ACME (A Common Mental Environment)–Driver
A Cognitive Car Driver Model

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ABSTRACT
When working on large-scale traffic observation projects very often simulations and therefore, models of the behaviour of the molecular simulation elements (the car-driver-units) are needed. Most of the models for traffic simulations are based on approximations of statistical real-world data. While fast in computation, they sometimes fail to show real-world phenomena.
Our project uses a different approach. We try to model a human driver's behaviour by modelling her or his cognitive information processing in a simulated environment. While several papers about experiments concerning single phenomena exist, this approach is meant to describe the whole information processing of a driver on a high abstraction level. This paper will show some topics of interest for a human cognition model. Possible applications are listed, too.

INTRODUCTION
When getting familiar with traffic simulations, the scientist will soon encounter their main discriminator, their granularity, which affects the simulation's speed and accuracy. The names of these simulation types from the finest to the most coarsest scale are: submicroscopic, microscopic and macroscopic (Diekamp 1995; Krauß 1998; Schreckenberg and Wolf 1998; Helbig et al. 2001). The basic data computed in macroscopic simulations is the load of the simulated road network's streets, in microscopic the vehicles driving on these streets, mostly assuming the behaviour of the vehicle to be an aggregate of both the vehicle's physical abilities to move and the driver's controlling behaviour (Krauß 1998; Janz 1998). Submicroscopic simulations deal with single vehicles as microscopic simulations do, but extend the model of these to parts of the vehicle like the engine's rotation speed in dependence to the vehicle's speed and the driver's prefered gear switching actions, which for instance allows more detailed computations of the exhausts produced by the vehicle compared to a simple microscopic simulation. Other submicroscopic approaches try to model the complete physical behaviour of a car while moving (Diekamp 1995). When going down from coarse to fine, of course more details must be computed, which slows down the simulation speed but also improves the quality of the computed data due to a more exact model used.

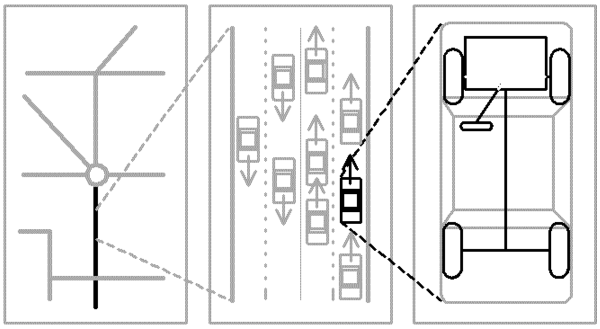

Figure 1: Simulation types from coarse to fine (from left to right: macroscopic, microscopic, submicroscopic)

Still, even when using a very coarse model, one must adjust this model's output to be as close to the reality as possible. This is where we got the idea to build a very detailed model which tries to describe the driving process of a human driver as well as possible at first. Having such a model would allow one to examine the most important factors the driving process depends on and the extraction of these for their usage in new, simpler microscopic simulation models which we hope to be better than existing ones. By this process we also hope to find the circumstances of some known but complicated artefacts that do arise in real world traffic situations like synchronized flow and traffic anticipation.
The wish for a new submicroscopic model is also motivated by a lack of useable models containing the whole cognition and the resulting manual actions of human beings, while information on some experiments about certain phenomena of car driving like the prediction of curves (Jürgensohn 1997), the motives of a driver (Jürgensohn 2001; Irmscher 2001) are accessable.

THE MODEL

Basic Paradigms
When talking about the simulation of a driver one must ask what is really needed to be a part of the model. The most simple approach is to view the driver as a control

loop. Sitting in his car, the driver receives information from the environment surrounding him using his senses. These information is processed by the driver and results in actions performed by the driver‘s haptic systems. These movements of the body are transfered to the car‘s input devices like the throttle or the steering wheel which affects the behaviour of the car. While moving, the car is also moving the human driver who receives a new input. Here the control loop ends. This is of course a simplification as not only the human driver is responsible for the car‘s behaviour but also the car‘s physical properties and the environment. Also, the driver is a control loop per se. He always receives information and generates some kind of output or reaction. Figure 2 shows a schematic representation of this control loop, leaving off the representation of more car-driver systems within the simulation the model is capable of containing.
While several submicroscopic models of a car‘s behaviour exist (Diekamp. 1995) and are available to the public at least as their descriptions, we will ignore this part and concentrate our work on the modelling of the second part that seemed to be responsible for the functioning of the control loop described above: the human driver and the process of information reception, information computation and the resulting movements. This list of involved processes is in fact very similar to the definition of the word "cognition", being: "the mental activity by which an individual is aware of and knows about his or her environment, including such processes as perceiving, remembering, reasoning, judging, and problem solving". The definition of cognition comes originally from psychology but has found its way to the Artificial Intelligence science.

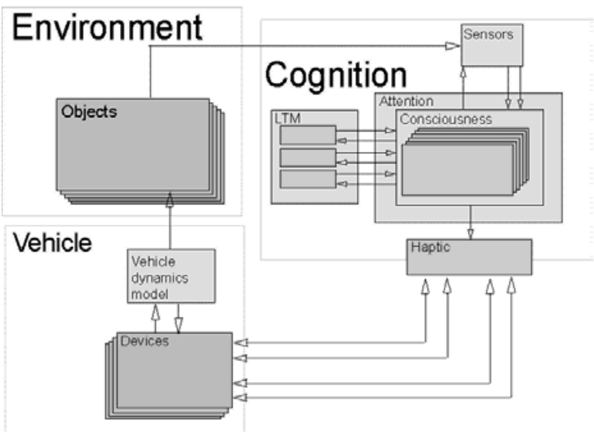

Figure 2: The control loop of the simulation. See the text for a more detailed description.

Of course we will not try to reproduce the complete cognition of a human. This would already fail when trying to implement the process of visual object perception, not because nothing is known about this topic but due to the complexity of the problem that would yield in too large simulation times. So, during the conception of the model, we must decide at which granularity level we want to operate, which mechanisms may be joined and described by models for themselves and which mechanisms are not needed for the simulation of the driving process at all. Further, our simulation environment must be able to support the simulated driver with information in a way similar to the real perception of objects.
During the conception of the project, we decided to use well-known paradigms from psychology that were involved especially by the research of learning phenomena instead of the computational hard models known from neurobiology. The most known model of the human cognition we use as the main paradigm was invented by (Atkinson and Shiffrin 1968) and is based on the distinction between three types of memory: the sensoric input register, the short-term memory (stm) and the long-term memory (ltm) which mainly diverge in the time the information stays available in each of these memory types. Figure 3 shows a diagram of an extended version of this model together with the approximate times of the information availability. The extensions also shown in figure 3 were made by (Tulving 1972) and (Baddeley & Hitch 1974). Tulving has proposed the distinction between three types of the long-term memory. The episiodic memory saves information about single situations from the human‘s life. The semantic memory is used to save common, logically expressable rules like rules of algebra. The third type, the procedural memory contains non-verbalisable information about movements. The second extension invented by Baddeley & Hitch extends the model of the short-term memory by the "articulatory loop" that enables a subject to repeat words in the mind for a better reproduction and memorisation process and the "visuo-spatial sketch-pad" that enables him to "see" mental images, pictorial reproductions of knowledge. These extentions show the importance of the short-term memory as the cognitive computation centre – the consciousness.

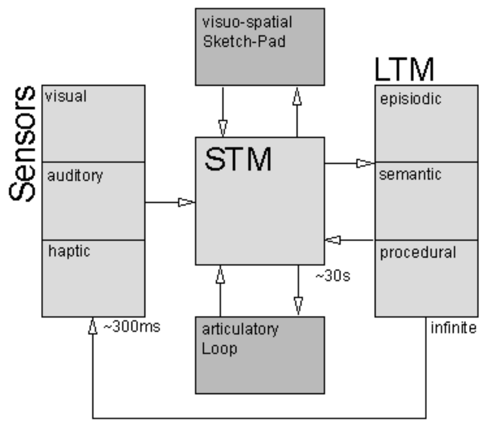

Figure 3: The memory model

Further, the model must be extended by the possibility of object representation – in the simulated environment itself as well as in the simulated driver, beginning at the sensors up to the consciousness, the information processing in the consciousness, the possibility of the driver to move and so to steer his vehicle and a basic

vehicle behaviour which depends on devices moved by the driver.
The following sections will now describe some of these parts of our model. The order is chosen to introduce the reader to the problems and show possible solutions for these with regard to the desired limitation of the problem‘s complexity. We apologize that not all parts can be listed due to the limitation of the document length.

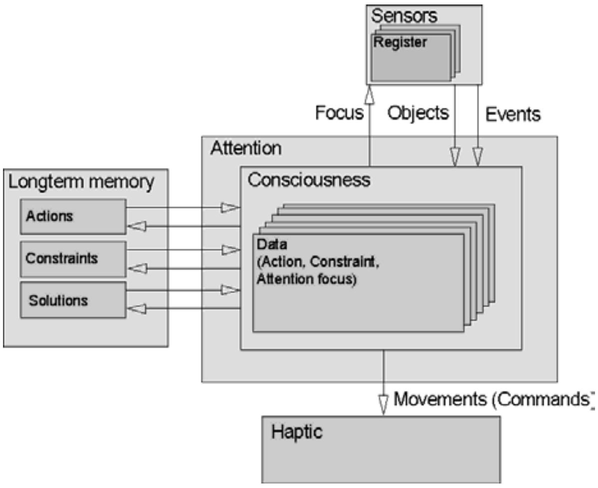

Figure 4: The cognition model used

Before starting with the description of the model‘s parts, it is necessary to discuss the time resolution of the system. A single simulation shall be capable of modeling a flow of about one hour real time using discrete time steps whose simulated duration may vary between 1 ms and 100 ms. Even when using discrete time steps, the cognitive processes shall be simulated quasi-continously.

Sensors & Abstract Object Representation

The first reduction we have done is the limitation of sensors needed to be simulated. We consider only the optical, the acoustical and the haptical. While the usage of the optical sensor is obvious, one may assume that no haptical sensors are necessary. However, they seem to be important when adapting the behaviour of the simulated driver to a reduction of acceleration forces, especially when driving in curves where they can get dangerous. Further, the haptic sensors are needed to "know" about the body movements made while controlling the vehicle. The acoustical sensor will be needed for simulations, too, as some investigations showed that drivers are using the loudness of their vehicles to estimate the velocity.
The next complexity reduction is done by avoiding the modelling of low-level information processing in the registers. The way physical properties of objects are perceived seems not to be important, while the resulting reception times and cognition states are. For a qualitative computation of cognition arising from the sensoral input we hope no more than the following attributes will be needed:

- the time of the recognition of the object,
- the time of the object‘s attributes‘ recognition (speed, approximate time-to-collision),
- the strength of reception in dependence of the environmental conditions (contrast, weather), the attentional focus and the cognition state,
- the meaning of the occurrence of a special object.

All these values may be perceived with an error which has to be modeled, too, as the cognition is known to be only approximate.

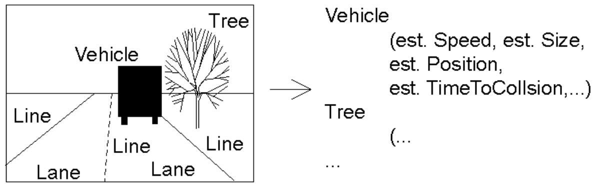

Figure 5: The transistion from the simulated environment where objects are already typed into a driver-internal object representation.

This approach still is a tremendous reduction of the problem as the mechanisms of object recognition may be downsized to some functions. This is possible, when the needed information, about the archetype of the perceived object („car“, „tree“, „street“, etc.), may be obtained directly from the simulation description.
Still, for a valid computation of the reception values mentioned above, we must include some object attributes that do constrain their reception. A light-blue car should be less visible against the sky than a bright red car is. This will be done by mapping the scene into a picture as received by the retinae using openGL and extracting contrast values from this picture.
For the representation of objects, we assume most of the real-world object properties like dirt, complex surfaces etc. as unimportant and manage the representation of important recognition and attention phenomena using the following modeled properties:

- the position and the rotation of the object inside the environment,
- a movement path,
- the object‘s shape which will be used to compute the object‘s visibility
- the color of the object for illustrational purposes only,
- the luminance, used for the simulation of opposite lights or reflections,
- a sound description.

Until now the environment is build from objects posessing these attributes. In the future, additional information about the transparency of objects may be needed, at the moment, windows are modeled by leaving them off of the object‘s description. For further experiments, the environment will also be extended by values describing the weather and we think, that fog, rain and/or snow density are sufficient for common purposes as their impact on object perception shall be simulated only. For the visualisation of the simulated environment other object representations may be loaded which incorporate more sophisticated computer graphics methods like textures, other material descriptions or more detailed object descriptions using a more detailed geometry or multiple materials but will not be used for simulation purposes.

The Consciousness and the Modeled Information Types

The main part of the simulation is the consciousness of the driver we have seen to be located in the short-term memory. The short-term memory has a limited capacity of about 7 items which may be compound items. As an example, nearly everyone knows that you have to join digits from the sequence "193919141871" to years to remember them better. We may differentiate between many types of information and we know that they are stored in the human brain as a wide, complex network of neurons with a very own representation. Together with the complicated perception process, this circumstance causes the usage of paradigms from psychology as we assume that up to now nobody knows how to model a valid representation of the needed information structures based on neural networks in the human brain.
Accompanying this breakdown of the data processed by the stm we also reduce the variety of their types. The controlling process needs actions from the controller. We have modeled such behaviours as complex action workflows consisting of sensoric actions which retrieve information from the environment, motoric actions which change the values of the vehicle devices and intermediate and logical actions needed to model relationships between actions. These actions are shall describe the psychological artefact of schemata. Additionally, to allow decisions the model incorporates logical constraints which are used to choose new actions from the long-term memory and that determine the choice of one of the possible branches within an action workflow. The instances of both the schemata (together with "calls" of sensoric and motoric subactions) and the constraints are not integral parts of the model, but may be modeled by the user and be referenced by the simulation description file to enable the simulated driver to use them. Figure 6 shows a diagram of the the process of overtaking another vehicle where the elements marked with an „a“ represent checking the possibility to overtake, „b“ the initiation of overtaking, „c“ the overtaking process and „d“ the return to the lane.
As one can see, actions are splitted into a hierarchy. Further, this view on actions is reduced as a decision may be a compound object built from comparing known information to the needed ones, sensoric actions like object perception and motoric actions when for instance the head has to be moved to allow one to look into one of the mirrors. As these actions are all build into the model of the driver, they don't have to be explicitly modeled.
Unfortunately, the number of possible actions a human subject may perform is close to infinite. Fortunately, driving a car is only a very small subset of the full set and most of the actions are learned by the driver during his training. So, for instance the diagram shown of the overtaking process should be familiar to you and should not vary between car drivers. At least in Germany, this process is taught to every car driving beginner. The case of a repetition of the decisions is modeled, but not shown in the diagram.

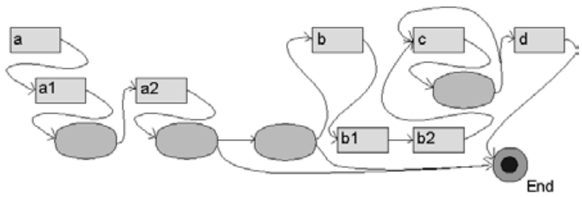

Figure 6: The schema of overtaking another vehicle; squares represent logical parts of the workflow, round objects complex decisions

A further information modeled is the sensoric focus. When trying to receive a special attribute of an object like its type, its distance etc. the driver may increase his concentration on this object and reduce the reception of other things. A focus is a special case of reception while in most cases the reception is rather undirected in the meaning of not being bound to an object or one of its attributes but rather relaxes to the whole situation.
Not modeled yet, but surely needed are plans and expectations (situation anticipations). While the basic mechanisms of these structures are known, we still have to look for descriptions of the comparison between the real situation and the plan regarding the current time and the situation in future time.
Together with the implicit models for the movement of the extremities and information reception, the structures described in the last passages are capable of modeling most of the functions of the procedural and the semantic long-term memory. Some assume the driver incorporates the vehicle and its behaviour as a part of his own body. Such a view would implicate the usage of procedural information only, an example may be the difference between different vehicle behaviour under different road conditions and the explicit, conscious derivation of rules like "ice is on the road – be careful". Still, any rule like stopping at the red light or velocity limitations are a part of the semantic memory. We take this difference into account, because these different structures may be processed differently, processing which implies different processing times.

Cognition Simulation Process

During the simulation we assume the consciousness as a container with seven places which may be filled with actions, constraints, foci, plans or expectations. After an action is over, the reception of a desired attribute has finished, or any other cause which makes the designated item unneeded, this item is removed from the container. New items may be added to the container as responses to new situations arising from newly perceived objects or situation constraints that must be revalidated. When adding more items to the stm while it is already full, special methods will be invoked that simulate the human problem solving. Forgetting or mal-adjusted actions are often the result of this process in real life.

Other model parts

Additionally, the human cognition model contains an attention and a haptic model. Attention is known to have a great importance on the reception process and due to this has gained the interest of traffic researchers in the past. As some models see attention as a steering/filtering process between the consciousness and the sensors which also affects the interiors of both structures, other make attention also responsible for the haptical actions.
The haptic consists until now of both hands, both feet and the head only. These extremities may be used by the cognition to move the vehicle's devices to a special position including their translation and rotation, which allows the modelling of pressing the throttle or turning the key. It is correct that this model is not yet capable of turning the steering wheel. Further research is needed to acquire information about this topic. We hope to manage this problem using our test car and a driver-observing camera. A more sophisticated sceleton model will also be needed.

THE IMPLEMENTATION AND THE PROGRESS OF THE PROJECT

The model is being implemented in Java. In the wish to allow the use of different models for each of the different cognitive structures like sensors or the stm, we hope that Java is the best language due to the possibility of an extensive usage of interface definitions.
The simulation input consists of a single XML-file which contains references to other XML-files for the description of object appearance, object movement paths, driver actions and situation constraints and devices for the simulated cars besides some basic values like the start and end time of the simulation and the simulation time-step length. The output consists of XML-files, too, where each object may generate its own output file that contains its physical attributes for each timestep. A simulated vehicle further reports information about the settings of its devices while a simulated driver saves the states of his short-term memory, the list of perceived objects and functions it has done in each time step.
This large amount of information is not that simple to evaluate. To manage this problem two different approaches will be used. At first, the simulation, when fully implemented, will have the ability to create animated views which allow post-mortem visual inspection. Further, additional tools will be produced to extract noteworthy information from the simulations output files.

CONCLUSIONS

Starting with common used cognition paradigms known from the psychology we will try to build a functioning, qualitative model of a human cognition including mechanisms of reception, information processing and vehicle steering. At the end of the conception phase there are only few questions left about the most coarse artefacts we wished to model. Still, the overall concept as well as the submodels used must be validated so that thea simulate a car driver according to this process in the real world.

FUTURE WORK

While studying the model and the assigned human cognition elements we hope to gain some further understanding about the following topics:

- The representation of actions in the human brain together with their grouping into action flows and hierarchical structures.
- The grouping of single piecesd of information into a situation representation within the human cognition.

The vehicle dynamics‘ model will be extended to a full model as described in (Diekamp 1995).

BIBLIOGRAPHY

R.C. Atkinson and R.M. Shiffring. 1968. „Human memory: A proposed system and its control processes“ In: *The psychology of learning ans motivation: Advances in research and theory*, K.W. Spence (Ed.), New York: Academic Press, 1968, 89-195

A. Baddeley. 1997. „Human memory: Theory and Practice (Revised edition)“. Hove, 1997

R. Diekamp. 1995. „Entwicklung eines fahrzeugorientierten Verkehrssimulationsprogramms“. Forschungsgesellschaft Kraftfahrwesen Aachen mbH (fka), 1995, ISBN 3-925 194-31-2

D.Helbig et al. 2001, „Traffic and Granular Flow'99“, Springer, 2000, ISBN 3-540-67901-2

M. Irmscher. 2001. „Modellierung und Simulation von Motivationseinflüssen auf das Fahrerverhalten“, , VDI Verlag GmbH, Düsseldorf, 2001, ISBN 3-18-300622-7

S. Janz. 1998. „Mikroskopische Minimalmodelle des Straßenverkehrs“, Diplom-thesis, 1998

T. Jürgensohn. 1997. „Hybride Fahrermodelle“. Pro Unniversitate Verl., 1997, ISBN 3-932490-22-3

T. Jürgensohn. 2001. „Kraftfahrzeugführung“. Springer, 2001, ISBN 3-540-42012-6

S. Krauß. 1998. „Microscopic Modeling of Traffic Flow: Investigation of Collision Free Vehicle Dynamics“. DLR (Hauptabteilung Mobilität und Systemtechnik), 1998, ISSN 1434-8454

R. Mayr. 2001. „Regelungsstrategien für die automatische Kraftfahrzeugführung“, Springer, 2001, ISBN 3-540-67518-3

M. Schreckenberg and D.E. Wolf. 1998 „Traffic and Granular Flow'97“, Springer, Singapore, 1998, ISBN 981-3083-87-5

VDI-Gesellschaft. 2001. „Der Fahrer im 21. Jahrhundert“. VDI-Berichte 1613, VDI Verlag GmbH, Düsseldorf, 2001, ISBN 3-18-091613-3