URGENT DRIVER BEHAVIOR MODELING IN COGNITIVE ARCHITECTURE

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ABSTRACT

The paper construct the driver behavior model in cognitive architecture of the urgent circumstance based on ACT-R theory, it strive to delineate the cognitive procedure of the driver's motor under urgent situation, and find the key cognitive factors of traffic accident avoidance, and then applying the model to the driver's training and instruction, and in the end the modeling method comes truth of decreasing traffic accident. The paper retrospect the research trips of traffic safety and driver behavior firstly, it is aim to point out that the cognitive science is the essential theory for problem-solving of traffic safety and that driver behavior modeling becoming one of the hottest research spot at present is necessary. On the basis of comparison of different typical cognitive architecture and analysis of the theories and researches of ACT-R, A driver behavior modeling method based on ACT-R is raised. A driver behavior model in ACT-R under the urgent circumstance at a hard braking of the preceding vehicle's driver is presented in this paper, and the methods which based on both the prediction of driver behavior and verification of cognitive model are proofed to be widely suitable and flexible. Finally, the illustration of the benefits of drive behavior modeling in cognitive architecture make it an assertion that the application of driver behavior model in the field of traffic safety will be set up effectively and take effects greatly.

INTRODUCTION

More than a million people are killed on the world's roads each year, the victims overwhelmingly young. In the United States more people die in a typical month in traffic crashes than died in the September 11 terrorist attacks. And for every fatality in a traffic crash, about 40 injuries occur, many of them severe. These traffic deaths and injuries include those among pedestrians and cyclists, as long as a motorized vehicle was involved. The number of traffic deaths worldwide continues to increase as more nations motorize. For over a century measures have been introduced in many countries aimed at reducing harm from traffic crashes. There is extensive world experience, many failures, and many successes. In his book Leonard Evans address the relative contributions of different countermeasures, he summaries, the information identifies driver behavior as the dominant factor in traffic safety.

The history of driver behavior modeling started in 1938 when Gibson and Crooks presented their theoretical field-analysis of automobile driving. Until 1964 Taylor presented his “drivers' galvanic skin responses and the risk of accidents”. From then on for more than 30 years to the end of the last century, one can hardly say that the task of modeling driver behavior reaches any consensus. Truls Vaa (2001) regard that driver behavior models address diverging aspects, several issues and/or concepts dealt with, discussions and disagreements prevailing, however, there is no breakthrough or unified theory within the traffic safety research regarding the difficult task of modeling driver behaviors. It is argued that this unpleasant situation occurs for lack of a thorough and comprehensive understanding of human cognition and emotion, i.e. how drivers think and feel, consciously, pre-consciously or unconsciously. There is no common understanding of driver behaviors according to recent researches in cognitive psychology and neurobiology. Nevertheless, Truls Vaa asserted that emotions are (part of) the risk monitor, and human emotions are the very instrument that enables men to monitor danger, consider and evaluate behavioral alternatives in given situations. In recent years, with the rapid development of informatics, computational models have emerged as a powerful tool for studying the complex task of driving, allowing researchers to simulate driver behavior and explore the parameters and constraints of this behavior. In the other hand, A growing interest in the neurobiology of emotion parallels a wider recognition of its importance to human experience and behavior. Driver behavior modeling in cognitive architectures also becomes a hottest research topic in traffic scientific research field at present.

There are numerous methods and approaches to modeling human cognition, each of them represent different points and may be possible to integrate models of human motion into different models of human cognition. The researches indicate that ACT-R provides a more detailed picture of behavior, and so the ACT-R cognitive architecture is selected for driver behavior modeling framework of this paper.

ACT-R COGNITIVE ARCHITECTURE

ACT-R cognitive architecture

ACT-R is a cognitive architecture, a theoretical model working mechanism of human cognition procedure. Researchers working on ACT-R strive to understand how people organize knowledge and produce intelligent behavior. On the exterior, ACT-R looks like a programming language; however, its constructs reflect assumptions about human cognition. These assumptions are based on numerous facts derived from psychology experiments. Researchers create models by writing them in ACT-R. By writing the models using this type of programming language, they are adopting ACT-R's way of viewing human cognition. Researchers write their own assumptions in the model and test the model by comparing its results with the results of people actually performing the task.

The ACT-R theory started first as an ACT production system, presented by Anderson in 1976. The ACT production system proposed a distinction between procedural knowledge and declarative knowledge. In 1983, Anderson provided a fuller description of the ACT and developed a theory called ACT*. Integrated with a set of neurally plausible assumptions about how production might be acquired, the ACT* theory was evolved into the ACT-R (Atomic Components of Thought) theory (1993), in which an architecture of cognition is modeled to explain how the process of acquisition can be tuned to the statistical structure of the environment. It has recently undergone a major development into a version called ACT-R 5.0 and this form offers some new insights into the integration of cognition. Including books, journal articles, and conference proceedings, there are well over 500 ACT-R publications to date.

One important feature of ACT-R that distinguishes it from other theories in the field is that it allows researchers to collect quantitative measures that can be directly compared with the quantitative measures obtained from human participants.

ACT-R work principle

The ACT-R cognitive architecture has been developed over the last 20 years. The basic architecture consists of a number of modules that are dedicated to different processes. ACT-R includes a declarative module that handles the retrieval of information from memory, a goal module that tracks the system's current step of the goals, a visual module that can identify objects in the visual field, and others. The goal stack from ACT-R 4.0 has been removed and replaced with the existing mechanisms for declarative memory. As a result, goal steps are tracked through the declarative module. The intentional module in ACT-R 5.0 as depicted in Figure 1 is currently a placeholder for future refinements. ACT-R does include a module dedicated to controlling motion of the hands. This manual module can move the hands in space, control a computer mouse, and type into a keyboard. ACT-R also includes a central production system that coordinates the activity of each of the modules. The production system accesses information in buffers associated with the modules and makes changes to the buffers. The development of a model in ACT-R consists of the specification of production rules that define changes to be made to the buffers based on the current state of the buffers. The continuous recognition of buffer contents, updating of buffer contents, and module activity make up the simulation of human cognition within the ACT-R framework. The majority of the effort in integrating a model of human motion with the cognitive architecture is in extending the functionality of the manual module.

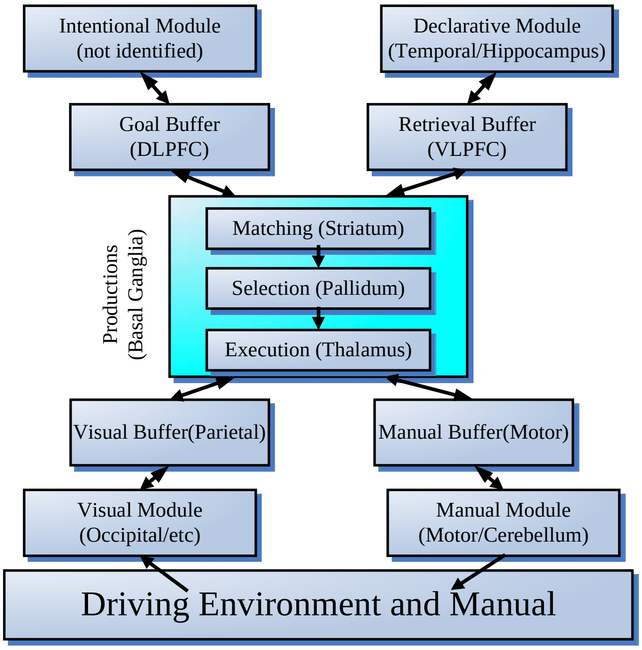

Figure 1. ACT-R cognitive architecture

ACT-R is a hybrid cognitive architecture. Its symbolic structure is a production system; the subsymbolic structure is represented by a set of massively parallel processes that can be summarized by a number of mathematical equations. The subsymbolic equations control many of the symbolic processes. If several productions match the state of the buffers, a subsymbolic utility equation estimates the relative cost and benefit associated with each production and decides to select for execution the production with the highest utility. Similarly, whether (or how fast) a fact can be retrieved from declarative memory depends on subsymbolic retrieval equations, which take into account the context and the history of usage of that fact. Subsymbolic mechanisms are also responsible for most learning processes in ACT-R.

Newest neurobiology and neuroimaging studies fundament for ACT-R

ACT-R is a human cognitive architecture, whose profound and lasting studies always relate to the newest studies in neurobiology and neuroimaging. Actually all parts of ACT-R are designed to reflect certain brain areas. The visual system: there are two built-in visual modules in ACT modules in ACT-R, that is, the dorsal “where” pathway (locations) and the ventral “what” pathway. As for the visual system, other modules have been designed to match specific brain areas: Manual buffer (motor and somatosensory cortical areas) and goal buffer (dorsolateral prefrontal cortex DLPFC). The retrieval buffer is ventrolateral prefrontal cortex VLPFC (long-term declarative memory). The basal ganglia is considered to implement production rules in ACT-R: striatum (correspondent with cortical areas, responsible for patter recognition) and Palladium (inhibitory component, performs conflict-resolution function). Thalamus: (projects to all major cortical areas, controls execution of production actions).

Driver Cognitive Behavior and Models

Driver Cognitive Behavior

For studying cognitive driver behavior, an important component is to understand the ETA triad; namely, that interactive behavior emerges from the constraints and opportunities provided by the interaction of embodied cognition (E) with tasks (T) and the artifact (A) (interfaces or devices) designed to accomplish the driving task..

In fact, the driving task is an ever-changing set of basic tasks which are integrated and interleaved. Michon discerned three driving task levels: strategic (route planning, higher goal selection), tactical (short-term objectives, such as overtaking and crossing an intersection) and operational (basic tasks, such as steering and using the clutch). Driving typically involves all three types of processes working together to achieve safe, stable navigation. Some tasks are not continual but intermittent, arising in specific situations. In addition, driving may include secondary tasks, perhaps related to the primary driving task, or perhaps mostly or entirely unrelated.

Embodied cognition entails the interaction of low-level cognitive, perceptual, and motor operations that manipulate the vehicle and execute the desired driving tasks. Even a routine driving requires cognition, most obviously for higher-level decision making, more subtly for lower-level vehicle control and situation awareness. Between cognition and the vehicle lies the embodiment of the driver, namely the perceptual processes (visual, aural, vestibular, etc.) and motor processes (hands, feet) that provide the input from and output to the external world. Undoubtedly, there can be parallelism in driver behavior model system, but there are also constraints and/or bottlenecks that sometimes result in degraded performance.

The “artifact” for driving is the interface between the driver and the vehicle, some parts of vehicle, and the vehicle itself. Most recognizably, this interface includes the steering wheel, the accelerator (throttle) and brake pedals, and possibly the clutch pedal (on a manual transmission); it also includes related controls such as switch signal lights, headlights and windshield wipers, etc. These components of the vehicle interface are, for most part, standardized among different vehicles. For secondary tasks, the artifact also includes any interface to the secondary device – such as knobs, buttons, and other inputs, small displays and other outputs; unlike the control-related components, secondary-task components are less standardized among vehicles.

The motivation of driver cognitive behavior modeling is to rigorously address all ETA three components: handling as many driving-related tasks as possible, incorporating realistic controls and vehicle dynamics, and performing the tasks through cognitive processes that interact through realistic perceptual and motor processes. In fact, many successful models have demonstrated the importance of rigorous modeling efforts for both theoretical understanding of driver behavior and practical application of these theories in real system development.

Driver Cognitive Behavior Models

As mentioned, ACT-R has three main components: modules, buffers, and pattern matching. Of the special driving task, the ACT-R-based driver behavior model consists of at least three basic components, which are monitoring, decision-making, and control (manipulation). The three components are integrated to run in ACT-R's serial cognitive processor as a tight loop of small cognitive (and related) operations. The entire model is implemented as an ACT-R production system including relevant procedural and declarative knowledge, and take advantage of the architecture's built-in features and human-like limitations that result in a more psychologically plausible model of driver behaviors.

The particular approach to driver behavior modeling of this paper revolves around the development of driver models in the framework of a cognitive architecture. A cognitive architecture is a general framework for specifying computational behavioral models of human cognitive performance. The architecture embodies both the abilities and constraints of the human system -- for instance, abilities such as memory storage and recall, learning, perception, and motor action; and constraints such as memory decay, and limited motor performance. As such, a cognitive architecture helps to ensure that cognitive models developed in the framework are rigorous and psychologically valid, thus abiding by all the limitations of the human system. The chosen framework for our driver behavior model is the ACT-R cognitive architecture, i.e. it is the architecture of production system based on chunks of declarative knowledge and condition-action production rules that operate on these chunks.

Driver models developed in a cognitive architecture such as ACT-R are especially well suited to addressing all three components of the ETA triad. Cognitive architectures have demonstrated the ability to model a range of tasks ranging from basic laboratory tasks to higher-level cognition and decision-making in complex dynamic tasks. Architectural models typically interact with a simulated environment identical to, or almost identical to, the environment used by human subjects, and thus the models must abide by the same input/output limitations and environment dynamics as human subjects. In doing so, architectural models represent and account for both the internal workings of human cognition and the external manifestations of cognition through perceptual processes and motor behavior. All these features make cognitive architectures extremely amenable to modeling many of the most important aspects of driver behavior.

A production rule "fire" a control task, the executive results are sent to manual buffer, the control task is implemented over maneuver; the monitoring task keeps continual perception of the external information over the visual module, and sends the accumulated information to the production system over the visual buffer, and tries to match the retrieved declarative knowledge whereas the unmatched information is abandoned and the matched information fire a production rule, the executive result are sent to motor buffers; the motoring task is implemented over operation; the decision-making task fires one or more production rules by monitoring retrieved messages and the contents of goal buffers from the goal module, and sending executive results to the motor buffer, the decision-making task is implemented over the manual module. Actually, it is more complicated inside the models, for usually several tasks request processes simultaneously and interact mutually.

Driver behavior modeling in cognitive architecture

As mentioned, the ACT-R driver model has three primary components: monitoring, decision-making, and control. The three components are integrated to run in ACT-R's serial cognitive processor as a tight loop of small cognitive (and related) operations. The entire model is implemented as an ACT-R production system including relevant procedural and declarative knowledge. This section describes this three components, the interaction of them and their integration with the simulated driving environment.

Monitoring Component

The monitoring component of the driver model handles the continual maintenance of situation awareness. For this model in driving environment, situation awareness centers critically on awareness of the vehicles head and behind the driver's vehicle. Monitoring is currently based on a random-sampling model that, with some probability, checks one of two areas -- namely, either forward or backward (i.e., in the mirror) -- with equal likelihood. When the model decides to monitor a particular direction, it moves visual attention to that area and determines whether there is any vehicle present, If so, the model determines the distance between the driver's vehicle and present vehicle, and then the model notes the vehicle's speed, current lane, and safe distance in ACT-R's declarative memory. Thus, declarative knowledge continually maintains the awareness of present vehicles. The model could, of course, be extended in a straightforward way to note other aspects of the surrounding environment, such as the preceding vehicle's brake light, the present of the vehicle behind and billboards, etc.

Decision Making Component

The decision-making component of the driver behavior model uses the information gathered during control and monitoring to determine whether any tactical decisions must be made. In the crash avoidance environment, the most common decision-making opportunity arises in the determination of whether, when and how to execute a brake. As an example of decision-making we describe it briefly. The decision of whether or how to brake depends on the distance to the head vehicle, since drivers attempt to maintain a safe following distance and a safe distance to the rear following vehicle. If you find the following distance become smaller or the heading vehicle has a urgent brake, you may need to slow down or stop quickly, and you must take your foot off the accelerator and "cover" the brake. Yet before you make a quick deceleration you must notice whether there is another vehicle following you. If you don't do this you may crash into the back of the vehicle ahead or be impacted. Simultaneously, you must increase the following distance between you and the vehicle ahead as you increase speed, for the reason is the faster you go the longer the stopping distance is essential.

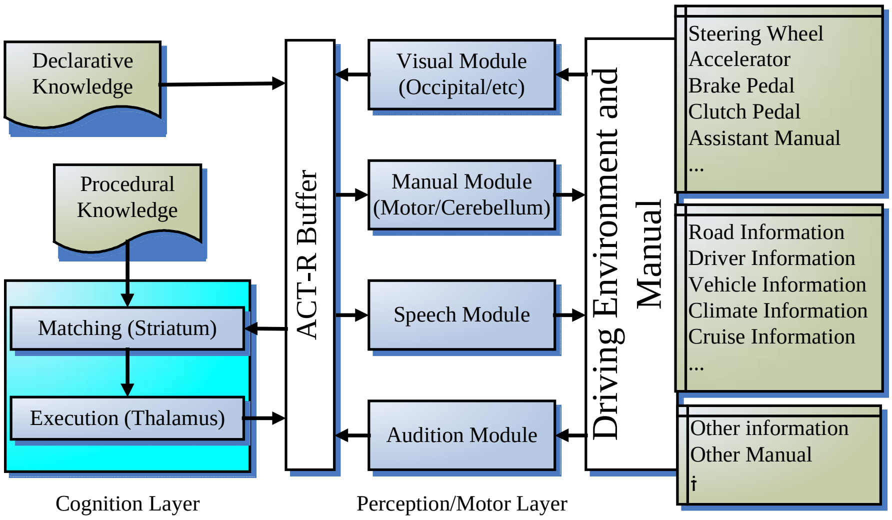

Figure 2. Driver behavior modeling in ACT-R cognitive architecture

Control Component

The control component of the driver model manages all perception of lower-level visual cues and manipulation of vehicle controls for lateral control (i.e., steering) and longitudinal control (i.e., acceleration and braking). Fig. 2 shows the relevant parts of the manual module and the driver manual, which include the steering wheel, throttle and brakes etc.

Experiments

Experimental Scenario

Rear-end crashes are not only one of the frequently occurring types of crashes, but also are responsible for a large number of injuries and fatalities and substantial property damage every year. A rear-end crash refers to a crash in which the front of one vehicle collides with the rear of another vehicle. Thus, a driver involved in such a crash may be the driver of a striking vehicle, of the struck vehicle, or of the vehicle that both struck and was struck. RTA(Researches of Road and Traffic Authority) of NSW(New South Wales) indicate that almost 90% of crashes fall within only 5 crash types, one of them that driver's vehicle colliding with the rear of another vehicle traveling in the same direction takes 25 percent proportion, here we give a relative simple case of rear-end collision running in the same direction as example.

There is often a circumstance under which the preceding vehicle suddenly take a urgent brake with a not too long distance when one’s vehicle running at a high speed on highways (Figure 3.). In this situation, if the distance between the two vehicles is rather smaller, even the following driver take an immediate brake, it is impossible to avoid the crash that the following vehicle run into the head vehicle. Moreover, if there is another following vehicle behind, the next coming vehicle maybe crash into the following vehicle (middle one), the multi-crashes happens. This is a typical urgent circumstance for the driver, and if the driver can’t adopt right behavior, the crash is hazard. The experiment in this paper of modeling driver cognitive behavior in ACT-R architecture is based on this urgent circumstance.

Figure 3. The preceding vehicle take a urgent brake

Model Components

Before elaborating the model's components, we first give a brief explanation of the "3 second rule", which has been HPT (Hazard Perception Test) method for driver practice of RTA of NSW. This simple rule applies at any speed and is easy to use. All driver need to do when driving is watch the vehicle in front of him pass an object at the side of the road such as a power pole, tree or sign. As it passes the object, start counting "one thousand and one, one thousand and two, one thousand and three". If the driver passes the object he picked out before he finish saying all the words, he is following too closely. Slow down, pick another roadside object and repeat the words again to make sure that he has increased his following distance enough.

Another conception we give here is the "space cushion". The more space that the driver has between his vehicle and other vehicles, the more time he has to detect and respond to hazards that might arise when driving. Hazards could be other vehicles changing lanes in front of him or the car ahead braking suddenly to avoid a pedestrian who walks onto the road. To stay safe, the driver need to manage the space around his car to the front, sides and the rear. The best way to do this is to imagine an invisible "space cushion" around his car.

The following are the main components of the driver cognitive behavior model in ACT-R:

1) Goal module (also declarative knowledge/memory):

- To avoid crash.
- To keep a safe distance to the rear.
- To maintain behind vehicle traveling not too closely.

2) Declarative knowledge:

For the reason the crash may be occur with both the preceding vehicle and the vehicle behind, here we give declarative knowledge both of them respectively. Of the behind vehicle, It is difficult to maintain a "space cushion" as the other driver controls the space. We declare the following knowledge:

- If the vehicle behind is traveling too closely, THEN slow down slightly.

To the preceding vehicle, the distance that it will take you to stop your car depends on the speed at which you are traveling. The faster you go, the longer the stopping distance. Here we give declarative knowledge according to 3 seconds rule:

- IF the distance at a less than 3 second following distance, THEN too close – unsafe!
- IF the distance at a 3 second following distance, THEN OK in good conditions only.
- IF the distance at a more than 3 second following distance, THEN better in wet and poor conditions.

The following is declarative knowledge when the driver at the urgent circumstance that the preceding vehicle take a hard brake.

- IF the preceding vehicle take hard brake, THEN it is a urgent circumstance.

3) Production rule (procedure knowledge):

- IF the vehicle behind is traveling too closely, THEN slow down slightly to increase the "space cushion" in front of you.
- IF the distance at a less than 3 second following distance, THEN decelerate to maintain a 3 second following distance.
- IF the distance at a 3 second following distance, THEN maintain current distance (or speed).
- IF the distance at a more than 3 second following distance, THEN according to other information make decision.
- IF the preceding vehicle braking light become luminant, and the distance at a 3 second following distance, THEN brake and decelerate immediately.
- IF the preceding vehicle braking light become luminant, and the distance at a less than 3 second following distance, and no behind vehicle or behind vehicle traveling not too closely, THEN rapid brake.

4) Visual Module

- The preceding vehicle.
- The behind vehicle (in the mirror).

5) Manual

- Slow down slightly (foot off the throttle).
- Slightly brake.
- Rapid brake.

Model prediction and experiments

ACT-R is a both a theory and a cognitive modeling tool. The theory of ACT-R is embodied in the ACT-R software as a set of functions and algorithms implemented in Common Lisp. The ACT-R Environment is a set of GUI tools for running, inspecting, and debugging ACT-R models. There is also a standalone version available for windows operating system that runs without the need of having Lisp installed. We use the standalone version software of the ACT-R Environment modeling driver urgent behavior and predicting the modeling result.

The experiment is implemented on a driver simulator, the simulator consists of a car cab, three display screens and a control computer. The visual world is displayed on three screens, as the driver turns the wheel, brakes or accelerates, the roadway that is visible to the driver changes appropriately. The computer generates the required video images of experiment during the simulation for the three display screen. Driver behavior and vehicle performance (steering wheel angle, speed, lane position, etc.) are recorded by the control computer.

In order to verify the model's validation and predicate the driver behavior for urgent circumstance, model simulation and real-world experiments are implemented separately. We divided experiment into two groups, one of them for 3 second rule and another group for urgent circumstance, each group include three cases: one for the distance large than 3 second rule, one for distance less than 3 second rule and there is vehicle behind, and the third is the distance less than 3 second rule but there is no vehicle behind. We sample each of them 50 items from five normal drivers. The experiment results show in Figure 4. It shows that the most of driver behaviors are fit in with model simulation results, especially in the situation of distance large than 3 second rule.

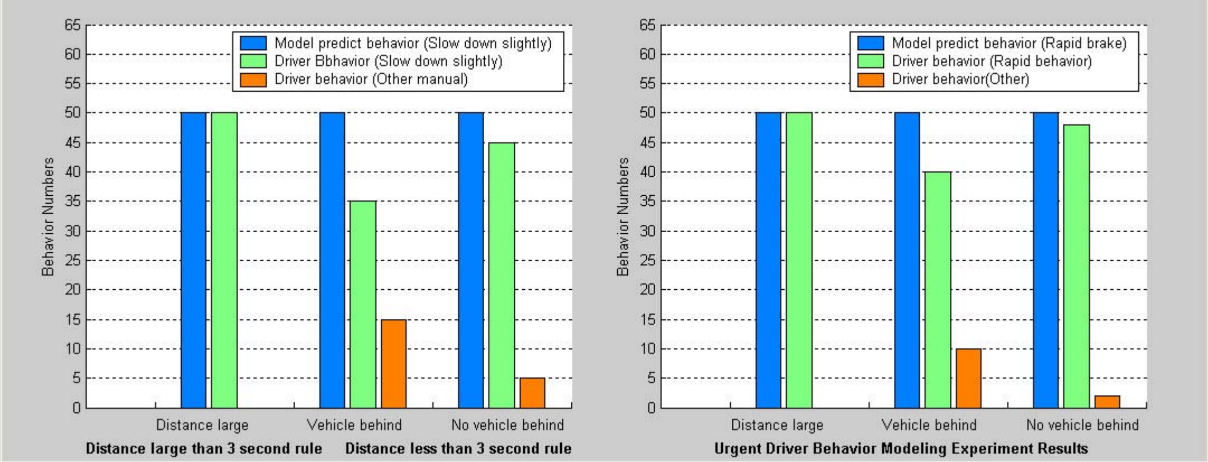

Figure 4. The model prediction and driver behavior

Experimental Analysis

In Figure 4, we find that the model simulation result coincides with the driver experiment result basically, especially when the distance between the driver's vehicle and preceding vehicle is large and no vehicle behind, it is congruent completely; Comparing the results of whether or not there is vehicle behind, it indicates that the result of no vehicle behind is better than that of vehicle behind; the figure 4 also shows that the result when the driver at the normal situation is better than that of driver at urgent circumstance. We may conclude that the driver's cognitive behavior will become more complicated in complex environment or crisis situation.

Discussion

The procedure of the driver's cognitive behavior is rather complicated, the driver's behavior may be influenced by many factors, in our experiment, the behind vehicle is not identified so mush clearly (such as how long it is to the vehicle's rear and how much its speed is), we believe that those parameters of the behind car must influence the driver's behavior greatly. In the other hand the speed 60 mph of the driver's vehicle we select here is only as a sample, it is inadequate to modeling of driver behavior ranging a wide range of vehicle speed, it is important to examine more different vehicle's speed or find the correlation of model and vehicle's speed. Moreover the models' parameter changes with different persons or in different situations, which given here are only for method evaluation for driver behavior modeling, and there should be more reliable methods and more samples for development.

Conclusion

Researches on the driver behavior modeling in cognitive architecture are effective. Cognitive architectures have been successfully employed in a wide variety of domains to model and study human factors. Surprisingly, there has been only little attempt to model driving in a cognitive architecture. However, we believe that cognitive architectures offer a host of benefits for modeling driver behavior that could nicely build on existing work in this area. Cognitive architectures are extremely adept at integrating lower-level perceptual and motor control processes with higher-level cognitive and decision-making processes. Architectures typically rely on a central cognitive processor to maintain a mental model and make decisions about higher-level strategies to execute. This processor communicates with numerous perceptual and motor processors that run in parallel with the cognitive processor, executing requested commands from cognition and communicating sensory input to cognition. Any model developed in a cognitive architecture necessarily brings to bear both these cognitive and perceptual-motor aspects of behavior. This feature greatly facilitates the integration of lower-level control models, such as for lateral or longitudinal control, with higher-level decision making models that act upon the current situation and the current needs and desires of the driver. This paper integrate the lower-level control manual with higher-level decision making procedure into driver cognitive behavior model, both the predication of driver behavior and verification of model's validation indicate that driver behavior modeling in cognitive architecture is remarkable.

One contribution of this paper is to demonstrate a driver behavior model in an ACT-R cognitive architecture under urgent circumstances. Another contribution is to present a detailed illustration of production-rules of 3 second rule and the driver cognitive behavior at the emergency of vehicle's suddenly brake in front of a car.

Further works

ACT-R is sophisticated cognitive architecture, and there are plenty of successful applications in many fields. This paper has proved that it is validation modeling driver behavior in an ACT-R cognitive architecture. Further work will include the following aspects: first, more production rules, declarative knowledge and procedural knowledge detailed dedicatedly. Second, to construct applicable driver behavior models, in which more driver cognitive behaviors will be integrated into the model. Last but not least, more relevant factors of emergency will be involved to enrich the model's flexibility.

However, despite progress in defining a functional anatomy of emotion, we still have little idea about how emotion relate to other major axes of affective experience represented by motivation and mood. This is an issue that is critical to a deep understanding of many psychiatric disorders, as a cognitive architecture, ACT-R needs to be further developed.

Acknowledgment

This work was supported by 863 National High Technology Program under Grant No. 2003AA1Z2080, "Research of Operating System to Support Ubiquitous Computing".

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