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Whom should I persuade during a negotiation? An approach based on social influence maximization

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ABSTRACT

During a negotiation, an agent must make several key decisions in order to achieve a profitable agreement. When the negotiation is carried out in a social context, agents can use persuasion, besides the traditional exchange of concessions. To carry out the persuasion and make concessions, the agents must employ resources that are usually scarce. For this reason, the agents should carefully decide which opponent they should persuade to maximise their profit, especially when the negotiation involves multiple parties. To make this decision, we propose that the agents should persuade the opponents with a high influence on the other agents involved in the negotiation. Therefore, we represent a negotiation context as a social influence maximization problem and solve it under a model that learns how influence flows in a network by analyzing historical information. This allows an agent to determine what opponents exert the highest influence. Finally, the agent uses this information to decide which opponent to persuade during the negotiation. Experimental results showed that the agreement rate increased when agents applied this approach.

1. Introduction

In multi-agent systems, negotiation is a fundamental tool to reach an agreement among agents with conflicting goals. Negotiation is a form of interaction in which a group of agents, with conflicting interests and a desire to cooperate, try to come to a mutually acceptable agreement on the division of scarce resources [1]. The essence of the negotiation process is the exchange of proposals. Agents make proposals and respond to proposals in order to make concessions and converge on a mutually acceptable agreement. However, not all approaches are restricted to an exchange of proposals. In argumentation-based approaches [2–4,1,5,6], agents are allowed to exchange some additional information as arguments, besides the information uttered on the proposals, where social factors play an important role. Thus, in the context of the negotiation, an argument is seen as a piece of information that supports a proposal and allows an agent (a) to justify its position of negotiation, or (b) to influence the position of negotiation of other agents [7].

In some scenarios, the negotiation includes multiple parties (for example, a group of personal agents that should negotiate date, place and topics of a meeting on behalf of users). In these scenarios, agents make proposals, present arguments to persuade other agents, and accept or reject other proposals. In general, when an agent persuades another agent, some scarce resources are affected by the succeeding concessions that it must carry out during this process. Particularly, this fact is further reinforced when agents exchange rewards and threats as a form of rhetorical arguments [8,9]. In other words, persuading an opponent and making concessions have additional costs to the act of simply uttering an argument or a proposal [8,10]. In this context, it is necessary for the agent to manage the concessions that it can offer, in order to ensure maximum influence on the rest of the participants. For example, once an agent is persuaded to accept a proposal, this agent is expected to continue participating in the negotiation in favour of such proposal. Thus, if the agent succeeds in persuading an influential participant, then this participant is expected to be able to persuade a great number of participants on its own account. In contrast, if the agent persuades a participant with little influence, the possibility of propagating the proposal will be smaller. For this reason, deciding which participant to persuade is a key task, due to the fact that the proposal spread will be higher if the influence of the persuadee is also higher.

Moreover, the agents of a multilateral negotiation usually form (implicitly or explicitly) a social network in which several social factors affect the negotiation result directly or indirectly. For example, these factors are the trust among participants [4], their reputation [11], and authority roles [3], among others. Additionally, these factors are related to the spread of influence through a social network. The study of the spread of influence exerted by users of a social network on other users has received great attention in the last years. A key problem in this area is the influence maximization problem. The influence maximization problem involves finding a set of users in a social network, such

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that by targeting this set, one maximises the expected spread of influence in the network [12,13].

In this context, we propose an approach that allows an agent to decide which opponent to persuade by observing the degree of influence that the agents exert during the negotiations, and assuming that the resources available during the negotiation are scarce. To do this, we adapt the traditional influence maximization problem to the negotiation context and apply a data-based approach to social influence maximization that learns how influence flows in a network by directly leveraging available propagation traces, named *Credit Distribution Model* [12].

On the other hand, the feasibility and benefits of using autonomous agents in negotiations with humans have been shown in several works [14–16]. For this reason, although we present our approach from a perspective of autonomous agents, we claim that our approach can also be applied to assist human negotiators by guiding them to make decisions, which increases their benefits, during a negotiation.

The experiments were carried out under several configurations, taking into account the number of agents involved in the negotiation, the number of previous negotiation traces used to train the model, the social network density (graph density), the average trust level among the agents, and the trust update rate (we took into account that trust among agents can change during the negotiations). Experimental results showed that the agreement rate increases when an agent decide, and is able, to persuade the opponent that maximises the expected influence spread according to the Credit Distribution model. Moreover, the results showed that the increase of the agreement rate is high in some configuration (e.g., when the social network density is low and the trust level is high) and low in others (e.g., when both the social network density and the trust level is high).

In short, we highlight two main contributions of this work. First, this work presents an approach that allows an agent to improve the agreement rate during multilateral negotiations by indicating which opponent to persuade. Moreover, we present an experimental analysis that shows in which scenarios the social influence plays an important role during the selection of an opponent to persuade.

The article is organised as follows. Section 2 introduces basic concepts about negotiation and social influence maximization. Section 3 presents the approach to decide which opponent to persuade according to its influence. Section 4 shows the results obtained from the experiments. Finally, Section 5, states our conclusions and suggests future work.

2. Backgrounds

In this section, we review two relevant fields for our work, namely, negotiation among intelligent agents and social influence maximization. Thus, in the next section, we review some concepts about negotiation. Next, we introduce the main concepts on social influence maximization, propagation models and algorithms.

2.1. Negotiation among intelligent agents

Negotiation is a form of interaction in which a group of agents, with conflicting interests and a desire to cooperate, try to come to a mutually acceptable agreement on the division of scarce resources [1]. Much work on negotiation is either concerned with bilateral (one-to-one) negotiation [17] or with auctions [18]. However, in many real negotiation scenarios groups of more than just two agents can freely come together and agree on a deal [19]. For this reason, several multilateral negotiation protocols have been proposed. In these protocols, a multilateral agreement is defined as an agreement that is reached iff one agent makes a proposal that is at least as good for each other agent as their own current proposal [19]. Obviously, as the number of agents increases, reaching a multilateral agreement is more difficult than reaching a bilateral one. Despite the fact that the multilateral negotiation protocols define the rules to guide the agents to an agreement, the agents must usually take some key decisions to reach a profitable agreement.

As stated previously, the agents can exchange proposals and arguments during a negotiation. To carry out this exchange, the agent must possess a set of resources over which the concessions are made. For example, from the point of view of the proposal exchange, when a seller reduces the price of a good in order to reach a deal with a buyer, the seller is also reducing her/his revenue in exchange for an agreement. Moreover, when the agents exchange rhetorical arguments, the use of a reward to persuade an opponent to accept a deal implies that the agent must concede some resources as a reward in exchange for the acceptance [8,9]. As a result, it is important that the agent carefully select the target of its concessions.

On the other hand, in addition to the utility of a proposal, there are other factors that determine whether an agreement will be reached or not. These factors participate actively during the persuasion process.

Mainly, the trust among the agents is a crucial factor. In the most abstract manner, trust is a relation between a trustor and a trustee in a context [20]. There are several kinds of trust. For example, we can distinguish between *human trust* and *computational trust*. Human trust refers to a mental state of humans. However, computational trust describes representations of trust used in trust management systems. Moreover, computational trust is usually processed in a manner that aims to replicate how humans reason about human trust. In addition, without explicitly making the distinction between human and computational trust, we can found more detailed definitions of trust. *Expectancy trust* is a subjective, context-dependent expectation that the trustee will choose a specific action in an encounter. Furthermore, *dependency trust* can be defined as the subjective, context-dependent extent to which the trustor is willing to depend on the trustee in a situation of uncertainty [20].

Particularly, in our work, we understand trust as expectancy trust, since this definition is widely adopted in the field of negotiation among intelligence agents [21]. Thus, trust is seen as a relation between two entities such that one entity (trustor) believes, expects and accepts that a trusted entity (trustee) will act or intend to act beneficially [22]. Trust is an especially important issue from the perspective of autonomous agents and multi-agent systems [21]. Agents usually maintain a trust network of their acquaintances, which includes ratings of how much those acquaintances are trusted, and how much those acquaintances trust their acquaintances, and so on [23]. Agents compute this trust from different information sources. Direct experiences (the experience based on the direct interaction with the acquaintance) and witness information (the information that comes from other members of the community) are the traditional information sources used by computational trust [21].

When agents use argumentation to persuade other agents during a negotiation, trust is used to determine which kind of argument they should utter as well as to evaluate the proposals and arguments that they receive. In agreement with this idea, Ramchurn et al. [4] proposed an approach for persuasive negotiation and defined rules for argument selection by observing the trust in the opponent and the expected utility of the proposal. For example, if the trust is low and the utility is high then the agent should send a strong argument, but if the trust is high and the utility low, then it should utter a weak one. The authors also proposed specific evaluation functions that agents can use whenever a proposal, whether or not supported by an argument, is received. These functions incorporate the notion of trust as the confidence in the opponent to fully carry out a proposed action (be it a proposal or an argument). For example, the agent evaluates a received proposal by calculating the expected utility of moving into the proposed state weighted by the trust in the sender, added to the expected utility of remaining in the present state weighted by the amount of distrust in the other party. Similarly, trust is applied in several negotiation-related scenarios: auctions [24,25], argumentation [23], multi-agent cooperation [26], and e-commerce [27], among others. Moreover, other social factors, such as authority roles, have been taken into account to