SUBJECT FOR THE INSA-UT PhD PROGRAM
OF THE CHINA SCHOLARSHIP COUNCIL

SESSION 2016

Institution: IRTES, Université de Technologie de Belfort-Montbéliard, France

Title of the subject:

Large-scale Agent-based Simulation of Traffic.

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1. Description of the PhD Subject

1.1 General Context

Microscopic simulation of traffic and crowd behaviors remains a major challenge. In the last decade, many works have been devoted to the study of collective behaviors and their inherent emergent properties such as spontaneous organizations of pedestrians into lines, oscillations at gates, etc. Agent-Based Simulation (ABS) is one of the approaches to support microscopic simulation. Agent-based modeling allows complex behaviors of various interacting entities to emerge from a set of simple individual rules. Phenomena such as flocks of birds, schools of fish, and complex biological systems of cells are good examples of how systems with simple goals can demonstrate complex emergent behaviors as a result of interactions between neighboring agents (local to global). MABS can therefore be regarded as an appropriate approach for pedestrian simulation and the study of associated emergent phenomena.

However, as soon as we consider a microscopic simulation of several individuals and their relationships, the complexity of the system and associated computational costs increase. We are therefore faced a dilemma common in the field of simulation: to manage a compromise between performance and accuracy. Our goal consists in designing a generic agent-based simulation model and a tool that are able to accurately represent phenomenon such as traffic in a time regarded as acceptable for an end-user (on a standard computer). The main goal is to dynamically adapt the accuracy of the simulation according to the volume of available computational resources. Our main application domain deals with the (quasi-) real-time microscopic simulation of large traffic and pedestrian crowds in virtual urban environments.

Solving this issue is not just a problem related to the implementation of the model or the design of the associated simulator. The entire design chain of the simulation is thereby impacted. Before further describing the approach we propose to address this problem, it is necessary to remind some fundamentals on the computer simulation and ABS.

According to Fishwick, computer simulation may be defined as follows: “Computer simulation is the discipline of designing a model of an actual or theoretical physical system, executing the model on a digital computer, and analyzing the execution output” [Fishwick, 1997]. This definition considers the simulation as an experimental process with three fundamentals phases (see also [Shannon, 1977]). This first approach was then refined by Zeigler et al. in the Theory of Modeling and Simulation [Zeigler et al., 2000] which presents the key component of a simulation experiment:

1. The source system: the real or virtual environment that we are interested in modeling.
2. The experimental frame/context: the conditions under which the system is observed or experimented with.
3. The model: a system specification. A set of instructions, rules, equations or constraints for generating system behavior.
4. The simulator: computation system capable of executing a model to generate its behavior.
5. The modeling relation: relation between a model, a system and an experimental frame. It defines the validity of the model, its ability to faithfully capture the system behavior within the extent demanded by the objective of the simulation study.
6. The simulation relation: relation between a simulator and a model. It defines the correctness of the simulator, its ability to correctly simulate the model, to faithfully generate the model's output trajectory given its initial state and its input trajectory.

In the remainder of this document the terms; system or source system, model and simulator will be heard in the sense defined above.
Zeigler's approach raises the fundamentals of the simulation in general. It must be specialized to study specific issues related to MABS. Fabien Michel, in his thesis [Michel, 2004], adopts a multi-view perspective to describe the four fundamental aspects of a MABS:

- **Behaviors**: includes the modeling of the agent’s deliberative processes (“agent mind”).
- **Environment**: defines various physical objects in the simulated world (the situated environment, its structure and the “bodies” of the agents) and the endogenous dynamics of the environment (environmental laws).
- **Scheduling**: deals with the modeling of the passage of time and the definition of scheduling rules and policies.
- **Interaction**: concerns the modeling of the result of the actions and interactions at a time $t$, management of simultaneous actions.

This first description was then extended by Stéphane Galland and Nicolas Gaud to manage issues related to the multilevel agent-based simulation [Galland et al., 2009, Gaud, 2007; Gaud et al., 2007, 2008].

Let's now return to our initial goal: to dynamically adapt the accuracy of the simulation according to specific constraints such as the volume of available computational resources. To tackle this problem, we adopt a multilevel perspective transversal to the whole simulation design process: from the source system analysis to the execution of the corresponding model within the appropriate simulator. Indeed, adjusting the complexity of a simulation requires a model that integrates different levels of abstraction and complexity, and that defines transitions between these levels. However, within ABS the model is decomposed into at least three distinct models: Behaviors and Interaction, Environment, Scheduling. Designing a multilevel ABS thus requires the integration of the multilevel perspective within these three kinds of models.

The multilevel approach also impacts the analysis process of the source system. These aspects require a methodology to assist the analysis of the system to extract its different levels of abstraction, and the design of the model. It also requires a collection of adapted concepts to describe a multilevel model. Moreover, the simulator must be capable of executing a multilevel model and adapt dynamically the complexity of this model according to the volume of available computational resources and simulation criteria to focus on.

Providing an effective solution to the described problem therefore requires an integrated approach covering the methodological aspects, the modeling approach and the associated concepts (meta-model), the design of an adapted simulator and finally the deployment and execution of the model on this simulator.

1.2 Aim of the PhD works

This project aims at designing an integrated approach covering the entire design process of a simulation and enabling the creation of a simulation tool able to dynamically adapt the accuracy of a simulation according to the volume of available computational resources. This tool will then be used to accurately and efficiently simulate large traffic in virtual urban environments and improving the understanding of related spatial dynamics (emergent phenomena).

To address this problem, we propose an approach combining three research axes:

- **Meta-model, models and algorithms**: first, provide a full set of abstractions to analyze a source system and design multilevel models whose accuracy/complexity can be dynamically adjusted according to dynamic constraints, in our case the available computational resources. Then, using
this meta-model, design multilevel pedestrian behaviors and understand the laws which govern the interactions of pedestrians between themselves and with their virtual environment. For example, on this point, we plan to use extensions and adaptations to multi-agent approach of Fast Multi-pole Methods (FMM, especially kernel-independent FMM and multilevel FMM) widely used in computational physics. FMM enable to approximately evaluate (with a specified precision) the product of particular dense matrices with a vector, in $O(N\log(N))$ operations, when direct multiplication requires $O(N^2)$ operations.

- **Methodology**: develop a specific methodology for analyzing a source system, designing multilevel agent-oriented models and assisting the deployment of these models on the proposed simulator.
- **Deployment and Execution**: design a multi-agent simulator able to execute the previously proposed multilevel models without introducing bias while providing optimal performance. Then optimize this simulator to reduce the computational cost of simulation. On this point, we may exploit the agent-oriented programming language SARL (http://www.sarl.io) and its associated platform (http://www.janusproject.io), and adapt the platform to be runnable on the new graphics processors (GPUs) or on grids.

These three axes will lead us to develop a prototype of multilevel multi-agent simulator on which we will deploy examples of traffic simulation in virtual environment. This application will provide support for the validation and a pragmatic evaluation of the simulator and the associated multilevel model of driver behaviors. An agent-based model (ABM) is a class of computational models for simulating the actions and interactions of autonomous agents with a view to assessing their effects on the systems as a whole. ABM is now widely used for modeling increasingly complex systems. Application of ABM is not only limited to the computer science domain. Currently, many research areas such as transportation behavior modeling need to analyze and understand the complex phenomenon of interactions between different entities. While traditional modeling tools in transport science may have difficulties to catch the complexity, ABM can do it through modeling the interaction of autonomous agents and deducing the rules for such a system. We, therefore in this PhD subject, propose to use an agent-based model for simulating traffic on a large area.

2. **Scientific Context**

2.1 **Position of the PhD subject in the works of research team**

This thesis is positioned on the interdisciplinary theme of the laboratory IRTES-SET, and their current national and international collaborations. It lays in the continuity of the works in the project ANR Cities on the coupling of traffic patterns with land use models. Moreover, it perfectly fits in our collaboration with the Institute for Research on Transportation (IMOB) of the University of Hasselt in Belgium. Both projects allow us to have a favorable context to undertake the research proposed in this subject. Indeed the ANR project Cities gives us part of the experiments on the Île de France region (12M inhabitants), and the collaboration with IMOB permits to access to the data on the Flanders region of Belgium (6M people). These two application cases will provide all the data needed to validate the simulation models: their levels are sufficiently large scale to demonstrate the scaling capabilities of the proposed models. Moreover, the PhD candidate will interact and use the data collected in the H2020 SmartCitizens project (pending approval) to create a model to predict the mobility behaviors of individuals in urban and suburban regions, and validate the traffic management policies.

The integration of this thesis, and its candidate in this context provides strong scientific background directly related with experts from different underlying scientific disciplines: analysis and control of traffic simulation in a virtual environment, planning...
Figure 1: Some case studies of the multiagent research group: « Eurockéennes » Festival of Belfort (top, bottom right), Airport microscopic simulation (bottom left).

2.4 H2020 project that is related to the PhD works

- MobiFuture « EMPOWERING LOCAL AUTHORITIES AND CITIZENS FOR SUSTAINABLE TRANSPORTATION IN THE SMART CITY OF THE FUTURE » Program MG-5.4-2015 (application deadline date: August 2015)
  Leader: GALLAND Stéphane (UTBM)
  **Partnership:**
  - Transportation Research Institute, Hasselt University, Belgique.
  - Centre d’Excellence en Technologies de l’Information et de la Communication, Belgique.
  - Technische Universität Berlin, Allemagne.
  - Voxelia S.A.S., France.
  - Delft Center for Systems and Control, Delft University of Technology, Pays-Bas.
  - University of Reading, UK.

2.4 International Collaborations

- GITIA Multiagent Group, Facultad Regional Tucumán - Universidad Tecnológica Nacional, Tucumán (Argentina).
3. References


