Towards a Multilevel Simulation Approach Based on Holonic Multiagent Systems

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Towards a Multilevel Simulation Approach based on Holonic Multiagent Systems

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Abstract

Simulation is an appropriate approach for studying complex systems that are inacessible through direct observations and measurements. In a simulation involving a great number of interacting entities, it is difficult to create a reliable and tractable abstraction of the real reference system. One of the involved problems is amount of computational resources required to handle microscopic simulation of large number of entities. One solution is to use macroscopic models. However, this type of models may be at hand unavailable or not reliable, or it doesn't allow observations of individual behaviours. In this paper a multilevel simulation model is proposed to dynamically adapt the level of simulated behaviours while being as faithful as possible to the reference model. Our approach is based on Holonic Multi-Agent Systems and provides a generic scheduling model for multilevel simulations.

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 [4]. 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 interactions, it is not trivial to infer the properties of the whole system [18]. 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 consists in dynamically adapting the behavioural level of simulated entities (microscopic, macroscopic, etc.) while trying to remain as precise and as faithful as possible to the reference model. This paper introduces an approach to conceive multilevel simulation using holonic multiagent systems (HMAS). The hierarchical and distribution properties of the holarchies (hierarchy of agents) are used to dynamically change the level of entities' behaviours.

This paper is organised as follows. After a short introduction on holonic multiagent systems and the associated organisational metamodel (section 2.1), section 2.2 details several key points on 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 summarises previous works on multilevel simulation.

2 Background

2.1 Modeling Complex Systems using HMAS

The holonic paradigm and its application to multiagent systems have already proven to be an effective solution to model complex systems. This section introduces an organisational metamodel called CRIO and dedicated to the analysis and design of complex

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systems under an holonic perspective. The core of the CRIO metamodel is embodied by the following four concepts : Role, Interaction, Organisation and Holon. Each of these concepts and their relations are summarised in figure 1 and will be briefly detailed throughout the remainder of this section. A more complete description of the CRIO metamodel may be found in [5].

An organisation is defined by a set of roles, their interactions and a common context (defined by an ontology). The aim of an organisation is to fulfill one or more requirements. A group is a concrete instance of an organisation. 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 behaviour of this role and the overall behaviour of a group must follow the specific interaction pattern described by the organisation that it instantiates. A role is the abstraction of a behaviour in a certain context defined by the organisation 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 organisation. 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.

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 substructures 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 organisation of holons (this is often called the *Janus effect*). At a given level of abstraction, the composed holon is called super-holon, its members sub-holons. A holon can play several roles in different groups and be composed of other holons.

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) [8]. Designing a simulation thus at least requires the creation of two models: a first for the system under study and a second for

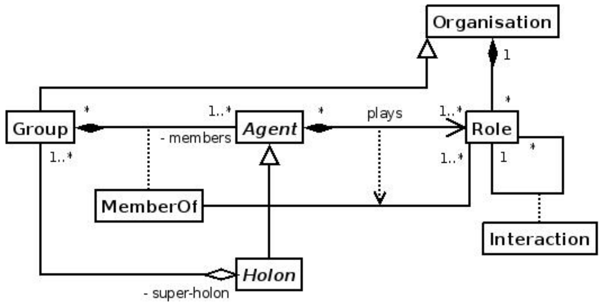

Figure 1. Fragment of the CRIO Metamodel

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 synchronisation, 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 multiagent systems. 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 multiagent system have to be clearly distinguished [7] : (i) the dynamics at the level of the agents that produce actions. (ii) and the dynamics at the system level that calculates the reaction of the environment according to all the simultaneous agents' actions. To compute this reaction, the agents' actions are considered according to the laws of the universe [7].

Multiagent-based simulation often leads to the emergence of local groups of entities [17], but rarely provides the means to manipulate them. Fully exploit this class of simulations certainly involves the dynamic creation of such agents' groups, but also their agentification so as to manage specific behaviours at each abstraction level. Therefore, hierarchical or holonic multiagent systems appear as an interesting approach.

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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' behaviours (microscopic to macroscopic) and the accuracy of the environmental reaction, while being as faithful as possible to the reference model.

In order to clearly separate the models from their execution, and the system from its environment, a multilevel simulation requires the creation of four multilevel models: one for the target system, a second for the system environment and the execution models associated to the two previous ones. Figure 2 describes the various models involved in the proposed approach and their relations. Each of these parts of a simulation is modeled using an holonic and organisational approach based on the abstractions provided by the CRIO metamodel and following the approach described in [9]. 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 multilevel mechanisms may be enabled or disabled for one of these two aspects, in a transparent manner for the other one.

The system's and environment's models are represented by an organisation hierarchy where each level corresponds to an abstraction level. These hierarchies are 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 enables the dynamic adaptation of the complexity for a given simulation. The level executed in the holarchy determines the complexity level of the simulation (microscopic, mesoscopic, macroscopic, etc.).

The concept of abstraction level 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 behaviours at each level. It must connect the holistic point of view — where the overall system behaviour 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 behaviour that should be simulated at multiple abstraction levels. For each of these types of behaviour, a behavioural hierarchy is created (cf. right part of figure 4). The lowest level of this hierarchy corresponds to the most specific behaviours (eg those of individuals) and the highest level to the overall behaviour 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 behaviours 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 behaviour.

A multilevel model thus consists of a set of behavioural hierarchies. Each of these hierarchies is then associated with a particular execution model to create an execution holarchy (cf. left part of the figure 4). This holarchy should ensure the synchronisation between holon of a given abstraction level, and it also manages the transitions between different levels according to the defined constraints (e.g. available computational resources).

Madkit [13] and Swarm [15] 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 synchronisation 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 subproblems. A partition is made within the agents to execute, in accordance with the scheduling policy or the synchronisation 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 organisational and hierarchical scheduling are preserved and extended to integrate the mechanisms required to manage multilevel 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 organisation. This approach helps to clearly distinguish the way to execute a simulation, the way to collect its results. Furthermore the multilevel problem-

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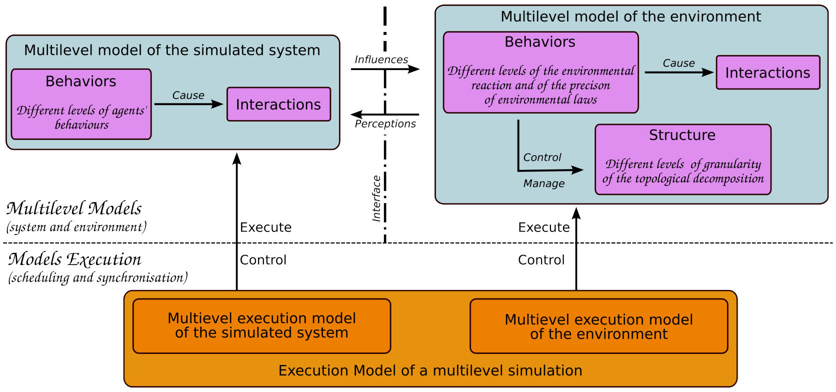

Figure 2. The various models of a multiagent multilevel simulation

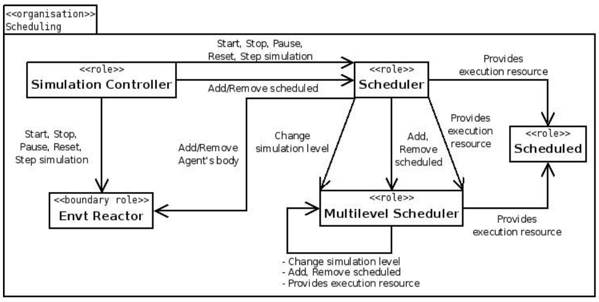

Figure 3. Multilevel Scheduling Organisation

atics does not really impact observation mechanisms while largely impact scheduling and synchronisation aspects. Only these two last aspects will be described in this paper.

The organisation in charge of managing the multilevel scheduling is described in a UML diagram presented 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 : one for each group of agents that a specific policy. 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 organisation 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 organisational 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

The multilevel model of a system is a hierarchy of roles. Each level of this hierarchy corresponds to a abstraction level of the studied behaviour (microscopic, mesoscopic, macroscopic, etc.). A behaviour 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 behavioural hierarchy are the set of roles which the level of abstraction is considered as the most accurate of the simulation, usually the microscopic level. In the directly upper level, a role coresponds to the aggregate behaviour of a set of roles belonging to the lower level. This aggregation mechanism is then reproduced, to obtain a single behaviour at the top of the hierarchy (cf. right part of figure 4). This behaviour is generally described as macroscopic and able to simulate the dynamics of the whole system (for the studied behaviour).

The execution holarchy is usually built using a bottom-up approach. The behaviours of the lowest level of the system hierarchy are associated with

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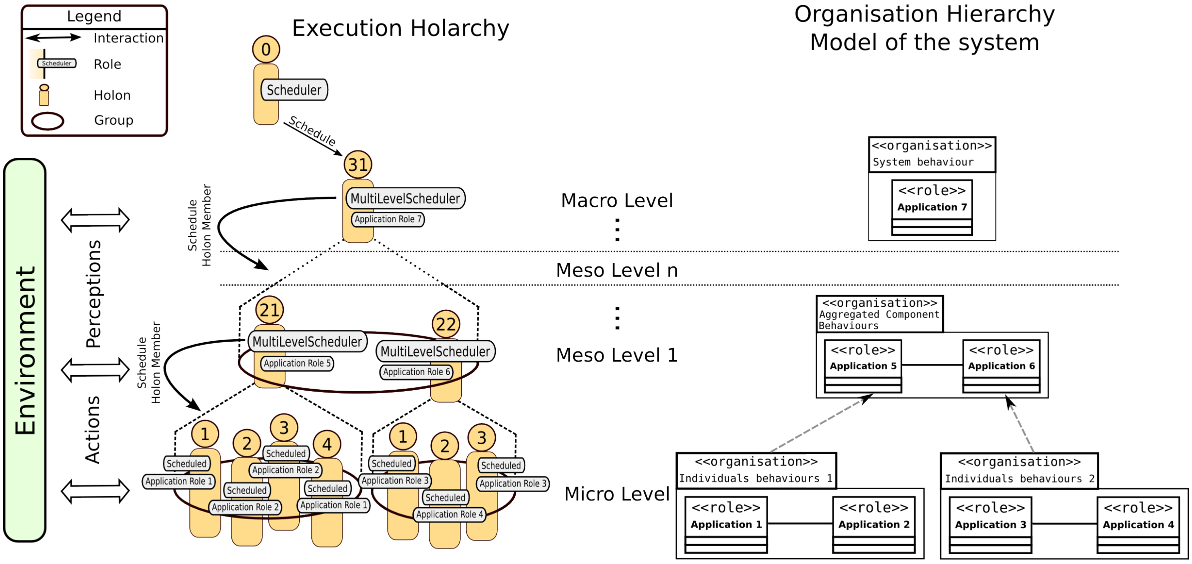

Figure 4. An example of the concrete structure of a multilevel scheduling holarchy

atomic holons. 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 (cf. left part of figure 4). 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 behaviour of this role is an approximation of the behaviour of the roles of members. (ii) and the *Multilevel Scheduler* role defined by a scheduling group, instance of the scheduling organisation (cf. figure 3). 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 at the lowest level of the holarchy are executed. 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 multilevel 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 [11] 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 [16], the concept of a level of autonomy for the simulation of virtual agents and crowds is proposed. They distinguish three levels of autonomy where the behaviour 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 behaviour is relatively low compared to that reached in a multiagent based simulation. However, the principle of the approach is one of our inspirations. In the same domain, [1] have adapted the concept of "*level of detail*", originally used to modulate the complexity of the geometric representation of a virtual environ-

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ment, the behaviour of the entities operating in this environment. Still in the field of the simulation in virtual environments, the work of [3] also aims at maintaining 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. [14] on hybrid approaches such as "*micro-macro*" and those of [2] or [19] for "*meso-micro*" hybrids may be highlighted. In the same domain, [12] propose an hybrid model for simulating pedestrians in large-scale environments. In such hybrid approaches, it is difficult to guarantee the compatiblity between the models used to simulate each abstraction level. The compatibility between their models may usually be achieved only under strict conditions (stationary conditions, equilibrium, etc). The multilevel approach attempts to incorporate intermediate levels of abstraction in order to achieve a progressive transition between levels of very different scale, thereby reducing the risk of incompatibility between corresponding models.

5 Discussions and Future works

This paper introduces an approach to manage multilevel simulation using holonic multiagent systems. This approach is based on the decomposition of the simulation model into three types of multilevel models: the model of the target system, the model of the environment, and the models of execution. The system's and environment's models are created using a hierarchy of organisations, where each level correspond to an abstraction level. These multilevel models are then projected on two holarchies that permit to dynamically change the simulation level and the complexity of the components' behaviours.

The proposed approach was successfully applied on pedestrian multilevel simulation in urban environment [10]. The associated simulation tools are integrated in the Janus [6] platform that was built in our lab and specifically designed to deal with the holonic and organisational aspects.

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