On Optimal Agendas for Package Deal Negotiation

(Extended Abstract)

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ABSTRACT

This paper analyzes bilateral multi-issue negotiation where the issues are *indivisible*, there are time constraints in the form of *deadlines* and *discount factors*. The issues are negotiated using the *package deal* procedure. The set of issues to be negotiated is called the *negotiation agenda*. The agenda is crucial since the outcome of negotiation depends on the agenda. This paper therefore looks at the decision making involved in choosing a negotiation agenda. The scenario we look at is as follows. There are $m > 2$ issues available for negotiation. But from these, an agent must choose $g < m$ issues and negotiate on them. Thus the problem for an agent is to choose an agenda (i.e, a subset of g issues). Clearly, from all possible agendas (i.e., all possible combinations of g issues), an agent must choose the one that maximizes its expected utility and is therefore its *optimal agenda*. To this end, this paper presents polynomial time methods for choosing an agent's optimal agenda.

Categories and Subject Descriptors

I.2.11 [**Distributed Artificial Intelligence**]: Multiagent Systems; K.4.4 [**Computers and Society**]: Electronic Commerce

General Terms

Algorithms, Economics, Theory

Keywords

Negotiation, Game-theory, Agendas

1. INTRODUCTION

The *package deal* procedure (PDP) is one of the key procedures for negotiating multiple issues [3]. The main advantage of this procedure is that it allows the negotiators to make tradeoffs across issues and thereby reach Pareto optimal agreements. Now, in many contexts, the agents need to make a key decision before they use this procedure. They must decide what issues to include for negotiation. The set of issues included for negotiation is called the negotiation *agenda* [1, 2]. The agenda is important because the negotiation outcome critically depends on it.

In more detail, different agendas give different utilities to the agents. Hence a utility maximizing agent will want to know what agenda maximizes its individual utility and is therefore its *optimal agenda*. In order to find an agent's optimal agenda, it is necessary to know the equilibrium utilities from the possible agendas. For m issues, there are $C(m, g)$ possible agendas of size g, one (or more) of which is the optimal one. A naive approach to find an optimal agenda would be to exhaustively search the entire space of $C(m, g)$ possible agendas. This approach may not be computationally feasible because of its combinatorial time complexity. However, we prove that such exhaustive search is, in fact, not always necessary. We identify those scenarios where an optimal agenda can be computed in polynomial time and provide methods for computing it.

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2. THE NEGOTIATION SETTING

Two agents (a and b) negotiate over a set $I = \{1, 2, \ldots, m\}$ of m issues. Each issue is a 'pie' of size 1. Since the pie cannot be split, the agents want to determine who will get which pie. Let $n \in N^+$ be the deadline and $0 < \delta \leq 1$ the discount factor for both agents. The issues are negotiated using the PDP. This procedure is an alternating offers protocol [4] where an offer specifies an allocation for all the issues. Also, an agent is allowed to either accept a complete offer (i.e., the allocations for all the issues) or reject a complete offer. If we let x^a denote a's shares for the m issues, then its cumulative utility at time $t \leq n$ is defined as follows:

$$U^a(I, x^a, t) = \delta^{t-1} \sum_{i=1}^{m} w_i^a x_i^a$$

where w_i^a denote the weight for issue i and is a positive real number. For b, $U^b(I, x^b, t)$ is analogous. An agent's utility for $t > n$ is zero. Agent a has different weights for different issues while b has the same weight for all of them.

Here, the agents are uncertain about the discount factor. This uncertainty is represented as follows. There are β possible values for the discount factor. These are denoted δ_i for $1 \leq i \leq \beta$. The discount factor δ_i occurs with probability γ_i. The two agents have common knowledge of β, γ_i, and δ_i for $1 \leq i \leq \beta$. Given this uncertainty, let $\bar{\delta}$ be defined as:

$$\bar{\delta}^t = \sum_{j=1}^{\beta} \gamma_j \delta_j^t \quad (1)$$

Then agent a's expected utility at time t from an offer x^a is:

$$\begin{aligned} EU^a(I, x^a, t) &= \sum_{j=1}^{\beta} \left(\gamma_j \delta_j^{t-1} \sum_{i=1}^{m} w_i^a x_i^a \right) \\ &= \bar{\delta}^{t-1} \sum_{i=1}^{m} w_i^a x_i^a \quad (2) \end{aligned}$$

For agent b, $EU^b(I, x^b, t)$ is analogous.

DEFINITION 1. ***Negotiation game***: *For the complete information setting, a negotiation game G is defined as a six tuple*

$$G = \langle I, n, m, \delta, w^a, w^b \rangle.$$

For the incomplete information setting, it is defined as a six tuple

$$\overline{G} = \langle I, n, m, \bar{\delta}, w^a, w^b \rangle.$$

Given this, the equilibrium strategies for t denoted SA-I(t) (SB-I(t)) for a (b) are as follows.

THEOREM 1. *For a given negotiation game $\overline{G}$, the following strategies form a Bayes' Nash equilibrium. For $t = n$ they are:*

$$\text{SA-I}(n) = \begin{cases} \text{OFFER } [\mathbf{1}, \mathbf{0}] & \text{if } a\text{'s turn to offer} \\ \text{ACCEPT} & \text{if } b\text{'s turn to offer} \end{cases}$$

$$\text{SB-I}(n) = \begin{cases} \text{OFFER } [\mathbf{0}, \mathbf{1}] & \text{if } b\text{'s turn to offer} \\ \text{ACCEPT} & \text{if } a\text{'s turn to offer} \end{cases}$$

For $t < n$, the equilibrium strategies are defined as follows:

$$\text{SA-I}(t) = \begin{cases} \text{OFFER TA-I} & \text{if } a\text{'s turn to offer} \\ \text{If } EU^a(I, x^a, t) \ge EQ^a_{t+1} & \text{if } a \text{ receives } (x^a, x^b) \\ \text{ACCEPT Else REJECT} & \end{cases}$$

$$\text{SB-I}(t) = \begin{cases} \text{OFFER TB-I} & \text{if } b\text{'s turn to offer} \\ \text{If } EU^b(I, x^b, t) \ge EQ^b_{t+1} & \text{if } b \text{ receives } (x^a, x^b) \\ \text{ACCEPT Else REJECT} & \end{cases}$$

where EQ^a_t (EQ^b_t) denotes a's (b's) expected equilibrium utility for time t. An agreement takes place at $t = 1$.

2.1 The Negotiation Agenda

The terms agenda and optimal agenda are defined as follows:

DEFINITION 2. ***Agenda***: *For a given negotiation game (G or $\overline{G}$), an agenda A^g of size $g \le m$ is a set of g issues, i.e., $A^g \subseteq I$ where $|A^g| = g$.*

Let AG^g denote the set of all possible agendas of size g.

DEFINITION 3. ***Optimal agenda***: *Given a game $\overline{G} = \langle I, n, m, \bar{\delta}, w^a, w^b \rangle$ and an integer $g < m$, an agenda (AA^g) of size g is agent a's optimal agenda if*

$$AA^g = \underset{X \in AG^g}{arg\ max} \quad EU^a(X, x^a, 1)$$

where x^a denotes a's equilibrium allocation (for agenda X and $t = 1$). For the complete information setting, EU^a is replaced with U^a. Agent b's optimal agenda AB^g is defined analogously.

For the set I containing m issues, Theorem 1 showed how to find equilibrium outcomes. Given this equilibrium, we show how to find each agent's optimal agenda: AA^g and AB^g for $1 < g < m$. The issues in all sets and agendas we will refer to in the subsequent sections will be in ascending order of a's weights.

3. OPTIMAL AGENDAS

Theorem 2 shows how to find a's optimal agenda and Theorem 3 that for b.

THEOREM 2. *For a given negotiation game G and a $g < m$, agent a's optimal agenda of size g is a set of g issues associated with the g highest weights for a, i.e.,*

$$AA^g = \{m - g + 1, \ldots, m\}$$

Agenda	b is first mover				a is first mover			
	U^a	U^b	a's Opt Agenda ?	b's Opt Agenda ?	U^a	U^b	a's Opt Agenda ?	b's Opt Agenda ?
$\{1,2,3\}$	45	10	No	No	25	20	No	Yes
$\{1,2,4\}$	40	20	No	Yes	40	20	Yes	Yes
$\{1,3,4\}$	40	20	No	Yes	40	20	Yes	Yes
$\{2,3,4\}$	65	10	Yes	No	40	20	Yes	Yes

Table 1: The agents' utilities for Example 1 (for $t = 1$) for all possible agendas of size $g = 3$.

Example 1 illustrates the use of Theorem 2.

EXAMPLE 1. *Let $m = 4$, $I = \{1, 2, 3, 4\}$, $g = 3$, $\delta = 0.5$, $n = 2$, $w^a = \{10, 20, 25, 40\}$, and $w^b = \{10, 10, 10, 10\}$. There are four possible agendas of size $g = 3$: $\{1, 2, 3\}$, $\{1, 2, 4\}$, $\{1, 3, 4\}$, and $\{2, 3, 4\}$. For each of them, the agents' equilibrium utilities for $t = 1$ (i.e., U^a and U^b) are as given in Table 1. Agent a's utility U^a is highest for the agenda $\{2, 3, 4\}$, so $AA^3 = \{2, 3, 4\}$ is a's optimal agenda. This is true when b is the first mover and also when a is.*

THEOREM 3. *For a given negotiation game G and a $g < m$, let $\overline{AG}^g$ denote the set of agendas (each of size g) such that $\{I_1, \ldots, I_{g-i}, I_z, I_{m-i+2}, \ldots, I_m\} \in \overline{AG}^g$ for $g - i + 1 \le z \le m - i + 1$, and $1 \le i \le g$. Then $\overline{AG}^g$ contains at most $(m - g + 1)g$ elements and $AB^g \in \overline{AG}^g$.*

The advantage of Theorem 3 is that it reduces the size of search space from $C(m, g)$ to $(m-g+1)g$. This is because, for exhaustive search, the search space is AG^g which contains $C(m, g)$ agendas where

$$C(m, g) = \frac{m!}{(m - g)!g!} \tag{3}$$

So one must search these $C(m, g)$ agendas to find an optimal one. In contrast, Theorem 3 reduces the search space to $(m - g + 1)g$.

4. CONCLUSIONS AND FUTURE WORK

This paper analyzed bilateral multi-issue negotiation where the issues are *indivisible*, there are time constraints in the form of *deadlines* and *discount factors*, and the agents have different preferences over the issues. The issues are negotiated using the *package deal* procedure. Polynomial time methods for finding an agent's optimal agenda were presented.

5. REFERENCES

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