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Automated negotiation in open and distributed environments ☆

Minyi Li [a,*], Quoc Bao Vo [a], Ryszard Kowalczyk [a], Sascha Ossowski [b], Gregory Kersten [c]

[a] Swinburne University of Technology, Melbourne, Australia
[b] University Rey Juan Carlos, Madrid, Spain
[c] Concordia University, Montreal, Canada

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ABSTRACT

Automated negotiation is one of the most common approaches used to make decisions and manage disputes between computational entities leading them to optimal agreements. Many existing works tackle single-issue negotiations and the negotiation environment is assumed to be static so that the agents can make decisions based solely on the proposals of the counterparts and their own fixed parameters. Most real-world scenarios, however, involve complex domains and dynamic environments. In such cases, it is no longer sufficient to consider negotiation as an isolated activity in a static environment. Therefore, a more general framework for automated negotiation is needed in which the negotiation agents can be very flexible and adaptive. In this paper, we describe a generic framework for automated negotiation, which captures descriptively the social dynamics of the negotiation process. The proposed framework enables the agents to behave responsively to the changes in the environment. Their strategies can adapt as the conditions outside of the negotiation change to ensure that their decisions remain rational. And the agents are proactive and responsive by searching for options, which are outside of the negotiation and which may improve their outcomes. The key ideas and the overall system architecture together with a specific negotiation instance in a basic bilateral setting are described, along with two illustrative examples. The first example is in the context of e-commerce, and the second example is an application scenario of service level agreement negotiation in service computing. We also describe a prototypical implementation of the proposed negotiation framework.

1. Introduction

Multi-agent systems are computational approaches that are increasingly being used for solving real world, dynamic and open system problems (Ferber, 1999). Many important scenarios are conceptualized as a collection of autonomous agents with multiple perspectives and/or competing interests that interact with one another to search for collective solutions. That is, they are required to reach an agreement on the joint action or the joint decision to be adhered to by all involved parties. Automated negotiation has been identified as one of the key mechanisms for efficient and effective cooperation of the computational entities leading them to optimal agreements (Jennings et al., 2001; Vo, Padgham, & Cavedon, 2007). A number of models have been proposed in the literature to support agents reaching mutually acceptable agreements in automated negotiations (see, e.g., Fatima, Wooldridge, & Jennings, 2004; Jennings et al., 2001; Kersten & Cray, 1996; Kersten & Noronha, 1998; Kowalczyk, 2002; Vo et al., 2007). Nevertheless, they are fairly restricted by assumptions about the agents' preferences as well as the fixed items or issues to be negotiated. Therefore, most existing approaches to automated negotiation treat the negotiation as an isolated activity in which a negotiator makes decisions based solely on the proposals of the counterparts and the negotiator's own fixed parameters, and they could easily become impractical in complex problem domains. However, in most real-world environments, multiple aspects of negotiation typically need to be taken into consideration with agents dynamically entering and leaving the environment, while new issues being proposed, and new requirements and constraints becoming available. In such cases, a negotiator's parameters and the dynamics of the interaction may be changed. Hence, a more general model for automated negotiation is required to accommodate and facilitate agents with flexible and adaptive behaviors.

To this end, we introduce a generic negotiation framework that enables the agents to capture the dynamic changes of negotiation environment, for instance, the newly arrived negotiation partners and market offers and the change of their positions and power in negotiation. In the proposed model, neither the process of

* Corresponding author. Tel.: +61 3 9214 8451.
E-mail addresses: myli@swin.edu.au (M. Li), BVO@swin.edu.au (Q.B. Vo), RKowalczyk@swin.edu.au (R. Kowalczyk), sascha.ossowski@urjc.es (S. Ossowski).

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negotiation nor the agent's negotiation strategy is considered as isolated activities. An agent involved in a negotiation may engage in other activities (including searching for options outside of the negotiation or concurrently negotiate for a similar deal). For instance, consumers of a scarce resource who are negotiating with providers over the resource price for a contractual period may actively search for alternative providers, engage in another negotiation with other potential providers, or decide to wait because of the providers' agreement for a significant capacity increase followed by price reduction. Moreover, the proposed model enables the agents to behave responsively to changes in the environment: they can adapt as the conditions outside of the negotiation change to ensure that their decisions remain rational. For instance, knowing that there is a much better option outside compared to the current negotiating outcome, an agent may strengthen her position against making further concessions. On the other hand, if an agent finds that there are not many good alternative options, she may be more willing to concede for reaching an agreement with the current negotiating partner. While such considerations make the negotiation problem more complex, they reflect better most real-world negotiation situations.

From a technical point of view, our proposed framework mathematically integrates the important concepts of the *best alternative to a negotiated agreement* (BATNA) and the agents' two forces, namely *resistance and concession forces* into automated negotiation. Instead of focusing on an isolated negotiation process, the proposed framework enables the agents to search for outside options, and thus, proactively improve their BATNA during negotiation. As their new BATNAs becoming available, the agents will then dynamically incorporate this information to update their resistance and concession forces in negotiation, and eventually, leading to a rational change towards their negotiation strategies and decisions.

The proposed negotiation framework can be applied to large-scale complex and open distributed systems, such as cloud computing and pervasive computing environments. In these systems, resources (including hardware and software) are not always available, with the need for on-demand provision of resources according to dynamic requirements. The usage models for such environments include a variety of owners, providers and consumers with different and varying usage, access policies, cost models, loads, requests and availability. This decentralized computing structure has benefits in terms of reduced coupling and increased flexibility; and is necessary where computing systems have to interact across organizational boundaries. In order for these entities to successfully interact and cooperate, it is essential that they communicate, negotiate and coordinate. For instance, coordination-based negotiation is a common need in service delivery frameworks and service aggregation where a service broker can also act as a coordinator between negotiating parties. As another example, in pervasive computing environments, mobile devices tend to engage in direct negotiation with other devices or services. We believe that the outcomes of this work will be of great importance to a wide range of application areas such as service economy, smart energy grids and smart transportation. It will enable the IT industry to utilize distributed systems and agent technologies in developing the software-driven knowledge economy of the 21st century.

The rest of this paper is organized as follows. In Section 2, we discuss some related work including multi-issue negotiation, resistance force and concession force, search in negotiation, as well as some existing negotiation systems. In Section 3, we start with a motivating example, followed by a description of the overall system model. We also discuss the negotiation ontology and protocols considered in this framework. Subsequently, we discuss the negotiation software agents in Section 4, in which we study the activities carried out by the involved agents during the negotiation process, and a generic software agent architecture. After that, we describe a specific instance of negotiation with a bilateral setting in Section 5, followed by an example of practical buyer and seller negotiation in Section 6, and another example of service level agreement negotiation in Section 7. We present a prototypical implementation of the proposed negotiation framework in Section 8. Finally, in Section 9 we give some concluding remarks about the framework and approaches discussed in this paper.

2. Related work

2.1. Multi-issue negotiation, IBN and BATNA

Automated negotiation can provide an efficient and effective mechanism for cooperation between computational entities leading them to optimal agreements (Sandholm, 1999; Jennings et al., 2001). Various interaction and decision-making mechanisms for automated negotiation have been proposed and studied in the literature, including game-theoretic analysis (Kersten & Cray, 1996; Kersten & Noronha, 1998; Kraus, 2001; Li et al., 2009; Rosenschein & Zlotkin, 1994; Ros & Sierra, 2006; Vo et al., 2007); heuristic-based approaches (Faratin, 2000; Fatima, Wooldridge, & Jennings, 2002; Kowalczyk, 2002; Kowalczyk & Bui, 2001); and argumentation-based approaches (Kraus, Sycara, & Evenchik, 1998; Parsons, Sierra, & Jennings, 1998; Sierra et al., 1997), etc. In real world scenarios, situations in which multiple issues are involved in a negotiation simultaneously are common. Examples include, the price, quality attributes and delivery time in a supply contract; or the response time, levels of security and traceability in a service level agreement; or multiple features of a product, e.g., resolution rate, weight and model of a camera for sale. In such situations, the negotiation agents are able to make trade-offs and search for possible joint gains. This means that they may increase their utility by lowering their requirements on some negotiation issues that are not so important to them while demanding more on other more important issues, thus leading to an agreement that is mutually better.

In Fisher and Ury's seminal monograph (1991), they discuss several important concepts to render successful negotiation strategies and achieve mutually optimal negotiation outcomes. The authors offer a systematic approach to negotiating and consensus building by asserting that the first step in negotiation or consensus building is to focus on the interests and not on the positions held by the parties involved. In negotiation, the parties have legitimate interests to be protected and advanced. Often the interests are not the same. Sometimes they are directly opposed. Subsequently, by exploring and learning about the parties' interests, "options for mutual gains" may be constructed. This technique is known as interest-based negotiation (IBN). Interest-based bargaining enables traditional negotiators to become joint problem-solvers and therefore creating win–win situations.

Since the introduction of the principled approach of interest-based negotiation (IBN), it has attracted significant interest and attention in social sciences (McCarthy, 1985). On the other hand, most research on automated negotiation by computer scientists has been centered on the game-theoretic approaches by establishing equilibrium for the negotiation games, see e.g., (Nash, 1950; Rubinstein, 1982). To the best of our knowledge, Rahwan (2004), Rahwan et al. (2003) and Rahwan, Sonenberg, and Dignum (2003) have been the only researchers who make an effort to bring the IBN approach to automated negotiation. Nonetheless, their approach is based on the argumentation frameworks and rational dialogues for multi-agent systems which assume that the agents share the same ontology and understanding of the arguments.