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Towards an Multilevel Agent-based Model for Traffic Simulation

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Abstract

Large scale road traffic is a complex system that could be modelled with a multilevel approach. Most of the multilevel models from the literature have fixed a priori level of details (micro-meso, micro-macro, meso-macro). This paper has two goals: it presents the state of the art related to large scale traffic models, and it gives the main research direction to create a novel multilevel model that support dynamic selection of the level during the simulation. Our proposal is based on an organizational modelling approach and the use of the concept of holon (agent composed of agents).

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Keywords: agent based modeling, large scale, traffic, organisational model, multilevel model, holon

1. Introduction

Road traffic has many advantages for both national and individual levels. Traffic facilitates the movement of goods and people, provides access to markets, education, care, leisure and so on. Traffic is ubiquitous[1] and it's a large scale phenomenon because it meets these criterias[2]: (i) traffic is composed by heterogeneous entities, (ii) The number of entities composing the traffic is very high and interactions between these entities are non-linear, (iii) traffic is geographically and fundamentally a distributed phenomenon, (iv) there are several level of detail of traffic observation. Traffic is therefore a complex system because interactions between the entities are non-linear and the collective behavior of these entities is non-trivial. However, in the recent decades, with the exponential increase of the number of users (vehicles, pedestrians, etc.), this transportation mode, although very practical for a user, was quickly faced of several financial, safety, energy and social issues. One solution to try to answer these issues is modeling and simulation of traffic. Modeling and simulation of road traffic helps to provide answers to the problems

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of improving the traffic conditions of goods and people. To model and simulate traffic, several approaches have been proposed and can be classified into microscopic, mesoscopic and macroscopic levels. However, to simulate large-scale traffic, it can be interesting to integrate different representations in the same model which leads to hybrid approach. Most of the existing hybrid models define a priori the different abstraction levels.

The work presented in this paper is devoted to overcome these shortcomings and lay the groundwork for organizational and holonic modeling of large scale road traffic that does not fixed a priori the different abstraction levels but selects the best one dynamically. The organizational approach allows to model complex systems like traffic, and also allows defining several levels of abstractions of the system. Its strengths are modularity, multiple architectures, heterogeneity of languages and application safety. Holonic modeling is used to model the intrinsic hierarchical nature of the traffic systems. A holon, according to Arthur Koestler 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. In this paper, we assimilate a holon to a software agent that could be composed of agents.

This paper is structured as follows: Section 2 gives a state of the art of traffic models. Section 3 makes a comparative study between hybrid traffic models. Section 4 presents the limits of existing solution and lays the foundations for multilevel traffic modeling. Section 5 concludes this paper and provides perspectives.

2. State-of-the art

This section presents briefly the various road traffic modeling approaches that are presented in the literature. To this end, two main families of models are presented in the literature: static models and dynamic models.

2.1. Static models

A static model[4] is a simplified representation of journey on a study area and a given time period that does not take into account the fluctuations of demand of journey over the considered period nor the interactions between the different time and distance steps. Static models are fairly widespread and can be used to evaluate major modifications of transport system or public policies. The most widely static model used in the literature is the four-step model (the other models are derived from the latter by often adding intermediate steps). The four-step model[5] is based on the division of the agglomeration into an area. The main steps of this model are trip generation, trip distribution on the network, the mode choice of transport and finally the assignment of demand on the network.

2.2. Dynamic models

A dynamic model is based on the principle of the variability of transport demand in the study period. Therefore, dynamic models are used to describe the physical flow of road traffic. Several modeling approaches were proposed:

- Microscopic models[6]: It's the most accurate and closest to real behaviors of the entities of the system because it represents the individuals and the interactions between the individuals, which create the dynamics of the system. There are generally two approaches. First, the driver behavior based approach called nanoscopic[7] model or behaviour[8] model. It emphasizes the behaviors of the drivers which are not always described by mathematical laws and mathematics[6] approach that is clearer. Second, microscopic models lead to emerging phenomena such as congestion, but require a high computational cost.
- Mesoscopic models[6]: Mesoscopic traffic models can be considered as intermediate between macroscopic models and microscopic models. Several approaches to design are presented in the literature: one in which individual vehicles are not taken into account because the vehicles are grouped in packets or platoons that move along the links, and the one in which the dynamics of the flows is determined by the simplified dynamics of individual vehicles. Another approach is cellular automaton[9] that present an interest because its speed and its dynamic behavior. In fact, the road is discretized into a set of cells each having the same size. Each cell is either occupied by a vehicle or empty. The simplicity of the rules would make it possible to deal with a large scale system. However, verification of cellular automaton reveals unconvincing results in urban network and highway at the macroscopic level.

- Macroscopic models[6]: They represent traffic as a flux in analogy with the kinetics of gases. Macroscopic models have the advantage of being simple, easy to manipulate because they need few parameters, making calibration and model validation is easy. Moreover, the execution time of the macroscopic models is acceptable. They are therefore according to an appropriate point of view able to model large-scale systems such as traffic. However, on the one hand, in urban areas they are quite limited and, on the other hand, they are incapable to model a simple microscopic phenomenon like changing lane.
- Hybrid models[10,11,12]: this approach integrates different levels of detail (micro, macro, meso) within the same model. These models are generally called multilevel models. It is an approach that generally combines the advantages of macroscopic models and microscopic models, but it is difficult to realize.

2.3. Comparison between static models and dynamic models

In order to examine the type of models which are able to solve our problem that is consisting to the proposition of a multilevel model for large scale traffic, we present Table 1 which compares the two large families of models.

Table 1: comparison static models – dynamic models

	Static models	Dynamic models
Spatial scale	Large scale (neighborhood, town, region, country, see beyond)	Restricted (highway, intersection, Neighborhood, town)
Time scale	No interaction between time step	Time step or event model
Congestion evaluation	Statistical results	Highlighting congestion (vehicles impacted, duration...)
Demand	Fixed : does not usually depend on the time (rush hour, day)	Evolutive according to the variation of time
Horizons	Short, medium and long term	Short and medium term

Table 1 shows that static models are suitable for large spatial scales. However, they give statistical results of congestion, which is one of the main purposes of traffic modeling. In addition, the trip demand is fixed, which makes it impossible to realistically capture reality. We are therefore turning to dynamic modeling because it allows to capture with more precision the congestion in order to answer our problematic. Among the dynamic models, those that are suitable for wide spatial scales are mesoscopic models and multilevel models. The main limit of mesoscopic models is its difficulty to represent the local effects of traffic because they exhibit coarse behavior. This analysis directs us towards the choice of multilevel models of traffic.

3. Comparison between multilevel models of traffic

Table 2 present a comparative study of the different multilevel traffic models present in the literature.

Table 2: Different multilevel of traffic

	Traffic mode	switch bet ween repre sentation	Methodology	Coupling scheme	Model highlighted	Level connecti on	Abstraction level
Magne et al[10]	vehicle	Static	Decomposition of road, Management of the virtual cells	Aggregation / disaggregation; Progressive transition of information (not punctual)	SITRA-B+, SIMRES (discretization of Payne model)	Fixed a priori	Micro, macro
Postinger and al[11]	vehicle	Static	Decomposition of road, Management of the transition zone (at the border),	Aggregation / disaggregation; Progressive transition of information (not punctual)	IDM, Payne	Fixed à priori	Micro, macro
Bourrel and Lesort[12]	vehicle	Static	Decomposition of road, Management of the transition zone (at the border),	Aggregation / disaggregation; Transmission of information to interfaces by phantom vehicles	Optimal velocity, LWR	Fixed à priori	Micro, macro
Burghout[13] (MiMe)	vehicle	Static	Mesoscopic virtual links and microscopic virtual links, consistency in network	Integration architecture based on common module	Mitsim, Mezzo,	Fixed à priori	Micro, meso

			representation at boundary				
Mammar and Haj-Salem[14]	vehicle	Static		Eulerian and Lagrangian discretization of macroscopic model;	Optimal Velocity ARZ	Fixed a priori	Micro, macro
Espié et al.[15]	vehicle	Static	Decomposition of road network; virtual transition zone at each interface	Founded on progressive information transmission	ARCHISM, SSMT	Fixed a priori	Micro, macro
El Hmam[16]	vehicle	static	Decomposition of highway in two parts. Management of the transition zone (boundary)	Management by Agent upstream and agent downstream	Agent based model, Payne	Fixed a priori	Micro, macro
Gaud et al[17]	pedestrian	dynamic and automatic	Environment model; interface between environment and system	Organizational approach; Self-similarity of holons	Force-based model	Not fixed, variable	Depending on the objectives of the simulation
Jason Sewal et al.[1]	vehicle	dynamic and automatic	Detailed road network; lane based representation; arcs road	Aggregation / disaggregation of vehicles; Flux capacitors, vehicle instantiation procedure based on Poisson process and kinetic theory of gases	Agent based model, ARZ	Fixed a priori	Micro, macro
JAMFREE [18]	vehicle	Dynamic and automatic	Semantic decomposition of road network in autonomous cluster	Aggregation and disaggregation of traffic variables; Formal multi-level agent-based meta-model	IDM, METANET	Fixed a priori	Micro, macro
Joueiai et al. [19]	vehicle	Static	Management of road with bridge exactly half-way.	Global consistency; local consistency	IDM, LWR	Fixed a priori	Micro, macro

4. Discussion

4.1. Limits of the existing solutions

According to Table 2, most of the multilevel models of traffic have fixed a priori levels of abstraction, e.g. micro-macro, micro-meso, meso-macro. For example, JAMFREE is able to switch dynamically and automatically between a micro and a macro representation. Moreover, several multilevel models of traffic are static. However, model of Gaud and al.[17] has interests because the levels of abstraction are not fixed a priori, but may be selected dynamically according to the objectives of the simulation (micro-meso$_1$-meso$_2$-…-meso$_n$-macro). However, in this work, the target population is homogeneous and composed only of pedestrians. Our goal is therefore to enrich the model of Gaud and al. by adding the vehicle mode.

Another interesting point is that the Gaud and al. model is organizational and holonic. To enrich this model, we identify first the main issues to address: is organizational and holonic model of road traffic interesting? Which meta-model will be used for the organizational model? How the multilevel aspects will be managed? How the self-similar behavior of vehicles will be managed? And how environment model can be managed? These different questions will guide us during your Research works.

4.2. Proposed solutions

We want to enrich the model of Gaud and al. [17] by adding an organizational and holonic model for vehicles. This target may be explained by the arguments of Vèque and al.[20]: the vehicles follow one another on a line and tend to regroup in convoys when approaching a heavy vehicle or when the road becomes winding. Whenever a spontaneous grouping of entities is possible organizational and holonic approach is interesting.

Multilevel simulation requires that the system is clearly distinguished from its environment in order to allow independent and specific management of their respective levels of abstraction[17]. This generates the need for a model for the source system (the vehicles, etc.) and a model for the environment. In this paper, we are interested by the source model because the environment model was already proposed by Galland and al.[21]. The model of system itself has structure and behavior. To build the model of source system, the following approaches are used:

- The organizational aspects will be managed with the meta-model CRIO[17] (Capacity - Role - Interaction - Organization). It is designed for the analysis and design of complex systems. CRIO seeks to exploit the hierarchical properties of complex systems in order to analyze and model them, based on the definition of roles played by autonomous entities in the system.
- Functional aspects of the system will be managed through flow model laws (appropriate car following model and lane changing model) and Agent-based Modeling (ABM).

- Multilevel aspects will be managed by holonic agent-based systems. The self-similarity of holons allows using the same behavioral model (of vehicle-driver pair) at different abstractions levels.
- Agent-based modeling supported by the Influence-Reaction[22] interaction model is used as a modeling principle for managing actions of the agents in the environment. In this interaction model, an agent produces influences (desire to modify the environment state) to the environment. This latter detects and resolves conflicts among influences and changes its state accordingly.

4.3. Toward an organizational road traffic model

Each couple driver-vehicle is an agent. Interactions between vehicle agents are based on Stigmergy, i.e. they communicate through the environment. The organizational model, including the interaction is represented by Figure 1(a). Two roles are defined: `Vehicle` role and `Environment` role. The `Vehicle` role is responsible for simulating the behavior of a single vehicle or a group of vehicles; while the `Environment` role gives a vehicle the means to perceive and to move in the simulated universe. Vehicles follow and tend to regroup in convoys when approaching a heavy vehicle or when the road becomes winding. These spontaneous convoys of vehicles are resulting from the interaction of vehicles as an emerging phenomenon. The vehicles in a convoy are modeled by the organization `Convoy` presented in Figure 1(b). Two roles are defined in this new organization: the Leader role and the Follower role. Each agent playing the `Vehicle` role must play one of the roles in the `Convoy` organization at the same time. A follower vehicle can be the leader of another follower vehicle and so on. When a vehicle agent does not play neither the Leader role not the Follower role (without interaction with the other agents), the agent is going to its desired speed.

Different levels of abstraction are considered for the role `Vehicle`. The most precise level is the microscopic level in which a vehicle is associated with a holon that is going from an origin to a destination with a car-following or a free driving behavior. At the high level, named mesoscopic, each super-holon simulates the behavior of a group of vehicles. The self-similarity of the holons makes it possible to use the same role `Vehicle` at all levels of abstraction and this for each holon. The model that describes the behavior of vehicles must be self-similar or recursive, that is, it must be able to adapt for both individual behavior and collective behavior. It is a constraint for the modeling of the agent behaviors in our Research works, as described in the next section.

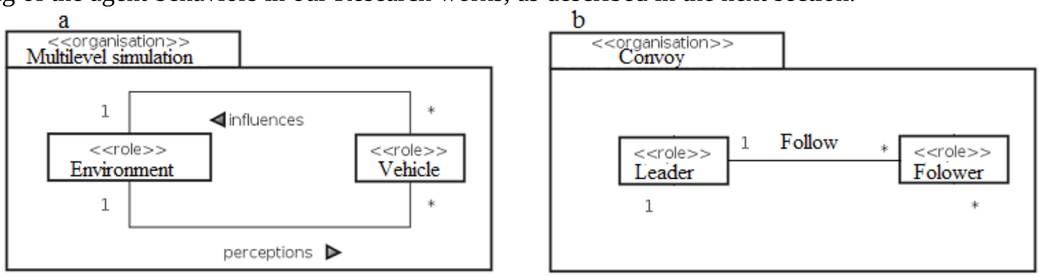

Fig. 1. (a) Organisation Multilevel simulation; (b) Organisation Convoy.

4.4. Towards an holonic road traffic model

In the literature, two possibilities are presented for the formation of holonic groups: the bottom-up approach (a set of holons associate to create a new super-holon in charge of satisfying a given objective) and the top-down approach (decomposition, a holon whose tasks become too complex decides to create a set of production groups to perform its tasks and distribute the calculation costs). The bottom-up approach for the formation of groups of vehicles is selected in order to enable the vehicle agents to regroup in convoy.

When a driver wants to move, he leaves an origin to a destination. Its objective is therefore to reach its destination. In order to effect a holonic decomposition of vehicles, it is necessary to ensure coherence between regrouping vehicles. To achieve a holonic decomposition of the vehicles, it is necessary to ensure the consistency between the groupings of the vehicles. Vehicles have a goal: to reach their destination. This objective can be decomposed into a series of intermediate sub-objectives which are navigation from intersection to intersection until its destination. Based on the work on the VANET[20], it would be advisable to group the vehicles according to:

- the direction of traffic. There are two possibilities: upstream to downstream and downstream to upstream
- the position (road segment, track, instantaneous distance)
- the distance between vehicles
- the speed difference between the leader and the follower

5. Conclusion and perspectives

In this paper, a first step towards a multilevel agent-based model for road traffic simulation is proposed. The main objectives of this step were firstly to do the state-of-the art of multilevel traffic simulation, secondly to identify the limits of the existing solutions, and finally to propose the major research direction to obtain an organizational and holonic multilevel model of traffic. Further work will focus on proposing a self-similar behavioral model of vehicle agents. This model will be based on the definition of affinity indicators between each level of abstraction in the hierarchy of agents. This will complete our organizational model and holonic model of the traffic system.

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