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An accelerated-time simulation for traffic flow in a smart city

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ABSTRACT

Traffic control is one of the most important problems related with urban development. Current trends for traffic control are based on the use of smart traffic lights and signals as a part of smart cities' projects. Different cities are currently involved in the design and implementation of smart traffic control. Since the cost of physically installing these systems is very high, in terms of both money and resources, accelerated-time simulations of traffic flow using smart traffic lights and signals significantly reduce these costs.

In this work we present a new model for accelerated-time simulations for traffic flow within. The philosophy of this model is based on previous works of the authors, where accelerated-time simulations for car traffic in a motorway or a roundabout and baggage traffic in an airport were developed. The philosophy of this model combines ideas from cellular automata and neural network theories, obtaining a mixed model.

This system was developed using a Computer Algebra System (CAS) called Maxima for mathematical computations and a Java based interface for graphical display. Maxima allows the system to support the use of ad hoc distribution functions for the different events dealt with in the simulations. The interface provides a friendly framework for entering input data and visualizing the simulations, providing also some statistical data.

1. Introduction

This work is an expanded version of a talk with the same title presented at the *FEMTEC'2013* Conference (Las Vegas) and a later version presented at the *ACA'2013* Conference (Málaga) entitled *Simulating Car Traffic with Smart Signals using a CAS* Galán et al. (2013) [1].

Information and Communication Technologies (ICTs) play a very important role in the development of sustainable cities. Smart city is a very broad concept which includes not only physical infrastructure but also human and social factors [2].

One of the main aspects of smart cities is a good control of the traffic flow within the city. Traffic jams or slow traffic are not only pollution and economic problems but also provoke frustration in drivers as well as pedestrians. The use of smart traffic lights and signals is one of the most important techniques that smart cities use to deal with these problems.

Smart traffic lights and signals are interconnected. Each sensor detects a different parameter of the traffic flow (speed of cars, density, waiting time, a traffic jam, etc). The system makes decisions according to the values of these parameters and gives the appropriate instructions to the lights and signals.

A good example of using smart traffic lights and signals was designed by Traffic21 project [3]. This project proved, among other things, that using smart traffic lights and signals reduced emissions by over 20%. To achieve this result, SURTRAC, a pilot implementation of an adaptive traffic signal control system, was implemented. This control system was installed for a nine-intersection road network in Pittsburgh, Pennsylvania (USA).

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Testing of a smart traffic light and signal system has a very high cost. These tests produce not only high costs in resources but also in traffic problems while physically implementing the system. Simulation techniques that help in the design of the system can drastically reduce these costs.

This work will deal with simulation techniques. Specifically, we introduce the ATISMART model, an accelerated-time model to simulate car traffic in a city using smart traffic lights and signals. The aim of the ATISMART model is to easily simulate a wide range of situations in order to test the system before its physical implementation. To achieve this goal, the ATISMART model has been programmed using a CAS that deals with exact and symbolic computations.

In Section 2 the main background related to this work is presented. Section 3 is the description of the ATISMART model while Section 4 shows its implementation. In Section 5, different results from using ATISMART in an example are provided. Finally, the conclusions and directions for future work are given in Section 6.

2. Background

Some of the foundations of the ATISMART model are based on ideas from: Cellular Automaton (CA) and Neural Network (NN) theories.

The starting point of CA gets us back to the decades of forties and fifties when Stanislaw Ulam and John von Neumann first introduced the idea [4]. But one of the best known example of CA is John Conway's game of "life" [5] which simulates the behaviour of a group of cells. The way that this group of cells evolve, is determined by the starting configuration and four basic rules. These four rules establish the state of each cell depending on its own and its neighbouring cells' state.

An easy way to understand how a CA can be applied to simulate movement, is the rule 184 of Wolfram [6]. This rule establishes if a cell will or will not be occupied in the next step depending on the state of the current, previous and following cells. Specifically, there are 8 possible situations displayed in binary from 000 to 111, where 0 or 1 means that the corresponding cell is empty or occupied. The first, second and third bits correspond to the previous, current and following cells, respectively. The result of applying rule 184 to a three-bit number is a bit which tells if the central position will or will not be occupied in the next step. The following table shows how the rule is applied for the 8 different possibilities.

Input	111	110	101	100	011	010	001	000
Output	1	0	1	1	1	0	0	0

For example, after applying the rule 184 to 101, a 1 is obtained since the current position (the central one) is empty and the previous is occupied and the object in this cell wants to move one step to the right. After this one-step movement, the central position will be occupied. In a similar way, after applying the rule to 011, a 1 is obtained since the current position is occupied but cannot move to the right because the next position is occupied and, therefore, the cell remains occupied.

The name of the rule comes from the binary number obtained in the output row of the previous table, that is, 184 is 10111000 in binary.

A more sophisticated CA related with movement was given by Nagel and Schreckenber [7] (the NaSch model). They introduced a stochastic discrete model of freeway traffic.

Knospe et al. [8] stated that the NaSch model could properly simulate macroscopic characteristics of freeway traffic. However, they also stated that the comparison of simulation results with empirical data on a microscopic level is not satisfactory. To overcome this situation, they introduced a new model (the KSSS model) whose rules take into account characteristics such as random braking in addition to velocity, position and normal braking which were already considered in the NaSch model. Therefore, the KSSS model uses a finer discretization than that used in the NaSch model.

With regard to our own background on the topic of this paper, we introduced a new model for car traffic simulation [9]. This new model uses the KSSS model as its starting point but introduces new characteristics such as the use of car indicator signals and more than one traffic line. Our model also considered typical concepts from neural network theory such as the use of state vectors and minimization of the objective function. In this paper, the model is applied as an example of simulating car traffic behaviour in a roundabout with several traffic lines and different inputs and outputs.

In [10], the GRAM model was introduced as an extension of the previous model and was used to generate car traffic simulations in motorways as well as roundabouts. In that paper the description of the GRAM model was presented, together with a computer implementation of the model.

Another related work is the ATISBAT model [11] that simulates the baggage traffic in the handling system of an airport from the check-in desks to the aircraft.

The computer implementations of the GRAM and ATISBAT models were developed using a CAS in combination with graphical interfaces developed in Java. This blending of Java with a CAS was first used by us in [12] where we introduced a graphic interface for generating counterpoints for a given melody.

Other authors have also used accelerated-time simulations for other applications. Some of these simulations are described in [13,14]. The first deals with simulations for departing passengers' flow in airport terminals while the second introduces accelerated-time simulations for a dedicated freight double-track railway line.