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Effective acceptance conditions in real-time automated negotiation

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ABSTRACT

In every negotiation with a deadline, one of the negotiating parties must accept an offer to avoid a break off. As a break off is usually an undesirable outcome for both parties, it is important that a negotiator employs a proficient mechanism to decide under which conditions to accept. When designing such conditions, one is faced with the acceptance dilemma: accepting the current offer may be suboptimal, as better offers may still be presented before time runs out. On the other hand, accepting too late may prevent an agreement from being reached, resulting in a break off with no gain for either party. Motivated by the challenges of bilateral negotiations between automated agents and by the results and insights of the automated negotiating agents competition (ANAC), we classify and compare state-of-the-art generic acceptance conditions. We perform extensive experiments to compare the performance of various acceptance conditions in combination with a broad range of bidding strategies and negotiation scenarios. Furthermore we propose new acceptance conditions and we demonstrate that they outperform the other conditions. We also provide insight into why some conditions work better than others and investigate correlations between the properties of the negotiation scenario and the efficacy of acceptance conditions.

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1. Introduction

Negotiation is an important process to reach trade agreements, and to form alliances or resolve conflicts. The field of negotiation originates from various disciplines including artificial intelligence, economics, social science, and game theory (e.g., [2,20,25]). The strategic-negotiation model has a wide range of applications, such as resource and task allocation mechanisms, conflict resolution mechanisms, and decentralized information services [20,32].

A number of successful negotiation strategies have already been established both in literature and in implementations, (e.g. [6,8,9,14,15,22]). And more recently, in 2010 seven new negotiation strategies were created to participate in the first automated negotiating agents competition (ANAC 2010) [3] in conjunction with the Ninth International Conference on Autonomous Agents and Multiagent Systems (AAMAS-10). During post tournament analysis of the results, it became apparent that different agent implementations use various conditions to decide when to accept an offer. It is important for every negotiator to employ such a mechanism to decide under which conditions to accept, because in every negotiation with a deadline, one of the negotiating parties has to accept in order to avoid a break off. However, designing a proper acceptance condition is a difficult task: accepting too late may result in the break off of a negotiation, while accepting too early may result in suboptimal agreements.

The importance of choosing an appropriate acceptance condition is confirmed by the results of ANAC 2010 (see Table 1). Agents with simple acceptance criteria were ranked at the bottom, while the more sophisticated time- and utility-based criteria obtained a higher score. For instance, the low ranking of *Agent Smith* was due to a mistake in the implementation of the acceptance condition [33].

Despite its importance, the theory and practice of acceptance conditions has not yet received much attention. The goal of this paper is to classify current approaches and to compare acceptance conditions in an experimental setting. Thus in this paper we will concentrate on the final part of the negotiation process: the acceptation of an offer. We focus on decoupled acceptance conditions: i.e., generic acceptance conditions that can be used in conjunction with an arbitrary bidding strategy. The reason for this is straightforward: we want to be able to re-incorporate the acceptance conditions that have been found most effective into new agent designs; therefore, the acceptance conditions under investigation should not be coupled with a specific agent implementation.

Our contribution is fourfold:

1. We give an overview and provide a categorization of current decoupled acceptance conditions.
2. We introduce a formal negotiation model that supports the use of arbitrary acceptance conditions.
3. We compare a large selection of current generic acceptance conditions and evaluate them in an experimental setting.

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Table 1
An overview of the rank of every agent in ANAC 2010 and the type of acceptance conditions that they employ. Agents using time and utility based acceptance conditions were ranked at the top, except for *Agent Smith*, which had a faulty acceptance mechanism.

Rank	Agent	Acceptance condition
1	*Agent K*	Time and utility based
2	*Yushu*	Time and utility based
3	*Nozomi*	Time and utility based
4	*IAMHaggler*	Utility based only
5	*FSEGA*	Utility based only
6	*IAMcrazyHaggler*	Utility based only
7	*Agent Smith*	Time and utility based

4. We propose new acceptance conditions and test them against established acceptance conditions, using varying types of bidding techniques.

The remainder of this paper is organized as follows. Section 2 defines the model of negotiation that we employ and provides an overview of current acceptance conditions. In Section 3, we also consider combinations of acceptance conditions. Section 4 discusses our experimental setup and results, which demonstrate that some combinations outperform traditional acceptance conditions. Finally, Sections 6 and 7 outline our conclusions and our plans for further research on acceptance strategies.

2. Acceptance conditions in negotiation

This paper focuses on acceptance conditions (also called acceptance criteria) that are decoupled: i.e. generic acceptance conditions that are not tied to a specific agent implementation and hence can be used in conjunction with an arbitrary bidding strategy. We first describe a general negotiation model that fits current decoupled acceptance conditions. We have surveyed existing negotiation agents to examine the acceptance criteria that they employ. We then categorize them according to the input that they use in their decision making process.

2.1. Negotiation model

We consider *bilateral* negotiations, i.e. a negotiation between two parties or agents A and B. The agents negotiate over *issues* that are part of a negotiation *domain*, and every issue has an associated range of alternatives or *values*. A negotiation outcome consists of a mapping of every issue to a value, and the set Ω of all possible outcomes is called the *outcome space*. The outcome space is common knowledge to the negotiating parties and stays fixed during a single negotiation session.

We further assume that both parties have certain preferences prescribed by a *preference profile* over Ω. These preferences can be modeled by means of a utility function U, which maps a possible outcome $\omega \in \Omega$ to a real-valued number in the range [0, 1]. In contrast to the outcome space, the preference profile of the agents is private information.

Finally, the interaction between negotiating parties is regulated by a *negotiation protocol* that defines the rules of how and when proposals can be exchanged. We use the alternating-offers protocol [29] for bilateral negotiation, in which the negotiating parties exchange offers in turns.

As in [31], we assume a common global time, represented here by $\mathcal{T} = [0,1]$. We supplement the alternating-offers protocol with a deadline at $t = 1$, at which moment both agents receive utility 0. This is the same setup as [10], with the exception that issues are not necessarily real-valued and both agents have the same deadline equal to $t = 1$. We represent by $x^t_{A\rightarrow B}$ the negotiation outcome proposed by agent A to agent B at time t. A *negotiation thread* (cf. [8,31]) between two agents A and B at time $t \in \mathcal{T}$ is defined as a finite sequence

$$H^t_{A\leftrightarrow B} := \left(x^{t_1}_{p_1\rightarrow p_2}, x^{t_2}_{p_2\rightarrow p_3}, x^{t_3}_{p_3\rightarrow p_4}, \ldots, x^{t_n}_{p_n\rightarrow p_{n+1}}\right), \tag{1}$$

which satisfies the following constraints:

1. $t_k \le t_l$ for $k \le l$, the offers are ordered over time $\mathcal{T}$,
2. $p_k = p_{k+2} \in \{A,B\}$ for all k, the offers are alternating between the agents,
3. All t_i represent instances of time $\mathcal{T}$, with $t_n \le t$,
4. $x^{t_k}_{p_k\rightarrow p_{k+1}} \in \Omega$ for $k \in \{1, \ldots, n\}$, the agents exchange complete offers.

Additionally, the last element of $H^t_{A\leftrightarrow B}$ may be equal to one of the particles {*Accept*, *End*}. We will say a negotiation thread is *active* if this is not the case.

When agent A receives an offer $x^t_{B\rightarrow A}$ from agent B sent at time t, it has to decide at a later time $t' > t$ whether to accept the offer, or to send a counter-offer $x^{t'}_{A\rightarrow B}$. Given a negotiation thread $H^t_{A\leftrightarrow B}$ between agents A and B, we can formally express the action performed by A with an *action function* X_A:

$$X_A\left(t', x^t_{B\rightarrow A}\right) = \begin{cases} End & \text{if } t' \ge 1 \\ Accept & \text{if } \mathbf{AC}_A\left(t', x^{t'}_{A\rightarrow B}, H^t_{A\leftrightarrow B}\right) \\ Offer\ x^{t'}_{A\rightarrow B} & \text{otherwise.} \end{cases} \tag{2}$$

Note that we extend the setting of [10,31] by introducing the *acceptance condition* $\mathbf{AC}_A$ of an agent A. When used in this way, the model enables us to study arbitrary decoupled acceptance conditions. The acceptance condition $\mathbf{AC}_A$ takes as input

$$\mathcal{I} = \left(t', x^{t'}_{A\rightarrow B}, H^t_{A\leftrightarrow B}\right), \tag{3}$$

the tuple containing the current time t', the offer $x^{t'}_{A\rightarrow B}$ that the agent considers as a bid (in line with the bidding strategy the agent uses), and the ongoing negotiation thread $H^t_{B\leftrightarrow A}$.

The resulting action given by the function $X_A(t', x^t_{B\rightarrow A})$ is used to extend the current negotiation thread between the two agents. If the agent does not accept the current offer, and the deadline has not been reached, it will prepare a counter-offer $x^{t'}_{A\rightarrow B}$ by using a bidding strategy or *tactic* to generate new values for the negotiable issues. Tactics can take many forms, e.g. time-dependent, resource dependent, imitative, and so on [31]. In our setup we will consider the tactics as given and try to optimize the accompanying acceptance conditions.

2.2. Acceptance criteria

Let an active negotiation thread

$$H^t_{A\leftrightarrow B} = \left(x^{t_1}_{p_1\rightarrow p_2}, x^{t_2}_{p_2\rightarrow p_3}, \ldots, x^{t_{n-1}}_{A\rightarrow B}, x^{t_n}_{B\rightarrow A}\right),$$

be given at time $t' > t = t_n$, so that it is agent A's turn to perform an action.

As defined by Eq. (1) in our negotiation model, the action function X_A of an agent A uses an acceptance condition $\mathbf{AC}_A(\mathcal{I})$ to decide whether to accept. In practice, most agents do not use the full negotiation thread to decide whether it is time to accept. For instance many agent implementations, such as [10,11,31], use the following implementation of $\mathbf{AC}_A(\mathcal{I})$:

$$\mathbf{AC}_A\left(t', x^{t'}_{A\rightarrow B}, H^t_{A\leftrightarrow B}\right) \Leftrightarrow U_A\left(x^t_{B\rightarrow A}\right) \ge U_A\left(x^{t'}_{A\rightarrow B}\right).$$

That is, A will accept when the utility U_A for the opponent's last offer at time t is greater than the value of the offer agent A is ready

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