Journal of Environmental Management 162 (2015) 148–157

Contents lists available at ScienceDirect

Journal of Environmental Management

journal homepage: www.elsevier.com/locate/jenvman

Review

Automated negotiation in environmental resource management: Review and assessment

Faezeh Eshragh*, Majeed Pooyandeh, Danielle J. Marceau

Geocomputing Laboratory, Department of Geomatics Engineering, University of Calgary, 2500 University Drive NW, Calgary, AB, T2N 1N4, Canada

ARTICLE INFO

Article history:
Received 18 November 2014
Received in revised form
15 July 2015
Accepted 24 July 2015
Available online xxx

Keywords:
Automated negotiation
Machine learning
Agent-based modeling
Artificial intelligence
Environmental resource management

ABSTRACT

Negotiation is an integral part of our daily life and plays an important role in resolving conflicts and facilitating human interactions. Automated negotiation, which aims at capturing the human negotiation process using artificial intelligence and machine learning techniques, is well-established in e-commerce, but its application in environmental resource management remains limited. This is due to the inherent uncertainties and complexity of environmental issues, along with the diversity of stakeholders' perspectives when dealing with these issues. The objective of this paper is to describe the main components of automated negotiation, review and compare machine learning techniques in automated negotiation, and provide a guideline for the selection of suitable methods in the particular context of stakeholders' negotiation over environmental resource issues. We advocate that automated negotiation can facilitate the involvement of stakeholders in the exploration of a plurality of solutions in order to reach a mutually satisfying agreement and contribute to informed decisions in environmental management along with the need for further studies to consolidate the potential of this modeling approach.

1. Introduction

Negotiation is one of the most common means for resolving conflicts in social interactions (Van Kleef et al., 2006). It can be defined as a discussion between two or more parties with conflicting interests aiming to reach an agreement (Pruitt and Carnevale, 1993). The involved participants may be individuals or groups of people who negotiate over single or multiple issues simultaneously. The agreement, which might be a mutually acceptable deal, new allocation of resources or new rules of behavior, has to satisfy all participants to some extent. A negotiation may also fail in case participants have nothing in common to agree on.

In the past few decades, negotiation has been studied from different perspectives such as psychology (Pruitt and Carnevale, 1993), economics (Kreps, 1990) and computer science (Jennings et al., 2001). The aim is to understand the complicated nature of a negotiation process and make it more efficient and reliable in terms of exploring the space of possible agreements, keeping track of negotiation rounds, and discovering negotiators' behavioral patterns. Environmental resource management is another domain that requires negotiation among stakeholders when one wishes to consider multiple viewpoints. This field of study deals with managing the effect of human activities on nature while guaranteeing the services provided by the natural resources (Pahl-Wostl, 2007). It is recognized that modeling tools designed to simulate negotiation of common-pool environmental resources, which are shared by a group of stakeholders and subject to overuse or congestion, can assist informed decision making (Gardner et al., 1994; Bousquet et al., 1998). Involving stakeholders with different viewpoints helps reducing the complexity and uncertainties involved by providing an insight about the stakeholders' goals and preferences, and allows the capture of a diversity of interests to satisfy diverse expectations (Reed, 2008; Kenny et al., 2012).

However, capturing the complexity of negotiation in such contexts is challenging. In addition to the conflicting preferences of the stakeholders, other factors such as power imbalance, time limitations, and the participants' attitude may also affect the results of the negotiation (Pruitt and Carnevale, 1993). Due to the large number of influential factors in the negotiation process, the space of all possible agreements can be hard to recognize and thus, difficult to be explored by human negotiators. Under such circumstances, some agreements, which could have been accepted by all participants, might have never been investigated. Additionally,

* Corresponding author.
E-mail addresses: feshragh@ucalgary.ca (F. Eshragh), mpooyand@ucalgary.ca (M. Pooyandeh), dmarceau@ucalgary.ca (D.J. Marceau).

http://dx.doi.org/10.1016/j.jenvman.2015.07.051
0301-4797/

stakeholders can act irrationally or have trouble keeping track of other parties' interests (Jonker et al., 2012). Considering all these concerns, a computational model can help to minimize the effect of biasing factors on the negotiation results and reach an agreement in a faster and more efficient manner. It can also be beneficial for understanding the complicated negotiation process and for engaging stakeholders into the decision-making process that could lead to better informed decisions.

One of the modeling approaches in which stakeholders are involved from the early phases of the model development is participatory modeling. It includes companion (Barreteau et al., 2014) and mediated modeling (Van den Belt, 2004) that have been widely applied in environmental studies. In these modeling approaches, stakeholders get involved in the model construction (*e.g.*, in mediated modeling) as well as scenario simulations and result interpretation (*e.g.*, in companion modeling). These approaches require a strong stakeholder's involvement over the whole modeling process, which might be difficult to obtain.

Another important scientific approach in this domain, which has its roots in Artificial Intelligence (AI), is *automated negotiation*. It is a distributed search in the space of potential agreements, facilitated by an agent-based model (ABM), which consists of a set of intelligent elements, called agents, designed to mimic human behavior. Each agent represents a purposeful component of the system that acts autonomously in its environment to meet its predefined goals (Wooldridge, 1999). To better capture the complicated nature of human negotiation, machine learning (ML) techniques have been proposed to help the agents learn other participants' perspectives and utilize this information to enhance the negotiation.

Automated negotiation was first employed in AI in the 1980s (Davis and Smith, 1983; Malone et al., 1988) where agents interact and negotiate to solve problems in a distributed way. With the widespread use of the internet and the World Wide Web, it has received a lot of attention in domains such as supply chain management (Fink, 2006), political studies (Aragonès and Dellunde, 2009), and especially e-commerce (Ramchurn et al., 2007; Jazayeriy et al., 2011). However, its application in modeling stakeholders' negotiation over environmental resources is still in its infancy (Akhbari and Grigg, 2013; Okumura et al., 2013; Pooyandeh and Marceau, 2013, 2014). This is largely due to the characteristics of environmental issues, such as the amount of uncertainty involved, the high-stakes decisions, the diversity of perspectives, and the inexistence of optimum solutions.

This study was undertaken to better understand the challenges related to automated negotiation in order to exploit its full potential in environmental contexts. The objective of this paper is to review ML techniques currently employed in automated negotiation and evaluate their potential in terms of their compatibility with the nature of stakeholders' negotiation in the particular context of environmental resource management. It attempts at bridging the gap between the contributions made in Artificial Intelligence, Machine Learning, and Agent-Based Modeling in the field of stakeholders' negotiation. We advocate that due to the diversity of viewpoints when dealing with environmental issues, automated negotiation can aid decision makers to explore uninvestigated solutions and therefore make more informed decisions.

The remaining of the paper is organized as follow. In Section 2, the major concepts in automated negotiation are reviewed followed by a description of three major approaches, namely game theory, the heuristic approach, and the argumentation-based approach. In Section 3, four well-established ML techniques are described and compared based on a set of criteria that have been selected according to the most distinctive properties of negotiation contexts. This comparison is then used to evaluate their suitability for specific negotiation domains. Finally, in Section 4, guidelines are provided for the selection of appropriate learning techniques when modeling stakeholders' negotiation in the context of environmental resource management.

2. Automated negotiation

Automated negotiation consists of three main components: negotiation protocol, negotiation object, and negotiation strategy (Lomuscio et al., 2000). The negotiation protocol defines the set of rules governing the interactions between agents. It determines the possible types of participants, the negotiation states, the state transition rules, and the possible actions for each participant in each state. The negotiation object corresponds to the range of issues over which the negotiation happens. It may contain a single (single-issue negotiation) or multiple issues (multi-issue negotiation). When an agent makes an offer, in the simplest case, the set of issues and the range of values for each issue are fixed in the offer and the opponent agents can only reject or accept it. In a more complex form, in response to a proposal, negotiating agents are able to make a counter-offer by changing the issue values based on their own objectives. In more complex negotiations, agents are able to dynamically add or remove negotiation issues and make a proposal based on a new set of negotiation objects (Jennings et al., 2001). The third component is the agents' strategy, used by agents to act according to the negotiation protocol to reach a satisfactory agreement; it is basically the agent's plan for achieving its goals (Lomuscio et al., 2000). While the negotiation protocol is public and available to all participants, the agent's strategy is always private. Revealing the agent's strategy can lead other participants to decipher its goals; in real-world negotiations stakeholders do not usually reveal their goals to negotiators to gain more benefits.

Given the set of negotiation objects, the negotiation issues form the dimensions of the space of possible agreements. Automated negotiation can therefore be defined as a distributed search by negotiating agents in the space of potential agreements (Jennings et al., 2001). Each agent has its own mechanism for rating the points in the space and finds portions of the space that contain its acceptable agreements. Having an idea about other parties' agreement space helps the negotiating agents reach an agreement in a more efficient way.

Three main approaches have been employed in automated negotiation: game theory, the heuristic approach, and the argumentation-based approach (Jennings et al., 2001). Game theory originates from a research conducted by Neumann and Morgenstern (1944) and has its roots in economics. Games are well-defined mathematical objects with three main elements: the players of the game, the set of actions available to each player at each state of the negotiation, and the utilities assigned to possible outcomes. Game theory techniques use a set of rules, called solution concept, to find a strategy for each player to take the most rational action at each negotiation state (MacKenzie and DaSilva, 2006). To find the best choice of action, the agents assume that their opponents are rational (*i.e.* they try to optimize their outcome). These techniques have been used in the design of negotiation protocol and strategy. The designed protocols should be simple, Pareto efficient scalable, convergent to an agreement, and rational (Jennings et al., 2001; Lopes et al., 2008). A solution is called Pareto efficient when there is no other outcome that improves all participants' payoff (Kanbur, 2005).

Game theoretic techniques have several advantages. They can be employed as a set of tools for the systematic analysis of negotiation contexts. They provide a clear view of different negotiation situations using mathematical analysis to determine the strategy that