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Regulating social exchanges in open MAS: The problem of reciprocal conversions between POMDPs and HMMs

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ABSTRACT

An important problem in open multiagent systems is that of the regulation of social exchanges, toward producing social equilibrium. This problem may be generalized to the regulation of autonomous agents' interactions when cooperating/competing in order to achieve their individual, collective objectives. In this paper, we take an abstract and generalizing approach to this issue. The problem is formalized as a regulation model for the sequential decision making of an agent, acting in an open partially observable stochastic environment, with the aim to induce another autonomous agent to interact in certain way, so as to lead both agents toward a target exchange state configuration. The regulation model is defined as a combination of a partially observable Markov decision process (POMDP), to structure the regulator agent decision process, with a Hidden Markov Model (HMM), to structure its exchange strategy learning process. The main challenge we face is the reciprocal conversion between POMDPs and HMMs. The solution we have found builds on the particular structures of the POMDPs and HMMs that arise in the context of the regulation of social exchanges, which allow for the establishment of a kind of isomorphism between the two models. This paper formally develops these ideas, stating and proving the conversion theorems, and shows their application to an example of regulation of social exchanges.

1. Introduction

Systems of social relationships have often been seen as systems of social exchanges, as extensively discussed and analyzed in the literature (see, e.g., [4,14,21,30]). Based on this, theories of social exchanges (e.g., the one introduced by Piaget [30]) have been frequently adopted for the modeling of agent social interactions in different contexts (see, e.g., [11,16,19,29,34]).

One such line of work is due to Rodrigues in cooperation with different partners [33,34]. In [33], Rodrigues, Costa and Bordini introduced an initial model of social exchange-based interactions in agent societies, including a social-reasoning mechanism and structures for storing and manipulating exchange values, presenting an example of a political process of lobbying through campaign contributions. In particular, Rodrigues and Luck [34] introduced an approach based on the Theory of Social Exchanges for the modeling of interactions in open multiagent systems, presenting a system for analyzing/evaluating partner selection and cooperative interactions in the Bioinformatics domain, which is characterized by frequent, extensive and dynamic exchanges of services. Grimaldo et al. [19] presented an application of the Piaget's Theory of Social Exchanges to the coordination of intelligent virtual agents and sociability in a virtual university bar scenario, as a market-based social model, where groups of different types

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of waiters (e.g., coordinated, social, egalitarian) and customers (e.g., social, lazy) interact with both the objects in the scene and the other virtual agents. In [20], they introduced a multi-modal agent decision making model (MADeM), in order to provide virtual agents with socially acceptable decisions, coordinated social behaviors (e.g., task passing or planned meetings), based on the evaluation of the social exchanges. Franco et al. [16] applied social exchange values in order to support arguments about the assessment of exchanges. Together with the power-to-influence social relationship, those arguments were also used to help the agents to decide about the continuation or the interruption of on-going interactions.

Analyzing the works mentioned in the previous paragraph, it is possible to observe that a central problem in systems of social exchanges is that of the *regulation of the exchanges*, toward producing social equilibrium as formalized by Piaget [30] in his Theory of Social Exchanges. The social exchange regulation problem is an important issue in MAS-based simulation of social management in environments rich in non-economic service exchanges, e.g., the urban ecosystems [7,8], the ecosystem markets [15], the service exchange networks [3], the social currency networks [31], and all kinds of open cooperative systems rich in services [34].

In our previous works [9–11], different models for the social exchange regulation problem were developed. In particular, Pereira et al. [29] introduced a regulation model based on BDI (Beliefs, Desires, Intentions) [32] agents, implemented in Jason [5], whose plans were derived from optimal policies of POMDPs (Partially Observable Markov Decision Process) [22] describing the agents' social exchange behaviors for decision making. However, the regulation of social exchanges becomes a difficult task when the social system is open, where the agents can enter and leave freely. Notice that, is this case, there is a no fixed number of POMDP models. For each new agent joining the society it is necessary to construct a new POMDP model that is able to provide the optimal police for dealing with such new agent's exchange behavior.

The objective of this paper is to introduce a general and formal approach for the problem of recognizing and learning models of social exchange strategies for the regulation of social interactions in open agent societies.[1] The regulation model is defined as a combination of the POMDP structuring the regulator agent decision process (as it was firstly proposed by Pereira et al. [29]) with a Hidden Markov Model (HMM) [25] to structure the exchange strategy learning process. In this way, the *social exchange regulation problem* can be stated as a problem of formally establishing the *reciprocal conversion procedures between the POMDP and HMM models*. The problem arises from the fact that the POMDPs have state transition and observation functions based on the actions performed by the agents in each state, whereas, in the HMMs, the state transition and observation functions are not explicitly related to action performances. The solution we have found for the reciprocal conversion problem builds on the particular structures of the POMDPs and HMMs that arise in the context of the regulation of social exchanges: the HMMs involved in such problems are structured on the basis of certain "extended" states, and that allows for the establishment of an isomorphism between the sets of states of the POMDPs and the sets of "extended" states of the HMMs. Such isomorphism forms the foundation, then, for the definition of the mappings that provide the reciprocal conversions between the POMDPs and the HMMs.

The paper is organized as follows. A contextualization of the core problem treated in this paper, namely, the formalization of the POMDP-HMM conversion procedures, is presented in Sections 2 and 3, showing its specific contribution for the state-of-the-art on models for the regulation of social exchanges in open MAS. Then, in Section 2, we present a discussion about the role of social exchanges in MAS, and, in Section 3, we briefly describe the models of regulation of social exchanges in (open) MAS introduced in [29] and [10], in which this work is based. Section 4 introduces, in a formal and more generalized approach, the main concepts necessary for the development of the work, defining the POMDP model for the strategy regulation problem. The HMM for the strategy learning problem is discussed in Section 5. In Section 6, we establish the formal relationship between POMDPs and HMMs, in terms of commutative diagrams, which allow the conversions between the models. In Section 7, we discuss the application of the proposed strategy regulation/learning model to the particular problem of regulating social exchanges in open MAS, giving some examples to clarify the formalism. In Section 8, we present a discussion on related work, mainly in some existing models for the problem of decision making of autonomous agents acting in the presence of other agents in uncertain environments. Section 9 is the conclusion.

2. The role of social exchanges in MAS

We take the viewpoint that the social relationships established between the agents that participate in a society can be analyzed in terms of the exchanges that those agents perform among them. In particular, we take the viewpoint of Piaget [30], that social relationships can be analyzed in terms of the exchange of services performed by the agents.[2] From such perspective, the society is seen as a complex system of exchange of services, where each agent serves one or more agents of the society, and any exchange of services is followed by an assessment of the exchange through the use of qualitative values (like: excellent, satisfactory, unsatisfactory, good quality but too slow, etc.).

The assignment of such qualitative values to the exchanges allows the agents to assess the interactions they perform with each other agent in terms of four different types of qualitative exchange values:

- investment values, that is, the qualitative sum total of what the agent invested in performing services for the other agent;
- satisfaction values, that is, the qualitative sum total of what the agent gained from services received from the other agent;

[1] A very initial proposal for solving this problem was presented in [10].

[2] A detailed computational version of Piaget's model of social exchange can be found in [11].