# Holonic Modeling of Environments for Situated Multi-agent Systems

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**Abstract.** In a Multi-Agent Based Simulation (MABS) special attention must go to the analysis, modeling and implementation of the environment. Environments for simulation of real world problems may be complex. Seeing the environment as a monolithic structure only reduces our capacity to handle large scale, real-world environments. In order to support this type of environments, we propose the use of an holonic perspective to represent the environment and the agents. In our approach, agents and environment are represented by holons. The environment defines a holarchy. Each agent belong to a specific holon in this holarchy following its needs.

**Keywords:** Holonic modeling, environment of MAS, simulation.

## 1 Introduction

It is generally accepted that multi-agent systems (MAS) operate within an environment [23, 19]. In a Multi-Agent Based Simulation (MABS), special attention must go to the analysis, modeling and implementation of the environment [20]. Indeed, it simulates a real-world environment and agents represent acting entities in this environment.

Environments for simulation of real world problems may be complex. Indeed, a real world problem, as the one we present in this paper, is frequently characterized by an environment composed of heterogeneous and numerous entities. However, current practice of MABS modeling and simulation tends to consider the environment as a monolithic structure. This approach, even if useful in certain situations, limits our capability to develop large scale agent based simulations.

In order to support large scale, real world environments, we propose to use a holonic perspective to represent both the environment and the agents. The interest of a holonic view of the environment is that it provides a scalable multi-level model to express real-world environments. The designer is able to represent different levels of detail, from a high-level coarse-grained view of the system to a low-level fine-grained one.

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Defined by Koestler [15] as entities that can not be considered as wholes nor parts in an absolute sense, Holons provide a possible answer to this problem. According to Koestler, a holon is a self-similar structure that consists of several holons as sub-structures. The hierarchical structure composed of holons is called holarchy. Holonic systems have already been used to model a wide range of systems, Manufacturing systems [3] Transportation [4], Adaptive Mesh Problem[30] and Cooperative work[1], to mention a few.

In order to show how holonic concepts can be applied to model and simulate large environments, we present in this paper a holonic based model for the traffic network of an important industrial plant of the east of France. The Peugeot SA (PSA) plant is located near two towns and directly connected to the highway and the railway. Within a surface of over 250 hectares, the plant produces more than 1700 cars per day. The plant can be seen as a small town with a high density of traffic that needs to be regulated. A simulator was built to detect possible bottle-necks and evaluate the plant's design. In order to produce a scalable and reliable traffic simulator, we must carefully model this environment to be both efficient and realist. The results we obtained from the simulations aimed first at identifying groups of buildings with an important product exchange and second at evaluate plant structure modifications. These results are not in the scope of this paper so we do not present them.

The use of holons to model both, environment and agents, is the natural consequence of seeing the environment as an active entity, and not merely as a passive component modified by agents at will. The environment is seen as an active entity, capable of interacting with agents and able to enforce the environmental principles [23].

The paper is organized as follows : section 2 introduces our framework for holonic multi-agent systems. Section 3 discusses the holonic environment model and simulation principles. Section 4 presents related works and, eventually, section 5 concludes.

## 2 Holonic Multi-agent Systems

Before discussing the holonic model of the environment, we introduce in this section the terminology used to address the holonic structure and the composition of holons. More importantly, we present a brief overview of our holonic framework [30].

We distinguish two main aspects that overlap in a holon. First, the status of the members (or sub-holons) in the composition of the higher level holon (or super-holon). Second, the coordination mechanism used by the sub-holons to achieve a goal or task. In other terms, the interactions undertaken by the member to exchange information, distribute tasks, etc.

In order to provide a clear distinction between these two aspects, the framework is based upon an organizational approach. While the framework offers means to model both aspects, in this paper we will limit the discussion to the organization used to model the structure of a super-holon. This organization will

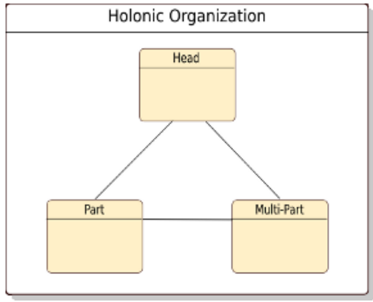


**Fig. 1.** Holonic Organization

provide a terminology that make it easier to discuss about the holonic model proposed for the environment in the next section.

The behavior of the members of a holon and their interactions are described in terms of roles. These roles represent the "status" of the holon inside a specific super-holon. From the super-holon's point of view, a member may play three roles : Head, Part and Multi-Part. To model this organization we have selected the Role-Interaction-Organization (RIO) model [14]. The choice of RIO is justified by the possibilities offered by this approach (eg animation and proofs). This organization, called *Holonic Organization*, is presented using a RIO diagram in figure 1.

Our approach is based in an HMAS as a moderated group, where the head represents the members of its super-holon with the outside world [9]. Different ways to select this representative can be stated, eg. voting, authority, predefined holon, etc. However, selecting the most suited one remains problem dependent.

In a complex system, multiple holarchies can be identified. A holarchy should be seen as a "loose hierarchy" in the sense of [33], where there are no subordination relation.

As the representative, the holon plays the *Head* role. According to the objective and rules of the super-holon, the *Head*'s responsibilities and rights may range from merely administrative tasks to being able to take decisions concerning all members. The head role may be played by several member simultaneously.

Members not playing the *Head* role may play either the *Part* or *MultiPart* role. The *Part* role is played by those members belonging to a single super-holon and the *MultiPart* role by those members belonging to more than one holon. These members may confer a certain degree of authority to the *Head* role player when they join the super-holon. Its autonomy is then reduced because of its obligations towards the super-holon. The degree of this autonomy lost may variate according to the holon's purpose.

The *MultiPart* Role is a special case of the Part Role. This role is played by holons belonging to more than one Holon. Interesting possibilities are available when a holon is shared. For instance, we can now see this holon as a gateway between super-holons, allowing message forwarding. Imagine that holon $a$ is

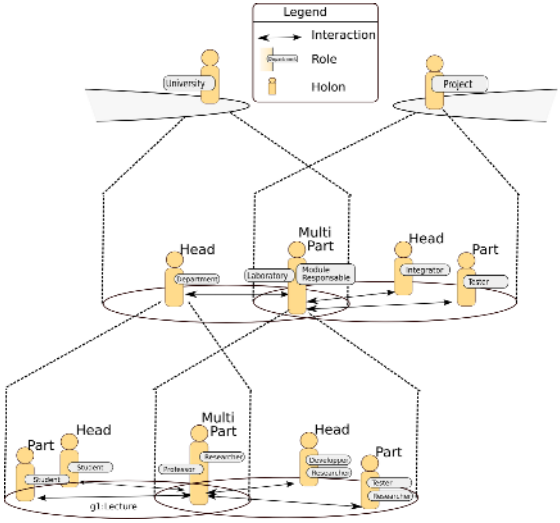


**Fig. 2.** University Example holarchy

shared by $h_1$ and $h_2$. Suppose that $h_1$ confers to $a$ the authority to accept new members coming from $h_2$. Now $a$ can not only forward requests among members of different super-holons, but also act as an ambassador of $h_1$ inside $h_2$. This can be used to reduce the administrative load to the Head of $h_1$, but also to provide means for members of $h_2$ to enter a new holarchy. Other possibilities are present like trust mechanism based on recommendations of shared members, translation of messages in different languages, etc.

These roles represent a generic framework describing high-level behaviors and interactions between components of Holonic Multi-Agent System.

Lets consider the case of an university to illustrate the use of these roles. If we consider the university as a holon, it can be model as being composed of *Departments* and *Research Laboratories*. In turn a department holon can be consider to be composed of professors and students. A professor may, in addition to the lectures given inside a department, be a member of a research laboratory. In this case, the professor is a *MultiPart* role player. This holarchy is depicted in figure 2. “Pawns” represent holons / agents. Each pawn / holon may be decomposed by dashed lines into sub-holons. We show in superscript the holonic roles and in subscript the application dependent roles.

The way member will interact with holons outside its super-holon should be specified in the holon’s creation. Depending on the goal of the holon different ways to interact with the “outside” world are possible. It is important to keep in mind, that *Head*, *Part* and *MultiPart* are roles and they describe the “status” and interactions of members of a holon. Evenmore, holons may change the roles they play at runtime.

This framework has been formalized using the RIO Model and properties concerning self-organization have been prooven [31]. The formal specification is based upon the OZS formalism [10], which is a component of the RIO model.

# 3 A Holonic Model for Traffic Networks

Multi-agent Systems operate within an environment [23, 19], and therefore, in an Agent Based Simulation (MABS) special attention must go to the analysis, modeling and implementation of the environment [20].

We propose the use of holarchies for the modelling of environments. In the PSA example we want to simulate the traffic within the plant. The environment of this simulation is defined by the topology of the plant. The agents will be the different vehicles driving through the plant.

The environment will be represented by a holarchy. This holarchy defines the organizational and topological structure in which agents will evolve. Each environmental holon will enforce contextual physical laws and represent a specific granularity level of the real plant topology. This holarchy is predefined as it represents the real plant environment. Indeed, the latter can't evolve and the physical laws we need to enforce are known *a priori*.

## 3.1 Environment Model

In order to represent the geographical environment of the plant as a holarchy, we have to find recursive concepts which represent the plant's components. The concepts we have chosen are described in the figures 3 and 4.

Figure 3 shows that a road is divided into links. A link represents a one way lane of a road. A segment is composed of two exchange points, called input and output exchange points, and, at least, one link. Exchange points let vehicles pass from one link to the other. And they are always shared by at least two segments.

Figure 4 presents the hierarchical decomposition of the environment of the plant. We can see that the industrial plant is composed of a set of zones, that

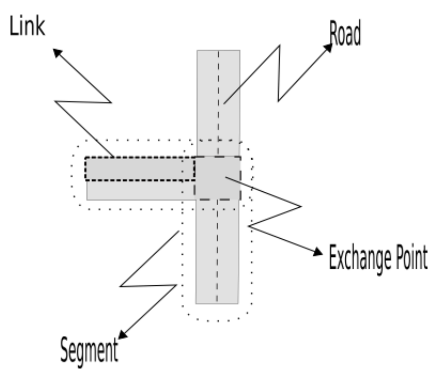


**Fig. 3.** Roads, Segments, Links and Exchange Points

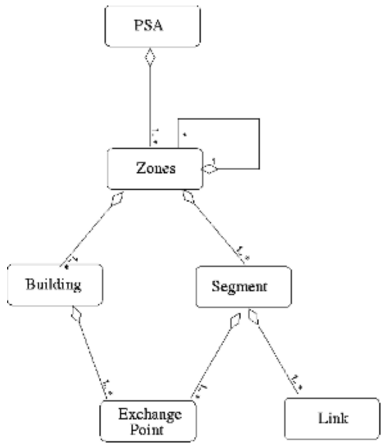


**Fig. 4.** Conceptual view of the plant

contain Buildings and Segments. Buildings and Segments can also communicate through shared exchange points. Usually, an exchange point represents a crossroad, but it can also represent an entrance used by trucks to access buildings. A zone may also be recursively decomposed into smaller zones.

*ExchangePoints* are always shared by two segments or one segment and a building. As we can see the exchange point is a “special” role from the “holonic point of view” since the role is actually shared by more than one super-holon (Segment or Building) by definition.

Such a hierarchical decomposition of environments is based on the idea of Simon, who defines a nearly decomposable system (NDS) [33] as presenting two distinctive characteristics. The first characteristic is that the short-run behavior of each sub-component is approximately independent of the short-run behavior of other components. The second characteristic is that in the long run the behavior of any one of the components depends only in an aggregate way on the behavior of the other components. Based on this definition, we can define a Nearly Decomposable Environment (NDE) as the environment where we can find a decomposition that respects the propositions stated for NDS. Traffic Networks can be seen as a NDE, since in the short-run the behavior and phenomena that may exhibit a zone of the traffic remains independent of the behavior of other components. Indeed, phenomena like congestion, jams and others, remain localized in a zone before spreading.

This model presents several advantages when compared to a global representation. First, no size limit is imposed by the model. This enables us to use the same environment decomposition to simulate the traffic inside a city or a (much) smaller industrial plant. If required, semantic information can be introduced; so instead of zones, we will represent quarters, blocks, etc. [7].

Another interesting characteristic is that all necessary information to simulate the traffic inside a link is local (other vehicles, roadsigns, etc). This makes the model easier to distribute in a network and leaves the door open to Real-Time applications as well as Virtual Reality implementations.

In this work we have concentrated in the traffic network, but the decomposition of the environment may continue to provide a higher level of detail. For instance, a building can be decomposed in Rooms and Exchange Points(doors). The model provides a simple and flexible way to decompose different types of environments. Even more, it offers means for these different environments to coexist in the same simulation.

In situated MAS, the environment contains its own processes that may change its state independently of the embedded agents [36]. These active processes are in charge of enforcing the environmental laws (in our case physical laws). In large scale simulation, hundreds, or even thousands, of agents may be present in the environment. As a possible solution, we advocate for the decomposition of the environment into regions capable of locally computing the proper reaction to agents' influences. However, each region is not self-contained but approximately independent in the "short-run". In the long run these region must be considered as parts of a whole, larger environment. This basic idea has been applied, in this paper, to the modeling of a traffic network.

Holonic MAS can be used to model and implement such an environment. This allow us to maintain multiple levels of granularity and to see each one of these regions as a holon.

On the other hand, this type of decomposition imposes a highly hierarchical and decentralized representation of the environment. This could present some disadvantages when the environment presents some global "variables" accessible to all agents.

### 3.2 Agent-Environment Interaction

The need to make a clear distinction between the body and the mind of the agent has been acknowledged by many MAS researchers [37, 19]. In this section we describe how this distinction is taken into account and how the agent interacts with the environment it is in.

Inside an industrial plant, different types of vehicles coexist (cars, trucks, etc). Furthermore, the drivers do not necessarily behave the same way. In an unorganized traffic scenario, the psychology of the driver is of great importance [24]. In our model, the driver is able to change a set of variable that affect the vehicle's state. The environment ensures that the environmental rules are respected. The model of a vehicle, and the relation between *body* and environment, has been influenced by the work presented in [19]. We consider the vehicle as composed of three fairly independent modules, figure 5.

**Physical Characteristics.** Contains physic related contants like maximal speed, maximal acceleration/deceleration, etc. and a set of variable that the agent can modify at will, like acceleration.

**Control Logic.** Provides a façade that maps driving logic commands, like "speedup", to values that can be assigned to the physic characteristics variables.

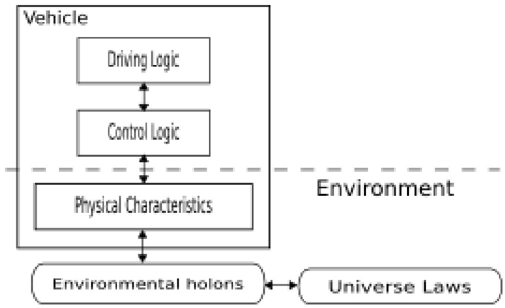


**Fig. 5.** Vehicle Model

**Driving Logic.** Encapsulates the actual behavior of the agent, including Route Planning.

In the real world, the driver (encapsulated in the *DrivingLogic*) does not control the vehicle's speed directly. He actually changes the speed by accelerating/decelerating. This fact is modeled by letting the driver modify only certain variables of the *PhysicalCharacteristics*. These variable are later used by the environment to adjust the vehicle's speed according to the environmental principles.

The *PhysicalCharacteristics* Module presents a standardized representation of the Vehicle's state to the environment. Every simulation loop the environment will take in consideration this state, the environment's state and the environmental principles, and generates the appropriate responses.

In order to provide an easier implementation of different driving logic, the *ControlLogic* module translates driving commands, like "speedup" or "slow down", into the precise values of acceleration. This approach enable a rapid prototyping of different behaviors using a high-level description.

Vehicles can query their current link to obtain information about road sign, traffic lights, maximal speed, etc. They can also request information about adjacent link to the exchange points.

### 3.3 Simulation

As presented in section 3.1, the environment is modeled as a holarchy. Each environmental holon represents a specific context. In the PSA example, it is a specific place in the plant. These places have different granularity levels according to their level in the holarchy. During the simulation, vehicle agents move from one holon to another and the granularity is chosen using execution or simulation constraints.

The dynamic choice of the environment granularity level during the simulation must be transparent for the agents. In order to do this, agents use our holonic framework and specifically *ExchangePoint* holons which enables the communication between holons of the same level and connected in the plant

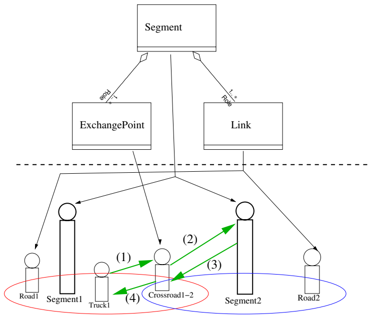


**Fig. 6.**

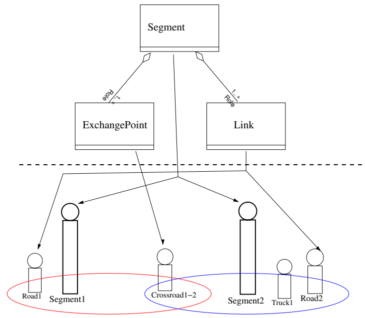


**Fig. 7.**

topology. Figure 6 describes the sequence of messages exchanged between the *ExchangePoint*, a vehicle and the Segment's Head. The truck agent is moving along segment 1 and requests the exchange point to forward a merging request. The exchange point forwards the request and receives a reply. The reply is then forwarded to the truck. If the reply is positive the truck can merge with the segment 2 holon as shown in figure 7. These interaction sequences are a mean to represent the influence/reaction model [8]. Indeed, the agent emits influences in asking to merge with a specific holon. The environment is able to determine the eventual answer according to jams or environment properties.

This approach enables one to describe the environment with multiple levels of granularity examples are given in figures 8 and 9. In figure 8 we can view the simulation of several roads, crossroads and buildings. The figure 9 is a more fine grain simulation of a crossroad. Nevertheless the simulation of the rest of the plant is always running in the two cases. Each level stores pertinent information

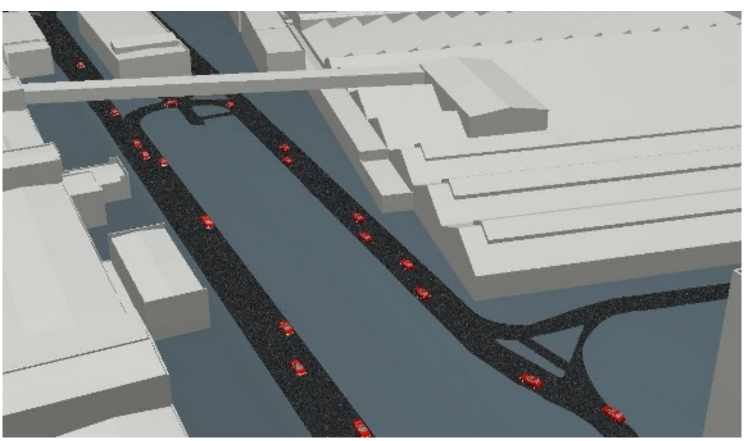

**Fig. 8.** View of different crossroads and buildings

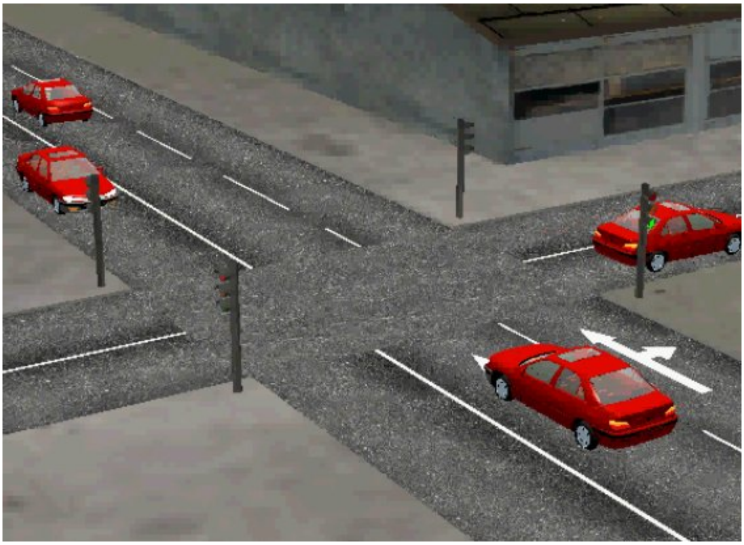

**Fig. 9.** Crossroad close up

about the topology, characteristics and environment laws such as adjacent links, road signs, etc. These different granularity levels can coexist during a simulation. The advantages of this approach is threefold. First, it enables the decomposition of the complexity of the environment in an holarchy of components with only pertinent aspects at each level. Second during the simulation the pertinent level of detail can be automatically chosen to be more efficient.

Finally, in order to support real-time application with high density of agents, the environmental rules can be assigned by zone or region. This lets us regulate the behavior of the system according to the simulation requirements. For instance, in a Virtual Reality simulation, a high level of precision is required in the surroundings of the avatar[1]. On the other hand, in distant regions, certain environmental rules can be relaxed or annulled, such as collision detection.

## 4 Related Works

Considering the importance of traffic flow simulation, it is not surprising that a vast number of models and simulators can be found. Although presenting a full survey of all these approaches is out of the scope of this work, in this section we present some of the most important models and their implementations.

Mainly two different approaches are used in traffic simulation, Macro and Micro Simulations. Macroscopic models [13] describe the traffic from its observable global behavior. They describe the system with a set of global variables like flow rate, flow density and average speed. Such macroscopic representations

[1] Virtual representation of the human user.

are based on hydrodynamic theory [18, 27] and queuing models [12, 38]. One important advantage of this type of model is the low computational resource required (compared to microscopic simulation). On the other hand, these models ignore any individual behavior. Various simulators, like NETSTREAM [35] or METANET [16] implement macroscopic models.

Microscopic models, on the other hand, intend to provide a precise simulation of the traffic state. Different approaches have been proposed, Cellular Automata [29, 22, 17], Particles [21], etc. It is in this type of models that ABS has emerged as a powerful tool for traffic simulation[28, 5, 2, 26, 32]. ABS offer the possibility to introduce individual behaviors, and simulate how their difference may influence traffic flow [24].

The Smartest project [34] provides an extensive survey of microscopic traffic simulators. These simulators where conceived with different purposes and aiming different types of traffic and networks (Urban, Free way, etc.).

The main difference between these simulators and our approach is in the scope and intentions of the developed systems. While those systems concentrate solely on traffic and its analysis, we include the possibility to analyze and understand its impact in depending activities. Even if the plants objects is to optimize its production traffic lays in the very heart of the system. Our model offers a modular design letting the responsibles concentrate in specific aspects without neglecting the consequences of their modifications in the infrastructure and/or functioning of the site.

## 5 Conclusion

In this paper we have presented an approach for the modelling of environments for situated multi-agent based simulations. The modelling is based upon holonic concepts. The environment is represented as a holarchy. Each holon models an environment part which may be decomposed in sub-entities. This approach presents several advantages when compared to a global representation.

First, no size limit is imposed by the model, this enables us to use the same environment decomposition to simulate the traffic inside a city or a (much) smaller industrial plant.

Second, the granularity may evolve during the simulation according to performance and precision needs.

Third, the distribution on a network of the simulation can be done easily by choosing which part of the holarchy could be executed where [30].

Using this approach we have simulated the traffic within the PSA plant and we have observed plant emergent properties such as functional exchange between buildings, traffic density, jams, etc. However, using the concept of Nearly Decomposable Environment, we can identify other types of environments that result as suitable candidates for a holonic modeling. In general terms, we can say that a specific environment is suitable for a holonic modeling, if we can divide the "global" environment into sub-components where the environmental processes can locally compute the response of the environment to agents actions / influences.

This type of hierarchical decomposition of the environment has already been successfully applied in several applications, mainly in the field of Virtual Reality [6, 7]. We can find a set of self-similar components to describe the environment in the model proposed by [25].

Future research will consider new simulation cases in order to extract a methodology from our approach. We are developping a formal specification model for the concepts we have presented which may enable verification and validation [31]. An API in JAVA using the MadKit platform [11] has been developed. In addition, we intend to further deepen the concepts of NDS and NDE for situated MAS simulation.

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