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研究課題名（英文） Development of a scripting language that allows reproducible traffic situations and its application to driving behavier study

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研究成果の概要（和文）：本研究の目的は、人の注意をそむけ渋滞の原因となるドライバーの交通状況への反応に関する調査である。我々が注目したのは、わき見運転である。相互作用型運転状況観測を可能とするために、我々は独自の表現言語（SML）を開発した。
我々が開発したフレームワークでは、１）マルチユーザドライビングシミュレーション、２）週変交通状況の視覚化、３）特定交通状況の再現、４）運転行動記録と採取、が可能となる。我々のフレームワークの特性の最大活用のために、我々はSML内で交通事故シナリオに特化し、よそ見運転という運転行動に関する研究を行った。

研究成果の概要（英文）：The goal of the research is to investigate the response to drivers to the traffic phenomenon that cause traffic congestion to surge by distracting them and drastically changing their rate of travel.
We focus on rubbernecking; a phenomenon in which drivers tend to crane their neck in order to get a better view of a nearby car crash. To study interactive driving behaviour of rubbernecking in a multi-driver shared simulated 3-D environment we developed Scenario Markup Language (SML). Our developed framework enables 1) the simulation of multiuser immersive driving; 2) the visualization of surrounding traffic; 3) the specification and creation of reproducible traffic scenarios; and 4) the collection of meaningful driving behavior data. To demonstrate the effectiveniess of our framework, we specified the traffic accident scenario in SML and conducted a study about the rubbernecking phenomenon.

研究分野： AI

キーワード： SML　マルチユーザドライビングシミュレーション

１．研究開始当初の背景

Traffic engineers study driving behavior by exposing human participants to specific traffic situations, such as an accident or a merging maneuver. The responses of drivers during These studies are captured and analyzed to validate relevant hypotheses about how drivers respond to some traffic situations
of interest. One interesting traffic phenomenon is *rubbernecking*; whereby drivers tend to crane their neck in order to get a better view of a nearby car crash. This phenomenon can cause traffic congestion to surge, for drivers may become distracted and drastically change their rate of travel. Recent field investigations have shown that the rubbernecking effect can halve traffic flow in the oncoming direction; and by more than half in the direction of the accident, due to lane obstruction.

However, there exists no effective method to understand the interactive driving behavior of human subjects at the individual vehicle level in multiple users' points of view: How does the slowing of the "lead driver" influence the driving behavior of following cars? Such questions could be answered by using a driving simulator, networked driving simulators. For example, Mourant *et al.* proposed a multidriver virtual driving simulator in two different configurations: 1) a distributed virtual environment, using standard networking; and 2) cloned data acquisition. Nagai *et al.* developed a dual-driver networked driving simulator. Further, Kevin *et al.* envisioned a multiuser, motion simulation framework intended primarily for ground-vehicle transportation. Recently, Cai and Lin introduced a simulation framework, which networked multiple standalone driving simulators, simultaneously run in a collaborative mode. On the commercial side, STsoftware developed a multicabin driving simulator system using standard networking. However, the utilization of driving simulators is often complicated by the knowledge gap that exists between: 1) the specification of traffic scenarios by experts, such as traffic engineers; and 2) the technical implementation by software developers. To bridge this gap, three challenges are to be addressed in an integrated manner where users are immersed in scenarios similar to the one depicted. Driving simulators have proven very useful in addressing several aspects of transport, including driving behavior, traffic flow, road safety, and road design. For example, Hattori *et al.* successfully used a driving simulator to elicit a driving behavior model from human driving behaviors.

Most of the related work relies on single-user driving simulators to study driving behavior, making it not possible to analyze more complex phenomena, such as the interaction among multiple human drivers. However, several researchers have explored Willemsen proposed an interpreted scripting language, and Devillers and Donikian presented a programming style language as authoring languages to orchestrate the events of traffic situations (the first challenge). However, the use of the language of Willemsen is tightly linked to a predefined road network and, hence, is difficult to reuse outside the framework of the authors. The language of Devillers and Donikian, on the other hand, assumes solid programming skills, which may not be possessed by traffic domain experts. In contrast, the design of our scenario language was informed by the domain experts and disentangled from domain specific information (e.g., road network). Willemsen addressed the mapping problem (the second challenge) by employing hierarchical concurrent state machines (HCSMs), whereas Devillers and Donikian used superstep semantics of state charts. As an alternative to the state machine representations, we propose Behavior trees (BT).

Compared with state machines, BT are scalable, reusable, and modular.

As for the third challenge, current approaches fall between two extreme cases of control schemes for ambient vehicles in driving simulators: 1) tightly controlled or scripted vehicles and 2) fully autonomous vehicles. Approach 1) leads to high reproducibility of scenarios, but requires complex scenario programming. Approach 2) makes reproducibility of traffic scenarios very hard and is thus rarely used in scenario creation. Willemsen introduced directable semiautonomous vehicles, which perform a normative autonomous driving in other circumstances, except when they can be commanded to alter their autonomous behavior to perform specific tasks (e.g., speed up). As an alternative, Olstam *et al.* propose to combine approaches 1) and 2), and separate phases of autonomous vehicles with phases of controlled vehicles. In the latter phase, add-on behaviors are attached on top of the “normative” behavioral models used by autonomous vehicles, i.e., dedicated parameters of the behavioral models underlying the “normative” behavioral updates are manipulated to create scenarios.

We will use a similar approach that combines: 1) autonomous vehicles for ensuring the realism of ambient environment; and 2) directable semiautonomous vehicles for guaranteeing the reproducibility of realistic traffic scenarios. In addition, for increased flexibility, we disentangle the module that simulates the autonomous vehicles from the scenario control scheme that is responsible for directable semiautonomous vehicles.

In this project, we propose the Scenario Markup Language (SML) Framework to address the challenges of scenario authoring, mapping, and scenario control. The SML Framework is an experimental space that supports the specification and creation of reproducible traffic situations integrated to the simulation of surrounding traffic. Our approach also proposes a multiuser driving simulator framework, based on our networking technology for hosting multiple drivers in a shared simulated environment.

Thus, we can investigate the interactive driving behavior of human subjects, a key concept in the rubbernecking effect.

２．研究の目的

We present a new framework for conducting controlled driving behavior studies based on multiuser networked 3-D virtual environments. The framework supports: 1) the simulation of multiuser immersive driving; 2) the visualization of surrounding traffic; 3) the specification and creation of reproducible traffic scenarios; and 4) the collection of meaningful driving behavior data. We use our framework to investigate the “rubbernecking” phenomenon, which refers to the slowing down of a driver due to an accident on the opposite side of the road, and its effect on the following drivers. The main contribution of the paper is the Scenario Markup Language (SML) framework, which is composed of: 1) the SML as a practical tool to specify dynamic traffic situations (e.g., an accident) and 2) the Scenario Control System to ensure the reproducibility of particular traffic situations, so that traffic engineers can obtain comparable data and draw valid conclusions. To demonstrate the effectiveness of our framework, we specified the traffic accident scenario in SML and conducted a study about the rubbernecking phenomenon. We report on the results of our study from two viewpoints: 1) the reproducibility of the traffic accident situation (i.e., state variables of interest are recreated successfully in 78% of the cases); and 2) the interactive car-following behavior of human subjects embedded in the traffic situation of the virtual environment.

３．研究の方法

In this section, we will explain the SML Framework, as illustrated in Fig. 6, by describing its main components. The SML Framework is a 3-D experimental space for driving behavior studies. The framework is designed on top of our previously developed technologies.

1) The distributed virtual environment (DiVE) framework [38] provides networking features for simultaneously connecting and synchronizing multiple users (i.e., a driving simulator) via Unity3D clients. 2) The OpenTraffic middleware integrates traffic simulation, road network, and users. 3) Driving simulator client provides an interface for driving, was developed by tweaking a high-end, physically accurate and realistic car model created by Unity3D.

The framework accepts SML scripts as input, generates a BT as the intermediate representation for a scenario specification in SML, and unfolds the scenario in the 3-D simulation space.

A. Behavior Tree Representation

We use BTs as an intermediate representation to handle the execution of the tasks of the “director” component of a scenario script. For instance, the tasks of the “director” component of a scenario are represented by the BT shown in Fig. 6. Tasks and temporal elements (e.g., seq, par, and sel) in the example script will become the main building blocks of the BT. The tasks will translate into action (leaf) nodes, which execute the task defined in it.

The temporal elements of the “director” component for a scenario will translate into the inner nodes of the BT. The tasks or other temporal elements, which are embedded into other temporal elements, will be converted into a BT with subtrees while preserving hierarchy of behaviors. The BT approach fits well here, because director’s tasks (mainly concerned with orchestrating the behaviors of entities) are embedded in the temporal elements. Hence, they are composed as hierarchies of subtrees in BTs.

B. Scenario Control System

One way to create specific traffic situations is to reuse the traffic simulator that populates all surrounding vehicles. In this approach, dedicated parameters of the driver behavioral models (underlying the traffic simulator) for some surrounding vehicles are manipulated to create traffic situations.

In our case, we devise a different method for creating traffic situations (e.g., an accident), because we use a general purpose traffic simulator to simulate ambient traffic in a multiuser networked environment. The traffic simulator does not support the required operations to create the traffic situations. Instead, we decouple the scenario creation functionality from the traffic simulator that populates ambient traffic. This way, we disentangle the scenario creation from the time step that calculates behavioral update for all surrounding vehicles based on the ordinary traffic models. Concretely, we build a special purpose simulator, by implementing driving behavior models, to simulate directable semiautonomous vehicles. We refer to these directable semiautonomous vehicles as artificial intelligence (AI) cars in this study for the sake of space.

４．研究成果

Using the SML Framework, we conducted an empirical study on the rubbernecking effect. For this, we specified and implemented a scenario where a traffic accident happens on the opposite side of the road from the perspective of the subjects who were driving as a group of four drivers on a single lane.

Our study investigates the rubbernecking scenario by testing

if our approach can reproduce certain important state variables regarding the accident location, such as the distance to the lead user car or the distance between the desired and actual accident location. We also analyze how drivers change their operational driving behavior at the incident site.

Precisely speaking, we investigate a special case of the rubbernecking scenario, where the accident just happened in the driver’s vicinity. In the general rubbernecking scenario, the accident has already happened and the driver is approaching the accident location [2].

We only analyzed the data falling within an observation (space) window. Anything outside this region was assumed to be irrelevant as far as the rubbernecking phenomenon was concerned. Thus, we used space as an independent variable and distance-to-incident as a reference point. The space windows were 2×S (meters), ranging from –S to +S. Here, S denotes the distance from vehicle to incident location, along the direction of travel. Negative values indicate that the incident location had yet to be reached.

We treated headway, speed and delta speed as dependent variables and obtained them from the data (position and time) falling within the observation window. These data from nine sessions were aggregated and analyzed as a whole. For each group of data, we performed the following data processing:

1) cluster the data into n space bins;

2) fit some, parametric, unimodal distribution (e.g., Gaussian or Gamma) that best describes the shape of the binned data;

3) compute the mode (i.e., the maximum of the distribution) and variance for each distribution for each space bin, in order to characterize the behavior of that bin

Step 1) enabled us to study the behavior of drivers at various locations of the road, before approaching the accident location.

In step 2), the use of parametric descriptions allowed a concise general description of the data. The disadvantage of parametric versus nonparametric distributions (e.g., histograms) is that in the former, the shape of the data is assumed to be known. By contrast, nonparametric approaches make no assumption on the dataset, although they are typically less robust to outliers in the case of small datasets and, by nature, cannot generalize.

Finally, step 3) was performed to determine the representative values for headway, speed, and delta speed; and the deviation from the overall behavior from all driver

５．主な発表論文等
（研究代表者、研究分担者及び連携研究者には下線）

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〔雑誌論文〕（計　4 件）

〔学会発表〕（計　0 件）

〔図書〕（計　0 件）

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〔その他〕
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