Development of a Simulator for Social Dynamics and Agent-Based Models

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Abstract: We developed a simulator called Decision-Space-Explorer for developing Socio-Informatica, a digital library system integrating academic papers with the social dynamics models and multi-agent models they explain. The integration will allow researchers to do double-checks of a model in a paper because it contains all the necessary information for double-checks in terms of Social Dynamics and Agent-Based Approach. The ability to double-check can be a tool for sharing knowledge in the humanities and social sciences based on social dynamics and multi-agent models. We provide examples and rough evaluations using the simulator for SDM and ABM respectively to demonstrate its characteristics. We also provide a set of programs using genetic algorithm (GA) to validate a model in SDM and ABM.

Keywords: system dynamics, multi-agent, simulation, decision-making, visual programming, digital library

1. Introduction

We developed Decision-Space-Explorer, a simulation engine of Socio-Informatica. It is a digital library system that realizes seamless integration between a social simulation model and its paper. We discuss how to describe system dynamics models (SDM) and agent-based models (ABM) using the simulator.

Social dynamics (SD) and agent-based analysis (ABA) share the common goal of analyzing social phenomena, although the fundamental elements of SD and ABA are macro elements like feedback loops and micro elements like agents' rules respectively, which complement each other.

However, there is no de facto standard for an ABM simulator due to the lack of a common tool to describe agents' rules, although there are several popular SDM simulators (i.e., DYNAMO, STELLA and VENSIM) owing to the concepts of stock and flow, which describe positive and negative feedback loops. To provide a common tool for ABM, we developed Decision-Space-Explorer, which describes agents' rules like IF-THEN style language. Employing the simulator, we discuss the interoperability of SD and ABM.

2. Background on Social Simulation

Many researchers from various academic backgrounds have done research in the social sciences using computer simulation, especially SDM and ABM, because it is one of the most effective methods for describing and analyzing social phenomena.

Describing a formal model has been employed in many fields of the social sciences, including economics, politics, sociology, and anthropology.

The social dynamics (SD) approach is one of the most popular approaches for describing social phenomena and finding good solutions in terms of a model's parameters in order to develop a good theory.

One interesting new approach is agent-based modeling (ABM). It employs multiple agents and allows them to interact with each other. Recent computer technology affords such a kind of simulation model, although it requires high computational power.

In 2.1 and 2.2 respectively, we will review the two modeling approaches. In 2.3, we will show their relative advantages and disadvantages.

2.1. SDM (System Dynamics Modeling)

Since the late 60's or early 70's, SD research has been headed by several researchers, e.g., Forrester (1969) and Meadows (1972). SD is also a vital field because economic growth is not feasible and sustainable societies are required to maintain the Earth (Meadows, Meadows, and Randers, 1992).

The fundamental concepts in SD are feedback loop, loop structure, and circular causality. Its fundamental elements are stock and flow. SDM composes flows between stocks as multiple positive and negative feedback loops. Positive feedback drives growth of a variable (e.g., population, market, pollution) while negative feedback restrains it and regulates its levels.

2.2. ABM (Agent-Based Modeling)

After the boom of complexity theory (CT) launched by the Santa-Fe Institute in the late '80s and early '90s, agent-based modeling was recognized by many researchers as an effective method of exploring collective behavior.

At the same time, many social researchers employed agent-based modeling to analyze social phenomena as computational and mathematical organization theory (CMOT), which is promoted by CASOS and NACSOS.

Advances in computer hardware and software help researchers in both CT and CMOT run their models, due to high computational power.

CT deals with broad fields from physics to economics and from computer science to social science. CT uses the artificial life approach to describe a model, i.e., simple cellular automata (CA). CA tend to be grid-based, immobile, homogeneous, and dense. A model tends to be more complex in CMOT than in CT because it mainly deals with social rather than biological phenomena.

The common goal of both agent-based modeling approaches is to explore globally-emergent phenomena from interaction between agents.

2.3 Advantages and Disadvantages of SDM and ABM

In this subsection, we will summarize the characteristics, strengths, and weaknesses of SDM and ABM.

The primary components of SD are a stock that describes a social state quantitatively and a flow that illustrates the relationship between two stocks. The stocks and flows are organized into positive and negative feedback loops, which illustrate growth and goal-seeking processes respectively. The strength of SD lies in finding a parameter set to show intended behavior if the formula is appropriate. If it is not, however, we cannot trust the result of a model. Moreover, modeling by stock and flow is inflexible, which means that model structure cannot change.

The primary components of ABM are an agent which has its own behavioral rule and learning and adapting abilities and an interaction between agents. The strength of ABM is its flexibility in employing a set of agents. However, ABM does not establish a set of formal standards due to its flexibility. Because each researcher who is adept at a particular computer language describes his or her model according to that language, there is no set of formal standards. Moreover, there is no standard procedure for validating ABM due to the countless combinations of parameters in a model.

Regarding the validation problem in SD, Scholl (2001) pointed out that optimization methods like genetic algorithm (GA) can be effective in exploring the space of huge parameters, citing ANTs by Miller (1997). The method can be also effective in ABM, e.g., the inverse simulation method by Kuraishi and Terano (2002).

3. SDM and ABM Simulators

What are the required characteristics of a simulator for describing both SDM and ABM? On one hand, there are a lot of popular SD simulators (e.g., Dynamo, STELLA, Vensim). On the other hand, there are also many ABM simulators and libraries (e.g., Swarm, RePast, KK-MAS).

In 3.1, we will provide an explanation of the advantages and disadvantages of selected simulators for each modeling approach. It clarifies the inflexibility of SDM simulators and the difficulty of ABM simulators. In 3.2, to develop a simulator that is both flexible and easy-to-use, we define the concept of a decision-making oriented approach to describe a model.

3.1 Advantages and Disadvantages of SDM and ABM Simulators

Bagni, Berchi, and Cariello (2002) developed their models concerning epidemics based on both SDM and ABM, employing Vensim and Swarm. They outlined the difference between SDM and ABM, and the advantage and disadvantage of an SDM simulator were described as follows:

> We took advantage of the availability of built-in features like optimisation and "goal-seeking", which are not present in the agent-based platform, in order to calibrate the parameters of the model and to verify their accordance with reference material.
>
> However, we must underline the well known limits of this approach: the target is depicted as a whole and it is impossible to design the fine structure of the model so that even important behaviours of model components are lost in the overall evolution.

The developed their model with Swarm, an ABM simulator for illustrating epidemic processes in detail. Its advantage and disadvantage were described as follows:

> The chance to work on agents and on their artificial world has been of enormous importance for a correct sketch of our problem. The definition of agents, of their states, and of the virtual world in which they can act, almost automatically lead to a representation which is closer to reality.
>
> ………..
>
> On the other hand, the implementation of the agent-based model requires a significant amount of programming compared with the visual approach allowed by system dynamics tools. Moreover, at this time, agent-based platforms do not offer functionality that can aid the calibration of the parameters.

In other words, an SDM simulator allows a researcher to describe his or her model as a kind of rough sketch of reality which he or she observed and test it. In comparison, an ABM simulator allows a researcher to depict his or her model in detail but it requires technical knowledge of computer programming, and there are no standard validation procedures.

In short, SDM is an explanatory method to explain the structure of a system, whereas ABM is an exploratory method to explore the structure of a system.

In following subsection, we will explain our strategy to equip standard procedures to describe and validate a model.

3.2. Decision-Making Oriented Approach

Various multi-agent simulation tools have been developed to make multi-agent modeling easy and to provide a de facto standard methodology and simulator. However, no de facto standard seems to have prevailed, due to the use of ordinary procedural programming languages and modeling approaches based on multi-dimensional space.

We have ascertained that the decision-making process and interdependence are important for model agents. To create easier-to-use development tools for multi-agent models, we developed a simulation engine for Socio-Informatica. Its modeling language is accurate at describing an agent's decision-making processes because it employs an IF-THEN style modeling language. The simulator enables us to describe complex models within a decision-making space easily, and its simple modeling language structure (i.e. IF-THEN) makes it possible to easily equip it with a GUI.

Because of the ease with which it allows multi-agent models to be modeled and combined with academic papers, Socio-Informatica is a promising candidate as a de facto standard for modeling multi-agents and publishing papers, and it shows good potential for solving the current replication problem between SDM and ABM.

4. Examples

In this section, we will outline the available decision-making oriented programming approaches to SDM, ABM, and GA, and we will provide an example for each.

4.1 Lorenz-Model in SDM

The Lorenz model is a well-known SD-type model because it uses differential equations to describe weather dynamics, which contain six feedback loops among three variables of x, y, z (i.e. convection, difference of horizontal temperatures, and difference of vertical temperatures).

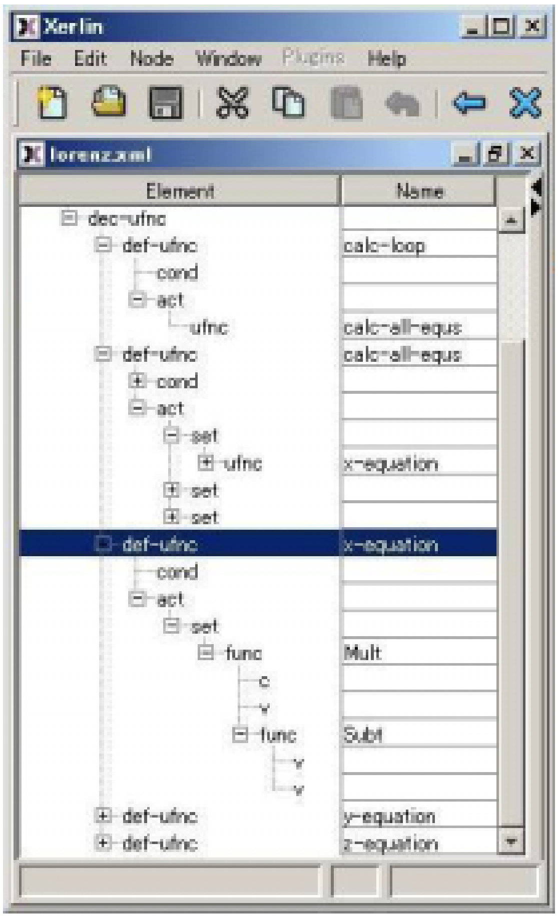

Figure 1: Rules of Lorenz Model

Using our simulator, we illustrate the model with a spreadsheet-like GUI in figure 1, instead of the usual graph-like GUI. The figure also shows a rule "x-equation" to calculate the variable on the X-axis. The other rules for Y-axis and Z-axis can be just as easily described in the same way as same as X-axis.

Figure 2 shows a setting to control the iteration of calculations in Lorenz equations. Using our simulator's XML facility, we can easily set up conditions for iteration without writing any programming codes.

Figure 2: Iterating Calculation

4.2. Cultural Dissemination Model in ABM

The cultural dissemination model is an agent-based model because of its rules of agents and their interactions. It explains two phenomena simultaneously: cultural assimilation in each local area and cultural polarization over the global area. The main factor of the phenomena is a parameter of cultural similarity, which is a kind of threshold of interaction in adjacent areas.

We can describe the rules of ABM in the same way as SDM is shown in figures 1 and 2. Figure 3 shows the most important rule, which describes the interaction between agents and transmitting culture.

4.3. Genetic Algorithm for Validation

One of the most effective techniques for validating models in SDM and ABM is genetic algorithm (GA) because it can find conditions to bring sustainable and critical results, as studied by Miller (1997) and Kuraishi and Terano (2002).

Figure 4 shows the rules of GA procedures, i.e., calculating score of each gene, selection, crossover, and mutation phase. We can describe the rules of GA procedures in the same way as SDM and ABM are shown in figures 1, 2, and 3.

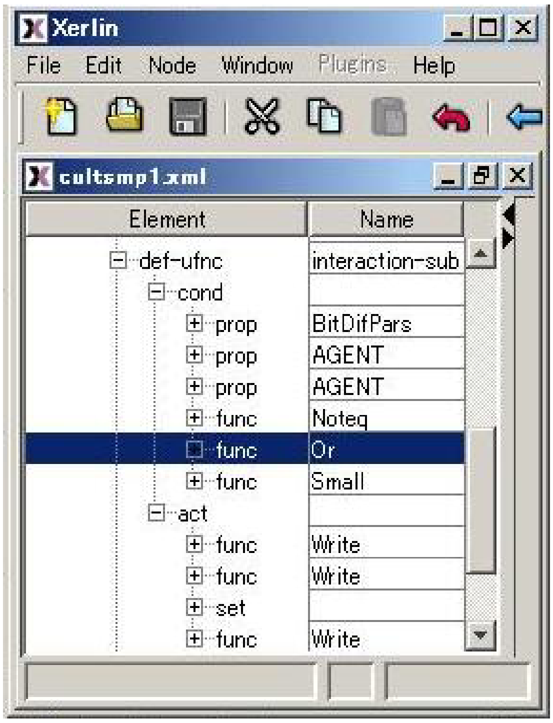

Figure 3: Rules of Cultural Dissemination Model

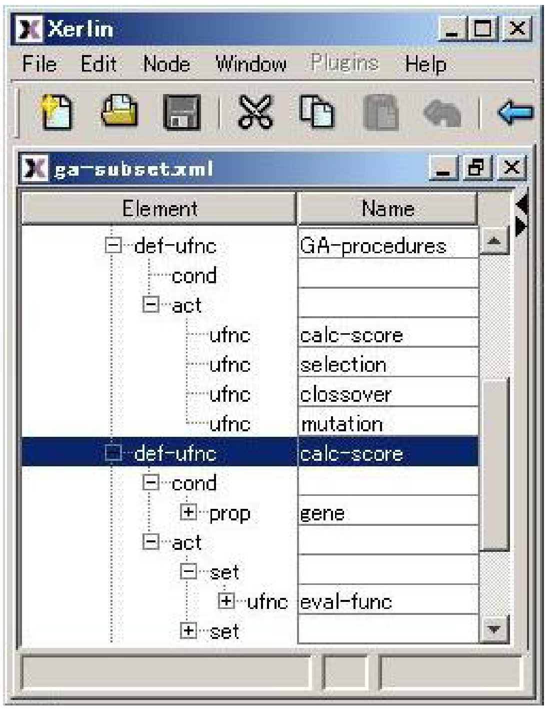

Figure 4: Rules of GA procedures

5. Conclusion

We developed a simulator called Decision-Space-Explorer for developing Socio-Informatica, a digital library system integrating academic papers with the social dynamics models and multi-agent models. We provided examples for SDM and ABM respectively, as well as a set of programs using genetic algorithm (GA) to validate them. The integration of papers of SDM and ABM will provide a tool for sharing knowledge in the humanities and social sciences based on social dynamics and multi-agent models.

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