A Preliminary result on a representative-based multi-round protocol for multi-issue negotiations

(Short Paper)

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ABSTRACT

Multi-issue negotiation protocols represent a promising field since most negotiation problems in the real world involve multiple issues. Our work focuses on negotiation with interdependent issues, in which agent utility functions are nonlinear. Existing works have not yet focused on agents' private information. In addition, they were not scalable in the sense that they have shown a high failure rate for making agreements among 5 or more agents. In this paper, we focus on a novel multi-round representative-based protocol that utilizes the amount of agents' private information revealed. Experimental results demonstrate that our mechanism reduces the failure rate in making agreements, and it is scalable on the number of agents compared with existing approaches.

Categories and Subject Descriptors

I.2.11 [**Artificial Intelligence**]: Distributed Artificial Intelligence - Multi-agent System

General Terms

Algorithms

Keywords

Multi-issue Negotiation, Nonlinear Function, Complex Utility

1. INTRODUCTION

Multi-issue negotiation protocols represent an important field of study. While there has been a lot of previous work in this area [1, 4]. Thus, we focus on complex negotiation with interdependent multiple issues [3]. Existing works have not yet been concerned with agents' private information. If all agents' utility is revealed, other agents can know their private information. As a result, the agents are brought to a disadvantage in the next negotiations. Furthermore, it is dangerous to reveal utility information explicitly as an aspect of security. For such reasons, our aim is to create a mechanism that will find high-quality solutions without revealing utility information.

We define an agent's **revealed area**, which represents the amount of his/her revealed utility space. The revealed area can numerically define which agents are cooperative and which are not. Additionally, the mediator can understand how much of the agent's private information has been revealed in the negotiation.

We employ the **revealed area** concept in the new negotiation mechanism proposed in this paper. In the negotiation, we first select representatives who revealed their utility space more than the others. These representatives reach an agreement on some alternatives and, propose the alternatives to the other agents. Finally, the other agents can express their own intentions on agreement or disagreement. This mechanism in our new negotiation drastically reduces the computational complexity.

We expand our mechanism to be multi-round by using the Threshold Adjustment Protocol [2]. The multi-round mechanism improves the failure rates and achieve fairness in terms of the revealed area. This means that the amount of the revealed areas are almost the same among agents.

We demonstrate low failure rates in finding solutions, and this mechanism has large scalability for the number of agents in the experiment. Additionally, we show our mechanism can have high optimality on agreement and keep an agent's revealed area minimized.

The remainder of the paper is organized as follows. First, we describe a model of multi-issue negotiation and an existing work's [3] problems. Second, we define the revealed area and prepare the new representative-based mechanism. Third, we describe the multi-round negotiation protocol. Fourth, we present an experimental assessment of this protocol. Finally, we draw conclusions.

2. NEGOTIATION USING COMPLEX UTILITY SPACE AND PROBLEM

2.1 Complex Utility Space

We consider the situation where N agents want to reach an agreement. There are m issues, and individual issues represent $i_j \in I$. An issue s_j has a value drawn from the domain of integers $[0, X]$, *i.e.*, $s_j \in [0, X]$. A contract is represented by a vector of issue values $\vec{s} = (s_1, ..., s_m)$.

An agent's utility function is described in terms of con-

Cite as: A Preliminary result on a representative-based multi-round protocol for multi-issue negotiations (Short Paper), Katsuhide Fujita, Takayuki Ito and Mark Klein, *Proc. of 7th Int. Conf. on Autonomous Agents and Multiagent Systems (AAMAS 2008)*, Padgham, Parkes, Müller and Parsons (eds.), May, 12-16., 2008, Estoril, Portugal, pp. 1573-1576.

straints. There are l constraints, $c_k \in C$ in agent's utility space. Each constraint represents a region with one or more dimensions, and has an associated utility value. A constraint c_k has value $w_i(c_k, \vec{s})$ if it is satisfied by contract $\vec{s}$.

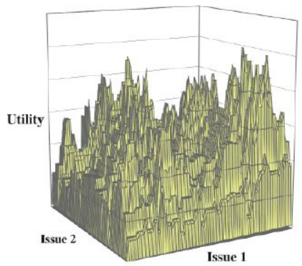

Figure 1: A Complex Utility Space

An agent's utility for a contract $\vec{s}$ is defined as $u_i(\vec{s}) = \sum_{c_k \in C, \vec{s} \in x(c_k)} w_i(c_k, \vec{s})$, where $x(c_k)$ is a set of possible contracts (solutions) of c_k. This expression produces a "bumpy" nonlinear utility space, with high points where many constraints are satisfied, and lower regions where few or no constraints are satisfied. This represents a crucial departure from previous efforts on multi-issue negotiation, where contract utility is calculated as the weighted sum of the utilities for individual issues, producing utility functions shaped like flat hyper-planes with a single optimum. Figure 1 shows an example of a nonlinear utility space. The utility space is highly nonlinear, with many hills and valleys.

2.2 Basic Bidding-based Mechanism

In the existing work[3], agents reach an agreement based on the following steps. We call this **basic bidding-based mechanism**.

[**Generate bids**] Agents create bids that each include a sub-region of their contract space, and submit them, along with a value for the bid to the auctioneer.

[**Find the Solutions**] In negotiation, there is a mediator who takes the middle position. The mediator identifies the final contract by finding all the combinations of bids, one from each agent, that are mutually consistent. If there is more than one such overlap, the mediator selects the one with the highest summed bid value

2.3 Issues on Scalability and Privacy

Computational complexity in finding the solutions exponentially increases according to the number of bids since it is a combinatorial optimization calculation. In order to handle the computational complexity, in the basic bidding-based protocol [3], we limited the number of bids for each agent. The concrete number of bids in this limitation was $\sqrt[N]{6,400,000}$. This number came from our experimental calibration in 2005. Because of the limitation of bids, the failure rate in finding agreements quickly increases along with increasing the number of agents. When the number of agents is 5 and the number of issues is 7, we observed experimentally that the failure rate is around 40%. Thus, increasing the number of total bids is not an effective approach for finding good quality agreements. Thus, it is necessary to build another mechanism that will find higher quality solutions without limiting the bids. Our mechanism proposed in this paper is highly scalable.

The other issue with existing protocols is that they are not concerned with privacy or security in the utility spaces. Even in a collaborative situation among people, it is normal to keep one's own utility space unopened as long as one is not asked to do otherwise. Our new mechanism will achieve such a situation by defining the **revealed area** in utility spaces, and including the Threshold Adjusting mechanism.

3. REPRESENTATIVE PROTOCOL BASED ON REVEALED PRIVATE UTILITY SPACE

3.1 Revealed Area for Agent

We focus on the amount of private information agents revealed in the negotiation. For an agent, it is important for him/her to know how much his/her private information is revealed compared with the other agents. The mediator can judge whether an agent is cooperative or not cooperative based on his amount of revealed private information.

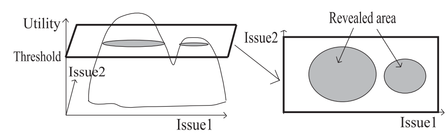

Figure 2: Revealed Area

We employ **revealed area** as the measure of the amount of revealed utility space. Figure 2 shows an intuitive example of a revealed area. The revealed area is defined as an agent's possible contract points that are revealed in his utility space on his/her threshold.

We use **threshold** that employed in generating bids as the measure of adjusting agents' revealed area. So, we consider adjusting their threshold to adjust their revealed area. Threshold is employed for an agent to generate his/her bids based on utility values above the threshold.

3.2 Representative-based Protocol

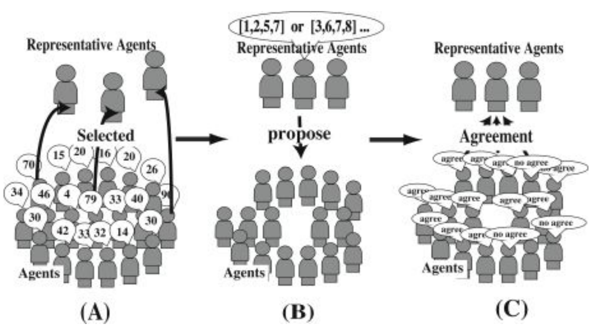

Figure 3: Representative-based Protocol

We assume each agent uses a reservation value for determining whether to "agree" or "disagree" with representative agents. Actually, for practical application, the reservation value can be determined by a human user. Thus, the reservation value is a constant number that is not changed in negotiation. The reservation value is set as lower or the same value as the threshold described in the previous subsection. This protocol consists of following steps.

[**Step 1: Selection of the Representative Agents**] Representative agents are selected based on the amount of their revealed area as shown in Figure 3 (A). First, each agent submits how much he can reveal his utility to the mediator. Namely, each agent submits the numeric value of the amount of his possible revealed area. The mediator selects the representative agents who could reveal a large area.

[Step 2: Proposing by the Representative Agents] Representative agents find the solutions and propose to the other agents as shown in Figure 3 (B). First, representative agents find the solutions. They employ a breadth-first search with branch cutting to find solutions.

Next, the representative agents ask to the other agents whether they will "agree" or "disagree". Step 2 is repeated until all the other agents agree or the solutions representatives found are rejected by the other agents.

[Step 3: Respond to the agreement by the other agents] The other agents receive the solution from representatives. Each of them will determine whether he/she "agrees" or "disagrees" with the solution (agreement) as shown in Figure 6 (C). First, the other agents receive the solution from the representative agents. Then, they judge whether they will "agree" or "disagree" with the solution. Each agent judges based on whether the solution's utility is higher than his/her reservation value or not.

Steps 1, 2 and 3 can be captured as follows:

B: A set of bid-set of each agent (B=$\{B_0, B_1, ..., B_n\}$, a set of bids from agent i is $B_i = \{b_{i,0}, b_{i,1}, ..., b_{i,m_i}\}$)
PB: A set of bid-set of each representative agent (PB=$\{PB_0, PB_1, ..., PB_m\}$, a set of bids from representative agent i is $PB_i = \{pb_{i,0}, pb_{i,1}, ..., pb_{i,l_i}\}$)
select_representatives() is a method for performing **Step 1**
ask_agent() is a method for performing **Step 3**.

procedure representative_based_protocol(B)
  $PB = select\_representatives(B)$
  $SC := PB_0$, $i := 1$
  while $i < Number\ of\ Representative\ Agents$ **do**
    $SC' := \emptyset$
    for each $s \in SC$ **do**
      for each $pb_{i,j} \in PB_i$ **do**
        $s' := s \cup pb_{i,j}$
        if s' is consistent **then**
          $SC' := SC' \cup s'$
    $SC := SC'$, $i := i + 1$
  while $i < |SC|$ **do**
    if ($ask\_agent(SC_i)$ is true & SC_i Utility is maximum)
      return SC_i
  return No Solution

4. EXTENSION TO MULTI-ROUND NEGOTIATION

We extend our protocol to multi-round negotiation based on threshold adjusting [2]. Multi-round negotiation will provide a kind of fair opportunity for agents to be representative agents by repeating negotiations. Also, it will facilitate finding more optimal contracts.

In our multi-round negotiation, representative agents are changed in each round. Consequently, total the amount of revealed utility space for each agent is almost same. Further, for each round, agents can find a different agreement point that has more optimal agreement. Thus, we can expect agents to find more optimal agreement as the entire negotiation process unfolds. Because of the above reasons, we employ a multi-round threshold adjustment mechanism to prevent and extremely detrimental situation.

The main idea of the threshold adjusting mechanism is that if an agent reveals a larger area of his utility space, then he should gain an advantage. On the other hand, an agent who reveals a small area of his utility space should adjust his threshold to agree with others. The threshold values are changed by each agent based on the amount of revealed area. If the agent decreases the threshold value, then this means that he reveals his utility space more.

This mechanism is repeated until an agreement is achieved or all agents refuse to decrease the threshold. Agents can decide whether to decrease the threshold or not based on their reservation value, i.e., the minimum threshold. The reservation value is the limitation that the agent can reveal. This means that agents have the right to reject the request to decrease their threshold if the request decreases the threshold lower than the reservation value.

5. EXPERIMENTS

5.1 Setting of Experiments

We conducted experiments to evaluate the effectiveness of our approach. In each experiment, we ran 100 negotiations between agents with randomly generated utility functions. In the experiments on optimality, for each run, we applied an optimizer to the sum of all the agents' utility functions to find the contract with the highest possible social welfare. This value was used to assess the efficiency (*i.e.*, how closely optimal social welfare was approached) of the negotiation protocols. To find the optimum contract, we used simulated annealing (SA)[5] because exhaustive search became intractable as the number of issues grew too large.

In terms of privacy, the measure is the range of revealed area. Namely, if an agent reveals one point on the grid of utility space, this means he lost 1 privacy unit.

Contract Space: Domain for issue values is $[0, 9]$. There are 10 unary constraints, 5 binary constraints, 5 trinary constraints, etc. The maximum value for a constraint: $100 \times (Number\ of\ Issues)$. Constraints that satisfy many issues thus have, on average, larger weights. This seems reasonable for many domains. In meeting scheduling, for example, higher order constraints concern more people than lower order constraints, so they are more important for that reason. The maximum width for a constraint: 7.

Representative based Protocol: The number of representative agents is 2. The reservation value for determining whether to "agree" or "disagree" is 200.

Threshold Adjustment Protocol: The threshold agents used to select which bids to make start with 900 and decrease until 200 in the threshold adjusting mechanism. The amount of the threshold is decreased by $100 \times (SumAr - Ar_i)/SumAr$. $SumAr$ means the sum of all agents' revealed area. Ar_i means agent i's revealed area.

Basic Bidding: The threshold agents used to select which bids to make is 200. The limitation on the number of bids per agent: $\sqrt[N]{6400000}$ for N agents.

5.2 Experimental Results

In "(B) Basic Bidding", the revealed rate increases as the number of issues increases. This means that if we do not use the threshold adjustment, agents need reveal their utility space too much more than the other mechanisms. On the other hand, in "(A) Representative Protocol" and "(C) Threshold Adjustment", the revealed rate decreases as the

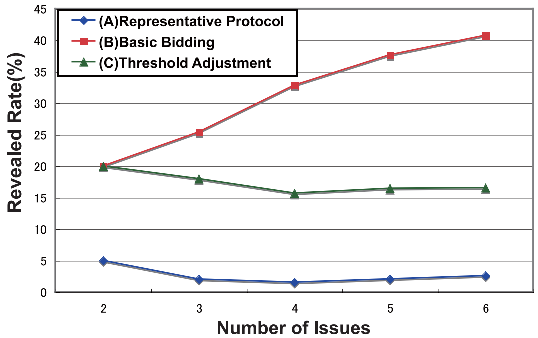

Figure 4: Revealed Rate

number of issues increases. Actually, the revealed area increases as the number of issues increases. This means that the increment of the whole area of utility space increases more sharply than the increment of the revealed area.

When we compare "(A) Representative Protocol" with "(C) Threshold Adjustment," the revealed rate of the representative protocol is less than the mechanism with threshold adjustment. There are two reasons for this. First, the representative protocol finds the solutions earlier than the threshold adjustment mechanism. Second, in the threshold adjustment most agents need to reveal their utility space. On the other hand, only representative agents reveal their utility spaces. Essentially, the representative protocol proposed in this paper drastically decreases the revealed rate compared with the other two mechanisms.

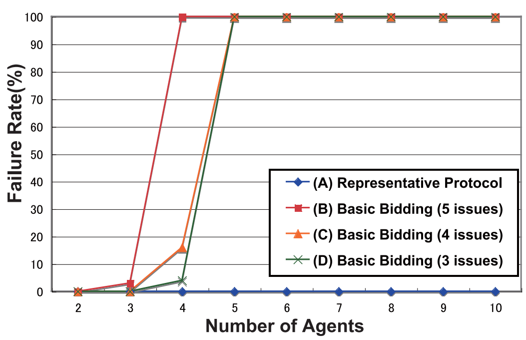

Figure 5: Failure Rate

The representative protocol considerably improves the failure rates on reaching agreements. Figure 5 shows the failure rates in "(A) Representative Protocol (5 issues)", "(B) Basic Bidding (5 issues)", "(C) Basic Bidding (4 issues)", and "(D) Basic Bidding (3 issues)". Even if the number of agents increases, the failure rate in the representative protocol is 0. On the other hand, the existing protocols (B), (C), and (D) show a drastic increase over 3 agents. This is because the bid limitation for computing winner determination starts when there are 3 agents. Also, for more than 5 agents, the existing protocol fails to find solutions.

The next experimental results show our negotiation mechanism is sufficiently scalable on the number of agents. Figure 6 shows the optimality when agents reach an agreement when the number of issues is 4 and the number of agents is from 2 to 100. In this experiment, we assume agents have a shared utility area that is agreeable for them. This is be-

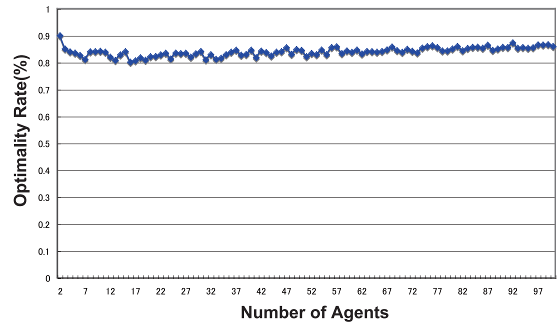

Figure 6: Scalability on number of agents

cause when the number of agents becomes large, it is quite hard to find an agreement point by using any negotiation mechanisms and it could be impossible to compare optimality. To create a common area, first, agents' utility space is randomly generated. Then, a common area whose value is more than an agent's threshold is randomly generated. The results demonstrated that the optimality is more than 80% in all cases. Although the high optimality came from the above common area assumption, scalability of our new mechanism is ensured by this experiment.

6. CONCLUSIONS

In this paper, we proposed a Multi-round Representative Protocol in very complex negotiations among agents. The representative protocol could always make agreements if the number of agents was large. It was important for agents to make agreements without revealing their private information in the negotiation. This proposed protocol could reach an agreement while revealing agents' utility space as little as possible. The experimental results demonstrated that the representative protocol could reduce the amount of private information that is required for an agreement among agents, and the failure rate in this mechanism was 0.

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