Available online at www.sciencedirect.com

ScienceDirect

Procedia Computer Science 134 (2018) 137–144

Procedia Computer Science

www.elsevier.com/locate/procedia

The 15th International Conference on Mobile Systems and Pervasive Computing (MobiSPC 2018)

A Brief Review of Holonic Multi-Agent Models for Traffic and Transportation Systems

Igor HAMAN TCHAPPI[a,b,*], Stéphane GALLAND[a], Vivient Corneille KAMLA[c], Jean Claude KAMGANG[c]

[a]*LE2I, Univ. Bourgogne Franche-Comté, UTBM, F-90010 Belfort, France*
[b]*Faculty of Sciences, University of Ngaoundere, Ngaoundere, BP : 454, Cameroon*
[c]*ENSAI, University of Ngaoundere, Ngaoundere, BP : 454, Cameroon*

Abstract

The paper presents a state of the art of multilevel models for traffic and transportation modeling and simulation using holonic multi-agent approach. After an introduction and presentation of holonic principles, concepts and framework, the paper summarizes research works on traffic models using holonic multi-agent systems. Then a discussion is given, in particular, a rationale of holonic systems in modeling and simulation of traffic and transportation and open issues are given.

Keywords: Holonic Multiagent Systems, Multilevel Model, Traffic, Transportation

1. Introduction

The increase of traffic demand and the limited capacity of the infrastructure cause several economical, financial and environment problems related to traffic and transportation in several countries. In order to better manage traffic and transportation problems, there has been more and more research on traffic modeling and simulation field. Agents based technologies is one of the powerful technologies for the development of distributed complex systems. The success of Agent based paradigm continuous growing because this paradigm allows a natural decomposition of the system into multiple agents that interact with each other to achieve a desired global goal. Agents based technologies are widely used for traffic and transportation modeling and simulation. As a particular type of agents based technologies, Holonic Multi-Agent System (HMAS) approach has been successfully applied to a wide range of applications successfully. Holonic organizations are among the successful organizational models that have been introduced in Multi-Agent System (MAS) [12]. The term "holon" was originally coined by the Hungarian philosopher Arthur Koestler [15],

* Corresponding author. Tel.: +237695206801
E-mail address: igortchappi@gmail.com

10.1016/j.procs.2018.07.154

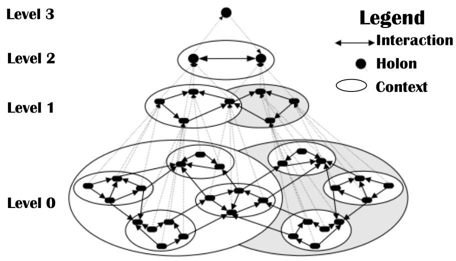

Fig. 1. A nested holarchy with four holarchical levels

basing it on the Greek word "holos" for "whole" and the suffix "-on" that denotes "part". According to Koestler [15], a holon is a fractal structure that is stable, coherent, and consisting of several holons acting as substructures. A biological example is given by Arthur Koestler. For example a human being consists of organs which in turn consist of cells that can be further decomposed and so on. None of these biological components can be understood without its sub-components or without the super-component it is part of. In the context of multi-agent systems [12], a holon is assimilated to an agent that could be composed by other agents. Holonic modeling is used to model the intrinsic hierarchical nature of the traffic systems. HMAS allows to model multilevel model of traffic by defining several abstraction levels of system ranging from microscopic to macroscopic level [24].

Three main approaches are presented in literature to model road traffic [24], for instance: microscopic, intermediate (mesoscopic and hybrid or multilevel) and macroscopic approach. These approaches differentiate the time and space scales. Each approach has his own advantages and disadvantages. Macroscopic level requires a high number of entities and generally is applied on highway. While, microscopic level requires a high computational cost and generally is applied on small urban area scale with a high degree of accuracy. Hybrid models or multilevel models were developed in order to study the situations in which macroscopic and microscopic models are not well adapted like modeling and simulation of large scale traffic [17]. Multilevel approach combines the advantages of macroscopic level and microscopic level but it may be difficult to realize [10]. The paper presents a state-of-the-art of the multilevel models of traffic and transportation using holonic multi-agent system (HMAS).

The paper is organized as follows: in Section 2, a brief description of HMAS, principles, concepts and framework is presented. Section 3 summarizes research works on modeling and simulation of traffic using HMAS. In Section 4, motivations, drawbacks and open issues of HMAS in traffic and transportation are given. Finally, Section 5 gives a conclusion and future works.

2. Holonic Multiagent Systems

The organizational approach allows to model complex systems. Its strengths are modularity, multiple architectures, heterogeneity of languages, application safety and reusability [7]. Organizational approach and holonic modeling are a suitable approach to reduce the complexity of complex systems by defining several abstraction levels [10]. Holonic modeling is used to model the intrinsic hierarchical nature of systems. Holonic organizations have proven to be effective solutions to several problems associated with hierarchical and self-organizing structures and have been successfully applied in a wide range of domains including multi-agent systems [12], philosophy [27], manufacturing systems [14], transportation [22] to name a few. A holon, according to Koestler [15] is defined as simultaneously a whole and a part of the whole. Thus, it can be made up of other holons, strictly meeting three conditions: being stable, having a capacity for autonomy and being able to cooperate. One of the most interesting properties of the holonic systems, which is the essence of their complexity, is that a holon can be both an entity and an organization. The holons are therefore stable and self-similar structures. A holarchy is shown on Fig. 1.

3. Paper Summaries

The modeling approaches and findings described in the most relevant studies are reviewed in the following. Although holonic approach has been successfully applied to a wide range of applications [12, 27, 14, 22, 10]. This review concentrates on HMAS simulation models for traffic and transportation. To this end, the paper focus on the review of HMAS modeling frameworks, holonic models of individuals (pedestrians and vehicles), holonic models of the environment (dedicated to traffic) and holonic models of traffic signals control.

3.1. Frameworks for Holonic Systems Modeling

Most of the works related to modeling and simulation of traffic with HMAS are based on CRIO metamodel [21, 3]. The CRIO (Capacity - Role - Interaction - Organization) model is one of the framework to design holonic multi-agent system. CRIO model is based on four main interrelated concepts:

- **Capacity:** A capacity is a description of a know-how/service. This description contains at least a name identifying the capacity and the set of its input and output variables which may have default values.
- **Organization:** A set of roles and their interactions pattern define an organization in a specific domain. The concept of organization combines roles and their interactions.
- **Role:** A role is the abstraction of a behavior in a certain context and confers a status within the organization. Roles may interact with other roles defined in the same organization.
- **Interaction:** An interaction links two roles in a way that an action in the first role produces a reaction in the second.

The CRIO metamodel aims at providing a full set of abstractions to model MAS and HMAS under an organizational perspective. CRIO uses the development approach defined in the Model Driven Architecture (MDA) [19]. The elements of CRIO are organised in three different domains: (i) The Problem Domain (CIM – Computation Independent Model) deals with the user's problem in terms of requirements, organizations, roles and ontologies; (ii) The Agency Domain (PIM – Platform Independent Model) addresses the holonic solution to the problem described in the previous domain; (iii) Finally, the Solution Domain (PSM – Platform Specific Model) describes the structure of the code solution in the chosen implementation platform.

CRIO has been extended to K-CRIO by Lin et al. [16] in order to model human activities. K-CRIO uses a semantic layer for collaborative softwares in order to enhance Knowledge Management within the targeted organizations.

CRIO has also been extended to NCRIO by Missaoui et al. [18] in order to include norms within the metamodel. NCRIO is used to design a normative holonic multi-agent system. This metamodel retains the properties of the holonic multi-agent systems and adds normative concepts (Norms and Contracts) to maintain social control in these systems.

3.2. Models of Individuals in Traffic using HMAS

This section presents the modeling of the individual behaviours, based on HMAS and the associated outcomes.

Hans-Jürgen et al. [13] propose TELETRUCK in order to support dispatch officers in route planning, fleet management, and driver scheduling. TELETRUCK model is among the first HMAS model in transportation. TELETRUCK model uses holonic multi-agent system in order to achieve a flexible, structured resource management in the planning process. The main components of TELETRUCK are driver, truck with loading space, truck without loading space, truck tractor, trailer, semitrailer, chassis, container. One of the main ideas underlying the TELETRUCK approach is to model his physical components explicitly by basic agents. The agents collaborate closely and join together forming holonic agents that act in a corporated way. The composed agents represent the physical transportation entities (e.g. road trains or articulated vehicles together with their drivers), which are able to execute the orders based on an integration with modern telecommunication facilities. The authors propose an algorithm and protocols in order to deal with communication, coordination, and resource control of their holonic agents. This algorithm starts with an initial sub-optimal schedule and improves the solution at every negotiation cycle. TELETRUCK increases efficiency, transparency and leads to a reduction of traffic congestion, air pollution, and energy consumption.

Gaud et al. [11] propose a holonic organizational multilevel model for real-time simulation of pedestrians by exploiting the hierarchical and distributed properties of the holarchies. Their model is bottom up and it's a force based model. The authors estimate the deviation of simulation accuracy between two adjacent levels, based on the use of physics-based indicators. These indicators allow to dynamically determine the most suitable level for each entity in application to maintain the best compromise between simulation accuracy and available resources. To evaluate the accuracy of their model, three measurements inspired by different energy values are proposed : Kinetic energy E_{c_i}, Goal potential energy E_{pg_i} and Constraints potential energy E_{pc_i}. The authors define the global energy of a holon i by $E_i = E_{c_i} + E_{pg_i} + E_{pc_i}$. This energy represents the current state of a holon and thus can be used to determine the deviation of the simulation accuracy between two adjacent levels. In this model, the pedestrian behavior of a super-holon is the same of its sub-holons but perceptions/actions are aggregated. Affinity between two holons i and j is defined according to three main functions : the distance between holon objectives, the distance between holon location, and the energetic affinity such that $Aff_{ener}(i, j) = {}^{1}/_{E_i^n - E_j^n}$. In experimentation, the authors validate their model saying that scheduling holarchy implies a reduction of computational cost.

Rodriguez et al. [22] propose a framework for modeling and simulation of an important industrial plant (Peugeot car manufacturer at Sochaux, France). The plant, produces over a 1,700 automobiles per day, counts 19,000 employees, occupies a surface of 250 hectares and contains even an internal railway. This work presents a model based on a multi-view analysis of a plant: Traffic Flow View (describing the structure and decomposition of the environment and the way vehicles interacted with this environment) and View Family of Building (identify the product exchange among buildings of the plant based on the available traffic information). Each view is modeled in terms of holons reducing the complexity and size of the model. The integrated model of the simulator is the fusion of the view models. Plant is recursively decomposed in order to build holons and holarchy. They simulate traffic containing different types of vehicles (cars, trucks, etc.) and estimate congestion in the plant. Vehicles are composed of three fairly independent modules: physical characteristics (contains physic related contents like maximal speed, maximal acceleration etc.), driving logic (encapsulates the actual behavior of the agent, including route planning) and control logic (provides a facade that maps driving logic commands, like speedup). The authors define satisfaction in order to allow holons to dynamically change their roles. To validate their model, authors present a 3D representation of the simulated world on a virtual reality platform.

3.3. Models of Road Network and Traffic Control using HMAS

Abdoos et al. [2] propose a method to construct the holarchy for a multi-agent urban area network based on graph theory in order to recognize and form the holons. They use graph based modeling approach to group a population of agents with a greedy method. Agents are modeled using an undirected and weighted graph, in which the weights denote the degrees of the dependencies between the agents. In order to evaluate the consistency of their method and to build the holarchy, the authors propose a quality measure based on the dependencies between the agents. It is a bottom up method. In the case study of the paper, the crossroads are modeled by nodes of a graph, and the roads by edges. The model has been tested on a road network with 18 crossroads and 39 two-way links, using the Aimsun traffic simulator. The experimental results show that the average delay time is reduced in comparison with an homogeneous method.

Abdoos et al. [1] extend the previous works by introducing a holonic Q-learning algorithm to control the signals. In this model, each agent represents a crossroad or traffic signal. The model uses HMAS to model a large number of signals' controllers agents. In order to reduce the complexity of traffic control for a large network, the authors divide the network into sub-systems, each assigned to a holon. In the case study, the method has been applied on a large network that contains 50 crossroads and 112 two-way links. The experimental results show that the holonic Q-learning prevents the network to be over-saturated. While, it causes less average delay time and higher flow rate.

Esmaeili et al. [6] propose a method, inspired by social networks, to build the initial holonic structures of a multi-agent network with a bottom-up approach. Their paper presents a holonification method for a population of interconnected homogeneous agents. The importance of the agents in this approach in the flat network structure is evaluated using the centrality concept in social network. The prerequisite of their method is an un-weighted undirected multi-agent network model. A networked multi-agent system is presented as a graph such that vertices are the agents and edges are the interaction relationship between agents. Having built the initial holons, the other agents of the network try to join these holons to form a multi-level holarchy. They use urban traffic signal control to evaluate the quality of the constructed holons. This method has been tested on an urban traffic road network containing 25 crossroads and

Table 1. Comparison between HMAS models in traffic modeling and simulation field

Models	Building Method	Clustering Method	Goal of the model
Gaud et al. [11]	Bottom up (holons grouping)	Holons affinity	Pedestrian simulation; compromise simulation accuracy / computational resources
TELETRUCK [13]	Bottom up (agents unification)	Components matching, transportation task requirements	Dynamic planning and on-line optimization of transport; Route planning; Fleet management; Driver scheduling
Rodriguez et al. [22]	Top down (plant decomposition)	Satisfaction based on task progress; holons affinity	Modeling and simulation of PSA Peugeot Plant; chain production optimization; traffic simulation
Esmaeili et al. [6]	Bottom up (joining basic holons)	Network position, neighbors eligibility	Modeling road network; Traffic planning; Intelligent traffic control
Abdoos et al. [2]	Bottom up merging nodes	Quality measure based on dependency of holons	Modeling road network; Traffic planning; Intelligent traffic control
Abdoos et al. [1]	Bottom (merging nodes, traffic network partitioning)	Quality measure on dependency of holons	Modelling a large traffic network; Development of a hierarchical control strategy; Traffic planning; Learn signal timing; Intelligent traffic control
Galland and Gaud [8], Galland et al. [9]	Top down (topological decomposition of environment)	Place, zone	Environment model for crowds simulation; Agentization of the environment model to support multilevel simulation
Salido et al. [23], Versteegh et al. [25]	Top down	Shortest path	Environment simulation of GATS in a manufacturing plant; Route planning

31 connecting roads. They use average traffic delay time to compare their method and the one of Abdoos et al. [2], saying that their method causes relatively lower delay time for the vehicles in the traffic network, and postpones the saturation time of the traffic.

3.4. HMAS Models of the Environment

The environment is an important part of the system that should be studied in details [26]. Several works dedicated to the environment model in traffic modeling and simulation have been proposed in literature.

Galland and Gaud [8], Galland et al. [9] propose a holonic model of a physical environment for the simulation of crowds in virtual 3D buildings. The environment model are agentified and therefore, the term agent refers in their papers to the agents, which are supporting the environment model. The method is a recursive top down topological decomposition of environment in places (a place is a semi-closed spatial area bounded by static objects). They propose three main families of energy indicators for evaluating the decomposition process: the mass of a zone which indicates the importance of a place of the environment, the structural depth describes the minimum or the maximum depth of the decomposition of a zone, and the resource constraint, which describes the limits of the available resources for a place to achieve its simulation. The experimentation's goal for this model is to ensure that the model provides similar results than other crowd simulation within airports, and to evaluate the impact of the approximation that is applied by the use of the energy indicators. To this end, the model is successfully applied to the simulation of two airports halls around 0.25 km^2, which are separated by gates. Experiments permit to evaluate the impact of the multilevel simulation on the simulation results, and the gain in terms of computational costs.

Versteegh et al. [25] present a distributed architecture for modeling Global Automated Transportation System (GATS) and the distributed algorithm for simulating it. They focus for that on holonic multi-agent system. The proposed algorithm ensures privacy for each holon. Salido et al. [23] extend this model by introducing an holonic simulation environment for the GATS in order to manage the dynamic events within this environment. This approach is designed for route planning in the context of a automated transport system. There are different transportation vehicles (guided vehicles, trucks, lift trucks and cars) with different features that make the transportation planning a complex problem. To overcome this issue, the model solves the shortest path between two points in the GATS, and guides the different vehicles in the transportation system. They applied the model to a manufacturing plant. The authors notice that the holon reorganization significantly decreased costs of solutions for cases with narrow time windows.

3.5. Summarized Overview

In order to allow a better comparison and a brief overview of the different modeling approaches, the presented papers are shortly summarized in Table 1.

4. Discussion

4.1. Motivations for HMAS in Traffic

Traffic system is a complex system, and it is a large scale phenomenon [24]: (i) traffic is composed by heterogeneous entities; (ii) the number of entities composing the traffic is very high and the interactions between these entities are non-linear; (iii) traffic is geographically and fundamentally a distributed phenomenon; (iv) there are several levels of detail for traffic observation. HMAS is a suitable tool to deal with this high complexity of traffic:

- Since traffic is geographically and fundamentally a distributed phenomenon, HMAS allows to model large scale traffic [10].
- HMAS allows to divide the system in perspectives, or views, in order to reduce the number of involved entities, and the complexity of the process [22].
- HMAS allows to represents a complex system under several views, ranging from microscopic to macroscopic approaches. In general, the multi-level modeling of road traffic combine simultaneously different road traffic models in one model [17, 20]. Each model is associated to a part of the road network. The goal of this hybridization is to manage the transition of the models at the border. Therefore, most of the multilevel models focus only on two abstraction levels (micro and macro, macro and meso, meso and micro). As stated before, one particularity of HMAS in multi-level modeling of road traffic is that HMAS can combine the three main abstraction levels (micro, meso and macro) in the same model according to a point of view.
- Although, it is widely recognized that the presence of groups influences microscopic and aggregated pedestrian or vehicles dynamics, a precise characterization of the phenomenon still calls for evidences and insights [4]. Several works analyzed the influence of the group behavior on an individual. However, there is still a need for additional insights, for instance on the spatial patterns assumed by the groups in their movement, and in general on the interaction among different factors influencing overall vehicles dynamics [4]. A holarchy is an effective solution to link micro and macro levels in order to understand well the influence of micro on the macro level.
- HMAS allows to change dynamically the modeling level (micro, $meso_1$,...,$meso_n$, macro) according to several criteria like visualization or computational resources [24, 1]. HMAS enables maintaining the best compromise between the simulation accuracy and the available resources [10]. Moreover, with HMAS, abstraction levels are not fixed priori, but depend on the application, and may be dynamically selected.
- The works presented in Section 3 show that HMAS can reduces simulation's computational costs, i.e. increases efficiency, and leads to a reduction of traffic congestion, air pollution, and energy consumption, etc.

4.2. Methodology of HMAS in Traffic

To model traffic using HMAS in literature, two main approaches are presented:

- **Gaud et al. [10] and Galland and Gaud [8]:** The goal of this approach is to find the same behavioral model for both the individuals and the groups. Considering that the individuals and the groups have a similar behavior, the self-similarity of the behaviors is directly exploited at different abstraction levels to build the holarchy, and to simulate the system at different levels. Although, this approach may ease the simulation process, his main drawback is related to the difficulties for finding the same behavior for both the individuals and the groups. Indeed, the individuals and the groups may not use the same time scale and features variables.
- **Abdoos et al. [1] and Esmaeili et al. [5]:** In this approach, the life-cycle of HMAS consists of two stages: building the initial holarchy and controlling its structure against internal, and external stimuli during its lifetime. The initial holarchy represents the structure configuration of HMAS at time $t = 0$, while control structure against internal and external stimuli represents the life of HMAS at time $t > 0$. Although, this approach may ease the building of HMAS (initial holarchy). Its main drawback is to manage self-organization over time particularly for a highly distributed and open system like a traffic system.

As shown in Table 1, building the holarchy can be made with the bottom up or top down approaches. In HMAS top down approach reduces the modeling complexity for a system (a holon with a complex objective can decided to decompose into sub-holon and so on). Otherwise, bottom up approach can leads to emergent properties of the system. The holons interacts together to achieve a complex behavior.

4.3. Drawback of HMAS in Traffic

Section 3 shows that most of HMAS models in traffic focus on road networks, environment and traffic control. The common feature of these systems is that there are little evolutive (static) in terms of extension. There are few works that focus on modeling of individuals, e.g. pedestrians, or vehicles. The models of the individuals presented in this paper are application dependent (pedestrians in airport, vehicles in plant). This can be explained by the fact that the modeling of a large, open and dynamic system with HMAS is still a challenge. In fact, if a system is too dynamic, HMAS spends more time for building the holarchy than running the system itself.

Another drawback of HMAS, which is one of its strengths, is the homogeneity of the holons. The principle of building holarchy is based on the homogeneity (affinity, satisfaction, quality measure etc.) of the holons' behaviors. In traffic, the behaviors of the drivers are generally not homogeneous.

Finally, visual tools representing the traffic flows using HMAS are not provided.

4.4. Open Issues

Several open issues are presented in this section regarding the modeling and simulation of traffic flow using HMAS.

- **Sub-microscopic models:** HMAS focus only on micro, meso, macro levels. However, it is interesting to focus on the submicroscopic level also. In this case, it will be possible to include the behaviors of the entities's components, e.g. the mechanical components of a car, in order to simulate the physical motion of the agents in a more realistic way.

- **Integration of norms:** In traffic application, the integration of norms may be an added-value in order to build the holarchy following application-dependent knowledge and rules. This issue may be solved by using the NCRIO framework [18]. This approach should enable the integration of the traffic regulations within the HMAS.

- **Take into account the driver behavior:** Several works focus on the driver behavior, but none using HMAS to the best of our knowledge. It is interesting to consider driver behaviors in HMAS, especially when facing the self-similarity of the holons' behaviors.

- **Modeling large scale, distributed and open system:** Since traffic is open and highly dynamic, HMAS can be apply in situation when traffic is low dynamic like peak hour, congested traffic, platoon, convoy. This affirmation needs a to be validated and proven.

5. Conclusion

This paper contains a review of relevant papers in the field of holonic multi-agent systems and traffic modeling and simulation. Table 1 summarizes the core characteristics of the cited works, and highlights the similarities and differences between the approaches. In Section 4, some of the current problems facing with HMAS are identified. HMAS research methodology requires further effort (in modeling of individuals) and a consolidation of the approaches pursued by the different research groups, especially those focus on the environment and traffic control is needed.

Future works include modeling large scale, distributed and open traffic system based on HMAS. Others multilevel indicators, which support the spatio-temporal properties of the system and the driver behaviors, will be studied and proposed.

References

[1] Abdoos, M., Esmaeili, A., Ana, L.C., B., 2013. Holonic multi-agent system for traffic signals control. Engineering Applications of Artificial Intelligence, Elsevier .

[2] Abdoos, M., Esmaeili, A., Mozayani, N., 2012. Holonification of a network of agents based on graph theory, in: Jezic, G., Kusek, M., Nguyen, N.T., Howlett, R.J., Jain, L.C. (Eds.), Agent and Multi-Agent Systems. Technologies and Applications, Springer Berlin Heidelberg, Berlin, Heidelberg. pp. 379–388.

[3] Cossentino, M., Gaud, N., Galland, S., Hilaire, V., Koukam, A., 2007. A holonic metamodel for agent-oriented analysis and design, in: Mařík, V., Vyatkin, V., Colombo, A.W. (Eds.), Holonic and Multi-Agent Systems for Manufacturing, Springer Berlin Heidelberg, Berlin, Heidelberg. pp. 237–246.

[4] Crociani, L., Gorrini, A., Feliciani, C., Vizzari, G., Nishinari, K., Bandini, S., 2017. Micro and macro pedestrian dynamics in counterflow: the impact of social groups. CoRR abs/1711.08225. URL: http://arxiv.org/abs/1711.08225, arXiv:1711.08225.

[5] Esmaeili, A., Mozayani, N., Motlagh, M., Matson, E., 2017. A socially-based distributed self-organizing algorithm for holonic multi-agent systems: Case study in a task environment. Cognitive Systems Research, Elsevier , 21–44.

[6] Esmaeili, A., Mozayani, N., Motlagh, M.R.J., 2014. Multi-level holonification of multi-agent networks, in: 2014 Iranian Conference on Intelligent Systems (ICIS), IEEE. pp. 1–5. doi:10.1109/IranianCIS.2014.6802553.

[7] Ferber, J., Gutknecht, O., Michel, F., 2008. Agent/Group/Roles: Simulating with Organizations, in: J.P., M. (Ed.), ABS'03: Agent Based Simulation, Montpellier (France). p. 12. URL: https://hal-lirmm.ccsd.cnrs.fr/lirmm-00269714. april 28-30.

[8] Galland, S., Gaud, N., 2014. Holonic model of a virtual 3d indoor environment for crowd simulation, in: Proceedings of the International Workshop on Environments for Multiagent Systems (E4MAS14), Springer.

[9] Galland, S., Gaud, N., Demange, J., Koukam, A., 2014. Multilevel model of the 3d virtual environment for crowd simulation in buildings, in: The 1st International Workshop on Agent-based Modeling and Simulation of Cities (AgentCities14), Procedia Computer Science.

[10] Gaud, N., Galland, S., Gechter, F., Hilaire, V., Koukam, A., 2008. Holonic multilevel simulation of complex systems: Application to real-time pedestrians simulation in virtual urban environment. Simulation Modelling Practice and Theory, Elsevier , 1659–1676.

[11] Gaud, N., Gechter, F., Galland, S., Koukam, A., 2007. Holonic multiagent multilevel simulation application to real-time pedestrians simulation in urban environment, in: Proceedings of the 20th International Joint Conference on Artifical Intelligence, Morgan Kaufmann Publishers Inc., San Francisco, CA, USA. pp. 1275–1280. URL: http://dl.acm.org/citation.cfm?id=1625275.1625482.

[12] Gerber, C., Siekmann, J., Vierke, G., 1999. Holonic multi-agent systems. Research Center for Artificial Intelligence (DFKI) Tech. Rep. 681, German .

[13] Hans-Jürgen, B., Klaus, F., Gero, V., 2000. Holonic transport scheduling with teletruck. Applied Artificial Intelligence: An. International Journal .

[14] Hendrik, Van, B., JoWyns, Paul, V., Luc, B., Patrick, P., 1998. Reference architecture for holonic manufacturing systems: Prosa. Computers in Industry , 255–274.

[15] Koestler, A., 1967. The Ghost in The Machine. Hutchinson.

[16] Lin, Y., Hilaire, V., Gaud, N., Koukam, A., 2011. K-crio: An ontology for organizations involved in product design, in: Cherifi, H., Zain, J.M., El-Qawasmeh, E. (Eds.), Digital Information and Communication Technology and Its Applications, Springer Berlin Heidelberg, Berlin, Heidelberg. pp. 362–376.

[17] Mammar, S., Mammar, S., Lebacque, J., 2006. Highway traffic hybrid macro-micro simulation model, in: 11th IFAC Symposium on Control in Transportation System.

[18] Missaoui, E., Mazigh, B., Bhiri, S., Hilaire, V., 2017. Ncrio: A normative holonic metamodel for multi-agent systems, in: Martínez de Pisón, F.J., Urraca, R., Quintián, H., Corchado, E. (Eds.), Hybrid Artificial Intelligent Systems, Springer International Publishing, Cham. pp. 638–649.

[19] Object Management Group (OMG), 2003. Mda guide. v1.0.1, OMG/2003-06-01 .

[20] Poschinger, A., Kates, R., Keller, H., 2002. Coupling of concurrent macroscopic and microscopic traffic flow models using hybrid stochastic and deterministic disaggregation. Transportation and Traffic Theory for the 21st century .

[21] Rodriguez, S., Hilaire, V., Koukam, A., 2005. Formal specification of holonic multi-agent systems framework, in: Sunderam, V.S., van Albada, G.D., Sloot, P.M.A., Dongarra, J. (Eds.), Computational Science – ICCS 2005, Springer Berlin Heidelberg, Berlin, Heidelberg. pp. 719–726.

[22] Rodriguez, S., Hilaire, V., Koukam, A., 2007. Towards a holonic multiple aspect analysis and modeling approach for complex systems: Application to the simulation of industrial plants. Simulation Modelling Practice and Theory, Elsevier , 521–543.

[23] Salido, M.A., Peinado, M., Giret, A., 2011. A holonic simulation environment for smart transportation systems. International Journal of Production Research 49, 1425–1439. URL: https://doi.org/10.1080/00207543.2010.519489, doi:10.1080/00207543.2010.519489, arXiv:https://doi.org/10.1080/00207543.2010.519489.

[24] Tchappi, I., Kamla, V., Galland, S., Kamgang, J., 2017. Towards an multilevel agent-based model for traffic simulation, Procedia Computer Science. pp. 887–892.

[25] Versteegh, F., Salido, M.A., Giret, A., 2010. A holonic architecture for the global road transportation system. Journal of Intelligent Manufacturing 21, 133–144. URL: https://doi.org/10.1007/s10845-008-0165-6, doi:10.1007/s10845-008-0165-6.

[26] Weyns, D., Parunak, H.V.D., Michel, F., Holvoet, T., Ferber, J., 2006. Environments for Multiagent Systems State-of-the-Art and Research Challenges, in: Third International Workshop (E4MAS 2006). Springer, Hakodate, Japan. volume 4389 of *Lecture Notes in Artificial Intelligence*, pp. 1–47.

[27] Wilber, K., 1995. Sex, ecology, spirituality: The spirit of evolution, Shambhala, Halifax.