AUTOMATED NEGOTIATIONS UNDER UNCERTAIN PREFERENCES

Research-in-Progress

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Abstract

Automated Negotiation is an emerging field of electronic markets and multi-agent system research. Market engineers are faced in this connection with computational as well as economic issues, such as individual rationality and incentive compatibility. Most literature is focused on autonomous agents and negotiation protocols regarding these issues. However, common protocols show two deficiencies: (1) neglected consideration of agents' incentives to strive for social welfare, (2) underemphasized acknowledgement that agents build their decision upon preference information delivered by human principals. Since human beings make use of heuristics for preference elicitation, their preferences are subject to informational uncertainty. The contribution of this paper is the proposition of a research agenda that aims at overcoming these research deficiencies. Our research agenda draws theoretically and methodologically on auctions, iterative bargaining, and fuzzy set theory. We complement our agenda with simulation-based preliminary results regarding differences in the application of auctions and iterative bargaining.

Keywords: Automated negotiation, Fuzzy Logic, Electronic Markets, Multi-Agent Systems, Intelligent Systems

Introduction

Electronic markets (e-markets) as a central domain of e-business (Grieger 2003) are part of an ongoing transition of economic activities. Processes in e-markets are divided in three phases: information, negotiation, and settlement (Schmid 1997). The information phase is characterized by information gathering and exchange, such as user ratings of goods or services. However, opinion-forming is complex and crucial information might be lacking resulting in vague preferences (Klaue & Kurbel 2001). For example, if user ratings are contradictory, the buyer might have problems to esteem payment reserves precisely. In the negotiation phase, the agents conclude a bilateral or multilateral contract based upon the information from the first phase. This phase is regulated by a negotiation protocol that governs the actions, negotiation states, and events (Jennings et al. 2001). The negotiation phase can be automated resulting in automated negotiation that stands for electronic deal making by intelligent software agents employing classical negotiations, by means of iterative proposals, or auctions (Beam et al. 1999). However, the assignment of negotiation decisions to digital business agents requires knowledge of preferences which can be imprecise. In the end, the arranged actions in the contract are executed in the settlement phase.

Automated negotiation is of great interest to multi-agent systems and artificial intelligence research as well as political and economic science (Kraus 2001). Automated negotiation enhances the application areas of e-markets drastically and constitutes an interdisciplinary market engineering challenge. Since we have to consider issues such as individual rationality or incentive compatibility, automated negotiations are inseparably connected with economics. The application areas for negotiations by software agents are manifold. Nowadays, digital business agents represent human principals, e.g., at algorithmic trading on stock markets (Hendershott & Riordan 2009), in automated procurement (Moon 2005), or at auctions employing bidding clients (Weinhardt et al. 2005). The latter is an early example for the vision of silent commerce, i.e., digital business agents order goods automatically and autonomously when needed. This can be a printer ordering a new toner or a smart phone application ordering a train ticket when entering the train (Meyer & Eymann 2003). Negotiation facilitates the tasks of digital business agents – especially in group situations. For instance, a group can automatically negotiate quantity discounts or dynamic prices. Furthermore, when several decision makers are in place, automated negotiation can find trade-offs for all parties. However, an optimal outcome of the negotiation process is not ensured. Since agents are led by self-interest, negotiations can come to a standstill in a local optimum. Therefore, there is a need for market design for intelligent negotiation protocols meeting following requirements: fair, socially beneficial, short running, simple, incentive compatible and individually rational (Jennings et al. 2001).

Digital business agents conduct negotiations thereby representing human principals. The principal-agent-relation results in a second task for market engineers: Because people are usually not able to deliver precise cardinal utility values, preference elicitation and representation are major problems in real-world applications (Beam et al. 1999). While the literature has accounted for various preference issues (e.g., Tong & Bonissone (1980), Bui & Sivasankaran (1991), or He & Jennings (2004)), it remains unclear how negotiation protocols can appropriately account for the impreciseness of subjective human preferences, such as an e-market participant's imprecise utility estimations of goods or services.

Addressing the major challenge for e-market designers to develop negotiation protocols that account for the aforementioned challenges and consider subjective and imprecise preferences of human principals, the contribution of this paper is the suggestion of an innovative "fuzzy set"-based e-negotiation design. In addition, the paper also makes a practical contribution to the design of e-negotiation applications by, firstly, allowing principals to overcome local optima in terms of social welfare and, secondly, by allowing the principals to express their preferences quantitatively in combination with a degree of uncertainty ("I value this issue with about $20 but am unsure; it could be less").

The remainder of this paper is structured as follows: The second section presents prior work and identifies the proposition of negotiation designs as research gap. Afterwards, the theoretical foundations of our research are laid and negotiation issues are derived. Then we present our research agenda and reveal preliminary results, before we conclude our research-in-progress paper.

Related Work

The field of negotiations was initially explored by game-theorists. Game-theoretical approaches are narrowed by assumptions and constraints so that these models are mostly not applicable for real-world information systems. Nevertheless, they are certainly helpful to get a view of the underlying problems and nexus (Neumann 2007). However, game theory can aid the analysis of market mechanisms and agent behaviour in an interdisciplinary context as presented at Binmore & Vulkan (1999).

Conitzer (2010), Jennings et al. (2001), Beam et al. (1999), and Ströbel & Weinhardt (2003) give an overview about automated negotiation, among others. In the field of non-auctionary protocols, Klein et al. (2007) and Fink (2006) propose mediated negotiation protocols and focus on mechanisms to ensure cooperation between the agents. Lai et al. (2006) propose a mediated negotiation protocol as well but focus on examination of the contract space under incomplete information and do not address fuzziness of preferences or preference delivery.

Modern types of auctions share important characteristics of traditional negotiations and are a smart mechanism for e-negotiations (Bichler et al. 2003). In the field of auctions, combinatorial auctions are particularly important because they consider interdependencies that play a major role in our negotiation model presented in the next section. Concerning this, Pekec and Rothkopf (2003) give a overview about combinatorial auction design. Central issues of combinatorial auctions are the NP-hard winner determination problem (e.g., Sandholm et al. 2002 or Lehmann et al. 2006) and incentive compatibility, i.e., there is no incentive to lie about your preferences (e.g., Lehmann et al. 2002 or Nisan and Ronen 2007). For instance, Sandholm (2002) applies combinatorial auctions to e-commerce.

The idea of fuzzy preference delivery was already presented in 1980. Tong & Bonissone (1980) developed a model for delivery by linguistic inputs. Bui & Sivasankaran (1991) adopt fuzzy logic for cardinal preferences in a negotiation support system by calculating a weighted value. Kowalczyk & Bui (2000) developed a prototype for automated negotiation under incomplete information, soft constraints, and imprecise preferences. Their fuzzy constrained-based negotiation system is constructed for choosing a single provider according to a single agent's preferences. He & Jennings (2004) implement a fuzzy set approach to auction-based trading negotiations supposing uncertain preferences.

Based on our literature review, we have identified two key research problems: a) the problem of multilateral, multi-issue negotiations with interdependent items, and b) the problem of accounting for uncertain preferences. To our best knowledge, the literature has not addressed these problems in combination. For instance, there are some approaches including combinatorial auctions that address the issue of interdependent items but not the issue of uncertainty. Research is rather restricted to price negotiations or allocation problems under certain preferences. In contrast, our research is focused on multi-agent, multi-issue problems including interdependencies and considers uncertainty as well.

Negotiation Setting

Computerized Agents and Human Principals

Generally, as shown in Figure 1, automated negotiations outline the negotiation situation in which software agents conclude contracts by negotiating or bidding (depicted by gray arrows) by order of human principals. Thereto, the software agents have to elicit the principals' preferences, or the principals have to enter their estimates (depicted by the white arrows). Commonly, the delivered preferences are assumed to be precise. In the following, we present a framework that accounts for imprecise preferences.

Negotiation Model

The negotiation setting represents a multi-agent, multi-issue scenario with interdependent items. Let J be the number of agents, who negotiate about a binary-coded N-item contract $c = \{c_1, \dots, c_N\} \in \{0,1\}^N =: C$, with C being the contract space and c_i indicating whether item i is selected ($c_i = 1$) or not ($c_i = 0$). The selection of each item is the result of the negotiation process of the agents. For each agent j we assume that the utilities of selecting or not selecting items are pairwise interdependent, i.e., the utility $P_j(p, q)$ of a selected item p also depends on whether another item q is selected or not. For example, the utility of a

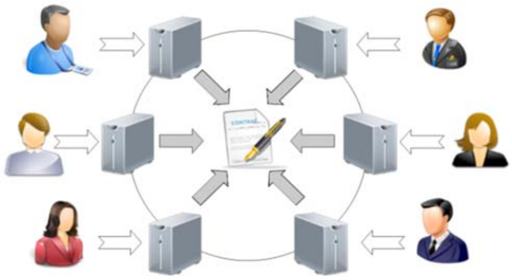

Figure 1. Negotiation Situation

	1	…	p	…	q	…	N
1	$U_j(1,1)$	…	$U_j(1,p)$	…	$U_j(1,q)$	…	$U_j(1,N)$
…		…	…	…	…	…	…
p			$U_j(p,p)$	…	$U_j(p,q)$	…	$U_j(p,N)$
…				…	…	…	…
							$U_j(N,N)$

Figure 2. Preference Matrix

new operating system could be high, but it would not be adopted due to lacking software for this system – consequently software and system are interdependent. Thus, we define $P_j(p,q) = (P_j(p,p) + P_j(q,q)) * (1 + \omega_{pq})$, $\omega_{pq} \in [-\alpha, \alpha]$. The magnitude of ω_{pq} determines whether superadditivity ($\omega > 0$; complementary item) or subadditivity ($\omega < 0$; substitute item) holds. As contract items are mutually interdependent, preferences can be arranged in a (triangular) matrix (see Figure 2). The overall utility $U_j(c)$ of a contract c for an agent j is given by $U_j(c) = f\left(P_j(p,q) \middle| p,q \in \{1,..,N\}\right)$, with f being the preference function. We provide a common preference function later on. As objective, the maximization of the social welfare (SW) is intended. There are other approaches to determine a socially beneficial or fair outcome such as a Pareto optimum (Lai & Sycara 2008). A Pareto optimum is an outcome where no agent can realize a benefit without worsening at least one other. This approach has the advantage that no cardinal values are needed and ordinal preferences are sufficient. Since a SW maximum is an element of the Pareto optima and a cardinal environment is supposed, the SW is proposed here as objective criterion: $SW(c) = \sum_{j=1}^{J} U_j(c)$.

Common Preference Delivery

Commonly in software prototypes, the cardinal preference order is elicited by simple preference input employing a software interface. There are also more sophisticated approaches, such as conjoint analysis, but their accuracy is ambiguous as well (Lloyd 2003). The elicited guesses are taken as distinct values, so that the overall utility of a full contract is calculated additively: $U_j(c) = \sum_{p=1}^{N} \sum_{q=p}^{N} P_j(p,q) * c_p * c_q$.

Negotiation Issues

Suboptimality of Negotiations

The interdependencies of contract items lead to non-linearity (Klein et al. 2007). In non-linear contract spaces, the negotiation process with adjacent contracts (here defined as a single contract item mutation) is characterized by local optima for each negotiator. Let us suppose that a mediator proposes a contract, which represents a mutation of a current contract draft, and the agents can agree or disagree to the proposal. If one agent rejects the proposal, another contract item is mutated becoming a new contract proposal for decision. However, if all agents agree, the proposal becomes the current contract draft and a mutation of this draft becomes a new proposal. This procedure is repeated until a stop criterion is reached (Klein et al. 2007). A typical bargaining history is depicted in Figure 3. As shown, Pareto-efficiency of contracts is not guaranteed. Agent 1 would obstruct the negotiation at contract (2) because of a individually worse position in contract (3). Thus, a Pareto optimum, the social welfare maximum, and individual optima, all in contract (4), are not reached. Now we suppose that agents might agree to small individual utility losses and so enable a utility gain for another agent (cooperative bargaining). Under this supposition, agent 1 could agree to contract (3) – despite the utility loss – and contract (4) can be realized making both better off. Hence, cooperation can lead to a socially desired outcome, whereas greedy bargaining, myopically aiming at individual advantages only, rather leads to socially inferior outcomes.

A big issue of negotiation research is to ensure cooperation between the agents so that beneficent contracts are realized. Unfortunately, the incentive structure may be misleading as shown in Figure 4 (Klein et al. 2007; Fink 2006). In a Nash equilibrium no player can improve her or his outcome by a unilateral change of strategy (Osborne 2010). Supposing both agents cooperate, they can unilaterally improve their

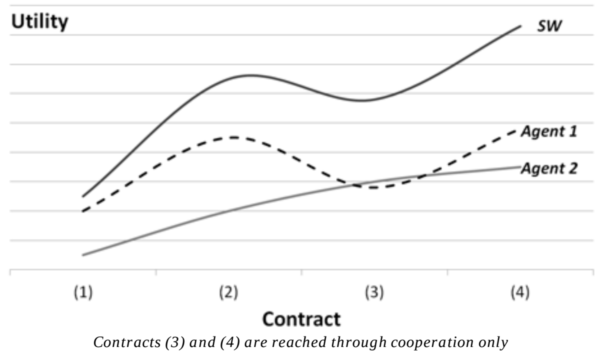

Figure 3. Negotiation History with Non-Linear Utilities

	Agent 2	
Agent 1	Greedy	Cooperative
Greedy	C; C	A; D
Cooperative	D; A	B; B

$A \gtrsim B \gtrsim C \gtrsim D \qquad A + D \gtrsim 2 * C \qquad 2 * B \gtrsim A + D$

Figure 4. A Bilateral Negotiation Game: A Prisoner's Dilemma

position by acting greedily ($A \gtrsim B$). The other agent breaks up the cooperative strategy then at the latest ($C \gtrsim D$). The strategy set {Greedy; Greedy} is reached. Since a unilateral change does not lead to a higher outcome, {Greedy; Greedy} is stable and constitutes the unique Nash equilibrium. Furthermore, this equilibrium is the social welfare minimum. Consequently, it is a central task for market engineers to develop adequate mechanisms or protocols for solving this incentive problem.

Impreciseness of Preferences

In standard settings, it is assumed that negotiation agents have available precise preferences. However, in the presence of human principals we have to acknowledge that their preferences are both subjective and imprecise. This informational uncertainty needs to be accounted for in negotiations in order to model appropriately and to deal with human preferences in negotiations quantitatively. Human uncertainty can have an effect on valuation of contract proposals in traditional negotiations and on the determination of bid levels in auctions. The following simple example demonstrates the failure of preference determination in the absence of the consideration of uncertainty: We assume that we have an arbitrary number of agents and, for simplicity, three items per contract. For a selected agent j, let the utilities per item be $P_j(1,1) = 20$, $P_j(2,2) = 21$, and $P_j(3,3) = 20$ ($P_j(p,q) = 0$ in all other cases) – ignoring interdependencies for demonstration purposes. An additive common preference delivery, as described earlier, is supposed. Furthermore, we assume that the elicitation of utilities of agent j reveals that the utilities of items 1 and 2 are based on an optimistic assessment (i.e., the utilities of items 1 and 2 are probably "a bit" lower than 20 and 21, respectively), while the evaluation of item 3 is based on a more pessimistic approach. Reflecting these biases, the direct comparison of contracts $c1 = (1,1,0)$ and $c2 = (1,0,1)$ is likely to make agent j prefer contract $c2$ over $c1$. However, the application of (crisp) common preference delivery would result in the opposite, thus wrong order, as $U_j(c1) = 41 > 40 = U_j(c2)$.

While preference elicitation is one major challenge (Lloyd 2003) in the consideration of human preferences, another key challenge is apparently the choice of an appropriate uncertainty calculus (Zimmermann 2000), which is capable of avoiding the defect described in the above example. As in the absence of statistical information and in the presence of subjective uncertainty "fuzzy set theory" has turned out to be a useful approach (Zadeh 1965, Zimmermann 2000, Zimmermann 2001), we account for informational uncertainty of principals' preferences and utilities with fuzzy numbers and fuzzy arithmetic (Buckley & Jowers 2008, Klir & Yuan 1995). The use of fuzzy set theory for addressing subjective preferences in negotiations is detailed in the next subsection.

A Fuzzy Preference Approach

Fuzzy set theory generalizes traditional set theory in such a way that it provides for a degree of membership with which an element belongs to a fuzzy set; in contrast to (crisp) set theory, wherein an element explicitly either comes with a set or not. A specific type of a fuzzy set is a fuzzy number (Buckley & Eslami 2002, Klir & Yuan 1995), which is formally defined by $\{(x, \mu_{\tilde{N}}(x) | x \in \mathbb{R}\}, \mu_{\tilde{N}}: \mathbb{R} \rightarrow [0,1]$ where $\tilde{N}$ is referred to as fuzzy number. $\mu_{\tilde{N}}$ is denoted as the membership function of $\tilde{N}$, and it outputs the degree with which $x \in \mathbb{R}$ belongs to N. For example, the fuzzy number $\widetilde{20}$, which is to be equivalently seen as "real numbers close to twenty" may be given by the membership function $\mu_{\widetilde{20}}(x) = (1 + (x - 20)^{-2})^{-1}$. Note that the membership function differs from a probability density function in two regards: Firstly, $\int_{-\infty}^{\infty} \mu_{\tilde{N}}(x)dx$ does not need to equal 1, and secondly it mirrors the subjective attitude of an individual rather than reflecting statistical evidence.

Fuzzy set theory provides a formal framework for arithmetic and logic operations on fuzzy numbers and crisp numbers (Buckley & Jowers 2008). These sound theoretical concepts allow for modifying the crisp negotiation model such that utilities are fuzzy numbers, utility and preference functions use fuzzy arithmetic operators, and preference orders are derived by means of fuzzy logical operators. While the fuzzy negotiation model is structurally identical to the crisp model (thus we do not provide it formally here), the semantics of data and operators are different. Figure 5 shows how using fuzzy preferences and numbers can deal with imprecise preferences and avoid deriving a faulty contract order.

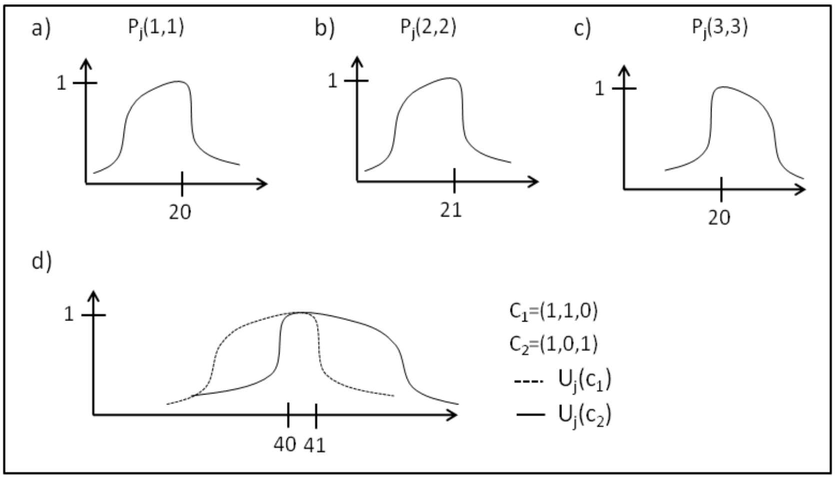

Figure 5. Fuzzy Utilities and Preferences of the Example

While subfigures a), b), and c) show the utilities of single items, subfigure d) shows the preferences of the two contracts $c1 = (1,1,0)$ and $c2 = (1,0,1)$. Applying appropriate fuzzy operational operators, such as Kerre's operator (Buckley & Jowers 2008), results in the preference order $U_j(c1) = \widetilde{41} < \widetilde{40} = U_j(c2)$, which mirrors the actual preference order of agent j.

Research Agenda and Preliminary Results

Research Agenda

We identified two major yet unresolved issues in current negotiation research. Firstly, negotiations can stay in a suboptimal state due to lacking cooperation and, secondly, humans are not able to state their preferences precisely, so that software agents have to consider imprecise preferences. Accounting for the challenges, we suggest and follow the research agenda depicted in Figure 6. It shows four tasks along the dimensions of protocols and (un)certainty of preferences. Tasks 1 and 2 are concerned with the comparison of auctions and traditional bargaining protocols under either certain or uncertain preferences. Iterative negotiations and auctions are two main negotiation methods and are suited for different problem cases. Auctions are in particular associated with payment contracts such as purchase contracts, whereas iterative negotiations rather cover non-payment contracts such as product configurations. However, there are also mixed types, e.g., purchase contracts that set a product configuration in combination with a purchase price. The main objective is to find suitable negotiation protocols for relevant problem cases. Task 2 concerns imprecise preferences and is intended to result in appropriate protocols accounting for uncertainty. Tasks 3 and 4 address the question how the consideration of uncertainty affects the outcome of different protocols compared to certain and precise preferences. The purpose of these tasks is to quantify

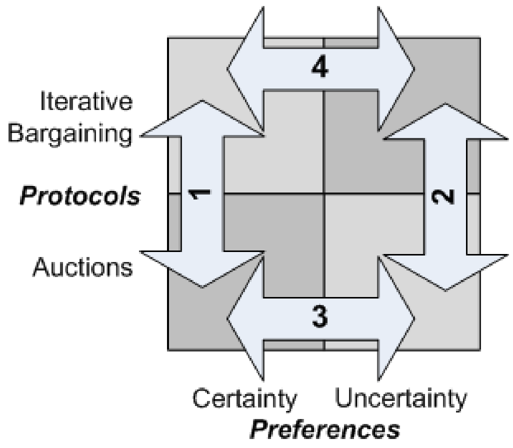

Figure 6. Scholarly Environment

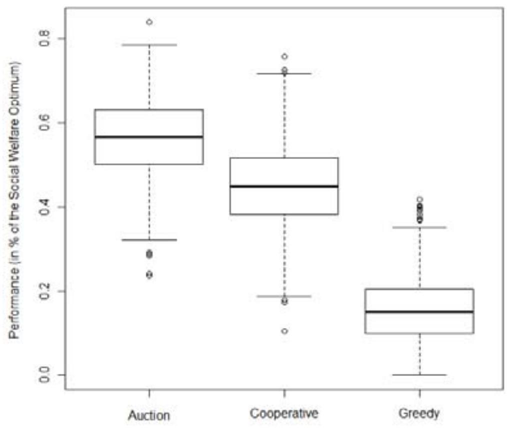

Figure 7. Comparison of Auctions & Bargaining

the utility loss, in case certainty is presupposed wrongly, and to design protocols that are applicable for both certain and uncertain environments.

Preliminary Results

Up to today, we have already undertaken task 1 (Lang & Fink 2011). The presented multi-agent, multi-issue setting with interdependencies was elaborated with an iterative negotiation protocol from the literature and a combinatorial auction (CA) approach using a simulation test bed.

The combinatorial auction protocol consists of an auctioneer and several agents. At first, the agents submit their bids consisting of sets of contract items (combinatorial) and bidding prices. Afterwards, the auctioneer solves the winner determination problem and allocates decision rights to the winners. Finally, the winners decide about their won contract items and hence constitute the final contract concerning all agents. Since we assume interdependencies between the different contract items, the combinatorial auction is better fitted than a common auction. Because the winner determination problem is NP-hard and we have supposed limited decision time, we have employed heuristics for this problem.

The iterative negotiation protocol is taken from Klein et al. (2007) with an extension from Fink (2006) for comparison and proceeds as follows: At first, a mediator randomly generates an initial contract, which becomes the active contract. Then, the mediator mutates this contract slightly resulting in a contract proposal. Afterwards, the agents choose between the proposal and the active contract. If all agents choose the proposal, it becomes the new active contract. Finally, the active contract is mutated again and the process starts over until an exit criterion is reached. In our study, the exit criterion was a certain elapsed runtime deduced from the combinatorial auction protocol's runtime. The protocol was tested with two agent types already presented earlier: greedy and cooperative agents. To ensure cooperation and overcome the dilemma of Figure 4, the agents had to fulfill acceptance quotas in defined subphases whereby the quotas were declining over time. This rule supports the overcoming of local optima and follows the idea of the simulated annealing metaheuristic.

In the preliminary work, we have disregarded imprecise preferences. With impreciseness in place, there need to be mechanisms supporting the agents' determination of the bidding level in the presented auction protocol as well as the agents' evaluation of the two contract alternatives in the presented negotiation protocol. Future work will be linked to these issues.

As shown – for the case of uniform distributed preferences, 7 agents, and 100 contract items – in Figure 7, the presented combinatorial auction protocol can outperform both greedy and even cooperative bargaining under the supposition of restricted decision time, many contract items, and several agents. However, the iterative negotiation protocol can handle small contracts with few agents better than the auction protocol and its performance increases significantly if more runtime is available (Lang & Fink 2011). This indicates that the selection and adoption of a negotiation protocol is heavily dependent on the application scenario and its corresponding restrictions.

Future Work

Future work will mainly concentrate on the design of negotiation protocols and their evaluation. However, there are also opportunities for the empirical analysis of preferences improving the validity of evaluations.

Protocol Design and Evaluation

The central research task is to develop suitable negotiation protocols to account for the challenges identified in the prior discussion. Besides developing protocol designs, the evaluation of these is a key aspect of constructive research (Hevner et al. 2004). We will use an agent-based simulation test bed for the evaluation of existing and proposed protocol designs. Furthermore, we are going to utilize the empirical ascertained data described in the next subsection, like fuzziness degrees and different abilities to express uncertain preferences, to improve the validity of the simulation results. The protocols shall take imprecise preferences due to uncertainty into account. This aspect has been disregarded in prior approaches. Moreover, we will develop a software prototype providing a dialogue for preference elicitation which has to be evaluated as well. Concerning this, focus groups are an effective method for artifact refinement (Tremblay et al. 2010). Furthermore, we will examine the concrete application of negotiation protocols to different problem cases in e-commerce, such as automated procurement executed by digital business agents.

Empirical Analysis of Preferences

The fuzziness of preferences is deduced from literature and theoretical insights so far. The next step will be to identify and quantify preferences by empirical observations in controlled experiments. To prove the usefulness of fuzzy preference elicitation, we will compare different elicitation methods. Thereto, a sophisticated elicitation method will be compared to a direct preference input by the user. For example, the choice based conjoint analysis is known for deducing preferences relatively exactly by ordinal comparison of different product configurations. These results can be compared to a direct cardinal estimate for the preferences showing if people can directly estimate their preferences correctly – especially when interdependencies are in place. If people cannot estimate their cardinal preferences correctly, it has to be examined whether they can specify degrees of fuzziness. At this, higher levels of fuzziness should lead to larger deviation from the indirectly ascertained values. Afterwards, we will evaluate human decisions under uncertainty and analyze how impreciseness affects decision making, e.g. auction bid levels.

Summary and Outlook

This work addresses major topics in automated negotiation research considering economic as well as behavioral issues like individual rationality and fuzzy preferences. Negotiations are an essential piece of the puzzle of automated commerce by digital business agents (Bichler 2001). As shown, negotiation decisions can vary if preferences underlie subjective uncertainty. Consequently, this work argues to go beyond the negotiation process of the autonomous agents by reconsidering the preference delivery and the actual underlying preferences of the human principals. The envisaged negotiation scenario comprises a scalable multi-issue, multi-agent environment with interdependent items under uncertain preferences. The scenario is not limited to price negotiations and is hence applicable to many kinds of contracts. Our approach is novel for the presented scenario because most literature ignores multilateral scenarios, negotiations without payments, uncertain and imprecise preferences or interdependencies.

Our research agenda presented in Figure 6 shows a framework how e-market research should be orientated to close the presented research gap. Our future work will address tasks according to the research agenda by drawing theoretically on fuzzy set theory and methodologically on simulation and experiments. In order to contribute to these tasks, we will use the described concepts of fuzzy set theory to build uncertainty models and extend the existing simulation test bed. As proof of necessity of fuzzy utilities, laboratory experiments are furthermore feasible in order to investigate the accuracy of preference elicitation or, more specifically, the particular types of fuzzy sets to be used. Moreover, fuzzy contract decisions beyond binary values will be analyzed and considered in future negotiation protocol designs to facilitate cooperation within negotiations. Until now, the scope of uncertainty in negotiations has not been explored very well. We expect that our research will provide new findings and solutions for the addressed issues.

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