Agent-Mediated Trading:
Intelligent Agents and E-Business

Matthias Klusch

German Research Center for Artificial Intelligence, Deduction and Multi-Agent Systems
Lab, 66123 Saarbruecken, Stuhlsatzenhausweg 3, Germany

Abstract

One prevalent vision of agent-mediated trading on electronic marketplaces is that intelligent, economically driven agents will form a rich, diverse, dynamic economic Web, and that agent-to-agent e-commerce transactions may eventually dominate the global economy in the future. Agents may facilitate a variety of relevant functions such as advertising, matchmaking and brokering. Current application of single agent and multiagent systems for e-commerce and business include, for example, shopbots, agent-based virtual marketplaces and auctions, respectively. This paper presents a general survey of basic key enabling techniques which are needed to build such institutions of agent-mediated trading in the Internet, and examples of systems of economically rational behaving agents.

Keywords: Intelligent agents, e-commerce, negotiation, marketplaces, auctions, coalition formation

1. Introduction

The electronic marketspace provided by the Internet and Web is about to establish itself as a significant economic factor worldwide. It does not only leverage relationships for strategic advantage in global commerce such as witnessed by increasing mergers and acquisitions of new market’s information technology and Internet-based companies. More strikingly, it also enables the formation of virtual enterprises capable of producing and delivering value-added services and products tailored to individual customer preferences just-in-time as well as building virtual auction houses for both, traditional and reverse auctioning online for the common user. On the other hand, it raises customer expectations regarding issues of new quality of shopping experience, and product and service quality of new brands on the Internet. Such brands can be destroyed as quickly as they have been established. This demands for advanced solutions not only for the rather traditional business-to-business/customer electronic commerce but also for integrated commerce in the future. Latter means the flexible and efficient coordination of operational business processes throughout the entire supply chain encompassing customer product order online, manufacturing of the desired product as well as its shipment to the customer.

Intelligent information agents (Klusch, 2000) are autonomous computational software entities which have access to multiple, heterogeneous data and information sources, and pro-actively acquire, mediate, and maintain relevant information on behalf of its users, or

1 klusch@dfki.de
other agents. Information agents are especially meant for (1) to provide a pro-active resource discovery, (2) to resolve information impedance of information consumers and providers, and (3) to offer value-added information services and products. That includes, in particular, retrieving, purchasing, filtering, fusing, and presenting relevant information to human decision-makers on demand and preferably just in time. The situation becomes even more complex since customers as well as merchants’ products, services, and quality may change rapidly over time.

Though e-business, including e-commerce on the Web, is not the original, classical application domain of information agents, but it certainly is the most steadily growing ones. Albeit, e-business might happen without any intelligent agents if agent technology in general fails to be injected into currently emerging Internet-mediated transaction standards and systems. That is independent from the fact that the integrated usage of personalised digital assistants in future e-business applications is expected to be more convincing, more attractive, and more qualitative for the common users’ everyday business on the Web.

In the remainder of the paper we provide latest facts and figures on the domain of e-commerce in section 2. In section 3 we give a brief introduction to intelligent information agents, and then focus on selected enabling techniques and examples for agent-mediated trading in section 4 before concluding the survey in section 5.

2. E-Commerce: Some Facts & Figures

Electronic commerce (Merz, 1999) may be defined as the set of activities of trading goods and services online. It can be structured into the market segments business-to-customer (B2C) such as online shops and auctions provided by portals, business-to-business (B2B), customer-to-business (C2B) such as reverse auctions, and customer-to-customer (C2C) e-commerce. As such it is part of electronic business which covers a broader range of issues including any business process and transaction on the Internet devoted to, for example, call centres, corporate’s Intranet, customer relationship, and supply chain management. E-commerce is steadily growing since around past five years. According to recent market research reports of Meta Group and Forrester Research 200 and 350 billion US$ e-commerce sales are expected this year in Europe and the States, respectively. Remarkably, the B2B market segment of e-commerce is predicted to still outweigh that of B2C worldwide by a magnitude, in values of 1.3 and 0.1 trillion US$, respectively. On the other hand, the consumer online spending raised from 7 billion USD in the whole holiday season of 1999 up to 2.8 billion USD in the month of January 2000. In any case, up to 71% of companies world-wide are expected to link to electronic marketplace in the Internet generating up to 20% e-business based turnovers in average in 2004. Of course, these numbers are due to changes but should clearly illustrate the long-term potential of e-business and e-commerce.

Basic key enabling technologies for the development of any e-business solution concern

- **standard data representation, retrieval and exchange**, like XML, UML, RDF(S), EDIFACT/WebEDI/EDIINT, standardised domain ontologies across domain boundaries (Gruber, 1992; Steels, 1998), methods for automated semantic mapping of heterogeneous ontological knowledge minimising loss of information (Sheth et al., 1996), data retrieval, and data mining tools,
- **secure user profiling and data**, like OPS (open profiling standard), W3C’s P3P (platform for privacy preferences), (a)symmetric coding schemes, digital signatures, and digital watermarks,
- **secure electronic payment**, like VISA/MC’s SET for payment with credit card, digital cash, like DigiCash’s eCash, DEC’s MiliCent, and smart cards, or deduction from a given customer account like at central virtual markets or cyber malls, and
- **standard protocols covering most issues of electronic trading**, like IETF’s IOTP (internet open trading protocol), OTP (open trading protocol), and OBI (open buying on the Internet).
Besides, any emerging consensus on an accounting and pricing structure, such as flat rate, capacity-based or usage-sensitive pricing, is as important as effective trust and security mechanisms to facilitate e-commerce transactions in a digital economy. Another challenge is how to model, measure, and reason on trust in e-commerce settings (Manchala, 2000). Notably, according to opinion polls conducted by Odyssey and Forrester Research Inc. in 1999 about 85% of all customers evaluated their online buying experience as to be „very good“, in particular trusting and showing more loyalty to online than traditional offline retailers.

Different trading models and schemes may be compared along (1) the design on economic principles such as dominant, competitive and adaptive strategies and equilibria, (2) privacy of interests of the participants and anonymity of identities, (3) complexity of trading mechanism in terms of computation and communication. In order to apprehend e-commerce and business in a more homogeneous way a variety of different architectures, frameworks, and reference models have been developed and are topic of ongoing research. These include, for example, the CBB (consumer-buying-behaviour) model developed at MIT (Guttmann, Moukas, and Maes, 1999), CommerceNet’s eCo framework², OMG’s BOCA (business object component architecture)³, and the SEMPER (secure electronic marketplace for Europe) layered architecture comprising services for trading at different stages and levels of complexity⁴. However, each of these approaches appears to be either too generally specified or too specific in part; an efficient, dynamic refinement of interfaces and service components by the user is, if at all, scarcely supported.

3. Intelligent Information Agents in Brief

Information agents are special kind of so-called intelligent software agents. Software agent technology originating from distributed artificial intelligence is inherently interdisciplinary. Thus, the notion of agency is quite broadly used in literature; it might rather be seen as a tool for analysing systems, not an absolute characterisation that divides the world into agents and non-agents. However, intelligent agents are commonly assumed to exhibit autonomous behaviour determined by its

- pro-activeness, means taking the initiative to satisfy given design objectives and exhibit goal-directed behaviour,
- reactive or deliberative actions, means perceiving the environment and timely change management to meet given design objectives, and
- social cooperation in groups with other agents and/or human users when needed.

It depends on the concrete application domain and view on potential solution for a particular problem what an intelligent agent in practice is supposed to do. Today, intelligent agents are deployed in different settings, such as industrial control, Internet searching, personal assistance, network management, games, software distribution, and many others. For a more comprehensive and introductory literature on intelligent agents we refer to (Wooldridge, 1999; Jennings and Wooldridge, 1998).

Agent technology is quite on its way to produce mature standards concerning software agent architectures and applications such as OMG MASIF (mobile agent system interoperability facility)⁵ and FIPA’s agent-related specifications⁶. Further, the European network of excellence for agent-based computing (AgentLink)⁷ which has been set up in 1998, international workshop series, and conferences on the subject such as ATAL⁸, CIA

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² http://eco.commerce.net/
⁴ http://www.semper.org/
⁵ http://www.fokus.gmd.de/research/cc/ecco/masif/index.html
⁶ http://www.fipa.org
⁷ http://www.agentlink.org
⁸ http://www.atal.org
Intelligent agents for the Internet are commonly called information agents. But what exactly is an information agent? We define an information agent as an autonomous, computational software entity (an intelligent agent) that has access to one or multiple, heterogeneous and geographically distributed information sources, and which pro-actively acquires, mediates, and maintains relevant information on behalf of users or other agents preferably just-in-time. Thus, an information agent is supposed to satisfy one or multiple of the following requirements.

- **Information acquisition and management.** It is capable of providing transparent access to one or many different information sources. Furthermore, it retrieves, extracts, analyzes, and filters data, monitors sources, and updates relevant information on behalf of its users or other agents. In general, the acquisition of information encompasses a broad range of scenarios including advanced information retrieval in databases and also the purchase of relevant information from providers on electronic marketplaces.

- **Information synthesis and presentation.** The agent is able to fuse heterogeneous data and to provide unified, multi-dimensional views on relevant information to the user.

- **Intelligent user assistance.** The agent can dynamically adapt to changes in user preferences, the information, and network environment as well. It provides intelligent, interactive assistance for common users supporting their information-based business on the Internet. In this context, the utilisation of intelligent user interfaces like believable, life-like characters can significantly increase not only the awareness of the user on its personal information agent but the way information is interactively dealt with.

Many (systems of) information agent have been developed or are currently under development in academic and commercial research labs, but they still have to wait to make it out to the real world of Internet users broadly. However, the ambitious and pretentious goal to satisfy all of the requirements mentioned above appears to be not very far away from being accomplished in the next ten years.

Information agents may be categorised into several different classes according to one or more of the following features (Klusch, 1999).

1. **Non-cooperative or cooperative** information agents, depending on the ability if the agents cooperate with each other for the execution of their tasks. Several protocols and methods are available for achieving cooperation among autonomous information agents in different scenarios, like hierarchical task delegation, contracting, and decentralised negotiation.

2. **Adaptive** information agents are able to adapt themselves to changes in networks and information environments. Examples of such kind of agents are learning personal assistants on the Web.

3. **Rational** information agents behave economically rational based on utilitarian decision making. As self-interested agents they aim to increase their own benefits. One main application domain of such kind of agents is automated trading and electronic commerce in the Internet. Examples include the variety of shopbots, and systems for agent-mediated auctions on the Web.

4. **Mobile** information agents are able to travel autonomously through the Internet. Such agents may enable, e.g., dynamic load balancing in large-scale networks, reduction of data transfer among information servers, applications, and migration of small business logic within medium-range corporate intranets on demand.

According to the definition and classification of information agents we can differentiate between communication, knowledge, collaboration, and rather low-level task skills as depicted in figure 1. In this figure, the corresponding basic key enabling technologies are

(Klusch and Kerschberg, 2000), Autonomous Agents, PAAM, and ICMAS strongly push software agent technology since its public breakthrough around five years ago.
listed below each of the different types of skills. Communication skills of an information agent imply either accessing information systems and databases, processing input from human users, or other agents. An agent naming service as well as an agent communication language (ACL) enable communication between intelligent agents on different levels. An ACL has to be considered rather on top of, for example, middleware platforms such as OMG’s CORBA and Sun’s Java RMI, or specific APIs such as JDBC (java database connectivity), ODBC (open database connectivity), or OKBC (open knowledge base connectivity).

Fig. 1. Basic skills of an information agent

Representing, and processing of ontological knowledge and metadata, user profiles and natural language input, translation of data formats as well as machine learning techniques enable an information agent to acquire and maintain knowledge about itself and its user, network, and information environment. High-level collaboration of an information agent with other agents can rely on methods for, for example, service brokering, matchmaking, negotiation, and collaborative (social) filtering, whereas collaborating with its human users mainly implies the application of techniques stemming from human-computer interaction and affective computing.

4. Agent-Based E-Trading

Despite the enormous potential of electronic commerce a more sophisticated, agent-based trading still remains to be a key challenge for economists, computer scientists and business managers as well. It might reshape the way we think about economic systems and business processes in an increasingly networked world.

In the open and increasingly commercialised cyberspace, personalised information agents not only may pro-actively discover and manage information relevant to its customers but are also paid and have to pay for any services they provide. Reasonably, trading information agents have to be equipped with effective and efficient methods for making economically rational decisions. This includes scenarios where rational information agents may (1) make purchases up to a pre-authorized limit, filter information and solicitation from vendors, (2) dynamically trade products and commodities such as even bandwidth and components within business-to-business/consumer digital market, (3) decide on bids from service providers to take for its customer in some reverse auction online in a consumer-to-business e-commerce setting, and (4) increase the level of trust in its actions gradually over
time involving only manageable risks for both, customers and vendors (Schillo, Funk and Rovatsos, 1999).

4.1 Basic Enabling Techniques for Agent-Mediated Trading

In addition to the techniques for developing e-business solutions mentioned in section 2 many negotiation schemes and trading mechanisms for agent-based systems rely on

- multi-attribute utility theory (Keeney and Raiffa, 1976), price comparison, content-based recommendation and user profiling, and blueprint learning of unknown Web pages,
- collaborative recommendation (Shardanand and Maes, 1995), coalition formation among autonomous agents (Kraus and Shehory, 1999), service matchmaking and brokering among trading agents (Sycara et al., 1999), voting (social choice), auction-based protocols (Milgrom, 1989), marketplaces (Wellman and Wurman, 1998), variations of the contract net protocol, and arbitration schemes in case of agents with conflicting interests (Tesch, Fankhauser, and Ouksel, 2000).

While the first three of these mechanisms are mainly used in the domain of non-cooperative shopbots, the latter are being used for multi-agent systems where different trading agents are provided with a common interaction (negotiation) protocol and individual strategies (Bouteiller, Shoham, and Wellman, 1997). The choice of negotiation protocol depends on what properties the system designer wants the overall multi-agent system to have. Negotiation protocols for trading agents can be evaluated according to different criteria such as social welfare (the sum of all agents’ payoffs in a given solution), Pareto optimality (there is no solution other than the negotiated one such that each agent is better off and no one is worse off), individual rationality (an agent’s payoff in the negotiated solution is at least as high as it would get when not having participated in the negotiation), stability of the mechanism (no agent is better off behaving differently) as well as communication and computational efficiency.

During negotiation rational agents may perform reasoning using quantitative utility functions in ways well known from decision theory, especially in computing optimal choices and assessing their sensitivity to variations in probabilities. Qualitative information might provide constraints on preferences that guide this reasoning by selecting or constructing appropriate quantitative utility measures, though, such a construction is hardly explored to date. A variety of methods have been invented to allow agents to determine which negotiation strategy is more successful, for example, using Bayesian learning (Sycara and Zeng, 1997), evolutionary computing supported by case-based reasoning (Matos and Sierra, 1998), and fuzzy similarity rules (Sierra, Faratin, and Jennings, 1999).

Many settings in which negotiations among trading agents takes place imply decision-making under uncertainty. Approaches to deal with uncertain, partial, tentative or generic information within a negotiation usually make use of, for example, the notion of expected value of information (Howard, 1966) and utility (von Neumann and Morgenstern, 1944) as well as the possibility theory (Dubois and Prade, 1986).

In the expected utility theory uncertainty is represented by probability distributions over a finite set $C$ of consequences regarding a finite set $S$ of situations and decisions (mapping $S$ to $C$). In a given situation $s$ the agent looks up its real-valued utility function $u$ (which models its preferences over $C$), and computes the global utility of a decision $d$ (or action) as the expected value of its utility with respect to the corresponding probability:

$$EU_u(d) = \sum_{c \in C} u(c) \cdot \Pr(c \mid d) = \sum_{c \in C} u(c) \cdot \Pr(c \mid d) .$$

For this purpose the agent has to know the probability of each possible consequence $c$ of a decision $d$ in a given situation $s$. Rationally behaving agents are then assumed to always maximize expected utility. However, this approach fails, for example, to address making decisions in unforeseen circumstances or changing assumptions.

The qualitative decision-theoretic approach of using possibility theory replaces numeric preferences and probabilities with linear orderings presuming that the scales for preferences and belief have been interrelated, and a decision-making policy, for example a minimax policy, has been adopted (Dubois et al., 1998). Uncertainty is represented by possibility
distributions over $C$, an ordered uncertainty scale $T$, and a possibility distribution (mapping $C$ to $T$) providing a plausibility ordering on $C$ which can then be used to define qualitative utility functions. An example for the application of this approach to a subsequent refinement of bids of an agent at an auction using individual information induced from a memory of cases composing the history of past auctions is given in (Garcia et al., 1998).

After negotiation, the deals trading agents have agreed upon need to be executed in terms of exchanging traded goods and respective payments. This implies the problem of trust and traceability of the real world parties associated with the trading agents. One option to carry out such an exchange without enforcement by trusted third parties or relying on communities of trust is to manage it by intelligently splitting the exchange into smaller chunks for a safe sequence of deliveries and payments such that no agent is motivated to defect. For both, merchant and customer agent at any point in the exchange, the future gains from carrying out the rest of the exchange are larger than the gains from terminating the exchange prematurely by vanishing. Latter can be tempting for a customer to do when, for example, the merchant at some point in the exchange delivered more than the customer has yet paid for. However, if the chunks are interdependent in value, the sequencing cannot be done in polynomial time in general (Sandholm, 1997).

Another related issue concerns the policy of contract agreements among trading agents in case an agent wants to be freed from the obligations implied by a specific contract. This can be taken into account such that the mechanism of contracting itself allows for unilateral decommitments at any point in time by specifying penalties to be paid by an agent to the other party of the contract. Such levelled commitment contracts have been proven to outperform the full commitment protocol by increasing both contract parties’ expected payoffs and enabling contracts in settings where no full commitment contract is individually rational for each of the parties (Sandholm and Lesser, 1996). A closely related approach for relaxing the full binding of classical contracts is to formalise and reason on conditional obligations. This corresponds to perform argument-based reasoning to identify explicit reasons for alternatives and generic preferences of contracts which may be compared with respect to importance measures (van der Torre, 1997).

In the following sections we briefly sketch the techniques of content-based and collaborative recommendation, coalition formation, and auctions. A more in-depth survey of techniques for automated, distributed rational decision making of self-interested agents can be found in, for example, (Sandholm, 1999).

### 4.1.1 Content-based and Collaborative Recommendation

Collaborative recommendation (or social filtering) focuses on identification of similar users and their opinions to recommend items (Good et al., 1999; Schafer, Konstan, and Riedl, 1999). It is a powerful method for leveraging the information contained in user profiles. In contrast to content-based filtering through which items are recommended to a user according to correlations found between the items’ descriptions (treated as text documents via traditional information retrieval techniques) and the given or observed users preferences stored in an automatically created and updated profile, an agent rates the items chosen by its user and compares the corresponding user preference vector to that of other known users projected to the same set of items. It then recommends other items which have been recommended by users who share similar likes and dislikes. For this purpose it has to collaborate with other agents to gain the respective knowledge.

Collaborative recommendation essentially automates the process of "word of mouth" in a given community and currently is one of the prevalent techniques for e-commerce targeting a special user community via a password-protected multiagent system such as Firefly or GroupLens (Resnick et al., 1994). In addition, trust among users and agents is even easier to gain, since it is very difficult to manipulate the recommendations an agent makes to its user via social filtering.

Common technique to find similar users and predict weighted average of user ratings is to determine the correlation between the users’ preference vectors using minimum square error, or the Pearson correlation:

$$
\sum_{i \in \{1, \ldots, k \times 1, \ldots, n\}} \left[ \tilde{r}_{u_i} (u_j) - \bar{\tilde{r}}_u (u_j) \right] \left[ \tilde{r}_{u_i} (u_k) - \bar{\tilde{r}}_u (u_k) \right]
$$

where $\tilde{r}_{u_i} (u_k)$ positive/negative ratings of user $k$
However, traditional collaborative recommendation has a few shortcomings. Initial users can bias ratings of future users, no different (context-based) points of view of users are taken into account, and there is no learning from negative cases involved. These drawbacks are significantly different from those of content-based filtering still used by many shopbots to date. In particular, content-based methods cannot help to recommend more of what the user has seen before and liked, and no assessments of style, quality, etc, can be offered to the user. Ongoing work on integrating content-based and collaborative filtering are reported, for example, in the RAAP project (Delgado, Ishii, and Ura, 1998).

4.1.2 Coalition Formation

Self-interested, autonomous agents may negotiate rationally to gain and share benefits in stable (temporary) coalitions. This is to save costs by coordinating activities with other agents. For this purpose, each agent determines the utility of its actions and productions in a given environment by an individual utility function. The value of a coalition among agents is computed by a commonly known characteristic function which determines the guaranteed utility the coalition is able to obtain in any case. In a characteristic function game the agents may use imposed individual strategies implied by desired type of economically rational behavior such as altruistic, bounded rational, or group rational. In any case, the distribution of the coalition’s profit to its members is decoupled from its obtainment but is supposed to ensure individual rational payoffs to provide a minimum of incentive to the agents to collaborate.

The formation of stable coalitions relies on derived concepts from cooperative game theory, economics, and operations research. It covers two main activities: (1) the formation of coalition structures, that is partitioning the set of agents into coalitions, so as to maximize the monetary value for accomplishing tasks in coalitions individually or group rational, and (2) the distribution of gained benefit among coalition participants. These activities may be interleaved and are not independent.

Most interesting, non-trivial cases of coalition formation concern non-superadditive environments where at least one pair of potential coalitions is not better off by merging into one which could be caused by, for example, communication and coordination overhead costs, decrease of coalition value as a result of restricting utility constraints posed by agents joining a coalition, or anti-trust penalties for specific coalitions (Kraus and Shehory, 1999).

The meaning of stability of formed coalitions relies on the chosen game-theoretic concept for payoff division within coalitions according to, for example, the Shapley value, the Core, the Bargaining Set, or the Kernel (Kahan and Rapoport, 1984). Searching for an optimal coalition structure (given a set $A$ of agents) among the exponential number of $|A|^{|A|}$ possible coalition structures is computationally hard since one has to try at least $2^{|A|-1}$ coalition structures (Sandholm et al. 1998, 1999).

In environments where published interests and utilities used for negotiation to form coalitions cannot be verified, most current protocols allow for fraud by different types of lies. Arbitration schemes for competing agents with conflicting interests may help to circumvent such situations (Tesch and Fankhauser, 1999).

Although well-grounded techniques for coalition formation among self-interested agents are known none of them has been used so far in the public Web. Current application domains include, for example, cooperative information systems (Klusch and Shehory, 1996) and decentralized power transmission planning (Contreras et al., 1999). A publicly available simulation environment for coalition formation based on selected coalition theories is provided by COALA.9

Further research issues include, for example, efficient methods for dynamic formation of multiple, overlapping coalitions, leveled trust, and stability. Dynamic coalition formation (DCF) theory deals with the problem of scenarios in which (1) agents may leave or enter the negotiation process at any time, and (2) utilities computed over a continuous stream of tasks to accomplish may rapidly change and not necessarily completely known to the agents (Klusch, 2000b). Classical game-theoretic notions of coalition stability and respective negotiation algorithms are not applicable in such settings. The problem of DCF is exacerbated by scenarios inducing uncertain, time-limited, context-based utilities and

9 http://www.dfki.de/~klusch/COALA/
coalition values. For example, an agent may determine the degree of membership to potential coalitions based on bargaining, and possible level of its commitment indicating the degree of collaboration that the agent desires. Related work on fuzzy coalition forming (Mares, 1997; Ketchpel, 1994; Aubin, 1981), rational revision of preferences, and other qualitative approaches to decision making based on partial, uncertain, and tentative information hold promise to be useful for coping with these issues of the DCF problem. DCF methods could be applied to, for example, formation of temporary customer coalitions on the fly for bidding, purchasing, and sharing an appropriately partitioned set of items available at multiple auction houses. In the work of (Sandholm and Huai, 2000) this is intended to be supported by mobile agents in the future.

4.1.3 Auctions

Auctions theory (Milgrom, 1989; Wolfstetter, 1996) analyzes protocols and agents’ strategies in auctions. An auction is a price-fixing mechanism of an auction house in which negotiation is subject to a very strict coordination process. It consists of an auctioneer who wants to mediate the exchange of given items between buyers and vendors for sale at highest possible price, and potential bidders who want to buy them at lowest possible price. Asynchronous bidding mechanisms mostly base on open-outcry with price changes or sealed bids with periodic partial revelation.

Online auctions appear to be unnecessarily hostile to customers due to the winner’s curse and offer no long-term benefits to merchants. If bidders have reasonable information about the worth of the item, then the average of all the guesses is likely to be correct. However, the winner offered the bid furthest from the actual value, thus, pays more for the item than its value, so any auction is basically a win-lose game.

Any auction may be classified along three dimensions of (1) bidding rules including, for example, bid format, and many-to-one or many-to-many participation, (2) clearing policy such as pricing, clear schedule and closing, and (3) information revelation policy including, for example, price quotes, quote schedule, etc. Prominent protocols for single-item auctions include the

- first-price, open-cry, so-called English auction. The dominant strategy for consumers here is to bid up to their true, maximum value.
- descending price, open-cry, so-called Dutch auction that guarantees the auctioneer the purchase of items at highest possible price.
- first-price, sealed-bid auction where each bidder submits one bid in ignorance of all other bids. The highest bidder wins and pays the amount he bid. This has the potential to force buyers and seller into price wars since the sealed bid of any bidder depend on what s/he believes of all other opponents bids.
- second-price, sealed-bid, so-called Vickrey auction where the winning bidder pays the price of only the second highest bid (Sandholm, 1996).

Auctions for multiple (identical or heterogeneous) items for sale are, for example, the discriminatory, the double, and the matrix auction. Further auction-based mechanisms are discussed in, for example, (Fischer, Russ and Vierke, 1998).

In a discriminatory auction sealed bids on multiple items are sorted from high to low, and items awarded at highest bid price until the supply is exhausted. Winners pay exactly what they bid but, of course, usually different prices for different items.

As a two-sided auction where bids and asks are allowed, the double auction (Wellman, Wurman and Walsh, 1998) enables both sellers and buyers to submit bids for single or multiple units of items which are then ranked highest to lowest to generate demand and supply profiles. From the profiles, the maximum quantity exchanged can be determined by matching selling offers (starting with lowest price and moving up) with demand bids (starting with highest price and moving down). This format allows buyers to make offers and sellers to accept those offers at any particular moment. A continuous double auction on multiple items in which many individual transactions are carried on at a single moment and trading does not stop as each auction is concluded (Preist and van Tol, 1998).

Under the assumption of subjective private value, all four basic auction types listed above can be shown to yield the same expected price and revenue to the seller when bidders are not risk-averse but risk neutral, and symmetric (means they use the same measurements to
estimate their valuations). This implies that auction choice is not crucial because each format yields on average the same payoff. But revenue equivalence does not hold true under common value assumption (when bidders have similar evaluations). Bidding is often the result of correct predictions about the behavior of others and sometimes that means guessing the extent of someone else’s information correctly. Information agents may provide background knowledge and additionally acquired information on competitors concurrently to support the bidding of its user, just in time. Another issue concerns shills, means agents planted by the auctioneer to manipulate the valuation of the auctioned good by raising bids to stimulate the market. The same goes the other way round with formation of coalitions of buyers who agree to not outbid one another but distribute the purchased items among themselves privately. Both issues are considered illegal but hard to detect; thus, mechanisms to reduce the agents’ incentive for both types of actions a-priori have to be embedded into the negotiation protocol explicitly or indirectly as part of the protocol’s theoretical features.

4.2 The Non-Cooperative Case: Shopbots

Quite popular but basically very simple examples of non-cooperative rational information agents are shopbots on the Web such as mySimon.com, Junglee/Yahoo!, Jango/Excite, shopfido.com, compare.net, or evenbetter.com. Shopbots do not sell any product but guide the customer to recommended merchants’ online stores offering these items. The recommendation is either determined by comparing prices of products, or by applying multi-attribute utility theory (Keeney and Raiffa, 1976; Fishburn, 1977). Latter theory provides a way of representing and calculating the utilities of outcomes of actions by decomposing the utilities into utilities of the value-relevant factors that make up the outcomes of recommendation actions. Recommendation is determined with fixed and defeasible (non-monotonic) assumptions about the independence of the values assigned to different factors and the magnitude of these values, respectively. In addition, this theory in practice offers methods for composing utility measures and construction of libraries of standard forms for utility functions. The first generation cross-merchants comparison shopping agents, such as BargainFinder of Andersen Consulting, are limited to comparing merchants offerings only on price. In contrast, second generation of shopbots such as frictionless.com recommend product items based on evaluation of multiple attributes such as price and quality of desired product, delivery times and costs, return policies, promotions and gift services as well as customer support and reputation of respective merchants. The underlying integrative negotiation between user and merchant agents analyses the decision problem of what and who to buy from in what terms of the transaction more qualitatively through attribute constraints, and solves it by applying finite-domain constraint satisfaction techniques (Tsang, 1993). Underlying assumptions for both generations of shopbots are that (1) merchants reveal the relevant information on their product items and business policies to the agent, and (2) the content of respective Web pages can be automatically scanned and understood by the visiting shopbot. However, dynamically created Web pages and information encoded in graphics, video, and audio format pose challenges to any of currently deployed shopbots. A theoretical study (Greenwald and Kephart, 2000) on the potential impact of widespread shopbot usage on prices, and the price dynamics that may ensue from various mixtures of automated pricing agents, so-called pricebots, that employ price-settings algorithms in an attempt to maximize its vendor’s profits reveals, among others, that price wars may appear and game-theoretic equilibria can dynamically arise. Though, it remains to be seen if shopbots can successfully compete with large portal sites such as amazon.com or barnesandnoble.com, and online retail auctions such as eBay in the long run. The raise of synthetic characters and avatars on the Web (Elliott and Brzezinski, 1998) such as Cyberella of DFKI GmbH (Andre, Rist and Mueller, 1998) or Cor@ at the Web portal of the Deutsche Bank holds great promise to increase users’ awareness and acceptance of personalized intelligent assistants for convenient guidance through merchants’ online stores thereby increasing expected profits significantly. A lot of life-like synthetic characters and personal assistants have been developed by, for example, Extempo Inc., DFKI, Microsoft, and MIT Media Lab. Such characters are programmable to behave in accordance to
different personality traits as specified by the developer in the context of the considered e-business application. For example, a set of different characters at a car dealer’s Web portal can simulate personalized sales dialogues between a virtual vendor and potential customers. Each of these characters adopts a different role trying to convince the real customer to purchase an advertised item through role-based argumentation in a simulated conversation. Though, one has to be aware that a rational information agent can present itself to the user in the form of such believable, synthetic character as a kind of alter ego but should never be identified with it, it’s just its intelligent user interface. One further step would be to inhabit 3D shopping malls on the Web such as culthouse.de or vira.de with 3D information agents assisting user on their virtual shopping tours; first attempts in this direction have been reported recently in the context of digital cities (Ishida and Isbister, 2000). Another species of single agents in the e-business domain is that of chatter bots which use low-complexity case-based reasoning techniques (Lenz et al., 1998) to guide users through Web-based product catalogues or to answer the 20% of questions that generate 80% of call volume to customer-service call centers.

4.3 The Collaborative Case: Agents on Markets and Auctions

Agents may collaborate for gaining and sharing benefits, though, the degree and rationality of collaboration depends on the outcome of negotiation. Such distributed negotiation among agents may concern, e.g., the amount of charges for provided services as well as the kind of services or goods itself. Negotiation can take place with or without any mediator agent and usually follows some given conventions on communication such as what ontology and language to use for this purpose, social behaviour of the agents in a system, and each agent’s individual rights, obligations, and commitments. Free markets and auctions are most common virtual institutions for e-commerce mediated by collaborating rational information agents; they are means for C2C and B2C e-commerce, respectively. Marketplaces (Wellman and Wurman, 1998) provide locations where multiple information agents of customers and vendors may meet to negotiate and exchange relevant data and information. Negotiation concerns, for example, the amount of charge to pay for services as well as the kind of services or goods itself. Almost all current Internet auction types are single-resource, one-sided, and not executed in real-time in a strong sense. Future trends include combinatorial auctions with lower and upper prices for product bundles as well as reverse auctions where service providers bid to satisfy some customer’s request for a kind of service. Prominent examples for agent-based marketplaces and auctions are Kasbah/MarketMaker (Chavez et al., 1997)\(^{10}\), ZEUS virtual marketplace (Collis and Lee, 1998), AuctionBot\(^{11}\), UMDL (Durfee, 1999), and FishMarket\(^{12}\).

**UMDL** (University of Michigan Digital Library) is an agent-based digital library offering electronically available information content and services in a distributed environment. It relies on a multi-agent infrastructure (the service market society SMS) with agents that buy and sell services from each other using given set of commerce and communication protocols. Within the SMS self-interested agents are able to find, work with, and even try to outsmart each other, as each agent attempts to accomplish the tasks for which it was created. Learning in the context of SMS provides a way for agents in the SMS to develop expectations and strategically reason about others, and exploit these expectations to their mutual benefit. **Kasbah/MarketMaker** is a simple agent-based marketplace which has been developed at MIT Media Lab. Trading of goods is performed among buyer and seller agents on a central marketplace using a simple language for advertisements and requests; each agent has knowledge about the (type of) good it has to buy or sell by pro-actively seeking out potential best deals and negotiate them on their user’s behalf. These deals are subject to user-specified constraints in terms of desired price, lowest (or highest) acceptable price, a date to complete the deal, and one of three pre-defined types of price decay functions. These linear, quadratic, and exponential functions correspond to greedy, moderate, and


\(^{11}\) [http://auction.eecs.umich.edu](http://auction.eecs.umich.edu)

\(^{12}\) [http://www.iiia.csic.es/Projects/fishmarket/newindex.html](http://www.iiia.csic.es/Projects/fishmarket/newindex.html)
anxious behavior of buyers or sellers, respectively. Upon completion of a deal (and respective transaction) both parties are able to rate the other parties’ part of the deal in terms of, for example, product quality, and timely completion of transaction. Agents may use these ratings to determine their willingness to follow up a negotiation with agents whose users do not match a given reputation threshold.

5. Conclusions and Outlook

Using autonomous trading agents may have different impacts on Internet-based economy and business of the future. Such agents may make purchases up to a pre-authorized limit, filter information and solicitation from different merchants, and dynamically trade any type of good pro-actively on behalf of its users on markets and auctions. For this purpose a variety of basic enabling techniques are available. Ubiquitous electronic marketplaces rationally brokered by heterogeneous, intelligent and life-like agents also strongly push R&D of related technologies such as generation and (re-)use of ontologies for electronic commerce, and the integration of mobile telecommunication and the Internet.

Mobile commerce supported by personalized, rational information agents residing on WAP-enabled access devices such as pagers, organizers, (sub)notebooks, or UMTS cell phones, still is a vision for the common Internet user but is not too far away from realisation.

Other future domains of agent-mediated electronic business are, for example, integrated commerce which encompasses an agent-based coordination of the whole supply chain associated with any product ordering by a customer, and collaborative customer relationship management. Smaller and buyer-centric niche markets become viable with more diverse goods, content, services, and less distributors but more loyal customers guided by personalised agents.

Currently deployed agents are able to, for example, notify users on stock prices, make intelligent recommendations, and negotiate in different settings on virtual auctions and marketplaces, though, most of the approaches reported in this survey are no fielded systems yet. Agent technology has just begun to be considered influential in terms of thinking of a new decentralized, digital economy but still fails to provide easy-to-use, secure concepts and standards for the public mass market including both online vendors and customers. It remains to be seen to what extent different types of trading agents in which domain of e-business will play a major role.

6. References

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