Efficient Issue-Grouping Approach for Multi-Issues Negotiation between Exaggerator Agents

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Introduction

Negotiation is an important aspect of daily life and represents an important topic in the field of multi-agent system research. There has been extensive work in the area of automated negotiation; that is, where automated agents negotiate with other agents in such contexts as e-commerce(Kraus 2001), large-scale deliberation, collaborative design, and so on. Many real-world negotiations are complex and involve interdependent issues. To date, however, achieving high scalability in negotiations with multiple interdependent issues remains an open problem. We propose a new protocol in which a mediator tries to reorganize a highly complex utility space with issue interdependencies into several tractable subspaces, in order to reduce the computational cost. We call these utility subspaces "Issue groups."

The remainder of this paper is organized as follows. We describe a model of multiple interdependent issues negotiation and the strength of interdependency between issues, and the structure of interdependency graph. Next, we present a clustering technique for finding issue sub-groups. We present the experimental results, demonstrating that our protocol produces more optimal outcomes than previous efforts. Finally, we present our overall conclusions.

Negotiation with Nonlinear Utility Functions

We consider the situation where N agents $(a_1, \ldots, a_N)$ want to reach an agreement with a mediator who manages the negotiation from a man-in-the-middle position. There are M issues $(i_1, \ldots, i_M)$ to be negotiated. The issues are shared: all agents are potentially interested in the values for all M issues. A contract is represented by a vector of values $\vec{s} = (s_1, ..., s_M)$. Each issue s_j has a value drawn from the domain of integers $[0, X_j]$, *i.e.*, $s_j \in \{0, \ldots, X_j\} (1 \leq j \leq M)$. Every agent has its own, typically unique, utility function $u_a(\vec{s})$.

The *strength* of an issue interdependency is captured by the interdependency rate. We define the interdependency rate between i_j and i_{jj} for agent a $(D_a(i_j, i_{jj}))$ as follows:

$$D_a(i_j, i_{jj}) = \frac{I_a(i_j) + I_a(i_{jj})}{I_a(i_j, i_{jj})} - 1 \qquad (1)$$

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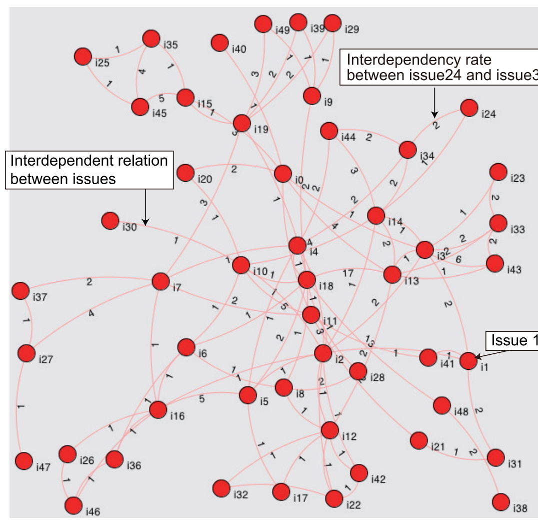

Figure 1: Interdependency Graph (50 issues)

$I_a(i_j) = \sum_{s_j \in [0, X_j]} \frac{V(u_a(\vec{s}))}{X_j + 1}$,

$I_a(i_j, i_{jj}) = \sum_{s_{jj} \in [0, X_{jj}]} \sum_{s_j \in [0, X_j]} \frac{V(u_a(\vec{s}))}{(X_j+1)*(X_{jj}+1)}$

In other words, the impact of i_j plus the impact of i_{jj} divided by the impact of them as a pair. In this paper, the impact of the issue means that average variance in utility when the issue is fixed. We consider that average variance in utility is one of the impact of the issue because the higher average variance in utility means that the issue is a higher value of decomposing the contract space.

Agents capture their issue interdependency information in the form of interdependency graphs i.e. weighted non-directed graphs where a node represents an issue, an edge represents the interdependency between issues, and the weight of an edge represents the interdependency rate between those issues. An interdependency graph is formally defined as: $G(P, E, w) : P = \{1, 2, \ldots, |I|\} (finite\ set)$, $E \subset \{\{x, y\} | x, y \in P\}, w : E \rightarrow R$. Figure 1 shows an example of an interdependency graph.

The objective function for our protocol can be described as follows: $\arg\max_{\vec{s}} \sum_{a \in N} u_a(\vec{s})$. Our protocol tries to find contracts that maximize social welfare, *i.e.*, the summed utilities for all agents. Such contracts, by definition, will also be Pareto-optimal. At the same time, all the agent try to find contracts that maximize their own welfare.

Negotiation Protocol based on Issue-Grouping

Step1: Analyzing issue interdependency. The first step is for each agent to generate an interdependency graph by analyzing the issue interdependencies in its own utility space.
Step2: Grouping issues. The mediator employs breadth-first search to combine the issue clusters submitted by each agent into a consolidated set of issue groups. For example, if agent 1 submits the clusters $\{i_1, i_2\}, \{i_3, i_4, i_5\}$, and agent 2 submits the clusters $\{i_1, i_2\}, \{i_3, i_4\}, \{i_5\}$, the mediator combines them to produce the issue groups $\{i_1, i_2\}$, $\{i_3, i_4, i_5\}$. In the worst case, if all the issue clusters submitted by the agents have overlapping issues, the mediator generates the union of the clusters from all the agents.
Step3: Finding Agreements. We use a distributed variant of simulated annealing (SA) (Russell and Norvig 2002) to find optimal contracts in each issue group. Each agent then votes to accept(+2), weakly accept(+1), weakly reject(-1) or reject(-2) the new contract, based on whether it is better or worse than the last accepted contract for that issue group. When the mediator receives these votes, it adds them together. If the sum of the vote values from the agents is positive or zero, the proposed contract becomes the currently accepted one for that issue group. If the vote sum is negative, the mediator will accept the contract with probability $P(accept) = e^{\Delta U/T}$, where T is the mediator's virtual temperature and ΔU is the utility change between the contracts. If the proposed contract is not accepted, a mutation of the most recently accepted contract is proposed in the next round. This continues over many rounds.

Exaggerator Agents

Any voting scheme introduces the potential for strategic non-truthful voting by the agents, and our method is no exception. For example, most of the agents' votes are always "strong," the final social welfare is reduced(Klein et al. 2003). What we need is an enhancement of our negotiation protocol that preventing the exaggerator votes and maximizing social welfare. We guess that simply placing a limit on the number of "strong" votes each agent can work well as the experimental results show.

Experimental Results

We conducted several experiments to evaluate our approach. In each experiment, we ran 100 negotiations. The following parameters of the utility functions were same setting as (Ito, Hattori, and Klein 2007). We compared the following negotiation methods: (A) applies the simulated annealing protocol based on the agents' votes, and performs the negotiation separately for each one of the issue groups, and combines the resulting sub-agreements to produce the final agreement. All agents tell the truth votes. (B) applies the simulated annealing protocol based on the agents' votes with issue-grouping. "All agents" tell the exaggerator votes. (C) is same situation with (B). However, the limitation of 'strong' votes is applied. The number of limitation of 'strong' votes is 250 which is the optimal number of limitations in this experiments. (D) is the method presented in (Klein et al. 2003), using a simulated annealing protocol based on the agents' votes without generating issue-groups.

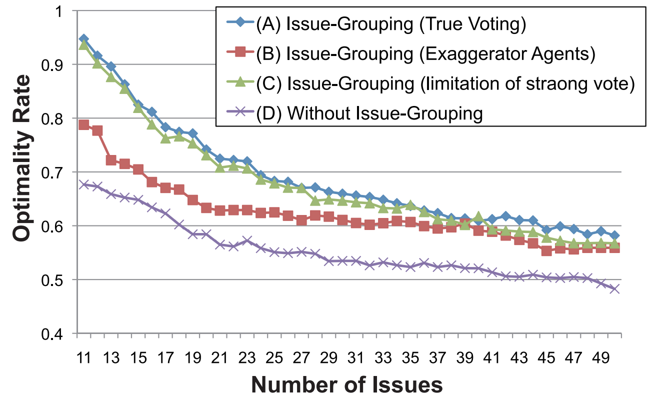

Figure 2: Comparison of optimality

Figure 2 compares the optimality rate in the sparse connection and dense connection cases. (A) achieved a higher optimality rate than (D) which means that the issue-grouping method produces better results for the same amount of computational effort. The optimality rate of the (A) condition decreased as the number of issues (and therefore the size of the search space) increased. (B) is worse than (A) because the exaggerator agents generate reduced social welfares in multi-agents situations. However, (C) outperforms (B) the limitation of 'strong' votes is effective of improving the social welfare reduced by the Exaggerator Agents.

Conclusion

In this paper, we proposed a new negotiation protocol, based on grouping issues, which can find high-quality agreements in interdependent issue negotiation. We demonstrated that our proposed protocol results in a higher optimality rate than methods that don't use issue grouping. In addition, the limitation of "strong" votes is effective of improving the reduced social welfare between exaggerators.

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