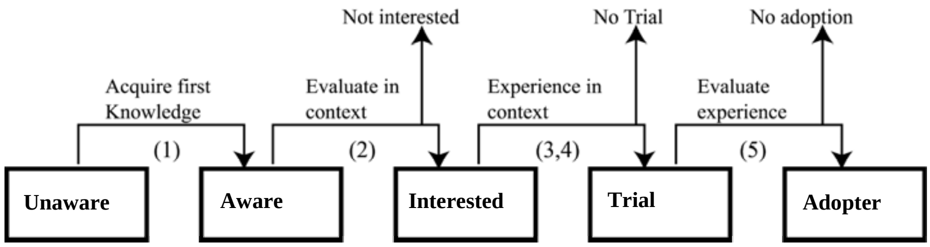

Fig. 2. A model of the change process. The numbers indicate the mapping to Rogers' model.

The classification of the users based on the level of knowledge sharing has been described and implemented using the principles of a fuzzy classifier system [24]. The classification process takes into account the *level* and the *type* of activity of the users. Based on the *type* of activity users are classified into: readers, writers, and lurkers. Based on the *level* of activity users are classified as: very active, active, visitor, inactive. The associated user modelling framework and user modelling mechanisms are described in more details in [25]. In addition to the user's *adoption state*, and *activity characteristics*, the user model includes a *learning agenda* describing the user's learning objectives (either explicitly declared by the user or deduced by the system on the basis of the user's activities), and a description of the user preferences and characteristics.

3.3. Expert Agents and their coordination in InCA

InCA relies on an architecture (see figure 3) in which a *personal agent* accesses the *user model* in order to coordinate the action of a set of *expert agents*. The aim of the *personal agent* is to provide adaptive curriculum generation.

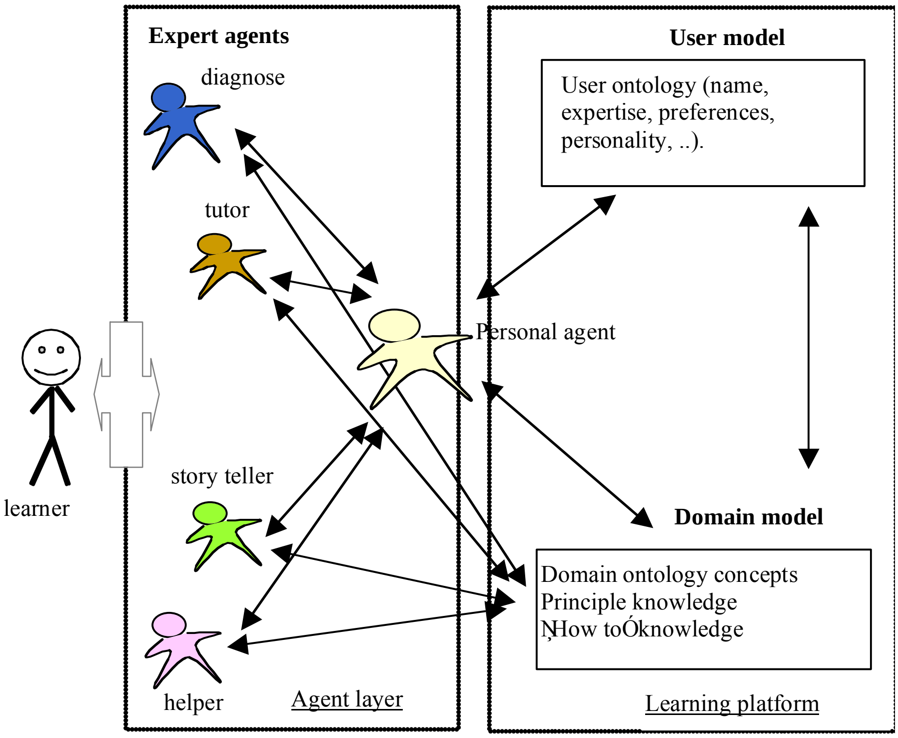

Fig. 3. InCA Architecture

Prompted by the *personal agent, expert agents* access the *domain model*, and propose intervention strategies to be presented to the user. *Expert agents* include story-teller, tutor, diagnose agents, etc. New expert agents can be defined and integrated gradually into the system.

The overall system behaviour is controlled by a four-steps loop [11, p.72, table 2]:

(1) Observe user's action
(2) Update user's state
(3) Select a learning objective and an intervention mode (*curriculum sequencing*)
(4) Execute the intervention

In particular, the curriculum sequencing is generated by a four-step procedure [11ibid, p.73]:

(1) the *personal agent* selects the current learning objective
(2) the *personal agent* solicits proposals from the *expert agents* by broadcasting a request for proposals for the selected learning objective
(3) the *expert agents* respond to the *personal agent*'s request by proposing to implement one or more intervention strategies to achieve some part of the learning objective
(4) the *personal agent* selects the most appropriate proposal.

4. Implementation and a Concrete Use Case with K-InCA

In this section we discuss a concrete example of the use of InCA in the context of an interactive learning system for knowledge management called K-InCA, Knowledge Intelligent Conversational Agents. As described in section 2.1, the learning, in K-InCA, is conceived as a change process and adapted to the context of organizational learning. The agents in K-InCA are designed to support knowledge management behaviours and in particular the knowledge sharing behaviours. These behaviours are stored in the domain ontology as described in section 3.1.

In the last few years synthetic characters designed as embodied conversational agents have started to be applied in educational environments [26-28]. Conversational agents aim at providing personalized guidance through the whole adoption process: from the introduction of the behaviours to the user (explaining what the desired behaviours are and why they should be adopted) to their practice within the community.

Nishida [29] defines a story as a collection of associative representations relevant to a specific subject in a workspace. Story telling has recently emerged as a practical, efficient technique for knowledge disclosure and communication in Knowledge Management. Snowden [30] affirms the role of story telling for Knowledge Management. "Managed and purposeful story telling provides a powerful mechanism for the disclosure of intellectual or knowledge assets in companies, it can also provides a non-intrusive, organic means of producing sustainable cultural change; conveying brands and values; transferring complex tacit knowledge."

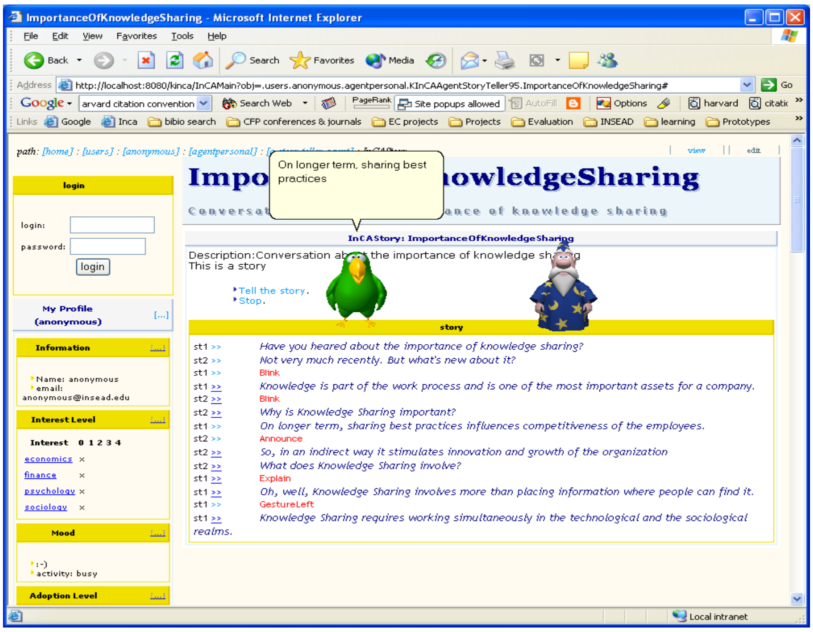

Fig. 4. Story telling agents in K-InCA.

In K-InCA, story teller agents address to the novices in the domain of knowledge sharing, namely *unaware* users, who get some basic ideas about the importance of sharing knowledge through an entertaining conversation which takes place between two synthetic characters. The different InCAs are able to engage themselves in a multimodal dialogue, using speech, tonality, gesture, and gaze in order to emulate a human face-to-face communication act in order to convey knowledge sharing practices as presented in figure 4. In this example, the *personal agent* has detected, after consulting the *user model,* that the user is *unaware* about knowledge sharing practices and it has determined that improving this adoption state is the highest-priority learning objective for the user. It has broadcasted to the *expert agents* a request for possible interventions to support the transition from *unaware* to *aware* for the *knowledge-sharing* practice. Amongst the interventions proposed by the *expert agents* it has selected, on the basis of the user characteristics stored in the *user model*, the one submitted by the *story-telling* agent.

4.1. Implementation

The InCA prototypes have been developed in Java, using servlet technology and a declarative formalism based on XML.
Story telling animated characters are implemented with Ms-agent technology. Each story is defined by an object structure, an XML representation is also used to generate structured and dynamic html pages (based on CSS) that the Microsoft Agent character technology is able to read, via a set of Javascript scripts.

5. Conclusion and Future Work

In this paper we have described InCA, a modular agent-based architecture, which integrates a set of interactive features allowing personalized and adaptive curriculum generation.
The architecture is open and modular and enables an incremental development and integration of different emerging technologies (semantic web technology, different types of expert agents, different types of learning objects, user modelling techniques which enable adaptive learning processes). The InCA architecture was exemplified within a story telling scenario.
A number of useful extensions of InCA system have been identified and some work has already been initiated. A first direction consists in the use of better story representation mechanisms (via a story telling mark-up language). The definition of a story telling mark-up language would enable to represent non-linear stories, and more sophisticated interactions with the user. In the longer term, this story telling representation could benefit of the advances in ontology languages, facilitating the exchange of stories between various systems and story telling agents.
A second direction of extension for InCA is towards better support for collaborative learning which, at the moment, is very limited. For this purpose, an instant messaging client based on the streaming XML protocols has now been incorporated into the system. This instant messaging system is intended to support real time collaboration and knowledge sharing processes between the users and the real time intervention of various personal agents.
Finally, another research direction is related to the design of new cognitive interfaces capable of focusing the users' attention and consequently deciding how to gain, shift, or maintain user's focus [31].

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