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A new Probabilistic Extension of Dijkstra's Algorithm to simulate more realistic traffic flow in a smart city

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Highlights

- PEDA: a Probabilistic Extension of Dijkstra's Algorithm is introduced.
- PEDA introduces probability distributions for assigning lengths and computing paths.
- In traffic flow, PEDA simulates that drivers do not have to know the optimal paths.
- The new ATISMART$^+$ model for traffic simulations in a smart city is introduced.
- ATISMART$^+$ produces more realistic simulations when using PEDA.

Abstract

Dijkstra's algorithm to solve the shortest path problem (SPP) is a very well-known algorithm. When applied to real situations, although the shortest path can be computed with Dijkstra's algorithm, it is not always the one that is chosen. In traffic situations, for example, the driver may not know the exact length of the lanes or the shortest path to follow. Even more compelling is the fact that although the driver knows the shortest route, he/she may prefer choosing a different route.

In this paper we present the new algorithm PEDA (Probabilistic Extension of Dijkstra's Algorithm) which introduces probabilistic changes in the weight of the edges and also in the decisions when choosing the shortest path. When PEDA is applied to traffic flow, more realistic simulations, in which the shortest path is not always chosen, are obtained. This more accurately simulates the more normal behavior of drivers.

As an example of an application, we introduce the ATISMART$^+$ model, an extension of the ATISMART model, where an accelerated-time simulation of car traffic in a smart city was described. In that previous work, all cars in the system used Dijkstra's algorithm to choose improved ATISMART$^+$ model, for accelerated time simulations of traffic flow in smart cities, uses the new PEDA algorithm. The results obtained show that ATISMART$^+$ produces more realistic simulations considering different drivers' behaviors.

Introduction

Car traffic has become one of the most important problems facing cities during the last decades. Problems arise in different areas:

- *Pollution*: slow traffic flow and jams provoke an increase in gas emissions which seriously increase the greenhouse effect.
- *Economy*: the amount of fuel consumption produces huge loss of money and natural resources. Additionally, wasted time in traffic jams turns into huge economic losses.
- *Emergencies*: police cars, ambulances, fire trucks and other emergency vehicles have severe delays due to traffic jams which can even lead to loss of life.
- *Mental health*: anxiety, frustration, stress, depression, among others, are some of the effects that traffic congestion can cause.

For example, the study developed in [1] estimated that "the monetized value of $PM_{2.5}$-related mortality attributable to congestion in 83 cities in 2000 was approximately $31 billion (2007 dollars), as compared with a value of time and fuel wasted of $60 billion".

Without doubt, slow traffic flow and jams are problems which highly decrease the quality of life.

Nowadays, Smart cities try to face the traffic congestion problems, among others, with different approaches. The use of Smart Traffic Signals (in the following Smart Signals) as reversing lanes signals and smart traffic lights (which can dynamically change the red and green periods) are one of the most important techniques. Examples of use of these kind of Smart Signals can be found in [2], [3].

A physical implementation of such smart traffic lights and reversible lanes is very useful but it is also expensive. Therefore, computer simulations of the traffic behavior can lead to a good design of the system and hence, savings in costs.

The ATISMART model [3] was developed by the authors of this paper using these types of computer simulations. In this model, Dijkstra's algorithm [4] is used to compute the path that a car follows from a starting point to its destination. Dijkstra's algorithm is one of the most well-known algorithms to solve the shortest path problem (SPP). But, when applied to real situations, although the shortest path can be computed with Dijkstra's algorithm, it is not always the path that is the chosen one. There are many situations where the driver does not know the shortest path to follow. Furthermore, even if the driver knows the shortest path, he/she may prefer choosing a different one.

There are different studies [5], [6], [7] where extensions of Dijkstra's algorithm are used when the lengths of edges are not fixed. These extended versions of Dijkstra's algorithm can be adapted in order to simulate real situations in traffic. Other approaches consist of considering fixed lengths on edges and introducing some variations simulating the drivers' behaviors.

In this work we present the new PEDA algorithm (Probabilistic Extension of Dijkstra's Algorithm) in order to simulate real situations in which the shortest path is not always chosen. This approach includes modifications on the way that Dijkstra's Algorithm calculates the path with non-fixed lengths on edges (simulating the fact that a driver may not know the right length of the lanes).

As an example of an application of the PEDA algorithm, we will extend the ATISMART model to the new model ATISMART$^+$. This model includes more realistic situations considering different drivers' behaviors. A prototype of ATISMART$^+$ was introduced, as a talk, during the ESCO 2014 conference. The abstract of this talk can be found in [8].

As in the previous model, the implementation of ATISMART$^+$ is carried out using a Computer Algebra System (CAS), specifically Maxima, together with a graphic user interface, developed in Java.

In Section 2 a brief summary of the ATISMART model is shown. In Section 3, the new PEDA algorithm is introduced. In Section 4, the ATISMART model is extended to the new ATISMART$^+$ model as an example of use of PEDA. Finally, in Sections 5 and 6, some conclusions and acknowledgments are presented.

Section snippets

Background: the ATISMART model

In order to make the paper self-contained, in this section a brief summary of the ATISMART model is shown. For a complete description of this model with examples, see [3].…

PEDA: a Probabilistic Extension of Dijkstra's Algorithm

Dijkstra's algorithm [4] efficiently provides an optimal path for moving from a starting node to a target node in a weighted graph. But when a person estimates a path to follow in a real situation (for example when driving between two different points in a city), the shortest driving time is not always obtained. Therefore, using Dijkstra's algorithm to simulate the behavior of drivers is not realistic.

To achieve more realistic simulations, we introduce in this paper the new PEDA algorithm, a…

An example of use: the ATISMART$^+$ model

As an example of use of the new PEDA algorithm, we have extended the ATISMART model [3] to the new ATISMART$^+$ model. In this new model, Dijkstra's algorithm has been substituted by the extended algorithm PEDA. The ATISMART$^+$ model provides simulations of car traffic flow using smart signals (traffic lights and reverse lanes) in a more realistic way when using PEDA. The graphical user interface (GUI) of ATISMART$^+$ is an environment for both: introducing data and providing a visual images step by…

Conclusions and ideas for future work

Some conclusions obtained in this work are:

- The new PEDA algorithm extending Dijkstra's algorithm in a probabilistic way, has been introduced.…
- Each part of PEDA, P–1 and P–2, and the combination of both, has been shown to produce more alternatives in the generated paths than Dijkstra's algorithm. This fact is more realistic since different drivers moving from and to the same points, normally do not use the same path.…
- The ATISMART$^+$ model has been shown to be a flexible and easy-to-use tool to…

…

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…Dinitz and Itzhak (2017) designed a hybrid algorithm based on Dijkstra's algorithm and the Bellman-Ford algorithm to minimize the running time for graphs with a sparse distribution of negative cost edges. Galán-García, Aguilera-Venegas, Galán-García, and Rodríguez-Cielos (2015) improved the Dijkstra algorithm to simulate real traffic flows in smart cities through probability. Neha and Kaushik (2016) improved the efficiency of Dijkstra's algorithm and the Bellman-Ford algorithm without adopting a parallel mode.…

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…Dijkstra's algorithm has been tested for performance using various architectures of implementation, both serial and parallel (Jasika et al., 2012). Since the algorithm was created several decades ago, it has been redeveloped and improved numerous times, and fuzzy (Deng, Chen, Zhang, & Mahadevan, 2012), probabilistic (Galán-García et al., 2015) and 3D (Gangsei & Kongsro, 2016) extensions and generalisations (Peyer et al., 2009) are available. One of its modifications has gained great attention from both practitioners and theorists: the A* algorithm is grounded in a heuristic approach, and the whole family of heuristic algorithms is primarily based on modifications to this algorithm.…

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