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Shadow traffic: A unified model for abnormal traffic behavior simulation

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ABSTRACT

Abnormal traffic behaviors are common traffic phenomena. Existing traffic simulators focus on showing how traffic flow develops after an anomaly occurs; however, they cannot depict the anomaly itself. In this paper, we introduce the concept of shadow traffic for modeling traffic anomalies in a unified way in traffic simulations. We transform the properties of anomalies to the properties of shadow vehicles and then describe how these shadow vehicles participate in traffic simulations. Our model can be incorporated into most existing traffic simulators with little computational overhead. Moreover, experimental results demonstrate that our model is capable of simulating a variety of abnormal traffic behaviors realistically and efficiently.

1. Introduction

Abnormal traffic behaviors describe behaviors of points on road networks which can be identified as irregular behaviors from normal ones [1–5]. They deviate from ordinary types and are not developed by their downstream traffic flows, such as road breakdowns, crash accidents, pedestrian and vehicle interactions, etc. Abnormal traffic behaviors are common phenomena in traffic systems, especially in bad weather, congested areas, and hybrid traffic, etc. Modeling these behaviors easily and naturally has direct influence on the effectiveness of virtual traffic simulations.

Existing traffic simulations focus on showing different kinds of traffic flows that can exist in different scenarios [6–16]. These simulations can give detailed reconstructions and representations about how the flow develops upstream of the place where a traffic anomaly happens, but they cannot depict the anomaly itself. Some methods in the pattern recognition and transportation fields were presented for traffic anomaly simulations [2–4,15,17–21]. However, they are primarily designed for traffic analysis: predicting and exploring the cause of anomalies. Therefore, most existing traffic simulation systems do not have anomaly generation and editing functions [22, 23, 24]. Users must generate and edit the anomaly indirectly by modifying some road and traffic elements, such as a lane closure, which is complicated. Moreover, these systems cannot give a detailed anomaly representation on their three-dimensional presentations.

In this paper, we introduce a novel concept, shadow traffic, to model a variety of abnormal traffic behaviors in a unified way. The shadow traffic is the hypothetical traffic at the abnormal point, where vehicles may not exist. We adopt the behaviors of shadow vehicles to model abnormal traffic behaviors (The red and translucent vehicles shown in Fig. 1 are shadow vehicles). Anomalies then participate in a traffic simulation through shadow traffic. In other words, we inject intangible factors into traffic simulations by embodying them in “physical” form and relying on the simulator's pre-existing functionality.

In our shadow traffic model, we firstly present a semantic description of an anomaly in a unified way, in which we use three intensities, including spatial intensity, time intensity, and state intensity, to depict the anomaly. We then introduce shadow vehicles into our model and transform these three intensities to the states of shadow vehicles. We present efficient algorithms to compute the states of shadow vehicles. We at last realize a traffic simulation containing both shadow vehicles and non-shadow vehicles. The shadow traffic formulation provides an elegant method for an anomaly to extend its influence to the traffic flow. A variety of anomalies can be easily depicted as the states of shadow vehicles.

The main contributions of this work are as follows: Firstly, we creatively map abnormal behaviors to the states of shadow vehicles and introduce a concept model to model a variety of abnormal traffic behaviors in a unified way; Secondly, we present a traffic

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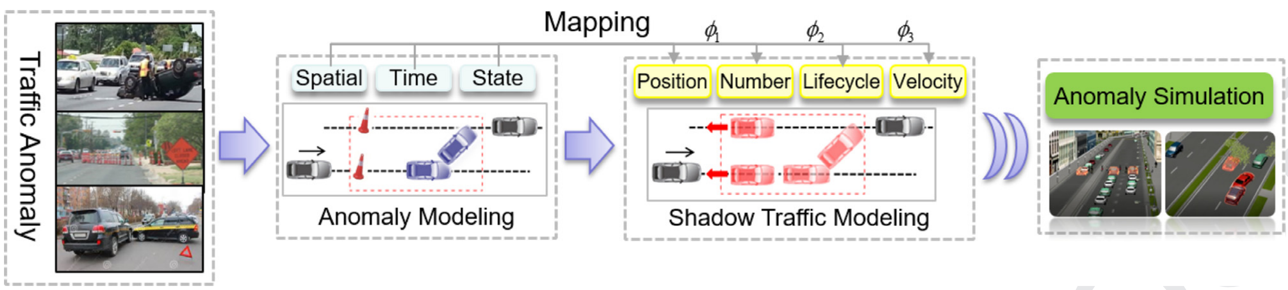

Fig. 1. The framework of our shadow traffic model.

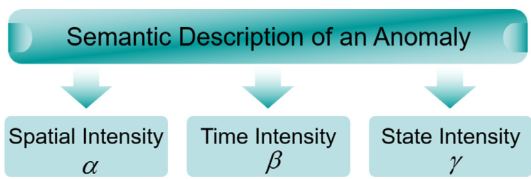

Fig. 2. The contents of the anomaly's semantic description.

simulation framework including an existing traffic flow model and our shadow traffic model, which can give realistic simulations both about traffic anomalies themselves and how traffic flow around them evolve. Last but not the least, our shadow traffic model has a high runtime efficiency. The computing time increases slightly when anomaly regions become larger. The runtime overhead of adding our shadow traffic model to traffic simulators is negligible.

To demonstrate the merits of our model, we give the efficiency analysis of our model in a traffic simulation system. We also show that it is capable of modeling commonly observed abnormal traffic behaviors, such as road breakdowns, crashes, unexpected breaking, vehicle-pedestrian intersections, etc.

2. Related work

With the increasing volumes of traffic data and software tools capable of modeling urban scenes, numerous efforts have been devoted to traffic simulations.

Since Sewall et al. first introduce the concept of "virtual traffic" [25], numerous detailed models have been proposed for realistic and efficient traffic simulations, including traffic flow descriptions [7–10,13,14,26,27], traffic flow reconstructions [11,12], and mixed traffic animations [28,29]. These models focus on physically based traffic simulations; that is, they aim to give a realistic description about the evolvement of traffic flows after an anomaly occurs. They assume that the properties of the leader vehicles in an anomaly are already known, and they only model traffic flows upstream.

A considerable body of work exists in simulating traffic anomalies in the pattern recognition and transportation fields. Zhong et al. present an unsupervised technique for detecting abnormal traffic behaviors in video using many simple features [3]. Owens et al. determine whether a point on a trajectory is normal using the distributions of flow vectors [1]. Sultani et al. use the well-known intelligent driver model for detecting and localizing abnormal traffic [4]. Hu et al. present a system to automatically learn motion patterns for anomaly detection and behavior prediction based on a proposed algorithm for robustly tracking multiple objects [2]. Sabel et al. propose methods to automatically identify and report road traffic accidents[17,19]. Markus et al. present methods to model the occurrences of accidents [15,21]. Brach et al. use practical analytical techniques and dynamic methods to solve a complex vehicle anomaly reconstruction [18]. Miaou et al. discuss the relationships between vehicle accidents and highway geometric designs [20]. These models are typically designed to model whether, when and why an anomaly occurs, but they do not describe how the anomaly itself is evolving.

To tackle the aforementioned challenges, we model traffic anomalies using shadow traffic, which is inspired by the concept of composite agents by Yeh et al. [30]. In their model, they use composite agents to model a variety of emergent behaviors in agent-based crowd simulations. They classify the agents into basic agents and composite agents. A basic agent is the agent representation native to a simulator. A composite agent is a basic agent that is associated with a set of proxy agents. The proxy agents could be thought of as hands extended from the basic agent which get extended towards other agents, encouraging those agents to step away to avoid collisions. The model is used to model the agents that have more influence than common agents in a crowd. In this paper, we introduce the idea into the modeling of abnormal traffic behaviors, which extend their influence over the upstream vehicles.

3. Model

In this section, we present an algorithm to model abnormal traffic behaviors by utilizing shadow vehicles. The framework of our model, as shown in Fig. 1, consists of three parts: (1) semantic description of an anomaly, (2) semantic description of shadow traffic, (3) mapping between the anomaly and shadow traffic. Each of these parts is discussed in detail below.

3.1. Semantic description of an anomaly

In our model, we describe a traffic anomaly by its spatial region, duration, and state. We introduce spatial intensity, time intensity, and state intensity, all of which are measurement values used for a semantic description of the anomaly, as shown in Fig. 2.

Spatial intensity: Spatial intensity describes the spatial region that is influenced by the traffic anomaly. It is determined by the number of lanes and the spatial region affected by the anomaly. Let α be the spatial intensity, then,

$$\alpha = \bigcup_{i=1}^{n} \alpha_{N_i} = \bigcup_{i=1}^{n} [s_{N_i\_start}, s_{N_i\_end}] \quad (1)$$

Here, n is the total number of lanes affected by the anomaly. N_i is the ID number of the ith lane with $1 \le i \le n$. α_{N_i} is the spatial intensity on lane N_i and $[s_{N_i\_start}, s_{N_i\_end}]$ describes the spatial range on lane N_i affected by the anomaly. $s_{N_i\_start}$ and $s_{N_i\_end}$ are the mileage of the beginning and the end of the range. Here, the spatial range affected by the anomaly is where the anomaly occurs.

Time intensity: Time intensity describes how long the anomaly affects the traffic in the influenced spatial region. This is determined by the duration of the anomaly. Let β be the spatial intensity, then,

$$\beta = \mu T \quad (2)$$

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