A space aware agent-based modeling process for the study of hierarchical complex systems

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ABSTRACT

Complex systems are composed of many heterogeneous elements organized in a hierarchical way, whose mutual interactions make emergent collective behaviors to appear at the highest levels of observation. In biology, as shown by the integrative physiology theory [2], space and geometry have a significant role in the simulation results. In this paper we expose a process, and its set of formalisms, for modeling and simulation of complex system, going from structural modeling to dynamic simulation while integrating geometrical information in behavior study. Our solution relies on three kind of concepts and techniques: hierarchical graphs for modeling the system structure and organization, Zeigler’s formalisms for the specification of components [6] and a space aware Multi Agent System for agent-based simulation.

Categories and Subject Descriptors
I.6.5 [Model Development]: Modeling methodologies; J.3 [Computer Applications]: Life and medical sciences

Keywords
complex system, hierarchical graph, agent-based spatial simulation, DEV&DESS, multilevel and multi-scale modeling.

1. INTRODUCTION

In the modeling of complex systems, space is often neglected but, although this oversimplified approach is acceptable in the first approximation, it has a significant meaning in biology. The integrative physiology theory [2] shows that space and time appear both in the speed of signal propagation (humoral, electrical or chemical), and in the changes of spatial relationships between elements (embryology). We propose here a process and a set of formalisms for building models of complex systems integrating geometrical data that goes from structure to behaviors, taking into account space and geometry.

The hierarchy property is found in the structural as well as in the functional organization of the complex systems we consider. In these systems, components at different spatial scales, or processes with different time scales, are related to each other. Using the modeling techniques summarized by Jennings in [5] (decomposition, abstraction and organization), modeling a complex system becomes more tractable and a hierarchical graph can be used to represent the structure and the communication scheme inside these systems in a better way than with other types of models, such as equation-based or cellular automata models. Multi-agent systems are a better candidate for modeling the structure of complex systems because, on the contrary to equation-based models, they focus on the constituent entities of the system rather than aggregate variables representing the average variation over sets of entities. The hierarchy as well as the geometry are well supported there. As a consequence, observations are related to populations rather than individual entities but, if needed, the chance to look at individuals is preserved. Unfortunately, the modularity of multi-agent models hides a lack of formalism.

2. A FORMALIZED MODELING PROCESS FOR HIERARCHY AND SPACE AWARE SIMULATIONS

Using both mathematical, biological and computer sciences concepts, we propose a process for studying system that goes from structure to dynamics. The first step is, from the real system, to describe the system structural organization using a hierarchical graph. Once created, this graph is enriched with the description of the real system functional organization figuring exchanges between components. Then, the behavior of each node (class of components) is described with Zeigler formalisms [6]. These three specifying steps use formalisms offering a recurrent scheme definition that makes them compatible. Finally, a space aware multi-agent system will be used as an exploration environment to observe the system dynamics.

From a modeling point of view, the graph appears as a
coupling intermediate between the physical system and its associated mathematical model. A hierarchical graph (see [4]) offers the opportunity to represent and view multiple levels both in the structure and in the functional organization of the system, thanks to its recurrent definition scheme. At this stage of the modeling process, space is not yet taken into account, only the hierarchy and the functional relations between components are represented.

The Zeigler’s set of formalisms was chosen thanks to its capacity to integrate heterogeneous models, its coupling possibilities and its recurrent hierarchical decomposition feature. DEVS, DESS, DTSS and DEV&DESS [6]), allows the system dynamics specification in a modular and hierarchical way matching the hierarchical graph formalism. Furthermore, Zeigler formalisms do not only model discrete event system, but also deal with continuous and hybrid system thanks to DEV&DESS, an extension of DEVS that includes DEVS, DESS and DTSS, thus giving the opportunity to face a typical situation in biology where discrete events triggered by a continuous process are common. Recent work shows that DEVS can encapsulate equation-based models ([6], [3]). This formalism is thus well adapted to the specification of the multi-agents models assuming the constituted models can be expressed in DEVS. In biological systems it has been shown (see [1]), that a perturbation of the system topology will affect its evolution both in its reorganization and its dynamics. These two aspect are indissociably linked, so that the dynamics may be considered as a consequence of the topological, geometrical and dynamical coupling of the processes involved. Unfortunately, the geometrical information cannot be represented in Zeigler’s formalisms.

Multi-agent systems (MAS) allow us to represent hierarchy and geometrical informations, but lack a formal specification, so we had to combine Zeigler formalisms and MAS in order to circumvent both the lack of formalism in MAS and the lack of geometrical representation in DEVS. The MAS recursion scheme allows us to represent the hierarchical nature of the functional organization of any biological system according to its hierarchical graph model. The environment of MAS, i.e. the structure in which agents evolve, will take into account the geometrical distribution of the constituent entities, and even the changes in the system geometry of biological systems.

3. CONCLUSION

The integration of well-known approaches (hierarchical graphs, DEV&DESS and agent based simulation) gives a formalized process for studying the dynamics of space sensitive complex systems made up of interacting parts, whatever the field of the considered system. In our proposed method, the system modeling process is based on the decomposition of a given real system into various inter-connected elements using hierarchical graphs to represent the system structural and functional organization. From the behavioral point of view, a hierarchical DEVS formalism is used to describe the behavior of components that are implemented as agents in a situated MAS where an explicit definition of the spatial structure of agents environment allows the definition of distance and adjacency among situated agents. Thus, our process provides a model that can take into account not only the system hierarchical nature but also the spatial and geometrical relationship between agents, which have a significant meaning in biology and spatialized ecological systems.

4. REFERENCES