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Improvement of ACT-R for Modeling of Parallel and Multiprocessing Driver Behavior

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Abstract- **In order to process multitasking driver behavior effectively, an improved driver cognitive behavior modeling method of ACT-R is proposed in this paper. The manual and visual modules of ACT-R are concatenated directly to cope with human subconscious/unconscious behavior. A parallel processing method is also proposed to mimic the parallel reaction style of a given cerebral area of human brain's reaction to the physical characteristics of the stimulus. Driver behavior assorting and risk level ranking methods are applied to improve the model's executive efficiency. The simulation results demonstrate that the ACT-R cognitive architecture is improved significantly with theses proposed improvements.**

***Index Terms*—Cognitive architecture, driver behavior modeling, multiprocessing and parallel driver behaviors, java multithread.**

1. INTRODUCTION

The history of driver behavior modeling started in 1938 when Gibson and Crooks presented their theoretical field-analysis of automobile driving. Taylor presented his "drivers' galvanic skin responses and the risk of accidents" in 1964. The debate of driver behavior research in psychological aspect went on till the end of the last century. Driver behavior modeling addresses diverse aspects of researches. Vaa studies some critical viewpoint of cognition and emotion in driver behavior models and concludes that there is no breakthrough or unified theory within the traffic safety research area (Vaa, 2001). This unpleasant situation results from the lack of thorough and comprehensive understanding of human cognition and emotion, i.e., how drivers think and feel, consciously, pre-consciously or unconsciously. Finally, Vaa concludes that human emotions are (part of) the risk monitor and the very instrument that enables drivers to monitor danger, consider and evaluate behavioral alternatives in a given situation.

Modeling parallel cognitive behavior becomes more and more important. Inspired by neuroscience, Anderson proposes a computational parallel system architecture and applies it to solve cognitive problems (Anderson, 2003). Court et al. develop a framework for modeling and analyzing risk-assessment and decision-making for evacuating large population (Court et al., 2004). This framework includes rare-event simulation methods, parallel and distributed simulations, and agent-based simulations. Lim and Liu propose a queuing network model for simulating eye movement. The model is built in cognitive-architecture and it can perform partial parallel processing (Lim and Liu, 2004).

With the rapid development of informatics in the recent years, computational models emerged as a powerful tool for studying the complex driving task. These models allow for researchers to simulate driver behavior and to explore model’s parameters and constraints. In addition, a growing interest in the neurobiology of emotion parallels a wider recognition of its importance to human experience and behavior. Therefore, driver behavior modeling in cognitive architectures becomes one of the hottest research topics in the field of traffic science. Salvucci proposes an integrated model to access driver distraction (Salvucci, 2003; Salvucci, 2002; Salvucci, 2001). Liu et al. develop a smart car driver cognitive model based on the pervasive computing concept (Liu et al., 2005; Liu et al., 2006). Kushleyeva and Salvucci study the decision-makings of task switching of multitasking behavior under the time-critical situation (Kushleyeva et al., 2005; Salvucci, 2005; Salvucci et al., 2004).

There are many methods to model driver cognition, each of which addresses different aspect of human cognition. It may be possible to integrate the human motion into different human cognition models. So far these researches indicate that ACT-R (Atomic Components of Thought), a dominant cognitive theory and architecture that focus on learning and problem solving, provides a relatively clear picture of human driving behavior. Salvucci proposes four approaches to predicting driver distraction from in-vehicle interfaces as secondary tasks (Salvucci, 2005). They all use an integrated-model method and rigorous driver model. Each approach has its advantages and disadvantages of simplifying cognitive modeling of rapid prototyping and evaluation of in-vehicle interfaces. Song et al. present a cognitive and hybrid model of a human driver (Song et al., 2000). Pompei et al. devote their efforts to the work of driver cognitive workload (Pompei et al., 2002). Matessa presents an ACT-R modeling framework for interleaving templates of human drivers (Matessa, 2004). Olivier et al. develop psychological models to access a driver's situation awareness (Olivier et al., 2005). Liu and Wu develop urgent driver behavior models for some critical circumstances (Liu and Wu, 2005).

ACT-R has been widely used to model different aspects of human cognitive behavior, such as solving the Tower of Hanoi puzzle, memory for text or for lists of words, language comprehension, communication and aircraft control. The mechanisms ACT-R are based on two foundational assumptions (Anderson, 1993). The first one is that “the implementation of ACT-R should be in terms

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of neural-like computation". The second one is that "cognition is adapted to the structure of the environment". Consequently, many of the mechanisms in ACT-R are designed to reflect the statistical nature of the environment (Johnson, 1997).

The driving task is an ever-changing set of basic tasks that are integrated and interleaved. Some of the tasks are not continuous but intermittent, arising from specific situations. In addition, driving may include the secondary tasks, which could be related to a primary task, or they could be entirely unrelated. Occasionally, two or more driving tasks have to be completed simultaneously within a very short period of time. Some tasks are completed subconsciously or unconsciously. Sometimes a more urgent case accompanies with another emergency case. Unfortunately, there are few discussions about subconscious/unconscious driver behavior in the literature. Most of them focus only on a serial processing order, but obviously such order is not congruent with real cases. Though the idea of parallel threads of a serial processing is prompted, Anderson et al. do not deliberate on the model's executive efficiency when dealing with multitasking driver behavior (Anderson, 2004).

There are several theories on how multiple tasks can be carried out at the same time, but they share the same basic idea that the cognitive system consists of several modules that can each operate asynchronously (independently) from each other (Taatgen, 2005). An early version of this idea can be found in CPM-GOMS (Gray et al., 1993). It is assumed that cognition, perception and motor actions can be done in parallel, although within each modality actions are serial. This idea is also the foundation of the EPIC (Meyer and Kieras, 1997) architecture, except that it assumes that cognitive actions can be done in parallel. Parallelization of behavior in these theories is a matter of optimizing the schedule of actions in all these modules. The APEX architecture (Freed et al., 2003) actually uses an algorithm to derive this optimal schedule. The EPIC modules are incorporated into the ACT-R architecture (Byrne and Anderson, 2001; Taatgen, 2005). However, ACT-R still assumes that central cognition is serial. Parallel behavior is often studied in dual-task experimental paradigms.

This paper describes four improvements of ACT-R for handling parallel and multiprocessing driver behaviors, i.e., subconscious or unconscious driver behavior, parallel production system, parallel perception module and parallel motor module.

2. ACT-R ARCHITECTURE AND DRIVER BEHAVIOR COGNITIVE MODEL

2.1 ACT-R Cognitive Architecture

ACT-R is a cognitive architecture, a theoretical model of a human cognition procedure. Researchers working on ACT-R strive to understand how people organize knowledge and exhibit intelligent behavior. On the exterior, ACT-R looks like a programming language; however, its constructs reflect the assumptions about human cognition. They are based on numerous facts derived from psychological 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 make their own assumptions in the model and test the model by comparing its results with the results of people actually performing a task.

ACT-R theory first starts with an ACT production system (Anderson, 1976). The system displays a distinction between procedural knowledge and declarative knowledge, the later essentially consists of known facts about the world. It is a unitary theory of cognition and has origins in human associative memory (HAM) theory of human memory (Anderson & Bower, 1973). It also borrows ideas from Newell's symbolic framework (Newell, 1973). In 1983, Anderson provides a detailed description of the ACT and developed a theory called ACT*(Anderson, 1983). Integrated with a set of neurally plausible assumptions about how production might be acquired, the ACT* theory is evolved into the ACT-R theory (Anderson, 1993) in which an architecture of cognition is modeled to explain how the process of acquisition can be tuned into the statistical structure of the environment. It has recently undergone a major development into a version of ACT-R 5.0 and this version 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 of the important features of ACT-R that distinguishes itself from other theories is that it allows for researchers to collect quantitative measures that can be directly compared with quantitative measures obtained from human participants.

2.2 Principle of ACT-R

ACT-R cognitive architecture was 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 by 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 is currently a placeholder for future refinements (Fig. 1). ACT-R includes a module dedicated to the controlling motion of human hands. It 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 changes 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 and 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 to extend the functionality of the manual module.

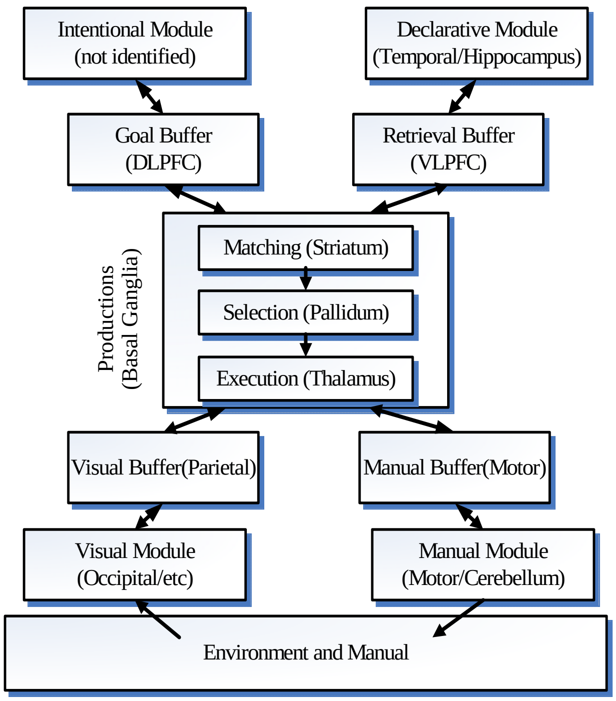

Fig. 1. ACT-R cognitive architecture.

2.3 Research Basis in Neurobiology and Neuroimage for ACT-R

ACT-R is a human cognitive architecture. It's always related to the newest research achievements in neurobiology and neuroimage. In fact all parts of the ACT-R architecture are designed to reflect certain human brain areas. There are two built-in visual modules in ACT-R, the dorsal "where" pathway (locations) and ventral "what" pathway. As for the visual system, other modules have been designed to match specific brain areas. For instance, the manual buffer matches motor and somatosensory cortical areas, the goal buffer matches DLPFC (dorsolateral prefrontal cortex), and the retrieval buffer matches VLPFC (ventrolateral prefrontal cortex, i.e., long-term declarative memory in ACT-R). The basal ganglia is used to implement production rules in ACT-R, the striatum corresponds to cortical areas and is responsible for pattern recognition, the palladium is inhibitory component and performs conflict-resolution functions, and the thalamus projects to all major cortical areas and controls execution of production actions in the production system.

2.4 Driver Cognitive Behavior

The usual driving situation should be the status of situation awareness. It can be divided into three stages according to the evolution phases. The first stage is the environment perception. As a driver, one should thoroughly acquaint oneself with the vehicle's information, the changes of the environment, and traffic signal and signs. The second stage is the comprehensive understanding. In this stage, the driver analyzes what the intentions of situation information are according to the relevant goals, and then conceives a clear and integral situation thought image. The third stage is the decision-making. At this stage, the driver makes predictions and decisions according to the knowledge of comprehensive understanding and refinement of current situation information.

Situation awareness guarantees a driver's finishing of a driving task overall. Drivers maintain situation awareness and try to keep/change certain situation, perceive the outside environment over sense organs, and implement the interactions with environment via manipulations. Therefore, environment monitoring and manipulations are important parts of driver cognition behavior. Together with the embodied decision-making of human cognition, they are composed of the three main components of a driver cognitive behavior procedure. They correspond to the components of an ACT-R model: visual, motor and manual modules, respectively.

2.5 Driver Behavior Model in ACT-R Cognitive Architecture

ACT-R has three main components: modules, buffers, and pattern matching. The architecture assumes a mixture of parallel and serial processing.

For performing a specific driving task, the ACT-R-based driver behavior model consists of at least three basic components, 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 the relevant procedural knowledge. It takes advantage of the architecture's built-in features and human-like limitations that result in a more psychologically plausible model of driver behaviors.

3. Multitasking Driver Cognitive Model

Three aspects related to the driver's parallel and multiprocessing behaviors are discussed as follows, subconsciousness, parallel information processing, and parallel operations. The driver behavior classification and risk level criteria of behavior are also discussed.

3.1 Subconscious/Unconscious Behavior

According to Mises' research (Mises, 1996), human beings generally mentally operate on a 5% conscious to a 95% subconscious ratio. This means that our lives are really ruled by our intuitive subconsciousness. The subconscious aspect represents our inner parts of ourself, those deep, highly personal feelings and qualities that provide the foundation for our entire being and give us the motivation behind our behavior, thoughts, emotions, and others. This is the realm of instinct, gut reactions, innate knowing, and personal potential. Unconscious behavior is in sharp contrast to conscious or purposeful behavior, i.e., the reflexes and involuntary responses of the body's cells and nerves to stimuli. The term "unconscious" as used in praxeology and the terms "subconscious" and "unconscious" as applied in psychoanalysis belong to two different systems of thought and research. From psychoanalysis, either the unconscious mind or the subconscious is the aspect of the mind of which we are not directly conscious or aware of. People are sometimes prepared to believe that the boundaries between conscious behavior and the involuntary reaction of the forces operating within human body are more or less indefinite. This is correct only as far as it is sometimes not easy to establish whether concrete behavior is to be considered voluntary or involuntary. But the distinction between consciousness and unconsciousness or subconsciousness is nonetheless sharp and can be clearly determined.

While driving, we often find that our reactions to certain situations are completely automatic when facing some urgent circumstance or most of normal situations. This is the subconscious/unconscious reaction. At least there are two benefits of these subconscious/unconscious processes: one is obviously the efficiency of handling this emergency. The other is that the automatic process would save driver's precious time and stamina in order to scan for potential dangers.

Therefore, the cognitive model should reflect all these aspects of human unconscious/subconscious behavior, i.e., some human behaviors react directly to stimuli without going through human brain. In order to map those subconscious/unconscious driver behaviors, the MONITOR and MANUAL module are connected directly in the proposed ACT-R driver behavior model, and the model responds immediately to the external events without going through the production system of the ACT-R architecture.

3.2 Parallel Processing of Human Behavior

As we know human brain has many parts including the cerebral cortex, brain stem, and cerebellum. Injury in one part may only disrupt a particular step of an activity that occurs in that specific part. The research work eventually helps to show that the areas of the brain have specific functions though some functions are repeated. This is the idea known as parallel distributed processing (Kandel, 2001). The functions of the particular parts of brain are listed in Table 1.

Since a different cerebral area reacts to stimuli and events separately, and information is conducted in a parallel way, so the serial production system in ACT-R is not ideal. Therefore, we improve the ACT-R driver cognitive behavior model with multi-production threads. The related work shows that it fits the real cases well, and improves model's efficiency for multitasking driver behavior processing.

Table 1: Functions of particular parts of brain

Brain area	Functions
CEREBRAL CORTEX	
Frontal Lobe	Reasoning. Planning. Parts of speech. Movement. Emotions. Problem solving.
Parietal Lobe	Movement. Orientation. Recognition. Perception of stimuli.
Occipital Lobes	Vision
Temporal Lobes	Perception and recognition of auditory stimuli. Memory. Speech.
BRAIN STEM	
	Breath. Heart rate. Swallow. Reflexes of vision and auditory (startle response). Sweat, blood pressure, digestion, temperature (autonomic nervous system). Affecting level of alertness. Ability of sleep. Sense of balance (vestibular function).
CEREBELLUM	
	Coordination of voluntary movement. Balance and equilibrium. Some memory of reflex motor acts.

3.3 Driver Behavior Classification

Michon discerns three driving task levels: strategic, tactical and operational. Driving typically involves all three types of processes working together to achieve a safe, stable navigation (Michon, 1985). A driving task involves different parts (hand, foot and eye) of the body and physiological systems (neural, motor). Of all the behaviors, some have no relationships, while others are inclusive or exclusive. Some operations can be executed in parallel, but other operations must follow different patterns. Some are urgent, but others are not.

3.3.1. Exclusive/joint driver behavior

As we know, one cannot maneuver two artifacts with one hand simultaneously. Some operations are in conflict with each other due to human bodily limitations. Also some manipulations must be completed following a certain operation. Therefore, the driver cognitive behavior model should abide the principles of a human system. Examples of conflicting driver behaviors and accompanying driver behavior are: brake and throttle are exclusive, clutch and gear are joint, while steering and throttle are irrelevant.

3.3.2. Driver behavior classification

Driver behaviors are classified here according to Michon's driving task leveland related body parts (Michon, 1985; Salvucci, 2006). A strategic-level task is completed by the human brain and neural system, while a tactical-level task is completed by the monitor system, and hands or feet execute the related driving operations. The primary driver behavior and related body parts are listed in Table 2.

Table 2: Primary driver behavior and body parts

Body Parts	Manual	Memo
Brain	Making decision Predicting Identifying	Making a sound decision Predicting what will happen. Scanning for potential hazards
Eye	Looking ahead Looking Behind Looking dashboard Scanning Looking to left side Looking to right side Checking vehicle's blind spots	Keeping eyes on ahead vehicle Keeping eyes on rear mirror Checking information on dashboard Keeping eyes moving to head road Moving eyes anterior - left position Moving eyes anterior - right position Moving head and checking vehicle's blind spots
Left foot	Controlling clutch Pushing/Releasing park	Pushing, holding on and releasing clutch Pushing/releasing park peddle
Right foot	Braking Accelerating	Pushing, holding on and releasing brake Pushing, holding on and releasing throttle
Both hand	Steering	Navigating
Left hand	Controlling light	Switching on/off light
Right hand	Shifting gear Controlling wash/swipe	Switching Gear Turning on/off wash/swipe

3.4 Driver Behavior Risk Level

There are different driver risk criteria. According to Vehicle Incident Prevention Program High Risk Driving Criteria (Risk Management Division of Oregon Department of Administrative Services), marks are assigned based on the driving history and experience. The higher the final score, the greater the potential risk for a particular group of drivers and the agencies they represent for. Reaction time to unexpected critical events is also being used to assess the differences in risk level. On-driving driver behavior risk level is applied here. It means that the risk level is defined according to the driver's driving situation and the environment. According to the estimated driver's hypovigilance state and the estimated level of traffic risk, the driver behavior risk level is categorized into five levels: high risk, moderate risk, low risk, contingency, and normal status.

3.4.1. Normal status

There is no risk for a driving task of normal status. In this level, the driver handles vehicle freely. Even there are cars in front of the driver's vehicle, it is in a safety distance and a driver can follow the car with the desired speed. There is no vehicle in both sides of the driver's car, and there is no vehicle in the rear-mirror and the vehicle behind is far from being dangerous. Drivers can drive their car in semi-conscious status, or driver behavior is subconscious.

3.4.2. Contingency

There are some unfavorable cases occurring for a driver. For example, the driver may find the distance between his car and the front one is becoming smaller or the driver finds the vehicle following is approaching his car and wants to overtake. But in this level, the driver has enough time or skills to avoid any crash from happening, even if the driver needs not react to the appearing cases. For this level, drivers are in awareness situation to avoid the accidental fluctuation.

3.4.3. Low risk

An example for this level is a pedestrian coming across in a far more braking distance than safety. Under this circumstance, drivers are in awareness situation. Unsuitable or mistaken driver behavior can result in crashes. But for most cases experienced or even amateur drivers can handle the cars skillfully and therefore the risk is still relatively low.

3.4. 4. Moderate risk

An example of this level occurs when a pedestrian comes across in safety brake distance. The sophisticated driver may avoid the crashes, but an unsophisticated driver may not handle it skillfully enough to avoid it.

3.4.5. High risk

By the urgent or emergency situation, it often means at a high-risk level. A sample scenario is when a pedestrian suddenly appears within safety brake distance. High-risk level drivers are those who demonstrate a pattern of frequent crashes and severe violations, this requires more personalized attention. In this level, it is rather difficult to avoid the accidents.

While driving, the more dangerous the situation, the higher the priority. The urgent ones can interrupt those less urgent ones being processed. So the risk level is defined here as the priority of the driver's behavior. The primary principle is that an event with high risk level will interrupt an event with lower level. This way guarantees that urgent cases be handled first.

4. General Ideas of Multiprocessing and Parallel Driver Cognitive Behavior

For the purpose of model efficiency and coincidence with the real world for multitasking, the parallel processing method and subconscious behavior thought are introduced in the development of an ACT-R driver behavior model.

4.1 Parallel Production System Module

In order to process multitask and solve the conflict of process priority of different risk level, a register is applied to store the driver behavior risk level of all the processing threads. When drivers perceive the irritation of a stimulus, an event, or a driving task that belongs to the subconscious/unconscious class, the model responds to it immediately and sends the related manipulation to the manual module directly for executions. Otherwise, the irritation reaches the model's production processing system through the visual buffer. The system compares the risk level with that of the risk level register. If the risk level is less than or equal to the stored risk level, and there is an empty production system thread, the irritation enters the SELECT and MATCH program. If there is no empty thread, it enters a queue to wait. If the risk level is higher than the risk level stored, and there is an empty production system thread, the irritation enters the SELECT and MATCH program. If there is no empty thread, the risk level in storage is replaced with the current irritation's risk level, and the irritation that is running in production system is paused and enters the queue, i.e., the high risk level behavior enters the production system. After the completion of an irritation process, the risk level register is cleared and reset to zero. The thread of the production system is set empty and waits for the next irritation. In the proposed model, three production system sub-modules are designed, and each of them has its own match, select and execute modules.

4.2 Parallel Driver Manipulation Module

Every production system or subconscious/unconscious reaction triggers the corresponding driver manipulation, which in turn results in a single driver operation. When manipulation is produced, the module probes whether or not there is exclusive manipulation in the other thread, and whether or not there are any joint operations in the declarative knowledge. If exclusive manipulations exist, the operation waits until the manipulation is finished. If there are joint operations, this operation and its joint operation are executed simultaneously on different manual modules. Otherwise, the operation is sent to the manual module to execute. In the proposed model, four parallel manual modules are concatenated to their own manual buffers. The related driver behaviors correlate to left hand, right hand, left foot, and right foot respectively.

4.3 Parallel Driver Monitor Module

Human beings with a complicated visual system have wide fields of vision, allowing them to resolve fine details, track a moving object, perceive depth, see colors, and look in many directions. To see more, they have to move their entire head or even body. Yet the visual system in the brain is too slow to process that information if the images are slipping across the retina at more than a few degrees per second (Westheimer, 1954). Thus, to be able to see while moving, the brain must compensate for the motion of the head by turning the eyes around. To get a clear view of the world, the brain must turn the eyes around so that the image of the object of regard falls onto the fovea (Grzywacz et al., 1995). As we know the movements of different body parts are controlled by striated muscles acting around joints, the movements of the eyes are no exception. But they have special advantages that are not shared by skeletal muscles and joints, and so they are considerably different. When the muscles exert different tensions, a torque is exerted on the globe that causes it to turn. This is an almost pure rotation, with only about one millimeter of translation (Carpenter, 1988). Thus, the eye can be considered as undergoing rotations about a single joint in eye's center (Roger, 1988). Comparing to the brain's slow processing, the eye's motion is rather rapid, and therefore we take the visual system as parallel input for the brain's different areas.

In contrast, the other parts of the body (such as ear and nose) may perceive the changing driving environment, such as sound from somewhere around can predicate that something may happen. There are also some subconscious/unconscious behaviors in driver behavior we mentioned above. So drivers' monitoring the driving environment may not be series, i.e., the model's monitor module should be in parallel processing mode. In our driver behavior model, three visual/monitor modules are designed to monitor the vehicle running environment.

The general architecture of the improvement of the ACT-R is summarized and shown in Fig. 2.

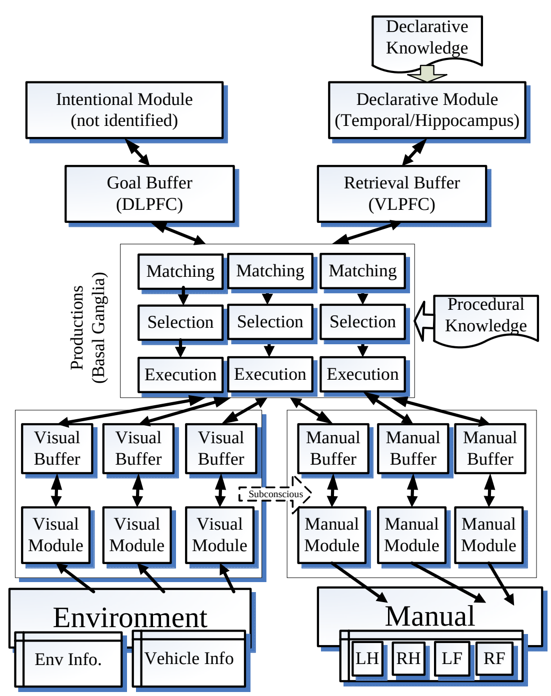

Fig. 2. Improved multitasking driver cognitive behavior model.

5. Implementation and Experimental Design

A software simulation method is used to test the verification of the improved ACT-R model. The software is developed in Eclipse platform Version 3.0.2 with Java programming language, and the parallel processing idea is implemented using the Java multi-thread program method. First, the software is designed for implementation of both improved model and normal ACT-R model, and then their executive efficiency is compared.

As the model runs, multi visual modules monitor the outside event. As multi events happen in parallel or simultaneously, the model judges whether there is subconscious behavior to be triggered. If so, the model triggers the related manipulation in multi manual modules in parallel. And then the mutli events (non-subconscious behavior) go into the multiprocessing production system in parallel. Finally, the model sends production results to multi manual module and fires the relevant operations. Figure 3 describes the general program framework.

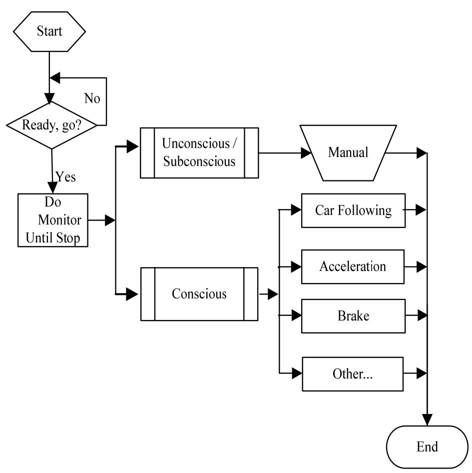

Fig. 3. Diagram of parallel multitasking driver behavior cognitive model.

5.1 Simulation of Parallel and Multiprocessing with Java Thread

The Java language has multithread support as an intrinsic part of its specifications. A method used by the Java language explicitly implements a design pattern that can be applied across most mutual exclusion problems that face the multitasking parallel processing programmer. Java allows for a programmer to spawn individual lightweight threads as part of the application or applet. A thread is a thread of execution in a program. The Java Virtual Machine allows for an application to have multiple threads running concurrently.

A thread - sometimes called an execution context or a lightweight process - is a single sequential flow of control within a program. Threads are applied to isolate tasks. When there is a parallel driver behavior, it creates a thread that performs the driver task. Each thread is a sequential flow of control within the same program (serial behaviors). Each parallel operation runs independently from each other but simultaneously.

Every thread has a priority. Threads with higher priorities are executed in preference to threads with lower priorities. Each thread may also be marked as a daemon. When the code running in some thread creates a new *Thread* object, the new object has its priority, initially set equal to the priority of the creating thread, and is a daemon thread if and only if the created thread is a daemon. The thread's priorities are designed according to the behavior risk level.

When a Java Virtual Machine starts up, there is usually a single non-daemon thread (which typically calls the method named main of some designated class). The Java Virtual Machine continues to execute threads until either of the following occurs, 1) the exit method of class Runtime has been called and the security manager has permitted the exit operation to take place, and 2) all threads that are not daemon threads have died, either by returning from the call to the run method or by throwing an exception that propagates beyond the run method.

There are two ways to create a new thread of execution. One way is to declare a class to be a subclass of *Thread*. This subclass should override the run method of class *Thread*. An instance of the subclass can then be allocated and started. The other way is to declare a class that implements the executable interface. That class then implements the run method. An instance of the class can then be allocated, passed as an argument when creating Thread, and started. In our following simulation programs, the second method is adopted.

Every thread has a name for identification purpose. More than one thread may have the same name. If a name is not specified when a thread is created, a new name is generated for it.

All the threads within a Java program execute within a shared memory space. Java threads within a program share access to objects (there are no global variables in Java) and can send notifications to each other to signal events of one kind or another. Figure 4 illustrates the strategy of multithread's management in the proposed model.

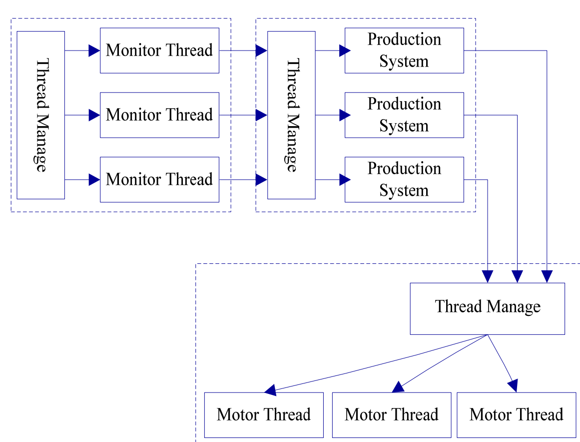

Fig. 4. Multithread processing structure.

Multi-monitor module adopts a rule that assign a task to a module according to an event. In other words, when external events trigger a driving task, an empty thread is selected to process it. If there is no empty thread, the model decides whether to terminate currently processing task or to send the new task into the queue according to the task's risk level. In the other two modules, the same methods are applied.

5.2 Experiment Design

Statistics analysis shows that the visibility conditions play one of the most important roles among all. The severity of injuries is much higher in dark conditions as at daytime. It is easy to extract from the statistics that in dark conditions the car driver detects pedestrians much more slowly than that in well-illuminated scenarios. The research of Klaus (2002) shows that approximately 2/3 of all collisions of vehicle-versus-pedestrian occur in situations with the vehicle's speed under 40 km/h. Collisions at higher speeds result in higher severity of injuries (e. g. death). In this domain with higher collision speeds, the reduction of the severity of injuries in case of accidents is quite low (Langwieder et al., 2001; Langwieder et al., 2003). Hence in this paper we focus on the dark driving condition.

An experimental scenario of a driver behavior model makes sense in the domain of collision speeds of approximately 40 km/h or lower. The impact in case of higher speeds can be reduced marginally only. The scenario selected to verify the model's validation is that a pedestrian appears in the front-right side of a running car in a certain distance. The pedestrian is just walking across the road when the driver finds him. The distance between the pedestrian and the car is very close. In this urgent situation, the total reaction time can be decomposed into a sequence of components, 1) Mental Processing Time, 2) Movement Time, and 3) Device Response Time. Mental Processing Time is the time it takes for a responder to perceive that a signal has occurred and for the responder to respond. It is composed of three sub-stages: sensation, perception/recognition and situational awareness, and response selection and programming. These stages are usually lumped together as "perception time," which is a misnomer since the response selection is an important component. The driver behavior may include 1) body percepts, 2) brain makes a decision 3) right foot releases accelerator, moves to brake peddle, and depresses, 4) left foot pushes clutch, and 5) hand steers to change the forward direction. Sometimes Step 3-5 driving tasks are subconscious for a driver who drives for a routine task. It means that Step 2 takes little time and can be skipped.

6. Software Implementation and Simulation Results

In the situation when a driver encounters an unusual circumstance, Green estimates that the best estimate reaction time is 1.5 seconds of which the perception time is 1.2 seconds and the movement time is 0.3 second (Green, 2000). Combined with our estimation of the other driver behavior elapse time, the elapse time of the 5 steps driver tasks mentioned previously are given in Table 3.

Table 3: Time elapse for special cognition and driver behavior

Driver behavior	Time (sec.)
Body parts percept	0.6
Brain makes decision	0.6
Right foot releases accelerator, moves to brake peddle and depresses	0.3
Left foot pushes clutch	0.2
Hands steers to change forward direction	0.5

6.1 Implementation of Simulation Software

Three program modules are developed to simulate the three corresponding cases when parallel and subconscious behaviors are considered, i.e., 1) serial processing of driver behaviors, 2) parallel behavior, and 3) subconscious and parallel behavior. These programs are available from the authors by e-mail.

In order to maintain the reaction time similarity in different verifications of the driver behavior model's simulation, we use a computer program to trigger all the human driving tasks, and give the same reaction time to the same driver behavior.

6.2 Simulation Results

To verify the proposed model, we conduct experiments for the following three circumstances. First, we test the normal model using series input of the above five driver tasks. Second, we use the model with a parallel processing method to process the above-mentioned driving tasks while considering the driver's behavior exclusively/jointly and the risk level. Finally, we use the second method and take tasks step 3-5 as subconscious behavior.

In the first software simulation, only one thread is designed to process the five continuous behaviors. The consequence of the five behaviors is 1) body parts percept, 2) brain makes a decision, 3) right foot releases accelerator, moves to brake peddle, and depresses, 4) left foot pushes clutch, and 5) hands steers to change the forward direction. In the second software simulation, three threads are designed to process cognition and motor behaviors respectively, one for body perception, decision making and release throttle/push brakes, one for pushing clutch and another for steering. In the final software simulation, four threads are designed to process cognition behaviors respectively, one for body perception and decision making, one for release throttle/push brakes, one for push clutch and another for steering. The executing time of every cognition and motor behavior is given in Table 3. The total elapse time of every simulation and the elapse time of every cognition and motor behavior are recorded and shown as the simulation results. Also, the start and end times of every thread and cognition behavior are marked. The simulation results are shown in Fig. 5.

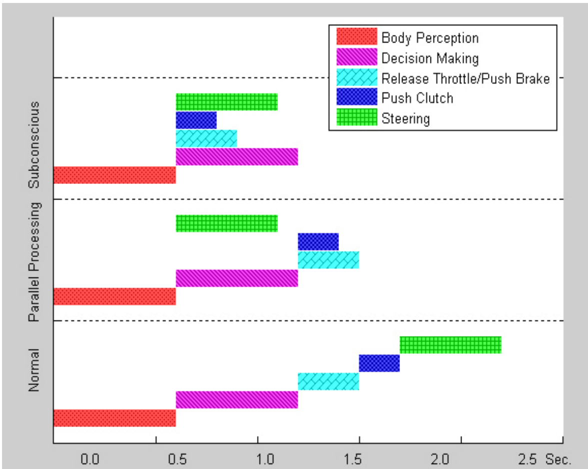

Fig. 5. Comparing simulation results.

From the above simulation results, we notice that the proposed driver cognitive behavior model is more effective for multitasking driver behavior. When the model run in normal serial processing, the five behaviors elapse time is about 2.2 second. As parallelism of the driver behavior and simulating it with multithread, the total elapses time of five driver behaviors is about 1.5 second. When both the parallel behavior and subconscious behaviors are processed with multithread, the executive time of five behaviors is only 1.2 second. Obviously, the executive efficiency is improved greatly.

7. Discussion

7.1 Verification of Model's Validation

Due to the space limit, we only show results from one experiment in testing the proposed model. However, more experiments are conducted to test the model and method, and the results indicate that the model is suitable and available for the experimental multitasking driver behavior. A typical example of the experiment is a car run as a vehicle follows closely while the front car exerted a sudden brake. Theoretically, it is undoubted that the proposed method improves the model’s efficiency that the CPU utilization is improved with a parallel processing method.

7.2 Reaction Times

Researchers also find that the reaction times are greatly affected by whether the driver is alert to the needs of brakes. Green divides the alertness into three classes, Expected, Unexpected, and Surprise (Green, 2000). To these three alertness classes, the time of the perception sub-stage is different. In this paper, the different sub-stage time is the best estimated time according to the related researches and empirical values. However, the result of the model verification indicates that this is of little influence on its availability and the proposed method always shortens the total reaction time. This is very important to the driver assistant system of the real world.

8. Conclusions and Future Work

By introducing the methods of subconscious, parallel processing, and the exclusive/joint/irrelevance driver behavior concept to the ACT-R driver cognitive model, the researches showed that the model’s execution efficiency of multi-driving-task behavior is improved.

One of the contributions of this work is to demonstrate a multitasking driver behavior model in an ACT-R cognitive architecture with the novel parallel processing idea. Another contribution is the realization of developing a multitasking driver behavior model in ACT-R cognitive architecture by using a Java programming language that has multithread support as an intrinsic property. These are essential for the real system of Driver Assistant System.

A parallel processing method improves the processing efficiency. However it also increases the computing complexity. As more and more driver behaviors are interactive, the task schedule and task priority may become influential factors of the model’s execution efficiency. This is one direction of our further researches.

The exclusive/joint/irrelevance and risk level of driver behavior are not always the same for different cases. The behavior’s exclusion/joint/irrelevancy changes with the driver’s habit, the environment, and the vehicles. It is very difficult to elaborate the exclusive, joint and irrelevant driver behavior vividly. Also there are difficulties to define the risk level clearly since the driver behavior risk level is related to the current scenario, individual drivers, and even vehicle’s performance. In order to develop a practical model, much more work on these aspects is needed.

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