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Partially observable Markov methods in an agent-based simulation: a tax evasion case study

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Abstract

Defining and testing a policy on a socioeconomic system is one of the main problems addressed by agent-based modelling. While research continues to be conducted to come up with hybrid frameworks that tackle the complexity of different problems, no model explicitly integrates computational replications of multi-agent systems, particularly in dealing with partially observable situations. We show in our work how a Markov based reinforced learning and partially observable computations in the behaviour of a taxpayer agent can contribute to refining the analysis of an audit policy.

Keywords: POMDP ; multi-agent ; tax evasion ; bottom-up simulation ; decision support.

1. Introduction

In many decision making situations, the decider whether a system or human agent does not have access to complete information about the system. This situation can be found in games such as poker or real situations such as trading or even in robotic systems where sensors does not provide concluding information about the environment. Indeed, exploiting such information to make appropriate actions constitutes one of the main features of intelligent systems, along with humans. Improving such an ability in a system is a continuous multidisciplinary research field, involving heuristic and probabilistic computations, statistical machine learning and high performance programming , which led to the development of advanced multi-agent systems such as automatic cars, automatic negotiating systems, etc. .Some real phenomena which are the subject of simulation research also express this property in different ways. In markets a hypothesis is made about the omniscience of agents, in a predator prey situation a guess is made about the potential pray. While the global architecture of multi-agent systems led to the advent of

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agent-based modeling that replicates real systems by executing simple agent actions and observing results, leading to an alternative approach that successfully simulated and replicated many phenomena, it has not integrated the tools available for defining partial observations, mainly partially observable Markov decision processes concepts (abbreviated as POMDP) which is the most widely adopted solution [1].

The goal of this paper is to explore how POMDPs can improve defining observations in an agent-based simulation and compare it to less explicit definitions of the concept. We illustrate this concept by modeling tax evasion. The taxpayer behavior being interdependent with many aspects of the environments and having different judgment and strategic actions/policies make it a suitable illustrative concept with both complexity and partial observations.

2. Related Literature

2.1. Computational techniques

A common way of defining a decision making situation in a partially observable environment is through a partially observable Markov process. It defines the possible states, transitions, actions, observations to compute a belief about the current state using dynamic programming which combines in sequence an optimal policy with appropriate actions for each situation. While solving a POMDP remains a computationally complex issue, POMDPs have been successfully applied in many situations such as goal recognition [2] thanks to efficient computer tools. One of the recent frameworks to provide directives defining a POMDP is JULIA POMDP [3] that sends instructions to a high performance SARSOP solver.
We can also note that such a formulation exists implicitly in reinforcement learning without the transition probabilities. Recent works exploit deep learning networking [4] to reach a policy without necessarily going through a solver, which is can also replicate the behaviour of a human agent.

2.2. Tax evasion simulation

Due to the increasing interest in fighting tax evasion, massive research have been conducted to understand the behaviour of tax payers behaviour and deduce measures to implement in a decision support systems that counters it. Mathematical theories define formulas based on different parameters and optimize a utility function for the expected penalty [5], which is a calibration of the risk taken with the expected penalty. Some models have modelled the tax payer as a Markov chain [6] which significantly reduces the dependency of the variables of the model on other factors. However, many variables can only be extracted from past data, leading many researchers to adopt a data mining [10] either for calibration or to totally build a decision system using tools such as neural networks. This does not eliminate the complexity of the tax payer behaviour which is interdependent with other tax payers and players of the environment. Such complexity explains the increase of agent based models in recent publications, defining simple agent actions without mathematical law hypotheses then executing the models and trying to observe patterns in the indicators in different configurations , what made possible taking into consideration important effects such as neighbours influence[7], auditor behaviour, regional characteristics, etc. A recent large scale model made an attempt to include these 3 approaches: calibration by official data, including all agents, and modelling the behaviour of the tax payer as a POMDP [8]. The latter part has only been done implicitly due to some difficulties in probability definitions and integration in the model, which is going to be the main concern in our study.

3. The model

We start our model by making explicit the elements of our POMDP:

- **The states** : tax payer is either selected for audit or not selected