On Efficient Mediation Approach to Multi-issue Negotiation with Optimal and Fair Outcomes

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ABSTRACT

Empirical evidence suggests that self-interested agents often fail to reach optimal agreements in multi-issue negotiations. Unfortunately, most existing works for increasing the optimality of the negotiated agreements either do not address the fairness issues; or ignore the computational concerns. To address these problems, the aim of this research is to introduce an efficient mediated negotiation approach to support multiple agents reaching an optimal and fair agreement under incomplete information. We use a trusted, non-bias mediator to coordinate the negotiating agents, while also protecting the negotiating agents from unnecessary disclosure of information to their opponents. We separate out the negotiation problems over continuous issues from those over discrete issues; and investigate different mediation techniques to deal with the negotiation problems over different type of issues respectively.

Keywords

multi-agent negotiation, fairness, Pareto efficiency, mediator

1. INTRODUCTION

Negotiation is a fundamental interaction mechanism in multi-agent systems. It enables self-interested agents to act cooperatively and benefit from mutually preferred agreements [3, 4, 6, 9, 11]. Such negotiations can involve, for instance, negotiation over the package deals in agent-based trading systems, negotiation about the resource allocation among different interest groups or departments, or negotiation between the service providers and customers to reach service level agreements as to enhance the quality of services, etc. [3, 6, 14]. When multiple issues are involved in negotiation simultaneously, like price, quality attributes, delivery time, etc., the agents with divergent preferences may achieve better agreements on issues that are most important for them by trading off some on those not so important[6, 11, 15]. Such situations where all the parties are better off, are normally called "win-win" situations [6, 11, 15].

However, empirical evidence suggests that self-interested agents often end up with inefficient results in multi-issue negotiations, even though a compromise does exist that the agents could have made others they all would have preferred [8, 4, 11, 15]. Lax and Sebenius [8] discuss the Negotiator's Dilemma in deciding whether to pursue a cooperative or a competitive strategy at a particular time during negotiation. Fatima et al. [4] point out that self-interested agents would like to reach an agreement that is as favorable to them as possible, whereas the final decision is jointly made and need to be agreed to by both the agents. Consequently, the problems met by the negotiation agents are not only to choose cooperative or competitive strategies, but also to consider how much they could gain individually if they cooperate and in which way of cooperation they could gain more, or at least receive a fair deal. Negotiation therefore, requires techniques that deal with rational agents fairly and lead them to mutually beneficial agreements. In classical negotiation theory, the typical solution proposed is the use of an independent mediator, which generally assumes that the perfect information of the negotiation parties is available for the mediator to compute the optimal outcomes and the computational concerns are often ignored.

As to address the above issues, the aim of this research is to introduce an efficient mediated negotiation approach to support multiple agents reaching an optimal and fair agreement over multiple issues under incomplete information. We use a trusted, non-bias mediator to coordinate the negotiating agents, while also protecting the negotiating agents from unnecessary disclosure of information to their opponents. We separate out the negotiation problems over continuous issues from those over discrete issues (the issues that take a finite set of values), investigate different preference representation model for different type of issues, and propose the according mediation techniques to deal with the negotiation problems with different type of preferences respectively.

The remainder of this proposal is as follows. In Section 2, we review some of the related literatures. Section 3 analyses the research problems and presents our methodologies on the designing the negotiation framework for continuous issues and discrete issues respectively. Finally, Section 4 outlines the future work in the upcoming one and a half years and the primary structure of PhD thesis.

2. REVIEW OF THE LITERATURE

2.1 Multi-issue negotiation in Economics

The research work on Multi-issue negotiation has been conducted in the fields of economics and artificial intelligence (AI). Multi-issue negotiation in economics is mainly conducted by game theory and it can be divided into two branches: non-cooperative and cooperative game theory.

Non-cooperative negotiation considers negotiation as a fully specified game, which refers to the negotiation protocol that the players follow during the negotiation process, for example, see [1, 13]. These protocols have been applied mainly to evaluate single-issue negotiations, for example negotiate over the price of a product. However, the problem with multiple issues is so complex that rigorous modeling and analysis with Non-cooperative game theory turns out to be intractable.

Instead of analyzing the negotiation process, the research in cooperative game theory aims at finding an outcome satisfying a set of axioms or conditions when given some possible outcomes. For instance, Nash [10] provides a unique solution, called the *Nash bargaining solution*, which satisfies the following Nash axioms: *Pareto-efficient, Symmetry, Invariance, Independence of irrelevant alternatives.* It can be characterized by the outcome that maximizes the Nash product of all the negotiators' payoff. Some researchers point out that the key axiom of "Independence of Irrelevant Alternatives" in Nash axioms is too strong a condition and lacks "monotonicity" [5]. The *egalitarian bargaining solution*, introduced by Ehud Kalai, is a third solution which drops the condition of scale invariance while including both the axiom of Independence of irrelevant alternatives, and the axiom of monotonicity. Egalitarian bargaining solution maximizes the payoff of the worst-off negotiator, attempting to grant equal gain to the negotiating parties. To summarize, the goal of cooperative game theory research on negotiation is to identify the optimal mechanisms with desirable properties. However, the research in this field is mainly conducted under complete information setting, which is too strong an assumption that cannot be maintained in the real world applications.

2.2 Multi-issue negotiation in AI

The research work in AI field on the other hand, emphasizes on designing appropriate models with automated and tractable negotiation mechanisms, such as negotiation framework, trading-off mechanism and searching methods.

2.2.1 *Multi-issue negotiation with utility functions*

Most of the existing works have been dealing with the utility-based negotiation problems, where the agents' preferences are mathematically represented by utility functions. For instance, Fatima *et al.* [4] propose an agenda-based framework for multi-issue negotiation under time constraints in an incomplete information setting. While the authors assume that, the utility functions of the agents are linear additive. Ehtamo et al. [3] present a mediation-based gradient search method for making trade-offs, while also creating joint utility gains for the negotiating agents. However, their proposed approach leaves the fairness issue between the agents' utility gains largely unanswered. Another mediation-based negotiation model with incomplete information is given by Lai et al. [6]. In their approach, the mediator conducts a Pareto efficient enhancement for a proposal in each negotiation period. The algorithm they develop is of high efficiency in the two-issue cases, however, it is not necessarily feasible and it does not guarantee Pareto optimality.

2.2.2 *Qualitative preference and collective decision making*

Utility functions are a powerful form of knowledge representation. Unfortunately, in many situations, the utility-based preference elicitation is complicated and typical users may not be able to provide much more than qualitative rankings of outcomes [2]. The researchers in AI have been developing languages for representing qualitative preferences in a succinct way, exploiting structural properties such as conditional preferential independence. Boutilier *et al.* [2] introduce a qualitative, graphical model of preferences, called **CP-net** (Conditional preference networks), which specifies individual preference relations in a relatively compact, intuitive, and structured manner.

Most existing works on CP-net focus on individual preference reasoning, including outcome optimization and comparison (See [2]), while negotiation involves multiple agents and the agents' preferences are not common knowledge. Rossi *et al.* [12] define a multi-agent extension to CP-nets and propose various voting semantics for aggregating multiple agents' preferences which are represented by CP-nets. However, they do not address computational issues. Lang [7] reconsider voting and aggregation rules in the case where the agents' preferences have a common preferential independence structure. The author addresses the decompositions of a voting rule following a linear order over variables. However, sharing common preferential independencies over all the agents is a demanding assumption that is unlikely to be met in practice. Furthermore, the above methods assume having complete information about each agent's CP-net, which is particularly hard to be applicable in the real world scenario.

3. RESEARCH PROBLEMS AND METHODOLOGY

3.1 Research Problems Summarize

To summarize, multi-issue negotiation is complex and challenging because of the following reasons.

- Incomplete information. In a multi-issue negotiation, the preference of an agent over multiple issues is complex and the outcome space is m-dimensional ($m > 1$) rather than a single-dimension line as in a single-issue negotiation. This makes the negotiation strategy in multi-issue negotiations complex. Increasing efficiency and fairness in multi-issue negotiation therefore, requires agents to share preference information, while disclosure of an agent's preference to the opponents puts it at a disadvantage in a negotiation. Consequently, in most of the real world applications, the agents' preferences are not common knowledge. Under incomplete information, the burden of computation and reasoning for the negotiation strategy become even higher, and thus it is difficult to reach efficient and fair outcomes.

- Computational complexity. In both individual and collective decision making with qualitative preference, the space of possible outcomes from which the agent (or the group of negotiating agents) has to choose often has a *combinatorial structure* (The number of all possible outcome is exponential in the number of variables). Much work in this field has concentrated on normative questions and on establishing abstract results regarding the possibility of designing mechanisms meeting certain requirements. Computational concerns, however, have mostly been neglected. For instance, what is the computational complexity of the mechanisms? What are the appropriate algorithmic techniques for these problems? What will happen if the number of possible outcomes to choose from becomes very large?

3.2 Solution Approach

To address the above issues, the aim of this research is to introduce an efficient mediated negotiation approach to support multiple agents reaching an efficient and fair agreement under incomplete information. We use a trusted, non-bias mediator to coordinate the negotiating agents, while also protecting the negotiating agents from unnecessary disclosure of information to their opponents. We separate out the negotiation problems over continuous issues from those over discrete issues, investigate different preference representation models for different type of issues, analyze the system goals of the negotiation problem with different type of preferences (e.g. Pareto efficiency, fairness, computational efficiency, etc.), and propose the according mediation techniques to deal with the negotiation problems with different type of issues respectively (See Figure 1).

For the type of continuous issues, we consider the classical negotiation theory that mathematically represents agents' preferences by utility functions. We have proposed a new mediated negotiation approach to support the negotiating agents reaching a Pareto optimal and fair agreement over multiple continuous issues under incomplete information. The proposed approach uses a non-bias mediator as a tool for step-by-step creation of fair joint gains. At each stage of negotiation, the mediator searches for the compromise direction based on the solution to a mathematical programming problem, called the DMP (Deviation Minimization Problem). The objective of this approach is to find more efficient outcomes, which improve all the agents' utilities while minimizing the difference between the agents' utility gains, leading to fair agreements. We have conducted a large amount of experiments and analysis the experimental results of the proposed approach in the context of several well-known social welfare metrics. It demonstrates that the proposed approach not only guarantees Pareto optimality, but also produces the outcomes that are close to the fair Egalitarian solution.

For the type of discrete issues, we investigate the theory of CP-net (Conditional Preference Network) as a formal model for representing and reasoning with the negotiation agents' preference. There are not much works for aggregating multiple agents' preferences represented by CP-nets. While the existing works either do not address computational issues, or depend on a strong assumption that all the agents share a common preferential independency structure. We have introduced an efficient mediated negotiation approach for negotiation with CP-nets under incomplete information, which also allows the agents to have different preferential independency structure. The proposed approach involves a recursive procedure, called `MNCP`, to generate a small fair set of Pareto optimal outcomes, which is the basis for choosing the final outcome preferred by multiple agents. We proof that the candidate outcomes generated by `MNCP` are guarantee to be Pareto-optimal. We have also conducted a large number of experiments with different scenarios varying agents' preferences and the number of variables. The experimental results demonstrate that the propose approach is computationally efficient and produces the results that are close to the corresponding social welfare metrics.

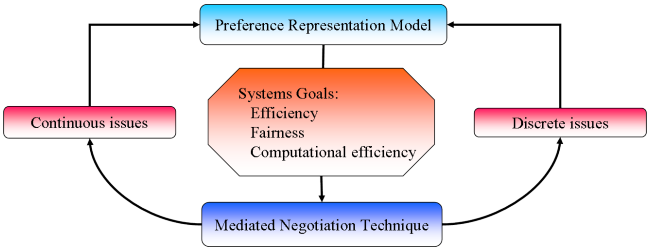

Figure 1: Methodology

Published Paper

- M. Li, Q. B. Vo, and R. Kowalczyk: Searching for Fair Joint Gains in Agent-based Negotiation. In *AAMAS '09: Proceedings of the Eighth International Joint Conference on Autonomous Agents and Multiagent Systems*, pages 1049-1056, Budapest, Hungary, 2009. IEEE Computer Society.

Submitted Paper

- M. Li, Q. B. Vo, and R. Kowalczyk: An Efficient Mediation Procedure for Multi-agent Negotiation with CP-nets, submitted to *the 20th International Joint Conference on on Artificial Intelligence*, 2010.

4. FUTURE WORK PLAN

4.1 Outline of Future Work

During the next one year (2009.10 - 2010.10) of my Phd, the main focus is on mediated negotiation with structural preference (i.e. CP-nets and its extensions).

In the previous work, we have not explored more powerful variants such as TCP-nets for representing agents' preferences in negotiation, although they can be similarly applied to support more expressive preferential semantics on preference trade-offs such as relative importance and conditional relative importance. We plan to explore in more detail how best CP-nets can improve the representation of the agents' preferences in negotiation and produces better outcomes for multiple agents. In addition, future work also includes the exploration of possible ways for generating the optimal outcomes in different semantics including Max, Majority and Lex optimal. During the final six months (2010.10 - 2011.04), the PhD thesis which enhances and summaries our entire work will be completed.

4.2 Primary Structure of PhD Thesis

Title: On Efficient Mediation Approach to Multi-issue Negotiation with Optimal and Fair Outcomes

Chapter 1 Introduction
1.1 Introduction to Multi-issue Negotiation
1.2 Key issues of this research
1.3 Overview of this thesis

Chapter 2 Literature Review and Problem Analysis
2.1 Multi-issue negotiation in Economics
2.2 Multi-issue negotiation in AI
2.3 Problem analysis
2.4 Summary

Chapter 3 Mediated negotiation over continuous issues
3.1 Utility function: a quantitative preference representation over continuous issues
3.2 Efficiency and Fairness in utility-based negotiation
3.3 Gradient search method
3.4 A mediation approach to bilateral negotiation with Pareto optimal and fair outcomes
3.5 A mediation approach to multilateral negotiation with Pareto optimal and fair outcomes
3.6 Summary

Chapter 4 Discrete issues and qualitative preferences
4.1 CP-net: a qualitative preference representation over discrete issues
4.2 Efficiency and fairness with CP-nets
4.3 NP-completeness of outcome optimization with multiple CP-nets
4.4 Summary

Chapter 5 Mediated negotiation with CP-nets
5.1 Generate the Pareto optimal outcome set with multiple CP-nets
5.2 An efficient mediation approach for multi-agent negotiation with CP-nets
5.3 Summary

Chapter 6 Mediated negotiation with TCP-nets and UCP-nets
6.1 TCP-nets: Introducing variable importance tradeoffs into CP-nets
6.2 Generate the Pareto optimal outcome set with multiple TCP-nets
6.3 An efficient mediation approach for multi-agent negotiation with TCP-nets
6.4 UCP-net: A directed graphical representation of conditional utilities
6.5 Generate the Pareto optimal outcome set with multiple UCP-nets
6.6 An efficient mediation approach for multi-agent negotiation with UCP-nets
6.7 Summary

Chapter 7 Conclusion and Future Work
7.1 Summary of this thesis
7.2 Contribution of this thesis
7.3 Future work

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