Autonomous Agents and Multi-Agent Sytems, 9, 285–301, 2004

Agent-Mediated Electronic Commerce

CARLES SIERRA sierra@iiia.csic.es
IIIA-CSIC, Campus UAB, 09193 Bellaterra, Barcelona, Spain

Abstract. Electronic commerce has been one of the traditional arenas for agent technology. The complexity of these applications has been a challenge for researchers that have developed methodologies, products, and systems, having in mind the specificities of trade, the interaction particularities of commerce, the strict notion of commitment and contract, and the clearly shaped conventions and norms that structure the field. In this paper I survey some key areas for agent technology which, although general, are of special importance in electronic commerce, namely, solid development methodologies, negotiation technologies and trust-building mechanisms. I give examples of systems in which I have directly participated, although I also try to refer to the work of other AgentLink Special Interest Group members over the last few years.

Keywords: agent-mediated electronic commerce, organizational theory, mechanisms, trust and reputation.

1. Introduction

Society considers Information and Communication Technologies (ICT) as one of the most important transforming forces of the turning of the Century. There is a clear agreement that ICT have had a positive impact on productive growth, on productive capacity and on international competitiveness, through the reduction of transaction costs, the increased efficiency of management, and the interchange and access to more information. This is especially true for commerce. A direct consequence of the development of ICT has thus been a fundamental change in how enterprises and economies work.

A recent study by the United Nations [50] highlights three foci of attention to be considered by electronic commerce, with special importance placed on developing countries:

1. *Business process outsourcing* (BPO): The management of the supply chain has been a central concern for decades as the key element in reducing costs. Advances in network topology and increased bandwidth have made the outsourcing of services easier, so that companies can now offload entire business functions. BPO may reach $585 billion in the next two years, where BPO varies from basic administrative tasks (such as data entry and billing) to complex tasks requiring decision-making and problem solving.
2. *Marketing agricultural exports*: Agricultural exports are key in many economies. These commodities' marketing chains involve many intermediaries that introduce inefficiencies in the system as the earnings are shared by a multitude of traders and processors, and producers receive only a small share of the final consumer price. Electronic commerce can allow producers to reach global markets at reduced

transaction costs, and electronic markets and online auctions offer excellent ways of achieving and improving this type of commerce.

3. *Online dispute resolution*: One of the biggest challenges for electronic commerce is how to deal with disputes (especially cross-border ones). Distance, different laws and jurisdiction are all potential obstacles to online business. Online Dispute Resolution (ODR), which is currently going through a process of regulation, is a clear mechanism for building trust in online transactions in situations where relationships are new or where there is a lack of efficient institutions that cover the transactions. The initial assumption that online markets would just need low prices has been shown to be wrong, as low risk transactions are equally relevant.

Each of these areas offers real commercial benefits, and agent technologies may be key in enabling solutions to address the challenges. We will center the structure of this paper on three important research areas in *agent-mediated electronic commerce* (AMEC) that offer potential answers to the challenges above.

In order to effectively manage business process outsourcing, the role of organizations is essential, especially when the trading is done across international borders. Thus, the use of electronic counterparts of organizations and institutions, in which interactions are regulated by norms will be the topic of Section 2. Mechanisms like auctions and negotiation, which are essential for market modelling, and which have been formally and practically devised for agent interactions, will be the topic of Section 3. Finally, as suggested above for online dispute regulation, the need for trust mechanisms between agents will be the concern of Section 4. The paper ends in Section 5 by considering some examples and real deployed AMEC systems.

By combining these three aspects of agent technologies, we can summarize the key message of this paper as the following equation:

$$eCommerce = organization + mechanism + trust$$

Most of the work reported in this paper relates to activities that have been directly or indirectly animated by the Special Interest Group on AMEC that has been supported over the last five years by the AgentLink network of excellence for agent-based computing [1].

2. Organizations and electronic business

Human organisations and societies have been dealing with the problem of co-ordination and co-operation for centuries. To do this, normative structures have been established, supported by organizations and institutions that back up the norms and enforce them. The success of these social abstractions in providing an answer to the co-ordination demands of citizens has served as inspiration for multi-agent systems designers facing similar complex problems. In the context of commerce and trade, there is a plethora of organizations and institutions that provide support for human interactions; thus it is not strange that electronic commerce multi-agent system developers have had a special interest in the use of these metaphors. In a sense, social order is the multi-agent system equivalent of robustness in classical software engineering.

2.1. Open Systems and organizational approaches

The complexity of designing and verifying multi-agent systems arises mainly from their distributed nature and from the flexible interactions among agents. Furthermore, the complexity of multi-agent systems increases notably as we consider open systems; that is, systems in which the components are not known in advance and/or can change over time. In these systems, agents cannot be assumed to be cooperative and working for the common good of the overall multi-agent system. Usually, assumptions of agents being selfish (utility maximisers, in economic terms) are made by the system designers. This is common in the different agent-mediated marketplaces developed in recent years. Openness not only imposes a certain view on what to expect from the agents' behaviour, but it also forces the system designers to think about the protection of the overall system from the misbehaviour of agents. Mechanisms should be put in place to permit the agents the execution of just those actions they are authorised for [7, 39].

Openness is unavoidable in the development of multi-agent systems due to the expansion and massive usage of networks like the Internet. Applications and service provisioning can no longer be thought about without facing this reality. Thus, applications naturally become web services, and the concept of computer expands into a grid of computing devices that interact. Services and computing devices appear, disappear, and change. Dynamism becomes commonplace. The problem of openness has to receive a methodological answer.

Organizational approaches seem to be the solution to this challenge. What they propose is to look into the system from a global perspective identifying the roles of agents and the potential interactions and relationships among the agents, without looking into their internals. This seems the right approach to deal with openness. Multi-agent systems have been designed mostly from an agent-centred perspective, and few have given the overall social view the importance that it merits; most current methodological approaches are extensions of methodologies used for other computer programming paradigms, especially object-oriented – see [51] for a review. The interest in methodological issues following an organizational approach has been especially important in recent years, particularly within groups working on electronic commerce applications: Gaia [52], MadKit [16], Electronic Institutions [11, 31, 39], or Tropos [17]. This is by no means strange, as electronic commerce has witnessed the first real applications of multi-agent systems, and its engineers have faced serious methodological difficulties in their development.

For example, the Gaia methodology understands multi-agent systems as computational organizations with interacting roles. In the first phase, the role and interaction models are defined. Each role is characterised by responsibilities, permissions, activities, and protocols. Responsibilities determine the functionality of the role, permissions represent the resources available, activities represent private agent actions, and protocols establish role dependencies and relationships.

MadKIT offers one of the most clear organizational approaches to multi-agent systems development. It works around three main concepts: group, role and agent. Groups are defined in terms of the roles that agents, being group members, can take. Also, the interaction within a group is structured around role-to-role protocols. Agents can belong to several groups at the same time.

Finally, the TROPOS methodology follows a cascade approach to software development: early requirements, later requirements, architectural design, detailed design, and implementation. The concept of actor is used to represent agents, roles, or groups of roles. The system itself is also represented as another actor, with relationships with the environment. The architectural design divides tasks into subtasks to which, again, actors are associated. In the detailed design phase, protocols using AUML are specified, and agent skeletons using a BDI architecture are deployed at the implementation phase using JACK.

In the next two subsections I expand on two methodologies based on a strong organizational view in whose development I have been active in the last years. These methodologies combine to form a view of agent development that is appropriate for use in the context of electronic commerce, especially in relation to these organizational concerns.

2.2. Electronic institutions

There are situations in which individuals interact in ways that involve: *Commitment*, *Delegation*, *Repetition*, *Liability and Risk*, and these situations usually involve participants that are Autonomous, Heterogeneous, Independent, Not-benevolent, Not-reliable, and Liable. Such situations are not uncommon: markets, medical services and armies are but ready examples of forms of collective problem-solving, coordinated tasks, and communities in which participants interact under the type of features mentioned above. Many more exist, and many have proven successful for dealing with their intended goals for a very long time.

In such situations, it is not uncommon to resort to a trusted third party whose aim is to make these interactions effective by establishing and enforcing conventions that standardize interactions, allocate risks, establish safeguards and guarantee that certain intended actions actually take place, and that unwanted situations are prevented. Such is the intuitive notion of an *institution*, as we normally use the term when we refer to the *institutional* character of markets, political organizations, religious communities or families. Similar intuitions underlie theoretical approaches to institutions such as the economic-theoretic, sociological, legal and psychological ones.

As institutions serve to articulate agent interactions, their crucial purpose is to facilitate, oversee and enforce commitment-making among participants in a repetitive situation. Also, their functionalities include: *to manage the identity of participants*, *to define and validate requirements on participant capabilities*, *to establish interaction conventions*, *to facilitate effective interactions*, and *to enforce satisfaction of commitments*. In order to transport these ideas to the agent world, we have proposed the idea of *Electronic Institutions* [11, 31, 39] as entities with three main components:

1. *Dialogical Framework*. Where most ontological aspects of the institution are addressed: the language used to communicate and the intended meanings of illocutions, and terms and entities that may be invoked in those communications *within the institution*.
2. *Performative Structure*. The conventions that establish the flow of interactions and the intended social consequences of the actions that take place within the institution.
3. *Norms for Individual Behaviour*. The conventions to which individual agents are subject while acting within the institution. These conventions address the preconditions that need to be satisfied by a given participant in order to establish a commitment, and the effects such commitments may have on the individual's existing commitments and ulterior behaviour.

In a broad sense, Electronic Institutions define the rules of the game for agent societies in a similar way as human institutions do in human societies. That is, they define what agents are permitted to do and the consequences of those actions. Moreover, electronic institutions have a strong dialogical point of view on agent interactions, and the structure of multi-agent systems is conceived as a set of scenes (virtual spaces in which agents playing different roles interact in a structured way) interconnected by links traversed by agents 'moving' among scenes. A deep analysis of the normative part of electronic institutions is on its way [9]. Several free tools give support to this approach (http://eInstitutions.iiia.csic.es), including a specification language editor called ISLANDER [12].

The next subsection zooms into a methodology that uses this electronic institutions approach in building a particular development *process* for multi-agent systems.

2.3. The SADDE methodology

The SADDE methodology [45] is a methodological step towards the building of organizational theories understood as theories that simultaneously: (i) explain the behaviour of organizations rather than the behaviour of selected individuals (or groups) within organizations, (ii) provide a model for individual choice and motivation, and (iii) give a clear translation mechanism between the individual and organizational behaviour [25].

To understand the multi-agent system dynamics, we focus our attention on the study of the relationships between the *a priori* desired global behaviour of an agent society and the actual emergent behaviour shown by the group of agents forming the society. The basic principle of the SADDE methodology [45] is that it is possible to define collective behaviours of agent societies without looking into the interactions and decision-making details of the individuals – what is usually called the Agent-Based Model (ABM, for short).

In the same way, an ecologist would describe how populations of lions and gazelles in a Savannah keep a dynamic equilibrium without modelling concrete lions and gazelles, and chemists would describe the evolution of chemical reactions without modelling each atom and molecule participating in it. Nonetheless, ecologists and chemists explain global behaviour by resorting to particular characteristics and properties of the individuals: lions eat gazelles, and certain pairs of molecules react while others don't. These characteristics guide and inspire the global expected behaviour, although the link between individual behaviour and collective behaviour may sometimes seem unrelated. Similarly, we expect that individual behaviours will guide engineers in the specification of the desired global properties of the system. For instance, the fact that the agents participate in a supply chain trade for goods suggests that that there is a flow of goods and money, and points to potential desired properties, like reaching equilibrium on prices, or keeping stocks at all points of the chain within reasonable levels.

We take the stance that this global behaviour can be modelled as a set of differential equations that explain the dynamics of a group of state variables. These equations are influenced by the boundary conditions established through a group of external environment variables that are not under the control of the equations. For instance, they relate to the rain cycles that determine the available food for gazelles, or the exogenous heating of the reactions made by a chemist. Given a set of particular values of the environment variables, and initial conditions for the set of equations, we can determine the evolution of the values of the state variables in the future, and verify hypotheses about the system's global behaviour: a cyclic pattern, a steady value reached at some point, chaotic behaviours for given parameter values, and so on. In this stance, we rely on the rich experience of system dynamics modelling techniques and tools [46].

We believe that in order to build a model for a society containing thousands or millions of agents, the general view provided by an equation-based model (EBM) provides succinct descriptions of population-level behaviours which we then attempt to replicate using models consisting of a society of individual interacting agents, the ABM. Our proposed lifecycle is graphically depicted in Figure 1.

An important characteristic of multi-agent systems design from a software engineering perspective is the decoupling of two aspects: the interaction process between agents, and the deliberative/reactive activity within each agent. This decoupling helps in simplifying the development of complex software systems, and has guided other methodological approaches [16, 52]. The notion of an *electronic institution* [11, 32, 39, 40] plays this role in the SADDE methodology by establishing a framework that constrains and enforces the acceptable behaviour of agents.

The different phases within SADDE are:

Step 1: *Equation-Based Model* (EBM) – In this first step, a set of state variables and equations relating them must be identified. These equations must model the desired global behaviour of the agent society but will not contain references to individuals of that society. Typically, these variables will refer to values in the environment and to averages of predictions for observable variables of the agents. Methodologically speaking, our approach has an essential difference with respect to the natural and social sciences that model their systems using EBMs. All other fields model *existing* systems: ecosystems, economies, physical systems, and so on. Instead, we are modelling yet-to-exist artificial systems. This distinction is crucial, as the EBM is the starting point of the construction of a system which, later on – once completely constructed – will be observed. Thus, a comparison between the EBM predicted behaviour and the actual ABM behaviour will be obtained.

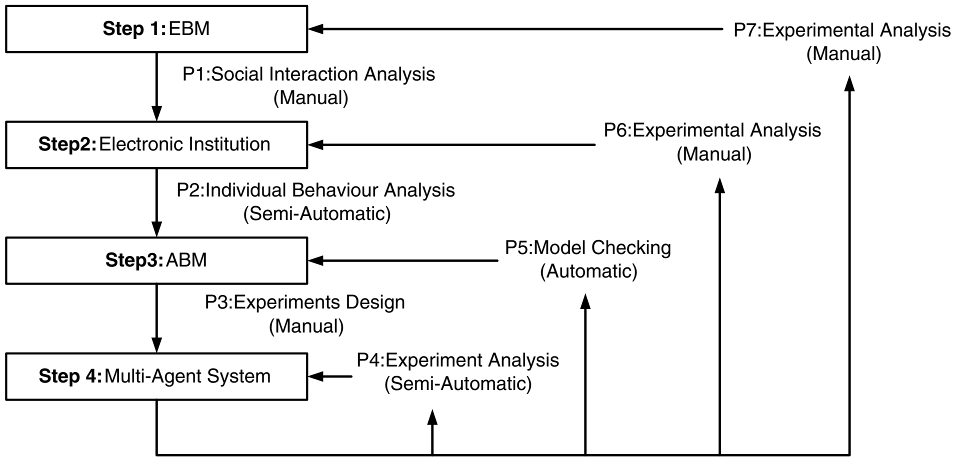

Figure 1. SADD Methodology.

Step 2: *Electronic Institution Model* (EIM). In this step, the focus is on the possible interactions among agents. It is a first "zoom in" of the methodology from the global view towards the individual models. This step is not a refinement of the EBM, but rather the design of a set of social interaction norms that are consistent with the relations established at Step 1.

Step 3: *Agent-Based Model* (ABM). Here, we focus on the individual, and we have to decide what decision models to use. This is the second "zoom in" of the methodology. New elements of the requirements analysis (new variables) will be taken into account here. For instance, some rationality principles associated with agents (*e.g*. producers do not sell below production costs), or negotiation models to be used, have to be selected.

Step 4: *Multi-Agent System*. Finally, the last step of our methodology consists of the design of experiments for the interaction of very large numbers of agents designed in the previous step. For each type of agent, the number of individuals and the concrete setting for the parameters will be the focus of decision here. The results of these experiments will determine whether the requirements of the artificial society so constructed have been consistently interpreted throughout the methodology, and thus whether the expected results according to the EBM are confirmed or not.

Once the experiments designed at Step 4 are run and analysed, several redesigns are possible. Next, we enumerate the different forward and backward processes of the methodology:

[P1] *Social Interaction Analysis*. Once the EBM has been constructed, the relations between the global variables and the analysis of the requirements of the society to be modelled will determine what sorts of agents exist (i.e., the roles), what sort of interactions the agents must have (i.e., the scenes), and what sort of transactions or dialogs they will have (i.e., ontology). This is an inherently manual process: there are many decisions to be made at this stage that have not been specified in the EBM.

[P2] *Individual Behaviour Analysis*. Once a complete picture of the institution is ready, the final aspect to consider is the modelling of the behaviour of the agents. Many aspects of this behaviour are already determined by the institution. For those aspects that are not completely determined, the methodology strongly encourages the design of parametric decision models to fill in the gaps. These parameters will be used to set different experiments and will be the target of agent design rules.

[P3] *Experiment Design*. By choosing agents to participate with (possibly) different decision mechanisms, and by giving concrete values to the parameters of those decision mechanisms, different experiments can be constructed. The experiments should be set so as to explore all the possibilities and to see whether the EBM is making the right prognosis.

[P4] *Experiment Analysis (ABM redesign)*. The analysis of the experiments will be done by comparing the values of the global variables predicted by the EBM and the actual values of agent variables and their averages.

[P5] *Model Checking*. The claims about the behaviour of a group of agents that the developer establishes when specifying an experiment will be model-checked at this stage. The outcome of the model-checking will help to change the agent-based models, i.e., change the decision-making models.

[P6] *Experiment Analysis (EIM redesign)*. Additionally, when the model-checking determines that certain properties can never be guaranteed, or that after several trials it is impossible to find parameter values that lead to the expected correct behaviour, different constraints over the agents' interactions could be explored. This means that a redesign of the EIM may be necessary. This is an intrinsically manual task.

[P7] *Experiment Analysis (EBM redesign)*. Finally, and if everything else fails, it may happen that the part of the requirements that led to the initial EBM were misunderstood, and that a variation in the initial EBM is necessary to explain why the experiments are showing unexpected behaviours.

3. Mechanisms for electronic commerce

In the previous section we discussed the need for framing the interaction among agents within a regulatory environment. This accounted for the first term in our equation (*eCommerce* = *organization* + *mechanism* + *trust*). The second term, *mechanism*, is concerned with the interaction itself. In this section, we consider the nature of the interactions that arise in electronic commerce and outline, in turn, techniques for managing these interactions effectively, and application domains in which we expect to see these techniques prove themselves in support of particular agent-mediated electronic commerce systems.

3.1. Interaction in electronic commerce

Commerce is all about interaction between buyers and sellers at all stages: finding, purchasing, and delivering. In order to support interaction, autonomous agents are increasingly being used in a wide range of industrial and commercial domains [27]. For instance, applications like user assistance through personal assistants [8] are common, and several filtering techniques like content filtering or collaborative filtering have been implemented in these personal assistants to enhance the electronic commerce experience of buyers. In a different context, auctions and electronic markets have been the focus of increasing attention in the last few years [44], and are set to become even more important. Additionally, and more recently, agents have been used to model web services, as they have the (strong) potential to improve and expand business transactions.

As already mentioned, agents have a high degree of self-determination – they decide for themselves what, when and under what conditions their actions should be performed. In most cases, such agents need to interact with other agents to achieve their objectives (either because they do not have sufficient capabilities or resources to complete their problem-solving alone, or because there are interdependencies between the agents). The objectives of these interactions are to make other agents undertake a particular course of action (e.g. perform a particular service), modify a planned course of action (e.g. delay or bring forward a particular action so that there is no longer a conflict), or come to an agreement on a common course of action.

3.2. *Mechanism design*

Mechanism design is precisely concerned with fixing the rules governing the interaction among agents in such a way that certain properties (such as stability, or equilibrium) can be guaranteed. By defining the rules of the game, we are focusing on how the interaction will take place, as we introduce constraints on the complete autonomy of agents and, by so doing, try to induce a given (rational) behaviour in them, if possible by determining dominant strategies. Auctions have been the most widely used mechanism in electronic commerce up to now (see [22] for a good survey of private value auctions), and popular sites like eBay and Amazon are currently trading using electronic versions of classical auction mechanisms. However, research is being developed on more advanced auction mechanisms that would permit the trade of multi-issue multi-attribute items, and some systems are already supporting this [41].

One of the driving ideas in designing mechanisms for agent interaction is to avoid full revelation of the preferences of agents. Although some proposals in this direction have been made in the area of auctions [43], most activity has concentrated on the strategic bargaining arena [5, 14, 15, 23, 34, 48]. There have been several proposals based on bilateral negotiation protocols (e.g. Kasbah [5] or Faratin's model [14]) and their extensions based on different techniques, like the suggestion of alternatives [6] or data mining [47]. Ways of addressing the problems associated with the negotiation dialogue itself have been proposed based on a plethora of alternatives, including constraint optimization [3, 24], argumentation [35], fuzzy similarities [15] and fuzzy constraints [28]. Nevertheless, most approaches to negotiation protocol design have been grounded on Multi-Attribute Utility Theory, as the negotiation objects are complex entities that have to satisfy different objectives.

It is not strange that so much attention has been paid to negotiation mechanisms within the AMEC groups, as negotiation can be used to co-ordinate or share limited resources among autonomous self-interested entities. In other words, an acquaintance needs to be convinced in order to act in a particular way (e.g. to accept a deal). Since agents have no direct control over one another, they must persuade their acquaintances to act in particular ways. That is, agents have to engage in negotiation – a process by which a joint decision is made by two or more parties. The parties first verbalise contradictory demands and then move towards agreement by a process of concession-making or by searching for new alternatives [36].

Negotiation problems can be categorized in many ways. One way to classify these problems is according to the underlying incentive and information structures:

1. The actual size of the limited resource to be shared is unknown (e.g., two agents must agree to split a "cake" the size of which is unknown at the time of signing contracts).
2. The set of agents who are, or may be, interested in the limited resource is unknown.
3. The set of agents is known, but their characteristics are unknown (e.g., agents bargaining with deadlines, which are private information, or several agents competing to buy an object, the worth of which is private information).
4. Everything is known but the strategy: for example, two agents with known time preferences bargain over how to split a dollar.

Depending on which category our problem falls into, a different negotiation model (mechanism) may be applied. When building an autonomous agent that is capable of flexible and sophisticated negotiation, three broad areas are considered in defining such a negotiation model [30]: what negotiation protocol will be used, what the issues are over which negotiation takes place, and what reasoning model the agents will employ. Papers describing research in this area focus on one or more of the above aspects. For instance, [14, 15] concentrate predominantly on the last point, and present a formal account of a negotiating agent's reasoning component. In particular, they concentrate on the processes of evaluating incoming proposals and generating outgoing counter-proposals. The model described specifies the key structures and processes involved in this endeavour, and defines their inter-relationships. Also, in [34], a reinforcement learning algorithm has been designed to enable agents to adapt themselves according to the changing environment, including the competitor agents.

3.3. Applications

The first application domains in which we expect to see agent-mediated electronic commerce applications with fully automated negotiation, will have some of the following characteristics:

- *Interactions are very fast*. For instance, for bandwidth trading, there is no time to go back to the user between trading rounds.
- *Interactions are repeated* with either (a) high communication overheads, or (b) a limited domain so that learning by the agent about user behaviour is effective. Many business-to-business (B2B) areas exhibit this characteristic.

– *Each trade is of relatively small value*. If each transaction is of relatively small value, it is possible to monitor the process and stop the automatic trade after some time without significant losses. It is important to stress the importance of *relatively* here. A small value for a company is completely different from a small value for a private end-consumer. This implies that we will most likely first see agents in business-to-business settings.
– *The process is repeated over long periods*. The reason for this is two-fold:

- There must be a significant value over time in order to justify investments in software, hardware, and/or training.
- Automatic agent learning of customer preferences is highly desirable, as explicit preference elicitation is a very time-consuming business.

– *The product is relatively easy to specify*. A number of traditional difficult computer science problems pose major difficulties for negotiations over complex objects. Such problems are mainly related to the semantics of the communication, but also to preference elicitation. It is simply too time consuming to tune huge numbers of different parameters.

4. Trust building

4.1. Distribution and risk

The last term in our equation is that of *trust*. In most real cases, organizations and protocols cannot completely guarantee that agents will behave as expected, or as agreed upon in a contract. Human societies and, naturally agent societies as well, have to face risks in interaction. And trust between agents has proven to be a good way to reduce risks.

In order to reduce risks, many aspects that currently require the attention of agent researchers in electronic commerce refer to a reliable communication channel between participants in trade, mainly confidentiality, integrity, authentication and non-repudiation. Distributed systems formed by thousands or millions of agents necessarily require new mechanisms to deal with security. This is especially important in electronic commerce environments where transactions involve a significant amount of money [50]. Traditional methods based on Access Control Lists[1] (ACL), or on Role-based Access Control,[2] stop working when the individuals may not be known ahead of time, as happens in open multi-agent systems. Different approaches have been proposed to overcome this situation: using chains of trust, rights, and delegation. That is, rights are given to trusted agents, which then decide to delegate these rights to their trusted agents. This method has proven to work well for supply chains [21], and initial proposals of semantics have been developed [33]. These approaches are examples of social mechanisms that shape the interaction at the social level (as described in [20]).

The uncertainty relating to the behaviour of an agent in a society can be perceived as a potential source or risk in a commercial transaction. This is why it is essential to find ways of removing this uncertainty if electronic commerce is going to be realised in open environments. Trust and reputation measures are the inspiring social mechanisms that researchers in the field of electronic commerce are looking into in order to increase the number of transactions. Here, we understand trust as the positive expectation that a partner will act cooperatively in situations in which defection would prove more profitable to itself.

Many natural and artificial systems tend to form complex networks of interacting autonomous entities (such as ecosystems, brains, communication networks, societies, and, certainly, open multi-agent systems). Although the dynamics that generate these networks are not completely well understood, it is clear that the tools to be put in place in order to manage these networks without central control may receive inspiration from other fields. For instance, routing on communication networks has been inspired by the biological study of colonies of insects [4]. In the same way, social mechanisms are certainly a fruitful source of inspiration for the management of societies of agents. Concepts like robustness and security, essential for good practice in software development, can therefore be seen from a completely new perspective, analysing normative systems or social order.

The most recent reputation models tend to rely on some sort of social network that gives meaning to the reputation measures and their aggregation. In electronic commerce applications, relationships like trade, competition, or co-operation give shape to the networks of relations that permit the interpretation of the opinions that humans (or agents) express about the other members of the network, although the elicitation of such networks is a difficult task. Some initial work on the automatic generation of these has already provided interesting results [37].

4.2. *Reputation for trust*

The role of gossip, understood as the exchange of information about other people's behaviour by means different from direct observation, is central to human language [10]. It seems essential to take into account the opinion of others when we are placed in an environment in which interactions are scarce, movement of individuals is high, and selfishness is a common behaviour. For instance, these characteristics are present in electronic markets populated with agents.

In recent years, the modelling of gossip has produced an explosion of reputation models that try to build trust in electronic commerce transactions. The models used by eBay, Amazon and OnSale Exchange, although rather simple, are good examples. All of them use some sort of average of user opinions. They share many problems that have been reported, and for which solutions have been proposed (e.g., Sporas and Histos [53]).

The use of social information appears to be a good solution to the problems associated with purely numerical models. Among the recent proposals, REGRET [42] represents a rather complex reputation model that combines different reputation measures:

- *Witness reputation* is a kind of direct gossip: we ask agents that know a given agent about their opinion of the agent's behaviour. There is no need to say that, as in human societies, the particular relationship that holds between our informant and the agent is essential in order to interpret the gossip. Friends might be over-positive, and enemies might under-estimate the agent's performance. Both might even lie on purpose, or hide information. Thus, an updated knowledge of the different society interrelationships is essential to correctly interpret this type of gossip.

- *Neighbourhood Reputation* is a kind of indirect gossip; we use the opinion transmitted to us, or built by us through direct interactions, about those agents that are somehow related to the agent whose reputation we want to assess. This is a sort of prejudice, that is usually considered morally unacceptable in human societies, but not necessarily so in agent societies.
- *Role reputation* is a kind of default reputation based on the role the agent incarnates in the society.

The use of fuzzy sets has been used in REGRET as well as in other recent models (notably CREDIT [38]) to assess the social credibility of an agent's opinions. That is, we need to consider how much emphasis to place on information received through gossip, depending on the social relationships. CREDIT, on the other hand, moves one step beyond, as the gossip itself is expressed using imprecise terms modelled as fuzzy sets.

5. System development in AMEC

During the last four years, there has been a significant effort in building tools and systems that integrate agent technology in order to give commercial solutions in the area of electronic commerce. The different meetings held by the AMEC Special Interest Group, supported by AgentLink, have served to foster an interchange of ideas among system developers, and have witnessed the creation of a plethora of small companies interested in selling products containing agent technology.

For example, iSOCO [19] has developed and commercialised iBundler [41], a decision support tool for highly constrained e-sourcing scenarios. As a combinatorial reverse auction solver, it extends current models by accommodating both operational constraints and multi-attribute, multi-item constraints. The tool offers a language, based on XML, to express offers, constraints, and requirements that can be integrated within e-sourcing solutions. It permits the automated generation of offers and counter-offers, and provides a scoring algorithm based on buyers' preferences and providers' profiles. iBundler won first prize in the agent technology competition sponsored by Agent Cities in 2003, for "its novelty and utility as a decision support service for highly constrained e-sourcing scenarios acting as a combinatorial negotiation solver".

Similarly, Lost Wax [26] has developed an agent based e-commerce platform that supports negotiation through a dialogue of offers and counter-offers with the ability to permit the user to select among several different negotiation strategies. Tryllian [49], too, is selling tools supporting distributed business process integration that incorporate mobile agent technology.

In addition, larger companies have also been applying agent technology to e-commerce applications – not to mention their interest in developing generic agent platforms, such as Zeus at BT, JADE at Telecom Italia, and FIPA-OS at Nortel. More specifically, a toolset called DOME has been developed at BT to integrate heterogeneous information sources; it uses agent wrappers to provide an integrated view over legacy systems. An application for the management of e-Catalogues has been built, which helps to minimize manual intervention in making the products included in a catalogue available in different formats.

MASFIT [29], integrated in the EUTIST-AMI cluster [13], is a commercial B2B e-commerce environment developed between a small company in the fish sector, AUTEC [2], and the IIIA (Artificial Intelligence Research Institute of the CSIC [18]). It supports the sale of fresh coastal fish by allowing auction houses to federate. MASFIT permits the auction houses to continue with the traditional downward bidding protocol, but expands their functionality by permitting the participation of remote buyers by means of Autonomous Intelligent Buyer Agents. It enables fish buyers to run their businesses more efficiently, as they are able to access many markets without having to be physically present. Commercial costs can thus be reduced, and purchases better planned. Buyer participation in the federated auctions is enabled via a Buyer Agents Server, which contains the following tools:

- Buyer Agent Creative (BAC) to help remote buyers in the creation of their own autonomous agents to participate simultaneously on their behalf in several federated auctions. The tool permits the customization of a generic buyer agent from a library incorporating the user's preferences and buying strategies.
- Buyer Agents Training (BAT) to train, test, and tune the Autonomous Buyer Agents before sending them to buy in the auctions. This tuning is achieved by simulating participation in real auctions.

The high interest that many companies show in the area of agents is slowly materializing in applications. However, although steadily increasing, the pace at which the technology is being adopted is slightly slower than we had expected five years ago.

6. Summary

Agents are slowly making their way through in electronic commerce applications. Their autonomous behaviour, their ability to manage customer preferences, and the intelligence they exhibit, are opening new opportunities in software development. New products and new services are possible thanks to this technology. And this is just the beginning, with whole new areas of product development in web services, mobile commerce, and deregulated markets appearing as business opportunities for software companies. In this paper, I have focussed on three aspects of the technology that are crucial to the development of electronic commerce applications, and that have received significant attention in the research community, especially within AgentLink member organizations: first, methodologies to develop agent societies; second, negotiation technologies to build agreements; and, finally, reputation mechanisms to build trust among agents in the open domains that electronic commerce applications represent.

Acknowledgments

This paper contains overviews of several other papers that have been co-authored by: Marc Esteva, Juan Antonio Rodríguez, Jaume Agustí, Pablo Noriega, Lluís Godo, Nick Jennings, Pere Garcia, Frank Dignum, Mike Wooldridge, Dave Robertson, Simon Parsons, and Jordi Sabater. Web-i(2) MCYT Project has partially funded this work.

Notes

1. With Access Control Lists, rights of access are attached to the subject that has gone through the authentication process.
2. In Role-based Access Control, rights are attached to roles.

References

1. AgentLink, "AgentLink," URL; http://www.agentlink.com/.
2. Autec, "autec URL," http://www.autec.es/.
3. M. Barbuceanu and W.-K. Lo, "Multi-Attribute Utility Theoretic Negotiation for Electronic Commerce," in F. Dignum and U. Cortés (eds.), *Lecture Notes in Artificial Intelligence* (2003), (AMEC Workshop 2000), 2001, pp. 15–30.
4. E. Bonabeau, M. Dorigo, and G. Theraulaz, *Swarm Intelligence*, Oxford University Press, 1999.
5. A. Chaves, and P. Maes, "Kasbah, an Agent Marketplace for buying and selling goods," in *First International Conference on the Practical Application of Agents and Multi-Agent Technology*, London, 1996.
6. G. E. de Paula, F. S. Ramos, and G. L. Ramalho, "Bilateral Negotiation Model for Agent-Mediated Electronic Commerce," in F. Dignum and U. Cortés (eds.) *Lecture Notes in Artificial Intelligence* (2003), (AMEC Workshop 2000), 2001, pp. 1–14.
7. C. Dellarocas and M. Klein, "Civil agent societies: Tools for inventing open agent-mediated electronic marketplaces," in *ACM Conference on Electronic Commerce (EC-99)*, 1999.
8. A. Di Stefano, G. Pappalardo, C. Santoro, and E. Tramontana: "A Multi-agent Reflective Architecture for User Assistance and its Application to E-commerce," in Matthias Klusch and Sascha Ossowski and Onn Shehory (eds.), *Lecture Notes in Artificial Intelligence* (2446), (Cooperative Information Agents VI), 2002, pp. 90–103.
9. F. Dignum, "Abstract norms and electronic institutions," in: *Proceedings of International Workshop on Regulated Agent-Based Social Systems: Theories and Applications (RASTA-02)*, 2002.
10. R. Dunbar, *Grooming, Gossip, and the Evolution of Language*. Cambridge, Mass Harvard University Press 1996.
11. M. Esteva, *Electronic Institutions: From Specification to Development*, vol. 19 of *IIIA Monographs* CSIC: Barcelona, 2003.
12. M. Esteva, D. de la Cruz, and C. Sierra, "ISLANDER: an electronic institutions editor," in: *First International Conference on Autonomous Agents and Multiagent systems*, Bologna 2002, pp. 1045–1052.
13. EUTIST-AMI, "EUTIST-AMI URL," http://www.eutist-ami.org/.
14. P. Faratin, C. Sierra, and N. Jennings: 1998, "Negotiation decision functions for autonomous agents," *Robot. Auton. Syst.* vol. 24 3–4, pp. 159–182. Electronic version in: ECOMMERCE RESEARCH

FORUM Volume 2, Issue 5, July 25, 2001. Editors: Prof. Erik Brynjolfsson, Prof. John D. C. Little, Massachusetts Institute of Technology.
15. P. Faratin, C. Sierra, and N. Jennings,"Using Similarity Criteria to make issue trade-offs in automated negotiations," *Artificial Intelliegence Journal*, vol. 142, no. 2, pp. 205 – 237, 2002.
16. J. Ferber, and O. Gutknecht, "A Meta-Model for the Analisys of Organizations in Multi-Agent Systems," in *Proceeding 3rd International Conference on Multi-Agent Systems (ICMAS-98)*, Paris, France, 1998, pp. 128 – 135.
17. F. Giunchiglia, J. Mylopoulos, and A. Perini, "The Tropos software development methodology: processes," models and diagrams," in: *AAMAS'02 workshop on Agent Oriented Software Engineering (AOSE-2002)*. 2002, pp. 63 – 74.
18. iiia, "IIIA URL," http://www.iiia.csic.es/.
19. iSOCO, "iSOCO URL," http://www.isoco.com/.
20. N. Jennings, and J. Campos: "Towards a Social Level Characterisation of Socially Responsible Agents,"in: *Proceedings on Software Engineering*, vol. 144. 1997, pp. 11 – 25.
21. L. Kagal, S. Cost, T. Finin, and Y. Peng: "A Framework for Distributed Trust Management," in *Second Workshop on Norms and Institutions in MAS*. Montreal, 2001, pp. 45 – 57.
22. J. Kalagnanam, and D. C. Parkes: *Auctions, Bidding and Exchange Design*, pp. 211 – 229, in press.
23. J. L. Koning, "Designing and Testing Negotiation Protocols for Electronic Commerce Applications," Frank Dignum and Carles Sierra (eds.), *Lecture Notes in Artificial Intelligence* (1991), 2001, pp. 34 – 60.
24. R. Kowalczyk, and V. Bui, "On Constraint-Based Reasoning in eNegotiation Agents," in F. Dignum and U. Cortés (eds.), *Lecture Notes in Artificial Intelligence* (2003), (AMEC Workshop 2000) 2001, 31 – 46.
25. A. Lomi, and E. R. Larsen (eds.), *Dynamics of organizations*. AAAI Press/The MIT Press 2001.
26. Lostwax, "Lostwax URL," http://www.lostwax.com/.
27. M. Luck, P. McBurney, and C. Preist, *Agent Technology: Enabling Next Generation Computing (A Roadmap for Agent Based Computing)*. AgentLink, 2003.
28. X. Luo, N. R. Jennings, N. Shadbolt, and H. F. Leung,"A fuzzy constraint based model for bilateral, multi-issue negotiation in semi-competitive environments," *Artif. Intell.,* vol. 148, no. 1 – 8, pp. 53 – 102, 2003.
29. Masfit, "masfit URL" http://www.masfit.net/.
30. H. J. Mueller, *Negotiation Principles*, New York John Wiley: 1996, pp. 211 – 229.
31. P. Noriega, *Agent Mediated Auctions: The Fishmarket Metaphor*, vol. 8 of *IIIA Monographs*, CSIC: Barcelona, 1999.
32. P. Noriega, and C. Sierra, *Auctions and Multi-agent Systems*, Springer, 1999, pp. 153 – 175.
33. T. J. Norman, and C. Reed, "A Model of Delegation for Multi-agent Systems," in Mark d'Inverno, Michael Luck, Michael Fischer and Chris Preist (eds.), *Lecture Notes in Artificial Intelligence* (2403), Foundations and Applications of Multi-Agent Systems, 2002, pp. 185 – 204.
34. E. Oliveira, and A. P. Rocham, 2002, "Agents advanced features for negotiation in electronic commerce and virtual organisations formation process," in Frank Dignum and Carles Sierra (eds.), *Lecture Notes in Artificial Intelligence* (1991), 2001, pp. 78 – 97, 1991.
35. S. Parsons, C. Sierra, and N. Jennings,"Agents that reason and negotiate by arguing,"*J. Logic Comput*. vol. 8, no. 3, pp. 261 – 192, 1998.
36. D. G. Pruitt, (ed.) *Negotiation Behavior*, Academic Press, 1981.
37. J. M. Pujol, and R. Sanguesa, "Reputation Measures based on Social Network metrics for Multi Agent Systems," in *Proceedings of 4th Catalan Conference on AI*, 2001, pp. 205 – 213.
38. S. D. Ramchurn, C. Sierra, L. Godo, and N. R. Jennigs: "A computational trust model for multi-agent interactions based on confidence and reputation," in: R. Falcone (ed.): *Proceedings of International Workshop on Deception, Trust, and Fraud, AAMAS03*. 2003 pp. 69 – 75.
39. J. A. Rodríguez, *On the Design and Construction of Agent-mediated Electronic Institutions*, vol. 14 of *IIIA Monographs* CSIC: Barcelona, 2001.
40. J. A. Rodríguez, P. Noriega, C. Sierra, and J. Padget, 2001. "A Java-based Electronic Auction House," in *Second International Conference on The Practical Application of Intelligent Agents and Multi-Agent Technology: PAAM'97*, London, 1997, pp. 207 – 224.

41. J. A., Rodríguez-Aguilar, A. Giovannucci, A. Reyes-Moro, F. X. Noria, and J. Cerquides, ''Agent-based decision support for actual-world procurement scenarios'. in *Proceedings of 2003 IEEE/WIC International Conference on Intellignt Agent Technology (IAT 2003)*. Halifax, Canada, 2003, pp. 371–377.
42. J. Sabater, *Trust and Reputation for Agent Societies*, vol. 20 of *IIIA Monographs*, CSIC: Barcelona, 2003.
43. T. Sandholm, and A. Gilpin, ''Sequences of Take-It-or-Leave-It Offers: Near Optimal Auctions Without Full Valuation Revelation,'' in P. Faratin, D. Parkes, J. Rodriguez, W. Walsh (eds.), *Lecture Notes in Artificial Intelligence*. AMEC Workshop 2003, in press.
44. C. Sierra, and F. Dignum (eds.), *Agent Mediated Electronic Commerce. The European AgentLink Perspective*, vol. 1991 of *Lecture Notes in Artificial Intelligence*, Springer, 2001.
45. C. Sierra, J. Sabater, J. Agustí, and P. Garcia, ''Evolutionary computation in MAS design'' in *European Conference on Artificial Intelligence*, Lyon, 2002, pp. 189–192.
46. Simile, ''SIMILE Web Page,'' http://www.simile.co.uk.
47. S. Simoff, and J. Debenham,''Curious Negotiator,'' in Matthias Klusch, Sascha Ossowski and Onn Shehory (Eds.), *Lecture Notes in Artificial Intelligence* (2446) Cooperative Information Agents VI, 2002, pp. 104–111.
48. K. Somefun, E. Gerding, S. Bohte, and H. L. Poutré': ''Automated Negotiation and Bundling of Information Goods,'' in P. Faratin, D. Parkes, J. Rodriguez, W. Walsh (eds.), *Lecture Notes in Artificial Intelligence*. AMEC Workshop 2003.
49. Tryllian, ''tryllian URL''. http://www.tryllian.com/.
50. United Nations, ''E-Commerce and Development Report 2003,'' http://www.unctad.org/ecommerce/2003.
51. M. Wooldridge, and P. Ciancarini, ''Agent-oriented software engineering: The state of the art,'' in P. Ciancarini and M. Wooldridge (eds.), *Lecture Notes in Artificial Intelligence* (1957). Agent Oriented Software Engineering, 2001.
52. M. Wooldridge, N. R. Jennings, and D. Kinny, ''The Gaia Methodology for Agent-Oriented Analysis and Design,'' *J. of Auton. Agents and Multi-agent Syst*., vol. 3, no. 3, pp. 285–312, 2000.
53. G. Zacharia, ''Collaborative reputation mechanisms for online communities,'' Master's Thesis, Cambridge, Mass, MIT, 1999.