Towards a Multilevel Simulation Approach based on Holonic Multiagent Systems

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Abstract. Simulation, which creates abstractions of the system is an appropriate approach for studying complex systems that are inacessible through direct observation and measurement. The problem with simulation of great number of interacting entities is that it is difficult to create a reliable and tractable abstraction of the real system. Indeed, simulating large numbers of entities requires great computing resources. A solution to avoid this problem is to use macroscopic models. However, this type of model may be unavailable or not reliable for the problem at hand and it doesn't allow the observation of individual behaviours. In this paper a multi-level simulation model is proposed to allowing the use of both microscopic and macroscopic techniques. This model is based upon Holonic Multi-Agent Systems and provides a generic scheduling model for multilevel simulations: dynamically adapting the level of simulated behaviours while being as faithful as possible to the simulated model.

Key words: Multilevel Simulation, Multi-agent based simulation, Holonic multiagent systems, Complex Systems

1 Introduction

The theory of complex systems has recently experienced a major burst, and researches on these systems are now considered as a discipline in its own right, transverse to many scientific fields. In the domain of complex systems, the simulation plays an important role because it may be considered as a proper approach for studying systems that can not be directly observed or measured [1]. A complex system may be considered as a system made up of a large number of components that have many interactions. In such systems, the whole is more than the simple sum of the components. Given the properties of the components and the laws of their interaction, it is not trivial to infer the properties of the whole [2].

To fully understand the dynamics of a complex system, it is often necessary to combine different views on it at various levels of abstraction. Since we consider several components and their relationships, the complexity of the system is increased. One issue in the complex systems simulation is to allow multilevel simulation. This type of simulation aims at dynamically adapting the simulation complexity according to specific constraints and especially available computational resources. One approach to adjust the complexity of a simulation aims at dynamically adapt the behavioral level of simulated entities (microscopic, macroscopic, etc.) while trying to remain as precise and as faithful as possible to the original model. This paper introduces an approach to conceive multilevel simulation using holonic multi-agent systems (HMAS). The hierarchical and distributed properties of the holarchies (hierarchy of agents) are used to dynamically change the level of entities' behaviors.

This paper is organised as follows. After a short introduction on holonic multi-agent systems and the associated organisational metamodel (section 2.1), section 2.2 details some key points on the multilevel multiagent-based simulation. Our approach to manage a multilevel simulation and the associated multilevel scheduling model is then introduced in section 3. Finally, section 4 briefly summarizes previous works on multilevel simulation.

2 Background

The holonic paradigm and its application to multiagent systems have already proven to be an effective solution to model complex systems. This section introduces a metamodel, called CRIO, for the modeling of holonic multiagent systems.

2.1 The CRIO metamodel for the modeling of HMAS

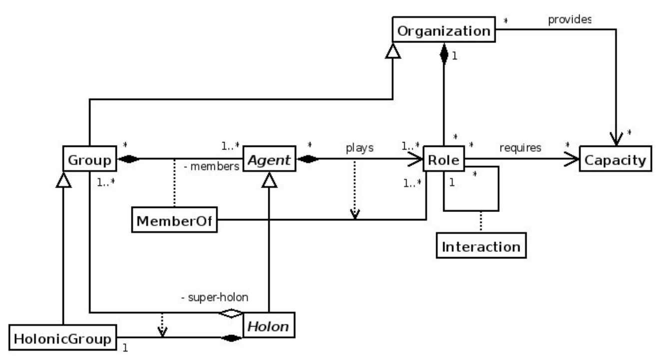

Fig. 1. Fragment of the UML Diagram of the CRIO metamodel

CRIO is an organizational metamodel dedicated to the analysis and design of complex systems under an holonic perspective. The core of the CRIO metamodel is embodied by the following five concepts : Capacity, Role, Interaction, Organization and Holon. Each of these concepts and their relations are summarized in figure 1 and will be briefly detailed throughout the remainder of this section. A more complete description of the CRIO meta-model may be found in [3].

An organization is defined by a set of roles, their interactions and a common context (defined by an ontology). The aim of an organization is to fulfill one or more requirements. A group is a concrete instance of an organization. It models a group of interacting agents, cooperating to meet one or more goals. Two agents may communicate only if they play a role in the same group. An agent playing a role must respect the behavior of this role and the overall behavior of a group must follow the specific interaction pattern described by the organization that it instantiates. A role is the abstraction of a behavior in a certain context defined by the organization and confers a status within this context. The status is defined as a set of rights and obligations made available to the role, and also defines the way the entity playing the role is perceived by other entities playing another role in the same organization. Specifically, the status gives the playing entity the right to exercise its capacities. An agent can play various roles in different groups. The same agent may participate to a group by playing one or more roles that are perceived as different (and not necessarily related) by the group and other agents.

To satisfy their needs and goals, agents often have to collaborate. An agent should be able to estimate the agent's competences in order to identify the most appropriate collaborators. A capacity is an abstract description of a know-how and represents a competence of an agent or a set of agents, while making abstraction of the internal agent architecture. A capacity describes what an agent should be able to do in order to satisfy the requirements it is responsible for. This represents a coherent functionality from the point of view of providers entities (owners : agents, holons, roles or organizations) and requesters entities (users : roles or organizations). The capacity is an interface between the agent and the role, to define the behavior of the role disregarding the architecture of the agent. This concept makes it possible to obtain generic models of organization. The role requires certain capacities to define its behavior. An entity that wants access to a role, should provide a concrete implementation for each of the capacities that the role requires.

In multiagent systems, the vision of holons is much closer to the one that MAS researchers have of *Recursive* or *Composed* agents. A holon constitutes a way to gather local and global, individual and collective points of view. A holon is thus a self-similar structure composed of holons as sub-structures and the hierarchical structure composed of holons is called a *holarchy*. A holon may be seen, depending on the level of observation, either as an autonomous "atomic" entity or as an organization of holons (this is often called the *Janus effect*). A holon can play several roles in different groups and be composed of other holons. A composed holon contains at least a single instance of a *holonic organization* to precise how members organize and manage the super-holon (holon government) and a set (at least one) of *production groups* describing how members interact and coordinate their actions to fulfill the super-holon tasks and objectives.

2.2 Background on Simulation

The objective of the simulation is to facilitate the understanding of the dynamics of a system and try to predict its evolutions and trends. Meeting this goal requires the development of a model of the studied system (model design), its execution on a calculator (model execution), and the analysis of execution results (execution analysis) [4]. Designing a simulation thus at least requires the creation of two models: a first for the system under study and a second for the simulator. The introduction of multilevel mechanisms impact all these models. The system model should be extended to integrate different levels of abstraction considered on the system. The model of the simulator must be adapted to incorporate the tools necessary for the synchronization, and the transition between these various levels of abstraction.

The multilevel simulation is a particular type of simulation where the proposed model of the system incorporates different levels of abstraction (at least two) and where the tools necessary to its implementation enable to live together these different abstraction levels within the same execution and ensure a dynamic transition between them according to defined constraints (Depending on the model or the experimental context).

In this paper, we focus on a particular kind of multilevel simulation, based on multi-agent system. Multiagent-based simulation (MABS) usually refers to individual-centered models and provides a tool to model and simulate the dynamics of populations composed of interacting individuals. This type of simulation associates the individual to an agent. In this kind of simulation, two dynamics which are usually combined in a multi-agent system have to be clearly distinguished [5] : (i) The dynamics at the level of the agent that produces actions. (ii) The dynamics at the system level that calculates the reaction of the environment according to all the agents' actions simultaneously produced. To calculate this reaction, the agents' actions are considered according to the laws of the universe [6].

Multiagent-based simulations often lead to the emergence of local groups of entities [7], but rarely provide the means to manipulate them. Fully exploit these simulations certainly involves the dynamic creation of such agents' groups, but also their agentification so as to manage specific behaviors at each abstraction level. Therefore, hierarchical or holonic multi-agent systems appear as an interesting approach.

3 Applying Holonic MAS to multilevel simulation

3.1 Overview of the multilevel simulation approach

To fully understand the dynamics of a complex system, it is necessary to combine different views on the system at various levels of abstraction. The multilevel simulation is a possible solution to this kind of problem by allowing the dynamic adaptation of the simulation complexity according to specific constraints. The proposed approach aims at dynamically adapting the level of entities' behaviors (microscopic, macroscopic) and the accuracy of the environmental reaction, while being as faithful as possible to the simulated model.

In order to clearly separate the models from their execution, and the system from its environment, a multi-level simulation requires the creation of four multi-level models: target system, system environment and finally the implementation models associated to the two previous ones. Clearly separate the environment model from the system model allows to adjust its complexity independently of the system. From the viewpoint of the multilevel management, the system and environment models are independent. The multi-level mechanisms may be enabled or disabled for one of these two aspects, in a transparent manner for the other one. Each of these models (system and environment) is represented by an organization hierarchy. The hierarchy is then instantiated and associated with its respective model of execution, so as to create at least two holarchies in charge of the simulation execution : a first one for the system and a second for the environment. The exploitation of the properties of these holarchies enable the dynamic adaptation of the complexity of a given simulation. Each level of these holarchies corresponds to a abstraction level of the corresponding model. The level executed in the holarchy determines the complexity level of the simulation (microscopic mesoscopic, macroscopic, etc.).

A multilevel simulation requires the creation of four multilevel models: one for the system, a second for the environment and an execution model for each of the previous models. Figure 2 describes the various models involved in the proposed approach and their relations.

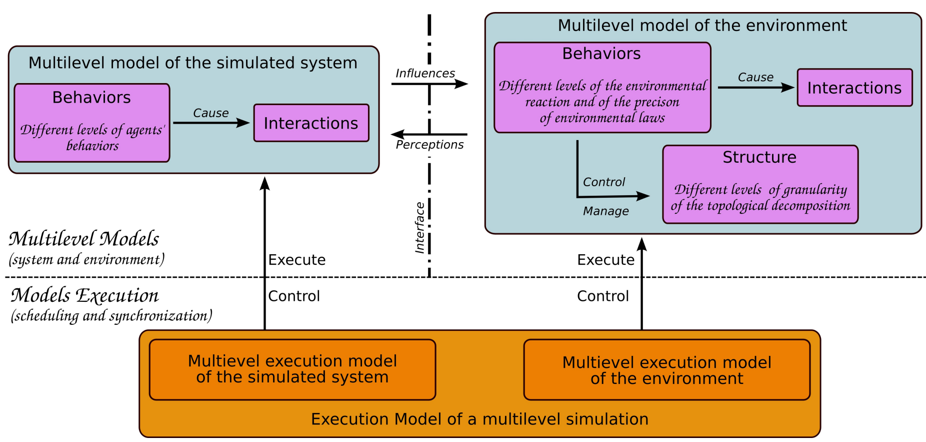

Fig. 2. The various models of a multiagent multilevel simulation

The concept of abstraction level in models is related to the way to structurally and functionally decompose a system into subsystems. A multilevel model must provide a description of the decomposition of the system structure and associated behaviors at each level. It must connect the holistic point of view where the overall system behavior is studied with the individualistic point of view where the system is regarded as a population of interacting individuals.

The first step in the design of a multilevel model consist in identifying the types of behavior that should be simulated at multiple abstraction levels. For each of these types of behavior, a behavioral hierarchy is created. The lowest level of this hierarchy corresponds to the most specific behaviors (eg those of individuals) and the highest level in the overall behavior of the system. Traverse the hierarchy in an ascendant way means that the characteristics of each system component are gradually aggregated, and the diversity and the complexity of their behaviors decreases. In a structural point of view, components are gradually aggregated into groups, each of these later being in turn aggregated, and so on until we reach a level where its remains a single component corresponding to the whole system. Each of these groups is then associated with a holon in charge of simulating its behavior.

A multilevel model thus consists of a set of behavioral hierarchies. Each of these hierarchies is then associated with a particular execution model to create an execution holarchy. This holarchy should ensure the synchronization between holon of a given abstraction level, and it also manages the transitions between different levels according to the defined constraints (eg available computational resources).

Madkit and Swarm are the two simulators that have mainly inspired the proposed approach. In most simulators, the simulation is usually based on a single agent scheduling policy : all agents are subject to the same synchronization principle. This contributes to make the system analysis difficult and limits the eventual extensions and modification of the system. To overcome this limitation, the approach adopted by Swarm and Madkit consists in dividing the scheduling problem of a global simulation under a set of specific problems. A partition is made within the agents to execute, in accordance with the scheduling policy or the synchronization method they require. Each group of agents is then processed independently.

The proposed approach is broadly based on the same principles as those Madkit proposed. The principles of organizational and hierarchical scheduling are preserved and extended to integrate the mechanisms required to manage multi-level simulation and the creation of multilevel models. These extensions are introduced in section 3.2.

3.2 Execution of a multilevel model

Our simulation management approach is essentially based on the scheduling and observation tools. Each of these two aspects is managed by a specific organization. This approach helps to clearly distinguish the way to execute a simulation, the way to collect its results. Furthermore the multi-level problematics does not really impact observation mechanisms while largely impact scheduling and synchronization aspects. Only these two last aspects will be described in this paper.

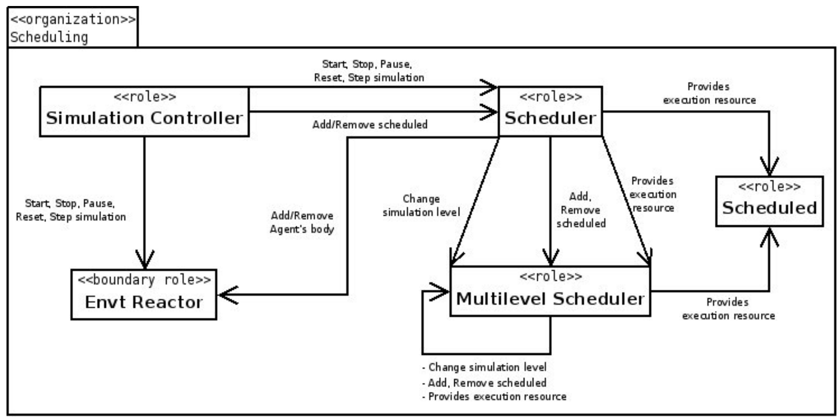

Fig. 3. UML diagram of multilevel scheduling organization

The organization in charge of managing the multilevel scheduling is described in Figure 3. It defines the five following roles :

- *Scheduler* provides all the rights and resources needed to schedule and execute holons who play the *Multilevel Scheduler* or *Scheduled* roles. To achieve that, it manages a set of scheduling policies represented by the notion of activators. This scheduler role must be played by a holon with its own computational resource (thread).
- The *Scheduled* role enables holons who plays it to execute their roles when the *scheduler* decides it.
- The *Multilevel Scheduler* role may only be played by a super-holon, and represents the combination of the two previous roles. It thus allows a holon to execute its roles and its members. This role provides all the necessary means to integrate specific constraints related to the level modification and to determine if the considered holon should execute its own roles (or a subset of), its members or possibly both (i.e. during a transition phase between two levels of abstraction).
- The *Environmental Reactor* role represents the environment of the simulation in this organization and enables other roles to interact with it if necessary.
- The *Simulation Controller* is dedicated to the control of the simulation and interactions with the outside of the simulation (GUI, initial settings, . . .).

Under the organizational approach, the fact to execute a holon is modeled as an interaction between the Scheduler and Scheduled roles where the first provides the computational resource to the second.

3.3 Integration of a multilevel model with its execution model

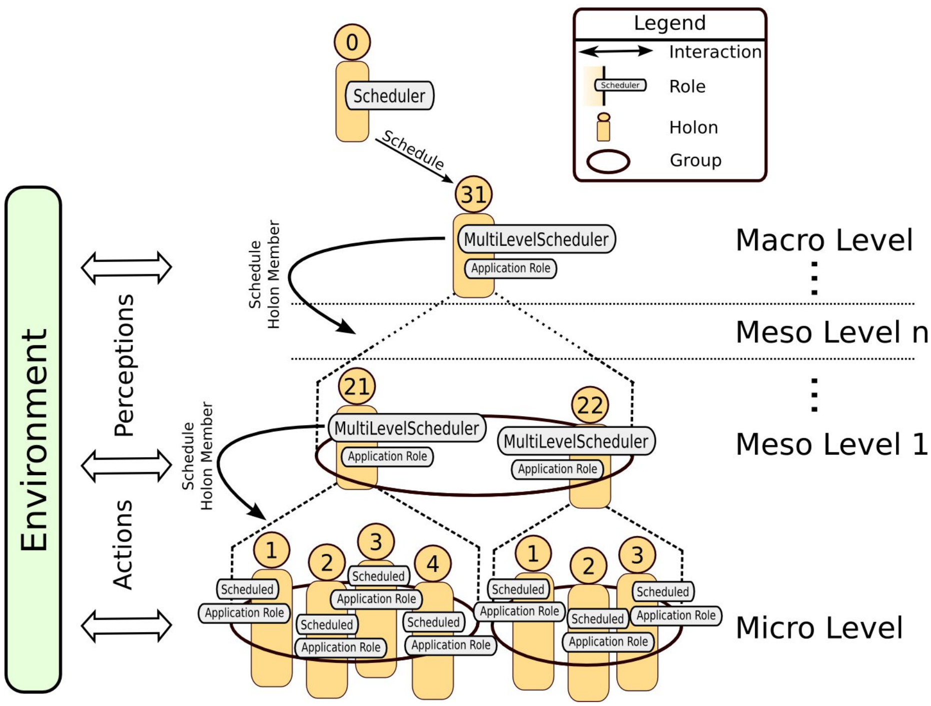

Fig. 4. An example of the concrete structure of a multilevel scheduling holarchy

The multilevel model of a system is a hierarchy of roles. Each level of this hierarchy corresponds to a abstraction level of the studied behavior (microscopic mesoscopic, macroscopic, etc.). A behavior of a given abstraction level is represented by a role. This role is obviously dependent on the system to simulate and on the application domain, and it is thus called *application role*.

At the bottom of a behavioral hierarchy are the set of roles which the level of abstraction is considered the most accurate of the simulation, usually the microscopic level. In the directly upper level, a role coresponds to the aggregate behavior of a set of roles belonging to the lower level. This aggregation mechanism is then reproduced, to obtain a single behavior at the top of the hierarchy. This behavior is generally described as macroscopic and able of simulating the dynamics of the whole system (for the studied behavior).

The execution holarchy is usually built using a bottom-up approach. The behaviors of the lowest level of the system hierarchy are associated with holons atomic charge of executing them. These atomic holons are gathered and associated with a super-holon. This mechanism of holons aggregation is reproduced until is built the entire execution holarchy of the system. In this holarchy, each super-holon plays at least two roles : (i) an application role whose level of abstraction is directly above the roles played by its members. The behavior of this role is an approximation of the behavior of the roles of members. (ii) and the *Multilevel Scheduler* role defined by a scheduling group. According to the simulation constraints, a super-holon determine whether it should execute its application role or that of its members. Based on this decision, the simulation locally will be more or less accurate. If all super-holons of the simulation execute their respective members, all holons the lowest level of holarchie will run. The simulation is then generally to its lowest level precise. Conversely, if only the role application associated with holon located at the top of the holarchie is executed, the simulation is at its lowest level of accuracy. The execution holarchy thus dynamically adjust the level of accuracy of a simulation.

4 Related Works

This section is intended to give a brief overview of existing approaches in the field of multi-level simulation. Most of current multilevel models have a limited and fixed number of simulation levels. Two levels are widely considered : microscopic and macroscopic, microscopic and mesoscopic, mesoscopic and macroscopic. These models are generally dependent on the target application.

In many approaches, the environment of the simulation is split in areas and the simulation level of each one is a priori determined for the entire simulation. The transitions between levels are made at determined connection points. In other approaches, it is the simulation level of entities, which is fixed for the entire simulation, a priori determined by the designer, based on its experience and experimental results of previous simulations. This view is shared by [8] who proposes one of the first dynamical multilevel simulation models. His scope is the simulation of electronic components. He uses a model based on the hierarchical decomposition of components, in which the level of decomposition may be dynamically changed. But the level is not automatically determined according to the constraints of the simulation or the conditions of applicability of the simulation level. The user chooses the level of decomposition.

The field of the simulation in virtual environments provides models with more dynamic. In [9], the concept of a level of autonomy for the simulation of vitual agents and crowds is proposed. They distinguish three levels of autonomy where the behavior of an entity is either fixed or *autonomous* (simple reactive agents), or directly controlled by the user. Another contribution of this work concerns the modeling of the structure of a crowd which is hierarchically decomposed in groups. The objective of this work is to ensure the highest level of visual realism to the simulation, while maintaining real-time performances. However, the level of accuracy of entities behavior is relatively low compared to that reached in a multi-agent based simulation. However, the principle of the approach is one of our inspirations. In the same domain, [10] have adapted the concept of "*level of detail*", originally used to modulate the complexity of the geometric representation of a virtual environment, the behavior of the entities operating in this environment. Still in the field of the simulation in virtual environments, the work of [11] also aim to maintain a maximum level of realism in a simulation while maintaining optimal performances. They introduce the concept of "*proxy simulation*" where entities, that are outside the field of user vision, are simulated at a low level of detail, using an event-based simulation. Dynamic transitions are performed in order to regenerate in a consistent state entities that will appear in the field of view of the user.

In the area of transport networks simulation, the work of Magne et al. [12] on hybrid approaches such as "*micro-macro*" and those of [13] or [14] for "*meso-micro*" hybrids may be highlighted. In the same domain, [15] propose an hybrid model for simulating pedestrians in large-scale environments.

5 Discussions and Future works

The proposed approach was successfully applied to the pedestrians simulation in urban environment [16].

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