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Learning and adaptation of strategies in automated negotiations between context-aware agents

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Abstract This work presents the hypothesis that guided the research efforts and a summary of the contributions of the doctoral thesis 'Learning and adaptation of strategies in automated negotiations between context-aware agents'. Succinctly, the thesis focuses on agents for automated bilateral negotiations that make use of the context as a key source of information to learn and adapt negotiation strategies in two levels of temporal abstraction. At the highest level, agents employ reinforcement learning to select strategies according to contextual circumstances. At the lowest level, agents use Gaussian Processes and artificial Theory of Mind to model their opponents and adapt their strategies. Agents are then tested in two Peer-to-Peer markets comprising an Eco-Industrial Park and a Smart Grid. The results highlight the significance for the automation of bilateral negotiations of incorporating the context as an informative source.

Keywords: Automated Negotiation; Multi-Agent Systems; Context-awareness; Artificial Theory of Mind; Peer-to-Peer Markets.

1. Introduction

Negotiation is a strategic interaction mechanism involving different actors (people, organizations or software agents) that allows them to obtain greater benefits than those they would obtain by operating individually [5]. The human capacity to negotiate competitively in each of the potential negotiation situations within today's complex markets is far exceeded by the dynamism and variability typical of those markets [12]. Likewise, the sustained increase in the quantity and variety of information available and the number of transactions that some markets demand prevent effective human intervention in the short periods of time available to negotiate. Hence, modern market models based on negotiation and collaborative economy approaches are often not implemented or are not sustainable [16].

Automated negotiation [13] between agents [15] is an important field of study in artificial intelligence today. This importance finds support in the possibilities offered by promising technologies in various fields such as computing (new machine learning algorithms and deep representations), electronics (for instance, the increase in computational power for calculations in BlockChain schemes) and robotics (smart sensors and actuators). The implementation of software agents with the capacity to negotiate and the integration with the available technology could provide new productive and predictable capabilities to scale and simplify the management of large volumes of information.

Negotiation agents were studied in simulated environments against different opponents and under different circumstances [14]. Promising results have been obtained [2] that demonstrate the relevance

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of addressing the study of the learning and adaptation of strategies. However, several aspects of the automated negotiation have not been resolved yet. Among them, the influence that the context has on the learning of negotiation strategies, on the strategies chosen by the opponent and the different levels of intelligence [4] stands out. Moreover, the analysis was relegated to theoretical cases that have not found a place as concrete applications that might foster cooperation and maximize benefits.

To mitigate the research gaps mentioned, the thesis addressed [3] focuses on negotiation agents endowed with abilities to model the opponent while simultaneously considering private and contextual circumstances in modeling other agents. The thesis builds on earlier progresses on the challenges of enabling transactions in Peer-to-Peer (P2P) markets of Eco-Industrial Parks (EIPs) and Smart Grids (SGs) founded on Multi-Agent Systems (MAS) [8, 6]. It also leverages the learning of strategies made considering the context during automated negotiations [11, 10] while constructing opponent's models to effectively negotiate [9] and integrating artificial Theory of Mind (aToM) to improve negotiation outcomes [7]. By combining these research strands, the thesis offers a novel approach to improve individual competitiveness and social welfare in bilateral negotiations and P2P markets.

The outline of the thesis is presented next. In Chapter 2, a framework is introduced for automated negotiation that considers private and contextual information together with context-aware (CA) agents and a two-level temporal abstraction. In Chapter 3, the highest level of abstraction is presented, together with a reinforcement learning mechanism by which CA agents select strategies while considering private and contextual information. In Chapter 4, the study continues at the lowest level of abstraction, in which an opponent and context-aware (OCA) agent models a CA opponent and adapts strategies using Gaussian Process. In Chapter 5, the research delves deeper into the lowest level of abstraction, providing agents with aToM abilities to adapt to an OCA opponent. In Chapter 6, a group of agents is placed in two different P2P markets. Firstly, CA agents represent companies in an EIP. Secondly, OCA agents represent prosumers in a SG. Finally, in Chapter 7, the main contributions are presented and argued, as well as an assessment of possible future work in the area of automated negotiation.

2. Hypothesis, motivations and main contributions

2.1. Hypothesis 1: context-aware learning

Negotiation agents that use the context to learn to select their strategies after a sequence of bilateral negotiations, achieve greater benefits than those who only focus on modeling the opponents' behavior.

The main motivation that gave rise to this hypothesis is the scarce attention that the negotiation context has received in the literature. This is a surprising fact, since the information that comes from the environment has proven to be key for agents to learn to behave in many areas of research, mainly in single-agent tasks, but also in MAS.

This hypothesis was mainly addressed in Chapter 3. Firstly, it was found that CA agents who consider their own private and contextual information to learn from reinforcements accumulate greater benefits than those opponents that do not. Secondly, it was discovered that, if any of the two agents involved considers contextual information, there is usually an increase not only in its own benefit, but also in the benefit perceived by the opponent. The flip side of the previous situation was also perceived: if any of the two agents does not consider key contextual information, it is not only detrimental to itself, but also to the opponent. Results indicate that those agents who do not consider the context do not know in which situation it is better to cooperate than to compete, and this impoverishes the outcomes of negotiations.

2.2. Hypothesis 2: adaptation to context-aware opponents

Negotiation agents that use the context in which a bilateral negotiation takes place to build a model of the opponent using aToM and adapt their strategies, achieve greater benefits than their opponents.

There are two motivations that gave rise to this hypothesis. The first one is closely related to Hypothesis 1: although many authors have advanced on modeling the opponent during negotiations [1], few have considered the effect that the context has on the opponent and the strategies it can use. The second motivation is linked to the usage of aToM in automated negotiations and the ability to model agents with different degrees of recursiveness in opponent reasoning while considering the context. This interaction between aToM and context-awareness is of utmost importance in opponent modeling for resolving uncertainties about possible mental states and the increasing complexity of the opponent [4].

This hypothesis was mainly addressed in Chapters 4 and 5. The results highlight that OCA agents modeling CA opponents with Gaussian Process obtain a competitive advantage over them. Even more, it has become evident that modeling the opponent is key when the margin for negotiation is smaller, since this allows the OCA agent to concede enough to reach an agreement whenever the private situation and the context warrant it. The competitive advantage is further improved as OCA agents incorporate the aToM ability, as this allows them to consider OCA opponents. Moreover, as the agent with the lowest complexity increases its order of aToM, the differences between both negotiation agents tend to disappear, although the agent with the highest order of aToM always keeps a competitive advantage.

2.3. Hypothesis 3: social welfare in P2P markets

Negotiation agents that use context to learn and adapt their negotiation strategies in a P2P market, such as an EIP or SG, help balance the market and improve social welfare.

The main motivation for this thesis materializes in this hypothesis. The need to generate greener systems to mitigate the effects of climate change, reduce waste and the associated economic losses, as well as investment and operation costs, is increasingly evident. This can be seen in the various programs that urge the creation of EIPs and SGs [16] and the recent literature that addresses these topics. In this regard, automated negotiation could be the coordination mechanism needed for the implementation of P2P markets in EIPs and SGs, while avoiding a third party with greater authority and the possible biases that this party can introduce to the market.

This hypothesis was mainly addressed in Chapter 6. To evaluate whether learning strategies of CA agents helped balance a P2P market and improve social welfare, an EIP was used as a case study. The results obtained showed that agents representing prosumer companies quickly learned to reduce sales to the main supplier. This was related to the strong demand for the exchange of services within the EIP, which allowed the prices of internal exchange contracts to increase. Also, the balance of the EIP has proven to be a context-dependent balance that considered the configuration of the market and the participants. These results confirmed what was stated in Hypothesis 1: it is key for negotiation agents to use the context to learn to negotiate strategically.

To evaluate whether the adaptation of strategies helped to balance a P2P market and improve social welfare, an SG was used as a case study. The results showed that, as the aToM order of the negotiation agents representing prosumers increased, the amount of energy exchanged between the prosumers also increased. This allowed the SG to have less dependence on the main network. In general, OCA agents with aToM decreased prosumers' costs and increased the social welfare within the P2P market if the energy exchanged internally was cheaper. These results confirmed what was stated in Hypothesis 2.

3. Concluding remarks

In the thesis addressed, a conceptual framework for automated bilateral negotiations between context-aware agents was developed. Agents used context to learn during interaction with others and adapt behavior to the opponent at two levels of temporal abstraction. For strategy learning, agents used reinforcement learning. For strategy adaptation, agents modeled the opponent with Gaussian processes and aToM. These context-aware agents then represented prosumers in two P2P markets: an EIP and a SG. The results showed that the incorporation of the context as an informative dimension not considered until now is key for agents to obtain greater individual benefits in bilateral negotiations. Furthermore, it was shown that context-aware agents in P2P markets tended to balance the market and improve social welfare.

There are still many issues to be resolved in the field of automated negotiation if it is to evolve from simple case studies to resolving conflicts of interest in real-world markets. However, the thesis addressed provided compelling evidence that the negotiation context is of supreme importance for the automation of this inherently human activity both for learning strategies and for adaptation to the occasional opponent.

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