Enhancing Knowledge Management Systems with Cognitive Agents (Améliorer les Systèmes de Gestion de la Connaissance avec des Agents Cognitifs)

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Summary. After identifying the key challenges of knowledge management and proposing a vision that address them, this paper explores how cognitive agents can be used to design management systems that implement this vision and that in particular support the knowledge management processes in both their social, organizational and individual dimension.

Keywords. Cognitive agents; knowledge management

Résumé. Après avoir identifié les principaux challenges de la gestion de la connaissance, et proposé une vision qui les adresse, cet article explore comment les agents cognitifs peuvent être utilisés pour concevoir des systemes de gestion de la connaissance qui implementent cette vision et qui en particulier supportent les processus de gestion de la connaissance à la fois dans leurs dimensions sociales, organisationelles et individuelles.

Mots clefs. Agents cognitifs artificiels; gestion de la connaissance; knowledge management

1. Introduction

The use of agents for enhancing information systems has received considerable attention in the past, first through information crawlers capable of searching huge amounts of information, and then with the more sophisticated data-mining agents (such as the Autonomy system (http://www.autonomy.com)) that are able to automatically extract useful knowledge patterns from an important mass of information.

Although providing sophisticated searching and extraction services represents a substantive value to the users that are overwhelmed by the huge amount of information available today, we believe that agents can play an even more useful role by supporting more directly and deeply all the knowledge related processes of the knowledge workers. Indeed, what the users ultimately need are not so much tools that will be able to process more efficiently an even larger amount of information, but rather “smarter” tools that are able to support more effectively the knowledge related processes that are inherently connected to their work, and the operations of organizations. Besides, the processes that have to be supported should not only include searching and storing knowledge, but also creating, transforming, manipulating, communicating, sharing, assimilating and applying knowledge. Also, these tools should try to help to manage and support any form of knowledge, from the knowledge explicitly formalized in repositories, to the knowledge present in the person’s head, and to the knowledge embedded in systems and that can mainly be acquired by practice. Finally, these tools should take into account human and social factors, since “the knowledge is inextricably bound up with human cognition, and the management of knowledge occurs within an intricately structured social context” (Thomas, Kellogg, and Erickson, 2001).

The objective of this paper is to present how cognitive agents can be used to fulfil this goal, and in particular how they can be introduced in next generation knowledge management platforms in order to support effectively, and at a high level, a broad range of knowledge related activities.

The first part of this paper analyses the limitations of the traditional knowledge management approaches (considered too document-centred), so as to identify the key challenges that the next generation knowledge management platforms should try to address. From this analysis, it derives a vision of the next generation knowledge management platforms that is articulated according to the 3 following dimensions: the support for the social dimension; the active support for the knowledge management processes in an organizational context; the personalisation of the interaction.

The purpose of the second part of this paper is to present the concept of cognitive agents. Cognitive agents indeed possess many characteristics that make them particularly adapted for implementing system that support deeply complex processes involving a strong human dimension such as the knowledge management processes that have been introduced previously.

In the next part of the paper, we present how cognitive agents can be used for implementing the next generation knowledge management systems. In particular, this section identifies and describes the different categories of cognitive agents that can intervene both at the social level (via for instance knowledge facilitator agents facilitating knowledge exchange in groups), at the organizational level (via service agents that can contribute to make the functioning of the organization easier) and at the individual level (with a personal knowledge assistant that not only automates the repetitive tasks but also stimulates the user). A set of scenarios and some references to projects help to illustrate more concretely the use of this approach in an operational setting. This section also makes a reality check of how cognitive agents have been used until now, how these approaches have been (or should be) validated, and what is the work that needs to be accomplished.

Finally, this paper concludes with the presentation of the perspective and the issues related to the progressive incorporation of advanced agents' features in the next generation of knowledge management systems in the future, and their adoption in organizations.

2. The challenges of knowledge management

Private and public organizations, and the environment in which they operate, have considerably changed in the last few decades. These organizations have to renew themselves more rapidly to adapt to a more competitive and changing environment, be much more flexible than in the past and also need more sophisticated ways of managing their knowledge assets (Dore, 2001). They have to manage efficiently the whole knowledge cycle (such as identification, creation, reformulation, capitalization, sharing of knowledge) and in particular have to better support social related processes. Modern organizations (1) are aware that a major part of their knowledge assets (for instance people know-how and experience) is available in the form of tacit knowledge that they need to better support; (2) need to integrate mechanisms which contribute to the dynamics of the circulation & exchange of the knowledge of the organization; (3) need to adapt the organizational work processes to the specific characteristics of the corporate users (such as his/her position in the organization, competence, cognitive style, interest and motivation) in order to maximize the quality of their work.

As a consequence, Knowledge Management Systems have to be defined to support these new settings and in particular the knowledge related activities of knowledge workers which have considerably evolved in this last decade.

Whilst a plethora of knowledge management systems have been and are being developed (which take advantage of the available technologies), they fall short of fulfilling these needs. Most of these systems have emerged from document-centric approaches and are able to support (very efficiently) only a fraction of the whole knowledge cycle (classifying, storing, and retrieving knowledge).

These systems have three main limitations:

- Limitation related to the management of tacit knowledge.
- Limitation related to the capability to engage users in a continuous, active and dynamic management of their knowledge.
- Limitation related to the support of the specificity of each user, taking into account the interaction of their particular role in the organization, their competency, cognitive style, interest, desires and motivation.

2.1. The need to support the management of tacit knowledge

Most of the traditional Knowledge Management Systems rely on the assumption that knowledge can be assimilated to objects that can be identified, separated from their initial context, and handled in information systems. This definition of knowledge is too restrictive (Davenport, 2002), and does not take into account all the knowledge that cannot be formalized, codified, structured and made explicit. This "tacit" knowledge, which includes all the experience, practices, skills and know-how that people acquire, possibly without being really aware while they are working, represents, however, one of the most important forms of knowledge for modern organizations (Nardi, Whittaker, Schwarz, 2000).

Why is managing tacit knowledge increasingly important for organizations? Firstly, modern organizations are continuously changing and do not have the time to codify all this tacit knowledge into explicit knowledge (which anyway becomes too rapidly obsolete to justify the cost). Secondly, this knowledge can be very difficult to codify, in particular the one that involves intangible factors such as subjective insights, beliefs, perspectives and emotions. Thirdly, this process of elicitation may raise some strong resistance from the people themselves (because they consider this knowledge as personal strategic assets that guarantee their position in the organization). Finally, tacit knowledge represents a critical element of the capacity of the organization to learn: for instance Nonaka and Takeuchi (Nonaka and Takeuchi, 1995) show that a firm's learning efficiency critically depends on an institutional set-up that facilitates a spiral-type interaction between tacit and codified knowledge.

As we will see later in this paper, the management of the tacit knowledge does not only consist in providing the members of a community communication means (such as e-mail, bulletin board, etc) but also in supporting the dynamics of social interaction (including trust, motivation, and social behaviours/attitudes). Indeed, and as pointed out by (Andrew, 2002), it is erroneous to assume that people automatically participate in online communities (and engage in some social exchange) without some reason to do so. For instance, social exchanges theories (Thibaut and Kelley, 1959) considers that voluntary relationships depend on receiving satisfactory outcomes, and that a person's commitment to an existing relationship is proportional to his/her satisfaction in this relationship and to the investment he/she has already put in this relationship and it is inversely proportional to potential alternative relationships. The establishment of a sustainable social exchange process in a group (real or virtual) is complex, takes time, and involves many factors (such as reaching a minimum level of trust) to be successful (see (Leidner and Jarvenpaa, 1998), (Dyer and Nobeoka, 2000), (Cothrel and Williams, 1999)) and therefore needs to be explicitly supported.

2.2. The need to provide active support for the dynamics of exchange and for the knowledge-related activity

Most of the conventional Knowledge Management Systems are passive, both in the processes used to manage the knowledge, and by the knowledge that they deliver (static documents). Usually, document-centred Knowledge Management Systems propose two modes of interaction: (1) in the first mode the users specify their search in a query form (in the form of key words, categories or domains), and the system returns a set of documents which match their query. The search algorithm can be very sophisticated, and for instance take into account word synonymy or exploit some automatic clustering techniques; (2) in the second mode, the users are able to locate knowledge by browsing a pseudo tree-like categorization of the knowledge (the Yahoo or the Open Directory project system classification illustrates this second mode). These two modes are complementary, the first one being used when the users know precisely in advance what they are looking for (and that they can express with a set of keywords) while the second one is used when the users have a less precise idea. In the latter case, the navigation in the structure of the classification helps them to progressively formulate and discover knowledge (serendipity).

We believe that knowledge management systems should provide more advanced assistance to the work processes of the users and in particular propose to them knowledge, guidance and assistance in all their knowledge-related activities proactively (both in an individual and social context).

In addition, the knowledge should also be delivered in a richer and livelier form than static documents which rapidly become obsolete and require a lot of effort to be adapted to the context, and it should also be made actionable. Knowledge (and in particular tacit knowledge) can also be delivered through story telling (Snowden, 2001), through an informal conversation with others, via a formal debriefing meeting, during a simulation (useful for skill acquisition).

Why is more active support for the knowledge processes important? It is important because knowledge in the new organization is itself active, living (some people even refer to knowledge ecology ((Pór, 1998), (Davenport and Prusak, 1997)) and continuously expanding. The knowledge workers do not need more sophisticated search engines to deliver yet more passive knowledge that they do not have the time to process, but more intelligent mechanisms that "digest" this knowledge and make it immediately usable.

2.3. The need to take into account the specificities of the user

Knowledge Management Systems do not usually take into account the specificity of the user, and in particular they usually provide the same interaction mode for all the users. When some form of personalization exists, this customisation is very shallow and superficial: for instance the user is able to specify some preferences in the presentation of the information (such as the position of the information displayed in a portal), and in more advanced cases is able to specify some interest that the systems will take into account to filter the information to be displayed.

Knowledge Management Systems should go far beyond this superficial support of users' specificity, and try to build a deeper understanding of the users. This understanding can include not only users' preferences, but also their role in the organization, their competencies, their cognitive style, their interests, their desires and their motivations.

Why is a deep understanding of the user information and personalization important? Firstly, this helps to increase the personal relevance of the knowledge that is delivered, and therefore to reduce cognitive load (the more a knowledge management system knows about a user, the more it will be able to deliver useful knowledge and intervene appropriately in knowledge-related processes). The second reason is that user-centred & personalized systems may be useful for defining, maintaining and expressing the identity of the users ((Blom, 2000), (Blom, 2002), (Nabeth and Roda, 2002)), and for facilitating the expression of the users' identity in the social environment (via the management of cyber-identities). The third reason is that these systems open the possibility to transform radically and tremendously the role, the perception and the value of Knowledge Management Systems. Knowledge Management Systems with a deeper understanding of the users (for instance their personality, their motivations, their goals) can be expected to develop a totally new relationship with these users and become virtual companions in symbiosis with the users (André and Rist, 2002), rather than being the external tools that they are today.

3. A vision of highly social, active and personalized knowledge management systems

It follows that the next generation knowledge management systems should try to provide some mechanisms for supporting the knowledge related processes both in their social, organizational and individual dimensions (Nabeth, Angehrn and Roda 2002).

3.1. Supporting the social dimension (management of tacit knowledge)

Different mechanisms supporting the social dimension and in particular facilitating the management of the tacit knowledge can be distinguished.

The first category of mechanisms includes all the communication mechanisms that help a community of users to communicate such as the different combinations of synchronous / asynchronous discussions between two / several individuals located at the same or two different places and using a different medium (text, voice or video) to communicate. Technological platforms propose different means to support these mechanisms with tools such as e-mail, forum, bulletin boards, videoconferencing or the telephone. The availability of these communication means represent however only a necessary condition, and never a sufficient condition nor a guarantee that the communication will take place and evolve in a satisfactory way (Dyer and Nobeoka, 2000), (Cothrel and Williams, 1999). As indicated previously, people need some good reasons to engage in a social exchange. They also need security and a minimal level of trust (Alfarez and Hailes, 2000).

The second category of mechanisms addresses these latter concerns, and more generally includes all the means that contribute to the establishment and the support of the social dynamics of communities. These mechanisms include components that facilitate the formation and the sustainability of social structures (groups and communities), trust and reputation or collaborative activities such as: (1) group formation systems (directories, matching services); (2) recommender/opinion systems, reputation systems (Resnick et al. 2000)(Glance, Arregui, and Dardenne, 1999), social activity visualization (Erickson et al., 2002), which contribute to the transparency and therefore to the social motivation, the adoption of share values and the construction of trust; (3) coordination systems (negotiation systems, conflict resolution systems, group decision systems, voting systems) which help to support more structured social activities and to maintain the cohesion of the group.

3.2. An active support for all the knowledge related processes

The interaction of the user with Knowledge Management Systems should not be passive. On the contrary, Knowledge Management Systems should engage users in a continuous and active management of their knowledge. Different approaches and mechanisms can be proposed to support pro-actively the user in his knowledge-related activities.

First the knowledge can be represented and delivered in a much richer and active form. Knowledge does not need to be represented as static documents, but also can take the form of (1) structured and evolving documents that are collaboratively authored and annotated (using opinion systems techniques); (2) access to people (expert, specialists, pairs) with whom the user can engage in an interaction. Of course this includes not only services for locating these people, but also assessing how much they can be trusted and the reciprocal benefit of the interaction; (3) forum / discussion threads (fuzzily structured text knowledge); (4) stories available in many forms (text, voice or video); (5) simulations, such as role playing simulation, in which the user acquire the knowledge by experimenting; (6) other knowledge management related tools (such as assessment or decision making tools).

Second the level of the interactivity with the users can be radically transformed by becoming more pro-active, and support “intelligently” the knowledge worker in the whole knowledge management cycle and in particular: (1) anticipate users’ needs; (2) propose pro-actively knowledge objects that they would not be aware of (3) guide them, assess problems, suggest solutions, and advise him/her during his/her work process (decision making, problem solving, knowledge creation); (4) assist them in their interactions with others (active support for the social process); (5) stimulate and motivate them (integrate the human dimension); (6) help them to reflect, to restructure and to acquire new knowledge (help them to learn).

3.3. Providing a high and deep level of personalization

Knowledge management systems should be user centric. More concretely, user-centred & personalized knowledge management systems can (1) support more efficiently the current activity of the knowledge worker by knowing his/her current focus, his/her goal and his/her role in the organization; (2) select and deliver knowledge in a way that maximizes its impact (for instance a conceptual user will feel comfortable with a book, whereas a more down to earth user will prefer a story or a case delivered in voice form, a very sociable person will prefer a conversation with a peer, and an engineer the access to a mock-up); (3) exploit the individual and social motivation of the user (people are driven by personal goals and believe that they have some strong influence on their commitment and therefore the quality of their work).

4. Cognitive agents: What they are, and how they can contribute to the design of Information Systems supporting more deeply human activities.

4.1. Defining the agent concepts

Let's first introduce the concept of agent in general. We will present later on how cognitive agents extend the traditional agent concept by incorporating in them an explicit and high-level representation of the environment in which they operate as well as some reasoning capabilities.

What is an agent

Our objective in this paper is not to provide an in-depth and exhaustive analysis of agent-hood (a good introduction of agent concepts can be found in (Bradshaw, 1997)), but rather to give a reasonably clear and unambiguous definition of what is an agent in order to understand how this concept can be useful i providing answers to the issues raised in the previous part of this document.

Let's first indicate elements that are often associated with the concept of agents, but do not characterise agent-hood. The level of sophistication (or of intelligence) of a computer program, the technology that is employed to design it (such as an agent framework like Jade http://jade.cselt.it/), an anthropomorphic interface, some level of spatial distribution or mobility do not make a programme an agent system. These properties cannot indeed be considered as mandatory for an agent system, and we can mention for instance the whole body of research of the domain of artificial life in which the agents are mainly reactive and incorporate none of these properties.

For Wooldridge and Jennings (Wooldridge and Jennings, 1995), an agent is a software entity that implements the following properties: autonomy (self direction), social ability (capability to interact with other agents), reactivity (perception of the environment), proactiveness (initiative). For Franklin and Graesser (Franklin and Graesser, 1997) an autonomous agent is a system situated within and a part of an environment that senses that environment and acts on it, over time, in pursuit of its own agenda so as to effect what it senses in the future. Patie Maes defines "autonomous agents as computational systems that inhabit some complex dynamic environment, sense and act autonomously in this environment, and by doing so realize a set of goals or tasks for which they are designed" (Maes, 1995).

In other words, agents are entities (artificial or not) that possess some properties of identity, autonomy, and sensing and that interact with the environment.

Basically two main categories of agents can be distinguished: reactive agents and cognitive agents. **Reactive agents** basically represent relatively unsophisticated autonomous entities which react to external signals in the environment by activating predefined behaviours. The simplicity of each reactive agent is counterbalanced by the important number and the diversity of these entities that can compose a system, and by the phenomenon of emergence that can occur (in particular collective intelligence that can result with the aggregation of many simple ones). **Cognitive agents** represent autonomous entities that basically have cognitive capability, i.e. entities that maintain an explicit and high level representation of their environment, have well expressed goals and motivation, and that have some reasoning capabilities. We will come back later in this paper to explore more in detail what are the characteristics of cognitive agents, and how they can be used in the design of systems that provide a deep support to the human activities.

Should we use cognitive agents or reactive agents in the systems that we design? In fact, these two categories of agents should be considered as complementary rather than competing, and actually should fulfil a different role in the same agent architecture. Reactive agents have the advantage of being simple (although the coordination of a large collection of reactive agents is not that simple), and very efficient, but their competency is limited to the accomplishment of very specific tasks. Cognitive agents on the other hand, with their deeper representation of the environment and their reasoning capabilities, are able to manage higher-level processes closer to human activities and understanding, but they can be very difficult to design. Cognitive and non-cognitive agent's good complementarity is for instance illustrated in some cognitive agent models (such as the Vmattie architecture (Franklin, et al., 1996) whose internal structure is actually composed as a large collection of reactive agents in interaction, the "intelligence" emerging from mechanisms of collective intelligence of the simple agents).

In the rest of this paper, of which the scope is related to the support of high-level and complex knowledge processes that are strongly connected to human activities, we will mainly focus our attention on the cognitive agents.

The reasons for using agents

Agent theories and technologies represent a powerful conceptual and technical framework that can be used for the design of complex systems (systems combining a high variety of elements) incorporating a strong human dimension. In particular, agent technologies can provide very useful tools and approaches that can be used to design applications that are very sophisticated, distributed, active, robust, can easily evolve over time, and that can be highly integrated in systems supporting complex human processes.

Indeed agent approaches help to break system complexity by distributing the control of the applications (i.e. logic of the applications) amongst a set of specialized, autonomous, and weakly coupled entities living in the environment constituted by the information system, and fulfilling specific tasks. The interactions between these entities, between these entities and the users, and between these entities and environment are made using some clearly predefined protocols, increasing modularity. Special mediator agents (for instance yellow page services agents) are used to further decouple the interaction between the different entities and guarantee evolution (which typically consists in the introduction of new entities delivering new services). It has to be noted that agent approaches can be considered as complementary to the object approaches, and address how the activities of a system are organized and coordinated (object oriented systems are principally reactive, and mainly deal with a single thread of activity).

Besides, agent approaches can particularly easily be introduced to support human activities, since human organizations can be considered themselves as inherently agent oriented (the agents in human organizations are the people!). In particular, the use of an agent approach helps to reduce considerably the impedance mismatch between information systems, and the human organization that these systems support. More concretely, artificial agents can be defined in symbiosis both with individual people (in particular with the introduction of the artificial personal agent that can assist the user), and groups (where agents evolving in the social space can help to enhance the effectiveness of highly social activities by proposing social related services such as mediation, or matchmaking).

Agent technologies and approaches

A certain number of agent technologies (such as Jade or the FIPA standard) have been defined to facilitate the design of complex systems that rely on an agent approach. However, as indicated previously, the use of these technologies is not a sufficient condition for implementing an agent system, and it is not a necessary condition.

These technologies provide an infrastructure (usually in the form of standards and middleware) that provides different services such as distribution transparency, interoperability, or a communication language, which help to hide the low level details and allow the designers to concentrate on the business logic of the application. This last assertion has however to be mitigated by the fact that these frameworks usually require some strong technical competences, and because the development of agent-based systems has many pitfalls attached (Wooldridge and Jennings, 1998).

The objective of this paper is not to enter into a debate about the benefits or limitations of these technologies. Let's just say that they have existed now for some time, but they still cannot be considered as totally mature since they still require an important technical effort (in particular they require highly skilled people), and are very technically focussed (they are still far from only manipulating the high level agent concepts that would be desirable to really exploit their full benefit).

On a less technical side, agent approaches propose a conceptual framework that can be applied to the design of complex systems. This conceptual framework relies on the idea of representing a system as an environment constituted of passive objects (resources), populated by a set of active entities (real or artificial agents) having some functions and goals to achieve, that enter in interaction. Interestingly, this conceptual framework has its origin in different non-technical domains such as economy (for instance we can mention here the work of H. A. Simon on bounded rationality); sociology; organization (for instance Fox (Fox 1981) introduces the idea of using organization as a metaphor that can be useful in helping to describe, study, and design distributed software systems); and ecology.

The application of agents in the domain of knowledge management

As indicated previously, agent approaches and technologies represent a general "paradigm" for designing complex systems, and therefore do not have a specific domain of application. Agent approaches and concepts have therefore been applied in a multitude of application domains ranging from air traffic control, to e-commerce, education, network management, or information management.

Agent approaches and technologies have in particular been applied for the design of Knowledge Management and CSCW (Computer Supported Collaborative Work) systems. This domain, which is often very complex and distributed, and for which the human component is important (for instance an important source of knowledge is present in the person's head) appears to represent a very good candidate to benefit from all the advantages promised by the agent approaches.

The application of these concepts in the domain of knowledge management is relatively straightforward: a knowledge management environment is constituted of an environment which contains a set of knowledge resources, some mechanisms, and in which different categories of agents (knowledge workers, artificial knowledge agents), access the resources, participate in the creation of new knowledge resources in the system, interact, exchange and trade knowledge, etc. This approach is actually relatively similar to the one that Thomas H. Davenport and Laurence Prusak prone with they concept of information ecology (Davenport and Prusak, 1997) which comprehend the relations between people, processes, support structures and the other elements of a company's information environment, as an ecological system that has to be managed as such. In this context, a knowledge management system is constituted by the subset of the digital components (services, mechanisms, artificial knowledge agents) of this environment that contribute to support and to accelerate of the knowledge related processes.

Agent approaches have been used for instance in the CoMMA project to support the management of corporate memory (Comma, 2000). The Frodo project has defined an agent-based middleware for supporting organizational memory (Van Elst and Abecker, 2002). And the OMAS platform proposes a multi-agent architecture for knowledge management (Tacla and Barthès, 2002).

4.2. The cognitive agents

What is a cognitive agent

Cognitive agents (or deliberative agents) represent the special category of agents that have a minimum level of consciousness of the environment in which they operate (they maintain a symbolic model of the world), and of their actions (they define some plans). In particular, cognitive agents know explicitly how to interact with the other (real or artificial) agents, can conduct some reasoning (their model of rationality is explicit), and can decide to engage in some action in order to fulfil some goals (they are driven by some motives).

Research on cognitive agents covers a very broad range of concepts that can be as diverse as agent believability (for agents with a strong interaction with the user (Bates, Loyall, and Reilly, 1994)) or inter-agent sociability (in particular in artificial agents co-ordination (Ossowski, 1999)).

Many models of cognitive agents have been elaborated which defines the different components of the "brain" of an agent. In the BDI (Belief, Desire & Intention) model of (Rao and Georgeff, 1995), the "brain" of an agent includes three components: a component which models and maintains a representation of the state of the environment (Beliefs), a component which deals with the objectives to be accomplished by the agent (Desire), and a component which manage the currently chosen course of action (Intention). In the agent architecture Tok, principally used to model believable interactive artificial characters (Bates, Loyall, and Reilly, 1994), agents are defined according to the following components: Perception; Reactivity and goal-directed behaviour; Emotion and social relationships.

Models of artificial cognitive agents have some resemblance to some models of human agents, and it is not a surprise to see some research studies trying to incorporate in artificial agents the same characteristics as for human agents (for instance Rosalind Picard (Picard, 1997) tries to introduce an affective dimension in artificial characters).

However, the ultimate goal of agent research is definitively not to replicate a human brain (although some research points in this direction (de Garis, 2003)) in order to substitute human beings, but rather to play the role of enhancers of human intelligence. Besides, the computational intelligence of cognitive agents does not need to be of the same nature as human intelligence, and we feel that the term "smartness" would be more appropriate, less confusing and actually easier to achieve in a reasonable time frame. Concerning the level of "intelligence" of these agents, it may vary considerably whether we prefer to have few but very complex agents or more agents but with more limited intelligence. Finally, the agents should not necessarily need to adopt an anthropomorphic visual representation (some back-office agent may not need any visualisation at all), although it may contribute to make the interaction with the system easier and more intuitive for the end user.

Why use cognitive agents

Cognitive agents represent the characteristics of modelling explicitly and at a high level their environment and of conducting some reasoning. Cognitive agents build a semantic representation of the world in which they operate, have some goals that drive them (they implement a model of motivation), and are able to define some relatively long term plans to try to achieve these goals.

One of the main advantages of cognitive agents over more reactive ones is that they really try to get a deep understanding of their environment. Consequently, they are able to support much more deeply the different processes for which they have been designed. For instance, cognitive agents can build a deep understanding of the model of the different users of the system (who these users are, what their preferences are, what their competencies are, what their psychological of social profile is, what motivates them, etc.) in order to try to provide a high level of personalization in their interaction. Cognitive personal assistance agents, by "knowing" better the user as an individual user, are able to enter in symbiosis with this user and become a better personal (intimate) companion. Cognitive social mediators are able to deliver much more effective matching services by "knowing" in a deeper way the profile of the people belonging to a group.

Cognitive agent architectures

Research on cognitive agent architectures has already a relatively long history, and the pioneering system SOAR can be cited as an illustration of this work (Laird, Newell, and Rosenbloom, 1987). However, the result of this preliminary work has proved difficult to apply given its complexity, and because of the computing power that was required to conduct the reasoning. After a period of relatively slow activity, a new wave of cognitive agent architectures has emerged in the last few years (Ercim, 2003): the computing power is indeed now available at a cheap price and the semantic approaches are again receiving more attention from researchers endeavouring to make the design of intelligent systems more achievable and attractive.

ConAg (Bogner, Maletic, and Franklin, 2003) is a reusable framework, written in Java, for creating "conscious" software agents. ConAg relies on the Global workspace cognitive theory of consciousness, which postulates that human cognition is implemented by a multitude of relatively small, special purpose, almost unconscious processes. Consciousness therefore emerges from the interactions of this multitude of basic behaviours (or reactive agents). The ConAg framework has successfully been deployed in two conscious agents: Cmattie, an agent gathering information from humans regarding seminars and seminar-like events such as colloquia, defence of theses, etc.; and IDA (Intelligent Distribution Agent), an intelligent agent assuring the role of an artificial Navy detailer (job assignment service for the US marines).

We have already mentioned the BDI framework (Rao and Georgeff, 1995) as a model for the brain of the artificial agent. The BOID architecture (Broersen, et al., 2002) extends the BDI framework by proposing Beliefs, Obligation, Intention and Desire as the right abstraction tools to specify agent behaviour. Two prototypes written in the Prolog language implement the BOID architecture. This architecture has been applied to design agents for managing conflicts.

ICARUS represents another integrated architecture for intelligent agents (Langley et al. 2003). The framework supports long-term memories for concepts and skills, and it includes mechanisms for recognising concepts, calculating internal reward, nominating and selecting skills, executing those skills in a reactive manner, repairing these skills when they fail, and abandoning them when they promise poor returns. This framework is articulated according to the following principles: Primacy of categorisation over problem solving; Primacy of

execution over problem solving; Internal origins of tasks and intentions; Value-laden nature of behaviour (linking rewards to cognitive structures like concepts and plans); and Internal origin of agent rewards.
It would be too long to enumerate all the cognitive agent frameworks, and we refer the reader to (Ercim, 2003) for some other examples.

5. Using cognitive agents to support knowledge management activities

The purpose of this section is to present more in detail how the concept of the cognitive agents that has been presented previously can be applied to the specific domain of knowledge management. In particular, this section is going to present three categories of agents that can be used to support some knowledge processes:

- Social agents that can be used to provide support to the social dimension in knowledge management systems.
- Activity agents that can be used to stimulate some knowledge related processes.
- Personal agents that can be used to establish new forms of interaction between the user and the computer programme.

5.1. Social Agents

Description
The role of social agents is to directly support the social dimension of knowledge management. Present mainly in the different digital communities hosted by the knowledge management platform to which they contribute to its social dynamic, they provide social facilitation services such as: group/community formation services; discussion facilitation and elicitation; discussion content extraction and structuring; mediation; opinion/reputation diffusion relaying and accelerator; assistance in the organization of social events; participation in socially related role-playing simulation; etc.
Social agents are able to intervene effectively because they have access to two categories of critical information: (1) the user profile information that the personal agents are ready to disclose to them (obviously trust issues have to be addressed here); (2) the monitoring of the activity occurring in the social spaces: in digital environments, it is relatively easy to monitor the level of activity, as well as to access the content and structure of the conversation and other interaction occurring.
User information can be exploited by matchmaking algorithms (that are embedded in the social agents) to facilitate the emergence of social structures such as groups. This approach has received a considerable attention some years ago with the research line of social collaboration filtering and social navigation. Exploiting monitoring information promises to be at least as fruitful a direction for agent research: first it provides social agents with some indicators that can be used to diagnose the quality of the knowledge exchange (and become the trigger for some corrective actions); second the social agents also intervene in the conversations to augment the social translucence (Erickson et al. 2002); third social agents can also analyse the structure of conversations and contribute to facilitate them (identifying conflicts and solving them, raising the awareness of people of the dynamics of the conversation, etc.); and least social agents are also able to exploit the social structure of the groups (the social networks) in order to maximize the impacts of their actions (for instance focussing their attention in the more central nodes).

An illustration in EdComNet: supporting the social process and people's autonomy in a knowledge exchange community.

EdComNet is a research project supported by the European Commission that aims at defining a virtual learning community for adult citizens. This community will act as a portal stimulating the active learning of social skills by the citizen, thus enhancing the social integration of individuals within urban communities. It will empower the individual citizen to be a self-reliant part of society, fostering creativity and autonomous opinion forming as well as decision-making.

EdComNet plans to provide social mechanisms supporting social processes and therefore knowledge exchanges. Social spaces are designed (using communication technologies such as forums, chat spaces, e-mail, multi-user virtual reality technologies), and services are defined to support the emergence and the operation of social activities. Services include: group formation systems (implemented via match-making agents that have access to the profile of the different users, the definition of human facilitation procedures that help groups forming or spin-offing from existing groups); facilitation and mediation services; coordination mechanisms which help the group to organize their activities (implemented using electronic calendars, collaborative project management systems, definition of people roles, voting & pooling systems); knowledge and opinion sharing services (using recommendation techniques) which facilitate knowledge exchange as well as trust and reputation creation, and also contribute to the adoption of share values in the community; active collaborative activities (such as the organization of role playing simulations).

5.2. Agents for supporting actively knowledge management processes

Description

This category of agents includes all the agents that can contribute to support the knowledge management process in knowledge management platforms, and make it more active. Of course, we could argue with reason that both the social agents that have been described previously and the personal agents that are to be presented later also fulfil this definition. However in some cases we have agents that do not clearly belong to these two categories and that definitively provide an active role in the knowledge management platform (for instance, this is the case of some service agents that automate some of the tasks of the document management system that we have decided to ignore in this paper). Besides we feel it is desirable to distinguish some categories of agents –as the one presented in the next chapter- which, although they have both a social and individual component, have a much broader impact at the level of how the whole organisationworks.

The KInCA example: Using cognitive agents to help the adoption of knowledge sharing processes in organizations

KInCA (Knowledge Intelligent Conversational Agent) is a research project sponsored by the Xerox Corporation, which aims at supporting managers in learning, understanding, and applying knowledge sharing processes in organizations (Angehrn et al., 2001)(Roda et al., 2003).

KInCA uses agents to stimulate and support the dynamics of knowledge exchange. The approach is based on the idea of associating to each user a personal artificial cognitive agent capable of helping her/him to progressively learn and adopt knowledge sharing behaviours. This personal agent cooperates with a set of expert agents implementing different strategies and modes of interaction. As a result the personal agent will, for

instance, give some diagnostic to the user, or it will tell her/him a story, or it will suggest a document to read, or will comfort her/him. Through this interaction, the user progressively becomes aware, gets interested, tries and adopts the desired knowledge-sharing attitude. KInCA's model of the dynamics of knowledge adoption is based on Everett Roger's theory of innovation diffusion (Rogers, 1995).
KInCA represents a perfect illustration of cognitive agents, since KinCA agents rely on a deep understanding of the people's attitude transformation, and build plans to support it.

5.3. Personal agents

Description

A personal agent is totally dedicated to a particular user. Personal agents continuously observe the behaviours and the actions of a user, and are able to build a deep understanding of this user (represented by a symbolic and sophisticated user model) that cover the many facets that can be relevant in a knowledge management context. Practically this knowledge may include elements as different as the basic identification of this user, but also his competencies, interests, current working context, motivation, cognitive style, personality or social network. The personal agents also maintain a representation of the environment: what are the different sources of knowledge, what are the current knowledge management processes running, what are the different services available in the platform, what are the other artificial agents (personal or not), who are the other users.
This representation of the world and of the user allows them to play the role of an extended knowledge management companion: they are able to assist the user in using the platform, automate some of the users' tasks, contributing to reduce information and work overload (Maes 1994). More interestingly, this in-depth knowledge of the user should allow them to intervene pro-actively in a very personalised and "quasi-intimate" way, and support the user taking into account the psychological and the social dimension. Practically, agents (1) can select and deliver the category of knowledge objects that will have the maximum impact on a user; for instance the agent can exploit the cognitive style of the user, his current working context to select the form of knowledge (such as a formal or an informal document, a conversation with a peer, or a simulation component) that the user is more able to apply to his problem. (2) Stimulate and question the users (Angehrn, 1993), engaging them to try and adopt alternative knowledge management processes (the agents assume here a learning role); (3) Guiding the users in better exploiting the less formalised and invisible knowledge.

Quite a lot of work has been done on artificial personal agents (personal secretary, interface agents, etc) to have to detail them. On the other hand, it is worth mentioning the work that is currently conducted in the domain of e-learning with the personalised learning platforms (PROACTe, 2002) for which we believe the results provide interesting insights for the design of personalised knowledge management platforms.

Ontologging: extracting social patterns and personalizing the interaction in a knowledge management system.

Ontologging (http://www.ontologging.com/) is a research project supported by the European Commission aiming to define a next generation knowledge management platform. Onto-Logging addresses the problem of corporate ontology formalization and

intends to better integrate formal ontology definition methods within Knowledge Management Systems in order to make them more adaptable to the user needs and to better support the exchange of knowledge in organizations.
Ontologging works on providing a deep level of personalization to the user. One of the most important aspects of this project is its use of a sophisticated model of the user in order to achieve certain adaptive features and personalized interaction. This user model is defined as an ontology describing the different characteristics of a user that can be relevant in a knowledge management context (including not only identity and preference, but also competency, cognitive style and behavioural profile). Part of this user model is dynamically inferred by tracking the user interaction with the system. This information will be used by personal agents (designed using the Jade platform) to select and deliver to the user the more relevant knowledge objects.

6. Final words and Conclusions

6.1. Reality check, and evaluation

Many of the so-called agent systems that exist in really operational knowledge management systems are essentially constituted by search bots, and data mining and profiling agents (that automatically cluster data into categories), and can be mainly considered as reactive (they do not belong to the cognitive category that was presented in this paper). Indeed these agents, that can be very sophisticated and powerful, have a very narrow picture (if any) of the environment and processes in which they intervene, and have only an extremely specialized role.
Most of the work related to cognitive agents that has been presented in this paper still remains very much in an experimental stage, is only present in laboratory prototypes, and needs some additional effort and time before being incorporated in real environments.
A legitimate question to ask is if these approaches work effectively, and in particularly how many of their promises have been validated. To our knowledge, very few systematic evaluation works have been conducted until now related to the effectiveness of intelligence agent techniques for designing systems supporting complex processes. We can however mention the work of (Barthès and Tacla, 2002) who have started to collect concrete evidence (via user feedback) on how cognitive agents can significantly augment the value of their knowledge management platforms OMAS. In the domain of e-learning, (Thaiupathump, Bourne and Campbell, 1999) have investigated the effect of applying intelligent techniques to an online learning environment. Practically, their study has used experimental groups and comparison groups to examine the association between the use of knowbots (knowledge agents) and workshop completion (attrition and dropout represent indeed a major problem in distance education). Their findings indicated that the use of knowbots was positively associated with higher learner completion rates in the workshops.
From a more theoretical perspective, (Langley, and Laird 2002) proposes a set of evaluation criteria for evaluating Cognitive architectures. These criteria include the scope of the agents (generality, versability and taskability), the rationality (do the agents really understand the rational for their actions), efficiency and stability, reactivity and persistence (ability to deal with unpredicted situations), improvability (do the agents learn), and autonomy and extended operation (are they able to take initiatives). Obviously, the measuring all these characteristics represents a major task that will require a minimum level of maturity of the systems that incorporate cognitive agents. However, a minimal evaluation of some of these factors represents necessary condition for the adoption of these techniques in the real words, since proven effectiveness is an element that will enter more

and more in consideration in the decision to have these approaches effectively used by real users.

6.2. Future outlook

Several elements make us believe that the vision of agents as more intelligent and more integrated in human related activities is progressing well. First, the very recent years have witnessed a considerable interest in the concept of the semantic web, whose objective is to define explicitly the semantic of the digital environments, and which will provide cognitive agents with the foundation they need to be able to really conduct "intelligent" reasoning. Second, knowledge management is increasingly considered according to a holistic perspective that include a large diversity of knowledge related processes (including not only the document management processes, but all the human related processes), and knowledge management system that will be able to support them will have to be able to take into account this complexity in a manageable way (be enough high level). Finally, agent technology has a momentum which can be observed for instance in new (sixth) framework programmes from the European commission, and from the Roadmap document that has been authored by the Agentlink Network of Excellence (Luck, McBurney, and Preist, 2003).

6.3. Conclusion

The relatively limited success in the adoption of Knowledge Management Systems in companies has raised some questions on the validity of the approach used currently to design these systems. We have argued in this paper that the limitations of these approaches come from too narrow a perspective of knowledge management which is viewed mainly as document centric and passive, and which almost ignores some of the most important knowledge related processes (such as knowledge creation or knowledge sharing) of modern organizations.
In this paper we have proposed a cognitive agent-based approach which tries to address these limitations: knowledge management "systems" are viewed as mixed digital / real world environments in which knowledge is created, transformed, communicated, shared, and applied by a set of active entities via different mechanisms. Obviously, the active entities include the knowledge workers that are also the main users and beneficiaries of the systems, and artificial agents which are used to enhance the functioning of the systems and to facilitate and accelerate this "knowledge ecology". In particular the role of the artificial agents is to facilitate the social processes, to support the knowledge-related processes, and to assist the individual user.

Let's admit that the complete realisation of the approach presented in this paper is not exactly for today, although some partial implementation of this vision is already in place in some operational systems (in particular in the domain of opinion systems) and in prototypes (for instance many research projects explore personalisation techniques). Besides, even if there are some good arguments that let us believe in the idea that cognitive agents can significantly augment the value of knowledge management platforms, no concrete evidence exists to our knowledge to support this hypothesis, although the users' feedback collection that is planned for the OMAS cognitive agents augmented knowledge management platform (Barthès and Tacla, 2002) may begin to deliver some answers.
If we want organizations to adopt this approach, it appears necessary to work in two directions: (1) the design of partial implementations of the vision that has already delivered

some substantive and visible value to companies (which means going beyond technical prototyping and inventing the "killer application"); (2) the collection of empirical data as well as going to some more systematic measure which helps to prove and to evaluate the validity of the approach.

Also, the success of the approach will also depend on the ability of the agent technologies and theories to deliver their promises, and in particular not to be distracted from the goal of focusing its effort on "practical intelligence" delivering real values to the end users, in favour of the pursuit of more hypothetic goals such as the search for mimicking human intelligence.

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