A Cognitive Driver Model

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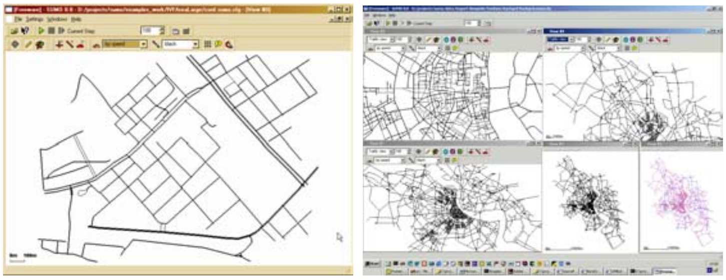
Abstract

While many different approaches to understand the process of driving a car exist, we try to simulate it within this project. This methodology fits well into our institute's work where traffic simulations play an important role. We not only hope to gain some information about the most concerned topics on driver related problems - issues on ergonomics and traffic security - but also some knowledge about traffic itself. We hope this knowledge will help us to improve microscopic traffic models used for large area simulations.
Herein, some basic concepts the model incorporates and the main problems during the research and implementation are described.

Introduction

The project presented here is based on our institute's investigations on traffic models and traffic simulations. Mainly, we work with so called microscopic models that use car-driver - objects. Such models are normally hold minimalist[1] as the simulations they are used in are meant to simulate large areas with several thousands of cars running simultaneously. Our investigations on these models include their comparison, calibration and validation (see [1]), but also the evaluation of data collected during test drives and the development of new models ([2], [3], and [4] for examples). Beside this, we develop a microscopic traffic simulation which is available as open source, called "SUMO" – "Simulation of Urban MObility". A description of this simulation package may be found in [5].

[1] see [2] and [3] for an example



Picture 1: Pictures from the microscopic traffic simulation „SUMO"; left: the area around our Institute at Berlin, Adlershof; right: the city of Cologne

Some years ago, traffic simulations that regard the behaviour of a single driver came upon (see [6]). There are several reasons for this. The assumption that more detailed models would also describe traffic more exact is one of them (see [7]). Also, there is a growing interest in taking a look at the driver as a controlling system. To reduce the amount of traffic accidents, researchers need better models of the driver and of the limitations of his abilities to control his vehicle, both when regarding the current driving process, but even more, when new assistance systems shall be introduced (see [8] or [9]). Such systems should not only fit to a driver's wishes for a better vehicle, but should also not overstrain him with additional information he can not manage. On the other hand, the evaluation of the driving process may also be the origin of new ideas on assistance systems.

Why do we need a new Model?

Needed is a model one can execute and work with. That means it should be possible to implement it using a programming language and to run it within a simulation. It must not be a black box as the assumptions made within it have to be validated. Further, it should replicate the whole process of driving a vehicle – the gathering of information, attentive processes, the derivation of actions from the current situation and the execution of actions. Due to some previous thoughts about driving and human cognition, we assume time steps of about 10-100ms to be the time granularity the model shall work with.

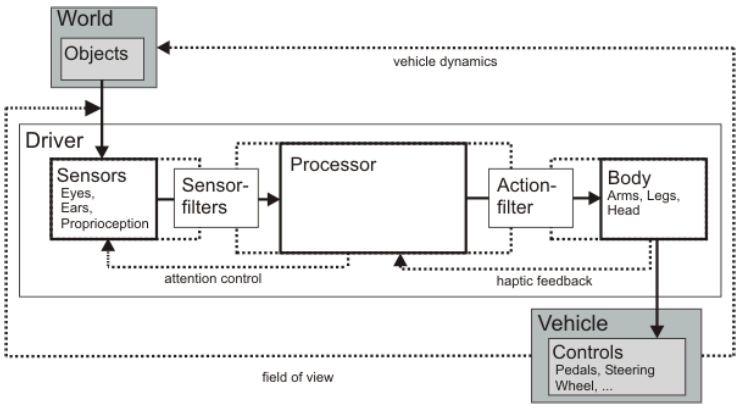
Some applications that model humans as operators do exist, such as MIDAS (presented f. e. in [10] and [11]) or PELOPS (see [12]), but these models are not available for free or better to say not available at all. The descriptions of these models include some modelling aspects, such as the list of implemented cognitive structures, but are not exact enough to allow a reimplementation or revalidation.

Some other models, which are available for free, do model human cognition, sometimes even in a very elaborative way (ACT-R, SOAR). These models are mostly embedded in an own framework and deal with information processing within the human mind. If one

tries to use them for traffic simulation, he has to implement a lot of interfaces to an own simulation framework – as beside a proper environment representation, things such as the vehicle's dynamics must be implemented. Such adaptations are very time consuming without solving any scientific questions.
Due to these limitations of existing models, we decided to implement an own framework and model from scratch. We also hope that this approach will bring us more insight into the cognitive processes than simply using an existing model.

Model Overview

What is the cognition? Neisser says that cognition is "…all processes by which the sensory input is transformed, reduced, elaborated, stored, recovered, and used." (see [13] f.e.) This quasi-definition is very proper for our purposes as – extended by perception and action execution – it completely covers the control loop of vehicle-driver-environment known from the science of human-machine-interaction (see [6] and picture 2). I will now describe some of the most important things to regard when implementing a model of a human cognition starting at the begin of the loop – at the sensors.



Picture 2: The regarded control loop driver-vehicle-environment

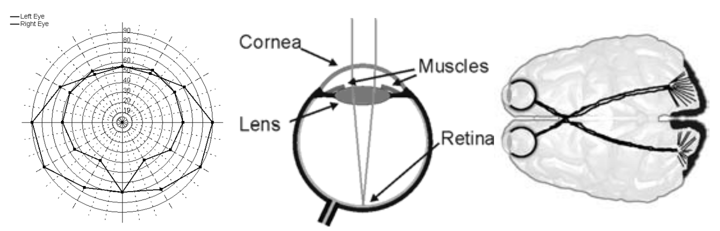
Sensors

A human's sensors were at first described by Aristoteles (-384 – -322). He distinguished between eyes, ears, skin, nose and tongue. Later, Sir Sherrington ([14]) described three types of senses: exteroception, responsible for reception of attributes from the world that surrounds the individual, interoception that delivers the state of inner organs (hunger, thirst etc.) and proprioception which lets the individual know at which position his extremities are. The modern physiology uses the following classification: optical (with

differences between the perception of lightness and the perception of colours), auditive, chemo-reception (tasting and smelling), somato-sensors (perception of the temperature, contacts with the skin, pain and the positions of the extremities). For the process of driving, we assume only the following senses to be of interest: the visual, the auditory perception and the perception of acceleration forces.
One could argue that also the haptic sense is necessary to be modelled, but it is ignored herein as the controls a driver uses within his vehicle are well known to him. He does not have to be aware that one of the controls is slippery, too hot or too strange in any other kind to be gripped.

Visual Perception

This sensor is the most important one for driving and many investigations on it have been performed. While the eye is theoretically able to view a field of about 90° in each direction, the field of view is limited by the shape of a human's head. The eyes do brake the light as glass lenses do and due to the limitations known from lenses, only objects in the fixated depth are seen sharp. The retinae's receptors – divided in color and brightness receptors – transcode light into electrical impulses. The first transformation of the perceived visual information is already performed within the retinae. The contrast is increased by a simple addition and subtraction of cells in neighbourhood, here. Further, some cells do transmit information about light, other about darkness. Such an encoding does save energy (see [15] pages 400- and [16] pages 33-).



Picture 3: Eyes; from left to right: occlusion by the shape of the head, parts the eye consists of, the optic nerves between the eyes and the brain

Information coming from the eyes is projected onto the LGN – a part of the brain that lies at the back of the head. Herein, the information from eyes is merged to lines, shapes, and objects. This process is performed through a massive parallel hierarchy of neural areas, connected both for- and backward. By now, physiologists are uncertain about the areas' functions, and no valid models are available. Due to this, it is not possible to build a physiological model of the cognition at all – the information we need is already not available for the first part of the process. Instead, one has to use the results from cognitive psychology.

We model the visual perception as following: the driver gains all information in his field of view – determined by the direction he looks at. The information is filtered twice – once within the simulated eyes where objects and their attributes are not recognized properly when the object lies outside the fovea. Further, the simulated attention ignores not regarded objects.

All attributes a driver would use as input, such as the relative speed of the vehicle in front or the distance to a certain point, are retrievable from the simulation without any error. To model a human being's perception inaccuracies, the model uses error functions. They influence the quality of the objects' and their attributes' perception by blurring the values retrieved from the simulation. The error applied to the attributes decreases both with the duration the driver looks at the object and the difference between the object's direction and the direction the eyes look towards. After this filtering, information about the objects and their attributes becomes available to the central executive.

Auditory Perception

By now, only the visual perception is implemented. Auditory perception will be included into the final model, too. It will regard the vehicle's engine and wheel noises only, and further, only their loudness. Auditory perception is needed when one wants to model the gear switching process as described in [7].

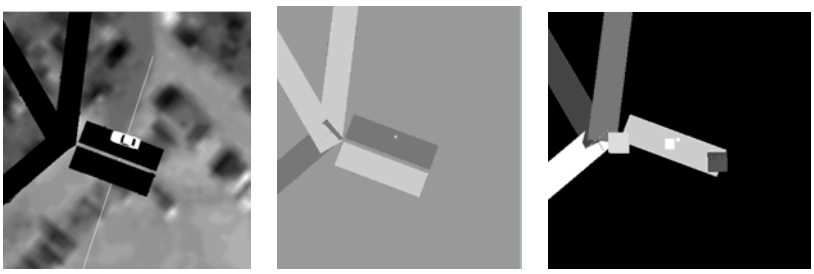
Perception of Movements

The perception of movements is not modelled as an information input like the visual and the auditory perception are. Instead – as it is known that a driver adapts his speed to pass curves in a way that does not bring up lateral acceleration forces larger than he likes (see [17]) – the knowledge about this is used as input to the simulated driver's decision processes. This approach disallows the investigations about what happens when the driver exceeds his favourite values, but at the current stage of research, we want to investigate normal situations only.

Central Executive

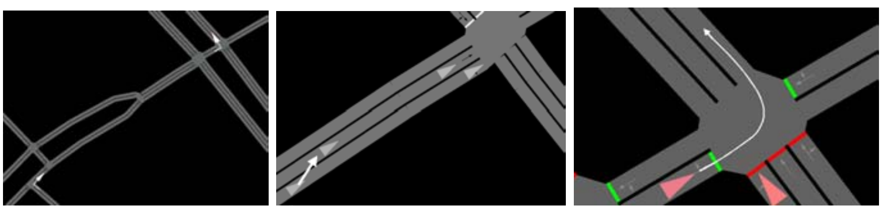
The simulated central executive retrieves information from the sensors. This information is then transferred into a mental model of the driver's surrounding – the internal environment representation. As the central executive does not operate on the objects he

perceives, but on the archetypes they are represented by, the objects stored within the internal world representation contain further information then the perceived one. If one sees a vehicle, for example, he may be sure, that this vehicle does need some time to decelerate from his current velocity. Even the trajectory of the vehicle can also be forecasted.
The description of the environment, both regarding other traffic participants and the street's shape the driver has to follow, is used to update a further structure, the "plan",. While only the first layer of Michon's control layer architecture (see [18]), the vehicle control layer, is given at the simulation's begin, all other planning is done by the simulated cognition. The plan contains information about the next actions to do including the process of following the current street's shape and the avoidance of collisions with other vehicles.



Picture 4: Simulation of the situation interpretation performed by the driver; from left to right: the original situation, visible and regarded objects (internal representation), the plan visualised by showing the interesting objects and points further actions are being executed.

When following the plan, the simulated driver has to perform actions, such as braking in front of a curve or following the road curvature. This is done by both taking decisions about what to do – modelled by explicit rules – and by following the desired path by not explicitly modelled control operations. These both paradigms do represent the middle and the lowest level of Michon's vehicle control hierarchy. At the middle level, called tactical or manoeuvring level, decisions about lane changing or gap acceptance are taken. The lowest (operational/control) level of vehicle control is the one at which a human driver follows the lane geometry. We have not yet investigated their fitting to Rasmussen's (see [19]) assumptions about the behaviour of human operators.



Picture 5: The three levels of vehicle control as reported by Ranney; from left to right: navigation level (abstract route within the road network), tactical level (decision to change the lane, marked by an arrow) and the control level (following the lane geometry)

Action Execution

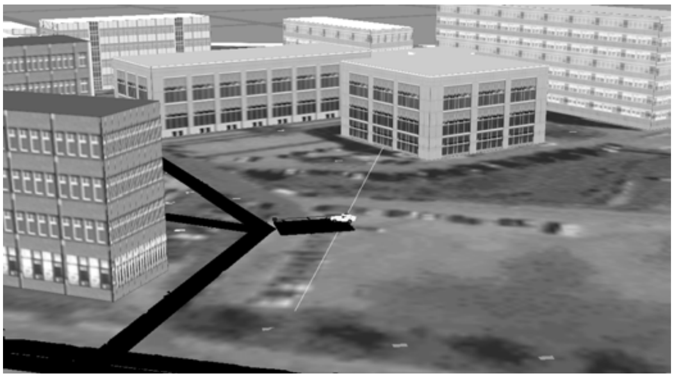
Explicit actions are named within the model, so the driver may decide to “switch the radio on”, “turn right” etc. These “motoric programs” or “schemata” (see [20]) are loaded at the simulation’s start to a structure which is meant to represent the long term memory and may be obtained from there by the simulated driver’s cognition. After this, they may be parameterised to fit to the situation the driver is currently in. When executed, the extremities move to the desired positions and move simulated controls of the car the driver sits in. Beside the extremities, the body of the driver is not regarded.

Vehicle Model

By now, a very simple vehicle model is used, based on the 2-wheel vehicle model described in [21]. It does not incorporate gears and dampers, yet, but will be extended by these in the near future. Still, the model is appropriate to model driving around curves if one concerns low speeds only.

Usage

Given the description of the environment and the navigation layer of the route the driver shall follow, the simulation is started. While the simulated driver tries to solve the task to accomplish his route – just like a normal driver – the actions he performs and the amount of cognitive afford he needs is logged. We hope to predict a situation’s complexity by the number of things the driver has to regard to stay collision-free and the number of decisions the driver has taken. This allows us to give a qualitative measurement of dangerous situation – a quantitative measurement is not possible as no valid measurement on this exists.



Picture 6: A screenshot from the simulation (a model of our institute's site)

There is also a further thing we want to measure – the simulated vehicle's speed. Traffic measurements do mostly cover only certain places of the road network, mainly the heavier occupied ones. Normally, such places are more interesting for the traffic research as jams occur there. But, if one wants to simulate a city and the movement of a vehicle within it, he has to know how a driver behaves when driving through the whole network. Such measurements are not common. Some experiments on the drivers' behaviour in front of junctions do exist, but they are not yet consolidated within simulations.

Occurred Problems

As the model runs within a simulated environment and beside this environment other scenario settings must be loaded, a huge overhead of information processing is needed before the simulation is ready to start. Also, the visualisation must be implemented, what not only needs further programming effort, but also some thoughts about which things should and how they should be visualised. Beside some atomic values, such as the current speed – both the speed, the simulated driver really drives with and the speed he thinks he has, the currently visible things, the things the attention is concentrated at and the internal environment representation are visualised by now.
A further problem when modelling the cognition is that most models use abstract data types. Within an implementation, one has to use explicit defined structures. A very hard work was the try to investigate how to implement something we normally call a "situation". Different ambiguous definitions of this term exist. One may use "state", "context" or some other similar words to describe things that are not really well distinguished. By now, our view is more to distinguish different situations rather by the actions performed within each of them than by the surrounding of the driver.

Calibration and Validation

After the whole loop has been implemented, the model has to be calibrated and validated. This will be done in two ways. The microscopic approach will take the sub models separately into account, the macroscopic one will consider the whole model's behaviour.

On the microscopic scale, we want to validate whether the driver' perception is modelled properly by comparing the model's visual perception with data gained from eye-tracking experiments. On this scale, the vehicle model has to be evaluated comparing its acceleration, deceleration and curve driving behaviour to values known from real-world cars.

On the macroscopic scale, we will use data gained from experiments where vehicle movement data have been collected. One data that is available for us contains the movement of a single vehicle within the real world regarding real-world situations such as paying attention to pedestrians or vehicles approaching the same junctions. Another one we can use is an experimental setting where 20 drivers were forced to drive one after another on a rounded course choosing their speeds in a special manner.

Summary

After two years of work, the simulation is ready to run and one scenario, a very small one, but one we can easily validate, is implemented. Other scenarios are easy to implement as the simulation can read road networks stored in NavTech's ArcView format after converting them into SUMO-format. Such networks are available for many countries in a high quality. Although no calibration and only a basic verification has taken place, yet, the results are quite promising: the simulated driver needs almost the same time to solve the trip as the real driver did. This at least shows the basic correctness.

One of the main already available deliverables is a computational, closed model of planning done within a car driver's mind. This model does not only resemble prominent assumptions about how a human being steers a car – Michon's three level hierarchy, but also integrates car-following, lane-changing and taking curves using only one main model. This is quite a new approach that fits to known cognitive paradigms but can not be found within driver models, yet.

Further Work

I hope this model to be completely implemented at this year's end. The missing things are basically a better vehicle dynamics model and reactions to other traffic participants. After then, one has to validate the model on different levels. Further, some other, more complicated scenarios will be generated, both ones we have real-world data for and some theoretic ones.

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