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Generating realistic urban traffic flows with evolutionary techniques

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ABSTRACT

In this article we present a novel approach for calculating realistic traffic flows for traffic simulators, called Flow Generator Algorithm (FGA). We start with an original map from OpenStreetMap and traffic data collected at different measurement points, published by the city's authorities, to produce a model consisting of the simulation map and a series of traffic flows (routes + vehicles) which match the real number of vehicles at those streets. Our approach does not need a full dataset to calculate the flows. In fact, just a few measurement points indicating the number of vehicles in the analyzed time interval were used. This and the use of evolutionary algorithms for such a complex task make our proposal different from the studies found in literature. Despite the fact we have chosen the SUMO traffic simulator for our experiments, this idea can be easily adapted to others. We have tested our proposal on two geographical areas of the city of Malaga, comprising different map sizes, number of sensors and vehicles, and have achieved measurement values from the simulation that are closer to the real values, showing an error lower than 10%. Our algorithm, as well as the realistic scenarios generated by using it, can be used as the basis for other research approaches, especially those focused on road traffic optimization.

1. Introduction

The number of vehicles on European streets is rising (SIMI, 2017), in fact this is a world-wide phenomenon (OICA, 2015). As a consequence, CO_2 emissions from fuel combustion have been rising worldwide since 1971, and this growing tendency has proved to be hard to reverse in the near future (OECD/IEA, 2012). However, one of the European Union's objectives for the year 2020 is the reduction of greenhouse gas emissions (Europe 2020, 2010). Hence, many articles have been published presenting different approaches to address traffic congestion problems, largely focused on traffic signal optimization (Florin and Olariu, 2015), traffic control (Li et al., 2014), intersection management (Chen and Englund, 2016), etc. Most existing work relies on a traffic simulator to study a large area of a city (not just a few junctions), whereas a realistic map is essential to obtain trustworthy results.

Traffic simulators such as SUMO (Krajzewicz et al., 2012), MATSim (MATSim, 2017), and Vissim (VIssim, 2017), have been used in the last decade to validate different research approaches involving not only mobility issues, but also other different disciplines. Some examples of these are traffic light optimization (Mckenney and White, 2013), intermodal traffic systems in disaster management (Duncan and Brebbia, 2009), reducing the required total vehicle fleet size (Boesch et al., 2016), alternative routes for preventing traffic jams (Stolfi and Alba, 2014), evacuation planning (Gan et al., 2016), optimization of transmission of live on-road videos (De Felice et al., 2015), vehicle congestion avoidance systems (Jabbarpour et al., 2014), taxi dispatching (Maciejewski et al., 2016), vehicle platooning under VANET environments (Jia et al., 2016), among others.

A mobility scenario is mainly composed of the map of a city (including streets, roundabouts, turn restrictions, traffic lights, etc.) and its traffic flows. These traffic flows are obtained from a origin–destination matrix (OD-matrix) where the travel demands between vehicles' origin and destination are specified. Since it is almost impossible to obtain data for an entire large city so as to estimate the OD-matrix, flows must be generated based on measurements from just a few sensors.

Our proposal consists in a new methodology to build realistic traffic flows, based on evolutionary techniques, to be used in mobility scenarios supported by maps from OpenStreetMap (OpenStreetMap Fundation, 2017) and vehicular data obtained from sensors placed around the city's streets. We feed these inputs into our Flow Generation Algorithm (FGA) and using an evolutionary algorithm (EA) and a traffic simulator, SUMO in our case, we obtain a realistic simulation model, which contains traffic flows calculated according to an estimated OD-matrix, so that the number of vehicles at each measurement point matches the real one.

The advantages of using FGA are:

- A realistic mobility scenario is built by using a city layout imported form OpenStreetMap.

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- Realistic vehicular flows (routes + number of vehicles) are calculated, based on a few measurement points in the actual city.
- In addition to SUMO, FGA works with other simulators as well.
- FGA uses evolutionary techniques in order to achieve good solutions in an affordable execution time.
- The resulting map can generated and used by researchers to test their smart mobility proposals and other research work involving road traffic simulations.
- FGA make possible smart mobility studies needing a set of flows for all streets in a city, even if there are only a few points measuring them.

The main concepts we will manage in this manuscript are the values collected from sensors in the city ($\vec{v}^{*}$), the values obtained from our simulated scenario ($\vec{v}$), the error we want to reduce ($\vec{e}_i$), and the vehicle flows that we will modify (f_i) to achieve it.

The rest of the paper is structured as follows. Section 2 presents the related works. Section 3 describes the problem. In Section 4 the FGA and its components are described. In Section 5 our case studies are presented. In Section 6 the parameterization of the EA is explained. In Section 7 our results are discussed. Finally, in Section 8 the conclusions and future work are given.

2. Related work

There exist several methodologies for obtaining a valid city map, many of them are based on importing it from OpenStreetMap (Haklay and Weber, 2008; Rieck et al., 2015). While data regarding the number of vehicles on city streets is being collected by different methods (Djahel et al., 2015). Some of them use Wireless Sensor Networks (WSN) (Tubaishat et al., 2009), magnetic sensors (Cheung et al., 2005), acoustic sensors (Lefebvre et al., 2017), or even WiFi and Bluetooth technology (Fernández-Ares et al., 2017). Furthermore, there are several studies (see Larsson et al., 2010 for a survey) about the allocation of sensors on city streets, taking into account aspects such as maximum flow coverage, and route coverage.

Other studies (Bera and Rao, 2011) are focused on the estimation of the OD-matrix based on traffic counting locations. They are classified as static (Lo and Chan, 2003; Li, 2005) or dynamic (Hazelton, 2008; Nie and Zhang, 2008). However, authors do not usually detail the scalability of their algorithms for larger networks nor do they test them in a traffic simulator, which is a key issue for the applicability of their solutions. These are two important issues. Furthermore, most of these algorithms usually assume that all link costs are available, which is certainly not true in our case study and the same is true for several other cities.

A genetic algorithm approach to find an optimal OD-matrix, showing the actual travel patterns of significant number of vehicles inside the city, is proposed in Saini et al. (2015). The authors use Call Detail Records (CDR) obtained from mobile operators and a simulated road network of Mumbai, to estimate travel demand for city planners to analyze the dynamic behavior of traffic on a typical day. Our proposal in turn uses public data from just a few sensors to calculate all the realistic vehicle flows in the city.

In Spiliopoulou et al. (2017) the deterministic Nelder–Mead algorithm, a stochastic genetic algorithm and the stochastic cross-entropy method are utilized to estimate the parameter values of the macroscopic traffic flow model METANET (Messmer and Papageorgiou, 1990) for a part of Attiki Odos freeway in Athens, Greece. The authors use real traffic data with a time resolution of 20 s during a month to model the network. In the FGA we follow a microscopic approach, analyze a bigger urban traffic case study, and individual vehicle data is not available.

The impact of transport policies is investigated in Ziemke et al. (2015) by generating a set of possible activity-travel plans using CEMDAP (Bhat et al., 2008) and MATSim (MATSim, 2017). Additionally, an evolutionary algorithm is used to adapt the transport demand to transport supply over the course of optimization process. The authors study the roadway network of two German federal states of Berlin and Brandenburg using activity-travel plans collected by the Berlin Traffic Management Center. We use a different technique to calculate traffic flows in the city, using the SUMO traffic simulator.

A Hopfield Neural Network (HNN) model is used in Zhejun Gong (1998) to estimate the urban origin–destination distribution matrix. The author finds the global optimal solution to the problem and experiments on a graph made up of just five nodes representing the same number of zones. To the contrary, our method focuses on individual streets rather than zones (finer grain, higher realism) and we route vehicles via individual streets. As a result, there are several routes available between the measurement points in which the vehicles are counted.

In Lundgren and Peterson (2008) the authors estimate an OD-matrix by using a general nonlinear bilevel minimization formulation of the problem. The lower level problem is to assign a given OD-matrix to the network according to the user equilibrium principle. On the other hand, a weighted measure of deviation from the target matrix and from the observed counts is the upper level objective. They solve this problem with the projected gradient method by reformulating the problem to a single level problem, with an implicitly defined objective function. After testing their solution in a small network, another network, modeling a portion of the city of Chicago, and finally a third network made from the city of Stockholm, the authors believe that their proposal can be applied to large-scale networks and contribute to improve OD-matrix estimation. This study uses networks comprising links, nodes and fictive traffic counts. Our proposal takes advantage of real maps imported from OpenStreetMap and real measurements. In addition, the generated road traffic is micro-simulated to deal with possible traffic jams which occur when the streets' capacity is exceeded.

In Papaleondiou and Dikaiakos (2009) an open-source software, called TrafficModeler, is presented. This program implements a traffic definition model consisting of a set of layers placed over a road network. Those layers allow specific traffic patterns associated with different attributes to be represented. Additionally, traffic flows can be obtained from virtual populations based on demographic data (i.e. transportation between home, school and work). This tool for modeling traffic flows cannot be applied to our case studies, where the only source of data is the number of vehicles measured by sensors.

Finally, there are two utilities included in the SUMO (Krajzewicz et al., 2012) software package called ACTIVITYGEN and DFROUTER. ACTIVITYGEN computes the mobility wishes for a group of citizens matching a map, while DFROUTER uses values from induction loops (sensors) to compute vehicle routes. The former is quite similar in some aspects to the aforementioned article although it does not provide a graphical user interface, while the latter is a tool that may be used in the same way as the work we present in this article. However, it assumes that the map is completely covered by sensors, and it also requires the exact timestamp in which vehicles were detected and their speed in all the measurement points. None of these options are suitable for the problem we are solving as they cannot be applied to model the traffic flows in the city based on just the number of vehicles counted by each sensor.

Our proposal is different from those discussed in this section as we address real, large maps, calculate the traffic flows by using an evolutionary technique, especially useful when there are just a few sensors and summary data, and provide a simulation model (map plus vehicle flows) which matches not only the urban layout of the city but also the real number of vehicles at the measurement points.

3. Problem description

In this article we aim to solve a problem consisting in calculating realistic SUMO scenarios, where the number of vehicles at measurement points is close to the real ones in the whole city, based on the data previously collected from a few real sensors which count vehicles in selected streets. That is a much-needed information in smart mobility which frequently is not available in the city.