Cellular Automata and Roundabout Traffic Simulation*

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Abstract. A new software package, named Archirota, for simulating traffic in roundabouts is introduced. Its simulation module is entirely based on cellular automata and is automatically configured for real-world geocoded data. Archirota can be used both as a support for designing new roundabout and for modeling and simulating existing ones. Tests on actual use cases testified the effectiveness of the implemented approach.

1 Introduction

Among the many applications of cellular automata to complex system problems, the study of traffic is getting more and more popular in these very last years. The reason for that is the ease with which the dynamic features of traffic can be simulated with a cellular automata algorithm. With few simple rules the complexity of traffic (transition from free to congested traffic, lane inversion, stop and go traffic, nucleation of jams in correspondence of ramps etc.) can be reproduced in a way which is hardly achieved by models using differential equations ([13],[10],[5],[4]). Being computationally extremely efficient, large scale simulations can be accomplished with low cost computers and traffic forecasts can be envisaged. In order to simulate with cellular automata traffic on a road, the road is divided into cells whose occupation corresponds to the presence of a vehicle in that place at a certain time. A set of rules specify the time and space evolution of the system, that is how each vehicle moves along that road [6].

A slightly more complex problem is that of simulating a roundabout, that is a multiple (at least three) road junction in the form of a circle, around which all traffic has to pass in the same direction. Roundabouts were originally a particular feature of the British landscape, but in the last two decades they have widely spread all over the world. They replace crossroads, contributing to reduce car accidents and to slow down fast cars. Yet, they increase the flow of vehicles in the road because they tend to avoid the complete stop of cars which has as a direct

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effect the formation of jams. The accidents rate at roundabouts is reduced on average to one half of that of signaled junctions [2]. Finally, they offer lower cost and safer operation and are seen as a way to embellish settings with green and floral displays. The increasing number of roundabouts and their importance for the limitation of traffic jams and the reduction of accidents, fostered researchers into creating some instruments to help traffic engineers projecting roundabouts. Different softwares have been designed [3], showing different features and being currently used in many countries.

In this article we describe a new software, named Archirota™, which can be used to simulate roundabout traffic. Its purpose is mainly to contribute to the proper design of new roundabouts and to the forecast of the traffic conditions which will be present in a given roundabout. A cellular automata algorithm is used in this software. The specific cellular automaton builds on the experience of the authors on cellular automata for environmental ([7], [8]) and specifically for traffic flow ([5]) simulation. Specifically, the algorithm is obtained essentially by modifying that used for modeling traffic on highways. Vehicles of different lengths occupy here from 1 to 9 cells (where each cell corresponds - parametrically - to 2 m length), a feature which offers a wide dynamic range to the simulations. Vehicle speeds depend on the correspondence among cells and actual space. Cellular automaton evolution rules are accordingly defined.

The Archirota™ software is written using the C++ language and its main features include: the capability to create the roundabout directly from a geocoded digital map; a variable number of roads and lanes per road; an average vehicle speed inside the roundabout depending on the radius of curvature of the roundabout; a variable insertion angle for each road; a dynamic and user-definable vehicle generation function and an easy modification of cellular automata rules. Finally, both a 2D and a 3D graphic interface are supported.

Archirota™ has two output types: a visual simulation and a quantitative analysis of the traffic occurring at the roundabout. This includes: capacity of the roundabout, average crossing time for a vehicle along each path'; delay queuing, average speed, vehicle density and flow inside the roundabout.

In the following we will first frame our work in current research on traffic simulation by means of cellular automata (2), then describe the essential features of the Archirota package (3) and finally show some use cases along with the output produced (4).

2 Cellular Automata for Traffic Simulation

In order to simulate traffic, we designed a cellular automata model which provides a simple physical picture of a road system and is easily implemented on computers. Each road is divided into lanes and each lane is divided into cells, which can be either empty or occupied by a vehicle. Each lane starts at cell 1; vehicles, which enter the road at its beginning move in discrete steps in the direction of increasing cell number.

A set of rules, described in details in reference [5], specify the time and space evolution of the system. These rules were derived from those originally developed by Schreckenberg and coworkers [11] and by Nagel and coworkers [12] to implement a multilane highway without ramps and with periodic boundary conditions. The rules specify at each step and for every car: a) the speed with which cars move along the road, b) how faster cars overtake slower ones and c) how cars slow down or accelerate according to the behavior of neighboring vehicles. Cars have a sufficient braking ability to avoid accidents.

In each traffic simulation a starting configuration is chosen. New cars enter the road at a chosen rate as follows. For all on-ramps, at each iteration the program checks if the cell is empty. If empty, a random number is generated in the [0,1] interval and if it is less than the threshold chosen for that simulation, a car is generated in that cell. A number of local and average quantities are regularly recorded. At selected positions, the flow of vehicles and their average speed are collected. Regarding the flow, this is done counting the vehicles passing trough that location in a time interval divided by that amount of time. From these quantities, all other quantities of interest such as density (density=flow/speed) or the average distance between vehicles are computed. The same data are also collected as space averages: counting the number of vehicles present in a segment of the road at a given time provides the density. Their (average) speed allows to compute again the flow (flow= density $\times$ speed) and all other quantities.

The use of averages is due first of all to the discreteness of cellular automata models. Cars in the model can only have as speed an integer number, while car speeds are real numbers in nature. Furthermore, experimental data are averages over time and/or space [9,13], so that a proper comparison again requires to average simulated data. As reported elsewhere [5], this model proved to be able to reproduce most of the experimental data available on traffic.

Some additional rules must be introduced when simulating a roundabout. First of all a new object must be considered: the ring which connects the roads. Its on/off ramps are the end/beginning of the lanes connected by the ring itself. While in a simple road a vehicle disappears from the simulation at the road end, now it is passed on to the roundabout. When approaching the roundabout, a vehicle slows down and possibly stops because it has to give way to vehicles already inside the roundabout. A new rule is chosen for the speed limit of vehicles inside the roundabout so that this speed increases with the radius of the ring. Finally there is an impatient delay rule: car drivers at a road end waiting to enter the roundabout get progressively prone (up to a limit) to brake the respect of the rule defining the distance and approaching speed according to which they give way to vehicles already inside the roundabout.

3 Archirota Specifications and Implementation

The Archirota package was conceived to provide simulation support in actual roundabout design practice. Prospect users are decision makers who have to decide whether and how to construct a roundabout for a particular road junction.

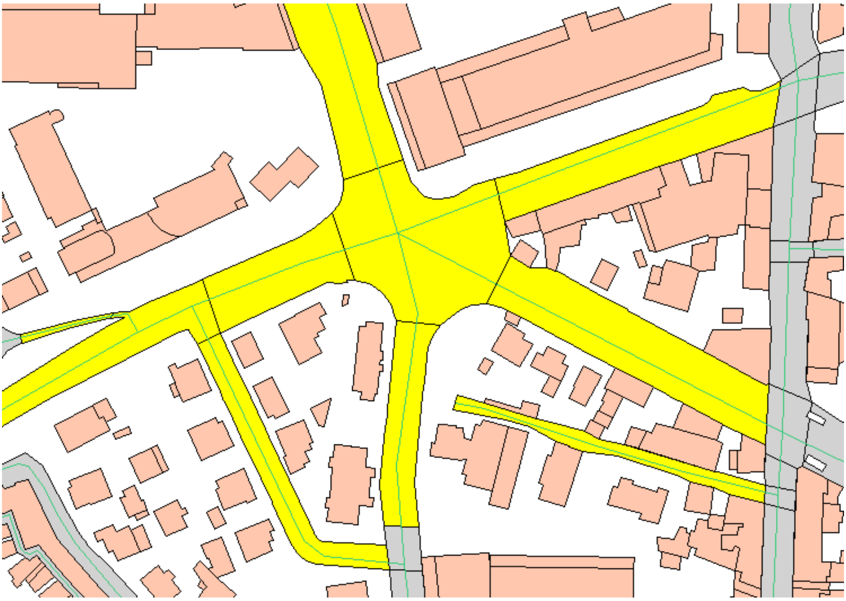

Fig. 1. The Ertha selection interface.

The main program specification are therefore:

- Possibility to work on actual digital city maps.
- Possibility to include any relevant driver style.
- Possibility to consider any relevant environmental influence.
- Possibility to derive aggregate simulation data in the format decision makers are used to.
- Possibility to easily define design alternatives and to support consequent what-if analysis.
- Low cost and ease of use for unskilled practitioners.

These specifications lead to the design of a very simple code, based on the cellular automata model introduced in section 2. The cellular automaton itself is of straightforward implementation, simply requiring to compute for each cell the next-iteration state on the basis of the current state of the cell itself and of those of its neighborhood.

More precisely, following the notation introduced in section 2, we associated a geocoded cell vector $\mathbf{c}_j$, $j \in J$, to each entering and exiting lane and one to each lane of the roundabout itself. For each cell c_{ij}, $i \in I_j$ of each vector J we then defined a cell-specific neighborhood $N(ij)$, automatically including all cells which correspond to location that are visible for a driver occupying the lane position associated to ij. Visibilities are computed by simple computational geometric routines working on GIS-derived layers, such as buildings, green areas etc.

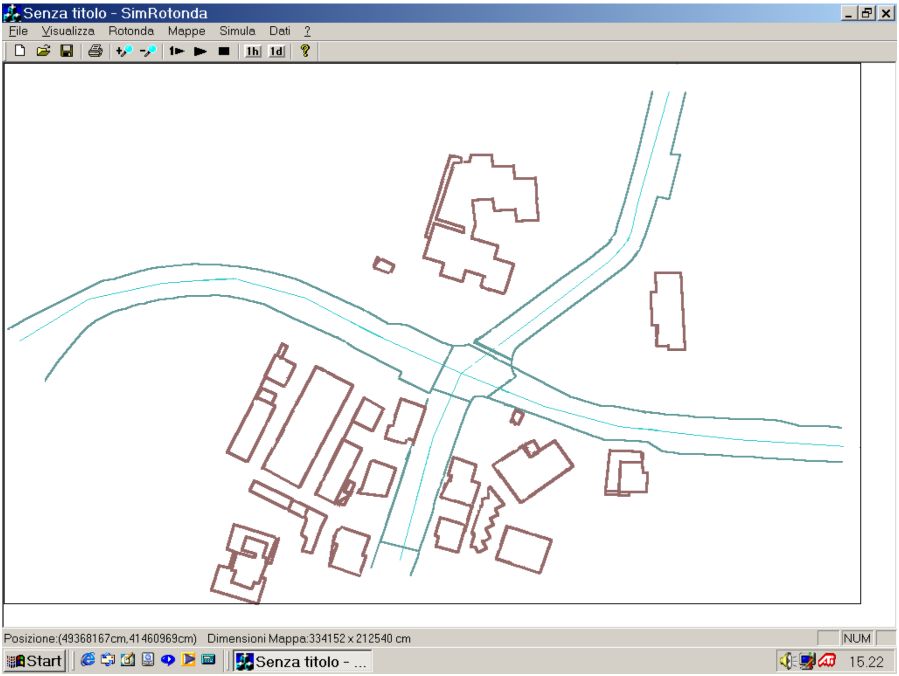

Fig. 2. The Archirota design environment.

The simulation goes on by updating in parallel each cell state at each time instant. An outer loop, time instants, iteratively commands each cell to check its own state and that of its neighbors and to accordingly update its own next-time state. As mentioned, we have defined cell-specific neighborhoods, whereas the state domain is shared by all cells. Basically, each cell can be either free or occupied by a vehicle, in which case the type, portion and speed of the vehicle is recorded. The new state is simply a computation of whether, and by which vehicle, the cell will be occupied on the next time interval. The rules according to which vehicle positions are defined, as mentioned in section 2, are the same as those described in [5] except for the fact that the behavior of all *visible* vehicles is taken into account.

Currently the architecture of the package requires the use of two different applications: a tailored GIS for selecting and exporting all relevant elements and the Archirota package itself.

The GIS activities are currently supported by means of the desktop client of the Ertha GIS [1]. Ertha is an open source project currently under development at the University of Bologna aimed at providing source code for a multi-platform, multi-tier GIS. At the present date desktop, PDA and web browser clients are available, the former of which has been used for supporting the upload of the GIS project of interest, selecting all relevant layers and exporting the selected geocoded data. Figure 1 shows the interface of the tailored Ertha module. The

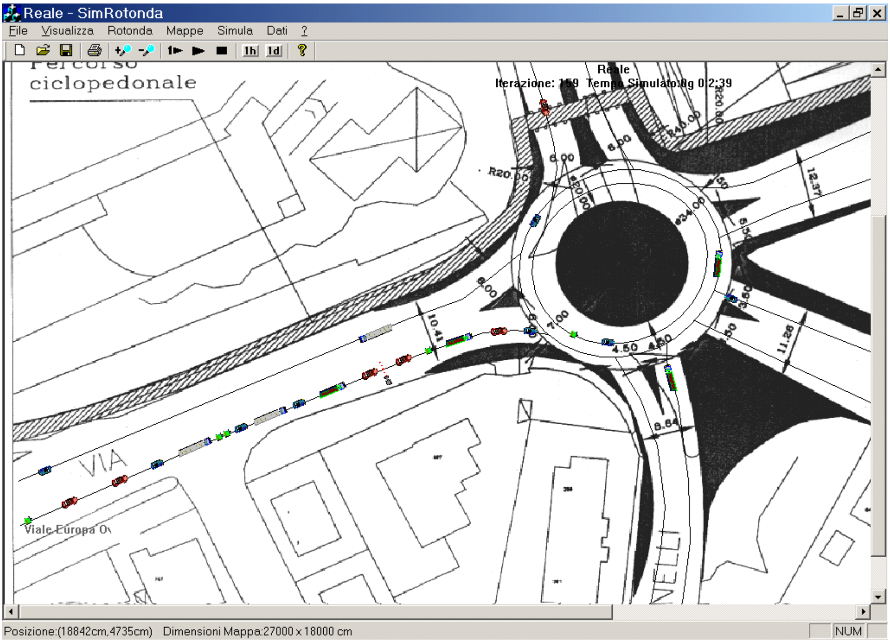

Fig. 3. Simulation of an existing roundabout.

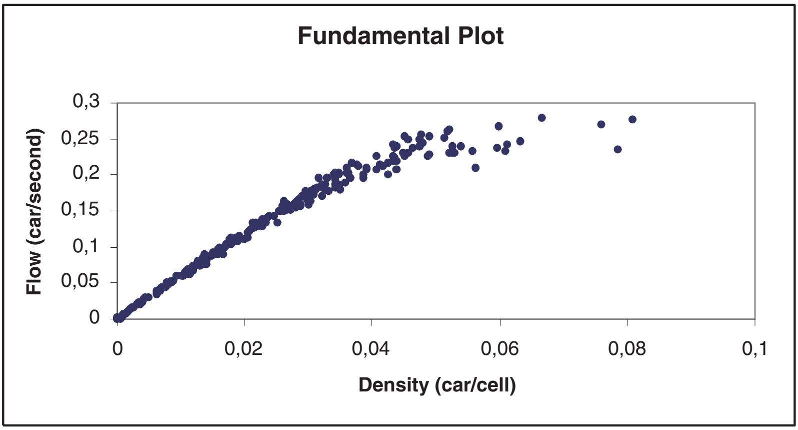

Fig. 4. Fundamental plot under light traffic conditions.

exported layers are later uploaded by Archirota, which is the environment where the actual roundabout design takes place. In Archirota, vectors are automatically defined and dimensioned for each lane reported in the input file and all neighborhoods $N(ij)$ are computed. Figure 2 shows the Archirota design environment.

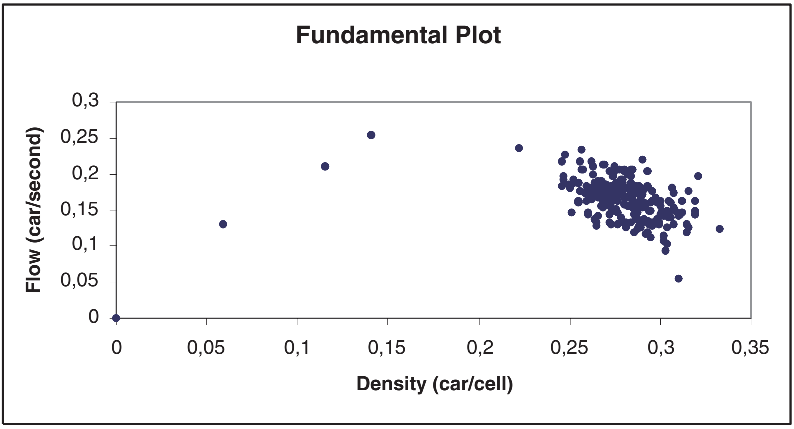

Fig. 5. Fundamental plot under heavy traffic conditions.

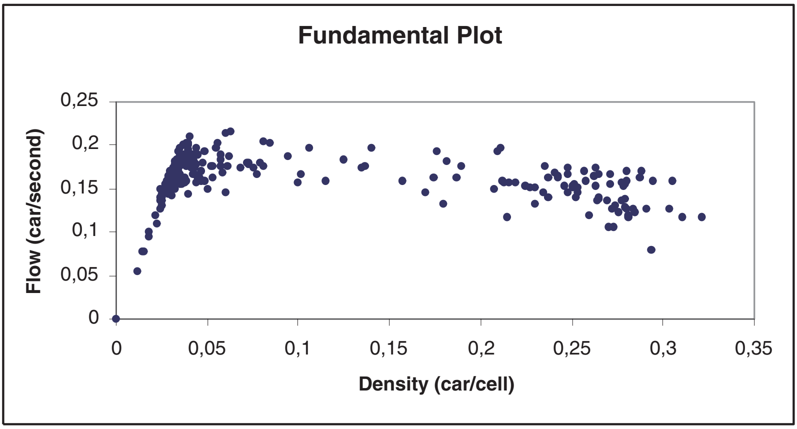

Fig. 6. Fundamental plot under mixed traffic conditions.

4 Computational Results and Use Cases

Archirota was implemented in C++ and runs under windows. Although still under development, the main simulation features are by now stable and have been used to model different real-world cases.

Figure 3 shows the main Archirota interface when a raster image of an existing roundabout is loaded and a simulation is run on it.

In this case we simulated the roundabout efficiency under two different traffic conditions. Specifically, we modified the incoming traffic rate for the roads from the left and from above. Figure 3 shows a snapshot of a congested traffic simulation case.

Quantified results are obtained directly from the cellular automaton by placing "sensors" (i.e., counters) in user-definable roadside locations and recording traffic data for each sensor at each iteration. This data is later processed to obtain reports customized to user needs, even though some output is provided by default, which is the case for example of the traffic fundamental plot.

Figure 4 shows the fundamental plot obtained under light traffic conditions, where traffic flows without developing significant queues. For this result we set a sensor on the road incoming from the left close to the entrance of the roundabout.

Figure 5 shows the fundamental plot for the same roundabout of figure 4 but with much increased incoming traffic. Now vehicle queues are permanent, and this is apparent from the plot since data points are not distributed along a line from the origin but are clustered in a region where a regression line has a definitely downward slope.

Figure 6 finally shows again the same roundabout under mixed traffic conditions, this is a simulation of a time interval when for some minutes traffic was regular but at a certain moment it increases substantially. This could be the case for example of office or school closing hours. From the plot one can see how data point are initially on a line from the origin (regular traffic) and then move toward the congested area.

5 Conclusions

This paper presented the essential features of new a software package, named Archirota, for simulating traffic in roundabouts. The simulation module is extremely simple and based on cellular automata. The neighborhood structure intrinsic to cellular automata supports a great flexibility in simulation conditions and output data, thus an easy adaptation to different use cases.

While the package interface still has to be improved, the simulation module and reporting facilities are by now stable and have been used to simulate real-world cases, both for designing new roundabouts and for modeling existing ones. In all cases the package results were adequate.

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