The Knowledge Engineering Review, Vol. 18:1, 33–46. © 2003, Cambridge University Press
DOI: 10.1017/S0269888902000516 Printed in the United Kingdom

Towards multi-agent electronic marketplaces: what is there and what is missing?

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Abstract

This paper gives an overview of electronic marketplaces which employ agent technology or similar techniques. Special attention is given to negotiation issues. A classification scheme for competitive negotiation depending on the type of the marketplace (business-to-business, business-to-consumer and consumer-to-consumer) and on the range of players (1 : 1, 1 : n and n : m) is introduced. Furthermore, we distinguish between one-issue and multi-issue negotiation, and we consider crisp and fuzzy constraints on either negotiating side. Several existing electronic marketplaces and prototypes of marketplaces are discussed with respect to the classification schema. Our analysis shows that agent-based e-marketplaces are a promising area of e-commerce but they are still far away from real marketplaces. In conclusion we formulate some challenges for further research in the field of multi-agent electronic marketplaces with negotiation between agents.

1 Introduction

Electronic marketplaces are electronic versions of traditional marketplaces, representing places where buyers and sellers come together and transact. They have become critical elements of electronic commerce both for business-to-consumer (B2C) and for business-to-business (B2B) transactions in one form or another, e.g. as auctions, product exchanges, online shopping markets, e-catalogues and so on (Weller, 2000; Kurbel, *et al*., 1999).

Recently, agent technology has been applied to e-marketplaces, promising a revolution in electronic commerce. For a detailed discussion of what a software agent is, its attributes, topologies based on these attributes, and an overview of different agent types, we refer to the papers of Nwana (1996) and Wooldridge and Jennings (1995). According to Nwana (1996), intelligent software agents should exhibit at least three characteristics:

- *Autonomy* – Agents process their work independently and proactively without the need for human management.
- *Cooperation* – Agents are able to communicate with one another, negotiating on certain issues.
- *Learning* – Agents are able to learn as they react or interact with their environment and other agents.

In a specific situation the emphasis may be more on one characteristic and less on another. Say, for collaborative agents, cooperation and autonomy are more important than learning whereas, for interface agents, there is more emphasis on autonomy and learning than on cooperation. Following Nwana (1996) we consider only such systems as exhibit at least two of the three attributes above as agents. On the other hand, Nwana and later Nwana and Ndumu (1999) pointed out that truly intelligent

* The authors are very grateful to the referees for their helpful comments and suggestions.

software agents which exhibit all three attributes equally well are rather an aspiration of agent researchers than reality. The reason is mainly that several serious multi-agent problems are still waiting to be solved. Nwana and Ndumu mention the information discovery problem (discovering where relevant resources can be found), the communication problem (standards for common communication protocols and communication languages), the ontology problem (standards for definition of concepts), the legacy software integration problem (integration of legacy software with agent systems), the reasoning and coordination problem (planning, contracting, negotiation and cooperation) and the monitoring problem (monitoring of internal and external events) as the core problems in this field.

Projecting the state of the art of agent systems to the special case of multi-agent-based e-marketplaces we have to admit that the agent-based marketplaces with truly intelligent agents do not exist yet. The aim of this paper is to analyse multi-agent e-marketplaces with collaborative homogeneous agents from the point of view of how far or how close are they from real-world marketplaces and why. We point out that agents acting on e-marketplaces are usually autonomous. Their capabilities to cooperate differ from marketplace to marketplace. The focus of this paper will be on the cooperation aspect. We also consider some e-marketplaces which are not agent-based in the sense of Nwana (1996) but can be evaluated to be important steps on the way to multi-agent e-marketplaces.

For our analysis we distinguish between controlled and uncontrolled marketplaces. An *uncontrolled e-marketplace* is entirely open and decentralised; no single site controls the market. Each participant initialises an agent that acts in the interest of its owner and uses strategies uniquely defined for him. Although quite promising, such e-marketplaces have to face all the unsolved problems in the field of multi-agent systems mentioned above and are difficult to implement. In spite of some interesting projects such as SICS MarketSpace (Eriksson *et al.*, 1998) and CommerceNet eCo System (`http://www.commerce.net/eco/`), uncontrolled multi-agent e-marketplaces are still a vision rather than reality.

In the framework of a *controlled e-marketplace* the participants have to agree upon a set of rules regarding both what can be bought and sold on this marketplace and how it can be done. In particular, the negotiation process requires regulation of three important questions (Jennings *et al.*, 2000):

- *negotiation protocols* – the set of rules which govern the interaction,
- *negotiation objects* – the range of issues over which an agreement must be reached,
- *agents decision-making models* – the decision-making apparatus the participants employ to act in line with the negotiation protocol in order to achieve their negotiation objectives.

When these topics are decided many of the general multi-agent problems like the information discovery problem, the communication problem, the ontology problem and the monitoring problem are much easier to tackle compared with an uncontrolled e-marketplace. The reason is that the standards are set by the makers of the marketplace and not separately by each agent's developer as in an uncontrolled e-marketplace. In the controlled e-marketplace the negotiation problem is still very difficult and has been solved successfully only in some special cases.

The term "negotiation" as used in this paper refers to automated negotiation where all parties involved are software agents. However, we do not assume that negotiation is always a complex process including reasoning, proposals and counter-proposals. For convenience a simple exchange of information between two agents is also considered to be a negotiation. Furthermore, we assume that the agents acting in an e-marketplace have some conflict of interest, i.e. their negotiation is competitive. Finally, we focus on controlled e-marketplaces. Noting that for controlled multi-agent e-marketplaces negotiation is the most critical element, we base our analysis on different attributes of e-marketplaces connected with agents' negotiation.

The remainder of this paper is organised as follows. In Section 2 we propose a classification of controlled multi-agent e-marketplaces involving four different attributes: the type of the marketplace (business-to-business, business-to-consumer and consumer-to-consumer), the range of players on the buyers' and on the sellers' sides (1 : 1, 1 : n and n : m), the number of issues over which agreement must be reached and the level of vagueness of constraints for these issues. In fact, these attributes are closely connected with the negotiation protocols, negotiation objects and agent decision-making models. In Section 3 we analyse existing controlled multi-agent e-marketplaces based on our classification. Section 4 discusses some challenges for further research in this field and Section 5 summarises the conclusions.

2 A topology of multi-agent e-marketplaces

A multi-agent e-marketplace is usually a very complex object possessing a lot of attributes connected with its architecture, security of information, tools for communication between agents, distribution of roles played by the agents and the marketplace and so on. In other words, e-marketplaces exist in a multi-dimensional space of their attributes. That is why any classification taking into account not all but only some attributes will be incomplete and inaccurate. However, for practical reasons the number of attributes has to be limited to the most important ones. Since the organisation of negotiation between agents is decisive for controlled multi-agent e-marketplaces we base our topology on negotiation-related attributes.

Various approaches to automated negotiation in multi-agent systems have been discussed, among others, by Beam and Segev (1997), Beer *et al.* (1999), Guttman and Maes (1998a; 1998b), Jennings *et al.* (2000), Klaue *et al.* (2001), Fatima *et al.* (2002), Parsons and Wooldridge (2002). As the focus of this paper is on a special case of a multi-agent systems, i.e. on agent-based e-marketplaces, we specialise on the general ideas for this case.

To start with, the most important attributes of negotiation in the framework of a multi-agent e-marketplace are determined. First of all, we note that the character of negotiations is different for different types of e-marketplace (business-to-business, business-to-consumer and consumer-to-consumer). Then it is important to distinguish whether agents are allowed to negotiate on a multilateral basis (i.e. with several other agents simultaneously) or not. In an online shopping market, for example, the negotiation model is bilateral for the merchants (supposing the merchants have big enough inventories) and multilateral for the consumers (supposing many merchants sell the same goods). A different situation is in online auctions where consumers compete with one another for merchant offerings: merchants may be involved in multilateral negotiations whereas for each customer the negotiation is bilateral. Finally, in the classified advertisements markets both buyers and sellers competitively negotiate on a multilateral basis for limited resources.

This means that basically three different constellations are possible for each different type of e-marketplace (business-to-business, business-to-consumer and consumer-to-consumer). In Figure 1, they are denoted by models A, B and C (Guttman & Maes, 1998a).

Let us imagine a real competitive negotiation between two parties (each of which is either a person or a company). First, the range of issues over which agreement must be reached should be known. In the simplest case it is a single issue (such as price), whereas in a B2B negotiation dozens of issues

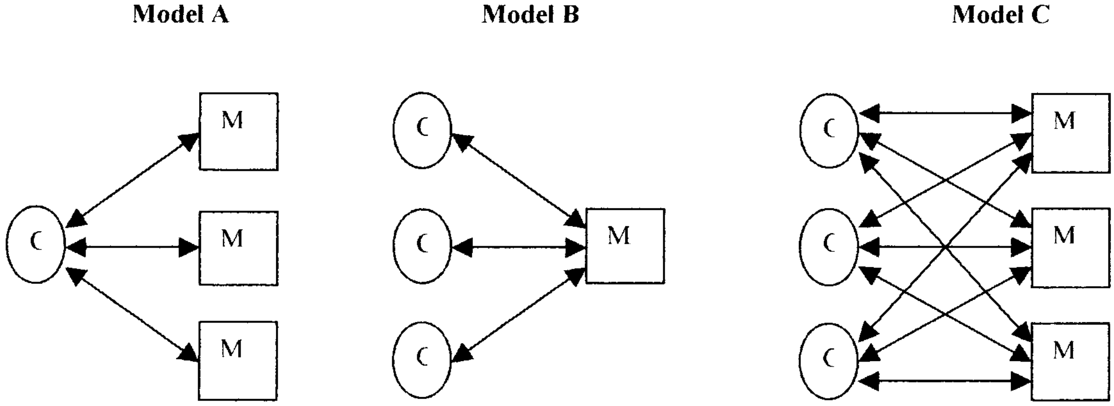

Figure 1 Three models of competitive negotiation in an e-marketplace

(related to price, quality, timings, penalties, terms and conditions and so on) may be discussed. As the dimension of the space of negotiation issues becomes larger the complexity of negotiation increases. Thus the number of issues over which agreement must be reached is one of the most important features of the negotiation process. Furthermore, in the dynamic process of negotiation some new negotiation issues can sometimes be added and some negotiation issues neglected. In the paper, we distinguish between one-issue and multi-issue negotiation as well as between negotiation with a fixed and a variable number of negotiation issues (only for multi-issue negotiation).

The next important feature to consider is whether the constraints regarding the negotiation issues are crisp or fuzzy. By fuzzy constraints we mean the following: suppose a certain scope of values (an interval or a set of intervals in the continuous case, or a set of values in the discrete case) for a negotiation issue exists such that any value from that range is acceptable for a person or his/her agent. Different points from those ranges are of different worth for persons or agents participating in a negotiation. The worth of a certain value of the negotiation issue may be modelled by a so-called scoring function. The bigger the value of a scoring function for a given value of issue, the more worth this value has. With the help of the scoring functions fuzzy constraints can be modelled as fuzzy sets. It is fuzzy or vague constraints which make it possible to truly negotiate, i.e. to accept or reject a proposal and make a counter-proposal based on a certain strategy. If all constraints are crisp negotiation is reduced to a simple comparison of preferences of two negotiating parts. In a real negotiation where both sides have the same status (say, C2C or B2B negotiation) an agreement can only be reached if concessions are made, i.e. due to vague constraints. That is why we consider the ability to negotiate and to make a decision in a vague environment one of the main characteristics of a software agent acting in a multi-agent e-marketplace. We distinguish between one- and multi-issue negotiations with either crisp or fuzzy constraints. Note that in case of multi-issue negotiation some constraints may be fuzzy and others may be crisp, i.e. the mixed situation is also possible.

Finally, we stress once again that negotiation is a process with (at least) two negotiating partners, and the outcome of the negotiation process depends essentially on the preferences and constraints of all negotiation participants. Summarising all attributes of negotiation presented earlier, we arrive at the classification of controlled multi-agent e-marketplaces given in Figure 2. The classification scheme is presented by using technique of morphologic boxes.

Having three negotiation types (business-to-business, business-to-consumer and consumer-to-consumer), three negotiation models (A, B and C), two choices each for the number of issues to negotiate (one- and multi-issue negotiation) and for the level of fuzziness of constraints (crisp or fuzzy constraints), and two sides in the negotiation process (say, consumers and merchants), we arrive at 72 different multi-agent e-marketplace models. The simplest cases are models A or B with one-issue negotiation and crisp constraints on either side whereas for real-life situations the model C with multi-issue negotiation and fuzzy constraints on both sides seems to be more relevant.

If we move from the simple cases towards more complex ones, the problems arising both in theoretical investigation and in the implementation of such marketplaces become increasingly difficult with each step. That is why only few of our models of e-marketplaces have been implemented and can already be found on the Internet, as we will see in the next section.

<table>
<tr><th>criterion</th><th colspan="4">possible values</th></tr>
<tr><td colspan="5"></td></tr>
<tr><td>type of e-marketplace</td><td>B2B</td><td colspan="2">B2C</td><td>C2C</td></tr>
<tr><td>type of negotiation model</td><td>1:n (A)</td><td colspan="2">m:1 (B)</td><td>n:m (C)</td></tr>
<tr><td>negotiation issues</td><td colspan="2">one issue (price)</td><td colspan="2">many issues</td></tr>
<tr><td>type of consumer's constraints</td><td colspan="2">crisp</td><td colspan="2">fuzzy</td></tr>
<tr><td>type of merchant's constraints</td><td colspan="2">crisp</td><td colspan="2">fuzzy</td></tr>
</table>

Figure 2 Classification of controlled multi-agent e-marketplaces

3 Critical analysis of existing agent-based e-marketplaces

In this section we give an overview of existing multi-agent e-marketplaces to determine how close or how far are they from real-world marketplaces. In the framework of a real marketplace, each participant is often involved in multilateral negotiation with many issues over which agreement must be reached. The process of negotiation is in fact a process of mutual concessions taken according to some underlying strategies. Concessions are possible if the participants' constraints regarding negotiation issues are fuzzy and not crisp. Translated to electronic marketplaces where agents act on behalf of their owners trying to satisfy their owners' preferences, this situation corresponds to model C with multi-issue negotiation and fuzzy constraints on both sides.

3.1 E-marketplaces with negotiation model A

Guttmann *et al*. (1998) refer to Andersen Consulting's *BargainFinder* (`http://bf.cstar.ac.com/bf`) as the first agent for comparison shopping. Given an artist's name and a description of a rock or pop CD, a consumer's agent gets and compares prices from nine virtual retailers. The retailers play passive roles in this process; they just provide information to the buying agents. The only criterion for comparison is the price of the CD. Constraints are crisp on the merchants' side (fixed prices) and on the consumers' side (the price should be "minimal"). Although the BargainFinder project received a lot of attention from software-agent researchers it was not without friction: Guttman *et al*. report that one-third of the online CD merchants accessed by BargainFinder blocked price requests. The reason was that they did not want to compete on price alone since they considered the price only one of many factors in the consumer's buying decision.

Multi-issue comparison could be a solution to this problem. Recently some online shopping markets employing this methodology were implemented. Strictly speaking they are not multi-agent e-marketplaces because the merchants are statically represented through information about their products and not through software agents. Neither are the consumer's agents sufficiently intelligent. They possess only some autonomy and very limited features for cooperation. Nevertheless, some of these online shopping markets can be regarded as important steps on the way to multi-agent e-marketplaces with negotiation model A.

As an example, we consider the *Frictionless Commerce Value-comparison Engine* (`http://www.frictionless.com`) which was used for the implementation of retail markets (Lycos, Brodia, WebHelp and Computer.com) and the financial services market WingspanBank.com (for more online shopping markets sorted by categories visit the internet.com site `http://bots.internet.com/s-shop.htm`). The technology used by Frictionless Commerce enables users to search for products on the Web based on value, not just on price. Online consumers use the Frictionless engine to initialise their agents by selecting individualised criteria, such as product features and merchant services. Consumers' constraints for product features can be fuzzy. In addition, consumers are asked to rate their preferences for product features ranging from "must have" to "not important". This information is used by the Frictionless engine to rank the products found. Since the number of product features can be quite large (between 20 and 30), consumers are given an option to choose a profile with pre-defined values.

In the Frictionless e-marketplace the merchants are represented through the Frictionless Retail Product Database containing hundreds of thousands of products from thousands of manufacturers. On the merchant's side all product constraints, including prices, are crisp. As a result of this crispness, negotiation in the framework of the Frictionless e-marketplace is reduced to search and comparison: consumers' agents ask for offers and the Frictionless engine responds with merchants' offerings. Counter-proposals are not available. The main problem in this approach is to rank the crisp proposals according to the consumer's fuzzy constraints and preferences. The Frictionless engine solves this problem using multi-attribute utility theory. The ranking returned to the consumer is easy to understand and well explained.

Although easy and quick to use, the Frictionless engine neglects one essential aspect of decision-making in a vague environment with fuzzy constraints and preferences: a consumer has no means to enter into the system how important different negotiation issues or product features are compared to each other. All are assumed to be equally important. Evidently this may not be appropriate in many real-life situations: for some people looking for a computer the processor speed may be more important than the amount of RAM whereas for others the opposite can be true, but all will require both features to be present in a computer.

This problem was tackled by the *Active Buyer's Guide System* (`http://www.activebuyersguide.com/`) developed by Active Research, Inc. The users are not only asked how desirable certain product features are for them but also how important each product feature is compared to others, and even how important certain combinations of features are compared to other combinations. This system uses fewer product features than the Frictionless engine does. For example, a consumer trying to buy a laptop has to input his constraints for 10 product features. Only one of them (the name of the company) is related to a merchant. In contrast, the Frictionless engine will altogether ask for 23 features: 7 basic features, 7 advanced features and 9 merchant features including payment method, return policy and warranty. So both the Active Buyer's Guide System and the Frictionless engine have disadvantages. Both of them exhibit, on the other hand, some very useful features to be taken into account for the development of truly multi-agent e-marketplaces with negotiation model A.

Online shopping markets like the Active Buyer's Guide System or Brodia are primarily found in the B2C field. Since the status of one partner (retailer) is different from the status of another partner (consumer), preferences and constraints regarding the negotiation issues are asymmetric: constraints are fuzzy on the consumer's side and crisp on the merchant's side. Merchants therefore have no need to be represented by agents that will negotiate with consumers' agents. Consequently, multi-agent e-marketplaces with model A, multi-issue negotiation and fuzzy constraints on both sides are unlikely to come into existence in the business-to-consumer field.

In the business-to-business field, however, where buyers and sellers have the same status it is conceivable that software agents with fuzzy constraints regarding the negotiation issues and multi-issue negotiation may be useful. In particular, we mention the MAGMA (Tsvetovatyy *et al*., 1997), the MAGNET (Collins *et al*., 1998) and the MASCOT (Sadeh *et al*., 1999) agent-based e-marketplaces as the first steps in this direction.

The MAGMA project is an attempt to develop a prototype of an agent-based e-marketplace together with additional infrastructure including a banking system, a communication system, a transport and storage system, plus administrative and policing systems. The MAGMA e-marketplace includes trader agents which are responsible for buying and selling goods and negotiating prices, an advertising server for searching and retrieving ads by categories, and a bank providing a set of basic banking services (Tsvetovatyy *et al*., 1997). Negotiation in the framework of the MAGMA system is about one issue (price) and is based on a limited form of Vickrey auction (the sale is awarded to the seller with the lowest price, but at the second-lowest price).

In contrast to the MAGMA system, the MAGNET e-marketplace is intended to provide support for complex agent interactions such as automated contracting in supply-chain management. The negotiation protocol consists of three steps: a consumer agent issues a call for bids, merchant agents reply with bids and the consumer agent accepts the most suitable combination of bids. Evaluation of

<table>
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<tr><td>type of negotiation model</td><td>1:n (A)</td><td colspan="2">m:1 (B)</td><td>n:m (C)</td></tr>
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</table>

Figure 3 Characteristics of the MAGMA e-marketplace

Table 1 Features of some multi-agent e-marketplaces with negotiation model A

	kind of negotiation	negotiation issues	type of consumer's constraint	type of merchant's constraint
Anderson Consulting's BargainFinder	search and comparison	price	crisp	crisp
Frictionless Commerce Engine	search and comparison	price, product futures, merchant's services	fuzzy	crisp
Active Buyer's Guide System	search and comparison	price, product futures	fuzzy	crisp
MAGMA	auction	price	fuzzy	fuzzy
MAGNET	auction	price, time constraints, risk	fuzzy	fuzzy

the bids received is based not only on cost but also on time constraints and risk. This means that the MAGNET e-marketplace supports multi-issue negotiation, although of a very simple type.

The MASCOT marketplace tries to solve problems similar to those attacked by the MAGNET system, i.e. to manage a supply chain. In contrast to the MAGNET system which uses some principles of expected utility theory to find the best combination of received bids, the criteria for accepting or rejecting a bid are not explicitly stated by the authors in the description of the MASCOT system.

3.2 E-marketplaces with negotiation model B

Online auctions are no doubt the largest class of Internet-based e-marketplaces. There are literally thousands of auctions both in the B2B, B2C and C2C areas (see, for example, `http://www.internetauctionlist.com/` for a list of more than 3000 auctions ordered by categories). For a very detailed field study of online auctions we refer to Beam and Segev (1998), who examined 100 online auctions and analysed their characteristics. They distinguish between six online auction types: English, first price sealed bid, Dutch, continuous double, sealed double, and Vickrey auction. Many auctions can be regarded as multi-agent e-marketplaces with negotiation model B. Subsequently we discuss some of their common features.

The first example is an English auction in the framework of eBay's Auction Web (`http://pages.ebay.com`). To sell something one has to provide a description of the item together with some constraints including payment method, where to ship, who will pay for shipment, minimum bid and reserve price (real amount the seller is willing to accept for this item). In fact, by providing this information the seller initialises an agent to negotiate about one issue (price) with fuzzy constraints (the price should not be less than the reserve price). For a bidder the auction system offers an optional "phantom" bidding service, called proxy bidding, which is equivalent to initialisation of a buying agent. In proxy bidding, a bidder can confidentially enter the value of the maximum bid – his only fuzzy constraint (the price should be not higher than the maximum bid).

The strategy of the buying agent is straightforward, i.e. bid the minimum amount necessary to exceed the current highest bid – up to maximum bid until the auction is over. The strategy of the selling agent is even simpler: do nothing until the auction is over. Then, if a bidder's maximum bid meets or exceeds the reserve, the bid will be automatically raised to meet the reserve. If no bidder meets the reserve price, neither the seller nor the highest bidder are forced to complete the transaction.

An English auction with a "phantom" bidding service can be considered a multi-agent e-marketplace with negotiation between agents, although of a very simple type. According to our

criterion	value		
type of e-marketplace	B2B	B2C	C2C
type of negotiation model	1:n (A)	m:1 (B)	n:m (C)
negotiation issues	one issue (price)		many issues
type of consumer's constraint	crisp		fuzzy
type of merchant's constraint	crisp		fuzzy

Figure 4 Characteristics of E-Bay's Auction Web

classification it is a multi-agent e-marketplace with negotiation model B, one-issue negotiation (price) and fuzzy constraints on either side.

One more example is the Fishmarket electronic auction house (Rodriquez *et al.*, 1997). This academic prototype of an online auction has the age-old institution of a fish market as the underlying model. Both software agents and human beings can trade there. According to the trading conventions of Spanish fish markets the downward bidding protocol or Dutch protocol is used. What makes Fishmarket different from most other agent-based auction sites is that not only market-owned agents with simple architecture and strategies are employed. In addition, user-encoded buying and selling agents of arbitrary complexity may compete in the auction through standardised Java agent interface applets.

Another interesting academic prototype is a free-to-use online auction called eAuctionHouse which is one of the services of the eMediator prototype developed by the Multi-Agent Systems Research Group at Washington University in St Louis (`http://ecommerce.cs.wustl.edu/emediator/`). This auction supports several important features including combinatorial auctions and bidding via software agents. In a combinatorial auction, bidders may place bids on combinations of items. This feature is very useful if a bidder has preferences for bundles of items as may be the case in electricity markets, equities trading and bandwidth auctions.

eAuctionHouse supports a variety of different combinatorial auctions and helps users in choosing the auction type (Sandholm, 1999). Similar to the Fishmarket auction house, the user is given an option to fully design their own software agents in Java. In addition, eAuctionHouse provides an interface where the user can specify what they want the agent to do; the system then automatically generates the Java code for the agent implementation.

Currently eAuctionHouse can be classified as an agent-based e-marketplace with model B, one-issue (price) negotiation and fuzzy constraints on both sides. Sandholm (1999) mentions partial support of combinatorial double auctions where multiple buyers and multiple sellers can participate. This type of auction would fall into the category of multi-agent e-marketplace with negotiation model C. Some other prototypes of that category will be considered in the next subsection.

When more relevant issues than just the price exist, the simple one-issue negotiation model is not appropriate. Especially in the B2B area additional issues like terms and conditions, payment method, who will pay for shipment, timings, penalties and so on may play an essential role; sometimes they are even more important than the price. In these cases model B with multi-issue negotiation and fuzzy constraints on both sides would be more suitable. Since manual bidding would obviously not be practical (or at least not effective), negotiations would have to be performed by selling and buying agents with sophisticated intelligent strategies. For B2B auctions this direction could be quite promising whereas C2C and B2C auctions probably would not benefit that much. The reason is simply that customers like the bidding frenzy; they enjoy placing bids, and the entertainment value of an online auction is a non-negligible component (Beam & Segev, 1998).

Table 2 Features of some multi-agent e-marketplaces with negotiation model B

	kind of negotiation	negotiation issues	type of consumer's constraint	type of merchant's constraint
eBay's Auction Web	English auction	price	fuzzy	fuzzy
Fishmarket auction house	Dutch auction	price	fuzzy	fuzzy
eAuction House	combinatorial auction	prices for combination of items	fuzzy	fuzzy

3.3 E-marketplaces with negotiation model C

In this subsection we analyse the few existing prototypes of multi-agent systems with multilateral negotiation between agents (model C). The first prototype we consider in the paper, Kasbah, was implemented at the MIT Media Laboratory (Chavez & Maes, 1996).

Users wishing to buy and users wishing to sell certain products in the framework of the Kasbah marketplace can initialise agents by specifying what they want to buy or sell, the desired price, the highest acceptable price (for buying agents) or the lowest acceptable price (for selling agents), the date they want the transaction to be completed and a negotiation strategy. The negotiation strategy for a selling agent is specified by the "decay" function the agent uses to lower the price over its given time frame. Similarly, a buying agent is given his price "raise" function. In the Kasbah system a user can choose one of three possible decay (for selling agents) or raise (for buying agents) functions: either linear, quadratic or exponential. These functions correspond to anxious, cool-headed and frugal (for buying agents) or greedy (for selling agents) strategies, respectively.

Negotiation in Kasbah is straightforward. After buying and selling agents have been matched, buying agents offer selling agents their current bids. Selling agents compare the bids with their current prices and reply with either "yes" or "no". According to our classification Kasbah is a multi-agent e-marketplace with model C, one-issue (price) negotiation and fuzzy constraints on both sides. Selling agents have a span from the desired price to the lowest acceptable price, and buying agents have a span from the desired price to the highest acceptable price.

Many real-world commercial negotiations have a multi-issue character. As a response to this challenge and as a continuation of the Kasbah project, a new project, Tete-a-Tete, was started at the MIT Media Laboratory (Guttman & Maes, 1998). The aim of this project was to extend Kasbah towards a multi-agent system in retail sales with multi-issue negotiation, including warranties, delivery times, service contracts, return policies and other merchant's value-added services.

Initially it was intended to allow fuzzy constraints on both sides (consumer and merchant) and negotiation with proposals, critique and counter-proposals. Due to several reasons the Tete-a-Tete

criterion	value		
type of e-marketplace	B2B	B2C	C2C
type of negotiation model	1:n (A)	m:1 (B)	n:m (C)
negotiation issues	one issue (price)		many issues
type of consumer's constraint	crisp		fuzzy
type of merchant's constraint	crisp		fuzzy

Figure 5 Characteristics of the Kasbah e-marketplace

project was later transformed into the very successful Frictionless Commerce project discussed above. As we mentioned in Section 3.1, the Frictionless Commerce Engine belongs to the category of multi-agent e-marketplaces with model A, multi-issue negotiation, fuzzy constraints on one side (consumer) and crisp constraints on the other side (merchant).

One reason for the transition from Tete-a-Tete to the Frictionless Commerce Engine was, as mentioned above, that each of the two negotiating sides in B2C e-commerce has different status and non-degenerate multi-issue negotiation with fuzzy constraints on both sides is neither practical nor really necessary. Further, the complexity of the negotiation problem in the framework of an e-marketplace of type C is substantially higher than one for an e-marketplace of type B so that the solutions used in the Kasbah project were not directly applicable to problems arising in the initial Tete-a-Tete project.

In the framework of a project described by Collis and Lee (1998) a prototype of a multi-agent e-marketplace with model C, one-issue (price) negotiation and fuzzy constraints on both sides was developed. The new and interesting thing about this project is that the authors used the ZEUS Agent Building Tool-kit for implementation of the multi-agent e-marketplace. The ZEUS toolkit (Nwana *et al*., 1998) facilitates rapid development of multi-agent systems. It provides a library of agent-level components and an environment to support the agent-building process. Since the ZEUS agents were not specifically designed for electronic commerce applications, new functionality for buying and selling goods has been added, including negotiation modelling. The authors report that the components provided by the ZEUS toolkit were generic enough to be used for other problems than negotiation, especially for the information discovery problem, the communication problem, the ontology problem and the co-ordination problem (Collis & Lee, 1998). This observation indirectly supports the assumption made in the beginning that negotiation-related attributes are decisive for the construction of controlled multi-agent e-marketplaces.

In the framework of the recent project, CASBA (Vetter & Pitsch, 1999), an agent-based e-marketplace, was implemented. The goal of CASBA is to use agent technology to improve the

Table 3 Features of some multi-agent e-marketplaces with negotiation model C

	kind of negotiation	negotiation issues	type of consumer's constraint	type of merchant's constraint
Kasbah	negotiation through offers; no critique and counter-offers	price	fuzzy	fuzzy
Tete-a-Tete (not finished)	negotiation through offers; critique and counter-offers	price and other value-added services (warranties, delivery times, return policies)	fuzzy	fuzzy
ZEUS-based e-marketplace	negotiation through offers; no critique and counter-offers	price	fuzzy	fuzzy
CASBA	negotiation through offers and counter-offers	price	fuzzy	fuzzy
FuzzyMAN	negotiation through offers and counter-offers	salary per hour, extra pay, number of working hours per week, employment duration	fuzzy	fuzzy

quality of electronic commerce services. The key component of the CASBA system is its auction module, offering support for all common auction types including auctioning of multiple units. All participants in the automated CASBA auctions are agents which can be of four different types: the administrator agent manages the whole market; auctioneer agents handle a single auction each, buy and sell agents execute the orders of their users. Agents participating in an auction communicate with each other in a language similar to the FIPA ACL. The rules for starting an auction, bidding and bid processing, and making the deal, are regulated by CASBA's negotiation protocol. CASBA also supports fully parallel negotiations where all the negotiable details are transferred in XML format and evaluated at once rather than being negotiated sequentially. These negotiations follow rule-based strategies, based on a utility function that evaluates each offer and counter-offer.

As each agent has exactly one order to fulfil (either to sell or buy) it still can be involved in negotiations with many other agents at the same time. According to our classification CASBA is a multi-agent e-marketplace with model C, one-issue (price) negotiation and fuzzy constraints on both sides.

Finally we mention the FuzzyMAN project (Fuzzy Multi-Agent Negotiation) at the European University in Frankfurt (Oder), Germany. In this project, a prototype of an agent-based job marketplace for users with fuzzy constraints was implemented (available at `http://www.wiwi.euv-frankfurt-o.de/wi-www/agent.htm`). Users wishing to find a new job and users wishing to hire new employees can initialise agents by specifying a profession, salary per hour, social benefits, number of working hours per week, period of employment, professional and additional skills, age, professional experience and a negotiation strategy.

In the FuzzyMAN project, negotiation as such is characterised by four issues: salary per hour, extra pay, number of working hours per week and period of employment. Since the negotiation issues under consideration are of different value for the negotiating agents, scoring functions are used to model that value. In a real negotiation, different negotiation issues are of different importance for each participant in a negotiation. To model this situation, the notion of relative importance that a participant assigns to each issue under negotiation is introduced. Using the scoring functions and the relative importance of issues under negotiation, the notion of a general scoring function is introduced. A negotiation strategy of an agent is a vector function with four components. Each one of them determines how the agent changes the values for salary per hour, social benefits, number of working hours per week, and period of employment, respectively, over time depending on the status of the e-marketplace and the status of the negotiation.

An important feature of the FuzzyMAN e-marketplace is that it employs a multi-lateral negotiation model with fuzzy constraints. The main idea behind the model is that not only issues under negotiation (like salary per hour, social benefits, number of working hours per week and duration of employment) but also other issues not directly involved in the negotiation (like age, working experience, professional and additional skills) are considered in the protocol for the multi-lateral negotiations. The model introduces for each employer's agent a partial order of the set of all employees' agents which are suitable for negotiation with the given employer's agent. This partial order is then used in the multi-lateral negotiation process.

FuzzyMAN is an example of a multi-agent e-marketplace with model C, multi-issue negotiation and fuzzy constraints on both sides. Despite some weaknesses, e.g. letting the agents use only predefined strategies of a very simple type (time-dependent strategies), the FuzzyMAN e-marketplace marks a step on the way to agent-based e-marketplaces with automated negotiation about multiple issues with fuzzy constraints.

4 Open research questions

Agent-based e-marketplaces are a promising area of e-commerce but they are still far away from real marketplaces. For example, participants of real marketplaces often negotiate multilaterally about many issues with vague or fuzzy constraints. Our analysis in Section 3 showed that corresponding agent-based marketplaces do not exist yet. Plenty of further research and implementation work is necessary to realise the promises of agent technology.

In the B2C field agent-based marketplaces exhibit a natural asymmetry between consumers and merchants, with the effect that a substantial level of practicality is already reached (e.g. in online auctions and shopping markets). In the fields of C2C and B2B, however, many unsolved problems still exist. Quite challenging, but on the other hand promising, are online B2B auctions with multi-issue negotiation and fuzzy constraints on both sides. Such auctions can be classified as multi-agent e-marketplaces with model B in our classification.

We note that negotiation in the framework of such e-marketplaces should be non-degenerated with proposals, critique and counter-proposals, and both buying and selling agents should possess really intelligent strategies. Based on their experience with the Kasbah multi-agent e-marketplace, Moukas *et al*. (1998) stated that for software agents to be widely accepted, it is crucial that the agents' behavior can be easily understood by the user.

Unfortunately, this is only possible in some simple situations, like the Kasbah system with one-issue (price) negotiation. Indeed, any negotiation can be viewed as a distributed search through a space of potential agreements. For multi-issue negotiation with fuzzy constraints on both sides the agreement space is multidimensional. Generally it has a complex structure, and each agent has its own rating of the points in the space. To come to the "best deal", non-trivial mathematical theories like game theory or fuzzy sets techniques have to be used for the agents' negotiation strategies. This, however, makes it more difficult to explain the strategies to the user in all detail. The better agents are (i.e. the more intelligent they are), the less their behaviour can be understood by the user.

Another challenge is the development of multi-agent e-marketplaces with model C, multi-issue negotiation, fuzzy constraints on one side (buying agents) and crisp constraints on the other side (selling agents). In real life, advertisement markets fall into that category since enquiries usually have multiple issues with fuzzy constraints and offers are fixed. Because of the multilateral character of negotiations (i.e. for each offer there are several potential buyers and each enquiry can be satisfied by several offers), proposals, critique and counter-proposals from both sides need to be included in agents' negotiations. The strategies of selling agents are simpler in this situation than those of buying agents because their constraints are crisp. The negotiation problem is difficult to solve because there is strong competition both among the buying agents and among the selling agents.

Finally, B2B and C2C marketplaces with multi-issue negotiation and fuzzy constraints on both sides are the most difficult to develop. All multi-agent e-marketplaces discussed above are in fact special cases of this general construct. The negotiation problem is a key element for research here. For multilateral multi-issue negotiation with fuzzy constraints, an appropriate formalism has to be found. With this formalism, the current state of negotiation between each pair of negotiating agents in a multi-dimensional negotiation space has to be represented. Furthermore, the direction of movement in this space in order to optimise the value of a deal has to be determined, and the closing and bumping rules for each agent have to be defined. Fuzzy sets and fuzzy logic can be used to approach these problems (Bojadziev & Bojadziev, 1997; Slowinski, 1998).

We concentrated in this paper on negotiation aspects of controlled multi-agent e-marketplaces without coalitions. Important problems such as the information discovery problem, the communication problem, the ontology problem, the monitoring problem, the security and law problems and the interplay between an e-marketplace and the software agents acting there were not considered. They all need to be solved in a commercial e-marketplace, not only the negotiation problem. However, the success of an agent-based e-marketplace will critically depend on the intelligence of the agents acting there and on their ability to optimally negotiate with each other. That is why we mainly analysed the negotiation problem, although in its simplest formulation. Other interesting problems to address are marketplaces with coalitions among agents (Lerman *et al*., 2001), and marketplaces with multi-task negotiation, i.e. with multi-issue negotiation about combinations of correlated items or tasks (Collins *et al*., 1998; Sandholm, 1999).

5 Conclusions

Multi-agent electronic marketplaces play an essential role only in B2C e-commerce today where commercial online shopping markets and agent-based online auctions have become very popular.

In the areas of C2C and B2B, multi-issue negotiation between selling and buying sides is a relevant model. Many problems need to be addressed here, especially regarding the organisation of negotiation. Methods and tools to process vague preferences, constraints and uncertain information are rarely used. This is definitely a shortcoming since the ability to negotiate and make decisions in a vague environment can be regarded as one of the main characteristics of an agent acting in an electronic marketplace.

Based on our analysis we stated some challenges for further research in the field of controlled multi-agent e-marketplaces without coalitions. When these problems are solved further challenges wait to be attacked, such as negotiation with coalitions between agents, negotiation about combinations of correlated items or tasks, and negotiation in uncontrolled multi-agent e-marketplaces.

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