Multiagent Negotiation on Multiple Issues with Incomplete Information

(Extended Abstract)

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ABSTRACT

We present a reactive offer generation method for general *multi-agent multi-attribute negotiation*, where the agents have *non-linear utility functions and no information* about the utility functions of other agents. We prove the convergence of the proposing method and characterize the convergence rate under a finite negotiation time. We also prove that rational agents do not have any incentive to deviate from the proposed strategy. We further present simulation results to demonstrate that on randomly generated problem instances the solution obtained from our protocol is quite close to the Nash bargaining solution.

Categories and Subject Descriptors

I.2.11 [**Artificial Intelligence**]: Distributed AI - MAS

General Terms

Algorithms

Keywords

Multiagent Negotiation, Incomplete Information, Convergence

1. INTRODUCTION

The objectives of mathematical models of negotiation are diverse. We study the negotiation problem from the perspective of designing intelligent agents that can negotiate on behalf of human.

Most work to date has focused on two party, single issue negotiation, although there has been some work on two-player, multi-issue negotiation (e.g., [3]) or with multi-player, single issue negotiation (e.g., [1]). Furthermore, computational modeling of multi-attribute negotiation has either assumed (a) complete knowledge of the preference structure of the opponents (e.g., [7]) or (b) a probability distribution over the preferences of the agents is known (e.g., [5, 2, 6]). Most of the literature also assumes linear additive utility functions. In this paper, we study the negotiation problem for general *multilateral multi-attribute* negotiation where the agents know their own (possibly nonlinear) utility functions but *do not have any knowledge about the other players' utility functions*.

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We prove that a sequential projection strategy for generating offers guarantees that the agents reach an agreement. Furthermore, we prove that if the agents use reactive concession strategies, i.e., each agent concedes by an amount proportional to her evaluation of the amount of concession of her opponents, then the agents have no incentive to deviate from the concession strategy. We also demonstrate the performance of the reactive sequential projection strategy through simulations.

2. THE NEGOTIATION FRAMEWORK

We consider m self-interested agents $i \in \{1, 2, ..., m\}$ negotiating on a set of issues $j \in \{1, 2, ..., N\}$. We assume that the utility function of agent i, $u_i(x), i = 1, 2, ..., m$ is continuous and concave. Each agent, i, has a *reservation utility*, ru_i. Any offer with utility less than its reservation utility is not acceptable to that agent. The set of all feasible offers that an agent i can accept is $A^i = \{x \in [0,1]^N \,|u_i(x) \geq ru_i\}$. The set A^i is strictly convex for each i. The *zone of agreement*, $\mathcal{Z}$, is defined as the common intersection of the feasible offer sets of all agents, i.e., $\mathcal{Z} = \cap_{i=1}^m A^i$. For a solution to exist to any negotiation problem, the zone of agreement has to be non-empty. Any point within the zone of agreement is called a *satisficing solution* to the negotiation.

The Negotiation Model: We use a sequential protocol in the multi-agent setting and assume that the agents propose their offers in a given order. An agent computes her own offer using the latest offers of all the other agents and either proposes a new offer or accepts the current offer, if it is within her acceptable offer set. When all agents accept the current offer the negotiation ends.

Problem Statement: Given m agents negotiating on n issues where (a) each agent, i, has a strictly concave private utility function, u_i, and a strategy for concession that is monotonically decreasing with time up to ru_i, and (b) the zone of agreement has a nonempty interior, find a method for computing the offer an agent should propose such that an agreement is guaranteed.

Agent Strategy: When it is the turn of agent i to make an offer, she accepts the current offer if it is satisficing. Otherwise, agent i uses the last two offers of every other agent j to compute the difference in the utilities of the offers to her, i.e., Δu_{ij}. The amount by which agent i reduces her utility to compute her current utility is equal to the minimum Δu_{ij} over all the other agents j.

2.1 Offer Generation Method

We assume at period 0, each of the agents propose an offer maximizing her own utility. Let x_t^i be the offer of agent i in period t. If a proposal by agent i is not agreed to by all at period t , agent

$i+1$ proposes her own offer by choosing the projection of the convex combination of all of the agents' latest offers to her current indifference surface in period $t+1$.

Convergence: The convergence of the offer generation method implies that the negotiating agents are guaranteed to reach an agreement if the zone of agreement is not empty. For multi-issue negotiation with private utility function, the agents don't know the non-empty zone of agreement, even if one exists. Therefore, the existence of non-empty zone of agreement cannot guarantee that agents will reach an agreement, even if they are given enough time. Thus, we need to examine whether the negotiation strategy is convergent or not.

THEOREM 1. *If the zone of agreement has a non-empty interior, the sequential projection proposing protocol will always converge to an agreement.*

Finite Time Convergence: Given that all the agents reach their reservation utilities in finite time, do the agents converge to an agreement in finite time? The answer to this question is yesin general and stated in the theorem below.

THEOREM 2. *For m agents negotiating on N issues, if the agents use concession strategies such that they reach their reservation utility in finite time, they can reach an agreement in finite time.*

2.2 Incentive of agents to concede

We show that there is a *reactive concession strategy*, namely, conceding by an amount proportional to the minimum of the perceived change in utility of other agents' offers that is rational. We prove that if any of the agents do not concede, it is possible for other agents to find this within a finite number of rounds and hence stop conceding. This combined with the fact that an agent does not know other agents' utility provides the threat of the negotiation coming to a stall, even if the zone of agreement is non-empty . Since the utility of an agreement is not worse than the utility for breakdown, it is rational for an agent to concede.

2.3 Simulation Results

In this section we present simulation results and evaluate our solution with respect to the Nash bargaining solution [7]. We assume a very general *hyperquadric* function [4] for the utility function.

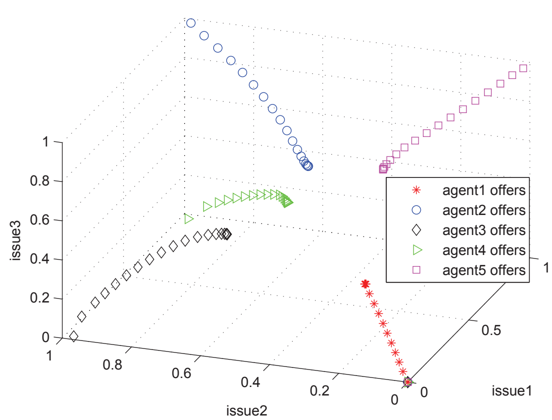

Figure 1: Sequence of offers made by 5 agents without a final agreement in a three-issue negotiation scenario with agent 1 stopping conceding during the negotiation.

Table 1: Performance of the sequential projection algorithm.

Number of agents	Number of rounds		Ratio of Joint Utility	
	Mean	SD	Mean	SD
2	72.07	10.30	0.9278	0.0874
3	86.39	15.57	0.8825	0.0865
5	94.68	7.49	0.8819	0.0851
7	95.46	6.74	0.8846	0.0740
9	96.72	5.17	0.9023	0.0691

Figure 1 shows a simulation where the agent 1 stops conceding after reaching half of its reservation utility. Since all other agents are reactive, they realize within a few steps that agent 1 is not conceding and they also stop conceding. Hence the agents do not reach an agreement, as the concession of the agents stop, although their zone of agreement is nonempty.

Table 1 shows the performance of the algorithm when the adjusted time-dependent concession strategy is used. As can be seen from Table 1 (second and third columns), the number of rounds required for convergence are fairly constant. The fourth column gives the ratio of our solution to the Nash solution. For randomly generated instances, the solution obtained is quite close to the Nash bargaining solution.

3. CONCLUDING REMARKS

We propose a sequential projection strategy for general multilateral multi-attribute negotiation where agents have no knowledge about the other players' utility functions. We prove that the method is guaranteed to enable the agents to arrive at an agreement given any nonlinear concave utility function. Further, the proposed strategy with a reactive concession function is a rational strategy for the agents. We also performed computational experiments to demonstrate that, in practice, the quality of solution obtained by our algorithm is quite close to the Nash bargaining solution. The negotiation converges in a reasonable number of iterations.

This work can be extended in several directions. One direction is to design rational strategies for agents to negotiate in the presence of hard deadlines. Another possibility is to extend this sequential projection method to negotiation between multiple teams.

4. REFERENCES

[1] K. Binmore. Bargaining and coalitions. *Game-Theoretic Models of Bargaining*, pages 269–304, 1985.

[2] K. Chatterjee and W. Samuelson. Bargaining under incomplete information. *Operations Reasearch*, 31(5):835–851, 1983.

[3] S. Fatima, M. Wooldridge, and N. Jennings. Multi-issue negotiation with deadlines. *Journal of Artificial Intelligence Research*, 27:381–417, 2006.

[4] A. J. Hanson. Hyperquadrics: smoothly deformable shapes with convex polyhedral bounds. *Computer Vision, Graphics, and Image Processing*, 44(2):191–210, Nov. 1988.

[5] J. Harsanyi and R. Selten. Two-person bargaining games with incomplete information. *Manage Sci*, 18(5):80–106, 1972.

[6] R. Lin, S. Kraus, J. Wilkenfeld, and J. Barry. Negotiating with bounded rational agents in environments with incomplete information using an automated agent. *Artificial Intelligence*, 172(6-7):823–851, 2008.

[7] J. Nash. The bargaining problem. *Econometrica*, 18:155–162, 1950.