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An adaptive fuzzy logic system for automated negotiations

Kostas Kolomvatsos *, Dimitrios Trivizakis, Stathes Hadjiefthymiades

Department of Informatics and Telecommunications, National and Kapodistrian University of Athens, Greece

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Abstract

The rapid growth of the Web means that humans become increasingly incapable of searching among millions of resources to find and purchase items. Autonomous entities such as agents could help in these situations. *Electronic markets* (EMs) are virtual sites where these autonomous entities can interact to exchange items and obtain specific returns. In this study, we consider the interactions between buyers and sellers in EMs, where we focus specifically on the buyer side. These interactions can be modeled as finite horizon negotiations. However, the buyer cannot be certain of the characteristics of the seller during negotiations (incomplete knowledge). Thus, to address this uncertainty, we propose a *fuzzy logic* (FL) system that is responsible for determining the appropriate actions of the buyer during every negotiation round. We also propose an adaptation technique that updates the FL rule base and system membership functions as necessary. Using this approach, the system can respond to even the complex strategies followed by a seller. A seller strategy estimation method is also adopted by the system, which employs the known *kernel density estimator* (KDE). We provide results for a large number of negotiations and compare our system with previous research in this area. Our results show that the proposed system exhibits good performance in many negotiation scenarios.

Keywords: Adaptive model; Fuzzy logic; Negotiation

1. Introduction

At present, Web users are confronted by vast volumes of information resources and it is impossible for humans to search through vast numbers of Web pages to find the most appropriate piece of information. This is particularly problematic during the purchasing of items, i.e., products or services, where users initially search for a store they like before proceeding with their purchase. The purchase action involves a negotiation between a buyer and a seller, where the final objective is the exchange of an item for specific returns. During negotiations, the entities act in a selfish manner and they try to maximize their utility. Thus, buyers want to buy items at the lowest possible price whereas sellers want to sell items at the highest possible price. In general, negotiations involve a number of alternating offers between the two parties (i.e., the buyer and the seller).

* Corresponding author.
E-mail addresses: kostasks@di.uoa.gr (K. Kolomvatsos), sdi0700146@di.uoa.gr (D. Trivizakis), shadj@di.uoa.gr (S. Hadjiefthymiades).

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These negotiations can occur in *electronic markets* (EMs), which comprise groups of members i.e., the buyers, sellers, and members located in the middle who help to facilitate tasks. Buyers represent users and they aim to buy specific items whereas sellers possess a number of items and they want to sell them at the most profitable price. *Intelligent agents* (IAs) can be responsible for representing buyers and sellers in EMs. IAs are autonomous software components with artificial intelligence capabilities, which can accomplish tasks that are delegated by their owners. They can participate in negotiations where they try to maximize their profits. To achieve this, IAs follow specific strategies that aim to obtain the best response to the opponent's offers. Many models and protocols have been proposed for handling negotiations, which employ well-known theories such as *game theory* (GT) [9] or *fuzzy logic* (FL) [36].

GT approaches provide means for modeling the behavior of entities to maximize profits. These models assume that entities behave rationally, which might not be the case in real scenarios. In addition, real scenarios involve incomplete information about the characteristics of entities. These characteristics include deadlines (the time available for concluding negotiations), the reservation values (upper or lower limits for item characteristics), or the players' strategies. In FL systems, the objects of discourse are associated with information that may be incomplete, partially true, or partially possible [37]. FL can handle incomplete information and provides knowledge representation models (i.e., fuzzy set theory) that allow an IA to make decisions automatically during negotiations. The principles of FL can express human expert knowledge and enable the automated interpretation of the results.

However, these theories have a number of disadvantages. For instance, GT requires the definition of the players' strategies and, in many cases, it assumes knowledge about some of the players' characteristics (e.g., the distribution of deadlines). In addition, reaching an equilibrium can be a tedious task, especially when players adopt complex strategies. FL systems also require expert knowledge to define the underlying fuzzy rule base. Thus, more complex systems could be generated when they are combined with frameworks for automatic rule base definition.

In the present study, we focus on the buyer side and propose an *adaptive FL system* (AFLS) that generates appropriate responses to the offers made by sellers. Our AFLS is fully adapted to the negotiation information in order to avoid the disadvantages associated with classic FL systems. New rules are added to the knowledge base in order to cover new aspects of the interaction. Changes in the membership functions ensure that the most effective decision is made during every round of negotiation. The use of FL involves: a) the representation of expert buyer knowledge, i.e., the decision rules related to the acceptance or rejection of a seller's offer; and b) the inference of the next decision that the buyer should make during every round of the negotiation.

The remainder of this paper is organized as follows. Section 2 provides an overview of related research. In Section 3, we present the negotiation model and the proposed FL system. In Section 4, we describe the proposed AFLS. In Section 5, we provide a comparative performance assessment and Section 6 concludes our study by discussing our key findings.

2. Related work

Finite horizon negotiations usually involve the exchange of alternating offers during the course of a number of rounds [29]. However, an infinite horizon is considered in some approaches [27]. Many models have been proposed to address this problem, as follows: a) approaches based on GT (bargaining); b) approaches based on machine learning; c) approaches based on FL; and d) approaches based on heuristic decision functions.

FL is used in many areas of the scenario addressed by this approach. In [6], the negotiation tactics are presented as fuzzy rules and a simple heuristic is employed to learn the preferences of the other party. The tactics employed by IAs are formulated explicitly as fuzzy inference systems and they are used to infer new offers. In [13], the authors described a mathematical model for calculating the seller's deadline and simulation results were presented. In [12], an FL model for deadline calculation was discussed, where the model was based on a set of fuzzy rules defined by experts. By extending the work described in [12], the authors of [14] employed clustering algorithms to automatically generate a FL rule base. This rule base helps to determine the deadline employed by an entity during a negotiation. A fuzzy constraint-based solution was presented in [20], where IAs seek to determine a fair solution for all of the parties involved in the negotiation and several options are determined that satisfy both parties. In [25], a fuzzy model was presented for negotiation by IAs. The authors investigated the performance of negotiations by handling offers based on fuzzy values on both sides. They employed a protocol that allows both fuzzy and non-fuzzy (i.e., crisp) prices to be proposed. In [19], the authors presented a sequential bargaining technique based on FL for estimating the reservation values of parties during attempts to form joint ventures among companies. In [33], the authors proposed