IMPROVING AGREEMENTS IN MULTI-ISSUE NEGOTIATION

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ABSTRACT

In bilateral negotiations with multiple issues, it is difficult to reach Pareto optimal outcome when the agents' preferences and relative importance of the issues are not known to each other. Self-interested agents often end up in inefficient agreements. Existing negotiation frameworks suggest solutions using trusted mediator, where agents will reveal their true preferences to the mediator. But in real life situations, a mediated solution is not always preferable, e.g., agents may not trust a third party to reveal their preferences. Without preference revelation, agents cannot improve the efficiency of the outcome. This paper presents an extended protocol for bilateral multi-issue negotiation. We show that with this protocol self-interested agents are able to explore and reach win-win agreements without revealing its complete preference.

Keywords: Software agents, multi-issue negotiation, efficiency.

1. Introduction

Both in human society and multi-agent society, negotiation is the main and most well known approach to resolve a conflict. With the massive growth of E-commerce, the research in automated negotiation is becoming increasingly important [Jennings et al. 2001, Kraus et al. 1995]. In automated negotiation, agents negotiate the contracts on behalf of the real life negotiating parties they represent. An agent negotiates over resources or services with other agents or humans. Many of these negotiations involve bargaining over multiple issues. The issues may be correlated or not. Here we have considered the issues are not related, that is, the utility of one issue does not depend on any other issue. We consider a negotiation scenario where two agents are negotiating over a multi-dimensional resource. Here, each dimension represents an issue. The preference of two agents may vary, *i.e.,* one agent may prefer one issue over other while the other agent may prefer the opposite. Even in case of same order of preferences, the *weights* may vary. Here, the interaction between agents is not repetitive. No agent has any information about the other agent’s preference structure. This is a reasonable assumption as with a rapid growth of electronic commerce, size of the market becomes so large that for some domain of e-negotiation it is not possible to know an individual and its preferences.

In multi-issue negotiation, agents with different preferences can cooperate each other to reach agreement that is beneficial for both the agents. We call a negotiation outcome efficient if it is Pareto optimal. A Pareto-optimal solution is one, where the utility of one agent cannot be improved without decreasing other agent’s utility. Consider a situation where two children is dividing two cakes kept on a table, one made of chocolate and the other made of strawberry. Both of them like both cakes but the first child likes chocolate more than strawberry and the other prefers the strawberry to the chocolate. If they cannot reach an agreement they get nothing. Then an optimal solution is that both the children get the cake they prefer most. But if the agents do not know each other’s preferences, then both will think, for each of the cakes, if the other guy is not offered at least half of the cake, he will not accept the offer. So, self-interested agents often fail to exploit the opportunity and end up in an inefficient “equal split” agreement. Note that, none of them has any incentive to sacrifice any portion of the cake unless it receives some which it prefers at least as much as what it relinquishes.

In the existing literature, there are two types of bargaining framework available for multi-issue negotiation. One is simultaneous framework, where, all the issues are negotiated simultaneously [Raiffa 1982] and the other is issue-by-issue negotiation, where, agents negotiate the issues one at a time [Bac and Raff 1996, Inderst 2000]. The former approach involves complex computations. In a simultaneous negotiation without knowledge of each others preferences, with a continuous decay in utility or a chance of breakdown, two agents end up in an inefficient equal-split agreement. In the later approach it should be determined in which order the issues will be negotiated. This ordering is known as agenda. Sometimes agenda may be exogenous but sometimes they are endogenous. In [Busch and Horstmann 1997], the agents bargain over the ordering of the issues before negotiation starts and then follow the order. In and Serrano [In and Serrano 2004] introduce issue-by-issue negotiation with endogenous agenda. These approaches reach Pareto efficient solution when each agent knows the preferences of the other agents. But do not deal with the situation where agents do not have any knowledge of each other's preferences.

Fatima proposed an optimal agenda based framework for multi-issue negotiation to improve the utilities of both agents, by exploring the opportunities of joint gains, using trusted mediator agent [Fatima et al. 2002, Fatima et al. 2003]. They have considered the situation under incomplete information where one agent does not have complete information about other agents' preferences. The problem of this solution is to find a trusted mediator such that agents will feel free to reveal their true preferences. Also, this mediator has to be unbiased. In real world, agents may not feel secured and comfortable to reveal its information to any third party. Some other research has also proposed the use of mediator agents for exploring efficient agreement [Ehtamo et al. 1999]. In this paper, we have proposed a two-phase negotiation protocol for bargaining with multiple issues. We assume that there is a very small or no decay in the utility over time but there is a possibility of breakdown if there is a disagreement over any issue. The agents have endogenous ordering of the issues. We have assumed that an agent has no knowledge about the preferences of the other agent. We have shown that in this framework agents explore the asymmetry in the preferences among the agents and can reach in an agreement where both the agents are better off. We have discussed situations where agents reach a Pareto optimal agreement. We have also discussed the possible situations where agents can only reach a near Pareto optimal agreement but fail to reach Pareto optimality. We have also compared the results with the existing negotiation frameworks and showed that this framework leads to more efficient agreements in the cases where the solutions are not Pareto optimal.

2. The bilateral multi-issue negotiation framework

Here, we assume a negotiation scenario where two agents, A_1 and A_2 are negotiating their share for multiple, say H ($H \geq 2$) issues. Both the agents know that for each issue the available share is of size unity and it is continuously divisible. This is a typical example of bargaining in Game Theory. Each agent has its own preferences for different issues. Every agent likes greater share in each issue compared to a smaller share but the weight varies. $\{U_1,U_2\}$ is the set of utility functions, where U_i is the utility function of agent A_i. We define the utility of A_i, as

$$U_i = \sum_{j=1}^{H} w_{ij} x_{ij} \tag{1}$$

where, for all i, j, $x_{ij} \in [0, 1]$, is the agent i's share of the j^{th} issue and $w_{ij} \geq 0$, is the the relative importance or weight of the j^{th} issue to agent i with $\sum_{j=1}^{H} w_{ij} = 1$. By complete preference of A_i, we mean the values of $w_{i1} \ldots w_{iH}$, which are known to agent i but other agent has no idea. It only knows that $w_{ij} \geq 0$ and $\sum_{j=1}^{H} w_{ij} = 1$. If the agents cannot reach an agreement, $x_{ij} = 0$ for all i and j. Otherwise, $\sum_{i=1}^{2} x_{ij} = 1$, for $j = 1 \ldots H$. A rational agent will try to maximize its utility given in Equation 1.

Now we have proposed the following two phase negotiation framework for bilateral negotiation. In our proposed framework, at the first phase, both agents propose at the same time. They can propose their share on any one of the issues which are yet to be negotiated. So, unlike other frameworks, here two agents do not have to propose share on the same issue. This asymmetry makes agents explore the opportunity for joint gains. Our framework consists of two phases: *allocation* and *reallocation*.

Allocation: In this phase, two agents propose at the same time. Agent i can propose any proportion y_i of any one of the remaining issues, not negotiated yet. If the agents propose share on different issues, they will receive the whole share of the corresponding issue and the two issues will be termed as negotiated. If both the agents propose for the same issue, and their total proposed share (y_1+y_2) is more than unity then there is a probability that the negotiation will breakdown, otherwise, the total share will be divided to the agents proportionally to their proposed share (i.e., agent i will receive $y_i/(y_1+y_2)$ proportions of the total share, $i = 1, 2$) and that issue will be removed from the set of issues remaining to be negotiated. Again this process will repeat for the remaining issues unless there is any issue left for negotiation. So, the agents do not need to reveal their preferences to each other. So, after *allocation* phase, each agent will have an initial allocation of the shares of all the issues. Here x_{ij} denote the share of the j^{th} issue to the agent A_i. But still it may be possible to exchange the shares possessed by the agents to improve the utility of both of them. The next phase, *reallocation*, provides an opportunity for such an exchange.

Reallocation: In this phase, any agent can ask for proposal to exchange any share of an issue it possesses. Suppose, agent A_i wants to know that if he can improve its utility by exchanging some share of issue *j* for which currently, $x_{ij} > 0$. So, it can ask the other agent, say $A_{i'}$, to propose some exchange offers for issue *j*. $A_{i'}$ will send its exchange offer which consists of a 3-tuple. The 3-tuple, T say, is represented as $\langle z, r_{zj}, q_{zi} \rangle$ where *z* is the name or number of an issue it can share, r_{zj} is the amount of share of *z* that $A_{i'}$ is ready to exchange for one unit of j and maximum amount of issue *z* it wants to share. Now, if A_i finds that $w_{iz} * r_{jz} > w_{ij}$, *i.e.*, the exchange of issue *j* with *z* is profitable, then the exchange takes place. Now, there may be a cost to ask for this exchange. We assume that α is the cost to host an exchange offer. We also assume that α will be spent only if there is a successful exchange. If $\alpha > 0$, then the agent hosting proposal has to make sure the gain through exchange is more than α. There is one restriction that one agent can host maximum one exchange for an issue. This restriction is necessary; otherwise there will be unnecessary delay to reach the negotiation. This phase continues unless no agent wants or is eligible to host anymore exchange.

3. Bilateral negotiation with two issues

First we discuss bilateral negotiation, involving two agents A_1 and A_2, with two issues. Then, we will discuss the problem for more than two issues. So, in this negotiation scenario H = 2. The utilities are $U_1 = w_{11}x_{11} + w_{12}x_{12}$ and $U_2 = w_{21}x_{21} + w_{22}x_{22}$.

3.1 A rational agent's strategy

The determination of the stable rational strategy of an agent in *allocation* stage consists of two decisions, which issue to propose and its proportion.

Proposition 1: *A rational agent will propose exact half of the share.*

Proof: In this negotiation scenario, there can be two possibilities; both agents can propose the same issue or different issues. In the second situation, each agent will get the whole share of the corresponding component if it proposes a positive proportion. So, the half is good enough. In the first situation, since both agents propose on the same issue, it is equivalent to single issue distributive bargaining. The Nash bargaining solution suggests equal split and it is the focal point. Hence the rational agent will always propose exact half of the share (The situation may differ if there is no chance of break down).

Proposition 2: *A rational agent will always propose the issue that has highest weight.*

Proof: For simplicity, lets consider H = 2. Without loss of generality, assume agent 1 prefers issue 1 than issue 2, that is $w_{11} > w_{12}$. From Proposition 1, we can assume that agent 2 will propose half share of the issue it chooses. We need to determine which issue it will choose.

Consider the first case, when agent 2 will propose issue 1. Now, if agent 1 proposes half share of issue 2, its utility is $U_1(0, 1) = w_{12}$. But if it proposes half of issue 1, in two steps shares of both the issues will be split equally and the corresponding utility is $U_1(0.5, 0.5) = 0.5(w_{11} + w_{12}) > w_{12}$.

Consider the second case, when agent 2 will propose issue 2. If agent 1 proposes issue 1, then its utility is $U_1(1, 0) = w_{11}$. But if agent 1 proposes issue 2, then its utility is $U_1(0.5, 0.5) = 0.5(w_{11} + w_{12}) < w_{11}$.

So, in both cases rational strategy is to propose issue 1 which is most preferred to agent 1.

Similarly we can extend this for H > 2 assuming the probability that the opponent agent will choose issue *j* is same for all *j*. Since the other agent's preference order is not known to it, it has no reason to assume that one issue is more probable to be chosen by the opponent compared to other issues.

So, in the *allocation* stage of this negotiation scenario, the optimal strategy for an agent is to propose half of the most preferred issue.

3.2 Efficiency of the agreements

Before we discuss the efficiency of the agreements reached, let us define few terms useful to describe the results.

Pareto optimality: An outcome *O* is Pareto optimal, if there exists no other outcome *O'* such that all agent's utility in *O'* is at least as good as their utility in *O* and at least one agent's utility is more in *O'*.

Marginal Rate of substitution (MRS): MRS^i_{jk} denotes the share of issue k that produces same utility to agent A_i as produced by one unit share of issue *j*. So, $w_{ij} = w_{ik} * MRS^i_{jk}$.

We will show the inefficiencies that arise when two self-interested agents negotiate with different preferences. Consider a negotiation scenario, where $w_{11} = 0.2$, $w_{12} = 0.8$, $w_{21} = 0.8$, $w_{22} = 0.2$. The agents want to maximize their utility, defined in Equation 1. In order to explain the results properly, we denote x_{ij} as the share of the agent A_i for issue *j* as we defined in the last section. We will also use utility pair to denote the utilities of the two agents, where the first number will be the utility of A_1 and the second number will be the utility of A_2. In case of single issue-by-issue negotiation, will lead to the agreement of "equal split" for both the issues and both the agents will receive 1/2 share of each of the issues. So, the resulting utility for A_1 is $0.2 * 0.5 = 0.1$ and for A_2, it is $0.8 * 0.5 = 0.4$ from the first issue and similarly, 0.4 and 0.1 respectively from the second issue as shown in Figure 1 (left, middle respectively). So, the total utility after the agreement will add up to 0.5 for both the agents. Since, none of the agent has any incentive to leave some share to the other agent as it does not know the preference of the other agent. For simultaneous negotiation, if the weights are not known it will lead to the same "equal split" allocation[1] for both the agents yielding the same utility (0.5,0.5) shown in Figure 1 (right), but if the weights are known the Nash bargaining solution will lead to the allocation, where, the whole share of the first issue is assigned to A_2 and whole share of issue 2 is allocated to A_1 yielding Pareto optimal utility pair (0.8, 0.8) shown in the same figure.

In this scenario, a rational agent A_1 in our proposed mechanism will ask for half share for the second issue and A_2 will ask for half share of the first issue. So, the allocation will be $\{x_{11} = 0, x_{12} = 1\}$ and $\{x_{21} = 1, x_{22} = 0\}$ and the corresponding utility will be (0.8,0.8) which is Pareto optimal as shown in Figure 2. So, for situations where agents have no knowledge about each other's preferences, if the preferences are not conflicting, agents in our framework reach the agreement where each agent gets the share it prefers. In other frameworks, without using the mediator, agents will reach the equal-split agreement as the agents will fail to explore the asymmetry in the preferences.

Now we consider the cases, where the agents have conflicting interests. So, we assume the ordering of the weights of different issues is same for both the agents. Without loss of generality we assume that the first issue is preferred by both the agents than the second issue. So, $w_{i1} > w_{i2}$, $i = 1, 2$. So, in the *allocation* phase both agents will receive half of the share for each issue, i.e., $x_{ij} = x_{2j} = 0.5$ for all j. Then in the *reallocation* phase, agents will be willing to explore the win-win situations. One of the agents will ask for an exchange offer for an issue, the other agent will submit its exchange rate with the other issue(s). If the offer is profitable the first agent will exchange. If the second agent state its true exchange then it is not gaining or loosing anything but the other agent gains some profit. So, the second agent has some incentive to hide its original value and under state its exchange rate and try to gain some profit. We will discuss the effects of agent's behavior in the *reallocation* phase on the efficiency of the reached agreement. Initially, we assume that in the *reallocation* stage when an agent asks for an exchange, the other agent bids according to its true marginal rate of substitution (*MRS*). By this we mean, the agent will inform the amount of the other issues that produces the same utility. Later on we will waive this assumption and show the effects of understating the substitution rate.

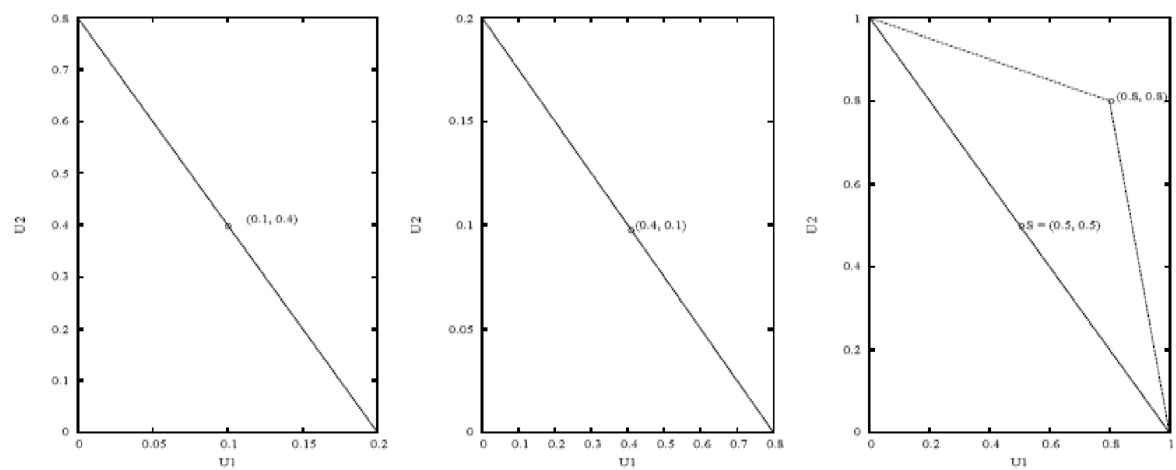

Figure 1: (left) Single issue negotiation for first issue. (middle) Single issue negotiation for second issue. (right) Simultaneous negotiation for both issues. {0.2,0.8} and {0.8,0.2} are the weight of the two agents respectively.

So, we have $w_{i1} > w_{i2}$, $i = 1, 2$. For illustration, we assume $w_{11} = 0.7$, $w_{12} = 0.3$. Now, there can be four different situations: (a) $w_{21} > w_{11}$, (b) $w_{21} = w_{11}$, (c) $0.5 < w_{21} < w_{11}$ and (d) $0.5 = w_{21} < w_{11}$. We have discussed the results following. In Figure 3, we describe the first situation. We take $w_{21} = 0.8$. So, after the *allocation* phase both agents will receive half of the share for each issue, i.e., $x_{1j} = x_{2j} = 0.5$ for all j. Now agent A_1 asked for offers for issue 2, agent A_2 being truthful offers $MRS^2{}_{21} = 0.2/0.8 = 0.25$. So, it can exchange $0.25 * 0.5 = 0.125$ unit share of issue 1 as for 0.5 unit share of issue 2. But for A_1, $0.125 * 0.7 < 0.5 * 0.2$. So, A_1 does not exchange. Now A_2 asks for exchange offer for issue 2 and A_1 offers $MRS^1{}_{21} = 0.3/0.7 = 0.43$. Now A_2 finds it profitable and it exchanges its

[1] This case is similar with the single issue bargaining with unknown weights where the size of the pie is double.

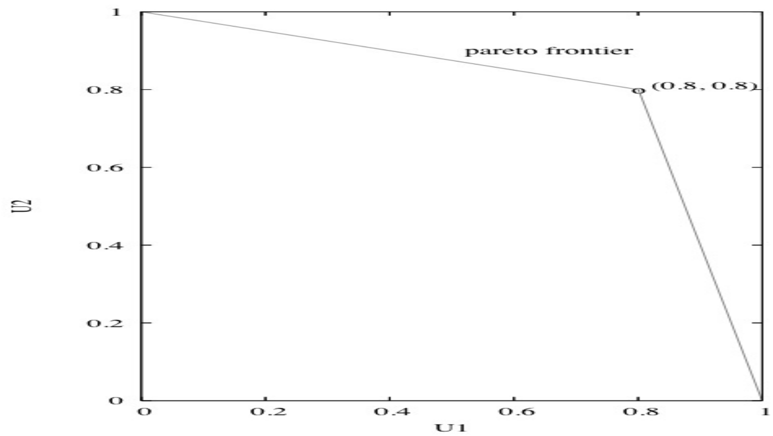

Figure 2: Pareto optimal agreement for agents with weight {0.2, 0.8} and {0.8, 0.2}

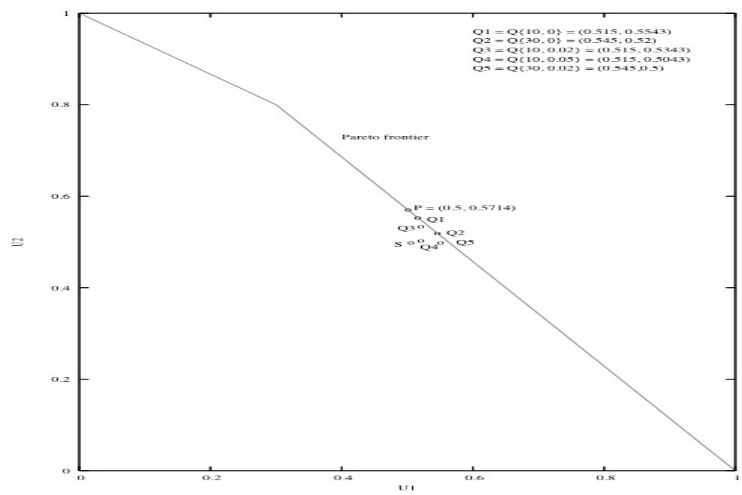

Figure 3: Bargaining solutions when two agents weights are {0.7, 0.3} and {0.8, 0.2} respectively.

0.5 share of issue 2 with 0.214 share of issue 1 from A_1. After one exchange, the share for A_1 is $\{x_{11} = 0.286, x_{12} = 1\}$ and for A_2 is $\{x_{21} = 0.714, x_{22} = 0\}$ when agreement is reached. The corresponding utility pair is (0.5, 0.5714), denoted by P, in the figure, lies in the Pareto frontier. Here, the agents report their true *MRS* value. Later, we will discuss the results waiving this restriction.

In the next situation, where both the agents have exactly same weights, we show in Figure 6 that without any exchange the agents reach the Pareto optimal agreement of $\{x_{i1} = 0.5, x_{i2} = 0.5\}$ share for both i = 1, 2 and the corresponding utility is P = (0.5, 0.5). To discuss the third situation, we take $w_{21} = 0.6$. In Figure 4, we show that the agents make one exchange and the final agreement is $\{x_{11} = 0.833, x_{12} = 0\}$ for A_1 and $\{x_{11} = 0.167, x_{12} = 1\}$ for A_2 leading to utility pair P = (0.5833, 0.5) lying on the Pareto frontier. In the last situation, where $w_{21} = 0.5$, that is agent A_2 is indifferent about the ordering. In Figure 5, we can see that, the agent A_1 has exchanged whole share of its least preferred issue with half of its most preferred issue. According to this agreement A_1 gets whole share of issue 1 and A_2 get whole share of issue 2. This is a Pareto optimal agreement. The corresponding utility is P(0.7,0.5).

3.3 Existence of exchange cost and strategic offer in Reallocation stage

In the last subsection, we have assumed that the agents offer according to their true *MRS* and also assumed that the cost for hosting an exchange is negligible. As we have mentioned earlier, an agent has an incentive to understate its exchange rate in order to gain some utility. In this subsection, we consider the cases where agents bid strategic offers in the *reallocation* stage. When asked for exchange offers, an agent offers *t%* less than their original marginal rate of substitution. More clearly, if an agent asks for an exchange offer for Sp share of issue p and the utility of a

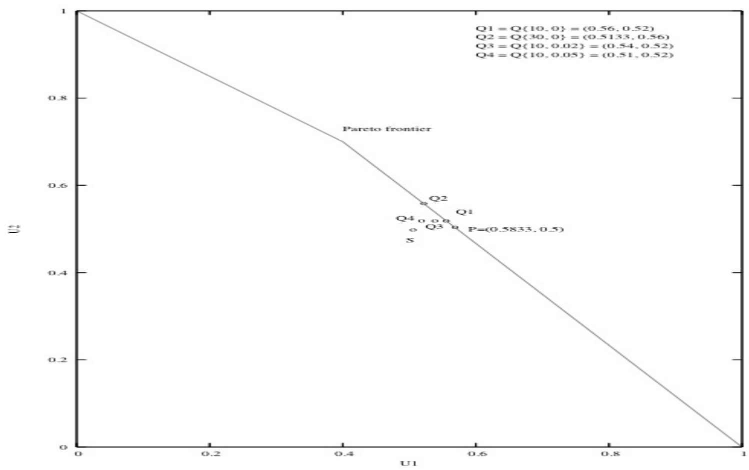

Figure 4: Bargaining solutions when two agents weights are {0.7, 0.3} and {0.6, 0.4} respectively.

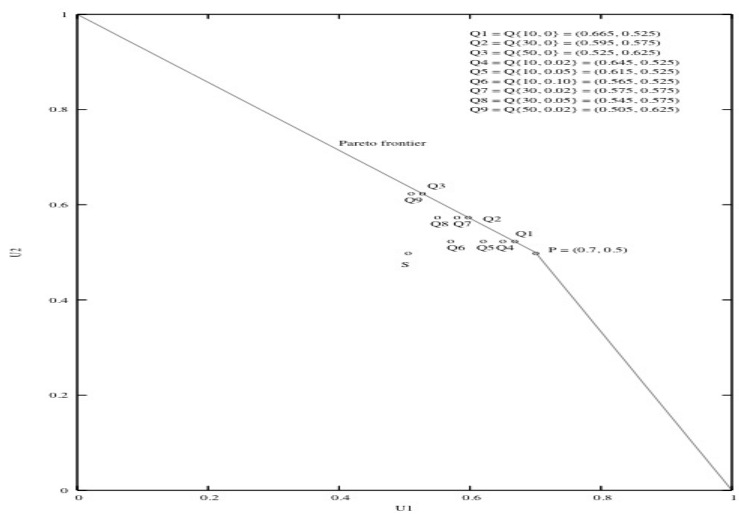

Figure 5: Bargaining solutions when two agents weights are {0.7,0.3} and {0.5,0.5} respectively.

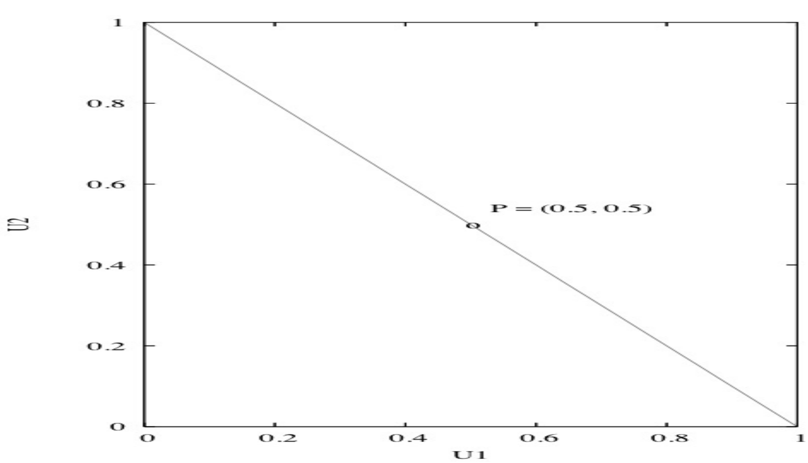

Figure 6: Bargaining solutions when two agents weights are {0.7, 0.3} and {0.7, 0.3} respectively.

share of Si of issue i produces same utility as S_p share of issue p to the responding agent, it will say $(1 - t/100)\ S_i$ share of issue i is equivalent to S_p. Also, the hosting agent accepts the proposal if the offer is more than α, the cost of hosting an exchange. We vary the values of t and α and investigate the possible inefficiencies for the same experiments we used in the last section. These two parameters t and α do not affect the negotiation solution when there is no conflict as shown in Figure 2. Again, when the preferences of the two agents are exactly the same, the agents will always reach a Pareto optimal agreement (Figure 6), independent of the values of t and α.

Now, we discuss the remaining cases where the preferences are conflicting but the weights are not exactly the same. We denote the solution point of the negotiation scenario with t and α by $Q\{t, \alpha\}$, as shown in Figure 3, 4, and 5. If any $Q\{t, \alpha\}$ point coincides with S = (0.5, 0.5), which is the "equal-split" solution, we do not plot it separatelyfor clear visualization. The possibility of an exchange decreases with an increment of α. We have observed that if the value of α is very high, there will be hardly any exchange. Similar effect is seen if the value of t rises. We have shown the effects of α and t on the bargaining solutions of the same scenarios described in the last subsection. We have varied t from 10 to 50 percent and taken α values equal to 0.02, 0.05, 0.1, which are, respectively, 2, 5 and 10 percentage of the maximum total value one can achieve from the negotiation. We have seen that when the value of α is zero, the bargaining solutions are Pareto optimal even for higher values of t. In Figure 3, agents reach Pareto optimal solution when t value is 10 and 30 but the bargaining solution coincides with S when $t = 50$. But when the value of α is positive then the solutions deviate from Pareto optimality. Though in the solution points like $Q\{10,0.05\}$ or $Q\{30, 0.02\}$ both agents are better of than being in S. We have shown the similar effects for different values of t and α in Figure 4 and Figure 5. In Figure 5, we have shown that asymmetry in the weights of the agents leads more opportunity for the agents to find a solution with joint gains even for higher values of t and α. It is clear that even when the agents are not exploring their true *MRS*, agents reach significantly improved agreement[2] points close to the Pareto-frontier. For an example, the point Q_7 in Figure 5, the agents reach an agreement producing utility pair (0.575, 0.575) even if an agent under states its true *MRS* by 30%. Q_7 is just α deviation from the point Q_2, which is on the Pareto-frontier. The deviation is because of the cost of hosting an exchange. So, unless the agents are very greedy and respond with an unreasonable rate of substitution, agents end up in a near optimal solution without true revelation of their preferences. This, we believe, is a significant improvement. Also, even if the agents are very greedy and there is no exchange in the *reallocation* phase, if there is any asymmetry in the order of preference of the two agents, this framework will lead to an improved solution. This is clear from the following proposition.

Proposition 3: *Allocation phase almost always improves the equal-split outcome.*

Proof: Consider an H-issue negotiation. For exact same preference ordering, the payoff is same as equal-split of all issues. But if there is at least one mismatch in the preference ordering, then there exists a pair of issues such that one agent prefers one than the other and the other agent prefers opposite. In this situation the rational players will improve their utility by taking the whole share of the individually preferred issues without splitting both in equal halves. Proportion of the possible preference ordering where the ordering is exact same is 1/H! . So, for $(1 - 1/H!)$ proportion of the possible preference ordering *allocation* phase improves the outcome.

4. Bilateral negotiation with more than two issues

Now we will discuss negotiation scenarios with more than two issues. We consider a negotiation with four issues. Here we consider that the agents will offer according to the true *MRS*. If they will not, then the effects will be similar to the effects in case of two issues.

Initially, we take a non-conflicting scenario. The weight distribution for agent A_1 is {0.5, 0.15, 0.1, 0.25} and agent A_2 is {0.1, 0.4, 0.3, 0.2}. Here without any exchange the agents will reach the agreement where A_1 will receive whole share of issue 1 and 4 and A_2 will receive whole share of issue 2 and 3. This is a Pareto efficient solution with utility pair (0.75, 0.7). We show this result in Figure 7.

Then we consider a scenario with conflicting preferences. We assume the same weight distribution for A_1 but change the weight distribution of A_2 to {0.35, 0.25, 0.3, 0.1}. In Figure 8, we have shown that after one exchange the agreement is reached. The share for A_1 is {0.857, 0, 0, 1} and {0.143, 1, 1, 0} for A_2. First, A_1 has exchanged its 0.5 share of issue 2 with 0.357 share of issue 1 and its utility raised from 0.575 to 0.6785 and A_2's utility is 0.6. The resulting agreement is a Pareto optimal solution. Similar experiments as previous section explores that, for different values of t and α, the agreement of the negotiation is improved and reached close to the Pareto frontier even if the

[2] An outcome O_1 is said to be improved over another outcome O_2, if the utilities of both the agents in O_1 are more than their corresponding utilities in O_2.

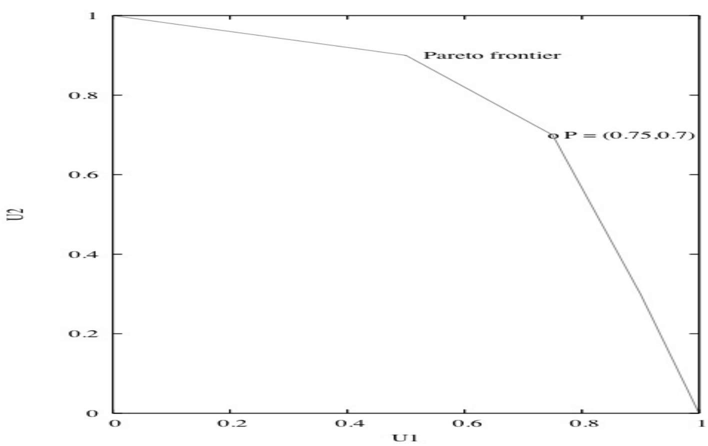

Figure 7: Bargaining solutions when two agents are negotiating four issues with non-conflicting weights {0.5, 0.15, 0.1, 0.25} and {0.1, 0.4, 0.3, 0.2} respectively.

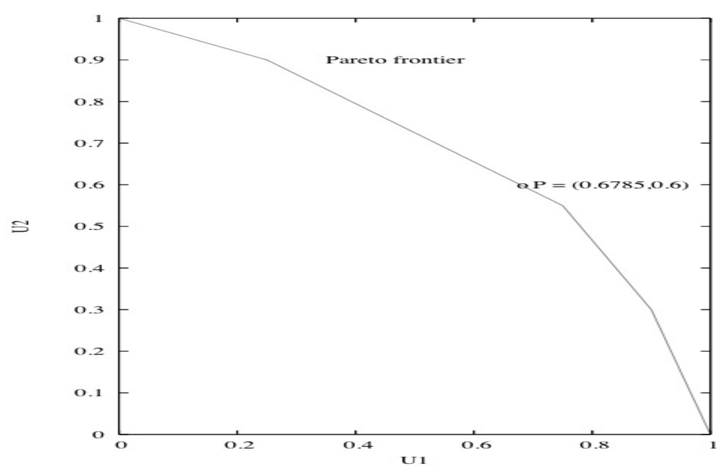

Figure 8: Bargaining solutions when two agents are negotiating four issues with weights {0.5, 0.15, 0.1, 0.25} and {0.35, 0.25, 0.3, 0.1} respectively.

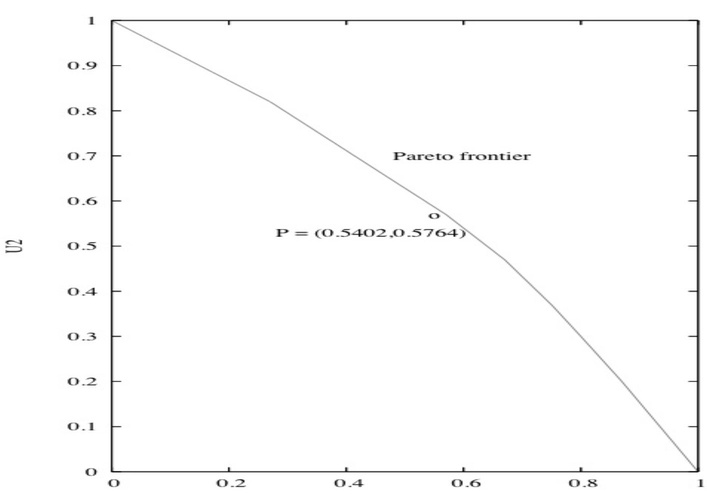

Figure 9: Bargaining solutions when two agents are negotiating four issues with weights {0.3, 0.15, 0.13, 0.12, 0.1, 0.08, 0.07, 0.05} and {0.25, 0.1, 0.2, 0.08, 0.1, 0.1, 0.1, 0.07} respectively.

agents do not truthfully reveal their preferences.

Now as the number of conflicting issues increases the scenario becomes more complex. The efficiency of the outcome depends not only on the value of α, the cost of exchange or how the agents say about the *MRS* but it also depends on the issue they are selecting to offer in the *reallocation* phase. Because of these reasons the agreements reached in this negotiation often may not reach Pareto optimality. But we have seen with extensive experimentation under varying preference that the negotiated outcomes reach close to Pareto frontier even when the agents do not reveal their preferences, except revelation of the ordinal preferences in the *allocation* phase. Next we have shown another experiments with number of issue equals to 8. In Figure 9, we can see that even with this large number of issues agents reach a solution very close to the Pareto frontier. In this experiment, we have considered the weight distribution of the two agents as {0.3, 0.15, 0.13, 0.12, 0.1, 0.08, 0.07, 0.05} and {0.25, 0.1, 0.2, 0.08, 0.1, 0.1, 0.1, 0.07} respectively. After two exchanges the agents reach a solution, which produces a utility pair of (0.5402, 0.5764). This is not a Pareto optimal solution but very close to the Pareto frontier and a significant improvement over the "equal split" solution.

5. Conclusion

This paper presents a framework for multi-issue, bilateral negotiation when agents have no knowledge about the preferences of each other. Here, the preference ordering of the agents are totally endogenous. We have discussed the possibility of exploration of joint gains by the agents under different negotiation scenario. We have shown that, for negotiations where asymmetry exists in the preferences of the agents, this framework helps the rational agents to exploit the asymmetry and find a solution which preferable to both of them with revealing only ordinal preferences. Our framework also guides the agents to reach an optimal or near-optimal solution quickly at the expense of few exchanges. The existing frameworks can lead to Pareto optimal agreement only if the preferences are known to each other, or after huge joint search, or using trusted mediator. The significant contribution of this research is to improve the agreement and reach a near optimal solution quickly even when agents do not truthfully reveal their preferences. We have also discussed the limitations of this framework.

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