Multi-Modal Simulation for Urban Mobility Analysis: An Approach Based on a Model of Behaviour and Infrastructure-related Anomalies

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Abstract. *This paper presents a distributed simulation system for urban scenarios where infrastructure anomalies are common, such as those present in Latin-American cities. A microscopic-based model has been developed in order to represent the behavioural characteristics of the different mobility actors in a discrete lattice. The visualization component allows an interactive and immersive experience of the simulation results, providing a detailed point of view (focus) in the global environment (context). It is possible to empower the users' interaction through devices for control and navigation of the data visualization.*

Keywords. *Simulation Support Systems, Modelling and Simulation (M&S), Traffic Simulation, Immersive Visualization*

Introduction

The physical and functional issues related to an urban mobility project are analyzed from various viewpoints such as traffic, infrastructure (pedestrian crossing, cycle lanes, traffic light, etc.), and air quality impact, among others. Beyond urban development aspects, it is important to consider the effect of the intervention on the local context and its integration with existing urban systems. Simulation software supports the analysis and evaluation stages of the project, based on the implementation of a spatial and functional model. The final goal is to recreate the dynamics of an urban space of interest.

Traffic simulators are, in general, developed under certain assumptions on the context such as traffic rules and regulations, vehicle ideal behaviour, and optimal state of road infrastructure, among others. This notion allows the use of well-known models like the psycho-physical vehicle-following model. In this model, vehicle acceleration is determined by some driver states in order to implement human components in traffic behaviour (Schulze, 1997). If such a model is used to simulate urban scenarios where the non-compliance of the conditions described is a constant, the results are far from the real situation to be simulated. Romero (2009) introduces a brief description of the context issues in Bogotá, where infrastructure anomalies are common, and where driver behaviour is characterised by a high percentage of road traffic offences.

This paper presents a distributed simulation system for urban mobility analysis. The aim of this work is to develop a microscopic-based model, a simulation system to simulate traffic and to integrate data from different points of view (traffic, air quality impact, noise pollution, etc.), as well as a 3D immersive visualization environment.

This paper is organized as follows: Section 2 describes the main concepts of the simulation model. The visualization environment is explained in section 3. In section 4, experimental results of the system execution are presented. Finally, section 5 gives some conclusions and briefly summarizes the future work of this ongoing development.

Model concepts

The mobile behaviour impacts the result in each simulation time step. For the drivers, Paruchuri (2002) defines micro goals. The micro goals involve the necessary decisions (at each point of time) in order to complete a macro goal (describes the general desired displacement). Also three (3) psychological traits are defined: aggressive, normal and cautious. In the same way, the approach proposed formalizes specific subgroups through the concept of belief. A belief characterizes the functional aspects of a mobile (vehicle, pedestrian, biker, etc.) and the way decisions are made in the current time step.

Behaviour is not only influenced by a psychological aspect. Neville (2009), presents a synthesis of causal factors in driver errors: environmental factors such as inadequate signs and signals, maintenance problems, design problems, etc; and vehicular factors like tire and wheel problems, engine system failures, among others. These are core aspects that must be considered in the modelling of traffic scenarios for Latin-American cities.

From the concepts mentioned above, a microscopic-based model has been developed in order to represent the behavioural characteristics of the different mobility actors in a discrete lattice, as well as infrastructure-related anomalies. This approach is based on the work of Ordóñez (2009).

Each lattice cell has a set of attributes (structural and functional): position, type (pedestrian crossings, road, boardwalk, etc.) direction (how mobiles should be moved), lane position (center, between two lanes, etc.) and status (optimal, gap/hole, odd). In order to represent flyover/underground infrastructure, it is feasible to define an overlay layer (discrete lattice) with the related structural information.

The population is composed of several groups: public service vehicles, private vehicles, bikers, pedestrian, among others. A mobile actor is defined by attributes (structural aspects such as size, status and velocity) and beliefs (functional aspects such as haste, compliance with traffic rules). The homogeneous representation of different groups of mobile actors (each with its own geometry and kinematics) lets us simulate their interaction in the same urban region (the multimodal characteristic). There are other objects in the urban space that determine environmental factors in the mobile actors behaviour: the signs. These elements are defined by structural aspects (orientation, size, status, etc) and functional aspects (active or passive, time of the red light, etc).

The basic structural and functional unit for building an urban scene is the road intersection; this means that the urban scene of interest is a set of intersections connected between them. This concept is used to distribute the simulation; each node is in charge of simulating an intersection. The generated conflicts by mobiles passing from an intersection to another are solved in a shared zone. Then, several algorithms can be developed to represent the behaviour of the mobile actors inside the urban space at each time step. Table 1 summarizes the basic definitions introduced by Romero (2009), and Figure 1 illustrates the model relationships.

Table 1. Basic model definitions.

Definition	Description
L^2	Discrete lattice of two dimensions
c^i	Cell I of the lattice.
A_{ci}	Set of attributes for Ci.
	A layer k is a set of cells.
	An intersection n is a set of layers that meet an association rule.
	Shared zone between In and In+1.
	Set of mobile actors.
	Set of attributes for a mobile actor.
	Set of beliefs for a mobile actor.
S	Set of signs.
$t \rightarrow t+1$	Time-discrete steps.
	State t for In.
	State t for a mobile actor.
	The transition function for a mobile actor.

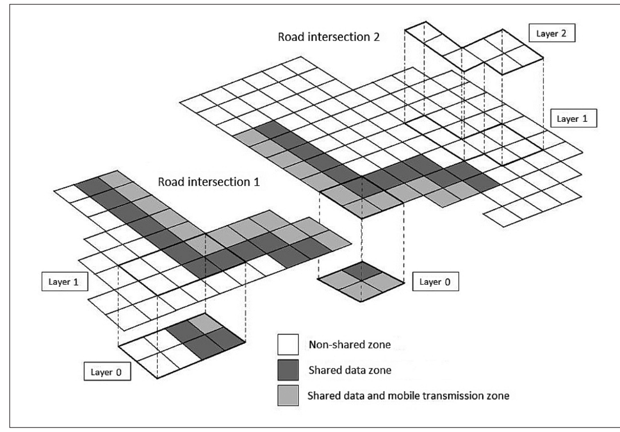

Figura 1

Figura 2

System overview

The system is made up of 2 main components: the simulation application and the visualization application. The simulation application is in charge of the lattice composition, starting from road infrastructure, vehicles and pedestrians; it is possible to set sensors (global and/or local) in order to acquire information like average vehicle speed, occupancy rate by location, etc. Given that, this application executes the simulation process. The visualization application allows an interactive and immersive experience of the simulation results. The aim of this application is to provide a detailed point of view (focus) inside the global environment (context). On the other hand, it is possible to empower the user interaction through devices such as wheel, joystick or virtual reality glove. This section introduces the visualization data structure, how visualization interaction works and the system display.

Visualization data structure

Hernandez (2008) proposes a data structure based on a focus + context approach on which information is mapped as a multilevel, multi-viewpoint structure.

This representation has a central data store composed of the complex system's physical structure and some subsets on this store that share functional characteristics. The physical information is organized in a tree-like data structure with some non hierarchical connections between nodes that provide traversal facilities. The functional information can be filtered through a theme composed of a subset of nodes, the focus. The system automatically estimates a subset of nodes that contextualizes this information thus widening the meaning perceived by the user. Also, there is an implementation called SVGAT: Anatomical and Thematic Graphs Visualization System (for its Spanish acronym) providing user interaction and stereo visualization capabilities (active, passive or anaglyph stereo) built upon the data structure. This kind of approach gives versatility to the system in terms of immersive scenario design.

An urban mobility example of its use takes a part of a city's physical structure as the main hierarchical definition. The buildings, roads, sidewalks, parks, among others are the nodes that describe a city in terms of the proposed data structure. From this structure the system sets a focus (nodes where the cars and pedestrians move in) and a context that completes the scenario (nodes where those actors cannot move in). The visualization component of SVGAT uses this differentiation to render structure nodes taking into account the set they belong to and therefore the static information. The dynamic information (simulation data) is fed through interfaces with the corresponding components (mobility simulator, air pollution simulator, etc) completing the visualization of the urban mobility scenario.

Interaction

One of the aspects that is widely studied in the use of 3d interfaces is the proposal for interaction metaphors that can be used for data acquisition, edition or simply data visualization. In this sense SVGAT provides a layer architecture that simplifies the process of using a wide set of devices with a common set of interaction techniques that are finally shown as interaction animations in the viewing environment presented to the user. The first layer is an acquisition component that uses a communication protocol with the devices through the use of VRPN (Taylor, 2001) as a communication library. The second and third components act as a bridge between the interaction device and the visualization environment. They translate the analogue or digital signals launched by the device into actions within the virtual space where the user is. The Interaction Techniques component is based upon basic interaction functions presented in the navigation events controller. Depending on the level of interaction complexity and where the interaction will take place in (structure or virtual world), the petition is answered properly. If the answer needs a visual feedback, it is shown through the visualization component.

System Display

One of the system requirements is the use of multiple displays that compose a single unified screen for a large-scale visualization in a 9x3 meters area.

Systems for cluster rendering such as chromium (Humphreys, 2002), equalizer (Eilemann, 2007) or VrJuggler(Cruz-Neira, 2002) are not a solution for Java-based visualization applications. To fulfil the objectives of immersive visualization and interaction, a cluster rendering component has been developed based on JOGL and Java3D. The solution is a server/client model where the server manages the devices and is the main node for the cluster rendering. It sends all the synchronization and interaction messages to all the tile clients until they have one visualization cycle. The process is repeated indefinitely until the application stops. The frame rate then is set to the slowest machine in the cluster. This approach uses a sort-first rendering where all the information is replicated in all the cluster nodes and each machine renders a tile depending on frustum parameters.

Results

Several tests were designed to evaluate the system capability for representing different subgroups of mobile actors and infrastructure anomalies. In the same urban space, we did two scenarios with the same initial mobile actor´s positions:

- In the first one, we set different belief parameters to the mobile actors (table 2), and the system reports some statistics of resulting kinematic variables (of the mobile actors), at the end of the simulation time (table 3).
- In the second one, we ran the system with mobile actors with the same beliefs, but with different infrastructure conditions, and the speed statistics were reported (table 4).

Table 2. Belief parameters.

Belief	Vmax (m/s)	Time of caution 1 (s)	Time of caution 2 (s)	Desire to move (%)
Common	20	2	4	25
Cautious	10	3	5	15

Table 3. Measurements of the average of all mobile actors.

Belief	Mean Speed (m/s)	Max Speed (m/s)	Min Speed (m/s)	Max Acceleration (m/s2)	Min Acceleration (m/s2)
Common	4.7	6.95	4.1	2.5	-4.05
Cautious	3.5	5.8	2.8	2.22	-4.17

Table 4. Measurements of the average of all mobile actors.

Condition	Mean Speed (m/s)	Max Speed (m/s)	Min Speed (m/s)
with hole	0.5	2.4	0.2
without hole	4	5.1	3.5

The visualization clustering system was tested in a 2x2 tile setup with four (4) machines (Intel QX6650 of3.0GHZ, 8GB RAM and NVIDIA Quadro 4600 of 768 MB graphic card). The frame rate with a simple geometry (507 vertices and 968 faces) was 1500 fps. With a more complex geometry including alpha blending (134954 vertices and 269103 faces) the frame rate was about 620 to 750 fps depending on the position of the tile and the quantity of triangles shown at a given time. All the visualizations had basic interaction (rotation, translation, zooming) through a wireless joypad plugged into the main server machine.

The simulated behavior (with the immersive visualization) was observed, and judged, by mobility experts and decision makers in a first step of usability testing. The qualitative feedback obtained from these experts was favorable and encouraging enough to pass to a second step of quantitative validation in “pathological” zones of urban mobility, and a more rigorous usability test in a decision process.

Conclusions and future work

This article described an approach to traffic simulation based on a model of behaviour and infrastructure anomalies. The urban information of interest is organized in a data structure that provides a detailed point of view (focus) in the global environment (context). The SVGAT component allows empowering the users’ interaction through devices such as wheel, joystick or virtual reality glove. A cluster rendering component has been developed in order to support applications based JOGL/Java3D and provide an immersive visualization environment.

The main direction of the future work is to integrate simulation data from different points of view (air quality impact, noise pollution, etc.) in the same space model. Other aspects to improve are the psychological behaviour model of mobile actors, and the system's input data entry. Then, it will be possible to represent complete Latin-American cities, simulating mobility in a microscopic model.

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