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SOFTWARE AGENTS FOR ELECTRONIC MARKETPLACES: CURRENT AND FUTURE RESEARCH DIRECTIONS

GEORGE KONTOLEMAKIS, National and Kapodistrian University of Athens
Department of Informatics and Telecommunications,University Campus,Athens 157 71, Greece, Tel: 30 210 7275217, Fax: +30 210 9231897, Email: kontolem@di.uoa.gr

PANAGIOTIS KANELLIS, National and Kapodistrian University of Athens
Department of Informatics and Telecommunications,University Campus,Athens 157 71, Greece, Tel: 30 210 7275217, Fax: +30 210 9231897, Email: kanellis@di.uoa.gr

DRAKOULIS MARTAKOS, National and Kapodistrian University of Athens
Department of Informatics and Telecommunications,University Campus,Athens 157 71, Greece, Tel: 30 210 7275217, Fax: +30 210 9231897, Email: martakos@di.uoa.gr

ABSTRACT

The premise of software agents to define the structural and operational models of the virtual marketplace of the future can account for the increased interest regarding their application in areas where they can add substantial value in terms of automation and functionality. At the heart of such a marketplace rests an ontology modeling the domain upon which a nucleus of agent-based services can be constructed. Negotiation services hold the dominant position in terms of the attention they have received in research. Complementary to them, but no less important, are the advising services representing support functionality that is required throughout the cycle of a deal; from the expressed intention of the two parties to eventual maturity and closure. In this paper we focus on research trends and on their possible future development for ontologies and the above service categories emphasizing on the role of software agents in this context. A review and analysis of past and present works helps to formulate sets of questions that future research will seek to address.

INTRODUCTION

Software agents form an essential part of an increasing number of computer-based information systems. This happens because agents are considered to be the next generation model for engineering complex distributed systems and necessary to design and built software entities. According to Jennings (2001) agents are clearly identifiable solving entities with well-defined boundaries and interfaces. They are embedded in a particular

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environment, receiving inputs related to the current state of their environment through sensors and acting on the environment through effectors. They are designed to fulfill a specific purpose as they have particular "goals" to achieve. They are autonomous since they have control over both their internal state and their own behavior and are capable of exhibiting flexible problem solving behavior in pursuit of their design objectives. In Electronic Commerce (EC), the use of agents means that they need to interact with one another, either to achieve their individual objectives or to manage the dependencies that follow from being situated in a common environment (2001).

The experience of a traditional marketplace was enhanced by the fact that it constituted more than just a place of economic transaction, which was often secondary to the opportunities for social contact. Electronic marketplaces are no different in a sense that represent one such environment where buyers and sellers can come together, exchange information, negotiate and transact as in traditional marketplaces (Kurbel and Loutchko 2002). As such, electronic marketplace design is becoming a very important research topic. For example, stemming from research on 3D Virtual Reality and online store technologies, it would not be long that customers would find online malls of the future more like their offline counterparts. Shoppers would 'walk around' the virtual mall using their avatars and controlling their moves by pointing their mouse or using simple voice commands (Shen, Radakrishnan and Georganas 2002). To find items of their interest or to compare prices they can find help from the matching services of a broker agent. They can also be advised for a certain product or purchase they are about to make, or already did, from advising agents. If they find items of interest during the navigation process, they can initiate a negotiation session so that they can buy them.

This paper presents the state of research for the agent-part of an electronic marketplace. It starts with a discussion of the benefits and impacts of agents in E-Commerce. It then defines the research landscape focusing on the functionality of an electronic marketplace that can be enabled by the agent process; its ontologies, its advising services and it's most fundamental and powerful mechanism for managing inter-agent dependencies at run time; negotiation. Based on this a research agenda for the future is outlined.

SOFTWARE AGENTS AND ELECTRONIC COMMERCE

There are two viewpoints from which the application of agents in EC can be examined, those of the customer and the vendor. For each one, and based mainly on the works of Schrooten and VanDe Velde (1997), Wagner and Turban (2002), Nwana *et al.* (1998) and Jin and Jun Lee (2001), this section provides a brief introduction summarizing the contributions of software agents in terms of specific EC functionalities.

From a customers' point of view, agents provide a better and more personalized

CONTRIBUTION

This paper presents and examines the state of research regarding the application of software agents in electronic marketplaces. It provides the reader with a description of the constituent elements of agent-based electronic marketplaces, expanding on architectures, ontologies, services, and techniques, and defining the state of the art as far as research is concerned. It sets out examples of existing working systems, methods used in them, and their limitations, helping thus the aspiring researcher by providing a pool of ideas for guiding future work. The above are discussed within a contextual framework which culminates to sets of specific research questions that have to be answered if we want to capitalize on the capabilities of software agents and increase their applicability and value to business. This is achieved by a distillation of both recently published and very current research efforts and ongoing work that is currently being undertaken. We must note however that this review does not strive for completeness in the sense that a 'traditional' scholarly review would seek to achieve. It nevertheless goes to sufficient depth and with the rigor required, sharpening in the interim the focus of the interested researcher who plans to conduct research into agent-based information systems.

service, having 'learned' about the preferences of a particular customer. Some customers want advice about the use of a product, possible alternatives, uses that it can be put to, etc. An agent can provide this information, preventing thus user information overload by filtering out the products that the customer would not have cared for. A customer can be informed by an agent about a specially priced item that might be of interest, since this sort of information can be propagated automatically to him in a 'push' fashion via email. An agent can even shop on behalf of the customer and try via the application of negotiation techniques, to get the best deal for its 'owner' providing interim advice during the process.

From the vendors' point of view, the use of agents can improve, for example, the efficiency of the catalogue maintenance process. The provider only adds the product together with its features to a database, where the agent will subsequently present the product to the potential buyer. Agents can also help in inventory management. An agent monitoring business transactions can initiate a number of replenishment actions should stock levels of particular products fall below predefined quotas. The effective application of agents can also result in lower transaction costs. For example, agents can automate the support processes underpinning the communication channels between a company and its customers. As it has become so easy for customers to send out requests for information or service by e-mail, companies such as Dell, receiving email messages in the tens of thousands every day, are increasingly dependent on agent technology in order to maintain high levels of service and support with marginal costs.

Finally, the parameter of time makes 'quick turnaround' a dependent success variable for EC. For example, customers of electronic brokerage firms want instantaneous order execution, and also expect response to inquiries within very short time frames. Hence, the on-line brokerage firm has to be able to respond to peak loads, while ideally not keeping too much overhead during 'low-load' periods. Here again, agents able to classify requests and answer routine inquiries can significantly lower the transaction costs and provide high service levels even in peak periods. An example is E-Trade's "ask" agent. The ability to close a deal with the help of an agent allows companies to handle business volumes that are deemed impossible otherwise. With the benefit of hindsight, one can argue that agents, for their part, may challenge certain research findings related to the IT-Productivity Paradox phenomenon of the last two decades, or in other words, the discrepancies observed between measures of investment in information technology and measures of output at the national level.

SOFTWARE AGENTS FOR ELECTRONIC MARKETPLACES

Electronic marketplaces are virtual marketplaces where buyers and sellers exchange information, negotiate, and transact. These marketplaces take various forms such as auctions, product exchanges, online shopping markets, e-catalogs, etc, and represent one of the best examples for illustrating the evolution of the Internet; from a mere technical infrastructure to business enabler.

Figure 1 presents the main areas related to marketplaces where agent-based functionality can be applied. Electronic marketplaces are distinguished to controlled and uncontrolled marketplaces (Kurbel and Loutchko 2002). In a *controlled* marketplace the participants have to agree upon a certain set of rules concerning both what can be bought and sold and how this can be carried out. An *uncontrolled* marketplace is entirely open and decentralized; no single party for example sets the rules or controls the market. Each participant may initialize an agent that will act on its owner's interest using strategies uniquely defined for this agent. Uncontrolled electronic marketplaces are quite promising but they have to overcome an abundance of problems and are very difficult to implement. Although some interesting initiatives, such as the CommerceNet eCo System (CommerceNet 2003) exist, uncontrolled multi-agent marketplaces are still rather a vision than a reality.

In this paper, we focus on controlled electronic marketplaces and the aspects or architectural elements where software agents can be applied. The categorization depicted in Figure 1 has emanated from both and

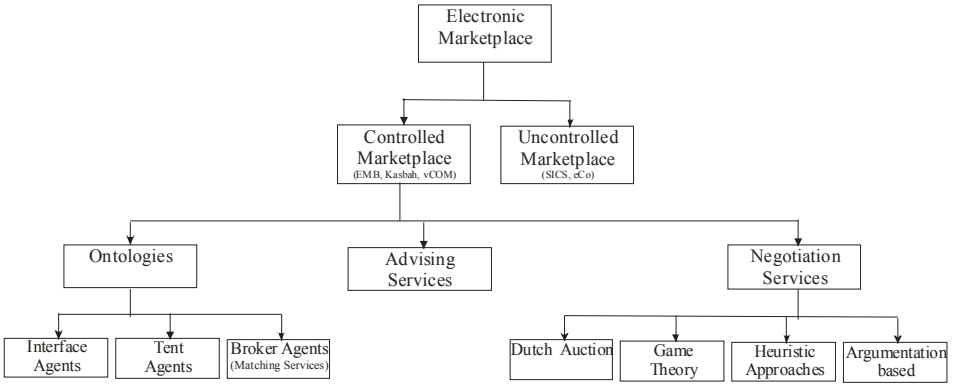

Figure 1. A categorization of the applications of agents in electronic marketplaces

examination of the trends exhibited by the existing body of research and the emphasis placed by current research efforts. For each of the identified categories we present the state of the art in research terms and identify the main issues, defining thus where research is heading. Based on this we offer a critical analysis by drawing upon sets of research questions and issues that are used to frame a research agenda for the future.

Agents in Controlled Electronic Marketplaces: Research Landscape

It can be argued that marketplace users now suffer from information overload rather than lack of information. They must analyze a wealth of information, negotiate over multiple contracts, and execute a lot of complex transactions on the Internet. Therefore, it has been asserted that the essence, and hence the success of an electronic marketplace lies in its inherent ability to offer such functionality that enables the effective and efficient management and control of this information overload (Jin and Jun Lee 2001). To this end, agents can play a significant role as is demonstrated by the research output concerning the identified application categories; namely the marketplace ontologies, the advising services and the negotiation function.

Marketplace Ontologies

By ontology we mean the specification of the knowledge structures used to define concepts and the relationship among those. To be effective, agents need to be interoperable; hence the primary focus when designing the ontology model of the marketplace is to satisfy those design requirements that will enable its extension, share and reusability both within and outside the boundaries of the marketplace infrastructure (Albers, Jonker, Karami and Treur 2000). The process of ontology construction is similar to constructing a document type definition (DTD) of an eXtensive Markup Language (XML) document and defining the concepts and relations. The defining axioms and the informal definitions of concepts should be logically consistent, and when adding new terms, concepts and relations to an existing vocabulary, the ontology should ideally not require a fundamental structural revision.

Ontology-mediated information integration provides an elegant framework for document integration, enforcing a conceptual structure for the documents, and allowing further integration with knowledge-based document search and retrieval. The vision for the next generation of the World Wide Web (WWW), called the Semantic Web (Berners-Lee and Fisischetti 2000), envisages the WWW full of data enriched with machine-processable semantic annotations and reasoning services processing this information. Researchers in this area are currently working on four major tasks. Firstly, they are trying to build semantic annotations for documents on the web and to define the appropriate annotation technologies. Secondly, to define the ways so as to perform ontology-based transformations of annotated documents. Thirdly, to infer conclusions and resolve inconsistencies that is the by-product of the ontologies/documents junction. Finally, they

are trying to scale ontologies that can be updated in real time (Omelayenko and Fensel 2001).

For electronic marketplaces, ontologies map and codify the domain within which agents offer their services. Not all agents are passive users of this domain; agents are employed to keep the ontological views current by constantly modifying and recodifying them. There are many different uses that agents can be put and they can be classified according to the functionality they offer. Three main categories are 'Interface Agents', 'Tent Agents' and 'Broker Agents' (Albers, Jonker, Karami and Treur 2000). The communication between the marketplace and its users is maintained through interface agents, where the latter specify and forward their inquiries to the marketplace and receive information back via the interface agents. Tent agents represent and control the products available at any single time in the marketplace. The available products are classified based on the category they belong to with each tent agent representing a distinct category of products. Brokers act as intermediaries between the consumers and providers. It is through a broker agent (sometimes called middle-agent) that buyers and sellers can communicate with each other without having to reveal their personal details to each other.

Most brokers found on the Internet focus on the selection of the right information provider based on the given user request. In the ICEBERG (Jonker and Vollebregt 2000) approach, the broker agent focuses on aiding the user in formulating the right request in an interactive process. The ICEBERG broker not only helps to sharpen the request's focus, it also helps in the disambiguation of the queries and in widening the scope of the user request. There are three major phases in dealing with a user request: query (re)formulation, information resource discovery, and response construction. If a new request from the user has been received by the broker, the broker first helps the user to reformulate the request as a precise answer needs a precise query. Given a "good" query the ICEBERG broker can solicit information from the appropriate providing sources and present the most precise answer to the user. In an iterative way the broker also constructs additional propositions to the user, which may help the user to reformulate and submit his request again.

Current research mainly focuses on requirements engineering and verification for agent systems. Within requirements engineering the aim is to obtain appropriate informal, semi-formal and formal representations of functional or behavioural properties of a multi-agent system, of the agents within a multi-agent system and of components within an agent (Brazier, Jonker and Treur 1999). An approach to this can be found in Herlea, Jonker, Treur and Wijngaards (1999). Requirement specifications can be expressed in generic forms and reused in conjunction with generic models. For example, compositional verification is an approach to establish the desirable behavioural properties of a multi-agent system, defining the properties of agents and of their components (Jonker and Treur 1998).

Another issue that researchers are currently working on is how the information broker agent model can be self-maintained by installing at run-time new ontologies and knowledge bases communicated to the agent by maintenance agents (instantiation of own process control). In Jonker, Lam and Treur (1999), a multi-agent architecture of an intelligent website is introduced, based on (a number of instantiations of) the information broker agent model, and illustrated simulating a departmental store context. The information agents play the role of servants at the website, who are able to have an informed dialogue with visitors of the website, tailored to the background and needs of the visitor.

Finally, it is anticipated that as ontologies represent uniform data layers, their effective utilization by software agents will lead to truly cooperative information systems in terms of enhanced interoperability. For this to be achieved the output of systems should be in machine-readable form and many research efforts are heading towards this direction. For example, as ontologies are fast becoming the standard technology for marking up electronic product catalogues, agent-based information systems using these mark-ups will significantly improve search capabilities and interoperability between different product catalogues, consequently leading to more

liquid and transparent electronic marketplaces (Abrams 2003).

Advising services

The definition of the advising strategy and service an agent is to deliver requires the consideration of a multiplicity of design issues and parameters such as *intent* (the goal of the advising agent), *timing* (when the agent generates advice), *intrusiveness* (how proactive the agent is in interrupting the user's workout), *presentation* (how the advice is displayed to the user), and *content* (the information the advice contains) (Chin-Ming Fu 1997). Those issues define in essence the main focus of research efforts regarding the utilisation of agents as information advisors. Silverman (1992), for example, describes the 'intent' and 'timing' parameters for a type of agents he names 'Critics' and clarifies the limitations and drawbacks emanating from their application. 'Before-Task Critics', according to Silverman, attempt to prevent errors before they occur. The problem with constructing such critics is that it is often difficult to predict the quantity and type of information that will be useful to the user as the provision of non-relevant or non-important information may distract the user from his or her task. 'During-Task Critics' detect and help to eliminate errors while the user is engaged in the task. This type of agents has the advantage of providing advice while the context of the problem is fresh in the user's memory. However, users may become solely dependent on this type of service and never question the validity of information they are receiving or perform their own analyses so as to verify it. 'After-Task Critics' detect errors after the task is completed, and thus have the advantage of providing advice based on complete information sets. The drawback with this type of agents is that the advice may be delivered too late to be of any practical use or the problem itself is too specific and the advice may have limited universal applicability for further reference.

Researchers are challenged first to discover the possible uses of agents as advisors and then to define the frameworks which, taking into consideration the design parameters mentioned in the beginning of this section, can be used to inform their eventual implementations. An example of applied research in this area is demonstrated with SEDAR (Chin-Ming Fu 1997), which uses the task-based attention model (TBAM) modelling the problem-solving process of human domain experts. The synchronization process uses the TBAM to map observed user actions into a representation of the tasks relevant to the user's focus of attention. In other words, TBAM is used as a framework for user-guided activation of after-task critics, where users are able to activate a critic of this type on a selected subtask. Another recent example is the DC-Train 2.0 (Bulitko and Wilkins 2000), a multimedia interactive damage control simulator system that is deployed at a Naval training academy. A component of this system is the automated instructor assistant. This assistant is based on a 'blackboard-based' expert system called Minerva-DCA, which is capable of solving damage control scenarios at the 'expert' level facilitating various forms of user assistance, including interactive explanation, advising, and critiquing.

Research efforts in the area of advising services tend to focus on exploring the possible advantages that the application of Dynamic Strategy Networks (Bulitko and Wilkins 2000) may hold. These networks come from a unification of the domain-level and strategy-level rules in real time.

Negotiation Services

There is a widely held belief that the next major step in the reorganisation of economic structures and activities is the emergence of market or sector-wide integrative applications such as open virtual marketplaces. According to the TEM research project (Babin *et al.* 2002), "…the idea is to offer a nexus of business services to the largest network of businesses possible; and ultimately to allow firms to lower their costs of doing business. At the centre of the marketplaces lie negotiation servers where deals are struck and prices determined; around it are complementary services including matching and advising services and the standard e-commerce infrastructure".

Negotiation is the process by which a group of agents come to a mutually acceptable agreement on some matter (Jennings *et al.* 2001). In negotiation, the seller-agent tries to

influence the buyer-agent by trying to convince it that it should act in a particular way. The means of achieving this state are to make proposals, trade options, offer concessions, and hopefully come to a mutually acceptable agreement. In this context, research on competitive agent-enabled negotiation is needed which, according to current needs and issues, will focus on the following:

- *Negotiation Protocols:* Negotiation protocols direct the negotiation through a set of rules. These can be the permissible types of participants, the negotiation states, the events that cause negotiation states to change, and the valid actions of the participants in particular states.
- *Negotiation Objects:* Negotiation objects are the matters over which the negotiating agents try to reach an agreement. The object may contain only price to its negotiations, or it may cover a plethora of variables of which researchers are currently assessing their viability for inclusion in negotiation schemes (i.e. price, quality, timings, penalties, terms and conditions, types of operation, etc). The simplest type of negotiation is when the participants can either accept or reject a deal. This type of negotiation is enhanced by the ability to change the values of the matters in the negotiation object (see for example, Shen, Radakrishnan and Georganas 2002). A dominant research trend is concerned with exploring how to allow participants to dynamically alter the structure of the negotiation object by adding or removing matters (e.g. a car salesman may offer two year's warranty in order to sell the car).
- *Agents' Decision Making Models:* This relates to the decision-making models employed by the participating agents that need to be coupled with the adopted negotiation protocol in order to carry out their tasks.

Representative systems utilizing agents as personal negotiation assistants for buyers and sellers in electronic marketplace settings are KASBAH (Chavez and Maes 1996) and MAGMA (Tsvetovatyy, Gini, Mobasher and Wieckowski 1997). The key idea in both these systems is that users describe to their assistants the task they would like to be carried out and then trust them to figure out the way to accomplish it. An example of an agent-enabled negotiation between a vendor and a consumer, using techniques from KASBAH, is demonstrated with vCOM (Shen, Radakrishnan and Georganas 2002). This negotiation scheme, based in the "Dutch Auction" technique, which is discussed in the following section, is conceptually simple but works very well in this marketplace setting for the simple reason that response time is critical for real-time applications. In a nutshell, the best working example of a multi-agent virtual marketplace in existence works with a simple negotiation technique and researchers are now challenged to utilize more complex, and perhaps more effective negotiation schemes, that can be applied without sacrificing the speed with which this service is delivered. An analysis of the research landscape regarding agent-based negotiation approaches and techniques follows in the next section. Descriptions are based largely on the work of Jennings *et al.* (2001).

Dutch Auction A Dutch auction is the simplest type of negotiation with one agent calling out the prices. When there is no signal of acceptance from other agents in the marketplace, the first agent makes a new offer which it believes will be more acceptable by reducing the price. The seller-agent in this type of negotiation cannot specify whether the agents are close to reaching an agreement or not, or what to do next in order to reach an agreement, or why they did not finally agree. To improve the efficiency of the negotiation process, the recipient needs to be able to provide more useful feedback based on an analysis of the proposals it receives. This feedback can take the form of comments on the parts of the proposal the agent likes or dislikes, or can be a counter-proposal altogether. On their own, comments, proposals and counter-proposals are statements of what agents want. Thus their scope is confined solely to the structure of the negotiation object. While most current negotiation models offer rich object structures, there are still limitations that restrict agents to perform the following:

- *Justify their negotiation attitude:* For example, a company may not be legally entitled to sell a particular type of product

to a particular type of consumer. In such cases, the ability to provide the justification for its attitude towards a particular matter can allow the buyer to fully understand the selling agent's constraints and behavior.

- *Persuade one another to change their negotiation attitude:* Agents seek to construct arguments that they believe will make their opponent look more favorably upon their proposal. Thus, arguments seek to identify opportunities for such change, create new opportunities for change, or modify existing assessment criteria.

An example of a Dutch auction implementation with one agent as a seller and many buyers can be found in Mobile Agent Reactive Spaces (MARS), (Cabri, Leonardi and Zambonelli 1999). MARS is a programmable coordination architecture based on the LINDA model. LINDA is a concurrent programming model with the primary concept being that of a 'tuple-space' (ordered sets of values), an abstraction via which cooperating processes can communicate. The basic operations defined on the tuple spaces permit to add or extract tuples and recent research shows that the LINDA model suits well heterogeneous scenarios such as the Internet, whilst in addition the programmable reactivity of tuple spaces permits to uncouple algorithmic issues from interaction issues, leading both to an easier programming style and to a clearer separation of concerns.

Another Dutch auction implementation can be found in the travel agent game in AgentCities (TAGA) (Zou, Finin, Ding, Chen and Pan 2003). TAGA is a framework that extends and enhances the trading agent competition (TAC) scenario to work in AgentCities, an open multi-agent system environment. An auction service agent (ASA) operates all of the auctions and markets in TAGA.

The current state of research concerning agent-enabled auctions ruled by the Dutch auction mechanism is to provide the seller-agent with the functionality of making the proposal more persuasive by providing additional meta-level information in the form of arguments which can be used for defending its position.

Game Theory In multi-agent negotiations the outcome of the negotiation will depend on the choices made by all agents in the process. This implies that in order for an agent to make the choice that optimizes its outcome, it must take into account the decisions that other agents may make and must assume that they will act so as to optimize their own outcome. According to game theory, agents will try to reach Nash equilibrium, a stable outcome for each agent based on the assumption of rationality. No rational agents will leave the Nash equilibrium they have reached, because any agent who leaves alone will get fewer payoffs. A strategy combination (si*, s -i*) is a Nash equilibrium if any agent will get less its payoff when it deviates from this strategy combination alone (mathematically: Vi,7ri(sf,s*i) > n7,(s~,sf,),Vs~). However, the Nash equilibrium may not always exist, and even if it does, it may not be the optimal solution.

In this context, Zlotkin and Rosenschein (1991) have carried out extensive work to cover agents that are not truthful, i.e. agents that can be deceptive. Using some simple demonstrators, they show that if an agent withholds certain information or deliberately misinforms other agents, this may result in better negotiation deals for the agent. In this work they view negotiation as a two-stage process — the actual negotiating and the execution of the joint plans. Their latest work focuses on a general theory of automated negotiation in which they classify complex domains into three categories — task-oriented domains, state-oriented domains and worth-oriented domains (Rosenschein and Zlotkin 1994). Kraus and Wilkenfield (1991) also examine agent-based negotiation using game theory principles proposing a strategic model that claims to take the parameter of time into consideration during the negotiation process.

There are two problems in negotiation that Game Theory can help to solve. Principles derived from Game Theory can be useful in designing an appropriate protocol that will direct the interactions between participants, and in defining a strategy that an agent can use while engaging in a negotiation process. Unfortunately, strategies that may be theoretically feasible tend to be computationally intractable, underlying a

number of challenges such as the following that future research attempts will be forced to overcome in order to enhance the applicability of Game Theory:

- Game Theory assumes that it is possible to characterize an agent's preferences with respect to possible outcomes. Humans, however, find it extremely hard to consistently define their preferences over outcomes.
- The theory has, so far, failed to generate a general model directing rational choice in interdependent situations. Instead, a number of highly specialized models that are applicable to specific types of interdependent decision making have been proposed.
- Game Theory models often assume perfect computational rationality meaning that no computation is required to find mutually acceptable solutions within a feasible range of outcomes. Furthermore, this space of possible deals is often assumed to be fully known by the agents, as is the potential outcome. This assumption rarely holds true in most real world cases.

Heuristic Approaches Negotiation heuristics is the knowledge that an agent uses to make negotiation decisions under various circumstances with heuristic approaches having the potential in addressing the obstacles posed by the application of Game Theory principles to negotiation. For example, the "A" search algorithm (Hart, Nilsson and Raphale 1968) is a best-first heuristic search algorithm that explores the nodes with minimal cost $f(n) = g(n) + h(n)$ first; n is the current node, $g(n)$ is the cost from the initial node to current node, and $h(n)$ is the estimated cost from current node to the goal node. It guarantees to return a minimum cost solution as long as the heuristic, $h(n)$, does not overestimate the remaining cost. Approaches such as this have the advantage that (a) the derived models are based on realistic assumptions and hence they provide a more suitable basis for automation with the potential to be used in a wider variety of application domains, and (b) the designers of agents, freed from the inherent complexities of Game Theory, can use alternative and less constrained models of rationality to develop different agent architectures.

Currently, research efforts are focusing on trying to model an agent's decision making process heuristically during a negotiation activity. The trend as is evidenced by the research undertaken in research laboratories is to enable the agent to make proposals that are more attractive to the opponent. The challenge in achieving this is not by conferring additional meta-level information but by providing contracts that are closer to the opponent's last offer. The aim is to increase the likelihood of coming to an agreement by adding or removing matters through negotiation, either by increasing the set of possible outcomes when the negotiation seems to be in a deadlock state, or, alternatively, by removing matters that are obstructing the its progress.

It must be noted that whilst heuristic approaches may hold the solution to specific problems encountered with the use of game theoretic models, they themselves also have limitations that future research should address. More specifically, heuristic-based models often select outcomes that are sub-optimal because they adopt an approximate notion of rationality and because they do not examine the full space of possible outcomes. Furthermore, such models require extensive evaluation since under normal circumstances it is impossible to predict precisely how the system and the constituent agents will behave in a wide variety of circumstances.

Argumentation-based approaches The three approaches to negotiation as discussed above suffer from two main limitations. Firstly, the only feedback that can be made to a proposal is a counter-proposal, which means that the other party's response can be either an acceptance or withdrawal. Secondly, it is hard to change the elements of the negotiation object during the course of the negotiation process.

The aim of argumentation-based negotiation is to remove these limitations with the basic idea being to allow additional information to be exchanged, over and above the proposals. This information can be shaped and offered in the form of arguments with the purpose of explaining explicitly the rationale

of the agent behind a specific proposal. As with human argumentation, agents may not have honest intentions when generating an argument. Thus, when evaluating an argument, the recipient needs to assess the argument on its own merits and then modify this by its own perception of the argument's degree of credibility in order to work out how to respond.

According to Jennings, Parsons, Noriega and Sierra (1998) the following are required in order to design and build an agent capable of effective argumentation-based negotiation: (a) mechanisms for *passing proposals* and their supporting arguments in a way that other agents understand, (b) techniques for *generating proposals* (counter-proposals or critiques) and for providing the supporting arguments, (c) techniques for *assessing proposals* (counter-proposals or critiques) and their associated supporting arguments, and (d) techniques for *responding to proposals* (counter-proposals or critiques) and their associated supporting arguments.

The effective utilization of argumentation-based techniques by agents means catering for the complexities of the agents' 'mental' attitudes, the communication between agents, and the integration of the argumentation mechanisms into a solid agent architecture. These issues are discussed in Parsons, Sierra and Jennings (1998), where the authors show how to augment a standard model of argumentation to work for agents who reason using beliefs, desires and intentions. Giunchiglia and Serafini (1994) also discuss how to utilize multi-context systems in order to integrate argumentation into a belief-desire-intention agent architecture. This stream of work is further developed in Sabater, Sierra, Parsons and Jennings (1999) where an implementation in which agents negotiate using argumentation in order to construct joint plans is presented. However, this does not mean that we are close to being able to build such agents. Before we will be able to claim so, such works on building, assessing and responding to agent-generated arguments must be further developed.

For the future, research endeavors focus on two main areas. The first concerns the definition of suitable argumentation protocols that specify how agents generate and respond to arguments based upon what they know. Initial attempts at describing such 'behavior' are given in Amgoud, Maudet and Parsons (2000a; 2000b), which define an argumentation protocol based on the attitude that an agent should have when negotiating, explaining, for instance, when an argument is found to be persuasive enough, or when its grounds need further questioning. Since this is a rather inflexible approach, continued investigating efforts aiming to discover more flexible argumentation protocols than those currently available, are needed.

The second main research area revolves around the following question: "When is the right time to start an argument?" There is a need to translate this high-level notion of 'rightness' into some more concrete decision criteria that can be built into agents. The problem with such approaches is that they add considerable overheads to the negotiation process, not least in the construction and evaluation of arguments. As a result, it is anticipated that at least for the foreseeable future, agents who can argue in support of their negotiations will only represent a small class of automated negotiators.

OUTLINING AN AGENDA FOR FUTURE RESEARCH

As is evidenced from the preceding sections, agent-based information systems and electronic marketplaces provide a fruitful avenue for research. In this section we attempt to outline the boundaries of a research agenda using sets of fundamental research questions as marking posts. These questions are being derived directly from an analysis of the research landscape and each one is matched with a number of identified concepts and representative works, producing as a result a set of concept matrices in line with the suggestions of Webster and Watson (2002) for structuring a review. Whilst we make no claim for completeness, concerning either research questions or concepts, it is our belief that the agenda albeit brief, describes the state-of-the-art and achieves its purpose which is to sharpen the focus of the interested researcher who plans to conduct research into agent-

based information systems. To this end, the reference lists will prove invaluable for making the necessary first steps for accumulating a complete census of relevant literature for each identified concept if one wishes to do so.

Research Questions and Issues for Marketplace Ontologies

Ontologies refer to models of a domain upon which agents rely for performing various tasks such as negotiation. Without defined ontologies, the application of agents in marketplaces and virtual communities will be severely limited and this fundamental need drives research on how ontologies can be shared and reused, how they can be revised when needed and how their consistency can be improved. Ontologies should be implemented in a way that they can be reused or even expanded with new terms but at the same time be resistant to structural revisions since they are created according to a logically consistent model (Albers, Jonker, Karami and Treur 2000). For example the approach presented in Omelayenko and Fensel (2001) helps in maintaining large sets of transformation rules by providing for their decomposition into smaller and more understandable pieces and facilitating rule reuse. But do such approaches make ontologies effective in terms of usability? Can different ontologies and large-scale product ontologies be aligned? Can we perform complicated and knowledge-intensive information transformation, including generation of conceptually different views on the same knowledge? For addressing these questions, research should also focus on the provision of semantic annotations for documents. If a document utilizes semantic annotations then it becomes easy for the ontology to tailor it to the specific needs of the user and resolve inconsistencies between groups of documents. If different ontologies can be aligned to large-scale product ontologies then conceptually different views on the same knowledge can be created. Reusability, consistency and providing for the effective and efficient revision of ontologies are challenges that future research on semantic annotations should seek to meet.

Future research should also focus on defining the ways and providing the means by which agents can help to automate the administration of ontologies. Consider the ways that the agent process and the ontology design are interrelated; for example, how a broker agent can enable a buyer and a seller to interact with each other without having to communicate any personal details to each other. To be enabled, this process requires a number of supporting activities such as responding to buyer requests for products with certain properties, maintaining information on customers, building customer profiles, maintaining information on products, maintaining provider profiles, matching buyer requests and product information and responding to new offers of products by informing customers for whom these offers fit their profile (Albers, Jonker, Karami and Treur 2000). In short, the underlying ontologies need to be efficiently maintained for the provided queries and answers or advice to be effective. Although there has been progress towards this direction, a number of limitations must be addressed. In general, an agent process does not know of any changes that may have been taking place at the ontology level unless a third party feeds this information continuously to the program. The agent cannot track the changes at run time and hence perform some form of auto-maintenance. Researchers should now focus on building agents that can maintain themselves and keep their ontologies current through the update of old and the installation of new objects at run time keeping thus the ontologies current and the quality of information high at all times (Jonker, Lam and Treur 1999). Finally, even though an agent may possess complete knowledge of the ontology it handles, in terms of usability it still cannot help the user in finding exactly what he really wants. Further research is needed so that agents can be used to effectively aid the user in formulating the right request and query in order to get the most accurate matches to his original question (Jonker and Vollebregt 2000).

Another major research question concerns the cooperation between different ontologies. At present, if we have two ontologies that differ in their structure having been created by different system developers using different techniques and tools, no cooperation or communication can be achieved

between the two agents using the ontologies. This happens because either the output produced by the systems is not in a general machine-readable form or it is in a non machine-readable form requiring the user to read and provide its own interpretation of the output. Research should focus in procuring and promoting the syntax and format of a general machine-readable output as a standard that can be used by all systems and ontologies enabling the collaboration of different agents that each understands each own ontology.

Research Questions and Issues for Advising Services

The provision of advising services as a means for aiding the user to complete a specific task enhances the overall usability of a systems and is thus deemed critical. Traditionally, manuals and help files aided the user in the quest to find if a certain task can be performed by the system and how it can be done. Soon after, help files made their appearance enhanced with search and query capabilities. The main problem with these is that a user must know the syntax and semantics for asking the question or the answer will not be a good match to the original query. Research on agent-enabled advising services focuses on the intent, the timing and the level of intrusiveness of an advising service with researchers having proposed three styles of critic agents. These are 'Before-', 'During-' and 'After-Task' critics (Silverman 1992). The main disadvantage of Before-Task critics is that as the information provided

Table 2. Research questions and issues for marketplace ontologies

RESEARCH QUESTIONS	**What should be done so as to extent the current level of ontology usability?**			**How can agents automate and maximize the efficiency of ontology administration?**			**How can agents enable cooperative ontologies?**	
Research Issues / **Representative Works**	Share & reuse	Consistency	Revision	Effectiveness through semantic annotations	Communicat-ion	Effective queries & answers	Keeping system updated & upgraded	General machine-readable output that can be a standard
Abrams 2003								X
Albers, Jonker, Karami and Treur 2000	X	X	X		X			
Baclawski, Kokar, Waldinger and Kogut 2002		X		X				
Berners-Lee and Fisichetti 2000				X				
Compatangelo and Sleeman 2000	X	X			X			
Jonker and Vollebregt 2000					X	X		
Jonker, Lam and Treur 1999					X	X	X	
Levy 1999						X		
Omelayenko and Fensel 2001	X	X	X	X				
Patel 2002	X							X
Valarakos 2000				X			X	X
Wang, Baclawski, Brady, Kokar and Lechowicz 1998				X	X	X		

cannot be processed and filtered to match the exact user needs, redundancy and user overload is the result. During-Task critics are considered to offer the best possible advising service to the user; the drawback here being the user becoming fully dependent on the agent and the system without being able or willing to exercise any critical abilities or generate personal inferences. In contrast, After-Task critics do not distract the user, but they cannot prevent a wrong decision being made as any advice follows on the execution of the task. For agent-enabled advising services to advance in terms of usability future research should focus to a multi-style advising service using a mixture of 'During-' and After-Task style critics because the former can help in avoiding mistakes and the latter can add value in offering alternative solutions.

The second main research question concerns the management of the presentation and content of the advice offered by agents. Agents should not only offer the user advice and help that matches exactly the user's needs but present it in the most efficient and effective manner. There are three frameworks that can be utilized for this purpose. These are the Hierarchical Task Decomposition, the 'Blackboard' and the Dynamic Strategy Networks. The hierarchical task decomposition described in Chin-Ming Fu (1997), decomposes the tasks of a system in a hierarchical manner starting from the most general form of advice and reaching to a specific task through several actions taken by the user. This framework, while being effective for certain applications such as medical diagnoses and problem-solving and tutoring, turned out to be not so effective for critiquing. In a blackboard-based architecture we typically have a common knowledge repository (blackboard) and a number of agents (knowledge sources) accessing it. Although blackboard systems are having distinct advantages compared to the hierarchical task decomposition approach they do not reach expert-level performance in challenging real-world and real-time domains. Dynamic strategy networks, described in Bulitko and Wilkins (2000) are seen as the future for agent-enabled advising services since they can provide domain and strategy level rules at run time. These networks which extend the classical blackboard architectures can provide an accurate advice for every single action taken by the user. Research should focus on dynamic strategy networks and researchers should seek to develop a single architecture that would be applicable in both static diagnosis and dynamic problem-solving situations.

Table 4. Research questions and issues for advising services.

RESEARCH QUESTIONS	**What is an effective agent-enabled advising service in terms of intention, timing and level of intrusiveness?**			**How can the presentation and content of the advice be managed best by agents?**		
Research Issues / **Representative Works**	Intent	Timing	Intrusiveness	Hierarchical task decomposition	Blackboard based system	Dynamic strategy networks
Bulitko and Wilkins 2000					X	X
Chin-Ming Fu 1997	X	X	X	X		
Palma, Marin and Balsa 2001				X	X	
Rahimi, Dessouky, Gounaris, Placencia and Weidner 2001				X		X
Silverman 1992	X		X			
Silverman, Bachann, Akharas and Balasubramanian 1999	X					

Research Questions and Issues for Negotiation Services

When agent-based negotiation techniques were first proposed the requirement was reaching a better price for buying a product. As negotiation as a process evolved, additional information was needed so that a user could better decide for a purchase of a product and a plethora of negotiation objects appeared. These objects can be price, quality, timing, penalties, terms and conditions or types of operation and are deemed as helpful in negotiating a product (Jennings *et al.* 2001). With agent-mediated negotiation users need to be sure that the agent would achieve the best possible deal for them and that the product they are negotiating for is what they really want. Researchers should emphasize on techniques that enhance trust amongst the user and his agent. This can be achieved by the continuous feedback given by the agent with additional information about the product and the negotiation phase. An agent should be able to support and advise the user for his/her actions. Research should also focus on armoring the agents from malicious attacks, providing the user with a trustful environment to sell or purchase products and services.

A number of techniques have been proposed with each one aiming to enhance the efficiency and effectiveness of the negotiation process. The Dutch auction technique (Jennings *et al.* 2001) is a very slow technique if none of the participants wants to buy the product. A viable solution is to provide the managing agent of the Dutch auction with additional meta-level information so as to speed up the process. Techniques borrowing principles from Game theory are generally regarded as much more efficient but suffer from one main limitation; the best possible solution is computationally intractable. With heuristic approaches, contracts that are closer to the opponent's last offer are provided but agents using these approaches often select outcomes that are sub-optimal so as to reach a deal. The best technique that has been proposed so far is the argumentation based technique where additional information over and above proposals is being exchanged. The main question for all these techniques is whether the provision of additional information to agents is the optimal solution in order to reach a deal as this adds a considerable overhead to the system. Research should focus in combining efficiency with speed with the use of multi-context systems (Giunchiglia and Serafini 1994). These systems were originally proposed as a means of providing efficient theorem proves for modal logics to integrate argumentation into a belief-desire-intention agent architecture. This latter strand of work was further developed in Sabater, Sierra, Parsons and Jennings (1999) and this has led to an implementation in which agents negotiate using argumentation in order to construct joint plans. Although, such agents are far from being build yet, this stream of research shows significant potential in addressing the limitations discussed above.

CONCLUSIONS

The promise of software agents to offer via their application advanced functionality to basically each type of information system has resulted to a considerable amount of research output in a rather short time frame. Although it is still very early to identify all the possible uses that this new technology will be put to and predict what its application will bring, it is the expectations somewhat veiled by the initial research results that makes any new research effort towards this direction worthwhile. In this paper we have attempted to present and analyze the landscape and outline a future agenda and the state-of-the-art regarding software agents in electronic marketplaces. We provided a layered taxonomy that distinguishes between two types of marketplaces, i.e. controlled and uncontrolled and, identified three main categories as possible sources for research thematics. This state-of-the-art is by no means all-encompassing and complete. Firstly, it was never meant to be, as the scope of this paper is to provide, rather like a compass, the coordinates of a destination and, not to pinpoint exactly what are the specific impediments for reaching it and then proceed to analyze them in depth. Secondly, the research issues that emanate from the software agent/electronic marketplace junction are indeed so numerous and varied that any claim to completeness would have to be judged relative at best. We believe however that the

Table 6. Research questions and issues for negotiation services.

RESEARCH QUESTIONS	What is needed in order to make a negotiation plausible?		How can we combine effectiveness and efficiency in agent-enabled negotiation?	
Research Issues / Representative Works	Negotiation Protocols	Negotiation objects	Additional meta-level information	Multi-context systems
Giunchiglia and Serafini 1994				X
Jennings *et al.* 2001	X	X	X	
Jennings, Parsons, Noriega and Sierra 1998	X			
Kraus and Wilkenfield 1991		X		
Krothapalli and Deshmukh 1998	X			
Parsons, Sierra and Jennings 1998				X
Sabater, Sierra, Parsons and Jennings 1999				X
Sprinkle, Van Buskirk and Karsai 1999	X	X		
Tewari and Maes 2000		X		

research directions presented in this paper exemplify a fruitful area for both applied and theoretical work on the application of agents in order to enable users to have an overall satisfying experience with services provided to them via the electronic marketplaces of the future. Perhaps, the potential that this field holds in terms of potential is also emphasized by the fact that at the present moment what works best in an applied sense happens also to be the simplest one conceptually (the case of vCOM; Shen, Radakrishnan and Georganas 2002). This proves that substantial effort is required for theory to mature in order to drive the design of rich agent-based services that are integrated and institutionalized successfully as parts of working electronic marketplaces.

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AUTHORS

George Kontolemakis is a doctoral candidate in the Department of Informatics and Telecommunications at the National and Kapodistrian University of Athens. He holds a BSc in Computer Science from the University of Crete. His research focuses on the design of software agents and their application in electronic commerce environments. His interests also cover large databases and information systems.

Panagiotis Kanellis is currently a program manager with Information Society S.A. in Athens, Greece. He is a member of the British Computer Society (MBCS) and a Chartered IT Professional (CITP). He was educated at Western Intl. University in Business Administration (BSc), at the University of Ulster in Computing and Information Systems (Post-Graduate Diploma), and at Brunel University in Data Communication Systems (MSc) and Information Systems (Ph.D.). He is a research fellow in the Department of Informatics and Telecommunications at the National and Kapodistrian University of Athens and an adjunct faculty member at the Athens University of Economics and Business.

Drakoulis Martakos is an Associate Professor at the Department of Informatics and Telecommunications at the National and Kapodistrian University of Athens. He received his B.Sc. in Physics, MSc in Electronics and Radio Communications, and Ph.D. in Real-Time Computing from the same university. Professor Martakos is a consultant to public and private organizations and a project leader in numerous national and international projects. He is author or co-author of more than 50 scientific publications and a number of technical reports and studies.